THE DEVONIAN OF THE UPPER PART OF THE VALLE DE ARAN, CENTRAL PYRENEES

by

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Summary

The Devonian stratigraphy in the Valle de Arán of the Central Pyrenees, is different from that of its surroundings.

In this area a zone of graded greywackes occurs together with a rock type of supposedly littoral facies, in an oblong basin, which has been filled longitudinally by sediments slipping down in turbidity currents from the delta slope in the West, thus building up the graded sediments of the deepest part of this basin.

The Hercynian orogeny has folded this area very strongly, developing an intense cleavage. This cleavage together with repeated alternation of sediments of different competency caused the enormous variety of secondary folds with their special tectonical problems.

Introduction

In the summer of 1955 and 1956 a detailed map (1:10.000) was made of a part of the Upper Valle de Arán (The Upper Valley of the Garona river), situated in the axial zone of the Pyrenees on the Spanish side of the frontier. The mapped area extends from the village of Salardu to the Franco-Spanish border W. of Viella, the principal town of the valley.

The Valle de Arán has been mentioned already by many authors, but has always played a subordinate role in a larger field of investigation. We only quote: CARALP (1888), CAREZ (1903—1909), DALLONI (1930), SCHMIDT (1931).

Since 1954, however, a systematic detailed mapping, started by the University of Leiden under the guidance of Prof. Dr L. U. de Sitter (see literature), has been in progress.

The present mapping together with previous results gives a somewhat clearer view of the geology of this part of the Pyrenees, and special attention is here given to the Devonian. In the Valle de Arán the rocks belonging to this period have a different character than in the northern and southern border zones of the Pyrenees.

The mapping was hampered by the lack of fossils and the prominent Hercynian cleavage of the rocks obliterating to a certain extent the original bedding. Therefore, the map is based purely on structural-lithological evidence.

Stratigraphy

1. *Cambro-Ordovician*

In the Valle de Arán the Ordovician is exposed only north of Bosost and of the Rio Barrados and in a narrow E—W band in the south from

the Rio Jueu to the Rio Negro. In the Jueu and Negro valleys it is exposed in the core of an anticlinorium plunging eastward. The rocks are slightly metamorphic and consist of a thick series of sericite-bearing slates, thin sandstones and quartzites with intercalations of calcareous slates. In the northern portion the Cambro-Ordovician is often strongly metamorphic, but when not under influence of this regional metamorphism, it has the same character as in the south.

2. *Silurian*

The Silurian occurs in a black slate facies, which is typical of the Pyrenees and far beyond this mountain chain. Elsewhere graptolites have been found in the Silurian (De Sitter, 1954b), but in the Valle de Arán these rocks remain unfossiliferous.

In the Valle de Arán two zones can be distinguished in the Silurian. The lower one, Silurian A, occurs in the NE and along the Rio Barrados and in the SW around the Ordovician anticlinorium. It consists of black pyritebearing slates which soils the fingers. Above the Silurian A and below the basal limestone of the Devonian occurs a zone of non-staining black slates, the Silurian B which locally contains pyrite. Sometimes this upper zone has a more or less sandy character. The Silurian B zone is a local development below the Devonian basal limestone, and is, for instance, well developed between the Rio Jueu and Rio Negro, between the villages of Garos and Salardu and north of the Sierra de la Pincela. Often the Silurian B is difficult to distinguish from the Devonian black slates which follow the basal limestone. It has also been found in the Plá de Berèt and is here called Siluro-Devonian by J. P. Snoep (1956). As this zone has a thickness of no more than 20 metres in the mapped area, it has been impossible to mark it separately on the map.

3. *Devonian*

The absence of fossils makes a stratigraphical subdivision of the Devonian impossible. Since, moreover, a lithological unit is not necessarily bound to a time unit, only lithological units are indicated on the map, thus avoiding difficulties in stratigraphical classification.

