Crustal structure of the Cantabrian Zone: seismic image of a Variscan foreland thrust and fold belt (NW Spain)

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Abstract: The ESCI-N1 normal incidence seismic reflection line (140 km long) shows much of the shallow structure of the foreland thrust and fold belt (Cantabrian Zone) of the European Variscan Belt in the Iberian Peninsula (NW Spain), as well as the deep structure of the transition to the hinterland (Westastur-leonese Zone), and allows a direct comparison with surface geology. Reflections, on the eastern upper part of the line (Cantabrian Zone), correspond to Palaeozoic rocks mappable on surface. The Palaeozoic sequence provided strongly reflecting and transparent zones. The general decollement surface beneath the thrust belt is visible as a set of reflections dipping westward and placed between 4 and 6 s two-way travel time (TWTT), establishing the thin-skinned character of the deformation. In the central part of the line, the reflectivity decreases in the upper crust, above the decollement, due probably to the strong deformation of the area. The crust underneath the decollement shows, in the eastern part of the line, short, subhorizontal and numerous reflections from 6 to 14 s. The thickening of the crust in this area is interpreted to be related to Alpine reworking. On the western part of the line, at the transition between the Cantabrian and Westastur-leonese zones (the Narcea antiform, cored by Precambrian rocks), a set of strong reflections dipping west joint the decollement (at 6 s TWTT) with the lower crustal levels (9 s). These reflections die out on the top of the lower crust (horizon of decoupling). The lower crust, in this region, is characterised by a zone of high reflectivity situated between 9 and 12 s TWTT, that seems to occur only in the area with thick-skinned tectonics, and with synmetamorphic deformation. The whole deep crustal structure of the transition zone may be interpreted as an indentation of the foreland basement into the hinterland crust producing a duplication of the lower crust and a complex antiform in the upper crust. The deeper structure of the Narcea antiform suggests that uplift of the Precambrian basement in this area was accomplished largely by thrusting rather than vertical doming

Keywords: Variscan Belt, foreland thrust and fold belt, CMP reflection profiling

Resumen: El perfil sísmico de reflexión profunda ESCI-N1, de 140 km de longitud, muestra la estructura de la zona externa de la Cordillera Varisca Europea (Zona Cantábrica) en la Península Ibérica y su transición a las zonas internas (Zona Asturoccidental-leonesa). Las reflexiones existentes en la parte superior y oriental de la línea (Zona Cantábrica), corresponden a las rocas paleozoicas. El contraste litológico entre las diferentes formaciones de la secuencia paleozoica da lugar a la existencia de bandas reflectivas y trasparentes. La superficie de despegue de la Zona Cantábrica se evidencia por la existencia de reflexiones dispuestas en una estrecha banda inclinada hacia el oeste, situada entre los 4 s (tiempo doble) al este y los 6 s al oeste. Esta superficie pone de manifiesto al carácter de téctonica epitelial de la zona externa del orógeno. La corteza por debajo del despegue, entre los 6 y los 14 s de profundidad, presenta reflexiones subhorizontales, cortas y poco coherentes. La Moho puede situarse a 14 s en esta zona. Este fuerte grosor cortical se debe a la deformación alpina. En la parte oeste de la línea, en la transición entre las zonas Cántabrica y Asturoccidental-leonesa, existen varias bandas reflectivas, entre 5 y 10 s de profundidad, inclinadas al oeste. La más profunda une la superficie de despegue de la Zona Cantábrica, con la corteza inferior. La deformación varisca afecta a la totalidad de la corteza en este sector. Una corteza inferior reflectiva está presente en la parte occidental del perfil. La estructura profunda en la transición a las zonas internas del orógeno, parece mostrar una indentación del basamento precámbrico de la Zona Cántábrica en la corteza de las zonas internas.

Palabras clave: Cordillera Varisca, estructura zonas externas de orógenos, sísmica de reflexión profunda.

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The European Variscan Belt is relatively continuous for almost 3000 km throughout western Europe. It is part of a large Palaeozoic belt that was constructed as a result of convergence and collision of two main continents, Laurentia-Baltica and Gondwana, after the closure of several oceanic basins (Matte, 1991). In Europe, it is a broad sinuous belt, sometimes more than 800 km wide that shows a prominent bend in the West. This bend is known as the Ibero-Armorican arc. Deep seismic reflection profiling studies have been carried out in different areas of

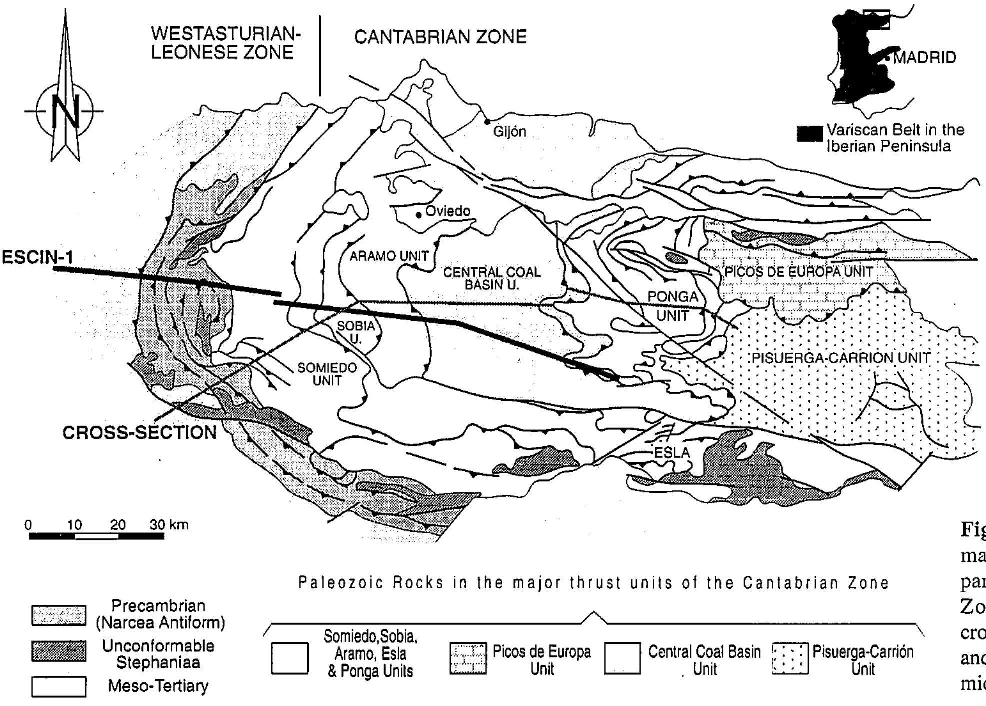

Figure 1.- Simplified geological map of the Cantabrian Zone and part of the Westasturian-Leonese Zone with the location of the cross-section reproduced in Fig. 2 and the trace of the ESCI-N1 seismic profile.

the northern branch of the Ibero-Armorican arc (BIRPS & ECORS, 1986; Bois *et al.*,1986; Matte & Hirn, 1988; DEKORP Research Group, 1985; Meissner & Wever, 1986; Franke *et al.*, 1990). The most outstanding characteristics of all these profiles include the existence of curvilinear reflections at different levels of the crust interpreted as Variscan thrust faults. They also show a highly reflective lower crust with a rather flat and sharp appearance of the reflection Moho at a mean depth of 30 km (Meissner *et al.*, 1987). The narrow foreland areas imaged in the northern part of the Variscides by ECORS and DEKORP profiles show thin-skinned style of deformation (Meissner *et al.*, 1981; Cazes *et al.*; 1985, Bois *et al.*, 1986; Raoult & Meilliez, 1986).

