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The Iberian Massif: a Carboniferous assembly

El Macizo Ibérico: un enfoque para el Carbonífero

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Abstract

A protracted history of strike-slip movements in Southwestern Iberia, throughout Carboniferous times, Westphalian and Stephanian in particular, has resulted in subparallel strips of terrain which are difficult to recompose into the original configuration. The nature and timing of major strike-slip movements have become apparent as a result of detailed work on the early Westphalian basin of Peñarroya (Córdoba province) and, also, by interpreting the published information on upper Westphalian and upper Stephanian strata in the Valongo structure northeast of Oporto, the Stephanian C (lower Autunian) basin of Buçaco near Coimbra, the Santa Susana Basin west of Évora, and the mid-Autunian basin of Valdeviar (Sevilla province). The geological history of the Peñarroya Basin is summarised; research data are analysed, and comparison is made with the Tertiary basins in California controlled by transform faulting. Published information on the Valongo, Buçaco, Santa Susana, and Valdeviar areas suggests similar histories to that of Peñarroya, with the corollary that major sinistral strike-slip operated in what is presently the Iberian Massif for most of Pennsylvanian times, perhaps some fifteen million years. The conclusion is reached that at least three major transforms existed, with additional subparallel strike-slip faults, which produced an assembly of different plate segments in late Carboniferous (Pennsylvanian) times. An Iberian Massif thus came into being from Permian onwards. Structural interpretations of Ossa Morena and the adjacent part of the Central Iberian Zone should take cognisance of the important effects of Carboniferous transform faulting.

Keywords: Pennsylvanian, Westphalian, Autunian, Sierra Morena, Iberian Massif, Iberian Peninsula.

Resumen

Las fallas laterales de tipo *strike-slip* que se hicieron notar en el Oeste-Suroeste de la Península Ibérica en todo el Carbonífero, aunque principalmente en tiempos westfalienses y estefanienses, han resultado en franjas subparalelas de terrenos que son difíciles de restituir a su configuración primitiva. La naturaleza y datación de los movimientos principales, de tipo transformante, han quedado patentes sobre todo como resultado de una investigación detallada sobre la cuenca westfaliense inferior de Peñarroya (Córdoba), provocada y deformada tectónicamente por una falla transformante; además de las interpretaciones posibles sobre la cuenca del Westfaliense superior y Estefaniense superior en el área de Valongo, cerca de Oporto, del Estefaniense C (= Autuniense inferior) de Buçaco, cerca de Coimbra, y de la cuenca del Viar (Sevilla), de edad Autuniense medio.

La historia geológica de la cuenca de Peñarroya se relata de forma resumida, con un análisis de los datos obtenidos, que la han permitido ver el gran parecido con Ridge Basin del Terciario de California, emblemática por su estrecha relación con fallas strike-slip de tipo transformante (Falla de San Andrés, sobre todo). La información publicada sobre las cuencas de Valongo, Buçaco, Santa Susana y Valdeviar sugiere que hayan tenido un origen parecido al de la cuenca de Peñarroya, lo cual induce a pensar que fallas transformantes actuaban durante buena parte del Pensilvánico, quizá unos 15 millones de años. Se llega a la conclusión que había tres transformantes como mínimo, y que el Macizo Ibérico no se consolidó en su configuración actual hasta los comienzos del Pérmico. Cualquier interpretación estructural de Ossa Morena y parte colindante de Centroibérica debe tener muy en cuenta el papel de las fallas transformantes carboníferas.

Palabras clave: Pensilvánico, Westfaliense, Autuniense, Sierra Morena, Macizo Ibérico, Península Ibérica.

1. Introduction

The geological literature on Sierra Morena, an essential part of the Iberian Massif, shows the structural complexity of this area which is characterised above all by approximately NW-SE striking faults along the grain of structurally deformed rocks of various Palaeozoic ages and showing various degrees of metamorphism. The Ossa-Morena Zone of Lotze (1945) coincides largely with Sierra Morena, with the Valdeviar Basin of early Permian age lying along part of its SW delimitation with the South Portuguese Zone,

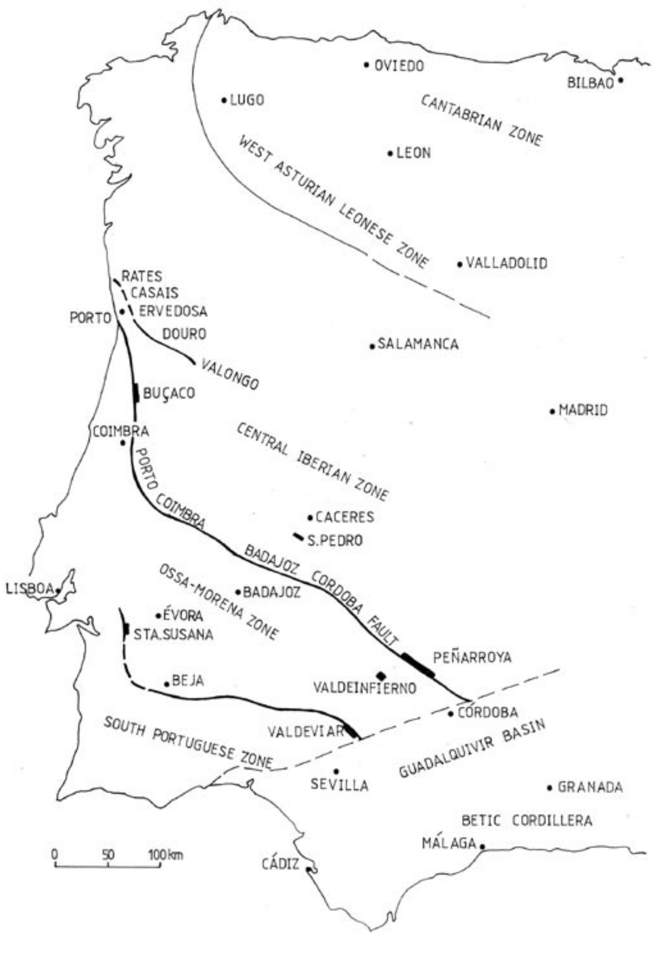

Fig. 1.- Iberian (Hesperian) Massif in the western Iberian Peninsula, showing approximate zonal boundaries of Lotze (1945) and Julivert *et al.* (1974), and Carboniferous occurrrences linked to the transform faults. The Tertiary Guadalquivir Basin is part of an unconformable cover. The Betic Cordillera is an extraneous element to the Iberian Massif.

Fig. 1.- Esquema del Macizo Ibérico (Hespérico) en el que se muestran de manera aproximada los límites de las zonas de Lotze (1945) y Julivert *et al.* (1974), y los diferentes afloramientos carboníferos relacionados con fallas *strike-slip* (¿transformantes?) mencionados en el presente artículo. La cuenca terciaria del Guadalquivir representa una cobertera discordante, mientras que la Cordillera Bética constituye un elemento foráneo al Macizo Ibérico.

whilst the granitic intrusion of Pedroches was chosen by Lotze as its northeastern limit. The strike-slip controlled Valdeviar Basin seems to coincide with a major suture of earlier (Pennsylvanian?) age, which is generally accepted as a valid separation of two major areas of different geological characteristics, but the northeastern delimitation of the Ossa-Morena Zone has proved more controversial. It is certainly of a very different nature geologically. Whereas it may be argued that Valdeviar coincides with the site of a major transform fault zone separating different terrains, the Pedroches intrusion cuts through Carboniferous (Mississippian?) strata belonging to one and the same basin. This cannot be regarded as a separation between different geological terrains. Transform faults separating different terrains exist in the general area SW of Pedroches, e.g. at Peñarroya and further South at the Azuaga Fault, and these might be considered as a more proper delimitation of the Ossa-Morena Zone. This point of view has already been put forward by different authors (e.g. Robardet, 2002). Lotze's zonal scheme, useful though it may have been, now needs to be critically reexamined in the light of modern, plate tectonic criteria, with transform faulting becoming a major consideration. Figure 1 shows currently accepted tectono-stratigraphic zones (Julivert *et al*., 1974) with the location of Carboniferous occurrences related (and possibly related) to major strike-slip faults.

The pioneer work of Burg *et al.* (1981) has drawn atention to the presence of a major NW-SE striking tectonic shear zone, the Coimbra-Córdoba shear (called by later authors the Badajoz-Córdoba fault zone), which has been linked by some geologists to the Coimbra-Tomar shear zone in Portugal. This runs not quite parallel to the Valongo Anticlinal shear zone NE of Oporto (Fig. 2). The structural analysis by Burg *et al*. (1981) suggested strike-slip movements with a displacement of at least 72 km and they mentioned the possibility of a transform fault. They also included a mention of two different Lower Palaeozoic palaeogeographic domains being represented on different sides of the shear zone, referring to data published by Robardet (1976). Whilst acknowledging the importance of the Córdoba-Badajoz Fault, the different authors of later papers have variously emphasised the strike-slip and compressional tectonic regimes detected with regard to this fault zone. These two regimes are by no means incompatible since the analysis of major strike-slip faults based, in the main, on the knowledge of Tertiary basins in California (Crowell, 1982; Christie-Blick and Biddle, 1985), has shown the alternation of tensional and compressional regimes along these faults. However, the main question in the case of the Badajoz-Córdoba fault zone seems to be the different time frames for major compressional tectonic

