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THE RELATIONSHIP BETWEEN OROGENESIS AND SEDIMENTATION IN THE SW PART OF THE CANTABRIAN MOUNTAINS (NW SPAIN)

BY

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ABSTRACT

The structures in the SW part of the Cantabrian Mountains have much in common with those of the Foothills Belt of the Rocky Mountains, the Alps and the Central European Hercynian orogene, and their origin can be explained in the same way as that of the structures in these orogenes. The greywacke sedimentation and the folding both migrated from the internal to the external part of the original basin during the Upper Carboniferous. The folds and thrust faults run parallel to the axis of the original basin. The basement has been broken into large blocks in the shape of parallelograms, along the boundary faults of which local deviations of the regional directions occurred.

INTRODUCTION

In this article the author will combine the data collected in the Luna-Sil region (van den Bosch, 1969) with some data from the adjacent regions (Evers, 1967; Rupke, 1965; Sjerp, 1967; van Staalduinen, 1969, and the recently published map by Julivert *et al.*, 1968); he will attempt to analyze the regional relationships during the Carboniferous and compare them with the concepts for the Foothills Belt of the Rocky Mountains, the Alps and the Central European Hercynian orogene.

For the names of formations, tectonic units and localities the reader is referred to van den Bosch (1969) and to figure 3.

According to Matte (1968) and Capdevila (1967) (fig. 1 and 2), the SW part of the Cantabrian Mountains constitutes a part of the Iberian Hercynian orogene, the strongly metamorphic core of which is situated in Galicia, the less metamorphic zone with large recumbent folds (West-Asturian-Leonese Zone) in eastern Galicia and western Asturias, and the generally non-metamorphic zone (Cantabrian Zone) in León and central and eastern Asturias.

PALAEOGEOGRAPHY AND DEVELOPMENT OF THE STRUCTURES

After the deposition in the SW part of the Cantabrian Mountains of the Ermita, Vegamián and Alba Formations over a large region in the same facies, and under quiet tectonic conditions, deposition of mainly shales, greywackes, conglomerates and limestones of the Cuevas Formation began south of the Sabero-Gordón line during the Namurian A (Boschma & van Staalduinen, 1968; Evers, 1967; Rupke, 1965). Contemporaneously deposition of the Caliza de Montaña limestones took place north and west of that line, but after the Middle Namurian B the greywacke facies spread out over the entire western Leonides (van den Bosch, 1969, fig. 51). During the deposition of this San Emiliano Formation in the Leonides, shales were

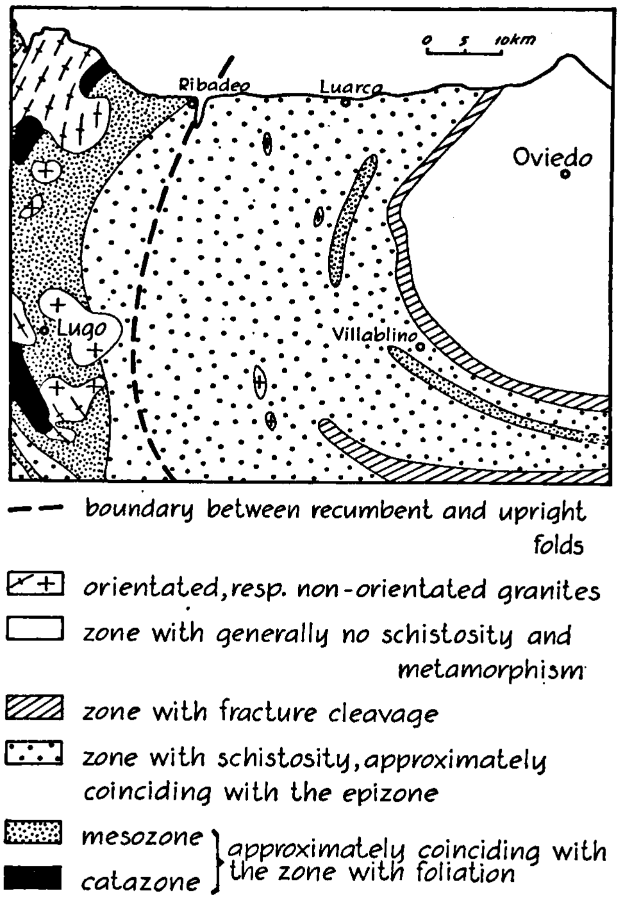

Fig. 1. Tectonic zones in the north-eastern part of the Iberian Hercynian orogene, after Capdevila (1967) and Matte (1968).

