

Basement Tectonics in the Spanish Variscides and Beyond

Conference Report

The 15th International Conference on Basement Tectonics was held at the Laboratorio Xeolóxico de Laxe near A Coruña, Galicia, in northwestern Spain on 4-8 July 2000. This conference was the latest in a long and distinguished series of international gatherings to exchange new results from the study of basement terranes that began with a meeting convened in Salt Lake City, Utah, a over a quarter-century ago by two industry geologists, S. Parker Gay, Jr., Applied Geophysics, Inc., and Robert A. Hodgson, Gulf Oil Company. This pioneering meeting, sponsored in part by the then fledgling International Basement Tectonics Association (IBTA), was organized around the subject of the influence on Phanerozoic tectonics of pre-existing deep fracture systems within Precambrian (or pre-orogenic) basement. Subsequent conferences, sponsored in part by the IBTA, have seen this subject broadened to include topics of Precambrian and Paleozoic plate tectonics, terrane accretion in mountain belts, and the assembly of continental crust. Basement Tectonics conferences, which usually include a substantial field geologic program, have been convened in such diverse geographic settings as the Middle East (Cairo, 1983), Australia (Canberra, 1990), central Europe (Potsdam, 1994), the Appalachians (Blacksburg, 1997), and South America (Ouro Preto, 1998). The Galicia conference, entitled “Variscan-Appalachian Dynamics: The Building of the Upper Paleozoic Basement” and set in the Spanish Variscide Mountains, was based on the themes of the construction of the Paleozoic basement of western Europe and eastern North America, and the evolution of the Gondwanan and Laurentian continental margins and their intervening ocean basins. This outstanding conference was convened by J. R. Martínez Catalán (Universidad de Salamanca), R. Arenas (Universidad Complutense de Madrid), and F. Díaz García (Universidad de Oviedo).

The conference was preceded by a five-day field trip in Galicia to study the Ordenes Complex, which is the largest of the well-exposed Variscan allochthonous complexes in northwestern Iberia. The rock units of the Ordenes Complex include low-temperature-pressure slates, phyllites, and metagraywackes; high-pressure, high-temperature metamorphic rocks, including eclogites; and ophiolitic sequences. The field trip, led by a team of Spanish geologists headed by R. Arenas, provided an excellent opportunity to observe these units where they developed in an accretionary wedge and subduction setting on the western edge of Gondwana. The Ordenes Complex consists of units derived from both the hanging wall and foot wall to the suture, as well

as from the main Variscan collisional suture itself. During an intermission in the conference, two one-day field trips were organized to the Cabo Ortegal Nappe Complex, which is a composite of allochthonous thrust sheets emplaced along the western margin of Gondwana during the late Paleozoic. One trip, led by A. Marcos (Universidad de Oviedo) and others, focused on structural geology, while the second, led by I. Gil Ibarguchi (Universidad del País Vasco) and others, dealt with petrologic aspects. Both trips took advantage of excellent exposures of mafic and felsic metamorphic rocks and eclogites along the Galician coast. All field trips were complemented by superb field guidebooks, prepared by the trip leaders, that included color photographs, charts, and fold-out maps.

The conference presentations were both numerous and diverse, including such far-ranging topics as the evolution of orogenic terranes, thermal and metamorphic history, microstructural analysis, mapping of crustal and mantle structure using geophysical methods, geochronology of tectonic, metamorphic and igneous events, and plate tectonic and paleogeographic reconstructions. The presentations consisted of nine invited keynote addresses, 48 volunteered talks, and 42 volunteered posters. The geological and geographical settings for the presentations were highly varied with studies based in Austria, Canada, the Czech Republic, Denmark, France, Germany, Ireland, Italy, Poland, Portugal, Russia, Spain, the United Kingdom, and the United States of America. Although the posters were an integral part of the conference, for convenience the following summary is based on the oral presentations, which were representative of the full range of topics covered.