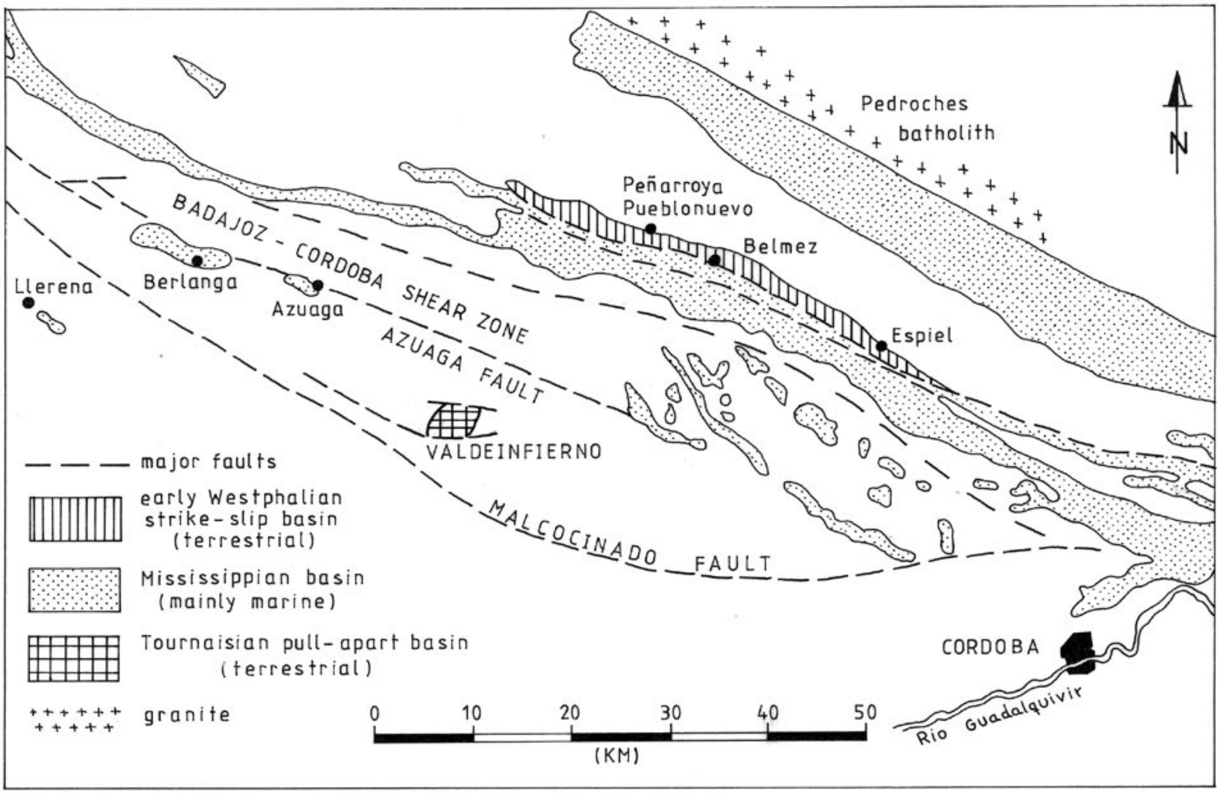

Fig. 2.- General map showing the position of the Peñarroya-Belmez-Espiel Coalfield (lower Westphalian) in relation to the outcrops of Viséan-lower Namurian sediments of a different, much earlier Mississippian basin, and the small upper Tournaisian pull-apart basin of Valdeinfierno. The Badajoz-Córdoba shear zone has the Azuaga Fault on its southwestern side and the Peñarroya transform fault on its northeastern side (after Wagner, 1999).

Fig. 2.- Mapa general en el que se muestra la posición de la cuenca minera de Peñarroya-Belmez-Espiel (de edad Westfaliense inferior, del Pensilvánico) y su relación con los afloramientos del Viseense-Namuriense inferior (Misisípico) pertenecientes a una cuenca diferente y mucho más antigua; además, figura la pequeña cuenca *pull-apart,* de Valdeinfierno, de edad Tournaisiense superior. La zona de cizalla Badajoz-Córdoba está delimitada por la Falla de Azuaga al Suroeste y por la falla transformante de Peñarroya al Nordeste. Según Wagner (1999).

(thrust) and strike-slip (transform faulting) events. This would not be the first case in which a major fracture zone experienced different kinds of tectonic movement at different times. Perhaps, the main discrepancy between the different authors lies in emphasising one or the other kind of movement without due regard for the times involved and in being sometimes rather selective in marshalling the evidence. A case in point is the recent paper by Martínez Poyatos *et al.* (2001) where the evidence of thrusting is emphasised with strike-slip faulting being mentioned but in the context of a collisional regime. Transform faulting is rarely, if at all considered. It is noted that the major strike-slip faults in the southwestern part of the Iberian Peninsula cut through and displace tectonic structures of pre-Carboniferous age, with Mississippian sediments forming an unconformable cover and Pennsylvanian basins of local occurrence being intimately related to the strike-slip faulting. Their location alongside major strike-slip faults as well as their sedimentary (basinal) and tectonic (deformational) history shows their relationship.

The Badajoz-Córdoba shear zone of Burg *et al.* (1981) is contained in between two major strike-slip faults, the northeastern one of which coincides with the transform fault on the SW border of the Peñarroya Basin (Wagner, 1999), and which finds its expression on the geological map in a later thrust fault just SW of the long and narrow Peñarroya-Belmez-Espiel Coalfield which is the principal subject of the present paper.

2. Peñarroya Basin

The knowledge of this sedimentary basin is based on a detailed study of the Peñarroya-Belmez-Espiel Coalfield of early Westphalian age in the province of Córdoba. This narrow, elongate coalfield, c. 50 km long at 0.7-1.2 km width at outcrop (Fig. 2), strikes approximately NW-SE along the grain of the country. Geological mapping was combined with 1:100 scale logging of up to 60,000 me-

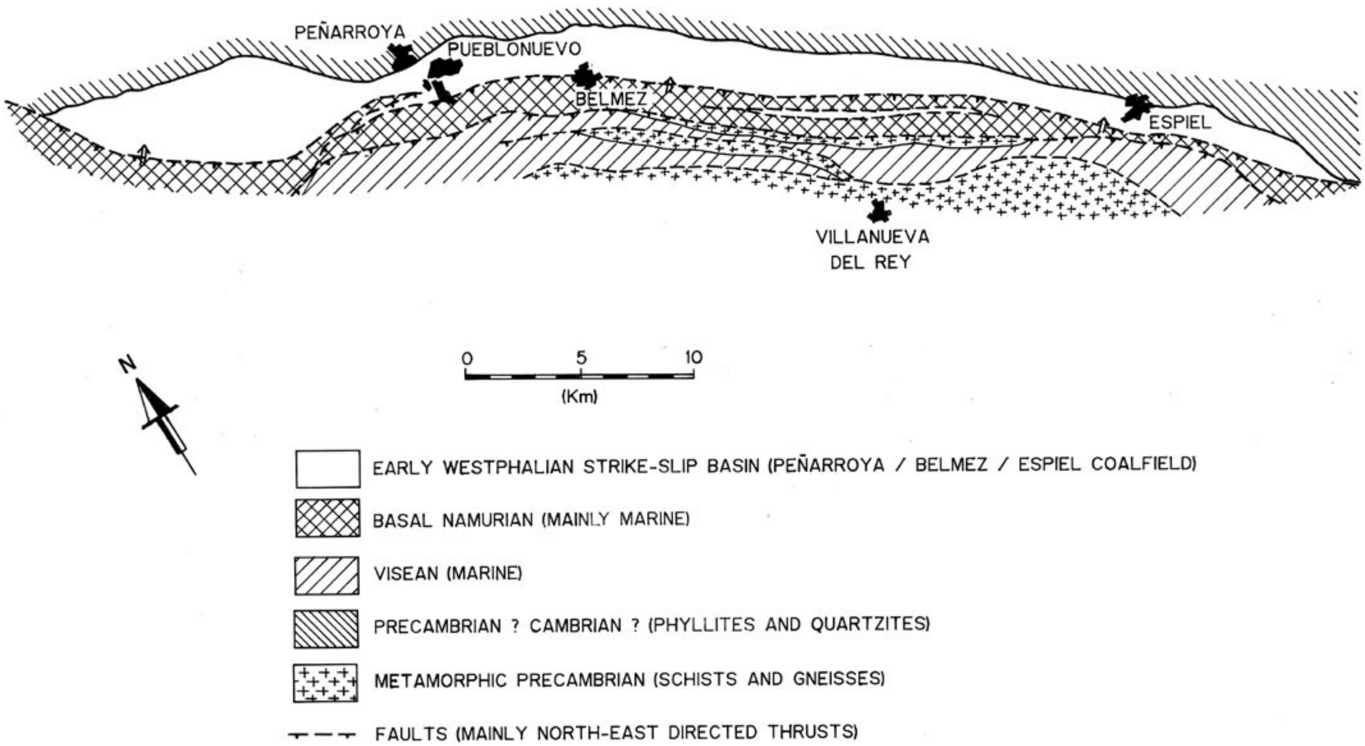

Fig. 3.- Outline map of the Peñarroya-Belmez-Espiel Coalfield showing the unconformable contact on the NNE border and a late thrust fault covering the SSW basin margin. The position of the transform fault on the SSW basin margin is shown by the occurrence of a high angle thrust fault (upthrust) delimiting a band of high grade metamorphic rocks. (for an explanation of the history of events on the SSW basin margin, see Fig. 4). After Wagner (1999).

