GEOLOGICA ULTRAIECTINA

Mededelingen van
het Mineralogisch-Geologisch Instituut der Rijksuniversiteit
te Utrecht

No. 10

GEOLOGY OF THE SPANISH PART OF THE GAVARNIE NAPPE (Pyrenees) AND ITS UNDERLYING SEDIMENTS NEAR BIELSA (Province of Huesca)

J.G.J. VAN LITH

GEOLOGY OF THE UPPER CRETACEOUS AND PART OF THE LOWER TERTIARY BETWEEN THE RIO ARAGON SUBORDAN AND THE RIO GALLEGO (SPANISH PYRENEES, PROVINCE OF HUESCA)

G.F.J. JEURISSEN

GEOLOGY OF THE UPPER CRETACEOUS AND PART OF THE LOWER TERTIARY BETWEEN THE RIO ARAGON SUBORDAN AND THE RIO GALLEGO

(SPANISH PYRENEES, PROVINCE OF HUESCA)

G.F.J. JEURISSEN

Aan mijn ouders
Aan Brigitta

CONTENTS

SUMMARY 6

1. INTRODUCTION AND MORPHOLOGICAL REMARKS 9
1.1. INTRODUCTION 9
1.1.1. Location 9
1.1.2. Purpose of the study 9
1.1.3. Methods of investigation 9
1.1.4. Previous writers 10
1.2. MORPHOLOGICAL REMARKS 10
1.2.1. Relief 10
1.2.2. Glaciation 10
1.2.3. Karst phenomena 12
1.2.4. Postglacial erosion 12

2. STRATIGRAPHY 12
2.1. INTRODUCTION 12
2.2. A-FORMATION 15
2.2.1. Introduction 15
2.2.2. Aa-member 15
2.2.3. Ab-member 15
2.2.4. Ac-member 18
2.2.5. Ad-member 18
2.2.6. Ae-member 18
2.2.7. Af-member 18
2.2.8. Conclusions about the age of the A-formation 20
2.3. B-FORMATION 20
2.3.1. Introduction 20
2.3.2. Bg-member 21
2.3.3. Bh-member 21
2.3.4. Bi-member 22
2.3.5. Bj-member 22
2.3.6. Bk-member 22
2.3.7. Bl-member 22
2.3.8. Bm-member 24
2.3.9. Conclusions about the age of the B-formation 24
2.4. C-FORMATION 24
2.4.1. Introduction 24
2.4.2. Cn-member 25
2.4.3. Co-member 25
2.4.4. Cp-member 26
2.4.4.1. Cp_{1-2}-bed 26
2.4.4.2. Cp_3-bed 26
2.4.4.3. Cp_4-bed 26
2.4.4.4. Cp_5-bed 26
2.4.5. Cq-member 27
2.4.6. Conclusions about the age of the C-formation 27
2.5. D-FORMATION 28
2.5.1. Introduction 28
2.5.2. Dr-member 28
2.5.3. Ds-member 29
2.5.4. Conclusions about the age of the D-formation 29

2.6. ENVIRONMENT OF DEPOSITION 29
2.6.1. Introduction 29
2.6.2. A-formation 29
2.6.3. B-formation 29
2.6.4. C-formation 30
2.7. CORRELATION WITH NEIGHBOURING REGIONS 30
2.7.1. Introduction 30
2.7.2. A-formation 30
2.7.3. B-formation 30
2.7.4. C-formation 49
2.7.5. D-formation 49
3. STRUCTURAL GEOLOGY 49
3.1. INTRODUCTION 49
3.1.1. Structural Setting 49
3.1.2. Structural Hystory 49
3.1.3. Main structural features 50
3.2. TECTONIC UNITS 52
3.2.1. Blanca Unit 52
3.2.2. Telera Unit 52
3.2.3. Retona Unit 53
3.2.4. Somolla Unit 53
3.2.5. Collarada Unit 54
3.2.6. Lecherines Unit 54
3.2.7. Garganta Unit 54
3.2.8. Aspe Unit 55
3.2.9. Bernera Unit 55
3.3. TECTONIC CONSIDERATIONS 55
3.3.1. Introduction 55
3.3.2. Basal detachment fault 56
3.3.3. Major internal low angle faults 56
3.3.4. Bedding plane faults 57
3.3.5. Transverse high angle faults 57
3.3.6. Conclusion 58
3.4. ORIGIN OF THE TECTONIC STRUCTURES 58
3.5. DATING OF THE ALPINE OROGENETIC MOVEMENTS 59
BIBLIOGRAPHY 70

SUMMARY

This study deals with the stratigraphy and the tectonics of the Upper Cretaceous and part of the Lower Tertiary between the Río Aragón Subordán (western boundary) and the Río Gállego (eastern boundary) in the Spanish Western Pyrenees. The thesis forms part of the geological investigations carried out in the Spanish Western Pyrenees by students of the Geological Institute of the State University of Utrecht, Holland, under the direction of Prof. M.G. Rutten.

STRATIGRAPHY

Following Van Elsberg (1968) the Upper Cretaceous and Lower Tertiary sediments are divided into informal A-B-C- and D-formations.

A-formation (Cenomanian-Turonian-Coniacian-Santonian).

In this formation which is about 175 m thick, two light-grey massive limestone units are typical for almost the entire region. Both between and above these clearly recognizable units, well bedded limestone occur which are strongly variable in grain-size and colour. Mostly, however, they are coarse-grained and red-coloured, owing to ferruginous material.

B-formation (Campanian-Maastrichtian)

This formation ranges in thickness from 380 m - 540 m. A yellowish-to-brown weathering colour is characteristic for this unit. It shows a predominantly calcareous development. In general it is composed of an alternation of marly limestones, either with limy marls, or with competent limestones. Only in the extreme western part do marls occur. Various amounts of quartz grains, ferruginous material and mica flakes are present throughout the entire B-formation. With the exception of the uppermost part of the A-formation mica flakes are encountered in the B-formation only.

C-formation (Paleocene)

The C-formation is about 130 m thick. In contrast to the yellowish-to-brown weathering colour of the B-formation this formation is, in general grey weathered. The absence of mica flakes and the occurrence of quartz and ferruginous material in a few members only, is also contrasting to the B-formation. The most characteristic sediments are : dolomites and dolomitic limestones at the base; limestones with Lithothamnium in the middle part; and limestones with chert nodules in the uppermost part.

D-formation (Paleocene-Eocene)

The D-formation which has an estimated thickness of 1 km - 2 km, is mainly composed of Flysch deposits. Only the lowermost part has a different development. This part consists of limestones which display well-developed fracture cleavage. Locally within these limestones marine slope breccies occur as lense-shaped bodies. However, in the greater part of the region this lowermost part of the D-formation is absent.

The main part of the D-formation, the Flysch deposits, have not been studied by the present writer.

The A-B-C- and D-formations are correlated by means of lithological and faunal data with the neighbouring regions studied by Van Elsberg (1968), Van der Voo (1961) and Van De Velde (1968). Moreover, a comparision of geochronological interpretations by different writers is given of these formations and their lithostratigraphic correlatives.

The sedimentary cover of Upper Cretaceous to Eocene sediments (A-B-C- and D-formations) forms part of the southern external zone of the Western Pyrenees, at least in the interpretation of Jacob (1930) and Rutten (1967). These sediments generally have an ESE-WNW strike and a southern dip.

The main structural features are :

(1) A Basal detachment fault.
(2) Internal low angle faults, in combination with thrust folds.
(3) Bedding plane faults, in combination with disharmonic folds.
(4) Transverse high angle faults.