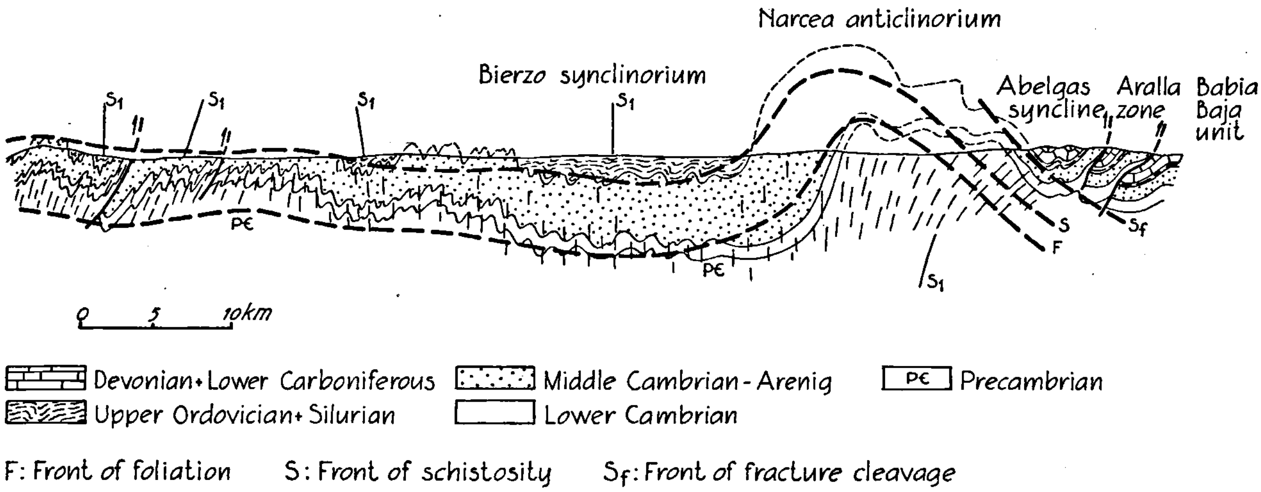

Fig. 2. Section through the West-Asturian-Leonese Zone and the south-western part of the Cantabrian Zone, after Matte (1968).

deposited in a condensed sequence in the Central Asturian Coal Basin and the San Isidro region (Ricacabiello Formation; Sjerp, 1967). After the Lower Westfalian A the greywacke sedimentation spread out over that region, too (Lena Formation). This shows that during the Namurian and Westfalian the greywacke sedimentation migrated towards the NNE (fig. 3; van den Bosch, 1969, fig. 51).