Fig. 3.- Mapa esquemático de la cuenca minera de Peñarroya-Belmez-Espiel en el que se muestra el contacto discordante del borde NNE, y el SSW cabalgante. La posición de la falla transformante en el borde SSW de la cuenca sedimentaria viene dada por una falla inversa que se sitúa en relación con las rocas metamórficas de alto grado al SSW de la cuenca, y que viene a ser una reactivación de la fractura antigua. Para una explicación de la secuencia tectónica, véase la Fig. 4. Según Wagner (1999).

tres of continuously cored boreholes drilled for coal at a time when the present writer was head of exploration of the state coal company ENCASUR. This allowed detailed analysis of the stratigraphic history of different parts of the coalfield and the understanding of lateral variations. Specialist studies on the sedimentology (Andreis and Wagner, 1983), palaeobotany (Álvarez-Vázquez, 1995), and palynology (R. Coquel, unpublished) completed the information which was summarised by Wagner (1999). The coalfield (Fig. 3) is bounded on its southwestern side by a NE-directed late thrust fault covering the original basin margin, whilst the northeastern margin presents a normal sedimentary contact, which is marked by alluvial fan lobes and interlobes along a syn-sedimentary fault line with a topographic relief of a few hundred metres beyond this line. Figure 4 depicts the sequence of events relating to the SW margin of the coalfield. Geological cross sections through the coalfield show a strongly asymmetrical profile, with low dips of 5-20º on the northeastern margin and steadily increasing dips southwestwards, leading to steeply dipping strata just before a faulted contact is reached with a generally overturned, sheared succession of strata on the southwestern side (Fig. 5). The opposed facing of strata at this tectonic contact creates the impression of a synclinal structure, which is compatible with a basinal sag, although the synclinal core is nowhere visible. This is presumably due to shearing on a faulted contact, and it may be assumed that this fault separating the northeastern and southwestern flanks of the coalfield structure is a minor strike-slip fault parallel to the major transform fault (Principal Displacement Zone in the sense of Christie-Blick and Biddle, 1985), on the SSW margin of the basin. The strongly asymmetrical profile, with a wide normally dipping flank and a narrow, steeply dipping opposed flank, is characteristic of strike-slip controlled basins as exemplified by Ridge Basin of Tertiary/Quaternary age in California (Crowell, 1982). This is one of the better studied sedimentary basins alongside the San Andreas Fault, which is a well known transform fault separating two different terrains in western North America. Although Ridge Basin is larger than the Peñarroya Basin, there is a clear similarity. Steep dips accompany the dominant strike-slip fault, with the opposed facing being partly attributable to basinal sag, with later compressional movements strengthening the impression of an apparent synclinal structure. These compressional movements were probably due to restraining bend conditions following upon a releasing bend episode on the transform fault (transpression following upon transtension in another terminology.) (see Wagner, 1999, for further details.)

The sequence of events detected in the Peñarroya Basin (Wagner, 1999) show shifts in depocentre southeastwards, along the strike of the basin (Fig. 6). This involves major shift in the sense of successive basinal areas with different time frames and a temporal separation of perhaps up to half a million years between two adjacent basinal areas, during which tectonic deformation of the earlier depositional area took place; and more minor shifts southeastwards within each of these successive basinal areas. At least two successive basinal areas have been conclusively demonstrated, i.e. one centred on the general region of Peñarroya (area I), and the other on Belmez-Espiel (area II) (Fig. 6). A third basinal area, further Southeast, in the area of La Ballesta (only partially shown in Fig. 6), is suggested by a different stratigraphic succession and a somewhat different fold structure. However, no appreciable time gap has been detected between the latter two areas, which are therefore marked IIa and IIb in Figure 6,

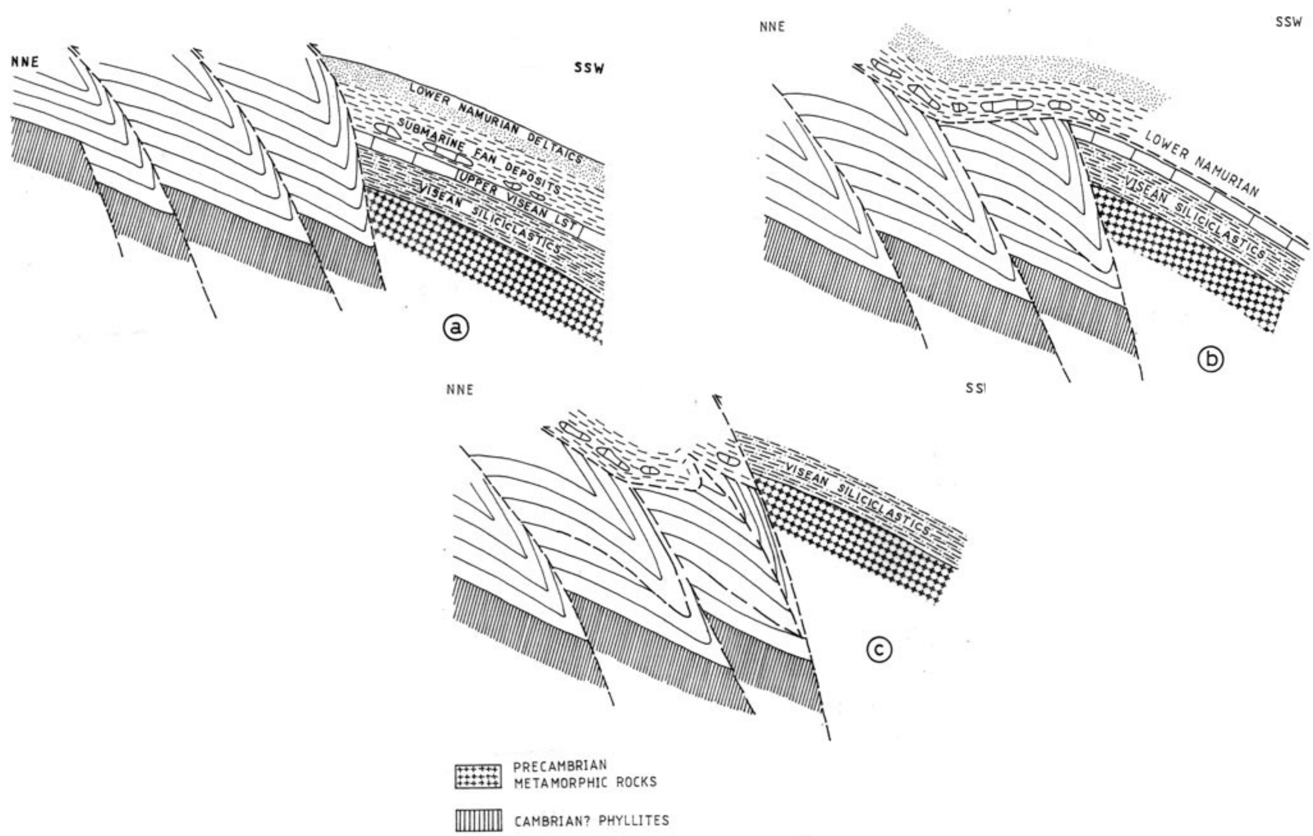

Fig. 4.- Diagrammatic geological cross sections illustrating the sequence of events (marked a to c) on the SSW border of the Peñarroya-Belmez-Espiel Coalfield. The position of the transform fault on the SSW side of the Peñarroya sedimentary basin is marked currently by a steeply angled thrust fault cutting through a decollement at the level of lower Namurian strata, and which puts Viséan and underlying high grade metamorphic rocks of Ossa Morena basement into contact with the lower Namurian sediments thrust across previously deformed lower Westphalian coal-bearing strata (after Wagner, 1999).

Fig. 4.- Cortes geológicos esquemáticos a, b, c en los que se muestra la secuencia de eventos acontecidos en el borde SSW de la cuenca minera de Peñarroya-Belmez-Espiel. La posición de la falla transformante en el borde SSW de la cuenca sedimentaria de Peñarroya viene dada por el contacto entre materiales siliciclásticos del Viseense, situados por encima de rocas metamórficas de alto grado (basamento tipo Ossa Morena), y sedimentos del Namuriense inferior, que cabalgan sobre los sedimentos hulleros del Westfaliense inferior mediante un plano de despegue. El contacto actual se debe a una reactivación de la fractura correspondiente a la falla transformante como falla inversa que se ha proyectado a través del plano de despegue de los sedimentos del Namuriense inferior. Según Wagner (1999).

even though later work may show the latter to have had an individual existence. The first basinal area (I), perhaps some 30 km long and an estimated 2-3 km wide originally (and less than half this width after tectonic deformation), has been dated on a collection of several thousand plant megafossils as late Langsettian and early Duckmantian (Álvarez-Vázquez, 1995). A coal petrographic analysis by Marques (1993) has shown a regional maturity of coking coal grade, with natural coke produced by diabase sill intrusions. These sills were folded together with the intruded sediments prior to the establishment of the second basinal area, and are thus dated as Duckmantian. The coals (and including the natural coke) in most of the first basinal area were transformed into a low grade anthracite by a later heating event, of uncertain, but almost certainly post-Carboniferous age. A compressional tectonic event folded this first basinal succession during a relatively short time span, perhaps half a million years, in Duckmantian times. A second basinal area (II) to the ESE, which came into being after the first area had been tectonically deformed, impinged slightly on the previous one, provoking the local steepening of fold axes in the earlier basin structure, where it was overlapped by the second basin sag in the vicinity of Peñarroya-Pueblonuevo (Fig. 6). Palaeobotanical dating (Álvarez-Vázquez, 1995) shows a late Duckmantian age for the second basinal area, and coal petrography has demonstrated a regional coking coal grade which has remained essentially unaltered. Tectonic deformation of area II is apparently limited to a steepening of the dip to near-vertical in the southwestern flank bordering the transform fault, with substantial shearing parallel to this fault, and to the generation of some minor folds in the wide, normally dipping northeastern flank of the general basinal structure. Figure 5 gives a cross-section through area IIa after tectonic deformation. Minor thrusting on the small, accessory anticlines in the overall monoclinal succession on the wide northeastern flank of the basin produced small tectonically induced coal accumulations in the anticlinal cores. Quite a different stratigraphic succession and a somewhat different fold structure is found in subarea IIb in the southeasternmost part of the coalfield, the La Ballesta region, but stratigraphic dating on megafloral assemblages has suggested the same late Duckmantian age as for the Belmez-Espiel area. However, it is noted that late Duckmantian