The opening session of the conference began with a series of talks on similarities and possible correlations between European and North American Paleozoic deformation realms. Both geological and geophysical approaches were used to describe structural styles at outcrop and crustal scales in the Appalachian, Caledonian, and Variscan orogens, stressing accretionary processes and the continuity into the deep crust of terrane boundaries mapped at the surface. The discussion of trans-Atlantic correlations also incorporated a paper on using porphyroblast orientations as a new tool for constraining regional paleogeographic reconstructions. Several presentations drew on examples of basement tectonics and reactivation from North America. Included were how mantle-derived kimberlite intrusions can be accommodated by a pre-existing rift system (e.g., the Midcontinent Rift of the central USA), reactivation and/or modification of basement or early Paleozoic structures in intracratonic basins (e.g., southern Oklahoma

aulacogen and Illinois basin) by late Paleozoic compressional tectonics, and examples of reactivation of the Brevard fault zone in the southern Appalachians by ductile followed by brittle deformation, and of the control of Paleozoic strike-slip faulting and rifting by the Laurentian (Precambrian) continental margin in the northern Appalachians.

During the second half of the opening day, the focus shifted to construction of the pre-Variscan “basement” in Spain and elsewhere in Europe. A pair of talks presented a faunal approach for establishing a pre-orogenic paleogeography for the Variscan belt and then outlined the contribution of Vendean-age magmatism, metamorphism, and deformation to Variscan belt basement. Two subsequent contributions first described the stratigraphic succession of “Alcudian” Cambrian sediments that were deposited in response to the accretion of the Ossa Morena zone (southwestern Spain) to the Iberian massif in southwestern Spain during the Cadomian orogeny and second, in contrast, described two high-grade metamorphic belts in this zone that developed in response to a pre-Variscan (Cambrian age) rifting and metamorphic event, unrelated to the Cadomian orogeny. Moving briefly to Bohemia, a succession of Neoproterozoic-Cambrian Cadomian orogenic tectono-lithofacies (Tepla Barrandian unit) were described and compared to coeval rocks elsewhere that contribute to a pre-Variscan basement, including the Ossa Morena zone.

The second day began with a group of talks on Variscan-age metamorphism and deformation mechanisms. The stage was set with a review of the structure of the allochthonous thrust sheets of the Variscan Ordenes Complex, in which the several tectonic units were shown to be separated by low-angle thrusts or extensional faults. These units can be placed in a context of subduction and accretionary processes related to the convergence between Laurentia and Gondwana. Next, an alternative model for the Iberian massif was presented in which two opposite-polarity subduction zones linked by a transform fault produced a bivergent structure for the Variscan orogen here. A petrological study of the Maures massif (southeastern France) provided an example of a suture zone within the Variscan belt characterized by an early Paleozoic tectonic *mélange* of island arc basement and oceanic crust separated by a highly sheared contact that involves a relict crust-mantle boundary. The following two talks elaborated a model that explains disparate terranes in the French and Spanish Variscides in terms of large-scale dextral transpression between Gondwana and Laurentia.

The early afternoon session commenced with a review of the Iberian Variscides that emphasized outstanding questions, such as the location of pre-Variscan sutures, the role of intervening oceanic basins, and the kinematics of island-arc development. A detailed description followed of two of the uppermost units of the Ordenes Complex (O Pino and A Coruña), which are situated above the Variscan suture and are separated from each other by an extensional detachment. In contrast, the next talk described rocks found as thrust sheets *beneath* the Variscan suture belonging to the Iberian lower plate (an indenter), that were exhumed by a multi-stage process involving lateral escape tectonics. This theme continued in the next talk, which outlined a model for the Iberian Variscides based on a transpressional orogen that operated during early Paleozoic until Middle Devonian time and subsequently evolved into an arcuate, compressional orogen. The final talk of the session provided a detailed mineralogical study of platiniferous chromites in the Cabo Ortegal Complex that crystallized from mantle-derived melts originating deep in the magmatic arc associated with the Variscan suture.