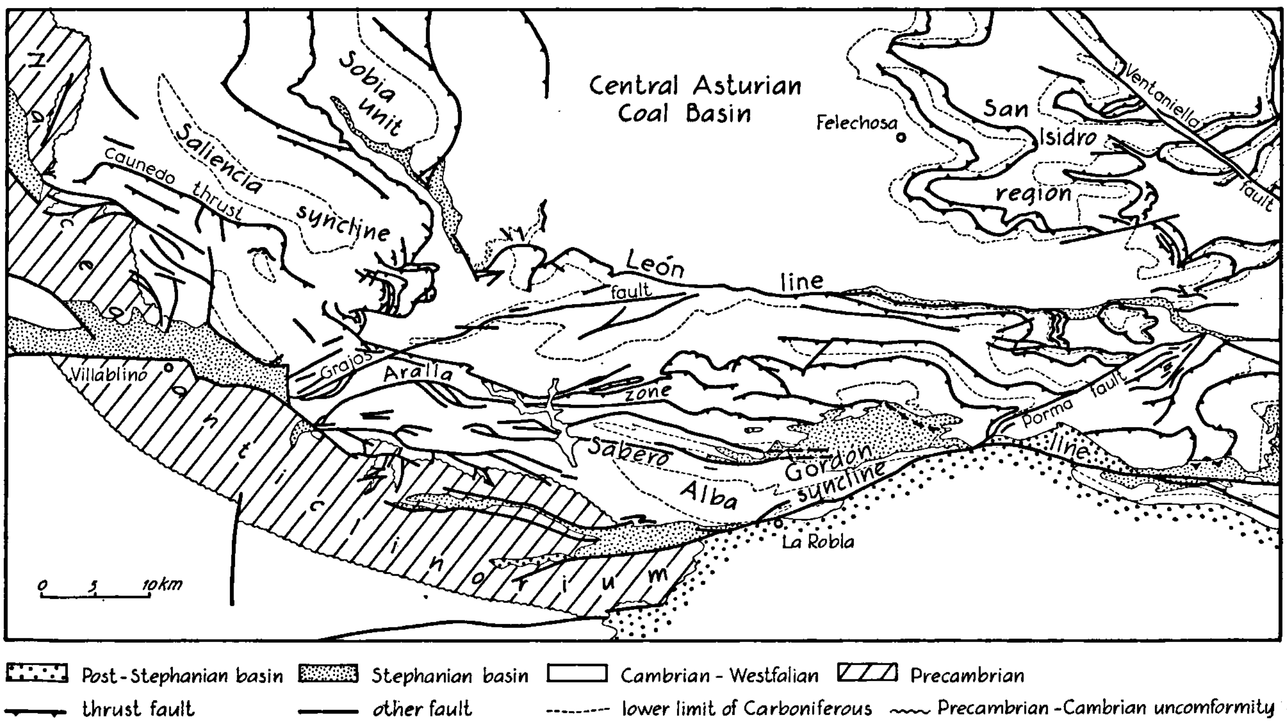

Fig. 3. Tectonic map of the south-western part of the Cantabrian Mountains.

The main direction of sediment transport was no longer from NNE to SSW (as during large intervals in pre-Upper Carboniferous times; Lotze & Sdzuy, 1961; van Adrichem Boogaert, 1967) but from SSW to NNE, as is demonstrated by SSW to NNE trending channels, filled with fine conglomerates, in the San Emiliano Formation of the Palomas syncline and, in the entire SW part of the Cantabrian Zone, diminishing grain sizes towards the NNE and NE in the sediments with an Upper Namurian B-Lower Westfalian A age. Consequently the source area which was formerly found in the NNE, was now situated in the SSW. Thus the palaeographic pattern had changed completely: the West-Asturian-Leonese Zone, where during the Lower Palaeozoic generally more than 12,000 metres of sediments had accumulated (Matte, 1968) in a rapidly subsiding basin, now became a positive region while the Cantabrian Zone became the negative region with rapidly subsiding basins which were filled with more than 2400 metres of sediments in the Leonides and nearly 4000 metres in the Central Asturian Coal Basin (Sjerp, 1967).

A comparable change in position of positive and negative regions was also described by Crosby (1968) in the Rocky Mountains, Krebs (1968) and Wunderlich (1964) in the Central European Hercynian orogene and Trümpy (1960) in the Alps.

During the largest part of the Westfalian the Leonides were probably already being folded and the source area for the sediments of the Lena Formation as grain sizes and sediment thicknesses increase towards the SSW in the Lena Formation in the Central Asturian Coal Basin, (Evers, 1967); the presence of green quartzite pebbles, from the Precambrian Mora Formation, indicate that a part of the sediments derived from an even more southerly source. Thus strong uplifts and erosion must have occurred in the Narcea Anticlinorium.

