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Estratto da/Reprinted from:

giornale di

GEOLOGIA

Rivista di
geologia sedimentaria
e geologia marina

Serie 3ª

Vol. 60, 1998

ISSN 0017-0291

Giornale di Geologia, ser. 3ª, vol. 60, 1998, pp. 167-196, Bologna

Stratigraphic and tectonic evolution of the uppermost Carboniferous succession of the Eastern Asturian Basin (Gamonedo-Areñas de Cabrales area), Cantabrian Mts. (NW Spain)

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Riassunto

Il presente lavoro esamina l'evoluzione tardo paleozoica del bacino orientale delle Asturie (settore Gamonedo-Areñas de Cabrales, Spagna NO). I risultati sono ottenuti attraverso l'analisi lito-e biostratigrafica (associazioni a fusuline), di facies e paleotettonica della successione tardo moscoviano-kasimoviana inf., potente circa 2.000 m. Viene presentato un quadro stratigrafico basato su un originale rilevamento geologico di dettaglio e sull'analisi di una serie di colonne ubicate in particolari zone che conservano i rapporti discordanti con il substrato ordoviciano-carbonifero e/o documentano l'attività tettonica sinsedimentaria, presumibilmente transtensiva, che ha condizionato l'apertura e l'evoluzione del bacino.

La successione, formata da alternanze di sedimenti terrigeni e carbonatici intrabacinali, risulta organizzata in cicli sedimentari che, specialmente nell'intervallo Moscoviano sup.-Kasimoviano inf. basso, denunciano un deciso controllo tettonico. L'alimentazione terrigena proviene da sud e da ovest ed è caratterizzata da tassi di accumulo inizialmente elevati. I relativi ambienti deposizionali spaziano dal fluviale al deltizio, a quello di prodelta. Le facies carbonatiche rappresentano ambienti di piattaforma, dai lagunari protetti a quelli di mare aperto.

L'analisi paleotettonica individua due sistemi di faglie sinsedimentarie e ne documenta l'attività attraverso il riflesso deposizionale. Inoltre, l'analisi dell'assetto deformativo del substrato comproverebbe che i due sistemi si sono originati precocemente, come faglie coniugate trascorrenti, durante la fase compressiva leoniana (fase orogenica ercinica, Moscoviano), la quale di fatto ha preceduto le transtensioni di età moscoviano sup.-kasimoviana.

Da ultimo vengono prese in esame le deformazioni post-kasimoviane subite dal settore e definite sulla base di un'analisi macrostrutturale. Si riconoscono due insiemi di strutture connessi a sforzi compressivi rispettivamente orientati circa NNE-SSO (?Gzheliano) e NO-SE (?Permiano) e generanti sistemi di pieghe ed accavallamenti. In particolare la compressione ?permiana ha riattivato alcune tra le precedenti faglie sinsedimentarie moscoviano-kasimoviane inducendo un'inversione tettonica di non elevata entità.

Parole chiave: Cantabria, tettonica tardo-paleozoica, tettonica sinsedimentaria, Moscoviano-Kasimoviano, stratigrafia, analisi di facies.

Abstract

In the Cantabrian region, northwest of Picos de Europa, field investigations have been carried out in the last two years on the upper Moscovian-Kasimovian succession of the Gamonedo-Areñas de Cabrales area which corresponds to the western part of the Eastern Asturian Basin. Aim of this paper is to focus on the new evidence about stratigraphy and palaeotectonics of the area. Correlations among the several measured sections are mainly based on lithostratigraphy with the benefit of biostratigraphic control (fusulinids and/or macrofloras) derived both from literature data and scattered, new fusulinid bearing sites.

As a preliminar result, the new biostratigraphic data confirm the upper Moscovian (upper Westphalian D)-lower Kasimovian age for the succession cropping out in this part of the Eastern Asturian Basin. Palaeotectonic investigations and facies analysis are consistent with an evolution driven first by NNE-SSW trending compressions (*Leonian* phase, late Moscovian), then by transtensional strike-slip tectonics (late Moscovian-lower Kasimovian). N-S and NE-SW trending palaeofault systems have been observed. They originated during the *Leonian* compression as conjugate right-and left-lateral systems. In late Moscovian-lower Kasimovian times, they turned into extensional faults which led to submarine collapses along active fault scarps producing megabreccia and debris flow deposits. The palaeofault systems are interpreted to have been active in a large scale wrench zone stretched between the Biscay-North Pyrenean and the Leon Faults.

Eventually the area experienced NNE-SSW and following NW-SE oriented trending compressions of supposed ?Gzhelian and ?Permian age, ultimately causing the tectonic inversion of the Kasimovian NE-SW syn-sedimentary faults.

Key words: Cantabrian Zone, Upper Palaeozoic tectonics, syn-sedimentary tectonics, Upper Moscovian-Lower Kasimovian, stratigraphy, facies analysis.

Introduction

The northeastern portion of the Iberian Massif is formed by the Cantabrian Mountains that roughly correspond to the Palaeozoic Cantabrian palaeogeographical Zone (Lotze, 1945).

In the Cantabrian Mountains crops out the outer folded and thrust Hercynian belt of the NW Iberian Peninsula. A great number of major thrusts define the peculiar arcuate pattern of the Asturian Arc (Fig. 1), whose the age and growth is still matter of discussion (Arthaud and Matte, 1975, 1977; Ribeiro *et al.*, 1995, *cum bibl.*).

The Hercynian sequence is made of Lower Cambrian to Carboniferous (late Moscovian) deposits; they have been subdivided in a pre-tectonic and a syn-tectonic succession (Marcos and Pulgar, 1983). The pre-tectonic succession has a Lower Cambrian to Upper Devonian age. It consists of a sedimentary wedge thinning eastward from 4500 m to 200 m reflecting stable platform conditions with sediments supplied from an emerged area located to the east which merged into the open sea. The syn-tectonic succession develops over a low angle Famennian unconformity. About 6.000 m of sediments stored up from upper Devonian (or lowermost Carboniferous) to late Moscovian.

The main Hercynian compression phase struck the area in late Moscovian times. Afterwards, according to the Authors some 'molassic' basins opened (Wagner, 1966, 1970; Wagner *et al.*, 1971; Wagner and Martinez-Garcìa, 1974; Martinez Garcìa, 1991) (Fig. 1). After a time and space varying gap the Hercynian sequence was unconformably sutured by uppermost Carboniferous deposits.

In the westernmost part of the Cantabrian Mountains, the unconformable succession has a Kasimovian age and was deposited in continental environments. In the eastern part, that partly corresponds to the study area, it has a late Moscovian to upper Kasimovian basal ages and is mainly characterized by marine facies (Martinez Garcìa, 1991, *cum bibl.*).

In the Cantabrian Zone, many attempts to correlate the coarse and thick terrigenous facies of the Devonian-Carboniferous successions and the several unconformities have been done to better identify widespread and time-equivalent tectonic movements. They were possible owing to the presence of conodonts bearing strata in the Upper Devonian-Lower Carboniferous succession and frequent fusulinid and macroflora assemblages distributed in the Upper Carboniferous-Permian beds successfully investigated by stratigraphers (Ginkel, 1965, 1971; Wagner, 1965, 1967, Marcos, 1967, 1968; Wagner *et al.*, 1970, 1977; Wagner and Winkler Prins, 1970, 1985; Martinez-Garcìa and Wagner, 1971; Wagner and Varker, 1971; Martinez-Garcìa *et al.*, 1985; Villa and Martinez-Garcìa, 1989).

In the Cantabrian Zone, Wagner and Martinez-Garcìa (1974) recognize three main tectonic phases respectively named *Palentian* (or Sudetic), which struck the area in Bashkirian times, *Leonian*, active in late Moscovian and *Asturian*, confined in latest Kasimovian-Gzhelian times. In Permian times, the *Saalic* phase also affected the area producing folding and angular unconformities. Little deformed Triassic deposits unconformably cover the Upper Palaeozoic sediments.

For the Cantabrian Zone Literature data attest the tectonic movements are far from clustering in well defined time intervals (Heward and Reading, 1980). Besides, at the same time near areas can experience strong tectonic activity and quite absence of tectonic movements (Wagner and Martinez-Garcìa, 1974).

The space and time distribution of deformations recorded in the Carboniferous (Bashkirian) succession of N Spain, together

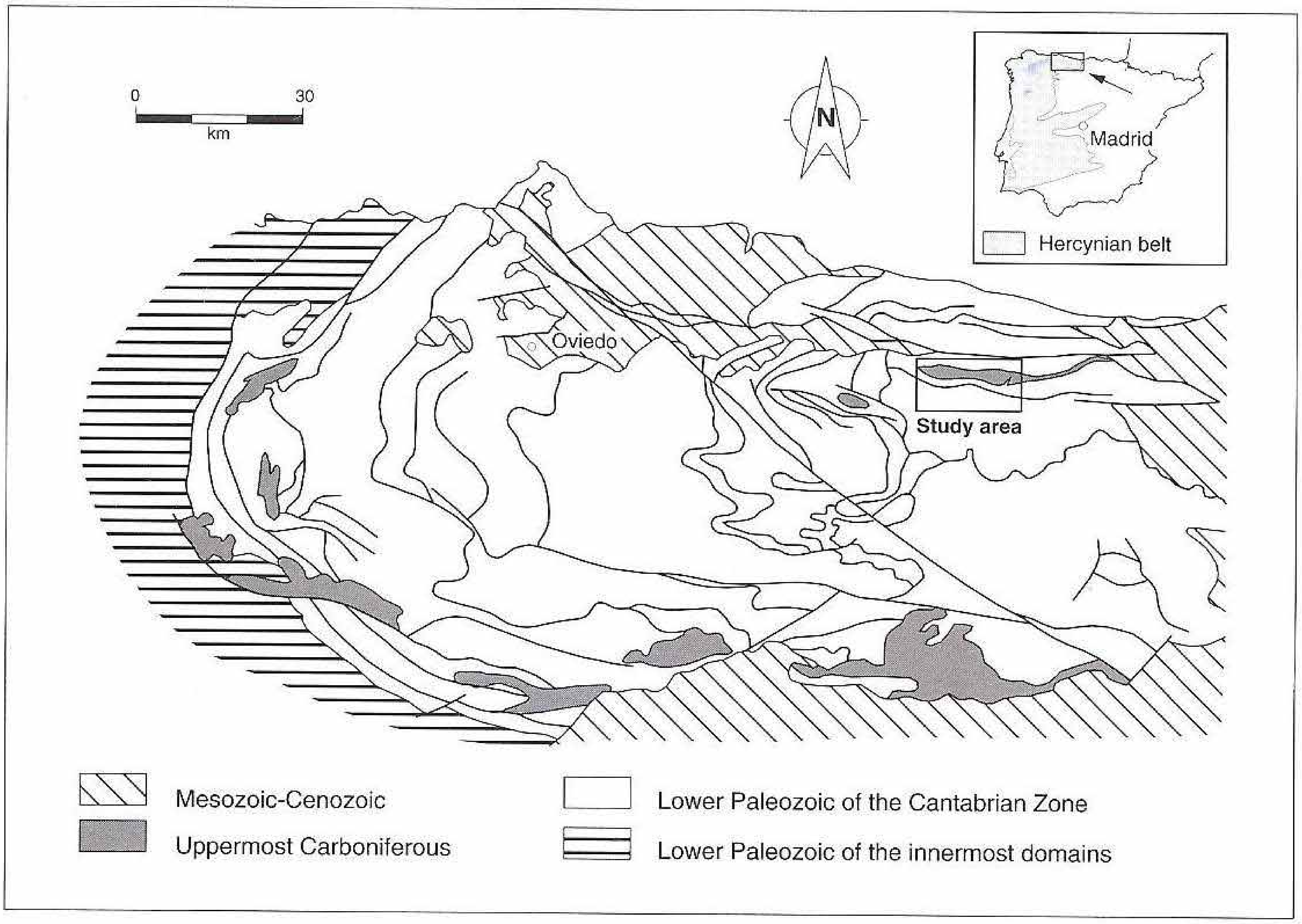


Fig. 1 - Geology of the Cantabrian Mountains (simplified after Alvarez-Marron, 1995).

with the sedimentological and stratigraphical evidence, suggested to Heward and Reading (1980) a regional transtensional strike-slip movement alternated with or adjacent to plain transpression for the Cantabrian Zone. The movements are thought as the local reflection of a supraregional transpressional regime developed through wide lateral movements during a continent-continent collision without subduction. The mechanism is supposed to have acted from early Late Carboniferous times, presumably reactivating syn-sedimentary palaeolineaments active since Middle Devonian at least. The geotectonic context was the major right-lateral shear zone supposed by Arthaud and Matte (1977) between the African and the American-European Plates.

The Eastern Asturian Basin (Upper Carboniferous)

The Eastern Asturian Basin is located north and northwest of the Picos the Europa. It is filled with an Upper Carboniferous succession unconformably suturing the Hercynian deformed sequence. A thicker than 2.000 m succession of upper Moscovian (Myachkovian)-upper Kasimovian age unconformably rests on very thick Lower Carboniferous (Visean-Moscovian) limestones or, at places, Ordovician quartz deposits ('quarzites' *Auct.*). The study area corresponds to the western part of the Eastern Asturian Basin. Here, the late Moscovian angular unconformity is well documented

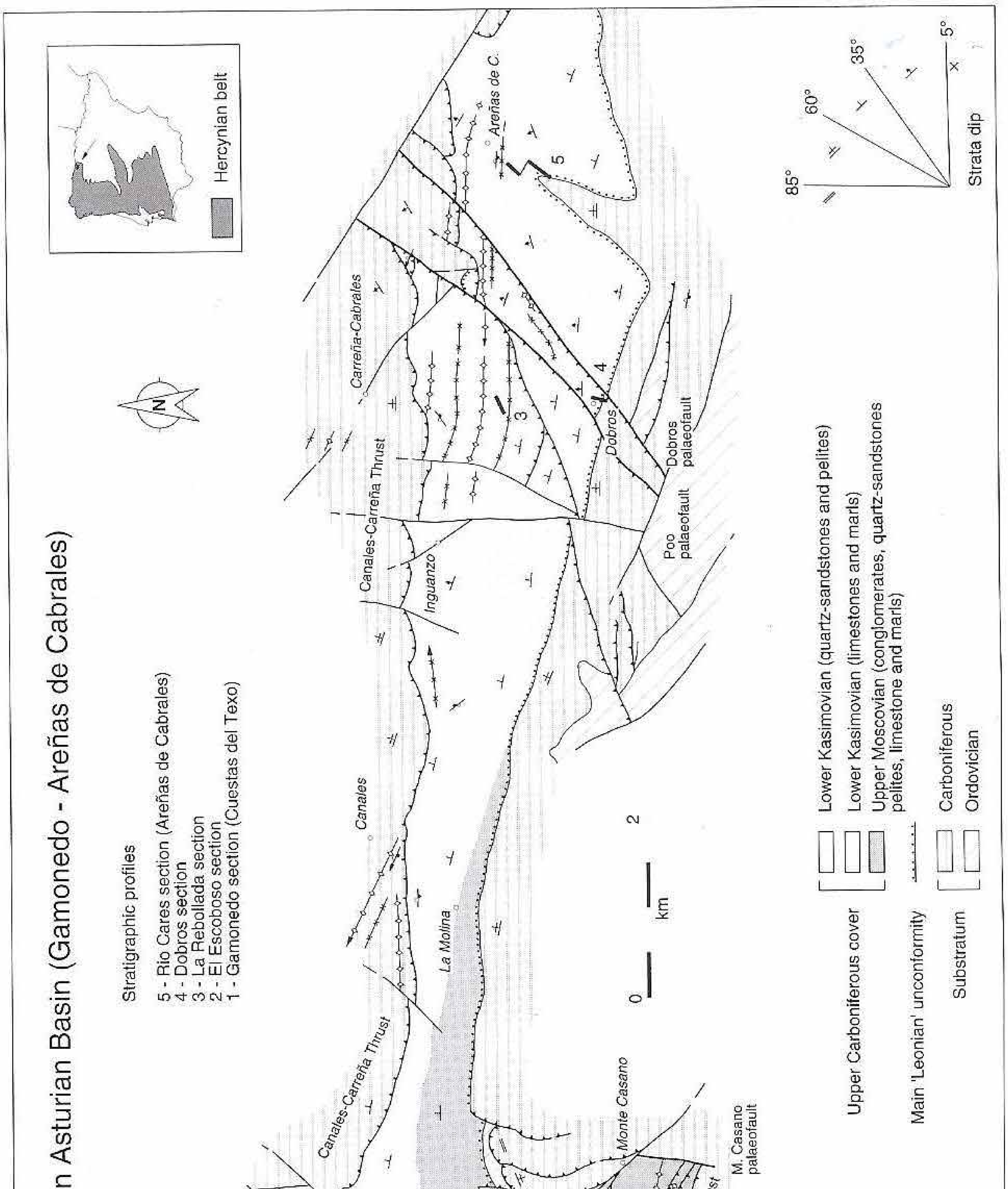


Fig. 2 - Schematic geologic map of the Gamonedo-Areñas de Cabrales area (Eastern Asturian Basin, NW Spain). Detailed geologic maps in Figs. 18, 19 and 20.

