CHAPTER 3

CARBONIFEROUS OF THE CANTABRIAN ZONE

Partial view of the Las Llacerías section (Picos de Europa), a stratigraphic succession representing most of the Carboniferous Period. In the foreground, limestone of the Moscovian Picos de Europa Formation, and next to it, prairies developed on Stephanian siliciclastics. The Picos de Europa Formation also crops out in the background, repeated by an overthrust.
The Carboniferous successions of the Cantabrian Zone are unique in the world due to their sedimentary features, extended geological record (360 through 290 Ma) and excellent outcropping conditions. These successions are the result of the development and evolution of a foreland basin formed in relation to the Variscan orogeny. During the first part of the Carboniferous (Mississippian), the Cantabrian Zone was still far from the orogen and had a stable marine platform with a low sedimentation rate. During a second stage (Pennsylvanian), sedimentation was strongly conditioned by tectonics, leading to the filling of this zone as a foreland basin.

As a consequence of the paleogeographical situation of the Cantabrian Zone, the Carboniferous rocks record very diverse sedimentary environments, offering the opportunity to analyze entirely marine stratigraphic successions as well as other contemporary ones of non-marine (terrestrial or continental) character. This exceptional situation allows the comparison of the temporal distribution of organisms living in completely different environments.

The Cantabrian Zone is part of the Iberian Massif (figure 1), a set of Precambrian and Paleozoic rocks where five different units or zones have been differentiated. These units are displayed as a warped structure which has traditionally been called Asturian Arch. In geographical terms, the Cantabrian Zone expands through most of Asturias, north of León and Palencia, as well as a small portion of the western end of Cantabria. To the west, its geological boundary is set by a large structure called Narcea Antiform. To the south, the Paleozoic of the Cantabrian Zone is covered by Mesozoic and Cenozoic units of the Duero basin, and to the east, by the Mesozoic units of the Vasque-Cantabrian basin. The Cantabrian sea does not allow the direct observation of its northern edge, but data recently obtained by hydrocarbon explorations reveal that it also dips underneath the Mesozoic cover.

Five zones can be distinguished in the Cantabrian Zone from a structural point of view, with boundaries set by major thrusts. These are, from west to east: Fold-and-Thrust region (Somiedo-Correcillas, Sobia-Bodón and Aramo units), Central Carboniferous Basin, Thrust Region (Ponga Unit), Picos de Europa Unit, and Pisuerga-Carrión Unit (figure 2). Overall, they show a vergence towards the east or the north, with the western units overthrusted by the eastern ones. The Pisuerga-Carrión Region or Unit, in the innermost part, is overthrusted by all the surrounding units.

The tectonics displayed in the Cantabrian Zone corresponds to a thin-skinned style, meaning that the deformation affects the cover and not the Precambrian basement, except for the Narcea Antiform separating the Cantabrian from the West Asturian-Leonese Zone. All of that occurred under the almost complete absence of metamorphism, and therefore without any conspicuous internal deformation of the rocks. However, under certain circumstances, a low metamorphic grade may have locally developed. On the other hand, upper crust deformation in the Cantabrian Zone has led to the sequential development of thrusts and associated folds contemporary to clastic wedge sedimentation ahead of the major thrust fronts, as well as other deposits in piggy-back basins (tectonic basins atop thrusted blocks).

All the structural units making up the Cantabrian Zone include Carboniferous sedimentary rocks with important differences between units resulting from tectonic deformation related to Variscan orogeny. The thickest units are found in the Central Carboniferous Basin (up
to 6000 m thick), while the most complete are those in the east. Picos de Europa, the easternmost unit of all, displays a continuous marine sedimentary record beginning at the very base of the Carboniferous and almost reaching the end of this system.

Broadly speaking, the Carboniferous of the Cantabrian Zone belongs to two profoundly different sedimentary contexts, a preorogenic one developed during the Mississippian, and a synorogenic or late-orogenic one, developed during the Pennsylvanian. The range of sedimentary environments (figure 3) is enormous, particularly in the Pennsylvanian successions, where it is possible to observe, from the foreland foredeeps related to the orogenic front, up to the wide paralic areas of the Central Carboniferous Basin; as well as from the large carbonate platforms of Picos de Europa and the Ponga river, to the intermontane, lacustrine or fluvial basins of the late orogenic stages. Standing out among these environments we find the coal generating environments, due to their socio-economical relevance, and the carbonate platforms developed throughout the Carboniferous, because of the spectacular landscapes and excellent outcrops.

