EVIDENCE OF AN UPPER ORDOVICIAN THERMO-METAMORPHIC EVENT IN THE SW-CORNER OF THE CANTABRIAN MOUNTAINS (N-SPAIN)

M. Keller * y S. Krumm *

ABSTRACT

According to Illite «crystallinity» (IC) data, the metamorphic evolution of the SW Cantabrian Mountains took place in several steps. After a Precambrian deformation with accompanying low-grade metamorphism a thermal event during the Upper Ordovician affected the Cambro-Ordovician sediments. This event is marked by anchizonal IC values in the Pre-Silurian sequence contrasting the diagenetic data obtained from Siluro-Devonian rocks.
Apparently, the metamorphic history in that part of the Cantabrian Mountains ended during the Late Ordovician, a Hercynian metamorphism cannot be proven conclusively.

Key words: *Spain, Cantabrian Mountains, Somiedo-Correcilla Unit, Narcea Anticline, Upper Ordovician, Illite crystallinity, very low-grade metamorphism, thermo-metamorphism.*

RESUMEN

Según la cristalinidad de Illita (IC) la evolución metamórfica de la zona sudoeste de la Cordillera Cantábrica tuvo lugar en varias etapas. Siguiendo una deformación precámbrica con un metamorfismo de bajo grado, un evento térmico durante el Ordovícico Superior afectó a la secuencia Cambro-Ordovícica. Este evento está marcado en las rocas pre-Silúricas por valores de IC indicando la anchizona. Estos datos contrastan con valores obtenidos de la secuencia Siluro-Devónica, que son característicos de la diagénesis.
Aparentemente, la evolución metamórfica del sudoeste de la Cordillera Cantábrica terminó durante el Ordovícico, un metamorfismo Hercínico no pudo ser comprobado.

Palabras clave: *España, Cordillera Cantábrica, Unidad de Somiedo-Correcilla, antiforme del Narcea, Ordovícico Superior, cristalinidad de Illita, metamorfismo de muy bajo grado, termo-metamorfismo.*

ZUSAMMENFASSUNG

Messungen der Illitkristallinität (IC) an paläozoischen Gesteinen belegen, daβ die metamorphe Ausgestaltung des südwestlichen Kantabrischen Gebirges in mehreren Schritten vonstatten ging. Nach einer präkambrischen Deformation mit begleitender epizonaler Metamorphose folgte ein thermisches Ereignis im Oberordoviz. Es hinterlieβ seine Spuren in Form anchizonaler IC-Werte in kambro-ordovizischen Schichten. Diese Werte stehen im Gegensatz zu jenen der siluro-devonischen Einheiten, die niemals das Diagenesestadium überschritten.

Introduction

The Cantabrian Mountains of Northern Spain are a Variscan thrust-and-fold belt with a sedimentary sequence of Early Cambrian to Upper Carboniferous rocks. This Paleozoic sequence, the «Cantabrian Zone» (CZ) of Lotze (1945) is bound by Precambrian rocks to the W and SW and elsewhere covered by Permo-Triassic and younger rocks. The main tectogenesis took place during the Upper Westphalian and lowermost Stephanian, when a high-level, thin-skinned thrust-and-fold belt was formed (Julivert, 1981).

* Institut für Geologie und Mineralogie, Universität Erlangen-Nürnberg, Schlossgarten 5, D-8520 Erlangen, Alemania

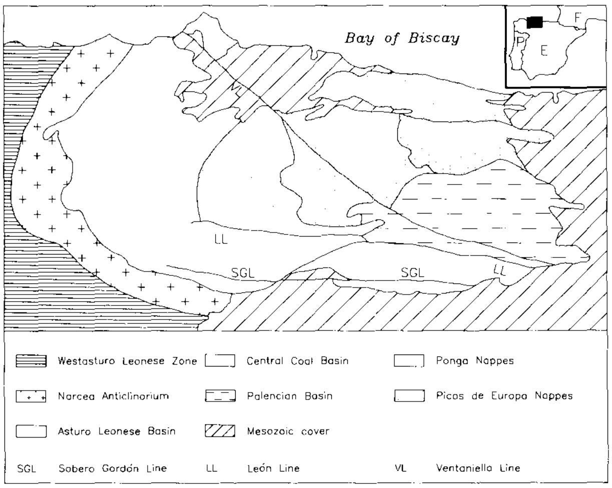

Fig. 1.—Paleogeography of the Cantabrian Mountains and adjacent areas with major faults; modified from Julivert (1971).