In the Devonian the following zones have been distinguished from the top downwards.

top: D_4 fine grained green or green-grey slates and sandstones.
D_3 Las Bordas zone:
D_{3b} grey graded graywackes and slates.
D_{3a} green graded graywackes and slates.
D_{2b} greenish-grey slates
D_{2a} blue-black slates
bottom: D_1 limestone

D_1 *Limestone.* — This basal limestone is very well exposed in the Esera syncline in the south-west, east and west of the Rio Jueu, further in the north-eastern part of the Valle de Arán and to a less extent along the Rio Garona north of the village of Arties. It nearly always rests upon the Silurian B.

In the west the limestone carries intercalations of fine grained sandstone and chert with a thickness of a few centimetres, which towards the top pass

in to an alternation of limestone and slates varying in thickness from a few centimetres to some metres. In the NE and SW the limestone also has sandstone-, slate- and chert-bands often showing beautiful microfolds. Locally it may be rather pure. Dolomitization occurs nearly always, especially in the south-west and near the Monte Calvo. Usually the rock has a bluish grey colour with a white weathering surface; remnants of crinoids are often found.

Near the Maladeta granite it has been marmorized.

The limestone varies in thickness: in the north from 70 to 100 m, north of Arties 15 m, and in the south from 40 to 100 m, occasionally up to 200 m (fig. 1).

D_{2a} *Blue-black slates.* — The blue-black slates resting upon the basal limestone, closely resemble the slates of the Silurian B. Locally they are strongly pyritic, but they do not soil the hand. Only a detailed structural mapping in the field reveals whether the slates belong to the Silurian B or to the D_{2a} zone of the Devonian.

The D_{2a} zone decreases in thickness from W to E. Near the mountain Areño, about 4 km north of Arties, the D_{2a} zone contains detrital limestones which show cross-lamination.

The absence of the D_{2a} slates and other Devonian zones in the Esera-syncline between the Devonian basal limestone and the Carboniferous, is remarkable. Considering the great thickness of the D_{2a} zone south of the Corbison mountain it is not likely that this zone has not been deposited in the Esera-syncline (fig. 1). A Devonian-Carboniferous disconformity is therefore probable, but is still not established by any evidence of gradual overlap on the map. The northern limit between the basal limestone and the Carboniferous is formed by a long fault, as for instance can be seen near the Guells de Jueu, an enormous source in the Upper Rio Jueu.

D_{2a} *Greenish grey slates.* — The D_{2a} zone usually rests directly on the basal limestone but in the extreme north-east near the Pico de Parrós, a series of greenish grey slates with intercalations of sandstones, D_{2b}, apparently replaces the black slates of D_{2a} (fig. 1). Nothing is yet known with certainty about this lateral change from D_{2a} into the D_{2b} zone. The thickness of D_{2b} is estimated at about 100 m.

D_3 *Las Bordas zone.* — This name is derived from the small village of that name in the Valle de Arán, downstreams from Viella, and was given to a zone of graded sandstones exposed nearby. Although it can now be said that this zone also included slates, quartzites and even non-graded beds, the present authors wish to preserve the name for the whole group of sediments including the graded sandstones.

The scale of the accompanying geological map does not allow to distinguish all the different rock types of the D_3 zone, and therefore it is shown by one colour.

On the Corbison mountain a type of rock occurs at the bottom of D_3 which provisionally is regarded as of littoral facies. It consists of slates with sandstone laminae, with a considerable variation in the relative proportions of sand and clay. The sand consists of well rounded and assorted (0,1 mm or 0,5 mm but never mixed) quartz- and feldspar-grains in a 3:1 ratio, bedded in a matrix rich in sericite. The sediment gives an impression of being formed on a shallow shore where the dash of the waves closely mingled clay and sand.

