STRATIGRAPHY AND STRUCTURAL GEOLOGY OF THE DISTRICT WEST OF THE MARIMANA GRANITE, VALLE DE ARAN

BY

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Introduction

In the summer of 1953 and 1954 a detailed 1:25.000 map was made of a part of the central Pyrenees. The mapping ranged from Salardu (Valle d'Aran) to Mongarri, (northeast of Salardu). Thanks to a grant from the Molengraaff fund a special study could be made of the structural geology of this district in the summer of 1954. In the course of this study, particular attention was given to the complicated folding tectonics and numerous "minor structures" were measured and examined. This method made it possible in some cases to locate synclines and anticlines without seeing their hinges so that some of the stratigraphy could be reconstructed. The stratigraphical sequence as a whole remains doubtful however, as all the layers in the district are nearly vertical and visible folds remain scarce.

Structural geology

1. *The Devonian district near Salardu*

A detailed map (1:10.000) was made of the area north east of Salardu, between Bagerque and the Pla de Beret, because here many different rocks occur and often bedding and cleavage are easy to distinguish. The limestones, occurring in many bands on the ridge between Rio Malo and Rio Iñola, end in wedge shapes above the valleys of these two rivers, while below a certain level only black slates occur. This arrangement might be considered as a system of isoclinally folded limestones with hinges ending wedge-shaped in the black slates. This is impossible, however, if we take into account the observations on cleavage and bedding. From these observations it appears that 70 % of the layers belong to the northern limb of anticlines, and more than half of the remaining observations appear to belong to obviously secondary structures of smaller wave length. If it were a monocline the layers would cross the valleys, and if it were a succession of folds we would expect a roughly equal proportional of north and south limbs. From this we conclude that the structure has an imbricated character. Four repetitions could clearly be proved. To the north of these four wedges we find a small fifth wedge (Puerta de Beret) which ends wedge-shaped in black slates to the east as well as to the west. Without its many characteristics such as cleavage, recrystallization and flow structures of quartzites and limestones this formation might be considered a sliced overthrust, but the aforementioned characteristics undoubtedly indicate strong lateral compression. We may assume the following sequence of events:

First during the Hercynian folding, flat thrust wedges were formed by a N—S stress or by gliding-down from the first domes of the rising granite of the Maladetta in the south. These wedges originated in the first place in the base of the formation (the limestones of the road to Puerta de Beret). Later, under the influence of a later folding a general compression occurred which caused the schistosity and cleavage.

Gliding tectonics in the Pyrenees are thought to be related to the sharp disharmony in folding between the Devonian and the Ordovician. The Ordovician occurs in large domes and the depressions are filled up by intensely folded Devonian strata (c. f. ZWART, 1954).

2. *The district between Salardu and Mongarri*

The greater part of this district is occupied by the broad valley called the "Pla de Beret". In the southern part of the ridge on the West side of

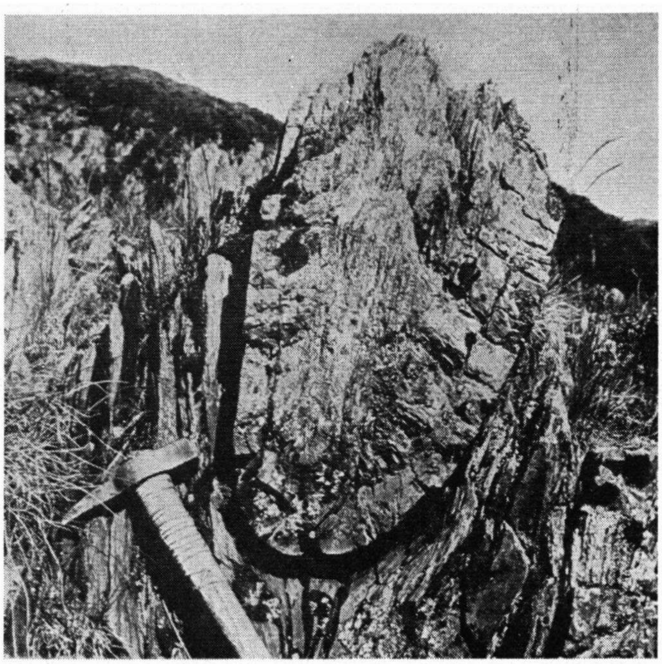

Fig. 1. Fold of sandstone bed in slate on the ridge between the Pla de Beret and the Iñola valley.

this valley, an alternation of limestone, calcoschists and black slates occur. Going north the series are getting poorer in limestones and intensely folded sandstones become frequent (fig. 1). The axial plunge is 60° east. In the neighbourhood of the Rio de Fourcail the limestones are becoming more frequent again and the last high ridge before this valley consists of one large anticline in a limestone also plunging east. The limestones of this anticline show less recrystallization than those near Salardu and are clearly stratified.