As the youngest sediments in the Central Asturian Coal Basin and the San Isidro region are of a Middle Westfalian D age and are overlain unconformably by sediments of a Stephanian B age, the sediments in that basin were folded between the Middle Westfalian D and the Stephanian B.

Thus it may be concluded that the source area and probably also the folding migrated during the Namurian, Westfalian and Stephanian A from the West-Asturian-Leonese Zone towards the San Isidro region.

This pattern of a rising land mass migrating towards the external side of the original basin, here towards the NNE, is a general property of an orogenesis (Auboin, 1961); a comparable picture was found by Crosby (1968) and Scholten (1968) in the Rocky Mountains, Krebs (1968) and Wunderlich (1964) in the Central European Hercynian orogene and Trümpy (1960) in the Alps.

Resuming it may be stated that during the Namurian A a land mass in the West-Asturian-Leonese Zone may have produced the sediments which were deposited south of the Sabero-Gordón line, and later also the sediments of the San Emiliano Formation. After the deposition of this formation, the land mass may have expanded towards the Leonides when the Luna and Babia Alta units were thrusted upon the Babia Baja unit and were subsequently, and partly simultaneously, folded (van den Bosch, 1969, p. 218; fig. 5). It is presumed that the Leonides now constituted a positive region and, together with the West-Asturian-Leonese Zone, the source area for the Central Asturian Coal Basin. This basin and the San Isidro region were thrusted and folded between the Middle Westfalian D and the Stephanian B. Possibly at the same time, further folding of the thrusts in the Leonides took place. Thus both the folding and the greywacke sedimentation migrated during the Namurian, Westfalian and Stephanian A from SSW to NNE.

In analogy with the palaeogeographic picture in the Rocky Mountains, the Central European Hercynian orogene and the Alps, the first stages of the thrusting in the Cantabrian Zone could have resulted in the development of island arcs at the place where the embryonic folds and thrusts were being formed. The sediments of the Cuevas, San Emiliano and Lena Formations might partly have derived directly from these island arcs and might have been redistributed along the axis of the WNW-ESE trending longitudinal basins by diverse manners of submarine transport (Kuenen, 1958). The generally uniform grain size distribution in the San Emiliano and Lena Formations, and the generally small changes in depth during their deposition, indicate that the rate of sedimentation kept pace with the rate of subsidence. During the final stages, however, sedimentation surpassed subsidence and no longer marine but paralic sediments were deposited, both in the upper part of the San Emiliano Formation in the Leonides and in the upper part of the Lena Formation in the Central Asturian Coal Basin. As time and deformation continued, the more SSW (more internal) island arcs probably coalesced and may have constituted a broad welt above sea level, while sedimentation continued or increased in the more external parts, forming the be-

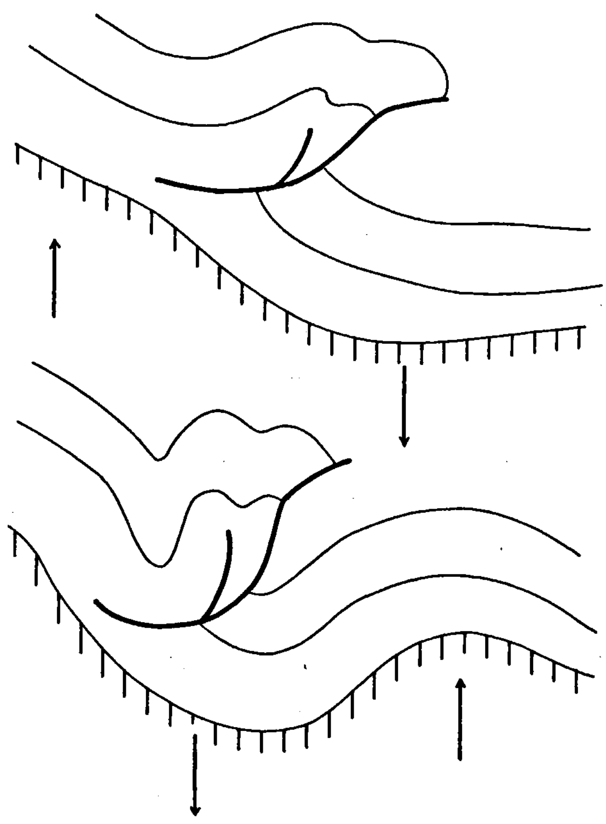

Fig. 4. Sketch illustrating the theory of the 'wave' movement.

ginning of the same sequence of events in those areas.