North and south of the Corbison layered quartzites occur with a

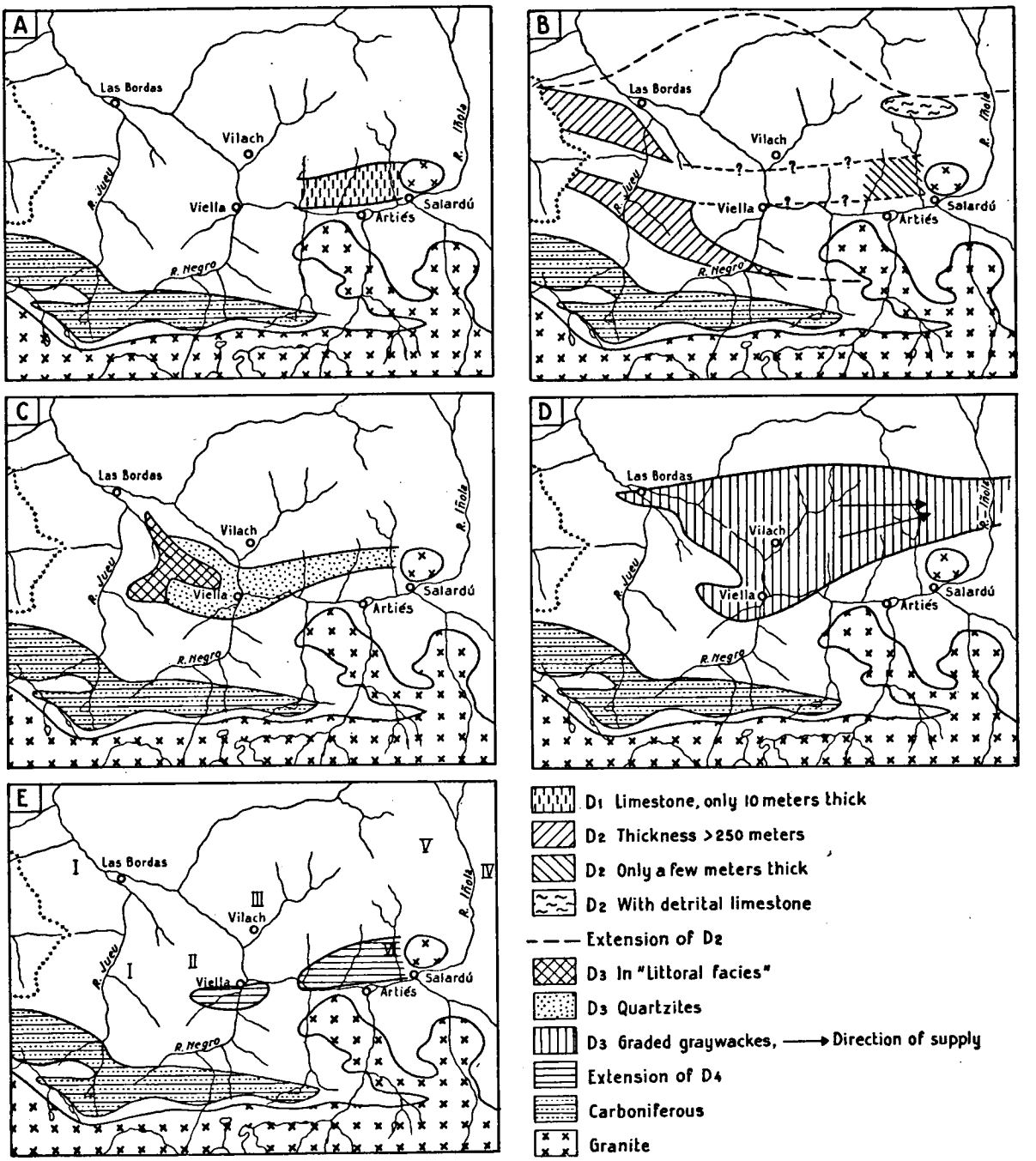

Fig. 1. Repartition of facies groups in the Devonian of the Valle de Arán.

thickness of 10 to 20 m and towards the village of Salardu these layers decrease in thickness to 5 m. The quartz grains are well sorted (ca. 0,75 mm) and fairly rounded. The beds are non-graded. North of Salardu the boundary between the quartzites and the graded graywackes is formed by a fault. North-east of Viella the fault is absent and the graded beds and quartzites merge into each other.