The rest of the day was devoted to understanding the general European setting for the Variscan orogeny leading to specific examples of emplacement history and metamorphism of the northwestern Iberian massif. After a review of the evolution of the Variscan belt throughout western Europe with special reference to the Armorican microplate, two presentations provided fresh U-Pb age constraints for interpreting the Ordenes and Cabo Ortegal Complexes (the objects of the pre- and mid-conference field trips, respectively) that indicate two pre-Variscan (Early Devonian and Early Ordovician) tectono-thermal events prior to collisional suturing. The Ordenes Complex was subjected to further scrutiny with a study on the pressure-temperature conditions for the development of corona textures of metagabbros that also supports a pre-Variscan event and with a study using mineral assemblages (Ky-St-Grt) in schists in order to reconstruct a pressure-temperature history related to a pre-orogenic (Early Ordovician) crustal thickening episode. One talk on the Ossa Morena zone provided new Pb/Pb and Rb/Sr ages for the southwestern Iberian massif that indicate both Variscan and pre-Variscan tectonic events.

The conference's third day led off with a review of the tectonic evolution of the suture between Avalonia and the "Armorican Terrane Assemblage" of central Europe, which formed during Cadomian subduction beneath Gondwana. A novel exhumation model for an anatectic dome was next proposed for the Montagne Noire, located in southern France. Using metamorphic rocks from the Adirondack Mountains (New York, USA), an alternative approach

was presented for determining the thermal history of migmatites based on electron microbeam, cathode luminescence, and isotope dilution analyses. Two further studies on metamorphic reactions were presented from the southern Central Iberian massif: a study integrating X-ray diffraction and structural techniques in order to document Devonian and Carboniferous events in an allochthonous and a paraautochthonous unit of the massif, and a study of a Late Carboniferous granitoid batholith (Nisa-Alburquerque) that was intruded after the main assembly of the Variscan belt, which was deduced to have been emplaced along a zone of weakness in the Variscan crust.

The remainder of the session considered examples from beyond the Spanish Variscides, beginning with a review of results from lithospheric-scale seismic exploration of the southern Urals (URSEIS'95), which has revealed new high-resolution images of the orogen including large-scale crustal shear zones, suture boundaries, and deep mantle (130-170 km) reflectors interpreted as mafic intrusions or shear zones possibly located at the base of the lithosphere. An integrated geological and geophysical study of the southern and middle Uralian orogen was next presented in which the Main Uralian fault (i.e., the main suture) was described as a complex composite of the original arc-continent suture in the southern Urals but was reactivated as a strike-slip fault system in the middle Urals. Our attention shifted west with the next talk, which offered new U-Th-Pb ion-microprobe evidence for a Hercynian-age (285 ± 5 Ma) metamorphic-magmatic event in the Betic Cordilleras, part of the Alpine nappe core complex system. Moving still further west to Nebraska (USA), an extraordinary data base from over 2200 basement drillholes provided a 1-1.8 Ga history of Precambrian accretionary growth of central North America. The following study used deformation patterns and seismic reflection data in southwestern Ireland (northwestern Avalonian continental margin) to show how basement structures controlled middle Paleozoic and subsequent Variscan deformation. The session closed with a talk on using a synorogenic sedimentological analysis of the Bagaud-Malalongue flysch (Tournaisian) of the Maures massif in order to document the southward migration of the Variscan orogenic front in southeastern France.