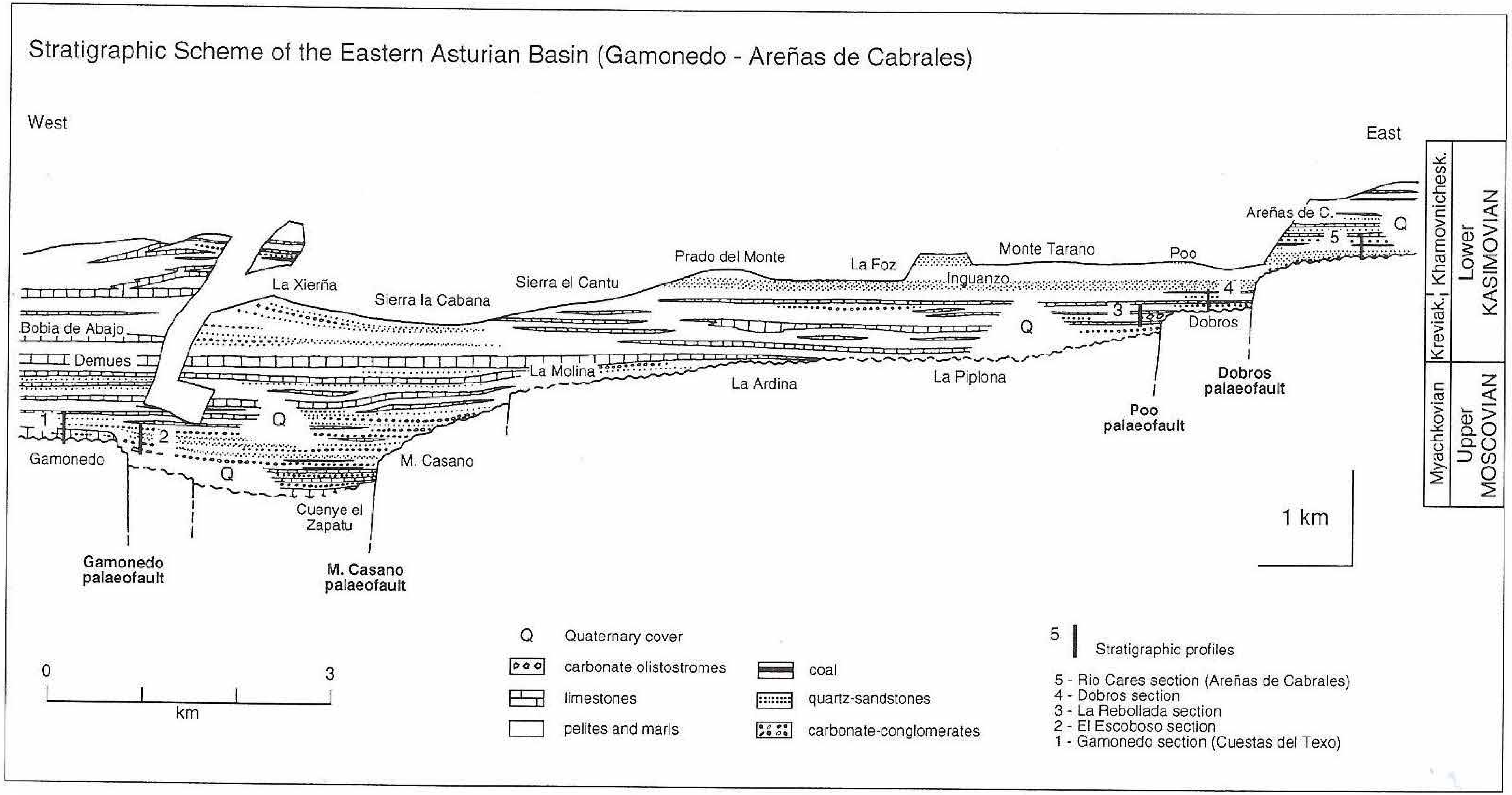
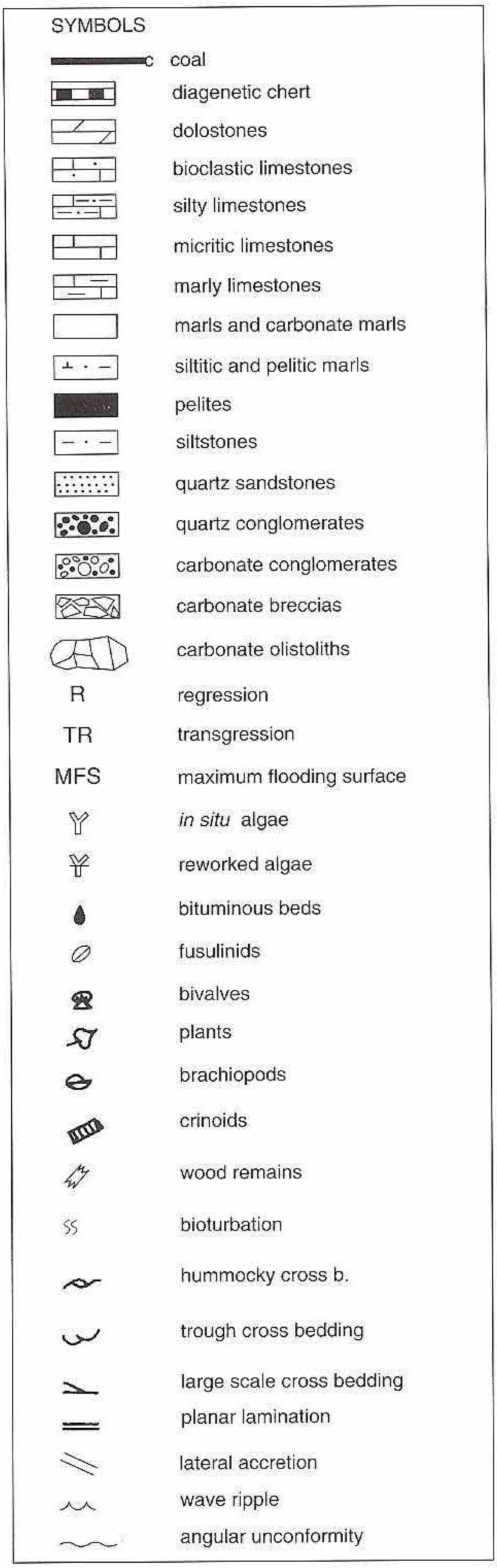


Fig. 3 - Cross-section of the Gamonedo-Areñas de Cabrales area, corresponding to the western part of the Eastern Asturian Basin. It is based on the field map of Figs. 18, 19, 20, the indicated sections (1-5) and several still unpublished stratigraphic data. The palinspastic restoration refers to lower Kasimovian times and takes into account the syn-sedimentary tectonics experienced by the area after the *Leonian* phase compression. First occurred the transtensional activity of the Gamonedo and M. Casano N-S trending palaeofaults; afterwards, they were inactivated and the Poo and Dobros NE-SW oriented palaeolines became active. Both fault systems were inherited from the *Leonian* compression.

Tab. 1 - Lithological and sedimentological symbols used in figs. 4, 6, 8, 11 and 15.



(Villa and Martinez-Garcìa, 1989) and is related to the so-called *Leonian* phase of the Hercynian orogeny (Wagner, 1959).

In the Eastern Asturian Basin, the upper Moscovian-Kasimovian succession ends in upper Kasimovian (or ?lower Gzhelian) times, which roughly correspond to Stephanian B-C, owing to the *Asturian* phase compression of the Hercynian orogeny (Wagner and Varker, 1971).

Here we use the term *Leonian* phase (as the *Palentian*, *Asturian* or *Saalic* phase) only with local significance, being aware that 'tectonic phases' are quite diachronous and induced deformations move forward through the crust.

In the last thirty years some works dealt with the stratigraphy of the Eastern Asturian Basin pointing out the presence of the so-called *Leonian* unconformity (Wagner and Martinez-Garcìa, 1974). The finding of some fusulinid and macroflora bearing sites allowed a stratigraphic subdivision of the thick Upper Carboniferous succession (Martinez-Garcìa, 1991 *cum bibl.*). It consists of five formations mainly recognized on palaeontological grounds rather than on lithofacies which are often organized in recurrent cyclothems. They are, from the bottom to the top, the Gamonedo, Pen, Dobros, Puentelles and Cavandi Fms.

The three lower units form together the whole stratigraphic record of the study area. However, the Eastern Asturian Basin lacks detailed geological maps, contrary to the best quality ones available in the classical Carboniferous basins of the southern Cantabrian Zone (van den Bosch, 1969; Wagner and Artieda, 1970; Wagner, 1971a, 1971b, 1971c; Wagner *et al.*, 1971; Savage and Boschma, 1980).

The upper Moscovian-lower Kasimovian succession of the Gamonedo-Areñas de Cabrales area

At present, the Upper Carboniferous succession of the Eastern Asturian Basin is tectonically split in two main outcrop belt arranged in an E-W elongated strip from Gamonedo de Cangas to Panes villages, east of Oviedo. The western part (about 50 km^2) is the main and wider. It includes the classical

Gamonedo, Inguanzo and Areñas de Cabrales outcrops and corresponds to the study area.

To better understand the stratigraphic and the tectonic evolution of the western part of the Eastern Asturian Basin a considerable effort was firstly devoted to the production of a detailed lithostratigraphic map (Figs. 18, 19 and 20) taking into account that the area experienced deformation in ?Gzhelian and ?Permian times. Facies analysis completed the field work.

Since now the upper Moscovian-lower Kasimovian succession of the Gamonedo-Areñas de Cabrales area has been investigated mainly through a biostratigraphical approach (Marcos, 1967; Martinez-Garcìa, 1991, *cum bibl.*). Our field data concern both the sedimentary and tectonic evolution including syn-sedimentary tectonics. Field data and interpretation are presented and discussed in two separate chapters.

The first chapter deals with the stratigraphic and sedimentological analyses of the classic and well known profiles of the succession: the Gamonedo, Dobros and Rio Cares (Areñas de Cabrales) sections. They comprise the lowermost beds of the succession which unconformably overlie the substratum folded during the so-called *Leonian* phase.

The second chapter is devoted to the tectonic data. They are related to both a) the effects produced by the *Leonian* compressions on the substratum and b) the syn-sedimentary tectonics which affected the basin during late Moscovian-early Kasimovian times. Syn-sedimentary tectonics played a fundamental role since the master syn-sedimentary faults were inherited from the Leonian compression. Besides, the chapter analyses c) the post-Kasimovian compressions which affected the basin itself and once more produced reactivations in some among the faults.

Stratigraphy of the lowermost unconformable succession

In the Eastern Asturian Basin the oldest terms of the Upper Carboniferous succession have been dated by several Authors by means of fusulinids and macrofloras.

Literature provides available data in four sites. They are, from the west to the east, Gamonedo, Inguanzo, Dobros, and Areñas de Cabrales (for location see Fig. 2). In particular, the Gamonedo and Dobros sections (Figs. 5 and 7) correspond to the stratotypes of respectively the Gamonedo and Dobros Fms. (Martinez-Garcìa and Villa, 1986; Villa and Martinez-Garcìa, 1989). In each section the lower beds which unconformably rest on the pre-upper Moscovian substratum have different ages from site to site.

More in detail, the Gamonedo succession is of upper Moscovian age (Martinez-Garcìa and Villa, 1986; Villa, 1989); the basal limestone beds of the Inguanzo succession have an 'upper Cantabrian' (lowermost Kasimovian) age (Wagner *et al.*, 1970). The lower deposits of the Dobros succession are lower Kasimovian (Villa and Martinez-Garcìa, 1989) and almost the same age is for the Areñas de Cabrales succession (van Ginkel, 1971; Tryols *et al.*, 1984), so that the age of the lower unconformable beds becomes younger and younger from Gamonedo to Areñas (Martinez-Garcìa and Wagner, 1971; Martinez-Garcìa and Villa, 1986).

The stratigraphic scheme (Fig. 3) also benefits under some newfound fusulinid bearing sites (Fig. 23 and Pl. 1). They are mostly located in the western part of the study area. As concerns the biostratigraphic control, it is plain that both the western part of the study area (Gamonedo-Monte Casano) and the eastern one (Inguanzo-Dobros-Areñas de Cabrales), which experienced strong deformations in post-Kasimovian times, are better investigated with respect to the little deformed central part (Fig. 2). This fact allows both litho- and biostratigraphic correlation between the western and eastern successions through the central lithozone (Figs. 2 and 3).

The following data concern three stratigraphic columns placed on the opposite sides of the study area and measured in the early sediments which overlay the *Leonian* unconformity. They are respectively the Gamonedo (Cuesta del Texo), the Dobros and the Rio Cares (Areñas de Cabrales) sections.

Gamonedo section (Cuestas del Texo)

This section has been measured along the northern cliff of the Cuestas del Texo, north

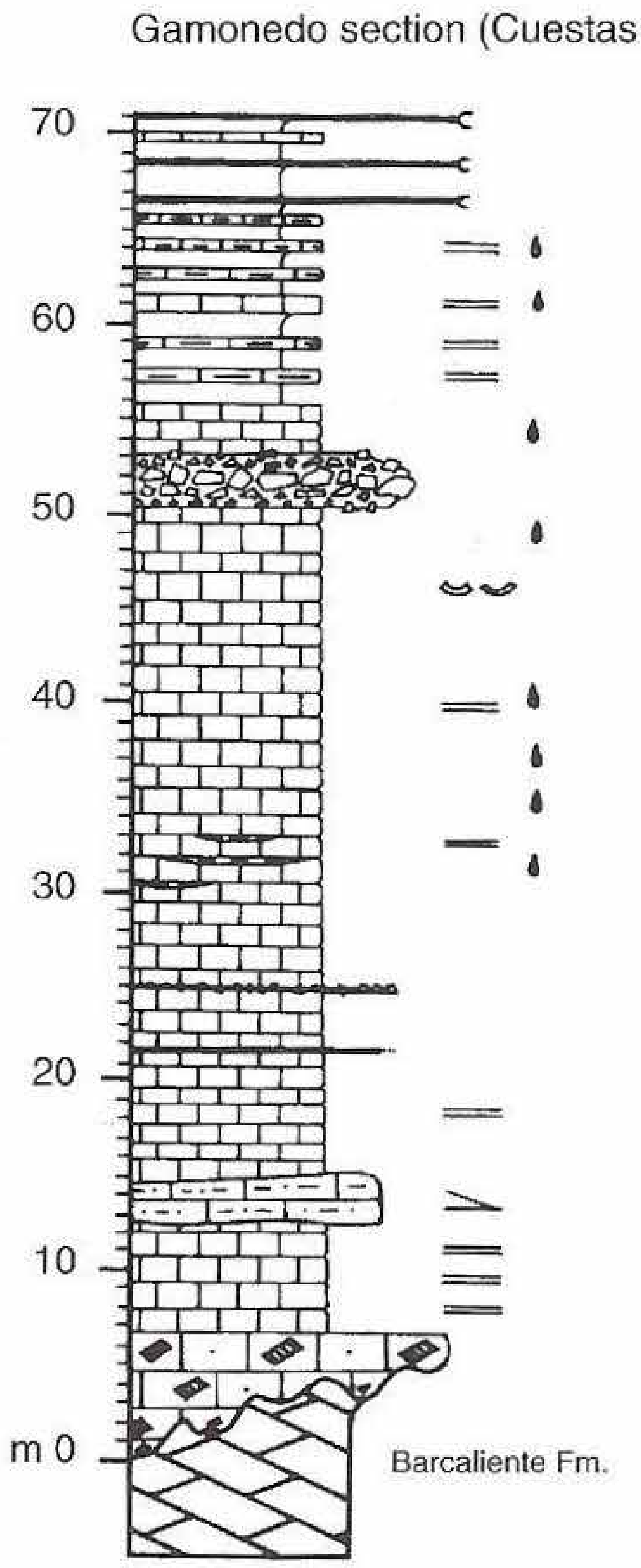


Fig. 4 - The Gamonedo stratigraphic columnar section, upper Moscovian. For location see Figs. 2 and 3. Symbols in Tab. 1.

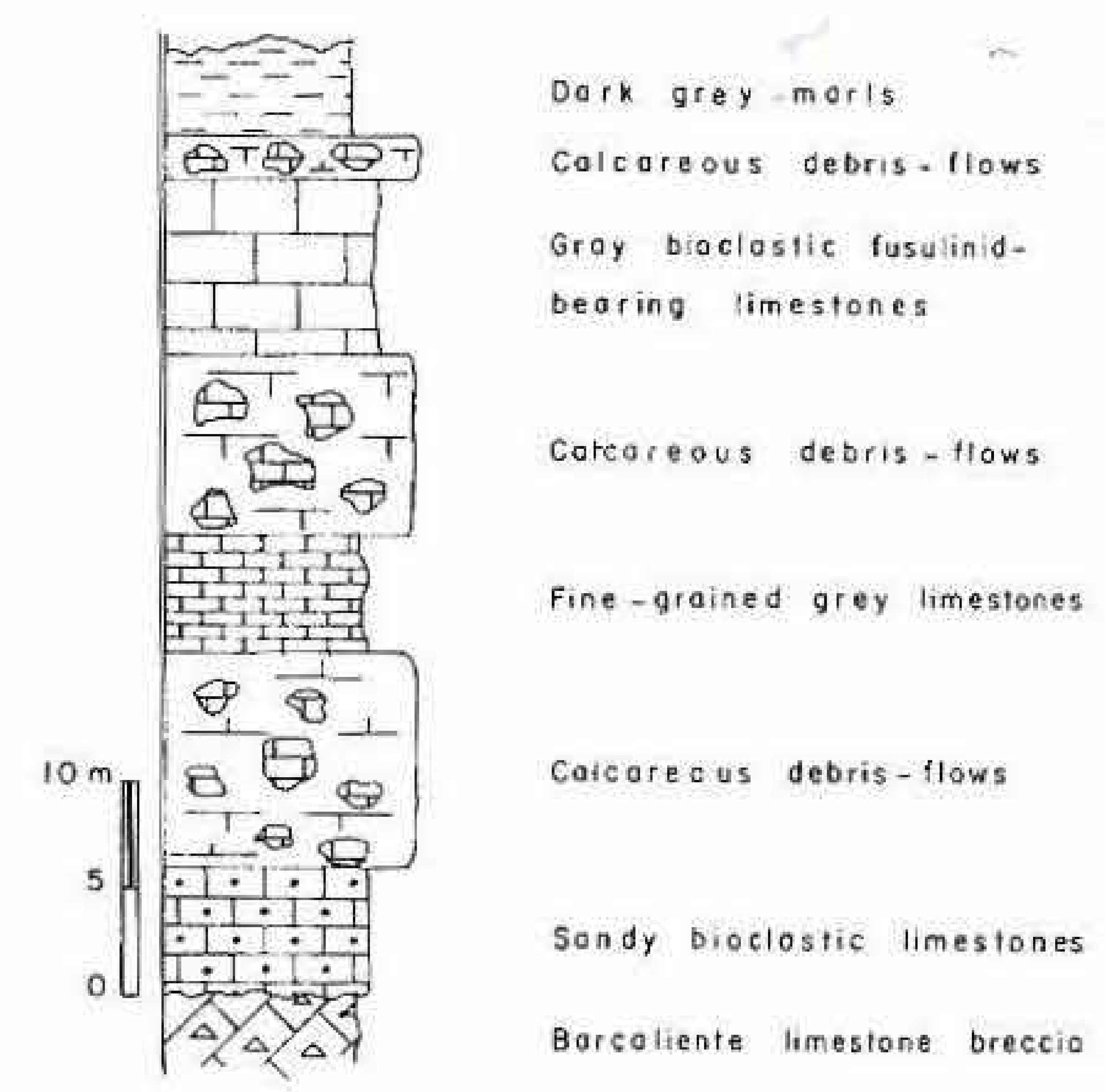


Fig. 5 - The Gamonedo Fm. stratotype, upper Moscovian (after Martinez-Garcìa, 1991).

of Gamonedo de Cangas. Here the *Leonian* unconformity is well exposed (Fig. 4).

The substratum is represented by the Barcaliente Fm., of lower-upper Moscovian age. It is made of thick light gray stromatolitic dolostones, black at exposure, and limestones. An erosion surface, with 4-6 m deep pockets probably due to karst dissolution, marks a well visible 30° unconformity.

The unconformable upper Moscovian succession starts with slightly reworked encrinites drapping the surface and filling the ?solution pockets. Their thickness ranges from 1.5 to 7 m. Almost 50 m of well bedded pelmicrites with at places parallel laminations follow. Rare large micritic intraclasts are present together with up to 5 cm sized oosparitic fragments. The micrites locally interfinger with thin calcsiltites which also form a 2 m thick level with cross bedding foresets and sharp but not erosional base. Thin chert lenses are present in the middle part of the limestone lithosome. In the upper part, a 3 m thick limestone breccia occurs. It consists of four overlapping debrites with angular and stratal fragments up to 20 cm in size. The clasts look reworked from both the unit itself and the substratum.

Towards the east, at about three hundred meters far from the measured section, the lower part of the micritic limestones is replaced by 10 m at least of fine biocalcarenites with amalgamated hummocky cross bedding. The upper part consists of massive limestones (30-40 cm thick beds) interfingering with parallel laminated pelmicrites and patchy thin calcsiltites with hummocky cross lamination. The carbonate lithosome grades upward to marls. A 20 cm thick oncolithic bed with 2 cm sized elements is also present. In both cases, the about 50 m thick limestone lithozone alternates upwards with marly limestones, calcareous marls and increasing marls. The whole thickness is over 55 m. The lowermost marls interfinger with 10-20 cm thick coal horizons.

Amalgamated debris flow deposits (4.4 m) are visible 30 m under the the transition from limestone to marl. They consist of angular clasts, up to 20 cm in size, of shallow water bioclastic limestones and plentiful crinoid fragments.

In the Gamonedo surroundings another section provides interesting data. It was published by Martinez-Garcìa and Villa (1986) and corresponds to the stratotype of the Gamonedo Fm. (Fig. 5). It is coeval and heteropical with the before described successions. However, it differs from the here described Gamonedo section owing to the larger amount of carbonatic debrites which interfinger with thick micritic to fine bioclastic limestones. This succession is dated to upper Myachkovian (uppermost Moscovian) by the presence of *Fusulinella schwagerinoides alvaradoi*, *Fusulinella brañoserae*, *Fusiella* cf. *typica sparsa*, *Schubertella* ex gr. *toriyamai*, *Schubertella* ex gr. *obscura*, *Schubertella* ex gr. *paraobscura*, *Millerella* cf. *mutabilis postera* (Villa, 1989).

Interpretation. The Carboniferous substratum, which experienced the *Leonian* folding (cfr. Tectonics), was partly eroded and/or karstified. The upper Moscovian transgression restored the Gamonedo area to the marine sedementation. Thick little reworked crinoidal beds are indicative of stable open shelf conditions without terrigenous pollution. Upwards and laterally, the environment graded to a protected lagoon (parallel laminated pelmicrites) with rare tidal bars, or a storm dominated shallow sea (lower shoreface with hummocky cross stratification). The massive limestone facies, which develops in the eastern section only, could represent part of a barrier-platform interbedded with the lagoon facies.