The northern branch of the Ibero-Armorican arc was affected by late-Variscan disintegration (Ziegler, 1988), involving wrenching and post-orogenic collapse. In addition, many of the Variscan areas investigated in those previous deep seismic studies contain Mesozoic and Tertiary basins that have undergone Alpine deformation.

The southern branch of the Ibero-Armorican arc is made up of the Iberian portion of the Variscan belt. It constitutes a 900 km wide, continuous cross-section across two possible major sutures. The section of the Variscan belt outcropping along the northwestern part of Iberia, provides one of the best sections for the study of Variscan tectonics because it is well exposed along approximately 300 km of coastline that runs perpendicular (E-W) to the strike of the orogen (Pérez-Estaún *et al.*, 1991). The external areas of the belt underwent Alpine tectonism, forming the Cantabrian Mountains that constitute the western extension of the Pyrenees. The Palaeozoic and Precambrian rocks cropping out in Asturias (N. of Spain), where this seismic study was achieved, form the core of a basement uplift formed during Tertiary times (Alonso *et al.*, 1995; Pulgar *et al.*, 1996).

Extensive geological mapping, detailed stratigraphic, structural and petrologic studies have been carried out in the northern part of the Variscides of Iberia over the past two decades (synthesised in: Julivert *et al.*, 1980; Julivert *in* Comba, 1983; Dallmeyer & Martínez García, 1990; Parga Pondal, 1982; Pérez-Estaún *et al.*, 1988). In addition, recent geophysical studies, refraction and reflection profiling (Córdoba *et al.*, 1987, 1988; Pérez-Estaún *et al.*, 1994; Pulgar *et al.*, 1996; Álvarez Marrón *et al.*, *in press*) and palaeomagnetic data (Perroud, 1982; Hirt *et al.*, 1992; Parés *et al.*, 1994), together with geochronological studies (Van Calsteren, 1977; Kuijper, 1979; Peucat *et al.*, 1990; Dallmeyer *et al.*, 1991) have aided greatly to the understanding of this complexly deformed region.

This paper presents the results of a deep seismic reflection survey (ESCI-N) acquired in north Spain. ESCI-N programme is one of the ESCI projects, a Spanish national programme to study the Iberian crust by deep seismic probing (**E**studio **S**ísmico de la **C**orteza **I**bérica). The survey was designed to provide a crustal cross-section of the Variscan orogenic belt in NW Spain, as well as the structure of the two continental margins to the West and North, the Galician and Cantabrian platforms respectively. The data presented here correspond to the 140 km long ESCI-N1 on-land profile across the external areas of the Variscan orogen (Fig. 1; Pérez-Estaún *et al.*, 1994). There is a detailed and complete coverage of surface geology in the area of the profile (Marcos, 1968, 1973; Julivert *et al.*, 1977; Marcos *et al.*, 1980a, 1980b; Parga Pondal, 1982; Aller, 1986; Álvarez-Marrón *et al.*, 1989; Bastida & Gutiérrez, 1989; Gutiérrez, 1992; Bulnes, 1994). A previous publication by Pérez-Estaún *et al.* (1994) presented a first interpretation of the ESCI-N1 profile, in which the present paper is based.

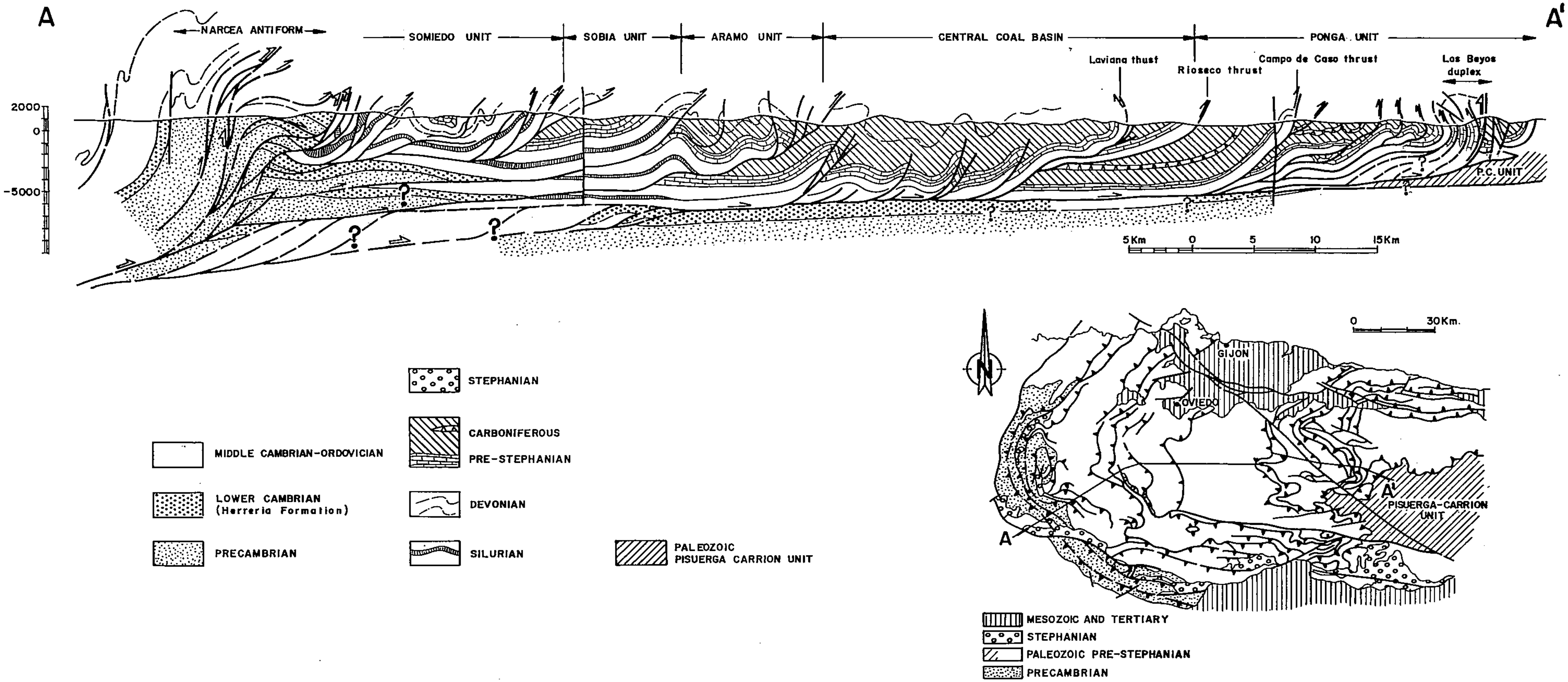

Figure 2.- Geological cross-section of the Cantabrian Zone (after Pérez-Estaún *et al.*, 1988).