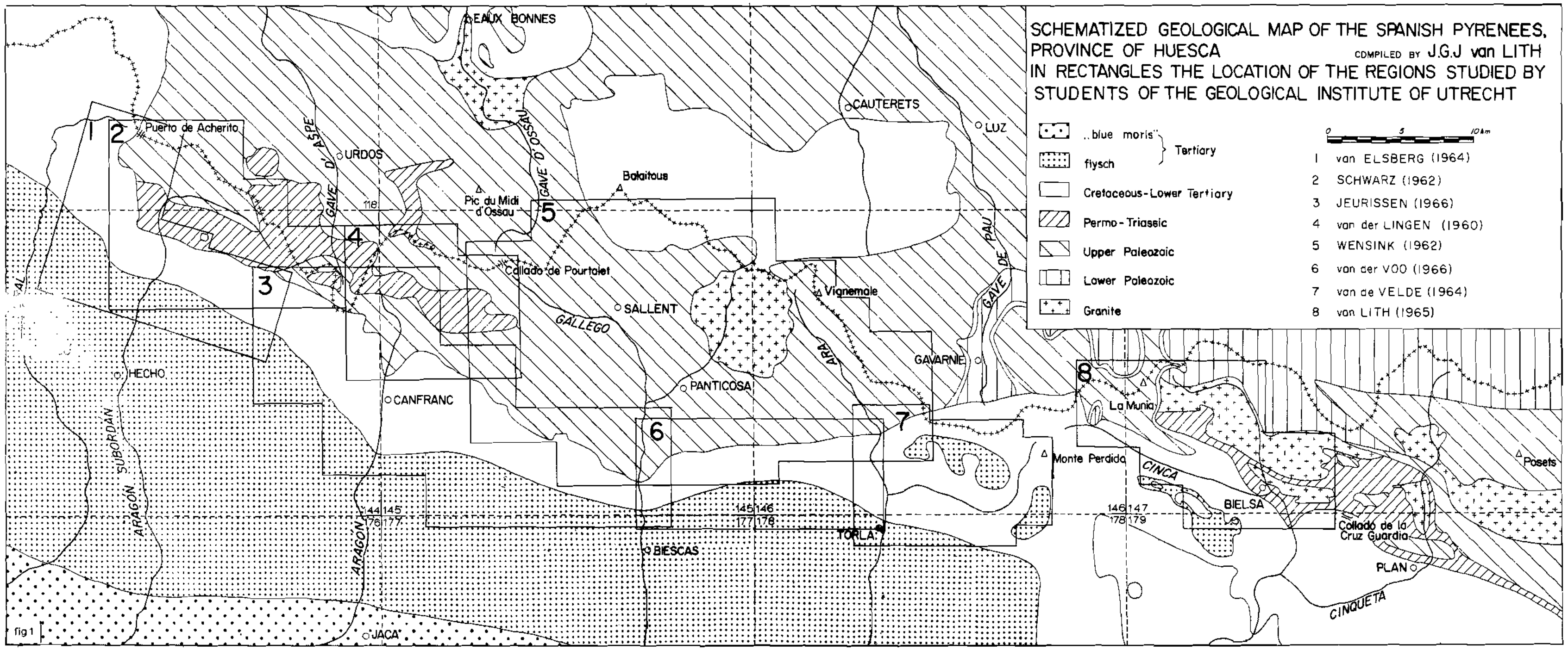
Few data are available about the movement over the basal detachment fault plane, since the exposures of this fault plane are scarce and only found along the northern boundary of the region. At these localities the fault plane coincides with the lower boundary of the sedimentary cover and separates gently S-dipping and ESE-WNW striking Upper Cretaceous sediments from, generally N-dipping and E-W striking Devonian and Carboniferous deposits. These Paleozoic rocks belong to the southern flank of the axial zone which form the basement of the Upper Cretaceous to Lower Tertiary sediments. The direction and the amount of displacement over the basal fault plane could not be established. However, we may conclude to a southward movement since all other movements within the sedimentary epidermis are southward directed. Moreover Van Lith (1968) established a southward movement along the same fault plane in the Cinca region.

Apart from the southward movement along the basal fault plane, internal southward movements along major low angle fault planes have taken place within the sedimentary epidermis. These internal southward movements cause repetition of the stratigraphic sequences, by forming piles of thrust slices. These thrust slices are in fact minor scale nappes of the Helvetian type. The amounts of minimum southward overlap range from 0,1 km to 2 km. The most striking example of the imbricated structure originating by these differential movements along major low angle faults, is found in the Western part of the region of study (e.g. Bernera Unit).

Besides these important internal movements also smaller differential movements along swarms of bedding plane faults do occur. The alternation of marly limestones either with limy marls or with still more competent limestones in the B-formation has permitted such movements. These movements are evidenced by locally observed down-dip striation on the bedding planes, which indicates southward movements.

The combination of both, southward movements along major low angle fault planes and along bedding planes, resulted in tectonic structures in which the higher strata have advanced farther southward than the lower ones. (German : 'Das Voraneilen der jüngeren Schichten').

The fourth important tectonic element that has to be discussed is formed by the transverse high angle faults. The orientation of these faults ranges from N to N 30° E and the dip from vertical to 60° E. These faults do not penetrate into the basement. They obviously made possible a differential southward movement of the sedimentary epidermis in semi-independantly advancing tectonic units; they are in fact strikeslip faults. However, it is not possible to establish the amount of displacement along such a transverse high angle fault. These faults are too complex to define them with merely one figure for the horizontal off-set, since three types of differential southward movements have been active along the fault planes : over the basal fault plane, over major internal low angle planes and over swarms of bedding planes. Consequently the amounts of horizontal off-set along these transverse faults change vertically as well as horizontally along their fault planes.


SCHEMATIZED GEOLOGICAL MAP OF THE SPANISH PYRENEES,
PROVINCE OF HUESCA
COMPILED BY J.G.J van LITH
IN RECTANGLES THE LOCATION OF THE REGIONS STUDIED BY STUDENTS OF THE GEOLOGICAL INSTITUTE OF UTRECHT
"blue marls"
flysch
Tertiary
Cretaceous-Lower Tertiary
Permo-Triassic
Upper Paleozoic
Lower Paleozoic
Granite
0 5 10 km
1 van ELSBERG (1964)
2 SCHWARZ (1962)
3 JEURISSEN (1966)
4 van der LINGEN (1960)
5 WENSINK (1962)
6 van der VOO (1966)
7 van de VELDE (1964)
8 van LITH (1965)
EAUX BONNES
CAUTERETS
LUZ
Puerto de Acherito
URDOS
GAVE D'ASPE
GAVE D'OSSAU
Pic du Midi d'Ossau
Balaitous
Collado de Pourtalet
SALLENT
GALLEGO
Vignemale
GAVE DE PAU
GAVARNIE
PANTICOSA
ARA
HECHO
CANFRANC
ARAGON SUBORDAN
ARAGON
La Munia
Monte Perdido
CINCA
BIELSA
Posets
Collado de la Cruz Guardia
PLAN
CINQUETA
BIESCAS
TORLA
JACA
fig 1

Southward movements of the Upper Cretaceous to Eocene sediments in the Spanish Western Pyrenees have been described by Van Elsberg (1968), Schwartz (1962), Van Der Lingen (1960), Wensink (1962), Van Der Voo (1961, 1967), Van de Velde (1968) and Van Lith (1968), all students of the Geological Institute of the State University of Utrecht. In order to obtain a clearer insight into the structural evolution, the main structural features described in some of the above papers are discussed in relation with the tectonics of the region of study. It is shown that the region under discussion forms structurally the transition from an area in which no important southward movements have taken place (Aragón Subordán region, described by Van Elsberg) to areas in which considerable southward movements are established (Ordesa region, described by Van De Velde and Cinca region, described by Van Lith). Apparently there occurred a general eastward increase of the southward movements of the Upper Cretaceous to Lower Tertiary epidermis. This can most probably be explained by an increase in the same direction of the Alpine uplift of the axial zone of the Pyrenees, which resulted in an increase from west to east of the potential relief energy. It is this gravitational energy accumulating during the vertical uplift, which was the cause of the tectonic movements of the sedimentary epidermis and which gave rise to the structures of the Upper Cretaceous to Lower Teritiary sediments, nowadays exposed in the southern flank of the Western Pyrenees.

1. INTRODUCTION AND MORPHOLOGICAL REMARKS

1.1. INTRODUCTION.

1.1.1. Location

The region investigated is situated n the Spanish Western Pyrenees, province of Huesca (figure 1).
The eastern boundary is formed by the Río Gállego (Río = river), the western one by the watershed between the Río Estarrón (a tributary of the Río Aragón) and the Río Osia (a tributary of the Río Aragón Subordán). Southwards the region is bounded by a series of often nameless brooklets, which follow the structural strike. For instance in the central part, south of the Peña Somolla (see geologic map). The region is limited towards the north by, in general, Palezoic rocks.

