ABSTRACTS

Variscan kinematics of the Ural and Tienshan junction area

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Late Paleozoic evolution of the Ural-Tienshan junction area was controlled by the processes of convergence and multiply collisions between Kazakhstan, Baltica, Turan, and Tarim continents. Subduction in the Valerianov arc since middle Visean till beginning of the Late Carboniferous (during ~335-315 Ma) was responsible for convergence between Kazakhstan and Baltica. Duration of arc magmatism for ~20 Ma suggest that minimum several hundreds of kilometers of an oceanic crust was consumed there that time. Collision of Kazakhstan started in the middle of the Bashkirian age (~315 Ma). It resulted in: a) formation of sub-meridional divergent thrust folded belt in Urals, b) Laramide-style deformations in the Southwest and South of the Kazakhstan continent, and c) iniciation of a north-dipping subduction zone in the South of the Kazakhstan continent within Central Tienshan. Ongoing subduction in the South lead to collision of the Kazakhstan continent with Tarim in the latest Carboniferous and with Turan in the Permian time.

Principal structural assemblages and deformation ages within the Ural–Tienshan junction area can be defined as the following. D1) Accretionary thrust folded belt of the South Tienshan (since ~330 Ma in the West and since ~315 Ma in the East); D2) Laramide-style thrust-folded belt in the SW and S of Kazakhstan in Karatau and Middle Tienshan, with major thrusts, directed toward the continent (since ~315 Ma); D3) North-South trending folds in the W and SW of Kazakhstan, mainly Karatau ridge, overprinting D2 structures (Permian?); D4) Left-lateral strike-slip faults and plunging folds within entire Tian Shan, due to oblique collision of Kazakhstan and Tarim (mainly Late Permian and early Mesozoic), and D5) East-West trending compressional structures and diagonal strike-slip faults due to shortenning in the North-to-South direction (Latest Triassic and Jurassic).

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Transected Folds with opposite patterns in Terena Formation (Ossa Morena Zone, South Portugal)

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The Terena Formation is a Lower Devonian flysch located in the Estremoz-Barrancos Sector (central part of the Ossa-Morena Zone, South Portugal).Taking advantage of the age of this unit which is contemporary with the beginning of the Variscan orogeny, it was possible to make a geometrical study of the evolution of the early stages of deformation.

At the regional scale, the Terena Formation outcrops in the core of a first order syncline from the second deformation phase, with nearly 100 km long, 10 km wide and having an unusual "Z" shape. The relation of this first order fold with the foliation, shows that the central part of the macroscopic structure, trending nearly N-S, is transected by S2 cleavage (NW-SE), showing a right transection pattern. The cartographic right transection is opposite to the left transection pattern showed by D2 folds at a mesoscopic scale, in the axial sector of the major synclinal. The transection of mesoscopic folds is coherent with geometrical patterns usually described in the Ossa-Morena Zone and interpreted as the effect of a left lateral shearing, contemporary of the regional flatening.The cartographic right transection can be explained by the generation of a near N-S trench, as the effect of the first deformation phase (trending also N-S but only present at lower structural levels). Several sedimentary features indicate that the genesis of this trench and the deposition of the Terena flysch are almost contemporaneous (strong lateral variations of facies, olistolits of Silurian rocks). The trench shape conditioned the deposition of flysch facies during Lower Devonian and the orientation of the first order D2 syncline. The right transection results from the superposition of the NW-SE upright S2 cleavage on this major regional structure.

The mesoscopic folds, observed on the upper levels of the sedimentary sequence were not influenced by the topographic anisotropy of the basin, and therefore they developed a left transection, according to the regional deformation mechanisms.

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New insights of the Variscan late-orogenic extension in South-Brittany: the Sarzeau Shear Zone

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Together with the Quiberon Shear Zone, the Sarzeau Shear Zone (SSZ, Morbihan) witnesses of the late Carboniferous extensional collapse of the Variscan thickened crust. The SSZ is a km-scale normal fault that exhibits a kinematic and dynamic continuity from a deep, synmagmatic and ductile activity to a shallow brittle one.The SSZ is an example of an E-dipping flat-lying ductile extensional shear zone evolving into a low-angle brittle detachment.

A clear continuum of extensional strain from ductile to brittle regime is observed in both footwall and hanging wall. The brittle deformation is characterized by shallow and steeply dipping normal faults associated with sub-vertical extensional joints and quartz veins. The earliest brittle structures are low angle normal faults which superimpose on, and reactivate, earlier ductile shear bands commonly located along pegmatite and aplite dykes, but newly formed muscovite-rich low-angle normal faults are also observed. The inversion of fault slip data collected within and away from the main detachment zone (50 stations over a 45 x 20 km area) shows a consistent N110 stretching for both ductile and brittle structures that are stochastically parallel. Top to the ESE ductile shear zones were then progressively exhumed and replaced by shallow dipping cataclastic shear zones when they reached the brittle field then accompanied by the formation of high angle normal fault in the hanging wall.

Most of the last increments of extensional strain are achieved through in the upper crust by the formation of a penetrative network of dominantly E-dipping normal brittle faults. This N110 extensional stress field is also responsible for the injection of N20 to N50 striking late Carboniferous granitic dykes interpreted as km-scale tension gashes. The chronological and structural relationships with the Carnac pluton that crop out to the west are discussed. E of the SSZ, at least two end-members geometries of granite dykes of same strike can be distinguished with (early?) 30 to 45° West dipping magmatic-structured ones and subvertical ones exhibiting no strain patterns. Towards the SSZ, a petro-structural analysis of oriented sections showed that these dykes are carrying a magmatic planar and linear fabric upon which ductile and brittle extensional structures overprint.

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Imaging the mantle roots of the Variscan orogen below the Paris basin: Insight from the P-wave velocity model PM0.5

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A growing number of recent seismological and geochemical studies have provided evidence for long-lived compositional anomalies at all scales in the mantle. Such lithological contrasts can induce lateral seismic velocity heterogeneities in the mantle persisting over several hundred million years, *i.e.* much longer than if they were exclusively due to temperature variations. Therefore, in old suture zones, mantle seismic tomography can significantly help in defining ancient deeply buried slabs and thus in constraining geodynamical models for past orogenic systems. In northern France, the Paris basin corresponds to the Late Paleozoic-Mesozoic episutural basin of the Late Devonian-Carboniferous Variscan collisional belt.

The large-scale P-wave velocity model PM0.5 developed by Piromallo and Morelli (2003) allowed imaging the lithospheric mantle roots of the Variscan orogen below the Paris basin, pointing to the existence of a significant high velocity anomaly in the upper mantle. The latter fits in map view, at ~150-200 km depth, the trace of the northern Variscan suture zone *i.e.* the Upper Carboniferous (ca 325 Ma) Lizard-Rheno-Hercynian (LRH) suture zone. Moreover, it is surprisingly spatially correlated to the well-known Paris Basin Magnetic Anomaly, however slightly shifted to its SW extension. In cross-sections, the main high-velocity anomaly seems to extend through the lithospheric mantle with a steep southern dip, to apparent depths greater than expected for a standard continental lithosphere (about 350-400 km depth).

As suggested in previous tomographical studies along ancient suture zones, these data argue for such anomaly being the remnant of a Variscan LRH oceanic slab that did not suffered any significant late orogenic removal. As the latter apparently cuts across another superficial high-velocity anomaly located upon the Late Devonian (ca 375 Ma) Ligerian-Massif Central (LMC) suture zone, it would imply an early orogenic process of LMC slab break-off before the initiation of the opposite subduction of the LRH slab.

As suggested by modelling experiments, this process could be considered as a major driving mechanism for the exhumation of HP and UHP metamorphic complexes along the LMC suture zone (unlike the low grade metamorphic LRH suture zone). As a whole, these new data question the long-term evolution of subducted oceanic lithosphere and in the case of the Western European Variscan belt, suggest the subduction of the LRH oceanic slab below the previously thickened Eovariscan crust to have played an important role in the late collapse of the belt inducing a significant amount of thermal erosion and softening of the overriding lithosphere all over Carboniferous times.

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Role of mantle lithosphere in Variscan orogeny - seismic anisotropy perspective

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Models of colliding micro-continents leading to crust thickening often neglect the mantle lithosphere, the volumetrically most important part of the plates. Knowledge of seismic anisotropy is a key to our understanding of tectonic fabrics in the deep lithosphere and asthenosphere. We have modelled three-dimensional seismic anisotropy of the mantle lithosphere from anisotropic parameters of teleseismic body waves by inverting jointly shear-wave splitting parameters (time delays between the fast and slow split shear waves and polarizations of the fast shear wave) and travel-time deviations of longitudinal waves (P-residual spheres).

The analysis is based on data from dense networks of temporary and permanent stations in the Bohemian Massif (Plomerova *et al.,* GJI 2007) and the French Massif Central (Babuska *et al*., Tectonics 2002). Changes in orientation of the large-scale anisotropy, caused by systematic preferred orientation of olivine, identify boundaries of domains of mantle lithosphere. Individual domains are characterized by a consistent large-scale anisotropy approximated by hexagonal or orthorhombic symmetry with generally oriented symmetry axes (inclined foliation and lineation). The domains are separated by mapped tectonic boundaries (sutures), which cut the entire lithosphere. Besides the change of anisotropy orientation at domain boundaries, we often observe a change of the lithosphere and/or crust thicknesses. We do not detect any fabric of the mantle lithosphere, which could have been produced by a collision of micro-continents in a volume detectable by large-scale seismic anisotropy.

The observations of consistent anisotropy within sharply bounded blocks of the mantle lithosphere reflect a pre-collision frozen-in olivine preferred orientation. The robust fabric is not easily overprinted by collision orogenic processes, such as those that led to assembly of the modern European landmass. Therefore, our findings support a plate-tectonic view of the continental lithosphere as a mosaic of rigid blocks of the mantle lithosphere with sharp contact zones, though sometimes of complicated geometry (Babuska and Plomerova, PEPI 2006). These mantle contacts are blurred by easily deformed overlying crust terranes.

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Palaeozoic evolution of the Armorican Massif: from Gondwana break-up to continental collision

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The Armorican Massif (western France) is divided in four main domains (namely the Léon domain to the NW, and the Northern, Central and Southern domains) by late-Variscan, transcurrent, shear zones. The Armorican massif preserves an undeformed to slightly deformed Proterozoic basement in the Northern and Central Armorican domains and is located between two main suture zones, namely the Lizard ocean to the North and the Galice-Massif Central (GMC) ocean to the South. Resorption of the Lizard ocean should be recorded by the tectono-thermal evolution of the Léon domain, while subduction of the GMC ocean leads to the building of the South-Armorican domain. The Northern and Central-Armorican domains are pieces of crust that were shortened and sheared in between the two main suture zones. The main stages of the tectonic evolution of the Armorican Massif are as follows.

During the Cambrian and Ordovician periods, the Armorica microplate was located at a palaeo-latitude close to the South Pole, as shown by palaeomagnetic data and Ordovician faunal communities (trilobites, ostracods, …). The Cambrian and Ordovician sedimentary sequences record two main episodes of continental rifting, leading to widespread continental rifts coexisting with narrow oceanic domains (Gondwana break-up). Latitudinal migration of the Armorica microplate from the Upper Ordovician to the Middle Devonian is recorded by late Ordovician dropstones associated to the Hirnantian glaciation, followed by development of reefal build-ups during the Early Devonian.

The nature and timing of the early stages of convergence are still disputed. Some metamorphic rocks, including eclogites and high-pressure granulites, whose ages span the 440-380 Ma range, indicate an earlier event. However, critical assessment of age reliability and independent geological data from the Loire valley (see Ducassou *et al.*, this volume) suggest a two-stage evolution, *i.e.* continental rifting during the Lower Devonian (possibly associated to back-arc opening) followed by the earliest mountain-building event at about the Lower/Middle Devonian (*i.e.* 400 Ma.). Continuing convergence during the Upper Devonian (at about 370-360 Ma) is recorded by high-pressure metamorphic rocks from both continental (*e.g.* lower unit of the Champtoceaux nappe stack) and oceanic (Groix – Bois-de-Cené) units.

The late Devonian to early Carboniferous is marked (i) by progressive stacking and exhumation of crustal sheets (*e.g.* the Champtoceaux Complex) and (ii) southeastward thrusting (*i.e.* backthrusting) of the Léon domain over the Central-Armorican Domain. Therefore, the dominantly lacustrine, early Carboniferous, deposits are unconformably resting over slightly deformed Devonian sequences (*e.g.* the Laval and Chateaulin basins in the Central Armorican domain) or on top of exhumed metamorphic units (*e.g.* the Ancenis basin on top of the Champtoceaux-Mauges stack).

At about 330 Ma, the whole Armorican massif was submitted to horizontal shortening associated with dextral shearing, that culminated with the development of the South-Armorican Shear Zone (about 200 km of left-lateral displacement). The late Carboniferous shear zones either rework or cut across previous plate boundaries, and deform the early Carboniferous basins as well as their Variscan basement. Moreover, the SASZ bounds a northerly domain where erosion was the dominant process during the Upper Carboniferous from a southerly domain where EW-trending crustal extension took place at about 310-300 Ma.

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Geodynamic setting of the Ordovician volcanic complexes in the South Urals

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Evolution of the Uralian thrust folded belt during the middle and late Paleozoic was well constrained during last decade. Development of the belt was generally controlled by two collisions of the Baltica craton – first, with an oceanic island arc in the Late Devonian, and then, with Kazakhstan continent in the Late Carboniferous and Permian. Geodynamic evolution of the region in the pre-Devonian time, hovewer is much poorly known and represents a subject of current study. Our research aims at the definition of the geodynamic setting and dating of the volcanic complexes related to Ordovician system, which form in the Variscan structures of the Southern Urals a number of thrust sheets, separated by serpentinite melanges.

Synthesis of petrochemical, geochemical, sedimentological and biostratigraphic data (conodonts) allow us to reconstruct in the South Urals an oceanic island arc system, which evolved since the end of the Llanvirnian age till the Early Silurian. Four distinct lithological complexes in the area of study indicate certain geodynamic settings. 1- Cherty-terrigenous and 2- Cherty-tuffaceous deposits accumulated presumably in a back-arc basin between the arc and continental margin. 3- Volcanic rocks of various composition formed within volcanic arc and sea mounts. 4- Cherty-basaltic complexes (MORB and intraplate varieties) and ophiolites correspond to paleo oceanic basin. First three complexes are broadly developed in the Sakmara zone and in the south of Sakmara-Voznesenka zone. Cherty-basaltic complex is widespread in the northern part of the West Magnitogorsk and Sakmara-Voznesenka zones.

New data provide important constraints on the earliest stages of the evolution of the Uralian belt.

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Early Paleozoic evolution of the basement of Southern Alps and of some Austroalpine Units

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The Ordovician magmatism is widespread both in Southern Alps (Serie dei Laghi, SdL, and Orobic basement, OB) and Austroalpine Units (Campo-Languard Nappe, AU), but its origins and geodynamic setting is still debated. Recent paleogeographic models assign this magmatic event to a short Middle Cambrian to Upper Ordovician orogenic cycle, but no evidence of a pre-Variscan metamorphism is present in the studied areas.

All Ordovician granitoids present similar geochemical features: they are granitic to granodioritic in composition with calcalkaline affinity and a metaluminous to slightly peraluminous character. Their REE patterns are enriched in LREE *vs*. HREE and negative Eu anomaly. The isotope geochemistry supports an origin of their magma due to crust-mantle interaction processes. The orthogneisses from OB recall those of the SdL, but their higher Y, Nb and REE contents suggest an involvement of an OIB-type mafic component. The Gneiss Chiari (OB) represent the only exception: they are compatible with a derivation by partial melting of pelites under fluid-absent conditions implying dehydration melting of Ms. The Ordovician magmatism was diachronous in Central Western Alps: the age of the protoliths (U/Pb SHRIMP on Zrc) ranges from 478±6 Ma (SdL) to 462±11 Ma (OB) until 448±14 Ma (UA).

Although the Ordovician orthogneisses show similar geochemical features, their magma sources were different. They were emplaced in different geodynamic settings: those of SdL show features indicating a back-arc environment, those from the OB are typical of an anisotropic transtensive domain.The country rocks of the Ordovician granitoids mainly consist of metasediments. Those of the SdL include Cenerigneiss and Gneiss Minuti (Strona Ceneri Zone) and metabasites (Strona Ceneri Border Zone, SCBZ, similar to the LAG). The protoliths of Cenerigneiss and Gneiss Minuti are geochemically similar to turbidite sands from continental island arcs, in turn derived from the erosion of rocks of different nature (intermediate to acidic source rocks, mafic to ultramafic sources) and age (mainly Neoproterozoic, U/Pb SHRIMP on Zrc). In the SCBZ, the amphibolites have irregular LILE patterns and relatively flat HFSE patterns, recalling some back-arc tholeiites. The leptynites display REE patterns similar to those of the Brevenne metavolcanics. Both amphibolites and leptynites plot in the field of the depleted mantle. They could represent arc/back arc bimodal volcanics from a common mantle source. U/Pb SHRIMP analyses on Zrc from leptynites give an emplacement age of 555±12 Ma, which could be related to the opening of the Rheic Ocean. The protoliths of metasediment from the Orobic basement consist of pelitic (Scisti di Edolo) and psammitic (Gneiss di Morbegno) siliciclastic rocks, which derive from intermediate to acidic Late Neoproterozoic crustal sources. Their REE pattern is uniform with LREE enrichment; their composition is close to the NASC. They present geochemical affinity with sediments from recent trailing-edge margin.

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Quartz veins in the Monts d'Arrée area, Central Armorica: remnants of the Variscan fluid system

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The Monts d'Arrée slate belt (MASB), situated in the western part of the Central Armorican Terrane (Brittany, France), is the result of an early Variscan ('Bretonian'), predominantly contraction-dominated deformation. Seven different quartz-vein generations could be identified and placed within the time frame of the deformation history. The aim of our research is to characterise the different quartz vein generations by means of combined hot cathodoluminescence, stable isotopes and fluid inclusion (cf. microthermometry and Raman analysis) analyses in order to reconstruct the spatial & temporal evolution of the fluid system, during Variscan deformation in the MASB.

Oxygen isotope values of vein quartz and associated host-rock have a mean value of 13.2 and a standard deviation of 1.1‰ V-SMOW. The different vein generations show no evolution throughout the deformation history. Differences between vein quartz and associated host-rock show that there is certainly no buffering by the immediate host-rock, but the abundance of veins throughout the MASB suggests a lot of fluid migration, possibly on a more regional scale.

Primary fluid inclusions, containing an aqueous-gaseous H_2O–CO_2–CH_4–N_2–NaCl fluid,show a gradually changing composition in the different vein generations (*e.g*. an increase in CH_4). The composition of these fluids may thus serve as a proxy for the progressive deformation history of the MASB under evolving metamorphic conditions.

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Hercynian tectonic structure of the Western Carpathians and position of granitic suites

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The tectonic setting of Western Carpathians is a product of two main orogeneses – Hercynian and Alpine. The principal constituents of the Inner Western Carpathian block are represented by the Paleoalpine crustal units (Tatricum, Veporicum, Gemericum) and detached near-superficial nappes. The crustal units are built by crystalline basement, having incorporated fragments of Hercynian tectonic units, and by Upper Paleozoic and Mesozoic cover formations.

Hercynian tectonic units are middle crustal nappes formed during Hercynian collisional processes. They are composed of complexes of metamorphic rocks differing in metamorphic degree and lithology intruded by granitoid bodies at various time. Granitoids may be divided onto suites reflecting their genetic relation to the geotectonic processes such as character of melted source rocks and physico-chemical conditions which operated during their genesis. The age of granitoid suites have been determined on the basis of Rb-Sr, U-Pb zircon isotopic dating and chemical Th-U-Pb probe datings of monazite. Each granitoid suite is formed by several petrographic types of granitoid rocks.

The oldest Early-Hercynian granitoids in age interval 525-470 Ma showing S-type character are ductile metamorphosed. They are represent by orthogneisses located in the Upper Hercynian lithotectonic unit. Meso-Hercynian collisional granitoids (360-340 Ma) which can be divided into three suites (S-type, I-type granites and I/S type) intruded Upper and Middle units. Neo-Hercynian Upper Paleozoic post-collisional granitoids, geotectonically in relation to the extension and large strike-slips tectonics can be divided into following suites: I-type granitoids (age interval 320-303 Ma), suite of Permian post-orogenic A-type granitoids and specialized S-type granitoids (age 280-270 Ma).

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The Variscan orogenic gold deposits of the French Massif Central as markers of a differential exhumation rates recorded at 310-300 Ma

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In the French Massif Central, the main gold event occurred in a short span of time between ca. 310 and 300 Ma, and coincided with the end of WNW-ESE syn-collision extension and ended just before submeridian post-collision extension. On the basis of their depth of emplacement obtained from fluid inclusion studies and other complementary information (*e.g.* textural and structural analysis), two types of Variscan gold deposit can be distinguished: the deep-seated deposits formed in rapidly exhumed crustal blocks (*e.g.* Salsigne, Bourneix-Lauriéras deposits) and the shallow deposits (*e.g.* Châtelet, Les Biards deposits) emplaced in relatively crustal stable blocks where they were preserved from erosion.

Both gold deposit types offer a similar two-stage paragenetic evolution marked by a first As-Fe stage and a second stage with Pb-, Ag-, Cu-, Bi-, Zn- and Sb-rich mineral phases. In deep-seated gold deposits, arsenopyrite-bearing stage 1 records the deepest conditions of formation in the crust, from 15 to less than 9 km. An abrupt transition, recorded between arsenopyrite-bearing stage 1 and native gold-bearing stage 2, is marked by: (a) a pressure drop from a lithostatic regime (stage 1: 15 to 9 km depth) to a hydrostatic regime (stage 2: 5 to 2 km depth) due to rapid host rock decompression, (b) a decrease in temperature, from 450 to 200°C, and (c) a dilution of low- to moderate-salinity CO_2–H_2O ± CH_4 deeply-sourced fluids by near-surface, low salinity fluids. This evolution is attributed to rapid uplift of the mineralized host rocks, and ended with metal gold precipitation. In contrast, shallow-type gold deposits (< 3 km depth) formed under hydrostatic pressure and most of the gold was introduced during Au–arsenopyrite stage 1. Consequently, shallow deposits do not record evidence of significant uplift during their two-stage emplacement or subsequent denudation.

In terms of fluid flow, the gold deposits were associated with crustal-scale plumbing systems that reused a complex network of re-activated regional faults extending down to the lower crust, interconnected at a regional scale. Moreover, crustal heterogeneities and normal faulting related to early emplacement (ca. 340 to 315 Ma) of migmatite–granite domes played a major role in the 3D distribution of gold deposits. For example, Salsigne deposit occurs on the southern flank of the Montagne Noire dome whereas Bourneix and Lauriéras deposits are located above a buried dome recognized by seismic profile. Between ca. 310-300 Ma, exhumation rate appears stronger close to older migmatite–granite domes than far away. Doming, crustal heterogeneities and regional open folds related to normal extensional faults are discussed as possible mechanisms at the origin of these differences in uplift rates.

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Protolith ages of eclogites and granulites from the Orlica-Śnieżnik complex (West Sudetes, Poland): results of an ionprobe U-Pb zircon study

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In the Orlica-Śnieżnik complex (OSC) at the NE margin of the Bohemian Massif small bodies of eclogites and ultra-high-pressure granulites occur closely associated with amphibolite-facies, partially migmatized orthogneisses. This rock association records a complex P-T-t-d evolution that is linked to Variscan and possibly also pre-Variscan metamorphic events. The temporal and structural relationships between the different rock types are yet not fully understood.

Many geochronological aspects of the UHP rocks are unknown or only poorly constrained, including the time of protolith formation, the duration of eclogite-facies metamorphism, the age of distinct P-T stages and the importance of regional age variations. Our main aim in the present study was to unravel the protolith ages of eclogites and granulites. For this purpose, we have applied ionprobe (SHRIMP, sensitive high-resolution ion microprobe) U-Pb zircon dating to samples collected in the surroundings of Międzygórze, Nowa Wies, Nowa Morawa and Stary Gierałtów.

These locations represent almost all known eclogite and UHP granulite occurrences in the Polish part of the OSC. The zircon population of an eclogite from Nowa Morawa yielded a homogeneous $^{206}Pb/^{238}U$ age group that clusters at 341±3 Ma. In all other samples, zircon dating yielded a large spread in apparent $^{206}Pb/^{238}U$ ages (ca. 331-497 Ma), conforming with results reported by Lange *et al.* (2005) for a UHP granulite from the study area. This spread is interpreted to be indicative for variable Pb-loss of magmatic protolith zircon during high-grade metamorphism. The initiating mechanism and the time of Pb-loss has yet to be resolved, however, we consider the last metamorphic overprint at ca. 350-340 Ma as the most plausible cause, although isotopic disturbance during earlier metamorphic processes remains a reasonable alternative. The maximum age within individual samples is interpreted to closely approximate the time of crystallization from a melt, suggesting protolith ages of ca. 500-480 Ma for eclogites and granulites. This age group largely correlates to the age of magmatic zircon of orthogneisses from the study area (ca. 520-490 Ma). Differences in the protolith ages of all three rock types can not unambiguously be documented. The new age data suggest that the magmatic precursors of eclogites and granulites formed largely coeval or only shortly after the protoliths of the associated orthogneisses.

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Geodynamic Regimes and Tectonic Settings for Extreme Metamorphism: Neoproterozoic to Paleozoic

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There is a close relationship between periods of extreme metamorphism in the rock record and the supercontinent cycle. Two models for the behavior of supercontinents are based on concepts introduced by Wilson (continental lithosphere breaks and reassembles along the same line by subduction of an internal ocean—the ‘Wilson cycle’) and Hoffman (a supercontinent fragments and turns inside out by subduction of the complementary superocean).

A Hoffman-type breakup was the process by which the Gondwanan elements of Rodinia were reassembled by subduction-to-collision orogenesis to form the network of Braziliano–Pan-African belts, leaving the orphaned Laurasian continental fragments to combine with each other and then Gondwana to form Pangea at a later time. Granulite–ultrahigh temperature metamorphism (G-UHTM) and eclogite–high pressure granulite metamorphism (E-HPGM) are associated with the Brasiliano–Pan-African belts, although the Trans-Saharan segment of the Pan-African also records the first coesite-bearing eclogite, and sutures within the Anti-Atlas and the South China block record the first blueschists.

In contrast, Wilson cycles dominated during the Phanerozoic, when the continental lithosphere was restricted to one hemisphere. The metamorphic style associated with Wilson cycles during the Phanerozoic is blueschist–high pressure metamorphism–ultrahigh pressure metamorphism (BS-HPM-UHPM), which may be linked with E-HPGM. In the complementary oceanic hemisphere, circumferential subduction creates accretionary orogenic systems that may develop paired metamorphic belts *sensu* Miyashiro with an outboard HP–LT terrane and an inboard HT–LP belt. Limited subduction and choking of subduction by continental lithosphere during Phanerozoic subduction-to-collision orogenesis may reduce transport of water into the mantle wedge, and supress development of small-scale convection and backarcs.

The Iapetus Ocean closed along the Appalachian –Caledonian orogenic system—intervening internally-generated lithosphere was consumed during assembly of Laurentia, Avalonia and Baltica in the Early Devonian forming Laurussia. UHPM has not yet been identified in the southern Appalachians, although HPM is a feature of the final (Alleghanian) phase of orogenesis, but UHPM is common in the Norwegian Caledonides. The Rhenohercynian and Rheic Oceans closed along the Variscide–Altaid orogenic system. In the Variscide sector, intervening internally-generated lithosphere of both oceans was consumed by subduction during terrane export from Gondwana to Laurussia, and was followed by collision between Laurasia (Laurussia and Siberia sutured along the Uralides) with Gondwana to form Pangea. UHPM rocks are common in the European Variscides. The evolution of the South Armorican metamorphic belt will be discussed within this framework.

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Peraluminous granites from the Třebíč pluton in the Moldanubicum

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Peraluminous granites derived from crustal sources are widespread in mountain belts formed by continental collision. In eastern part of the Moldanubicum they are spatially associated with the Třebíč pluton, and two distinct types of medium- to fine-grained, biotite and muscovite-biotite peraluminous granites were distinguished.

(i) Two mica granites (TG) with tourmaline (XFe = 0.38-0.93) concentrated in orbicules or disseminated compose small intrusive bodies and dykes. The accessory minerals include apatite, andalusite, cordierite, ilmenite, zircon, allanite, xenotime and monazite. The tourmaline-quartz orbicules and veins seem to be a product of crystallization of evolved, B-rich fluid during solidus to subsolidus stage of the granite formation and disseminated tourmaline crystallized directly from granitic melt.