The afternoon session included two presentations on the allochthonous basal units of the Ordenes Complex, which represent a subducted part of the Gondwanan margin during the Variscan orogeny. The first of these reviewed current knowledge of the high-pressure metamorphism of the basal units and how the variation in metamorphism indicates a west-directed subduction polarity. In the second talk, one of these units, the Santiago Unit, was the

subject of a detailed study of the mineral assemblages that make up the eclogites and amphibolites of the unit. Two consecutive presentations were made on the exhumation history of the Ile de Groix metamorphic rocks (offshore Brittany, France), which form part of the Armorican massif: one study offered new $^{39}\text{Ar}/^{40}\text{Ar}$ and Rb-Sr isotopic age dates for metapelites and the second used bulk rock geochemistry and geothermobarometry of amphibole assemblages to reconstruct pressure-temperature paths that support a complex middle-to-late Variscan uplift history. The following talk moved to the onshore Armorican massif with a study of eclogite-facies rocks (Champtoceaux Complex) citing geothermobarometric and geochronological data in order to formulate a tectonic evolution similar to that of the allochthonous units of the Spanish Variscan belt. The final talk of the day presented a new model for part of the orogenic root of the Variscan belt (Vosges Mountains, northeastern France) that featured a three-stage, “oscillating” tectonic development defined by extension (345-340 Ma), compression (340-335 Ma), and compressional exhumation grading to extension (335--325 Ma) prior to final exhumation.

The fourth and final day of the conference opened with a talk on the plate tectonic evolution of pre-Variscan terranes of peri-Gondwana wherein a three-stage model was proposed: a Late Proterozoic volcanic arc active margin setting related to subduction beneath Gondwana; drift of Avalonia and opening of the Rheic Ocean; and amalgamation of exotic terranes with Gondwana prior to the Ordovician opening of the Paleotethys Ocean. A complementary talk built upon this model in order to derive a Silurian paleo-tectonic configuration which features Variscan elements forming a ribbon-like “Hun composite terrane” detached from the Gondwana margin. Two presentations provided new constraints for interpreting the pre-Variscan docking of the Baltica-Avalonia terranes with Gondwana, one using an integrated petrographic, geochronological, geochemical, and palynological study of lower Paleozoic sediments in the southern Baltic Sea region, and the other performing a provenance study of detrital zircons from Cambrian sediments in central Poland. Examples of Variscan orogenesis beyond the Spanish-French areas so far studied were presented that morning from (1) Sardinia that documented a transpressional Variscan shear zone and (2) the Alpine-Carpathian-Dinaride belt for which a geodynamic evolution was proposed. A pair of talks furnished detailed examples of the geodynamics of two early Paleozoic massifs: the Mérida massif of southwestern Spain, which was interpreted as a syn- to post-kinematic intrusion consisting of a dioritic and a leucotonalitic

unit; and a metamorphosed mafic and ultramafic oceanic terrane of the Bohemian massif. Finally, two studies of ophiolitic units of the northwestern Iberian massif were given, one emphasizing a structural approach (e.g., as a suture within the Variscan belt) and the other a geochemical and geochronological approach in which the protoliths might be related to basins that formed along the early Paleozoic Gondwanan margin.

The conference and field trips were held in commemoration of Professor Isidro Parga Pondal (1900-1986) for his early mapping of the geology of Galicia, beginning about 1940, and for his founding of the Laboratorio Xeolóxico de Laxe. The pioneering work done in the Galician allochthonous complexes in the sixties and seventies by the team of the University of Leiden directed by Prof. E. den Tex, was also acknowledged.

Copies of the conference field trip guide books and expanded abstracts volume can be obtained by contacting F. Díaz García, Departamento de Geología, Universidad de Oviedo, Arias de Velasco s/n, 33005 Oviedo, Spain (e-mail: bt15@asturias.geol.uniovi.es).