Deformation started with the development of large-scale thrusts, crustal shortening is estimated to be in the order of 1/3 to 1/2 (Julivert & Arboleya, 1986). In a second stage, the thrust sheets were folded and faulted. Locally, this deformation was accompanied by a moderate metamorphism, which never exceeds the low-grade stage (Raven & Pluijm, 1986). In many areas, only achizonal phenomena are observed. The SW-corner of the Cantabrian Mountains differs from this pattern, in that the whole sequence younger than the Ordovician does not show any signs of metamorphic overprint of the sediments, whereas Cambro-Ordovician rocks indicate metamorphic conditions of the anchizone. This part of the Cantabrian Mountains is referred to as Somiedo-Correcilla Unit (SCU; Julivert, 1971).

The present study is part of a project, which deals with the determination of the metamorphic degree and subdivision of the rocks at the transition from diagenesis to low-grade metamorphism. The study is mainly based on the determination of illite crystallinity (IC) with additional data from clay mineral associations, the conodont colour alteration index (CAI) and quartz recrystallisation.

Geological setting

The Cantabrian Mountains are subdivided into several paleogeographic units, which all show a different sedimentary history: The Asturo-Leonese Basin (fig. 1) is the former shelf area, where sedimentation started during the earliest Cambrian (Bosch, 1969b) and persisted until the Upper Carboniferous. Important are stratigraphic gaps in the Upper Ordovician, uppermost Devonian and near the Westphalian/Stephanian boundary. Several smaller gaps in the Devonian and Lower Carboniferous are of lesser importance.

In the Pisuerga-Carrión Unit to the E (Palencian Basin in fig. 1), sediments older than the Silurian are not preserved. Siluro-Devonian rocks (Palencian facies) are pelagic equivalents to the shelf sequence of the Asturo-Leonese Basin. Here too, sedimentation continued up to the latest Stephanian.

In the Ponga and Picos de Europa nappes (fig. 1) the sedimentary record starts with Lower Cambrian to Lower Ordovician rocks. Siluro-Devonian strata are completely missing, but as in the other regions, Carboniferous rocks are well developed.

The Central Coal Basin (fig. 1) is characterized by Westphalian and Stephanian sediments, which were deposited to the N of the northward migrating orogenic front.

For further details regarding the different stratigraphic units and their evolution the reader is referred to Dallmeyer & Martínez García (1990) and Truyols *et al.* (1990).

For the purpose of this study the sedimentary sequence in the SW Cantabrian Mountains was subdivided into three major tectono-sedimentary sequences (fig. 2): The first is the Precambrian of the Narcea Anticline, «NA» (Mora Fm.: Sitter, 1962) with metasediments of the greenschist facies, mainly slates, sandstones and greywackes and some volcanics (Pérez-Estaun, 1978; Julivert, 1981). This unit is separated from the Paleozoic rocks by an angular unconformity.

The second sequence consists of Lower Cambrian to Lower/Middle Ordovician rocks. Siliciclastic sediments, deposited in shallow-shelf areas, predominate (exception: the late Lower Cambrian carbonates of the Láncara Fm.). The Cambro-Ordovician sequence is separated from Siluro-Devonian rocks by an hiatus, but there is no obvious angular unconformity. Everywhere, the Silurian Formigoso Fm. rests upon the Barrios Fm. (Arenig/Llanvirn?). Frequently, magmatic rocks occur in the Cambro-Ordovician sequence. Where they lie on top of the Barrios Fm., they form a relief, which later was covered by Silurian sediments. As they never penetrate into the Siluro-Devonian strata, they must be of Ordovician age.

The third sequence comprises the Silurian and Devonian with a rapid alternation of siliciclastics and carbonates. It is separated from the younger rocks (which will not be considered here) by an hiatus and a large-scale unconformity, caused by epirogenetic uplift in the central part of the Cantabrian Mountains.

Methods and sample material

This study is based on about 900 samples of different lithologies. Investigation of a total of nearly 2000 samples from the whole Cantabrian Mountains proved that the dependence of IC on lithology is within the overall error of IC determinations. There is no single lithology which in general provided either higher or lower IC values.

