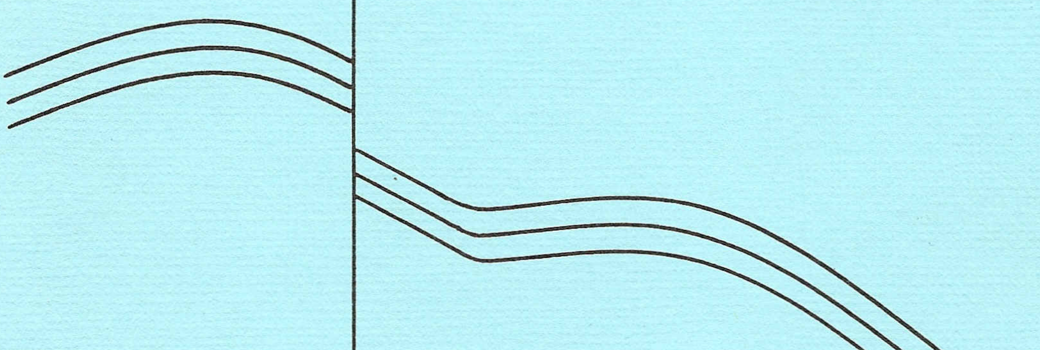
THE GEOLOGY OF THE CINQUETA REGION, SPANISH PYRENEES, PROVINCE OF HUESCA



CORNELIS GROEN

STELLINGEN

I

De verplooing van de Mesozoische sedimenten in de Sahara-Atlas ten noorden van Laghouat (Algerije) staat in verband met dextrale schuifbewegingen in het Hercynisch grondgebergte.

II

De door Boersma voorgestelde correlatie van de top van de Basibé Formatie in de oostelijke centrale Pyreneeën met de Upper Limestone Formatie van v.Lith in het Cinca gebied is op zijn minst twijfelachtig te noemen.

Boersma,Kerst Th.,L973.Devonian and Lower Carboniferous conodont Biostratigraphy,Spanish central Pyrenees.Leidse Geol.Meded. 49,p.303-377.

III

Indien de door v.Lith waargenomen vlakliggende cleavage in de Paleozoische gesteenten van het Gavarnie dekblad van Hercynische oorsprong zou zijn,dient het huidige structurele beeld van de Hercynische Pyreneeën herzien te worden.

Lith,J.G.J. van,1965.Geology of the Spanish part of the Gavarnie nappe and its underlying sediments near Bielsa (Province of Huesca).Thesis Utrecht 1965.Geologica Ultraiectina no. 10,67 p.

IV

Bekkenanalyse aan de hand van lithologische facies kaarten,die geen rekening houden met tectonische verkorting,is onjuist en dient derhalve vermeden te worden.

V

Sandwave complexen vormen goede potentiele reservoir gesteenten voor aardolie.

Nio,S.D.,1977.Marine transgressions as a factor in the formation of sandwave complexes.Geol.Mijnb.55,p.18-40.

VI

De conclusie van Cogné,Millot en Scheibling,dat de intrusie van de granieten in de omgeving van Andlau verantwoordelijk is voor het gelijktijdig ontstaan van een ongericht maaksel in de Schistes de Steige in de binnenste contactzone en microplooiing in dezelfde gesteenten op grotere afstand van het contact,is met zichzelf in tegenspraak.

Cogné,J.,Millot,G. en Scheibling,C.,1961. Relations des phénomènes microstructuraux (schistosité et microplissement) avec le métamorphisme des schistes de Steige au voisinage des granites de la région d'Andlau.Bull.Serv.Carte géol. Als.Lorr.,t.14,p.39-58,Strasbourg,1961.

VII

De bewering van Seguret,dat de Alpine cleavage in de sedimentaire bedekking van het Hercynicum onder de Gavarnie overschuiving samenhangt met deze overschuiving wordt niet door voldoende feiten gestaafd.

Seguret,M.,1972.Etude tectonique des nappes et des séries décollées de la partie centrale du versant sud des Pyrénées.Publ.Ustela.Montpellier. Série Géol.Struct.,no.2,169 p.
dit proefschrift.

VIII

Hooggebergte geologie dient niet bedreven te worden door eenlingen.

IX

Het tegengaan van spelverruwing bij het schaken door de zich misdragende partij te verplichten een zet over te slaan,zou onder omstandigheden een averechtse uitwerking kunnen hebben.

X

De toenemende criminaliteit kan mogelijk tegengegaan worden door op de televisie en in de bioscopen films te vertonen,waarin het kwaad zegeviert over het goede.

Stellingen behorende bij het proefschrift van C.Groen

THE GEOLOGY OF THE CINQUETA REGION, SPANISH PYRENEES, PROVINCE OF HUESCA

GEOLOGICA ULTRAIECTINA

No. 18

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE WISKUNDE EN NATUURWETENSCHAPPEN AAN DE RIJKSUNIVERSITEIT TE UTRECHT, OP GEZAG VAN DE RECTOR MAGNIFICUS PROF. DR. A. VERHOEFF, VOLGENS BESLUIT VAN HET COLLEGE VAN DECANEN IN HET OPENBAAR TE VERDEDIGEN OP MAANDAG 3 APRIL 1978 DES NAMIDDAGS TE 4.15 UUR

DOOR

CORNELIS GROEN

GEBOREN OP 30 NOVEMBER 1945 TE AMSTERDAM

promotor: Dr. E. ten Haaf

Aan Jikke

Aan Πυρηνη

Voorwoord

Bij de voltooiing van mijn proefschrift wil ik graag mijn dank betuigen aan al diegenen,die hebben bijgedragen aan de totstandkoming ervan.
In de eerste plaats dank ik Jikke voor haar mentale steun gedurende de afgelopen jaren en voor het meelopen tijdens de eerste veldwerk periode.
Mijn ouders ben ik dankbaar voor de mogelijkheid,mij geboden,om te kunnen studeren en voor hun voortdurende interesse in mijn studie.
Mijn broer Peter,mijn zwager Ytzen en Wijnand Langeraar dank ik voor hun bereidheid mij te vergezellen op tochten,die niet altijd zonder gevaar waren.
Mijn promotor,Dr.E. ten Haaf,dank ik in de eerste plaats voor zijn bereidheid mij,als Pyrenees buitenbeentje,onder zijn Apennijnse hoede te willen nemen en verder voor de vele waardevolle suggesties bij het schrijven van het proefschrift.
Dr.H.Wensink ben ik zeer erkentelijk voor zijn begeleiding in het veld en de vele waardevolle discussies die we hadden als Pyreneeën geologen onder elkaar.
Dr.J.Broekman ben ik grote dank verschuldigd voor zijn steun bij het schrijven van het hoofdstuk Stratigrafie.
Prof.Dr.H.J.Zwart dank ik voor zijn bereidheid een belangrijk gedeelte van het manuscript te willen lezen en voor zijn waardevolle suggesties en kritiek.
De heren Henzen,Santoe,Smit,Meyer,Dubbelman en Smits dank ik voor de grote vaardigheid aan de dag gelegd bij het prepareren van kaart,profielen,fotos en tekeningen en voor hun bereidheid om,in de laatste dagen van voorbereiding, het werk-tempo nog eens extra op te schroeven.
De heren de Groot en Bliek dank ik voor het maken van de vele slijpplaatjes, soms van keien die bij aanraking al uit elkaar dreigden te vallen,hetgeen hun vakmanschap nog eens mag onderstrepen.
Een gedeelte van het typewerk werd verricht door Hetty Wynia.Hiervoor mijn hartelijke dank.
De heren de Ruiter en Frederiks dank ik hartelijk voor het hoge tempo waarin het manuscript werd gestencild.
Beste Joop,Jan,Jules en Manfred,hartelijk dank voor het geduld,aan de dag gelegd bij het aanhoren van mijn theorieen over geologische problemen,die zó a-Apennijns zijn.
Beste Jan Schroten,hartelijk dank voor het corrigeren van de spaanse samenvatting

CONTENTS page

SUMMARY

In the investigated area rocks are exposed of which the ages probably range from Cambro-Ordovician to Upper Triassic. The pre-Hercynian sedimentary rocks generally show a low grade dynamo-metamorphism, upon which is superposed a thermal metamorphism related to the intrusion of late Hercynian granodiorites. Regional metamorphic rocks also occur, but they are restricted to the northern part of the area (Cinqueta de la Pez unit). The following lithostratigraphic units were distinguished in the pre-Hercynian sedimentary rocks :

The Cinqueta de la Pez complex, consisting of regional-metamorphic sandy and pelitic sediments which are generally attributed to the Cambro-Ordovician.

The Viladós Formation, constituted by slates, hornfelses and quartzites, which represent the non- or thermally metamorphosed equivalent of the Cinqueta de la Pez complex.

The Madera Formation consists of black coal-bearing shales with some dark limestones at the top. This unit is attributed to the Gotlandian and probably ranges into the Lower Devonian (Lower Gedinnian). It is overlain by an alternation of limestones and slates in which four formations are distinguished :

The Puyarésto Formation (an alternation of marly limestone and sandy slate), the Ardaña Formation (massive limestones), the Sein Formation (sandy slates with a few marly limestones in the upper part) and the Barbarisa Formation (calc-schists, marly limestones and thin layers of sandy slate).

This sequence probably ranges in age from the Lower Gedinnian into the Eifelian (Lower Devonian and lower Middle Devonian).

The pre-Hercynian series is terminated by the slates of the Sahun Formation, which may be of Carboniferous age.

The crystalline Paleozoic is represented in the Cinqueta region by the Rechanzadas-Descubridores and Cinqueta granodiorites with their associated dikes.

The pre-Hercynian Paleozoic is unconformably covered by the Poma-Viciele Formation (red sandstones, conglomerates, siltstones and shales) which general opinion attributes to the Permian and Lower Triassic). This formation is overlain in its turn by limestones, dolomites, gypsiferous shales and gypsum, thought to represent the Middle and Upper Triassic.

The Hercynian orogeny probably reached its greatest intensity during the Middle Carboniferous. Several phase of the deformation have been recognised : A first phase produced NE-SW trending folds without a cleavage in the low grade metamorphic rocks. These folds are directly only observable in the north-eastern part of the area (Posets area). In the regional metamorphic rocks of the Cinqueta de la Pez area there is a foliation parallel to the original bedding which predates the mainphase deformation.
The second or mainphase deformation generated tight to isoclinal folds accompanied by an axial plane cleavage, trending WNW-ESE.
Going southward from the northern part of the area the attitude of the mainphase cleavage changes from vertical to steeply N dipping in the central part, to gently N dipping in the southern part, thus producing the picture of a large scale fan.

In the regional metamorphic rocks of the Cinqueta de la Pez area only a few mesoscopic isoclinal (slightly asymmetrical) mainphase folds were observed. The mainphase cleavage is developed as a crenulation foliation superimposed upon the already existing first phase foliation.
A third deformation phase was restricted to the regional metamorphic rocks, and is manifested by internal rotation about N-S directed axes, caused by E-W shear along the mainphase (crenulation) foliation.
Recrystallization due to regional metamorphism was at least partly contemporeneous with the mainphase deformation.
A fourth phase locally produced an E-W trending refolding of the mainphase cleavage and also a crenulation or fracture cleavage. In the regional metamorphic rocks no traces of this phase have been observed.
The intrusion of the Rechanzadas-Descubridores and the Cinqueta granodiorite and of the associated dikes probably took place directly before this fourth phase.
The southward tilting of the mainphase structures in the southern part of the area (San Juan stratigraphic window) predates the fourth phase, but could not be dated with respect to the third phase in the north.
Post-Hercynian deformation started with movements along vertical faults which have been active from pre-Permian until at least Upper Triassic.
More important deformations, however, took place during the Alpine orogeny.
First came a local intense folding of the post-Hercynian unconformable cover, accompanied by an axial plane cleavage, that only affected a part of the basement.
This was followed by large scale thrusting along a weakly N dipping plane, the Sahun-Tres Bogas thrust. Subsequent differential movements produced several large basement anticlinoiria and synclinoria in the western part

of the area, and probably caused also the southward gliding of the Mesozoic cover above the Upper Triassic gypsum and gypsiferous shales.

INTRODUCTION

The present report deals with the geology of a part of the central and southern axial zone of the Pyrenees, composed mainly of sedimentary and crystalline rocks of Paleozoic age (fig. 1).

The main field work was carried out during the summers of 1971, 1974, 1975 and 1976. Earlier studies of the area had been performed in the years 1960-1968 as part of a training program in geological mapping for students of the Geological and Mineralogical Institute of the University of Utrecht, under the supervision of Professor Dr. M.G. Rutten. The internal reports and geological maps resulting from these earlier investigations were used as a starting-point for our own study.

Use was made of the topographical maps on scale 1:50.000 of the Instituto Geografico y Catastral de Madrid, sheets Liena (147) and Benasque (180), which were enlarged to a scale of 1:20.000. Aerial photographs of the region exist, but were not available at the time.

The area is situated directly south of the Spanish-French border. It is cut across by the rio Cinqueta, a tributary of the rio Cinca, which in its turn debouches into the Ebro river south-west of Lerida.

The strongly accidented terrain shows a great range in altitude, varying from 1000 m in the extreme south along the rio Cinqueta to 3000 m ore more in the north-east and north. Generally the summit heights exceed 2600 m. Outstanding mountains are : the Posets, which with its 3375 m is the second-highest peak of the Pyrenees, the Machimala, 3177 m, the Valinier, 2949 m and the Punta Suelza, 2973 m.

The area is very thinly populated; only three small villages, Plan, San Juan de Plan and Gistain, are situated in the extreme southern part. They are connected by a partly asphalted road with the main road leading from France via the Bielsa tunnel to Barbastro.

Two practicable dirt roads are present, one leading from Plan to the Collado de Sahun (and recently extended into the Esera valley) and another running from Plan northward to Viladõs.

A mountain cabin, which is opened during the months of July and August, is located directly West of Viladõs.

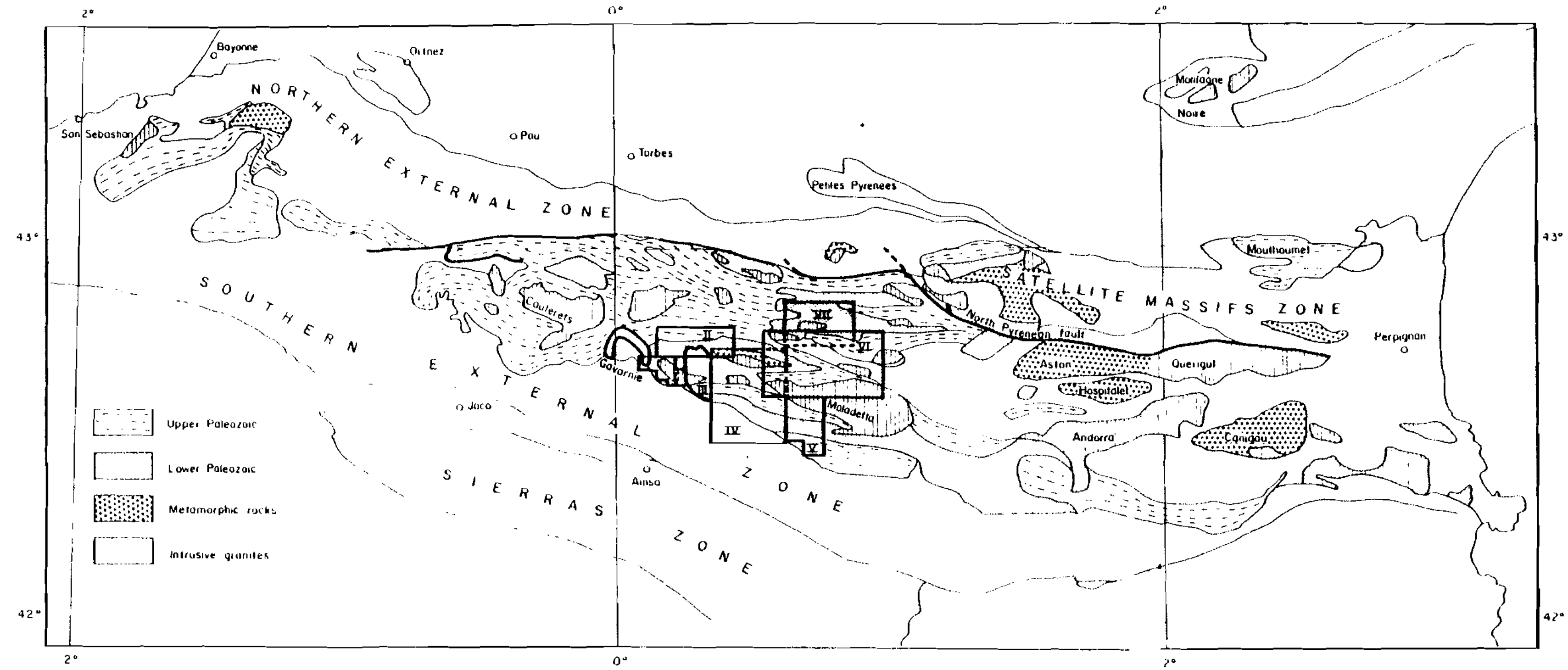


Fig.1.Schematic geological map of the Pyrenees with locations of mapped area and areas studied by authors frequently cited in the present report.
I:M.Clin,1959.II:J.G.J.v.Lith,1965.III:present area.IV:J.H.N. Wennekers.1968.V:P.H.W.Mey,1967.VI:W.F.J.Kleinsmiede,1960. VII:H.J.Zwart,1963.

Geological setting

The Pyrenees form a straight, narrow (40-80 km) mountain chain with a length of approximately 400 km, which separates the Iberian peninsula from France. They essentially constitute part of a Hercynian orogene, reactivated by Alpine deformations and subsequent uplift, which also determined their present configuration.
In a simple scheme the Pyrenees may be subdivided into three longitudinal zones (fig. 1) :
1. The axial zone, which forms the central belt, has a width of about 35 km and consists of Paleozoic rocks, which have undergone intense deformation in several phases and locally also regional metamorphism during the Hercynian orogeny.
In places an unconformably post-Hercynian cover is present. The Alpine orogeny affected the post-Hercynian cover (mainly Permo-triassic) by folding, whereas the rigid Hercynian basement reacted chiefly by large and small scale thrusting and faulting and movements along existing (Hercynian) cleavage planes. The axial zone is bounded in the north by the North Pyrenean Fault, an E-W trending strike-slip fault zone which probably is of late Hercynian origin.
2. North of this fault zone lies the northern external zone, which is constituted by Mesozoic and Tertiary sediments, folded during the Alpine orogeny. In its eastern part the so-called satellite massifs, consisting of Paleozoic crystalline and sedimentary rocks with a mantle of Mesozoic, add an extra element to the northern external zone. The Alpine folding dies out northward towards the Aquitanian basin.
In the South the axial zone is bounded by the "southern border zone", a moderately to steeply S dipping monoclinal structure.
3. Beyond this the southern external zone is situated. Like the northern external zone it is characterized by folded Mesozoic and Tertiary sediments. Here the intensity of the folds decreases southward.
Extra elements are presented by the gravitational gliding structures of the Gavarnie, Monte Perdido and Cotiella nappes, and by the non-metamorphic Paleozoic outliers of the Nogueras Zone.

Acknowledgements

The present report has very much benefited from the assistance of Dr. E. ten Haaf and Dr. H. Wensink, which is greatly appreciated. Many thanks are also due to the technical staff of the Geological Institute for the preparation of the map, sections, drawings and photographs. I want to thank especially Prof.Dr. H.J. Zwart (University of Leiden) for his critical reading of a part of the manuscript. Many thanks are due to Dr. J. Broekman for his valuable advises and criticism concerning the stratigraphical part of the report. My thanks are also extended to Miss H. Wynia for the typing of the manuscript. I feel greatly indebted to Mr. Y. Tamminga, Mr. P. Groen and Mr. W. Langeraar for their company in the field on trips which were not always without danger. Finally, I am very grateful to my wife Jikke, not only for her mental support during the years past, but also for her company in the field during our first stay in the Pyrenees.

CHAPTER I

Stratigraphy

Introduction

In the Cinqueta region a rather incomplete sequence of Paleozoic and early Mesozoic sedimentary rocks, often influenced by regional or thermal metamorphism, is met with. Large parts of the area are occupied by intrusive rocks of granodioritic composition with associated dikes.
Hercynian deformations (intense folding, frequently accompanied by cleavage or foliation), thermal metamorphism and low to medium grade regional metamorphism, as well as the overall lack of fossils are responsible for the great difficulties that were met with in establishing lithostratigraphic successions, thicknesses of individual units and their litho- and chronostratigraphic relations.
Chronostratigraphic correlations are based mainly on the presence of one well characterised marker : carbonaceous black slates, which are generally accepted to be of Gotlandian (Silurian) age. Boersma (1973) has dated correlable lithostratigraphic units in adjacent areas to the east with the aid of conodonts.
Previous stratigraphic studies in this particular area have been carried out by Dalloni (1910), Schmidt (1931) and Martinez (1968).
Due to the fact that the effects of metamorphism (regional, dynamo and thermal) are almost ubiquitous in the Hercynian rocks of the Cinqueta region, it could not be avoided that petrographical terms like schist, hornfels, quartzite and calc-schists etc. mix up with sedimentary designations like marl, marly limestone, sandstone etc. in the descriptions of the various units.
Furthermore the names that have been given to our lithostratigraphical units do not necessarily indicate the presence of proper type localities. This ensues from the already mentioned problems in defining and describing these units. Consequently the names that were given merely refer to areas or localities where the units they belong to are reasonably well exposed.

In the Cinqueta region we have distinguished the following lithostratigraphical units :

1. The Cinqueta de la Pez complex, consisting of biotite-muscovite schists with large porphyroblasts of staurolite, andalusite and cordierite, sericite-schists, phyllites, quartzites and some recrystallised impure limestones.

2. The Viladós Formation, made up by slates, hornfelsed slates and quartzites.
3. The Madera Formation, characterized by black carbonaceous slates or shales and some dark coloured limestones.
4. The Puyaresto Formation, presenting an alternation of recrystallized limestone and marly limestone, and thin slate or hornfels layers.
5. The Ardaña Formation, consisting of massive and thick-bedded recrystallized limestones with thin streaks of pelitic material.
6. The Sein Formation, presenting slates and quartzites with some intercalated impure recrystallized limestone.
7. The Barbarisa Formation, made up by calc-schists, and alternations of recrystallized limestone and thin slate or hornfels layers.
8. The Sahun Formation, characterized by dark strongly cleaved slates with detrital micas.

Post-Hercynian sedimentary rocks :

9. The Poma-Viciele Formation, consisting of red sandstones, conglomerates, siltstones and shales. This unit is overlain by :
10. Yellow to violet limestones, cellular dolomites, gypsiferous shales and gypsum.

The Cinqueta de la Pez complex.

This unit is named after the rio Cinqueta de la Pez in the upper valley of which (North of the so-called Gistain-Esera fault) rocks belonging to this complex occur exclusively.
It is characterized by sandy-pelitic rocks and some impure limestones, which by regional metamorphism have been turned into staurolite-andalusite-cordierite bearing biotite-muscovite schists, sericite schists, phyllites and meta-limestones. These rocks are unanimously believed to be of Cambro-Ordovician age.
The rocks we attribute to the Cinqueta de la Pez complex are situated on the southern limb of a large scale anticlinorium the axis of which runs across the Puerto de la Pez with a WNW-ESE direction (see chapter III, the section on the Cinqueta de la Pez structural unit). The dimensions of this structure, which as a width of several kms, are such that the rocks belonging to the Cinqueta de la Pez complex may be expected to become progressively younger going from North to South in spite of repetitions due to folding on mesoscopic scale.
Since it is very hard to give sensible estimates of thicknesses, due to intense isoclinal folding and the monotonous aspect of this unit, we will confine ourselves to describing the different types of rocks belonging

to the Cinqueta de la Pez unit as we encountered them from North to South along the rio Cinqueta de la Pez.
From the Puerto de la Pez southward, over a distance of about 2000 m measured along the valley bottom, reddish brown weathering grey to brown schists and greyish quartzites are exposed. The thickness of the quartzitic layers varies from 10 cm up to 20 m, whereas the schists may reach thicknesses from ca. 10 cm up to 100 m.
Biotite prisms and andalusite crystals (sometimes up to 15 cm in length) are macroscopically visible in the schists, where the biotite is responsible for the reddish weathering colour.
Bedding of the quartzite layers is believed to be the original sedimentary bedding. In the schists no trace of macroscopically visible bedding was found, as it has been totally obliterated by strong deformation resulting in the formation of one, sometimes two generations of foliation.
Thin sections revealed the presence in the schists of staurolite, andalusite, some cordierite, two generations of biotite, muscovite, quartz and some potassium feldspar (not necessarily occurring together, though). In the quartzites some biotite and muscovite may be present.
Directly South of these schists and quartzites a conglomerate of about 20 m thickness was found. The quartzitic components have been strongly flattened and lie with their long axes parallel to a foliation, which is fairly well displayed by the schistose matrix.
South of this conglomerate, grey green schists and some grey quartzites occur over a distance of about 450 m. Small dark crystals may be see on the foliation planes in the schists, which thin sections show to be chloritoid. Microscopical investigation also revealed the presence of (flattened) quartz, dark isotropic material, muscovite and biotite.
South of these schists, grey phyllites occur over a distance of about 600 m. Thin sections revealed these phyllites to consist mainly of small muscovite flakes and quartz. At the base thin-bedded impure meta-limestones with a total thickness of about 15 m are present.
The unit is bounded in the South by the Gistain-Esera fault, which brings into contact the phyllites of the upper part of the Cinqueta de la Pez complex with the black carbonaceous slates of the Madera Formation.
Subtracting the effects of metamorphism, the original lithology of the rocks belonging to the Cinqueta de la Pez complex probably was as follows :

a. A lower part characterized by an alternation of sandstones and sandy shales overlain by a conglomerate.

b. An upper part characterized by few sandstones, sandy shales and shales in which an intercalation of impure limestone may occur.

Direct correlation, because of continuous outcropping, is possible with metamorphic rocks in the Lys-Caillouas area (Wennekers, 1968), situated North-East of the Cinqueta region and in the Rioumajou-Plan de Fredançon area (Clin, 1964) in the North and North-West.

Descriptions by both authors of rocks they attribute to the Cambro-Ordovician show more or less the same characteristics as the Cinqueta de la Pez complex; pelitic and sandy meta-sediments, overlain by a massive conglomerate or discontinuous conglomerates of variable thickness, in a few calcareous elements may occur, constitute the lower part of the series. In the upper part sandy meta-sediments are less abundant, but meta-limestones occur frequently.

Wennekers estimates a thickness of at least 600 m for his Cambro-Ordovician. As has been mentioned no estimations of the thickness of the Cinqueta de la Pez complex could be made, so this figure can not be confirmed.

Clin calls the corresponding rocks "pre-Gotlandian" and attributes a Middle Cambrian to Upper Ordovician age to them. Most other authors, however, use the term Cambro-Ordovician for the regional metamorphic rocks occurring in the central part of the axial zone of the Pyrenees.

The Viladós Formation

This formation is named after the Granjas de Viladós, North and South of which it is exposed most completely.

The unit is characterized by an alternation of bluish-grey slates, slaty hornfels and some quartzites.

The Viladós Formation is overlain by the carbonaceous slates of the Madera Formation. No sharp boundary could be established because of the intense isoclinal folding. Furthermore the slates of the upper part of the Viladós Formation show a strong resemblance to the lower slates of the Madera Formation. Generally, we have put the boundary where the rock started to stain the fingers, as an indication of the higher coal content of the Madera Formation.

No lower boundary could be found exposed.

Repetitions, due to tectonic doubling would be very difficult to establish in this formation because of its monotony. Not taking this into account a minimum thickness of 100 m seems acceptable.

In the type area the Viladős Formation is represented by NNE dipping, sometimes reddish weathering bluish-grey slates,hornfelses and quartzites. The slates show one or two generations of cleavage, while any original bedding has been totally obliterated. The thickness of the intercalated quartzites does not exceed 50 cm. Generally these quartzites display a somewhat lighter colour. Small knots are to be seen on the cleavage planes in the slates, which increase in size and number as one gets nearer to the contact with the Rechanzadas-Descubridores granodiorite in the South. With increasing recrystallization due to thermal metamorphism the older cleavage is sometimes hardly visible anymore.
In thin section the slates appeared to consist of a fine-grained matrix of flattened quartz and sericite, small grains of opaque material (possibly carbonaceous matter) and strongly altered chiastolite and cordierite crystals, which give the cleavage planes their spotted appearance. Also some small flakes of biotite were found to occur.
The Viladős Formation is exposed in a zone of about 2 km in width, striking WNW-ESE, which extends from Tres Bogas in the West to the lower slopes of La Ardaña in the East, where it is cut off by the Rechanzadas-Descubridores intrusive body. In the central part this zone is almost cut in two by the Monto Descubridores granodiorite.
In small isolated outcrops it is very hard to distinguish the slates of the Viladős Formation from the slates of the Sein Formation or those occurring in the lower part of the Puyaresto Formation.

The slates and quartzites constituting the Viladős Formation can be correlated directly with the blue schists and sericite-bearing quartzites mentioned by Clin. These occur South of the Puerto de Urdiceto (NW of Tres Bogas) and form the westward continuation of the type area.

As no fossils have been found, no age could be attributed to this unit. Clin, merely basing his opinion on ideas of other authors, gives an Ordovician age for the blue schists and quartzites South of the Puerto de Urdiceto. However, since we can only be sure that these rocks are older than the overlying coal-bearing slates of the Madera Formation, which without doubt have a Gotlandian age, we prefer the term Cambro-Ordovician for the age of the Viladős Formation.

So far, we have described two lithostratigraphical units, the Cinqueta de la Pez complex and the Viladós Formation, which both are assumed to have a Cambro-Ordovician age. Although no direct correlation is possible we think that, at least partly, these two units represent regional metamorphic (Cinqueta de la Pez complex) and non-metamorphic or thermal metamorphic (Viladós Formation) equivalents. This is confirmed by observations in the Lys-Caillouas area (Wennekers) where non-metamorphic slates and quartzites with intercalated impure limestones, overlain by black carbonaceous slates of Gotlandian age, grade westward into regional metamorphic rocks; the latter prolongate directly into the Cinqueta de la Pez complex.

The Madera Formation

This formation is named after the Barranco de la Madera, as it is best exposed in a zone parallel to this brook, along the slopes West of the rio Cinqueta de la Pez.
The Madera Formation is defined as a series of black, very fossile, carbonaceous slates which stain the fingers when being handled, with some intercalations of dark blue limestones in the upper part. It is overlain by dark slates of the Puyaresto Formation. As has already been mentioned no sharp boundary with the underlying Viladós Formation could be found. The upper boundary was taken directly above the limestones where the slates no more stained the fingers.
Because of the highly incompetent character of the rocks belonging to this formation and their role as a tectonic lubricating zone, thickness estimations are bound to be very inaccurate. The exposed thickness in the Cinqueta region varies from well under 100 m to several 100 m, not taking into account tectonic doubling.
In the type area the Madera Formation occurs as a series of fissile black carbonaceous slates in which a few thin (5-10 cm) beds of sandy slate or quartzite were encountered.
The slates are intensely cleaved and sedimentary bedding has been totally obliterated. In many outcrops the cleavage planes show small whitish needles (up to 2 mm in length), which in thin sections appear to be chiastolite crystals. In weathered outcrops the slates are sometimes covered by a white alum efflorescence or a yellowish efflorescence of sulphur.
The top of the formation includes three (sometimes fewer) thin-bedded bluish-black limestone intervals, which are separated by several meters of black slates. The thickness of these limestone intercalations does not exceed 10 m. They are porous and when crushed by hammering form a black powder, which stains the fingers, as do the slates.

Thin sections of the slates revealed the majority of the grains to consist of black opaque carbonaceous matter, and flaky material, which we believe to be sericite. Quartz grains do also occur, but are quite rare.

Besides occurring in the type area s.l. (which stretches from the Puerto de la Madera in the West to the slopes of the Posets massif in the East, occupying a large WNW-ESE striking zone) the Madera Formation is present in the Barbarisa-Sein unit, along the Sahun-Tres Bogas thrust and in the vicinity of San Juan de Plan and Gistain.
In the Barbarisa-Sein area only the upper part of the formation is exposed more or less completely along the Barranco del Sein at 1800 m, where fissile black slates and blackish limestones are overlain by blue slates and sandy slates, representing the lower part of the Puyaresto Formation. Along the Sahun-Tres Bogas thrust the Madera Formation occurs as fissile black slates, which are generally strongly distorted, probably due to the movement along the thrust plane.
Finally, near San Juan de Plan and Gistain thin lenses of crushed carbonaceous slates of the Madera Formation were found, under- and overlain by bluish slates and grey quartzites, which have been mapped as undifferentiated Paleozoic. The presence of crushed slates of the Madera Formation here is thought to be related to thrust (or fault) planes in the undifferentiated Paleozoic.

No fossils have been found in the Madera Formation, except some badly preserved graptolites, orthocerids and crinoid stems, the latter occurring in the limestones constituting the top of the formation.

Direct correlation of this unit, based on lithology and continuous outcropping, is possible with rocks showing the same characteristics in the Sierra Negra area and its western continuation East of the type area and in the synclinal de Moudaing West of the type area. Moreover, black graptolite bearing slates with black limestones in their upper range have been reported from all over the Hercynian Pyrenees.
West of the Cinqueta region, in the Bielsa area, Van Lith (1965) found black graptolite bearing slates with some limestones at the top, which he attributed to the Silurian, based on the occurrence of Monograptus, the lithology and the continuity to dated localities outside his area.
Clin (1964) in dating his "schistes carburés et calcaires Gothlandiens" of the cirque de Troumouse and the cirque du Lys area, where the synclinal de Moudaing is situated, directly refers to Destombes (1953), who gives an age ranging from Upper Llandoverian to Lower Ludlovian.
Stratigraphic studies, carried out by Degardin (1977) in the Benasque

region, revealed ages ranging from Middle Llandoverian to Lower Ludlovian for the graptolite-bearing slates and Upper Ludlovian/Lower Gedinnian for the upper black limestones. Finally, Boersma (1973) attributed a Lower Gedinnian age to the upper black limestones occurring directly below the slates and limestones of his Rueda Formation, which is to be correlated with our Puyaresto Formation.

Both Degardin and Boersma draw attention to the fact that these upper limestones should not be confused with the limestones of Upper Wenlockian age occurring lower in the slates and which are generally referred to as Orthoceras limestones. These lower limestones have not been encountered in the Cinqueta region.

In view of the very uniform distribution of the coal-bearing slates and black limestones and the general agreement in dating them, an age ranging from Lower Llandoverian to Lower Gedinnian seems quite acceptable for the Madera Formation.

The Puyaresto Formation

This formation derives its name from the Barranco de Puyaresto, on the western slopes of the Posets massif, along the upper part of which it is very well exposed.

The Puyaresto Formation is defined as a succession of recrystallized marly limestones, alternating with sandy, somewhat carbonaceous slates, which frequently have turned into hornfels by thermal metamorphism. The lowermost part of the formation, directly above the black limestones of the Madera Formation, mainly consists of slate and shows only a few thin limestone beds.

The boundary with the overlying massive limestones of the Ardaña Formation is not sharp; generally a boundary was taken at the first massive limestone with a thickness of more than 2 m.

In the type area s.l. (the Posets area) this unit shows the following characteristics : dark-grey to black fine-grained slates or hornfelses alternate with greyish weathering blue medium-grained recrystallized limestones.

Apart from the lowermost slates with few thin limestone layers, which have a total thickness of some 10 to 20 m, the slate intervals in the lower part of the formation present thicknesses varying from 30 to 50 cm. The limestones show thicknesses varying from 10 to 30 cm.

A rather gradual upward decrease of the thickness of the slates occurs resulting in values of only 1 or 2 cm in the upper part of the formation. The thickness of the limestones does not show much variation.
Due to differential weathering of the limestones and the hornfelsed slates the latter protrude from the limestone surface, imparting a ridged appearance to the outcrops (barrégienne or sandwich limestone), which is very characteristic for the Puyaresto Formation as well as for some parts of the Ardaña Formation and the Barbarisa Formation all over the area (fig. 2).
Thin sections revealed the pelitic layers to consist of flakes of what is supposed to be sericite, black opaque materal, small flattened quartz grains and carbonate matter. The limestones are quite pure, but may contain some argillaceous material,sericite and some quartz grains.

The thickness of the Puyaresto Formation may vary from about 100 m or even less on the flanks to 250-300 m in the hinges of Hercynian mainphase folds. Apart from the Posets area the formation occurs on the Peña Blanca, the Punta Suelza, the Bargasera and in the Barbarisa-Sein area. Ridged limestones in the stratigraphic window north of San Juan de Plan show much resemblance to those of the Puyaresto Formation and have also been mapped as such. However, as this window is situated in a different tectonic level, one might put question marks to this correlation. On the Punta Suelza and in the Barbarisa-Sein area it was very hard to locate the boundary between the Puyaresto Formation and the Ardaña Formation, due to intense deformation. As a result of extreme stretching on the limbs of the isoclinal Hercynian folds, furthermore, the total thickness of both formations taken together often does not exceed 100 m. In these areas, therefore, the Puyaresto Formation and the Ardana Formation have been mapped as an undifferentiated complex. In small isolated outcrops it was often hard to decide whether one was dealing with rocks belonging to the upper part of the Puyaresto Formation, or with alternations of recrystallized limestone and hornfelsed pelitic layers such as occur occasionally in the Ardaña Formation and the Barbarisa Formation.
The Puyaresto Formation together with the Ardaña Formation generally form ridges and escarpments because of their resistance to erosion, contrasting with the shales and slates of the adjacent formations.

