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The transition from passive to active margin sedimentation in the Cantabrian Mountains, Northern Spain: Devonian or Carboniferous?

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ABSTRACT

In the Cantabrian Mountains of northern Spain, a Cambrian through Pennsylvanian sedimentary succession is preserved that was deformed during the Hercynian orogenic cycle. Within this succession, Silurian and Devonian strata indicate sedimentation on a passive margin. Pennsylvanian deposits are the product of syndeformational uplift and erosion of the newly forming orogen and were deposited in a rapidly filling foreland basin in front of the orogenic belt. The intervening Mississippian succession is strongly condensed and consists of coarse-grained sandstones mantling a regional angular unconformity, crinoidal limestones followed by phosphatic black shales, nodular limestones and siliceous shales. This succession shows abundant erosional surfaces and mass-flow deposits and it is here interpreted as the initial starved foreland basin fill. If this interpretation is correct, the foreland basin system had already developed during the Late Devonian, much earlier than hitherto assumed. Its initiation can be correlated to processes in the internal zones of the Iberian Hercynian orogen where during the Late Devonian there is the change from subduction of oceanic lithosphere to intended continental subduction, its blocking and the subsequent collisional-type deformation. As a direct, long-distance effect of these changes in the plate-tectonic regime, the Cantabrian Hercynian foreland basin was created.

1. Introduction

In the history of (micro-) continental plates, the switch from passive to active margin sedimentation marks the initiation of a new plate-tectonic regime including the potential formation of a foreland basin (e.g., Jordan, 1981, 1995; Chanier and Ferrière, 1991; Cloetingh et al., 1989; Cant and Stockmal, 1989; Erickson and Arkani-Hamed, 1993; Dickinson, 1995; Bahlburg and Furlong, 1996; DeCelles and Giles, 1996). The exact timing of this transition, however, is often difficult to establish because the sediments accompanying active deformation of the foreland, its exhumation and its erosion may be very voluminous, and cover or mask the immediately preceding events. Historically, the onset of deposition of mass-flow-deposits including breccias and turbidites has been taken as an indicator of the onset of active thrusting (Heller et al., 1988; Burbank et al., 1988). In the Cantabrian Mountains, such deposits are interpreted to record the onset of the Hercynian deformation during the Early Pennsylvanian (Namurian; Julivert, 1978, 1979; Reuther, 1977; Kullmann and Schönenberg, 1975; Heredia et al., 1990; Marcos and Pulgar, 1982).

In many orogenic belts, similar coarse-grained deposits are underlain by a succession of stratigraphically condensed sediments of black shales, siliceous shales, and nodular limestones ascribed to a phase of tectonic quiescence. In recent years, modeling of geological processes has shown that such successions may form during the initial stages of crustal loading generating basins with starved sedimentation on the foreland plate (Sinclair and Allen, 1996; Jordan, 1995; Miall, 1995; Sinclair, 1997).

In the Cantabrian Mountains of northern Spain, a thin and strongly condensed succession (100 m of sediment deposited during approximately 40 Ma) of Upper Devonian through Mississippian rocks (the "Mississippian condensed succession"; Keller et al., 2007) is separated from older strata by a regional angular unconformity. Towards the internal parts of the orogen, the unconformity is represented by a continuous, prograding siliciclastic wedge, which exhibits the first vestiges of an additional source area, the beginning of a fundamental reorganization of the depositional system, of basin configuration, and a profound change in paleogeography. The tectono-sedimentary environment in which the Mississippian condensed succession formed is still awaiting a satisfactory explanation. The aim of this paper is to show that this succession may be the first response of the depositional environment to crustal loading and flexure of the continental lower plate representing the basement of the former passive-margin basin. This reorganization is attributed to the switch from a passive margin

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to a subduction-dominated compressional regime followed by collision with large-scale thrusting and nappe formation in NW Spain. These events record the initial collision between the eastern margin of Laurentia and Iberia. We focus on the sedimentary evolution of the shelf facies preserved in the southwestern part of the Cantabrian Zone.

As the main Carboniferous tectono-sedimentary turnovers and the timing of deformation correlate quite closely to the boundaries of the Mississippian and Pennsylvanian periods, and as this paper describes interactions between Laurussia and Gondwana we have decided to use these terms rather than the old European or Russian stage names.

2. Regional setting

Hercynian rocks constitute a major part of the western Iberian Peninsula (Fig. 1). Based on the differing tectonic, magmatic, metamorphic, and pre-orogenic sedimentary history, several zones are distinguished within this two-sided Hercynian orogen (Lotze, 1945; Julivert, 1971; Julivert et al., 1972). The northern branch of the orogen is composed of the Central Iberian Zone, the West Asturian Leonese Zone and the Cantabrian Zone (Fig. 1), one of the external high-level thrust-and-fold belts of the Iberian Hercynian orogen. Oroclinal bending is responsible for the arc shaped nature of the Paleozoic outcrops that is known as the Ibero-Armorican Arc or as the Asturian Arc (Fig. 2). This arc is largely of Late Hercynian to post-Hercynian origin (Weil et al., 2000, 2001) and the displacement of facies and structures by the curvature has to be considered in all reconstructions.