An extensive description of the sample preparation and measurement conditions used for the determination of IC-data is given in Krumm & Buggisch (1991) and in Krumm (1992). The latter discusses the background of the procedures adopted in more detail. Only a brief summary especially on the differences to the recommendations of the IC working group (IGCP 294, see Kisch, 1991) will be given.

The IC data were obtained on very thin sedimentation slides (0.25 mg/cm^2) in order to avoid grain-size gradation effects and to achieve a maximum in preferred particle orientation.

The peak breadth is expressed as integral breadth, which is the integrated peak area divided by the count rate at the peak maximum. The advantage of this parameter is its higher sensitivity to various kinds of peak broadening. Broadening at the peak tails is in most cases underestimated by the normally used half-height width.

However, due to the thin slides and the alternative peak breadth parameter used, our data can *not directly* be compared to the Kübler scale. A preliminary estimate of the limiting values for the transition between diagenesis and anchizone and anchi- to epizone can be deduced from regression analysis (Krumm, 1992). For the time being, these are 0.57 $\Delta°2\sigma$ and 0.32 $\Delta°2\sigma$ respectively. More reliable values are expected from a multi-laboratory study currently carried out. The correlation mentioned above has been determined on non-glycolated specimens. Therefore, all values reported in this paper also refer to non glycole-solvated material.

The typical diffractometer resolution under the conditions used is 0.085 $\Delta°2\vartheta$ in half-height width and 0.094 $\Delta°2\vartheta$ in integral breadth for a muscovite single crystal. The narrowest peak breadth of a sedimentation slide is 0.104 $\Delta°2\vartheta$ (half-height width) and 0.134 $\Delta°2\vartheta$ (integral breadth).

Results

Comparing the different tectono-sedimentary units, there is a clear dependence of the IC-data on the stratigraphic position:

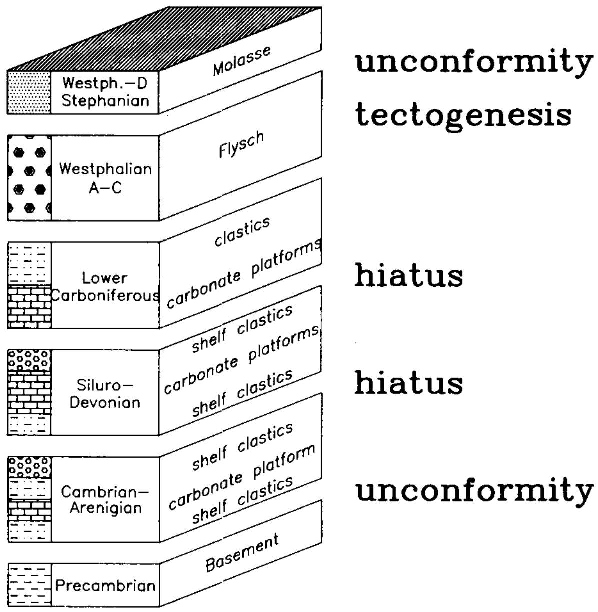

Fig. 2.—Tectono-sedimentary sequences of the Somiedo-Correcilla Unit.

A) *Precambrian (Mora Fm.)*

IC-Data from the NA show values between 0.2 $\Delta°2\vartheta$ and 0.3 $\Delta°2\vartheta$ (fig. 3) which are characteristic of the lower greenschist facies. This is in accordance with data from Pérez-Estaun (1978) as well as with our own observations on quartz- and phyllosilicate recrystallization. Illite/mica and abundant chlorite dominate the phyllosilicate assemblage in the Mora Fm. Biotite and paragonite were not detected in the samples investigated, but the presence of biotite in the central part of the NA was mentioned by Pérez-Estaun (1978). Expandable phases together with higher illite peak breadths are observed at localities where Tertiary sediments overly the Precambrian and are probably dure to intense Tertiary weathering. However, our data confirm the tendency of increasing peak breadth (i.e. lower crystallinity) towards the boundary between the NA and the SCU as mentioned by Pérez-Estaun (1978).