Up to now six theses and one publication have appeared or are in press : Van Der Lingen, 1960; Wensink, 1962; Schwartz. 1962; Van Elsberg, 1968; Van De Velde, 1968; Van Lith, 1968 and Van de Voo, 1967. The location of these regions are indicated in figure 1.

The present paper has been set up to get an insight in the structural geology and stratigraphy of the Upper Cretaceous and Lower Tertiary sediments. Special attention is given to the correlation of the structural and stratigraphic features with those of the neighbouring region.

1.1.2. Purpose of the study.

This thesis forms part of the geological investigations, carried out in the Western Pyrenees by students of the Geological Institute of the State University of Utrecht, The Netherlands. These studies are directed by professor Dr. M.G. Rutten.

1.1.3. Methods of investigation.

The geologic mapping was carried out during the summers of 1961, 1962 and 1964. Use was made of the topografical maps, sheet 144 (ANSO), 145 (SALLENT) and 177 (BIESCAS), scale 1: 50.000, published by the Direction General Del Instituto Geographico y Catastral de Madrid. These maps have been photographically enlarged to a scale 1 : 20.000 to enable detailed mapping.

The laboratory work was done in the Geological Institute of Utrecht, where also the collections are deposited. This laboratory work embraces the paleontological and sedimentological study of thin sections. The determination of the foraminifera was carried out by Dr. J.E. Van Hinte (E.P.R.E. - 213 cours Victor Hugo-Bègles-Dép. Gironde France).

1.1.4. Previous writers.

Lucas Mallada (1878, 1881) has given a description of the geology of the Huesca province. Carez (1882) studied the Mesozoic and the Teriary of northern Spain. Dalloni (1910) made a general study of the Pyrenees of Aragón, Selzer (1934) of the Sierras of the Pyrenees of Aragón. Most recently Souquet (1964) studied in detail part of the Cretaceous Series in the Western Pyrenees. In the region under discussion, Souquet investigated the stratigraphy of the lowermost part of the Upper Cretaceous (see 2.2.8.). Lels (1963, internal report) studied the central part of this thesis.

1.2. MORPHOLOGICAL REMARKS

1.2.1. Relief

The highest peaks are found along the southern boundary of the region of study. The lowest topographical points are found 4 km south of Canfranc (1000 m) in the Aragón Valley and near Polituara (980 m) in the Gállego Valley.

The highest peaks are all composed of massive light-grey weathered limestones of the C-formation (2.4.). Viewed from a northern direction these light-grey tops contrast with the underlying yellowish-to-brown strata of the B-formation (2.3.). To the distinct ESE-WNW ridge formed by these mountain tops belong from west to east: Macizo De Bernera (2566); Aspe (2636 m), Garganta De Borau (2503 m) Lecherines Alto (2364 m), Collarada (2886 m), Somolla (2700 m), Retona (2724 m), Puerto Rico (2762 m), Zarrambucho (2564 m), Telera (2764) and Blanca (2541 m). Towards the west this chain extends into the Visaurin (2668 m), Agüerri (2420 m), Forca (2390 m) and Alano (2159 m). Towards the east the extension is formed by the Sierra De Tendeñera (2600 m - 2800 m). The northern slopes of this chain always constitute an escarpment as a result of the easily weathered limestones of the underlying B-formation. The southern slopes are gentle dip-slopes composed of the massive light-grey limestones which are found also on top of the mountain chain. In the western and central part of the region another ridge is present which is composed of limestones of the middle part of the B-formation (dolomite level and overlying competent limestones, 2.3.). To this ridge which is less pronounced than the foregoing belong: the peaks between the Tortiellas Alto and the Tortiellas bajo (alto = high bajo = low) and the tops north of the Collarada.

Southwards of these longitudinal mountain chains the Flysch deposits are exposed of which the morphology differ considerably. Much gentler slopes and rounded forms are characteristic for this formation. Three important transverse valleys intersect the whole Upper Cretaceous to Eocene Mountain chain from north to south. From west to east: The Aragón Valley, the Aurín Valley and the Gállego Valley. The Río Aurín is a tributary of the Río Gállego. The minor tributaries of the Río Aragon, Río Aurín and Río Gállego follow in general the structural strike (subsequent rivers).

1.2.2. Glaciaton.

During the Pleistocene most parts of the region of study have largely been covered by ice. Morainic deposits are scarce in the region. They are only found in the Aragón Valley, 10 km S of Canfranc and in the Gállego Valley 2 km S of Polituara.

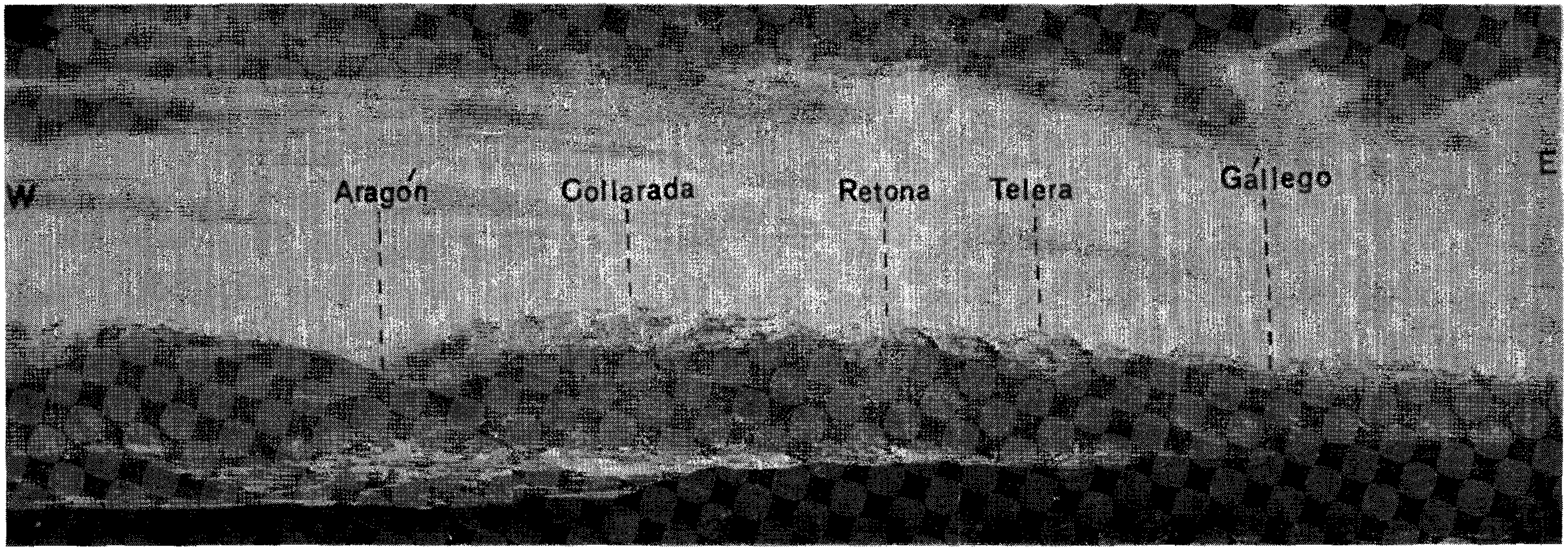


Fig. 2 Panoramic view of the Upper Cretaceous to Lower Tertiary mountain chain, form El Monasterio De San Juan De La Peña (30 km SW of Jaca).

Cirques are common features at attitudes above 1600 m. For instances, in the central part: The upper Escarra Valley, the upper Aurín Valley, Circo de Ip; in the western part: Tortiellas Alto, Tortiellas bajo and the upper Aspe Valley. The Ibón (ibón = lake) De Ip, Ibón De Tortiellas Ibón De Bucuesa are glacial lakes, which evidently originated by local overdeepening of the valleys by the glaciers.

1.2.3. Karst Phenomena.

Clints have been observed in the massive limestones of the A- and C-formations (fig. 3). Dolines are common in the massive limestones of the C-formation.
The Barranco (=mountain river) De Tortiellas, running W-E in the Tortiellas bajo (west of Canfranc Estación) disappears in a sinkhole; the Ibón the Tortiellas Bajo is only filled with water in early springtime.