So many different environments gave rise to an equally remarkable variety of life forms. Especially relevant is the fact that many of the successions include obviously marine and non-marine intervals, which provides, all along the Upper Carboniferous (Pennsylvanian), a mixed paleontological record unparalleled in any other European zone, and from which it is possible to extract crucial correlations between both biostratigraphic scales, the one based on marine fossils and the one based on non-marine (terrestrial or continental) fossils.

The preorogenic sedimentation of the Lower Carboniferous (Tournaisian-Visean) consists of thin condensed series, widely extended laterally, and deposited on a stable platform. The Devonian-Carboniferous boundary is found within white, bioclastic limestone (called Baleas Formation, Candamo Formation or Las Portillas Formation, depending on the sector) deposited throughout most of the Cantabrian Zone. In those areas where these limestones do not appear, the base of the Carboniferous is represented by black slates with rare manganese nodules (Vegamián Formation). These are overlain by a characteristic lithostratigraphic unit consisting of red or pinkish, micritic and nodular limestones (Alba Formation, also called Carboniferous “griotte”, and Genicera Formation). The predominant pelagic character of the sedimentation in this stage is evident from the low sedimentation rate facies and the fossil content (goniatitids, orthoceratids, conodonts, etc.).

At the end of the Mississippian, the effects of Variscan orogenesis on the Cantabrian Zone are already visible. In some places, turbiditic sedimentation began, indicating the formation of a synorogenic basin and changing sediment provenance compared to the general trend during the Devonian: the source area is now

Figure 2. Main structural units of the Cantabrian Zone (based on Julivert, 1967).
placed towards the west and southwest, whereas the open sea is towards the east. Carboniferous sedimentation is conditioned by the migration of the orogenic front, and since it keeps moving towards the east, the different units record its influence later in time the more eastward their position is. This situation is typical of a “foreland basin”, for which the Cantabrian Zone is a remarkable example.

A reconstruction of the Carboniferous of this zone (figure 4) shows that the successions of the different allochthonous units, create several clastic wedges thinning towards the east. These wedges are diachronous and last longer towards the east. Their creation is related to the movement of the thrusts in the nearby western units, since the emplacement of each large allochthonous thrust unit must have caused a subsiding foredeep in the adjacent foreland basin, where huge amounts of sediments were deposited. The foredeep shallowed towards distal areas of the orogen, gradually disappearing in the still unaffected areas.

During this stage, the last of the Lower Carboniferous and the beginning of the Upper Carboniferous (Serpukhovian, equivalent to the lower Namurian), turbiditic successions (Cuevas Formation and its partial equivalent, Olleros Formation) in the westernmost part of the Fold and Thrust Region (Somiedo-Correcillas Unit) filled in the foredeep adjacent to the orogen (figure 5A). In the rest of the Cantabrian Zone, the turbidites are replaced by a thick succession of black, thinly-bedded, micritic, very fossil-poor limestone (Barcaliente Formation) deposited on a carbonate platform. The evaporite pseudomorphs and breccias at its top have usually been related to evaporite dissolution phenomena and to gravitational instability induced by tectonism.

Beginning in the early Bashkirian (equivalent to the middle Namurian), a shallow carbonate platform, well oxygenated and with frequent bioherms is seen in many sections of the basin (La Sobia-Bodón, Aramo, Picos de Europa, and northern Ponga Units), achieving great development (Valdeteja Formation) (figure 5B). In the western platform, a turbiditic trough (Antromero “flysch”) represents the foreland foredeep, which, as a consequence of the east migration of the orogen, is now located further east than earlier. In the Central Carboniferous Basin and the southern Ponga Unit, there is another trough with siliciclastic sedimentation, moderately deep, which, as it is separated from the continent by the carbonated platform, receives scarce sediment contribution (“Fresnedo Package” of the Central Carboniferous Basin and the Ricabiello Formation of the Ponga Unit). At this stage, the situation in the Pisuerga-Carrión Region is clearly synorogenic, turbiditic sedimentation is terrigenous siliciclastic, although it includes several carbonate
breccias and olistoliths derived from platform carbonate formations.

Between the Bashkirian and the Kasimovian, and with different ages in different areas, the successions in the Cantabrian Zone show abundant examples of deposits originated in braided deltas and coastal alluvial fans (fan deltas). Within them it is possible to observe every kind of facies typical from these sedimentary environments, from the most proximal to the most distal ones. The Curavacas Conglomerate (Pisuerga-Carrión Unit) is a remarkable example representing a coastal alluvial fan which distally connected with a turbiditic trough. The closeness and elevation of the orogen, as well as its quick evolution, are shown here in an interesting facies association.