B) *Cambro-Ordovician*

Cambro-Ordovician sediments show IC-values which in general are in the field between 0.35 $\Delta°2\vartheta$ and 0.58 $\Delta°2\vartheta$, although there are regional differences. The lowest values were found in the area around Los Barrios de Luna (transect G in fig. 4; see also

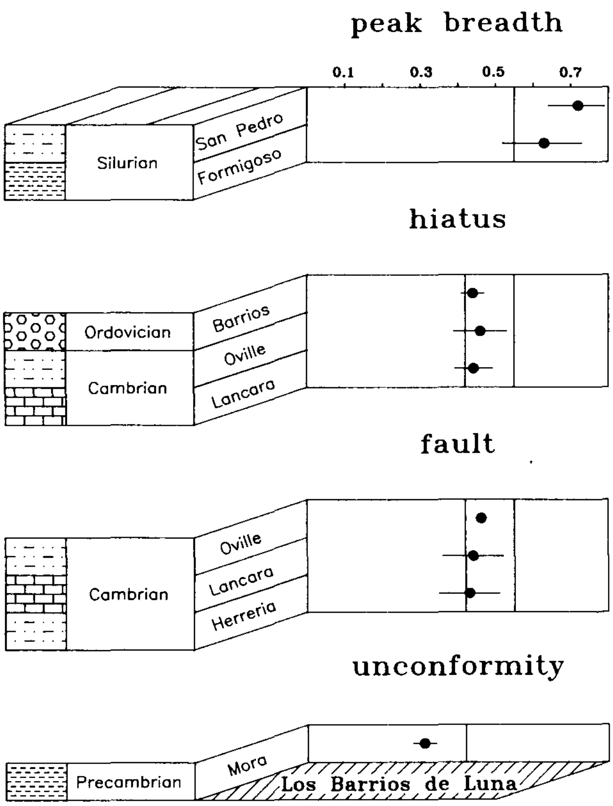

Fig. 3.—Distribution of IC in the section near Los Barrios de Luna (transect G in fig. 5): The average of all samples of each formation demonstrates the jumps at the Precambrian/Cambrian and Cambro-Ordovician/Siluro-Devonian contacts as well as the repetition of the IC trends below and above faults. Means and corresponding 95 % confidence levels are plotted.

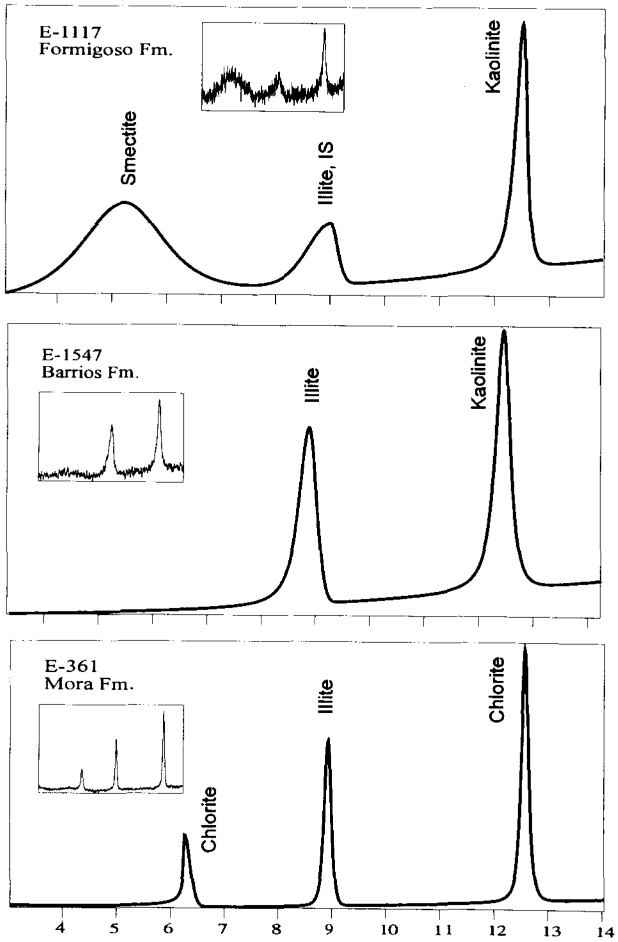

Fig. 4.—Split-Pearson fits of X-ray patterns for each of the tectono-sedimentary sequences discussed in this paper (below: Precambrian; middle; Cambro-Ordovician; above: Siluro-Devonian). Insets are original diffractometre traces.

Brime, 1981). There (fig. 3), values are in the range of 0.3 $\Delta°2\vartheta$ to 0.6 $\Delta°2\vartheta$ with a marked decrease of peak breadth from the Lower Cambrian (Herreria Fm.) towards the Lower Ordovician (Barrios Fm.). This decrease is repeated below and above thrust planes (fig. 3; cf. Brime, 1985).