By the measurement of strike and dip of this limestone, and the combination of these observations in a stereographic projection, a regular plunge of 30—24° East was found.

This anticline is cut off in its Northern limb near the valley of the river Fourcail by an important fault, which brings the typical black schists of the Silurian to the surface.

Near the junction of the Rio de Fourcail with the Pallaresa, younger formations, consisting of sandy pelites and sandstone can be seen. The flow cleavage of the slates and limestones makes room for fracture-cleavage. As one approaches Mongarri the rock loses more and more of its pelitic character until it finally becomes a grey sandstone. It is difficult to explain, that, wherever cleavage is observable, the beds are steep but overturned, therefore although they are dipping south, they are younging towards the north. The conclusion is, that the sandstone series of Mongarri is the youngest formation of this area.

Going south from Mongarri we pass again the sub-graywacke and the sandy pelites mostly overturned and showing recumbent folding plunging East. In spite of this folding the series change quickly in southern direction in a variety of slates, limestones and sandstones. The dip is invariably south. On the ridge, the black slates are dominating while the sandstones are lacking altogether. Some limestones and quartzporphyries occur. These layers also are most probably overturned. We think that this group can be correlated with the limestones of Salardu. The overturning then might be effected by the uplift of the dome of the Marimaña-granite. As the limestones of the ridge south of Mongarri do not extend to the west and those of Salardu do not extend to the east a fault must intervene, which must be a lefthand wrench fault, whose movement is probably related to the intrusion of the granite. During the intrusion the Mongarri group of rocks has been pushed to the South along this wrench fault plane.

Although the wrench fault of the Pla de Beret is nowhere observable, neither by a mylonite or by brecciating there are indications of such a mechanism in the minor structures. At one locality folded cleavage was found, and several perpendicular foldaxes were encountered in this zone.

3. *The limestones round the Marimaña-granite*

The Marimaña-granite is surrounded by limestones of astonishing thickness. The limestones which are closest to the granite, or even lying on the granite, are thick, metamorphosed, usually without visible bedding, but probably flat lying. In the northwestern part of the granite they disappear and they reach their greatest thickness where the Rio Malo coming from the granite cuts through the limestone belt. The position of the beds can only be concluded from the contact with the slates. This contact seems to be a normal stratigraphic boundary since the black slates contain a thin limestone bed following the contact along a certain distance.

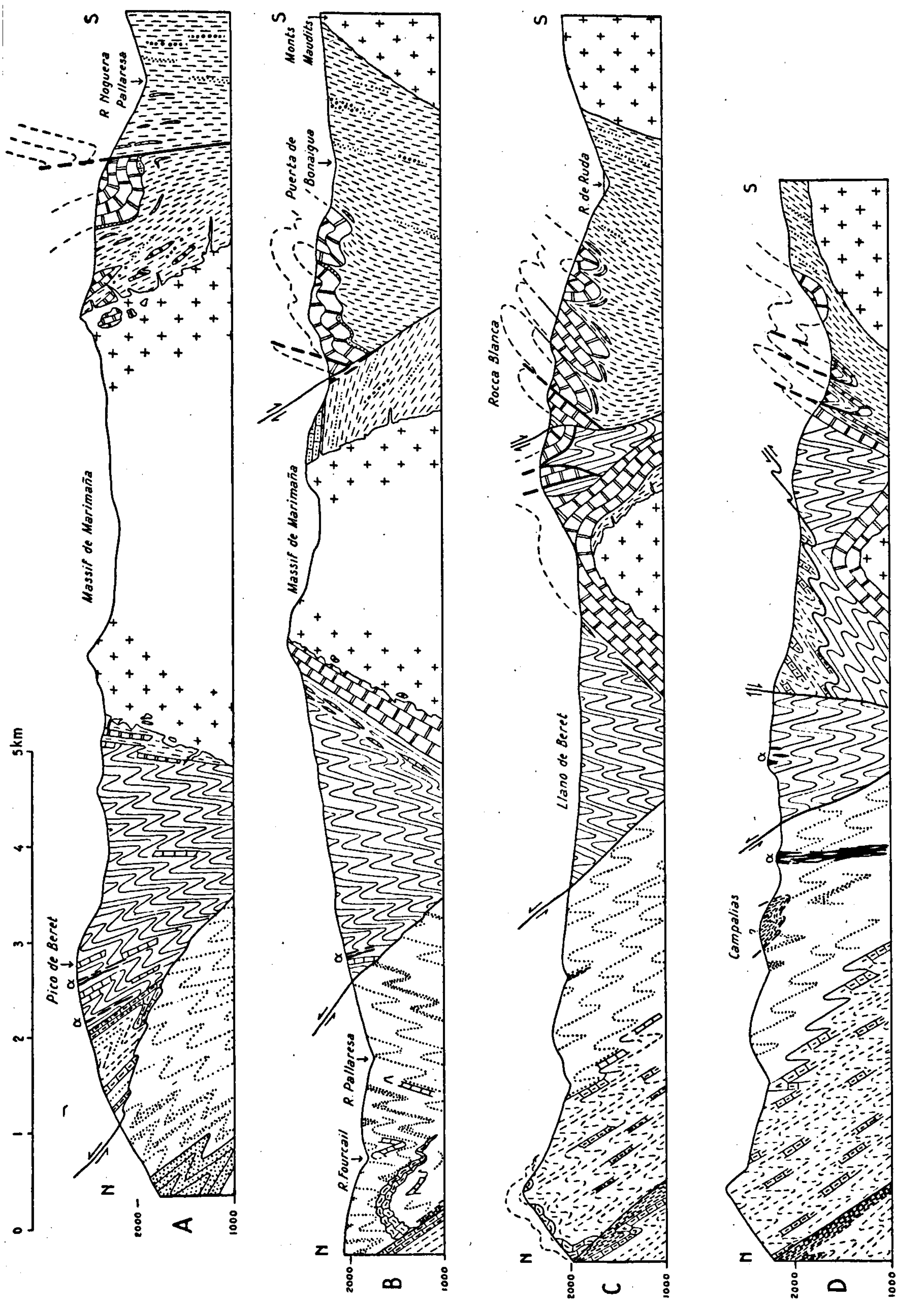
A
B
C
D
N
S
2000
1000
0
1
2
3
4
5km
Pico de Beret
Massif de Marimaña
R Noguera Pallaresa
R. Fourcail
R. Pallaresa
Puerta de Bonaigua
Monts Maudits
Llano de Beret
Rocca Blanca
R. de Ruda
Campalias