The bulk of the Las Bordas zone is taken up by graded graywackes and slates, which occur from Las Bordas to north-east of Salardu, where the graded beds form a W—E strip flanked by slates. In the region north of Viella the graywackes can be divided into a green graded type (D_{3a}) at the bottom, overlain by grey graded graywackes and slates (D_{3b}). It is not possible, however, to make this distinction elsewhere in the Valle de Arán.

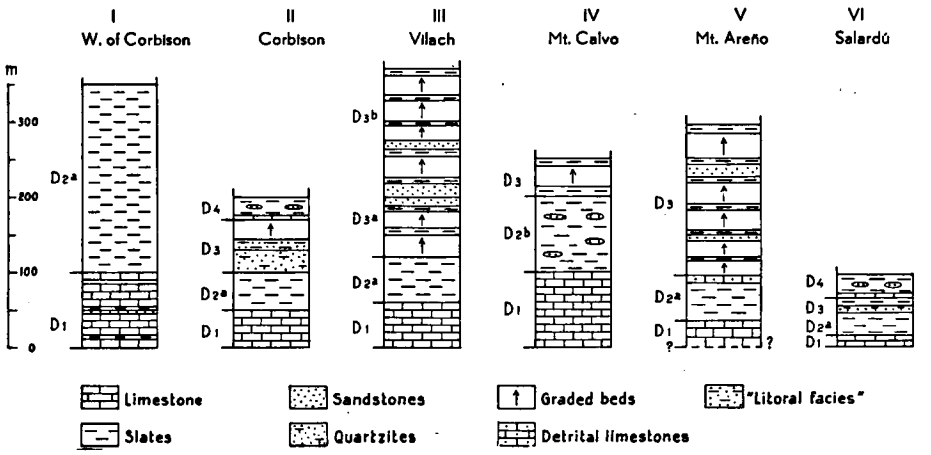

Fig. 2. Sections of facies variation in the Devonian of the Valle de Arán
For location of sections see fig. 1 E.

Microscapically there is not much difference between D_{3a} and D_{3b}. Both are graywackes with a high percentage of quartz (ca. 80 % and 0,4 mm diam.) in a matrix of sericite and quartz. The graded cyclothems of the graywackes vary in thickness from 20 to 200 cm. Non graded cyclothems also occur, in which the repetitional layering has a thickness between 10 and 100 cm.

The greatest development of the Las Bordas zone lies between the village of Vilach and the Monte Areño where its thickness grows to 200 metres. On the Monte Calvo, however, it decreases to 50 m only, but there the Devonian as a whole is reduced to about 100 metres (fig. 1).

D_4 *Green slates.* — Green slates with intercalations of sandstone occur in a narrow east—west running zone between Viella and Salardu. This D_4 zone as a whole has a thickness of about 50 m and its base is formed by a thin sandy limestone. In some very good outcrops south of the Monte Calvo it is clear that the green slates overlie the Las Bordas zone, whereas, further west, especially between Viella and Betren, the position of these rocks in the sequence is not so evident. The same is true of the green slates south of Viella along the Rio Negro (fig. 1).

4. *Carboniferous*

The Carboniferous is restricted in the Valle de Arán to the northern margin of the granite massif of the Maladeta. It occurs there in the core of the Esera syncline. Its stratigraphical position is given by plant remains in black micaceous sandstones which indicate a Westphalian age. DALLONI (1930) erroneously classifies the Upper Devonian graded graywackes also in the Carboniferous, this error has been corrected already by DE SITTER (1954a).

As everything from D_2 to D_4 inclusive and probably the Visean also is missing in the Esera syncline it is a problem for further investigation to decide whether the Devonian-Carboniferous boundary is conformable or not.

Geological History

On the basis of the distribution of the lithofacies and the thicknesses of the Devonian zones an attempt will be made to retrace the history of this part of the Devonian geosyncline.