In the north-central part of the SCU (transects B and D: fig. 5), IC data were obtained from several thrust sheets. All values are in the range of the anchizone (fig. 6).

In the Esla area (transect F: fig. 5), illite peaks are broader (fig. 6) and correspond to values near the transition from diagenesis to the anchizone. This pattern is observed in both the authochthon and the allochthon of the Esla nappe. Although IC data generally point to anchizonal conditions kaolinite can be observed in many samples (for discussion of kaolinite in very-low-grade metasediments see Krumm, 1992). The fabric of quartzites typically shows overgrowth of non-undulating cements on detrital grains and only weak pressure solution. However, near Los Barrios de Luna (transect G: fig. 5) beginning undulation of cements in the Barrios quartzite was observed by Eppinger (pers. comm.).

C) *Siluro-Devonian*

In all sections peaks are broader than 0.55 $\Delta°2\vartheta$ (fig. 6) and well within the field of diagenesis. In contrast to the older strata, the clay mineral association of the Siluro-Devonian is characterized by the frequent occurrence of kaolinite and expandable phases like illite-smectite and discrete smectite. Conodont colours vary between 2 and 4, which is in accordance

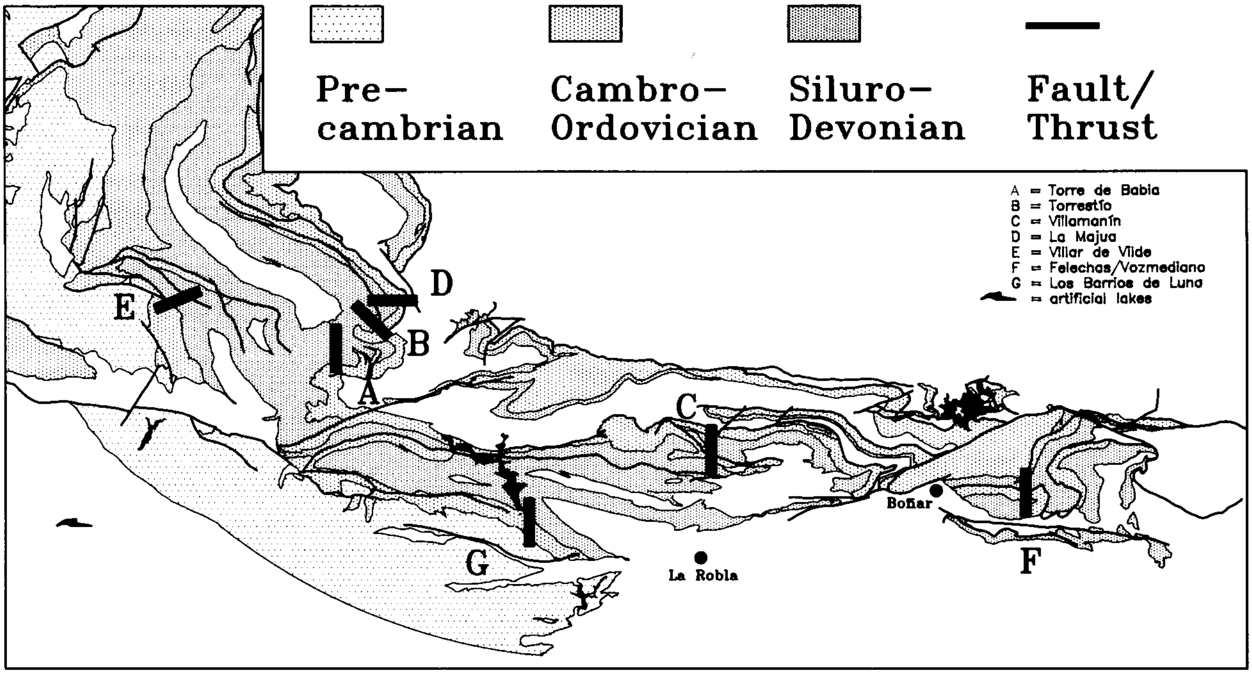

Fig. 5.—Geological sketch map of the SW Cantabrian Mountains (Somiedo-Correcilla Unit and Narcea Anticline) with distribution of the tectono-sedimentary sequences mentioned in the text.

with the illite data. Similiar results for conodonts were reported by Raven & Van der Pluijm (1986) and recently by Marschik (1992) for IC.