Fig. 2

The westplunge of the Marimaña granite is surrounded by a thick limestone anticline or dome plunging 45° West.

On the south-west side of the granite we observe two small synclines plunging South. This unusual plunge is also due to the intrusion of the granite. South of these structures a zone of breccias and quartzveins is visible, doubtlessly representing a large fault. Also due to this uplift south of this fault we find a calcareous and dolomitic plateau without a clearly defined structure. More to the south and west these limestones seem to be folded in synclines and anticlines, with the underlying hornfelses clearly exposed in the anticlines. The southern extension of these limestones continues further east in a pinched syncline passing the Puerta de Bonaigua.

The age of these limestones is certainly Ordovician because they are obviously underlying the black Silurian slates of the Pla de Beret (anticline of the Rio Malo) and belong at the same time to the large Ordovician dome east of the Marimaña-granite. These Caradoc(?) limestones are therefore older than the black slates and younger than the sericite schists, conglomerates and quartzites of the Puerta de Bonaiga. The black slates on the southwest bank of the Rio de Ruda also contain micro-conglomerates, graywackes and slates with angular quartz-grains. This suggests an Ordovician age for this series also.

4. *Tectonics of the intrusive Rocks*

a. *Granites.* — The area which we studied is lying between four granite massifs. In the south is the granite of the Maladetta and the granites south of Salardú and Tredós. In the west is the small granite stock of Salardú and in the east the Marimaña granite. A study was made only of the last three intrusions.

The granite of Tredós has a dome-like character with surrounding limestones parallel to the boundary. Only one roof pendant on its eastern margin shows a discordancy with the tectonical structure.

The Marimaña-granite belongs, like the before mentioned granites, to the "granites circonscrits" of Raguin which in the Pyrenees are represented by large massifs in the axial zone with the mineralogical composition of biotite-granodiorite. The Marimaña also has clear a domelike character. It is surrounded by Ordovician limestones. It looks as if the ascent of the granite intrusion was stopped by these limestones. No limestones were found as xenoliths in the granite, whereas hornfels xenoliths are abundant.

b. *Quartz-porphyries.* — Between Salardú and Mongarri in several locations dykes of granite-like character occur. These dykes have a varying mineralogical composition, but usually contain: phenocrysts of quartz, albite and sometimes biotite, and a matrix consisting of potash feldspar. The rock is obviously cataclastic, shows a primary flow structure and a secundary structure of orientated sericite. Even traces of a kind of cleavage making an angle with the dyke boundary faces were found in one location. Raguin (1946) describes identical rocks of the Pic de Paragrano and the Pic de Bulard. He describes them as rhyolite flows effused during a short uplift in the early Silurian. Later surveys of our Leiden group showed that these so called rhyolitic rocks are frequent in that region in every formation from the Ordovician to the Devonian and are generally post tectonic. The sandstone in our area are intensely folded and cut by the general cleavage and the quartz-porphyries are always parallel or subparallel to the cleavage.