The conditions prevailing during deposition of the typical black slate facies of the Silurian is not yet completely known. It is clear, however, that towards the end of this period changes in conditions arose. The uppermost zone, the Silurian B, becomes somewhat sandy and gradually passes into the basal limestone (D_1) of the Devonian. In the Valle de Arán this limestone has not everywhere the same thickness. In the north and west of this district it is about 100 m. thick and along the northern margin of the Maladeta massif sometimes up to 200 m. In a narrow E—W strip north of Arties and near Salardu, however, the thickness does not exceed 15 m. (fig. 1 A). This reduced thickness of the basal limestone indicates a central longitudinal ridge in the Devonian geosyncline, which, as will be shown further on, must have persisted until after the sedimentation of the D_3 zone.

The D_2 zone, which extends over a large area, varies more abruptly in thickness and facies (fig. 1 B). It reaches its greatest thickness, more than 250 m, in two strips respectively west and south of Las Bordas and west and south of the Corbison. These strips thus occur on either side of the same central ridge of Salardu if we are allowed to project the latter westwards as is indicated by the reduced thickness of the basal limestone in the region of Viella. On the Salardu ridge the thickness of the D_2 zone amounts merely to a few metres and can hardly be marked on the map as a separate zone. On the Viella ridge it is present in a thickness of much less than 250 m. The linking up of the ridge of Salardu to that of Viella as forming one and the same trend is not yet quite assured.

The very thick development of D_2 north and south of the Viella ridge and its decrease further to the east, suggest that the direction of supply must have been from the west. The old shoreline has thus to be sought in the west. This assumption finds support in the development of the D_2 zone.

The shallow water facies in the top of the D_2 zone near the Monte Areño (fig. 1 B) is interesting. Some limestone bands with a detrital character indicated by cross lamination occur alternating with the black slates. They reach some 10 cm in thickness. North of this the D_2 slates are absent and the D_3 zone lies directly on the basal limestone. We suggest that the basal limestone has supplied the material of the detrital limestones, which implies that an erosion period occured after D_1 was formed.

West of Viella on the Corbison a rock type, consisting of slate and

sandstone laminae, is found which was evidently formed under shallow water circumstances as appears from its composition. Provisionally this is considered to represent a littoral facies (see also chapter Stratigraphy). North, south and east of this occurrence (fig. 1 C) thickbedded (up to 20 m) quartzites exist and can be followed as far as Salardu, but they decrease in thickness in that direction to about 5 m. Both the littoral facies and the quartzites belong to the lower part of the D_3 zone and are situated apparently on the central longitudinal ridge. A connection between the Viella and the Salardu ridges is thus indicated.

In our opinion the western shoreline of the geosyncline located further to the west during deposition of D_2 has moved eastward in D_3 time close to the Viella region. The D_3 sediments form the most seaward part of a delta.

To the NE and E the littoral facies and the quartzites pass rather quickly into graded and non-graded graywackes and slates which take up most of the D_3 zone (fig. 1 D). The graded beds are situated in an easterly trending strip north and south of which only slates occur. It appears from structures such as, grading, flowmarks, closs-laminations and convolute laminations in these rocks, that they have been supplied by turbidity currents (KUENEN, 1953). Data obtained from the cross-laminations give a direction of supply ranging between W and WSW (fig. 1 D).

The maximum thickness of the graded beds (up to 200 m) occurs between Vilach and the Monte Areño and west of Viella the thickness decreases rapidly. North of Arties the southern margin of these beds is formed by the Salardu ridge. Between Arties and Viella the D_3 zone crosses the Rio Garona so that the Viella ridge has lost its former significance.

From the evidence given above it can be deduced that this oblong part of the geosyncline was filled longitudinally.

In the north-east the graded graywackes occur as far as the village of Montgarri (outside the map) (SNOEP, 1956) where the Devonian changes into a limestone-slate facies (ZANDVLIET, 1957). The graded graywackes thus occur in the deepest part of the Devonian geosyncline. This deepest part is oblong in shape, has a supply from one end and is fringed by sediments with a shallower facies. As was pointed out lately such a longitudinal filling of oblong basins is not uncommon in the past as well as in recent times (KUENEN, 1957). In the west the delta slope evidently became to steep and its sediments slipped downwards in turbidity currents building up the graded sediments of the deepest part of the geosyncline (KUENEN and MIGLIORINI, 1950). The reason for this down sliding of sediments must be found in a rapid steepening of the delta slope due either to rapid emergence of the delta or to sinking of the geosyncline or to both.