At some localities thermally unstable, poorly ordered «protodolomites» with excess of Ca are preserved.

The problem of preservation and recognition of prehercynian metamorphic events in the CZ

Our own data and those from the literature leave no doubt about a greenschist grade metamorphism on the Precambrian Mora Fm. However, timing of this metamorphism in highly controversal between Dutch authors of the Leiden school (Staalduinen, 1973; Savage & Boschma, 1980) and the Spanish ones (e.g. Matte, 1968; Pérez-Estaun, 1978; Leyva *et al.*, 1984; Aller *et al.*, 1987).

The crucial point is the existence of a slaty cleavage, which not only affects the Precambrian, but penetrates some 30 m into the lowermost beds of the Cambrian Herreria Fm. (Bosch, 1969a,b). Whereas the Spanish authors take this as a proof of a single (Hercynian) phase of cleavage development, the Dutch workers believe in an Hercynian reactivation of a Precambrian cleavage system. This opinion is supported by the restriction of the schistosity to a narrow zone near the contact between the Precambrian and Cambrian and clasts in the basal conglomerate of the Herreria Fm. which show a cleavage perpendicular to the main shear system. These clasts are probably derived from the Mora Fm. (Krumm, 1992).

Any interpretation of the metamorphic history of the SW-corner of the Cantabrian Mountains must take into consideration the following facts:

Precambrian structures are cut by the unconformity at the base of the Cambro-Ordovician sequence.

There is a jump in IC between the Precambrian of the Mora Fm. (greenschist facies) and the Cambro-Ordovician sequence (anchizone; fig. 3).

There is another jump between the Cambro-Ordovician sequence and the younger rocks (fig. 6), which were never exposed to anchizonal metamorphic conditions. The differents IC values of these two sequences cannot be explained by a simple burial thermal gradient because in this case a linear increase in IC should be present (see also Marschik, 1992).

This jump is observed in sedimentary sequences below and above major thrust planes and in the autochthon and allochthon of the Esla nappe.