In one location a porphyry band has a total thickness of 250 m, but it contains several wedges of slates. The dykes sometimes look as if they were injected "lit par lit" into the slates, sometimes they form long and narrow sills parallel to the layers of limestone.

Summarizing we can say, that the quartz-porphyries are intruded at a clastically deformed and moreover epizonal recrystallization and cleavage After their intrusion compression continued during which the dykes were clastically deformed and moreover epizonal recrystallization and cleavage occurred.

c. *Conclusions and tectonical problems.* — When we observe the close relation between cleavage and folding we see that there is nowhere an anomaly, and that the cleavage planes are only very rarely folded. Neither does the axial plunge direction show anywhere a clear deviation from the normal E—W trend. This leads to the conclusion that there has been only one important folding period, during which the greater part of all the observed phenomena happened. There remains a serious problem however. According to FOURMARIER the required thickness of covering rock under which cleavage folding can take place, must be several thousands of meters (FOURMARIER, 1948, 5000—6000 meters!). This cover is not available in the Pyreenees according to the generally accepted ideas.

Since neither Upper Devonian (griotte) nor marine Carboniferons were found in the axial zone, we believe that the axial zone was already slightly uplifted during the late Devonian and Carboniferous. The terrestrial facies of the Carboniferous in this area also indicates a regression.

For this reason only Devonian (and older) rocks participated in the Hercynian folding. A thickness of 5000 meters of the Upper Devonian series is impossible even 500 m would be too much. The contradiction might be solved by the assumption of the aforementioned gliding tectonics in the early Hercynian period. By this mechanism the Devonian strata might have gained considerably in thickness and folding under the high pressure of the overlying rock might have caused the cleavage.

After these gliding movements — an early phase of the Hercynian folding —, the cleavage folding, recrystallization of limestones and sandstones could have taken place, followed by the intrusion of quartz-porphyries and finally the granites. These granites caused a direct thermal metamorphism forming andalusite schists and knotted schists. Moreover they caused domes by which cleavage and bedding were rearranged parallel to the boundary. Finally, after the crystallization of the granite, another compression occurred which produced cataclastic textures in the quartz-porphyries, the hornfelses and in several places the granite itself, after which another partially pneumatolytic, partially epizonal metamorphism occurred. This metamorphism caused the sericitization of the quartz-porphyries, the recrystallization of fractures in the hornfelses and the granite. The granite became zoisitized and chloritized whereas joints in the granite were in many places covered by tourmaline.

The effect of the Alpine folding cannot be distinguished from the late Hercynian movements. It is not likely that the Alpine folding was limited to the marginal zones of the Pyrenees only, and did not affect the axial zone at all. Some evidence of Alpine movement in the axial zone along faults seems to be available.

Stratigraphy

1. *Introduction*

Little and only superficial study was ever made of the stratigraphy in the upper part of the Valle de Arán to which the area in question belongs. The early profiles through the area are not supported by detailed mapping but based on accidental observations. Due to lack of space we only quote the works of CARALP (1889), BERTRAND (1907), CAREZ (1912), DALLONI (1930) and SCHMIDT (1931).