Geology of the Variscides foreland thrust and fold belt

The portion of the Variscan belt that crops out in NW Spain corresponds to one of the continental margins involved in the Variscan collision, the margin of Gondwana. A geological zonation was established from the hinterland areas in the West to the foreland in the East (Lotze, 1945; Julivert *et al.*, 1974; Farias *et al.*, 1987). This zonation was based on metamorphic, structural and palaeogeographic differences that reflect the varying deformation styles in the footwall to the Variscan suture that is located to the West. Palaeozoic and Upper Proterozoic rocks crop out largely in this region with a main northwest-southeast structural grain. Descriptions of the structure of this portion of the Variscan belt can be found in Julivert *et al.* (1980), Julivert (1987) and Pérez-Estaún *et al.* (1991).

The foreland thrust and fold belt of the Variscan orogen, named Cantabrian Zone, contains several east-directed thrust units emplaced during Carboniferous times that show a rather tight arcuate trend (Julivert, 1971; Julivert & Marcos, 1973) (Fig. 2). Deformation took place without metamorphism and penetrative cleavage is generally absent in the rocks. Balanced geological cross-sections provide a reasonable interpretation of the structure down to a depth of 6-7 km (Pérez-Estaún *et al.*, 1988; Fig. 2). The tectonics are interpreted as thin-skinned, with a main detachment located near the Precambrian-Cambrian boundary. The Lower Cambrian calcareous rocks constitute usually the base of most thrust units pointing to a general decollement level at this stratigraphic level. The accumulated displacement in this section is some 150 km.

Lower Cambrian to Upper Devonian rocks of the Cantabrian Zone are pre-tectonic and show shallow marine facies including alternating carbonate and clastic rocks (Fig. 3). This sedimentary package has a wedge shape, thinning towards the East. There is an unconformity at the Precambrian-Cambrian boundary. Precambrian rocks consist of metapelites and metapsammites mainly with turbiditic facies; volcanoclastic rocks and less frequently volcanic rocks are also present. The Carboniferous sequence constitutes the foreland basin infill that can be up to 5.5 km thick and contains several syntectonic sedimentary wedges related to the emplacement of different thrust units (Marcos & Pulgar, 1982). These syntectonic wedges thin towards the East and contain mainly siliciclastic rocks (Fig. 3).

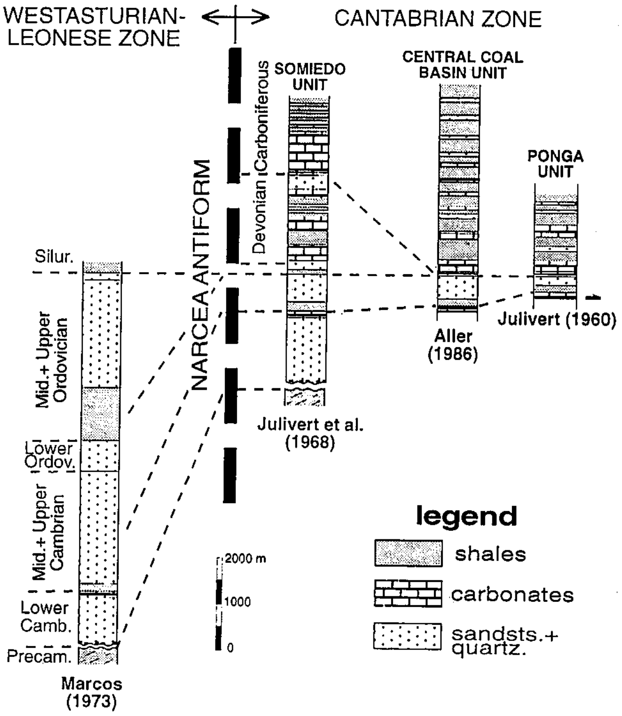

Figure 3.- Synthetic stratigraphic columns of the Cantabrian Zone and the Westasturian-Leonese Zone at both sides of the Narcea antiform.

To the West, the Cantabrian Zone is separated from the hinterland areas of the orogen by the Narcea antiform (Figs. 1 and 2). The Narcea antiform is an antiformal stack with Precambrian rocks exposed in its core. The whole antiform has been thrust onto the Palaeozoic rocks of the Cantabrian Zone (Julivert & Marcos, 1973; Pérez-Estaún & Bastida 1990; Gutiérrez, 1992). The front of Variscan metamorphism and cleavage is located near the hinge zone of this antiform. The Narcea antiform separates areas of marked palaeogeographic differences in the Lower Palaeozoic rocks (Fig. 2) representing the inversion of a former extensional basin. The Cambro-Ordovician sequence contains 11 km of terrigenous sediments in the western side, while only 3 km are recorded in the eastern side (Marcos, 1973; Pérez-Estaún *et al.*, 1990).

Seismic data acquisition and processing

The location of the ESCI-N1 seismic lines are shown in Fig. 1. The steep topography between CDP points 2600 and 2700 resulted in an abrupt bend in the trace of the line and therefore the profile was divided in two separate seismic lines Part 1 and Part 2. Seismic lines cross the most important thrust units of the Cantabrian Zone as perpendicular to the trend of the structures as possible, taking into account the high topographic relief of the region. Elevation changes along the line are of the order of 1000 m and topographic changes across the geophone arrays created significant static problems. Data acquisition and a first processing was carried out by CGG (Compagnie General Geophysique).

The energy source used for acquisition was dynamite, 20 kg at a depth of 24 m, being the shot point interval of 240 m. The data were recorded using a 240-channel SERCEL SN 348 telemetric system. The interval between traces was 60 m and the number of geophones per group 18. Total spread length was 14.5 km. Record length for the survey was 25 s and sample interval 4 ms. The configuration was of symmetric split-spread along most of the profile, although end-on spread geometry was used at the western edge of Part 2, to allow a better coverage. The coverage is around 30 fold along most of the profile length. Lower coverage (15 to 20) occurred between CDP's 2000 and 2500 (Fig. 3) due to acquisition difficulties. The data presented here (Figs. 4 and 5) were processed with a processing sample interval of 8 ms, following the sequence listed in Table I.