(ii) Biotite granites (BG), with garnet typically occur in marginal zone of the Třebíč pluton. They form relatively small bodies (up to several hundred m thick) and are associated with migmatites, biotite granites and aplites. Granites frequently contain tourmaline (XFe = 0.49-0.57) or dumortierite (XFe = 0.23-0.25), further accessory minerals include ilmenite, apatite, zircon, spinel (ZnO 17-29 wt.%), sillimanite and pseudomorphs after cordierite. Euhedral tourmaline grains occur in coarse-grained pegmatoid facies, subhedral intersticial grains in rare quartz + tourmaline ± feldspars orbicules, up to 5 cm in diameter. Garnet occurs as rounded tu subhedral poikilitic grains. The chemical composition (Alm82-84 Sps6-12 Prp5-11 Grs2-1) is similar to garnet from migmatites near the contact with Třebíč pluton (Alm81-85 Sps4-6 Prp9-10 Grs2) and indicate xenocrystic or restitic origin. The geochemical signatures suggest relatively primitive character of both granite types (Rb = 142-505 ppm, Sr = 21-407 ppm, K_2O = 3.8-6.14; Na_2O = 2.97-4.64; Fe_2O_3tot = 0.21-2.04). Zircon saturation temperatures (Watson and Harrison, 1983) 670-833°C obtained for BG are higher then these from TG (638-754°C). The observed range of $\delta^{18}O$ values of both granite types, reflect different evolution TG (9.2-11.7‰) and BG (8.4-8.6‰) melts. Generation BG melt corresponding with emplacement of the Třebíč pluton (338±4 Ma, U-Pb zircon, Kotková *et al.*, 2003). The high CaO/Na_2O (up to 0.66) ratios and lower Rb/Sr are typical for melts generated from plagioclase-rich psammitic rocks (Sylvester, 1998). The mineral assemblage recorded PT conditions at ~5 kbar and ~730°C (calculated by Thermocalc v 3.25). The TG dykes cut across the rocks of Třebíč pluton and that is in a good agreement with obtained CHIME monazite ages 323±9 Ma. Lower CaO/Na_2O ratios (0.05-0.23) in TG are typical for melts derived from clay-rich, plagioclase-poor pelitic rocks (Sylvester, 1998).

The magma was formed by fluid-absent melting during exhumation of Moldanubicum. The relatively variable Rb/Sr, Rb/Ba and XFe ratios indicate conditions of muscovite and biotite dehydration melting. Geotermobaromeric estimations reveal crystallization temperatures 670-730°C and pressure 1-3 kbar.

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Paleozoic tectonics of the Tien Shan and Pamir

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Lower Paleozoic rocks of the present-day Tien Shan and High Asia belonged to the Eastern Gondwana and Alay-Tarim continents, as well as to a few micro continents and oceanic basins. In the Early Paleozoic the Kunlun ocean basin separated the Alay-Tarim and Eastern Gondwana continents.

The Turkestan ocean basin separated the Alay-Tarim continent from the assemblage of micro continents (island arcs with continental crust) and oceanic basins. Rocks of the assemblage composed the Borohoro, Issyk Kul, and Syr Darya micro continents that were separated by the Terskey and Ili oceanic basins. The Terskey and Ili Basins were closed during the collision of the micro continents in the Late Ordovician and Silurian and the Kazakhstan-Kirgiz micro continent was built by the amalgamation.

The Vanch-Jinsha, Kunlun and Turkestan ocean basins were main oceans in the Middle and Late Paleozoic. The Vanch-Jinsha oceanic basin opened in the Early Carboniferous when the Kurgovat-Songpan Block was separated from the Eastern Gondwana. The Vanch-Jinsha Basin expanded rapidly and turned into a vast ocean that spread over two climatic belts of the Earth. Some small basins with an oceanic crust (Hissar, Kalayhumb-Oytag) were originated and closed in the Carboniferous. The fragmentation of the Eastern Gondwana continued in the Permian, when Rushan-Shuanghu rift opened.

A collision between the Kazakhstan-Kirgiz micro continent and the Alay-Tarim continent began in the Moscovian stage. It stimulated the Variscian Orogeny, which spread the Tien Shan in the Late Carboniferous and Permian. Nappes, containing rocks of Turkestan oceanic crust, accretion prism and passive margin sediments had been thrust over the edge of the past Alay-Tarim continent and folded.

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Variscan magmatism in the Alpine Lower Penninic Domain

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Magmatic rocks linked to the Variscan orogeny, mostly granites, are found in all pre-Mesozoic basement units of the Alpine belt. Their typology and distribution in space and time provide important constraints for Palaeozoic geodynamic reconstructions. They also contribute to the characterization of Alpine tectonic units and the identification of their paleogeographic position in the Mesozoic Alpine realm. Overall, the age of the Variscan magmatism in the Alps decreases from external to internal domains of the belt. The oldest ages are recorded in the most external crystalline massifs (330-340 Ma in Belledonne, Aiguilles Rouges); they decrease to 300 Ma in the Aar, 294 Ma in the Gothard, 291 Ma in the Lower Penninic Verampio nappe, and jump down to 270 Ma in middle Penninic (*i.e*. Briançonnais) units (see compilation in Steck *et al*., 2001).

This study focuses on the Variscan magmatic record in the Maggia nappe, which belongs, together with the Verampio, Antigorio, Monte Leone, and Lebendun nappes, to the lower Penninic domain of the Central Alps. The Maggia nappe has an unusual structural position which raises questions about its Tethyan paleogeographical location and domain's affiliation. Its Palaeozoic basement hosts an unusual and spectacular co-magmatic association of (1) a voluminous crust-derived peraluminous granite (Matorello), (2) calc-alkaline, bimodal mafic-acid stocks and composite dykes, and (3) late lamprophyric dykes, the last two of (partly) mantle origin. LA-ICP-MS dating on zircon yielded ages of 297.0±2.6 Ma for the Matorello granite, 298.4±3.6 Ma for the acidic part of the bimodal association, 296.2±2.5 Ma and 299.1±2.9 Ma for an orthogneiss and associated lamprophyre in the locality of Peccia, and 290.5±3.7 Ma for the late lamprophyres. Similar lamprophyres found in gneiss blocks (one orthogneiss block dated at 288.9±7.1 Ma) in the upper sedimentary cover of the nearby Antigorio nappe yielded comparable ages of 290.0±1.3 and 284.8 ±1.7 Ma. Thus, the Maggia nappe is the inferred source of the block-bearing wildflysch series of Antigorio; it was immediately adjacent to the latter in its Tethyan paleogeographic position.

This is supported by Variscan magmatic ages similar to those recorded in the other Lower Penninic nappes. Our results and those of Bergomi *et al.* (2007) show that ages are not decreasing from external to internal parts of the Lower Penninic Domain (*i.e.* Verampio ca. 290 Ma, Antigorio 290-296 Ma, Mte. Leone 302 Ma, Maggia 297 Ma), unlike expected from the general picture stated above. These ages are clearly older than those recorded in more internal zones like the Briançonnais and Austro-Alpine domains.

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Zircon geochronology and Sr-Nd isotopic study of the Ordovician magmatic events in the southern Variscides (Sardinia)

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An extensive in situ U-Pb zircon dating of felsic volcanites coupled with new geochemical and Sr-Nd isotopic data on whole rocks (16 samples) for basic and felsic igneous rocks from Nappe Zone and Internal Nappe Zone of the Sardinia Paleozoic basement has been carried out. The results enable us to describe a succession of igneous events occurred in different and subsequent geodynamic environments, on the ground of stratigraphy, elemental and isotope geochemistry and U-Pb radiometric dating.

In the Internal Nappe Zone, the calc-alkaline intermediate acidic volcanics (Canaglia and Li Trumbetti Units) are interbedded with a supposed Cambro-Ordovician metarenaceous-metapelitic sequence. The radiometric zircon dating yielded ages of ~486 Ma and ~480 Ma. The sequence continues with mafic alkaline metavolcanic rocks, emplaced as sills and stocks into the diamictic metapelite and oolitic ironstones of uppermost Ordovician age and in the black phyllite of Silurian age. The change from calc-alkaline to alkaline magmatism, appears to have occurred, on the basis of trace element and Sr-Nd isotopic contents, following a change from active continental margin to within plate tectonic setting.

In the Nappe Zone, the thick sedimentary sequence of Middle Cambrian–Early Ordovician metasandstones (San Vito Fm., Genn'Argiolas Unit) is covered by rhyolites in turn capped by Upper Ordovician transgressive deposits hosting subalkaline basaltic pillow lavas. A radiometric age of ~490 Ma has been obtained on zircons from the rhyolite. The subalkaline basaltic pillow lavas show strong enrichment in LIL elements, poorly to slight fractionated REE patterns, negative Eu anomalies, and high Th/Ta and La/Nb suggesting an arc-related geodynamic setting. The negative initial εNd values, between -4.88 and -6.54 are consistent with a relatively enriched source with respect to a depleted mantle.

In the Meana Sardo and Gerrei Units, the mafic alkaline lavas occurred within reworked metavolcanites and metasandstones transgressive on Mid Ordovician rhyolites. The mafic alkaline lavas show REE fractionated and enriched patterns, characterized by positive Eu anomalies. An "anorogenic" geochemical signature can be envisaged by the Th/Ta and La/Nb ratios, typical of intraplate alkali basalts. The initial εNd values range between +1.89 and +4.09, supporting a depleted mantle source. A continental rift setting is suggested by the geochemistry of the alkaline mafic rocks.

The Mid Ordovician andesites of the Genn'Argiolas Unit yielded ~465 Ma (U-Pb zircon dating); they display elemental and isotopic data (initial εNd = -5.70, initial $^{87}Sr/^{86}Sr$ = 0.70967) consistent with a subduction-modified mantle source and accord with the early Ordovician consumption of the embryonic eastern Rheic ocean. The andesites are not cogenetic with the Mid Ordovician rhyolites of the Gerrei Unit, the rhyolites are characterized by positive initial εNd values, between +1.17 and +2.44 and low $^{87}Sr/^{86}Sr$ initial of about 0.70751.

The epiclastites of dacitic composition, interbedded with Upper Ordovician–Silurian metasediments of the Gerrei Unit, laying on mid-ordovician metarhyolites yielded the radiometric age of ~440 Ma and likely represent the volcanism associated with the collapse of the Cambro-Ordovician cordillera.

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Structure of the Lithosphere of the Alcudia area (ALCUDIA Transect), Central Iberian Zone (Iberian Massif)

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A new project on the structure and nature of the lithosphere of the central Iberian Zone is being developed, the ALCUDIA Transect. It includes the acquisition of a deep high-resolution seismic reflection profile and, detailed geological mapping, cinematic, petrologic and geochemical studies, together with other geophysical studies (potential methods). This new transect will extend the previous IBERSEIS Transect towards the northeast, completing 500 km of deep seismic profiles, crossing the southern half of the Iberian Variscides. The transect crosses some important structures, such as the Toledo fault, Puente Génave-Castelo de Vide fault, Alcudia anticline, Almaden syncline, Pedroches batholith and some major magnetic anomalies.

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The Badesi - Li Paùlis shear zone: timing constraint of the central sector of the Variscan axial zone in Sardinia (Italy) from zircon and monazite Pb geochronology

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An analogous polyphase tectonic evolution has been documented in the central sector of axial zone in Sardinia. After the D1 deformation phase developed during the collisional phase, all the metamorphic complexes have been affected by a change in the compressive direction from orthogonal to parallel to the main trend of the belt. As consequence an important transpressive tectonic setting affects the axial zone of the Variscan belt in Sardinia producing the large amount of exhumation of medium- and high-grade metamorphic rocks (Carosi *et al.*, 2005).

Recent structural and kinematic data (Frassi, 2006) reveal that the central transect has been interested by a more complex post-collisional evolution. Two different systems of shear zones with the same direction and dip but opposite sense of shear have been documented in the Badesi - Li Paùlis area. Geometric relationships reveal that the top-the-SE shear system, developed initially during the D2 deformation event, was active for a long period of time until the later deformation phases at high structural levels. On the other hand textural and geometric features reveal that the mylonitic belt with top-to-the NW sense of shear develops before or slightly contemporaneous to the dextral shear system. To constraint the chronology of the shear zones activity in this sector of chain 5 samples have been collected in dextral and sinistral shear zones.

Zircons and monazites crystals have been analyzed using laser ablation (LA)-ICPMS. Although the two minerals record the same Carboniferous events, zircons seem to better constraint the collisional stage whereas monazite the later events at the lowest metamorphic conditions. D1 deformation phase was constrained at ~350 Ma (zircon) whereas the post-collisional stages develops from ~325-330 Ma (the early activation of sinistral shear zones) to ~300 Ma (monazite) which could be related to a later phyllonitic event.

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The interplay between deformation and metamorphism in collisional orogens: an example from the Variscan Basement of Sardinia (Italy)

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Geometrics and kinematics data in the axial zone of the Variscan belt in Sardinia highlighted the occurrence of a D2 transpressional deformation affected by later folding phases both in the orthogneisses and in the surrounding micaschists and paragneisses. Transpressional deformation is characterized by dextral shearing at 315-320 Ma (Carosi & Palmeri, 2002; Di Vincenzo *et al*., 2004; Carosi *et al.*, 2005) and F2-F3 fold interference pattern producing a telescoping and the bending of the Barrovian isograds.

The new structural picture allows to explain the occurrence of previously unrecognized large outcrops of staurolite-bearing micaschists nearly 10 km southward with respect the first appearance of staurolite described in the classical metamorphic framework of northern Sardinia (Franceschelli *et al.*, 1982; Ricci *et al*., 2004).

Moreover, the overall Barrovian sequence in the field from kyanite to sillimanite is only apparent, since kyanite was pre-S2 and sillimanite from syn- to post S2. Whereas kyanite porphyroblasts grew during increasing pressure and temperature, sillimanite grew during the decompressive stage of medium-pressure rocks. The existing petrological data and P-T-t paths support this evolution (Carosi & Palmeri, 2002; Di Vincenzo *et al*., 2004; Ricci *et al*., 2004). In particular, the D2 transpressional deformation related to the exhumation stages of deep seated rocks, strongly affects the occurrence and distribution of metamorphic rocks in the inner part of the belt during post-collisional tectonics.

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Tectonic regimes in the NE-Iberian segment of the Variscides: regional implications for the belt zonation

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The basic trends of the Variscan zonation are well established across central and Western Europe. However the setting of some massifs where Variscan rocks are exposed are often excluded or vaguely located from maps correlating different major areas. There are three main reason for this: 1) some massifs are located in Alpine belts (*e.g.* Alps and Betics) and the effects of reworking make difficult the reconstruction of original Variscan and pre-Variscan geology. 2) Some massifs were subjected to rotation and translation in eo-Alpine (*e.g.* Iberia) or late-Alpine (*e.g.* Sardinia) times. 3) The basic correlation is based on the main structures of major Variscan massifs while the geology of minor massifs is often not sufficiently taken into account. All this three circumstances are applicable with different degree to the Variscan massifs of NE-Iberia (Pyrenees, Catalonian Coastal Ranges, Iberian Chain and Minorca).

Particular tectonic features are presented which are relevant for these massifs to be coherently placed. Among them, (i) the transpressional character of main and late deformations and the association of these with HT/LP metamorphism and related magmatism, and (ii) the presence of rocks and structures that do not correspond to an external position in the belt indicate that slight changes in the Variscan belt zonation and interpretation.

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The significance of the Ordovician deformations and the beginning of the Variscan cycle in the Pyrenees

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In the Pyrenees an extensional scenario can account for the large volume of plutonic rocks emplaced during Early Ordovician times, as in other segments of the European variscides. This widespread magmatic episode can be linked to an Early Ordovician rifting event related to the break up of the northern Gondwana margin and the detachment of Avalonia. After this Early Ordovician magmatic event and prior the development of the main Variscan folding we have characterized two deformational events: a Middle (?) Ordovician folding event and a Late Ordovician fracture episode. The Middle (?) Ordovician folding event gives rise to N-S to NE-SW oriented, metric to hectometric sized open folds, neither without cleavage formation nor related metamorphism. These folds can account for the deformation and uplift of the pre-Upper Ordovician sequence, the formation of the Upper Ordovician unconformity and controls the orientation of the Variscan main-folding phase minor structures (fold axes and intersection lineations). The Late Ordovician extensional tectonic event has been recently documented. A set of normal faults affect the lower part of the Upper Ordovician series, the basal unconformity and the underlying Cambro-Ordovician sediments. Displacement of the faults progressively diminishes upwards of the series and dies out in the upper part of the Upper Ordovician rocks, indicating that faults become inactive during the Late Ordovician, before deposition of the Ashgillian rocks. The normal faults can be related to the Upper Ordovician volcanic activity widely described in the Pyrenees.

From these results, in the Pyrenees two individual extensional events can be identified (Early Ordovician and Late Ordovician to Silurian), separated by a Middle Ordovician deformational event instead of considering a continuous extensional regime through the entire Ordovician and Silurian times. These results point out to a more complex evolution of the northern Gondwana margin during the Ordovician, as suggested by some reconstructions.

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U-Pb SHRIMP zircon ages for late Cadomian and Lower Ordovician magmatism in the Eastern Pyrenees: new insights in the pre-Variscan of the northern Gondwana margin

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New geochronological data in six samples from low- to medium-grade metamorphic areas of the Eastern Pyrenees (Canigó, Roc de Frausa and Cap de Creus massifs) confirm the presence of two significant pre-Variscan magmatic events: Ediacaran-Lower Cambrian and Lower Ordovician. The Ediacaran-Lower Cambrian (575-540 Ma) magmatism is represented by metavolcanic plagioclasic gneisses ("metatuffs", 540-560 Ma) coeval with the deposition of the Canaveilles series and sheets of granitic orthogneisses emplaced in the lower part of the sedimentary series. The metatuffs are spatially associated with metabasites. Both lithologies occur as massive layers of lava flows, discontinuous lense-shaped subvolcanic gabbroic bodies or volcanoclastic tuffs interbedded in the lower and middle part of the pre-Ordovician metasedimentary succession.

This magmatism is bimodal and has tholeiitic and calc-alkaline affinity. The granitic orthogneisses represent thick laminar intrusions of subaluminous (~575 Ma, Port orthogneiss) and aluminous (560 Ma, Mas Blanc orthogneiss) composition. Lower Ordovician magmatism is represented by laccoliths of aluminous granitic orthogneisses emplaced in the middle part of the pre-Ordovician succession (~475 Ma, Roc de Frausa orthogneiss). These geochronological data reveal the existence of an Ediacaran metasedimentary sequence (the Canaveilles series) and late Cadomian magmatism in the Pyrenees and allow their correlation along the Eastern Pyrenean massifs. The data also show different ages (from Ediacaran to Lower Ordovician) and significance for the large bodies of granitic orthogneisses intruded at different levels of the series.

Both events represent the final stages of the Cadomian orogeny and the beginning of the Variscan cycle, respectively, in the Eastern Pyrenees and can be related to the dynamics of a probable transpressive basin in a back-arc context tied to the evolution of the northern Gondwana margin. A Cambrian rifting event linking both cycles has not been identified in the Pyrenees. The results of this work provide a better fit of the pre-Variscan sequences of the Pyrenees with the Iberian Massif, which is characterized by the large development of Precambrian series and the presence of Neoproterozoic to Ordovician volcanic and plutonic bodies, and allow their comparison to other pre-Variscan complexes in Europe.

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The emplacement of the granite-migmatite dome of the Montagne Noire Axial Zone (French Massif Central): new insights from AMS and petrostructural studies

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In the southern French Massif Central, the Montagne Noire Axial Zone is a NE-SW elongated granitic-migmatitic dome surrounded by recumbently folded Palaeozoic sedimentary series with a southern vergence. The Axial Zone is composed of micaschist and augen gneiss, cordierite migmatite, and anatectic Laouzas granite from edge to centre, respectively. Syn- to late kinematic granitoids intrude the dome. Anisotropy Magnetic Susceptibility (AMS) study (135 sites and almost 830 cores) and petro-structural study have been carried out on anatectic cordierite/garnet granites and migmatites. Thermomagnetic experiments indicate that biotite is the main carrier of the AMS fabric.

The attitude of the magnetic foliation complies with the preferred orientation of biotite, schlierens, enclaves and host-rock septa in granite and with migmatitic foliation. The AMS foliation confirms the shape of the Axial Zone inferred from the migmatitic and gneissic envelopes. The southward dipping foliation recognized in both flanks is in agreement with a asymmetric dome, overturned to the North. Conversely, the magnetic linear fabric exhibits a contrasted pattern with a dominant NE-SW trend, and also a N-S one. The different models invoked to account for the tectonic setting of the Montagne Noire Axial Zone will be discussed on the basis of these new AMS results as well as petro-structural observations.

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Interpretation of deep orogenic fabrics superposed in continental accretion wedge (NE Bohemian Massif)

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We examine progressive development of orogenic fabrics in large scale continental accretionary wedge based on detailed structural, microstructural analysis and existing petrological and geochronological datasets. Orogenic fabrics are examined in eclogites, HP granulites, gneissified mid-crustal granitoids and upper crustal schists. All rock types reveal existence of early flat fabrics associated with WNW-ESW stretching developed in peak pressure conditions in eclogites, granulites and amphibolite facies rocks. In mid-crustal gneisses this event is associated with complete reworking, syntectonic partial anatexis and high grade mylonitisation while in supracrustal schists first Barrovian assemblage developed.

These fabrics are subsequently affected by crustal scale folding with NNE-SSW oriented hinges leading to alternations of eclogite and granulite facies anticlines, medium grade mylonitic gneisses and supracrustal schists synclines. The degree of folding increases towards eastern continental buttress and it is associated with alternations of oblate and prolate fabrics in gneisses and retrogression of lower crustal and continuous prograde metamorphism in supracrustal rocks. This deformation pattern results from post buckle flattening of crustal folds leading to constriction in fold hinges and flattening to fold limbs associated with vertical material transfers in cores of anticlines and synclines.

Finally, the vertical fabric is heterogeneously affected by flat amphibolite to greenschist facies flat mylonitic fabric under medium to low pressure conditions. This fabric is interpreted to result from ductile thinning of actively vertically extruding orogenic material and collapse of orogenic lid. This complex structural pattern is interpreted in terms of continental subduction driving crustal material circulation in large (100 km wide) crustal wedge with: 1) early fabrics recording inflow of material into deepest apex of continental wedge, 2) vertical fabrics and folding associated with vertical extrusion parallel to continental buttres associated with local vertical exchanges of deep and shallow crustal materials and 3) ductile thinning of vertically extruded rocks resulting from lateral spreading of orogenic lower crust in mid crustal levels. Finally, we propose a tectonic model suggesting dynamic development of crustal fabrics, prograde and retrograde PT evolutions associated with differential displacements of crustal segments and mechanical role of far field forces on building of lithospheric scale continental wedge structures.

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The Autun Shear Zone (northeastern Massif Central, France): age, kinematics, significance and regional correlations

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Located in the northeastern tip of the French Massif Central (Morvan area), the Autun Shear Zone consists of an N70°E-trending, 500 m-wide, mylonite belt separating Variscan migmatites and granites to the south from Late Carboniferous (Stephanian) to Early Permian (Autunian) sedimentary deposits of the Autun basin to the north. The contact between the mylonite belt and the Autun basin is either a brittle fault or an onlap of the Permian deposits on the shear zone. The age of the Permian strata unconformably covering the shear zone can be estimated at about 295 Ma (lowermost Autunian). The ductile deformation is therefore older than about 295 Ma. To the south of the mylonite belt, the deformed granites have yielded a monazite U-Th/Pb chemical age of 318±4 Ma. The age of the ductile deformation is thus bracketed between 320 and 295 Ma.

One of the pending questions is the exact timing of the mylonitic event. Either deformation took place during the late stage of the granitic pluton emplacement in syn-tectonic setting, or is the ductile shearing overprinted upon an already emplaced and cooled pluton. In the undeformed granite exposed to the south of the shear zone belt, the magmatic foliation, striking N45°E and dipping 80°NW progressively parallels to the mylonitic foliation in the shear zone. In parallel to this spatial evolution, the textural evolution of the mylonitic fabric from the undeformed but magmatically oriented granite to the strongly foliated and lineated ultramylonite appears also gradual. This progressive transition from undeformed to deformed rocks suggests that the deformation took place during the late stages of pluton emplacement.

In the Autun Shear Zone, the mylonitization affects the migmatite, the post-migmatite two-mica granite, leucogranite and granite-derived dykes. Whatever the protolith, the mylonites are characterized by a foliation striking N60 to N80°E and dipping 45 to 80° to the north and by a lineation trending consistently N45°E. The direction of shear is therefore oblique since it combines a strike-slip component and a dip-slip component. Unambiguous top-to-the-NE shear sense criteria observed on hand sample sections and thin sections indicate that the sense of shear is normal and right-lateral. Further east of the study area, beyond the Oligocene Bresse graben, in the La Serre massif, the Median Fault Zone includes a mylonite belt whose geometry, internal fabrics and sense of shear are similar to those of the Autun Shear Zone. Therefore, the Autun Shear Zone and the La Serre Median Fault Zone constitute a unique Late Paleozoic shear zone subsequently separated by Oligocene extensional tectonics. The NE-SW trending Autun-La Serre ductile shear zone accommodates the Late Carboniferous post-orogenic extension in the eastern part of the French Variscan belt.

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Presence of large north-verging folds in the eastern sector of Pallaresa massif and the western sector of Hospitalet dome: main features and tectonic implications. Andorra, central Pyrenees

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The Pallaresa massif and Hospitalet dome are large E-W trend variscan structures, located in the Axial zone of the central Pyrenees. Both structures are developed in Cambro-Ordovician metasedimentary rocks. Two vertical different structural domains have been recognized traditionally in the Axial zone of the Pyrenees: i) infrastructure, seated deep with medium to high metamorphic grade and main flat-lying foliation and ii) suprastructure, a shallow domain with lower metamorphic grade and main steep foliation. Different and contradictory interpretations have been proposed to explain this structural zonation (Carreras & Capellà, 1994). Nowadays, the main disagreements refer to: timing of deformation, tectonic regime and deformational event giving rise to the flat-lying infrastructural foliations.

The geological mapping, the new limbs map, detailed cross sections and microstructural study have allowed us to recognize kilometric-scale recumbent north verging folds with E-W trend. The main foliation in the study area is linked with these folds. Moreover in this study we have been able to identify three deformation events to all scales and to establish the deformational sequence for the studied area. So the first structures are slaty cleavage (S1), observed in thin section, associated with south-verging structures. This cleavage is defined by lattice preferred orientation of quartz and mica grains. Under a microscope we can see this slaty cleavage deformed by a crenulation foliation (S2) which is associated with north verging folds. Similar structures were deduced by sedimentary polarity data at outcrop scale. This S2 foliation is ubiquitous in the study area and can be considered the main foliation. Both the D2 folds and the associated main foliation are folded by upright folds with NE-SW to E-W trend. This folding can be observed to all scales. Thin sections show another crenulation foliation associated with upright folds (S3).

The relation of deformational events with metamorphism has been studied in thin sections. Many rocks show axial planar foliation defined by preferred orientation of biotite and micas parallel to the axial plane of D2 folds and biotite grain folded by S3 foliation. Therefore, we can consider that the metamorphism in this area is approximately simultaneous with main deformation (D2) development and earlier than third deformation event.

In conclusion, we think that the new macrostructural features described in this work for these sectors included traditionally in the infrastructure, can be interpretated essentially as a result of crustal shortening and brings into question the crustal extension models previously presented by others authors.

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New geochronological constraints on Variscan orogenic evolution deduced from the Tanneron massif study (SE France)

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Detailed $^{40}Ar/^{39}Ar$ dating on single grain of muscovite and conventional U-Pb monazite dating were performed in the Variscan Tanneron massif (SE France) to precise the timing of magmatic and metamorphic events, and the post-collisional exhumation history. A pre-Variscan event is recorded by monazites from an orthogneiss sample, which yielded ages from 440 to 410 Ma.

The $^{40}Ar/^{39}Ar$ plateau ages on muscovite are scattered from 321±2 to 302±2 Ma, reflecting an heterogeneous exhumation of the crust lasting about 20 m.y. during late Carboniferous times. The closure of the K-Ar system in muscovite occured around 311-315 Ma in the eastern part of the massif, and at around 317-321 Ma in the central part. The corresponding laterally discontinuous cooling path may be ascribed to differential exhumation of two crustal blocks controlled by a major ductile fault separating the two domains. In the western part of the massif, $^{40}Ar/^{39}Ar$ plateau ages on muscovite decrease from 318 Ma to 304 Ma, approaching the Rouet granite age of 303.6±1.2 Ma. Such age distribution can be explained by the occurrence of a thermal structure spatially associated to the magmatic complex. These ages argue in favour of a cooling of the magmatic body and gneiss of the dome core below ~400°C about 14 m.y. after the western Tanneron country rocks. This late closure of the muscovite K-Ar chronometer in the dome relative to its surroundings rocks is related to the emplacement of the magmatic body, and fold amplification due to an uprise of partly melted rocks in the core of a crustal-scale anticline.

These results clearly outline that various processes contribute to the exhumation of the lower crust in the later stage of collision. During the first stage between 320-310 Ma, post-collisional exhumation is controlled by differential motion of tectonic blocks limited by ductile shear zones. This event could be related to orogen parallel shearing associated with crustal-scale strike-slip faults and regional folding. Final exhumation at 300 Ma takes place within a syn-convergent tectonic context in which doming is associated to anatexis and mantle-derived magmatic intrusions, which took place in the core of antiform structures.

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The southern European Variscan belt: an analog of the Himalayan syntaxes?