Throughout the Moscovian (or Westfalian, in terms of the West European scale, equivalent to most of the Moscovian), orogen migration led to the emplacement of thrusts, which finally caused the emergence of the units located in the western end of the Cantabrian Zone, and therefore the foreland foredeep took up a more eastern position than in the previous stage (figure 5C). At the beginning of the Westphalian, the La Sobia-Bodón and Aramo Units represent the westernmost area of the Cantabrian Zone receiving marine sedimentation. The turbidites, which on those units began to be deposited during the Bashkirian (lower San Emiliano Formation), are later replaced by deltaic deposits with limestone and coal layers (middle and upper part of the San Emiliano Formation).

The complexity of the sedimentary systems increased, and paralic sedimentation, responsible for the formation of abundant coal layers, reached its maximum development in the Carboniferous Central Basin (figure 6) and the southern Ponga Unit, whereas the carbonate platforms prevailed in the east and north. The accumulation in the Central Carboniferous Basin of the distal clastic wedge of La Sobia-Bodón, and other later ones on top of it, created the thickest clastic wedge formed during the following stages of the Variscan orogen advance: almost 6000 m of sediments were deposited over the limestones of the Barcaliente Formation (over the Valdeteja Formation towards the north). In a first stage, from...
the Langsettian to the Westphalian (that is to say Westphalian A to Westphalian C), deltaic and shallow platform environments developed, creating deposits with abundant limestones and some coal layers (Lena Group and lateral equivalents) (figure 5C). Next, in the Westfalian D, followed a situation with similar environments. A predominantly siliciclastic sedimentation took place (Sama Group), where coastal alluvial fans developed closest to the orogen, and a deltaic platform in the transitional area towards marine environments (figure 7). In this stage, all the basins record the formation of coal layers, but they are much more abundant in the intermediate zone (deltaic platform), with more than 70 productive layers worked during the 200 years of mining in the Asturian central region.

The eastwards advance of tectonic deformation meant the arrival of important detrital contributions to the center and south of the Thrust Region (Ponga Unit), corresponding to the distal clastic wedges. This succession (Beleño, Escalada and Fito formations) is similar to the Central Carboniferous Basin, whereas north of the Ponga Unit (Sierra del Cuera area, figure 8) and in the Picos de Europa Unit, important platform carbonate deposits developed (Picos de Europa Formation).

In the Pisuerga-Carrión Unit, the situation is different, as it developed a marine synorogenic basin with sedimentation dominated by important siliciclastic input arriving from uplifted reliefs located to the south. Turbiditic sedimentation was frequent and often comprising carbonate olistoliths, evolving towards shallower platform, deltaic and even fluvial-deltaic environments, upon which carbonate bodies of certain importance developed.
At the end of the Moscovian (end of the Westphalian), orogen advance had already caused the withdrawal of the seas from most of the Cantabrian Zone, so that during the following Stephanian stage (almost equivalent to the Kasimovian and Gzhelian marine-based stages), there was marine sedimentation only in the Picos de Europa and Pisuerga-Carrion units, and a small portion of the Ponga Unit (Sebarga area), with a clear synorogenic character. The development of extensive carbonate platforms continued in Picos de Europa, leading to the important Stephanian carbonate units present in that area (figure 9). The most important units among them are the Moscovian to early Kasimovian Picos de Europa Formation, the early and middle Kasimovian Llacerías Formation, and the late Kasimovian and Gzhelian Puenteles Formation. The turbiditic series, such as the Lebeña and Cavandi formations in Picos de Europa, or the Brasoñera Formation in the Pisuerga-Carrion Unit, often represent the last stages of marine sedimentation.

Inside some of the areas of the Cantabrian Zone (mainly the Somiedo-Correcillas Unit, as well as in the Narcea Antiform and the West Asturian-Leonese Zone), isolated exposures of Stephanian continental deposits unconformably overlie a basement with unknown Precambrian to Carboniferous age. It is not known whether any of these exposures belongs to a different basin, or if some of them were connected. In any case, there is general agreement to consider the Stephanian series as the final filling of basins related to late Variscan tectonics, linked to extensional stresses and to the re-activation of previous directional faults. The thick successions within these continental basins contain abundant layers of coal and record alluvial and lacustrine sedimentation with coarse detrital proximal facies, and distal fossiliferous slates.

The peculiarities of the Carboniferous of the Cantabrian Zone are evident if the Pennsylvanian successions in this area are compared to those in the rest of the European Carboniferous areas. A relevant fact becomes immediately apparent: the Cantabrian successions display a much more complete stratigraphic record, and some intervals are not present in the classical European basins. The case of the Westphalian/Stephanian transition is especially remarkable, corresponding in the Cantabrian Zone to a thick succession not recorded in other zones (Cantabrian stage). This is
the most noteworthy, but not the only case: transition intervals between certain stages have been observed in other world regions (for example, the Bashkirian/Moscovian and Moscovian/Kasimovian boundaries) revealing a much more continuous and thick sedimentary record than in the respective stratotype sections. It has been proven that stages which have been used taking other European Carboniferous areas as a reference, such as the Westphalian D or the Stephanian A, show in the Cantabrian Zone a much more complete sedimentary record than in any of those areas. For the first case, the definition of Westphalian D as Asturian stage has been proposed, with the type area in the region of Asturias, and for the second case, the name Stephanian A has already been replaced by Barruelian, with the type area north of Palencia.