No fossils except for some badly preserved Orthocerids and crinoid stems have been found. Wessels Boer, who studied the area in 1961 and 1962, came across Phacops sp., Odontochile sp. and Zaphrentis sp.

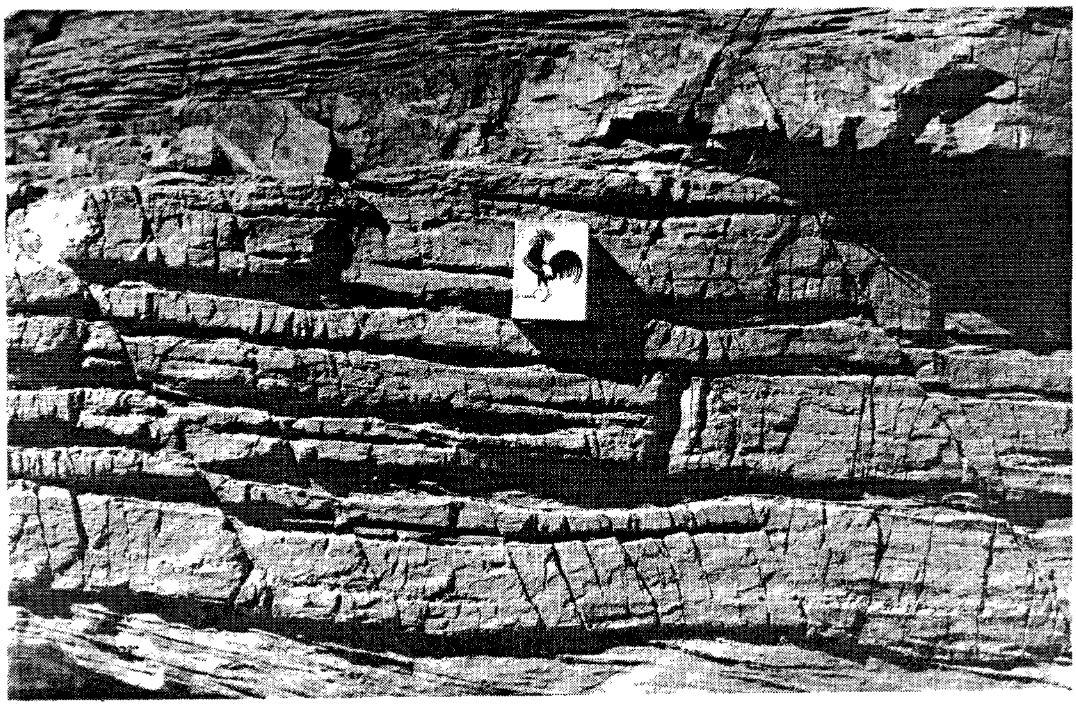


Fig.2.Sandwich limestone (barrégienne)of the metamorphic Puyaresto Fm.,caused by differential weathering of recrystallised limestone and hornfels.

By continuity of outcrop the Puyaresto Formation can be correlated with the Rueda Formation, established by Mey (1967) in the Sierra Negra area and showing the same characteristics : an alternation of sandy slates and marly limestones (fig. 3). In the Esera area Wennekers subdivides the Rueda Formation into two formations, the Aneto Formation and the Gelada Formation, thus distinguishing the lowermost slates with only few limestones and the slate-limestone alternation.

Conodont faunas collected from the Rueda Formation by Boersma (1973) indicate a Gedinnian age. In view of the rather uniform occurrence of the Rueda Formation in the areas East of the Cinqueta region as far as lithology and thickness are concerned and the great similarity to the Puyaresto Formation, a Gedinnian age might be attributed also to the latter.

The Ardaña Formation

This formation is named after the Ardaña mountain, South-West of the Posets, on the western slopes of which it is widely exposed.

The Ardaña Formation is characterized by a succession of massive grey weathering bluish limestones which generally have been recrystallized. Thin streaks of hornfelsed pelitic material (in contrast with the thicker slate intercalations of the Puyaresto Formation) frequently occur throughout the formation.
The Ardaña Formation is overlain with a sharp boundary by the dark slates with intercalated impure limestones of the Sein Formation.

The thickness measured in the type area varies from about 100 m on the limbs to maybe 250 m or more in the hinges of Hercynian mainphase folds. In the type area this formation occurs as a series of massive or thick-bedded pure limestones. Where bedding is visible thicknesses up to 2.5 m are measured. The upper 10 to 15 m are rather thin-bedded and show somewhat darker weathering colours than the general light grey of the major part of this unit.
Because of recrystallization due to thermal metamorphism, thin streaks of argillaceous material or of marly composition protrude from the weathered limestone surface, accentuating the original bedding and the internal folding.

Thin sections show the limestone to be very pure, except for some sericite flakes and small quartz grains; the calcite grains exhibit form orientation. The pelitic intercalations contain carbonaceous material, sericite, dark isotropic grains and occasionally some epidote.

Except in the type area and the adjacent Posets area, the Ardaña Formation occurs on the Pena Blanca, the Punta Suelza and in the Barbarisa-Sein area. The lithological characteristics are the same as in the type area, but on the Punta Suelza and in the Barbarisa-Sein area the Ardaña Formation had to be mapped together with the Puyaresto Formation for reasons already mentioned.
A massive limestone, overlying ridged limestones mapped as Puyaresto Formation in the San Juan stratigraphic window, shows much resemblance to the Ardaña Formation and consequently has been mapped as such. As has been put forward in the section on the Puyaresto Formation, caution is required here, since the San Juan window is part of a different structural unit.

As bedding is usually poorly visible because of their homogeneous composition and massive habit, the large scale structures in the limestones of the Ardaña Formation are best studied from a distance. They then clearly contrast with the ridged appearance and the somewhat darker weathering colours of the underlying Puyaresto Formation and the dark colours of the overlying Sein Formation.
Karst phenomena such as clints or "Karren" and dolines occur in these rocks, especially in the Posets area. The name Posets, probably derived from "pozo", being spanish for deep pit or precipice, may refer to these phenomena.
No fossils, except for some crinoid stems, were encountered in this formation. Because of continuous outcropping, direct lithological correlation is possible with the Castanesa Formation, defined by Mey (1967) in the Sierra Negra area, and the Basibé Formation in the Esera region (Wennekers, 1968). The name Castanesa Formation was originally given by Mey to the equivalent of the Basibé Formation in the Sierra Negra area. In more recent publications, however, this name has been dropped in favour of Basibé (Mey, 1968; Habermehl, 1970 en Boersma, 1973).
The descriptions of the Castanesa (Basibé) Formation in the Sierra Negra and the Esera area show a great resemblance to our own observation concerning the Ardaña Formation (fig. 3).

Boersma collected conodont faunas (in the upper Isabena valley) indicating an Upper Gedinnian to upper Lower Emsian/lower Upper Emsian age for the Basibé Formation. He suggests that at least the lower part of the formation grows older to the West.

The Sein Formation

The Sein Formation is named after the Barranco del Sein, which cuts across the Barbarisa-Sein area, where the formation is well exposed.

This unit is defined as a series of dark slates and sandy slates, a few quartzites, and some impure bluish-grey limestones in the upper part of the formation. Because of thermal metamorphism the slates frequently have been changed into hornfels, or rocks resembling hornfels, in the field. The boundary with the overlying Barbarisa Formation, which is sharp, is taken at the first limestone with a thickness clearly exceeding 5 m.

Because of the incompetent behaviour of the slates belonging to the Sein Formation great differences in thickness may be expected to occur. These differences moreover are accentuated by disharmonic folding between the underlying Puyaresto and Ardana Formations and the overlying Barbarisa Formation to which the slates of the Sein Formation had to accomodate themselves.
We estimate the original thickness to be at least 100 m.

In the type area the Sein Formation is characterized by sometimes reddish-brown weathering dark slates and sandy slates with a few thin quartzites. Intense cleavage has totally obliterated the original bedding in the slates. The cleavage planes have a shiny appearance and occasionally show small spots, which in thin section are seen to been altered cordierite and andalusite. In the northern part of the type area the slates have turned into hornfels and the cleavage planes are hardly visible anymore. Four intercalations of impure limestone occur in the upper part of the formation. Their thickness varies from 1 m for the upper one to 5 m for the lowest one. Generally they have been turned into calc-schists by flattening. The cleavage is visible in thin sections, represented by form-oriented small calcite grains.
Beyond the type area the Sein Formation occurs in the synclinal cores of the Hercynian folds in the Posets massif. Especially on the slopes west of

Las Espadas it appears to be well developed but the inaccessability of these slopes prohibited investigation.

From a distance this formation is generally easily recognizable because of its dark, occasionally reddish colours, which are in strong contrast with the lighter colours of the over- and underlying limestones.

In small outcrops it was found impossible to distinguish between the slates of the Sein Formation and those of the Viladós Formation, especially when recrystallized by thermal metamorphism. In such cases a decision was based on the general setting and the position with respect to the over- and underlying limestones.

To the East the Sein Formation lithologically correlates with the dark slates and sandy slates with intercalations of marly limestone and thinly bedded sandstones, attributed to the Fonchanina Formation in the Esera region and in the Sierra Negra area (Wennekers, 1968; Mey, 1967). The thickness of the Fonchanina Formation in the Esera area was estimated by Wennekers to be at least 50 m. (fig. 3)

Conodonts collected by Boersma (1973) from the lower part of the Fonchanina Formation indicate an upper Lower Emsian/lower Upper Emsian age. For the upper part of this formation, from which he did not take samples, Boersma suggests an uppermost Emsian/lowermost Couvinian age. The finding of two (!) conodont specimens, identified as Icriodus Corniger, in a sample from calc-schists of the Barbarisa Formation directly above the Sein Formation supports this suggestion.
Thus, an age ranging from upper Lower Emsian to uppermost Emsian may be attributed to the Sein Formation.

The Barbarisa Formation

The Barbarisa Formation is named after the Barbarisa mountain in the South-East of the area, where it is well exposed on the summit as well on the southern slopes.

The Barbarisa Formation is characterized by an alternation of greenish-grey, bluish-grey and yellowish-grey calc-schists and recrystallized limestones with thin streaks of pelitic material.
The boundary with the underlying Sein Formation is sharp. East of la Esti-

veta and on the South ridge of the Barbarisa, intensely cleaved slates, that we attributed to the Sahun Formation, were found above the Barbarisa Formation in the synclinal cores of folds. However, no contact was found exposed.
Thickness may vary from ca. 70 m on the limbs of Hercynian mainphase folds to 200 à 300 m measured parallel to the axial plane.

In the type area the Barbarisa Formation, before cleavage flattening and recrystallization, is supposed to have been a regular alternation of thin (1 à 2 cm ?) layers of limestone and marly limestone, and thin streaks of pelitic material. In the upper part this alternation may be more thick-bedded, especially as far as the argillaceous layers are concerned. Here the thickness of the pelitic layers may have values up to 3 cm.
As a result of recrystallization these pelitic layers are changed into hornfels, protruding from the weathered limestone surface, which gives the rock an appearance very similar to the Puyaresto Formation (sandwich limestone or barrégienne). A cleavage is generally present, giving the limestone the aspect of a calc-schist.
Thin sections revealed the limestones to consist of small calcite grains, form-oriented parallel to the cleavage, small sericite flakes, a few quartz grains and occasionally some epidote.
Besides in the type area the Barbarisa Formation occurs in the highest parts of the Posets massif (notably on the summit of Las Espadas), where investigation was impossible because of the inaccessability of this part of the Cinqueta region. Looking from a distance, however, one gets the impression that the transition from the Sein Formation into the Barbarisa Formation is more gradual here, through a regular alternation of light (limestone) and dark (slate) layers (fig. 4).

In very intensely folded areas, where the normal stratigraphic succession is hard to recognise, the Barbarisa Formation may be distinguished from the Puyaresto Formation and the Ardaña Formation, because of its slightly different colours : yellowish- and brownish-grey for the Barbarisa Formation, light grey for the Ardaña Formation and dark grey for the Puyaresto Formation.

To the East this formation can be correlated by continuity of outcrop with the Mananet Formation of Wennekers (1968) in the Esera area and the Mananet Griotte defined by Mey (1967) in the Sierra Negra area (fig. 3). Although the characteristics of the Mananet Griotte described by the latter differ considerably from the characteristics we gave for the Barbarisa Formation, one should bear in mind that we could only describe these rocks in a metamorphic state. Lithological resemblance becomes more apparent when we quote Mey on the subject of Mananet Griotte when metamorphic : "In the metamorphic state some of the highly typical characteristics, such as the nodular aspect and the vivid colours, are entirely lost. The greenish and cream colours remain, establishing the differentiation from the other limestones. The thin pelitic layers between the calcareous nodular beds change into hornfels".

According to Boersma (1973) conodonts indicate an age ranging from Eifelian to Visean for the Mananet Griotte. The two specimens of Icriodus Corniger found at the base of the Barbarisa Formation at least do not contradict the assumption that the lower part of this formation is to be attributed to the Eifelian. (Couvinian).

The Sahun Formation

This formation is named after the Collado de Sahun in the extreme South-East of the Cinqueta region. On the ridge leading from the Collado de Sahun to the Barbarisa, some outcrops of dark strongly cleaved slates were found, which are thought to lie on top of the Barbarisa Formation because they occur in the cores of synclines. No boundary could be found exposed.

The cleavage planes have a lustrous appearance due to the presence of sericite. The occurrence of muscovite which may be detrital, makes it possible to distinguish between the slates of the Sahun Formation and those of the Sein Formation.

Since the Sahun Formation only occurs in a small area and could be studied only fragmentarily, it seems inappropriate to attempt correlations with formations in other areas. We will confine ourselves to mentioning the presence of a monotonous sequence of shales, which conformably overlie the Mananet Griotte East of the Cinqueta valley (Mey, 1967; Wennekers, 1968) and are believed to be of Carboniferous age.

A summary of the characteristics of the formations we established in the Cinqueta region from the Madera Formation up to the Sahun Formation and the proposed correlations with formations Mey and Wennekers established in the Sierra Negra and Esera areas, is given in fig. 3.

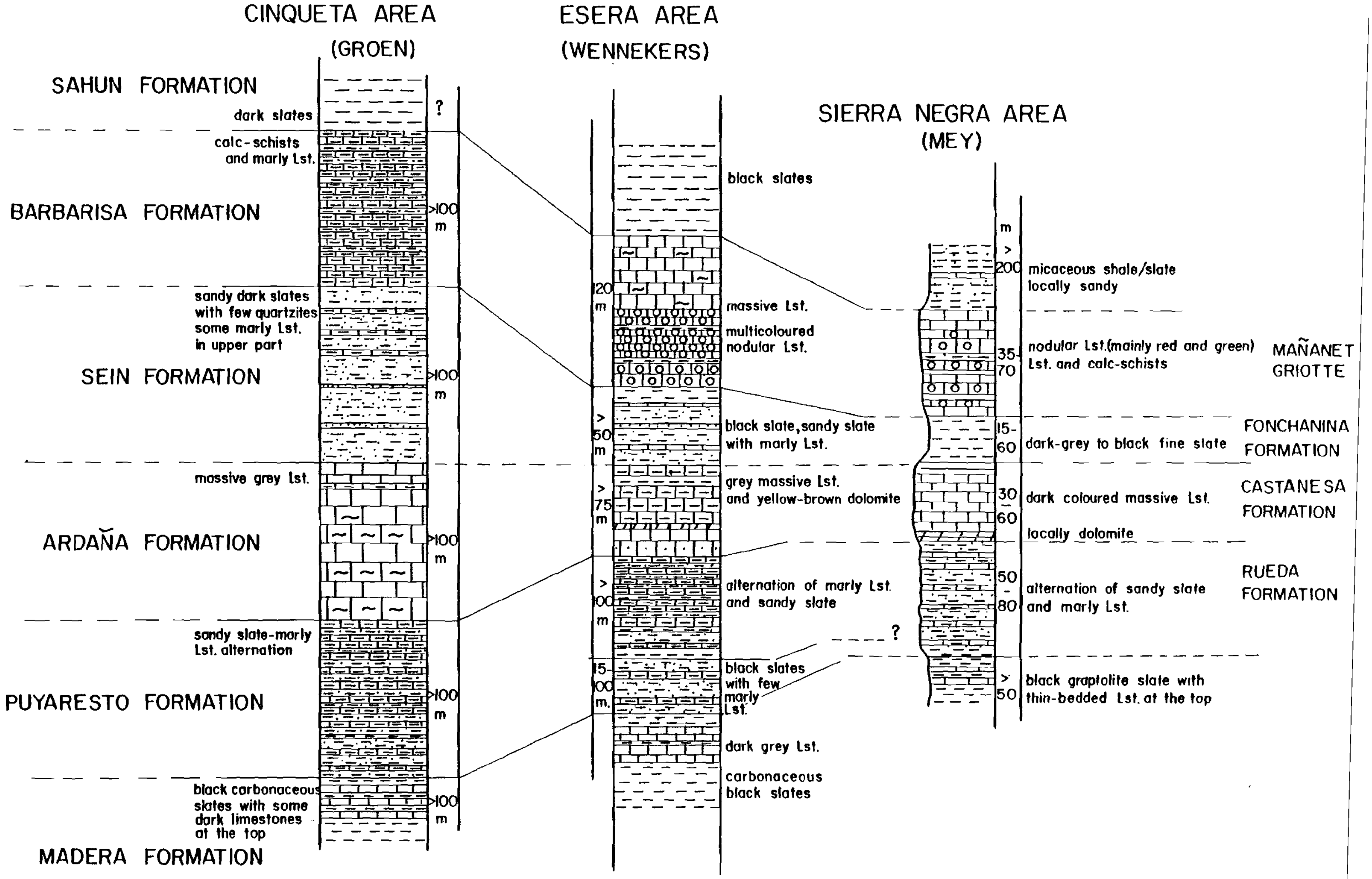


Fig.3.Simplified lithostratigraphic section of the Puyaresto Fm. up to the Sahun Fm. in the Cinqueta region, compared with correlatable sections in the Esera and Sierra Negra areas.

Post-Hercynian sedimentary rocks

Introduction

In many parts of the Pyrenees the Paleozoic sediments, which have been folded, thrusted and intruded by granitic and associated rocks during the Hercynian orogeny are overlain unconformably by a succession of reddish sandstones, conglomerates, siltstones and shales.
To avoid the risk of losing ourselves in the overwhelming quantity of literature existing on this subject we refer the reader to more or less elaborate recapitulations given by Clin (1959), Van Lith (1965), Nagtegaal (1969) and Martinez (1968). Generally these red detrital series are believed to be of Permian and Lower Triassic (Buntsandstein) age, a statement merely based on their lithology.
In the Cinqueta area a comparable succession of reddish detrital sediments, unconformably overlying the late Hercynian Cinqueta granodiorite and folded Paleozoic sedimentary rocks, has been mapped and described as the Poma-Viciele Formation. Our description is mainly based upon the observations of Wessels Boer (1961, 1962, internal reports) and Martinez (1968).

The Poma-Viciele Formation

This formation is named after the Barranco de la Poma and the Barranco de Viciele, which are to be found in the western part of the Cinqueta region, where this formation occupies large areas.

The Poma-Viciele Formation has been defined as a succession of red to violet sandstones, conglomerates, siltstones and shales. The boundary with the underlying Paleozoic is sharp and unconformable. Yellowish to violet limestones alternating with thin layers of shale overlie the Poma-Viciele Formation by means of a sharp stratigraphic contact.

In the type area the base of the formation is formed by a coarse conglomerate, mainly consisting of quartz and quartzite, the matrix being formed by reddish argillaceous material. According to Martinez (1968) thickness may vary between 0 and 5 m. The conglomerate is overlain by an alternation of red shales and impure sandstones, which are generally rich in detrital micas. The thickness of this alternation may vary from 100 to 150 m. In the sandstones graded bedding and large scale cross-bedding may frequently be observed.

Next a light grey weathering conglomerate occurs (thickness from some cm up to 2-3 m), consisting of well rounded quartz components (1-3 cm diameter) in a matrix of red argillaceous material. This conglomerate in its turn is overlain by an alternation of red and greenish-grey shales and impure sandstones with a thickness of ca. 30 m.
The Poma-Viciele Formation occurs all over the type area and along the southern border of the Cinqueta region, but is restricted to main unit B (see structural scetch map).

The Poma-Viciele Formation is overlain by yellowish to violet limestones, occasionally cellular dolomite (spanish : carneola), gypsiferous shales and gypsum. The limestones and the cellular dolomite were locally encountered below strongly contorted gypsiferous shales and gypsum near the Sahun-Tres Bogas thrust. However, since these rocks are only locally exposed, they were not studied in detail. The thickness may vary between 50 and 100 m in the Cinqueta area.

Generally they are attributed to the Middle and Upper Triassic (Muschelkalk and Keuper).

The characteristics of the post-Hercynian sediments in the Cinqueta region are given in fig. 4.

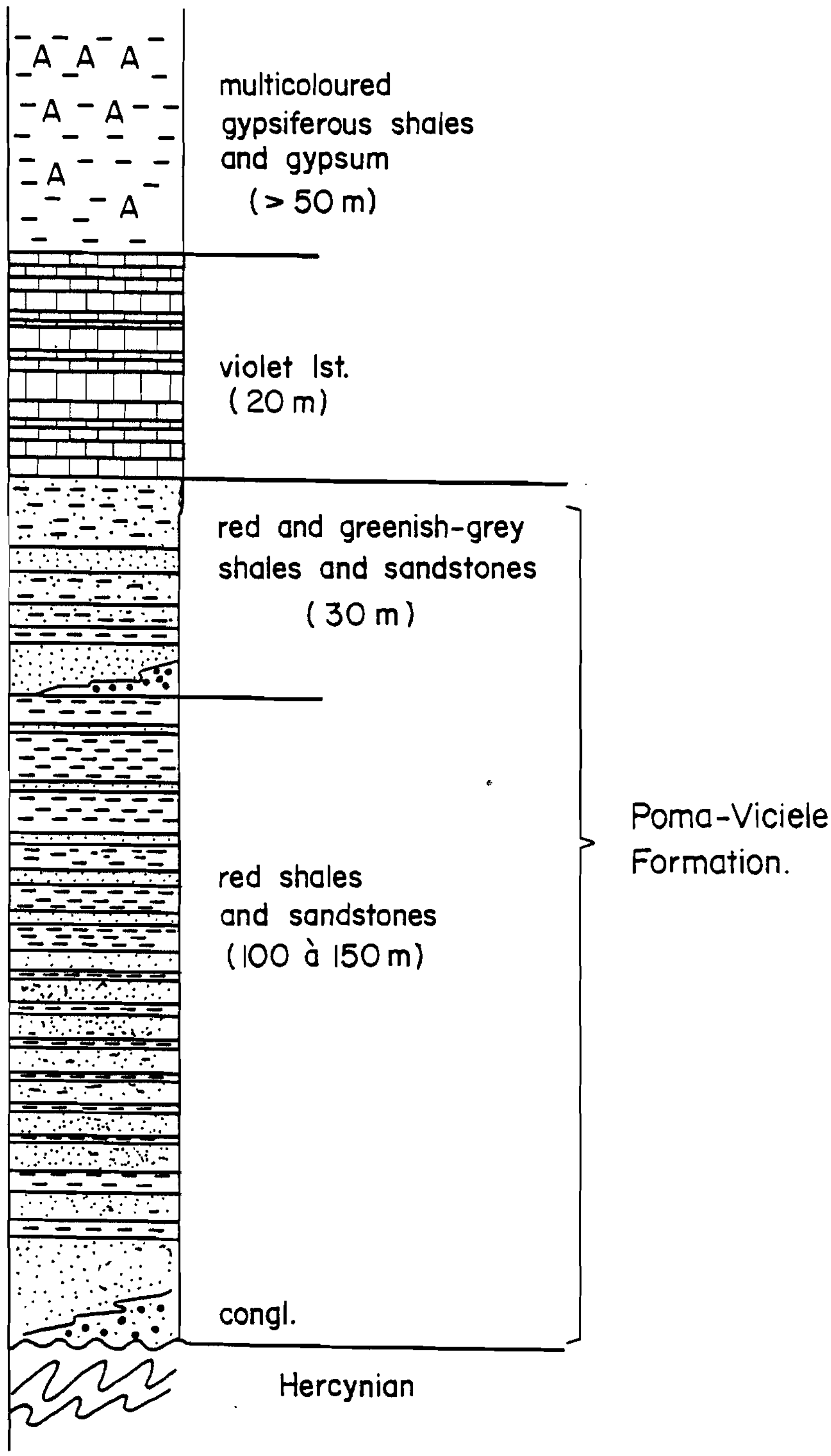


Fig.4.Columnar section of the post-Hercynian sediments in the Cinqueta region.

CHAPTER II

Igneous rocks and thermal metamorphism

Two major intrusive bodies occur in the investigated area : the Rechanzadas-Descubridores granodiorite and the Cinqueta granodiorite.
The Rechanzadas-Descubridores granodiorite extends across the central part of the area in an E-W direction. It generally has a sharp contact with the surrounding Paleozoic rocks in which it intruded. The rock usually is grey coloured with sometimes a touch of brown weathering.
The Cinqueta granodiorite occupies large areas in the central western part of the Cinqueta region. An intrusive contact with black coal-bearing shales of the Madera Formation (Gotlandian) in the extreme North-West near Tres Bogas is probable (Clin, 1964). North of San Juan de Plan the Paleozoic sedimentary rocks, exposed in the San Juan stratigraphic window, have been influenced by thermal metamorphism, but a contact with the Cinqueta granodiorite is not visible.
The Cinqueta granodiorite is unconformably overlain by the red sandstones and shales of the Poma-Viciele Formation (Permian-Lower Triassic). It has a several meter thick mantle of weathered material, which as it occurs also below the Poma-Viciele Formation, must have been formed before deposition of these rocks (Van Lith, 1965). The Cinqueta granodiorite generally is somewhat darker coloured than the Rechanzadas-Descubridores granodiorite.
The granodiorites have been investigated only superficially. No great differences in composition were found. Thin sections revealed the main constituents to be quartz, plagioclase (25-35% An), potassium feldspar, biotite (frequently altered to chlorite) and/or hornblende. Muscovite may also occur, but is less abundant than biotite. Potassium feldspar occurs in smaller quantities than plagioclase.
Apart from the weathered mantle of the Cinqueta granodiorite and the extreme rim (near the contact) of the Rechanzadas-Descubridores granodiorite, which both present a schistose appearance, these rocks are completely unoriented.
There are associated dikes, with colours varying from grey to greenish grey and occasionally brownish. In thin section these appeared to be strongly altered. The main constituents are : sericitised plagioclase, chloritised biotite, hornblende, quartz and potassium feldspar. Generally these dikes intruded parallel to the mainphase cleavage.
Thermal metamorphism has altered the pelitic rocks into hornfels and spotted

slates. In the hornfelses the cleavage has been largely obliterated; they are made up by a fine-grained matrix consisting of quartz, muscovite and biotite in which porphyroblasts of andalusite and altered cordierite occur.

The black carbonaceous slates of the Madera Formation retain their fissility, even in the vicinity of the intrusive bodies, and never change into true hornfels. Chiastolite is the most important newly formed mineral.

Near the contact limestones have been recrystallized to coarse marble, thus obliterating the form orientation of small calcite grains resulting from dynamo-metamorphism during the Hercynian mainphase. Diopside and epidote were encountered in the limestones situated in the inner zone of the contact aureole.

The time-relationship between the emplacement of the granodiorites and the fourth Hercynian deformation phase of E-W refolding (see next chapter) is revealed by rotated and deformed andalusite or chiastolite crystals in the spotted slates in the contact aureoles. As these rotated porphyroblasts occasionally show a slightly s-shaped Si near the rim, their final stage of growth must have been synchronous with the onset of the fourth deformation phase. Consequently the intrusion of the granodiorites must have occurred mainly before this fourth phase. Their emplacement was clearly subsequent to the mainphase, as is indicated by the dikes intruded along the mainphase cleavage.

CHAPTER III

Structural Geology

HERCYNIAN TECTONICS

Introduction

The Hercynian structures in the Pyrenees have been the subject of many investigations,which revealed that several successive phases of deformation have been active.According to Boschma(1963),Zwart(1963),De Sitter (1964),Oele(1966) and Mey(1967,1968) the following phases can be distinguished (see also Fig.5):

a.The pre-mainphase or pre-cleavage period,during which N-S to NE-SW trending folds developed in the northern and southern borders of the axial zone.In the central part of the axial zone this phase is much harder to trace due to the parallellism of the trends of pre-mainphase and mainphase folds,both having an E-W direction here.

The mainphase,which produced NW-SE to E-W striking folds.A distinction has to be made between the regional metamorphic areas,belonging to the so-called infrastructure,where deformation is characterised by a flat-lying foliation and small scale recumbent,isoclinal or asymmetrical folds(size up to some metres),and areas of low grade dynamo-metamorphic rocks,belonging to the suprastructure.The latter show open to tight folds of variable size (cm. to hm. dimensions) and the accompanying cleavage has a steep attitude in the central and northen part of the axial zone,which flattens out to the south,where it dips moderately to gently to the N.

c.A third phase gave rise to N-S trending small scale folds and axes of internal rotation,and seems to have affected only the metamorphic rocks of the infrastructure.Either a second foliation developed or the mainphase foliation was reactivated.

d.A conjugate set of folds with sub-vertical axial planes,one striking NW-SE and another striking NE-SW,characterises the fourth phase.The plunge of the fold axes depends on the attitude of the s-planes before the folding.The folds are asymmetrical with a long north limb and a short south limb.These structures seem to be most frequent in the regional metamorphic rocks of the infrastructure.

e.The fifth phase was responsible for E-W trending folds with vertical to steeply N dipping axial planes.The development of an axial plane cre-

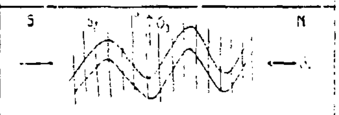
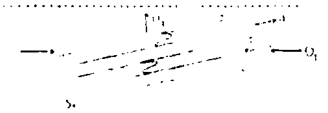
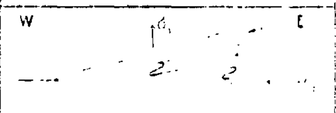
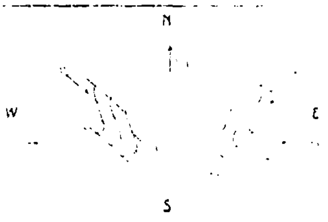
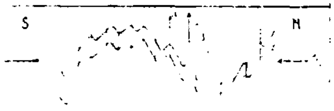
DEFORMATION PHASE	FOLD-AXIS	S-PLANE	SYMMETRY	TECTONIC AXES	STRESS FIELD	SECTION PERPENDICULAR TO THE B-AXIS
1	E-W	Suprastructure: vertical E-W	Orthorhombic	a Vertical b E-W c N-S	σ_3 Vertical σ_2 E-W	
		Infrastructure: flat	Monoclinic	a N-S flat b E-W c Steep	σ_1 N-S	
2	N-S	flat	Monoclinic	a E-W flat b N-S c Steep	σ_3 Vertical σ_2 N-S σ_1 E-W	
3	Vertical to NW-SE and NE-SW	Vertical NW-SE Vertical NE-SW	Monoclinic Monoclinic (together: Ortho-rhombic)	a NW-SE b Vertical c NE-SW a NE-SW b Vertical c NW-SE	σ_3 N-S σ_2 Vertical σ_1 E-W	
4	E-W	Vertical E-W	Orthorhombic	a Vertical b E-W c N-S	σ_3 Vertical σ_2 E-W σ_1 N-S	

Fig.5 (from Zwart,1963).Scheme presenting the successive deformation phase during the Hercynian orogeny in the Pyrenees(phases described in the text under a. and f. are not presented.

nulation cleavage probably depended on whether the axial planes coincided with the mainphase cleavage or made an angle with it large enough for a new cleavage to be produced.In the first case only reactivation of the existing planes,with flattening and shear,would take place.
The granodiorite intrusions,among which the Maladeta and those occurring in the western Esera area (Perramó,Vall) and in the Cinqueta region predate this last folding phase.
f.This last phase is,in contrast with the previous compressional phases, of a tensional character,which is expressed by the development of kink bands,indicating a dilatation in N-S direction.Another phenomenon related to this phase would be the southward fanning of the cleavage,caused by tilting from an original vertical attitude.
It has been found impossible to date these phases individually for the lack of biostratigraphic data.However,it is generally assumed that real folding started after the deposition of rocks of Lower Westphalian age, and lasted until the end of the Upper Westphalian.

Since a lot of confusion still exists concerning the use of terms like cleavage,slaty cleavage,schistosity,foliation etc.,either in a descriptive or in a genetic sense,we give the following definitions,according to which the terms shall be used in this paper.
a.Cleavage or slaty cleavage:pervasive surfaces in fine grained rocks,the distance between which is microscopic.In slates and phyllites the cleavage is caused by parallel arrangement of phyllosilicates,whereas in limestones it is due to the orientation of calcaite grains.
b.Foliation:pervasive surfaces in schists and gneisses,which only differ from cleavage in this respect,that the phyllosilicates are macroscopically visible.In limestones individual calcite grains are distinguishable with the naked eye.
c.Crenulation cleavage or foliation:this type of pervasive surfaces occurs only in rocks,in which an older cleavage or foliation is folded on a microscopical scale.The crenulation cleavage is parallel to the axial plane of the micro-folds and may be delineated by the (short)limbs of the micro-folds or by micro-faults parallel to them.
d.Fracture cleavage:here the cleavage surfaces are at intervals varying from some mm. up to several cm.Fracture cleavage may grade into any of the three types of cleavage described above.
By adding "axial plane" a genetic relationship with a certain fold generation is intended.

The mapped area has been subdivided into two structural main units: unit A covers the northern and eastern part of the area and consists of folded,cleavaed or foliated,Paleozoic rocks.These have overridden in southward direction main unit B,formed by the autochtonous Hercynian basement covered unconformably by rocks of presumably Permo-Triassic age (see structural sketch map).Main units A and B are separated by the Sahun-Tres Bogas thrust.

Main unit A,in its turn,has been subdivided into two smaller units:

unit I.The Cinqueta de la Pez unit,which consists of regional metamorphic rocks possibly of Cambro-Ordovician age.Well developed foliations are the most outstanding features in this area.

unit III.The Posets-Peña Blanca unit,which includes mainly folded Gotlandian and Lower Devonian rocks.Both pre-mainphase and mainphase folds occur.The cleavage and axial planes of the mainphase folds have a steeply dipping attitude in the northern and central part,whereas in the southern part they flatten out to a moderate northward dip.

unit III.The Barbarisa-Sein unit,which also includes the Paleozoic outliers of the Punta Suelza and the Bargasera,overthrust on the Permo-Triassic of main unit B.Rocks of Gotlandian and Lower Devonian age are present almost exclusively in this unit also.It differs structurally from the Posets-Peña Blanca unit in this respect that pre-mainphase folds cannot be distinguished in the field;but they may be inferred from the position of the mainphase fold axes.Furthermore,the axial planes of the mainphase folds show only gentle to moderate dips to the N.

Main unit B:The Hercynian basement consists mainly of granodiorite,which has not been affected by Hercynian deformations.However,Hercynian structures may be observed in a small stratigraphic window north of San Juan de Plan, where Paleozoic rocks of sedimentary origin are exposed below the Permo-Triassic cover.

The second deformation phase,distinguished in the regional metamorphic rocks of the Cinqueta de la Pez unit,as well as the second phase occurring in the low grade dynamo-metamorphic rocks of the Posets-Peña Blanca unit,the Barbarisa-Sein unit and the San Juan window of main unit B have been correlated with the Hercynian mainphase.We have adopted the existing usage of designating this phase "F1".

The phase predating the mainphase in the regional metamorphic rocks of the Cinqueta de la Pez unit and the one predating it in the low grade metamorphic rocks in the other units has been designated "Fp" (pre-mainphase).

Main unit A

The Cinqueta de la Pez unit

Introduction.

The Cinqueta de la Pez unit is situated in the extreme north of the Cinqueta region.To the north it extends across the Spanis-French border. IN the south it is separated by the Gistain-Esera fault from the Posets-Peña Blanca unit (see structural sketch map).

Several phases of deformation could be recognised:

The first phase (Fp) gave rise to the formation of a foliation (Sp) parallel or subparallel to the bedding.This phase may correspond with the pre-mainphase of Zwart et al..