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The Variscan orogeny results from the collision of Gondwana and/or Gondwana derived-microplate with Laurussia megacontinent (Matte, 2001). The early orogen history consists of nappe stacking and subsequent crustal thickening associated with regional metamorphism until middle Carboniferous times. In contrast, the late Carboniferous period is mainly characterized by voluminous granite and migmatite emplacement in LP-HT conditions. This later evolution results in intense erosion of exhumed crustal segment and formation of intra-continental sedimentary basins along extensional faults. In the French Massif Central, this late evolution is generally interpreted as the reequilibration of the Variscan crust during a post-collisional extensional regime (Faure, 1995). Extension is generally invoked for the formation of dome structures such as the Montagne Noire and Velay granite-migmatite complexes (Echtler and Malavieille, 1990; Ledru *et al.*, 2001).

New structural, petrological and geochronological data from the Maures-Tanneron massif (SE France) allow us to propose that dome structures are the result of syn-convergence exhumation of the lower crust coeval with crustal-scale folding and erosion in late Carboniferous times (at c. 320-300 Ma). A similar evolution is also described in the External Crystalline Massifs of Western Alps, Corsica and Sardinia located in the southeastern part of the Variscan belt.Therefore, metamorphic, geochronologic and magmatic late Variscan evolution are similar to what is observed in the NW and NE Himalayan syntaxes and towards the core of the thickened crust of the Tibet region.

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Migmatites and partial melting in the Variscan chain of NE Sardinia, Italy

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The axial zone of the Variscan chain of Sardinia mainly consists of igneous- and sedimentary-derived migmatites which underwent polyphase deformation during the Variscan orogeny.

An old gneissose layering (D1) is followed by a composite D2 deformation, associated with tight folds and regional S2 schistosity. D2 deformation is followed by later folding (D3) associated to more or less pervasive foliation. The Sardinian migmatites show a clockwise P-T path with maximum pressure of about 1GPa and thermal peak up to 700°-750°C. Ages of about 345 Ma and 325 Ma have been tentatively attributed to the thickening stage and to the thermal peak in the highest grade zones, respectively.

The leucosomes of the metasedimentary migmatite range from trondhjemitic to granitic compositions. They consist of variable amounts of plagioclase, quartz, K-feldspar, biotite, garnet, and retrograde muscovite. The Al-silicates encountered in the leucosomes are fibrolitic sillimanite and subordinate kyanite. Accessory minerals include zircon, apatite, rutile, and monazite. H_2O-fluxed melting, followed by muscovite dehydration melting, could explain the formation of trondhjemitic and granitic leucosomes in the Sardinian Variscides.

Ordovician granitoids of NE Sardinia show incipient to extensive partial melting. The leucosomes, mainly granitic in composition, are folded by D2 deformation or intruded along shear zones. Worthy of note is the occurrence of amphibole-bearing migmatites formed by partial melting of a biotite + plagioclase + quartz assemblage with the contribution of an H_2O-rich fluid phase.

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Geochemistry of metabasites in the Variscan basement of NE Sardinia, Italy

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Metabasite lenses widespread occur within the Migmatite Complex and in the micaschists and gneisses of the Posada Valley, in the axial zone of the Variscan chain of NE Sardinia. These rocks often preserve eclogite and/or granulite facies relics.

The metabasite of Montiggiu Nieddu (a few km north from Olbia) consists of a sequence of banded amphibolites with minor ultramafic cumulates. The trace element patterns define a flat trend characterized by selective enrichment of incompatible elements of low ionic potential (Sr, Rb, Ba, Th) and depletion in K, Cr, Ni, as well as other elements of low ionic potential.

The amphibolite of Monte Plebi (Olbia) consists of a banded sequence of alternating ultramafic, mafic and silicic layers with geochemical features similar to those of the leptyno-amphibolite complexes. These rocks are characterized by low Nb, Ta, Zr, Hf, and high LILE/HFSE ratios. The mafic and ultramafic layers show slight and strong LREE enrichment, respectively, while the silicic layers have lower total REE content, as compared to the previous ones.

Most of the metabasite lenses with eclogite facies relics (Punta de li Tulchi, Punta Tittinosu), as well as the amphibolite bodies cropping out along the Posada Valley, have tholeiitic affinity. On the contrary, a decametric metabasite lens cropping out at Punta Orvili (near to Posada village) have alkaline affinity. The protolith emplacement age of the metabasite of Punta de li Tulchi is Ordovician. The metabasites are often associated to Ordovician orthogneiss ranging from granitic to granodioritic compositions.

The geodynamic significance of the acidic and mafic magmatism will be discussed in the light of the Variscan orogeny of Sardinia.

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Late Variscan tectonic and stress field evolution in the Ardennes Allochthon of the North Variscan Front, Belgium

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The evolution of fold belts frequently involves orogen-parallel strike-slip movements at some stage of the orogeny. One of the best examples is the so-called Altaïd Collage of the Central-Asian fold belt in which important lateral movements occurred during the Late Paleozoic. This also the case for the Variscan fold belt in Western Europe, where a late Variscan stage of dextral strike-slip movement has been evidenced. Within the Ardennes Allochthon of the North Variscan Front in Belgium, revision of the geological map and kinematic analysis of fault-slip data collected at various places evidence also a rich Late Variscan tectonic history.

Both map-scale structures and minor brittle structures show that the late stages of the Variscan history include normal faulting at a high angle to the main tectonic trend as well as dextral transpressional deformation under E-W to ESE-WNW compression, oblique to the general structural trend. Structures intermediate between these two types also exist, suggesting a progressive evolution from one end member to the other. The relative timing of these deformations is some times difficult to assess. Depending on the location in the Ardennes Allochthon, normal faulting appear either before or after the transpressional deformation. A stress field with normal faulting regime (Sigma 1 axis more inclined than 45° from the horizontal) was, however, also operating during the main Variscan deformation stage as shown by major folds with subhorizontal axial planes in the southern flank of the Dinant Synclinorium/ northern flank of the High Ardenne and subhorizontal to weakly inclined (< 30°) slaty cleavage in the High Ardenne massif along the Meuse river.

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Small-scale transpressional and transtensional shear zones: biaxial volume loss and gain; structures and fabrics

DEWEY John *

Transpressional and transtensional shear zones at the lithospheric scale Involve bulk constriction because of isostatic forces. At the small (outcrop and small regional) scale, transpressional and transtensional shear zones must be biaxial (plane strain). Therefore, at the small-scale, transpression involves volume loss and transtension involves volume increase. Transpressional shear zones combine oblique Ramsay and Graham S fabrics, extensional crenulation cleavages, S/C fabrics, and Riedel (R) Shears that thin the shear zone, whereas transtensional shear zones combine anti-Riedel (R') shears and kink bands, and P shears that thicken the shear zone. Volume loss is effected by solution cleavage; volume gain is effected by en echelon tension gashes.

In transpression, the shear zone loses quartz and/or calcite; in transtension, the shear zone gains quartz and/or calcite. All these structures and fabrics can be achieved by compatibility between zone boundary walls with no boundary wall slip. There are simple geometric techniques for estimating volume loss or gain from the transport direction (slip vector), determined from the tip angles of tension gashes and S fabrics, and from quartz/calcite in tension gashes and clay/mica concentrations on S films.

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The structural and sedimentary record within the Ancenis basin (Armorican Massif, France): from early Devonian rifting to middle Devonian collision

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Isotopic ages from high-pressure metamorphic rocks in the Variscan belt (Massif central and Armorican Massif) indicate an Early – to Middle Devonian age for the early stages of the plate convergence. However, the sedimentary record of this event is poorly known, because Devonian sediments from the internal zones were largely deformed and metamorphosed during the Variscan orogeny. The Ligerian Domain, located along the suture zone between Armorica and Gondwana, preserves uncleaved and unmetamorphosed sedimentary sequences covering the Ordovician to Carboniferous period. It thus offers us a unique opportunity for correlating the nature and timing of deformation recorded in the sedimentary sequences with the metamorphic record of the internal zones.

Ordovician to Devonian sediments outcrop along the boundary of the Ancenis Carboniferous basin. Several models for their structure have been proposed, the prevailing interpretation being one of huge olistoliths at the bottom of the Carboniferous basin (Dubreuil, 1980). The main results of our combined stratigraphical and structural study of the pre-Carboniferous sediments drastically challenge this view.

1. The pre-Carboniferous sediments are not olistoliths at the base of the Carboniferous basin, but define coherent sequences that can be followed for several kilometres along strike and constitute the basement of the Carboniferous of the Ancenis basin.

2. Two units are identified. The southern unit consists of Ordovician marine sediments unconformably overlained by Devonian reefal carbonates (Emsian) followed by arkosic sandstones (Emsian to Eifelian). The northern unit consists of an Upper Ordovician (Ashgill) to Early Devonian (Emsian) condensed sequence.

3. The southern unit represents the Palaeozoic cover of the Proterozoic basement of the Mauges Unit. The northern unit, in reverse position, has been thrust over the southern unit.

4. The angular unconformity identified between the Ordovician (Caradoc-Ashgill) siltstones and the Devonian reefal limestones is interpreted here as evidence for an Early Devonian rifting, possibly related to the opening of a back-arc basin (Saint-Georges-sur-Loire) associated to a north-dipping subduction zone.

5. Petrographical (coarse- to fine-grained, immature, feldspar-rich sandstones), sedimentological (flood deposits in the front of a submarine delta) and palaeontological (abundant debris of early tracheophytes) data on the Early to Middle Devonian sandstones imply the proximity of an emerged land, thus recording the earliest evidence for mountain erosion in the Variscan belt. This is consistent with the isotopic ages of the oldest eclogites from the Variscan belt (*e.g.* la Bessenoits: 408±7 Ma according to Paquette *et al.*, 1995).

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Geodynamic significance of the top-to-the NW thrust tectonics in the French Massif Central

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In Late Devonian-Early Carboniferous times, the French Massif Central was widely affected by a D2 top-to-the NW event that reworked an early top-to-the south nappe stacking D1 event of Early Devonian age. Recent studies dealing with metamorphic petrology, structural geology and seismic profile survey have shown that this top-to-the NW shearing was related to a compressional tectonic setting. This D2 tectonic event has recently been interpreted in terms of nappe tectonics in which the Thiviers-Payzac Unit (TPU) overlies a relative autochthon composed of the Upper Gneiss Unit (UGU) and the Lower Gneiss Unit (LGU). The (TPU) experienced a prograde P-T path with maximum conditions around 600°C and 7-9 kbar.

Nevertheless, the geodynamic setting of D2 still remains poorly understood. Several lines of evidences show that the TPU was not the uppermost unit implied in the D2 event. In the S. Limousin, the Génis Unit that overlies the TPU, displays mafic rocks with geochemical MORB signatures, cherts and Late Devonian limestone associated with undated terrigeneous sediments. The Génis Unit has been considered as an olistostrome with ophiolitic rocks resedimented in a Late Devonian or Early Carboniferous terrigeneous matrix. Moreover, Devonian MORB basalts are also found in the Chantonnay Syncline in Vendée. These mafic rocks are coeval with calc-alkaline volcanic and sedimentary rocks. These data raise the possibility that a distensive tectonic event implying an arc/back-arc system took place prior to Late Devonian. Then the oceanic basin was closed in Late Devonian-Early Carboniferous by the D2 compressive event.

The question of the exact location of this oceanic domain remains unsettled. Some answers might be provided by geophysical data. NW-SE trending positive magnetic and gravimetric anomalies are found below the northern margin of the Mesozoic Aquitaine Basin. These anomalies have already been previously interpreted as due to mafic or ultramafic masses of Variscan age, possibly representing the relics of a limited oceanic domain. We propose that in the S. Limousin, the D2 event is responsible for the closure of this oceanic domain in a similar way to the Brévenne oceanic area in NE Massif Central.

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Paleomagnetic constraints on the evolution of the Variscan belt in Carboniferous times

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Paleomagnetic investigations on Late Devonian – Early Carboniferous volcanic, plutonic, metamorphic and sedimentary rocks from central and western Variscides show that most have been remagnetized in middle-late Carboniferous times. Three major overprint phases have affected rocks of the Armorican Massif, Central Massif, Vosges, Black-Forest, Odenwal, Spessart and the Bohemian Massif. These phases occurred after main amalgamation of Armorica – North Gondwana collage responsible for the development of Variscan orogenic root system, i.e. in the interval between 340 Ma and 300 Ma.

Our investigations demonstrate that geochronologically and geologically unconstrained paleomagnetism cannot provide satisfactory information about evolutions of orogenic systems. For instance, the large majority of the published poles obtained in Cambrian to Devonian series of the Bohemian massif fit with the poles of the middle-late Carboniferous overprints and cannot be considered as Early Paleozoic in age. Only in two specific areas, the northern Vosges and the Central Bohemian Massif, Early Carboniferous granitoids and metamorphic rocks emplaced in the time range 340-330 Ma rocks have escaped the late overprinting phases and allow deciphering the tectonic evolution during the Carboniferous convergence and subsequent tectonic evolution of assembled system. These paleomagnetic results are in favour of the following evolution:

1) the interval of 335-330 Ma is characterized by 50° counter-clockwise rotations of the assembled Variscan collage, associated with activity of large dextral strike slip faults (presently striking NW-SE: Bray, Bavarian, Elbe faults).

2) Interval of 330-325 Ma marked by south-eastward tilting associated with activity of NE-SW striking normal shear zones (*e.g.*, the Tepla- Barrandian or Central Vosges collapse). Structural investigations show that this event is connected with subsurface horizontal flow in the root domain.

3) Clockwise rotation by about 70° of the whole belt, associated with N-S shortening Variscan belt in between converging Gondwana and Baltica. This event is manifested by development of wide sub-vertical deformation zones and important anatectic-magmatic event. N-S shortening related deformation is followed by major and pervasive magnetic overprinting.

4) Finally, the time interval between 315-310 Ma is characterized by a new phase of clockwise rotation by ~45° associated with important magmatic and tectonic activity along marginal parts of orogenic system. During and after docking of the Rhenohercynian series onto the London-Brabant block, northern Europe and Baltica participate to this clockwise rotation until Mid-Permian.

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Structure of the central and western Europe Variscides in the light of gravimetric, magnetic and seismic data

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About 65 percent of the Paleozoic basement of Western and Central Europe is covered by sedimentary sequences and can be only investigated by geophysical methods. We present a new tectonic map of the Central European Variscides from the Paris Basin to the Polish Sudetes based on transformed maps of the gravimetric and magnetic anomalies (derivatives, downward and upward continuations, analytical signal) constructed using rock densities and induced and remanent magnetizations. The tectonic model of the Variscan crust is based on three deep reflection seismic sections, the ECORS-DEKORP profiles trough the Saar-Loraine basin, the Vosges and Black Forest massifs, the DEKORP2 profile through the Mid-German-Crystalline-Rise and the Kraichgau gravity high, the DEKORP9502/9503 and 9HR profiles through the granulite zone, the Tepla Barrandian and the Moldanubian of the Bohemian Massif.

2D and 3D gravimetric and magnetic modelling was performed along these seismic sections in order to image deep structures which are also shown in the interpretative tectonic map. From the gravity and magnetic data, tectonic maps and seismic sections the following main features arise:

- Succession of two south-east dipping subduction zones seen on the western and eastern seismic sections and confirmed by 3D modelling of gravity and magnetic anomalies plunge beneath the margin and the thickened orogenic root. The reflective zones are associated with heavy anomalies and magnetic structures which in the southern zone corresponds to Devonian ultramafic and high grade rocks of the subducted oceanic slab.

- Large dextral wrenching along the NW-SE striking Bray fault zone, the Franconian and south Bohemian fault zones, the Elbe zone and the Teisseyre-Tornquist zone in the northeast affected the belt during the late Devonian-Early Carboniferous subduction of Rhenohercynian ocean beneath the Saxothuringian margin. As a consequence: (1) the crystalline ridge in the north of the Vosges and the Mid-German-Crystalline-Rise, (2) the Saverne-Sarrebourg and Kraichgau heavy structures and, (3) the south-Bavarian basement beneath the Molasse Basin basin correspond to (1) western continuation of the Erzgebirge, (2) the Tepla-Barrandian upper crust and (3) Brunia continent. According to paleomagnetic results in northern Vosges and Bohemian massif, these strike slip motions are associated with counterclockwise block rotations that were achieved around 330 Ma.

- NE-SW normal faults seen in seismic sections, documented by paleomagnetism and confirmed by structural geology affect the whole Variscan crust.

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The Alleghanian orogeny of the Appalachian Mountains

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In the Early Carboniferous, the African portion of Gondwana closed against the southern or Appalachian side of Laurentia obliquely from the ESE, an orientation that would favor dextral transcurrent faulting along the margin of Laurentina.

In fact, the final assembly of Pangea was also marked by a supercontinent-scale dextral strike-slip system extending from the Appalachians to the Urals (Arthaud and Matte, 1977). The initial phases of Alleghanian tectonics starts with Serpukhovian clastic wedges at several points along the Appalachian-Ouachita mountain chain. A Bashkirian forebulge marks the oblique loading of the New York Promontory by the Requibat Promintory of Africa. Dextral strike-slip faults in the Appalachian Piedmont dating from the Bashkirian and continue well into the Permian. The Alleghanian foreland is characterized by an Appalachian-wide stress field (AWSF) dates from the 10-15 My period straddling the Carboniferous-Permian boundary.

Following > 10 My of dextral slip during tightening of Gondwana against Laurentia, the AWSF was disrupted by local stress fields, Sakmarian to Artinskian in age, associated with thrusting on master basement décollements to produce the local orocline-shaped Alleghanian map pattern seen today. Whether or not Alleghanian deformation in the Appalachian foreland is manifestation of zipper tectonics with the rotation of Gondwana (*i.e.*, Hatcher, 2002) or manifestion of a purely transpressional tectonics, a thickened mantle lithosphere is required to accommodate the 200 + km of foreland shortening.

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Evidences of former eclogite facies metamorphism in a granulite recorded by inclusion pattern and compositional zoning in garnet

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Garnet with prograde zoning in the mesosome of a migmatitic granulite gneiss from the Moldanubian Zone, Bohemian Massif, was studied for PTt evolution using multicomponent diffusion modelling. Garnet in the leucosome has preserved an eclogite facies core, with a granulite facies rim having low Ca and high Fe, Mg and Mn. Both the mesosome and leucosome garnets show partial resorption indicated by inward zoning of Mn and variable Sm/Nd ratio at the garnet rims. Diffusion modelling of the interface between eclogite and granulite facies garnet suggests that modification of the compositional gradient occurred mostly during the granulite facies conditions, above 600-650°C.

Based on the inferred PT path, heating to the granulite facies conditions of 800°C/2GPa with isothermal decompression to 0.8 GPa followed by cooling to 600°C would require ~1.6 Ma for heating and cooling and ~2.4 Ma for relaxation and decompression. This corresponds to heating and cooling rate of 250°C/Ma which was calculated for the Mn zoning in the garnet rim, and a vertical exhumation rate of ~1.7 cm/a.

An increase of temperature to 850-900°C for the same heating/cooling and exhumation rate would homogenize the garnet, which is the case in most felsic granulites in the Moldanubian Zone. Previous Sm-Nd dating of the prograde zoned garnets constrains their minimum crystallization age to 354 Ma, that is ca 10-20 Ma older than ages recorded by U-Pb system in zircon in felsic granulites. Recognition of two discrete metamorphic events and the calculated PTt path for the granulite may explain the compositional homogenization of garnets in felsic granulites and the reported age differences between eclogites/garnet peridotites and granulites in the Bohemian Massif.

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Polycyclic Variscan orogeny recorded in French Massif Central

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The Massif Central and the southern part of the Massif Armoricain, belong to the North Gondwana margin. The bulk architecture of the Massif Central consists of a stack of nappes resulting of three main tectonic-metamorphic events that follow an Early Late Silurian (ca 415 Ma) high-pressure metamorphism and tectonic event, D0, whose associated structures are poorly documented.

The Early Devonian D1 event is responsible for top-to-the-SW nappes coeval with migmatization and exhumation of high-pressure rocks around 385-380 Ma. In the northern part of the Massif Central, the migmatites that enclose retrogressed eclogites, are unconformably covered by Late Devonian undeformed sedimentary rocks.

The Late Devonian-Early Carboniferous D2 event is a top-to-the-NW shearing coeval with an intermediate pressure-temperature metamorphism dated around 360-350 Ma. The Visean D3 event is a top-to-the-south shearing widespread in the southern Massif Central. Coevally, in the northern Massif Central, the D3 event corresponds to the onset of synorogenic extension.

The Variscan Belt is also characterized by a widespread magmatism. The pre-orogenic magmatism of Cambrian and Early Ordovician age is related to the rifting of the Armorica microcontinent from the North Gondwana Margin. During Early-Middle Devonian, two types of magmatism took place. The calc-alkaline one represented by volcanic series and by dioritic plutons belongs to an arc related to the southward subduction of the Rheic Ocean. A tholeiitic magmatism is also recognized in the Brévenne-Beaujolais area and in the S. Limousin (Génis Unit). The Brévenne ophiolites formed in a back-arc basin located south of the magmatic arc.

The Carboniferous magmatism represents the crustal melting response of the D2 and D3 events. The Late Visean, and Namurian-Westphalian magmatic stages are coeval with syn-orogenic extensional tectonics controlled by NW-SE stretching whereas, the Late Carboniferous one corresponds to a post-orogenic extension. These structural, metamorphic and magmatic events are replaced in a geodynamic evolution model involving two cycles of microcontinent drifting, rewelding and collision.

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Kinematical analysis of the recumbent Courel syncline (Variscan belt, NW Spain)

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The Courel syncline is one of the best examples of a regional scale recumbent fold outcropping in the north-western Iberian massif. It is located in the Ollo de Sapo domain of the Central Iberian zone and was developed in lower Palaeozoic rocks. A detailed analysis of this structure has incorporated field data, measurements of strain, c-axis quartz fabrics and kinematical models for the minor folds.

The analysis has allowed us to propose an evolutionary model for the Courel recumbent syncline that begins with an episode of layer shortening and follows with buckling and body rotation associated with deformation dominated by simple shear. Subsequently, the fold was flattened by dominantly irrotational strain with maximum shortening perpendicular to the axial surface and maximum stretching parallel to the fold axis. This occurred during the first phase of the Variscan deformation, and gave rise to a fold with an axial surface dipping moderately towards the hinterland of the orogenic belt (SSW).

The recumbent character of the fold was increased during the third phase of the Variscan deformation, which produced a large scale open structure with a subhorizontal limb in which the Courel syncline is located.

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Complex deformational response of middle and lower crust to multistage Variscan shortening, southern Moldanubian domain of the Bohemian Massif

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We focus on structural evolution of the W part of the Moldanubian root domain in the Bohemian massif to reveal mechanical behavior of mid- and lower-crustal rocks in the collisional setting and to outline possible exhumation mechanisms of lower crust into shallow levels. Studied region covers 130x30 km area of Southern Bohemia, roughly following the 9HR reflection seismic line. Field structural data supported by microstructural investigations are correlated with reflection seismics, available petrology and geochronology, and discussed in terms of geotectonic model of the Bohemian massif.

Structural pattern of the studied part of Moldanubian domain is dominated by pervasive moderately NW dipping amphibolite facies foliation developed between ~342-337 Ma. This fabric is parallel to strike of the Brunian and Saxothuringian margins. Its attitude can be correlated to the flat lying amphibolite facies foliation dominating the eastern Moldanubian, interpreted by Schulmann *et al.* (2005) as a result of flow of Moldanubian rocks over the Brunia margin.

In the SW, this fabric is overprinted by a younger crenulation cleavage with mesoscopic structures indicating a dextral transpressive strain. It documents a late-Variscan NE-directed shortening that was induced at the SW boundary of the Moldanubian, nevertheless a hypothetical continental block that caused such shortening remains unknown. Syntectonic magmatism, anatexis and presumably deformation culminates here at ~320 Ma, about 17 Ma after previous Moldanubian deformations. Due to the distinct orientation and timing, this shortening must be treated as a late isolated episode at the end of the Variscan collision in the Bohemian Massif. In the centre of the studied region several large massifs of rheologically stronger felsic granulites crop out, causing disturbation of the described fabrics. Inside them the older Variscan structures have been well preserved, documenting two-stage exhumation history of these HP-HT rocks. Based on the kinematic model of granulite exhumation history we use these fabrics to point out additional stress changes in space and time during the Variscan collision.

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Not only thrusting: major strike-slip displacements in Variscan Europe

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While orthogonal shortening in an orogenic belt is easily assessed by unfolding folds and unstacking nappe piles, reconstruction of strike-slip faulting is much more difficult, because markers are mostly absent.

This applies especially to the dextral, orogen-parallel faults in the Variscan belt, which are detectable from c. 380 Ma onwards. Well-known examples are the sutures between Saxo-Thuringia/Bohemia, Bohemia/Moldanubia (?Gondwana), and the “Moldanubian Thrust” between the Bohemian Massif and Moravo-Silesia (a zone of dextral transpression). In their present positions, these NE-trending faults about against the SW margin of the East-European Platform.

Therefore, major displacements along these faults imply either NE-ward overthrusting of the northwestern blocks over the platform, or else SW-directed rifting of the southeastern blocks away from the platform. None of these effects is detectable in the field.

The solution of this paradox lies with the NW-trending strike-slip faults which parallel the SW margin of the East European Platform. These faults accommodate orogenic shortening in Variscan Europe, which has not affected the stable platform. The amount of orthogonal shortening permits to estimate the minimum amount of dextral displacement along the NW-trending faults. A conservative estimate reveals ≥ 1.500 km of shortening across the Variscan belt.

Hence, Variscan microplates must have been positioned between several 100 and ≥ 1,500 km further to the SE, *i.e.*, in the area of the Black Sea or even beyond. In such a position, off the SE margin of Baltica, Variscan microplates were allowed “free play” for major dextral displacements along ENE-trending faults. As Philippe Matte has demonstrated, W-ward movements along such faults effected closure of the southern Iapetus ocean and the building of the Southern Appalachians. And S-Bohemia is continued in Sardinia ...

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Syntectonic leucogranites and coeval granulite facies metamorphism: structural and U-Pb investigations in the Millevaches Massif, France

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The Variscan granite plutons in the Limousin region (Massif Central, France) are spatially associated with major synmagmatic strike-slip shear zones that merge to the northwest with the South Armorican Shear Zone (SASZ). New structural, geophysical and geochronological data ($^{40}Ar/^{39}Ar$ and U/Pb) on the Limousin region provide new constrains on the timing and tectonic setting of late-Variscan granite magmatism during this orogeny. Previous investigations have emphasized the role of late-orogenic extension in the emplacement of granite plutons in the Limousin region.

In contrast, the new dataset is consistent with syntectonic emplacement of magma in a dextral simple shear active from 350 to 300 Ma in a transpressional regime. New U/Pb and microstructural data on leucogranite mylonites indicate that the leucogranites were emplaced and sheared simultaneously at 313±4 Ma in a right-lateral strike-slip regime. This age is coeval with the granulitic metamorphism which affected the surrounding micaschists. The linear regression on five single grains of monazite coming from the paleosome part, gives an age by upper intercept of 315±4 Ma that is interpreted to minimum age of the granulitization. The weighted average on the $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ages on five single grains of monazite of the leucosome part are 316±2 Ma and 315.5±2.2 Ma respectively, interpreted as the anatexis ages. The 3-D shape at depth of these granite bodies, investigated using gravity modelling, is that of laccoliths, less than 4 km thick. To explain the large aspect ratio of the Limousin plutons and their large horizontal extent, we propose that vertical shear zones may have helped channeling magmas from a deep source to their middle crust emplacement level. Then, magmas were trapped in the subhorizontal micaschist host-rock, sub-horizontal foliation.

Granitic magmatism and granulitic metamorphism took place in a transpressional context, demonstrated by strike slip shearing and thrusting, during continental collision between Laurentia and Gondwana. The Limousin region can be described as a ductile, right-lateral, wrenching “pop-up” zone within which granitic magmas were channelled. The Galician region, in the western end of the Ibero-Armorican tectonic arc, exhibits major left-lateral ductile shear zones associated with voluminous granite magmatism which can be interpreted as conjugate structures to the Limousin and Armorican shear zones.

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Structural and thermochronological constraints on the late orogenic evolution of the Trás-os-Montes Zone (Galicia Hercynian belt, NW Spain)

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New structural, petrological and geochronological data allow establishing the tectonic and thermochronological evolution of the central schistose domain within the Galicia Trás-os-Montes Zone (Central Galician Hercynian orogenic segment, NW Spain). Four generations of granite have been recognized and dated with U-Th-Pb chemical age using electron microprobe on monazite (G1-335 My; G2-322 My; G3-318 My and G4-303 My).

The G1, G2 and G3 granites were supposed to emplace during a progressive and continuous D3 deformation event. D3 is characterized by a stress tensor that combined an horizontal EW-trending shortening direction with a N-S trending horizontal shearing, dominated by a north-directed verging. D3-related structures and associated granites were particularly developed within a triangular domain limited westward and eastward by left and right lateral shear zones, respectively.

The left lateral one is oriented N20°W whereas the right-lateral one trends N30°E. The right-lateral shear zone is underlined by four G3 granites assumed to emplace coeval to the dextral shearing, thus explaining their "en-echelon" geometry.

The two major shear zones define a central spoon-shaped domain that escapes towards the north as a result of the combined motion along these two sheared flanks. $^{40}Ar/^{39}Ar$ dating has been performed on white micas from: i) the four generations of granite; ii) hydrothermal features such as Sn-W and Au-mineralizations related to G2 and G3 magmas, respectively; iii) enclosing micaschists. The results indicate Ar/Ar ages bracketed between 309 My and 291 My. In regard with the ages of granite emplacement, these results suggest either a regional Ar resetting during G4 emplacement at ca. 300 My or a general cooling through temperatures of 300°-400°C during exhumation since 305 My. Whatever the case, the late-orogenic evolution of Galicia herein presented and discussed strongly suggests the existence of combined lateral escape and horizontal shortening, and highlights the absence of pure extensional features.