The carbonate debrites occurring at places are indicative of tectonic activity in the nearby areas. At present there are no data about the age of the reworked clasts; most of them look as belonging to the Gamonedo Fm. The fact would be coherent with weak syn-sedimentary movements still confined within the basin. The thick but not widespread debrites seemingly support this hypothesis. In the upper part of the succession the limestone to marl transition is here interpreted as the reflection of a regression trend.

Dobros section

The section develops at about 550 m altitude along the path climbing from the Poo village towards the south-southwest (Fig. 6). The *Leonian* angular unconformity (25°) is quite visible. It parts the Barcaliente Fm. (Moscovian limestones and dolostones) from a lower Kasimovian succession. The succession starts with basal carbonatic breccias (0-80 cm) deriving from the underlying formation and filling irregular scars, presumably karstic.

The lower part of the unconformable succession (about 25 m) consists of alternating intrabasinal carbonates and terrigenous sediments. The carbonates are algal limestones organized in up to 2.6 m thick banks. The only basal limestones have *in situ* (or very little reworked) *Dasycladaceae* and phylloid algae. The most frequent calcareous facies is made of bioclastic storm layers mostly made of broken algae and rare fusulinids. The terrigenous input usually consists of pelites with frequent bioturbation, plant remains and hummocky cross laminations. An isolated conglomeratic body (1.2 m) occurs with well rounded clasts up to 5 cm in diameter and erosional base.

The upper part of the section shows the gradual transition from intrabasinal to terrigenous lithofacies. The uppermost carbonates consist of marly limestones interlayered with increasing marls. Marls grade to about 30-40 m of mudstones, bioturbated at places, which upwards alternate with siltstones.

Not far from the measured profile crops out the stratotype of the Dobros Fm. (Fig. 7), described in Villa and Martinez-Garcìa (1989) and Martinez-Garcìa (1989). It is dated to lower Kasimovian, equivalent to the Khamovnichesky Horizon of Russia on the base of *Triticites* (*Montiparus*) *priscus* sp. nov., *Triticites* (*Montiparus*) spp., *Fusiella* ex gr. *lancetiformis*, *Fusiella* ex gr. *rawi* and *Ozawainella* sp.

The stratotype is coeval with the lower part of the Dobros section. Remarkable is the occurrence of debris flow deposits, 1-8 m thick, which lack in our section. They interbed with carbonate facies common to both sections.

Interpretation. The lowermost algal limestones resting on the karstified substratum record a transgression followed to the main *Leonian* unconformity. The algal storm layers mark a shallowing upward trend. Sedimentation occurred in a carbonate shelf with recurring extrabasinal inputs. They first

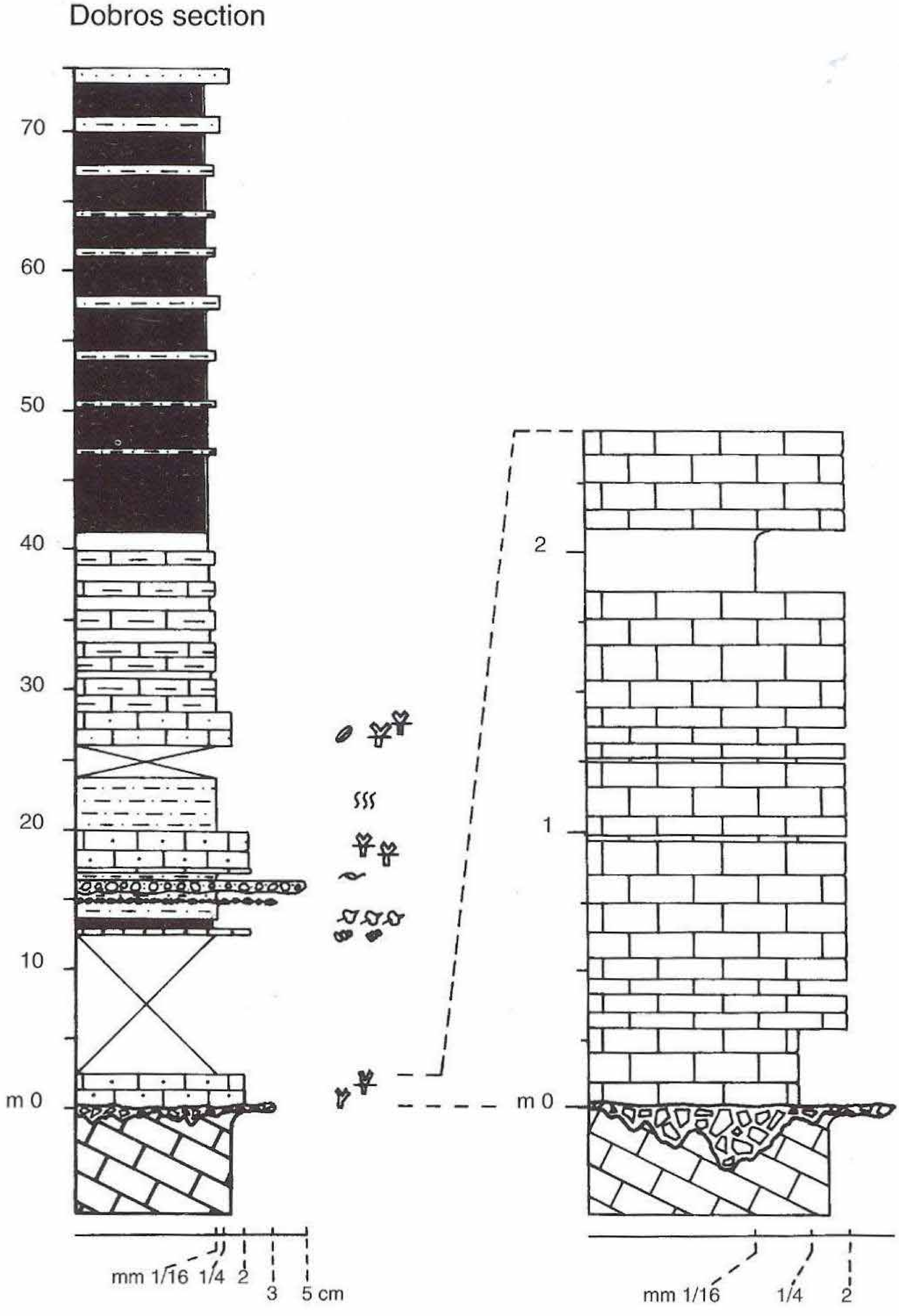


Fig. 6 - The Dobros stratigraphic column, lower Kasimovian. For location see Figs. 2 and 3. Symbols in Tab. 1.

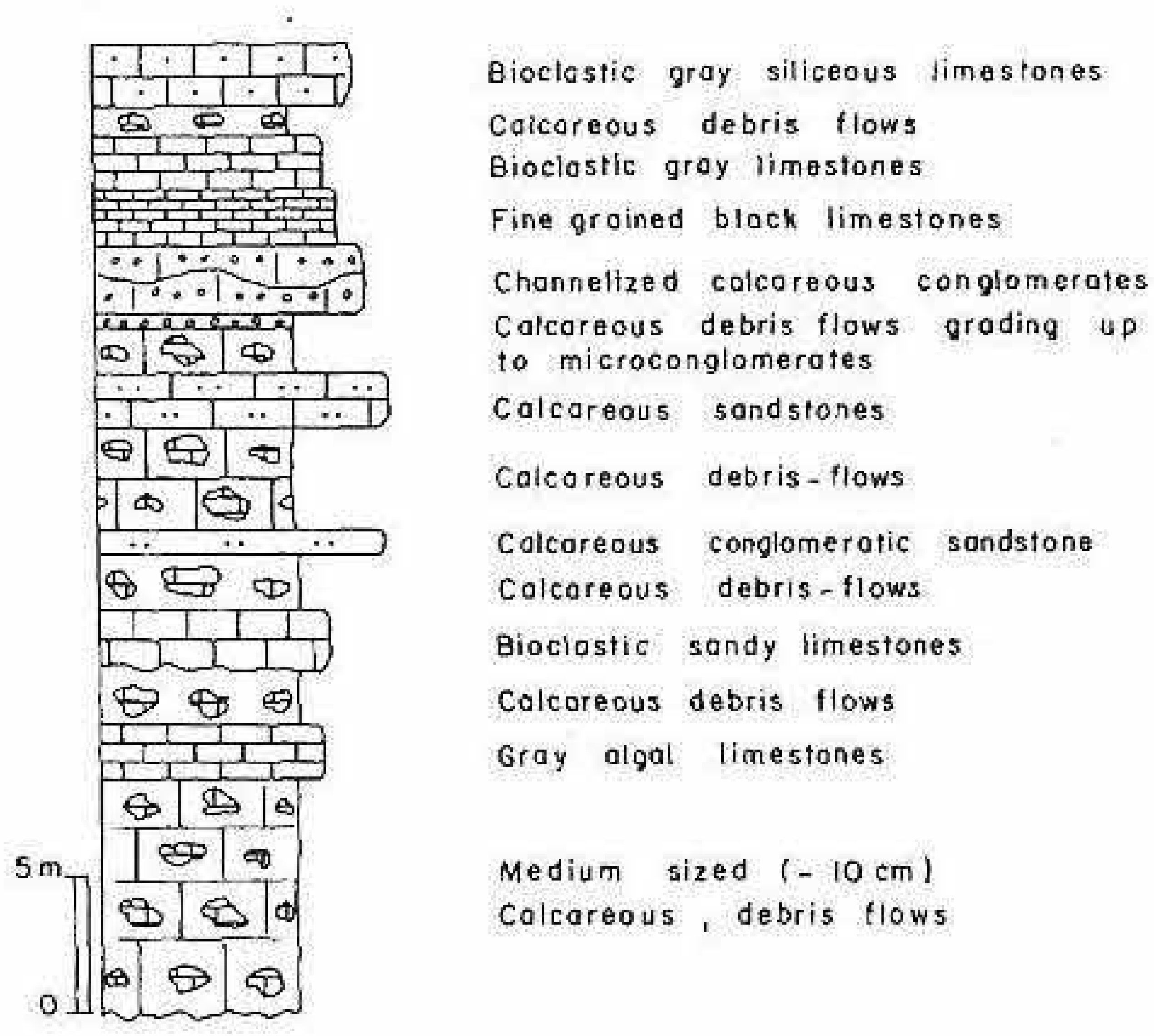


Fig. 7 - The Dobros Fm. stratotype, upper Moscovian (after Martinez-Garcìa, 1991).

occur as quartz and carbonate deposits organized in a coarsening and thickening upward sequence ending with a channalized conglomerate body. The channel fill can be interpreted in a fluvio-deltaic setting (cutting a mouth bar). The reduced thickness of the sequence could be related to sudden tectonic uplift of emerged areas close to the basin margin.

The upper part of the profile records the transition from offshore carbonatic shelf deposits to prodelta fine grained terrigenous sediments (distal mouth bar) with a gradual coarsening upward trend. It presumably developed in high stand sea level conditions.

Rio Cares section (Areñas de Cabrales)

The section crops out along the main road, few hundred meters southwest of Areñas de Cabrales. First it develops on the Rio Cares right side, then, after a bridge, on the left one. The substratum consists of lower-upper Moscovian limestones and dolostones (Barcaliente Fm.) cut by an erosion surface. It is covered by 0-50 cm of limestone breccia which fills scours made in the substratum. The erosional gap is marked by a 24° angular unconformity. About 50 m of exposed succession follow. The profile opens with 23 m of prevailing quartz sandstones passing upwards to 24 m of conglomerates and debrites made of carbonate clasts and interfingered with increasing bedded micrites and dolomites.

The succession has been subdivided into 13 intervals (A-O) on the base of the facies analysis (Fig. 8). From bottom to top:

A – 0.5 m of fine not cemented sands with plant remains rest on the breccia horizon.

Interpretation. The deposit records a trasgression followed to the subaerial erosion (and presumably karst solution) of the carbonate substratum.

B – 4.3 m of bedded quartz-sandstones organized in fining upward sequences with erosional base. Thickness ranges from 0.5 to 1.5 m. When preserved, the topmost sediments of each sequence are capped by intensely bioturbated very fine grained sandstones or siltstones. Wood remains are present. Internal structures are not always well preserved. At places individual beds exhibit planar lamination.

Interpretation. The facies represents the fill of nested channels producing a multistoried complex. Lacking more sedimentological data and comparing the facies with the similar one stored up in the D interval, it is tentatively referred to the fill of fluvial entrenched channels.

C – Thin mudstones with 10 cm thick coal horizon covered by half meter of highly bioturbated siltstones which pass into ca. 1 m of fine silty sandstones organized in horizontal dm thick beds. Their trend is thickening and coarsening upward.

Interpretation. The facies could represent overbank sediments lateral to the fluvial channels of an alluvial plain with swamps which evolved into a shallow lake rapidly filled by silts and silty sands presumably related to crevassing.

D – 9 m of quartz sandstones organized in stacked channalized bodies with erosional base and fining upward trend. Plane parallel laminated beds (25-30 cm) show clinostratification. Each channel fill is thicker and coarser than the older. The topmost one is characterized by thin and pelitic horizons (2-3 cm) interbedded with the epsilon-cross stratified sandstones.

Interpretation. Lateral bar of fluvial sinuous channels. The coarsening trend is supposed as induced by fluvial progradation in high stand conditions. Pelitic draping in the uppermost channalized body could indicate the approaching of an estuarine environment.

E – Black coal siltstones (5-15 cm), interbedded with a thick coal horizon, draping the uppermost quartz-sandstone bed. Parallel laminated siltstones (50 cm) with several plant remains follow. They pass to hummocky cross laminated quartz siltstones (10 cm) with intrabacinal algal bioclasts. The interval is capped by black bioturbated marls (30 cm) with thin and scattered siltstone beds with hummocky cross laminations.

Interpretation. The lower beds could represent the clay plug of an abandoned fluvial meander. The upper layers testify to marine ingression. The ox-bow lake first turned into a swamp than was submerged by shallow sea whose bottom was occasionally winnowed by storms.

F – 5-10 cm thick siltstone beds with parallel lamination interbedded with thin bioturbated mudstones and marls followed by ca. 1 m of fine pebbly sandstones in 5-10 cm thick beds with sharp but not erosional base. Thick tabular beds of fine sandstone follow with parallel laminations and not erosive base. Then, 2 m thick channelized sandstone body with scars up to 50 cm deep with a carbonate lag of 1-3 cm rounded clasts is present. 3 m of quartz-sandstones follow, mixed at places with rounded carbonatic clasts and limestone conglomerates with basal erosion surfaces. The whole sequence shows a well defined coarsening and thickening upward trend. The channel fill, instead, is fining up and clinostratified.

Interpretation. The lower siltstones and sandstones can be interpreted as the distal to proximal mouth bar of a prograding deltaic wedge. The 2 m thick channelized body could represent the encroaching distributary channel. Coarser alluvial deposits follow. The sandstone and conglomerate composition testifies to two distinct coeval sources. They both pertain to the substratum succession: the Ordovician 'quarzites' and the Carboniferous (pre-*Leonian* phase) limestones and dolostones.

G – The former deposits are abruptly covered by marly pelites with thin siltstone beds. Well preserved macrofloras and large unbrocken *Pecten* shaped bivalves have been found.

Interpretation. The fine terrigenous facies suggests a lagoonal environment associated with a transgressive pulsation.

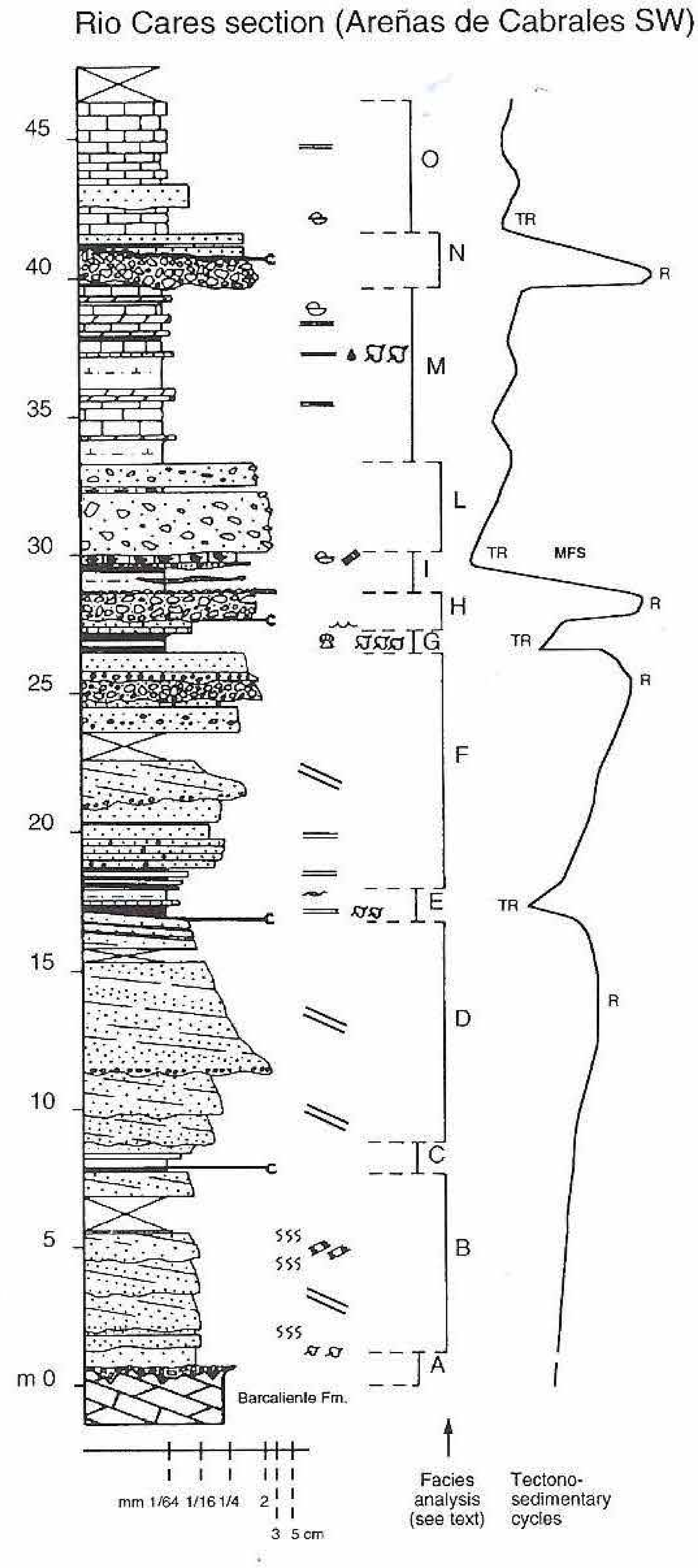


Fig. 8 - The Rio Cares section (Areñas de Cabrales SW), lower Kasimovian. For location see Figs. 2 and 3. Symbols in Tab. 1.

H – Half meter of calclithites overlying the fine sediments with sharp but not erosional contact. Wave ripples, and scours draped by a thin coal seam are observed. A further erosion surface introduces a conglomerate made of rounded carbonate clasts with 1 cm maximum size.

Interpretation. Erosional scores have canceled a substantial part of the succession. The conglomerate is tentatively interpreted as fluvio-deltaic.

I – A thin residual lag made of 5 cm sized carbonate rounded clasts overlies the conglomerate and is covered by marly pelites, passing to a pebbly sandstone lens made of extrabasinal limestones. At the top, a carbonate condensed horizon rich in brachiopods, crinoidal debris and algae occurs.

Interpretation. A rapid rise of the relative sea level and reduced sediment input led first to the formation of the transgression shoreface lag and then to the spreading of muddy offshore deposits. The following condensed horizon records maximum marine flooding conditions.

L – A 3 m thick debris flow deposit is present. It consists of four pebbly sandstone 'events' showing sharp but not erosional base made of calcareous extrabasinal clasts. They form together a thinning and fining upward sequence.

Interpretation. The facies represents gravity emplaced submarine deposits. Sedimentary features exclude that they are part of a prograding deltaic system. On the opposite, it is possible that they record submarine slidings of proximal mouth bar facies induced by seismic shocks or gravity failure.