Observations on clay mineral assemblages, on

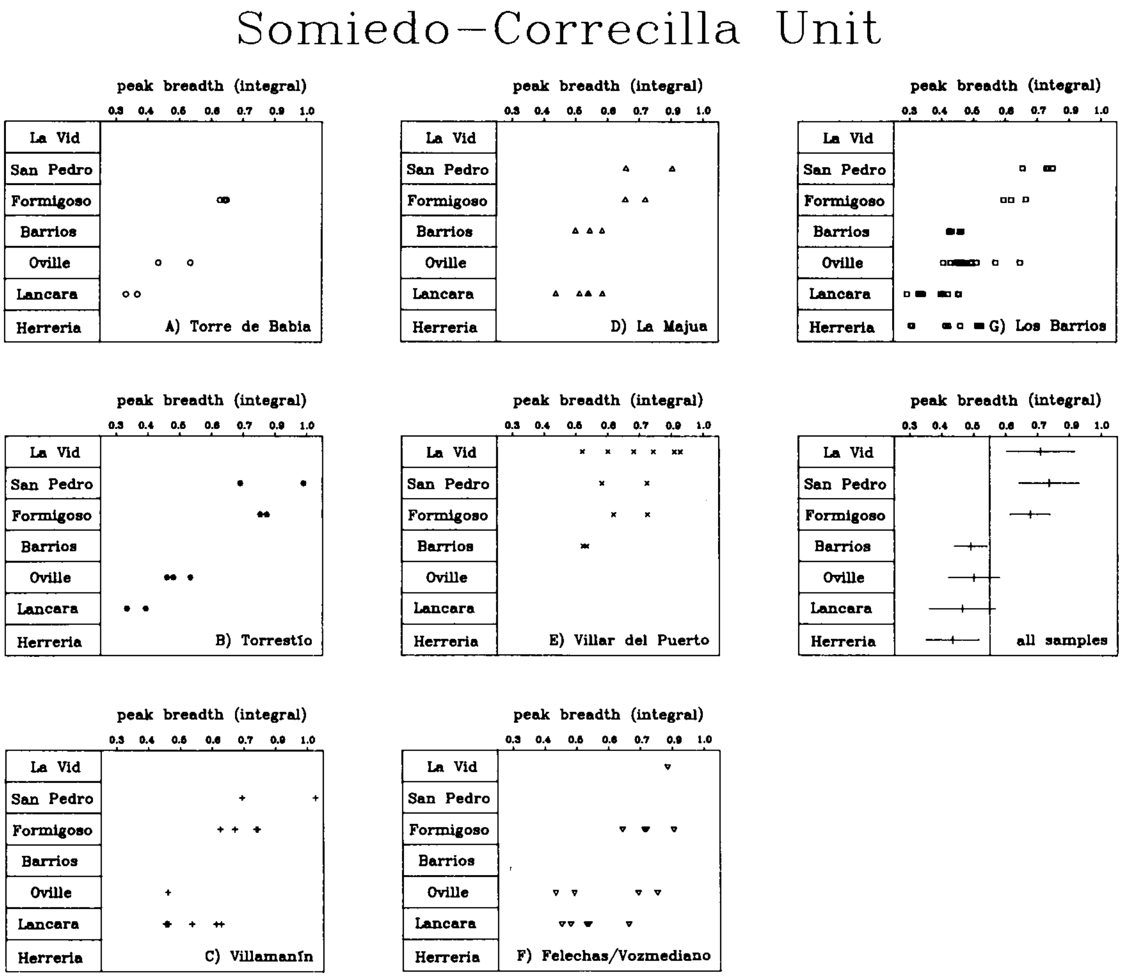

Fig. 6.—Dependence of the IC on the stratigraphic position at several localities in the Somiedo-Correcilla Unit. Everywhere, the jump from the anchizone (Cambro-Ordovician) to diagenesis (Siluro-Devonian) is obvious. Localities as in fig. 5. In the «all samples» diagram, means and their 99 % confidence levels are given.

quartz recrystallisation and on the CAI of conodonts support this pattern.

The regional distribution of the metamorphic grade and its dependancy on the stratigraphic position is inconsistent with and Hercynian metamorphism.

The occurrence of metamorphic «stockwerks» within single thrust sheets, transported during the initial stage of Hercynian deformation, indicates that these stockwerks were are related to an older metamorphic event.

Conclusions

In the SW-corner of the CZ and the NA different metamorphic events can be distinguished:

After deposition of the Precambrian sediments deformation led to the development of large open folds (Pérez-Estaun, 1978; Leyva *et al.*, 1984). According to Bosch (1969b) and Staalduinen (1972) this event was accompanied by an intensive shearing and the development of a cleavage. These structures are cut by the Precambrian-Cambrian unconformity, although it was observed that the cleavage penetrates about 30 m into the Herreria Fm. Whether this is due to a reactivation of the main shear system in Precambrian structures during the Hercynian orogeny (Staalduinen, 1973; Bosch, 1969b) or an exclusively Hercynian phenomenon (Pérez-Estaun, 1978; Leyva *et al.*, 1984; Aller *et al.*, 1987, is still a matter of debate. According to our own data the metamorphic history of the Cantabrian Mountains took place in at least three steps. In a first step Precambrian sediments were affected by a deformation accompanied by a regional metamorphism. During that event the sequence was folded with the development of a first cleavage and heated up to the epizone.

In a subsequent stage Cambro-Ordovician sediments were deposited above the Precambrian «basement» with an angular unconformity. Important magmatic activity in the CZ is reported from the Middle and Upper Ordovician (Gallastegui *et al.*, 1992, Heinz *et al.*, 1985). This magmatism was related to an extensional regime and is observed in various units of the Iberian pre-Variscan strata (Pérez-Estaun & Marcos, 1981; Loeschke & Zeidler, 1982; Quesada, 1991), which in turn might have been caused by the development of a mantle plume beneath western Europe (Calsteren, 1977; Den Tex, 1979). Towards the end of the Ordovician epirogenetic uplift is responsible for the hiatus between Ordovician and Silurian sediments.

After this event, during which Cambro-Ordovician sediments were affected by anchizonal conditions, sedimentation in the SW-corner of the Cantabrian Zone restarted during the Early Silurian and was more or less continuous up to the Upper Carboniferous. The main deformation then took place near the Westphalian/Stephanian boundary with the development of large thrusts and nappes. However, no thermal event exceeding the zone of diagenesis is recognized in the Somiedo-Correcilla Unit.

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