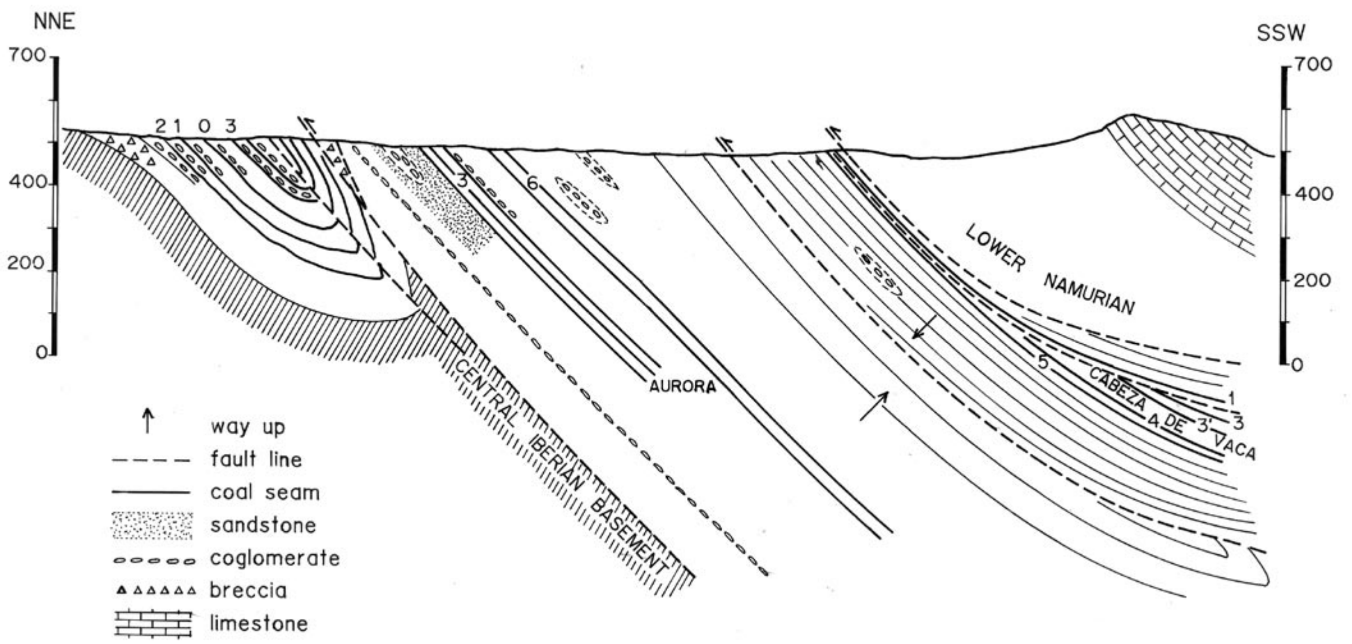

Fig. 5.- Cross section through the Peñarroya-Belmez-Espiel Coalfield in the Belmez area showing tectonically deformed basinal areas IIa and IIb (the small syncline on the left), both of Duckmantian age. Opposed facing is indicated by arrows. The synclinal core shown at depth is interpretative, not based on actual observation. The overturned flank on the SSW side is extensively sheared in parallel with the transform fault controlling the Peñarroya Basin. Decollement thrust underlying lower Namurian sediments is shown on the SSW side (after Wagner, 1999).

Fig. 5.- Corte geológico a través de la cuenca minera de Peñarroya-Belmez-Espiel en el área de Belmez, mostrando las áreas de sedimentación IIa y IIb (el pequeño sinclinal a la izquierda), ambas de edad Duckmantiense. Las flechas indican la polaridad opuesta de los dos flancos de la estructura principal. El núcleo del sinclinal dibujado en profundidad es interpretativo. El flanco invertido del borde SSW está muy laminado, con fallas paralelas a la transformante que controlaba la cuenca sedimentaria de Peñarroya. El borde SSW de la cuenca minera viene dado por un cabalgamiento por despegue de los estratos del Namuriense inferior del “basamento” de la cuenca westfaliense. Según Wagner (1999).

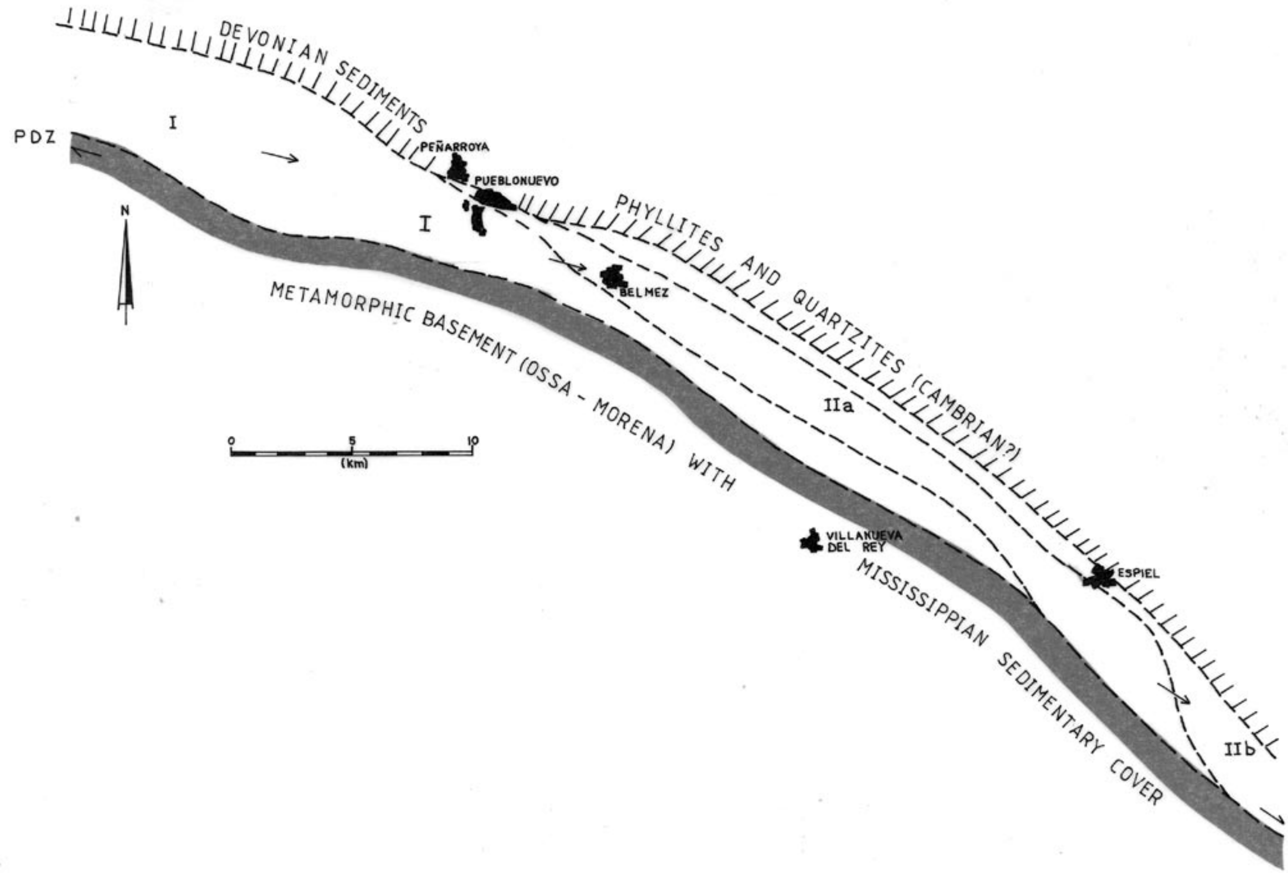

Fig. 6.- The relative position of successive basinal areas and the direction of shifts in depocentre (as indicated by arrows) in the Peñarroya Basin. The Principal Displacement Zone (PDZ), a transform fault separating two different terrains, experienced sinistral strike-slip with an additional, less important vertical component. It moved high grade metamorphic rocks on the SSW (Ossa Morena) side southeastwards, with a subsiding plate alongside consisting of Cambrian? phyllites and lower Palaeozoic rocks (including Devonian) being affected by synthetic faulting which controlled the NNE basin margin. Successive basinal areas marked as I, IIa and IIb (after Wagner, 1999).

Fig. 6.- Posición relativa de las sucesivas áreas de sedimentación y dirección de traslado de los depocentros (indicado por las flechas) de la cuenca sedimentaria de Peñarroya. La falla transformante que separaba a dos terrenos diferentes, tuvo un movimiento principal en dirección (*strike-slip*) con una componente vertical menos importante. Esta falla trasladó hacia el Sureste las rocas metamórficas de alto grado del borde SSW (Ossa Morena) y provocó la subsidencia de la placa pasiva Centro-ibérica con filitas y cuarcitas (¿Cámbrico?) y sedimentos paleozoicos, Devónico inclusive. La placa subsidente fue afectada por fallas sintéticas en el borde NNE, subparalelas a la transformante. Las sucesivas áreas de sedimentación están señaladas como I, IIa y IIb. Según Wagner (1999).

and early Bolsovian ages cannot be easily discriminated on palaeobotanical data, and the possibility exists that the La Ballesta area is Bolsovian rather than late Duckmantian, and that a third basinal area is involved.