Table I.- General processing sequence of ESCI-N1 deep reflection profile.

PRE-STACK SEQUENDE
Demultiplexing
Amplitude recovery
Dynamic trace equalisation
Bad trace edition
Slalomline CMP gather to 25 s, CMP interval 30 m
Anti-alias filter and resample to 8 ms
Elevation static correction (datum+1000 m asl)
Mute
NMO correction
Surfate consistent residual statics.
Stack

POST-STACK SEQUENCE
Bandpass filtering
F/X domain random noise attenuation
Dynamic trace equalisation
Static correction from FDP to survey datum
Time and depth migration
Semblance coherency filtering

Description of the ESCI-N1 profile

The ESCI-N1 near-vertical seismic reflection profile shows in its eastern part (from CDP 2900 eastwards) the deep structure of the Cantabrian Zone, and in its western part the structure of the Narcea antiform and the transition to the more internal parts of the Variscides. Stacked and semblance coherency-filtered sections of Part 1 and Part 2 ESCI-N1 lines are reproduced in figs 4,5,6 and 7. The reflection pattern varies laterally and vertically along the profile. A major lateral difference is observed between the Cantabrian Zone and the Narcea antiform parts of the profile.

In the eastern part of the profile (Cantabrian Zone), the upper 5 s TWTT (reaching 6 s in the West) are characterised by strong, closely spaced, and discontinuous reflections that are present mainly at the base of this panel (D in Fig. 7) and sometimes (specially from CDP's 1 to 1300) crossing the panel entirely and reaching the surface (stacked and migrated sections of Figs. 7 and 8). The basal band of this reflections (D; about 1 s thick) is gently-dipping towards the West (from 4 s on Part 1 to 6 s in Part 2) and sometimes shows an imbricate character. This disposition and planar character is emphasised in the migrated section (5 km/s) reproduced in Fig. 8. From CDP's 300 to 1300 (in Part 1), a set of strong events can be followed from the basal zone of reflections, at 4 s, rising 2.7 s and displaying afterwards a subhorizontal disposition for more than 15 km (A in Figs. 7 and 8). Other curved reflections are present above D reflection, reaching the surface. Poorly defined reflections, dipping towards the west are also present in the upper 4 s, from CDP's 1900 to 2500. Also worth to mention the set of events, dipping to the west and reaching the surface in the western part of Part 1 line (B in Figs. 7 and 8).

The crust underneath the 4-6 s zone of reflections, in the eastern part of ESCI-N1, is less reflective and present strong lateral variations. Sets of short, subhorizontal reflections, grouped in bands are present from 6 to 14 s TWTT, in the easternmost part of the profile, from CDP's 1 to 1600 (M in Fig. 7). The lowermost band of reflections (1.5 s thick) is more marked (O in Fig. 7). The western deep part of the Cantabrian Zone area is almost transparent and only very small and discontinuous events can be seen. The deepest part of the profile is transparent.

The western part of ESCI-N1, beneath the Narcea antiform outcrop, is characterised by the presence of numerous reflections between 5 and 12 s TWTT (Figs. 4 and 6). The crust is poorly reflective above 5 s. Between 5 and 9 s TWTT, is where the reflections show larger coherency and amplitude. A set of reflection bands (three) formed by strong and relatively long reflections (D, E and F, in Fig. 6) dipping towards the West, describing a fan-like structure opened to the West, is present between CDP's 2800 and 3700. This set of bands merge to the east and joint the subhorizontal to west-dipping set of reflections described in the eastern part of ESCI-N1 (labelled D, in Figs. 6 and 8). The other two bands are less significant (E and F in Fig. 6), fading out to the west. From 9 to 12 s many short, curved, non-parallel reflections exist. Two bands, about 1.5 s thick, formed by these reflections, with very similar character are outstanding (G and H in Fig. 6), outline a synform between CDP's 3000 and 3600. The upper band, G, dips gently towards the east from about 9 s, were it merges into the west-dipping band D, down to 10 s where it merges into the lowest reflective layer (H). The lower band H is placed between 10 s and 12 s.

Interpretation

The regional geological knowledge enables to interpret most of the reflection features of ESCI-N1. The high degree of correlation between seismic reflectivity and surface geology allows to identify some reflections of the upper part of the Cantabrian Zone (the reflections placed above band D) with lithological boundaries. There are no wide ductile shear zones related to thrusting in the Cantabrian Zone, neither penetrative fabrics developed during deformation, to permit a different interpretation. The existence of a multilayered Palaeozoic sequence containing fine and medium grained siliciclastic rocks and alternating calcareous beds provides good impedance contrasts that may be responsible for the high reflectivity of the upper part of the profile. The pre-orogenic sequence, made up of thick shelf clastic and carbonate formations provides stronger and more continuous reflections than the synorogenic sequence (see the Central Coal Basin Unit part of the profile, between CDP's 900 and 1800 (Figs. 7 and 8), where Carboniferous rocks are cropping on surface). The subhorizontal to gently dipping 4-6 s reflective band, D, is interpreted as the Cantabrian Zone detachment at the base of the Palaeozoic se-