The presence of terrestrial Carboniferous facies probably resting directly on an eroded surface of the basal Devonian limestone supports the view of the emergence of a part of the central geosyncline prior to the folding.

As the last phase of the Devonian geosyncline the sedimentation of the D_4 zone sets in with the formation of a sandy limestone facies with a maximum thickness of about 2 m. Then follows a series of fine grained green clays with sandy intercalations. The D_4 zone is now situated on the former longitudinal ridge (fig. 1 E). Apparently the ridge has lost its significance during D_4 times and possibly the D_4 sediments were deposited over a larger area but have now been removed as a result of the uplift of the central Pyrenees. The top of the D_4 zone has nowhere been found.

Structural Geology

The Pyrenees are a Tertiary mountain chain which in accordance with ARGAND (1927) can be seen as having a Hercynian-folded core, of which the basement, hardened by migmatization and granite-intrusion, was not folded again by later orogenic cycles. These later forces were absorbed in the core by re-activated existing faults, limiting tilted blocks dipping to the North. These post-hercynian orogenic stresses caused only some refolding in the northern and southern borderzones of the central Hercynian block. The Hercynian folding mechanics of the central block, the axial zone, is an intensive cleavage-folding with the general exception of the terrestrial Carboniferous, which has been folded concentrically.

The Valle de Arán is situated in the centre of the axial zone and shows this intensive Hercynian cleavage very clearly. The visible intensity of folding and the size of the folds, is closely related to the lithological character of the sedimentary rocks. In the South, the boundary of the Valle de Arán is formed by the rigid mass of the Maladeta pluton, flanked by a longitudinal carboniferous basin, the Esera syncline. In the NW and N we find a more or less competent infra-Palaeozoic region, locally metamorphosed and in the E the Marimaña pluton. In the centre of the Devonian synclinorium we find a relative competent mass of quartzites and graded graywackes, the D_3 zone. The folding of this Devonian basin is characterized by an intensive folding, accentuated by the Silurian black shales, which act as a detachment horizon from the infra-Palaezoic and as a lubricating horizon for the Devonian. The small sized folds show anticlines and synclines somewhat overturned to the South with a well developed cleavage, dipping to the North, with values, varying from 70° to almost 90°. This secundary folding is superimposed on a set of primary folds, which are in general very quiet synclines and anticlines with gently dipping flanks reflecting the folding of the upper surface of the Cambro-Ordovician. The intensively folded secondary folds have amplitudes ranging from 500 metres in D_2 and probably D_1 to a minimum of 50 metres in D_3, due to lithological differences in rock composition. Much smaller folds and microfolds are numerous in limestone, when intercalated with slate, sandstone or chert, but are also found in the other formations.

According to FOURMARIER (1953), a sediment burden of 5000 to 6000 metres thick is necessary for the development of cleavage. In our region an estimate of a total thickness of the Devonian of 500 metres is ample; the present thickness of the Carboniferous in the Esera syncline never reaches more than a 1000 metres and has probably never been more than 2000 metres. Together not more than a maximum of 2500 metres of sediments has been folded, of which the lower 500 metres show a strongly developed cleavage much less than the burden required by FOURMARIER.

FOURMARIER suggests that a rise of temperature might lift the cleavage boundary to a higher level, but as most of our sediments are outside the influence sphere of migmatization, this factor can hardly have been active here. Some structures in marmorized limestone near the granite contact do suggest the influence of temperature.

The German school of thought supposes that the development of cleavage is wholly dependent on the lithological character of the rocks; DE SITTER (1956) thinks that the stress level is an important factor.