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External-internal tectonics of the eastern margin of the Bohemian Massif and tectonic evolution of Variscan foreland basin

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Carboniferous basin at the eastern margin of the Bohemian Massif represents the easternmost termination of Variscan foreland basins of the European Variscides. Compared to generally equatorial trend of Rhenohercyanian basins the studied Visean (Culmian) foreland basin shows SSE-NNW trend consisting of deep marine turbiditic formations 8 km thick.

Recent dating of detrital micas and HP pebbles show that the flyshoid sedimentation was synchronous with unroofing of easterly Moldanubian orogenic root system and successive elevation and erosion of deep seated lower crustal rocks. Towards east and southeast, the thickness of sedimentary infill decreases, which corresponds to thinning of Variscan sedimentary wedge towards Brunia foreland. During Lower Namurian the flyshoid Culm sedimentation is followed by development of parallic and subsequently coal bearing molasse of the Upper Silesian basin. The flyshoid sedimentation starts cca. 10-15 km earlier than development of similar basins in Western Europe, which indicates earlier involvement of Variscan accretionary belt with colliding Brunia indentor? Specific position of south prograding Variscan front with respect to southerly moving Brunia indentor is responsible for dextral oblique collision and development of highly partitioned thrust and fold structures in SSW-NNE direction. From structural point of view, we can distinguish Western zone of lower grade sediments associated with westward backthrusting of weakly metamorphosed Culm over higher grade Variscan internal belt. Central part of anchimetamorphic Culm accretionary wedge is characterized by positive structural fan associated with extrusion of Devonian volcano-sedimentary sequences underlying Visean Culm sediments along compressional duplexes and horses. Eastern part of the Culm accretionary prism is characterised by eastvergent thrusts and typical thin-skinned tectonic features above basal decollement thrust zone. Apical zone of the accretionary wedge is fanning out in the easternmost Upper Silesian basin area and is affected by small scale; mostly intra-coal measures thrusts with south west vergence. We provide detailed account of structural features, combined with published seismic line features and existing geochronological datasets to show intimate coupling between deep Brunia tectonics and shallow accretionary prism tectonics.

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Evidence for a main Paleozoic suture zone in the External Crystalline Massifs, Western Alps, the contact between Armorica and Gondwana?

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In the Western Alps, the External Crystalline Massifs (ECM) represent pre-Alpine basement only locally interested by structural and metamorphic re-organization during Alpine collision. From south to north, they are Argentera, Oisans, Belledonne, Mont Blanc, Aiguilles Rouges, Gotthard and Aar, underlining the alpine curved shape. The definition of the main lithotectonic units of these massifs and their signification at the scale of the Paleozoic belt is still problematic. Gneissic units of high metamorphic grade preserve eclogitic relics related to an early stage of lithosphere subduction, as the Upper Gneiss Unit in the French Massif Central.

The main compressional deformation stages achieved before the deposition of the Stephanian while syn-collisional extension is recorded since the Westphalian. Granites and migmatites are widespread, synchronous of large crustal scale strike-slip faulting and normal faulting related to late orogenic extensional tectonics.

We present a new synthesis of the available lithologic, geochemical, structural, metamorphic, geochronologic data about External Crystalline massifs (Western Alps). This synthesis allows outlining the geodynamic evolution of this area, from Lower Ordovician to Upper Carboniferous times. Three domains are identified. A western domain, mainly western part of Argentera massifs the Belledonne massif and the Aiguilles Rouges massif, corresponding to an active margin zone from Ordovician to Devonian, as observed in the Moldanubian zone. An eastern domain, corresponding to the internal part of the Oisans massif and the Mont-Blanc massif which recorded only the Lower Ordovician rifting, then the Lower Carboniferous collision and that could be considered part of the passive Gondwana margin. An intermediate domain, including the internal part of Belledonne massif and the Grandes Rousses massif, recording a complex orogenic evolution from Ordovician to Devonian, with eclogitic relics, migmatites, Mg-K granite intrusion, syn-collisional sediments and volcanics, corresponding to the main Visean suture zone between the northwest Moldanubian zone and the passive Gondwana margin.

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The relationships between Upper Palaeozoic syntectonic magmatism and ductile sinistral shear zones in the Western High Atlas, Morocco

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The Western High Atlas (Morocco) is located in the external domains of the Variscan orogen. It is composed of Late Proterozoic to Lower Paleozoic sequences, variably affected by metamorphism and deformation during Upper Carboniferous times. Detailed structural mapping in the Adassil – Medinat region shows that the Variscan deformation is related to several crustal-scale shear zones: the coeval ENE-WSW dextral Amizmiz and Tizi n'Test shear zones and the slightly younger WNW-ESE-trending sinistral Medinat shear zone. The first stage of deformation (D1a) is predominantly associated with dextral shearing and produced a N-S pervasive axial planar cleavage (S1), which was subsequently re-oriented by the sinistral shear zones (D1b). These complex fault zones, in particular the transpressive sinistral shear zones appear to have controlled the emplacement of two small intrusions of granitoids: the Adassil and the Medinat massifs.

The Adassil Massif is composed of medium-grained equigranular S-type two-mica monzogranites showing heterogeneous deformation and a WNW-ESE directed foliation. It exhibits a restricted range of silica contents (SiO_2 = 69 to 71%), a strong peraluminous character (A/CNK = 1.22-1.39) and relatively low Ca, Mg, Sr and ΣREE. The REE patterns are LREE enriched with negative Eu anomalies. The major and trace element geochemistry of the Adassil monzogranite is consistent with moderate degrees of partial melting under water-undersaturated conditions of metasedimentary crustal sources.The Medinat tonalite occurs as a discordant intrusion, bearing little or no petrographical evidence of solid state deformation. It consists of plagioclase (andesine), hornblende, biotite, interstitial quartz and accessory sphene, magnetite and zircon.

The Medinat tonalite shows silica contents ranging from 61 to 64%, metaluminous to slightly peraluminous signatures (A/CNK = 0.9-1.0) and high-to intermediate-K calc-alkaline affinities. The chondrite-normalised REE patterns are characterized by very low LaN/YbN ratios (6-14) and absent or slightly positive Eu anomalies. Two alternative petrogenetic models may be proposed to explain the origin of this granitoid: (a) mixing between mantle-derived gabbroic magmas and lower crust materials; (b) partial melting of lower crustal metaigneous granulites.

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Transforming mylonitic metagranite to migmatite by open-system interactions during melt flow

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The Gföhl migmatite ranges from banded mylonitic orthogneiss with recrystallized monomineralic bands, through stromatites and schlieren migmatites (metatexites), to isotropic nebulites (diatexites). This sequence was classically attributed to increasing degree of anatexis, but the field relationships suggest that they were all derived from the same protolith. Under the microscope, the evolution is characterised by progressive destruction of the monomineralic banding that characterises the original mylonitic orthogneiss.

Throughout, the mineral assemblage is biotite-K-feldspar-plagioclase-quartz ± garnet ± sillimanite but the mineral compositions exhibit systematic changes with progressive banding disintegration. From banded orthogneiss to nebulite, the garnet composition changes systematically, Alm75→94Prp17→0.8Grs2.5→1.2Sps2→11 and XFe= 0.45→0.99, and for biotite, XFe=0.80→1. This is consistent with a decrease in equilibration temperature and pressure of 790°C and 6–8.5 kbar, to 690°C and 4–5 kbar.

There is also a systematic change of whole-rock composition, marked by an increase in SiO_2 (71→77 wt. %) and XFe (0.62→0.85) and by a decrease in Al_2O_3 (16→13 wt. %) and CaO (1.50→0.43 wt. %). Assuming that the rocks started with the same composition, these systematic changes indicate open-system behaviour. The predicted consequences of various open-system processes are assessed using THERMOCALC modelling. The observed variations are interpreted to be a consequence of pervasive melt flow through, and interaction with the rocks, and, in order to change the rock composition sufficiently, a large volume of melt must have been involved.

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Variscan inheritance in the South Carpathian basement: tectono-metamorphic zonation and deep seated structural markers

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The Pre-Mesozoic metamorphic-magmatic basement of the South Carpathians is well preserved in the Alpine/Cretaceous Danubian and Getic-Supragetic nappe stacks, lately involved in the Tertiary tectonic events.

The Getic-Supragetic basement includes low grade Paleozoic sequences and medium to high-grade rock assemblages whose protoliths ages (Paleozoic and Proterozoic) are poorly constrained. The Variscan tectono-metamorphic history is better documented for Early Carboniferous collision period (Ledru *et al.*, 1997; Medaris *et al.*, 2003). Mafic-ultramafic HP rocks of diversified metamorphic conditions are widespread but LP rocks are also present in some units of the pre-Mesozoic nappe piles. Our petrologic data suggest that the regional "tectono-metamorphic zonation" is a composite effect of the contrasting history of individual tectono-stratigraphic units, inside of the Variscan nappe stacks. The apparent metamorphic zonation can be related to nappe stacking processes and gives a false metamorphic zonality. Tectonic inversion can be connected with an apparent upward increase in the general metamorphic degree (metamorphic inversion). Narrow metamorphic zones and structural discontinuities (fault zones) separate different tectono-stratigraphic units, marking significant breaks in the metamorphic zonation distribution. Some isolated areas preserve prograde metamorphic zonation inside of a coherent tectono-stratigraphic unit, especially at the level of the late metamorphic history (M2). Different by this, post-nappe metamorphic imprints connected to up-lift and extension processes have a uniform distribution of the mineral phases, finally resulting in cooling related recrystallization.

Within the Danubian Basement, the Variscan tectono-metamorphic events involved Late Neoproterozoic metamorphic-magmatic basement and Paleozoic Formations (Iancu *et al*., 2005). The main feature of the Danubian basement is the preservation of Late Proterozoic protoliths and Pan-African affinities of the metamorphic-magmatic terranes (Liegeois *et al*., 1996). The internal part of the Danubian preserves a Late Neo-Proterozoic to Early Paleozoic ophiolites complex and volcano-sedimentary formations connected to a new cycle of oceanic spreading followed by polyphase Variscan tectono-metamorphic reactivation and magmatic arc activities. HT/LP mylonites are connected with progressive deformation and granitoid intrusions and mark contrasting features of earlier metamorphic zones. Tectonic inversion of the pre-orogenic, ophiolites complexes and oceanic sediments is connected with convergent Paleozoic events, followed by late collisional magmatic arc activity. Metamorphic inversion is well expressed by upward increase of the Paleozoic shear zone related metamorphism (detailed maps and explanation).

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Pre-Variscan oceanic crust in the Tatric Unit of the Western Carpathians: geochemical and Nd isotope evidence

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In the Pre-Alpine basement of the Malé Karpaty Mts., supposed to represent the uppermost part of the Tatric Unit of the central Western Carpathians, two different lithostratigraphic groups have been distinguished: (1) the Devonian Pezinok Group represented by the complex association of metamorphosed clastic sediments with sporadic limestones and small basaltic bodies with OIB geochemical signature and (2) the Pernek Group, a large complex of basic rocks, intercalated with four thin belts of sediments including stratiform Cu-pyrite mineralization, and metamorphosed under greenschist to amphibolite facies conditions. Based on petrographical, geochemical and isotopic studies, the Pernek group has been identified as a relic of oceanic crust of Late Devonian–Early Carboniferous age (ca. 360-380 Ma, as suggested by preliminary U-Pb zircon data, Putiš *et al.*, 2006). Only rocks from the upper part of the oceanic crustal section are present. Metamorphosed analogues of deep-sea sediments (cherts, clays), basalts and isotropic gabbros together with dykes intersecting both igneous rock-types have been found. Four possible source components could be traced in metamorphosed sediments, by using minor element distribution: (1) pelagic chert, (2) organic matter, (3) fine-grained continental material and (4) weathered/hydrothermally altered oceanic basalts. Most of basalts have chemical compositions very close to that typical for N-MORB. They crystallized from liquids formed by ca. 10-15% melting of a time-integrated depleted mantle source (εNd370=ca.+9).

Their composition was variably modified by fractional crystallization, giving rise to Fe-Ti rich types. Some accumulation of olivine, plagioclase and also pyroxene is indicated by major and trace element distribution in gabbros and gabbroic dykes. Oceanic crust of the Pernek Group was obducted on the rifted-arc-related Pezinok Group in Pre-Visean time, as indicated by ca. 350 Ma old granitoids intrusive in both groups. Converging lines of evidence suggest that the Pernek Group, together with the Ochtiná Group (the other Western Carpathian group similar in age and origin) highlight a Variscan suture zone, left after the Carboniferous closure of the Devonian-Lower Carboniferous oceanic domain which probably separated two Early Palaeozoic domains, specifically, the Gemeric terrain on the one side, and the Veporic plus substantial part of Tatric terrains on the other side.

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Early Paleozoic volcanic arc complex in the inner Western Carpathians: evidence from geochemistry metamorphosed acid volcanic rocks of the Gelnica Group

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The Gelnica Group represents a flysh-like complex of redeposited acid volcaniclastic rocks with subordinate small bodies of acid to basic effusive rocks and sporadically occurred thin intercalations of black shales, cherts and allodapic carbonates. The complex is Ordovician in age may be with some overlap in Lower Silurian. It was metamorphosed in several stages but intensity of metamorphism did not exceed greenschist facies conditions. Major and trace element distribution in the metamorphosed acid volcanic and sedimentary rocks from the NE part of the Gelnica Group have been studied to identify original type of volcanism, its tectonic setting and character of the source material transported into sedimentary basin. Based on petrography the following groups have been discerned: (1) rhyolites, (2) dacites, (3) oriented volcanic/volcaniclastic rocks with phenocrysts traditionally termed as porphyroids, (4) psammitic volcaniclastic sediments, (5) pelitic sediments and (6) pelitic sediments rich in haematite pigment. Majority of these rocks displays strong enrichment in K or Na as a result of regional hydrothermal metasomatic alteration, whereas the distribution of REE, HFSE or some compatible elements (Cr, V, Sc) were unaffected by this process. Rhyolites geochemically resemble those of medium-K calc-alkaline series. Two types of rhyolites differing in intensity of Eu-anomaly and HREE fractionation have been identified. Some of porphyroids are compositionally an equivalent of rhyolites, other represent acid volcanic material with some admixture andesitic/basaltic composition. The same admixture and compositional effects of the quartz and feldspar phenocrysts fractionation have been found in all types of volcaniclastic sediments. As follows from relevant trace element ratios the acid volcanic and volcaniclastic material was generated in uniform tectonic setting conforming to the evolved magmatic arc. Small basaltic bodies with CAB, BABB or most frequently OIB signatures indicate the incipient arc rifting. Analogues of the subduction-related Gelnica Group are known from the Southern Alps and Eastern Alps (so called Pre-Hercynian rhyolite plateau).

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Intraplate origin of some retrogressed eclogites from the Early Paleozoic of the Veporic Unit (Western Carpathians): evidence from geochemical data

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Early Paleozoic of the Veporic Unit (central Western Carpathians) is represented by migmatitized and phyllonitized bimodal igneous complex termed as leptynite-amphibolite complex (LAC). Retrogressed eclogites are present in this complex as small bodies up to several tens of meters in diameter. Clinopyroxene-albite symplectite, garnet, pale brown amphibole, quartz, clinozoisite and rutile are common mineral components in the most preserved varieties. Omphacite has been only found as small inclusions in garnet. Diablastic texture sometimes also with indications of ophitic or gabbroic textures is typical. Peak metamorphic conditions are estimated to reach ~2,5 GPa and ~700°C. Eclogites underwent several stages of retrogression which led to their successive transformation to garnet amphibolites, amphibolites and greenschists. Based on major and trace element distribution three geochemical types of protolith of retrogressed eclogites have been identified: OIB, N-MORB and primitive IAT. In contrast to other types the occurrence of the OIB-type is restricted to small area - probably a separate slice within the LAC – where also metaultramafic rocks of the same geochemical signature composed of amphibole, olivine, orthopyroxene and spinel have been found. OIB-type retrogressed eclogites originally crystallized from basaltic magma the composition of which was between E-MORB and alkali OIB. Enrichment in HFSE (Nb=11.7-27.6 ppm; Nb/Y=0.50-1.15) and selective LREE/HREE enrichment (La_N=43.46-103.37; La_N/Yb_N=3.30-9.26) are typical. Mineral fractionation led to formation of cumulates rich in olivine and spinel (metaultramafic rocks), rarely also in plagioclase or Fe-Ti oxides (some metagabbros). Rocks with OIB signature in the LAC of the Veporic Unit could be interpreted as a sea mountain material forming a part of the exhumed relics of the subducted ancient oceanic crust.

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Age, geotectonic setting and petrogenesis of Variscan calc-alkaline plutonism in Central Europe – examples from the Central Bohemian Plutonic Complex, Czech Republic

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The vast majority of the Variscan Central Bohemian Plutonic Complex (Bohemian Massif) is made up of the oldest, calc-alkaline (Sázava) and high-K calc-alkaline (Blatná) igneous suites.

The Sázava suite is formed by Amph–Bt tonalites, (quartz-) diorites and trondhjemites, with associated Amph ± Cpx gabbros. The age of the tonalite is 354.1±3.5 Ma (U–Pb Zrn: Janoušek *et al.,* 2004). The Kozárovice and Blatná Amph–Bt to Bt granodiorites are typical of the Blatná suite, together with minor intrusions of K-rich Cpx- and Amph-bearing quartz monzonites–monzogabbros. The new SHRIMP U–Pb Zrn dating produced indistinguishable ages of 346.1±1.6 Ma (2 sigma) and 346.7±1.6 Ma for the Kozárovice and Blatná granodiorites, respectively, the former with a small proportion of inherited cores c. 610 Ma and 2.1 Ga old.

The early calc-alkaline intrusions (Sázava suite) were emplaced into the upper crust of the Teplá-Barrandian Unit during regional transpression. Later, multiple magmatic to sub-solidus fabrics of the younger Blatná suite recorded both regional transpression and the onset of exhumation of mid-crustal orogenic root (Moldanubian Unit). For both suites, textural and mineralogical features, chemistry and Sr–Nd isotopes suggest a prime role for magma mixing with mantle-derived magmas. In the Sázava suite, their composition was close to CHUR (εNd(354) ~+1), but the monzogabbros of the Blatná suite were derived from enriched mantle domains (εNd(347) ~-3). The new geochronological data provide a time bracket for this principal switch in geodynamic setting and sources of the granitic magmas in the Late Devonian–Early Carboniferous magmatic arc.

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The pre-Stephanian Sillon Houiller fault: a ductile normal fault coeval with the Mid-Carboniferous syn-orogenic extension of the Massif Central?

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In the Variscan French Massif Central, the Sillon Houiller Fault (SHF) is a major sub meridian discontinuity and its pre-Stephanian kinematics and evolution remain poorly understood. In order to better understand the faulting process, the Montmarault granitic pluton and the Glénat, Omps, Boisset massifs, located respectively on the northern and the southern parts of the SHF, have been chosen as targets for a multidisciplinary study. The Namurian Montmarault, Glénat and Omps plutons exhibit a consistent NW-SE trending magnetic lineation, which is perpendicular to the SHF.

The 3D modelling integrating structural, AMS, gravity and aeromagnetic data, show that 1. the Montmarault granitic pluton is a kilometre-thick laccolith that roots to the East in the SHF; 2. no genetic relationship between the southern plutons and the SHF can be demonstrated. The northeastern margin of the Montmarault pluton is mylonitized with a NW-SE lineation. Kinematic indicators show a synmagmatic normal motion with a top to the SE shearing. The central part of the SHF is devoid of Namurian plutons, but exposes east-dipping mylonites and ultramylonites. Shear criteria along a NW-SE lineation indicate a top-to-the SE motion. Several hypotheses on the tectonic significance of the pre-Stephanian SHF will be discussed in light of these new results.

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The northern margin of the Rheic Ocean in the Ordovician: characterization of Avalonian manganese-rich metasediments by means of isotope, REE and trace element geochemistry

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Constraining the extent and the continuity of the Avalonian composite terrane, which marks the northern margin of the Rheic Ocean in the Ordovician, is of major importance when looking at Variscan orogenic processes. As an attempt to correlate several marker horizons across Avalonia, this study investigates the geochemical and Sr-Nd-Pb isotopic systematics of Ordovician manganese-rich meta-sediments from Southern Mainland Nova Scotia, Canada, the Ardennes Mountains, Belgium, and the Harz Mountains, Germany. The rocks exhibit a characteristic enrichment in Mn, Cu and Mo and depletion in Li, Rb, Cs and Tl. A Sr-evolution diagram for whole rock and carpholite suggests that this is a primary signature, further supported by the REE patterns which resemble those of recent shallow-water ferromanganese nodules.

All samples display uniformly high initial $^{87}Sr/^{86}Sr(t)$ values (0.71047 to 0.71372) and low initial $\varepsilon Nd(t)$ isotopic compositions (-5.0 to -11.2), indicating a mature, continental provenance. While spessartine quartzites (coticules) and other manganese-rich meta-sedimentary strata occur throughout the Caledonian-Appalachian orogen (Thompson, 2001), they have not been described from Armorica and thus seem to be a feature unique to Avalonia, representing a suitable palaeogeographic marker and providing a less ambiguous means of correlation than e.g. a sequence-stratigraphic approach.

The results are in line with Murphy *et al.* (2004), who argues that Meguma and Avalonia were contiguous already in the Early Palaeozoic. Attributing the metal enrichment to nodule forming processes which today take place in marginal seas of higher latitudes might have significant palaeogeographical and palaeoclimatological implications.

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Contrasting Early Carboniferous field geotherms recorded in granulites and eclogites of the central Erzgebirge: evidence for accretion of a thickened orogenic root and subducted Saxothuringian crust

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Subduction of Saxothuringian ocean and later collision of the Saxothuringian domain with the Teplá-Barrandian block is considered to be a major process controlling the tectonic evolution of the Bohemian Massif. However, character and exact position of this first-order tectonic boundary remains not well understood mainly due to its Cretaceous to Tertiary cover of sediments and volcanic rocks of the Eger rift. Extensive database of samples from drill holes reaching the basement of the sedimentary basins in the Eger rift allowed construction of a map of pre-Cretaceous geology along the Saxothuringian–Teplá-Barrandian boundary and correlation of geological units with those exposed in the Saxothuringian and Teplá-Barrandian domains. At the same time, existing petrological and geochronological data can be used for delimitation of the suture between these two domains.

In the eastern part of the Saxothuringian domain, the age of granulite-facies metamorphism corresponds to the age of formation of mafic eclogites. Granulite-facies conditions in felsic continental crust and eclogite-facies conditions in mafic eclogites developed at the same time of about 342 Ma, suggesting the existence of two distinct tectonic units with contrasting initial geothermal gradients. We propose that juxtaposition of rocks with contrasting thermal histories is the result of subduction of the Saxothuringian crust and its later collision with a thickened continental orogenic root existing to the SE. A short time span between the formation ages of high-pressure rocks and cooling ages of the host lithologies suggests extremely fast exhumation of a coupled subduction zone–orogenic root system during continuing Variscan collision.

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Time evolution of the Silesian domain from K-Ar and Th-U-Pb dating (Bohemian Massif)

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Recent models of geodynamic evolution of Variscan belt suggest that the indentation of Moldanubian orogenic root by Brunia continent produced a Brunia derived crustal wedge, which exhibits inverted metamorphic zoning from chlorite-biotite, garnet, chloritoid, and staurolite in the easterly par-autochthon (the Desná dome), staurolite-sillimanite-andalusite in the deeper part and staurolite and garnet in the upper part of the westerly lower allochthon (the Keprník nappe). Kyanite-bearing metapelites host eclogite boudins in the westernmost upper allochthon (the Velké Vrbno unit). The structural mapping distinguished relic fabrics related to burial during continental underthrusting, a compressional folding associated with crustal stacking and early exhumation and heterogeneously developed extensional fabrics associated with large calc-alkaline pluton emplaced during late stages of exhumation. In order to put age constraints on the structural and metamorphic history, micas and monazites were dated by K-Ar and Th-U-Pb methods, respectively. In the eastern part (Desná dome and Keprník nappe) the monazites in matrix and in garnet porphyroblasts show similar range of ages from 250±13 Ma to 288±14 Ma.

In the western part (Velké Vrbno Unit) monazite included in garnet shows the average age of 322±8 Ma, while monazite in the matrix exhibits younger ages of 297±7 Ma. Two samples from the eastern border of the Desná dome give the cooling ages of muscovites of 343±5.1 Ma and 320.2±4.7 Ma. The micas from the central part of the Keprník nappe and the Desná dome show significantly younger cooling ages on biotites ranging from 262.6±4.0 to 292.7±4.4 Ma and on muscovites in between 259.6±3.8 and 301.9±4.4 Ma. In the Velké Vrbno unit, the biotite is dated to 332±5.1 Ma and muscovite to 313±4.7 Ma. The oldest cooling ages around 340 Ma obtained on low grade rocks at the eastern border of the accretionary wedge are interpreted as closely reflecting the peak of metamorphism during continental underthrusting. This was followed by synconvergent exhumation at 320-330 Ma and the up-doming of the crustal wedge accompanied with intrusion of large granite and final extensional collapse at about 300 Ma. The surprisingly young ages along the NE margin of the Variscan front differ significantly from the central and southern part where crustal cooling occurred at around 325-330 Ma and from adjacent root material (Lugian domain) with cooling ages at 350-335 Ma. This discrepancy is clearly connected with important crustal scale NNE-SSW trending folding and extensional tectonics which are missing in both southern sector of orogenic front and Variscan orogenic root system.

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Model of successive granite sheet emplacement in transtensional setting (Vosges Mts.): integrated AMS and microstructural study

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Successive emplacement of three granite plutons (Thannenkirch, Brézouard, Bilstein granites – BBTC complex) separates medium to high pressure rocks to the north from low-pressure anatectic domain to the south. We present a model of emplacement and fabric development in the BBTC and southerly anatectic domain based on anisotropy of magnetic susceptibility (AMS), microstructural analysis, and geochronology supported by numerical modelling.

The data reported in this contribution show the successive emplacement of three granite sheets in a transtensional deformation regime. The emplacement history is controlled by the pre-extensional syn-convergent history of the lower and middle crust in the central Vosges Mountains (France).The Variscan deformation revealed the complex compressional orogenic structure which recorded a vertical exhumation-related fabric in mid-crustal levels which was further overprinted by the regional extension event. Three successively emplaced granite sheets exploited the inherited vertical anisotropy obliquely oriented with respect to the applied tensile stress. This progressive opening of original steep fabric leads to the sequential generation of free spaces towards the south, emplacement and deformation of granite sheets during extension (~328 Ma).

The results of AMS fabric modelling suggest a highly partitioned oblique extension divided into pure shear dominated deformation close to the central and northern margins of intrusions consistent with the large extensional-related southerly migmatites, and wrench-dominated shear along the southern margins of intrusions. The AMS modelling suggests the importance of overprinting of the intrusive fabrics by the transtensional deformation. Microstructural zoning combined with the thermal modelling of intrusions sequence indicates that the vertical anisotropy has been progressively reactivated from its interior towards the southern margin. Successive intrusions of granites towards the south are responsible for re-heating the southern margins of the already solidified granites, which became reactivated under lower ambient thermal conditions related to the overall cooling of rapidly exhumed crustal zone.

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K/Ar ages of white mica/illites at Late Variscan and post-Variscan sulphide and uranium deposits of the Bohemian Massif (Czech Republic)

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Different grain-size categories of white mica/illite from hydrothermal alterations at the Kutná Hora and Příbram vein-type sulphide deposits and the Rožná shear zone-hosted uranium deposit were dated using the conventional K/Ar method.

The K/Ar ages of the hydrothermal white mica from the Kutná Hora Fe-Zn-Pb-Ag sulphide deposit range from 307.6±6.0 to 304.2±5.8 Ma and correspond to the K/Ar age of white mica from the pre-uranium sulphide-siderite mineralization at the Rožná uranium deposit (307.5±6.0 Ma). The age of hydrothermal mica formation is consistent with the time span of the emplacement of young granites and lamprophyre dykes in the Bohemian Massif. The high temperature of mineralization and low salinity of hydrothermal fluids at the Kutná Hora deposit indicate a close genetic relation of the mineralization to Late Variscan metamorphism and magmatism. Huge granite-migmatite domes in the middle crust probably acted as the fluid source and heat engines for the Kutná Hora-type mineralization during the post-thickening collapse and melting of orogenic roots of the Variscan orogen.

The K/Ar ages of hydrothermal illite from the Příbram Pb-Zn-Cu-Ag sulphide deposit (274±7 to 268±7 Ma) and of hydrothermal alterations at the Rožná uranium deposit (277.2±6 to 264.1±4 Ma) indicate a large-scale hydrothermal event during the late Early Permian. The high salinities of hydrothermal fluids of sulphide and uranium mineralizations indicate an infiltration of formation waters of the Late Stephanian – Early Permian wrench-type basins into basement rocks. The late Early Permian mineralization at the Příbram and Rožná deposits is controlled by regional brittle structures that represent a Late Stephanian–Early Permian conjugated sinistral and dextral shear system that overprinted and partly disrupted older Variscan structures. Propagation of brittle structures to the lower crustal level, together with a very deep infiltration of formation waters, gave origin to the reduced, high-sulphide hydrothermal system at the Příbram deposit. In contrast, uranium mineralization at the Rožná deposit is interpreted as having originated during a gradual reduction of the originally oxidized formation waters circulating at the upper crustal level. The source of uranium can be seen in local metamorphic rocks.