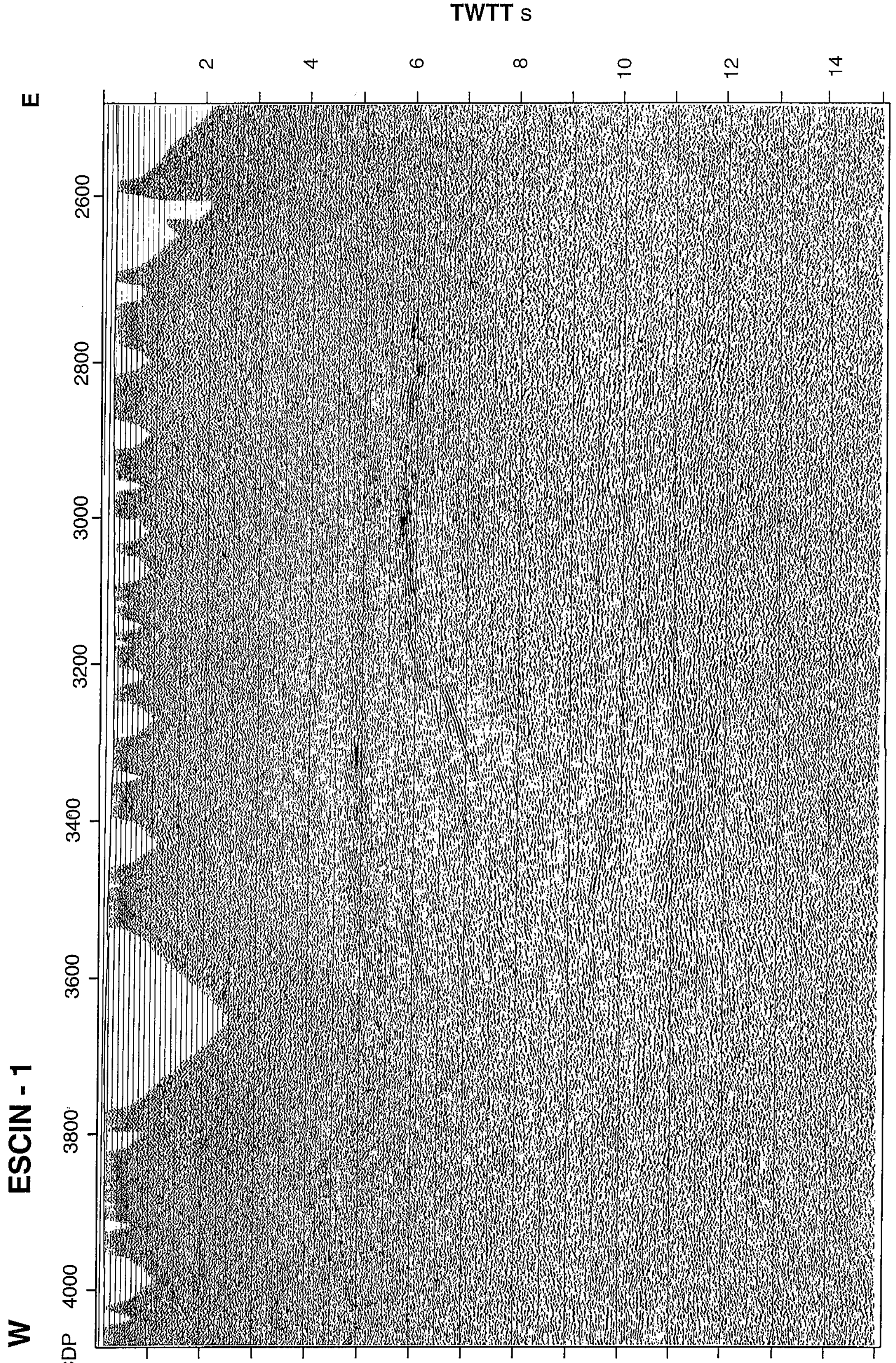

Figure 4.- Unmigrated stack from ESCI-N1, Part-2 (Narcea antiform).

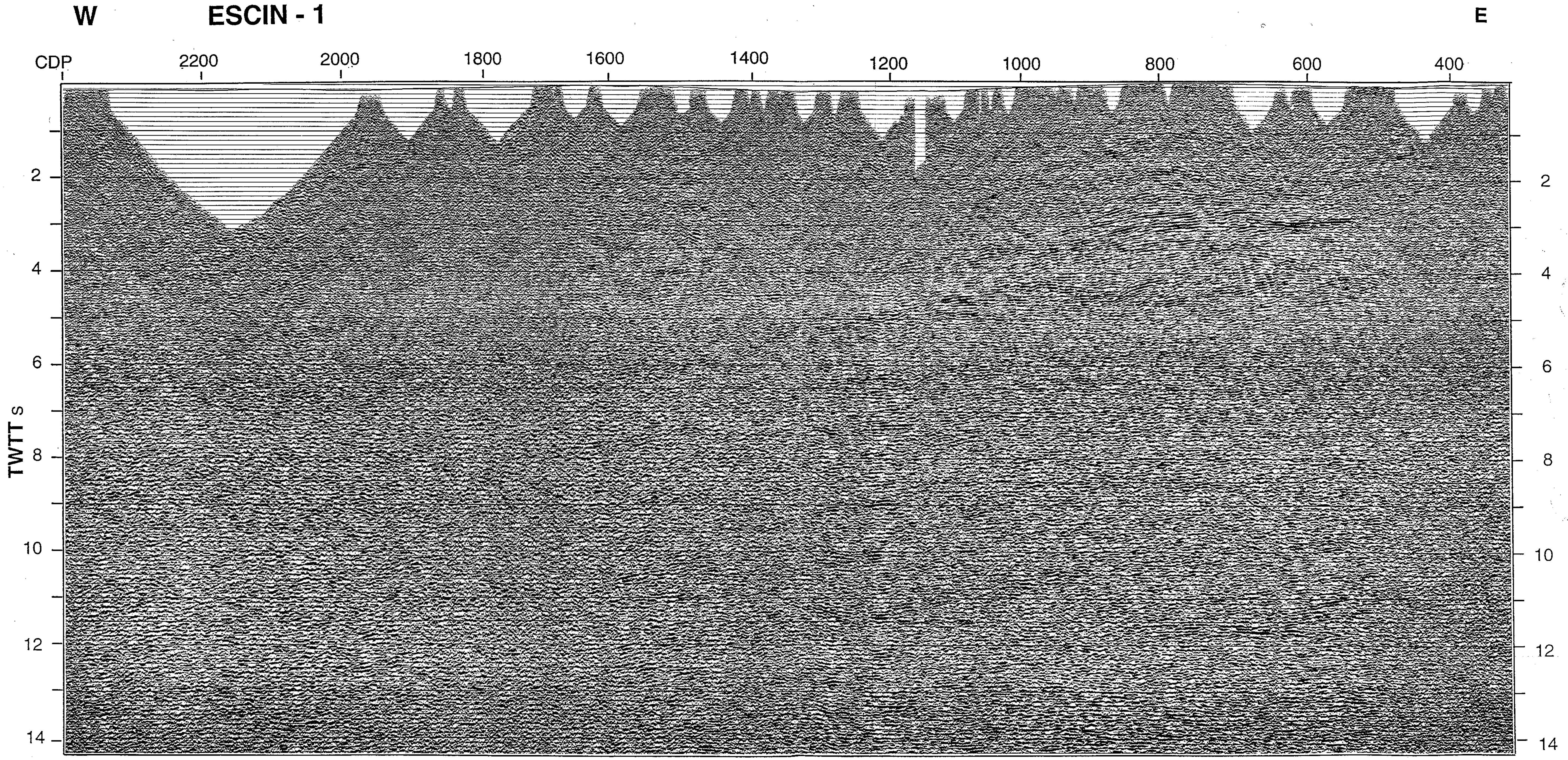

Figure 5.- Unmigrated stack from ESCI-N1, Part-1 (Cantabrian Zone).