M – Marly siltstones and upward increasing bedded micrites. Frequent dm-thick dolostones, laminated at places, interbed with limestones. A thin siltstone bed with both carbonate and quartz grains, is present. It is black, bituminous and rich of plant remains.

Interpretation. Carbonate platform with restricted lagoon to open shelf conditions are inferred. The lithosome needs more microfacies investigations to be more precisely defined.

N – The limestones are overlain by a 1.3 m thick carbonate conglomerate body with basal erosional surface. Its top is cut into by an irregular surface draped with a 0-30 cm coal seam. Half meter of coarse carbonate sandstones follow; they interbed with thin siltstone beds.

Interpretation. A rapid fall of the relative sea level induced the sudden downward shift of the fluvial facies which intersected the carbonate platform deposits. Two stacked sequence boundaries are recorded in a close space. The coal seam and the overlying sandstones (?shoreface) attest the in progress transgression trend.

O – About 5 m of laminated micrites with ?eolic silt mark the end of the measured profile. A massive quartz grainflow (0.8 m) interbeds with limestones; the base is weakly erosive.

Interpretation. Carbonate platform conditions (lagoon to open sea) became prevalent again (cfr. M interval). The grain flow could be genetically comparable to the L interval.

Tectonics

From the late Moscovian to Permian times, the Gamonedo-Areñas de Cabrales area experienced deformations different in kind and orientation. The oldest tectonic structures of late Moscovian age (Wagner and Martinez-Garcìa, 1974) are related to the so-called *Leonian* phase. They are followed by syn-sedimentary tectonics which led to the opening of the Eastern Asturian Basin and favoured the accumulation of the upper Moscovian-Kasimovian succession. The youngest deformations are the result of presumed Gzhelian to Permian compression.

Late Moscovian tectonics: the Leonian phase

The well exposed *Leonian* unconformity has been checked along the southern margin of the basin. On the opposite side, the northern margin is buried under a younger thrust surface (Fig. 2). Close to the unconformity, the strike and dip of both the over- and the underlain successions have been measured (ignoring primary clinoforms). The upper beds have been back-tilted to obtain the former horizontal palaeosurface. As a consequence, the lower beds too modify their trend giving an idea about the orientation they inherited quite before the deposition of the upper unconformable succession. The pre-and post-tilting values are reported in Fig. 9.

The southern margin of the Eastern Asturian Basin – As concerns the *Leonian* unconformity, some considerations can be put forward. Four main syn-sedimentary faults of late Moscovian-early Kasimovian age have

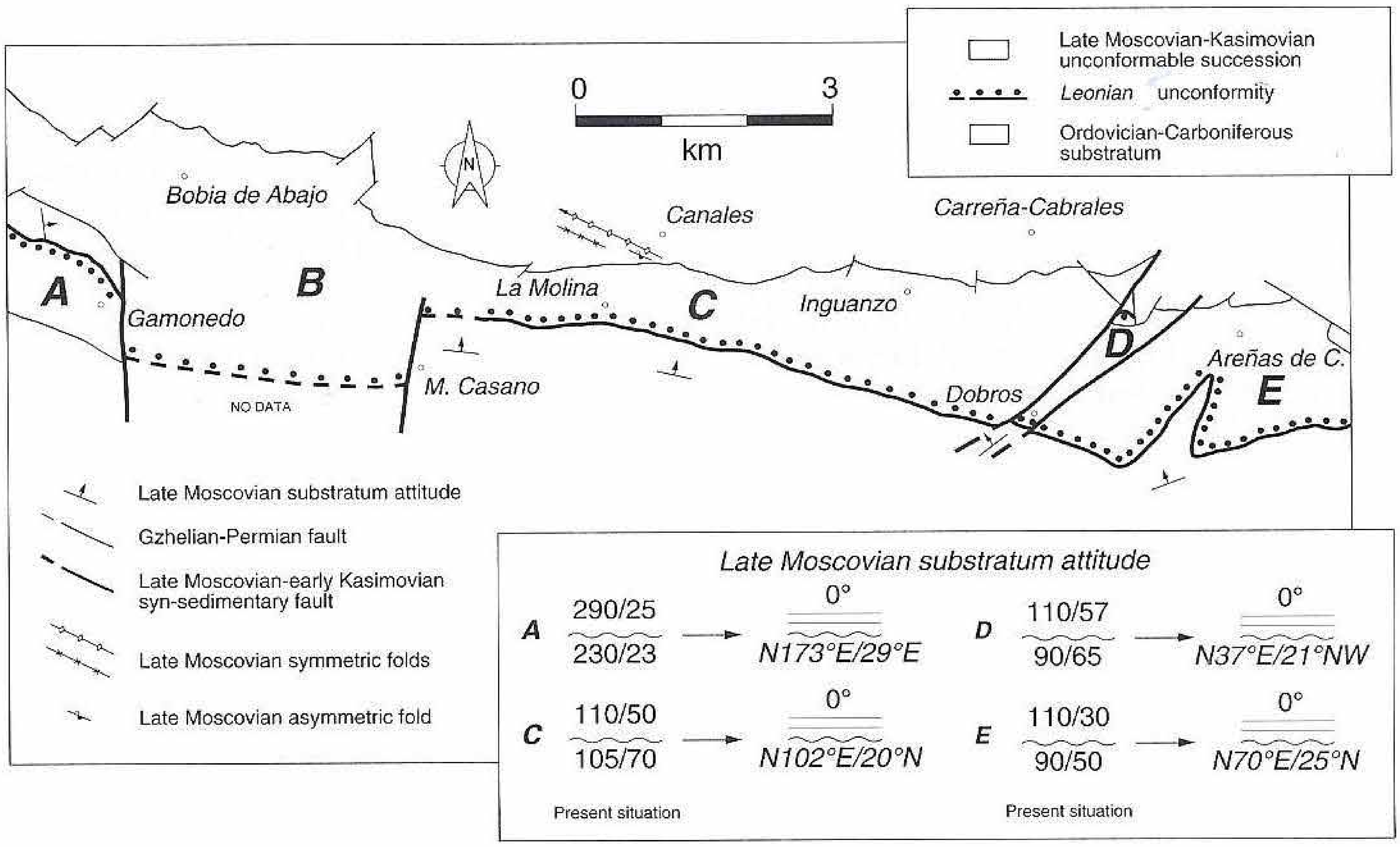


Fig. 9 - The late Moscovian substratum attitude is shown. It is obtained through the back-tilting of the present bed setting. The basin has been subdivided into five zones (*A-E*) bounded by sub-vertical faults already active during the *Leonian* compression as conjugate strike-slip faults. In the Monte Casano area, the remarkable ?Permian deformations have been removed (see geologic map of Fig. 2).

been recognized on the field (Fig. 9). Each fault has been inferred from the type, distribution and thickness of lithofacies and the age of the lowermost unconformable beds suturing the nearby substratum (see after). The faults belong to N-S and NE-SW trending systems. The N-S system is present in the western part of the study area (Gamonedo and Monte Casano palaeofaults), the NE-SW system is developed in the eastern part (Poo and Dobros palaeofaults). Besides, the NE-SW trending faults show reactivations due to the ?Gzhelian and ?Permian compression (Fig. 20). The faults acted as syn-sedimentary structures quite after the *Leonian* phase and drove the post-*Leonian* evolution of the Gamonedo-Areñas de Cabrales area (see after). This analysis reveals that they originated during the *Leonian* compression.

The mapped area has been subdivided into five zones (*A-E*) bounded by the quoted faults (Fig. 9). For each zone, the substratum attitude before the sedimentation of the unconformable succession has been worked out. In the study area the substratum is almost everywhere made of Bashkirian-Moscovian carbonates. Only north of Monte Casano (*C* zone), it consists of Ordovician 'quarzites'.

In the *A zone*, the sedimentation of the unconformable succession started in upper Moscovian. The substratum bed attitude was N173°E/29°E. The nearby palaeoline is the N-S trending Gamonedo palaeofault.

The *B zone* is the only devoid of data, owing to the effects of the ?Gzhelian and ?Permian tectonics (see after). However, it shows evidence attesting to severe syn-sedimentary movements during the deposition of the unconformable upper Moscovian succession (see El Escoboso section). The zone is bounded by the N-S palaeoline system (Gamonedo and M. Casano palaeofaults).

The *C zone* is the widest (7 km) among the five. The lower Kasimovian beds unconformably overlie the substratum which had a N102°E/20°N trending attitude. Besides, in the hangingwall of the Canales-Carreñas Thrust, occurs a N120E° trending fold system, with SSW vergence. At present, it plunges at high angle (40°) toward the west due to the NW-SE compression experienced by the area in the post-Kasimovian times. The fold system too can be ascribed to the *Leonian* phase compression.

In the *D* and *E zones*, the substratum was respectively N37°E/21°NW and N70°E/25°NW oriented during the lower Kasimovian sedimentation of the early unconformable beds. The zones are bounded by NE-SW trending palaeolines (Poo and Areñas palaeofaults).

Interpretation. In the *C zone*, the Ordovician-Moscovian substratum crops out for many km not broken by palaeofaults. The N120°E fold system and the N100°-105°E trending substratum attitude, sutured by the unconformable beds, were inherited in late Moscovian times during the *Leonian* compression. It happened scarcely before the sedimentation of the upper Moscovian sediments. We assume that, in the whole area

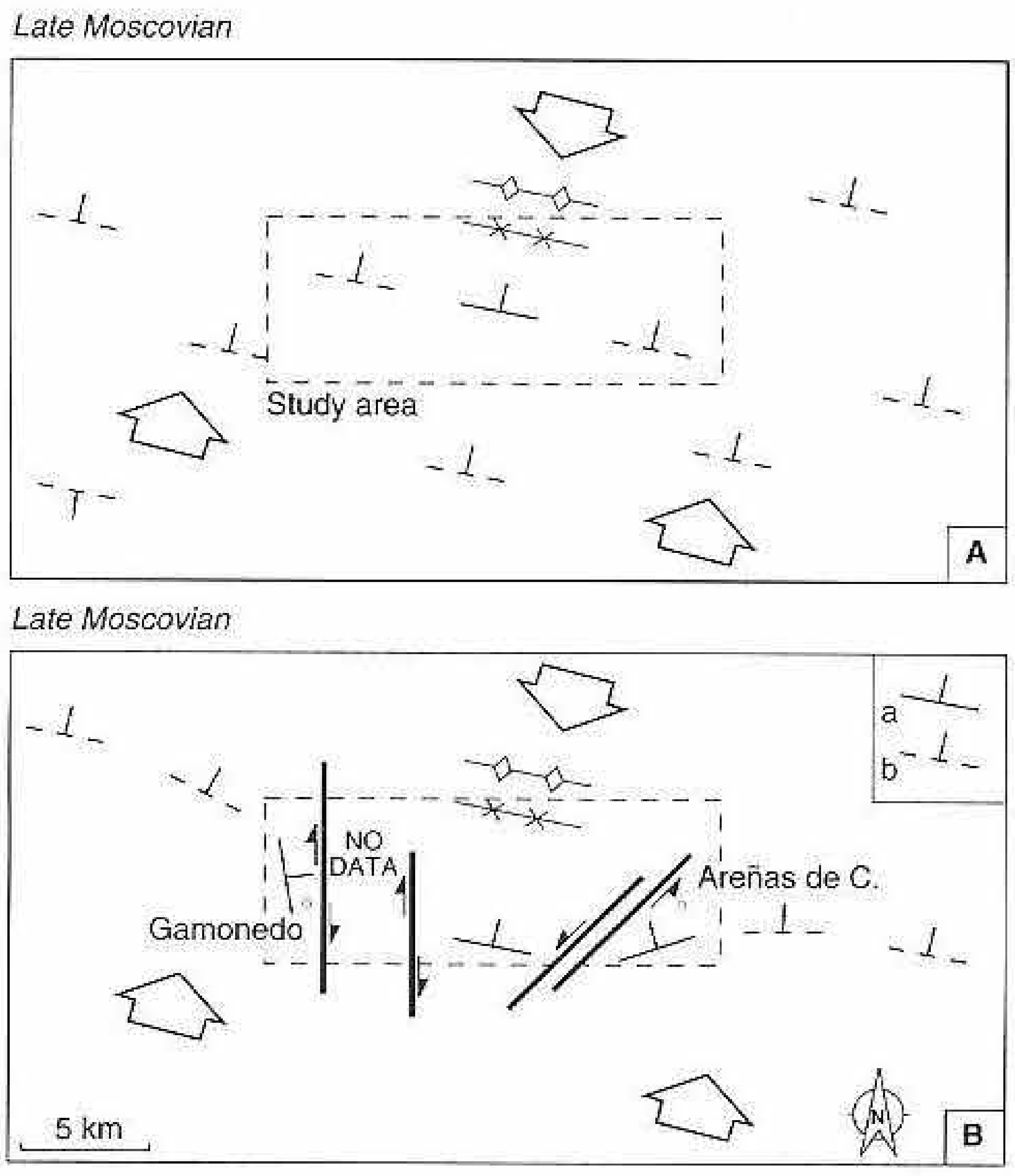


Fig. 10 - Tectonic evolution of the Gamonedo-Areñas de Cabrales area during the *Leonian* compression (late Moscovian). The large arrows show the inferred maximum stress direction. **a**, late Moscovian substratum attitude based on field data; **b**, inferred late Moscovian substratum strike. A fold system due to the *Leonian* compression is also shown.
A, production of open folds. **B**, twisting of the substratum attitude and growth of conjugate fault systems (black lines).

(*A-E zones*), the substratum was trending about N110°E (Fig. 10A) at least until the growth of the palaeofault systems. The inferred maximum stress was about NNE-SSW.

In the *A zone*, quite before the sedimentation of the upper Moscovian beds, the attitude of the substratum twisted from N100°E to N173°E and the dip changed from the N to the E. The effect can be explained as due to sinistral strike-slip movements along the N-S trending Gamonedo palaeofault (Fig. 10B).

On the eastern side of the study area (*D* and *E zones*) the substratum attitude turned from N100° E to N37°E and N71°E respectively and the dips from N to NW. The values are coherent with dextral strike-slip movements along the N50°E trending Poo and Areñas palaeofaults (Fig. 10B). Consequently, all deformations and movements during the *Leonian* phase happened in a close time span confined into late Moscovian (Marquinez *et al.*, 1982).

In conclusion, we assume that the *Leonian* phase produced the following effects:

1) the N100°-120°E trending substratum attitude (open folds);

2) two conjugate systems of strike-slip faults, N-S and NE-SW oriented;

3) local twistings due to the trascurrent movements induced along the conjugate faults.

All the tectonic effects seem the consequence of a steady local maximum stress NNE-SSW oriented.

Late Moscovian-lower Kasimovian tectonics: the post-Leonian movements

The second group of data concerns some newfound megabreccias and angular unconformities recorded inside the post-*Leonian* succession (upper Moscovian-lower Kasimovian).

The syn-sedimentary tectonics has been attested through the identification of repeated angular unconformities and amount of bed tilting, and the megabreccia occurences.

El Escoboso section (B zone) – A well exposed succession (Fig. 11) crops out along the road going round and climbing up the El Escoboso cliff, 1 km far from Demués, towards south-southeast. The *Leonian* unconformity (buried) seems not far (some tens of

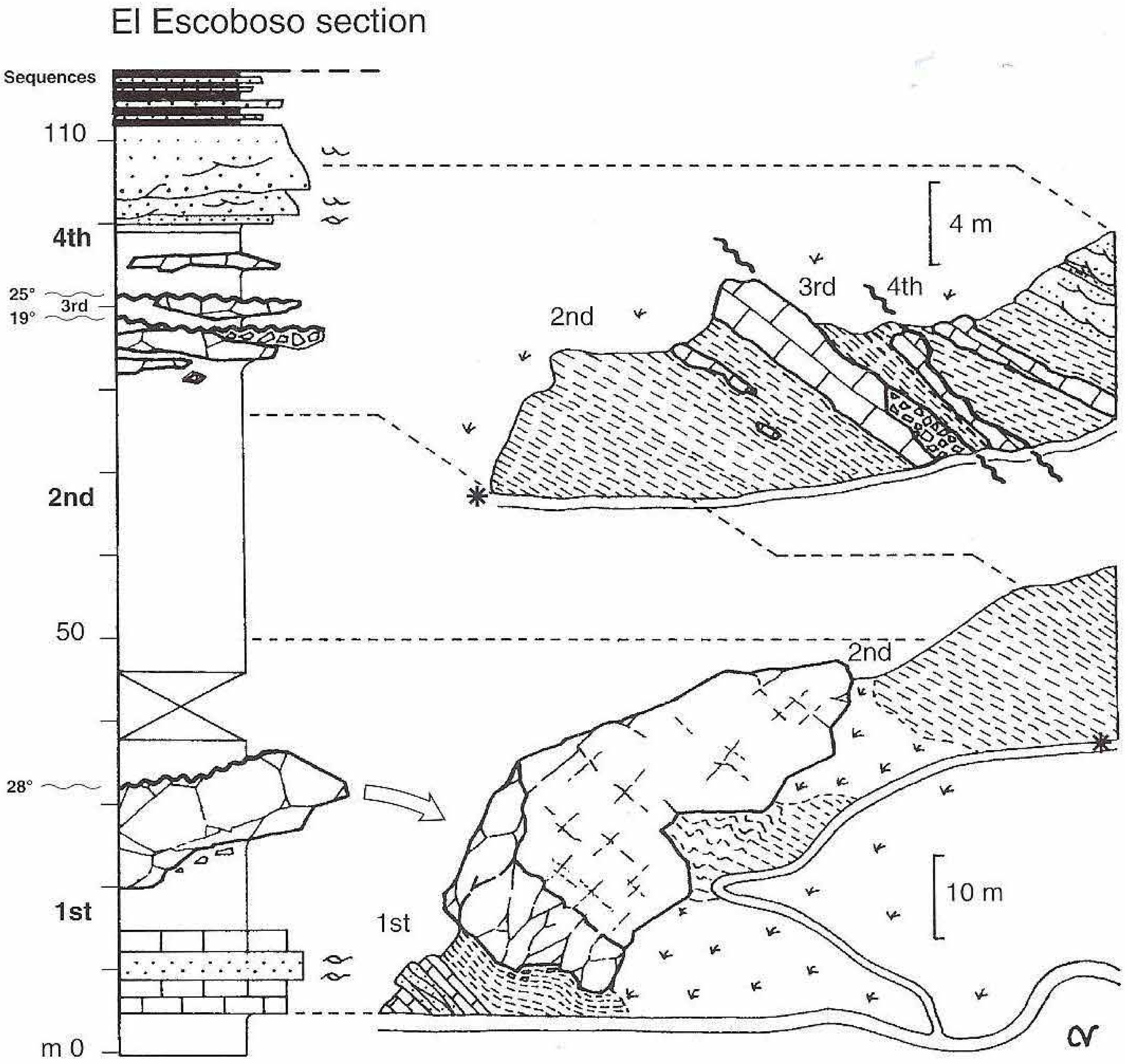


Fig. 11 - El Escoboso stratigraphic profile. For location see Figs. 2 and 3. Symbols in Tab. 1. Three intraformational unconformity surfaces have been recognized. They delimit four tectono-sedimentary sequences. At the sequence tops, megabreccia and debris flow horizons overlain by unconformable beds.

m) from the lowermost measured strata according to the upper Moscovian age of the sediments and the correlation with nearby sections (Fig. 3). The measured succession (Fig. 11) is made of more than 100 m of prevailing marls and calcareous marls passing upward into quartz sandstones. Three angular unconformities bound four staked sequences, each one capped by a megabreccia or debris flow horizon. The procedure shown in Fig. 12 obtains the amount (strike and dip) of the early tilting experienced by each sequence.