Microfloral assemblages studied by Coquel (Lille), proved difficult to interpret with regard to stratigraphic age, as a result of extensive reworking, which is readily apparent where darker palynomorphs from Viséan strata occur, but more difficult to discriminate where lower Namurian grains with a lesser degree of maturity of the organic matter are found intermingled with equally light-coloured lower Westphalian spores and pollen. The microfloral remains obtained from coal samples, where reworking is less of a problem, belong to palaeoecologically controlled assemblages, which are less varied and therefore less useful stratigraphically. The important effect of reworking is understandable in the light of tectonically active basin margins, only a few kilometres apart. Viséan and lower Namurian strata constitute an unconformable succession on top of Lower Palaeozoic sediments and earlier metamorphic rocks, and occur in the immediate vicinity of the Peñarroya Basin. These strata show dislocation into a number of local successions which are difficult to relate mutually (Cózar and Rodríguez, 1999), probably as a result of early Westphalian strike-slip movements.

The sedimentary analysis of bore logs and surface mapping shows a consistent pattern of facies distribution which reflects the relative importance of the SSW border, which is interpreted as being coincident with the transform fault controlling basin subsidence and the shifts in depocentre. The NNE border had a less permanent location, but the similar stress regime at different times produced an alignment of fractures provoked by synthetic faulting subparallel to the main strike-slip fault, i.e. the Principal Displacement Zone (in the sense of Christie Blick and Biddle, 1985). The position of this synthetic fault changed with time as the different finds of alluvial fan breccia in the area SE of Belmez have shown, but the alignment of alluvial fans of different ages and corresponding to successive basinal areas creates a semblance of continuous fracture on the NNE border of the Peñarroya-Belmez-Espiel Coalfield. Indeed, this northeastern border which is undisturbed by later tectonics, displays an almost continuous line of alluvial fan lobes with interlobes. These are indicative of a tectonically active border with upstanding relief of the order of several hundred metres (Andreis and Wagner, 1983). Basin analysis has shown these fans to be of different ages, younging from WNW to ESE, with the shifts in depocentre in this direction. The alluvial fans grade both upwards and laterally (basinwards) into a system of braided stream deposits leading into an alluvial plain which bordered onto a lacustrine area near the Principal Displacement Zone (Fig. 7). This pattern is repeated in the successive basinal areas existing at different times; thus showing that the tectonic controls on the basin were basically the same at various times. Temporal variations in the relative width of the different facies belts may have been due to the degree of closure at the two ends of the basin, in northwestern and southeastern directions; generating either a larger or a smaller lake and consequently restricting or enlarging the alluvial plain area. Climatic control on the size of the lake is excluded because the composition of the fossil flora is similar throughout the entire time span represented (some 3 million years, as suggested by the absolute ages for the late Langsettian-Duckmantian interval, according to Burger *et al.* 1997). The southeasterly shifts in depocentre within each of the successive basinal areas do not appear to have resulted in any substantial change in the facies distribution which may have been due to tilting of the basin floor towards the transform fault where there was a greater loss of cohesion. Facies belts thus strike WNW-ESE in parallel with the faults controlling the basin.

Whilst the northeastern border of the basin is accessible to direct observation, due to the absence of later tectonic deformation, the southwestern basin margin is hidden from view as a result of a late thrusting event which moved lower Namurian strata of the basin margin on top of an already deformed lower Westphalian basin fill (Fig. 4). As a result of this thrusting there is a general lack of information on the sediments generated along this basin margin, which coincided with the transform fault controlling basin subsidence and the successive shifts in depocentre. Only in the vicinity of Belmez, corresponding to basinal area IIa of late Duckmantian age, there are outcrops of breccias interpreted as alluvial fan deposits near the southwestern border of the coalfield, thus suggesting that the southwestern basin margin also generated alluvial fans (as indicated in Fig. 7).

In the course of the history of each successive basinal area, it is assumed that the SSW basin margin as determined by the transform fault, on which continual movement would have taken place, occupied approximately the same place permanently. The alluvial fans generated on the ENE basin margin as provoked by subparallel synthetic faulting as a result of stress generated on the plate functioning as the passive tectonic unit alongside the transform fault, show the effects of backfaulting by which the width of the sedimentary basin marginally increased during the life span of each basinal area. The clast composition of these alluvial fans show provenance from the subsiding plate which constituted the basin floor. These clasts are phyllites and quartzites of presumed Cambrian age. The actively moving plate on the other, southwestern side of the transform fault, contains metamorphic rocks including gneisses, representing a different terrain corresponding to a much lower structural level.

The amount of lateral movement can only be estimated, but it is likely to have been considerable. Azor *et al*. (1994) mentioned a figure of 200 km lateral displacement between the Central Iberian and Ossa-Morena Zones, placing the zonal boundary on the northeastern side of the Badajoz-Córdoba shear zone; this boundary is here regarded as coincident with the transform fault on the southwestern border of the Peñarroya sedimentary basin. They pointed out that strike-slip faulting, though mainly involving horizontal movement, would also have had a vertical component and that this would explain the marked difference in metamorphic grade between the different tectonic units on the SW and NE sides of the fault. This very reasonable argument was backed up by structural measurements such as stretching lineations which were not completely horizontal but dipping 10º. Since measurements are always local, there is inevitably a certain amount of extrapolation, but a cumulative vertical throw of ten kilometres or more, as Azor *et al.* (1994) suggested, may be a reasonable estimate. It is interesting to quote their conclusion that their "kinematic and geometric" (i.e. structural) "data and the different metamorphic histories of the differentiated units integrate into a model involving development of a zone of oblique crustal thrusting that progresses southeastward and whose hanging wall is affected at the rear by an important extensional left-lateral shear zone, causing the exhumation of a unit with high pressure metamorphism". This model based on the structural analysis of pre-Car-

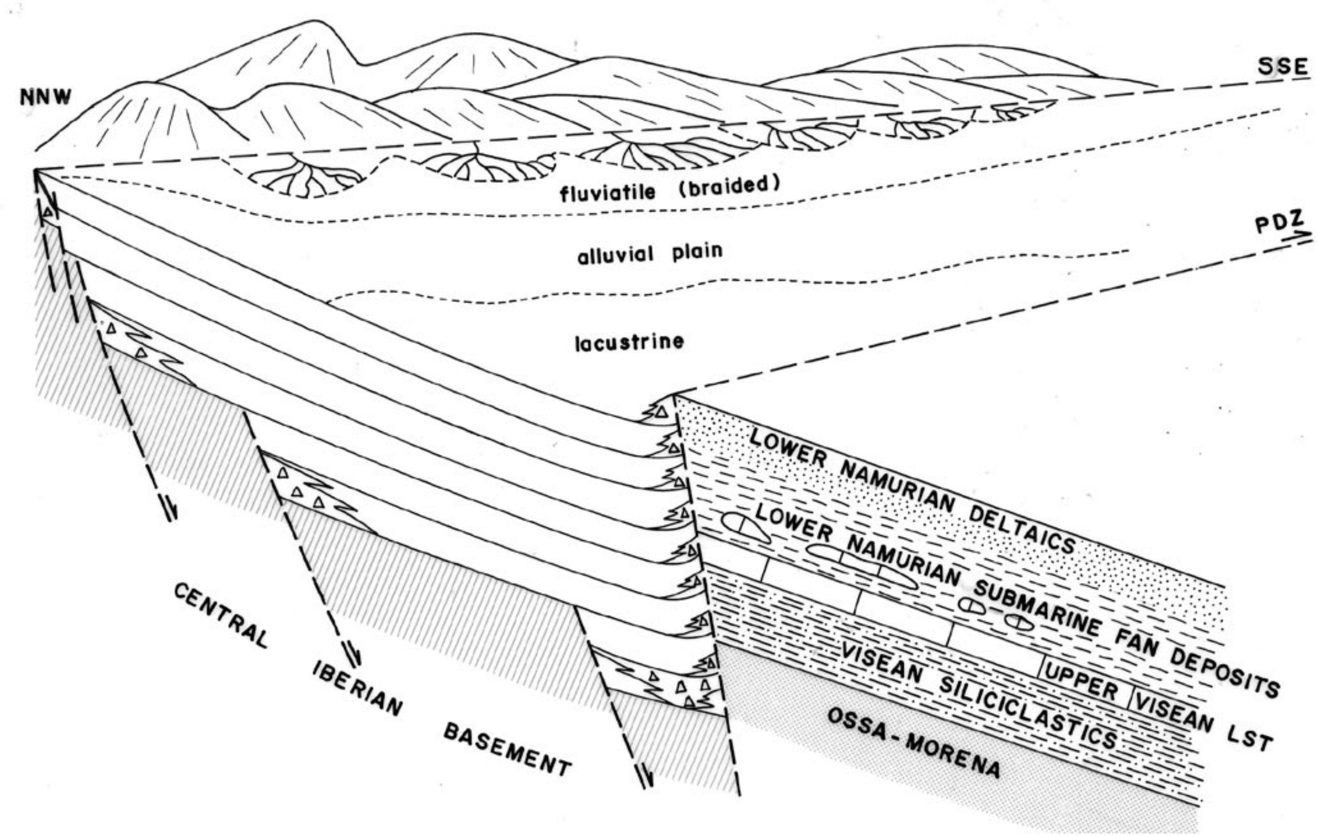

Fig. 7.- Block diagram representing the sedimentary basin in the Belmez area (basinal area IIa). The contrast between the different terrains on the two sides of the transform fault (PDZ = Principal Displacement Zone) is clearly apparent, with high grade metamorphics of the Ossa-Morena Zone covered by unconformable Mississippian strata and the lower Westphalian basin being underlain by Central Iberian "basement" (mainly Cambrian? phyllites and quartzites). Parallel belts of different sedimentary environments (alluvial fan lobes, braided streams, alluvial plain and lacustrine area) show control by a tilted basin floor allowing lacustrine flooding near the transform fault. The NNE border of the basin, with alluvial fan lobes, coincides with synthetic faults originated by stresses provoked by continual movement on the transform fault (PDZ). Alluvial fan breccias indicated by triangles (after Wagner, 1999).