1.2.4. Postglacial Erosion.

After the retreat of the ice, fluviatile erosion attacked the glacial relief. Locally the valleys are filled with alluvial deposits. A distinct example of an alluvial plain is found in the eastern part of the region, in the valley of the Barranco Del Puerto, a tributary of the Río Gállego (southwest of Polituara). The two important Valleys of the Río Aragón and the Río Gállego are locally deeply incised by the fluviatile erosion.
The Flysch deposits of the main mountain chain are strongly attacked by gully erosion.

2. STRATIGRAPHY

2.1. INTRODUCTION

The oldest deposits of the region investigated consist of limestones of Cenomanian-Turonian age, whereas the youngest are formed by Limestones and limy marls of Late Paleocene age.
The rocks are, in general, very well exposed, except on the lower valley slopes which are locally covered with woods. Along the northern boundary of the region the Cretaceous sediments are separated from the Permo-Triassic and older Paleozoic rocks by an angular uncomformity (figure 4). Along the southern boundary the Lower Tertiary sediments are comformably (?) overlain by flyschtype deposits of Eocene age.
The data concerning the Permo-Triassic and older Paleozoic rocks have been taken from van Lingen (1960), Schwartz (1962) and Wensink (1962). Following van Elsberg (1968), four informal rock stratigraphic units are distinguished: The A- B- C- and D-formations. Each formation is divided into members and in special cases into beds.

These units are correlated by means of lithological and faunal data (fig. 6.) with the neighbouring regions studied by Van Elsberg (1968), Van De Velde (1968) and Van Der Voo (1961, internal report).
Figure 1 shows the location of these regions.
A comparison of geochronologic interpretations by different authors of the A- B- C- and D-formations and their lithostratigraphic correlatives is given in figure 5.
The determination of foraminifera was carried out by Dr. J.E. Van Hinte (E.P.R.E. - 213 cours Victor Hugo-Bègles-Dép. Gironde France).

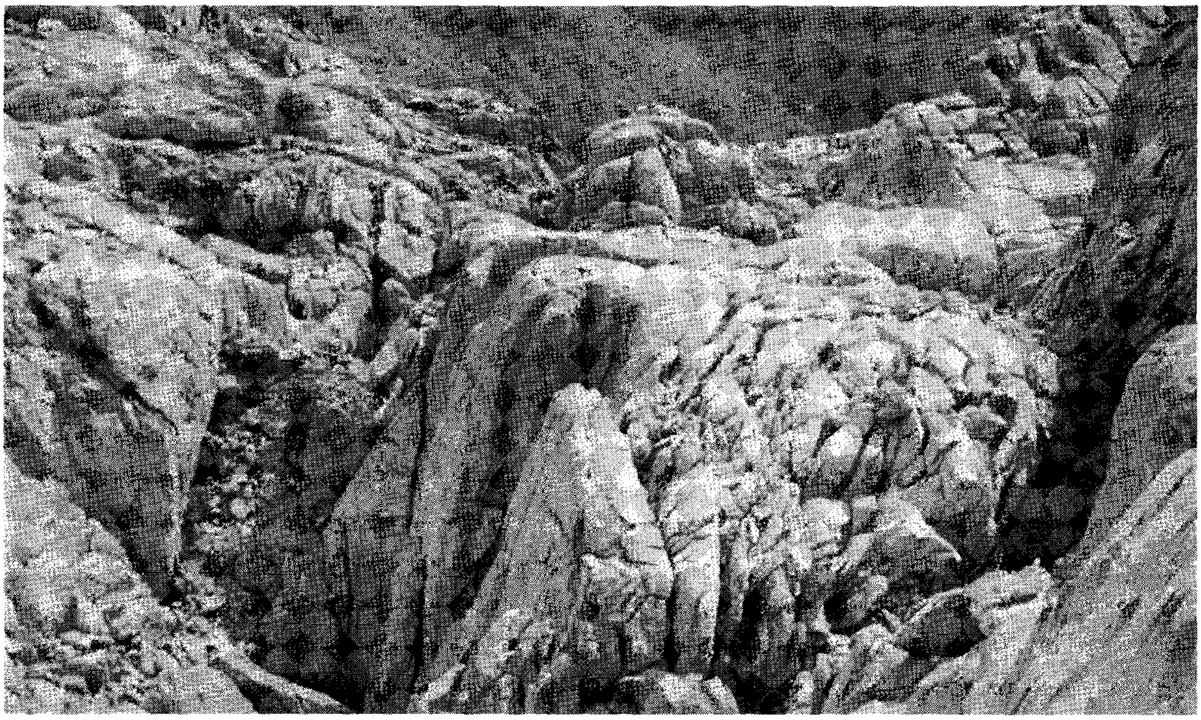


Fig. 3 Clints in the massive limestones of the C-formation (southern slope of the Aspe Mass).

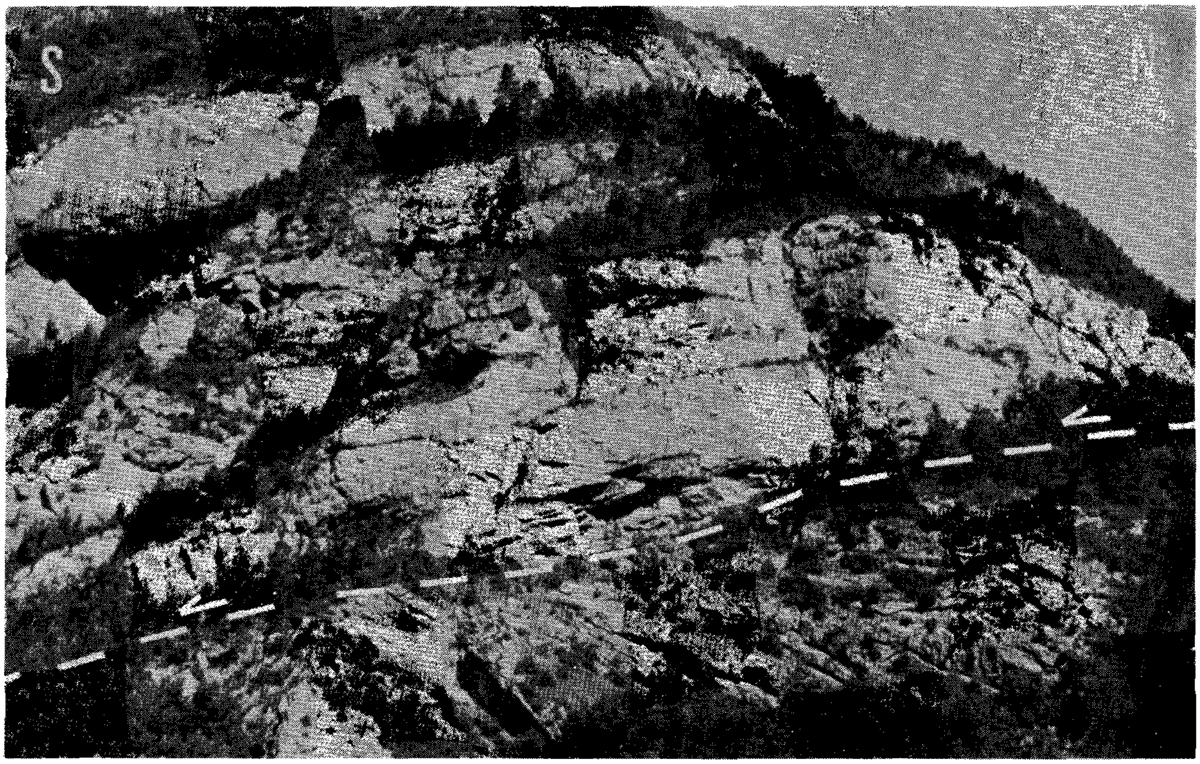


Fig. 4 Paleozoic limestones (Middle Devonian) uncomformably overlain by Upper Cretaceous strata of the A-formation. (along the road, south of Canfranc Estación).