The K/Ar ages of illite from the hydrothermal alterations that form a part of the post-uranium Pb-Zn sulphide mineralization at the Rožná deposit range from 233.7±5.5 to 227.5±4.6 Ma. The apparent K/Ar ages of illite are interpreted as representing a Middle to Late Triassic hydrothermal event associated with early Alpine transcurrent movements in the area of the Bohemian Massif. Geochemical characteristics of this mineralization type indicate a surface-derived, meteoric source of hydrothermal fluids and a local remobilisation of metals and sulphur from older types of mineralization.

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Assembling of Armorican terranes during the Variscan orogeny. A view from the allochthonous domain of the Saxothuringian Zone

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The importance of continental subduction during the Variscan orogeny has proposed by Philippe Matte 20 years ago. Since this time numerous high pressure domains have been observed along the entire internal part of the orogen. The allochthonous domain of the Saxothuringian Zone now juxtaposed with the Cadomian blocks of Lusatia and the Tepla Barrandian (Peri-Gondwana) contains information about at least two successive continental subduction events. Derived from the compilation of structural, petrological and geochronological data a subduction-accretion scenario for the Armorican Terrane Assemblage (ATA) is proposed and provides an explanation for the juxtaposition of the different Cadomian blocks of the ATA during ongoing convergence and the subduction of continental crust of the same lithospheric plate beneath early accreted blocks.

In such a model the ATA does not necessarily represent an independent microplate but can also be a part of the Gondwana plate. The reason for the contrasting material paths of the crust (*i.e*. subduction *vs*. accretion) are related to differences in crustal thickness as well as the composition of the Peri-Gondwana crust. Post-Cadomian inhomogenous crustal thinning in Cambro-Ordovician times possibly led to the evolution of variously arranged Cadomian blocks surrounded by thinned continental crust. The continuous subduction of the latter finally lead to the accretion of the Armorican Terrane Assemblage during the Variscan Orogeny, *i.e*. the long lasting convergence between Gondwana and Laurussia.

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The Meuse Valley Recess, an example of transpressional deformation within the Ardennes Variscan fold-and-thrust belt

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The 3D kinematics of the fold-thrust structures within the Meuse Valley Recess (Ardennes Variscan thrust belt, N France-S Belgium) have been investigated using an integrated approach combining geological mapping, cross-sections analyses and studies of magnetic fabrics and paleomagnetic data on a total of 52 sites distributed within the study area. Fold-thrust geometries, strain distribution and thrust-sheets rotational pattern lead to a conceptual structural model illustrating natural deformation processes at lateral boundaries of propagating thrust-sheets.

The Meuse Valley Recess results from distributed transpressional deformation of the Ardennes Basal Thrust hangingwall above a buried lateral/oblique ramp inherited from the Lower-Middle Devonian extensional tectonics of the sedimentary wedge. This deep lateral/oblique discontinuity basically controls the depth and strength of the basal Ardennes décollement zone inducing differential displacement at the base of the Western and Eastern Ardennes thrust wedges. The resultant out-of-plane strain includes some varying components of normal-to-bedding shear and lateral shortening depending on the proximity with the buried lateral discontinuity.

A gradient of lateral shortening is evidenced towards this discontinuity thus acting as a butress zone. We emphasize the high friction conditions prevailing along the lateral borders of the thrust sheets, which potentially result in drag effects during foreland-directed thrust propagation. Such additional shear strain is suggested to be accommodated by late pervasive thrust-sheet rotation and lateral broadening of the deformed zone subsequent to oblique folding close to the lateral/oblique boundary. From the English Channel to the Eastern border of Belgium, other zones of recess are identified. They seem to result from the oblique confrontation between the Brabançon Unit, and the western Ardennes fold-and-thrust belt migrating towards the NNW.

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Disharmonic folding within heterogeneous sedimentary series

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Twenty years ago, many models of deformations have been proposed to account for the formation of the folds in the external zones of orogens. The majority of geometrical models aims at reproducing the shape of the fold-faulted structures (volume, distance …) always answering insufficiently the reality of outcrop data. Their validation requires a confrontation with kinematics data resulting from the study of the fold deformation markers.

From this point of view, three folded units of deca- to hectometric scale in the Rheno-Hercynian zone (Ardennes) were the subject of a detailed structural study. These studies include a precise geometrical restitution of the folded structures coupled to a macroscopic analysis of the deformation (cleavage, micro faults, tension gashes) and Anisotropy of Magnetic Susceptibility.The folded structures present all a strong dissymmetry. The short limb represents a synthetic discharge of shearing applied to the sedimentary pile. The disharmonic character appears by the presence of several anticlinal hinges in the anticlinal hinge zone. These multiple hinges are controlled by the presence of the incompetent levels which locate interstratified décollements.

From a kinematic point of view, the repartition of deformation markers is symmetric in both side of the hinge (synclinal and anticlinal zones), indicating the fixity of the hinges zones during the folding. The quantification of the shearing rate in the limbs agrees with a mechanism of deformation corresponding to a progressive rotation of the limbs around the zone of the hinge zones.

The whole of these data suggests that the studied folds correspond to décollement folds whose development is controlled by the existence of incompetent levels distributed in the series. The amplitude and the wavelength of the folds are a function of the relative thickness of the competent and incompetent levels.

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Lower Palaeozoic events in the Rocroi Massif (Rheno-hercynian domain, Northern France)

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The Rocroi Massif constitutes the most meridian puzzle piece of the Lower Palaeozoic rocks in northern France. The Lower sedimentary rocks are dated by acritarch microfossils (Vanguestaine, 1986) from Early Cambrian to Middle Ordovician and form two sedimentary units (Dumont, 1836). The lower one corresponds to the Deville Group, which is characterised by thick quartzite, sandstone, and siltstone clear beds and interstratified metric slaty levels.

The upper one, the Revin Group, is marked by thin stratified sandstone and siltstone dark beds and rarely thin slaty levels. The acquisition of new cartographic, sedimentary and paleontological data allowed refining the geological history of the Rocroi Massif and to constrain the paleogeographic models. The principal characteristics are not modified (Anthoine, 1939). A new stratigraphic column is proposed, more compact with a 1,500 meter thick succession. The middle and the upper parts of the Revinian Group are redefined and two major hiatus are identified, the first one by the absence of the acritarch zones 3 and 4a and the second one at the limit between the Upper Cambrian and the Ordovician.

The outcrops observations show the presence of numerous synsedimentary instabilities such as: centimetric to pluri-decametric slumps, convolutes, sedimentary breccia, unconformities and gaps mainly in the Devillian Group. The major gravitary instability periods occur during the base of the Middle Cambrian, at the base of the Revin Group and accompany the change of facies. This slope destabilisation seems to testify for a tectonic activity during the Middle Cambrian. Structural analysis of the Upper Palaeozoic cover shows that the cleavage and a part of folds structures are dated from Variscan tectonic and the Caledonian tectonic is less important than that described until now.

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The tectonic evolution of North-Eastern Mongolia is not related to the Variscan orogeny

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A model of continuous accretion of Palaeozoic arcs, backarc/forearc basin assemblages, associated subduction complexes and continental slivers from Neoproterozoic to Triassic time has been recently proposed for the evolution of Mongolia (Badarch *et al*., 2002). This scheme constitutes a major contribution to the understanding of the lithostratigraphy of the Paleozoic terranes and provides new insights on the possible extension of the Variscan orogeny in Asia. However, a geotraverse realised in Eastern Mongolia and detailed structural analysis on some selected areas reveal that an alternative model may be proposed at least for some key areas situated to the North of the Gobi Altaï suture and may be correlated with the tectonic evolution described in Siberia and Northern China.

The following tectonic features are identified:

- Magnetic and gravimetric potential field data has been reprocessed in order to identify the main tectonic boundaries. Anomalies are mainly related to NE-SW trending volcanic assemblages, like the Selenga Permian volcanic ridge, and to sub-circular structures corresponding to large regional batholiths and related volcanics of Mesozoic age, some of them reaching diameters of about 100km. A single NE-SW lineament presents geophysical features that could correspond to a suture zone and fits with the Adaatsag terrane of Badarch *et al.* (2002).

- Paleozoic units from the Hangay-Hentey basin are generally of low metamorphic grade, some contact metamorphism being locally recorded around Paleozoic (*e.g.* Ordovician granite at 442±9 Ma, U/Pb on zircon/laser MC-ICPMS method, Cocherie and Robert, 2007) to Early Mesozoic magmatic intrusions. No signs of significant crustal thickening are recorded.

- Zones of high metamorphic grade, like the Onon-Tsagaan Ovoo zone, are associated with flat lying foliations indicating dominant pure shear strains. A retrograde evolution is recorded in the vicinity of extensional normal simple shear zone. Syntectonic granites and migmatites yielded ages between 150 and 125 Ma, in good agreement with metamorphic core complexes identified in Northern China and Siberia. Rather than related the collage of contrasted Palaeozoic terranes, observed variations are attributed to a variable degree of transformation induced by Mesozoic tectonics and by the emplacement of large igneous bodies and related volcanics ranging from Permian up to Jurassic times (rhyolite dated at 179±3 Ma, U/Pb on zircon; laser MC-ICPMS method). The first collage of continental blocks occurred during Mid-Jurassic. Following Zorin *et al*., 2001, collision between Mongolia-North China to the South and Siberia to the North is marked by divergent imbricate zones that contain preserved oceanic slabs as the Adaatsag ophiolite dated at 325±1 Ma (Pb-evaporation age, Tomurtogoo *et al.*, 2005). Early to Mid-Jurassic mesothermal gold deposits (*e.g.* Boroo) are structurally controlled by this collage. This closure of the ocean is followed by a major extensional event marked from North China to Transbaikalia (South-Russia) by the development of metamorphic core complex, emission of rhyolites, ignimbrites related to epithermal gold deposits (*e.g.* Baley) and alkaline basalts during Upper Jurassic and Lower Cretaceous, just prior to the formation of coal-bearing Cretaceous half-grabens. No signs of collision during Paleozoic times, that could be related to the Variscan orogeny, have been so far clearly been identified in North-Eastern Mongolia. Further work is needed to interpret the age and signification of the Adaatsag suture zone.

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Role of magmatic sills in material transfer processes in hot orogens: NE extremity of the Variscan Orogeny

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The role of magmatic shear zones in the development of orogens is not fully understood. The lower crustal bulge exhumed at the NE edge of the Variscan orogen is surrounded by large scale sills of at least 1 km large for a total length of 130 km. Combined structural studies of the areas of intrusion, microstructural and AMS investigations of the magma and thermocalc modelling of the host rocks are performed. Three different tectonic relationships between magmas and host rocks have been found.

1/ On the northern area, the 20 km long NNE-SSW trending sill is emplaced between the lower crust and middle crustal rocks. The deformation patterns suggest an intraorogenic NW-SE shortening. Magmas intrud during vertical material transfert on the interior of the orogen

2/ On the east the 60 km elongated NNE-SSW sill is intruding at the major tectonic boundary between the lower crust and the orogenic back stop. The emplacement of the intrusion occurs in a NW-SE shortening and its long lasting cooling facilitates the thrusting toward the NNE of the deep seated rocks of the root over the back-stop.

3/ The southern magmatic sills are trending WNW-ESE and are emplaced into the lid of the orogenic dome.

The radiometric U-Pb and Pb-Pb ages of the northern sill yield crystallisation ages at 353 Ma. The Eastern and Southern magma are younger, ranging between 345-339 Ma. These preliminary results allow discrimination between early intraorogenic processes, mature orogenic backstopping and the behaviour of the lid of the orogenic dome. The northern sill intrudes at the early stage of the orogenic growth marked by vertical material transfert between gneissic lower crust and the suprastructure. Here, the active boundary between the upward moving lower and downward moving upper crustal rocks were lubrified by the magma at 353 Ma. The second sill event is the thrusting of the already assembled root over underlying basement along narrow granulite facies belt at 340 Ma. High temperature of overlying rocks precluded rapid cooling of magma and allowed long lasting transport of lower-and middle crustal root assemblage to the NE. Simultanously, the magmatic emplacement on the south triggers the detachement of the lid of the orogen toward the south.

The final deformation pattern at the scale of orogen emphasis a rotation of the far field forces from NW-SE compresion around 350 to N-S shortening correlated with vertical shortening at 340 Ma.

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Geodynamics of the Southern Tian Shan in the Phanerozoic

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Southern Tian Shan represents Variscan collisional thrust-folded belt, which was reactivated in the late Cenozoic during collision of Indostan and Eurasia. Tectonic history of the area can be divided in four stages.

1) Since the late Riphean, the region was dominated by extension, which lead to formation of the Turkestan paleoocean. During the Early Paleozoic it comprised a uniform basin with isolated volcanic buildups. Structural reorganization in the middle of the Silurian lead to formation of local uplifts, which later evolved into shallow marine carbonate sea mounts. This event can reflect change from extensional to compressional regime within oceanic plate, which caused flexural instability and re-distribution of rock masses in the Earth crust.

2) General shortening of the area due to subduction began in the middle of the Carboniferous. The process of accretion lead both to formation of major overthrust structures and smaller-scale floating synclines. The later developed from carbonate sea mounts and volcanic uplifts and represent allochthonous blocks, bounded by oppositely-directed conjugated thrusts. Smaller scale sutures between such blocks are typically formed by intensively deformed deeper marine deposits. The process of subduction was terminated by collision, which lasted during the late Permian to Early Mesozoic.

3) Since the end of Triassic the area represented an inactive mountain belt, which has been almost completely eroded and flattened by the late Cretaceous.

4) Activization of the region since Eocene, especialy in the late Oligocene to Quternary is connected with collison of Indostan and Eurasia. The mountain growth and basin formation is a result of redistribution of the rock masses at the lower and middle crustal levels due to general shortening in the North-to-South direction.

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Invisible gold in arsenopyrite of the Variscan Au-Sb Brecca mineralization (Gerrei district, Southeastern Sardinia)

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Mineralisation of the Au-Sb Brecca prospect is hosted by Ordovician porphyritic acidic metavolcanites located in the tectonic Sarrabus-Gerrei Unit and belonging to the regional antiform of Flumendosa (Gerrei district, southeastern Sardinia). The mineralisation is controlled by sub-E-W trending structures, with a dip of 45° northward, which locally exhibit significant gold content (21 m with 1.21 g/t Mineralization show three successive stages:

1) disseminated sulfides associated with early fissural hydrothermal alteration in metamorphosed porphyritic volcanic rocks,

2) network of veinlets and centimeter-sized lenses of grey quartz with sulfides as dissemination or veinlet, and

3) veinlets of comb quartz and Sb-bearing sulfides crosscutting the precedent mineralization. Disseminated sulfides of the first stage consist essentially of coarse-grained arsenopyrite showing a significant chemical zoning. The core of grains are Sb-rich and contain rare inclusions of electrum with aurostibnite, pyrrhotite, biotite, K-feldspar. The rim of grains shows a homogeneous gold content suggesting invisible gold in the lattice of arsenopyrite. Mineralization of the second stage consist of medium-grained arsenopyrite and pyrite preferentially occurring close to highly reworked elements of early hydrothermalized metarhyolite, and as fine veinlets in grey quartz. This arsenopyrite exhibits heterogeneous gold contents, suggesting that gold occurs as micronic gold inclusions in arsenopyrite rather than in its lattice. Micronic grain free gold was observed one time in grey quartz, in association with disseminated micronic grains of arsenopyrite. Mineralization of the late stage consists of stibnite with minor chalcopyrite, sphalerite, jamesonite, tetrahedrite, freibergite and berthierite.

Sardinian gold mineralization of Brecca are characterized specially by the main deposition of gold at the early fissural hydrothermal stage with coarse-grained arsenopyrite. Gold is present as electrum and aurostibnite in inclusions in core of arsenopyrite grains, then as gold in the lattice of the same generation of arsenopyrite. Consequently, gold appears mainly located in altered hostrock than quartz veining. The other particularity of the Brecca mineralization is the presence of antimony in the mineralizing fluid, as attested by the early deposition of aurostibnite and Sb in traces in core of coarse-grained arsenopyrite. Then, early condition of arsenopyrite crystallisation are favorable for free gold expression.

Brecca shows numerous similar features with the Châtelet invisible gold deposit in French Massif Central, belonging to orogenic shallow deposit type.

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Indium in the Sn-polymetallic ore deposits of the Western Variscan belt

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About 30% of the indium mineralization is associated with the Variscan Belt orogeny (Schwarz-Schampera and Herzig, 2002). Indium mineralization was deposited

(1) during the Mesovariscan period in Middle to Late Devonian sediment-hosted Pb-Zn±Cu massive sulphide deposits in the Central Hercynides (Rammelsberg: Large, 1992) and in the uppermost Devonian to lower Carboniferous volcanic-hosted Cu-Pb-Zn massive sulphide deposit of Neves-Corvo in the western Hercynides (Benzaazoua *et al.*, 2003), and

(2) during the extensional period (Neovariscan II), in the Sn-polymetallic district of Freiberg (Seifert and Sandman, 2006).

In order to research the presence of indium at the scale of the Variscan belt, we realized systematic EPMA analyses of cassiterite and associated minerals from nine Sn-polymetallic ore deposits associated with the emplacement of late-Variscan granite in Brittany (St-Renan, La Villeder, Abbaretz), in the French Massif Central (Beauvoir, Montebras, the Châtaigneraie district, Vaulry, Charrier), in Galicia (Beariz district) and in Corwall (St Agnes).

Heterogeneous indium contents in cassiterite (up to 1,000 ppm In) are only locally detected in association with greisen alteration in rare-metal and specialized granites. On the contrary, indium is absent in cassiterite from schist-hosted Sn-W quartz veins and cassiterite-bearing disseminations. In all deposit types, other indium carriers are sulfides such as stannite (up to 3,000 ppm In), chalcopyrite (up to 2,800 ppm In), pyrite (up to 15,490 ppm In), sphalerite (up to 700 ppm In) and arsenopyrite (up to 740 ppm In), or even in oxides such as rutile (up to 1,100 ppm In) and columbo-tantalite (425 ppm In), giving however evidence of the persistence of indium in the mineralization. Preliminary statistical analyses of trace elements in cassiterite show a correlation between In and Nb-Ta contents, that could be related to the coupled substitution 2 (Sn^{4+}, Ti^{4+}) <—>(Fe^{3+} , In^{3+}) + (Nb^{5+}, Ta^{5+}).

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Rhenohercynian passive margin evolution in SW England

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Re-mapping of SW England by the British Geological Survey over the last 25 years has refined models of Rhenohercynian passive margin evolution and Variscan convergence. The passive margin developed over ~50 Ma from the Lochkovian and involved the sequential formation of six sedimentary basins. Convergence and closure of the southernmost Gramscatho Basin (and Lizard 'ocean'), initiated by the late Eifelian and continuing for some 35 Ma, was contemporaneous with continued rifting further north. The onset of continental collision was marked by the emergence of nappes comprising, upwards, deep marine sedimentary and volcanic rocks (Carrick and Veryan nappes), oceanic lithosphere and pre-rift basement (Lizard nappe) and upper plate high-grade gneisses (Normannian Nappe) onto the northern passive margin by the earliest Carboniferous. Deformation migrated through the passive margin during the Dinantian and early Namurian inverting the rift basins filled with Devonian deposits and the southern parts of the Carboniferous Culm Basin.

Style of deformation, including the presence of 'facing confrontations' was strongly influenced by basin geometry. The Culm (rift) Basin evolved, during ongoing contraction, into a late Namurian-Westphalian foreland/ thrust-top basin; its sediments, derived from the east and then the north, indicating the influence of penecontemporaneous movement along the Bristol Channel-Bray Fault. As this basin locked, late in the Westphalian (c 305 Ma), province-wide deformation occurred and the late Namurian and Westphalian infill of the Culm Basin was inverted and deformed for the first time. A few 'open questions' regarding the development of the Rhenohercynian Zone in SW England will be posed.

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Mechanisms of exhumation of orogenic lower crust in Variscan belt

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We use large database of structural, geochronological and petrological data combined with the Bouguer anomaly image of the subsurface basement to develop a two stage model of exhumation of deep seated rocks in the Variscan belt. The early vertical fabric originated in the orogenic lower and middle crust during the intra-crustal folding process combined with the vertical extrusion of weak lower crustal rocks. This event is responsible for the exhumation of the orogenic lower crust from a depth of 70 km to ca. 35 km. The vertical flow was followed by a vertical shortening due to the process of ductile thinning. The corresponding fabrics developed as a response of the building of a continental accretionary wedge driven by the SE directed Saxothuringian subduction between 360-340 Ma.

The second stage of exhumation is associated with the indentation of a continental plunger into the rheologically weaker rocks of the orogenic root resulted in horizontal channel flow. The already exhumed rocks along the NNE-SSW trending vertical belts were folded by upright folds in front of the southwards moving indenter and finally thrusted over in form of a large hot nappe. This channel flow operated in between 335 and 325 Ma and is responsible for mixing of all rock types in a partially molten mass and a progressive thermal re-equilibration of these rocks in the northward flowing channel. The depth levels as well as the degree of reworking of rocks decreases from the south to north, pointing to an outflow of lower crustal materials to the surface. This indentation of the continental plunger operated highly noncoaxially with respect to the SE oriented subduction, suggesting a major change in plate configuration or kinematics between 340 and 330 Ma.

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Correlation of the Pre-Upper Ordovician series of the Eastern Pyrenees based on U-Pb zircon ages

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New geochronological data obtained in the Eastern Pyrenean Axial Zone: Cap de Creus, Roc de Frausa and Canigó massifs support the existence of a Late Neoproterozoic/Early Cambrian series in the pre-Variscan materials of the Pyrenees. The data has been obtained from U-Pb on Zrn analysis in metavolcanic acidic rocks interlayered in the series. The lower part of this series consists of a thick sequence (up to 3,000 m) of metapelites and metagreywackes, locally cut by orthogneiss sheets near the base of the sequence. The orthogneisses correspond to former metagranites intruded at different levels of the series. Zrn analyzed on the orthogneisses reveal Ordovician ages for the upper gneiss layer of the Roc de Frausa massif and Ediacaran ages for the lower gneiss layer of this massif (Mas Blanc gneisses) and for Port gneisses in the Cap de Creus massif.

These results together with other recent dating and detailed geochemical and stratigraphic information allow us to correlate the pre-Ordovician metasedimentary sequences and the orthogneiss layers in the three massifs. The series of the Canigó and Roc de Frausa massif are lithologically very similar. The acidic metavulcanites dated by us and by other authors give comparable radiometric ages (~550 Ma), in consequence, correlation of the series is straightforward. Lithological characteristics of Cap de Creus sequence are different to the sequences of the other two massifs, nevertheless, Cap de Creus series also shows acidic metavolcanic layers giving ages of 560±11 Ma which allow correlation with Roc de Frausa and Canigó metavulcanites. Roc de Frausa orthogneisses (476.2±7.3 Ma) are comparable in age to Canigó gneisses. They result from a widespread Early Ordovician magmatic event in the Pyrenees and in the rest of the European Variscides. Mas Blanc gneisses are similar in age (560.1±7.3 Ma) to Port gneiss (576.4±8.1 Ma) and probably could be comparable to Casemí or Cadí gneisses in the Canigó massif and represent the final stages of the Cadomian orogeny.

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Geodynamic significance of the post-Variscan magmatism in the Ligurian Briançonnais (Italy)

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New geochronological data from post-Variscan ignimbrites of the Briançonnais domain in the Ligurian Alps, ascribing the volcanic-dominated stratigraphic sequence to a short interval (ca. 15 Ma) of Early Permian, furthermore highlighting a hiatus of ca. 20 Ma in sediment deposition and volcanic activity between the Early Permian and the Uppermost Permian.

Since in the basement the age of high-grade Variscan metamorphism is set between 340-320 Ma and the low-grade overprint at 310-300 Ma, while the first volcanic episode (directly spread over the basement) is dated at about 284 Ma, the exhumation rate of the basement results in ca. 1 mm/y. Therefore, following the collision, the orogen collapse mostly occurred driven by tectonic unroofing that triggered a crustal anatexis in the lowest crust. Later, in the time span between 284 and 274 Ma, a wide volcanic activity took place in subsiding strike-slip basins. The upwelling and the emplacement of magma, associated with high thermal flow and enhanced by widespread intracrustal magmatic reservoirs, was facilitated by transtensional faults tapping magmatic reservoirs at depth. In this regard, the Ligurian Alps underwent a generalized lithospheric attenuation associated with a large-scale mechanism of crustal delamination characterizing other sectors of the Variscan belt (Provence, Sardinia, Corsica, Southern Alps). The volcanic activity ended ca. 273 Ma, when the change from calc-alkaline to alkaline activity suddenly occurred, as elsewhere in Southern Europe. The sharp end of magmatic activity and the next gap in sedimentary deposition are in agreement with the model of large scale transformation of the Pangea (Muttoni *et al.,* 2003). The structural-stratigraphic features and the magmatic products of the Ligurian Alps are compatible with the generation of magma during the initial transtensive phase of this continental reorganization.

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Small amount of melt responsible for extreme weakening of orogenic middle crust of the Bohemian massif

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In the eastern part of the Bohemian massif highly strained middle crustal rocks separate varied lower crustal slices marked by presence of HP granulites and associated mantle rocks. This unit consists of strained porphyritic granite and kyanite bearing metasediments and recorded Carboniferous tectono-metamorphic history ranging between 340 and 320 Ma. The last tectonic stage is compatible with non-coaxial deformation marked by a NW-SE oriented stretching axis associated with dextral movements parallel to the lithospheric Elbe fault zone. The deformation study of deformed porphyritic granite at mid-crustal conditions reveal extreme weakness of feldspars compared to strong quartz. The rheological inversion is manifested by significantly higher strain intensities of feldspar aggregates compared to quartz. In order to explain this rheological paradox a detailed microstructural analysis has been performed and three types of microstructures corresponding to evolutionary stages of deformed granite were recognized. The original weakening of alkali feldspar is achieved by decomposition into albite chains and K-feldspar resulting from heterogeneous nucleation process. Extreme deformation of feldspars and their progressive mixing are attributed to syn-deformational melting of Mu-Bi rich layers associated with production of 2% melt by dehydration melting.

The syn-deformational melting is associated with grain boundary sliding controlled diffusion creep of feldspars. It is suggested that small amount of melt is responsible for extreme weakening of feldspar aggregates which overcome melt connectivity threshold thus triggering grain boundary sliding deformation mechanisms. Strong quartz show dislocation creep deformation mechanisms throughout the whole deformation history marked by variations in activity of slip systems, which are attributed to variations in stress and strain rate partitioning with regard to changing rheological properties of deforming feldspars. Extreme ductility of mid-crustal rocks is responsible for last stage of exhumation of orogenic lower crust operating in conjunction with downthrows of the upper crustal lid and sedimentation of high grade rocks in Culm basin. This event takes place at the final orogenic development of the Bohemian massif during the time span of 330-320 Ma.

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A rootless suture and the lost roots of a mountain chain: the Variscan belt of NW Iberia

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Exotic terranes occurring in the allochthonous complexes of NW Iberia represent a Paleozoic suture zone, probably that of the Rheic Ocean. They include ophiolites of different ages, pieces of the outermost Gondwanan margin and fragments of a volcanic arc of peri-Gondwanan derivation. Several of them bear the imprint of Paleozoic subduction.

The suture is rootless, which hinders its interpretation, but the counterpoint is the excellent exposure of the associated exotic terranes, which can be followed along tens of kilometres. Their relative structural position in the nappe pile and the age of metamorphic events have been used to establish their sequence of emplacement and to envisage their relative original position, which can be used to try paleogeographical reconstructions.

Several of the Iberian exotic terranes were progressively accreted to Laurussia in the Silurian and Early Devonian, during the opening of the Rheic Ocean. Oceanic closure occurred during the Middle and Late Devonian, first by intraoceanic subduction and later by subduction of the continental edge of Gondwana. When continental subduction became aborted, the accretionary wedge first acted as a buttress that induced recumbent folding in the passive continental margin of Gondwana during the Early Carboniferous. This was followed by development of an out-of-sequence thrust system that emplaced the exotic terranes over the margin also during the Early Carboniferous.

Thickening associated to recumbent folding and thrusting of the exotic terranes led to heating and weakening of the continental crust, which collapsed forming extensional detachments and granite-migmatite domes during the Middle and Late Carboniferous. Crustal extension and voluminous granite production were responsible for the elimination of the orogenic roots and the formation of a new Moho, rather flat but with one step, as seen in a seismic profile, which reflects differences in the degree of the crustal equilibration reached.