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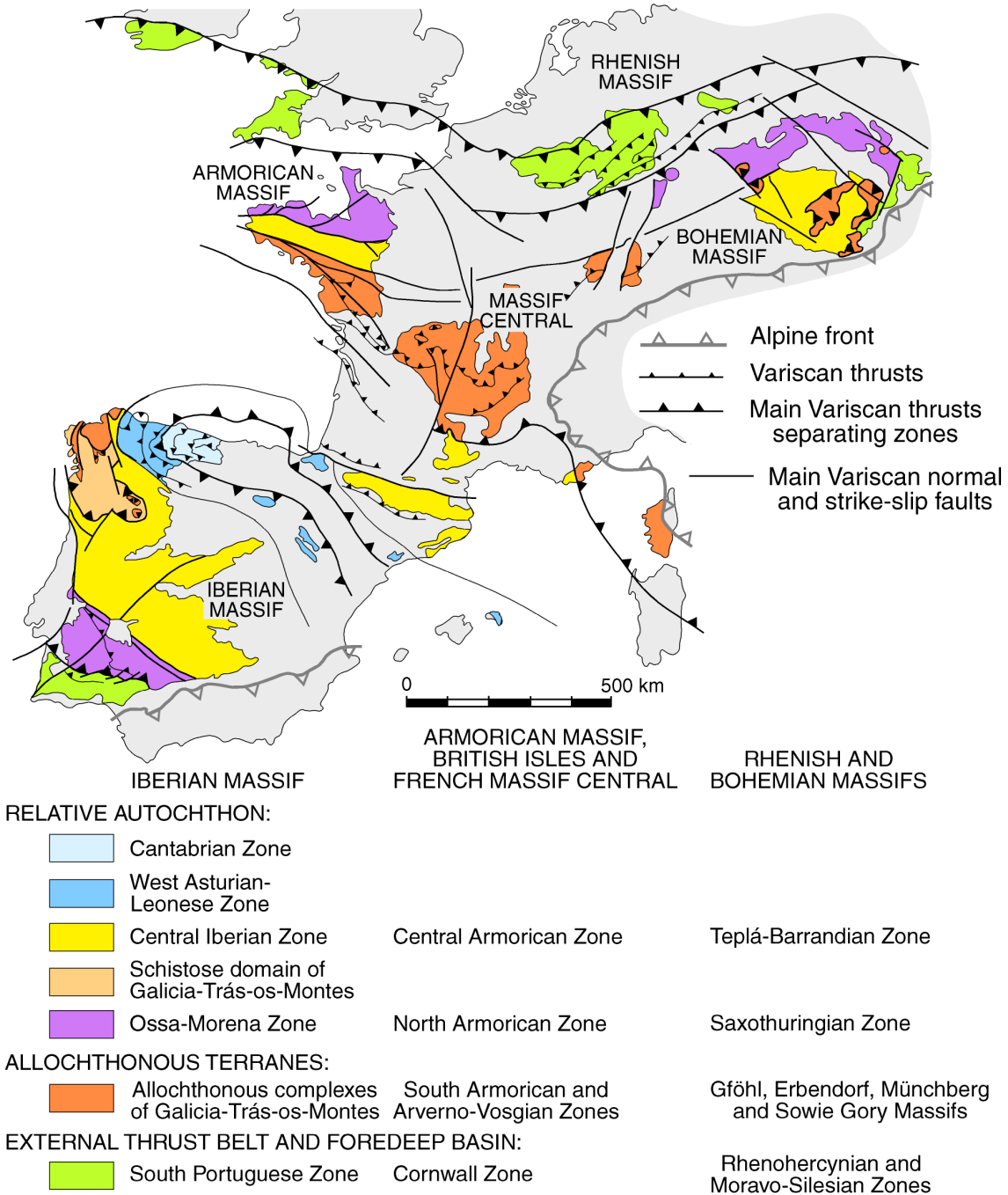


Figure 1. Generalized geological map of the European Variscan orogen. Source: Martínez Catalán, J. R., 1990, A non-cylindrical model for the northwest Iberian allochthonous terranes and their equivalents in the Hercynian belt of Western Europe: *Tectonophysics* 179, 253-272. Illustration courtesy of José R. Martínez Catalán.