The second phase (F1) generated folds of varying dimensions:from microscopic scale up to map scale.The folds are tight asymmetrical or isoclinal, with moderately to steeply dipping south limbs and vertical to slightly overturned north limbs.A second foliation (S1) caused by crenulation of Sp is nearly always present,conforming to the attitude of the axial plane of the folds,and dips generally to the SSW.This phase has been correlated with the mainphase of the Hercynian orogenesis.

During a third phase (F2) an internal rotation about N-S directed axes took place,due to shear along S1.This deformation was only revealed in thin sections.It has been correlated with the second phase of N-S refolding of Zwart (1962,1963).

Minor deformations,postdating F2,resulted in the generation of a very poorly developed N-S striking cleavage,some small scale folds with N-S axes and,in a few localities,a conjugate system of kink bands,intersecting along an E-W direction.

Regional description

The Cinqueta de la Pez unit consists exclusively of regional metamorphic rocks,such as biotite-muscovite schists,some of them bearing andalusite, staurolite and cordierite,sericite schists and phyllites.S1 and Sp are present throughout the earea,but it depends on the intensity of S1 whether Sp is still observable.S1 has a very constant attitude,dipping 50-70^{o} to the south and striking 100-130^{o}.

Sp and So(bedding)have been folded relative to S1.Such folds,however,are only rarely visible in the field.

The Cinqueta de la Pez unit is a part of a large antiformal structure, called by Clin(1959)"Anticlinal de Fredançon-Aygues Tortes".Its culmination runs across the Puerto de la Pez with a direction of 120-130^{o}.

In the west this structure is cut off by the Gavarnie thrust near the Pic d'Aret,while the Lys-Caillouas intrusive body partly obliterates its eastern prolongation.Sections presented by Wennekers(1968) and Kleinsmiede(1960)support the idea that the Fredançon-Aygues anticline together with some smaller structures north of it,is to be correlated with the central anticline of Kleinsmiede in the Valle de Arán area.

Deformational history

The first deformation phase (Fp).
A frequently well developed foliation striking WNW-ESE is the only trace left by this deformation phase.Due to (re)folding during the mainphase dips vary from gently S to vertical.
Where sedimentary bedding,or what appeared to be sedimentary bedding in thin sections,was found,the foliation was always parallel or subparallel to the bedding.Only in one thin section,taken from a sericite schist,this first foliation,though almost obliterated by strongly developed second foliation planes (S1),seemed to run across what was supposed to be transposed bedding.
On many occasions it was very difficult to decide,in the field,whether one was dealing with (Sp) or S1,as intense flattening due to the second deformation phase (F1) has brought Sp and S1 into a near-parallel position.
Actually three types of relationship were found to occur:
1.Both Sp and S1 are present.S1 is easily distinguished from Sp as it cuts through the latter.Usually So is not visible.
2.Sp as well as So are found,being parallel to another,while S1 is less well developed.
The situation already mentioned,where S1 and Sp are subparallel and distinction between them is difficult.
In the first and second case Sp is always dipping less steeply than S1.Thin sections revealed that in the third case Sp is nearly parallel to S1.If they do make a slight angle,Sp is the steeper.So case 1 and 2 occur on the south limb and case 3 on the steep north limb of an F1 fold.
In some slides only one foliation is visible.This is thought to represent S1, as an older foliation is sometimes preserved as a relict structure,enclosed in poikiloblasts.
Thin sections of samples taken from outcrops where both Sp and S1 could be distinguished,showed this first foliation to be well developed,being displayed by parallel arrangement of small muscovite and biotite flakes (in the biotite-muscovite-schists) or muscovite flakes only (in the sericite-schists

and phyllites),and by form-oriented quartz grains.S1 may vary from an incipient crenulation cleavage to a strongly developed crenulation foliation.

When sedimentary bedding was visible in outcrops,thin sections revealed an alternation of layers rich in micaceous material and layers rich in quartz. The mica-rich layers show a well established Sp,which is micro-folded or cut across by a second foliation,depending on the intensity of deformation during S1.The quartz-rich layers were found to posses no or an only slightly developed Sp,and no effects of later deformation (F1) are present.The quartz grains show hardly any orientation.

Field measurements of the attitudes of Sp (parallel to So) and the attitudes derived from oriented samples are presented in a structural diagram (Fig.6). Though too few readings are available to give this diagram any statistical value,it conveys an idea of the folding style related to the second deformation phase (F1).

No intersections of So and Sp have been found because of the general parallellism of the two.Measured intersections of Sp and S1 are presented in Fig.7. The diagram shows maxima which lie close to the general strike of S1,suggesting that Sp was either flatlying or but gently folded before F1,or that the strike of Sp was parallel to the strike of S1.Though,in this case also,too few measurements are available to state this with certainty.

Since no fold hinges related to Fp have been found,it is hard to say whether one is dealing here with isoclinal folding to a degree that Sp is nearly everywhere parallel to So,or that Sp developed as a concentric cleavage (De Sitter,1964,p.292).Concentric cleavage is thought to be generated by shear exerted on layers rich in phyllosilicates,by competent beds moving differentially on the limbs of large folds.Movement would take place mainly in the layers rich in pelitic material,without affecting the competent quartz-rich layers.

A third possibility might be load metamorphism,causing mimetic recrystallization parallel to the original bedding.

General parallellism of cleavage or foliation and bedding combined with scarce isoclinal folds might also be produced by shear more or less parallel to the bedding,as has been suggested by Zwart (1963) for the flatlying mainphase foliation in the infrastructural Cambro-Ordovician domes and anticlinoria in the eastern central Pyrenees.For the Cinqueta de la Pez this mechanism has to be discarded,as it would without doubt give rise to boudinage of the competent layers,no trace of which has been found.

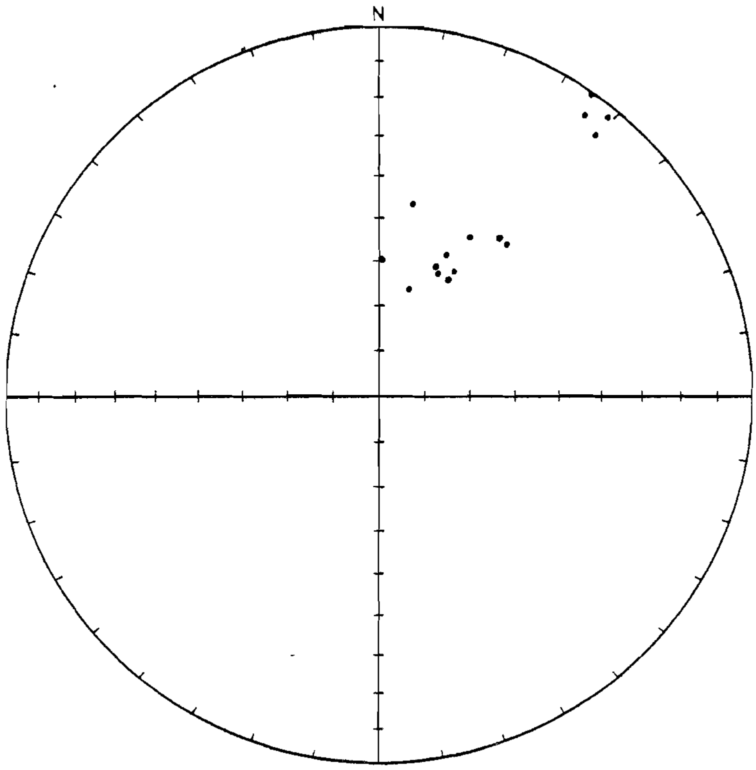


Fig.6.Distribution of normals to Sp in the Cinqueta de la Pez unit(Schmidt's projection,lower hemisphere).

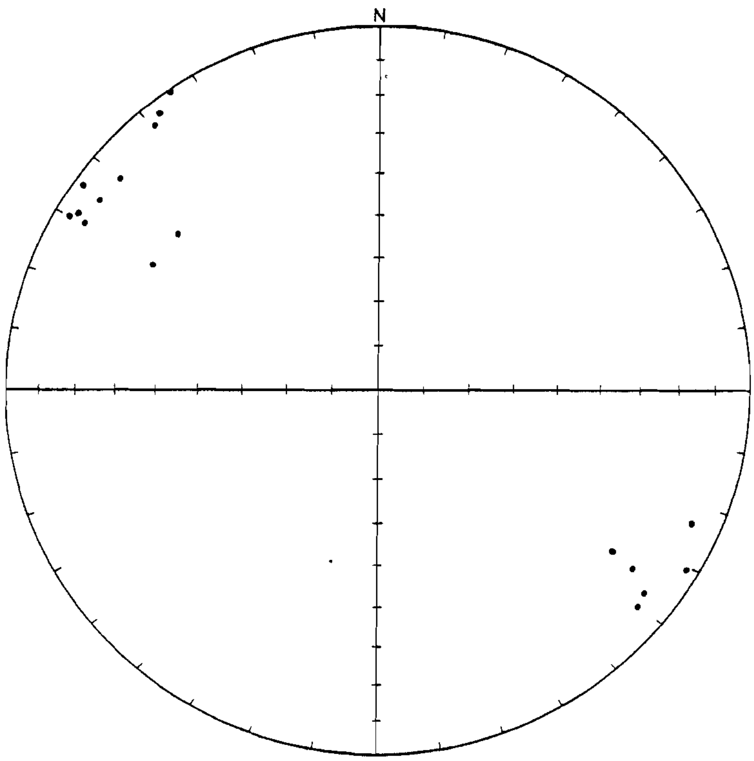


Fig.7.Distribution of intersections of S1 and Sp in the Cinqueta de la Pez area(Schmidt's projection,lower hemisphere).

Load metamorphism causing mimetic recrystallization does not explain the presence of form-oriented quartz grains in the micarich layers.So,a mechanism such as proposed for the generation of concentric cleavage seems the most plausible for the first deformation phase,possibly under conditions of epizonal metamorphism,facilitating the recrystallization of phyllosilicates.

Correlation of Fp with phases in adjacent areas is impossible because the mainphase or F1,which can be correlated with the second deformation phase in the Cinqueta de la Pez area,is the oldest phase mentioned in publications on the surrounding areas (Clin,1959,Wennekers,1968). However,as the mainphase is supposed to be ubiquitous and more or less contemporaneous throughout the Pyrenees,and on the assumption that our correlation of the second phase in unit I with the mainphase is correct (see next section),correlation of Fp with the pre-mainphase of other authors,mainly of the Leiden school,does not seem improbable.During this phase folds of varying trends and dimensions were produced,including NE-SW trending structures in the Upper Paleozoic (Devonian and Carboniferous),e.g. those observed in the Baliera area (Mey,1967) and in the Posets area (this report);and probably also E-W striking metamorphic structures like the Aston and Hospitalet massifs in the eastern central Pyrenees (Zwart,1963).
Large E-W trending pre-mainphase structures have been described by Hartevelt (1970) in the Seo de Urgel area.A slaty cleavage,invariably parallel to the bedding and predating the mainphase deformation,is present in all pre-Hercynian pelitic rocks occurring in the latter area.Hartevelt suggest that this cleavage may be interpreted as a "concentric cleavage" related to the generation of the large scale structures during the pre-mainphase.A similar origin may be proposed for the pre-mainphase foliation in the Cinqueta de la Pez unit:during a first stage of gentle folding,trending approximately parallel to the subsequent mainphase folding (for the mainphase fold axes are horizontal or show but gentle plunges) a "concentric cleavage",Sp,was produced.Renewed compression during the mainphase probably accentuated this fold to form the Fredançon-Aygues Tortes anticline.

The second or mainphase deformation (F1)
The second phase generated a foliation,which in thin sections nearly always is revealed to be associated as a crenulation of Sp.The intensity of the micro-folding,and so the intensity of the crenulation foliation

appear to be dependent on the the lithological composition of the rock and the situation within the profile of the mesoscopic folds developed during this phase.In the field it was found that,in the moderately S dipping limbs of F1 folds,S1 is generally well developed in pelitic layers, cutting across Sp,whereas in quartz-rich layers S1 is but poorly visible or not at all.In the vertical to slightly overturned limbs,S1 is always very well-developed. However, because of the subparallel position of Sp and S1 here,conclusive evidence that one is dealing with S1 has to be given by thin sections(see also the previous section).

The attitude of S1 is very constant throughout the area,as is demonstrated by the distinct concentration in a structural diagram (Fig.8).The strike does not deviate more than 15 degrees from the 120° direction,while the dips vary between 50 and 80 degrees S.Folds of mesoscopic dimensions,to which we already referred in the preceding,have been observed sporadically.Their relation to F1 is demonstrated by the parallellism of S1 and the axial planes.The style of the folding is tightly asymmetrical,with a short vertical to overturned north limb and a long south limb,dipping moderately S.Some examples of F1 folds are present in the upper valley of the Barranco de Agnes Cruces.Fig.9 presents an F1 antiform with a north limb dipping approximately $70^{\circ}$to the S (overturned),which is nearly parallel to the axial plane as displayed by S1.The south limb dips approximately 40^{0} S.

In the steep walls east of the Barranco de Agnes Cruces and north of the Barranco de Gistain asymmetrical folds may be observed with rather flatlying south limbs and almost vertical north limbs (Fig.10).

At 2000 m. in the Cinqueta de la Pez valley part of an antiform fold was found in a conglomerate,with an axial plane dipping about 55° S,as displayed by the intense cleavage in the matrix and the attitudes of the long axes of the flattened components.The subvertical north limb and the moderately dipping south limb suggest a tight asymmetrical fold similar to the one shown in Fig.9.

Folds of mesoscopic dimensions frequently occur in the steep inaccessible walls east and west of the rio Cinqueta de la Pez.Seen from a distance these folds also seem to have moderately dipping south limbs and slightly overturned to vertical north limbs,making but a small angle with the general attitude of S1.

According to Clin(1959) the large"Anticlinal de Fredançon-Aygues Tortes, which has already been mentioned in the preceding,has an axial plane pa-

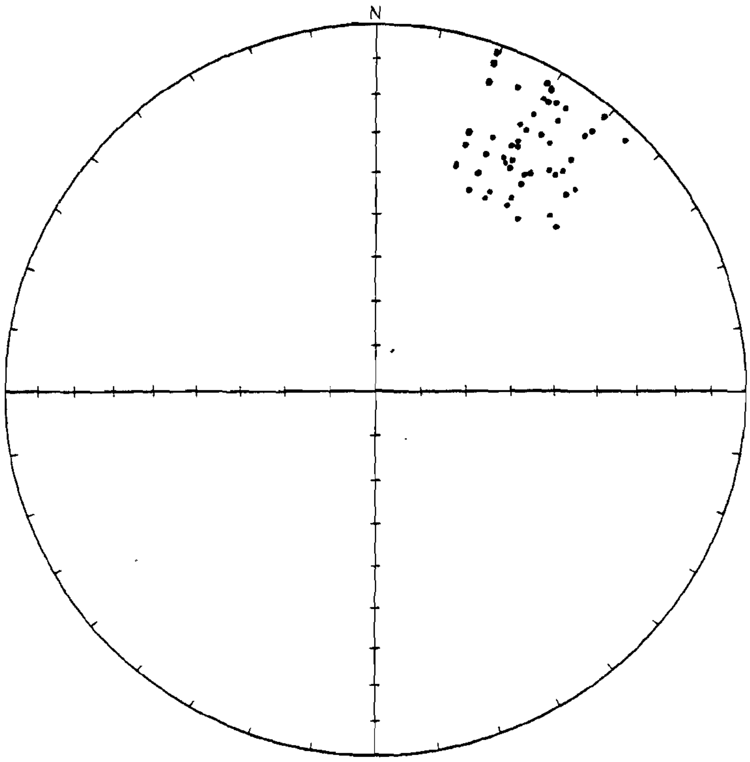


Fig.8.Distribution of S1,Cinqueta de la Pez unit(Schmidt's projection,lower hemisphere).

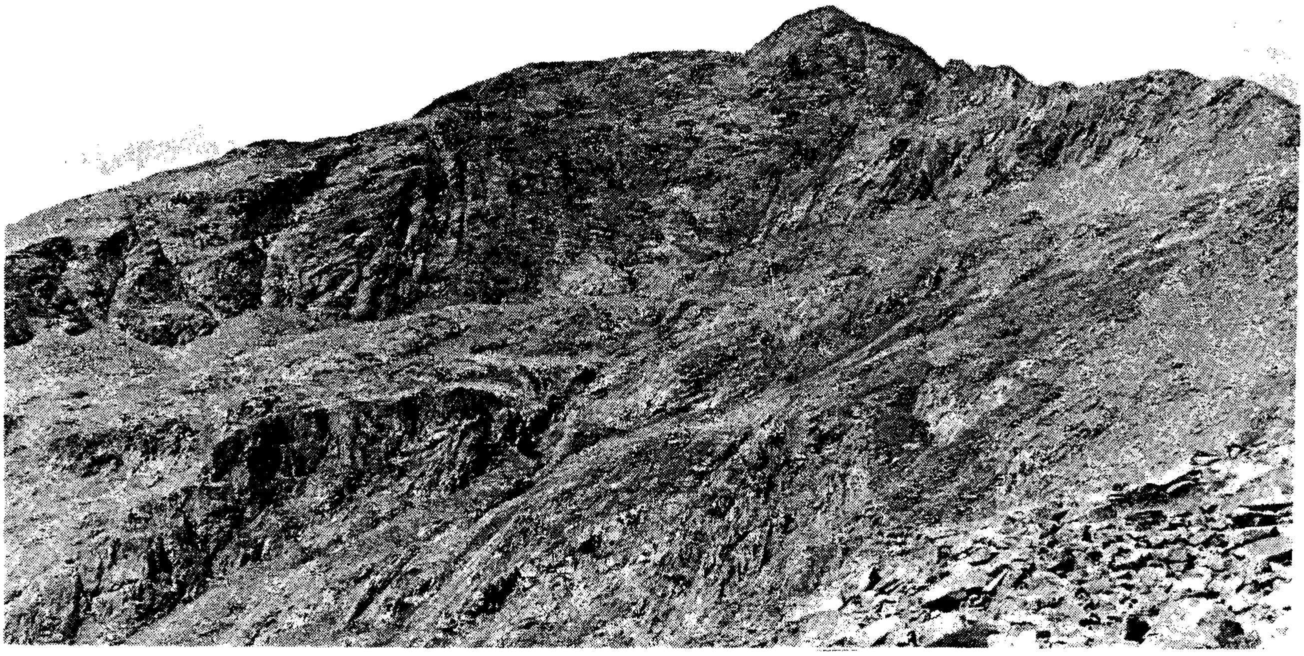


Fig.9.Hinge of a nearlv isoclinal mainphase fold in the upper Agnes Cruces vallev(seen from the east).The mainphase foliation dips steeply to the S and is weel visible in the right part of the photo.Slightlv dipping cleavage in the upper left hand part of the photo represent Sp and/or So.

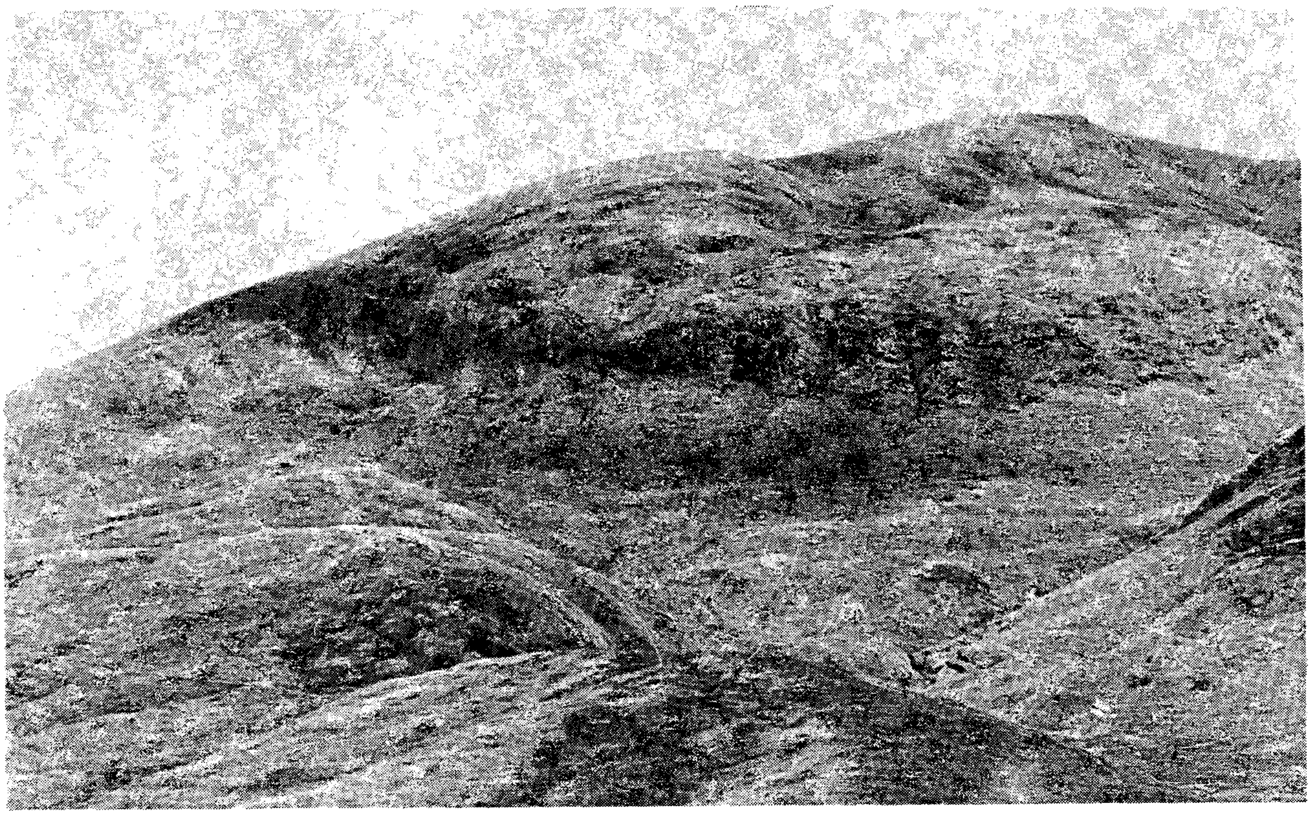


Fig.10.Asymmetrical mainphase folds,seen from the south-east. in the upper part of the Agnes Cruces vallev.North limbs are almost vertical,while south limbs present gentle dips.

rallel to S1 and a vergence to the north.The north limb,situated on the French side of the frontier,shows dips varying from steeply N to vertical and occasionally overturned.The foliation is said to be parallel or subparallel to the bedding.Although we are of different opinion concerning the dip of the south limb (Clin mentions dips of 70-80^{o} S,presumably confounding S1 and So or Sp) we agree with the general picture of an asymmetrical anticline.The similarity of this large structure to the mesoscopic folds described above,as well as the attitude of the axial plane,which in both cases is parallel to S1,points to a contemporaneous origin,related to the same deformation phase.
The occurrence of rotated porphyroblasts (see also section on micro-structures and metamorphism) indicates that S1 was not only a plane of flattening,but also a plane of shear.This is moreover confirmed by the presence of asymmetrical folds as described above.

F1 in the Cinqueta de la Pez unit is correlated with the main deformation phase elsewhere on the following grounds:
1.The attitude of S1 is identical with the axial plane cleavage or foliation accompanying mainphase folds in the Lys-Caillouas area (Wennekers,1968).
2.In the northern part of the Posets-Peña Blanca unit the attitude of the axial plane cleavage related to mainphase folds more or less parallels S1 in the area under discussion.

The suggestion put forward by Zwart (1978,pers. comm.)that our S1 should be correlated to his F2 (N-S refolding)and consequently our Sp to the Hercynian mainphase (see Fig.5)does not seem very acceptable because of the distinct difference in trend between the N-S direction of his F2 and the WNW-ESE direction of the F1 folds in the Cinqueta de la Pez unit and the"Anticlinal de Fredançon-Aygues Tortes" as a whole,which does conform so very well to the general trend of the Hercynian mainphase.However,to be more certain about the correlation of F1 in the Cinqueta de la Pez unit,very detailed microstructural investigations are required.

As has already been mentioned in the introduction,in the Hercynian Pyrenees two major structural levels can be distinguished,generally called infrastructure and suprastructure.In the non- or low grade metamorphic rocks of the suprastructure,the mainphase deformation generated symmetrical folds with a vertical axial plane cleavage (at least in the central part of the axial zone),indicating that the main stress was compressive and horizontal(Zwart,1963,Oele,1966).In the Cinqueta region the upright folding

of the suprastructure is nicely demonstrated in the northern part of the Posets area.
In the regional metamorphic rocks of the infrastructure recumbent asymmetricacal folds,rotated porphyroblasts and a flatlying foliation which is generally parallel to the bedding,suggest shear to have been a prominent mechanism of deformation during the mainphase (Zwart,1963,Oele,1966).
In the transition zone between the infrastructure and the suprastructure the flatlying attitude of the mainphase foliation changes gradually into a steeply dipping position.According to Zwart(1963) the thickness of the transition zone may be connected with the depth of the metamorphic front. in the Garonne dome this is demonstrated by a very high position of the metamorphic front in combination with a thin transition zone,which is restricted here to the incompetent carbonaceous slates of the Gotlandian (Fig.11a). Fig.11b demonstrates the gradual transition from flatlying to steep attitudes of the foliation in the Hospitalet massif.Here the transition zone is much thicker,which is probably due to the lower position of the metamorphic front.
The different behaviour of rocks in the suprastructure and in the infrastructure would be related to temperature (Zwart,1963,Oele,1966).The former states:"As far as the cause for the different behaviour of rocks in supra- and infrastructure is concerned,it seems evident that temperature plays a dominantrole,since the change in structural behaviour corresponds to a change in metamorphic grade.With higher temperatures the plasticity of the rock increases,friction decreases and then laminar flow apparently is favoured in preference to simple flattening which occurs during cleavage folding".
This picture does not seem to fit in the Cinqueta de la Pez unit,as here rocks metamorphosed under amphibolite facies conditions (see section on micro-strctures and metamorphism)would yet structurally belong to the transition zone because of the moderate to steep attitude of the mainphase foliation and the character of the deformation,which comprises both flattening and shear.

The third deformation phase (F2)
This phase was only observed in thin sections,where it is made visible by rotation of porphyroblasts (see section on micro-structures and metamorphism):Metamorphic minerals,among which andalusite and staurolite,which had been formed during the mainphase defromation,have rotated about approximately N-S directed axes lying in the S1 plane.

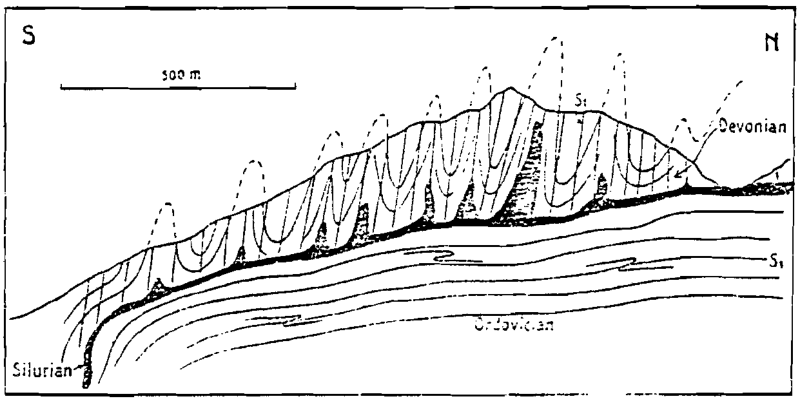


Fig.11a(from Zwart,1963).Sectionin Bosost area,showing infrastructure and suprastructure.The transition zone is situated in the Silurian black slates.

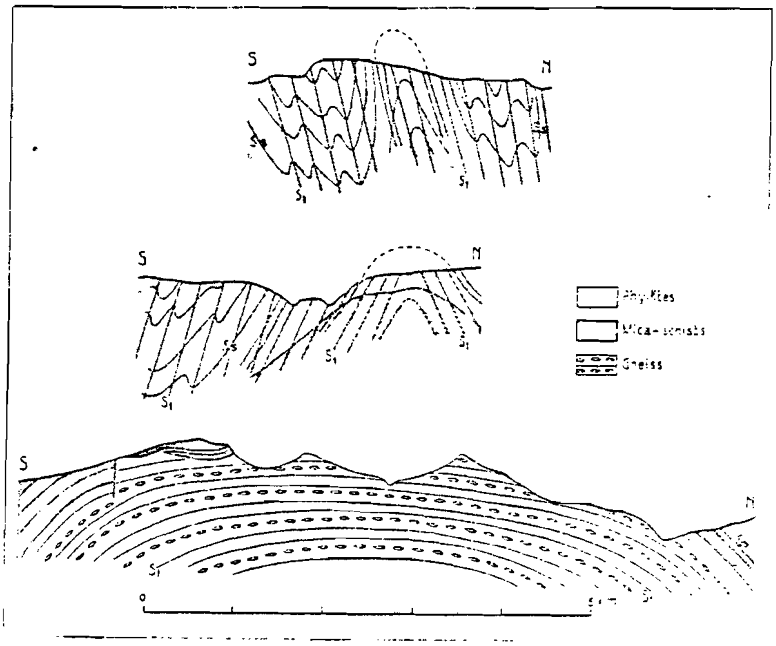


Fig.11b(from Zwart,1963).Three sections through the Hospitalet massif and anticline,showing a transition from flatlying attitudes of S1 in the infrastructure to steep positions in the suprastructure,which is more gradual than in the Bosost area.

We correlate this phase (F2) with the second phase of N-S refolding defined by other authors in the infrastructure in the eastern central Pyrenees and in the Lys-Caillouas area.In the Bosost area (Zwart,1962,1963)and in the Vall Ferrera area (Oele,1966) this phase produced either recumbent small scale folds accompanied by a new foliation,or reactivation of the mainphase foliation by shear along it.
Neither in the Lys-Caillouas area (Wennekers,1968)nor in the Cinqueta de la Pez area have folds with N-S axes been observed,but only shear movement along S1 that caused the rotation of the porphyroblasts.Zwart and Oele established the general sense of rotation to be anticlockwise looking southward.
The limited number of observations in the Cinqueta de la Pez area,however, does not justify the assertion that rotation took place in the same sense here.

Deformations of minor importance

In some outcrops in the southern part of the Cinqueta de la Pez area,a steeply plunging ,rather widely spaced,lineation occurs on S1.In thin sections vertical planes of kinking of S1and corresponding to these lineations, are present.Since the S1 planes have been deformed,these structures must postdate F1.
Some large andalusite crystals,which are postkinematic with respect to F2 as they enclose staurolite rotated about N-S axes,have been bent about axes also having an approximate N-S direction.This deformation therefore must postdate F2.
Finally,in some outcrops a conjugate set of kink bands was found,which may belong to a last phase connected with uplift of the axial zone at the end of the Hercynian orogeny in the Pyrenees.

Microstructures and metamorphism in the Cinqueta de la Pez unit

Metamorphism has produced rock types with different mineral assemblages in the Cinqueta de la Pez unit.We roughly distinguish two main zones (see map):a.A southern zone in which occur successively,from the south to the north phyllites,sericite schists and muscovite-biotite-schists.
b.A northern zone,where biotite-muscovite-schists,containing andalusite, staurolite,cordierite and biotite porphyroblasts crop out.

The time-relationship between mineral growth and the various deformation periods was studied in order to establish the geologic history.
Foliated rocks may be affected by deformation in three different ways (Zwart,1962):
1.The foliation is a plane of shear usually combined with flattening.

2.Flattening takes place parallel to the flattening.
3.The foliation is microfolded due to flattening perpendicular to the foliation.

In case 1 and 3 a new (crenulation)foliation may develope,whereas in case 2 only the existent foliation is intensified.
Crystallization of porphyroblasts may be prekinematic,synkinematic and postkinematic with respect to a certain deformation.If mineral growth takes place in a foliated rock this time-relationship may be established by comparing the foliation outside the porphyroblasts (Se) and the relict foliation enclosed in the porphyroblasts (Si).Nine basic diagnostic configurations occur,which shown in Fig.12.These nine possible situations are obtained by combining the three different types of deformation with the three possible time-relationships with crystal growth.
In the thin sections we studied,Si always appears to be a relict Sp (on the assumption that Sp is the oldest foliation that was formed).As generally two foliations (Sp and S1) occur outside the porphyroblasts in the matrix, we will refer to them as Spe and S1e.

As has already been mentioned,during the first deformation period (Fp) small muscovite and biotite flakes were formed,probably under greenschist facies conditions (Winkler,1967)to produce together with form-oriented quartz grains the first phase foliation (Sp).Only in the south-western part of the Cinqueta de la Pez unit no biotite was formed.No growth of Staurolite, andalusite or cordierite took place before or during Fp.This may be concluded from the fact that no relations between these minerals and Sp,as presented in Fig.12 nrs. 4 and 5 were found to occur.
During the first interkinematic period (post Fp)blastesis of biotite,staurolite and andalusite started.Growth of these minerals during a period of nondeformation is attested by a straight Si.Subsequent shear and flattening by F1 caused rotation of the porphyroblasts and generated S1 in the matrix,which resulted in an Si-Se relationship presented in Fig.12 nr.1.Examples are given by Figs.13, 14 and 15.
During F1 growth of biotite,staurolite and andalusite continued.This is demonstrated by an s-shaped Si at the edge of the crystals,indicating rotation during a late stage of growth(situation intermediate between Fig.12 nr.1 and 2).Examples are given by Figs. 16 and 17.
Some staurolites were found to show a slightly folded Si at the edge of the crystals,which also points to pre- as well as synkinematic growth(Fig.12 nr. 8).
Staurolite and andalusite continued crystallizing after S1,which is shown by helicitic folds in Si,that have the same intensity as the micro-folds

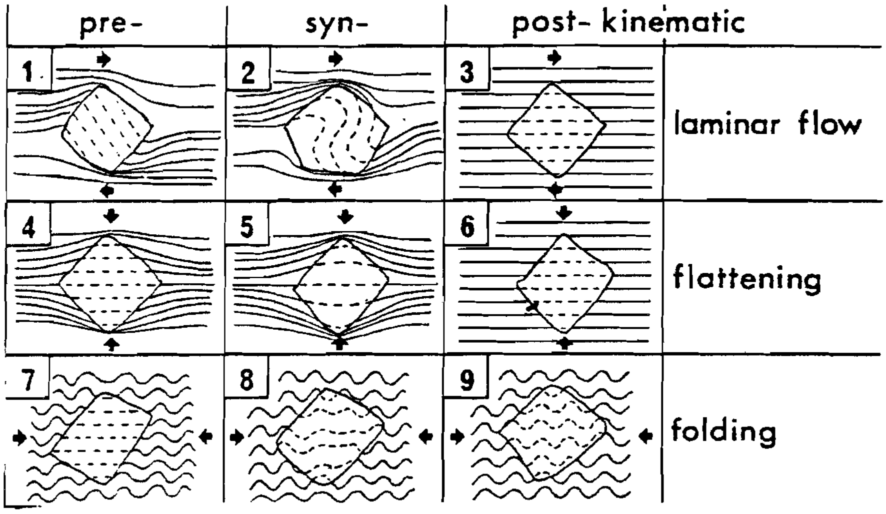


Fig.12(from Zwart,1963).Nine diagnostic forms of porphyroblasts with respect to time of recrystallization and deformation.

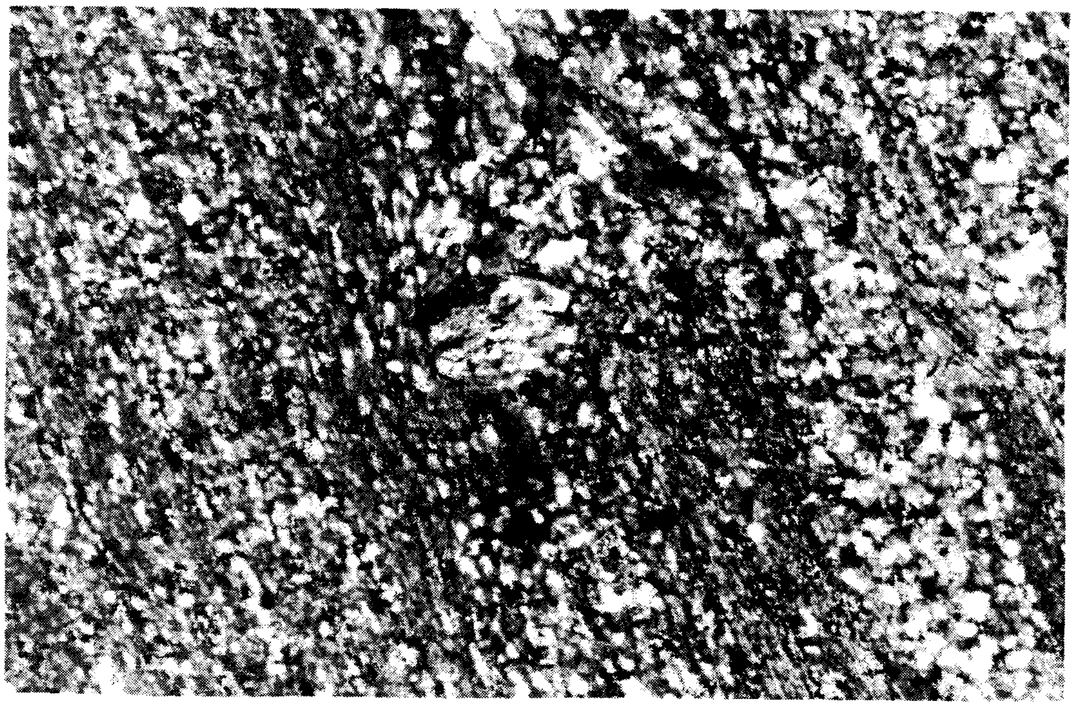


Fig.13.Small andalusite with straight Si rotated during F1.