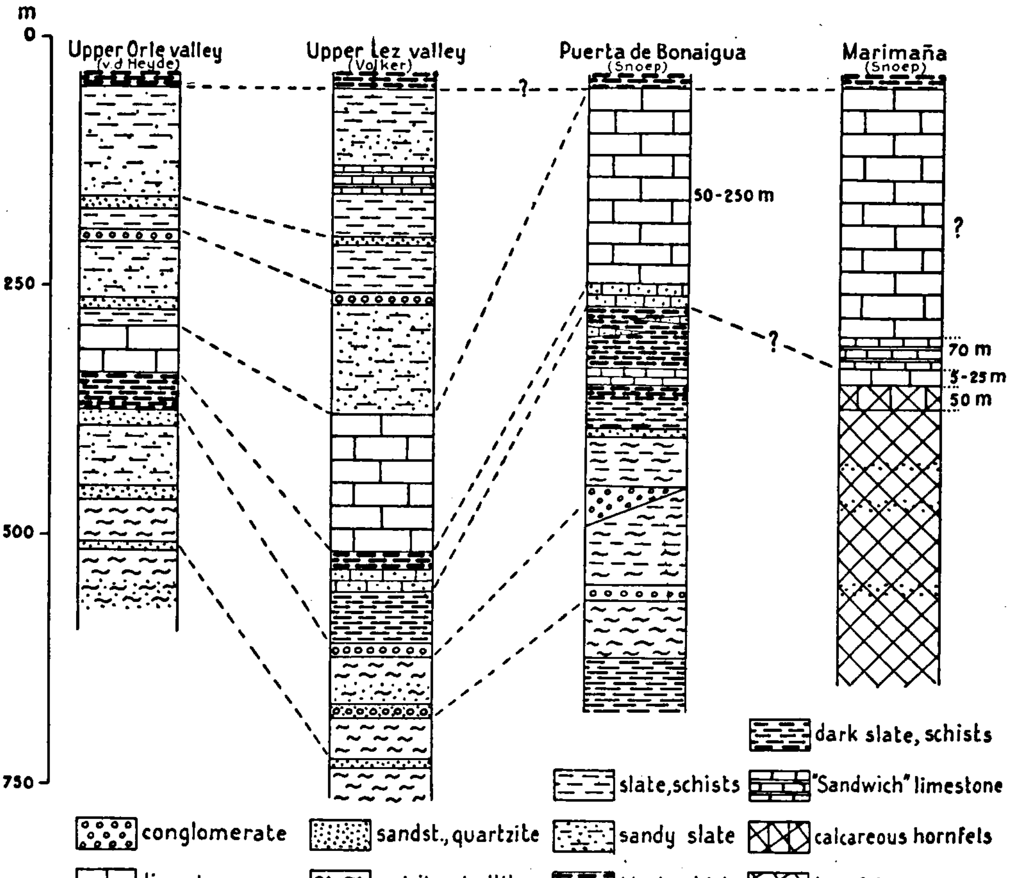

Fig. 3. Comparison of four sections through the Upper Ordovicien.

2. *Age determination and facies description*

a. *Ordovician.* — The district east of the Marimaña-granite consists of a large anticlinorium in Lower Paleozoic rocks. The predominating rocks are dark phyllites, quartzites, microconglomerates, graywackes, conglomerates and on a higher level the Caradoc limestone (DALLONI, 1931; RAGUIN, 1944; DESTOMBES, 1949). On top of these limestones we find a strongly varying series of little metamorphic schists and slates.

VOLKER (1954) found in the region of Bentaillou below the Caradoc limestone black slates, impure limestones, a conglomerate and finally sericite phyllites, sandstones and micro-conglomerates. This section shows a striking resemblance to the section of the Puerta de Bonaigua. Here we find from bottom to top: Sericite-schists and mica-schists with conglomeratic quartzites and conglomerates with quartzitic pebbles and a matrix consisting of sericite-phyllite. Higher up we find black slates with calcareous layers with dark schists and graywackes with angular quartz-grains and micro-conglomeratic sericite schists. On top of all this we find the Caradoc limestones which are partially dolomitized., The stratigraphy of the Ordovician as described by v. D. HEIDE from the region southeasth of Bentaillou (1955) also shows resemblance to VOLKER's section and also describes a thick series of limestones representing the Caradoc.

In the section of v. D. HEIDE and VOLKER (fig. 3) these limestones are shown to be lying on a bed of black slates. This is in perfect accordance with our own observations on the left bank of the Río de Ruda and near the Puerta de Bonaigua, but does not quite conform to the sequence of the limestones of the Río Malo. There the sequence shows a section like that described by ZANDVLIET (1957), which is characterized by thinly bedded alternations of limestone and quartzite at the base of the Caradoc limestone. This