2.2. A - FORMATION

2.2.1. Introduction.

In this formation, which is about 175 m thick, two light-grey massive limestone units are characteristic for almost the entire region. Both between and above these clearly recognizable units, well-bedded limestones occur which are strongly variable in grain-size and colour. Mostly, however, they are coarsegrained and red-coloured, owing to ferruginous material.
In the literature this formation is known as 'Calcaires des Cañons' (Fournier, 1905) or 'Calcaires à Hippurites' (Coquand, 1869). Following Van Elsberg (1968) the A-formation is divided into six- informal members:

(2.2.7.)	Af-member :	well-stratified nodular limestones.
(2.2.6.)	Ae-member :	well-stratified, yellow- to reddish-weathered, coarse-grained limestones.
(2.2.5.)	Ad-member :	non-stratified, grey-weathered limestones.
(2.2.4.)	Ac-member :	well-stratified, yellow- to reddish-weathered, coarse-grained limestones.
(2.2.3.)	Ab-member :	non-stratified, grey-weathered limestones and dolomites.
(2.2.2.)	Aa-member :	strong lateral variation does not allow a summarizing discription.

2.2.2. Aa-member

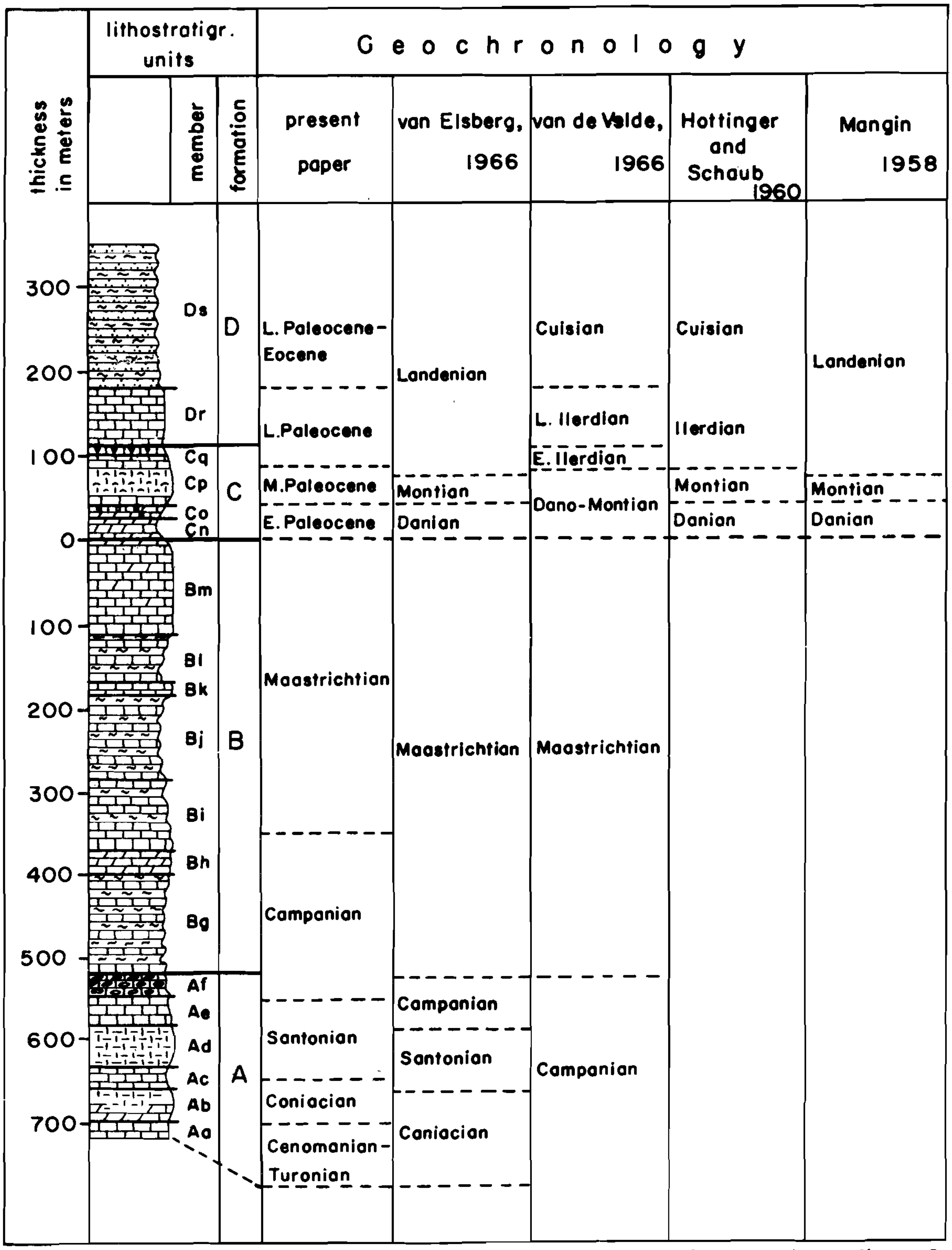
thickness : 2 m - 25 m.
carbonate : 75% 1)
The strong lateral variation of this member requires a description of different localities.

1) The percentage carbonate is given throughout this paper because it indicates the maximum percentage of non-carbonate materials which generally are: quartz, mica and ferruginous material.

South of Ibón de Estanés (to the west of the region) : Coarse-grained and partly conglomeratic limestones, which are well layered (0,3 m - 1 m), reddish-coloured and ferruginous. At its base a thin quartzose conglomeratic layer of 0,3 m is found. It has a reddish-brown colour and crossbedding occurs. Its components are mostly well rounded (cf. Van Elsberg, 1968).
North of the Tortiellas (western part of the region) : Yellow- to brown-weathered pudding stone, containing small quartz pebbels (0,5 cm - 2,0 cm). (cf. Dalloni, 1910). In the Aragón Valley, west of Canfranc Estación (western part of the region) :
Light- to-dark grey, massive weathered calcipelites, which contain cherty and sideritic concretions. Quartz grains are quite common in these limestones. The grainsize of these quartz grains varies from 0,1 mm - 2,0 mm. Locally styloliths occur, filled with ferruginous material.
Eastwards, between the Aragón and Gállego Valleys the Aa-member is not exposed. In this region most of the basal layers are covered with scree. Fossil content:
Only rudistid and other mollusc fragments were found.

2.2.3. Ab-member

thickness : 20 m - 45 m
carbonate : 90%
This member is composed of massive limestones with *Hippurites (Vaccinites) giganteus* d'Hombre Firmas. Both on fresh and on weathering surfaces their colour varies from light- to-dark grey. The locally fetid, dolomitic limestones are, in general, rich in fossil detrites (figure 9).
In the eastern part of the region (north of the Peña Zarrambucho) the limestones are ferruginous.
Fossil content : (see figure 9)
Lacazina elongata Munier Chalmas, *Cuneolina pavonia* d'Orbigny, *Cyclolina* sp., *Rotalia*, sp., '*Textularia*', smaller and larger Miliolidae, Rotaliidae, small arenaceous Foraminifera, Bryozoa, Algae, Echinoidea, rudistid and other mollusc fragments, *Hippurites (Vac-*



for legend see figure 6.

Fig. 5 Comparison of geochronological interpretations of the A-B-C- and D-formations, by different writers.