The lowermost megabreccia slide located at the top of the 1st sequence is the most evident and amazing. It mainly consists of a large carbonate boulder, irregularly shaped and more than 50 m of maximum lenght (Fig. 11). Contour is angular and corresponds to fracture systems. Lithology is similar to the ones recorded in the Moscovian substratum (Barcaliente Fm.) but fossil re-

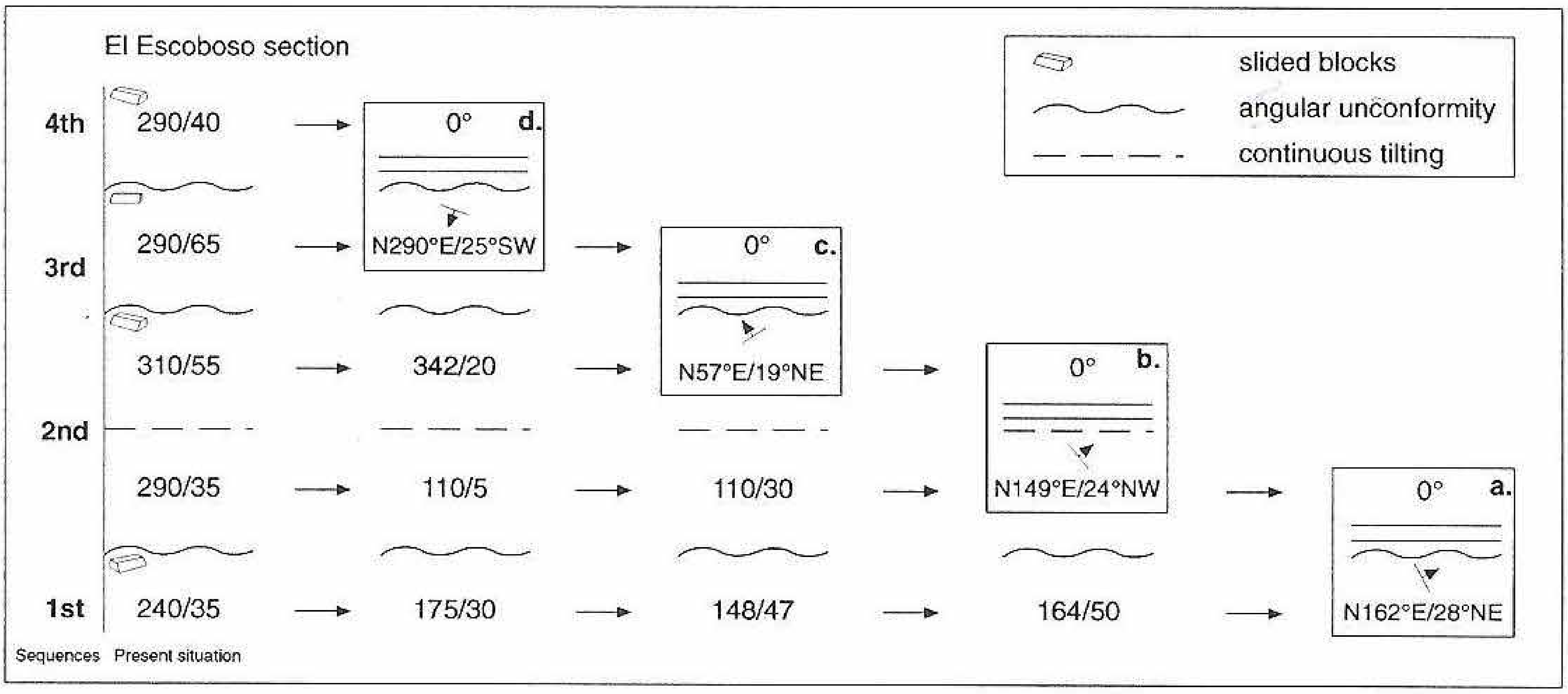


Fig. 12 - El Escoboso section. The successive back-tiltings (a.-d.) define the original bed settings as they resulted from the syn-sedimentary tectonic movements which led to stacked intraformational unconformities.

mains have been not found. A few small fragments of the same composition are present into the marls bounding the lower side of the boulder. The marls show peculiar load deformations near at the contact with the exotic boulder. It is stratified at places and its attitude (N340°E/65°SW) is different with respect to that of the marls (N240°E/35°SE).

Along the steep road climbing the outcrop, the 1st sequence is sutured through a 28° angular unconformity by some ten metres of marls and limestone marls with scattered bryozoans. The upper marls contain some large olistoliths (Fig. 11). The boulders are internally bedded and irregularly shaped. Their maximum sizes are respectively >2 m × 0.3 m and >10 m × 0.5-3 m. They consist of encrinites with large crinoidal fragments. The lithofacies is quite similar to the basal crinoidal limestones (1-7 m) which crop out at the very base of the Gamonedo section that is significantly located only few hundred meters far from the El Escoboso section (Fig. 2). It is further noted that the Gamonedo and El Escoboso sections face the opposite sides of the main N-S trending Gamonedo palaeofault (Fig. 3). The large boulder is part of a 3 m thick debrite mainly made of 3-7 cm sized carbonatic breccia. Some breccia elements contain a fusulinid fauna (Fig. 23) with *Hemifusulina* aff. *elegantula* Rauser, *Neostaffella* and *Millerella*, attesting also to the reworking of the lower-middle Moscovian substratum.

The strike of the 2nd sequence attitude turns slowly from the present N290°E/35°S of the lower beds, to the N300°E/55°SW, N305°E/55°SW and N310°E/55°SW in uppermost beds, which are sutured through a 19° angular unconformity by the 3rd sequence. It consists of 0.6 m thick marl limestones with, at the very top, a large exotic crinoidal limestone boulder (>3.8 m × 0.25-0.75 m) similar to the formers.

The 4th sequence follows after a 25° angular unconformity. It is made of about 7 m of marly limestones and marls with a further limestone boulder (> 2.5 m × 0.8 m). The marls upward grade to increasing silicoclastics without detectable unconformities.

Interpretation. The stacked sequences, the unconformities and the coarse marine debris flows and megabreccias with large angular olistoliths slided from nearby sources, all point out strong syn-sedimentary tectonics (Figs. 13 and 14). The movements can be dated as late Moscovian, according to the presence of *Fusulinella* spp. (Pl. 1) found in the same succession, about 90 m above the top of the last unconformity (Figs. 18 and 23, sample Ñ 144). Looking at the stratigraphic scheme (Fig. 3) the vertical movements can be interpreted as due to extensional or

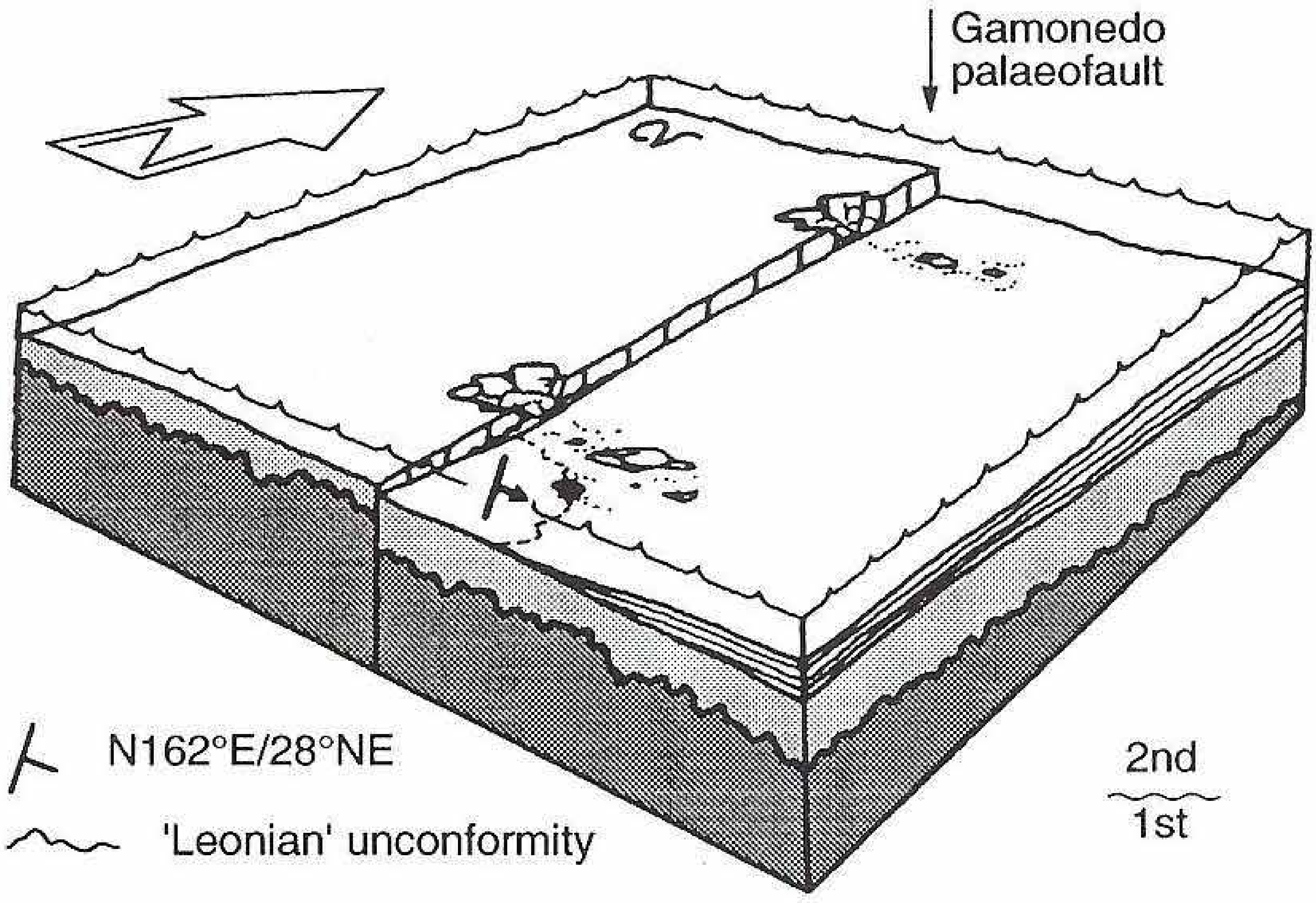


Fig. 13 - El Escoboso section, upper Moscovian. The 3D reconstruction depicts the syn-sedimentary activity of the Gamonedo palaeofault. The lower intraformational unconformity and the induced tilting are represented.

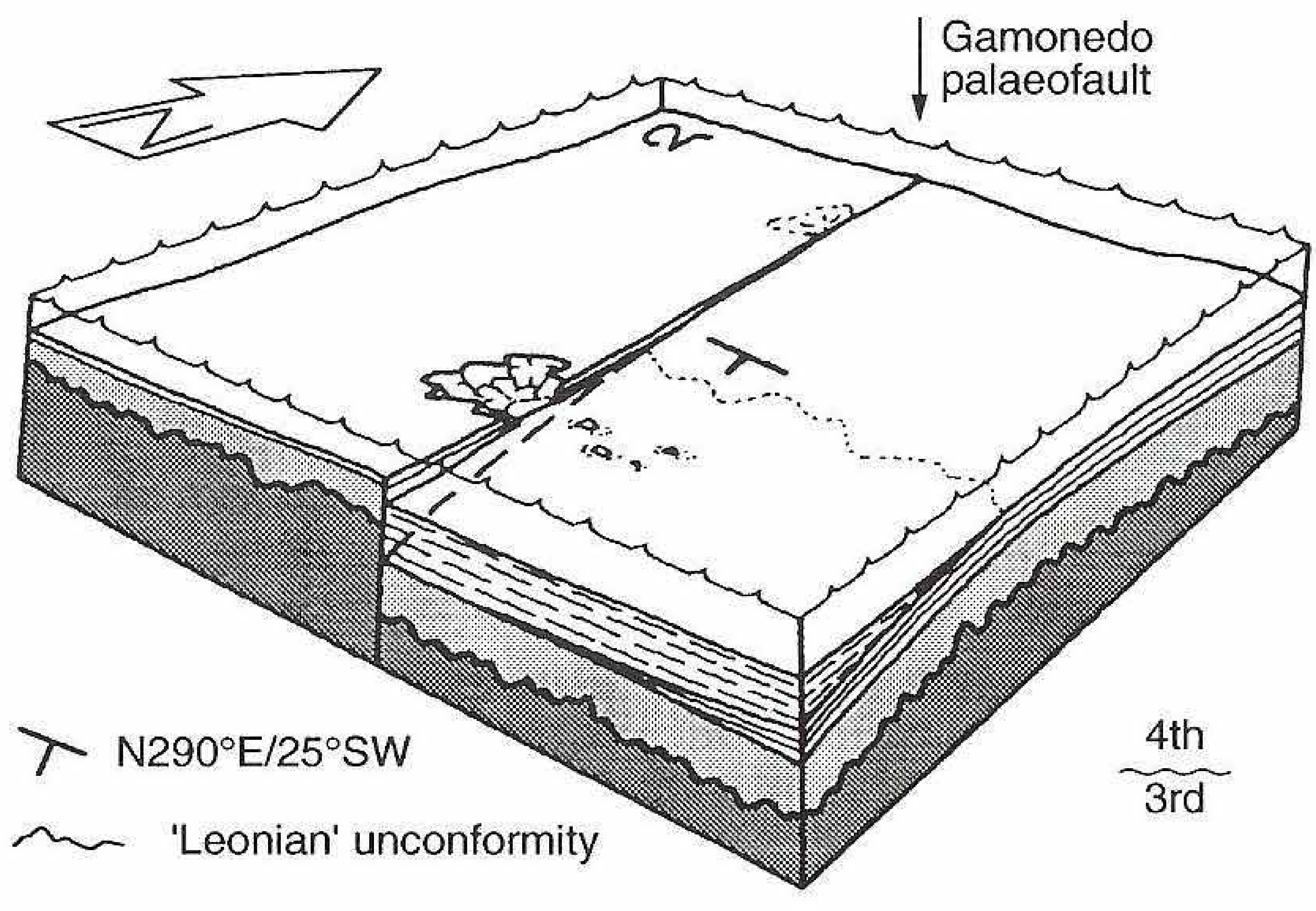


Fig. 14 - El Escoboso section, upper Moscovian. The 3D reconstruction depicts the syn-sedimentary activity of the Gamonedo palaeofault. The uppermost intraformational unconformity and the induced tilting are represented.

transtensional tectonics active in the early life of the Eastern Asturian Basin.

La Rebollada section (C zone) – The section is located 0.7 km far from the Poo village, towards the southwest (Fig. 15). It crops out quite near the La Rebollada farm. Lithostratigraphical correlations suggest a lower Kasimovian age. The succession consists of some metres of basal marls and limestone marls followed by a 12 m thick megabreccia made of shelf limestone boulders and cobbles. The breccia is made of two overlapping debrites, 9 m and 3 m thick respectively. The basal horizon has angular boulders (1 m maximum size) coming from a nearby source made of Moscovian substratum.

Almost 3 m of turbiditic layers follow. They consist of extrabasinal coarse to fine grained carbonate sandstones mixed with less terrigenous quartz, and are organized in 5-10 to 30 cm turbiditic beds. Another megabreccia occurs near at the top. Two debris flow deposits, 3 m and 5.5 m thick, are visible. The lower event includes a huge shelf limestone boulder (≥ 6 m). A further turbiditic set follows quite similar to the former.

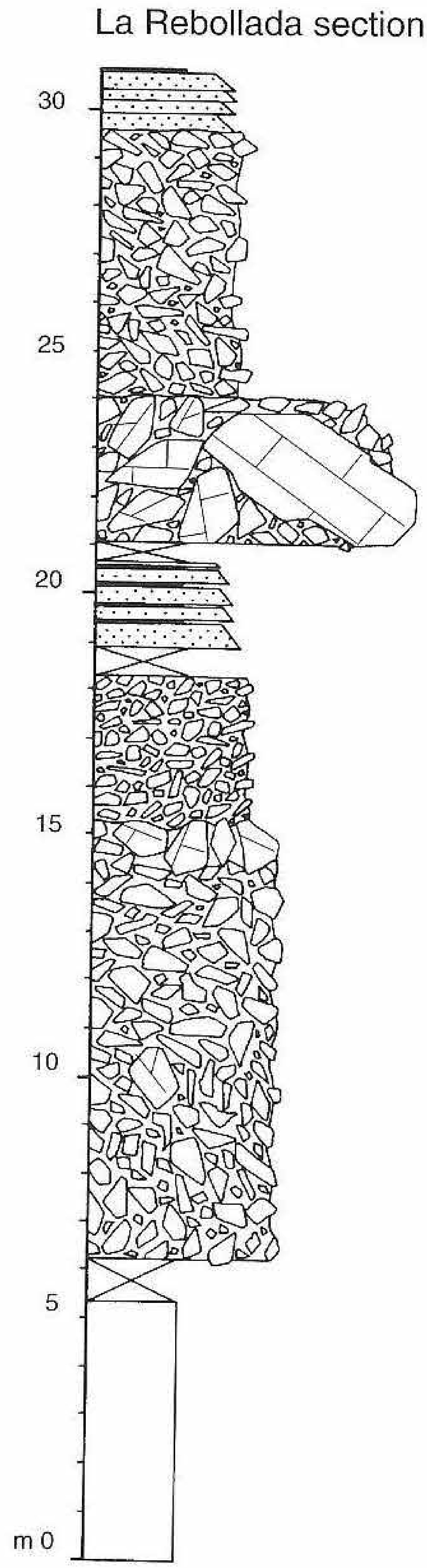


Fig. 15 - La Rebollada stratigraphic profile, lower Kasimovian. For location see Figs. 2 and 3. Symbols in Tab. 1.

No angular unconformities have been noted.

Interpretation. Megabreccia horizons and turbiditic calclithites can be both interpreted as due to syn-sedimentary tectonics active in lowermost Kasimovian times. The debris flows with huge boulders are related to submarine slidings from an active fault scarp not far placed. The syn-sedimentary structure can be recognized as the Poo palaeofault.

In general, the faults inherited from the *Leonian* phase (Gamonedo, M. Casano, Poo and Dobros palaeofaults) seem to have acted as master faults also during the post-paroxismal evolution of the area. They acted as extensional (transtensional) faults driving the opening of the post-*Leonian* basin (Fig. 3).

During the late Moscovian-early Kasimovian times, syn-sedimentary tectonics strongly influenced the sedimentary record, causing local intrabacinal slides but also attracting from the southern margin of the basin a lot of terrigenous sediments (Fig. 16 and 17).

?Gzhelian and ?Permian tectonics

The present analysis is grounded on macrotectonic investigations carried out during the field mapping. Conclusions and comments are thus preliminary. As it emerges from the geological map, the upper Moscovian-Kasimovian succession of the Eastern Asturian Basin experienced fair deformations. According to the literature, they took place mostly during the Gzhelian (Stefanian C)-Permian times. On the contrary, the effects due to the Alpine orogeny are always considered weak and scanty (Alvarez-Marron, 1995). However, it might be the large structures experienced low reactivations during Alpine tectonics.

The study area lacks sediments suturing the latest Carboniferous-Permian tectonics, so that it is only possible to get a deformation chronology by the interfering and intersecting structures.