Crosby (1968) and Wunderlich (1964) (respectively in the Rocky Mountains and in the Central European Hercynian orogene) stated that the combination of negative movements in front of and positive movements behind the folding front caused a rotation which migrated towards the external part of the basin and they compared this with a wave movement. During this movement a thick succession of sediments accumulated in front of the folding front. These sediments were folded and thrusted immediately on passage of the folding front. After the folding, the rocks were exposed to erosion on being passed by the 'wave' of most pronounced rise. After this 'wave' had passed the folded and thrusted region, a slight backward rotation of these structures, accompanied by a continued folding of the folds and thrusts, occurred on the rear side of this 'wave' (fig. 4). If this theory is applicable to the SW part of the Cantabrian Mountains, this explains why several folds, especially in the Babia Baja unit and the lower levels of the Babia Alta and Luna units, have their vergence towards the south and many thrusts are overturned.

The direction of movement during the folding and thrusting was from the positive West-Asturian-Leonese Zone towards the negative Leonides, perpendicular to the strike of the original basin (fig. 5 and 6). Local

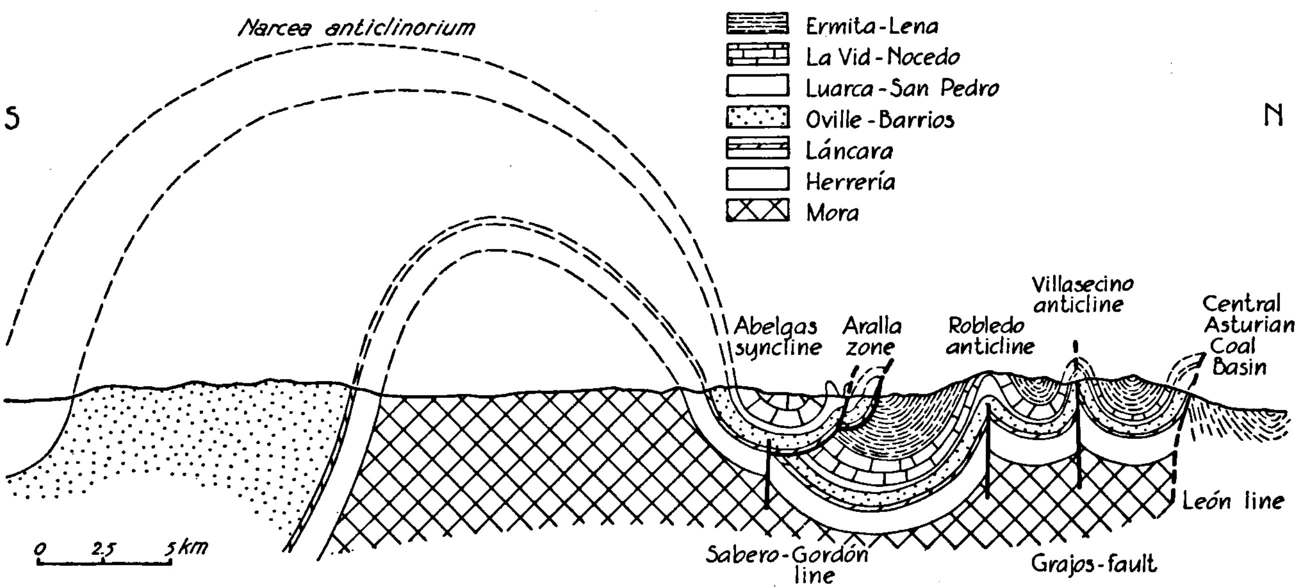

Fig. 5. Section through the south-western part of the Cantabrian Mountains.

