CALEDONIAN AND LATE CALEDONIAN EUROPE: A WORKING HYPOTHESIS INVOLVING TWO CONTRASTED COMPRESSIONAL/EXTENSIONAL SCENARIOS

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RESUMEN

La estructuración tectonomagmática y metamórfica del dominio caledónico europeo sugiere que dos escenarios, compresional y extensional, mutuamente perpendiculares, se desarrollaron durante el Ordovícico-Devónico. Como resultado del esquema compresional del Ordovícico medio (Grampian, caledónico s.s.), en el O de Europa continental se desarrolló una provincia extensional localizada al E de la faja de plegamiento caledónica. Esta situación finalizó hacia el Devónico inferior/medio, cuando la convergencia de América del Norte, Báltica y Gondwana dio origen al supercontinente Pangea. Esta colisión generó un ambiente tectónico caracterizado por: 1. plegamiento y plutonismo en Europa continental occidental, y 2. extensión y volcanismo en la parte N de la faja de plegamiento caledónica (Escocia, SO de Noruega y E de Groenlandia). Este evento puede ser tentativamente denominado «Tardicalédonico». En términos globales, la evolución del dominio caledónico puede ser explicada en términos de «tectónica de inversión» (s.l.), esto es, periodos de adelgazamiento cortical (extensionales) seguidos por periodos de engrosamiento cortical (compresionales) y viceversa.

Palabras clave: Caledónico, Tardicalédonico, provincia extensional, tectónica de inversión.

INTRODUCTION

The western European realm has been traditionally ascribed to either Caledonian (western Scandinavia and most of the British Isles) or Variscan (southern British Isles and western continental Europe) domains. In this sense, the question of Paleozoic pre-Variscan events, particularly within the continental sector, has been a subject of controversy, as illustrated by the fact that no specific differentiation between Caledonian and Variscan cycles exists in some areas.

Another polemical question is related to the age of the final configuration of Pangaea (either Devonian, or Carboniferous/Permian), an issue which is of vital importance for the overall scenario. In this sense, the list of proposals (based on paleomagnetic and/or paleontological data) is very long. The «late

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Pangaea» hypothesis sustained by Perroud and Bonhomme (1981) and Zonenshain et al. (1985), among others, proposes that this supercontinent was not consolidated till Carboniferous or Permian time, when the northward drifting Gondwana was finally welded to the septentrional continental mass (Laurentia, Baltic, and Armorica). The alternative «early Pangaea» scheme (McKerrow and Ziegler, 1972; Keppie, 1977; Morel and Irving, 1978; Livermore et al., 1986; Miller and Kent, 1988), suggests a supercontinent configuration by early to mid Devonian time.

In this paper, we will argue that the structuration of the European Caledonian realm is characterized by the following points: 1. An early link between the different continental masses shaping Pangaea in this area. 2. Two contrasted tectonic scenarios, each of them defined by perpendicular deformational trends: Caledonian s.s., and «late Caledonian». 3. A globalized Caledonian cycle ending by late Devonian time, which can be clearly separated from the Variscan one.

The shaping of the European Caledonides

The controversial issue of a Caledonian continental Europe is not new, and in fact, pre-Variscan unconformities, tectono-metamorphic events, and magmatism have long been recognized in this realm (Alvarado, 1980; Atran and Peterlongo, 1980; Behr et al., 1980; Weber, 1984; Serrano Pinto, 1987, among others). However, these phenomena have been mostly regarded as local peculiarities, and no clear relationships to the main Caledonian foldbelt have been established. Additionally, the existence of tectonic events taking place in continental Europe, while the main Caledonian foldbelt was being shaped westward, favours the hypothesis of an early Paleozoic unified and unstable domain in the continental European realm, thus posing serious doubts on the models based on a series of microplates adrift at different paleolatitudes. Prior to the Caledonian cycle, this realm was affected by the Cadomian orogenesis (Precambrian/Cambrian), a scenario which changed in continental Europe with the onset of extensional conditions (Atran and Cogne, 1980) heralding the Caledonian. Sawkins and Burke (1980) suggest that extension continued in continental Europe during more advanced stages of the Caledonian cycle.

Two orogenic events, with associated compressional and extensional provinces, can be recognized in the European Caledonides (figs. 1A and 1B): 1. Caledonian s.s., a mid Ordovician-early Devonian event characterized by compressional conditions in the Caledonian foldbelt (C1), and extension in continental Europe (E1). 2. «Late Caledonian», a post-early Devonian-pre Dinantian episode characterized by extensional conditions in the northern part of the Caledonian foldbelt (E2), and compression in western continental Europe (C2). The first episode (Caledonian s.s.) is defined in continental Europe by extensional conditions, as revealed by the following data: epeirogenic movements, granulite facies metamorphism, basic volcanism, plutonism and crustal thinning-rifting (Behr et al., 1980; Luettig, 1980; Weber, 1984) in Germany; plutonism in France (Cogné and Wright, 1980), particularly within the axis of Moëlan-Lanvaux and Saint-George-sur-Loire, both accompanied by basic and ultrabasic rocks and alkaline intrusions (Zwart and Dornseifen, 1980); rifting along the so-called blastomylonitic graben in northwestern Spain (accompanied by some Ordovician alkaline granites: Zwart and Dornseifen, 1980), as well as volcanism, northwest-trending basic dykes (Gumiel, 1982; Hernández, 1984), rifting, block twisting, and peralkaline magmatism in central Spain (Pieren and Dallmeyer, 1989). Metallogenic processes (Sawkins and Burke, 1980) during this first extensional event (E1) gave rise to important ore deposits, such as those of Lahn Dill (volcanogenic BIF facies; Germany) and Almadén (volcanogenic mercury deposits; Spain; Pieren and Dallmeyer, 1989). This extensional event E1 was coeval with metamorphism and nappe tectonics in the Moines region within the main Caledonian foldbelt (Scotland, D1-D2 deformation, M2 metamorphic peak, circa 450 Ma; Soper and Barber, 1982; crustal shortening during Arenigian-Llanvirnian time, Dewey and Shackleton, 1984). This Grampian compressional event (C1) was related to other orogenic movements within other parts of the Caledonian/Appalachian belt (Scandinavia: Finnmarkian; Newfoundland: Humberian; Appalachians of New York and New England: Taconic; Dewey and Shackleton, 1984; Park, 1988). The final configuration of this compressional realm was achieved by late Silurian-early Devonian, when the Iapetus Ocean closed (Dewey and Shackleton, 1984; Miller and Kent, 1988).