To correlate (Fig. 3) the here discussed sections and the several unpublished stratigraphic profiles measured in the mapped area, we had also to remove some post-Kasimovian deformations. In particular, they are responsible for the displacement and partial erasure in the succession of the Gamonedo-M. Casano and Inguanzo-Areñas de Cabra-

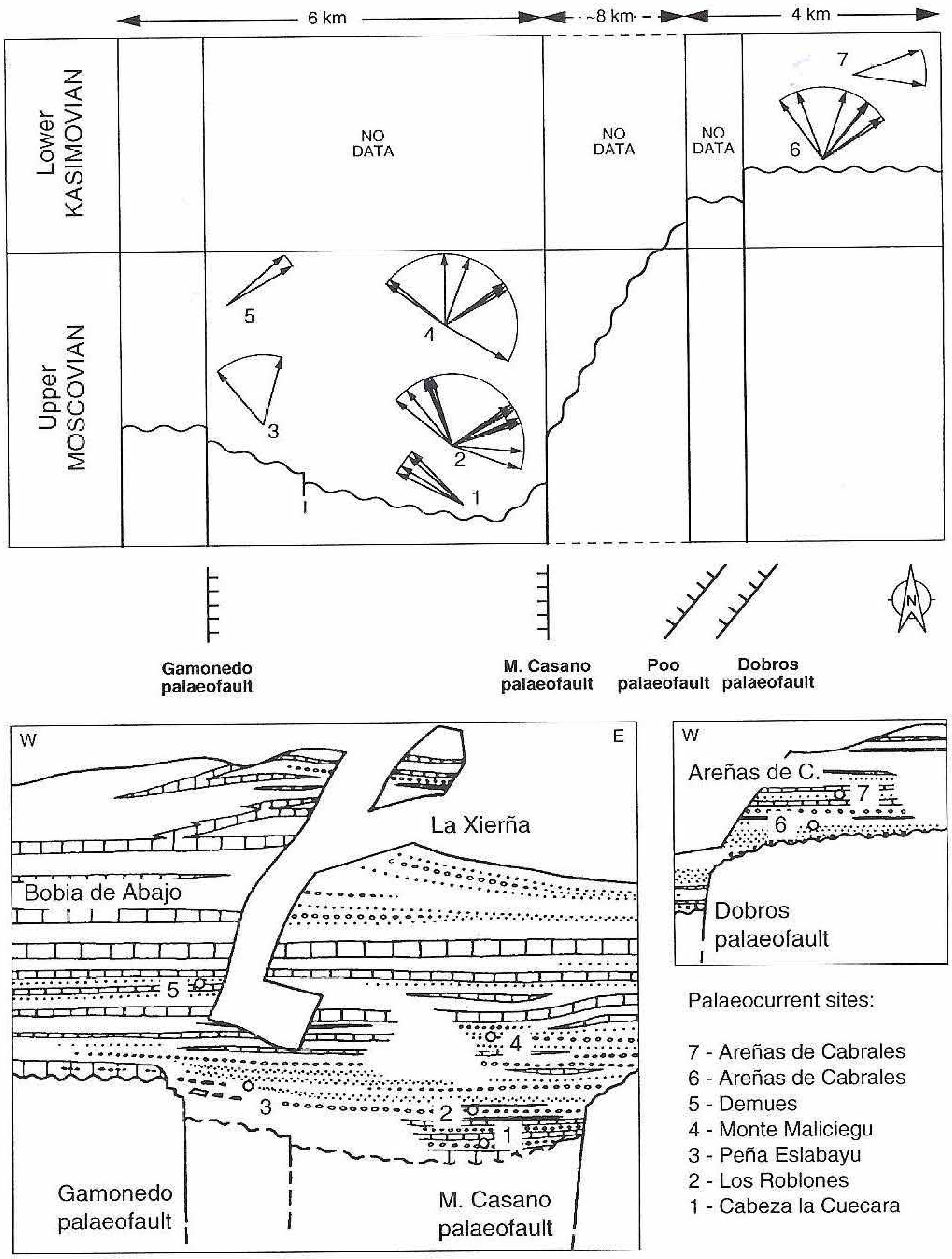


Fig. 16 - Palaeocurrents from the upper Moscovian-lower Kasimovian succession (see Fig. 17) of the Eastern Asturian Basin (western nucleus). Lithology symbols in Fig. 3. The palaeocurrents are derived from channel erosion and foreset progradation.

les areas (Figs. 18 and 20). Therefore the mapped area has been subdivided, from the west to the east, into three sectors to better expose and discuss the field data.

Western sector – In the western sector (Fig. 18) the older deformation system consists of folds and thrusts with hinge and fault strikes ranging from N100° to 120°E orientations.

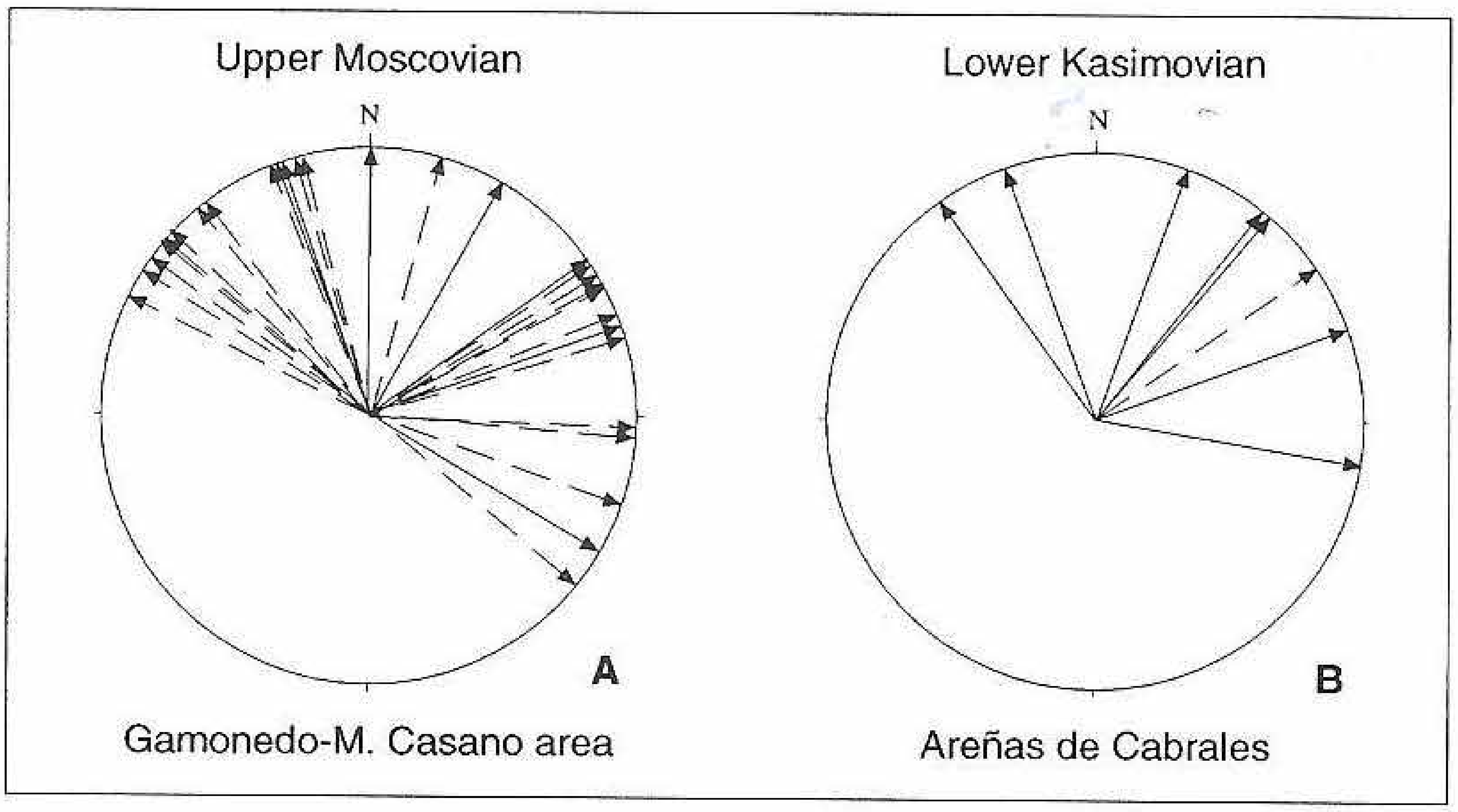


Fig. 17 - Palaeocurrents measured in the upper Moscovian and lower Kasimovian terrigenous sediments of the Gamonedo-Areñas de Cabrales area (Eastern Asturian Basin). The palaeocurrents are derived from axis of channel forms (continuous arrows) and foreset beds (dashed arrows). (See also Fig. 16).

They are responsible for: a) the uplifting of the Hercynian substratum along the SSW dipping Jermosa and Covadonga Thrusts (see Fig. 2, southern side of the basin); b) the Peña de Eslabayu close macrofold (detail in Fig. 18); c) the uplifting of the Hercynian substratum along the NNE dipping Canales-Carreña Thrust (see Fig. 2, northern side of the basin); d) the N100°-120°E strike of the upper Moscovian-lower Kasimovian succession. We believe these effects developed in ?Gzhelian times under about NNE-SSW oriented maximum stress.

Besides, looking at the geological map of the sector (Fig. 18), a large scale arcuate structure shows up in the Monte Casano area. It was accomplished through the left-lateral offset of the Monte Casano tectonic block along a NW-SE trending fault. As a consequence, the Hercynian substratum, with the lowermost unconformable beds, overthrust onto the uppermost Moscovian succession, as it appears in Fig. 18.

The northwestern shifting of the Monte Casano Hercynian block was responsible for the NE-SW trending Fuente Thrusts, cropping out southeast of the Bobia de Abajo village (see Fig. 2). The uppermost Moscovian succession thus was twisted and uplifted between the two opposite dipping thrusts (geologic profile of Fig. 18).

The depicted structural frame is interpreted as due to NW-SE trending compression of ?Permian generic age.

Central sector – In the central sector (Fig. 19), tectonic data attest to the presence of only one compressional phase. Deformations are represented by N90°E trending folds and thrusts. They involve both the substratum and the unconformable uppermost Moscovian-lower Kasimovian succession which is overthrust by the Hercynian units through the Canales-Carreña Thrust. We interpret such tectonic features as induced by an about N-S trending maximum stress of ?Gzhelian age.

Eastern sector – The eastern sector (Fig. 20) includes the classic Dobros and Areñas de Cabrales stratotype sections. The best expressed deformations are represented by the N110°-90°E trending open folds mapped in the lower Kasimovian succession which crops out in the norther part of the area. The fold system is a consequence of the north dipping Canales-Carreña Thrust which overthrust the Hercynian sequence onto the Kasimovian succession. All structures can be related to an about N-S oriented maximum stress (?Gzhelian).

In the southern part of the sector the bed strikes show a twisting from the E-W to the NE-SW. Data are visible in a large zone southwest of Areñas de Cabrales (Fig. 20). The Poo and Dobros palaeofaults, N50°E oriented, experienced tectonic inversion. The Kasimovian succession between the two reactivated fault surfaces developed open fold with N50°E trending hinges. We do not belive that the fold system was induced by left trascurrence along the Poo palaeofault during the N-S compression. That is because evidences of lateral offsets large enough to

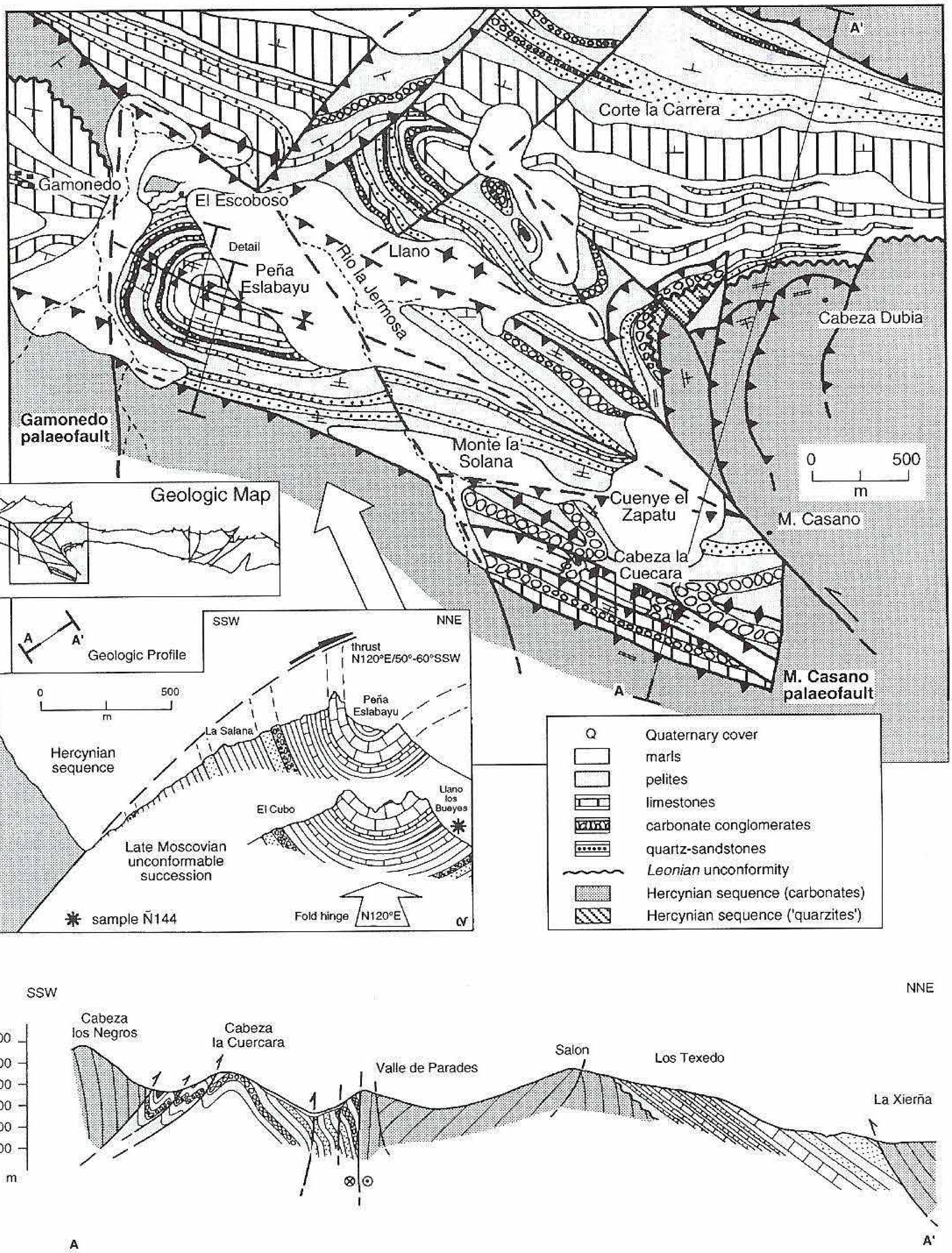
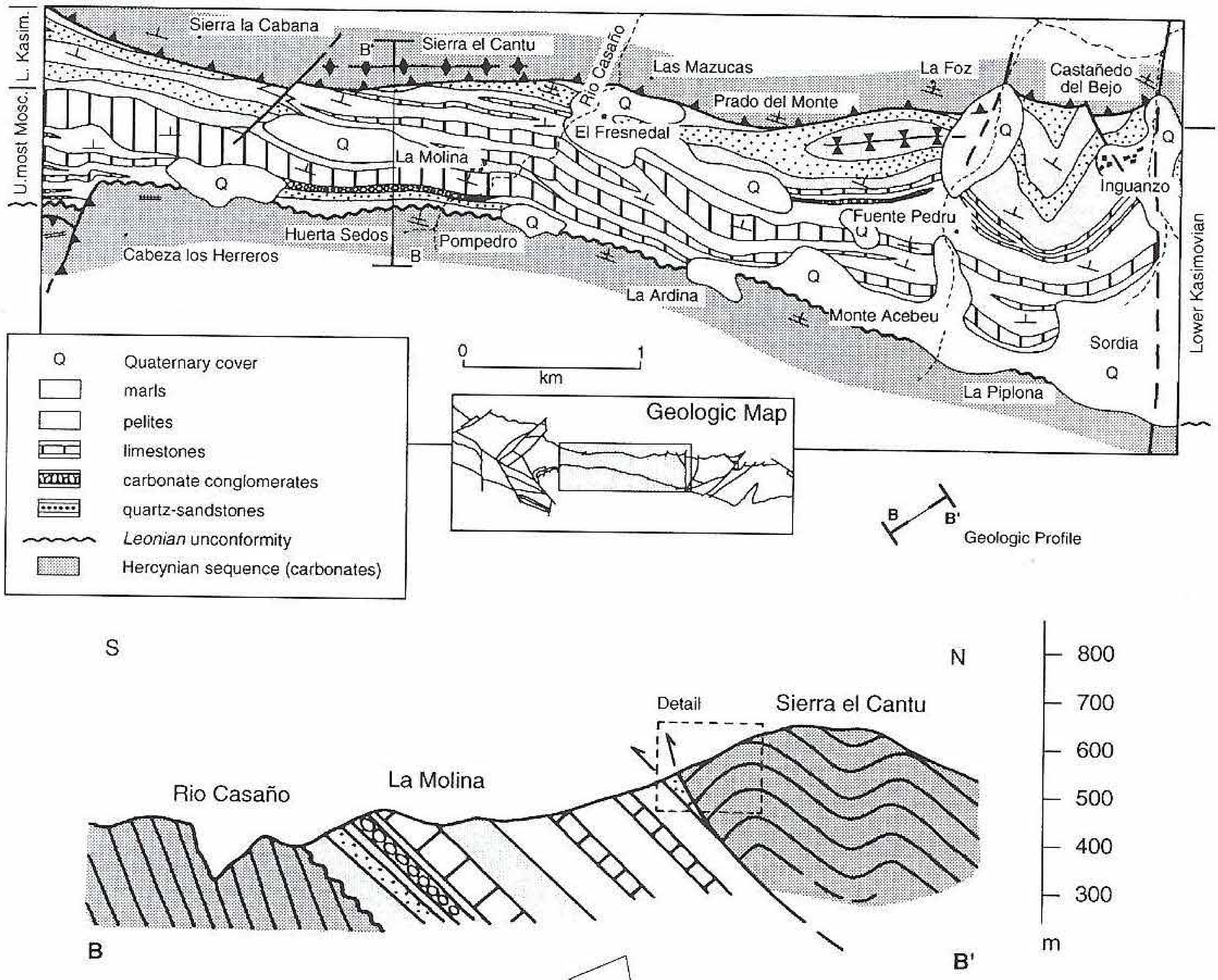


Fig. 18 - Geologic map of the western sector of the Gamonedo-Areñas de Cabrales area (Eastern Asturian Basin). The geologic profile stresses the strong deformations developed west of Monte Casano. The structures (folds and thrusts) are N100°-120°E oriented. They can be roughly referred to a NNE-SSW trending maximum stress due to the 1st post-Kasimovian compressional phase (?Gzhelian). The fold system ends against a vertical surface. It was originated during the 2nd compression phase (?Permian) as left-lateral strike-slip fault.



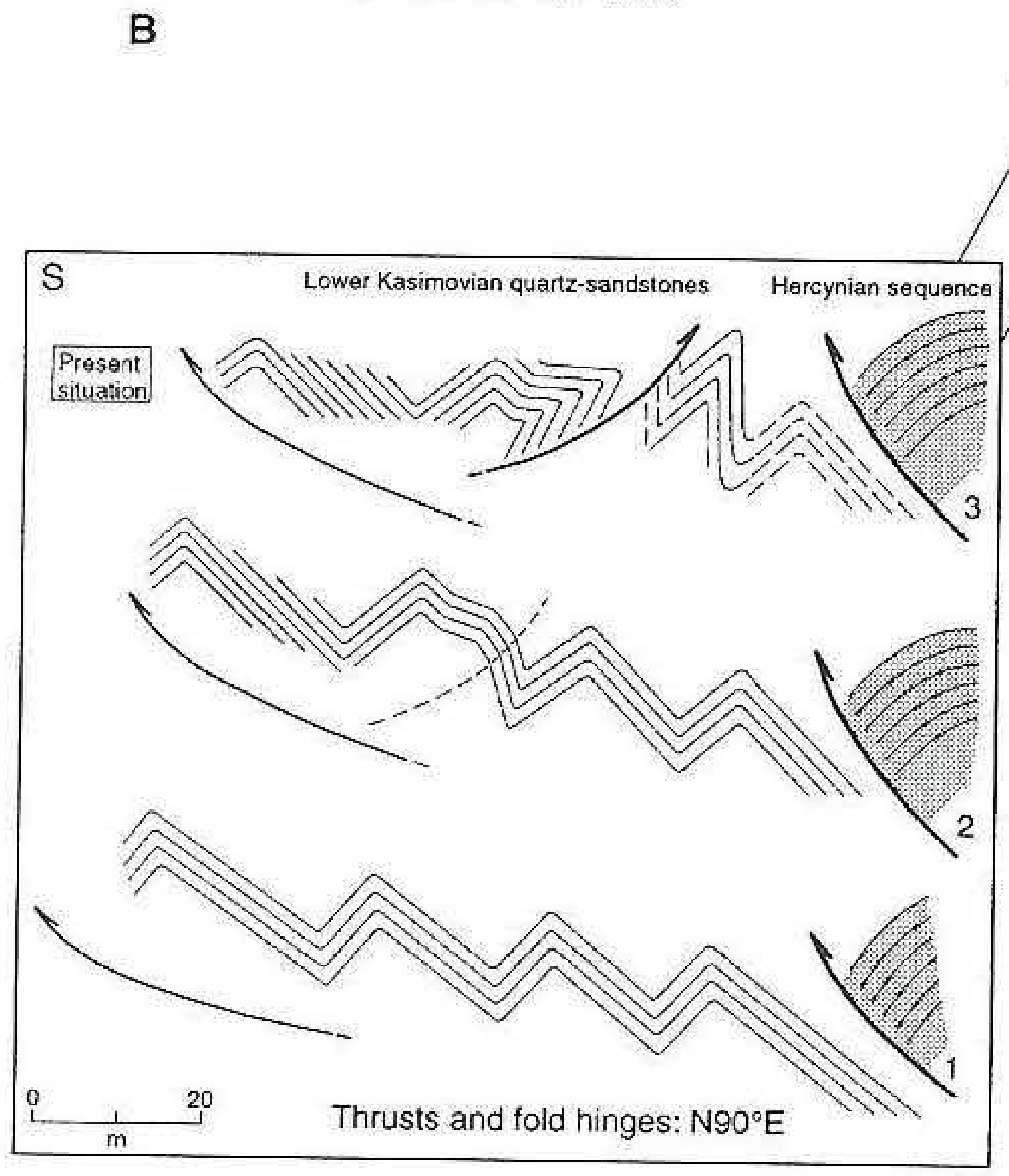


Fig. 19 - Geologic map of the central sector of the Gamonedo-Areñas de Cabrales area (Eastern Asturian Basin). The geologic profile points out the structures due to the N-S trending maximum stress (?Gzhelian). The fold and thrust systems are both E-W oriented. The detail shows the speculative evolution of a backthrust developed in deltaic mouth bar sandstones. It originated inside a small tectonic slice at the front of the main tectonic structure which overthrust the Hercynian sequence onto the Kasimovian succession.