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Carboniferous synorogenic basin with Palaeozoic olistoliths in SW Central Iberian Zone: implications for the Variscan tectono-sedimentary evolution of the SW Iberian Massif

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The Kilva syncline lies within the Allochthonous Unit of the Obejo-Valsequillo Domain of the southermost Central Iberian Zone. The southern border of this unit is the Badajoz-Córdoba suture, which separates the Central-Iberian and Ossa-Morena Zones. The Kilva syncline includes a remarkable Serpukhovian synorogenic flysch succession with fossiliferous olistoliths derived from different Ordovician, Silurian, Devonian and Visean formations. These pre-Carboniferous olistoliths were progressively incorporated into the Serpukhovian succession from younger to older stratigraphic provenances, resulting in an inverted stratigraphy. Remnants of the *in situ* platform which served as source of the olistoliths crop-out in the Villaharta area, located to the west of the Kilva syncline and in the same Allochthonous Unit. Facies development and biogeographic data from the Lower Palaeozoic sequences occurring in the Villaharta and Kilva successions show intermediate characteristics between the well known passive margin Ordovician and Silurian formations of the Central Iberian Zone and those coeval from the Ossa Morena Zone. The occurrence of pre-Carboniferous olistoliths in the Kilva syncline supports the existence of a Serpukhovian tectonic event along the southern border of the Central Iberian Zone. This event succeeded to the two main ones already established for this region: a first Devonian compressive event that brought together the two zones and, subsequently, a second early Carboniferous extensional event. We therefore propose a tectonic event of Serpukhovian age which led to the formation of synorogenic “piggy back” basins such as the Kilva syncline and Central Belt of the Guadiato Basin, during the thrusting of the Allochthonous Unit onto its Central Iberian para-autochthonous.

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Strike-slip thrusting, “en échelon” folding, horizontal stretching parallel to the trend of the Variscan belt in Northern Iberia: the origin of the Ibero-Armorican arc

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The Ibero-Armorican arc or orocline is a prominent feature of the Variscan belt of western Europe comparable to other curved belts as the western and eastern “syntaxis“ of the Himalaya. In the Himalayas it is clear that these arcs are the result of the collision and penetration of India into Asia by northward continental subduction and progressive curvature of the structures (1). For the Variscan arc, the same mechanism: indentation of a promontory of a southern continent (Gondwana) into a northern one, Laurasia has been proposed by many workers (1, 2, 3, 4 ,5). Progressive bending of the structures is evidenced by, paleomagnetic data (6). Recently (7) another hypothesis was proposed :

The Ibero Armorican arc would have been originally a straight, N-S trending belt, later folded around a vertical axis by a N-S Later Carboniferous early Permian shortening.

Observations on the southern arm of the Iberian arc in the Alcanices synform (northwestern Spain) are not in agreement with this last hypothesis. Imbricated units in Siluro-Devonian sediments trending WNW-ESE show a northeastwards vergence (8). These structures are associated to “en échelon” folds in the Lower Ordovician quartzites of the Sierra de la Culebra and a stretching near-parallel to the trend of the structures, clearly evidenced by strongly elongated pebbles in the Siluro-Devonian conglomerates.

All these structures reveal large-scale ductile strike-slip sinistral movements in this southern arm of the Ibero-Armorican arc. Dextral ductile strike-slip tectonic is observed on the northern arm of the ibero-armorican arc at more or less the same time, (340-320 Ma) in Brittany.

These features are compatible with a progressive indentation of a promontory of Gondwana into Laurasia during the Carboniferous better than with a late folding of a previous straight N-S trending Variscan orogen.

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In situ LA-ICP-MS U-Pb zircon geochronology in the West European Variscan belt. New insights for Precambrian protoliths and Early Paleozoic magmatism

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Pre-Devonian inherited ages are known for a long time in the European Variscan massifs. However, most of these data, in particular Archean and Paleoproterozoic ages, never were the subject of a systematic geo-referencing.

A preliminary inventory of the pre-Devonian ages obtained in the French Variscan massifs allowed us to draw a distribution map of these relict ages and to highlight the importance of Paleoproterozoic, Neoproterozoic and Cambrian-Ordovician ages. Neoproterozoic ages are particularly abundant in the northern part of the Massif Armoricain and the southern part of the French Massif Central whereas Cambrian and Ordovician inherited zircons are widespread in the southern part of the Massif Armoricain and in the centre of the French Massif Central.

Sampling of para and ortho derived formations was made along a North-South cross-section in each unit of the stack of nappes in the Limousin (western part of the Massif Central). Zircons were extracted and analysed by the U-Pb method using the coupling laser / MC-ICPMS, allowing a precise dating of the various growth zones of the mineral, in particular the inherited cores (Cocherie & Robert, 2007). Our results emphasize the importance of the Cambrian and Ordovician crustal melting events related to the rifting episode responsible for the separation of Armorica micro continent (*i.e.* the central and northern parts of the Massif Armoricain) from the Northern Gondwana margin represented by the southern Massif Armoricain and the entire Massif Central. Moreover, the discovery of Neoproterozoic (ca around 600 Ma), Paleoproterozoic (ca 1,750±50 Ma) and Archean (ca around 3,100 Ma) magmatic episodes casts new light on the Precambrian evolution of the Northern Gondwana margin.

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The main types of the paleosedimentary basins in the Paleozoic basement (Tatric Unit, Western Carpathians, Slovak Republic)

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In the Late Paleozoic crystalline basement of the Tatric Unit of the Western Carpathians three main types of the sedimentary environment of the protolith of metamorphosed sedimentary rocks were observed: (1) the Active Continental Margin Environment Sedimentary Rocks (ACMESR), (2) the Deep Ocean Basin Ridge Environment Sedimentary Rocks (DOBRESR), (3) the Passive Continental Margin Environment Sedimentary Rocks (PCMESR).

(1) The chemical composition of ACMESR (variable composition, values of the ratio Th/U > 1, values Th/Sc 0.3-0.8, values LaN/YbN > 5 and values Eu/Eu* 0.6-0.9) indicates components derived from the Young Differentiated Arc provenance type. The identical geochemical parameters of various types of metamorphosed sedimentary rocks (metapelites, metapsammites, black schists, gneisses, contact metamorphosed rocks) of this group indicate: the same protolith (greywackes, lithic arenites ± organic matter), the same parental rocks (tonalite-granodiorite resp. dacite-rhyodacite), the same source area (active continental margin) and the same sedimentary environment (continental slope). Metamorphosed sedimentary rocks of the Tatric Unit, crystalline basement of the Malé Karpaty Mts. (Pezinok Group), of the Strážovské vrchy Mts. And of the Malá Fatra Mts., belong also to this group.

(2) The chemical composition of Dobresr indicates the components being derived from the Young Undifferentiated Arc provenance type (variable composition, ratio Th/U < 1, ratio Th/Sc < 0.25, ratio LaN/YbN < 6 and values Eu/Eu* ~1). The protolith of metamorphosed sedimentary rocks of this group consisted of pelagic shales + organic matter, protolith of metasilicites was formed by pelagic silicites + organic matter, protolith of actinolite schists and chlorite-actinolite schists was represented by halmyrolytic altered hyaloclastites and basalts of N-MORB type ± organic matter. The sedimentary environment of the protolith of this group of metamorphosed sedimentary rocks was the ocean floor; the sedimentation was accompanied by rift volcanism producing basalts of N-MORB type and hydrothermal activity forming the stratiform hydrothermal sulphidic bodies in sediments. To the same group of metamorphosed sedimentary rocks also belong the pelagic oceanic sediments from the crystalline complexes of the Malé Karpaty Mts. (Pernek Group) and of the Strážovské vrchy Mts.

(3) The chemical composition of PCMESR indicates extensive chemical weathering by high values of CIA and PIA indexes. Th/U, Eu/Eu*, Th/Sc, LaN/YbN, Th/Yb vs. Ta/Yb ratios indicate a material derived from ancient upper continental crust. Trends in Th/Sc vs. Zr/Sc and Th/Sc vs. Hf ratios are typical for recycled sedimentary rocks/metamorphosed sedimentary rocks. Mutual relations in La-Th-Sc and Th-Sc-Zr/10 resemble a sedimentary basin in the passive continental margin setting. Protolith of this group of metamorphosed sediments was characterized by intercalation of mineralogically mature quartzous sands and chemically mature clays. Lack of basaltic rocks is typical here. Lower unit in the High Tatra Mts. crystalline complex can be put as example. Also micaschists and quartzous gneisses of the northern part of the Považský Inovec Mts. and micaschists of the Tribeč Mts. could be classified in this group as follows from preliminary data.

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Orogen-parallel extension: strain partitioning around mantled gneiss domes - implications from the Axial Zone of the Pyrenees

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Elongated structural and metamorphic domes are a common feature in the cores of orogenic belts. They are characterized by alignment of their long axes parallel to the trend of the orogenic belt and gneissic or migmatitic cores mantled by deformed metasedimentary rocks.

Different levels of exposure of gneiss domes are observed in the Bossòst and Aston-Hospitalet domes of the central and eastern Pyrenees. The exposed core of the Bossòst dome comprises undeformed late Variscan leucogranite, with older - as yet undated - foliated tonalite observed only in the central part of the core. The Aston-Hospitalet dome displays deeper structural levels with complete exposure of its orthogneiss core, whose pre-Variscan protolith age is currently under investigation. The mantling metasedimentary cover is mainly exposed at the eastern and western margins of the Aston-Hospitalet dome, while it covers the Bossòst dome more completely. Both dome structures are actually a pair of half domes, as they are cut by easterly trending steep fault and mylonite zones, the Bossòst and the Merens fault, respectively, that are of latest Variscan or Alpine age and that resulted in relative uplift of the northern half domes.

The main structural fabrics of both domes are similar. The major schistosity forms girdles around shallowly plunging, easterly trending fold axes. Conspicuous mineral lineations shallowly plunge to the SE-ESE or NW-WNW. The orthogneiss cores of the Aston-Hospitalet half domes show the same orientation of gneissic schistosity and mineral lineation, suggesting coeval deformation of the metasedimentary cover and the orthogneiss during the main Variscan deformation phase. In the southern Bossòst dome mineral lineations are associated with a flat-lying extensional shear zone that facilitated uplift of the underlying higher metamorphic core. A similarly oriented extensional shear zone has been reported previously from the eastern Hospitalet dome.

Metamorphic studies in both domes show that the development of the main schistosity occurred at pressures around 5 kbar, while later metamorphism associated with emplacement of late Variscan granitoids near or partially into the orthogneiss core occurred at much shallower depths (6 km). The previously emplaced, and during the main Variscan deformation foliated, orthogneisses acted as strain partitioners during later N-S directed compression. Enhanced by beginning uplift of the more rigid orthogneiss cores and pluton emplacement, the roofing metasedimentary cover rocks experienced orogen-parallel extension.

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The geometry of the Northern Variscan thrust front in the Artois area (Northern France): Insight from seismic imaging and 2.5-D gravity modelling

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The Northern Variscan Thrust Front is a major structural feature of Northern France. Its main expression is a crustal-scale S-dipping thrust zone the emerging part of which corresponds to the classical "Midi Fault Zone", an out-of-sequence composite thrust that truncates the coal-bearing Namurian-Wesphalian foreland basin and its Brabant-type substratum. This thrust system has been mainly studied in the Boulonnais and the Ardennes-Avesnois areas that form the primordial exposures of Palaeozoic rocks, respectively at the western and eastern tips of the arcuate Variscan belt of Northern France.

Elsewhere, like in the Artois region, the Variscan thrust front is concealed below the relatively thin meso-cenozoic deposits of the Paris basin. Since the end of the 19th century, coal and petroleum exploration have therefore contributed to characterize the thrust front geometry mainly through boreholes but also in more recent years through seismic reflection profiles and gravity data. We propose here a reappraisal of the deep geometry of the Variscan thrust front in the Artois area using unpublished industrial seismic profiles acquired, perpendicular and parallel to the WNW-ESE structural strike, during the Boulogne-Maubeuge campaign in 1984-1985. Interpretations of the profiles are constrained by boreholes and localized Paleozoic outcrops and checked using 2.5D gravity modelling and balanced cross-sections concepts.

As a whole, these data depict a thrust-front geometry strongly different from that evidenced easterly towards the Nord-Pas de Calais coalfield and the Western Ardennes with a significant reduction of the thrust throw onto the Namurian-Westphalian foreland basin. On the other hand, a very striking feature is the existence of a basement-involved frontal triangle zone implying deeply buried back-thrusts affecting the thick Silurian silico-clastic sequence and folding the more superficial N-verging Variscan thrust system. We suggest that these deeply seated back-thrusts could have resulted from the reactivation of Caledonian thrusts from the Brabant Massif that therefore formed a sort of intracutaneous wedge hindering the northward propagation of Variscan thrusts and inducing the out-of-sequence dislocation of the thrust front.

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Was the European Variscan geodynamic cycle driven by a mega–shear zone? Clues from Sardinia-Corsica Massif and Calabria-Peloritani Arc

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Sardinia-Corsica Massif, SCM, and Calabria-Peloritani Arc, CPA, provide a good example as regards the role played by the middle Ordovician tectonics, during the Variscan geodynamic cycle. CPA (at present in south Italy and northeast Sicily) was placed, before the opening of the Thyrrenian Sea, east of the SCM.

In SCM-CPA, middle Ordovician is characterized by contemporaneous development, in adjoining areas, of transtensional and transpressional tectonics. The transtension is documented by the following phenomena.

1- Opening of a narrow ocean in north Sardinia-west Calabria-north Peloritani.

2- Effusion, in central Sardinia-east Calabria-south Peloritani, of acidic and basic calc-alkaline volcanics. These were followed, during late Ordovician-early Silurian, by basic alkaline volcanics. The transpression affected above all central Sardinia, with formation of wide-open folds (“Sardic phase”).

Key points are the following.

1- The volcanics effused in connection to the transtensional tectonics, which, in turn, caused the opening of the ocean. Therefore, they are not linked, despite their geochemical characteristics, to subduction processes of oceanic lithosphere. Rather, they are connected to the transtension, which marks thinning of continental crust and subsequent opening of the ocean.

2- Ordovician transtension developed at the same time as transpression (“Sardic Phase”). This phase is recognizable in several areas of the European Variscides. Regional co-existence of transpression and transtension is consistent with development of strike-slip displacements of the continental crust.

3- In this frame, the ocean should be considered a pull-apart basin, formed in areas affected by maximum of transtension.

It is noteworthy that the Variscan chain is characterized, in the whole Europe, by scarcity of ophiolite remnants. This may be due to the activity of the strike-slip dynamics that led to the opening of several pull-apart basins, within a mega-shear zone. The mega-shear zone model can also account for the extraordinary geometric complexity of the European Variscan chain, its unusual width, and the time-transgressive opening (from late Cambrian to middle Ordovician) of several oceanic basins.

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Zircon U-Pb and Pb-Pb geochronology of the Cambro-Ordovician Ollo de Sapo formation and related magmatism (Central Iberan-zone, Spain)

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The Ollo de Sapo Formation constitutes the largest lineament of Cambro-Ordovician magmatic rocks, both volcanic and plutonic, in Iberia. It is mainly composed of acid metavolcanites, ignimbrites and tuffs of rhyodacitic composition, and some small granitic to granodioritic intrusions, all of which were transformed to augen-gneisses during the Variscan Orogeny. The geochronology of these rocks has been historically difficult, owing to the effects of the Variscan metamorphism and, especially, the unusually elevated fraction of inherited components in the zircons. About 85-95% of zircon grains from the metavolcanites and 75-90% of zircon grains from the metagranites contain inherited cores, as revealed by cathodoluminescence imaging and U-Pb microanalysis. This paper summarizes a survey to date the Ollo de Sapo Formation and associated metagranites in five localities distributed along the formation: Hiendelaencina, Villadepera, Puebla de Sanabria, Puebla de Trives, and Vivero. Age determinations were done on single zircon grains by U-Pb (ion microprobe and laser ablation ICP-MS) and Pb-Pb (stepwise evaporation-TIMS).

In a few cases, Rb-Sr was also used. Results are as follows: Hiendelaencina region: The lower metavolcanites gave a U-Pb concordant crystallization age of 495±5 Ma. They also contain inherited populations at 603±8 Ma (very abundant), 650-700 Ma, 850-900 Ma, and some discordant older crystals which define an upper intercept at 2,016±49 Ma. By ^{207}Pb-^{206}Pb stepwise evaporation, they yielded a crystallization plateau-age of 494±4 Ma. The upper metavolcanites gave a U-Pb a concordant crystallization age of 485±5 Ma, and an iden-tical Pb-Pb crystallization plateau-age of 483±2 Ma. It seems, therefore, that the upper metavolcanites are notably younger that the lower ones. They, however, have the same inherited populations. The Antoñita metagranite gave a Rb/Sr isochron age of 477±27 Ma and a Pb-Pb crystallization plateau-age of 474±4 Ma, identical within error range. It is, therefore, about 10 Ma younger than the upper metavolcanites.

Villadepera region: The thin metavolcanites gave a U-Pb concordant crystallization age of 483±3 Ma, two concordant inherited populations at 614±12 Ma, 1,968±35, and a discordia line with an upper intercept at 2,997±37 Ma. The Miranda do Douro metagranite gave a U-Pb concordant age of 483±3 Ma, an inherited population at 605±13, and a discordia line with an upper intercept at 3,176±57 Ma. Two zircon grains were nearly concordant at ca. 3.2 Ga. Here, in contrast to Hiende-laencina, the metavolcanites and metagranites are coeval.

Puebla de Sanabria region: The lower metavolcanites gave an U-Pb concordant crystallization age of 492±2 Ma, and concordant inherited populations at 605±3 Ma and 1,067±34 Ma. Upper metavolcanites gave a U-Pb concordant crystallization age of 488±2 Ma and concordant inherited populations at 607±8 Ma, 1,958±41 Ma, a discordia line with un upper intercept at 2,596±10 Ma and three nearly concordant points at ca. 3.2 Ga. The Viana do Bolo metagranite gave a U-Pb concordant crystallization age of 487±4 Ma, confirmed by a Pb-Pb plateau at 488±4 Ma, a sub-concordant inherited population at 609±10 Ma and a discordia with upper interception at ca. 2.6 Ga.

Puebla de Trives region: The metavolcanites yielded a U-Pb concordant crystallization age of 488±5 Ma and concordant inherited populations at 610±9 Ma and 2,015±40 Ma.

Vivero Region: The metavolcanites of El Barquero and Mañón areas yielded the same age distribution: a U-Pb concordant crystallization age of 486±3 Ma (identical to the Pb-Pb evaporation age), inherited concordant populations at 608±10 Ma and 1,056±10 and a discordia line with an upper intercept at 2,566±10 Ma.

Our data reveal that the Ollo de Sapo Formation is the result of magmatic activity over a maximum of 12 million years, from 495 to 483 Ma. The maximum duration of the episode occurred in the Hiendelaencina region, probably reflecting the vicinity of the Cambro-Ordovician batholith of Guadarrama. The high zircon inheritance reveals that the protolith was crustal, composed of intermediate to felsic magmatic rocks of Panafrican origin, or young, immature metasediments derived from them. It also indicates that the kinetics of melting was extremely fast, which suggests an underplating mechanism in a rifting environment.

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The tectonic style of the Western Ardennes-Avesnois Variscan fold-and-thrust belt: evidence for décollement tectonics and widespread back-thrusting

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The Western Ardennes-Avesnois Paleozoic massif forms the primordial exposure of the Variscan deformation front in Northern France. It includes folded and thrusted units composed of non-metamorphic to epimetamorphic sedimentary rocks of mostly Devonian-Carboniferous age, initially deposited upon the northern margin of the Rheno-hercynian basin *i.e*. the southern Avalonian margin. Along a Western Ardennes transect imaged by the M146 seismic profile (Lacquement *et al.,* 1999), the thrust front is characterized by a major crustal scale south-dipping thrust zone whose emergence corresponds to the classical "Midi" thrust zone. The latter induces the thrusting of the Ardennes-Avesnois fold-and-thrust belt onto the dismembered molassic Namurian-Westphalian coal-bearing foreland basin and its Brabant-type substratum.

The main Ardennes basal thrust accommodates a total displacement of more than 70 km towards the NNW, a significant part of the motion occuring during a late out-of-sequence event. South of this main thrust, the Western Ardenne-Avesnois area display second order thrust-related folds with a general ENE-WSW trend and a NNW vergence. These structures involve a strongly heterogeneous lithological sequence, characterized by silicoclastic rheologically weak horizons about several hundred meters thick (*i.e*. the Lower Devonian, Famennian and Upper Carboniferous levels) interstratified with two limestone competent sequences (the Mid-Devonian and Dinantian levels). The induced rheological contrasts strongly control the deformation style. New cartographic and structural studies, mainly carried out in the Famennian sequences (initially less studied owing to relatively bad outcrops conditions), allowed us to precise the geometry and kinematics of the fold-thrust structures both in cross-sections and at the outcrop scale. As a whole, these data indicate.

(1) that the thick incompetent Famennian layers acted as a distributed complex décollement-zone decoupling shortening between the Mid-Devonian and Dinantian layers and

(2) that the foreland-directed thrust related folds were lately deformed by backwards thrusting. Together with the significant out-of-sequence dissection of the thrust front, this late back-thrusting event document the overall difficulty of the forward propagation of the thrust front onto the Brabant foreland.

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Long lived dextral strike-slip tectonics in the Southern Variscan Belt: evidences from two sinkynematic intrusions of North Sardinia (Italy)

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Several strike-slip dextral shear zones affect the Variscan basement of north Sardinia. The mean trend of tectonic lines is about N120 E, with local E-W and N-S deflections. The major shear zone is the 120 km long Posada-Asinara line, which brings into contact the kyanite-bearing metasediments of the Medium-Grade Complex and the K-feldspar + Sillimanite paragneisses and diatexites of the High-Grade Complex. Greenschist-facies mineral assemblage in textural equilibrium testifies the retrograde character of deformation. Field, micro-scale structural analyses, quartz lattice preferred orientation (LPO) analyses and U-Pb (ICPMS-MC) dating were performed on the Badesi granodiorite and Cala Muro peraluminous monzogranite. Both intrusion are synkinematic, and emplaced within the Posada-Asinara line and S. Maria shear zone, respectively.

The Badesi granodiorite (300.1±6.1 Ma) is a biotite-hornblende granodiorite. The intrusion core preserve a chiefly magmatic foliation that is parallel to the shear-zone boundary. In this domain, quartz grains exhibit patchy undulose extinction and poorly sutured boundaries, whilst feldspars are fractured. Approaching the pluton margins the fabric increase in intensity. Feldspars are somewhat rounded augen, with thin recrystallized tails. Quartz grains are highly stretched ribbons with undulose extinction, and regions of dynamically recrystallized subgrains developed along the quartz-quartz contacts. The quartz-LPO patterns consist of two types of distribution: i) a weak Y-maximum occurs in the core samples; ii) asymmetric single girdle occurs in the peripheral samples.

The Cala Muro granite (321.2±8.3 Ma) is an eye-shaped muscovite + andalusite granite with homogeneous S-C fabric. The intrusion emplaced within a 500 m wide shear zone which is exposed along a couple of kilometres in the Santa Maria island, about 40 km north of the Posada-Asinara line. Under the optical microscope the quartz grains have undulose extinction and forms core-and-mantle structure. Feldspars are fractured and lack any evidence of dynamic recrystallization. Quartz-LPO patterns approach the c-axis distribution of the granodiorite margin, though indicating lower temperature and/or high strain.

Microstructural observations in and around the Badesi granodiorite and the Cala Muro granite support a synkinematic emplacement model within dilatational, dextral strike-slip zones. U-Pb dating are in good agreement with a general Late-Variscan age, though the 20 Ma time-span indicate the dextral, strike-slip tectonics would be a long-lived feature. The occurrence of a chiefly magmatic fabric in the core of the granodiorite intrusion, any case, suggests that melt conditions partly outlast the strike-slip tectonics.

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Constraints on the lithosphere across the Variscan orogen of SW-Iberia from dense wide-angle seismic reflection data

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Two wide-angle seismic transects have been acquired across the SW Iberian Massif. They run across three major geological zones (South Portuguesse Zone, Ossa-Morena Zone and Central Iberian Zone). A total of 690 digital seismic recording instruments from the IRIS-PASSCAL Instrument Pool have been used. The transects (A and B) are, approximately, 300 km long and consist of 3 and 6 shot points, respectively, with an, approximately, 60 km shot point interval. The charge sizes range from 1,000 kg at the edges to 500 kg at the centre. These experiments were designed to provide velocity constraints on the lithosphere and to complement the previously acquired normal incidence seismic profile (IBERSEIS).

The acquisition parameters provide closely spaced wide-angle seismic images of the lithosphere beneath SW-Iberia. The interpreted PmP arrival, located at approximately 11 s (normal incidence travel time), is characterized by a high amplitude and relatively low frequency (6-12 Hz). Also well-defined Pn arrival appears at offsets beyond 120 km. Within the upper crust the shots records feature a relatively high velocity arrival, located at 4-5 s normal incident travel time. A preliminary analysis of this arrival indicates that it probable corresponds to the top of the Iberian Reflective Body identified in the IBERSEIS deep seismic profile. The velocity models obtained by forward modelling show a complex crust, especially in the middle crust. The velocity depth functions derived from the velocity models have higher middle crust velocities than the average continental middle crust velocities. A comparison between the laboratory seismic velocity measurements and the velocities of the models was carried out in order to obtain the crustal and the upper mantle composition. Results indicate that the high middle crust velocities correspond to rocks with a mafic content. All these data reveal new aspects related to the lithospheric evolution of this transpressive orogen, and allow us to attempt an interpretative cross-section of the upper lithosphere in the SW Iberia.

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2D and 3D gravity modeling of the Bohemian Massif (Czech Rep.)

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A new compilation of gravity datasets of the full Bohemian massif as well as partial gravity datasets of its neighbours countries have led to the creation of new 2D and 3D gravity models of the entire massif. This contribution is mostly focused on the large scale structure of the massif, and its south-eastern contacts with the Brunia.

The Bouguer Anomaly signal was filtered to remove all the mantellic-associated wavelengths to focuse on the custal part of the lithosphere. All the gravity profiles were modelled following the same method with a depth-model of 40 km, and density values of the different units are averages from measured samples. The software used to model the Bouguer anomaly was IGMAS, and it was chosen to keep the 2D and 3D calculation. The seismic line 9HR (personnal communication, Tomek) was used to constrain at depth the profiles.

The preliminary results show that, a unit located in depth below the Eastern part of the Moldanubian, with a density similar to the Brunia, is necessary to fit the calculated and observed Bouguer anomalies. The Brunia is interpreted to have indented into the bohemian massif (into the Western part of the Moldunabian), and can be geophysically observed as far as 60 km away from the surface contact (north-easterward). The slope of the indenter is very gentle for most of the 60 km length, and increase drastically in the last 5 km to become almost vertical. In the north central part of the massif, two separate units are observed, and are interpreted as the remnants of two subduction slabs.

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Metamorphic conditions of the Variscan collision inferred from metasomatic shear zones (Ile d'Yeu, Armorican Massif, France)

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The island of Ile d'Yeu is mostly made of moderately deformed granitoid orthogneisses of Cambrian age. A network of amphibolite-facies shear zones developed within the orthogneisses during the Variscan deformation. Based on the geometry and geochemistry of the shear zones, argued that some of them developed early during the prograde, compression-related part of the Variscan P-T evolution and remained active until the temperature peak. Within the shear zones, intense fluid circulation transformed the granitoids into "micaschists", which locally display interesting mineral parageneses including staurolite, cordierite, corundum, kyanite, sillimanite and andalusite.

The paragenetic sequence has been interpreted in terms of a simple Barrovian clockwise P-T path. Careful paragenetic analysis and reinterpretation of the crystallisation sequence of the Al_2SiO_5 polymorphs (Ky→And→Sil) leads us to propose a qualitatively different evolution. Based on phase diagrams calculated with THERMOCALC, we infer that the fluid-assisted syntectonic development of kyanite-bearing peak parageneses occurred at temperatures and pressures higher than 580°C and 6 kbar, respectively.

Pseudomorphic replacement of kyanite by andalusite and the development of cordierite coronas indicate decompression, possibly associated with cooling. Local development of corundum + cordierite symplectites around staurolite and kyanite suggests fluid-deficient conditions at this stage. Subsequent crystallisation of sillimanite implies renewed heating at low pressures, possibly accompanied by further infiltration of fluids. The cause of this heating is a matter for discussion. We conclude that the transformation of the granitoid orthogneisses into aluminous lithologies results from long-lasting, probably episodic fluid-rock interaction during a complex P-T path involving heating and compression, decompression and further heating.

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New field observations on the Carboniferous formations of the Saint-Pierre-La-Cour basin (Armorican median synclinorium)

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In Brittany, Carboniferous basins are located along the North Armorica Shear Zone. The realization of the geological map of Laval (Mayenne, France) at 1/50 000 scale, provided conditions to revisit numerous outcrops. More particularly, the study of the Saint-Pierre-la-Cour Quarry (Lafarge Group), on the western ending of the Carboniferous Laval basin, led us to decipher the sequence of the events that characterized the evolution of the basin, from the beginning of the Carboniferous sedimentation until the end of the Variscan shortening.

The Carboniferous sedimentary rocks lay on unconformity on the deformed Lower Palaeozoic basement. Field observations highlight 3 main events during the Carboniferous:

1/ The first event corresponded to the sedimentation on the deformed basement of Tournaisian siliciclastic and volcaniclastic formations, postdated by a Visean carbonated platform. This carbonated sedimentation was replaced by siliciclastic sedimentation from Upper Visean to Namurian (Laval Schist Formation). This evolution was accompanied by synsedimentary tectonic stretching (formation of normal faults), sharp variation off thickness and facies according to Houlgatte *et al.* (1988).