Fig. 7.- Bloque diagrama que muestra la configuración de la cuenca sedimentaria en el área de Belmez (área IIa). El contraste entre los terrenos a ambos lados de la falla transformante (PDZ = *Principal Displacement Zone*) es muy claro, ya que por un lado se encuentran rocas metamórficas de alto grado de la Zona de Ossa Morena con una cobertera de sedimentos misisípicos discordantes, y por otro unas filitas y cuarcitas ¿cámbricas? de la Zona Centro-Ibérica que constituyen el basamento de la cuenca westfaliense de Peñarroya. Una ligera inclinación de este "basamento" hacia la falla transformante produciría inundaciones lacustres cerca de esta falla que controlaba la distribución de las franjas subparalelas de facies diferentes (abanicos aluviales, ríos anastomosados, llanura aluvial y área lacustre). El borde NNE, marcado por abanicos aluviales, coincidiría con las fallas sintéticas provocadas por el régimen de tensiones generadas por la transformante. Las brechas de abanico aluvial se han distinguido por triángulos. Según Wagner (1999).

boniferous strata in the general region agrees largely with the data obtained from the tectono-stratigraphic history of the Peñarroya Basin of early Westphalian age, although the present writer finds no evidence for "oblique crustal thrusting" beyond the temporary, local thrusting associated with restraining bend tectonic deformation at certain intervals on a transform fault. Indeed, a transform fault as that which controlled the history of the Peñarroya Basin would almost certainly combine some vertical movement with the predominantly horizontal strike-slip. The actively moving plate with metamorphic rocks on the southwestern margin of the basin would have functioned as an upstanding area with regard to the subsiding basin floored by markedly less metamorphic rocks of the more passively deformed plate. In agreement with data provided by Ridge Basin in the Tertiary of California (Crowell, 1982), a major transform fault would not move in an entirely straight line and this would provoke releasing bend (transtensional) and restraining bend (transpressional) situations. During the transpressional episodes the actively moving plate would thrust itself onto the basin, increasing the vertical component on the transform fault. This kind of behaviour is obvious in the tectonic deformation of basinal area I near Peñarroya, where compression generated a composite of two synclines with an intervening anticline, with overturning of the SSW flank nearest the transform fault. Continuing strike-slip produced a local repetition of the steeply dipping, overturned SSW flank of the synclinal

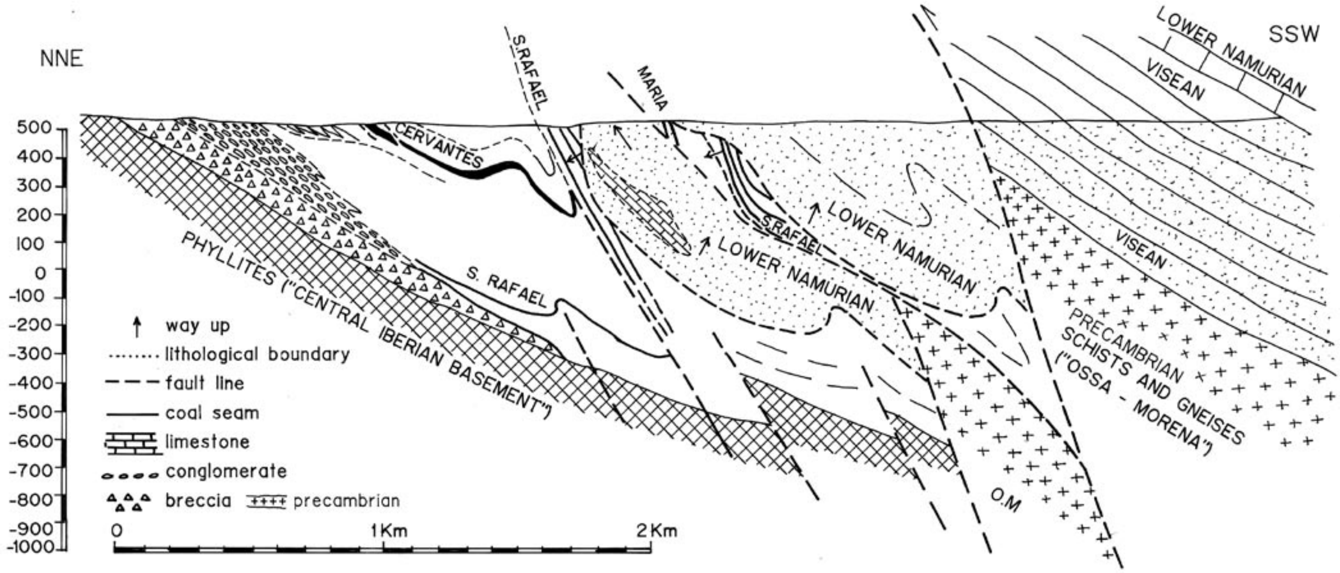

Fig. 8.- Cross-section through the tectonically deformed basinal area I near Peñarroya, showing a folded normal NNE flank, and an intensely sheared, overturned SSW flank which is repeated to the SSW. The position of the Principal Displacement Zone (transform fault) coincides with a steeply angled thrust fault which represents the latest movements on the PDZ after it ceased to function as a transform, and which cut through the decollement thrust underlying lower Namurian sediments of a Mississippian basin unrelated to the Peñarroya Basin of early Westphalian age. Principal coal seams in the lower Westphalian succession are mentioned by name. Arrows denote way-up (after Wagner, 1999, modified).

Fig. 8.- Corte geológico en las cercanías de Peñarroya, a través del área de sedimentación I, tectónicamente deformada antes de instaurarse el área IIa, y en el que se observa un flanco NNE normal y un flanco SSW invertido y laminado por fallas en dirección; este flanco invertido está repetido hacia el SSW en un tramo corto (ver Fig. 3) por una falla en dirección. La falla transformante (PDZ) aparece como una falla inversa que representa los últimos movimientos tectónicos sobre esta fractura después de dejar de funcionar como transformante. La falla inversa se proyectó a través del cabalgamiento a nivel de los sedimentos del Namuriense inferior que forman parte de la cuenca misisípica anterior e independiente de la cuenca westfaliense de Peñarroya. Las capas de carbón principales de la sucesión westfaliense están identificadas por su nombre. Las flechas indican la polaridad. Según Wagner (1999), modificado.

structure (Fig. 8) (the site of Mina María, the last working underground coal mine), and is also supposed to have produced the internal shearing within the steeply dipping overturned flank parallel to the upthrust SSW basin margin. Numerous small tectonic lenses were thus created in the overturned southwestern flank of the basinal structure in lower Westphalian sediments, and this resulted in an overall thinning of the stratigraphic succession, which is well attested to by the coal-mining experience.

Of course, thrusting of this kind is local and steeply angled. In this tectonic regime there is no room for large-scale movement across the strike as proposed by Martínez Poyatos *et al*. (1998), who postulated successive Carboniferous basins being carried "piggy-back" northeastwards. These authors interpreted largely out-of-date stratigraphic data culled from the literature, and did not study the Peñarroya Coalfield directly. They displayed only a sketchy knowledge of the different Carboniferous successions, and failed to separate a Viséan to early Namurian marine basin from the early Westphalian intramontane, terrestrial basin (i.e. the Peñarroya Basin proper), although these two basins are quite different in origin and palaeogeographic configuration, and separated in time by several million years during which no sedimentation took place. Since they were also unaware of the southeasterly shifts in basinal areas and depocentres in the Peñarroya Basin, they did not realise the fundamental contradiction with their "piggy-back" model, which required continual northeasterly shifts in basinal area. Insufficient local geological information thus led to an invalid, rather simplistic model.

The minimum time allotted to movements on the transform fault which provoked subsidence followed by deformation and, subsequently, by subsidence of another basinal area southeast of the earlier one, is that corresponding to the late Langsettian and Duckmantian. The time interval involved is variously calibrated by the different authors, but is about 3 Ma, during which horizontal movement was consistently in one direction. If the passively fractured, subsiding plate on the northeastern side of the fault is regarded as more or less static, and the actively displaced, uplifted high metamorphic area on the southwestern side has been the one moving southeastwards, this will have produced the successive transtensional, transpressional, and, again, transtensional and transpressional situations during these c. 3 Ma. The two successive basinal areas (I and II) produced by a releasing bend (transtensional) situation seem to have been each about 30 km long. Since there is an intervening interval of restraining bend situation, during which tectonic deformation took place, another 30 km movement may have been involved. This suggests some 90 km movement southeastwards of the active plate with high metamorphic rocks. The second basinal area has also been tectonically deformed so that approximately a 100 to 120 km displacement may be postulated for a time interval which probably did not exceed 4 Ma. These figures are of a similar magnitude to the 200 km mentioned by Azor *et al.* (1994). Of course, one wonders how long this transform fault continued to be active. The 3 Ma interval attested to by the Peñarroya Basin represents the minimum time to be considered.

The fairly late, shallowly dipping thrust fault on the SSW side of the Peñarroya-Belmez-Espiel Coalfield extends east-southeastwards well beyond the exposed lower Westphalian deposits, thus preventing the observation of possible additional (later) basinal areas further along the transform fault in this direction. This means that the 100 to 120 km lateral displacement is very much a minimum figure. It is also possible that earlier basinal areas lay along the transform fault in west-northwestern direction. A 200 km displacement as suggested by Azor *et al.* (1994) thus appears within the realm of possibility.