Fig.14.Twinned staurolite with straight Si,rotated during F1.

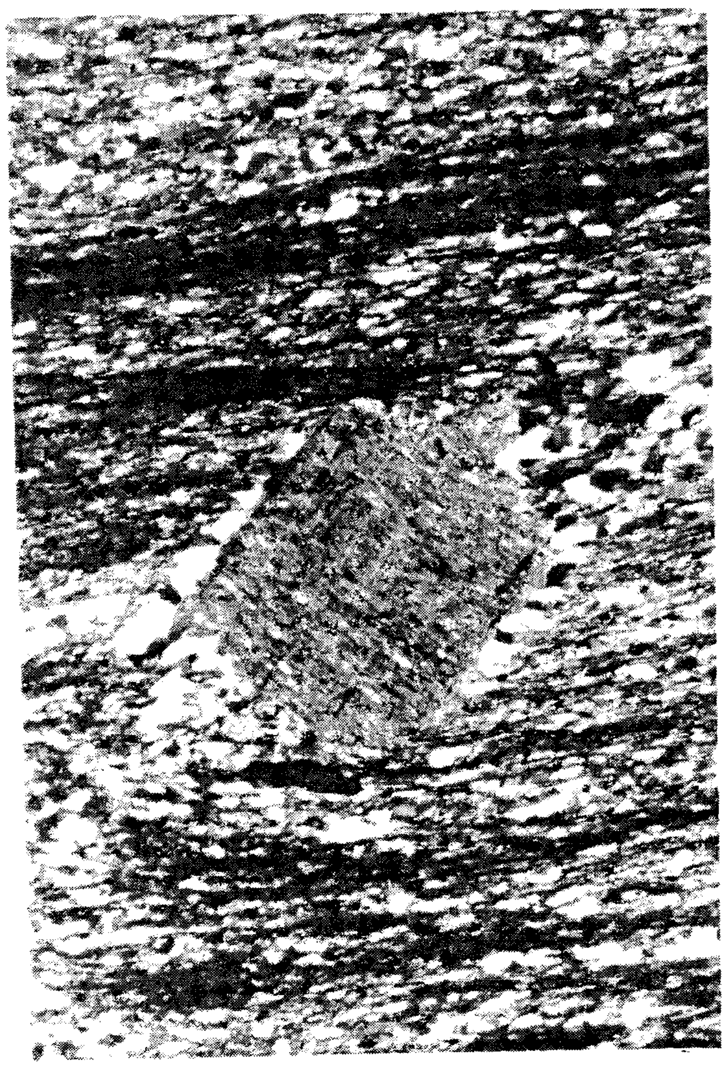


Fig.15.Biotite with straight Si and small pressure fringe,rotated during F1.

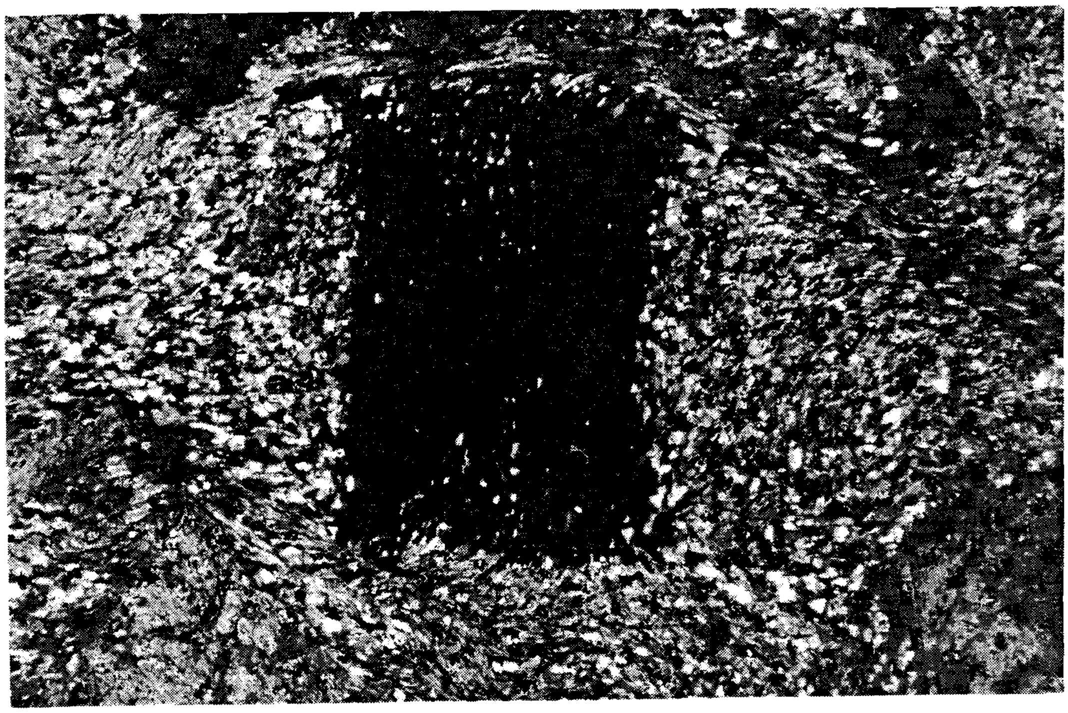


Fig.16.Andalusite with s-shaped Si,indicating crystal growth partly contemporaneous with F1.

Fig.17.Biotite with s-shaped Si,formed during F1.

Fig.18.Staurolite with helicitic Si,indicating growth post-dating F1,which did not generate a foliation,but only micro-folds.

displayed by Spe (Fig.12 nr.9).Examples are presented by Fig.18 and 19. Biotite flakes were frequently found to grow across the deformed matrix indicating that they crystallized later than F1.

The third deformation phase (F2) gave rise to rotation about axes,directed N-S.This is shown in sections cut along strike perpendicular to S1. Staurolite,andalusite and biotite with a planar Si have been rotated with respect to Se,producing the the relationship presented in Fig.12 nr.1.Fig. 20 gives an example of this rotation.Since Si appears to be almost exclusively straight in these sections,crystal growth must have stopped before the onset of F2.

Large andalusite porphyroblasts,up to the size of an entire slide have formed postkinematically with respect to F2.This can be concluded from the presence of enclosed staurolite crystals,which had been rotated during F2. The smaller size and the poikiloblastic habit of the andalusites associated with F1 makes it easy to distinguish them from the large crystals produced after F2.The latter are not sharply bounded and they seem to have overgrown the matrix parallel to the bedding,following the mica-rich layers.

Cordierite,aften strongly altered,was encountered sporadically.The relationships between Si and Se suggest crystallization pre-,syn- and postkinematic with repect to F1.A nice example of postkinematic growth is shown in Fig.21.

Although we are well aware that insufficient sampling may be responsible for an incomplete picture,the following conclusions concerning the metamorphic history of the Cinqueta de la Pez unit seem to be justified:

During the first phase of deformation (Fp) metamorphic conditions,not exceeding those of the greenschist facies gave rise to the recrystallization of muscovite and biotite,defining Sp,in the main part of this unit.

During a later period,which straddled F1,staurolite,andalusite ,biotite and cordierite were formed.Metamorphic conditions were comparable to those in the Bosost area;the Staurolite-andalusite-cordierite subfacies of the amphibolite facies.This subfacies is related to a steep geothermal gradient,which in the case of the Cinqueta de la Pez unit may be connected with the vicinity of the Lys-Caillouas massif in the north-east (Wennekers,1968).

The influence of this metamorphism decreased from north to south,which is demonstrated by the disappearance of staurolite,andalusite and cordierite. Biotite porphyroblasts occur beyond the boundary of the staurolite-andalusite-cordierite zone but for lack of data a biotite isograd could not be drawn on the map.

Temperature probably dropped before the onset of F2,as no growth of staurolite,andalusite,cordierite and biotite took place during this phase.

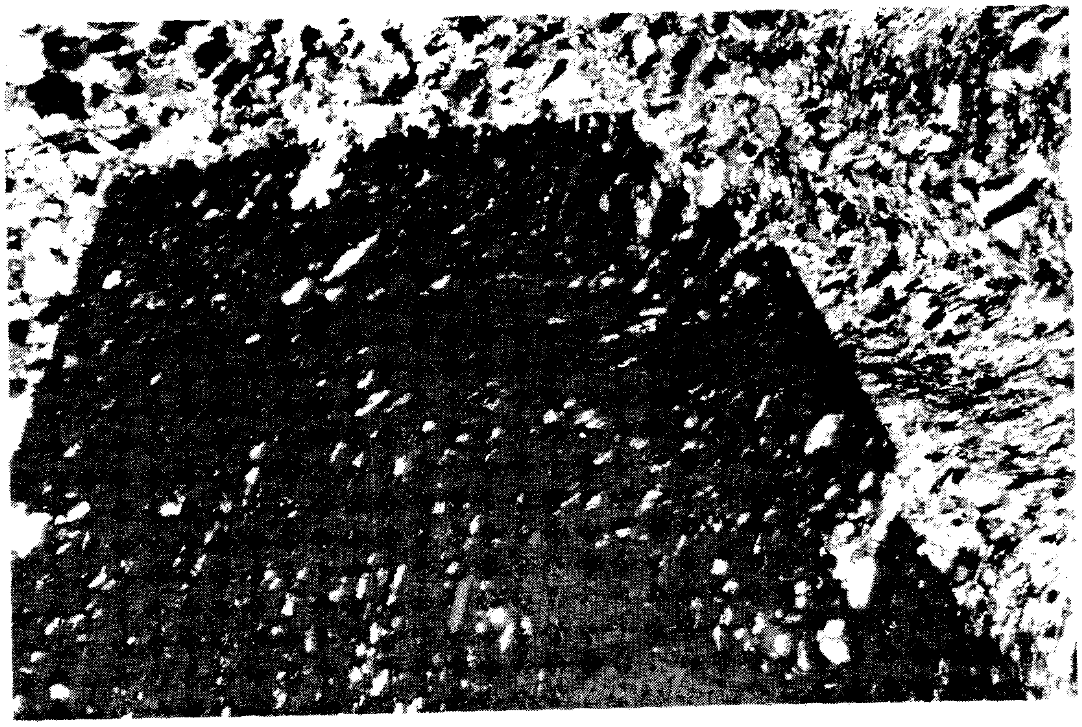


Fig.19.Detail of Fig.18.

Fig.20.Staurolite with straight Si,rotated during

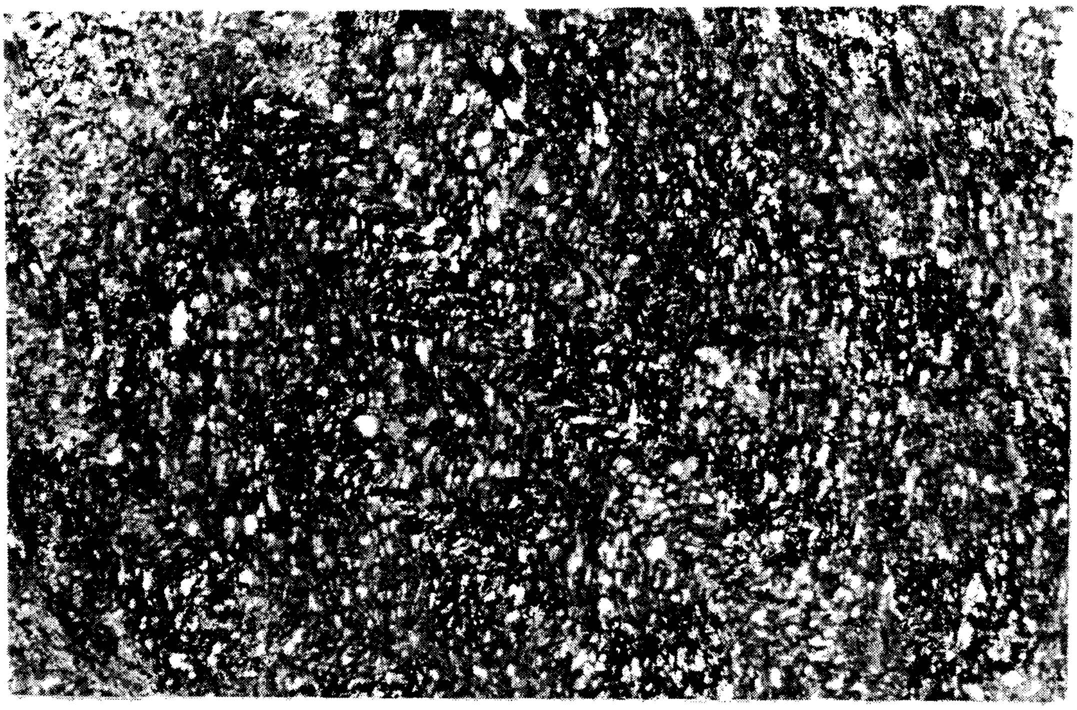


Fig.21.Cordierite with mocro-folded Si,formed after F1.

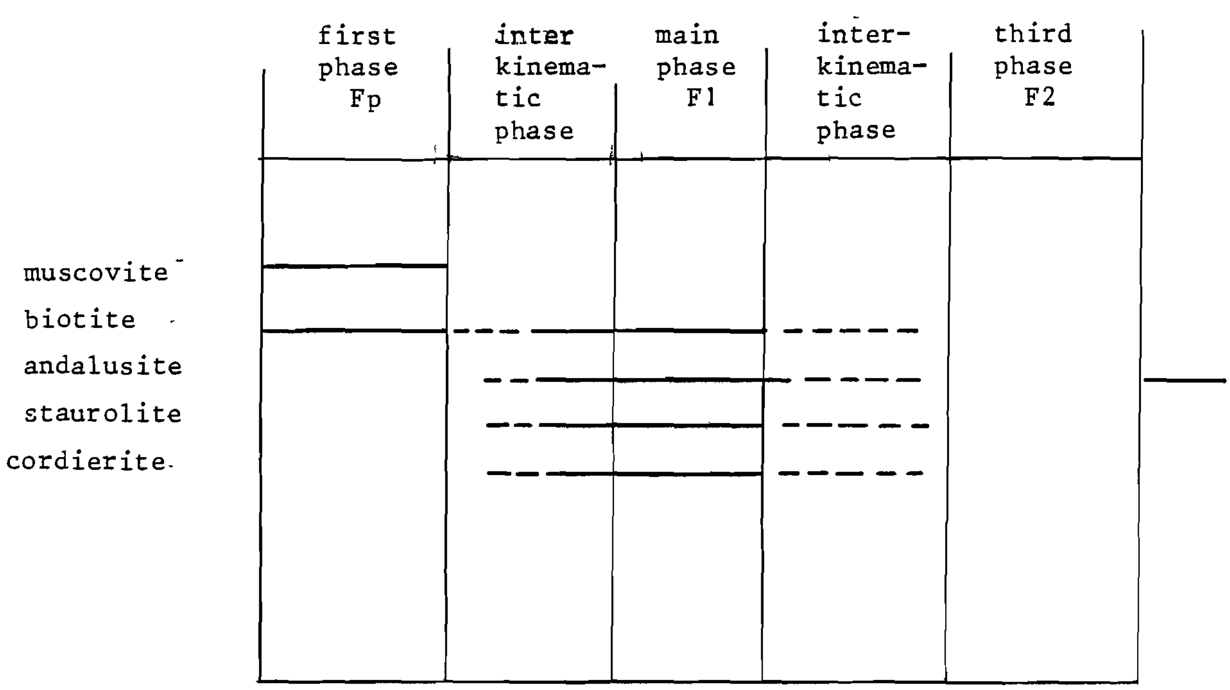


Fig.22.Time-relationship between crystal growth and deforformation in the Cinqueta de la Pez area.

The large andalusite crystals which postdate F2 may be related to the intrusion of the Lys Caillouas granodiorite into the sillimanite-cordierite bearing schists and migmatites of the Lys-Caillouas massif during a later stage.
The time-relationship between metamorphism and deformation is summarised in Fig.22.

The Posets-Peña Blanca unit

Introduction

The Posets-Peña Blanca unit is bounded in the north by the Gistain-Esera fault,which separates the regional metamorphic rocks of the Cinqueta de la Pez unit with structures typical of the"transition zone",from the low grade metamorphic Paleozoic rocks.The latter,partly influenced by late Hercynian thermal metamorphism,belong to the suprastructure.In the south the Solana fault separates this unit from the Barbarisa-Sein unit (see structural sketch map).
Three major phases of deformation could be established:A first phase (Fp) which produced NE-SW trending large scale folds without a cleavage.A second phase,representing the Hercynian mainphase (F1) caused large WNW-ESE trending folds,accompanied by a steep axial plane cleavage.
A third phase (F2),correlated with the late Hercynian F4 of Boschma (1962), Zwart (1963) and Oele (1966),originated small folds in the northern part of the Posets-Peña Blanca unit,accompanied by an axial plane crenulation cleavage trending E-W. Generally, phenomena related to F2 are only found in the fissile carbonaceous slates of the Madera Fm.(Gotlandian) and in the slates of the Viladós Fm.(Cambro-Ordovician).Before this last phase,intrusion of the Perramó granodiorite (east of the mapped area) and the Rechanzadas-Descubridores granodiorite in the south took place.

Regional description

The Posets-Peña Blanca unit presents itself in its eastern part (referred to as Posets area) as a sheaf of several large folds,showing carbonaceous slates of the Madera Fm. in the anticlinal cores,while the shape of the synclines is magnificently displayed by the limestones of the Puyaresto and Ardaña Fms.(Fig.23).
The northern part of the Posets area shows tight E-W trending folds with a vertical axial plane,whereas in the southern part an intricate pattern of

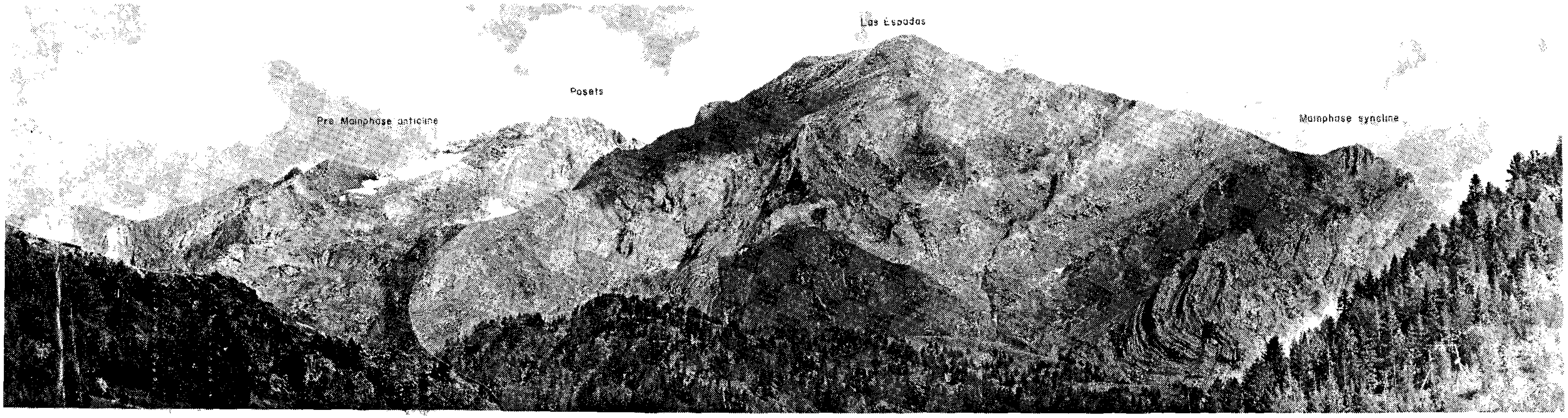


Fig.23.Panoramic view of the Posets massif,seen from the west. Large syncline in right hand part of the photo represents an F1 fold,whereas in the left central part a NE-SW striking Fp fold may be observed.

interfering NE-SW and WNW-ESE trending folds occurs.
The central and western part of the Posets-Peña Blanca unit is wholly occupied by the black slates of the Madera Fm. and slates and quartzites of the Viladós Fm.Because of the monotonous,mainly pelitic character of these rocks,mainphase and third phase cleavage are the only macroscopically visible structures.Only on the Pena Blañca,situated on the Spanish-French border,a synclinal remnant of Lower Devonian limestones (Puyaresto and Ardaña Fm.)is present.

Unit II forms part of a large structure with a trend of 110^{o},which extends eastward to the area south of the Maladeta granodiorite,where it may even be traced across the rio Noguera Ribagorzana;its prolongation is represented by the mainphase folds of the Sierra Negra unit (Mey,1967,Wennekers,1968). In the west,beyond the frontier,unit II is prolonged by the so-called"synclinal de Moudaing et de l'Hospice de Rioumajou"(Clin,1959),showing a central zone of black carbonaceous slates bounded in the north and the south by slates and quartzites of Cambro-Ordovician age.

Deformational history

The first deformation phase (Fp)
The existence of a deformation phase prior the the mainphase is revealed by NE-SW trending folds west of the Pico Posets,near the upper part of the Barranco de Puyaresto (Fig.23).The mainphase cleavage (S1),which strikes 300^{0} and has a vertical attitude in this part of the Posets area,cuts across these folds.Since the mainphase cleavage has not been folded,it is clear that these NE-SW folds predate the mainphase (F1).No cleavage was found to accompany the pre-mainphase folds.

In areas of superimposed folding like the Posets area,caution is required in establishing the original trend of the first folds directly from the interference pattern.Hence it is questionable,whether the NE-SW direction mentioned above really represents the original pre-mainphase trend or just a random result of interference.We have reasoned as follows (Fig.24):
In a certain zone west of the Posets,the NE-SW folds present steeply dipping to vertical limbs with parallel strikes ($240-250^{o}$).Intersection of So and the mainphase cleavage (attitude ca. 300-90) would produce steeply N and S plunging or vertical mainphase fold axes.Considering the fact that mainphase folds with horizontal or gently plunging axes are usual,it seems very improbable that folding of any importance could have happened about steeply plunging or vertical axes.So it is most likely that the NE-SW direction

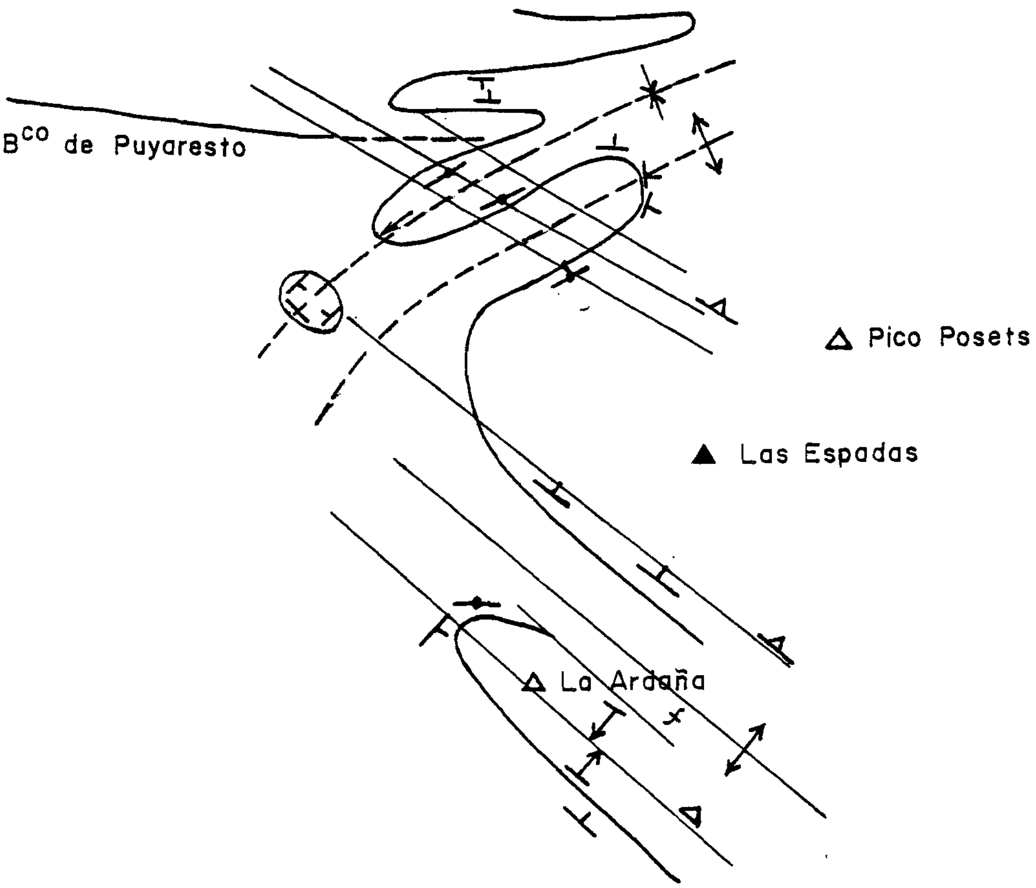


Fig.24.Structural sketch map of the southern Posets area.
—— S1 traces, ---- axial plane traces of Fp folds,
So attitudes, S1 attitudes,
trace of boundary between the Madera Fm. and the Puyaresto Fm.

represents the original direction of the pre-mainphase folds,while the steep to vertical dips represent the original attitude of the limbs of these folds.
Towards the north-east the original,probably flatlying,attitude of the Fp fold axes changes to present a moderate plunge to the NE as a result of folding during F1.The prolongation of Fp folds further to the north-east is shown by small dome-and-basin structures north of the Posets.
To the south-west a small saucer-like structure was formed by refolding of a pre-mainphase syncline.
In the slates of the Madera Fm. Fp structures could not be traced,as So has been completely obliterated in these rocks.South of Viladõs,however, on the ridge running north-east of the Barranco de la Solana,several NE plunging folds were found in limestones belonging to the Viladõs Fm., which may represent the western prolongation of the Fp folds in the Posets area.South of Las Espadas the presence of folding predating F1 can be inferred from NE plunging fold axes (see next section).
In the northern part of the Posets area (north-east of the Barranco de Puyaresto) no indications of pre-mainphase folding were found and an interference pattern,comparable to that of the Posets area,is absent.Whether this indicates that Fp structures do not occur in this area,or that their trend parallels the trend of F1,could not be decided.At first sight the strike of F1 and the mainphase folds,which have a direction varying here between 70^{o} and 90^{o},seem to be in favour of the latter possibility.But this argument does not hold,as these trends are not an original phenomenon,but caused by later deformation (see next section).

The first folding in the Posets area can be correlated with the approximately NE-SW trending folds without cleavage,predating the mainphase folding, observed in other areas,e.g. the Baliera area (Mey,1967),where it is called pre-cleavage folding.In the scheme given in the introduction,it is the first folding phase to occur.

The second or mainphase deformation (F1)

During this phase large folds of hectometre dimensions were formed,accompanied by small scale folds measured in centimetres to metres.The large folds, as has already been mentioned,are magnificently exposed on the western face of the Posets massif (Fig.23).A well developed axial plane cleavage (S1) is generally present.In the slates of the Viladõs Fm.,the Madera Fm. and the Sein Fm. this cleavage is a slaty cleavage,whereas in the limestones of the Puyaresto Fm. and the Ardaña Fm. it presents itself as a rather closely spaced fracture cleavage.A beautiful example of this axial plane cleavage combined with small scale folding was observed in a limestone-slate alternation of the Puyaresto Fm.,exposed in the upper part of the Agnes Cruces valley (Fig.25).On the higher slopes of the Posets massif,however, cleavage in the limestones is hardly visible anymore,probably due to thermal metamorphism.Capricious small scale folding in the limestones of the upper part of the Puyaresto Fm. and the massive limestones of the Ardaña Fm. suggest a high mobility at the time of the mainphase folding,possibly due to an already elevated temperature (see also section on F1,Barbarisa-Sein unit).

As has been mentioned in the preceding,the F1 folds in the northern part of the Posets area have horizontal fold axes with a 70-90^{o} trend (Fig.26). This direction differs from the general 290-320^{o} trend characteristic for the rest of the Posets Peña Blanca unit.According to Wennekers (1968), a pushing aside,due to the intrusion of the Perramó granodiorite which is situated directly east of the Posets massif,was responsible for the deviating directions in the northern part of the Posets area,

The central part of the Posets area is occupied by a large F1 syncline, in the core of which the Pico Posets and Las Espadas are situated. The outcrop pattern of this large scale structure is quite complicated due to the interference of Fp and F1 folding.Fold axes of small mainphase structures show great variation in attitude for the same reason.

The mainphase anticline and syncline and syncline running across La Ardaña constitute the southernmost structures of the Posets area.The axial plane of these folds strikes ca.310^{o} and dips 60^{o} to the N.No interference pattern is visible,but the attitude of the mainphase fold axes,which plunge moderately to the E,indicate that folding prior to the mainphase must have taken place.

The azimuth and plunge of these mainphase axes were obtained by intersecting the So measurements of the limbs of the folds.Because of the fact that in the case of superimposed folding"virtual" (false) axes may be obtained in this way,these attitudes were compared with the axes obtained by intersecting So measurements with the attitude of the axial plane,represented by the average S1.As the fold axes obtained in both ways coincided rather well,the conclusion,that the constructed fold axes are real F1 axes,is justified (Fig.27)

Disharmonic folding of the massive limestones of the Ardaña Fm with respect to the well bedded limestones and marly limestones of the Puyaresto Fm and

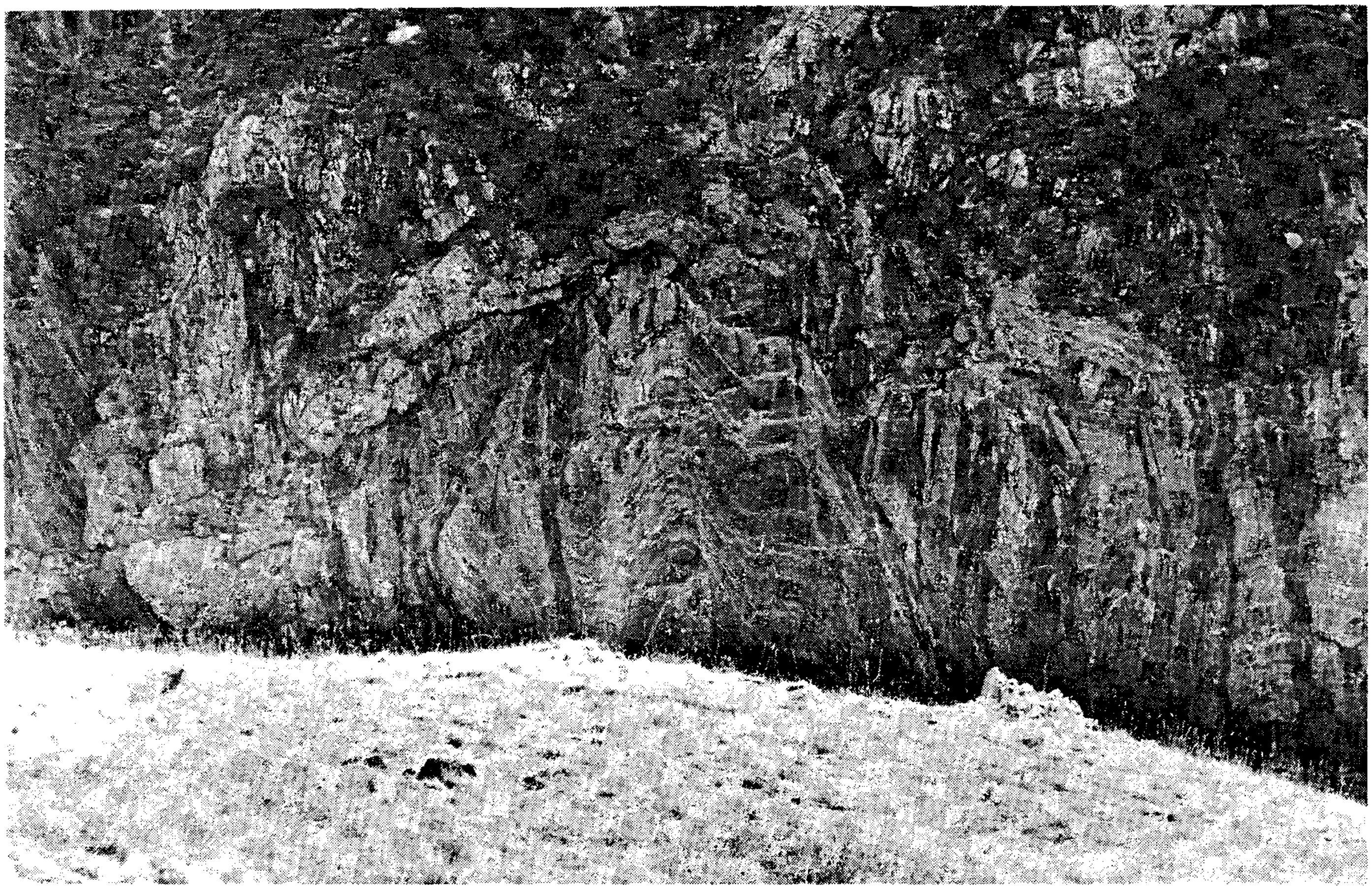


Fig.25.Small scale F1 folding with a vertical axial plane fracture cleavage in a slate-limestone alternation of the Puyaresto Fm.

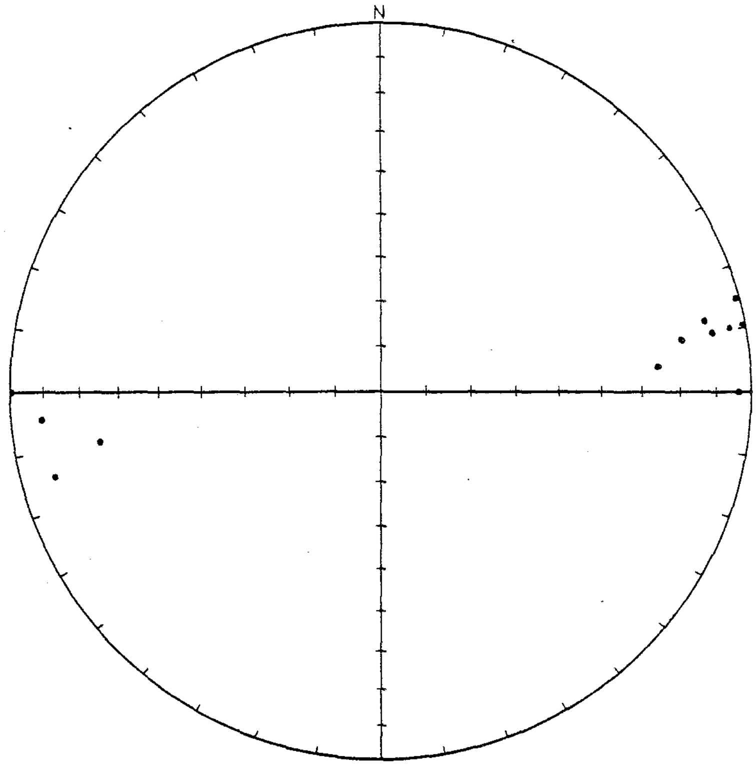


Fig.26.Attitudes of F1 fold axes in the northern part of the Posets area (Schmidt's projection,lower hemisphere).

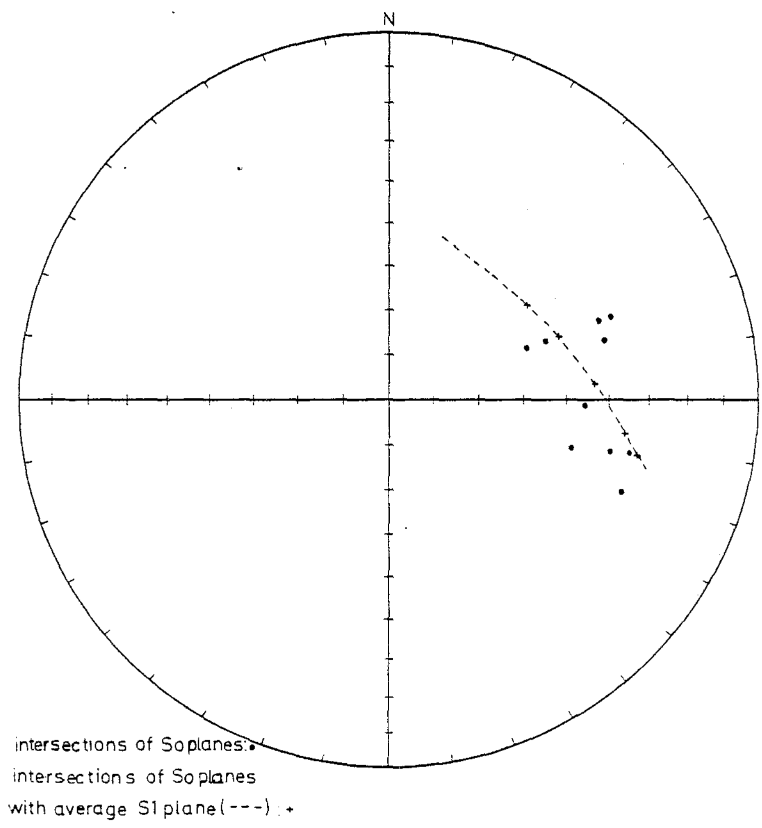


Fig.27.Construction of the F1 fold axes in the southern part of the Posets area.The positions obtained by intersecting the So attitudes of the limbs rather well coincide with the fold axes resulting from the intersection of these So planes with the average axial plane cleavage (Schmidt's projection,lower hemisphere).