2/ The Namurian-Westphalian shortening caused folding and faulting of previous formations. The E-W trending synsedimentary faults were inverted and accommodated the main deformation. The geometry of the basin controlled the morphology of the shortening structures.

3/ After erosion and weathering -including karstification- of the Visean limestone, Westphalian and Stephanian sediments were deposited on unconformity on the previous Lower Carboniferous formations. Following the first siliciclastic sandstone deposits, the Westphalian sedimentation seems to correspond to a marine environment which was followed by Stephanian heterogeneous lacustrine sediments (conglomerate, sand, silt and mudstone with numerous fossil plants). During Upper Stephanian, all Carboniferous formations were then deformed during folding and northward thrusting of the Stephanian formations associated to the wrench fault zone (Houlgatte *et al.*, 1988).

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Orogeny in the Urals: Timing and Mechanics

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Only the first stages of orogeny in the Urals coincide in time with the Variscides. The orogenic processes creating the Uralides had a much longer duration: they started in the Late Devonian and went on through the whole Carboniferous and Permian. After a time of a relative quiescence interrupted by the activity of the Uralo-Siberian superplume at the Permian/Triassic boundary, the last orogenic deformations (Old Kimmerian) took place in the first half of the Jurassic. Most of the Uralide structures were created by several interplate collisions combined with and followed by strike-slip movements. Morphology of the orogen was strongly influenced by plate anisotropy. Especially important was anisotropy of the continental margin, involved into the collision, which was determined by strength and strikes of Precambrian structures of the crystalline basement and a presence of promontories and embayments in the continent's outline. During the orogeny, general stress directions were changing from orthogonal to oblique, leading to a change from a frontal thrust-and-fold style to a transpressional one.

The predominant dip of subduction from the continent of Baltica resulted in a collision of an arc-continent type along the passive margin. The collision was diachronous (Late Devonian in the South and Early Carboniferous in the North), being accompanied by the east-sourced greywacke flysch and HP-LT metamorphism. The following collisions were of a continent-continent type. The foreland structures are predominately of a thin-skinned type, but in the direction to the axis of the orogen they change through a pronounced ramp to thick-skinned ones due to a sharp change in the state and properties (temperature, fluid saturation, plasticity) of the deformed masses.

Most if not all the collisional orogens were primarily bivergent; the Urals has preserved this feature very well. The hot root of the orogen was formed in the Permian time under the East Uralian zone as a result of the most strong collisional thrusting, when palingenetic granites of the Main Granitic Axis were formed. A cold root exists under the Urals now, as a consequence of high density of rock masses in the Tagil-Magnitogorsk zone – a site of an unusually good preservation of extremely thick and dense ophiolite and island-arc complexes. The modern Urals mountains are the result of very recent intraplate compressional deformations. Nevertheless the root is not correlated with the crest of the modern mountains and is not connected with the neo-orogeny.

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Evolution and origin of the West-Carpathian pre-Mesozoic basement, dated by SHRIMP

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The Central West-Carpathian basement, included into Cretaceous-Early Tertiary structures, shows remnants of pre-Alpine, mainly Variscan tectonics. The paper documents *in-situ* U-Pb zircon (SHRIMP) ages of a major Cambrian to Ordovician magmatic event, which occurred in the West-Carpathian basement. Cambrian to Ordovician, less Early Silurian concordia magmatic ages, with older 525-470 Ma and younger 480-440 Ma age intervals are registered in layered amphibolites and granitic orthogneisses of the tectono-stratigraphically Upper Variscan structural Unit. The zircon cores, especially in orthogneisses, often show Cadomian mainly magmatic source (protolith) ages spanning 638-549 Ma, with a concordia age at 617±11 Ma. Older Proterozoic to Archaean protolith ages (2,000 up to 3,400 Ma) are much less common. Cadomian ages are highly predominating in kyanite-garnet orthogneisses, as tectonic slices within the metasediments of the Middle Variscan structural Unit. Orthogneisses show magmatic ages spanning 649-554 Ma, with concordia ages at 607±10 and 558±7 Ma, while metamorphic ages between 540-530 Ma. These ages corroborate the source ages of surrounding metasediments with a lower intercept around 500 Ma. Early Ordovician ages were also found from the calcalkaline metavolcanics (482±6 Ma, metarhyolite, or 476±7 Ma, metadacite) of low-grade volcano-sedimentary complexes in the Lower Variscan structural Unit. Long-term magmatic/volcanic activity due to melting of the crust and subcrustal lithosphere is coeval with the rifting and probably a two-stage break-up of the Gondwana northern active continental margin.

The ages of 430-380 Ma of layered amphibolites and orthogneisses could reflect the early collision metamorphic event, following a HP metamorphism in the Prototethyan realm. The extension collapse of thickened crust led to partial melting within the Upper Unit, generating 380-340 Ma old zircons, and/or S-/I-type granitic-tonalitic plutons (360-320 Ma), coeval with the collision of the Armorica with the amalgamated Avalonia/Laurussia since the Middle Devonian.

Meta-gabbro, associating with deep-water meta-sediments, with 383±3 Ma magmatic concordia age, already represents evolving Palaeotethyan ocean crust. Magmatic age of a meta-gabbro-dolerite crosscutting (Pernek) ophiolite complex is 371±4 Ma. Magmatic age of 350±5 Ma from the “hanging wall” Sr-rich gabbro-eclogite, associating with a meta-peridotite (Radvanec, 1999), indicates supra-subduction mantle melting and onset of mantle wedge formation. The age group ranging 320-300 Ma is interpretable as their detachment by subducting slab, eclogitization and exhumation. Tectonic emplacement of Sr-rich Jd eclogite into (Rakovec) greenschist facies rocks occurred at ca. 300 Ma.

Northward subduction/accretion led to the post-orogenic collapse and plutonic/volcanic activity in the late-Variscan orogenic wedge during the 300-260 Ma time span as inferred from the newly-formed zircons of dated meta-igneous rocks. The Permian S-type granites (275-262 Ma) we relate to the late-Variscan orogenic collapse, while dated A-type granites (267-258 Ma) to the early Alpine continental rifting/metamorphic-melting event and opening of the Neotethys realm.

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A model of exhumation of St. Leonhard granulite massif (Lower Austria) based on structural analysis of orogenic fabrics

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The flat fabric of St. Leonhard granulite massif served for decades as an excellent example of lower crustal nappe transported over distances of hundred kilometres in E-W directions over lower grade rocks of the Moldanubian orogenic root domain. This is because of structural position of granulite on top of less metamorphosed sequences (granulite facies mafic rocks, amphibolites, high grade felsic orthogneiss and medium grade schists) downwards, bowl like distribution of main metamorphic fabric in granulite and its host rocks and extremely intensive E-W mineral and stretching lineation. The detailed structural analysis of this key area revealed following structural pattern:

1) granulite and the adjacent mafic host rock reveal existence of an early steep metamorphic foliation N-S trending in the south and E-W trending in the north,

2) this fabric is reworked by flat granulite to amphibolite facies fabric which shows the “bowl” like distribution,

3) mineral lineation is trending N-S in the south and E-W in the north of granulite body, while underlying felsic orthogneiss and medium grade rocks reveal only N-S stretching. Large scale structural analysis supported by detailed microstructural study shows, that the stretching lineation pattern results from superposition of subhorizontal fabric on vertical one during generalized N-S shearing. Variations in mineral lineation directions are interpreted in terms this flat shearing where E-W lineation is not regarded as transport lineation but stretching fabric resulting from almost orthogonal fabric superposition. Orthogonal character of steep fabrics is interpreted as a result of N-S shortening resulting in crustal scale buckling of originally NNE-SSW trending deep orogenic fabric. These crustal scale folds with west plunging steep axis originated in front of southward moving continental piston. At late stages of buttressing the whole system was thrust over rigid piston generating flat fabrics with northward kinematics generally observed in this part of Bohemian Massif.

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Cambro-Ordovician *versus* Carboniferous Event in the Śnieżnik Metamorphic Unit, Sudetes, Poland

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In the north-east edge of the Bohemian Massif, the Śnieżnik Metamorphic Unit is a border unit of Lugian (West Sudetes) domain with the adjacent Silesian terrain. Long-lasting debate regards a sequence and an age (Caledonian *vs*. Variscan) of deformational events in the region. In the light of new structural (Grześkowiak & Żelaźniewicz, 2002; Grześkowiak, 2004; Jastrzębski, 2005) and SHRIMP data (Grześkowiak *et al.*, 2005; Murtezi & Fanning, 2005) these events shell be related to widespread in the whole Bohemia the 500±3 Ma magmatic event. What precedes the intrusion of the Śnieżnik (meta)granite refers to 515-490 Ma early phase of Caledonian deformation (Grześkowiak *et al*., 2005) and is observed in migmatitic variants of the Gierałtów gneisses. Early mylonitic foliation or non-mylonitic layering S1, involved in small-scale disharmonic folds F1defines D1 (see Grześkowiak, 2004); the F1 axial planes (presently subhorizontal) form the cleavage foliation S2 accompanied with felsic, polymineral (Kfs+Qtz+Pl±Bt) porphyroblasts coming from syntectonic migmatization (M1 with "top-to-the-W" kinematics), followed by occasional F2 folds and/or small-scale shearing zones, emphasized by M2 migmatization, with "top-to-the-E" kinematics (M1 & M2 define D2). As the second (HT) mylonitization is the deformation observed already in the Śnieżnik (meta)granite, the D3 must have developed during the time of 350-325 Ma (Turniak *et al*., 2000; Grześkowiak *et al*., 2005). The D3 overprints the migmatitic fabric by its elongation (L3) and flattening (mylonitic S3). Effects of D3 can be mainly observed in the Stronie formation (stages from 1 to 5 according to Dumicz, 1988 and Jastrzębski, 2005). Shear zones S-C and S-C' bands overprint the main foliation with greenschist facies mineral assemblage. The late concentric folds, kink folds and crenulation cleavage defining the D4, demonstrate retrogressive, semi-brittle conditions preceding variscan Kłodzko-Złoty Stok intrusion (see Jastrzębski, 2005).

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U/Pb dating study of augen orthogneisses from the Axial Zone of the Montagne Noire (Southern of Massif Central): new insight into the Variscan Belt

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Within the southern part of the French Variscan Belt (French Massif Central, Pyrenees) numerous metamorphic gneiss domes occur: Montagne Noire, Canigou, Aston…. These gneisses overlain by Lower Paleozoic schists and marble series have been interpreted as a granitic Precambrian basement (1, 2, 3). However Ordovician ages determined for the Canigou gneisses (4, 5) indicate clearly that the knowledge of the absolute age of the granite protolith is a data of great importance for understanding stratigraphy and further occurrence of variscan nappe tectonics. The challenge is to determine wether the gneisses constitute a Precambrian basement or must be considered as Ordovician laccolites.

U/Pb dating of six felsic augen orthogneisses from the Axial Zone of the Montagne Noire (French Massif Central) have been performed using TIMS on zircons and monazite as well as SIMS on zircons. The zircon data indicate Cambrian (520-510 Ma) and Ordovician ages (460-450 Ma) for different samples. These ages are interpreted as the granitic protolith emplacement age. If Cambrian ages were known in the Axial Zone, the Ordovician ages are new (6). Even if such an event has been suggested in other part of the Variscan orogen, always in the light of precise dating on calc-alkaline gneisses: Canigou (4, 5), Sierra de Guadarrama in Central Spain (7). They have been interpreted as possible relicts of an Ordovician continental magmatic arc associated with the early stages of the separation of Avalonia from Gondwana leading to the opening of the Rheic ocean (7). In our mind the Ordovician period should be better related to extension than to convergence.

Single monazite data have been performed on the same Ordovician samples. The ages are 305±5 Ma, indicating the clear imprint of the Variscan event within the Axial Zone of the Montagne Noire. These monazite grains have not the record of the Ordovician magmatism.

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Mechanics of thick- skinned Variscan overprinting of Cadomian basement (Iberian Variscides)

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Variscan tectonics is well exposed in the Iberian Peninsula and corresponds to a major event in the evolution of the European lithosphere. However, over large domains of the Iberian Variscides (IBVA), the relative role of neoformation and recycling remains uncertain and the clarification of this issue is of at most importance to understand the geodynamics of the Variscan Cycle. Relics of Cadomian basement in the IBVA is demonstrated by sedimentary Neoproterozoic and Lower Palaeozoic sequences, as well as by major geological events that have been dated within the age range of 620-540 Ma.

Indeed, near the Cambrian–Ordovician boundary, a pervasive episode of magma underplating and extensional tectonics (associated with bimodal magmatism and high heat flux) caused basement thinning and transient tectonic thickening in the IBVA Internal Zones, reflecting contemporaneous migration of an intracratonic rifting from the Central-Iberian Zone to the SW Variscan suture, between the Ossa-Morena Zone and the South-Portuguese Terrane. Orogenic thin-skinned tectonics is expressed by décollements of deformed and undeformed Palaeozoic and Cadomian basement in the IBVA External Zones (Cantabrian and South-Portuguese), whereas in the IBVA Internal Zones thick-skinned tectonics (without cover-basement interface décollements) generated Helvetic/Penninic style nappes (in tangential tectonics domains) and flower upright axial structures along transpressive, intraplate shear zones (Tomar-Badajoz-Córdoba Shear). The mechanical behaviour reflects attenuation of rheological contrasts between Cadomian basement and Palaeozoic cover caused by thermal softening during the Lower Paleozoic extensional regime. Deeper décollements (and subsequent strain partitioning) are also inferred to occur at the upper-lower crust (and at the Moho?) transition, as imaged by seismic profiling (and MT surveys) and tectonic data. The whole data implies a significant discontinuity between Cadomian and Variscan Cycles that should have constrained subsequent lithospheric evolution.

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Progressive shortening axis rotation monitored by 370-320 Ma syn-kinematic granites in the French Variscan belt (Armorican and western French Central massifs)

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The Variscan continental collision has led to the development of large strike-slip shear zones in Western Europe. Our study focuses on the regional deformation and shear zone patterns in the Armorican massif and the French Central Massif. Together with new datations, the synthesis of granite ages related to different deformation fields, allows to propose a geodynamic model for the tectonic evolution of this part of the Variscan belt between 370 Ma–320 Ma (Upper Devonian–Mississipian). After the first steps of the continental subduction-collision, leading to high temperature and anatexis associated with NNE-SSW shortening at 380-370 Ma (Givetian to Famennian), the southern part of the Armorican massif and western part of French Central massif underwent large dextral shearing along N110-N125 trending shear zones up to early Visean time. These large-scale displacements progressively decreased at around 350-340 Ma, during the first emplacements of biotite bearing granites (Moulins-les Aubiers-Gourgé massif and Guéret massif intrusions).

During middle Visean time, the shortening axis direction rotated towards a NE-SW direction implying changes in the regional deformation field. The occurrence of N70-N100 sinistral and N110-N130 dextral conjugate shear zones within leucogranites are related to that time. Finally, new dextral trending N130-N160 shear zones system also appeared at middle to late Visean time, along the Parthenay and the Pradines shear zones for the main ones (respectively in the SE Armorican Massif and the Millevaches massif). These shear zones could have been conjugated to the sinistral Sillon Houiller in the French Central massif. They reflect brittle continental deformation conditions in the French Variscan belt during middle to late Visean time.

Well-monitored by the age of syn-kinematic granite intrusions, this middle Visean change of shortening axis direction probably corresponds to a major change in the Iberian plate displacement and indentation during Mississipian collision.

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Syn-convergent formation of dome structures, due to mantle magmatism, anatexis and crustal-scale folding during the Late Variscan period in the Maures-Tanneron massif (SE France)

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During the late Carboniferous period, the Variscan belt has suffered generalized extension. Dome structures have developed due to intense partial melting of the Lower crust. However, the cause of such extension is still unclear, and this extension regime may be explained by several processes such as thermal relaxation of previously thickened crust, extension at the limits of the belt, and heat advection through continental crust. In the southern part of the Variscan belt, in the Maures-Tanneron massif, several new observations and data from the literature allow to precise some of the processes occurring in this mature collisional context.

(1) Two metamorphic stages are recognized with (i) a generally MP-MT Barrovian event, dated at 330-315 Ma, and (ii) a localized LP-HT event, associated with a dome structure within the Western Tanneron massif at c. 300 Ma.

(2) The tectonic structure of the Maures-tanneron massif includes upright N-S isoclinal folds, affecting a mainly top-to the south nappe pile and the overlying carboniferous basins. This is in agreement with (i) a major tectonic transport towards the south refolded in a (ii) mainly E-W shortening context, with strike-slip faulting along major blocks, including basin infill during the Late Carboniferous.

(3) Magmatic rocks are formed in a two-stage evolution (i) The first syn-collisional melts are formed at c. 320-315 Ma, and are related to a pure crustal anatectic source. (ii) The late magmatic rocks have a hybrid mantle-crust signature at 310-304 Ma. These observations are coherent and reflect a two-stage evolution: (i) Main foliation and regional metamorphism may be attributed to N-S convergence, since at least 330 Ma, which has resulted in a significant thickening and anatexis at 320-315 Ma. (ii) a superposed transcurrent E-W shortening episode affects this tectonic pile at 310-300 Ma, with efficient magmatic transfer from the mantle. This event is associated with a second event of partial melting and doming as elsewhere in the belt.

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Evidence of Panafrican and Variscan basements in the Maures and Corsica Massifs (France). Comparisons and connections with Middle Europe

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The organization of the various sutures and paleoplates at the end of the Variscan orogeny was recently revisited (Matte, 2001) with quite a good fit in Western and Central Europe. However, the reconstruction of the Southern realm –*i.e* External (=Variscan basement) and Internal (=European crust) massifs of the Alps, the Maures massif, Corsica and Sardinia– is more uncertain because a large segment was parcelled out and/or partly absorbed during the Tethyan oceanization, the alpine collision and the opening of the Mediterranean back-arc basins.

In the Maures massif, two types of pre-alpine basements having undergone different episodes of metamorphism and deformation are to be distinguished:

- In the Eastern part, a high-grade basement (amphibolite facies with granulitic remnants), intruded by granitoids, mobilized during the Variscan orogen and reworking Palaeozoic formations.

- In the Western part, a very low- to low-grade basement mainly made up of quartzite, shale, conglomerate, metabasalt (Cape Sicié, Toulon) that suffered a pre-Variscan deformation. These formations are post-dated by low-grade Ordovician (?) formations (blue phyllite), quartzite (Pierrefeu) and Upper Llandoverian graptolites bearing schists (Fenouillet).

- These two types of basements were juxtaposed before Early Carboniferous.

This same duality occurs in Corsica where one can observe:

- Panels of high grade metamorphic basement (amphibolite facies to granulite (Belgodere, Porto-Vecchio), intruded by granitoids, which rework Palaeozoic formations.

- A series of polydeformed low-grade micaschist and metabasalt (= Cadomian or Panafrican) outcropping namely at Argentella near Galeria. They are covered in unconformity by detrital Palaeozoic formations: conglomerate related to Upper Ordovician and shale (Ashgill); shales are overlaid by Upper Ordovician glaciomarine diamictite topped by graptolite-bearing Llandoverian lydite. The contact with Tournaisian flysch-like sediments interbedded with lenses of conglomerate and limestone is a fault.

- The emplacement of the early 345 Ma Mg-K granitoids sealed the juxtaposition (collage) of these two types of basements.

The formations of the Western Maures and Argentella can be thus considered as equivalents. In the organization of the Variscan belt, they characterize the Saxo-Thuringian zone or –in terms of paleo-plate tectonics– the formations of the Armorica micro-plate.

On the other hand, the high grade formations subjected to Variscan tectonic-metamorphic events characterize the Moldanubian zone comprising the ophiolitic nappes rooted in the Galicia-Southern Brittany suture and the Schistose nappes in the southern Variscides.

The connections between these two domains and those well defined and exposed in Western and Central Europe remain conjectural, namely due to a strong reworking by the Alpine events.

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Continuous Variscan deformation during granitoid intrusion in the Léon Domain (Armorican Massif, France)

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Within the frame of Cadomian and Variscan zones in the Armorican Massif, the Léon Domain has been regarded as “exotic” unit. Due to a population of 552-517 Ma Y-rich monazite in paragneisses (dated by the CHIME method with electron microprobe) it is now recognized as a slice of Cadomian crust which was displaced from the northern margin of the former Armorican microplate during dextral shear in the late stage of Variscan crustal accretion. The Leon Domain to the W is characterized by ENE-WSW trending rock units, foliations and metamorphic isograds. A younger 340-300 Ma population of monazite should have crystallized after the thermal peak of Variscan amphibolite-facies metamorphism with increasing grade towards the N. We used the anisotropy of magnetic susceptibility (AMS) method for fabric characterization in the Le Conquet coastal section and compared AMS geometries from different lithologies and age settings. Youngest unit in this context is the ~330 Ma granite de Tregana, with discordant contact to the Variscan foliation in the Brest orthogneiss. Typical feature of this granite is the schlieren-type appearance and absence of any solid state deformation. Magnetic susceptibility is very low (2 to 30 x 10^{-6} SI units) compared to the other metagranitoids (Pt. des Renards, orthogneiss de Brest) which are all in the range of 200 to 300 x 10^{-6} SI units. Despite the low susceptibility and a weak anisotropy typical for magmatic fabrics in granites (P`< 1.1) the magnetic lineation forms a distinct cluster. The direction of magnetic lineations (230°) is supported by elongation of magmatic schlieren. This preferred orientation parallels stretching lineations in the Conquet-Penze micaschists, in the Penzer meta-porphyroid and in the metagranites of Pt. des Renards (stretched quartz rods) and is also significant in the magnetic fabrics of these lithologies. This gives a hint that stress fields in the southern Leon Domain persisted during the intrusion of the Hercynian granitoids.

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EMP monazite dating of P-T evolution in the French Massif Central Variscan inverted metamorphic series of Haut Allier and La Sioule

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The regions of La Sioule and Haut Allier belong to the characteristic sites of the Variscan inverted metamorphism and crustal-scale nappe tectonics. Thrusting of migmatic high-grade gneisses and leptyno-amphibolitic complexes of an Upper Gneiss Unit UGU (unité supérieure des gneiss) upon anatectic sillimanite-biotite-gneisses of a Lower Gneiss Unit LGU (unité inférieure des gneiss) and amphibolite-facies mica schist units during a Variscan contractional tectonic process is considered to be responsible of an inverted metamorphic stratigraphy ("inverted metamorphism"). Growth-zoned garnets with different Mn-Mg-Fe-Ca evolution trends in metapelites in combination with microstructurally controlled geothermobarometry allowed to reconstruct syndeformational P-T paths for each nappe unit. The maximal temperatures and the range of pressures as well as different shapes of P-T paths in UGU, LGU and the micaschist units confirm the inverted metamorphic stratigraphy. The timing of the P-T evolution has been evaluated by detailed EMP-monazite-dating (CHIME-method) in 30 garnet-bearing samples. The bulk of monazite ages uniformly ranges between 320 and 335 Ma. Cores of large zoned monazites and monazites enclosed in garnet crystallized at 350 Ma. Monazite crystallization can be correlated to growth of garnet at the thermal peak and continued when garnet crystallization ceased during decreasing temperature and/or due to appearance of staurolite. Similar P-T conditions and shapes of P-T paths in the UGU and LGU, and the uniform monazite ages for a common syn/post-Tmax evolution in the three main units support concepts of maximal tectonic allochthony for the Variscan nappe-stacking stage in the Massif Central.

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Latest Carboniferous - Early Permian extensional reactivation of the inverted Rhenohercynian passive margin of SW England

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Variscan convergence across southern Britain ceased during the latest Carboniferous (c. 305-300 Ma) and, to the west of the Bristol Channel-Bray Fault, was post-dated by a NNW-SSE extensional regime that persisted until c. 275 Ma. Early post-convergence deformation brought about extensional reactivation of the Rhenohercynian suture and thrust faults in the subjacent inverted northern passive margin. The associated secondary folds, cleavages and faults indicate a dominant top to the SSE shear sense. Anomalous zones of steeply dipping primary cleavage were formed by forced folding above faults in pre-Devonian basement during this episode. Thinning and exhumation of the lower plate was contemporaneous with alluvial/fluvial 'red-bed' sedimentation and the development of the Plymouth Bay Basin above the reactivated upper plate. Bimodal magmatism in the lower plate initiated at c. 295 Ma, persisting until c. 270 Ma, and post-dates structures developed during thrust fault reactivation. Steeply dipping fracture networks, in both granites and their host rocks, locally hosting magmatic-hydrothermal Sn-Cu mineralization, reflect continued NNW-SSE extension until c. 275 Ma. The generation and anomalous thickness of the Cornubian Batholith was strongly influenced by extensional reactivation of the Rhenohercynian suture zone to the west of the Bristol Channel-Bray Fault.

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Relationships of SW Iberia with NW Iberia and the Moroccan Variscides

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The study of old, broken and reworked orogens must face the problem of putting together their dispersed fragments. This is not an easy task, since orogens change across and along strike. Here, two issues of this problem in the Variscan orogen are addressed: correlations within the Iberian Massif as well as between SW Iberia and the African Variscides.

The Iberian Massif raises a main problem of relationships between its northern and southern parts. Suture terranes including ophiolites and high-pressure rocks crop out to the north, but only as allochthonous terranes unconnected from the root suture(s). The geometry of the Ibero-Armorican arc suggests that the lost roots of those allochthons can appear in SW Iberia, where two main tectonic contacts reputed as suspect sutures crop out, *i.e.* the boundaries South Portuguese/Ossa-Morena and Ossa-Morena/Central Iberia. I discuss the main features of these contacts, including new, surprisingly young (Early Carboniferous), radiometric ages in oceanic-type amphibolites of the contact South Portuguese/Ossa-Morena.

I conclude that correlation with the northern allochthons of Iberia is still uncertain. On the other hand, I feel confident in broadly correlating Central Iberia with the Moroccan Variscides, despite a number of significant singularities. Moreover, the Moroccan Variscides show the transition to the southern Gondwanan basement, which is a critical point to discuss some basic problems of palaeogeographic reconstructions.

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Early Variscan contraction-dominated deformation in the Monts d'Arrée (Brittany, France) and its relationship to the closure of the Rheic Ocean

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In the Monts d'Arrée (western Brittany, France) a high-strain slate belt is well-exposed. An extensive structural analysis has demonstrated that the slate belt primarily reflects a coaxial, contraction-dominated deformation history, resulting from a top-to-the-NW shearing on top of a weakly dipping décollement. Only during the later stages of the deformation history, incipient strain partitioning on the primary mechanical anisotropy (*i.e.* steeply dipping pervasive cleavage) lead to the development of punctuated strain heterogeneities, consistently reflecting dextral, belt-parallel, strike-slip strain. The deformation, largely predating the emplacement of early Carboniferous granitic complexes in Central Armorica, can be fairly attributed to the late Devonian-early Carboniferous, 'Bretonian' orogenic event. The kinematics, inferred in the Monts d'Arrée, moreover, comply with the thrusting and nappe stacking, inferred in the Léon terrane, situated north of Central Armorica. This allows linking the early Variscan deformation in Central Armorica with the closure of the Rheic Ocean and the continental collision of the Léon microcontinental block with Armorica.

Our research has not only demonstrated the relative importance of the 'Bretonian' orogenic event in Central Armorica, but also infers a diachronous evolution of the main – cleavage-generating – deformation across Central Armorica. These new kinematic insights should be the basic assumptions of future geodynamic research in Central Armorica.

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Early Palaeozoic orogenic events north of the Rheic suture (Brabant, Ardenne): a state-of-the-art

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In the Lower Palaeozoic of Belgium and northern France (Brabant, Ardenne) three early Palaeozoic orogenic events are classically recognised: (1) the middle Ordovician “Ardennian“ event, (2) the late Silurian-early Devonian “Brabantian“ event, and (3) the Emsian “Bollandian“ event. Based on a number of recent studies, a state-of-the-art can be made with respect to these assumed early Palaeozoic events north of the Rheic suture.

Identifying the “Ardennian“ orogeny in the basement inliers in the Ardenne allochthon (Belgium, northern France) has always been a matter of controversy, primarily because of the pervasive Variscan overprint. More and more evidence accumulate, however, to question seriously the existence of this supposedly middle Ordovician orogenic event. Currently, the ‘Ardennian’ angular unconformity is rather attributed to the onset of the late Silurian-Devonian basin development in an extensional setting.

The “Brabantian“ orogeny is evidenced in the Brabant basement, north of the Variscan deformation front (Belgium). We have demonstrated that this orogenic event is long-lived and diachronous, lasting for at least ~30 Ma, from the late Llandovery to the Eifelian. Consequently, the assumed “Bollandian“ event only forms part of the “Brabantian“ orogeny. The ‘Brabantian’ orogenic event, causing the inversion of an early Palaeozoic basin (Brabant basin), is considered to be related to the collision of two continental blocks of the Avalonian terrane assemblage (Midlands-Ardenne, Far Eastern Avalonia). This orogenic event coincides with the development of the Ardenne-Eifel basin in the northern passive margin of the Rheic/Rhenohercynian ocean.