The extensional conditions in continental Europe prevailed till early/mid Devonian time, when the onset of the Acadian compressions («late Caledonian» compressional event C2; fig. 1B) induced generalized folding and plutonism in Iberia, France and Germany (Serrano Pinto et al., 1987; Park, 1988). This event probably contributed to release the stresses within the previously overthickened Caledonian foldbelt, thus allowing the gravitational extensional collapse through detachment systems occurring further north (Scotland, southwestern Norway, and southeastern Greenland; McClay et al., 1986), generating a series of northeast to north-south-trending exten-
sional basins in which the Old Red Sandstone facies were deposited and volcanics extruded (extensional event E2). However, the stresses responsible for this collapse were mainly due to intraplate unstable conditions triggered by the previously overthickened orogenic welt. If we assume that an early or mid Devonian Pangaea existed, as suggested by some authors (McKerrow and Ziegler, 1972; Keppie, 1977; Morel and Irving, 1978; Gambles, 1984; Livermore et al., 1986; Miller and Kent, 1988), then the final locking of North America, Baltica and Gondwana (370 Ma, Gambles, 1984) can adequately account for the compressional event C2. Since by Devonian time, the British segment of Iapetus had closed (Dewey, 1982; Dewey and Shackleton, 1984), it is conceivable that the main stress component may have been provided by the northward drifting and collision of Gondwana against Europe by early/mid Devonian time.

Finally, soon after the cessation of this late Caledonian scheme, new extensional conditions prevailed during Dinantian time in most of Europe, a si-
tation which already belongs to the Variscan cycle. During this event the following features developed: the Basin/Block province, volcanism, and the so-called Irish-type ore deposits in Britain and Ireland (Leeder, 1982; Evans, 1987); the «Basin and Swell» zones in Germany (Luettig, 1980); basic and acid volcanism in France (Chauvel and Robardet, 1980); and rifting and bimodal volcanism in southern Portugal and Spain (Swakins and Burke, 1980). To the latter is associated a major volcanosedimentary complex hosting some of the most outstanding massive sulphide deposits of the world (e.g. Aznalcollar, Neves Corvo, Río Tinto). This extensional episode, the first of two during the Variscan cycle (a late Variscan extensional event is also recorded in France, Germany and Spain; Menard and Molnar, 1988; Doblas el al., 1988), ended by late Visian time, when a major Variscan compressional episode induced folding, metamorphism and plutonism throughout continental western Europe (Sudetic phase).

The extensional events: Contrasted genetic models

The case of the «late Caledonian» extensional event (E2; post-early Devonian-pre Dinantian) is analyzed first, as a model has already been proposed to explain it. As suggested by McClay et al. (1986), extensional detachment tectonics (as a consequence of the gravitational collapse of a previously overthickened orogenic welt) seems a plausible mechanism to account for the northern Devonian basins in which the Old Red Sandstone facies were deposited during this event. In this sense, the «late Caledonian» Basin and Range-type extensional province thus defined, bears many similarities with southern Spain and northern Africa during late Alpine time (Neogene), when the overthickened Betic-Rif orogenic edifice collapsed through detachment systems (Doblas and Oyarzun, 1989). Even if intraplate stresses arising from a gravitationally unstable crustal welt seem to be the major cause of this extension, the final locking of North America, Bältica and Gondwana (generating a northward-directed compressional stress pattern), may have been the triggering event contributing to release the stresses generated within the Caledonian foldbelt, thus allowing the extensional collapse of its northern sector. By contrast, the Ordovician-early Devonian extensional event (E1) developed as related to different circumstances. Since no previous overthickening can be advocated for continental western Europe, then another cause must account for this extension. In this sense, stresses arising from the building of collisional-type mountain belts are known to trigger extensional provinces in their continental forelands (e.g. Alps, Illies and Greiner, 1978; Hima-...
tensive events: 1. Caledonian s.s., with crustal thinning occurring in the foreland realm (E1; fig. 1A), a scenario which can be understood in terms of interplate stresses generated as a result of an Himalayan-type collision/indentation model (Tapponnier et al., 1982); and 2. A «late Caledonian» extensional scheme (E2) related to intraplate stresses, probably resulting from the gravitational collapse of a previously overthickened orogen, a process which might have been initially enhanced by the compressions occurring in western continental Europe (C2; fig. 1B).

Finally, the overall evolution of the European Caledonides can be ascribed to an «inversion-type» (s.l.) tectonic model, in that, regions subject to crustal thickening were later thinned (e.g. northern Caledonides; C1 followed by E2) and vice versa (e.g. western continental Europe; E1 followed by C2).

References


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