Barbarisa Fm.,was occasionally observed.Beautiful examples are visible in the eastern slope of the Leschabre mountain (Fig.28) and in the large composite Posets-Espadas syncline.In the latter case the general profile is obviously determined by the massive Ardaña limestones (delineating the"false"Espadas syncline,see map),while the thin-bedded limestones of the Barbarisa Fm. show some additional tight to isoclinal mainphase folds in the core of the major structure (Fig.23).The incompetent slates of the Sein Fm. show a tendency to follow the style of folding of the Barbarisa Fm,as is displayed by the intercalated limestones near the top of this formation. The distribution of So measurements in the northern and southern part of the Posets area are presented in Figs. 29a and b.

In the broad zone west of the Posets massif,constituted by the slates and quartzites of the Viladós Fm. and the carbonaceous slates of the Madera Fm., S1 shows a very uniform strike,while the dip varies,from 70^{o}S to vertical in the north,to 30-40^{o} N in the southern part of the area (Fig.29c).Zones of equal dips trend parallel to the strike.A similar fanning is shown by the axial plane of F1 folds in the Posets massif,though here the strikes in the north probably have been influenced by the intrusion of the Perramó dome,causing the strike to turn to a 70-90^{o} position,as has been mentioned above.

The concomitant fanning of the cleavage,from approximately vertical to steeply S dipping in the north to ca. 35^{o}N in the south of the Posets-Peña Blanca unit,may be either an original tectonic feature or a phenomenon caused by regional warping of an originally vertical cleavage. According to Hoeppener (1955)tilting of an originally vertical cleavage may be effected by normal fault movement parallel to the cleavage(Schieferungsparallele Abschiebungsflächen)simultaneously producing kink bands, as a result of stretching in a horizontal direction.
Zandvliet (1960),whose sections across the Upper Salat and Pallaresa area show a fanning of the mainphase cleavage very much comparable to the sections across the Posets-Peña Blanca unit,relates this fanning,as well as the frequent occurrence of kink bands to a stretching in a N-S direction. According to his ideas this stretching was the result of a late Hercynian arching of the axial zone,which warped the originally vertical mainphase cleavage into N dipping positions.
Zwart (1963) describes this mechanism of warping as "an uplift of the central portion of the axial zone whereby the cleavage falls apart in analogy to the leavas of a book when the latter is being opened".
In the Posets-Peña Blanca area (and in the Cinqueta region in general),how-

Fig.28.Disharmonic folding on the eastern slopes of Leshabre, seen from the east.Tight folds in a slate-limestone alternation of the Puyaresto Fm.,displayed in the central and left hand lower part of the photo,strongly contrast with the more open,irregular,folding style of the massive limestones of the Ardaña Fm. in the right hand part of the photo.

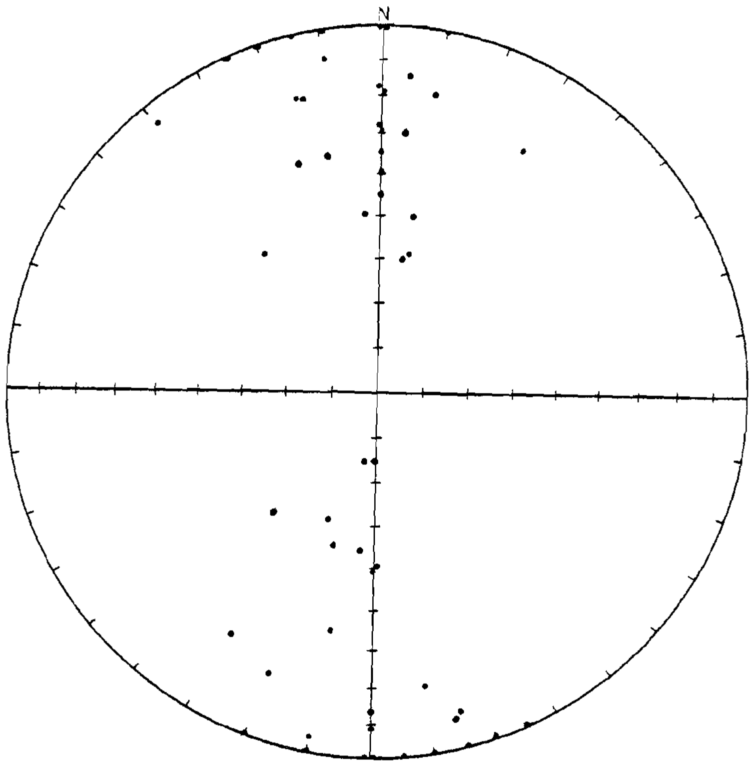


Fig.29a.Distribution of normal's to So in the northern part of the Posets area,indicating the general trend of F1(Schmidt's projection,lower hemisphere).

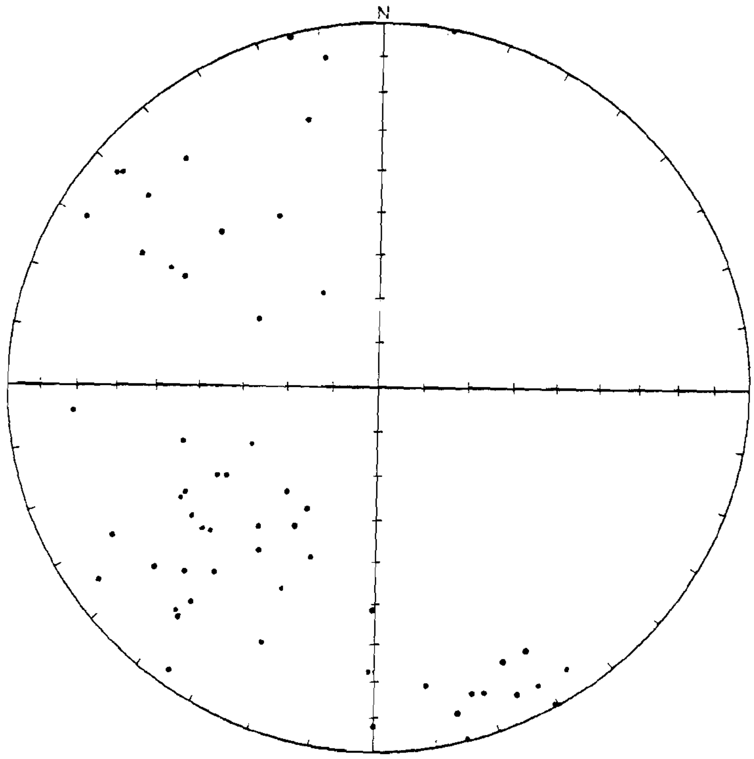


Fig.29b.Distribution of normals to So in the southern part of the Posets area.Concentrations in the NW and SE correspond with Fp folds,whereas the concentration in the SW corresponds with F1 folds.Note the distinct difference with the distribution of normals to So in the northern part of the Posets area (Fig.29a).

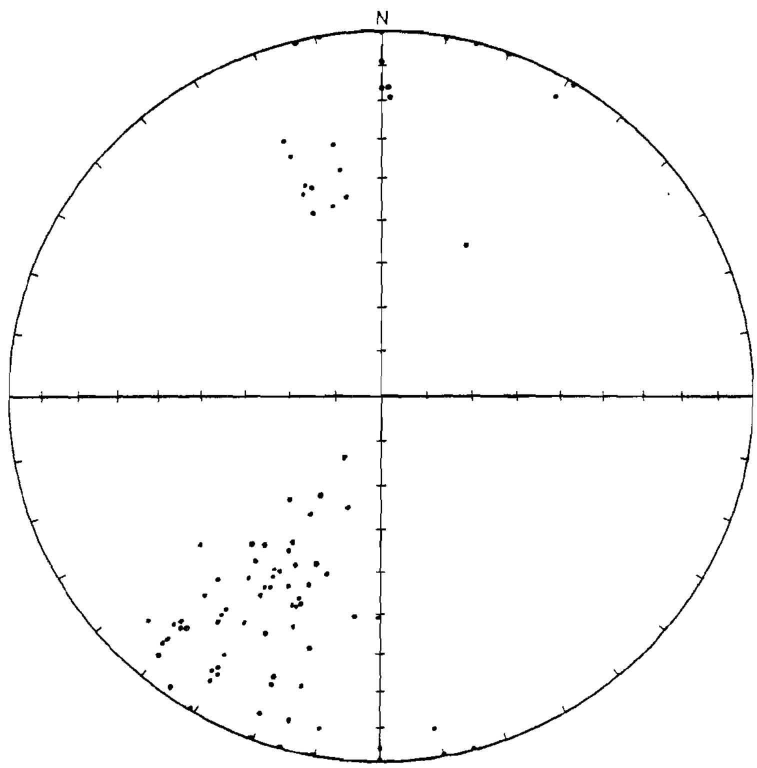


Fig.29c.Distribution of normals to S1 in the Posets-Peña Blanca unit.The N-S and NNW-SSE directions correspond with the attitudes of S1 planes in the northern part and the SSW concentration with S1 planes in the southern part (Schmidt's projection,lower hemisphere).

ever,several arguments exist against a late Hercynian warping of the mainphase cleavage and rather suggest this phenomenon to be an original tectonic feature.

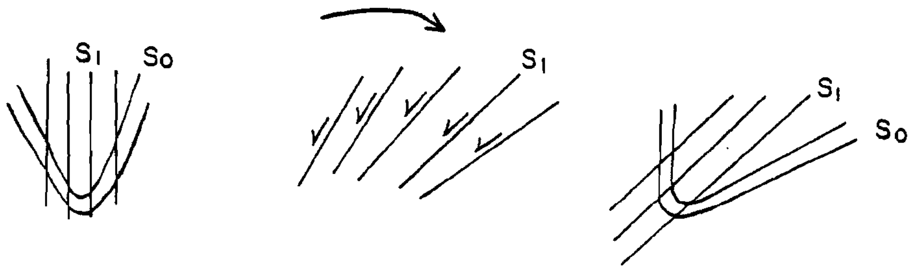
Firstly,in the Posets-Peña Blanca unit the cleavage (S1) shows a fanning over an angle of about 60° from approximately 80°S in the northern part of this unit to dips of about 35°N in the south.One would expect features related to subsequent warping,like normal faults parallel to the cleavage associated with kink bands to be very common. No kink bands have been found, though,in the Posets-Peña Blanca unit,nor do normal faults parallel to the cleavage occur.Only a few reverse faults dipping to the N are present in this area.

The only fault fitting into the model suggested by Hoeppener would be the Gistain-Esera fault,but as this fault is situated north of the zone were the fanning occurs it may be left out of consideration.

Secondly,consider the S vergent Ardaña anticline and syncline,which are almost isoclinal,and the isoclinal nearly recumbent folds of the Barbarisa-Sein unit in the south.It is hardly probable,that originally steep folds, which must have been symmetrical with respect to the S1 cleavage like the folds in the northern part of the Posets area and their eastern continuation in the Esera area,would retain such a symmetry after warping accompanied by slip parallel to the cleavage planes,as proposed by Hoeppener.On the contrary,folds originally symmetrical with respect to the cleavage would assume an asymmetrical shape,since slip parallel to the cleavage would cause one limb to rotate away from the axial plane cleavage,while the other limb would rotate towards it (Fig.30).Thus fanning of the mainphase as an original tectonic feature seems most likely to us,as far as this part of the axial zone of the Pyrenees is concerned.

The third deformation phase (F2)

This phase produced small scale folds of decimetre to metre dimensions, accompanied by an axial plane crenulation cleavage in the slates of the Viladós and Madera Fms.No traces of this phase were encountered in the limestones of the Puyaresto and Ardaña Fms of the Posets area.The small scale folds were only observed in the Cinqueta de la Pez valley.Here some dikes intruded parallel to the mainphase cleavage (S1),have been folded with axial planes parallel to S2,the third phase crenulation cleavage(Fig.31). South of this location the scale of the folding diminishes rapidly within some 100 metres.The third phase cleavage cleavage and associated crenulation of S1 persists,though,in slates all over this unit.Only in the vicinity of the Descubridores granodiorite crenulation is less well visible,



Original position | warping of the cleavage by "Schieferungs-parallele Abschiebung" | final position

Fig.30.Schematic representation of an originally symmetrical fold with a vertical axial plane,turned into an asymmetrical fold with and inclined axial plane by warping.

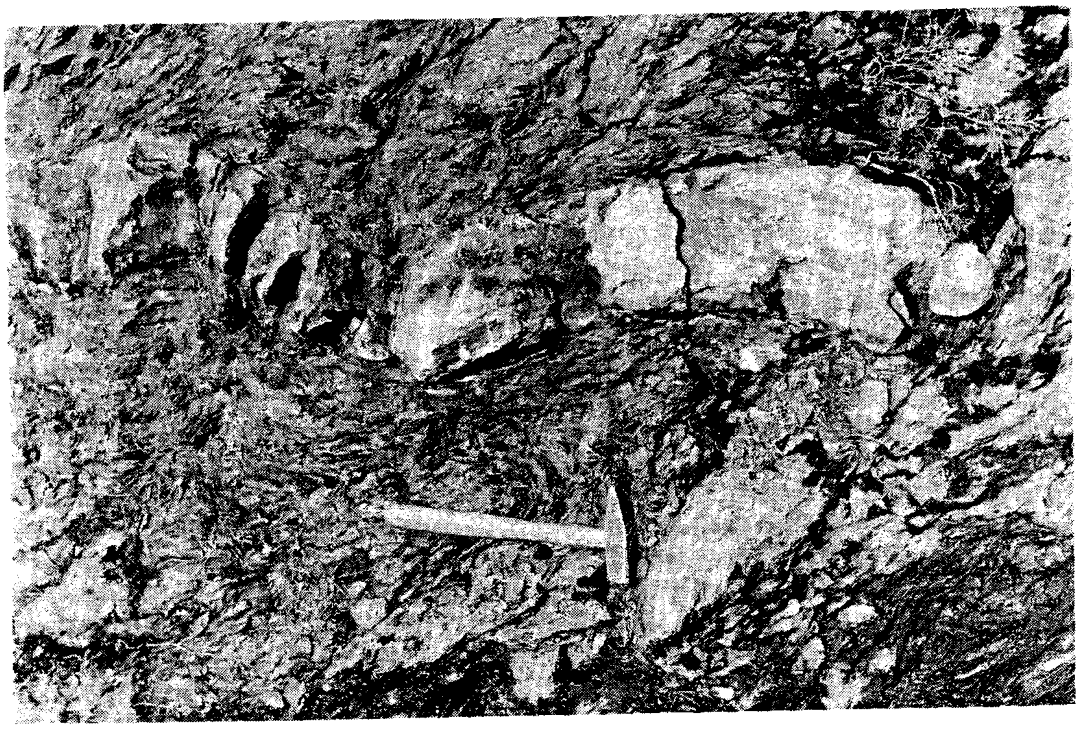


Fig.31.Dike intruded parallel to S1 and folded during F2.The axial plane of the fold is parallel to S2.

because of obliteration of S1 by thermal metamorphism.
The S2 planes show a very constant dip (60-80°N) and a strike which turns from an approximate E-W direction in the north to a WSW (240-250°) direction in the south of the Posets-Pena Blanca unit (Fig.32).
Chiastolite crystals formed by thermal metamorphism,due to the intrusion of the Perramó and Rechanzadas-Descubridores granodiorites,sometimes reveal a slightly s-shapes Si,which is rotated with respect to Se. The well-developed S2 bends around these crystals.From this we conclude that F3 postdates the intrusion,the beginning of this phase possibly being contemporaneous with the last stage of intrusion.

We correlated this phase with the late Hercynian F4 of the Leiden school on the following grounds:
1.The attitude of S2 is similar to the attitude of the F4 cleavage inthe Esera area (Wennekers,1968),and in the Sierra Negra area (Mey,1967).
2.The F3 cleavage in the Cinqueta region postdates the emplacement of the late Hercynian granodiorites,which is in accordance with observations concerning the time-relationship of the F4 cleavage and intrusion in the areas to the east (Zwart,1963,Mey,1967,Wennekers,1968).

No phase of N-S refolding or rotation like in the Cinqueta de la Pez unit (see F2 of this unit) was observed neither in the Posets-Peña Blanca unit nor in the Barbarisa-Sein unit.However,because of the correlation of the F2 deformation in the Cinqueta de la Pez unit with the second phase of N-S refolding and the F2 (E-W) refolding of the units II and III with the late Hercynian F4 of the scheme given by Zwart (1963) (see Fig.5),the E-W trending phase of units II and III is thought to postdate the N-S phase of unit I.

The Barbarisa-Sein unit

Introduction

This unit is bounded in the north by the Solana fault,along which the Posets-Peña Blanca unit has been thrust to the south (see structural sketch map).This WNW-ESE trending fault probably correlates with the Erices thrust in the Esera area (Wennekers,1968).West of the Monto Descubridores it probably extends to the north-west across the Spanish-French border,but becomes very hard to trace because of the lack of outcrops on the grassy slopes south of Tres Bogas.Its age could not be established with certainty,Wennekers,however,supposes it to be Alpine.
In the south and west the Barbarisa-Sein unit is bounded by the Sahun-Tres

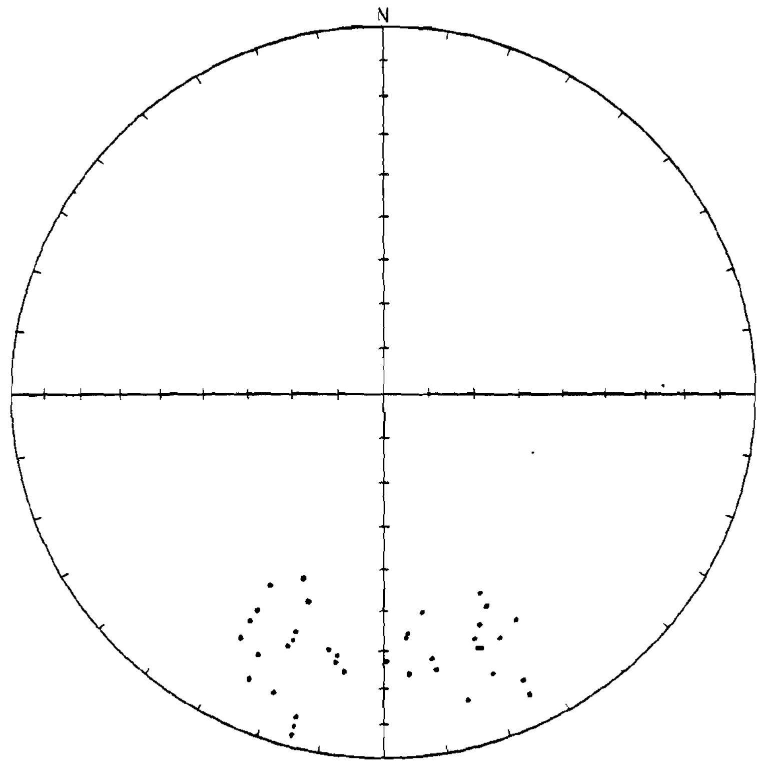


Fig.32.Distribution of normals to S2 in the Posets-Peña Blanca unit (Schmidt's projection,lower hemisphere).

Bogas thrust,a thrust of Alpine age,along which the Paleozoic rocks of main unit A have been overthrust southward upon the autochtonous Hercynian basement with its sedimentary cover of Permo-Triassic rock (main unit B).The Sahun-Tres Bogas thrust extends to the east into the Esera area (Eriste-Sahun thrust of Wennekers) and possibly even further in the Baliera area,where it may link up with the Castanesa and Basibé thrusts (Mey,1967).To the west,its continuation becomes uncertain because of the lack of exposures.A more detailed description and discussion will be given in the section on post-Hercynian tectonics.
The outliers of Lower Devonian limestones of the Puyaresto and Ardaña Fms, occurring on the Punta Suelza and the Bargasera,which overlie the sedimentary Permo-Triassic cover of the Cinqueta granodiorite,represent remnants of the western continuation of the Barbarisa-Sein overthrust mass.

At least three phases of deformation acted during the Hercynian orogeny in this part of the Cinqueta region.
The first phase produced very gentle folds,probably trending NE-SW without a cleavage and is to be correlated with the first phase (Fp) in the Posets-Peña Blanca unit.
During the mainphase (F1) large isoclinal,almost recumbent folds were formed,accompanied by a well developed axial plane cleavage (S1),which generally dips gently to the NE.The attitude of the fold axes is variable.
The third phase correlated with F2 in the Posets-Peña Blanca unit,originated a poorly developed N dipping fracture cleavage,which restricted to the south-eastern part of the Barbarisa-Sein unit.
Finally,a NE dipping fracture cleavage,also restricted to the south-eastern part of this unit,is assumed to be of Alpine age (section on post-Hercynian tectonics).

Regional description

In the area where unit III has its largest extension,east of the rio Cinqueta and south of the intrusive contact with the Rechanzadas-Descubridores granodiorite (henceforth called Barbarisa area),the Paleozoic rocks have been thrown into large isoclinal folds.The axial planes strike 300-330^{0} and dip ca.30^{o} to the NE.The coes of the anticlinal structures are occupied by the black carbonaceous shales of the Madera Fm. and the slates and limestones of the Puyaresto Fm.,whereas the synclines show the presence of the Barbarisa Fm. and,occasionally,on the south ridge of the Barbarisa,the dark slates of the Sahun Fm.The amplitude of these folds may vary from one decimetre up to several hectometres.Beautiful examples can be observed in the

steep slopes east of the Barranco del Sein (Fig.33),the summit of the Barbarisa,and east of La Estiveta (Fig.34).
Further east,in the Esera area,the Barbarisa-Sein unit continues as a narrowing zone of Lower Devonian limestones,displaying the same style of large scale folding(the "Sahun syncline",Wennekers,1968),until cut off by the Erices thrust.A general view of the southern part of the Barbarisa area is presented in Fig.35.
North of the Barranco de Huerbena,unit III continues as a poorly exposed zone bounded in the east by the Rechanzadas-Descubridores granodiorite.No large folds were observed here.North of the Plans de Lavet this zone crosses the rio Cinqueta.The dip of the Lower Devonian limestones (Puyaresto and Ardaña Fms.)changes from 50^{o}NE along the to the Granjas de Viladós east of Hospital de Gistain to 70^{o}N west of this location.
Further to the west the Barbarisa-Sein unit extends in a north-west direction as a poorly exposed zone,which probably crosses the frontier in the vicinity of Tres Bogas.
The basal part of the Barbarisa-Sein unit,except in the outliers of the Punta Suelza and the Bargasera,consists of strongly distorted carbonaceous slates of the Madera Fm. (Gotlandian).On the Punta Suelza and the Bargasera the Lower Devonian limestones of the Puyaresto Fm. directly overlie the red sandstones and and siltstones of the Poma-Viciele Fm.(Permian and Lower Triassic) and the platy limestones and gypsiferous shales of the Middle and Upper Triassic.
A well developed cleavage,coinciding with the axial plane of the large folds,is present in the slates of the Sein and Sahun Fms. and the calc-schists of the Barbarisa Fm. in the southern part of the Barbarisa area. North of the ridge running from the Barbarisa to El Yerri,this cleavage becomes much less evident,due to the effect of thermal metamorphism,related to the Rechanzadas-Descubridores granodiorite.Many fine-grained light coloured dikes were found to cut across the large structures,following the cleavage.

Deformational history

The first deformation phase (Fp)

No direct evidence of this phase such as folds or a cleavage predating the mainphase deformation,has been found in the Barbarisa-Sein unit. Still,indications for a phase predating F1 may be inferred from the direction and plunge of the F1 fold axes.The diagram given in Fig.36 presents the normals to the mainphase cleavage (S1) as well as the measured and constructed mainphase fold axes.Intersections of So and S1 were only observed occasionally,which is probably due to thermal metamorphism and

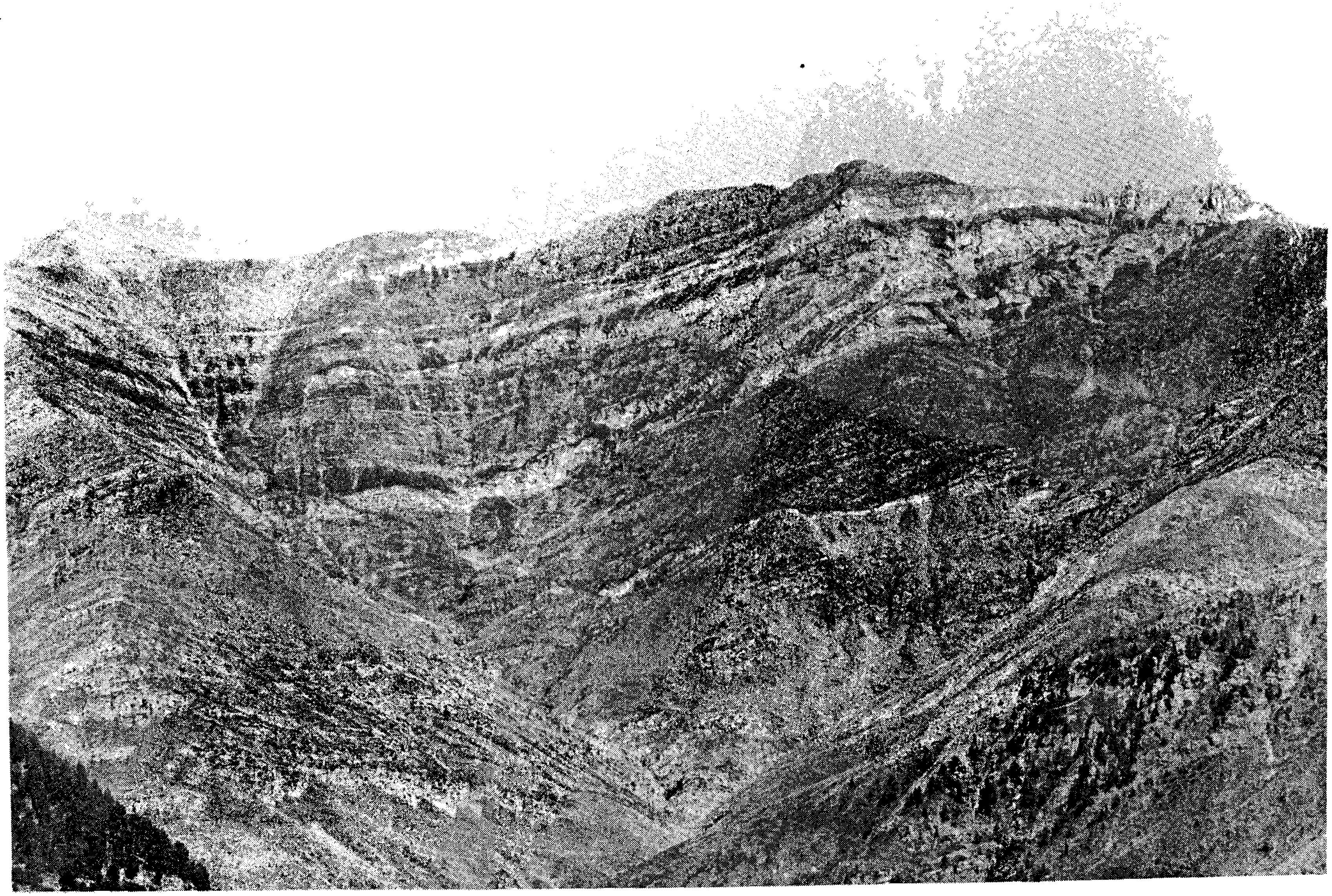


Fig.33.Large isoclinal F1 fold in limestones of the Puyaresto and Ardaña Fms. in the northern part of the Barbarisa area, seen from the west.

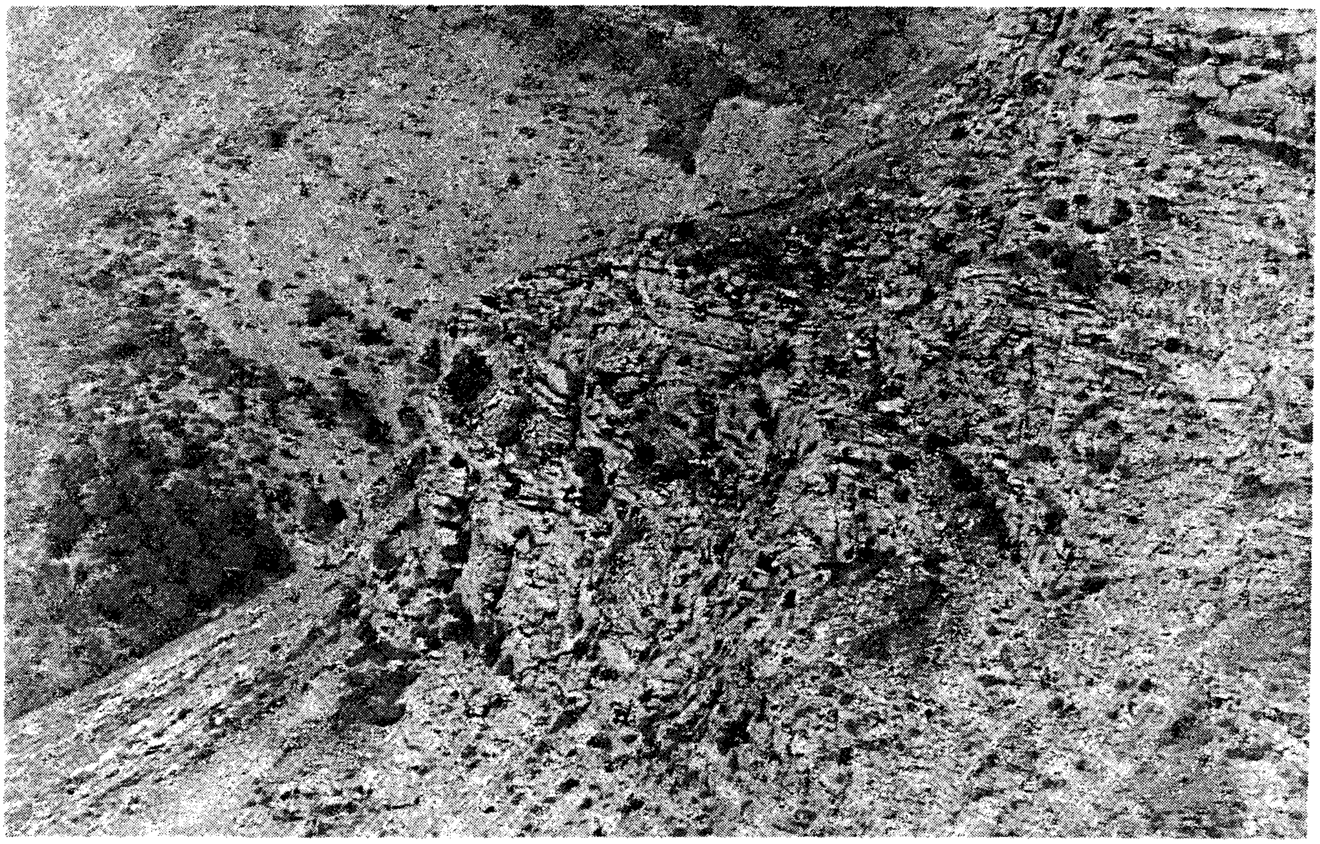


Fig.34.Fl fold in the Barbarisa Fm. on the southern slopes of the Barbarisa,seen from the south-east.

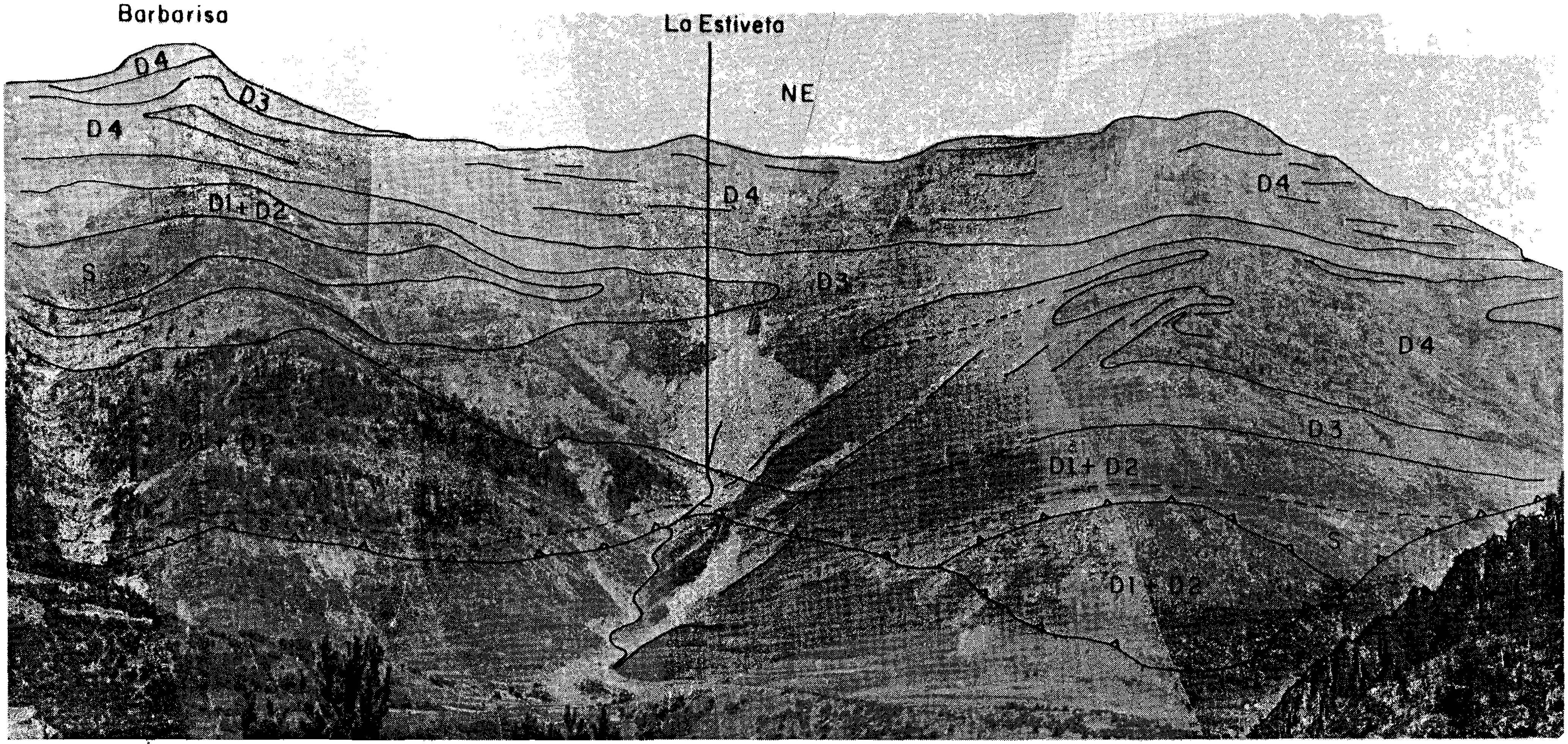


Fig.35.Panoramic view of the southern slopes of the Barbarisa,
seen from the south-west.