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Burial and exhumation processes in upper-crustal metasediments exemplified by EBSD inclusion trails analysis and thermodynamic modelling (NE Bohemian Massif)

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Constraining P-T-d paths of polydeformed and polymetamorphosed rocks requires different analytical approaches that can help reconstruct the global tectono-metamorphic history of a larger metamorphic unit. Thus, electron backscattered diffraction (EBDS) measurements of lattice preferred orientation (LPO) of staircase inclusion trails contained in garnet porphyroblasts and thermodynamic modelling are performed on up to kyanite-grade metasediments from the north-eastern border of the Bohemian Massif in order to infer the general evolution of the Lądek Metamorphic Unit. LPO measurements of ilmenites included in garnets clearly indicate sequential growth of porphyroblasts in diversely oriented foliations that correspond to macroscopic field observations. Moreover they point to a succession of horizontal and vertical foliations formed after rotation around respective foliation intersection axes (FIA) that are consistent from one sample to the others. Prograde P-T path modelling in the Mn-NCKFMASH system based on garnet inclusions and zoning gives peak pressure conditions of ca. 6 kbar-625°C whereas retrograde thermal evolution is documented by the appearance of sillimanite, andalusite and cordierite in later deformation stages. Combination of structural, microstructural and petrological data represents a powerful tool to understand burial and exhumation paths in complex polyphase history of deep orogens.

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Reading the metamorphic record: application to orogenic lower crust in the Bohemian Massif

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The key to understanding the tectonics of the orogenic lower crust, now observed at the Earth surface in the Bohemian Massif, is being able to read the metamorphic record of the rocks involved. Detailed field studies involving structural geology provide a geological context for the rocks. Thorough petrography then allows the succession of crystallization of the phases to be determined and the textural relationships identified, in the context of the structural record. With mineral chemistry studies, the petrographic information provides the basis for phase equilibria calculations. Forward modelling, *i.e*. using the rock composition to predict phase relations in P-T or T(P)-X diagrams, provides a powerful tool for interpretation of petrographic observations in rocks, in order to establish P-T paths and identify metamorphic processes.

This approach is illustrated by application to various lower crustal rocks exposed in the Bohemian Massif as eclogites, garnet-orthopyroxene and garnet-clinopyroxene granulites and migmatitic paragneisses. The thermal state of the orogenic lower crust during burial, peak metamorphism and exhumation is discussed. Individual P-T paths of rocks now occurring together in particular fabrics are compared to understand whether their burial, peak and exhumation were shared, or whether just parts of P-T paths were shared. The implications for the overall geodynamic context of orogenic root evolution within the Bohemian Massif are discussed.

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Magmatism in the SE Variscan Belt: Geochemical and geochronological constraints from the Tanneron massif (SE France)

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The Maures-Tanneron massif (SE France) is an intriguing part of the Variscan Belt since some of its features are quite different from those observed in the other parts of the belt in France. Those features are generally not taken into account in the current models of the Variscan Belt. Whole-rock geochemistry (major, trace and isotopic data) and geochronology (U-Pb and $^{40}Ar/^{39}Ar$) investigations have been carried out on several granite and orthogneiss samples in the Tanneron massif in order to constrain the sources of the magmatism and the geodynamic evolution of this segment of the Variscan Belt.

Several magmatic events have been recognized. (1) An early magmatic event at 440-410 Ma related to Silurian subduction stage. (2) Incipient anatectic melting and emplacement of a leucogranite-dyke complex at 320-315 Ma that may be closely related to an active tectonic exhumation and subsequent isothermal decompression melting following a phase of crustal thickening. (3) Emplacement of tonalitic to granitic magmas at 310-300 Ma in a post-collisional context involving a mantle source. A model of the geodynamic evolution of the Tanneron massif taking into account those different magmatic events is proposed and discussed.

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Ante upper Visean ductile shear of the Sillon Houiller (Massif central, France) : new cartographic and radiometric datas

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The Sillon Houiller is a major crustal wrench fault of the french Massif Central. It is characterized by a brittle fault on which lies several Stephanian pull-apart coal basins. Dating of their opening has been established on the basis of their sedimentary filling. Even if the ante basin-opening wrench faulting was already known, it has never been dated.

New data on the Sillon Houiller between the Sioule and the Chavanon metamorphic sequences show a ductile shear that affects the metamorphic basement west from the fault. In this area, this ductile fault is intruded by granitic bodies or hidden by undeformed volcano-sedimentary basins. Datation of these bodies allows to seal the ductile shear of this fault.

We have worked on 3 specifically chosen areas that clearly exposes these phenomenons. The Pontaumur basin itself allows to seal the ductile shearing on two locations. The filling of this basin is made of volcano-sedimentary tuffs. Moreover, to the north, undeformed granitic bodies cuts across the shear zone. To the south, the Messeix granitic dyke presents the same disposition.

On the basis of a 325±3 Ma radiometric age obtained on tuffs from the Pontaumur basin, we argue that the shearing of the Sillon Houiller is ante upper Visean. It's worth noting that a 332±3 Ma age has already been obtained in the Decazeville coal basin, located more to the south on the Sillon Houiller.

To the west, the monzogranitic Crocq batholith exhibit a typical retort shape along the Sillon Houiller, which may indicate a syn-kinematic emplacement. Its age (337±3 Ma) suggests that the shearing took place in mid visean times.

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Central parts of the Bohemian Massif revisited: New interpretation of deep reflection seismic line 9HR in West and South Bohemia

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The deep reflection seismic line 9HR (NW – SE direction) crossing the West and South Bohemia with a length of 226 km is reinterpreted. The line was shot using explosive technology with a high density of shot points. This enabled relatively high folding of 24 with shot point distance of 200 m and geophone group distance of 50 m. Many high amplitude reflections were revealed in the crust and some even in the lithospheric mantle down to depth of 20 s of TWT. The quality of the seismic signal and reflections is amazingly high.

Several tectonic crustal units were passed by line 9HR. From NW to SE these are: Saxothuringian continent (Armorica), Tepla –Barrandian supracrustal block and Moldanubian high grade domain – the root. The Saxothuringian domain is imaged in its southern most part of the Krušné hory Mts. (Erzgebirge). The Tepla-Barrandian block is crossed in the whole extent and the Moldanubian domain is imaged between the marginal Tepla-Barrandian - Moldanubian fault and the eastern end of the South Bohemian granulite terrain. All three major units are divided by near-vertical crustal (lithospheric?) faults. These deep faults are seen as outstanding reflection discontinuities through the whole crust.

The interpretation of the deep seismic line crossing the main Bohemian Massif geological structures brings new fresh ideas enabling us to understand better the Variscan and pre-Variscan geology of this very important part of the Variscan mountain belt in Europe. We are able to distinguish clearly two totally different parts of the Bohemian Massif. (1) Subduction and collision features dominates in the Tepla-Barrandian and the Saxothuringian lithospheres; (2) Volcanic and plutonic arc features dominate in the Moldanubian root zone and the HP – HT granulites belonging to this area were emplaced along the major shear zone imaged there.

Two important mantle reflection packages were imaged by the line 9HR. The northern one beneath the western part of the Tepla-Barrandian domain is inclined to the SE and is observable on 16 to 17 seconds of TWT. The southern one dips to NW and occurs in the very SE end of the line. The length of the first reflection is about 10 km and is tentatively intepreted as representing the Late Variscan collisional suture. We suggest that the 50 km long thick mantle reflection package beneath the South Bohemian Moldanubian domain represents the seismic expression of the Brunovistulian mantle subduction or back-arc and arc mantle transition zone.

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Palaeozoic plate organisation from a palaeomagnetic and faunal perspective

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During the 300 Ma from 550 to 250 Ma the geography of the Earth evolved greatly. At the beginning of this period there was only one superterrane, Gondwana, undoubtedly the largest terrane during the Lower Palaeozoic and comprised all of Africa, Madagascar, Arabia, India and East Antarctica. Gondwana totalled approximately 95 million square km, *i.e*. 64% of all landmasses today or 19% of the total Earth surface. However, surrounding it were numerous small terranes, many of which originally formed part of the Gondwanan superterrane, including Avalonia, Perunica and Armorica, and which became separated from it at various times during the Palaeozoic. Avalonia separated from Gondwana during the Early Ordovician and subsequently collided with Baltica (Late Ordovician) and Laurentia to form Laurussia during Silurian times. From Late Carboniferous and onwards Gondwana collided with Laurussia and intervening terranes, and the Variscan belt of Europe became part of an approximately 8,000 km long belt. By the end of the Palaeozoic, at the end of the Permian, most terranes had coalesced to form Pangaea, the largest superterrane in Phanerozoic history. Evolution of the biota over this huge time interval had progressed enormously, with great consequent diversity: at 550 Ma there were no animals or plants with substantial hard parts, and the colonization of the land by animals had not yet begun. In contrast, by the Permian there were probably millions of different animals and plants, not only in the marine habitats, but also over much of the land, a great part of which was covered with forests and jungles comparable in size with those known today. The end of the Permian also saw the largest faunal and floral turnovers and extinction event in the whole Phanerozoic.

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Peridotites of the Moldanubian domain, Bohemian Massif – their nature, strain history and emplacement mechanisms to a granulitized crust

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In the Bohemian Massif, garnet peridotites occur as isolated lenses mostly within the Gföhl unit (felsic granulite, orthogneiss, migmatite) of the Moldanubian domain. According to previous classification, the most common types I and III of peridotite (Medaris *et al.,* 2005) were investigated by mean of lattice preferred orientation (LPO), petrology and geochemistry. The strongly depleted Type I peridotites with ortho- and clinopyroxene, olivine, spinel and garnet are devoid of garnet clinopyroxenite layers and tectonic bodies of eclogite. Two LPO patterns have been measured, yielding foliation orientations discordant to each other. The former shows a higher temperature [100](0kl) pattern and, occurs in the spinel-bearing part of the body (peak P=2.2GPa and T=1,100ºC), and its origin is attributed to the Devonian back-arc spreading. The latter, a lower temperature axial [010] pattern, occurs in mylonitic microstructure, but is restricted to HT garnetiferous peridotites (P≥2.2-2.7GPa and T=1,200-1,300ºC) along the margin of the body. It is suggested that garnet growth is strain-induced within a shear zone that originated below thickened orogenic root (360~340 Ma), and then reactivated during orogenic extrusion transporting the sliver of hot mantle peridotite to much cooler (P≥1.5GPa and T=850ºC) granulitized orogenic root.

In the type III garnet peridotites with layers of garnet clinopyroxenites and eclogites, olivine LPO shows either [100](010) or [001](010) pattern. Foliation in the peridotites has a variable orientation, but is always steeply dipping. Enclosed eclogites are either metamorphosed pre-existing MORB basalts or HP melts, and their foliation is coherent to the peridotites. Both peridotites and eclogites show peak PT conditions of 3.5 GPa and 900ºC reached in a HP-LT gradient. Clinopyroxenites corresponds geochemically to a product of reaction/crystal accumulations of the transient basaltic melt with the peridotites. They form vertically oriented and closely-spaced layers discordant to the peridotites, but parallel to the surrounding coarse-grained granulites. The type III peridotites are supposed to be relics of mantle wedge hydrated to a various extents above the Saxothuringian Ocean subduction zone (380-360 Ma) that triggered mantle wedge flow. During orogenic thickening (360~340 Ma) hydrated mantle deformed and the basaltic melt flow from the subduction zone became strain-controlled. It is very likely that exhumation of the Type III peridotites occurred along rheological boundary between hydrated and non-hydrated mantle during vertical mantle wedge flow towards orogenic root in the hanging-wall.

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The “hot orogen”: two separate variscan low-pressure metamorphic events in the Central Iberian Zone

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The Central Iberian Zone (CIZ) contains large metamorphic complexes forming a high-grade infrastructure separated from an overlying low-grade suprastructure by major ductile extensional shear zones produced during the D2 regional deformation. In contrast to other “hot” portions of the Variscan belt in Central Europe, peak metamorphism and plutonism in the CIZ happened relatively late, during the Middle and Late Carboniferous. U-Pb dating on the metamorphic complexes of Central Spain indicate that peak Barrovian metamorphism (M1) in the high-grade infrastructure was reached at 332 (340)-328 Ma (Somosierra, Honrrubia, Hiendelaencina), after the initial D1 compression. The orogen-parallel, D2, extensional event was responsible for the isothermal decompression leading to extensive migmatization and anatexis of the infrastructure at 329-326 Ma (Martinamor; Somosierra), and growth of low-pressure / high temperature paragenesis (M2) at 323-320 Ma (Somosierra, Tormes Dome). This was followed by a D3 transpressional event, upright folding of both infrastructure and suprastructure, intrusion of the large bodies of “early” granodiorite at ca. 325-320 Ma (Sayago granodiorite) and emplacement of 318 Ma syn-D3 granite, locally sealing the D2-shear zones (Villarino granite; Tormes Dome). Plutonism was particularly intense along the border with the Portuguese sector of the Central Iberian Zone. Dating of syn-kinematic dykes and anatectic granite at 316-314 Ma in the Lumbrales Antiform (Salamanca) indicate the presence of a separate, second low-pressure metamorphic event (M3) while parts of the high-grade infrastructure were cooling down below 450°C (314-310 Ma, Ar-Ar; Bt-Ms; Somosierra). This second low-pressure metamorphic event appears to be associated with the intrusion of large masses of syn- and late-D3 granitoids (313 Ma Valderrodrigo granodiorite). Removal of the orogenic root, during the D3 transpression, could explain the formation of large volumes of 316-310 Ma granitoids and mantle-derived hybrid melts, and the second low-pressure metamorphic event produced by heat advection during their intrusion.

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Evidences for late-orogenic collapse in the northern external part of the Central European Variscides (High-Ardenne slate belt, Belgium)

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The High-Ardenne slate belt, forming part of the northern frontal parts of the Rhenohercynian foreland fold-and-thrust belt, consist of highly shortened siliciclastic Lower Devonian metasediments. Contraction of this thick Lower Devonian sequence took place at greenschist facies conditions during the Visean – early Namurian Sudetic stage of the Variscan orogeny, giving rise to a pervasive cleavage, forming the main structural feature in the slate belt. Our current research allows recognising a tectonic inversion during a late stage of the Variscan orogeny, destabilising the Variscan cleavage. The previously south-dipping cleavage has been reworked into south-verging, decametre-scale folds. Compressional kink bands and crenulation cleavages are predominantly present in one of the limbs of these large-scale folds as well as in low-displacement, south-dipping shear zones, all indicating a southwards normal faulting, still under mid-crustal, low-grade metamorphic conditions. Apart from these deformations of the variscan cleavage, the tectonic inversion also triggered the emplacement of lens-shaped veins and fault-related veins potentially allowing a focused fluid flow along these low displacement (normal) faults. The remarkable crosscutting relationship between the veins and the foliation indicate that the lens-shaped veins behaved as mobile structures during their emplacement. The sense of shear deduced from these "mobile flanking structures" confirms the southward simple shear. All these structural elements may be considered indicative for extensional tectonics associated with a late Variscan orogenic collapse of the slate belt. The structural, microstructural and microthermometric analysis of these veins and associated structures, which will allow to better characterise this tectonic inversion, are, however, still in progress.

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Early vein generations in the High-Ardenne slate belt (Belgium, Germany): the earliest manifestations of the Variscan orogeny?

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The High-Ardenne slate belt (Belgium, Germany) exposes low-grade, siliciclastic Lower Devonian metasediments of the Ardenne-Eifel extension basin, pervasively deformed during the early – 'Sudetic' – stage (early Carboniferous) of the Variscan orogeny. Our research has revealed that several quartz-vein sets reflect a regional fracturing event, predating the main Variscan fold-and-cleavage development.

In the central part of the slate belt (Bertrix-Bastogne-Bütgenbach area), exposing the deepest parts of the basin (highest degree of burial-related metamorphism), a regular and regionally consistent set of bedding-perpendicular veins occurs in Lochkovian-Pragian psammitic layers. Structural and fluid inclusion studies evidenced that overpressured fluids caused a hydraulic fracturing event, occurring beneath the brittle-ductile transition in a highly anisotropic stress field. This highly anisotropic stress field infers that this event may be considered as the earliest manifestation of the Variscan orogeny in its northern foreland.

In the periphery of the slate belt (Rursee, Germany), exposing higher levels of the basin (lower degree of burial-related metamorphism), early bedding-perpendicular vein sets are still present. The structural control of the veins is, however, less obvious. Different cross-cutting early vein generations in Pragian-Emsian sandstones suggest that fracturing/veining occurred in a less anisotropic stress field than in the central part of the slate belt. Structural observations furthermore indicate that the veins opened episodically by a crack-seal mechanism.

The ultimate objective of our research is to reconstruct both regional fluid system and stress field evolution in an overpressured basin during the tectonic inversion at the onset of an orogeny.

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Brittle tectonics deformation in Variscan domain in North West Europe

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Brittle structures in Carboniferous and Givetian limestones in the Paleozoic basement have been investigated in view of estimating the impact of the Mesocenoic tectonics (Vandycke, 2002, 2007) on the Paleozoic rocks. Relationships with karstic events is established but also relationships with Variscan folding. Faults and joints are well developed, with conjugated sets of strike-slip and reverse systems.

Strain is greater in the western part, in Wales, along the Variscan Front with shear zones, thrust belts, orthogonal sets of stylolites and complex tension gashes systems. These structures are mainly related to ductile to semi-ductile regime (Lisle and Vandycke, 1996; Srivastava *et al.*, 1994) but stress analysis is still possible with relevant results.

In the Belgian Ardennes, Variscan folding in the Givetian limestones is accompanied by reverse faulting, strike-slip faults systems, tension gashes, stylolites and extrados normal faulting (Havron *et al.*, 2006). Like in Wales, the maximum stress axis in compression is parallel to the direction of the Variscan Front propagation. Folded Givetian limestones are also affected by jointing. The main and effective system is the extensional joint system in NE-SW extension related to the recent activity of the Lower Rhine Graben.

At the North of the Variscan Front, in the Brabant Parautochthone, where limestones appear in monoclinal structures, four different types of structures have been identified. Reverse faults on the bedding planes and ramps can be directly attributed to the Hercynian thrusting tectonics. Two main strike-slip systems have been recognised in a pull-apart geometry. One of these transcurrent systems seems to be slightly older than the Variscan dynamics, the second one just younger. Abundant hectometric tension gashes with metric spacing occur also in the Carboniferous limestones. Some tension fibers can be observed in the calcite filling. But the main spectacular brittle structures are the extensional joints. Some of them are hydrogeologically active and karstified (Quinif *et al.*, 1997).

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The Hercynian orogen in the Mauritanide belt (West Africa)

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The Mauritanide belt is extending over 2,000 km, from the Morrocco to the Guinea-Bissau. The Hercynian orogen affects the main part of the West African Fold Belts which include two previous Panafrican orogen. Classically, the Hercynian Belt is divided in two main parts: the “foreland” and the “Thrust Belt” separated by the “Hercynian Front Thrust” (HFT).

East of the HFT, the foreland corresponds to the Neoproterozoic to Palaeozoic sedimentary covers of the Taoudeni basin which are slightly folded close to the HFT. West of the HFT, the “Thrust Belt” presents four parts (or units) with rocks of various origins. The two central units contain volcanic and granitic rocks coming from the Panafrican Belts with a thin Palaeozoic sedimentary cover. The two other external units contain the relicts of the thick Late Proterozoic to Palaeozoic folded covers. These are slightly metamorphosed in the eastern unit and, on the contrary, strongly metamorphosed in the western unit.

The geodynamical model proposed here to explain this Hercynian Belt is an East-West succession of horsts and grabens filled with the post 650 Ma sedimentary deposits. These horst and grabens suffered a “tectonic inversion” during the Hercynian tectonic event induced by the collision between the West African Craton (WAC) and the North American Craton (NAC) during the 330-300 Ma interval. This collision led to the formation of the Pangea supercontinent by collage of the Mauritanian and Appalachian Folds Belts.

So, the Mauritanide Hercynian Belt is considered as the Panafrican thinned margin of the West African Craton largely reworked during the Carboniferous to Permian collision between the West African and North American Cratons.

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The Variscan Basement in the Alps

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The Alpine basement areas and those composing the Variscan basement in Central Europe have many steps of their Palaeozoic evolution in common, the real differences appearing only during their Permian-Alpine evolution. Consequently, comparative considerations need to be guided by their common origin at the Gondwana margin, many relics testifying a plate-tectonic evolution at least since the Cambrian, and involving Cadomian basement. As the hitherto used Variscan plate-tectonic models and the related nomenclature revealed to be insufficient, a new nomenclature classifies the many basement areas of the Alps based on their evolution at the Gondwana margin. The Alpine realms (External domain, Penninic domain, and parts of the Austro-Alpine domain) share a similar geological evolution since the Neoproterozoic, and relics of different plate-tectonic situations were preserved, like Cambrian intracontinental rifting or back-arc opening accompanied by formation of arc-volcanics or oceanic crust. Eclogites and high-pressure mineral relics prove Early Palaeozoic active margin settings, and Ordovician anatectic melts and granitoids close an Ordovician orogenic cycle. From the Silurian onwards, shelf-sediments and volcanics represent the opening of the Palaeotethys separating the future Variscan basement areas from the Gondwana margin. Earliest high-pressure events since the lower Devonian (obduction at the Gondwana side, and/or subduction at the Laurussia side) and subsequent decompression trigger formation of HP-melts. The subsequent evolution during the Variscan collision was accompanied by nappe stacking, triggering the formation of great volumes of migmatites and intrusion of granites. Contemporaneous transtensional strike-slip favoured the emplacement of sedimentary troughs collecting the coarse-grained detrital sediments, produced by the erosion of the uplifting mountain chain. Post collisional collapse triggered the formation of wide spread rifts during the late Carboniferous-Permian, accompanied by the emplacement of granitoids.

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Paleozoic southward subduction, accretion and collision of microcontinents in the west part of the Chinese Tianshan

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The Chinese Tianshan Belt is subdivided by sutures and fault zones into North Tianshan, Yili Block, Central Tianshan and northern margin of Tarim. The Yili Block is a key for understanding Paleozoic evolution of west part of Chinese Tianshan. The southern boundary of the Yili Block is formed by Proterozoic basement and Early Paleozoic platform sediments, which are tectonically overlain by oceanic high-pressure metamorphic rocks and ophiolite. It has been involved in a south-dipping subduction associated with the closure of the Tianshan Ocean and the subsequent collision with Central Tianshan. This tectonic event resulted in top-to-the-north ductile thrusting observed in oceanic HP metamorphic rocks and Proterozoic basement as well. During the Late Paleozoic, the Yili Block was an active continental margin related to the southward subduction of the North Tianshan oceanic basin, which is represented by Late Carboniferous ophiolitic mélange. During Permian, the southern and northern boundaries of the Yili Block have been both reworked by dextral strike-slip faults, which are confirmed by both kinematic observations and the CCW rotation of the Yili Block with respect to Tarim during Late Carboniferous to Late Permian. The lateral extension suggests that the convergence between microcontinents in west Chinese Tianshan completed in Late Permian.

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Allochthonous nappes from the Tepla-Barrandian - Saxothuringian suture, contrasting rheology of lower to middle felsic crust

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We have carried out a detailed microstructural study on orthogneisses from two allochthonous nappe units in the central part of the Saxothuringian domain in Bohemian massif. Strong strain partitioning between constituent mineral phases (K-feldspar, plagioclase and quartz) is questioned in terms of operative deformation mechanisms and current rheological models of felsic crust.

Metamorphic conditions associated with emplacement of the "Lower crystalline nappe" (LCN) were estimated at 600ºC and 1,400 MPa (Konopásek and Schulmann, 2005). In contrast, the "Upper crystalline nappe" shows conditions 700°C and 900 MPa. In LCN orthogneiss, the rock's strength is strongly decreased by partial replacement of K-feldspar and complete replacement of plagioclase by fine-grained (10 micrometers) aggregate of albite-oligoclase grains (with interstitial quartz and mica grains). This process is attributed to host-controlled nucleation of new grains (*e.g.*, Putnis, 2002). Fine-grained aggregates deform via grain-boundary sliding (GBS) deformation mechanism. In UCN orthogneiss, both feldspars show extremely elongated monomineralic bands enclosing only weakly elongated quartz lenses. Feldspars show equi-dimensional polygonal grains and K-feldspar contains interstitial grains of albite and quartz grains at grain boundaries perpendicular to the stretching lineation. This microstructure and apparent weakness of feldspars with respect to quartz is explained by melt-enhanced GBS mechanism operative in feldspars in contrast to dislocation creep in quartz.

In summary, deformation of orthogneisses in both units is strongly influenced by diffusion controlled deformation mechanisms of both feldspars. Our observations are in contrast with of experimentally based assumptions that the creep strength of felsic rocks is controlled by weaker quartz with respect to feldspars at dislocation creep regime (*e.g.* Jaoul *et al.*, 1984; Handy, 1994). Instead, neo-crystallization and subsequent GBS and melt-enhanced GBS in feldspars are recognized as dominant deformation mechanisms that was operative in various felsic lithologies in Bohemian massif and the latter is possibly responsible for accommodation of large vertical displacements during the Variscan orogeny at amphibolite-granulite facies conditions.

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The Sudetes: not all HP rocks can be ascribed to the Variscan orogeny

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Current interpretations of geology of the Variscan belt in central Europe assume that HP rocks which occur in this orogen were metamorphosed, at depths reaching even 130 km, and exhumed between 387 and 329 Ma as suggested by isotopic datings. Diapirism, vertical extrusion and lateral flow, tectonic extrusion, extension on low-angle detachment, thrusting, wholesale uplift, and erosion have been proposed as mechanisms for exhumation of these rocks. However, the matter remains controversial, not substantiated enough by material data, so that the offered explanations can be hardly tested and verified in the field. Recent findings in the Sudetes show that the problem may be even more complex. Structural relationships of some HP rocks with the ca. 515-480 Ma orthogneisses and migmatites reveal that the former could not develop during Variscan subduction.

In the Izera-Karkonosze Block, the ca. 500 Ma Izera metagranite enclosed gneisses with relic mineral assemblages indicative of metamorphism under granulite facies conditions at T = 680-640°C and P = 17-12 kbar. In the W limb of the Orlica-Śnieżnik Dome, there are retrogressed, Ca-Fe garnet-bearing granulite inliers within migmatitic gneisses of ca. 485 Ma age. In the E limb of this dome, renowned (U)HP eclogites (derived from CAB, MORB, Fe-tholeiites) and quartzofeldspathic granulites occur amidst gneisses on numerous locations in the Śnieżnik, Gierałtów, Góry Złote and Międzygórze areas (T = 1,000-650°C, P = >30-12 kbar).

Near Międzygórze, eclogites in small dispersed boudins to various extent yielded to amphibolitization and migmatization. Zircons from a cross-cutting neosome yielded a U-Pb age of 500 Ma, which constrains the minimum age of the altered eclogite. Accordingly, not all eclogites and granulites found in the Sudetes may be assigned to the Variscan orogeny and a part of them requires another explanation. It is proposed that the ~pre-500 Ma HP rocks originated during Cadomian (or older) cycle and then were uplifted to mid/lower crustal depths due to mid-Cambrian-early Ordovician extension, crust attenuation and mantle upwelling related to Rodinia/Gondwana breakup. At these depths, they underwent anatexis and migmatization together with the country gneisses, followed by granite intrusion at 515-480 Ma. In the next stage the more or less retrogressed HP rocks became built in the Variscan orogen.

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The relationships between two suspect terranes in the West Sudetes: new data from the Nové Město Group and the Stronie Group of the Orlica-Śnieżnik Dome

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he Orlica-Śnieżnik Dome (OSD) in the Sudetes is flanked on the west by the Nové Město Group (NMG) which comprises phyllitic metagreywackes and bimodal metavolcanites considered, though without evidence, as equivalents of the Neoproterozoic series of the Teplá-Barrandian Block. The latter were deformed and metamorphosed during the Cadomian orogeny and discordantly covered by Cambrian sediments.

The NMG was proposed to belong to the same Bohemia (Teplá-Barrandian) terrane. Its eastern boundary was envisaged to follow a tectonized zone of the lithologic contact between the NMG and adjacent mica schists (Stronie Group, SG) and gneisses of the OSD which are assigned alternatively to the Saxothuringian or to the Moldanubian terrane by different authors. New U-Pb SHRIMP analyses of zircons retrieved by us from a variety of the NMG rocks yielded Cambrian/ Ordovician ages for metarhyolites (514 Ma and 506 Ma) and for metabasites (490 Ma), whereas the youngest detrital grains in metagreywacke appeared to be ~560 Ma old. These results unanimously show that the NMG is a lower Palaeozoic sedimentary-volcanogenic complex, similar to other basinal sequences of the same age in the Sudetes, and does not represent a part of the Cadomian orogen. Magmatic and structural characteristics of the NMG and SG are generally consistent. Both units have very similar acid metavolcanites and MORB-like tholeiites, although their WP tholeiites differ slightly with the amount of crustal contamination of the parent magma. Deformation of rocks at the border zone between the two units was clearly contractional, with ESE-vergent Variscan crustal stacking under peak metamorphic conditions. It gave pace to dextral transpressional to N-vergent thrust regime, which was in turn followed by extensional collapse with the W-directed dip-slip/oblique motion under lower amphibolite/greenschist facies conditions. This event produced a 0.5–1 km wide ductile normal fault zone in the NMG rocks (parallel to the NMG/SG border defined by later brittle fault), with total downthrow of ca. 10 km calculated from the difference in pressure signatures in the fault walls. Consequently, this zone does not separate different terranes, and the NMG and SG represent but two lithotectonic domains in the same Early Palaeozoic Saxothuringian basin.

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