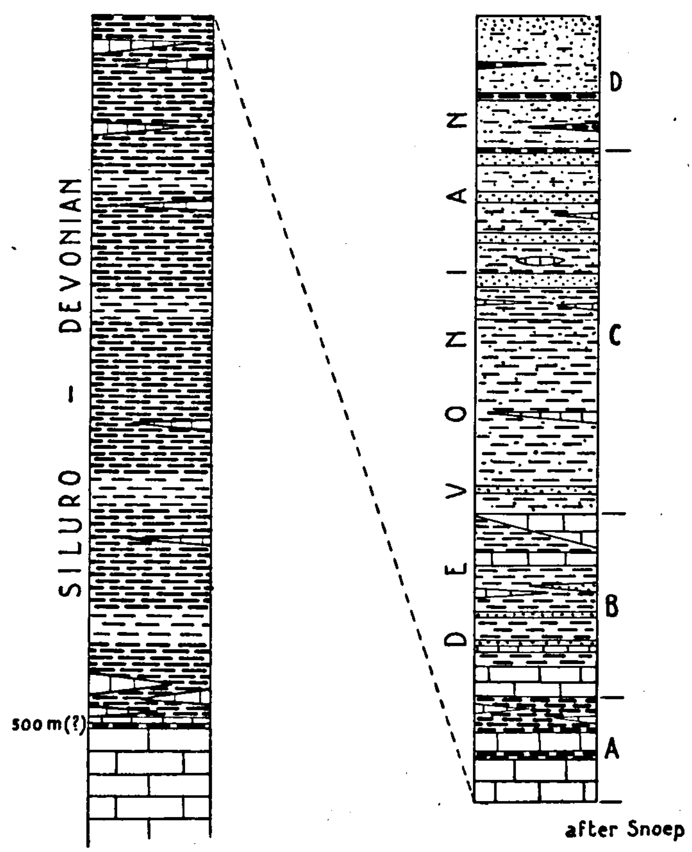

Fig. 4. The Siluro-Devonian and Devonian sequence, scale 1: 7500.

to different weathering of limestone and quartz. Below this sandwich-limestone a very characteristic bed of pure limestone can be found. Below these beds we find a series of hornfelses with limy, conglomeratic and quartzitic beds.

b. *Siluro-Devonian.* — When we look at the area in question as a whole, it is striking, that the whole Pla de Beret area, including the areas of Campalías, Bagérque and Tredós consists of black slates with some limestone, but no sandstones. In these black slates area we find in several places black ampelitic shales (Campalías). These shales were also found in the torrent facies is also described by VOLKER as the so called "sandwich-limestone" due descending from the Pic de Beret to Mongarri. In these black shales the only fossils were found. Difficult to determine *Orthoceras* and in an adjacent limestone bed some *corals* and *brachiopods* of which the species could not be determined. No superficial iron hydroxyde deposits were encountered which elsewhere are always characteristic for the black shale of the Silurian.

It is difficult to determine the exact age of the black shale-slate sequence. The group is certainly younger than the Caradoc limestones and older than the Devonian limestones of Salardú and the Devonian limestones and sandstones of Mongarri. It is not likely that this series is to be regarded as Upper Ordovician since this latter formation is characterized by a different facies. It shows a much greater resemblance to the typical ampelitic Silurian facies and the Lower Devonian slates, hence we call it the Siluro-Devonian.

c. *Devonian.* — The stratigraphy of the Devonian could not be based on any paleontological data. The original relation of the beds was concluded partly from a tectonical interpretation, the results are therefore not very convincing (fig. 4).

The *Devonian A* is best represented along the path leading from Salardú to the Puerta de Beret. We see several repetitions of limestones and calcoschists with a clearly argillaceous component, as a result of which cleavage is well expressed. Intercalated with grey and greenish phyllites are black roof-slates. In this series occurs a typical bank consisting of a triple cycle of limestone-calcareous sandstone-calcareous slate. This cycle is many times repeated in a thickness varying from one foot to a yard. The sandstone as a rule is graded.

The *Devonian B* shows some resemblance to A but the calcoschists and marly slates are disappearing, whereas the limestones are often more dolomitic and the black roof-slates are making room for dark phyllites. Near the top the first dark graded sandstones occur.

The *Devonian C* consists for the gretaer part of sandy slates, schists and phyllites having a more siltlike composition. Limestones are rare and are often brownish and dolomitic and contain much quartz.

The *Devonian D* forms a thick series of subgraywackes, consisting of grey fine grained argillaceous sandstones, sometimes graded so that between the sandstones small bands of mudstone are intercalated. Near the top of this series a purer coarsely grained bank of sandstones occurs.

The intrusive rocks and their metamorphism

1. *Intrusive rocks*

a. *Biotite-granodiorite.* — All the batholith intrusions of the area in question have the mineralogical composition of a biotite-granodiorite. Although four different massifs occur in the area, we studied only the Marimaña-granit.

The mineralogical composition is always: plagioclase (andesine), quartz, biotite, microcline and hornblende (decomposed).

The andesine usually has a core replaced by sericite-muscovite, zoisite and clinozoisite. The biotite is partially chloritized, and sometimes replaced by clinozoisite. Sometimes it looks as if hornblende was replaced by biotite and clinozoisite. Occasionally the granite contains hornblende mostly in the marginal zone. The biotite-granodiorite is rather homogeneous in composition but contains many xenoliths and "fishes" rich in biotite.