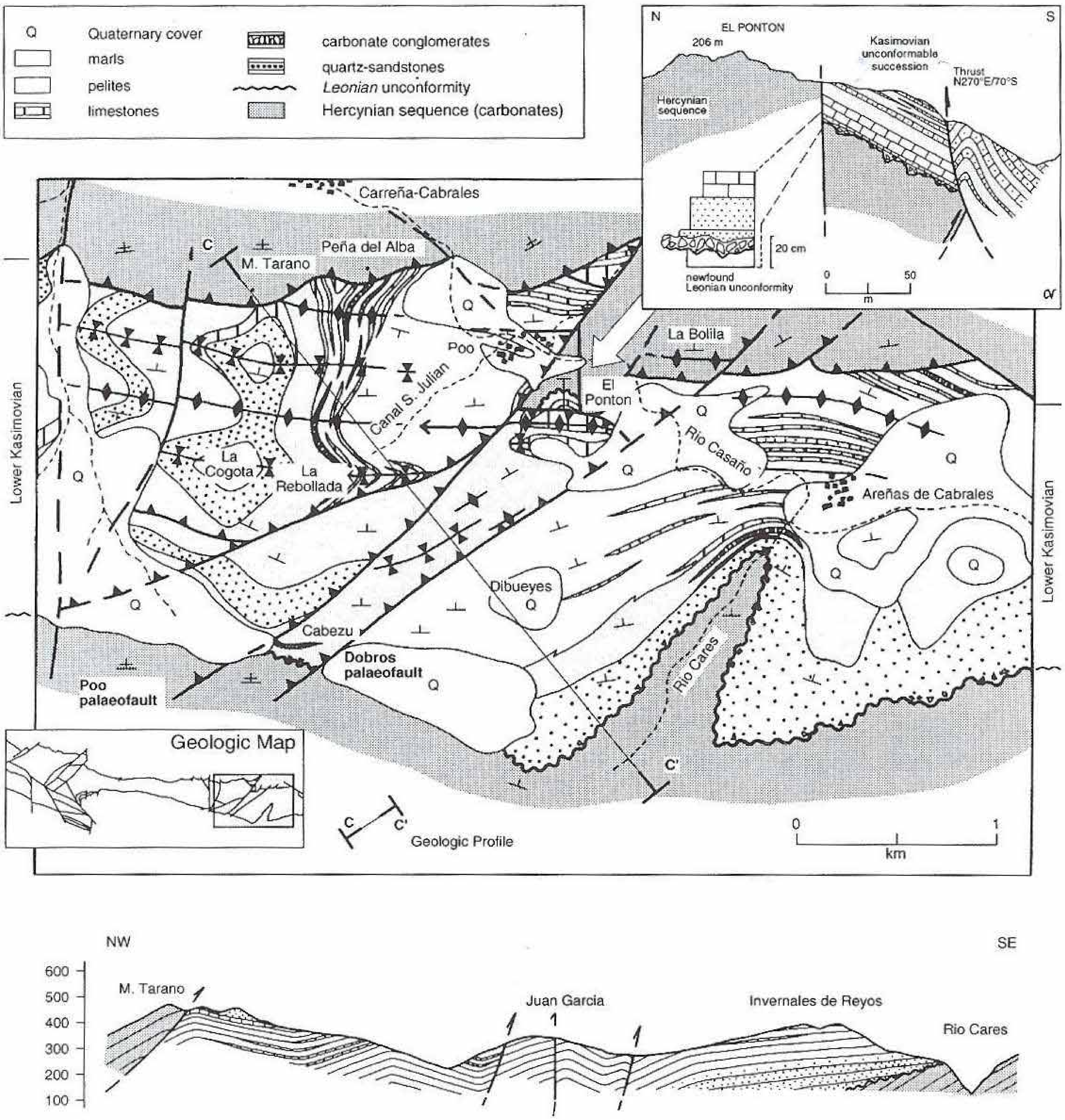


Fig. 20 - Geologic map of the eastern sector of the Gamonedo-Areñas de Cabrales area (Eastern Asturian Basin). Two different systems of thrusts and coeval faults are present: the N110°-90°E and N50°E trending systems. It is clear that E-W system developed first. It is well expressed in the northern part of the sector and is depicted in the left part of the section. Between the Poo and Dobros palaeofaults, the Kasimovian succession is deformed by a N50°E trending fold system. It can be interpreted as due to the 2nd compressional phase (?Permian), related to an about NW-SE oriented maximum stress.

support this hypotesis are lacking. Moreover, in the hangingwall of the inverse reactivated Poo palaeofault the former E-W trending folds experienced hinge tiltings of about 20° towards the west. All the exposed data confirm a NW-SE oriented maximum stress.

Summarizing, data collected in the whole Gamonedo-Areñas de Cabrales area are consistent with two superimposed deforma-

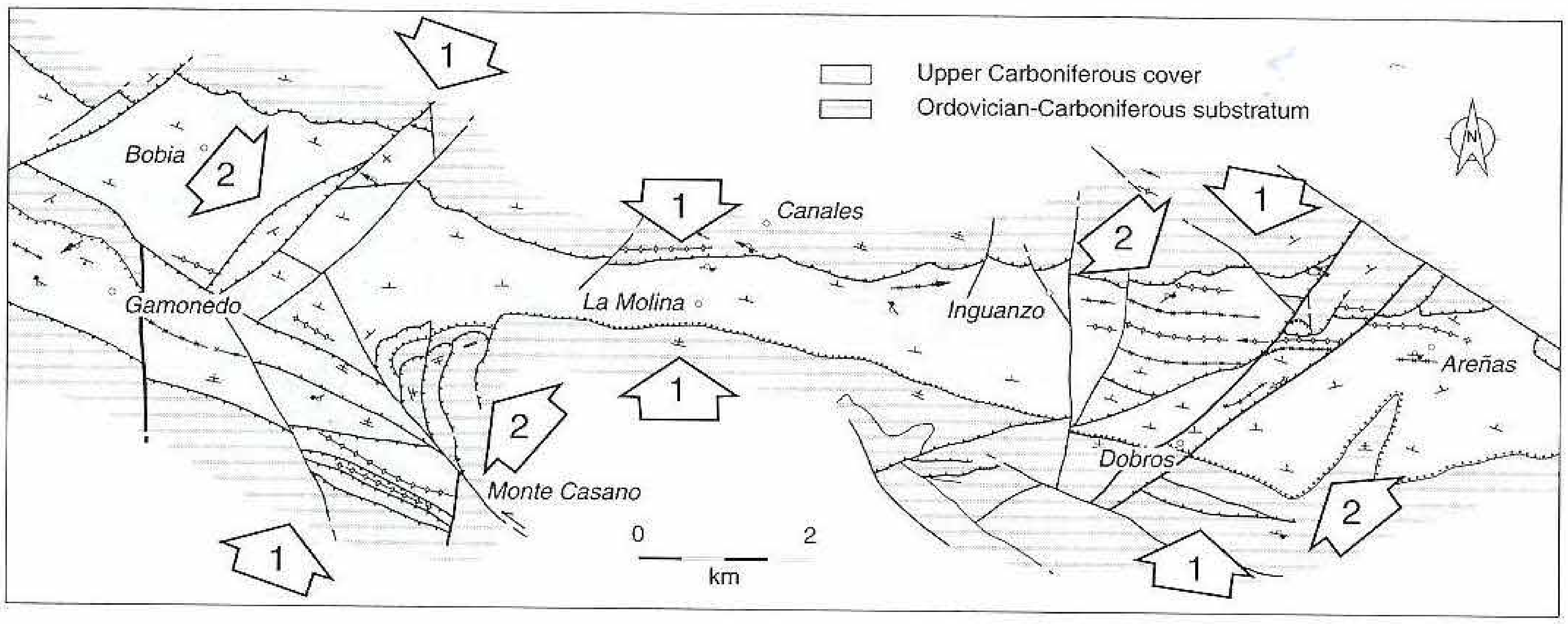


Fig. 21 - The Gamonedo-Areñas de Cabrales tectonic map. The white arrows show the local maximum stress orientations responsible for the post-Kasimovian deformations as desumed mainly from macrotectonic data. The relative chronology (**1**, ?Gzhelian; **2**, ?Permian) is inferred from the structure interferences.

tion systems tentatively referred to: a) a compressional phase confined in ?Gzhelian times and defined by a NNE-SSW to N-S trending maximum stress; b) a compressional phase active in ?Permian times and defined by a NW-SE trending maximum stress (Fig. 21).

Conclusive remarks

In the Late Palaeozoic times the Cantabrian Zone (NW Spain) was interested by severe syn-sedimentary tectonics which led to the opening of the Easter Asturian Basin (late Moscovian-Kasimovian). More than 2.500 m of sediments stored up in the fault controlled basin. In the study area (Gamonedo-Areñas de Cabrales), which corresponds to the western part of the Eastern Asturian Basin, field data testify to the main syn-sedimentary faults were inherited from the *Leonian* phase compression (late Moscovian) and were later on reactivated during latemost Palaeozoic compressions.

The following succession of events have been recognized.

Compression tectonics, *Leonian* phase (late Moscovian)

Late Moscovian. a) The pre-latemost Moscovian succession experienced open folding N100°-120°E striking. The inferred maximum stress was about NNE-SSW (fig. 10A). *Late Moscovian.* b) The compression went on producing two conjugate systems of vertical faults (N-S and NE-SW) which accomodated right- and left-lateral strike-slip respectively. As a consequence, the setting of the gently folded substratum twisted in accordance with the fault displacements (Fig. 10B). Besides, the area was slowly uplifted, mainly in the central C zone, between the converging fault systems. The compressional phase was responsible for a short-lived gap limited to late Moscovian times. The whole area emerged and suffered scanty erosion mainly centered along the faulted bands; moreover, local karst took likely.

Transtensional strike-slip tectonics (late Moscovian- Kasimovian)

Latemost Moscovian (Myachkovian)-lower Kasimovian. The study area experienced tectonic subsidence. According to literature and to the present field data, it first developed in the *A* and *B zones*; afterwards, it extended to *C*, *D* and *E zones* (Fig. 9) as documented by the ages of the basal beds (Martinez-Garcìa and Wagner, 1971; Martinez-Garcìa and Villa, 1986; Villa, 1989) and the lithostratigraphic correlations (Figs. 2 and 3). The subsidence made use of the N-S and NE-SW trending faults inherited from the late Moscovian compression (*Leonian* phase), as indicated by the location of the megabreccia horizons (Figs. 11 and 15), and the different age and thickness of the unconformable succession. The basin was fed by two different clastic inputs. Minor but significant clastic contributions came from intrabasinal fault scarps which provided also megabreccia slides. However, the main source was represented by uplifted reliefs located south of the study area.

Facies analysis carried out on the here presented sections and many still unpublished stratigraphic profiles points out environments ranging from fluvio-deltaic to open shelf. Fan delta bodies were supplied with mostly quartz sandstones and pelites (quartz conglomerates are very rare) and with carbonate conglomerates and sandstones. The clastic content derived from dismantled sources few to some tens of km far from the deltaic bodies. According to palaeocurrent analysis (Figs. 16 and 17), the supply areas were located toward the south and the west and consisted of close by Ordovician and Carboniferous reliefs. In the Gamonedo-Areñas de Cabrales area, the same units also represent the substratum of the upper Moscovian-lower Kasimovian succession. The basinal sedimentation rate had its acme in the early stage (upper Moscovian), then decreased and reached on steady values in lower Kasimovian times. That is in agreement with the decreasing importance of syn-sedimentary tectonics.

The terrigenous input cyclically alternated with intrabasinal carbonate sediments. The carbonates were firstly deposited in restricted lagoon environments rapidly evolving to open sea platform conditions. Both intra- and extrabasinal sediments were commonly winnowed by storm waves. The quartz sands were often organized into regressive sequences attesting the distributary channel-deltaic mouth bar progradation onto the distal prodelta facies. They likely formed during high stands. Regressive episodes were usually interrupted by transgressive pulses which abruptly restored the carbonate sedimentation. Besides, the prograding deltaic facies laterally passes to carbonatic sediments as it clearly appears in the lower Kasimovian succession (Fig. 3).

The result is a lower rank cyclicity characterized by sequence thicknesses ranging from few metres to some tens of metres. A high rank cyclicity is also detectable at the scale of the entire post-*Leonian* succession (Fig. 3). At this purpose, it is to note that both the lower and high order cyclicity are the result of a combined influence of eustatic and tectonic control.

The coarse and well rounded carbonate conglomerates which interbed at places with the main quartz input (Figs. 6 and 8), could be reasonably due to sudden rejuvenation of the reliefs placed south of the study area. That implies that adiacent areas experienced coeval downwarp and uplifting. This suggests that the late Moscovian-early Kasimovian deformations were driven by strike-slip tectonics. At the same time, it could have induced transtension in the Gamonedo-Areñas sedimentary basin and transpression south of it. Palaeotectonic evidence and sedimentological data are consistent with this interpretation.

As working hypotesis, looking at the main faults which were supposedly active in Late Carboniferous times (Arthaud and Matte, 1975, 1977; Heward and Reading, 1980), we assume that the late Moscovian-early Kasimovian evolution of the Eastern Asturian Basin was driven by the N100°E trending North Pirenean and Leon Faults (Fig. 22). These lineaments acted as right strike-slip faults in the regional wrench tectonic context supposed by Arthaud and Matte (1977) between the African and European crustal plates.

Compression tectonics (?Gzhelian-?Permian)

The precise age is uncertain due to the lack of sediments suturing the tectonic deformations. It is indirectly inferred from the literature concerning the regional tectonics of the Cantabrian Zone (Wagner and Martinez-Garcìa, 1974).

?Gzhelian. The mapped macrotectonic structures (Figs. 18, 19 and 20) are coherent with a NNE-SSW to N-S maximum stress. This is confirmed by the mesoscale asymmetric folds measured in the upper Moscovian-lower Kasimovian succession (Fig. 2). The compression gave origin to the Canales-Carreña and the Covadonga Thrusts. Consequently, the Hercynian sequence thrust over the post-*Leonian* succession

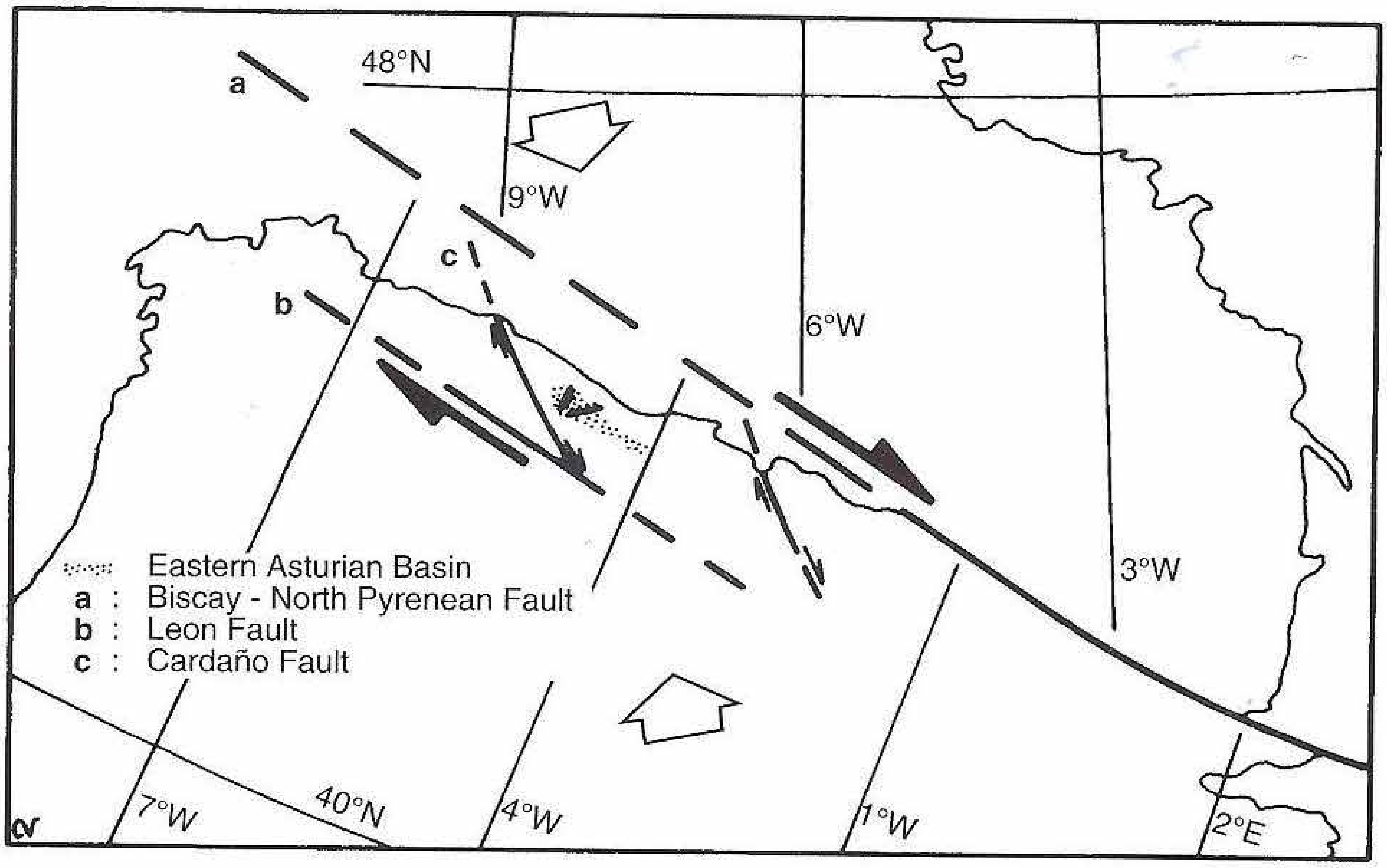


Fig. 22 - The large scale right-lateral shear zone between the Biscay-North Pyrenean and the Leon Faults is suggested as responsible for the late Moscovian-late Kasimovian transtension which led to the opening of the Eastern Asturian Basin. The white large arrow shows the inferred local maximum stress direction.

from both southwest and north (Fig. 2). The Covadonga Thrust induced strong deformations and shortening in the area between Gamonedo and Monte Casano. The result is a thick bundle of folds and minor thrusts located close to the main structure (Fig. 18).

On the opposite side, the Canales-Carreña Thrust gave origin to open folds inside the post-*Leonian* succession, between Inguanzo and Areñas de Cabrales (Fig. 20). At some places, under and near at the thrust surface, a system of south verging close folds is present; they show E-W trending hinges (detail of Fig. 19).