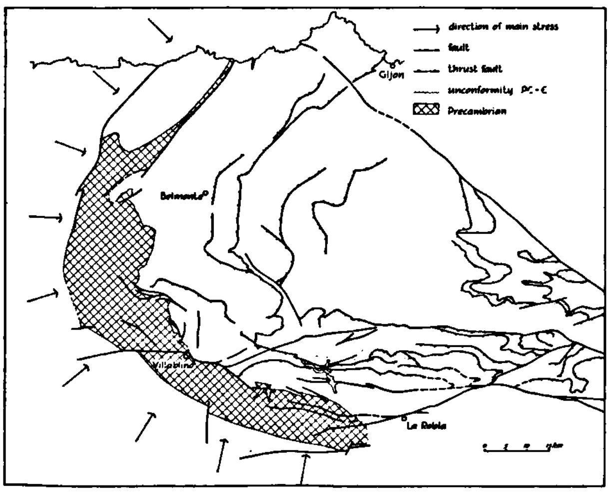

Fig. 6. Structural sketch-map of the Narcea anticlinorium and the western part of the Cantabrian Zone, and the directions of the regional stress field in these regions during the Hercynian orogenesis.

deviations from this direction occurred where major faults cross the basin, e.g. along the WSW trending Grajos fault (van den Bosch, 1969, p. 221; fig. 3) and along the WNW trending Caunedo thrust fault and accompanying faults (Julivert *et al.*, 1968; fig. 3).

As at the few places where it is exposed, the Láncara-Herrería contact at the northern flank of the Narcea anticlinorium seems to be generally normal, no sliding took place along this horizon. Thus the thrust faults are restricted to the frontal and lower parts of the thrust blocks. These thrust faults developed from faulted anticlines (van den Bosch, 1969, fig. 110).

Only structures north of Genestosa reveal to any extent how the thrust faults continue downwards. In the western part of the Caunedo thrust fault the throw diminishes rapidly, and near the western end of this fault Láncara lies in fault-contact upon Herrería with the thrust fault in between; still further to the west the Láncara-Herrería contact seems normal (Julivert *et al.*, 1968; fig. 3).

The Rozo thrust fault presumably ends near the Sabero-Gordón line (fig. 5). The rocks SSW of this line may therefore be considered as autochthonous, the rocks in the region between the Sabero-Gordón line and the Rozo thrust fault as allochthonous.

Figure 5 and the 'wave' theory suggest that gravity energy, caused by the upheaval of the Narcea anticlinorium, might have stimulated the folding initial to the thrusting.

Some thrusting took place along a fault on the old fundamental León line, which probably steepens at depth and extends into the basement as it cuts off the Herrería of the Villasecino anticline obliquely.

Thrusting in the Babia Baja unit was not as intensive as that in the Babia Alta and Luna units (fig. 5). The WSW trending folds in the Babia Baja unit clearly follow basement faults and some southwards directed thrusting took place along these faults.

The rate of movement along the thrust faults is difficult to ascertain. The maximum time involved in the thrusting in the western Leonides is 25 million years, i.e. the time between the deposition of the Lower Westfalian A (San Emiliano Formation) and the unconformable Stephanian B (van den Bosch, 1969, table A); the total magnitude of the thrusting along the Rozo and Babia thrusts is in the order of 8 kilometres, so that a mean movement of not less than 0.3 mm/year occurred along the thrust faults. This is of the same order of magnitude as has been recorded along recently active faults. Between the Namurian A and the Stephanian B (about 35 million years), the folding migrated from the West-Asturian-Leonese Zone towards the San Isidro region, a distance of more than 100 kilometres; the folding thus moved on average less than 3 mm/year towards the external side of the basin, which is comparable to the data of Wunderlich (1964) (1–3 mm/year). His values are of the same order of magnitude as those found for the flowage of the plastic substratum of the earth mantle (0.1–10 mm/year) and he concluded that the orogenesis did not consist of sharply divided Stille phases, but of one long period of continued movement in the mantle, and on the other hand that local folding phases could not be found to be contemporaneous in the entire orogene. The history of the Cantabrian Zone is in agreement with this latter conclusion (de Sitter, 1960; de Sitter & Boschma, 1966, p. 237), as is the history of the Rocky Mountains (Crosby, 1968).