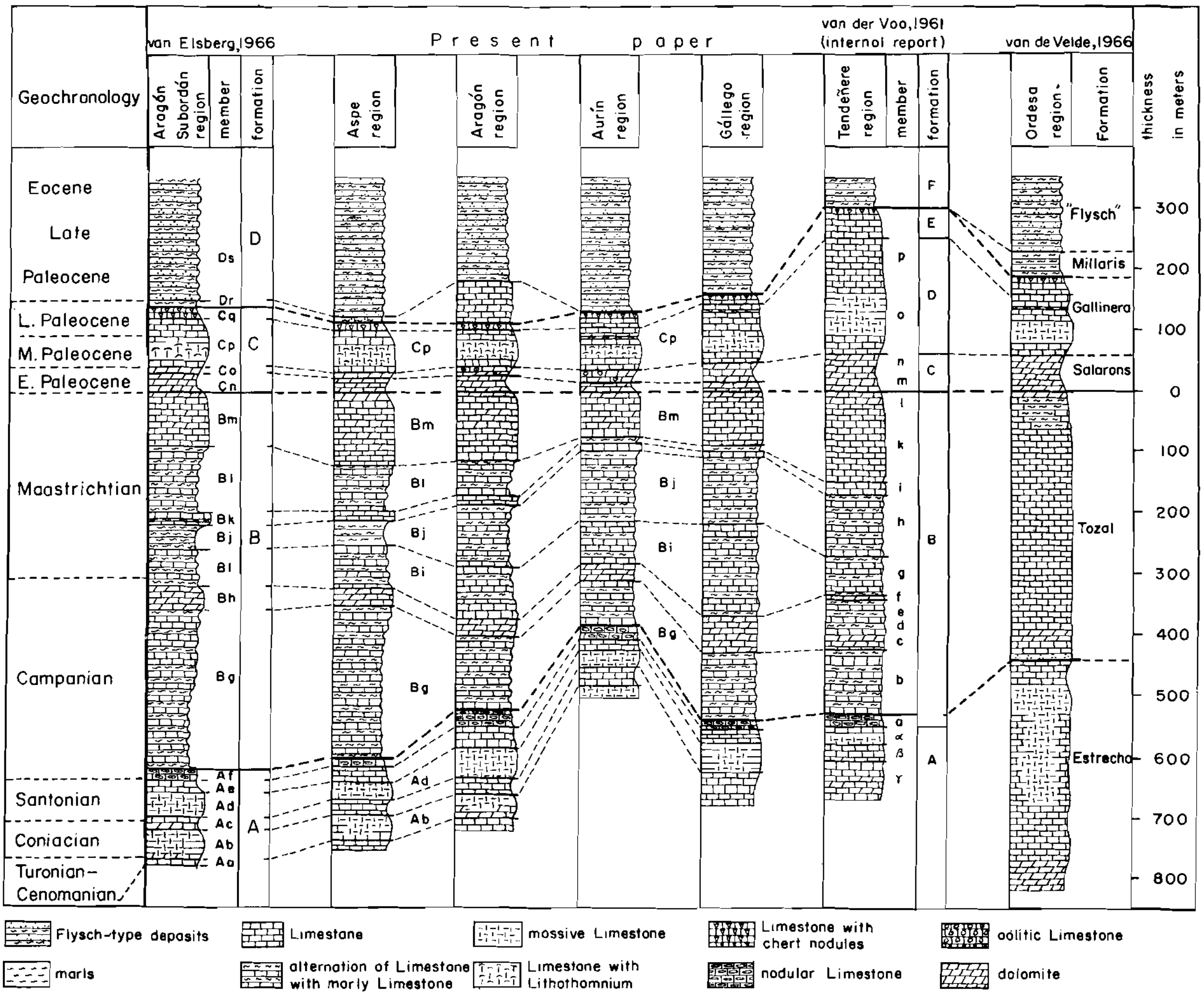


Fig. 6 Lithostratigraphic correlation of sections through Upper Cretaceous and Lower Tertiary sediments of the Western Pyrenees.

cinites) giganteus d'Hombre Firmas. The last mentioned index fossil has not been determined, but was described by Dalloni (1910), Astre (1955) and Van Elsberg (1968) in the same unit.

2.2.4. A.c. -member

thickness : 15 m - 50 m.
carbonate : 65% - 90%
The Ac-member consists of greyish, yellowish, brownish or reddish limestones, which are mostly dolomitic.
Locally the alteration to dolomite is complete and thin sections show the mozaic structure of dolomite crystals. If the limestones have not been dolomitized, they will be composed of well-rounded organoclastic material. Towards the east (north of the Peña Zarrambucho) gravel lenses occur, consisting of quartz pebbels (grainsize : 1 mm - 4 mm). These lenses are 1 m - 3 m thick. The Ac-member is always well stratified in layers of from 0,5 - 1,0 m, which always contain quartz and ferruginous material.
In contrast to the massive, greyish-weathered Ab- and Ad-members, the Ac-member is well stratified and yellow-to-reddish weathered.
Fossil content:
Lacazina elongata Munier Chalmas, small Pseudosiderolites, 'Textularia', Cyclolina sp., Globotruncana sp., Vidalina sp., Cuneolina sp., smaller and larger Miliolidae, Rotaliidae, Bryozoa, Algae, Echinoidea, rudistid and other mollusc fragments.

2.2.5. Ad-member

thickness : 30 m - 54 m
carbonate : 90%
This member is composed of light- to-medium grey, very fine-grained, massive limestones, with lenses of coarse-grained detrital material. Rudistid and other mollusc fragments are particularly abundant in these lenses. In thin sections, the massive limestones are found to be calcipelites (see figure 10 and 11).
Locally the limestones are dolomitized and contain quartz and ferruginous material. In the entire region, the Ad-member is predominantly developed as a massive unit, in contrast to the Ac- and Ae members. (see figure 7).
Fossil content: (see figures 10 and 11).
Cuneolina pavonia d'Orbigny, Lacazina elongata Munier Chalmas, Nummofallotia sp., Goupillaudina sp., 'Textularia', Lituola sp., Periloculina sp., Cyclolina sp., Idalina sp., Pseudosiderolites sp., Meandropsina sp., smaller and larger Miliolidae, Rotaliidae, Bryozoa, Algae, Echinoidea, rudistid and other mollusc fragments.

2.2.6. Ae-member

thickness : 20 m - 35 m
carbonate : 80%
This member is composed of yellow- to reddish weathered, organoclastic calcarenites. They always contain quartz grains and ferruginous material. Locally these limestones are dolomitic. In the eastern part (north of the Peña Telera) a zone is present which contains small quartz pebbels (grainsize 1 mm - 3 mm). The Ae-member is always well stratified.
The Ae-member has also a uniform development without strong lateral variations throughout the entire region, similar to the Ac-member. In contrast to the Ac-member cross stratification often occurs.
Fossil content:
Monolepidorbis sanctaepelagiae Astre (figure 12), Lacazina elongata Munier Chalmas, Nummofallotia sp., Vidalina sp., Goupillaudina sp., Globotruncana sp., smaller and larger Milliolidae, Ostracoda, Algae, Bryozoa., Echinoidea and mollusc fragments.

2.2.7. Af-member

thickness : 15 m - 25 m
carbonate : 65% - 75%
This member is composed of well-layered,