?Permian. A NW-SE trending maximum stress followed. The compressional phase is well recorded in the western and eastern sectors. No field evidence has been noted in the central sector. The northwestern shifting of the Monte Casano block along a left-lateral strike-slip fault is the most prominent effect. The Hercynian block was thus deformed in an arcuate shape with a high angle plunging fold hinge (*Schlingentektonik*), and the Monte Casano palaeofault was partially deformed too (Fig. 18).

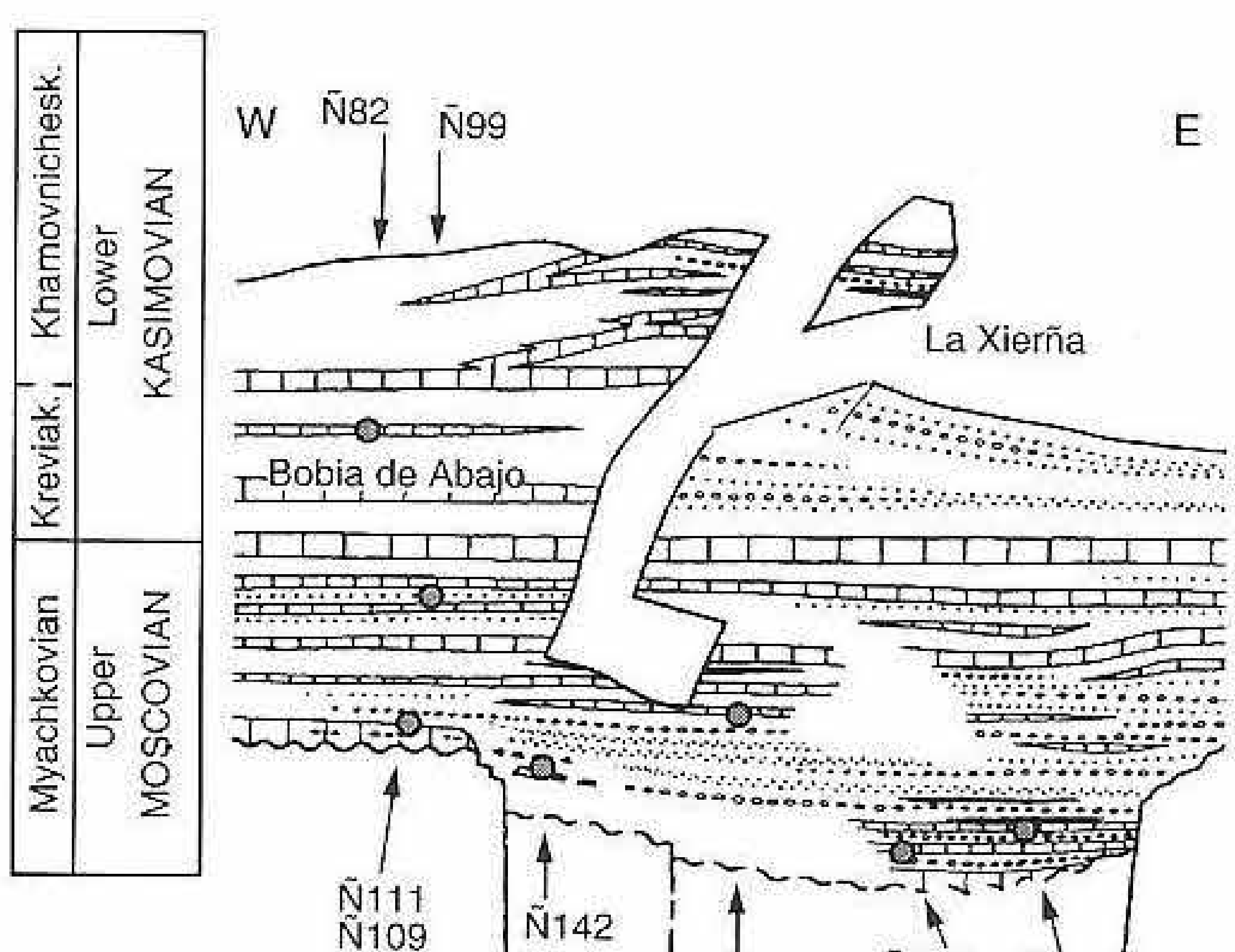
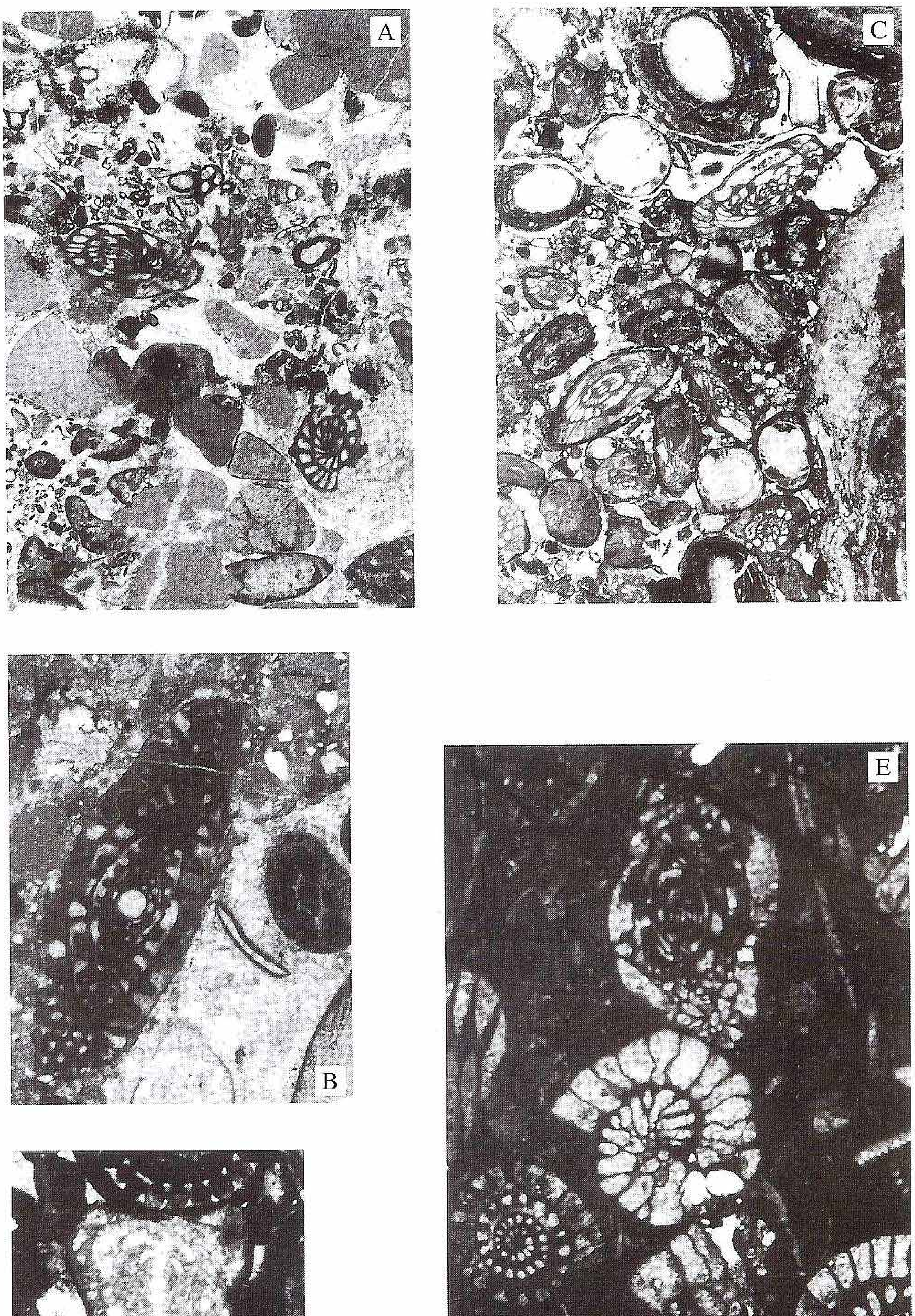


Fig. 23 - Location of the fusulinid bearing samples in the stratigraphic record.
Ñ82: ?*Triticites*. Ñ144: *Fusulinella* sp. (plentiful level!). Ñ111: *Fusulinella* cf. *pulchra* Rauser. Ñ109: *Beedeina* ex gr. *ozawai* Rauser. Ñ119: *Fusulinella* sp., *Fusiella* sp., *Staffella* sp. and *Neostaffella spheroidea cuboides* Rauser. Ñ117: (clast reworked from substratum) *Millerella* sp., ?*Archaeodiscidae*. Ñ115: *Fusiella* sp., *Schubertella* sp. Ñ116: *Fusiella* sp., *Pseudoendothyra* sp. Ñ99: *Schubertella* cf. *subkingi* Putrja. Ñ81: *Fusulinella* sp. Ñ142: (clast reworked from substratum) *Hemifusulina* aff. *elegantula* Rauser.


A
C
B
E
D

Pl. 1 - Fusulinids from the Gamonedo-Monte Casano area (Eastern Asturian Basin, western nucleus). **A**, sample Ñ81. Grainstone with *Fusulinella* sp. (× 10). **B**, sample Ñ109. Grainstone with *Beedeina* ex gr. *ozawai* Rauser (× 20). **C**, sample Ñ119. Oncolitic bed with *Fusulinella* sp., *Fusiella* sp., *Staffella* sp. and *Neostaffella* cf. *spheroidea cuboides* Rauser (× 10). **D**, sample Ñ119. *Neostaffella spheroidea cuboides* Rauser (× 20). **E**, sample Ñ144. Grainstone with *Fusulinella* spp. (× 20); a deformed specimen is also visible.

The same compression was probably responsible for the tectonic inversion into pure thrust surfaces of the Poo and Dobros palaeofaults. Moreover, the compression produced N50°E trending thrust and folds, both symmetric and asymmetric, randomized over the whole study area (Figs. 2 and 20).

The inferred maximum stress orientations for the ?Gzhelian and ?Permian compressions are summarized in Fig. 21.

Acknowledgments

C.V. highly appreciates the stimulating field discussion with E. Martinez-Garcia and S. Rehm. Besides, we gratefully acknowledge F. Ricci Lucchi for the helpful critical comments and the kindly improvement of the English text.

Financial supports were provided by grant MURST ex 40% (Resp. G.B. Vai) and the Consiglio Nazionale delle Ricerche of Italy, grant n. 95.003.88 C.T. 11.5286.17 (Resp. W. Cavazza).

REFERENCES

ALVARES-MARRON J., 1995. Three dimensional geometry and interference of fault-bend folds: examples from the Ponga unit, Variscan Belt, NW Spain. J. Struct. Geol., 17, 549-560.

ARTHAUD F. and MATTE P., 1975. Les décrochements tardi-hercyniens du sud-ouest de l'Europe. Geometrie et essai de reconstitution des conditions de la déformation. Tectonophysics, 25, 139-171.

ARTHAUD F. and MATTE P., 1977. Late Paleozoic strike-slip faulting in Southern Europe and Norhtern Africa: result of a right-lateral shear zone between the Appalachians and the Urals. Bull. Geol. Soc. Am., 88, 1305-1320.

BOSCH van den W.J., 1969. Geology of the Luna-Sil region, Cantabrian Mountains (Spain). Leidse Geol. Med., 33, 1-62.

GINKEL van A.C., 1965. Carboniferous fusulinids from the Cantabrian Mountains (Spain). Leidse Geol. Med., 34, 1-225.

GINKEL van A.C., 1971. Fusulinids from uppermost Myachkovian and Kasimovian strata from northwestern Spain. Leidse Geol. Med., 47, 115-161.

HEWARD A.P. and READING H.G., 1980. Deposits associated with a Hercynian to Late Hercynian continental strike-slip system, Cantabrian Mountains, northern Spain. Spec. Publ. Int. Assoc. Sedim., 4, 105-125.

LEVEN E.J., 1998. Stratigraphy and fusulinids of the Moscovian Stage (Middle Carboniferous) in the Southwestern Darvaz (Pamir). Riv. Ital. Paleont. Stratigr., 104, 3-42.

LOTZE F., 1945. Zur Gliederungder Varisziden der Iberischen Meseta. Geotekt. Forsch., 6, 78-92.

MARCOS A., 1967. Estudio geologico del reborde de los Picos de Europa (Region de Onis-Cabrales, Cordillera Cantabrica). Trabajos de Geologìa, 1, 39-46.

MARCOS A., 1968. Nota sobre el significado de la León Line. Breviora Geol. Astúrica, 12/3, 1-5.

MARCOS A. and PULGAR J.A., 1983. An approach to the tectonostratigraphic evolution of the Cantabrian Foreland thrust and fold belt, Hercynian Cordillera of NW Spain. N. Jb. Geol. Palaont., 163, 256-260.

MARQUINEZ J.L., 1978. Estudio geologico del sector SE de los Picos de Europa (Cordillera Cantabrica, NW de España). Trabajos de Geologìa, 9, 295-315.

MARQUINEZ J.L., MÉNDEZ C.A., MENÉNDEZ ALVAREZ J.R., SÁNCHEZ de OOSADA L.C. and Villa E., 1982. Datos biostratigraficos de la sucesión carbonifera (Turnesiense-Kasimoviense) de Las Llacerias, Picos de Europa, Norte de España. Trabajos de Geologìa, 12, 187-193.

MARTINEZ-GARCÌA E., 1984. Outline of Paleozoic Stratigraphy and Structure of the Eastern Cantabrian Mountains. IX Congreso int. de Estratigr. y Geol. del Carbonifero. IX-ICC, 3, 329-344.

MARTINEZ-GARCIA E., 1986. The Iberian Massif. In: Int. Conf. on Iberian Terranes and their Regional Correlation, IGCP 233, Oviedo, 1986. Guidebook A-1, 1-39.

MARTINEZ-GARCIA E., 1991. Hercynian syn-orogenic and post-orogenic successions in the Cantabrian and Palentian zones (NW Spain). Comparison with other western European occurrences. In: C. VENTURINI (Ed.), Workshop Proceedings on Tectonics and Stratigraphy of the Pramollo Basin (Carnic Alps). Giorn. Geol., 53/1, 209-228.

MARTINEZ-GARCIA E., RODRÍGUEZ ARANGO R. and VILLA E., 1985. The unconformable marine Kasimovian strata of the Sellaño Basin (Cantabrian Zone, NW Spain). In: M.L. LEMOS de SOUSA and R.H. WAGNER (Eds.), Papers on the Carboniferous of the Iberian Peninsula (sedimentology, stratigraphy, paleontology, tectonics and geocronology). An. Fac. Cienc. (Supl.), 64, 35-40.

MARTINEZ-GARCIA E. and VILLA E., 1986. Una discordancia importante en el Carbonifero de los Picos de Europa (Asturias, NW de España). Actas IX Congr. Nac. Sedim. Salamanca 1980. Acta Salamanticensia, 50/II, 719-726.

MARTINEZ-GARCIA E. and WAGNER R.H., 1971. Marine and continental deposits of Stephanian age in Ea-

stern Asturias (NW Spain). Trabajos de Geologìa, 3, 285-305.
MARTINEZ-GARCIA E. and WAGNER R.H., 1984. The Post-Asturian marine Basin of Late Stephanian age in Northwest Spain. IX Congreso int. de Estratigr. y Geol. del Carbonifero. IX-ICC, 3, 508-516.
RIBEIRO A., DIAS R. and BRANDÃO SILVA J., 1995. Genesis of the Ibero-Armorican arc. Geodinamica Acta, 8, 173-184.
SAVAGE J.F. and BOSCHMA D., 1980. Geological maps of the Southern Cantabrian Mountains (Spain). Leidse Geol. Med., 50, 75-114.
TRYOLS J., GONZALEZ LASTRA J., MARQUÍNEZ GARCIA J., MARTÍNEZ DÍAZ C., MÉNDEZ FÉRNANDEZ C., MÉNDEZ ALVAREZ J.R. and SANCHEZ de POSADA L.C., 1984. Preliminary note on two marine sections (Tournaisian-Kasimovian) in the Picos de Europa area (Cantabrian Mountains, NW Spain). In: C.R. IX Congr. Int. Stratigr. Géol. Carbonifére, Washington DC. Southern Illinois University Press, 2, 148-156.
VILLA E., 1989. Fusulináceos carboníferos del Este de Asturias (N de España). Ph.D. Thesis, Univ. Oviedo, 1-378.
VILLA E. and MARTINEZ-GARCIA E., 1989. El Carbonifero superior marino de Dobros (Picos de Europa, NW de España) y su contenido en fusulináceos. Trabajos de Geologia, 18.
WAGNER R.H., 1959. Sur la présence d'une nouvelle phase tectonique 'leonienne' d'age Westphalien D dans le Nord-Ouest de l'Espagne. C.R. Acad. Sci. Paris, 249, 2804-2806.
WAGNER R.H., 1965. Stephanian B flora from the Ciñera-Matallana coalfield (León) and neighboring outliers, III: Callipteridium and Alethopteris. Not. Comun. Inst. Geol. Min. Esp., 78, 5-70.
WAGNER R.H., 1966. Paleobotanical dating of Upper Carboniferous folding phases in NW Spain. Mem. Inst. Geol. Min. Esp., 86, 31-40.
WAGNER R.H., 1967. Apuntes sobre las floras de la zona de Gamonedo-Cabrales en la parte oriental de Asturias. Trabajos de Geologìa, 1, 47-58.
WAGNER R.H., 1970. An outline of the Carboniferous stratigraphy of Northwest Spain. Congr. Coll. Univ. Liège, 55, 429-463.
WAGNER R.H., 1971a. The stratigraphy and structure of the Ciñera-Matallana coalfield (Prov. León, NW Spain). In: The Carboniferous of Northwest Spain. Part II. Trabajos de Geologia, 4, 385-429.
WAGNER R. H., 1971b. Account of the international field meeting on the Carboniferous of the Cordillera Cantabrica, 19-26 Sept. 1970. In: The Carboniferous of Northwest Spain, Part I. Trabajos de Geologìa, 1-40.
WAGNER R.H., 1971c. Carboniferous nappe structures in north-eastern palencia (Spain). In: The Carboniferous of Northwest Spain, Part II. Trabajos de Geologìa, 431-459.
WAGNER R.H. and ARTIEDA J.L., 1970. La Cuenca Minera Ciñera-Matallana, León. Soc. Hullera Vasco-Leonesa, León, 1-288.
WAGNER R.H., JONES D.G., SPINNER E. and WAGNER GENTIS C.H.T., 1970. The upper Cantabrian rocks near Inguanzo, eastern Asturias, Spain. In: M. STREEL and R.H. WAGNER (Eds.), Colloque sur la stratigraphie du Carbonifére, Congr. Coll. Univ. Liége, 55, 465-486.
WAGNER R.H. and MARTINEZ-GARCÌA E., 1974. The relation between geosynclinal folding phases and foreland movements in Northwest Spain. Studia Geologica, 7, 131-158.
WAGNER R.H. and VARKER V.J., 1971. The distribution and development of post-Leonian strata (upper Westphalian D, Cantabrian, Stephanian A) in Northern Palencia, Spain. Part II. Trabajos de Geologia, 4, 533-601.
WAGNER R.H. and WINKLER PRINS C.F., 1970. The stratigraphic succession, flora and fauna of Cantabrian and Stephanian A rocks at Barruelo (prov. Palencia), NW Spain. In: Colloque sur la stratigraphie du Carbonifére, Congr. Coll. Univ. Liége, 55, 487-551.
WAGNER R.H. and WINKLER PRINS C.F., 1985. The Cantabrian and Barruelian stratotypes: a summary of basin development and biostratigraphic information. In: M.L. LEMOS DE SOUSA and R.H. WAGNER (Eds.), Papers on the Carboniferous of the Iberian Peninsula (sedimentology, stratigraphy, paleontology, tectonics and geocronology), An. Fac. Cienc. (Supl.), 64, 359-410.
WAGNER R.H., WINKLER PRINS C.F. and REDING R.E., 1971. Lithostratigraphic units of the lower part of the Carboniferous in northern León, Spain. In: The Carboniferous of Northwest Spain. Part II. Trabajos de Geologia, 4, 603-663.