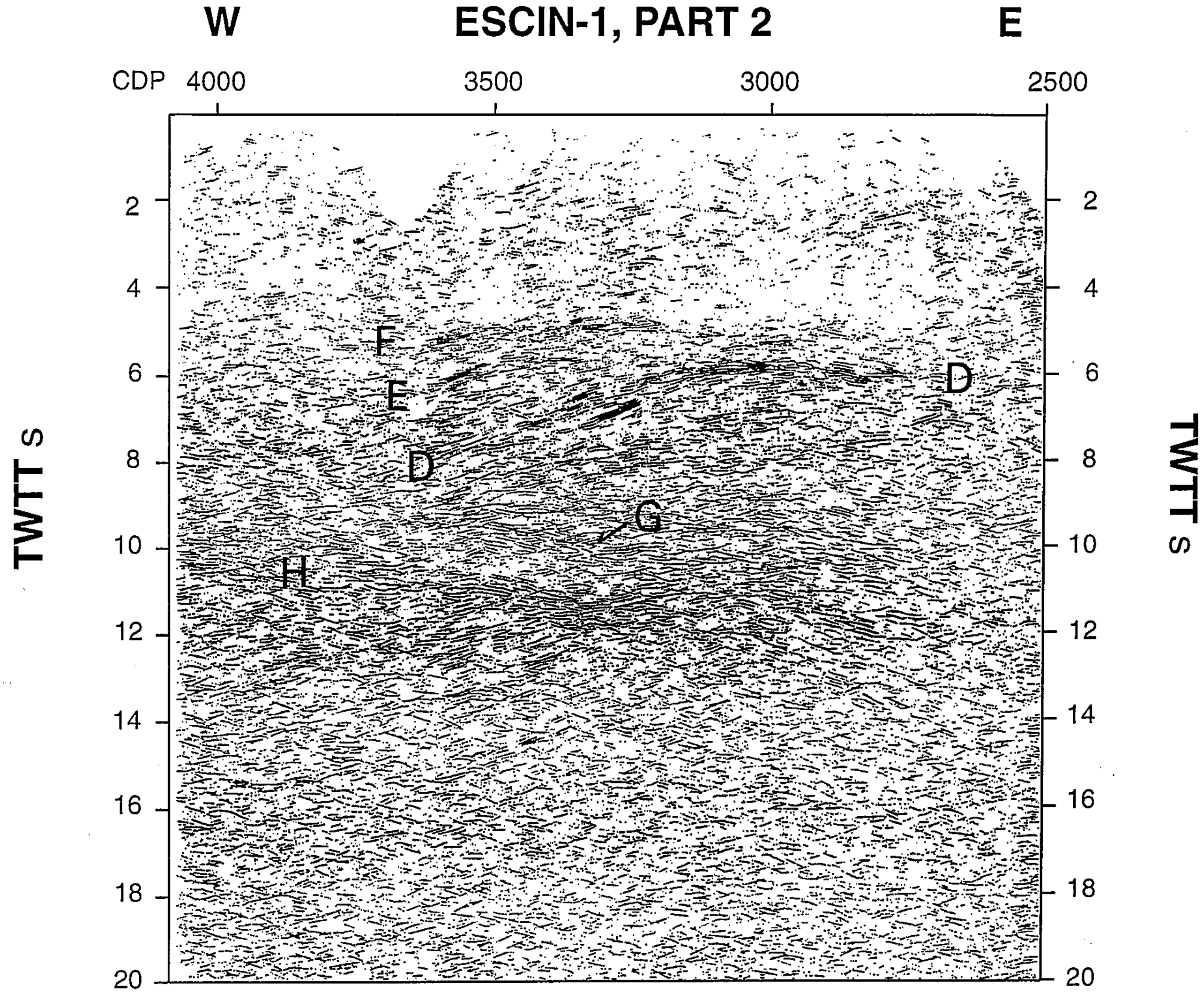

Figure 6.- Unmigrated, coherency filtered seismic data from ESCI-N1, Part-2.

quence (Julivert, 1971; Pérez-Estaún *et al.*, 1988). The crust beneath the detachment can be interpreted as forming part of the Precambrian basement of the foreland thrust and fold belt. The length of the detachment shown in this profile is of 90 km. Assuming a constant velocity of 5 km/s, the dip obtained for the detachment is close to 3° towards the West. The reflective pattern of the upper part of the seismic profile could be correlated with the geological cross-section shown in Fig. 2, although the position of the detachment is deeper than estimated. The disrupted pattern of reflections immediately above the Cantabrian Zone detachment is interpreted as being caused by a set of blind thrusts and duplexes breaking through the lower Palaeozoic sequence. An interpretation of the Cantabrian zone structure is proposed in Fig. 9.

The Aramo, Sobia and Somiedo thrusts are outlined by disrupted shallow-angle west-dipping reflections (Figs. 7, 8 and 9). The quality of the seismic data in this part of the profile makes the interpretation of the structure of this sector open to question. The thickness of the sedimentary sequence in these nappes is of the order of 4000 m. Significant thickness of Carboniferous rocks of the Central Coal Basin Unit may be buried underneath those nappes in order to justify the position of the detachment in this area (6 s TWTT in depth). The interpretation in Fig. 11 propose a duplication of the sedimentary pile implying more displacement than was expected. The complex cross-folding geometry of the synorogenic clastic paralic Carboniferous sequence at the surface in the Central Coal Basin (Julivert & Marcos, 1973; Aller, 1986) is underlain by blind thrusts and duplexes (Fig. 8). A good example of thrust ramp-flat geometry can be seen in the eastern part of the section between CDP's 300 and 1350 (Fig. 7, 8 and 9).

The Narcea antiform corresponds to a complex culmination formed by a stack of thrust slices containing Precambrian and Lower Palaeozoic rocks. A different reflective pattern along the upper part of the profile can be recognised when crossing the Narcea antiform, in contrast with the Cantabrian Zone, although a clear boundary with the Palaeozoic rocks of the Cantabrian Zone cannot be traced precisely. We believe that the scattered, diffuse, poor and relatively incoherent pattern of reflections seen above 5 s, in the Narcea antiform, is a manifestation of the heterogeneous distribution of deformation zones, steep dips of Variscan foliations, and interference between Variscan and Precambrian structures present in the Precambrian rocks of the Narcea antiform.