A very special character shows the Marimaña-granite near the small lake 2.5 km northeast of the Puerta de Bonaigua. Here big lumps of limestone are enclosed in the granite like roof pendants. The granite has here a dirty greenish colour and is mineralogically a zoisitized quartz-diorite, which will be discussed further on.

b. *Hornblende-diorite.* — In several locations in the Marimaña batholith small intrusive bodies of hornblende-diorite were found. Near the hairpin curves of the road west of the Puerta de Bonaigua a small intrusion of sericitized hornblende diorite is visible with a clearly chilled margin. It contains 40 % greenish hornblende and 60 % feldspar completely replaced by sericite, muscovite, calcite and quartz.

c. *Quartz-porphyries.* — The quartz-porphyries of the area in question show a variation, which is also known in the Massif de l'Arize (J. KEIZER, 1954). He describes these rocks as quartz-diorite-porphyrites, diorite-porphyrites and granite-porphyrites and regards them, as intrusive dykes, contrary to the opinion stated on the geological map, where they are depicted as "roches extrusives" like RAGUIN regarded the rhyolites of the Pic de Paragrano.

The mineralogical composition of the quartz-porphyries is variable but certain characteristics are general:

(1) felspar is replaced by sericite, zoisite and specially calcite;

(2) cataclastic textures like broken phenocrysts, cataclastic rims, quartz with wavy extinction and in one case even fracture cleavage and always a oriented texture.

As phenocryst may occur: bipyramidal quartz with corroded forms, felspar (sometimes albite) always replaced by sericite and calcite, chloritized biotite, ore.

The matrix is mostly completely sericitized. The thicker dykes still show in the matrix relics of felspar crystals but always strongly replaced by sericite and calcite. Only the very thick dykes show determinable minerals in the ground mass. Albite, quartz and a little potash-felspar and in between micrographic aggregates having a core of a very finely grained mixture of albite and quartz, and a rim of radial oriented crystals of albite. These aggregates are also visible in cavities formed by corrosion in the phenocrysts. These aggregates are therefore not caused by deformation but have a primary origin.

2. *Assimilation and autometamorphism*

It is a striking phenomenon that in all smaller intrusives in the studied area calcite occurs as a secundary mineral, as well in the acid dykes as in the hornblende diorite. Especially the occurrence in the relatively acid quartz-porphyries, which show sometimes primary albite as phenocryst, leads to the conclusion that the magma assimilated $CaCO_3$ from the countryrock. Meanwhile, obviously the $CaCO_3$ did not have the opportunity to influence the mineralogical composition of the acid dykes, since no mineral rich in calcium was encountered.

It is probable, that in a late stage of the metamorphism, immediately after the crystallization of the granite an autometamorphism took place, represented by a definite resorption of Ca from the country rock. The discussed quartz-diorite contains plagioclase, 80 % of which was replaced by zoisite and a little sericite, whereas veinlets occur containing clinozoisite and a little actinolite. The hornblende in this rock is completely replaced by actinolite and chlorite. These phenomena were only observed in the green chloritized and zoisitized granites near the little lake 2 km northeast of the Puerta de Bonaigua. Since the Ca-content of these rocks exceeds by far the normal composition even of an anorthosite it seems probable, that the granite either in a completely crystallized or in a half crystallized stage has assimilated Ca frem the country rock. The more frequent occurrence of hornblende near the granite outskirts might be due to resorption of limestone in the purely magmatic stage but this should be studied in more detail.

3. *Thermal metamorphism*

The granite intrusions are surrounded everywhere by a thermal metamorphic aureole.

a. *Lime-silicate-hornfelses.* — These can be found best along the southwest boundary of the Marimaña granite around the lake 2 km northeast of the Puerta de Bonaigua, and on the granite boundary on the left of the Rio de Ruda. The occurring minerals are: garnet (grossularite), idocrase, diopside, clinozoisite, epidote, zoisite, adulare, albite and calcite.

It appears that after the metamorphism movements still took place, because most of the metamorphic minerals are broken, and calcite fills the fractures. The rocks near the aforementioned lake all have the property that they are rich in clinozoisite. This is true as well for the granite as for the lime-silicate-hornfelses and even for the sericite schists. After the crystallization of the granite apparently the whole area was soaked by calcium rich fluids that caused everywhere crystallization of clinozoisite.

b. *Hornfelses.* — All granites caused in many places the formation of catazonal and mesozonal hornfelses. The following minerals occur: biotite, muscovite, andalusite, quartz and sometimes actinolite. Near the granite of Salardú the andalusite hornfelses show broken crystals of andalusite with sericite on the fractures. In most hornfelses the original appearance of the sedimentary bedding has been greatly enhanced by the metamorphism.

c. *Thermal metamorphic schists.* — Spotted slates are not found everywhere as the most external metamorphic zone, but all granites have them in different places in their surroundings. Spotted slates are abundant on the northwest boundary of the Marimaña-granite.

Chiastolite-schists occur in several places in the area in question. In particular the black slates in the contact zone often contains this mineral. Beautiful chiastolite is visible in the black slates on the left bank of the Rio de Ruda.