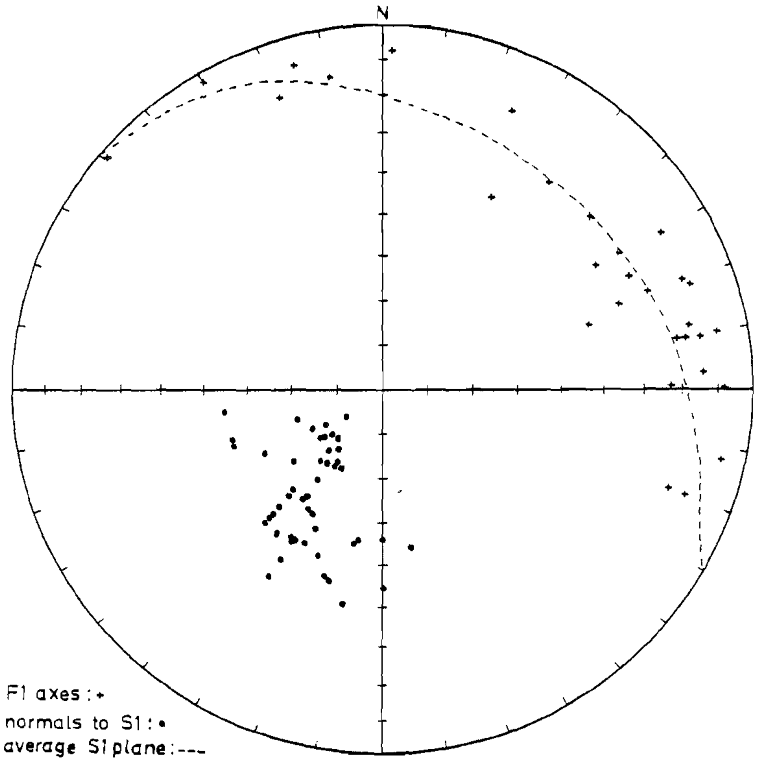


Fig.36.Structural diagram,presenting the normals to S1 and the attitudes of constructed and measured F1 fold axes (Schmidt's projection,lower hemisphere).The latter coincide quite well with the average S1 plane.

to the parallellism of bedding and cleavage on the limbs of isoclinal folds.So,the F1 fold axes had to be obtained from the measurements of hinge lines of small scale folds,and from the constructed intersections of sedimentary bedding and mainphase cleavage,measured separately in the same outcrop.

The diagram shows that the F1 fold axes are scattered around a great circle representing the average mainphase cleavage plane.The varying attitude of the fold axes can be explained by differences in attitude of the bedding before the mainphase folding.

The scarcity of fold axes,directed NNW,in comparison with those having a plunge to the NE ,is due to a more limited number of observations. The slopes and ridge west of the Barranco del Sein,where these NNW directions occur,are far less accessible than the terrain east of this barranco and on the Barbarisa mountain,where the NE directions predominate. The original direction of the pre-mainphase folding can,of course,not be inferred from Fig.36:in principle any direction between NE and NW is a possible one.

Considering the general NE-SW trend of pre-mainphase folds in adjacent areas,e.g. the Posets area and the Sierra Negra and Baliera areas (Mey, 1967),a similar direction for the pre-mainphase folding in the Barbarisa area does not seem improbable.On this assumption,the gentle plunges to the NNW and the NE of the mainphase fold axes suggest large gentle pre-mainphase folds (see structural sketch map and Fig. 37).

We must admit,however,that this reconstruction is rather interpretative and not based on and overwhelming number of observations.More certainty about the trend and style of the pre-mainphase folds would require a very detailed investigation and measuring.

In the Sahun syncline,the eastern continuation of the Barbarisa-Sein unit, gently to moderately NE and NW plunging mainphase fold axes have been reported by Wennekers,who,however,explains this variation in attitude by post-mainphase deformation,probably of Alpine age.The mechanism proposed by Wennekers includes large scale folding due to shear movements along moderately N dipping planes (Fig.38a).Although such planes might be represented by the N dipping third phase cleavage (S2,see next section)in the Barbarisa area still this explanation has to be rejected for this area. The mechanism would imply,that the S1 planes,containing NE plunging fold axes,should present a steeply SE dipping attitude (Fig.38b):A plane dipping 30° to the NE (representing the average attitude of the mainphase cleavage) and a moderately N dipping third phase cleavage plane (as required by Wen-

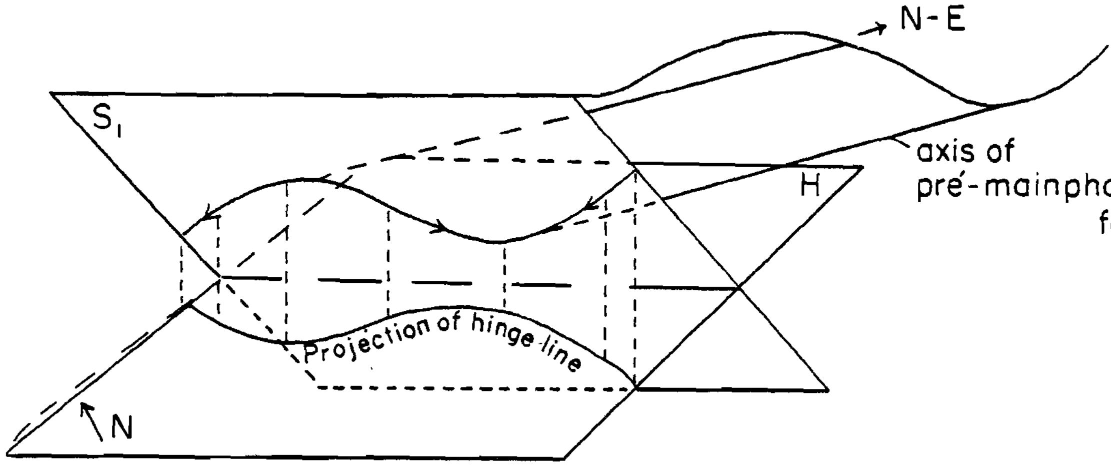


Fig.37.Schematic representation of the reconstruction of pre-mainphase folds in the Barbarisa-Sein unit.

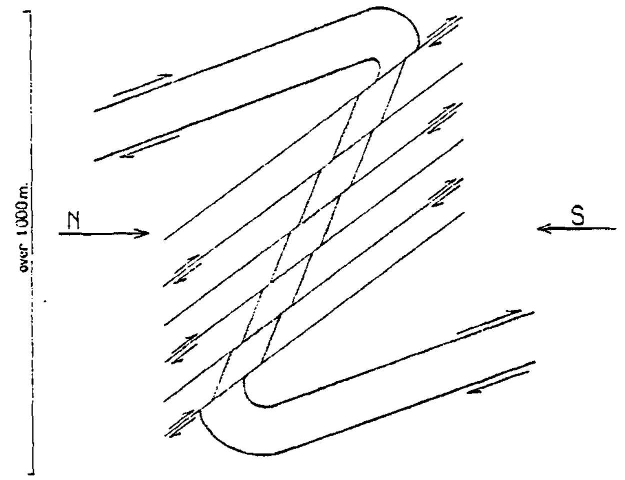


Fig.38a.Schematic representation of folding of S1 by shear along N dipping planes (from Wennekers,1968).

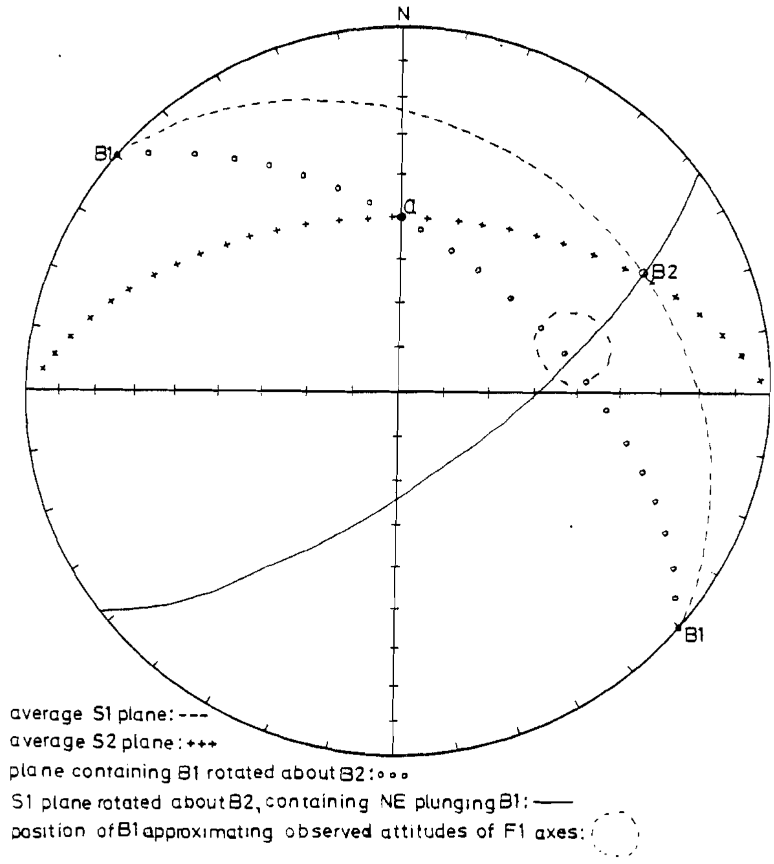


Fig.38b.Construction,demonstrating that the NE plunges of the F1 fold axes in the Barbarisa area can not be a result of later folding (Schmidt's projection,lower hemisphere).

nekers and in the Barbarisa area represented by S2)would have a NE plunging intersection B2,about which S1 would rotate.Mainphase fold axes (B1) ratated about B2 should lie on a great circle passing through the the assumed originally horizontal position of B1 and through the direction of maximum extension a (Whitten,1966).As B1 axes must stay in the S1 planes during rotation about B2,it will be clear that NE plunging B1 axes can only occur where S1 planes dip steeply SE as defined by the position of B2 and the NE plunging B1.

As S1 does not present such attitudes in the Barbarisa-Sein area,but on the contrary has a very constant gently NE dipping attitude (Fig.36),a post-mainphase origin for the plunge of the mainphase fold axes can be excluded.

The second or mainphase deformation (F1)

The characteristics of the mainphase structures have already been largely described in the preceding:large isoclinal folds accompanied by a gently NE dipping axial plane cleavage,which in the contact zone of the Rechanzadas-Descubridores granodiorite has been partly obliterated by the effects of thermal metamorphism.

However,even in this zone,thin sections of the slates of the Sein Fm. still display the mainphase cleavage by a parallel arrangement of small mica flakes and form-oriented quartz grains,while in the limestones of the Puyaresto and Ardaña Fms. and the calc-schists of the Barbarisa Fm. S1 is shown by small form-oriented calcite grains.

Tight to isoclinal small scale F1 folds of decimetre to metre dimensions are very common (Fig.39 and 40) and underline the intensity of deformation already indicated by the style of the large scale folding.From these small folds the amount of flattening can be estimated by comparing the thickness of an individual bed in the hinge and on the limbs of a fold (De Sitter, 1964,p.274-277).In the limestones ratios varying between 2:1 and 5:1 were established,indicating a flattening of 30-55%.The latter figure is quite common in isoclinal folds.Notice should be taken.however,that primary shortening by concentric folding,which may be up to 36% (De Sitter,1964) is not included in these figures,so that the total amount of shortening (shortening by concentric folding + shortening due to flattening) may be well up to 70%.

The bedding attitudes (Fig.41) show a concentration of normals,which more or less coincides with the concentration of normals to S1 (Fig.36),a phenomenon to be expected in isoclinal folding.

Fig.39.Small scale F1 folds in limestone of the Barbarisa Fm, beautifully displaying the thickening in the hinge and the stretching on the limbs.

Fig.40.Mesoscopic F1 folds in sandwich limestone of the Puyaresto Fm. along the Barranco del Sein.

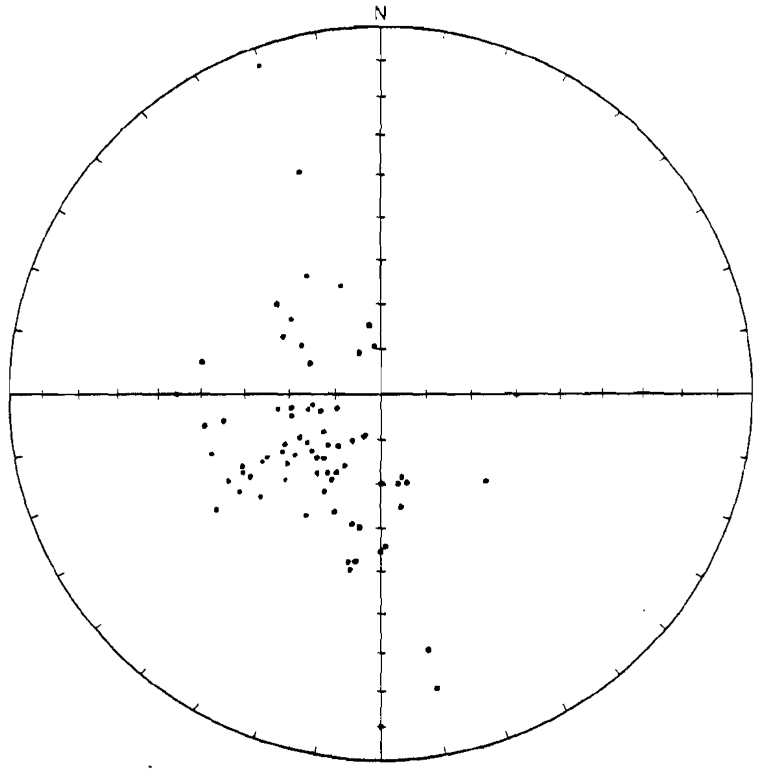


Fig.41.Distribution of normals to So in the Barbarisa area (Schmidt's projection.lower hemisphere).

An interesting phenomenon was observed in an F1 folded limestone-hornfels alternation of the Puyaresto Fm. near Hospital de Gistain along the track to the Granjas de Viladõs (Fig.42).Here the limestones have respnded by flow without disruption of the original layering,while the hornfels layers show small scale faulting sub-parallel to the bedding,thus causing gross thickening of the hinge,and thinning by boudinage of the limbs.Such different behaviour of limestone and of pelitic material (which was probably the original composition of the hornfels layers) would be unlikely under the low confining pressure conditions,which are generally assumed to have prevailed during the Hercynian orogenic event in the Pyrenees.An explanation might be given on the assumption,that temperature was already elevated at the time of the mainphase deformation. Then the pelitic layers might have been at least partly recristallized, thus explaining their brittle behaviour,while the limestones would have behaved in a plastic way.Furthermore,such conditions would have facilitated the tight to isoclinal folding characteristic for the suprastructure in the Cinqueta region.
The gentle dips of the mainphase cleavage in unit III contrast strongly with thevertical and steeply dipping S1 in the Posets-Peña Blanca unit. In the preceding we have already argued that this is an original tectonic feature,at least in the Cinqueta region.

The third deformation phase (F2)

This phase,which can be correlated with F2 in the Posets-Peña Blanca unit, only produced a poorly developed fracture cleavage,dipping moderately to the N,which was encountered in but a few locations.A faint crenulation of the S1 planes appears in thin sections as a slight micro-folding of the latter parallel to an incipient S2.
Thin sections of thermally metamorphosed slates of the Sein Fm.reveal small rotated chiastolite crystals,with an Si which is occasionally slightly s-shaped at the rim.This suggests that,as in the Posets Peña Blanca unit,the third deformation phase largely postdates the emplacement of the late Hercynian granodiorites.The occurrence of large calcite crystals with curved pressure fringes may support this.

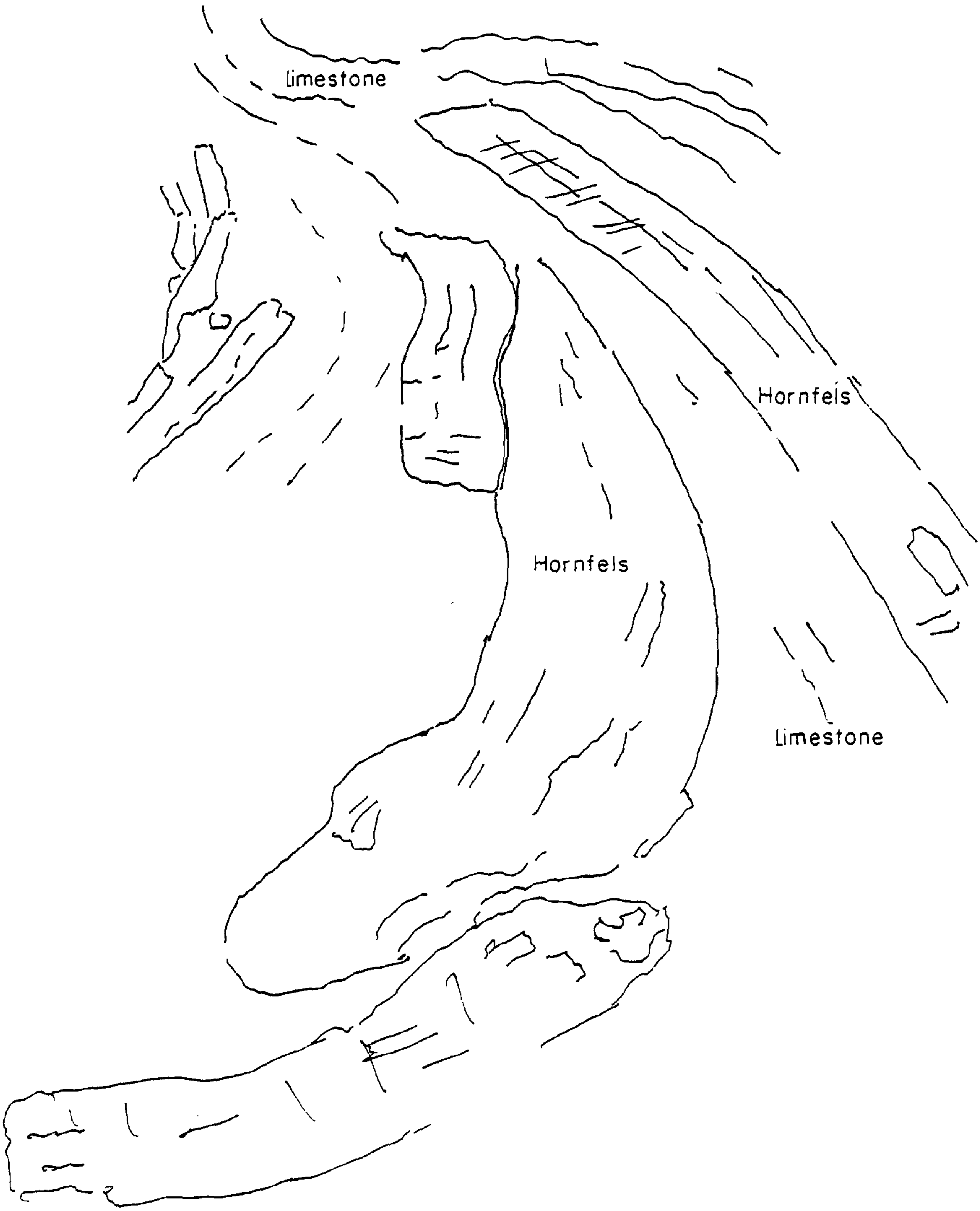


Fig.42(drawing after photograph).Folded limestone-hornfels alternation of the Puyaresto Fm. near Hospital de Gistain. For explanation,see text,

Main unit B

Introduction

This unit comprises the autochtonous Hercynian basement,together with its sedimentary cover of red sandstones,siltstones and shales of the Poma-Viciele Fm.(generally attributed to the Permian and Lower Triassic) and the overlying (dolomitic) limestones,gypsiferous shales and gypsum attributed to the Middle and Upper Triassic.
Its northern boundary is formed by the Sahun-Tres Bogas thrust,along which the Paleozoic rocks of the Barbarisa-Sein unit have overridden the rocks of main unit B (see structural sketch map).
In the south it is bounded by a S dipping zone,extending from the Collado de Sahun in the east to the Collado de la Cruz de Guardia in the west,in which distorted gypsiferous shales and gypsum overlie the Poma-Viciele Fm.Over this the Mesozoic cover is supposed to have slid to the south.
As large parts of this unit are covered by post-Hercynian rocks,structures postdating the Hercynian orogenesis,mainly of Alpine age,prevail. These structures will be dealt with in the next chapter together with the evidence of Alpine deformation found in the basement.
Hercynian structures could be studied in the San Juan window,an isolated stratigraphic window north of San Juan de Plan,where Paleozoic rocks of sedimentary origin are exposed.A cleavage dipping moderately SW,parallel to the bedding and to the axial plane of small isoclinal folds,is supposed to be related to the Hercynian mainphase deformation (F1).The abnormal SW dipping attitude of this cleavage is the result of subsequent tilting from an originally gently N dipping position.
Locally a steeply N dipping cleavage was observed.This cleavage postdates the mainphase cleavage and may be correlated with the third phase (F2) in the Posets-Pena Blañca and Barbarisa Sein units,and with the fourth phase (F4) of Zwart et al.

Regional description

The main part of the Hercynian basement of main unit B is constituted by the Cinqueta granodiorite (generally referred to as Bielsa granite by other authors:v.Lith,1965,Clin,1959),which extends from the rio Cinqueta in the east into the Cinca area in the west.Vast outcrops of this plutonic body occur along the rio Cinqueta and north and north-east of the Punta Suelza. Besides an E-W trending vertical joint system, no deformational structures have been observed in the Cinqueta granodiorite.

The San Juan window,with its Paleozoic sedimentary rocks,turned out to be a very complicated area.In spite of the large number of available observations certain aspects remain obscure.

North of San Juan de Plan recrystallized massive limestones overlie an alternation of thin limestone and hornfels layers,which dip moderately (30-40°) to the SW.Above these limestones there are slates and quartzites dipping SW to WSW.We could not establish whether the contact with the massive limestones is stratigraphic or tectonic,because it is nowhere found exposed.

At several levels in these clastic rocks a massive layer (about 10 m. thick) was encountered consisting of recrystallized limestone with thin hornfels intercalations.It appeared impossible,however,to decide whether we were dealing with one single layer appearing at different levels because of isoclinal folding,or with different layers in a normal stratigraphic succession.

The upper boundary of the slates and quartzites was found well exposed only along the road to Gistain about 500 m. east of this village.Here strongly tectonised slates occur,which are overlain by equally tectonised and distorted carbonaceous slates with fragments of bluish limestone,attributed to the Madera Fm.(Gotlandian).Small isolated outcrops of carbonaceous slates were also found on the slopes north of Gistain and along the rio Cinqueta east of San Juan de Plan.

On top of this tectonized zone slates and quartzites with intercalations of recrystallized marly limestone occur again and show great resemblance with the rocks below this zone.

An alternation of thin limestone and hornfels layers overlain by thick-bedded recrystallized limestone,dipping about 30° to the SW,was found on la Codera.Again it is uncertain,whether the contact with the underlying slates and quartzites is stratigraphic or tectonic.

About 50 m. south of the summit of La Codera massive limestones are unconformably overlain by the post-Hercynian Poma-Viciele Fm.,which dips approximately 50° to the S.

Although direct correlation of the limestone successions north of San Juan de Plan and on La Codera with the Puyaresto and Ardaña Fms. in units II and III is not possible,as they occur in different structural levels,resemblance is such that it justifies mapping the limestone-hornfels alternation as Puyaresto Fm. and the overlying massive limestones as Ardaña Fm.

The slates and quartzites with their intercalation(s?) of limestone-hornfels alternations could not be correlated,as their description fits the characteristics of the Viladõs Fm. as well as those of the Sein Fm.,and no lower or upper boundaries could be established with limestones supposed to represent the equivalents of the Puyaresto Fm. and the Ardaña Fm.Moreover,the lithological characteristics of the Viladós Fm. and the Sein Fms. need not to be the same in the San Juan window,as it belongs to a different structural level.Consequently,these rocks have been mapped as undifrenciated Paleozoic.

A well developed SW dipping cleavage occurs in the slates of this undifferentiated Paleozoic in the southern part of the San Juan window.This cleavage is generally parallel to the original bedding and coincides with the axial plane of some small scale isoclinal folds.To the north it was found to become less well observable due to the effect of thermal metamorphism in the vicinity of the Cinqueta granodiorite.In thin sections,however,the cleavage is still defined by a parallel arrangement of small muscovite flakes and form-oriented quartz grains.

Large folds related to this cleavage have not been observed.Still it is very well possible that such folds exist,as may be inferred from an outcrop along the track to Viladós just west of San Juan de Plan.Here the bedding is marked by a massive layer of ribbed limestone,which dips 50°to the SW. The cleavage in the over- and underlying slates has a horizontal attitude and parallels the axial plane of minor folds in the limestone.In view of the prevalence of isoclinal folding and of the general parallellism of bedding and cleavage,the angular relationship described above would indicate the proximity of a major fold hinge.

A rather widely spaced cleavage,dipping steeply to the N and trending 230-260°,was found sporadically in the southern part of the San Juan stratigraphic window along the road to Gistain and west of San Juan de Plan,and in the northern part of the window.It crenulates the first cleavage,but no related folding has been observed.A still later cleavage dipping moderately to steeply NE,is probably of Alpine age and will be discussed in the next chapter.

Deformational history

First we shall deal with the overall structure of the Paleozoic in the San Juan window.

Martinez (1968) believes the Paleozoic of the San Juan window to represent one large synformal anticline with a SW dipping axial plane,the limbs constituted by the limestone successions (attributed to the Devonian by Martinez) and the core by slates and quartzites (Ordovician and Gotlandian according to Martinez).This synform would have originated during the Hercynian orogeny as an anticline with a gently N dipping axial plane,subsequently tilted to the south by Alpine movements (Fig.43a).This picture,though,does not agree with the normal (upright) succession of the limestones north of San Juan de Plan as well as on La Codera;their repetition can only be explained by thrust movements.The crushed zone accompanied by distorted carbonaceous slates (Madera Fm.) probably represents such a zone of thrusting (Fig.43b). Subsequent tilting was responsible for the present southward dips of the bedding,first cleavage and thrust planes (see below).The thrusting must have taken place during the Hercynian orogeny,as no dislocations or repetitions occur in the post-Hercynian cover represented by the Poma-Viciele Formation.

No evidence of a deformation phase prior to the mainphase has been found in the San Juan window.
The first cleavage and associated isoclinal folding are probably due to the mainphase deformation (F1).However,as no direct correlation with mainphase structures outside the San Juan window is possible and because of the fact that things have been complicated by later tilting or folding,we can not claim with full certainty a mainphase origin for the first cleavage and related folds.
In the north,the window is bounded by a fault,which brings the Paleozoic into contact with the S dipping sandstones and shales of the Poma-Viciele Fm.,covering the Cinqueta granodiorite.In the north-east,just south of this fault,the bedding as well as the first cleavage in the Paleozoic show moderate dips to the NE.This cannot be explained by drag movement along the fault,as the overlying Poma-Viciele Fm. does not show any folding or drag phenomena in the vicinity of this fault,but has a flatlying attitude. Assuming that these moderate dips to the NE more or less represent the original attitude of the first cleavage (which would be in accordance with the general position of the mainphase cleavage in the southern part of the axial zone elsewhere),this would imply that the SW directed dips in the major part of the San Juan stratigraphic window are the result of tilting or refolding predating the deposition of the post-Hercynian cover.
Because of the very uniform N dipping attitude of the second cleavage,a post F2 (see below) origin for this rotation has to be discarded,nor is it plausible that it took place during this phase,as the latter is not found to haproduced any large scale folding in the Cinqueta region.So the tilting or refolding can only be dated as between F1 and F2.
There are two arguments for relating the second cleavage in this window to F2 (the third phase)in the Posets-Peña Blanca and Barbarisa-Sein units:
1.As in these units,the deformation which produced the second cleavage started

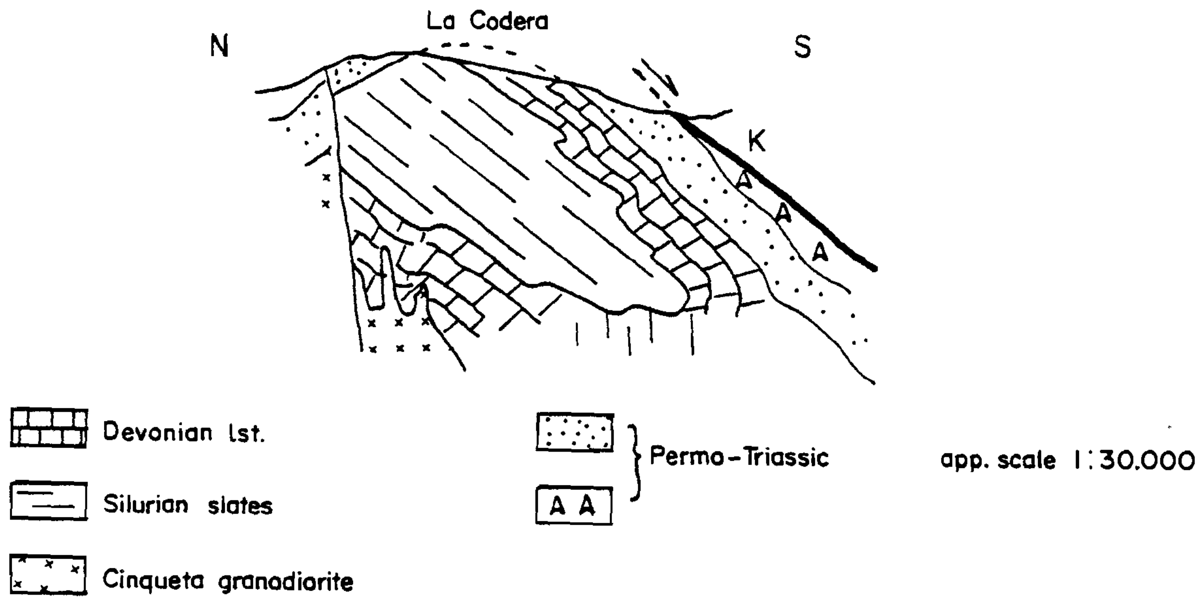


Fig.43a.Martinez' interpretation of the overall structure of the Paleozoic in the San Juan stratigraphic window.

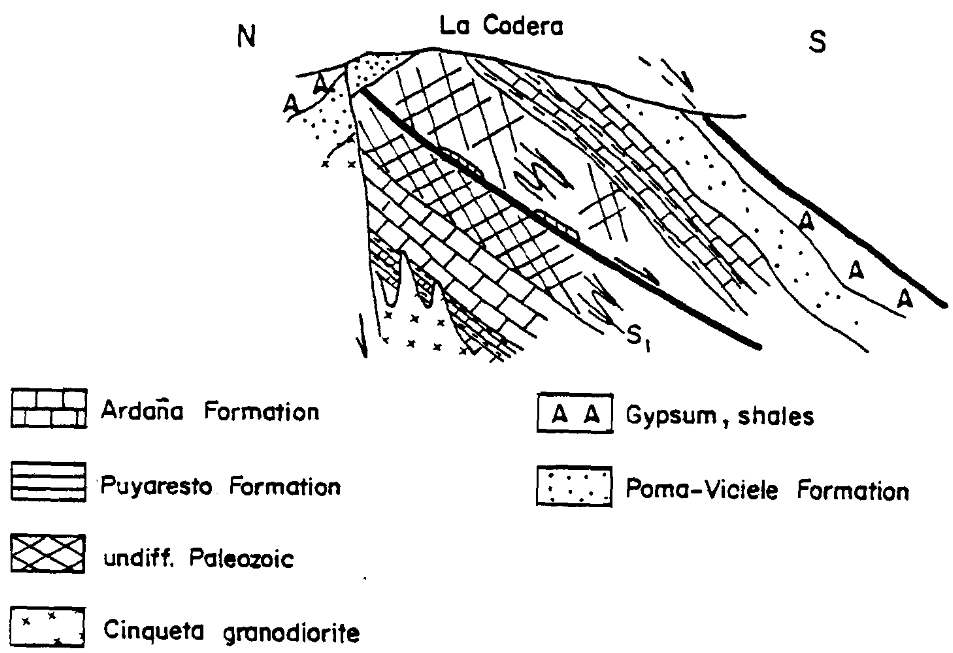


Fig.43b.Interpretation of the present author.

in a late stage of the emplacement of the Cinqueta granodiorite.This appears from andalusite crystals rotated into the second cleavage and showing an Si which is slightly s-shaped at the rim of the crystals.

2.The attitude of the second cleavage is very similar to the attitudes of S2 in the units mentioned above.

Summary of the successive Hercynian phases that have been active in the Cinqueta region

At the conclusion of the description and structural analysis of the various units,it may be useful to summarize the different major Hercynian deformation phase in chronological order:

1.A first phase which predates the mainphase.The southern and central part of the Posets area was affected by NE-SW striking folding without the development of a cleavage.In the Barbarisa area the pre-mainphase folds are much less pronounced;the attitudes of the mainphase fold axes suggest that only very gentle folding took place.

A foliation parallel to the bedding,which predates the mainphase foliation, is present in the regional metamorphic rocks of the Cinqueta de la Pez unit. No direct correlation is possible,however,with the NE-SW folding in the non-metamorphic areas.

2.The second or mainphase deformation produced large tight folds,accompanied by a well developed axial plane cleavage,in the Posets-Peña Blanca and Barbarisa-Sein units.Except for the extreme north-eastern part of the Posets area,where they present an E-W trend,the general strike of the axial planes and the mainphase cleavage is WNW-ESE.Their dips show a large scale fanning,a feature we consider as original.

In the regional metamorphic rocks of the Cinqueta de la Pez unit asymmetrical to isoclinal folds were produced during the mainphase.A crenulation foliation which occasionally has completely obliterated the older foliation,developed parallel to the axial plane of the folds.The strike of this foliation parallels the general trend of the mainphase cleavage in the areas not affected by regional metamorphism,with steep to moderate southward dips.Regional metamorphism was partly synchronous with the mainphase deformation.

3.A third phase affected only the metamorphic rocks of the Cinqueta de la Pez unit.Shear along the mainphase foliation produced internal rotation about N-S directed axes.

4.The fourth or late Hercynian phase produced small scale folds,which deform the mainphase cleavage,and a related cenulation cleavage,which generally dips moderately to steeply to the N.The folding was observed only in the northern part of the Posets-Peña Blanca unit.

After the mainphase,but before the fourth phase,occurred the tilting or refolding affecting the major part of the San Juan atratigraphic window. The intrusion of the Rechanzadas-Descubridores and Cinqueta granodiorites and the emplacement of the accompanying dikes,facilitated by the well developed mainphase cleavage took place directly before the fourth phase.

POST-HERCYNIAN TECTONICS

Introduction

Post-Hercynian deformations are restricted to the Hercynian basement of main unit B and its sedimentary cover with exception of a moderately to steeply NE dipping fracture cleavage,observed in the southern part of the Barbarisa-Sein unit,which may be of Alpine age.

We have established the following chronology for the post-Hercynian deformations:

1.Pre-alpine blockfaulting along faults striking approximately E-W.

2.Alpine deformations.

a.locally intense folding accompanied by an E-W to SE-NW trending axial plane cleavage in the sedimentary cover,and small scale thrusting of the basement.

In other parts of main unit B the cover was not or only very gently folded and no thrusting of the basement was observed.The cleavage,however,was found to persist in these less deformed areas.

b.large scale thrusting along the Sahun-Tres Bogas thrust.

c.doming of the Cinqueta granodiorite together with its sedimentary cover and the overthrust mass of Paleozoic rocks,culminating in the Punta Suelza and the Pico de Verdemene in the west.It seems likely,but cannot be proved, that htis updoming was contemporaneous with the uplift of the axial zone during which the monoclinal southern border zone was formed,causing gravitational southward gliding of the Mesozoic cover above the Upper Triassic.

Before we started the investigations in the Cinqueta region,Cl.Martinez of Montpellier University made a detailed study of the southern part of this area,dealing mainly with the post-Hercynian tectonics(Cl.Martinez.Etude structurale de la region du haut Cinqueta,substratum de la nappe de Gavarnie. Thèse 3^{me} cycle,Montpellier,1968).His description of main unit B agrees very well with our own observations(some of the figures going with the regional description and the structural analysis of this unit are taken from Martinez' thesis),but our interpretation differs in some respects.

Regional description

As the description of main unit B in Martinez' thesis is a very complete one and because of the fact that it has not been published we will give here a summary of Martinez' description,with some additional remarks based on our

own observations.
The major part of main unit B,situated north of the boundary fault of the San Juan stratigraphic window,consists of the Cinqueta granodiorite covered by presumably Permo-Triassic sediments (Poma-Viciele Fm. with overlying limestones,gypsiferous shales and gypsum).
This area is split up by a fault ,striking approximately E-W,along which the Cinqueta granodiorite has been brought into contact with the Poma-Viciele Fm. The Sahun-Tres Bogas thrust cuts off this fault in the east.In the west it disappears below the Paleozoic of the Bargasera outlier.
North of this fault,the granodiorite together with its sedimentary cover forms some large scale anticlinal and synclinal structures (Fig.44,section I), the axes of which plunge gently to the ENE.These structures die out eastward. Apart from these large scale structures the sedimentary cover of the granodiorite below the Paleozoic of the Punta Suelza,on the ridge running from the latter to the Pico de Verdemene and on the southern slope of this mountain show intense folding independently from the basement.The tight to isoclinal folds are accompanied by an axial plane cleavage,which presents itself as a slaty cleavage in the shales and as a fracture cleavage in the more competent rocks.The size of the folds varies between several 10 m. and 100 m.The strike of the cleavage is rather constant and varies between 90 and 130^{o},but the dips show great diversity:on the south facing limbs of the large scale structures affecting the granodiorite with its cover,the cleavage dips gently to moderately to the north,whereas vertical attitudes occur in the core of the syncline which separates the anticlines culminating below the Punta Suelza and in the Pico de Verdemene.
East of the rio Cinqueta,between Hospital de Gistain in the north and the fault which has been mentioned above,the sedimentary cover is only gently folded.The cleavage strikes about E-W and the dips vary between 80^{o} N and 70^{o} S.It was locally observed by Martinez to run from the sedimentary cover into the underlying granodiorite,but this is restricted to the upper few metres ,which consist of altered rock (see chapter II).Thin sections,taken from samples of unaltered granodiorite revealed the rock to be completely unoriented.
Several minor N dipping reverse faults affect the basement as well as the cover in the Punta Suelza-Pico de Verdemene area.The displacement along these faults does not exceed 100 m.The basal thrust zone of the Paleozoic outlier of the Punta Suelza truncates the cleavage folds of the cover as well as these reverse faults.