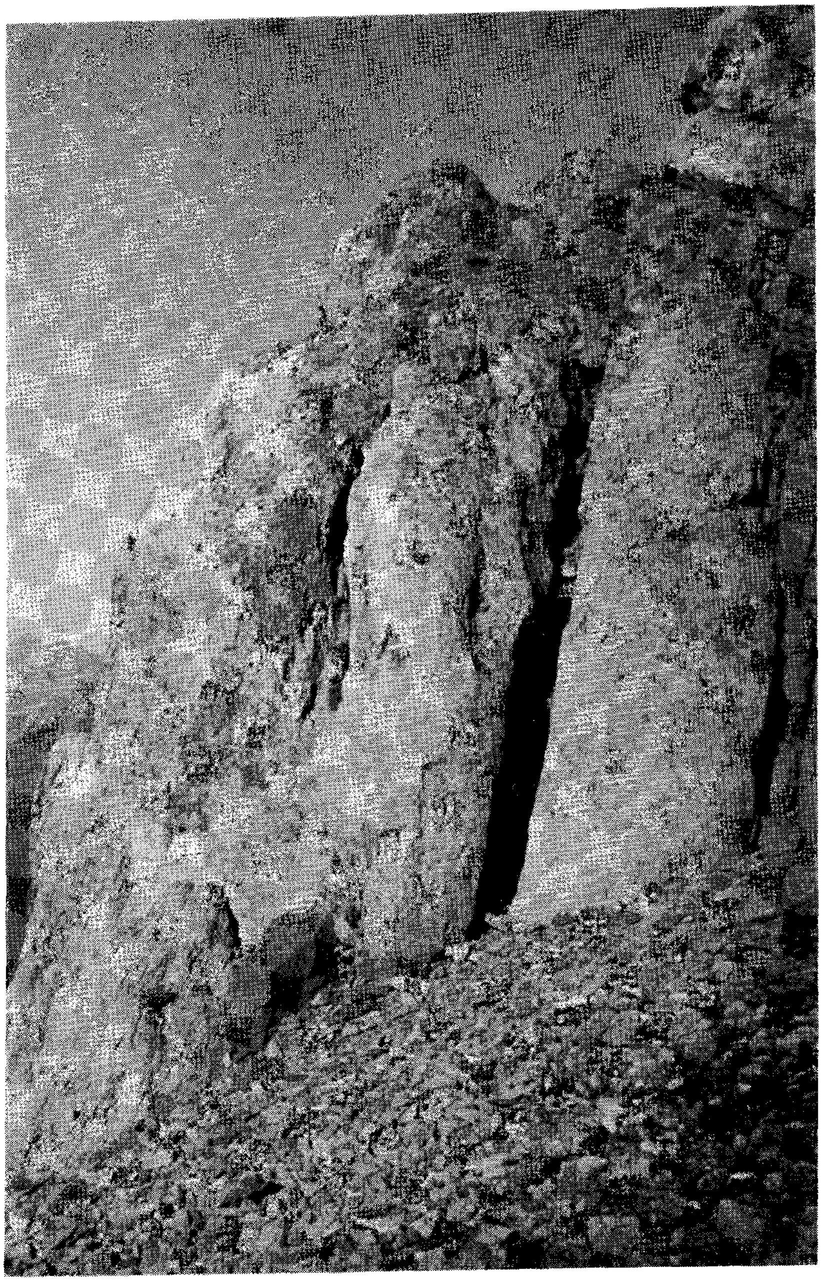


Fig. 7 Weathered massive limestone of the A-formation (Ad-member) (north of the Zarrambucho).

yellow- to-brownish weathered calcipelites containing a considerable amount of small quartz grains, ferruginous material and mica plates. The fresh colour is bluish-grey. The thickness of the layers varies from 0,5 1,0 m.
Within the individual beds thin layers of yellow- to-brownish weathered calcipelites alternate with brownish weathered ferruginous calcipelites. These ferruginous calcipelites either possess a parallel or an irregular lamination. Mostly, however, the irregular lamination has been developed and in that case the layers have a nodular appearance (c.f. van Elsberg, 1968). The facies of these nodular limestones is most strongly developed in the western part of the region.
Fossil content:
Goupillaudina sp., Pseudosiderolites sp., smaller foraminifera, Exogyra sp., Alectryonia sp., Bryozoa and mollusc fragments.

2.2.8. Conclusions about the age of the A-formation

Following Souquet (1964 b) a CENOMANIAN-TURONIAN age may be attributed to the Aa-member. In this member we found only rudistid and other mollusc fragments.
Souquet, however, reports in the lowermost deposits of my region the presence of: Prealveolina cretacea, P. simplex, Cuneolina sp., Dicyclina sp., Pithonella ovalis, Stomiosphaera sphaerica.

A CONIACIAN age may be assigned to the Ab-member, because the occurrence of the following fossil association: Lacazina elongata, Cuneolina pavonia and Hippurites (Vaccinites) giganteus.

A CONIACIAN-SANTONIAN age is assigned to the Ac-member because the fossil content does not allow a more precise decision of the age.

A SANTONIAN age may be assigned to the Ad- and Ae-members because the occurrence of the following fossil association Lacazina elongata, Cuneolina pavonia, Nummofallotia sp., Goupillaudina sp., and Monolepidorbis sanctaepelagiae. In contrast to fixed opinion, the species Monolepidorbis sancta pelagiae Astre may not be indicative of a Campanian age only, but also of a Santonian age, since the species is probably synonymous with Monolepidorbis douvilei (Silvestri) (cf. Van Hinte 1966b). The last mentioned species occurs in the Santonian of Belvês (Aquitaine Basin).

A SANTONIAN-CAMPANIAN age is assigned to the Af-member because the fossil content does not allow a more precise dicision.

2.3. B - FORMATION

2.3.1. Introduction

This formation varies in thickness from 380 m - 540 m.
A yellowish-to-brown weathering colour is characteristic for this unit. It shows a predominantly calcareous development. In general it is composed of an alternation of marly limestones,. either with limy marls, or with competent limestones. Only in the extreme western part of the region marls occur. Variable amounts of quartz grains, ferruginous material and mica flakes are present throughout the entire B-formation. With the exception of the uppermost part of the A-formation (Af-member), mica flakes only occur in the B-formation.
Following Van Elsberg (1968) the B-formation is divided into seven informal members:

(2.3.8.)	Bm-member	: limonitic, competent limestones.
(2.3.7.)	Bl-member	: limonitic, marly limestones.
(2.3.6.)	Bk-member	: Two thick competent limestones layers.
(2.3.5.)	Bj-member	: alternation of marly limestones with limy marls

(2.3.4.) Bi-member : thickly layered marly limestones and competent limestones.
(2.3.3.) Bh-member : dolomite level.
(2.3.2.) Bg-member : alternation of marly limestones with limy marls.

2.3.2. Bg-member

thickness : 250 m - 100 m (from west to east)
carbonate : 50% - 90%
The composition of this member is different in the western and eastern part of the region:
West of the Río Aragón the lower part of the Bg-member consist of an alternation of limy marls with marly limestone layers of the same thickness (0,2 m); The upper part of the Bg-member consists of a similar alternation, but the marly limestone layers are thicker (1 m) (cf Van Elsberg 1968). Both the marly limestone layers and the limy marls have a yellowish-grey to yellowish-brown weathering colour and they always contain small amounts of quartz and mica flakes.
In the eastern part of the region (north of the Peña Telera) the Bg-member consists only of a regular alternation of competent limestones and marly limestones. These limestones are medium-grey weathered and always contain considerable amounts of quartz and mica plates. Locally, layers with fossil mudcracks and conglomeratic intercalations occur, both varying in thickness from 0,2 m - 0,6 m. The intraformational conglomerates consist of a finegrained ferruginous matrix in which rounded pebbles (0,01 m - 0,15 m) of yellowish-grey or yellowish-brown limestone- and mollusc fragments are enclosed. A reddish colour is characteristic for these conglomerates (cf. Van Elsberg, 1968). The layers which display fossil mudcracks are similar to the intraformational conglomerates, however, the stratification within the 'pebbles' of these layers are always parallel to each other and to the bedding plane (Van Elsberg, 1968, fig. 11 and 12).
The Bg-member is thinning from west to east (see figure 6), while in the same direction the quartz contents increase considerably.
Fossil content:
Orbitoides tissoti Schlumberger, Oribitoides media (d'Archiac), Lepidorbitoides sp., Pseudosiderolites vidali (Douvillé), Goupillaudina sp., (fig. 13), 'Textularia', Nummofallotia sp., Miliolidae, Rotaliidae, Terebratula sp., Ananchytes sp., Pinna sp., Inoceramus sp., Gryphea sp., Exogyra sp., Bryozoa and Algae. Ananchytes sp. is present, especially, approximately 60 m from the base of the Bg-member (cf. Van Elsberg 1968).

2.3.3. Bh-member

thickness : 30 m - 65 m (from west to east)
carbonate : 60%
The Bh-member is composed of well layered, yellowish-brown and locally reddish weathered limestones, dolomitic limestones and dolomites. Fresh colours vary from bluish-grey to pearl-grey. In the upper part of this member intraformational conglomarates (see 2.3.2.) and lenses of quartz pebbels (grainsize : 2 mm - 5 mm) occur. From west to east these gravel lenses increase in number and thickness. The limestones and dolomites always contain considerable amounts of quartz, which just as in the Bg-member, increase from west to east.
The dolomites, dolomitic limestones and limestones laterally grade into each other, which makes it probable that dolomitization is a secondary feature.
The Bh-member is a key horizon and it has been mapped (see geologic map). It is not difficult to trace this member from Van Elsberg's region (see figure 1) up to the middle part of my region, because it stands out in relief from the underlying marly Bg-member. To the east it becomes more difficult because of the increasing sand content of the underlying Bg-Member.

In contrast to the thickly layered, overlying Bi-member, the Bh-member is, in general thinly layered.
Fossil content:
Only indeterminable plant remains have been found in this member.