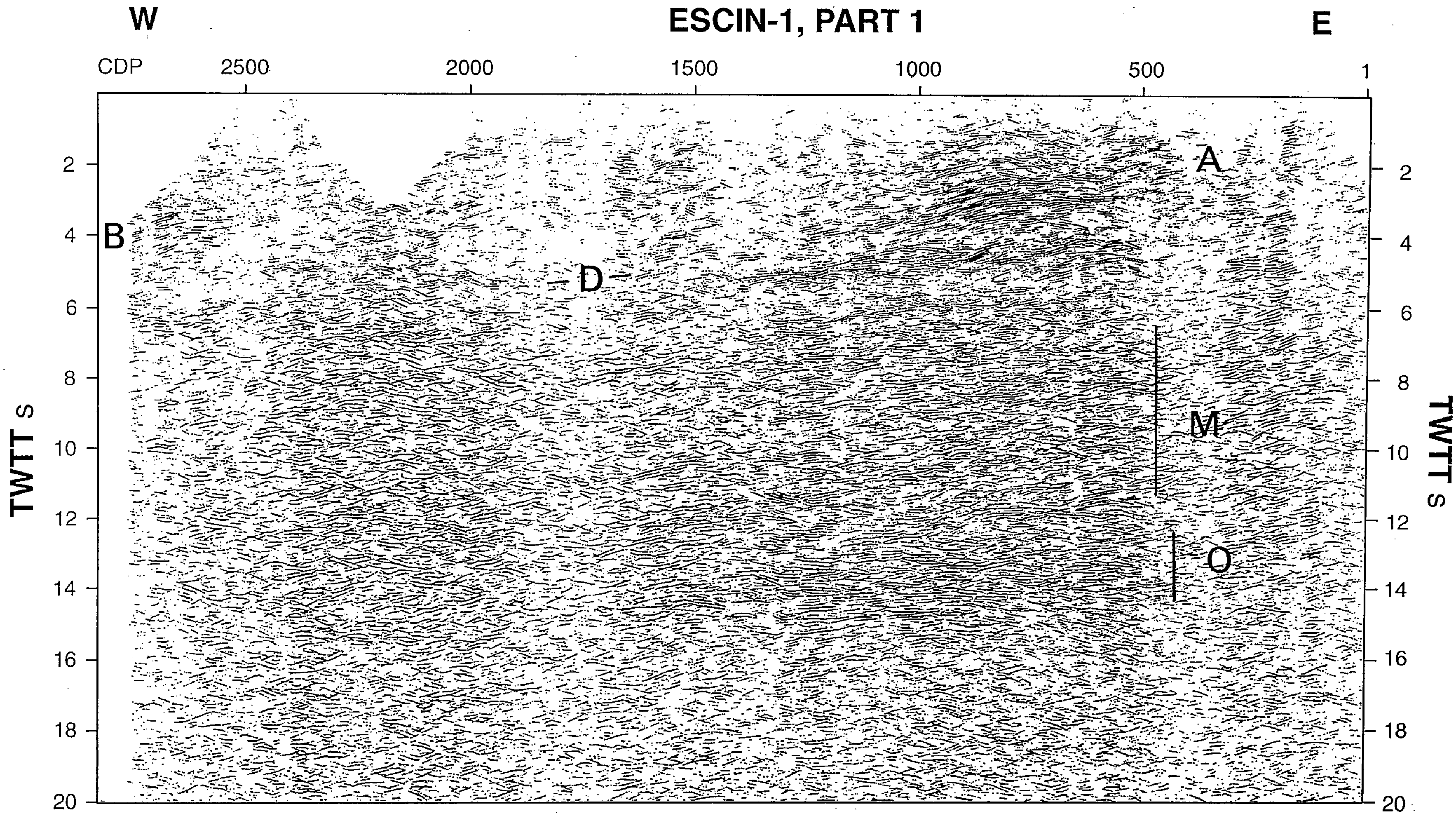

Figure 7.- Unmigrated, coherency filtered seismic data from ESCI-N1, Part-1 (CDP's 320 to 2400).

The interpreted Cantabrian Zone detachment, D, can be followed beneath the Narcea antiform at about 6 s, joining to the west a crustal-scale ramp (reflection D, from 6 to 9 s). This ramp can be interpreted as a Variscan ductile shear zone deforming basement rocks related with the formation of the Narcea antiformal culmination (Narcea thrust, Figs. 6 and 9). The west-dipping reflections at this level (E and F of Figs. 6 and 9) represent ramps, where thrusts of the foreland are rooted, cutting down into the basement and deforming deep crustal levels. These west dipping ramps transferred the displacements from the hinterland areas of the orogen (Westasturian-Leonese Zone) to the basal detachment of the Cantabrian Zone. The seismic images demonstrate that the internal zone of the orogen has been subjected to a crustal-scale style of deformation.

The lowermost reflective band, at the western part of the line, H, can be interpreted as the layered lower crust. The reflective Moho may be defined as the lower boundary of this reflective domain. The reflective band placed above it, G (Fig. 9), may be part of the same reflective lower crust or a repetition by thrusting of band H. A deflection of the interpreted Moho is seen beneath the Narcea antiform showing a small thickening of the crust in relation with this structure.

The whole deep crustal structure of the Narcea area, may be interpreted as an indentation of the foreland basement into the hinterland crust producing a duplication of the lower crust and a complex antiform in the upper crust. The deeper structure of the Narcea antiform suggests that uplift of the basement in this area was accomplished largely by thrusting rather than vertical doming. It represents the boundary between the thin-skinned and the thick-skinned tectonics of the Variscan deformation.

The deep structure of ESCI-N1 between CDP's 1600 and 2600, beneath the Cantabrian Zone detachment, is less clearly defined. Most of the profile show very short reflections with a scattered and diffuse pattern, and no discrete reflective zone or marked reduction in reflectivity corresponds to Moho in this part of the line. On the contrary, the eastern and deep part of the profile (below 6 s) shows a well structured crust with several reflective packages down to 14 s. The base of this reflective domain can be interpreted as the reflective Moho. Such a thick crust may be the result of the Alpine deformation. Seismic data acquired onshore, ESCI-N2 (Pulgar *et al.*, 1996), help to maintain this interpretation. The reflection bands present between 6 and 14 s, in this zone, may also be correlated with Alpine thrusts interpreted in ESCI-N2 profile (Pulgar *et al.*, 1996).

The crustal structure imaged by ESCI-N1 profile shows many characteristics in common with other crustal sections of external areas of orogenic belts, such as the Appalachians or the north european Variscides, with the existence of a detachment beneath the foreland thrust and fold belt and huge crustal ramps at the transition to the hinterland areas (Cook *et al.*, 1979; Ando *et al.*, 1984; Cazes *et al.*, 1985; Bois *et al.*, 1986; Allmendiger *et al.*, 1987; Matte & Hirn, 1988).