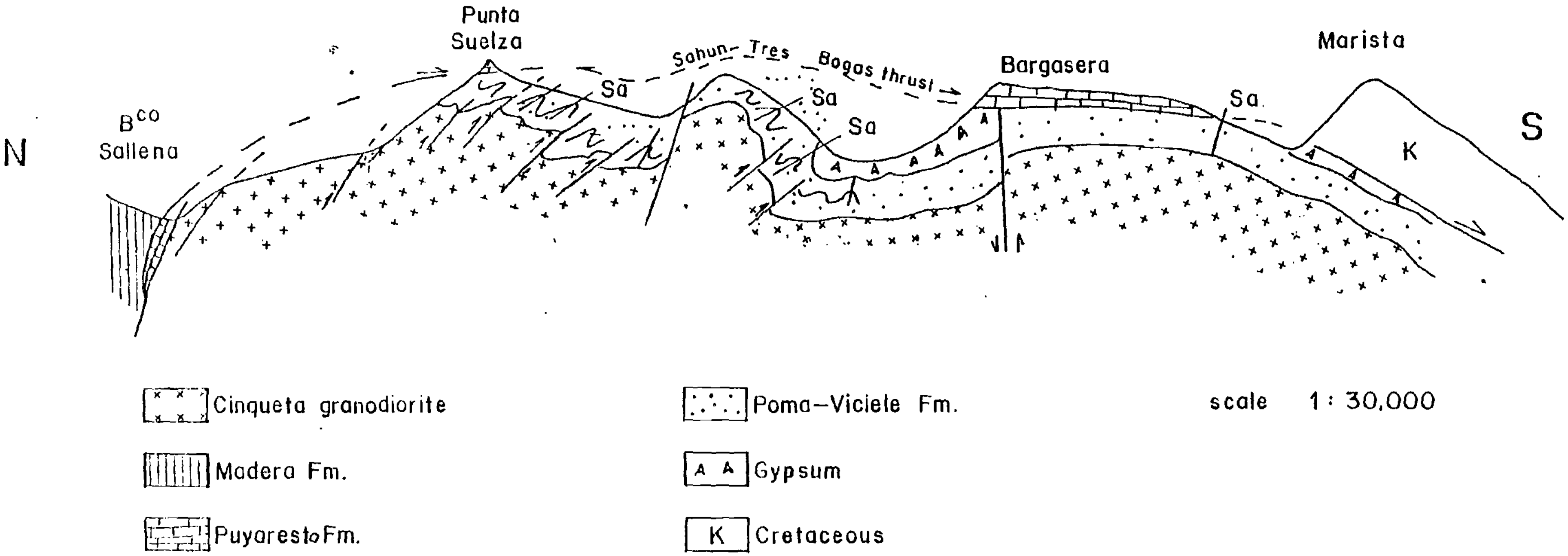


Fig.44(from Martinez,1968).Section across the Punta Suelza, the Pico de Verdemene and the Bargasera,showing steeply N dipping reverse faults affecting the basement,and small scale folding of the cover superposed upon large undulations of the basement.

South of the fault running from the Bargasera to the Plans de Lavet,the autochtonous presents itself as a gently domed structure,dipping to the E,SE and S from its culmination below the Paleozoic thrust mass of the Bargasera.The dome descends to a lowest point in the south-east,where the Barranco de la Poma debouches into the rio Cinqueta.No folding of the cover was observed in this part of main unit B.However,a cleavage frequently is present.In the flatlying sandstones and shales of the Poma-Viciele Fm. east of the rio Cinqueta it shows a vertical attitude and a strike which is approximately E-W.
Here also,the cleavage was found to persist across the unconformity plane into the upper altered zone of the granodiorite.
The Poma fault,which is cut off by the Sahun-Tres Bogas thrust in the east and dies out in the west,brings the Paleozoic sedimentary rocks of the San Juan window into contact with the post-Hercynian sediments covering the Cinqueta granodiorite.
A minor complication occurs east of the rio Cinqueta directly north of this fault,where a small wedge of granodiorite,together with its cover, has been thrusted to the north over the main structure (Fig.45).
Sofar a combined summary of Martinez' and our own observations.

The Paleozoic of the San Juan stratigraphic window has been fully discussed in the section on Hercynian tectonics.A cleavage,trending 300-340°,which is probably of Alpine age occurs in the southern part,
The window closes to the east and west,where the Paleozoic is overlain unconformably by more or less flatlying post-Hercynian sediments.
Monoclinally S dipping sandstones and shales of the Poma-Viciele Fm., overlain by limestones,gypsiferous shales and gypsum delimit the San Juan window in the south.They form part of the southern border zone, which stretches from the Collado de la Cruz de Guardia in the west (extending across this pass into the Cinca area)across the Collado de Sahun in the east into the Esera area.North of Plan a gently N dipping was observed in this zone.In the east,below the Collado de Sahun,intense cleavage folding occurs in the sandstones and shales of the Poma-Viciele Fm.The axial planes of the folds are represented by a gently to moderately N dipping cleavage and the axial envelope dips approximately 50° to the S,which is a position more or less parallel to the attitude of the southern border zone.The amplitude of these folds does not exceed 100 m.

As the Sahun-Tres Bogas thrust is a structure of Alpine origin,we will

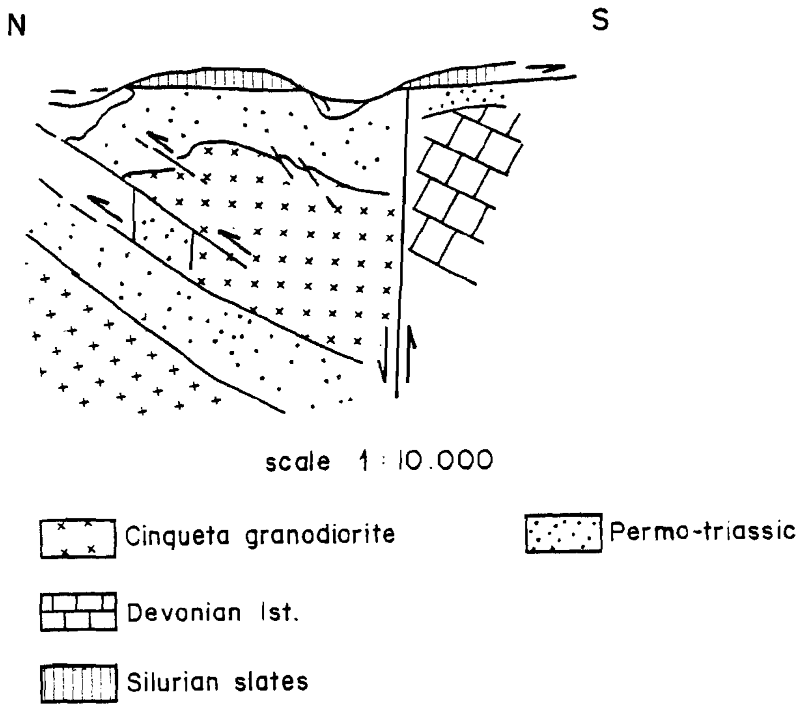


Fig.45(from Martinez,1968).Small wedge of granodiorite with Permo-Triassic cover,thrusted to the north over the main body of the Cinqueta granodiorite and its Permo-Triassic cover.

give a short description of it here:The thrust plane occurs as as zone of considerable thickness (up to 100 m. or more),which is generally but poorly exposed or not at all.East of the Cinqueta valley it has a flat-lying attitude and its vicinity is marked by distorted slates of the Madera Fm.(Gotlandian) at the base of the Barbarisa-Sein overthrust mass. Near the Collado de Sahun the attitude changes to a moderately N dipping one.Here the thrust plane could be located rather accurately between the limestones of the Ardaña Fm.(Lower Devonian) and the sandstone-shale alternation of the Poma-Viciele Fm.

In the north,near Hospital de Gistain,its flatlying attitude changes into a steeply N dipping position.The thrust zone is marked here by a mixture of slabs of granitic material,Devonian (Puyaresto Fm.)limestone and crushed carbonaceous slates (Gotlandian) (Martinez,1968).

On the Punta Suelza,Paleozoic rocks belonging to the Puyaresto and Ardaña Fms. are overlying thr Poma-Viciele Fm.The thrust plane dips gently to the NE here.

Finally,below the Bargasera thrust mass it has a flatlying to gently S dipping attitude.Here the limestones belonging to the Puyaresto Fm. were found overlying the sandstones and shales of the Poma-Viciele Fm. and,locally the limestones and gypsum on top of the latter.

To the east the Sahun-Tres Bogas thrust continues into the Esera area (Eriste-Sahun thrust of Wennekers,1968).Its western prolongation is badly exposed and very hard to locate(see section on the Barbarisa-Sein unit in Hercynian tectonics).

The Solana fault (see structural sketch map),a reverse fault which probably links up with the Erices thrust in the Esera area,may also have an Alpine age (Wennekers,1968),but in the Cinqueta area this could not be proved.

Deformational history

Post-Hercynian deformation started with block-faulting along E-W trending vertical planes,dissecting the Cinqueta granodiorite with its Permo-Triassic cover.The last movements along these planes postdate the deposition of the sedimentary cover which has been displaced by them,but predate Alpine thrusting,as the Sahun-Tres Bogas thrust cuts off the faults. It is very probable however,that at least some of the faults were already active before deposition of the cover.This is demonstrated by the fault

running along the Barranco de la Poma,where the juxtaposition of the Cinqueta granodiorite with its Permo-Triassic cover and the Paleozoic sedimentary rocks of the San Juan stratigraphic window with their unconformable cover of sandstones and shales can only be explained by repeated movement along the fault.During a first stage,prior to the deposition of the Permo-Triassic the northern block must have moved upward to bring the Cinqueta intrusive body into contact with the Paleozoic sediments of the southern block.Movement in opposite sense took place after sedimentation ,which is displayed by the Permo-Triassic in the northern block thrown downward with respect to the to the Permo-Triassic covering the Paleozoic of the San Juan window.
As no sediments younger than Upper Triassic gypsum and gypsiferous shales are present,it will be clear that the fault movements cannot be dated more exactly.We can only state with certainty,that movement started before deposition of the Permo-Triassic and ceased before Alpine thrusting.

Compression in a N-E to NW-SE direction took place probably during the Pyrenean phase of Alpine deformation.Locally the post-Hercynian cover was affected by intense folding accompanied by an axial plane cleavage(Sa), whereas in other areas it was but gently folded with or without a cleavage being developed.A beautiful example of folds in the sedimentary cover is given in Fig.46.
In the flatlying or very gently folded parts of the cover the cleavage, when present,has a vertical or steeply dipping attitude.
The distribution of normals to Sa in the northern part of main unit B, west of Hospital de Gistain,is presented in Fig.47.The diagram shows a cleft girdle distribution as aresult of later warping and to a lesser degree of the movement along the Sahun-Tres Bogas thrust.The original position of the cleavage and consequently of the axial plane of the folds probably was vertical or steeply dipping.This is demonstrated by the vertical attitude of the cleavage in areas which were not affected by later warping movements,e.g. along the east bank of the rio Cinqueta and in the core of the large scale syncline between the Pico de Verdemene and the Bargasera. Beautiful examples of tectonic features related to (concentric) folding, such as tension gashes,striae and joint systems may be observed in the sandstones of the Poma-Viciele Fm.However,as these phenomena have been elaborately described and discussed by Seguret,Martinez and Choukroune

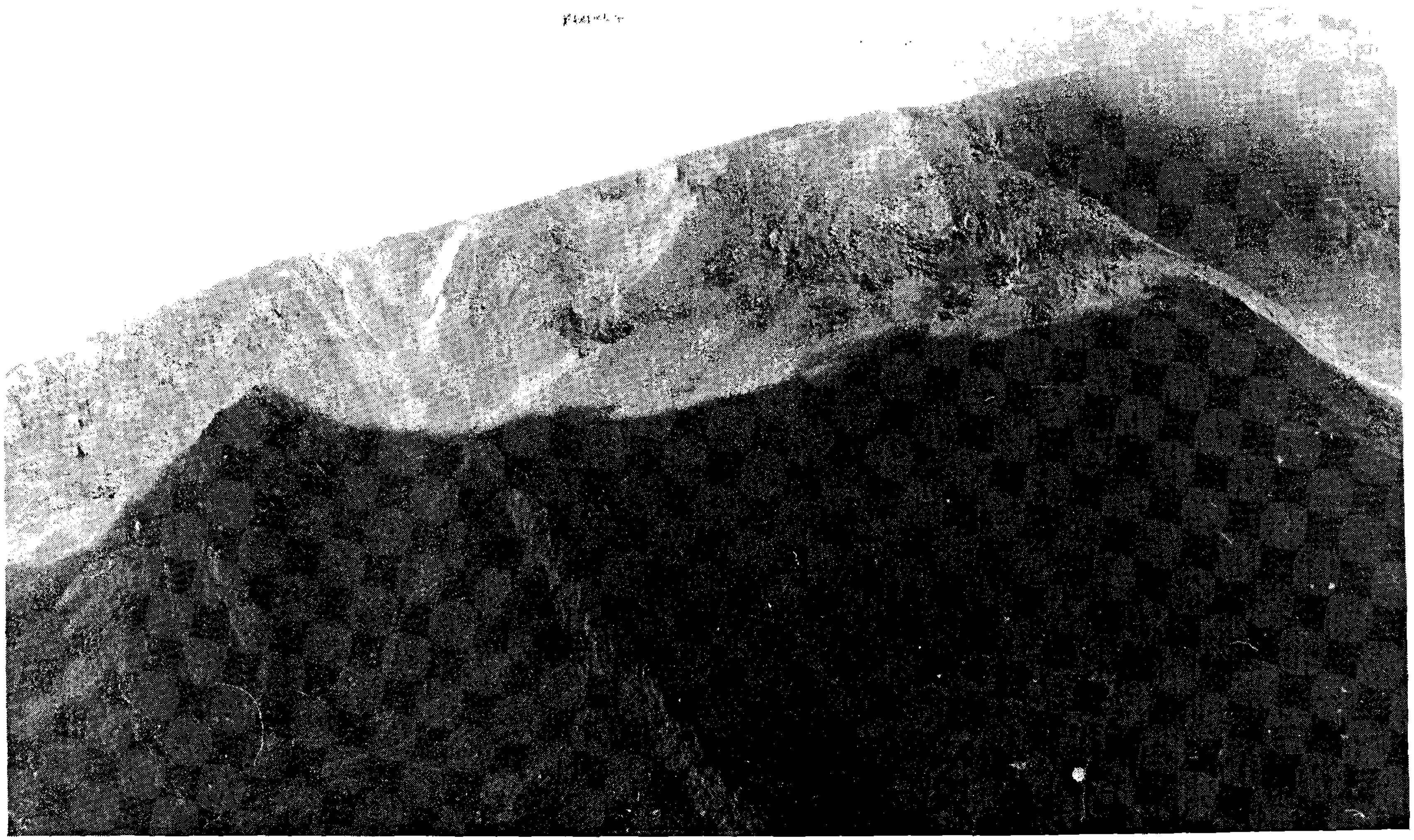


Fig.46.Tight foldsin the Permo-Triassic on the south-west ridge of the Punta Suelza (seen from the south-east).Note the vertical attitude of the axial plane in the central and left hand part of the photo,which near the Sahun-Tres Bogas thrust (situated just above the cloud base)shows a moderate N dip(right hand part of the photo).

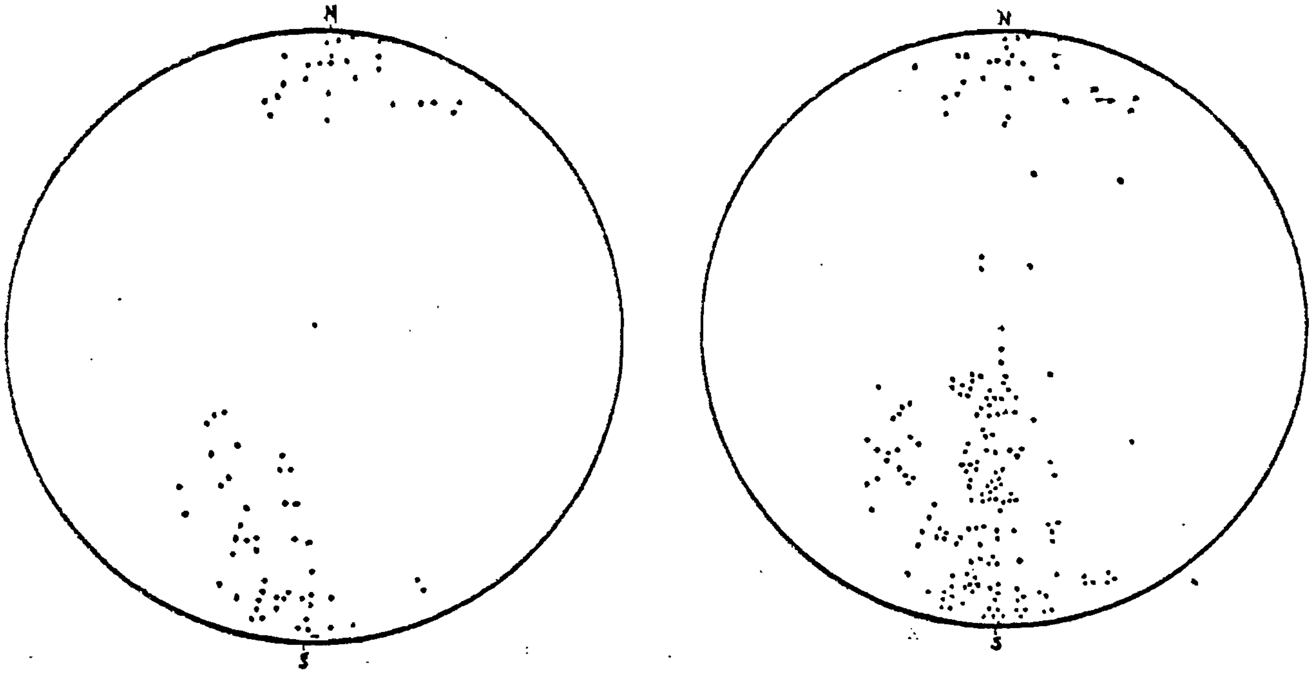


Fig.47(from Martinez,1968).Distribution of normals to Sa in the north-western part of main unit B.

(1968),we did not study them in detail.
Apart from the presence of Sa in the upper,altered zone of the granodiorite no traces of shear and/or flattening (apart from some broken biotite crystals and occasionally undulous exstinction of quartz)were observed in the unaltered rock neither in thin sections nor on a macroscopical scale.The situation in the sedimentary Paleozoic of the San Juan stratigraphic window is different.Here frequently a cleavage,which postdates the late Hercynian fourth phase and is interpreted as an Alpine feature,is found as well in the upper part directly below the unconformity plane as in the lower part.The attitude of this cleavage more or less parallels the Sa in the Permo-Triassic cover.
A fracture cleavage,which was frequently observed in the south-eastern part of the Barbarisa-Sein unitin in the frontal part of the overthrust mass,was interpreted by Martinez as an Alpine cleavage.However,we could not find any arguments to support this interpretation.Especially not because the strike of this cleavage (appr. 330°)differs markedly from the strike of the Sa in the Permo-Triassic below the thrustplane.(appr.270).

The absence of an Alpine cleavage in the cristalline basement does not pose so much of a problem in those areas where the sedimentary cover is not or only gently folded,and shortening consequently was not very important.The same holds for the sedimentary cover of the San Juan window, which is also overlain by flatlying post-Hercynian sediments,so that except for the cleavage mentioned above no other deformational phenomena like folding are to be expected.
However,one can hardly imagine an intensely folded and consequently shortened,coherent cover,like in the Punta Suelza-Pico de Verdemene area, without more or less equal shortening of the basement,and a decollement of the cover from this rigid basement.
In our opinion the granodiorite reacted to compression by thrusting along the small scale reverse faults mentioned in the regional description,while the cover gave way to compression by folding and detatching itself from the basement along the upper zone af altered granodioritic material.This assumption is supported by the absence of such reverse faults in areas where the cover was not or but slightly folded.
Martinez,though,postdates these faults with respect to the folding,as they frequently cut across the folds,and relates them to a subsequent stage of thrusting,during which also the Sahun-Tres Bogas thrust originated.Still,we

think it very well possible that the faults already existed in an earlier stage,at the time of the folding,and were merely reactivated as a consequence of the large scale thrusting.
We agree with Martinez' idea that movement along the Sahun-Tres Bogas thrust started after the folding and the formation of the cleavage in the sedimentary cover.Locally these structures can be seen rotated from their originally vertical position into a position at small angles with the thrust plane,due to shear exerted by the overriding Paleozoic mass.This may be observed in the Permo-Triassic cover below the Paleozoic of the Punta Suelza (Fig.48).
Seguret,on the other hand,is of a different opinion,regarding these flatlying structures below the Punta Suelza.He states that "La schistosité du Permo-trias autochtone ne traverse pas le contact de base de la nappe mais a tendence a se coucher sous le contact,ce qui démontre la contemporanéité de la mise en place de la nappe et la developpement de la schistosité".As he also connects the cleavage with the folding,in his opinion the generation of both the folds and the cleavage is due to the movement along the Sahun-Tres Bogas thrust.This interpretation,however,does not seem very acceptable,since it does not take into account the fact that cleavage folds with a rather flatlying attitude are restricted to the Punta Suelza-Pico de Verdemene area.Assuming that these folds are related to the movement of an overthrusting mass,though,one would expect such folds below the Sahun-Tres Bogas thrust to occur not only on the Punta Suelza, but also in the Barbarisa-Sein and the Bargasera areas.In these areas,however,the Permo-Triassic below the thrust plane is flatlying or but gently folded.Moreover the cleavage,when present here,has always a steep attitude,so that it can hardly be produced by shear along a horizontal thrust plane.

Three important questions arise concerning the Sahun-Tres Bogas thrust:
1.Its possible relation to another,very famous,Alpine thrust;the Gavarnie thrust.
2.The continuation of the thrust plane to the west.
3.The steeply dipping attitude of the thrust plane west of Hospital de Gistain.
In discussing the structural position of the Sahun-Tres Bogas thrust with respect to the Gavarnie the following remarks have to be made:Firstly,we will only consider the basal Gavarnie thrust plane,below the Gavarnie Paleo-

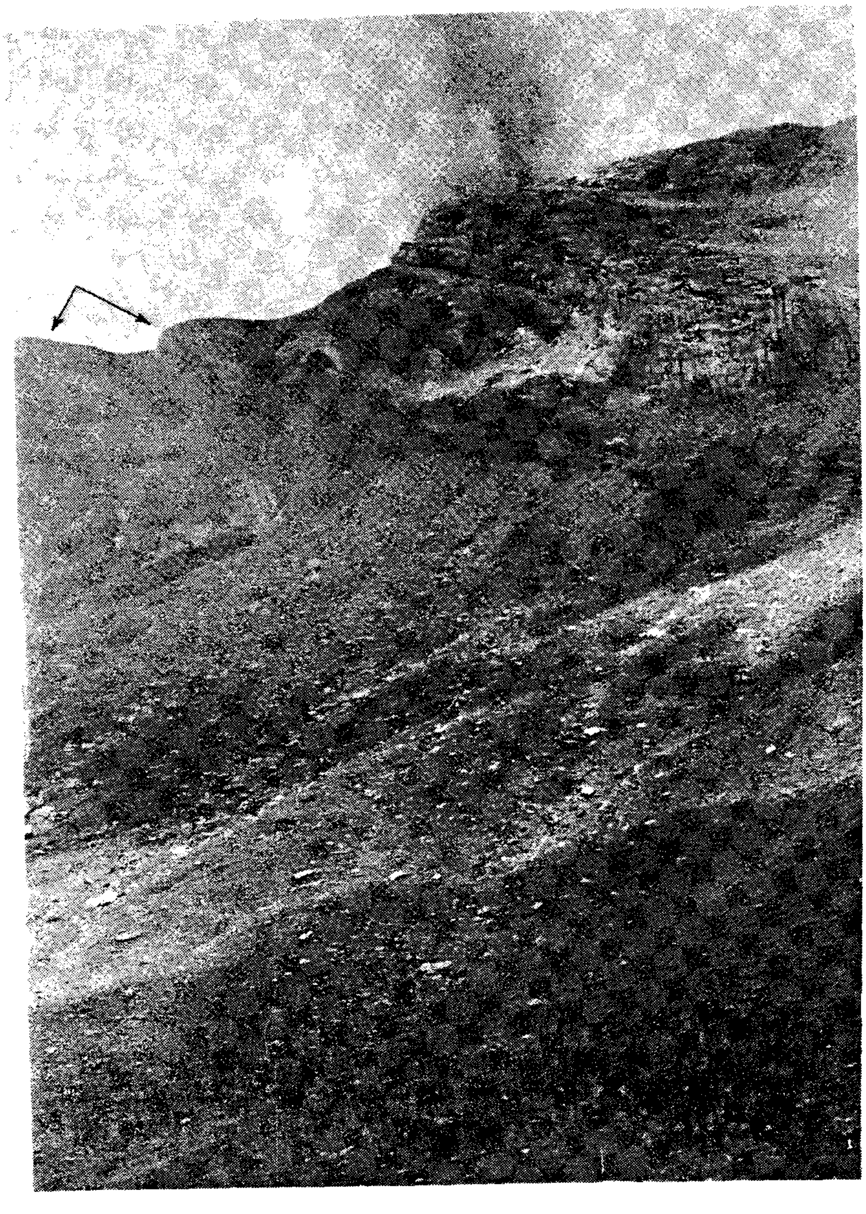


Fig.48.Fold with gently N dipping axial plane,just below the Paleozoic thrust mass of the Punta Suelza,seen from the south-east.

ozoic overthrust mass,and not its possible continuation inside the Mesozoic cover south of the southern border zone.Secondly,although we have attributed the Paleozoic outliers of the Punta Suelza and the Bargasera to the Barbarisa-Sein unit of main unit A,and consequently attached the thrustplane below them to the Sahun-Tres Bogas thrust,other interpretations are given by Seguret,Choukroune and Martinez (1972,1967 and 1968). We will come to this later and first consider the position of the Paleozoic overthrust mass of main unit A (the Cinqueta de la Pez unit,the Posets-Peña Blanca unit and the Barbarisa-Sein unit) with respect to the Gavarnie overthrust mass.

The eastern continuation of the Gavarnie thrust plane is present directly north of the Fredançon-Aygues Tortes anticline (see Hercynian tectonics, Cinqueta de la Pez unit)where,near the Pic de Sarrouyes,Gotlandian black slates are overlying Cretaceous rocks which unconformably cover rocks of Cambro-Ordovician age (Seguret,1972).As the Fredançon-Aygues Tortes anticline constitutes the northern continuation of main unit A,the Sahun-Tres Bogas thrust must be situated below the Gavarnie thrust.

According to Choukroune(1967) and Seguret (1972) the Paleozoic of the Punta Suelza and the Bargasera represent remnants of the Gavarnie overthrust mass,whereas Martinez correlates the Punta Suelza outlier with the Gavarnie overthrust mass and the Bargasera to the Sahun-Tres Bogas thrust mass of main unit A (Chevauchement du haute Cinqueta of Martinez).

However,this would mean that the Sahun-Tres Bogas thrust mass,which has in the Barbarisa-Sein area in the east a thickness of at least 1000 m., would have totally disappeared below the Paleozoic of the Punta Suelza and the Bargasera or of the Bargasera only.Considering the horizontal distance between the outliers and and the Barbarisa-Sein area,which does not exceed 5 km.,we think this to be very improbable,and therefore correlate both the Punta Suelza and the Bargasera outlier with the overthrust mass of main unit A.

To the west,across the Spanish-French border,the Sahun-Tres bogas thrust becomes very hard to trace,except north of Bielsa,where according to Seguret it is represented by an abnormal contact between rocks of Paleozoic and Cretaceous age (see map,Seguret,1972).North-west of Bielsa the Paleozoic of the Gavarnie thrust mass directly overlies the autochtonous Bielsa granite, which represents the western continuation of the Cinqueta granodiorite.The absence of the Sahun-Tres Bogas thrust mass here may well indicate that this thrust plane dies out to the west.

The steeply N dipping attitude of the thrust plane west of Hospital de Gistain is explained by Martinez on the assumption that it originated during pre-Permian times as a steeply dipping normal fault,and became reactivated during Alpine compression as a reverse fault,representing the"root" of the Sahun-Tres Bogas thrust.
This interpretation,though,is very unattractive,since it does not account for the large horizontal displacement of the overthrust mass.
In our opinion,the steep attitude of the thrust plane is the effect of later differential movements,in a vertical sense,of the Cinqueta granodiorite,that have also resulted in the large ENE-WSW trending anticlinal structures of the Punta Suelza,the Pico de Verdemene and the dome structure of the Bargasera.
Such warping movements would moreover give an explanation for the differences in altitude at which the thrust plane occurs:2850 m. dipping eastward to 2500 m. on the Punta Suelza,2300 m. on the Bargasera and 1600-1900 m. in the Barbarisa-Sein area.
Also the differences in attitude of the cleavage (Sa) would be explained; vertical in the core of the synclinal structures between the Punta Suelza and the Pico de Verdemene and between the latter and the Bargasera,and dipping N on the limb of the Pico de Verdemene anticline.(The gentle dips to the N on the south limb of the Punta Suelza anticline are less representative,as these attitudes have also been influenced by the movement along the Sahun-Tres Bogas thrust.)
An originally vertical to steeply dipping cleavage would rotate into a N dipping position on the south limb of a later fold,whereas in the core of such a fold nochange of the original position is to be expected.
The S dipping monocline of Permo-Triassic rocks,constituting the southern border zone postdates the Alpine cleavage (Sa).This is shown by the gently N dipping attitude of Sa in the 50° S dipping Permo-Triassic north of Plan, and also by the behaveour of the presumed equivalent of Sa in the Hercynian basement of the San Juan stratigraphic window,which directly north of the S dipping sandstones and shales of the southern border zone shows a change from steep to moderate and gentle NE dips going southward.Moreover it is demonstrated by the gently N dipping attitude of Sa and the axial planes of mesoscopic folds west of the Collado de Sahun (Fig.49).The prolongation of the Sahun-Tres Bogas thrust south of the Collado de Sahun has a dip to the S.The same goes for the dips of the presumed prolongation of the thrust inside the Mesozoic cover south of the mapped area (Martinez,1968).
This suggests that the tilting movements which produced the southern border

zone also postdates the stage of thrusting.So it is likely that the vertical movements mentioned above are more or less contemporaneous with the generation of the southern border zone.
Probably as a consequence of these movements the Mesozoic cover above the gypsiferous shales and gypsum of the Upper Triassic moved southward by gravitation.

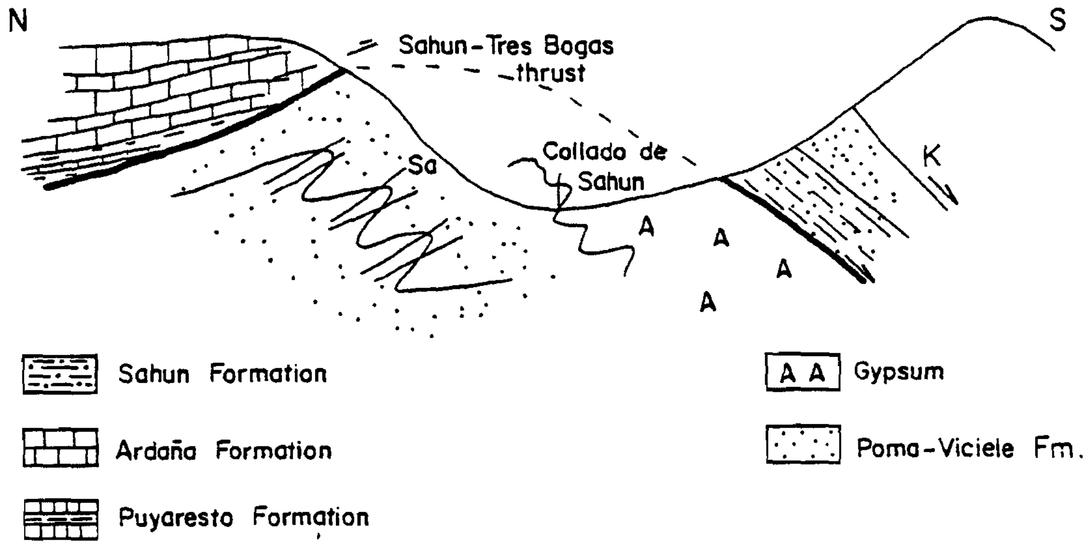


Fig.49.Schematic section across the Collado de Sahun (not to scale).

SAMENVATTING

In het gekarteerde gebied worden gesteenten aangetroffen met ouderdommen, die waarschijnlijk reiken van Cambro-Ordovicium tot en met Boven Trias. Met uitzondering van het noordelijk gedeelte van het gebied, waar epizonaal tot mesozonaal regionaal metamorfe gesteenten voorkomen, vertonen de Paleozoische gesteenten een zwakke dynamo-metamorfose met daarop gesuperponeerd een wisselende graad van contact-metamorfose, gelieerd aan de intrusie van granodioritische lichamen. De Hercynische orogenese veroorzaakte intensieve deformatie in de vorm van sterke verplooiingen en druksplijtingen. De Hercynische gesteenten worden discordant bedekt door veelal rood gekleurde zandige en kleiige sedimenten, kalken, dolomieten en gipsen, die algemeen tot de Permo-Trias gerekend worden. De post-Hercynische deformaties, waarvan de belangrijkste plaatsvonden tijdens de Pyreneese fase van de Alpine orogenese, veroorzaakten plaatselijk intensieve deformatie van de Permotriadische gesteenten, gepaard gaande met een druksplijting. Eveneens vond beweging plaats langs belangrijke overschuivingen, die zowel het Hercynisch grondgebergte als ook de discordante bedekking doorsnijden.

Vanwege het ontbreken van fossielen, de intensieve deformaties en de rekristallisaties door metamorfose bleek het onmogelijk de in het gebied voorkomende Paleozoische gesteenten op zichzelf te dateren. Lithologische correlatie van de door ons onderscheiden eenheden met gedateerde eenheden in aangrenzende gebieden maakten het niettemin mogelijk om te komen tot een waarschijnlijke datering.

Van onder naar boven zijn de volgende eenheden onderscheiden :

1. Het Cinqueta de la Pez complex :

Een afwisseling van zandige en kleiige sedimenten met inschakelingen van onzuivere kalken, die door regionale metamorfose zijn omgezet in biotiet-muscoviet-schisten al of niet met porfieroblasten van stauroliet, andalusiet, cordieriet en biotiet, sericiet-schisten, phyllieten en meta-kalken. De dikte van deze gesteenten wordt in aangrenzende gebieden op minimaal 600 m geschat. Algemeen wordt een Cambro-Ordovicische ouderdom aangenomen voor dit type regionaal metamorfe gesteenten, voorkomend in de axiale zone van de Pyreneeën.

2. De Viladós Formatie :

De gesteenten behorende tot deze eenheid vormen het niet regionaal metamorfe, hoewel vaak sterk thermaal beïnvloede, equivalent van de schisten en phyllieten van het Cinqueta de la Pez complex. De formatie is gekarakteriseerd door een afwisseling van blauwgrijze leien, verhoornrotste leien en kwartsieten.

3. De Madera Formatie :
Zwarte kolige schalies met aan de top inschakelingen van donkere kalken. De dikte kan varieren van minder dan 100 m tot enkele honderden m. Deze gesteenten reiken waarschijnlijk in ouderdom van Onder Llandoverien tot in het Onder Gedinnien.
4. De Puyaresto Formatie :
Deze eenheid bestaat uit een afwisseling van dunne kalken en zandige leien, die zeer frequent zijn gerekristalliseerd tot hoornrotsachtige gesteenten. De dikte varieert van ca. 100 tot 250 à 300 m. De formatie kan gecorreleerd worden met gesteenten ten oosten van het gekarteerde gebied, waarvoor een gedinnien ouderdom wordt aangenomen.
5. De Ardaña Formatie :
Deze is gekarakteriseerd door massieve tot dikgebankte kalken met zeer dunne tussenlaagjes van gerekristalliseerd kleiig materiaal. De dikte kan wisselen van 100 tot 250 m. Aan massieve kalken, voorkomend ten oosten van het Cinqueta gebied, waarmee deze eenheid gecorreleerd kan worden, wordt een ouderdom van Boven Gedinnien tot boven Onder Emsien-onder Boven Emsien toegekend.
6. De Sein Formatie :
Donkere leien en zandige leien met enkele dunne kwartsieten en in het bovenste gedeelte enkele onzuivere kalken. De dikte bedraagt minstens 100 m, maar is zeer variabel. De ouderdom beslaat het Boven Emsien.
7. De Barbarisa Formatie :
Deze eenheid bestaat uit een afwisseling van gerekristalliseerde kalken met dunne tussenlaagjes van pelitisch materiaal en kalk-schisten. De dikte varieert van ca. 70 m tot 200 à 300 m. Het onderste gedeelte van de formatie heeft waarschijnlijk een Eifelien ouderdom.
8. De Sahun Formatie :
Donkere fijn splijtende leien met detritische glimmers. De ouderdom van deze gesteenten is onbekend (Carboon ?).