3. Evidence of other strike-slip basins in the Carboniferous/Early Permian of SW Iberia (Fig. 1)

3.1 Valdeinfierno

The earliest example of a strike-slip controlled basin in Sierra Morena refers to a small pull-apart, the Valdeinfierno Basin (Roldán and Rodríguez, 1989), which straddles the Córdoba-Sevilla provincial boundary south of Fuenteovejuna (Fig. 2). Although pull-aparts are different to the basins formed alongside a transform fault, the Valdeinfierno pull-apart basin, of late Tournaisian age (Wagner, 2001) shows that stress fields producing predominantly horizontal slip were already in evidence at a very early date in the Carboniferous of Sierra Morena.

3.2 Sierra de San Pedro

A poorly known conglomeratic occurrence with lower Westphalian floral remains is known from the Sierra de San Pedro, South of Cáceres (Bochmann *in* Walther, 1977). This is the only occurrence of similar age to the Peñarroya Basin in the general vicinity. Too little is known of this occurrence (Fig. 1) to speculate on its possible link with transform faulting.

3.3 Buçaco

This NNW-SSE striking, narrow elongate strip of Stephanian C (= lower Autunian) strata lies alongside the Coimbra-Tomar Fault which is regarded as the NW extension of the Badajoz-Córdoba shear zone (Domingos *et al.*, 1983). The tectonic structure is apparently synclinal, with a probable cross fault separating the general occurrence into the Santa Cristina Syncline in the South and the Algeriz Syncline in the North (Wagner *et al.*, 1983). Total length of the occurrence is almost 30 km at 0.5-2 km width. Like the Peñarroya Basin it presents a tectonically undisturbed unconformable contact with alluvial fan deposits on the eastern side, whereas it is delimited on its western side by a steeply angled thrust fault. Basement rocks are quite different on these two sides, denoting a tectonic contact connecting two different terrains. Only one stratigraphic section has been measured in detail on the eastern flank of the Algeriz Syncline, and there is no information on possible shifts in depocentre. The 87 m thick succession measured, shows alluvial fan deposits which are followed by alluvial plain sediments with fluviatile conglomerates in the higher part. Fossil plant remains have allowed stratigraphic dating.

If the Coimbra-Tomar fault is indeed the same as the Badajoz-Córdoba fault zone, the nature and configuration of the Buçaco Basin would suggest that tectonic movements on this fault zone lasted at least until latest Carboniferous times. However, this assumption flies in the face of southeastward younging of Carboniferous (Pennsylvanian) basins on the Badajoz-Córdoba transform fault, so the Coimbra-Tomar Fault should probably be regarded as a later fracture which may be partly coincident with the earlier fault zone.

3.4 Valongo

The transform fault which controlled the development of succesive depocentres in the Peñarroya Basin, is not the only one of its kind that has been detected in the western Iberian Peninsula. In the area northeast of Oporto, NW-SE striking faults in the complex structure of the Valongo Anticline delimit a narrow strip of squeezed-in terrestrial Carboniferous successions of late Westphalian and late Stephanian ages, with the earlier strata occurring in the northwestern part. Worthy of note is the progression of stratigraphic ages, younging southeastwards, since this invites comparison with the progressively younger ages found in southeasterly direction in the Peñarroya Basin, from Langsettian to Duckmantian. Little is known about the structure and stratigraphic history of presumed Bolsovian (Westphalian C) strata in the Casais-Alvarelhos area to the Northwest (and even less of that in the Serra de Rates further North). Carboniferous strata at Ervedosa, dated as early to mid-Westphalian D (Wagner and Lemos de Sousa, 1983), lie in apparent continuity southeastwards with the strata found at Alvarelhos. More information is available on upper Stephanian (B-C) occurrences further southeastwards, in a narrow strip, some 90 km long and only a few hundred metres wide, lying east-southeast of Oporto. This strip has been mined intensively in what has been called the Douro Coalfield, with the principal mines at São Pedro da Cova and Pejão/Germunde. There is apparent structural continuity between these upper Stephanian coal-bearing strata and the upper Westphalian deposits to the Northwest, and it is noted that both have been attributed to a single basin with progressive younging southeastwards (Domingos *et al*., 1983). This may be so in terms of structural control, in which case a large time interval, several million years, without apparent basinal subsidence, separates the late Stephanian B or Stephanian C deposits of the Douro Coalfield from the much earlier mid Westphalian D strata at Ervedosa. Although the tectonic contacts appear as steeply angled thrusts, Domingos *et al*. (1983, p. 189) note that "the shear zone has also an important strike-slip sinistral component". Domingos *et al*. (1983, p. 190) further note that "The internal deformation of the sedimentary fill is quite variable. Near the shear zone all the beds from Westphalian B to Stephanian C are strongly deformed with subvertical axial planar slaty cleavage parallel to the shear zone and a downdip stretching lineation, but where the trough is wider, as at São Pedro da Cova, the penetrative deformation of Upper Carboniferous strata dies out rapidly southwestwards".

It would appear that the sum total of the data available on the Carboniferous strata east of Oporto is compatible with the presence of a transform fault which operated during an interval of at least 6 MA, from late Westphalian to late Stephanian times. It may well be that the Valongo transform fault took over in time from the earlier one at Peñarroya. Both acted in the same direction.

3.5 Valdeviar

An important geological boundary, that between the Ossa Morena and South Portuguese zones (Lotze, 1945), coincides with the Autunian basin of Valdeviar, in Sevilla Province. This basin strikes NNW-SSE and crops out in c. 30 km length and 3.5-5 km width. It is dated on fossil flora as middle Autunian (basal Permian) (Wagner *in* Sierra *et al*., 2000). Simancas (1983, 1985) studied the stratigraphy and structural context of the Viar Basin, and concluded that this basin was a half graben with a faulted northeastern border where drag produced a marked steepening of the dip of Lower Permian strata. The undeformed, flat-lying strata on the southwestern side of the basin display an irregular, undeformed unconformable contact with Lower Palaeozoic strata and intrusives. Simancas postulated that the NE boundary fault would represent a reactivated Late Palaeozoic fracture zone coincident with part of the Ossa Morena/South Portuguese boundary which he interpreted as a major strike-slip fault, with some 50 km lateral displacement. A later study by García-Navarro and Sierra (1998) emphasised tectonic movements across the strike, which they regarded as extensional during basin subsidence and compressional when the steeply dipping upthrust on the northeastern side of the basin came into being, thrusting Ossa Morena rocks onto the Autunian basin sediments. With regard to the stratigraphic succession they accepted the informal subdivisions proposed by Simancas (1985), commencing with red conglomerates and basaltic flows, followed by grey clastic deposits (with volcanoclastics – see Sierra *et al*., 2000), a more major interval of basalts, and a red detrital succession. The map shows this last stratigraphic interval to be overlapping the earlier deposits, thus suggesting a southeasterly shift in depocentre.

The overall configuration of the Viar Basin suggests strike-slip control, similar to that of the early Westphalian Peñarroya Basin. The Ossa Morena/South Portuguese boundary fault, which is generally regarded as a major separation between areas of different geological history, could easily be a transform fault as Simancas (1983) has suggested. A rejuvenation of this transform fault in earliest Permian (mid-Autunian) times would have produced the Viar Basin as a result of subsidence of the South Portuguese side of the fault zone. A southeasterly shift in depocentre is indicated by the onlap relationship, this being easily understood as the result of a tectonically active plate moving alongside a more passive plate with marginal subsidence. In this case, the movement would be dextral, with the Ossa-Morena Zone moving southeastwards. However, Simancas (1983) regarded the earlier, pre-Permian movements as sinistral. The Viar Basin would thus represent a late reactivation of earlier transform faulting, with a reversal of the strike-slip movements. The thrust fault on the northeastern side of the Viar Basin is consistent with restraining bend (transpressional) conditions after the releasing bend (transtensional) conditions leading to subsidence had ceased.

4.6 Santa Susana

Another late Palaeozoic basin alongside the Ossa Morena/South Portuguese boundary fault is the occurrence at Santa Susana, in South Portugal (Fig. 1). This is a 12 km long and 0.1-5 km wide strip of upper Westphalian D or basal Cantabrian strata of terrestrial facies. Domingos *et al*. (1983) describe the occurrence as 150 m of conglomerates, arkoses and coal-bearing shales, which overlie possibly Namurian volcanic rocks and shales. These Namurian? strata with unconformable upper Westphalian D or basal Cantabrian cover are thrust westwards on top of possibly Devonian phyllites attributed to the South Portuguese Zone. Too little is known about the Santa Susana Basin to allow speculation on the tectonic controls of this basin, but its position alongside the Ossa Morena/South Portuguese boundary fault suggests a link with this probable transform fault.

4. General discussion

The Viar Basin seems to mark the end of major strike-slip movements in the present-day area of the Iberian Massif. Since strike-slip faulting in Sierra Morena goes back to the late Tournaisian (as shown by the Valdeinfierno pull-apart basin), the stress pattern giving rise to these movements lasted some 30 Ma. However, the most important strike-slip faulting attributed to transform faults seems to correspond to Westphalian and Stephanian times, i.e. some 15 million years. These seem to have been mainly sinistral movements which apparently amount to hundreds of kilometres displacement altogether. This may explain the contention of certain authors (e.g. Oliveira *et al*., 1979) that the South Portuguese Zone has its nearest equivalent in northwestern Europe. Whatever the total amount of Pennsylvanian transform faulting may have been, it is clear that the Iberian Massif did not acquire its present configuration until the end of the Carboniferous and that the concept of an Iberian microplate, as postulated in some of the literature cannot be regarded as valid for any configuration prior to the Permian. Even so, the southeastern part of the Iberian Peninsula may be a later addition.