The exceptional character of the sedimentary succession in the Cantabrian Zone, together with the great diversity of sedimentary environments, have resulted in a paleontological record for the Upper Carboniferous unparalleled in the rest of Europe. The succession of marine fauna extends from the base to almost the end of the Carboniferous, showing many different environments, from open sea to coastal. Due to their chronostatigraphical interest, it is important to mention the abundant presence of goniatitids in the Mississippian (Lower Carboniferous) and of fusulinids (figure 10) in the Pennsylvanian (Upper Carboniferous), as well as the presence of conodonts in both sub-systems.

As already mentioned, the successions with a strong non-marine (terrestrial or continental) influence (deltaic, fluvial-deltaic or even lacustrine) contain a unique fossil record of macro and microflora, including associations which belong to unknown time gaps, or are scarcely represented, in other Carboniferous areas. Another fortunate fact is the existence of mixed successions with paleontological marine and non-marine elements, supplying crucial information to solve a long time debated stratigraphic problem: the correlation of the western and eastern Europe Carboniferous scales.

Figure 11, above. The Cantabrian Zone provides an excellent record of Carboniferous floras, as well as some exceptional paleontological sites, such as the fossil “forest” of Verdeña (Palencia), where the molds of trunks of big lycopsids dragged by strong currents are preserved (Wagner et al., 2001). (Photo: E. Villa).

Figure 10. The study of fusulinids, microfossils of carbonate shell, is one of the main methods to date and correlate the Pennsylvanian series of the Cantabrian Zone. (Length of the specimen in the center of the picture: 9.8 mm).
Apart from the global interest and relevance of the aforementioned stratigraphic and paleontological record, the Carboniferous of the Cantabrian Zone presents sedimentary and paleogeographical features of extraordinary geological heritage value. Of particular importance are those which allow the observation of the clear transition between the sedimentation from siliciclastic wedges to carbonate platforms. The quality of the exposures, and the fact that the sequence is vertical and with scarce deformation, has allowed the detailed analysis, in the eastern part of the Cantabrian Zone, of the sedimentary features of the carbonate platforms (internal and external platforms, margin, talus and talus base). This is a unique case in the world in what regards the Carboniferous system: the reconstruction of a platform geometry and of the lateral relations between the different environments, as it has been achieved in Sierra del Cuera (north of the Ponga Unit, figures 8 and 13). Two major episodes have also been identified in the region. In the first stage, a prograding platform was created (Valdeteja Formation, mostly Bashkirian) with...
progradation higher than 10 km, clinoforms up to 35°, and talus higher than 650 m. In the second stage, an aggradational platform was developed (Picos de Europa Formation, Moscovian), with vertical growth reaching 850 m.

Another exposure with the same features (vertical layers, possibility of analyzing platform margins and laterally following its evolution along extended distances) and belonging to a later episode, crops out in the Las Llacerias sector (Picos de Europa Unit) and has enabled to study platform growth from the upper Moscovian to the lower Kasimovian.

Besides the aforementioned examples, the Cantabrian Zone also contains other heritage features equally relevant, such as the marine paleoreliefs made by bioherms present in the Valdeteja Formation (Bashkirian-basal Moscovian) of the La Sobia-Bodón Unit, or the spectacular platform margin visible in an outcrop of the Escalada Formation in Tiartordos Peak (Ponga Unit), basically of upper Moscovian age (figure 12).

In several areas of the Cantabrian Mountain Range, especially within the Pisuerga-Carrión Unit, several levels of the stratigraphic column present olistostromic formations with abundant olistoliths variable in size. These olistoliths (figure 14) are generally made of Carboniferous limestone, although there are also some olistoliths made up of different older rocks. The most common interpretation for all these olistostrome formations considers them deposits resulting from mass transport by dense gravity flows. They may only include basal elements (endolistoliths) or include a mixture of blocks from different pre-orogenic successions (exolistoliths).

Figure 14. Carbonate olistolith included within the Perapertú Formation (lower Moscovian), at the Perapertú location, Pisuerga-Carrión Unit, north of Palencia. (Photo: E. Villa).
REFERENCES

Data compiled in this chapter comes from the articles listed below, or from those cited in the synthesis review publications also included in the list.