Discordant op de Hercynische gesteenten liggen :
9. De Poma-Viciele Formatie :
Veelal rode zandstenen, conglomeraten, kleistenen en schalies ter dikte van 150 tot 200 m. Deze gesteenten worden algemeen een ouderdom van Perm tot en met Onder Trias (Bontzandsteen) toegekend.
10. Op de Poma-Viciele liggen geel tot violette platige kalken, cellige dolomieten, gipshoudende schalies en gipsen met een gezamenlijke dikte van 50 tot 100 ? m. Algemeen worden de kalken tot de Midden Trias (Schelpkalk) en de gipshoudende schalies en gipsen tot de Boven Trias (Keuper) gerekend.

Structureel is het Cinqueta gebied op te splitsen in verschillende eenheden : De meest noordelijke, hoofdeenheid A, bestaat van noord naar zuid uit : de Cinqueta de la Pez eenheid (eenheid I), de Posets-Pena Blanca eenheid (eenheid II), en de Barbarisa-Sein eenheid (eenheid III). Hoofdeenheid B is van de vorige gescheiden door de Sahun-Tres Bogas overschuiving, waarlangs hoofdeenheid A op hoofdeenheid B geschoven is.
Gedurende de Hercynische orogenese, die in de Pyreneeën waarschijnlijk zijn maximum intensiteit bereikte tijdens het Midden Carboon, volgden verscheidene deformatie perioden op elkaar. De volgende fasen konder onderscheiden worden :
Fase 1. Tijdens deze fase, die voorafgaat aan de hoofdfase van de Hercynische orogenese vormden zich in de niet regionaal metamorfe gesteenten van de Posets-Pena Blanca eenheid plaatselijk NE-SW strekkende plooien, zonder dat het kwam tot de ontwikkeling van een druksplijting of cleavage. In het Barbarisa Sein gebied is deze plooiing niet direct waarneembaar, maar de stand van de hoofdfase plooiassen suggereert wel een zeer flauwe plooiing voorafgaand aan de hoofdfase.
In de regionaal metamorfe gesteenten van de Cinqueta de la Pez eenheid komt een foliatie voor, die ouder is dan de hoofdfase foliatie. Een directe correlatie van deze oudere foliatie met de NE-SW gerichte plooien in de niet regionaal metamorfe gesteenten is echter niet mogelijk.

Fase 2. Tijdens deze fase, de belangrijkste plooiingsfase van de Hercynische orogenese, ontstonden grootschalige nauwe tot isoclinale plooien met een goed ontwikkelde assenvlaks-cleavage in het grootste gedeelte van hoofdeenheid A. Deze cleavage heeft doorgaans een zeer constante WNW-ESE gerichte strekking. De helling daarentegen vertoont een waaiering op zeer grote schaal, blijkens de steil S hellende tot verticale standen in het noordelijke en centrale Posets-Pena Blanca gebied, die naar het zuiden overgaan in vlakke N hellingen, zoals die voorkomen in het Barbarisa-Sein gebied.
De structuren, die gedurende de hoofdfase werden gevormd in de regionaal metamorfe gesteenten van de Cinqueta de la Pez eenheid verschillen enigszins van de bovengenoemde; hier ontstonden asymmetrische tot isoclinale plooien van mesoscopische afmetingen met een foliatie parallel aan het assenvlak. Aangezien de vorming van deze foliatie het gevolg is van micro-plooiing van de pré-hoofdfase foliatie, treedt zij te voorschijn als een crenulatie foliatie. Micro-tectonische relaties tussen deze foliatie en porfieroblasten wijzen op een gedeeltelijk gelijktijdig optreden van de metamorfose en de hoofdfase deformatie.

Fase 3. Deze fase blijkt alleen uit een rotatie van genoemde porfieroblasten om N-S gerichte, in de hoofdfase foliatie gelegen assen als gevolg van schuifbewegingen evenwijdig aan de foliatie.

Fase 4. Gedurende deze laatste Hercynische fase werd de hoofdfase cleavage locaal verplooid om E-W gerichte assen. Tevens kwam het opnieuw tot de vorming van een secondaire (fracture of crenulatie) cleavage. Deze structuren zijn slechts redelijk ontwikkeld in het Posets-Pena Blanca gebied.
De intrusie van de Rechanzadas-Descubridores en Cinqueta granodiorieten met de erbij behorende contact metamorfose en het indringen van zure en basische gangen evenwijdig aan de hoofdfase cleavage vond plaats direct voor het begin van de laat-Hercynische vierde fase.
De zuidwaartse kanteling van de Paleozoische gesteenten in het zuidelijk gedeelte van hoofdeenheid B (stratigrafisch venster van San Juan de Plan) vond plaats na de hoofdfase en vóór de vierde fase, maar kon niet nader gedateerd worden.

Post-Hercynische deformaties.
Afgezien van bewegingen langs verticale breuken, die dateren van voor het Perm tot in elk geval na de Trias, vonden de belangrijkste vervormingen plaats gedurende de Alpine orogenese. Na een stadium, waarin plaatselijk intensieve verplooiing plaatsvond van de post-Hercynische bedekking, gepaard met de ontwikkeling van een cleavage die locaal ook het Hercynicum aantast, trad beweging op langs grote vlakliggende opschuivingen (Sahun-Tres Bogas thrust). Latere differentiële opheffing veroorzaakte enkele grote synclinale en anticlinale structuren in het noordwestelijk gedeelte van hoofdeenheid B en was waarschijnlijk verantwoordelijk voor het zuidwaarts afglijden van de Mesozoische bedekking boven de Trias gipsen.

RESUMEN

En la área mapeada se encuentra una sucesión incompleta de rocas con edades probables que remontan del Cambro-Ordovícico al Triásico superior.Los sedimenstos pre-hercínicos generalmente exhiben un dinamo-metamorfismo de bajo grado al que se superpuso un metamòrfismo termico causado por la intrusión de las granodioritas tarde-hercínicas.Hay rocas que muestran un metamorfismo regional en la parte septentrional del terreno.
Se distinguen varias unidades lito-estratigráficas:
El complejo de Cinqueta de la Pez,compuesto por micacitas,filitas y cuarcitas; La Formación de Viladós,compuesta por pizarras y cuarcitas,representando el equivalente poco metamórfico de las rocas que consuyen el complejo de Cinqueta de la Pez;La Formación de Madera,compuesta por pizarras carbonosas atribuidas al Gotlandense;Encima de la formación precedente,hay una alternación de calizas y pizarras en la cual se reconocen cuatro formaciones,que han sido atribuidas al Devónico inferior:La Formación de Puyaresto (calizas margosas y pizarras en alternación rapida);La Formación de Ardaña (calizas macizas);La Formación de Sein (pizarras con algunas calizas margosas,frecuentemente transformadas en filitas calcicas,en la parte superior;La Formación de Barbarisa (calizas margosas,calci-filitas que alternan rápidamente con pizarras débiles.
La sucesión pre-hercínica termina en pizarras micáceas de la Formación de Sahun (posiblemente de edad carbonífero.
El paleozoico cristalino está representado por las granodioritas de Rechanzadas-Descubridores y de Cinqueta.

El paleozoico pre-hercínico está cubierto por la Formación de Poma-Viciele (areniscas,conglomerados y lutitas rojas) del Permico y del Triásico inferior,que está cubierta por calizas,carneolas,lutitas con yeso y yeso puro del Triásico medio y superior.

Los movimientos hercínicos alcanzaron su intensidad mayor durante el Carbonífero medio.Han sido reconocidas varias fases de deformación:
La primera de ellas produjo pliegues orientados aproximadamente NE-SW,sin desarrollo de crucero,en las rocas de bajo grado de metamorfismo.En los terrenos,que muestran metamorfismo regional hay una escistosidad paralela a la estratificación anterior a la fase principal.
La segunda fase,la principal,produjo pliegues estrechos o isoclinales acompañados de un crucero de plano axial orientado WNW-ESE.La inclinación del mencionado crucero abanica de posición vertical en el norte a una posición 30^{o}N en el sur.

En los terrenos metamórficos se desarrollaron pliegues isoclinales acompañados por una escistosidad de plano axial superpuesta a la escistosidad de la primera fase.
La tercrea fase de deformación efectuó una rotación interna,causada por deslizamiento a lo largo de la escistosidad de la fase principal,en las rocas metamórficas.Los ejes de rotación están orientados N-S.
La cuarta fase produjo un nuevo plegamiento con desarrollo de un crucero de crenulación de plano axial,orientado E-W.
Las granodioritas de Rechanzadas-Descubridores y de Cinqueta y sus diques acompañantes intruyeron directamente antes de la cuarta fase.
El vuelco de las estructuras de la fase principal de la ventana de San Juan en la parte meridional del terreno se efectuó después de la fase principal,pero antes de la cuarta fase.

Las deformaciones post-hercínicas empezaron por movimientos por fallas verticales, que se remontan desde el pre-Permiano hasta,por lo menos,el Triásico superior.
Sin embargo,deformaciones más importantes se produjeron durante la orogenía Alpina.
Hay un plegamiento local,muy intensivo y acompañado por un crucero de plano axial en los sedimentos post-hercínicos cubriendo dicordantemente los terrenos hercínicos en la parte sudoeste de la área mapeada.
Seguió movimiento por un corrimiento aproximadamente horizontal,el Sahun-Tres Bogas "thrust".
La última fase Alpina produjo movimientos verticales que resultaron en culminaciones en el terreno hercínico autóctono causando al mismo tiempo un deslizamiento gravitacional de cobertera mesozoica

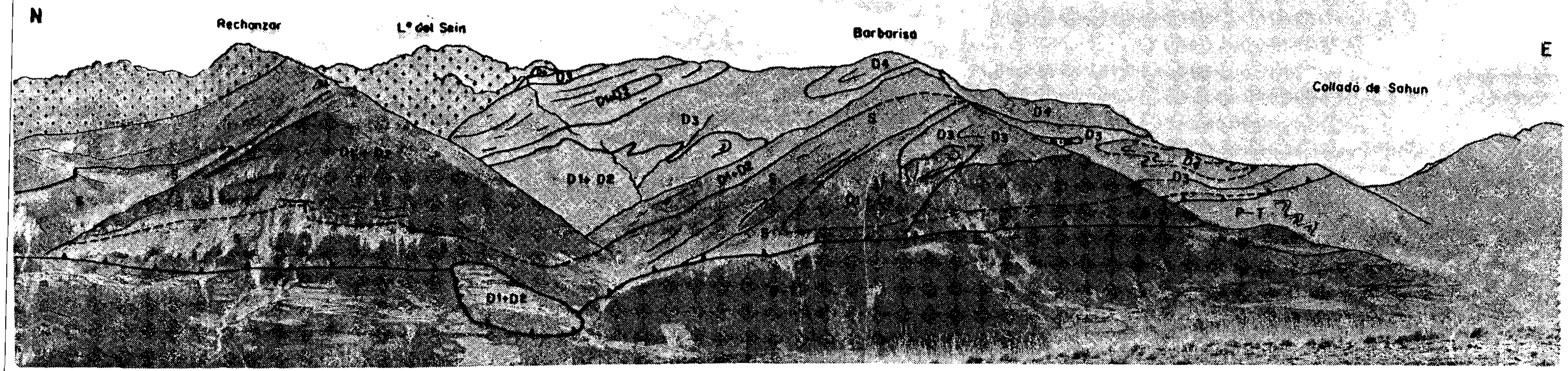
BIBLIOGRAPHY

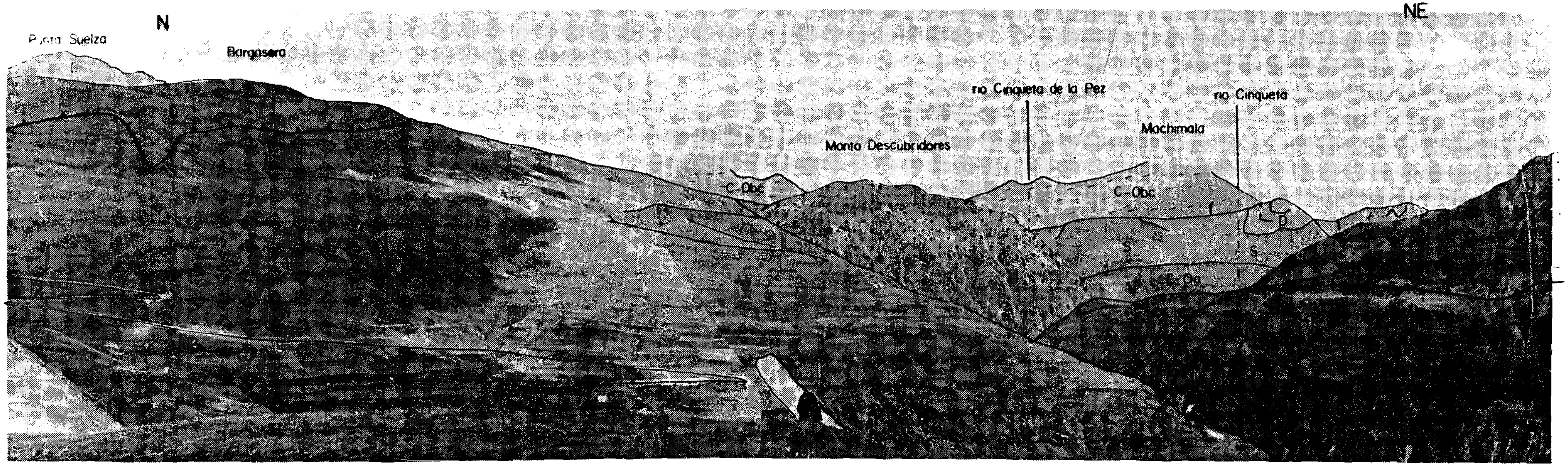
Almela,A.,Rios,J.M. & Alastrue,E.,1957.Explicación al mapa geológico de la provincia de Huesca,escala 1:200.000.Rev.Inst.geol. y minero España,253 p.
Almela,A. & Rios,J.M.,1962.Structures d'ensemble des Pyrénées aragonaises et decouvertes récentes dans cette région.Livre a la mémoire de P.Fallot.
Boersma,Kerst Th.,1973.Devonian and Lower Carboniferous conodont Biostratigraphy,Spanish central Pyrenees.Leidse Geol.Meded. 49,p.303-377.
Boschma,D.,1963.Successive Hercynian structures in some areas of the Central Pyrenees.Leidse Geol.Meded. 28.p.103-176.
Choukroune,P.,1967.Thèse 3^{me}cycle,Paris.
--,1971.Contribution à l'étude du mécanisme de la déformation avec schistosité grâce aux cristallisations syncinematiques dans les"zones abritées" (Pressure shadows).Bull.Soc.Géol.France,1971.
Choukroune,P.,Martinez,Cl.,Seguret,M. & Mattauer,M.,1968.Sur l'extension, le style et l'age de la mise en place de la nappe de Gavarnie (Pyrénées centrales).C.R.Acad,Sc.,vol.266,p.1360-1363.
Choukroune,P. & Seguret,M.,1968.Exemples de relations entre joints de cisaillement,fentes de tension,plis et schistosité.L'autochtone de la nappe de Gavarnie,Pyrénées centrales.Rev.Géog.Phys. et Géol.Dyn. vol.X,fasc.3,p.239-246.
Choukroune,P.,Seguret,M. & Mattauer,M.,1968.Sur quelques caractères géometriques de la nappe de Gavarnie (Pyrénées centrales)C.R.Acad. Sc. vol. 267,p.2088-2091.
Clin,M.,1956.Sur la limite orientale de chevauchement de Gèdre-Gavarnie.C.R.Acad.Sc. vol. 242,p.2374.
--,1959.Etude géologique de la haute chaîne des Pyrénées centrales entre le cirque de Troumouse et le cirque du Lys.Thèse Fac.Sc.Nancy, 379 p.
Clin,M.,Heddebaut,C.,Muller,J. & Roger,P.,1968.Déformations transverses et plis couchés anté-stéphaniens,plis de revêtement pyrénéen dans la haute vallée du rio Gallego (Pyr.Occ.Esp.).C.R.Acad.Sc. vol. 267,p.1131-1132.
Dalloni,M.,1910.Etude géologique des Pyrénées de l'Aragon.Ann.Fac.Sc. Marseille,vol. XIX,436 p.
Degardin,J.,1977.Contribution a l'étude géologique de Silurien de la région de Benasque (Province de Huesca,Espagne).Thèse 3^{me}cycle,Un. Sc.Tecn. Lille.
Fontbote,J.M.,Solé Sabaris,L.,Masachs,V. & Virgili,C.,1956,1958.Elementos estructurales de la zona axial en el alto Ribagorzana.II^{e} Cong. Inst.Est.Pir.,vol. 2,Toulouse,1956.Bol.Real.Soc.Hisp.Nat.,vol. LVI,no.2.
Habermehl,M.A.,1970.Depositional history and diagenesis of quartz-sand bars and lime-mud environments in the Devonian Basibé Formation (Central Pyrenees,Spain).Leidse Geol.Meded. 46,p.1-55.
Hartevelt,J.J.A.,1970.Geology of the upper Segre and Valira valleys, central Pyrenees,Andorra,Spain.Leidse Geol.Meded. 45,p.167-236.
Hobbs,B.E.,Means,W.D. & Williams,P.,1976.An outline of Structural Geology.John Wiley & sons,inc. New York,571 p.
Kleinsmiede,W.F.J.,1960.The geology of the Valle de Arán (Central Pyrenees).Leidse Geol.Meded. 25,p.131-241.
Lith,J.G.J. van,1965.Geology of the Spanish part of the Gavarnie nappe (Pyrenees)and its underlying sediments near Bielsa (province of Huesca).Thesis Utrecht 1965.Geologica Ultraiectina no. 10,67 p.
Llopis Llado,N.,1948.Problemas tectonicas de la zona axial pirinaica. Bol.Inst.Geol. y Minero de España,vol. 59,pp.167-219,Madrid
Mallada,L.,1881.Descripción física y geológica de la provincia de Huesca. Mem.Com.Mapa Geol. de España,vol. 15,439 p.,Madrid.

Martinez,Cl.,1968.Etude structuralde de la région de la Cinqueta-substratum de la nappe de Gavarnie (Pyrénées centrales,Espagne). Thèse 3^{me}cycle,Montpellier,1968,107 p.
Mattauer,M.,1964.Sur les schistosités d'âge tertiaire de la zone axiale hercynienne des Pyrénées.C.R.Acad.Sc. vol. 259,p.2891-2894.
--,1968.Les traits structuraux essentiels de la chaîne pyrénéenne. Rev. de Geogr.Phys. et Géol.Dyn.,vol.X,fasc.1,p.1-13.
Mattauer,M. &Seguret,M.,1966.Sur le style de déformations tertiaires dans la zone axiale hercynienne des Pyrénées.C.R.som.Soc.Géol.France., fasc.1,p.10-11.
Mey,P.H.W.,1967.The geology of the upper Ribagorzana and Baliera valleys,Central Pyrenees,Spain.Leidse Geol.Meded. 41,p.153-220.
--,1968.Geology of the upper Ribagorzana and Tor valleys,Central Pyrenees,Spain.Leidse Geol.Meded. 41,229-292.
Mirouse,R.,1962.Recherches géologiques dans la partie occidentale de la zone primaire axiale des Pyrénées.Toulouse,thèse doctoral,Sc.Nat., 2 vol.,672 p.
Misch,P.,1934.Geologie der mittleren sudpyreneen.Abh.Ges.Wiss. Göttingen Math.Phys.Kl.T.III,H.12,p.1597-1764,Berlin.
Muller,J.,1967.Sur la superposition des déformations dans les Pyrénées occidentales.C.R.Acad.Sc.Fr.,vol. 265,p. 400-402.
Nagtegaal,P.J.C.,1969.Sedimetology,Paleoclimatology and Diagenesis of post-Hercynian continental deposits in the south-central Pyrenees, Spain.Leidse Geol.Meded. 42,p.143-238.
Oele,J.A.,1966.The structural history of the Vall Ferrera area,the transition zone between the Aston massif and the Salat-Pallares anticlinorium (Central Pyrenees).Leidse Geol.Meded. 38,,p.129-164.
Ramsay,J.G.,1962.The geometry and mechanics of formation of "similar" type folds.Journal Geol. 70,p.75-93.
--,1964.The uses and limitations of beta-digrams and pi-diagrams in the geometrical analysis of folds.Geol.Soc.London Quart.Journal,120,p. 435-454.
--,1967.Folding and fracturing of rocks.McGraw-Hill,New York,568 p.
Rutten,M.G.,1955.Nota preliminar sobre la geología de los Pirineos de la provincia de Huesca.Est.Geol. no.25,p.19-26,Madrid.
--,1969.The geology of Western Europe.Elsevier,Amsterdam,520 p.
Schmidt,H.,1931.El Paleozoico del Pirineo Español.Trad. in:Publ.alemanas sobre geol de España,vol. II,1943,p.100-194.
Seguret,M.,1969.Contribution à l'étude de la tectonique sud-pyrénéenne: sur le style et l'importance des déplacements ver le sud des séries secondaires et tertiaires de la partie centrale du versant sud des Pyrénées.C.R.Acad.Sc.Fr. vol. 268,p.907-910.
--,1971.Etude tectonique des nappes et des séries décollées de la partie centrale du versant sud des Pyrénées.Publ.Ustela,Montpellier.Série Géol.Struct.,no.2,160 p.
Seguret,M. &Proust,F.,1968.Contribution à l'étude des tectoniques superposées dans la chaîne hercynienne:l'allure anticlinale de la schistosité à l'Ouest d'Aston (Pyrenees centrales).C.R.Acad.Sc.Fr.,vol. 266,p.317-320.
--,1968.Tectonique hercynienne des Pyrénées centrales:signification des schistosités redressées,chronologie des déformations.C.R.Acad.Sc. Fr.vol. 266,p.984-987.
Sitter,L.U. de,1956.A cross section through the Pyrenees.Geol.Rundsch., vol. 45,p.214-233.
--,1964.Structural Geology,2nd ed.McGraw-Hill,New York,551 p.
--,1965.Hercynian and Alpine orogenies in northern Spain,Geol.Mijnb., 44,p.373-383.
Sitter,L.U. de & Zwart,H.J.,1960.Tectonic development in supra- and infrastructures of a mountain chain.21 Intern.Congr.Rep.,vol. 18

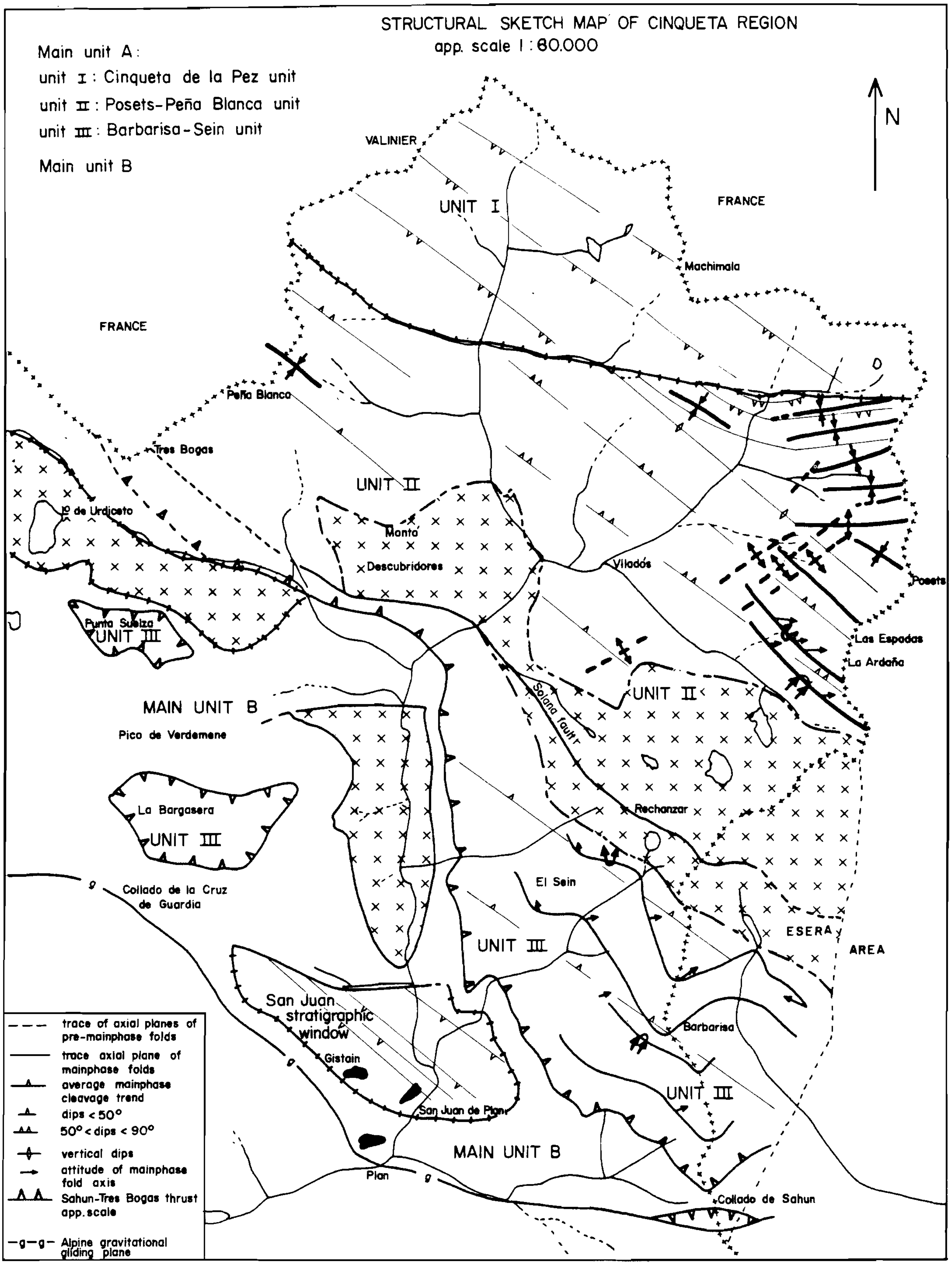
p.248-256.
Spry,A.,1969,Metamorphic textures.Pergamon Press,Oxford,350 p.
Turner,F.F. & Weiss,L.E.,1963.Structural analysis of metamorphic rocks. McGraw-Hill, New York,545 p.
Velde,E. van de,1967.Geology of the Ordesa overthrust mass,Spanish Pyrenees,province of Huesca,Thesis Utrecht,1964.Est.Geol. 26,p.163-201. Madrid.
Wennekers,J.H.N.,1968.The geology of the Esera valley and the Lys-Caillouas massif,sheet 7,Central Pyrenees,Spain-France.unpublished thesis,Leiden.
Wensink,H.,1962.The Paleozoic of the upper Gallego and Ara valleys,Huesca province,Spanish Pyrenees.Thesis Utrecht 1961.Est.Geol. vol.18,p.1-74.
Whitten,E.H.Th.,1966.Structural Geology of folded rocks.Rand & McNally editorial comp.,New York,663 p.
Winkler,H.G.F.,1967.Petrogenesis of Metamorphic rocks,2nd ed. Springer Verlag,NewYork.
Zandvliet,J.,1960.The geology of the Upper Salat and Pallaresa valleys, Central Pyrenees,France-Spain.Leidse Geol.Meded. 25,p.1-127.
Zwart,H.J.,1960.Relation between folding and metamorphism in the Central Pyrenees and their chronological succession.Geol.Mijnb.,22,p.163-180.
----------,1962.On the determination of polymetamorphic mineral associations and its application in the Bosost area (Central Pyrenees).Geol.Runsch. 52, p.38-65.
----------,1963.Metamorphic history of the central part of the Pyrenees,part 2,Valle de Arãn,sheet 4.Leidse Geol.Meded.,28,p.321-326.
----------,1963.The structural evolution of the Paleozoic of the Pyrenees. Geol.Runsch.,53,p.170-205.
Zwart,H.J. & Mey,P.H.W.,1965.Quelques remarques sur la schistosité et la zone des Nogueras dans les Pyrenees.C.R.som.Soc.Géol.France 3,p.107-108.

Internal reports :
Wessels Boer, H.R.,1961,1962.
Freudenthal, T.,1962.
De Jong, B.H.,1964.
Van Vreumingen,M.J.,1968.





Panoramic view of the Cinqueta area,
seen from La Codera.



STRUCTURAL SKETCH MAP OF CINQUETA REGION
app. scale 1 : 60.000
Main unit A:
unit I : Cinqueta de la Pez unit
unit II : Posets-Peña Blanca unit
unit III : Barbarisa-Sein unit
Main unit B
N
VALINIER
FRANCE
UNIT I
Machimala
FRANCE
Peña Blanca
Tres Bogas
UNIT II
Io de Urdiceto
Monta
Descubridores
Vilados
Posets
Punta Suelza
UNIT III
Las Espadas
La Ardaña
UNIT II
Solana fault
MAIN UNIT B
Pico de Verdemene
La Bargasera
UNIT III
Rechanzar
Collado de la Cruz de Guardia
El Sein
ESERA AREA
UNIT III
San Juan stratigraphic window
Barbarisa
Gistain
UNIT III
San Juan de Plan
MAIN UNIT B
Plan
Collado de Sahun
trace of axial planes of pre-mainphase folds
trace axial plane of mainphase folds
average mainphase cleavage trend
dips < 50°
50° < dips < 90°
vertical dips
attitude of mainphase fold axis
Sahun-Tres Bogas thrust app. scale
Alpine gravitational gliding plane

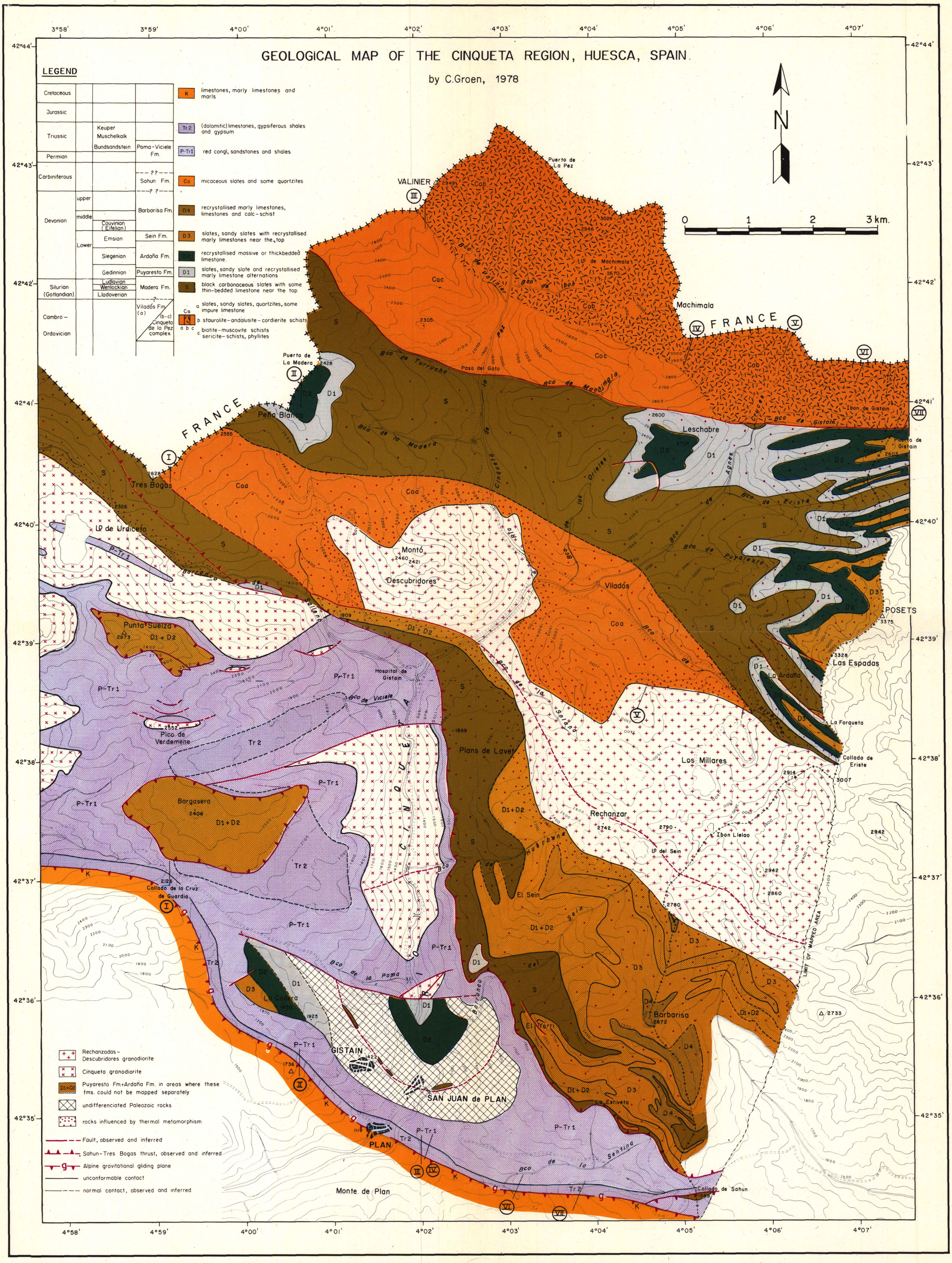
Errata

To our regret the geological map and sections still show some imperfections.
Map:SE of La Estiveta ($4^{\circ}04'20''$ $42^{\circ}34'50''$) a"horse" of D1 limestones has been designated by D3 colours.

N of the Collado de Sahun ($4^{\circ}05'$ $42^{\circ}35'$)slates of the Sahun Fm.(Ca) have been designated by the colours of the Madera Fm.(S).

N of la Forqueta ($4^{\circ}06'30''$ $42^{\circ}38'25''$) a small wedge of D1 limestones has been designated by D3 colours.

Sections:the Sahun Tres Bogas thrust below the Punta Suelza and the Bargasera (section I and II) have not been designated as such.



GEOLOGICAL MAP OF THE CINQUETA REGION, HUESCA, SPAIN.
by C.Groen, 1978
LEGEND
Cretaceous
Jurassic
Triassic
Keuper
Muschelkalk
Bundsandstein
Poma-Viciele Fm.
Permian
Carbiniferous
Sahun Fm.
Devonian
upper
middle
Couvinian (Eifelian)
Lower
Emsian
Siegenian
Gedinnian
Barbarisa Fm.
Sein Fm.
Ardaña Fm.
Puyaresto Fm.
Silurian (Gotlandian)
Ludlovian
Wenlockian
Lladoverian
Madera Fm.
Cambro-Ordovician
Viladós Fm (a)
(b-c) Cinqueta de la Pez complex
K limestones, marly limestones and marls
Tr 2 (dolomitic) limestones, gypsiferous shales and gypsum
P-Tr1 red congl, sandstones and shales
Ca micaceous slates and some quartzites
D4 recrystallised marly limestones, limestones and calc-schist
D3 slates, sandy slates with recrystallised marly limestones near the top
D2 recrystallised massive or thickbedded limestone.
D1 slates, sandy slate and recrystallised marly limestone alternations
S black carbonaceous slates with some thin-bedded limestone near the top
Co
a. slates, sandy slates, quartzites, some impure limestone
b. staurolite-andalusite-cordierite schists
c. biotite-muscovite schists sericite-schists, phyllites
Rechanzados-Descubridores granodiorite
Cinqueta granodiorite
D1+D2 Puyaresto Fm.+Ardaña Fm. in areas where these fms. could not be mapped separately
undifferenciated Paleozoic rocks
rocks influenced by thermal metamorphism
Fault, observed and inferred
Sahun-Tres Bogas thrust, observed and inferred
Alpine gravitational gliding plane
unconformable contact
normal contact, observed and inferred
N
0 1 2 3 km.
FRANCE
GISTAIN
SAN JUAN de PLAN
PLAN
Monte de Plan
POSETS
Las Espadas
Los Millares
Viladós
Montó
Descubridores
Rechanzar
Barbarisa
Leschabre
Machimala
Tres Bogas
Peña Blanca
Punta Suelza
Pico de Verdemene
Bargasera
Plans de Lavet
El Sein
La Ardaña
La Forqueta
Collado de Eriste
Collado de la Cruz de Guardia
Collado de Sahun
Puerto de La Madera
Puerto de La Pez
Puerto de Gistain
VALINIER
LIMIT OF MAPPED AREA

STRUCTURAL SECTIONS OF THE CINQUETA REGION by C. GROEN, 1978

Scale 1 : 40.000