After the main folding, the deformed rocks were locally broken into large rigid blocks with vertical movement along their boundary faults (Stephanian B and C). On the downthrown blocks a number of oblong intramontane basins developed which were filled during the subsidence with a thick sequence of generally continental sediments (fig. 3). These normal faults bounding the basins may have been the result of the previous rapid uplifts (Scholten, 1968). The mainly vertical movements along these faults were independent of the preceding folding and thrusting. Movement along the boundary faults and folding of the Stephanian basins continued during the Lower Permian.

RELATION BASEMENT-SEDIMENTARY COVER

It has already been stated above that the WSW trending major faults and the WNW trending faults accompanying the León line and the Sabero-Gordón line penetrate into the basement. The WNW trending faults near the Caunedo thrust fault, in the Muxivén zone and between Los Barrios de Luna and Salce were also found to cut both the basement and the sedimentary cover (fig. 3 and 7). The N–S trending Lumajo fault is also assumed to continue into the basement. Only along the faults accompanying the León line and along the WNW trending faults near the Caunedo thrust fault, did any important vertical displacement occur, whereas along the other faults only relatively little displacement in either a vertical or horizontal direction occurred. The map and the sections NE of Villasecino show, for example, that along the Grajos fault a displacement of not more than approximately 800 metres in a horizontal and vertical direction occurs.

It is conspicuous that the main direction of the thrust faults in the Leonides is consistently WNW, interrupted by the WSW trending Grajos fault and parallel structures, although the original basin curved from a WNW to a N–S strike (fig. 7). This probably indicates a continuation of important WNW trending basement faults below the rocks involved in the thrusting.

It may be concluded that the basement in the SW part of the Cantabrian Mountains was broken into several blocks in the shape of parallelograms which moved along their boundary faults: the WNW trending faults mainly in a vertical direction and the WSW trending faults and the N–S trending Lumajo fault both in a horizontal and a vertical direction. These faults are essentially older than the folding and fit into a primary wrench-fault system under simple compression (van den Bosch, 1969, fig. 114). The regional stress field was often deflected in a direction perpendicular to these faults, as is especially demonstrated near the WSW trending Grajos fault and the WNW trending faults accompanying the Caunedo thrust fault (fig. 3).

Comparable configurations have been described from the Jura. Just as in the region concerned, the basement there was broken into blocks generally in the shape of parallelograms, with horizontal and vertical movements along their boundary faults. These faults preceded the folding and determined the shape and place of the folds and thrust faults (Aubert, 1949, 1959; Laubscher, 1961, 1965; Lloyd, 1964; Pavoni, 1961; Wegmann, 1961, 1963). In particular the fault pattern in the southern French Jura is strikingly similar to that in the SW part of the Cantabrian Mountains (Clin, 1966; fig. 8).

The concepts presented in this article demand further evidence and it is hoped that specialists will investigate the critical areas and contribute to the solution of the regional problems.