The result of a stress field on a sedimentary sequence of thin slates between thick sandstones is different from that on thick slates with thin sandstones. Although the folding of the thick sandstone sequence has more of a concentric character than that of the thick slates sequence, the cleavage is better developed in the thin slates than in the thick slates (see fig. 3).

In the Valle de Arán we find both thick homogeneous pelitic sediments (D_2) and sediments characterized by rapid change in lithology and alternations of rocks varying competency (D_3).

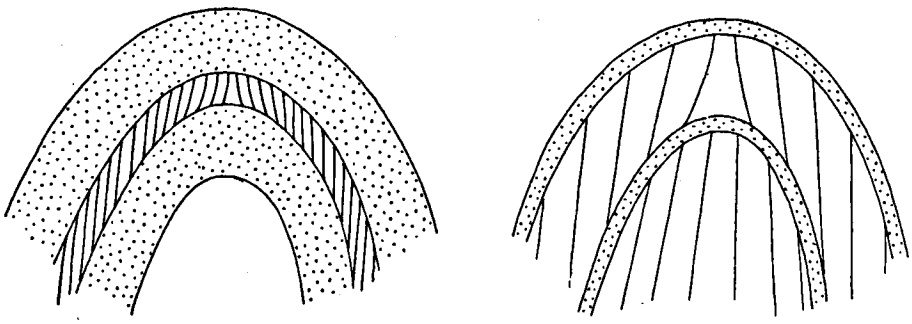

Fig. 3. Development of cleavage in thick and thin slates between competent beds.

An alternation of competent and incompetent layers as occurs in D_3 gives an alternation of concentrical and cleavage folding, which gives rise to very complicated folds. The excessive values of the axial plunges in this zone (up to 70°) are probably related to this kind of folding.

It was always possible to find the direction of younging, where graded beds occur. The cleavage/bedding method was less successful, because of the slight overturning of the folds to the South and in the overturned southern flank cleavage becomes parallel to the bedding. Sometimes it was very hard to find the correct plunge of the anticlinal axis by measuring the lineation, due to intersection of cleavage and bedding, because of intensive surface creep, and deviation of the dip of cleavage, due to alternation of beds of different lithological type or to grading.

The folding mechanics of the cleavage folding is remarkable well exposed in a small valley, north of the vallage of Gessa, where the Devonian sequence is very thin. Also between the villages of Vilach and Viella many secundary folds are well exposed in the D_3 zone.

Faults are a common phenomenon in this folded Devonian; they are mostly of small size and they are practically always indicated by small E—W running creeks.

North of the Maladeta pluton the Esera syncline is flanked on both sides by faults, indicated by fault breccias and quartz dikes. Very pronounced is also the fault running through the Ordovician anticline from the Rio Negro to the Rio Jueu; south of this fault line the Devonian limestone is marmorized. North of the Rio Garona, between Viella and Salardu, a fault line, marked by limestone lenses and accompanied by quartz veins, has been mapped over quite a distance.

Further to the North the basal limestone shows an imbricated structure and the Silurian has penetrated along each of the fault lines. The faults

are mostly directly connected with the folding, but some of the larger ones are of a late Hercynian age, a period of elevation and faulting.

In the Devonian slates kind of fracture cleavage is occasionally found, mostly developed in pairs and dipping southwards. This much more widely spaced fracture cleavage is thought to be related to the late Hercynian elevation.

Igneous rocks

A few notes on the intrusive rocks and the quartz- and diorite-porphyrites seem indicated. The southern part of the Valle de Arán is occupied by the Maladeta pluton, a biotite-granodiorite intrusion of late tectonic Hercynian age, together with some smaller stocks (Salardu).

Dykes of quartz- and diorite-porphyrites occur very frequently in the Devonian, mostly in the D_3 zone but also in great quantities in the Devonian basal-limestone. Their composition varies little: phenocrysts of chloritised biotite, sericitised plagioclase and sometimes of quartz or hornblende in a very fine-grained, much altered groundmass containing the same minerals.

In the field these dykes appear mostly concordant with the cleavage of the folded sediments, rarely discordant. Their border zones sometimes show cleavage.

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