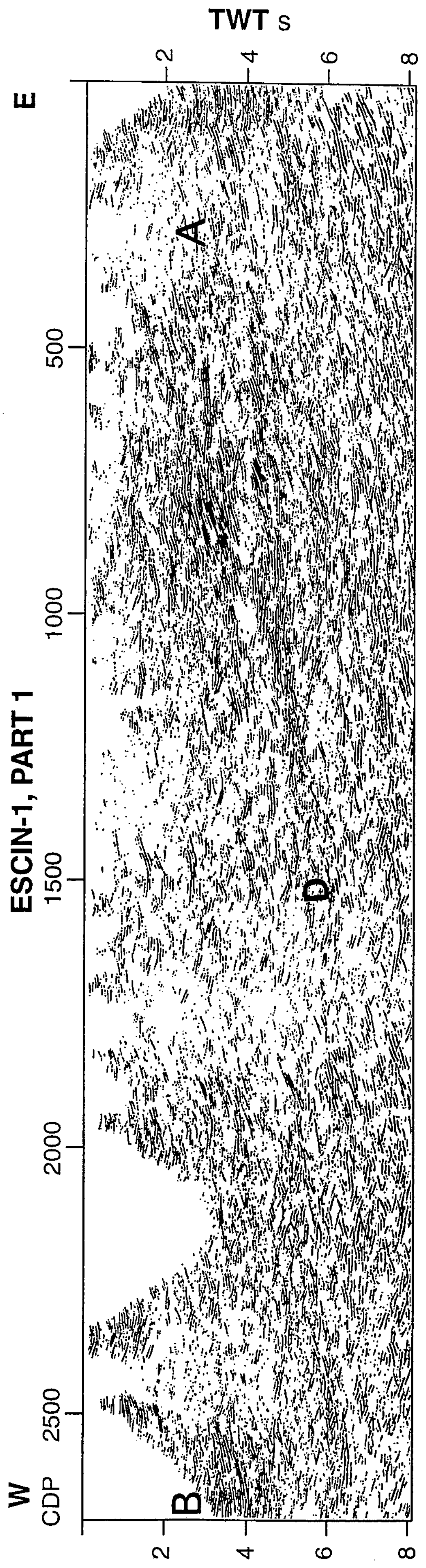

Figure 8.- Uppermost 8s of the migrated coherency filtered ESCI-N1, Part-1 (constant migration velocity: 5 km/s).

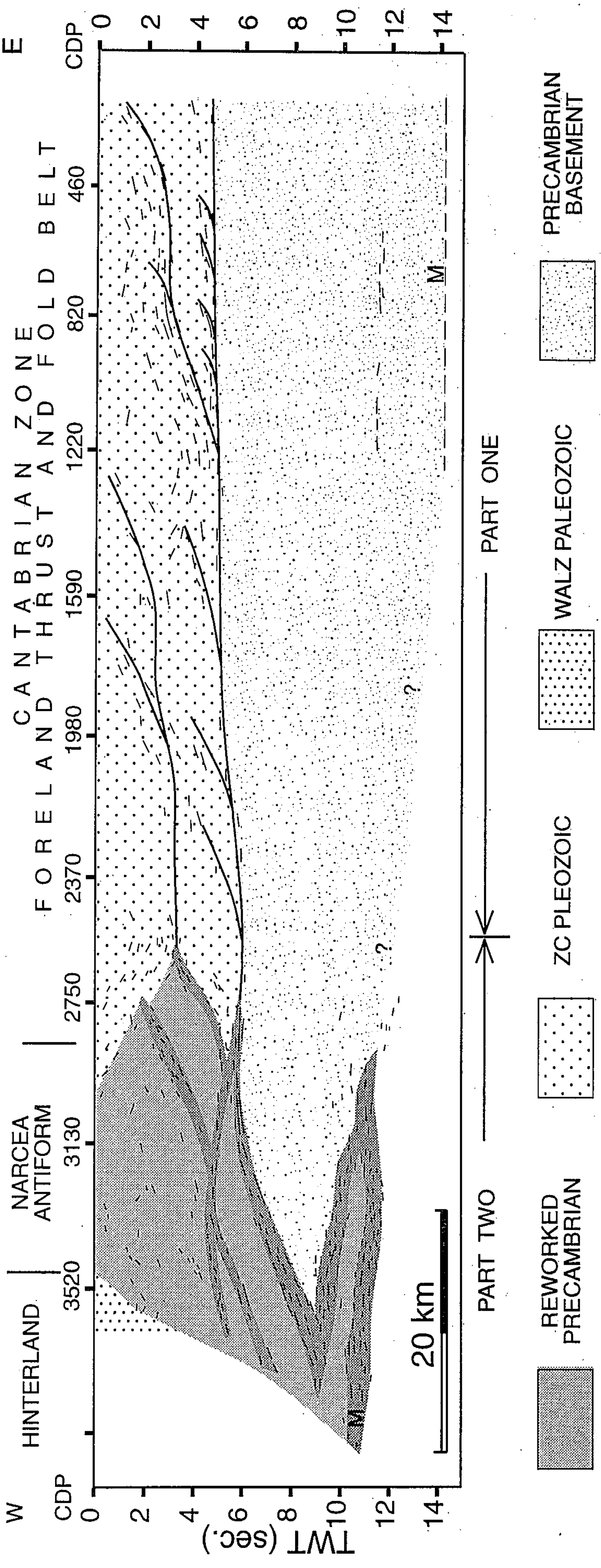

Figure 9.- Schematic interpretation of ESCI-N1. M, Moho discontinuity.

Conclusions

The ESCI-N1 seismic profile confirms previous interpretations, based on surface geology and section balancing, about the structure of the Cantabrian Zone (the external part of the Variscan belt in NW Spain) and provides a detailed image of the present crustal configuration of this geological zone. The seismic images demonstrate conclusively the thin-skinned tectonic style of deformation in the Cantabrian Zone with a gently basal west-dipping detachment located at 5-6 s TWTT.

The major thrusts in the Cantabrian Zone show an Appalachian style geometry. The accumulated displacement is larger than previously proposed and there seems to be a large amount of Carboniferous rocks buried beneath the western nappes. The existence of blind thrusts and duplexes beneath folds of the Central Coal Basin thrust unit is confirmed.

The seismic fabric in the area of the foreland thrust and fold belt strongly differs from that in the transition to the hinterland areas. The foreland-hinterland transition zone corresponds at depth with a crustal scale ramp that joins the foreland thrust belt detachment with the deeper structures at lower crustal levels in the hinterland. The Narcea antiform sits on this crustal scale ramp. The deeper structure of the Narcea antiform suggests that uplift of the basement in this area was accomplished largely by thrusting rather than vertical doming. A highly reflective lower crust is present in the transition to the hinterland and a topography of the Moho producing thickening of the crust is recognised. The existence of a possible duplication of the lower crust is interpreted. A "crocodile" like structure is proposed for the foreland/hinterland transition (Meissner, 1989).

The crustal structure revealed by the profile presented here demonstrates that the internal zone of the Variscan orogen has been subjected to a crustal-scale or thick-skinned style of deformation.

The crustal structure revealed by ESCI-N1 profile shows many characteristics in common with other crustal sections of external areas of orogenic belts, such as the Appalachians or the northern european Variscides.

An Alpine reworking of the middle and lower crust can be inferred in the eastern part of ESCI-N1, giving rise to a crustal thickening (14 s TWTT).

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