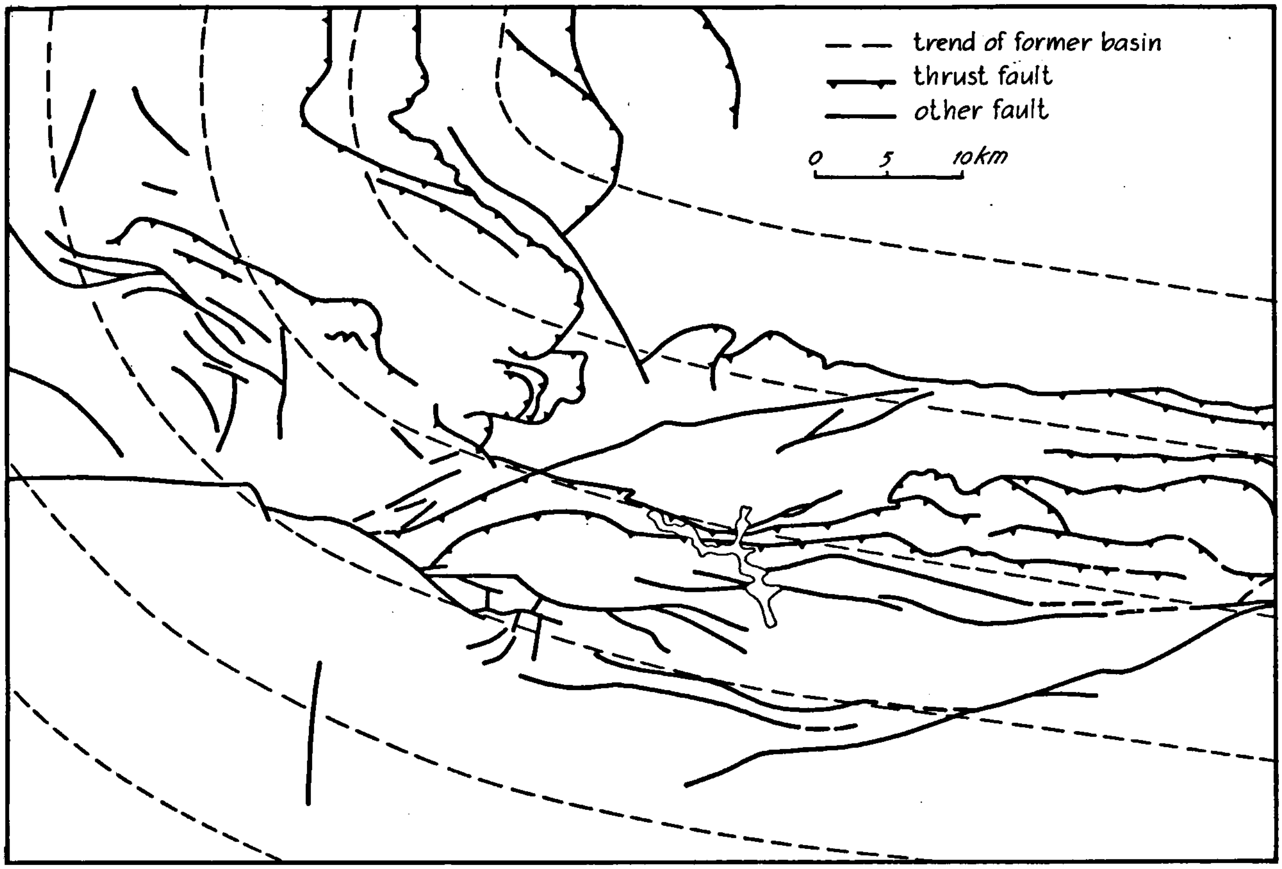

Fig. 7. Relationship of WSW and WNW trending faults with the curved shape of the former basin.

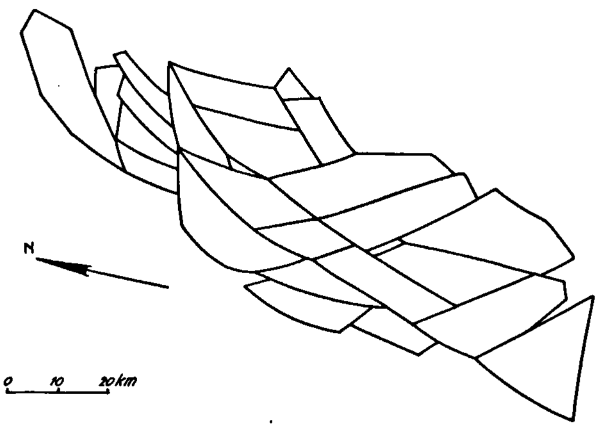

Fig. 8. Basement faults in the southern French Jura, after Clin (1966).

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