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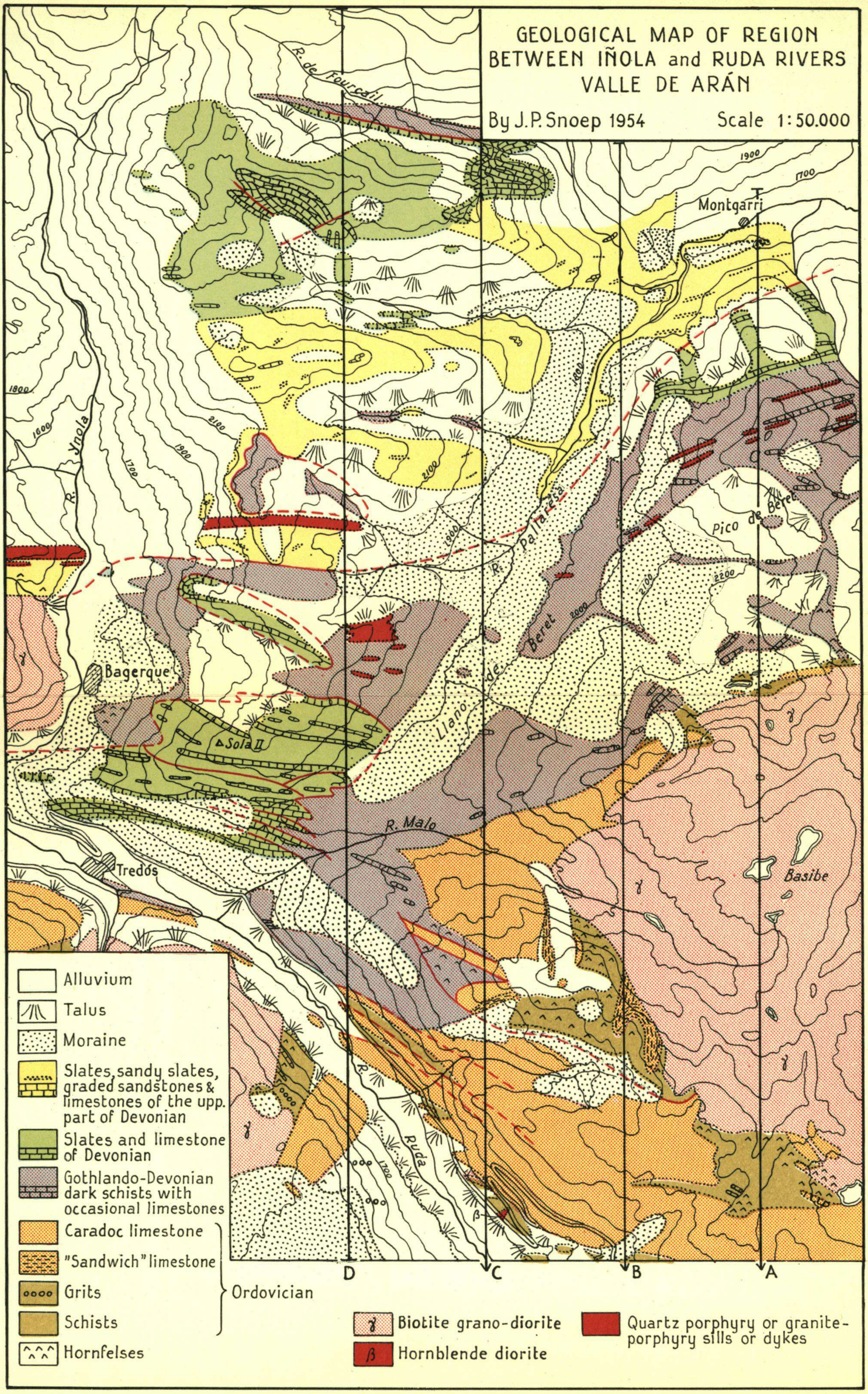
GEOLOGICAL MAP OF REGION
BETWEEN IÑOLA and RUDA RIVERS
VALLE DE ARÁN
By J.P. Snoep 1954
Scale 1:50.000
R. de Fourcail
Montgarri
R. Ynola
Pico de Beret
R. Pallaresa
Llano de Beret
Bagerque
Sola II
Tredós
R. Malo
Basibe
R. Ruda
D
C
B
A
Alluvium
Talus
Moraine
Slates, sandy slates, graded sandstones & limestones of the upp. part of Devonian
Slates and limestone of Devonian
Gothlando-Devonian dark schists with occasional limestones
Caradoc limestone
"Sandwich" limestone
Grits
Schists
Hornfelses
Ordovician
Biotite grano-diorite
Hornblende diorite
Quartz porphyry or granite-porphyry sills or dykes