A large question mark looms over Morocco up to and including the Atlas Mountains. (Southeast of the High Atlas lies the northern edge of the Gondwana continent of Carboniferous and Permian times.) This is not the place to analyse the Moroccan evidence, but some of the Carboniferous basins in central Morocco have been explained as being due to strike-slip fault movements.

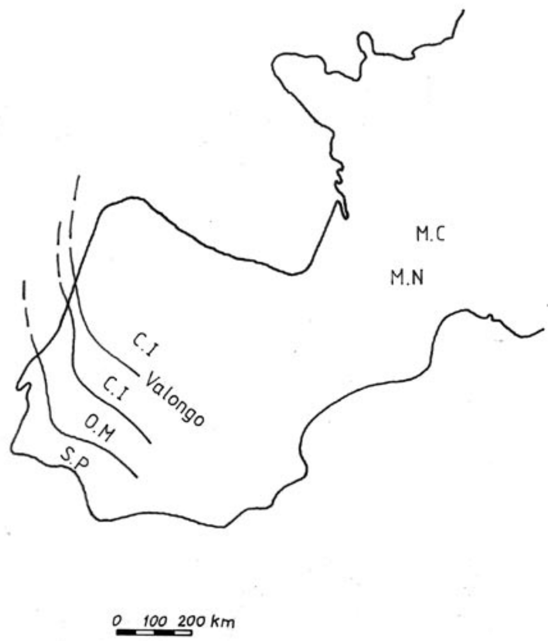

Fig. 9.- Position of the three most major transform fault zones in the western Iberian Peninsula, i.e. from North to South: Valongo (V), Coimbra-Badajoz-Córdoba (C.B.C.) and Ossa Morena/South Portuguese boundary fault (O.M.S.P.). Valongo lies within the Central Iberian Zone (C.I.), whereas CBC may be regarded as the boundary between the Ossa Morena (O.M.) and Central Iberian (C.I.) Zones. M.N. is Montagne Noire; M.C. Massif Central.

Fig. 9.- Posición de las tres fallas transformantes mayores del Paleozoico de la Península Ibérica, de Norte a Sur: Valongo (V), Coimbra-Badajoz-Córdoba (C.B.C.) y falla límite Ossa Morena/Sudportuguesa (O.M.S.P.). Valongo se encuentra dentro de la zona Centroibérica (C.I.) de Julivert *et al*. (1974). M.N. significa Montaña Negra; M.C. Macizo Central.

The recognition of Pennsylvanian transform faulting in the Iberian Massif and the possibility that most of Morocco may have to be regarded in a similar context, opens up a wide range of possibilities for Carboniferous plate reconstruction, even across the present-day Atlantic. It also suggests that the contact between the Atlas Range and the Gondwana continent is a very major suture separating different plates during Carboniferous times. (Earlier configurations leading to the accretion of parts of a Lower Palaeozoic Gondwana becoming part of Europe belong to a different time frame.)

A plate tectonic reconstruction of the Iberian Peninsula of Palaeozoic age will have to take into account the transform faulting that took place during the Carboniferous (Pennsylvanian in particular). This reconstruction must perforce ignore the Mesozoic and Tertiary configuration as exemplified by the Betic Cordillera and the Tertiary basins in this area. Only the Iberian (Hesperian) Massif of the present-day configuration may be considered in the

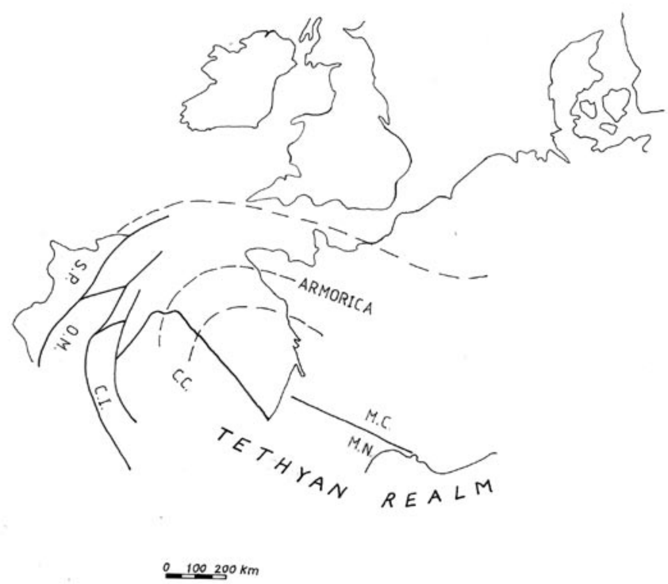

Fig. 10.- Palaeogeographic reconstruction of the different segments of the Western Iberian Peninsula during Carboniferous times. The NW Iberian Peninsula is slightly rotated to emphasise links with Armorica. The Montagne Noire (M.N.) is included with northern Spain in recognition of its Tethyan affinities and connection with the Pyrenees. The principal transform faults are shown with what may be regarded a minimum displacement. M.C. is Massif Central, M.N. Montagne Noire, C.C. Cordillera Cantábrica, C.I. Central Iberian Zone, O.M. Ossa Morena, and S.P. South Portuguese Zone.

Fig. 10.- Reconstrucción paleogeográfica de los diferentes segmentos desplazados (terrenos) en el Oeste de la Península Ibérica durante el Carbonífero. El NW de la Península Ibérica ha sido ligeramente rotado para enfatizar las relaciones con Armórica. El área de la Montaña Negra (M.N.) se incluye junto con el Norte de España reconociendo su relación directa con el Pirineo y sus conexiones con el Tethys. M.C. significa Macizo Central, M.N. Montaña Negra, C.C. Cordillera Cantábrica, C.I. Zona Centroibérica, O.M. Ossa Morena, y S.P. Zona Sudportuguesa.

context of the present paper.

Although the Ossa-Morena Zone in particular most likely contains a larger number of strike-slip faults than those discussed in the present paper, only the three major fault zones attributed to transform faulting of Pennsylvanian age (Fig. 9) are considered for the reconstruction of Figure 10. Lateral movements of the order of 100 to 200 km are likely to have taken place on each of these major transforms. Starting off from a slightly rotated northwestern part of the Iberian Peninsula (Galicia, Cantabrian Mountains, and Pyrenees including the Montagne Noire in southern France), with a presumed tectonic contact between the French Massif Central and the Montagne Noire (compare Martínez-García, 1996), the three major transform fault zones are drawn in such a way as to place the South Portuguese Zone more or less in line with equivalent parts of northwestern Europe. It would appear that the Cantabrian Mountains and the Palaeozoic Pyrenees, together with the Montagne Noire, all with Tethyan connections linking this North/Northwestern Iberian area with the Carnic Alps and areas further afield (e.g. Donbass in Ukraine and Russia), are to be regarded as separate from the West/Southwestern part of the present-day Iberian Peninsula where transform faulting of Pennsylvanian times brought in terrains with North European/North Atlantic connections (Fig. 10).

As happens with most plate tectonic reconstructions, many different kinds of geological data should be taken into account, so the present attempt at reconstruction based on an analysis of Carboniferous basins should be tested and modified, if necessary, by means of other specialist information. However, if this attempt succeeds in drawing attention to the evidence for major transform faulting in western Iberia, it may stimulate a reappraisal of structural interpretations which failed to assign a major role to the transform faulting as discussed here.

5. Conclusions

Detailed study of the Peñarroya Basin has shown major strike-slip faulting (possibly a transform) to be the controlling factor in the genesis of this sedimentary basin and its tectonic deformation. Its geological history parallels that of Ridge Basin along the San Andreas Transform Fault in California. The evidence for major strike-slip (transform?) faulting in the West-Southwestern Iberian Peninsula, in relation to local basins of Carboniferous (Pennsylvanian) age (Casais-Ervedosa-Douro, Buçaco, Santa Susana), is apparently widespread in Ossa Morena and adjacent parts of the Central Iberian Zone, and additional transforms are likely to be present in areas where there is no evidence of strike-slip controlled basins alongside the transform faults. Although the evidence for strike-slip faulting in general includes the Tournaisian pull-apart basin of Valdeinfierno, transform faulting is shown to be essentially of Westphalian and Stephanian ages, an interval of up to 15 Ma. Many hundreds of kilometres of lateral displacement are likely to have been involved, and it is clear that tectonic reconstructions of the West-Southwestern Iberian Peninsula will need to take this into account. Palaeobiogeographic reconstructions for the Lower Palaeozoic (Robardet, 2002) provide support for this contention.

Whereas the Ossa Morena and South Portuguese zones are clearly different, with a probable transform fault intervening, the Ossa Morena/Central Iberian boundary is more questionable. Indeed, part of the Central Iberian Zone seems to be involved in the transform faulting which brought Northwest European elements to the southwestern Iberian Peninsula. This puts into question the validity of Julivert *et al.*'s (1974) combination of Lotze's Lusitanian-Alcudian and Galaico-Castilian zones into a single Central

Iberian Zone. The West Asturian-Leonese and Cantabrian zones, which are mutually linked, both tectonically and palaeogeographically, show evidence of Tethyan connections, and may be regarded as essentially in place, without major strike-slip intervening. (Even though it is noted that Martínez-García, 1996, has postulated "late Hercynian" strike-slip along East-West lines for northern Spain and southern France. This is clearly different to the late Carboniferous strike-slip faulting discussed in the present paper.)

The zonal scheme as proposed by Lotze (1945) and modified by Julivert *et al*. (1974) needs to be reexamined in the light of plate tectonics.

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