Hitherto, the onset of orogeny and of synorogenic sedimentation in the Cantabrian Zone was mostly assigned an Early Pennsylvanian age (e.g., Julivert, 1978, 1979; Reuther, 1977; Kullmann and Schönenberg, 1975; Heredia et al., 1990; Rodríguez Fernández, 1993, 1994). This was based primarily on the onset of deposition of turbidites and debris-flow deposits (Nardin et al., 1979). Marcos and Pulgar (1982) regarded the uppermost Devonian and Mississippian deposits as transitional between a stable shelf sedimentation and synorogenic deposition. Contrastingly, Keller (2000) and Keller et al. (2007) proposed that the Mississippian condensed succession might represent the underfilled stage of foreland basin evolution and that this evolution might have already started during the Late Devonian.

Paleogeographically, three areas are distinguished in the Cantabrian Zone (Fig. 2). (1) The fold-and-nappe province with a more or less complete succession of Silurian and Devonian deposits in shelf facies (Asturo Leonese facies of Brouwer, 1964); (2) the Cantabrian Block (Radig, 1962), an area characterized by the almost complete absence of these strata, which is structurally contained within the Central Asturian Coal Basin, the Ponga nappes and the Picos de Europa nappes; and (3) the Pennsylvanian flysch basin also known as the Pisuerga Carrión Province (Julivert, 1971) or Pisuerga Carrión Unit (Pérez Estaún et al., 1988). The Pisuerga Carrión Unit contains the Palencian nappes with Silurian and Devonian sediments in pelagic facies, the Palencian facies of Brouwer (1964). There is still considerable discussion about the provenance of these allochthonous complexes which were emplaced in the Pisuerga Carrión Unit during the Pennsylvanian (Westphalian; Ambrose, 1974; Wagner, 1971; Frankenfeld, 1983, 1984; Marquínez and Marcos, 1984; Wagner and Winkler Prins, 2000). However, there is a growing structural and sedimentologic evidence that the Palencian facies originally formed in a position south or west of the Cantabrian Zone, probably within the West Asturian Leonese Zone (Frankenfeld, 1983, 1984; Marquínez and Marcos, 1985; Rodríguez Fernández and Heredia, 1987; Carls, 1988; Weh, 2004; Keller et al., 2007). The assumption that the Palencian nappes root in the West Asturian Leonese Zone is fundamental for the interpretation developed in this paper.

3. The pre-orogenic history of the fold-and-nappe province

Several Paleozoic tectono-sedimentary episodes are distinguished in the southern and western parts of the Cantabrian Zone (Fig. 3), Cambrian–Late Ordovician, Silurian–Middle Devonian, Late Devonian–Mississippian, and Pennsylvanian. Each of these episodes has a distinct depositional history and is separated from the underlying and overlying successions by well-developed unconformities (Fig. 3).

Above a Precambrian meta-sedimentary succession, basal Cambrian through Lower Ordovician sediments are characterized by a dominance

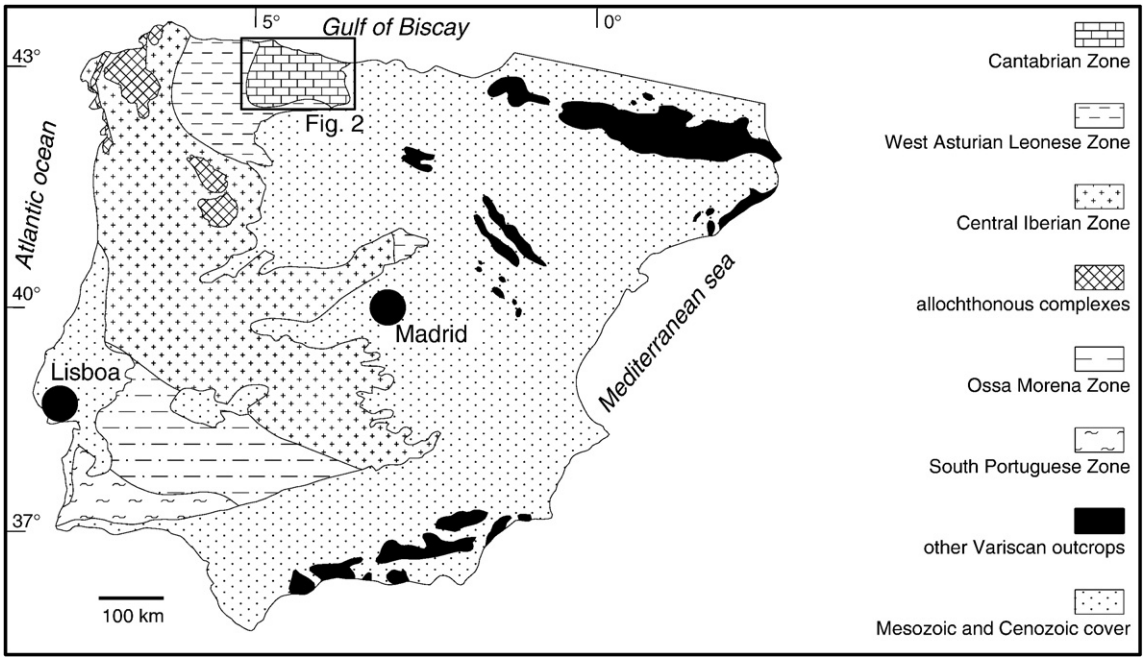

Fig. 1. Major Variscan units of the Iberian Massif following Lotze (1945) and Julivert (1971). Also shown are the allochthonous complexes of NW-Iberia (from Martínez Catalán et al., 2002). Rectangle depicts position of Figs. 2 and 4.