2.3.4. Bi-member

thickness : 85 m - 150 m (from west to east)
carbonate : 90% (derived from specimens of the lowermost part only)
The Bi-member consists of thickly layered (1 m - 3 m) marly limestones and competent limestones, always containing quartz, ferruginous material and mica plates. Within the individual beds an alternation is mostly present of coarse- to-fine grained ferruginous calcarenites, which locally show crossbedding (figure 8).
Also, locally, layers with fossil mudcracks and intraformational conglomerates occur which are similar to those described in the Bg-member (2.3.2.). In the lowermost part of the Bi-member the layers are composed of organoclastic limestone (figure 14).
Fossil content (see also figure 14) :
Orbitoides media (d'Archiac), Orbitoides sp., Lepidorbitoides sp., Pseudosiderolites vidali (Douvillé) Nummofallotia sp., Goupillaudina sp., Robulus sp., 'Textularia', Rotaliidae, Lagenidae, Miliolidae, other smaller foraminifera, Alectryonia sp., Ostrea sp., Echinoidea, Algae and Bryozoa.

2.3.5. Bj-member

thickness : 100 m - 130 m
carbonate : 45% - 90%
In the western part of the region the composition of the Bj-member alternates between yellowish to brownish weathered, limy marls and marly limestones. In the eastern part of the region this member consists of yellowish to brownish weathered limestones and marly limestones alternating with bluish limy marls in the lower part and greyish limy marls in the upper part.

In the entire region the layers of the Bj-members contain variable amounts of quartz, ferruginous material and mica flakes. The amount of quartz increases from west to east.
In contrast to the thickly layered Bi-member, the layers of the Bj-member vary in thickness from 0,2 m - 1,5 m.
Fossil content:
Navarella sp., (see figure 15), Lepidorbitoides sp., Siderolites calcitrapoides Lamarck, 'Textularia' Goupillaudina sp., Lagenidae, Rotaliidae, other smaller foraminifera, molluscs, Bryozoa and Echinoidea.

2.3.6. Bk-member

thickness : 10 m - 15 m
carbonate : 90%
In the entire region the Bk-member is composed of greyish brown weathered organoclastic limestones, which are almost everywhere weathered into two massive layers. A marly intercalation separates the two thick layers, which always contain a low percentage of quartz and of mica flakes.
The Bk-member stands out in relief from the under- and overlying members and can often be used as a key horizon in tectonic interpretations (see figurre 33).
Fossil content:
Siderolites calcitrapoides Lamarck, Clypeorbis mamillata (Schlumberger) (see figure 16), Lepidorbitoides socialis (Leymerie), Nummofallotia sp., 'Textularia' Rotaliidae, smaller foraminifera, Echinoderms, molluscs, Bryozoa and Algae.

2.3.7. Bl-member

thickness : 9 m - 55 m (from east to west)
carbonate : 55%
In the western part of the region the Bl-member is composed of an alternation of marly limestones and limy marls which have yellowish-brown weathering colours. In the eastern part this member is composed

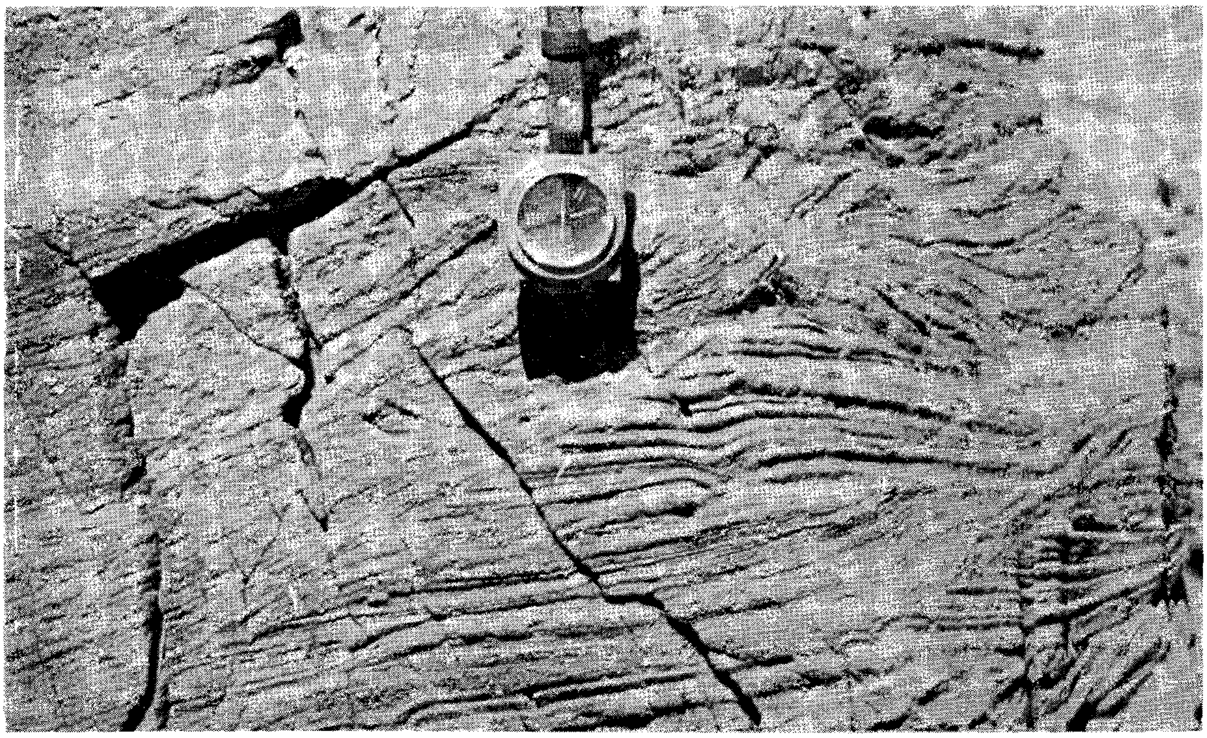


Fig. 8 A cross-bedded layer of the Bi-member. The photograph shows a variation in thickness of the laminae and internal noncomformities. The laminae consist of an alternation of coarse- and fine-grained ferruginous calcarenites. The base of the overlying layer is just visible as a straight line (left hand top).

of marly limestone layers, which have the same weathering colours. In the entire region the layers of the Bl-member contain quartz, ferruginous material, and mica flakes. The amount of quartz increases from west to east.
The transition toward the competent layers of the following Bm-member is gradual.
Fossil content : (see figure 17 and 18). Siderolites calcitrapoides Lamarck, Orbitoides apiculata Schlumberger, Lepidorbitoides socialis (Leymerie). Nummofallotia sp., Rotaliidae, Bryzoa and molluscs.

2.3.8. Bm-member

thickness : 80 m - 115 m
carbonate : 50% - 90%
In the entire region the Bm-Member is composed of well stratified, blue to dark grey, fine- to coarse-grained, competent limestones which have yellowish-brown to reddish-brown weathering colours. They always contain considerable amounts of quartz, ferruginous material and mica flakes. In the middle and uppermost part of the Bm-member the limestones are dolomitized.
In general, the layers are horizontally or irregularly laminated. These laminations are similar to those described in the Bi-member (2.2.4.). In some cases the layers show cross-bedding and also graded bedding (grainsize decreases from bottom to top). Also locally layers with fossil mudcracks and intraformational conglomarates are found. They are similar to those occurring in the Bg-member (2.3.2.). This member marks the upper limit of both the B-formation and the Maastrichtian deposits.
Fossil content : (see figure 19)
Orbitoides apiculata Schlumberger, Siderolites calcitrapoides Lamarck, Lepidorbitoides socialis (Leymerie), Globotruncana stuarti (de Lapparant), Subalveolina dordonica Reichel, Cuneolina pavonia d'Orbigny 'Textularia', Cyclolina sp., Operculina sp., Hellenocyclina Visserae (Hofker), smaller and larger Miliolidae, Rotaliidae, other smaller foraminifera, Exogyra sp., Alectryonia sp., mollucs, Bryozoa.
Foraminifera especially occur, in horizonts parallel to the bedding plane varying in thickness from 0,1 - 0,5 m.

2.3.9. Conclusions about the age of the B-formation

A CAMPANIAN age can be assigned to the Bg-member and the lowermost part of the Bi-member because of the following fossil assemblage : Orbitoides tissoti, O. media and Pseudosiderolites vidali (cf. van Hinte, 1966a).
A CAMPANIAN age can be assigned to the Bh-member based on its stratigraphic position.

Only to the lowermost part of the Bi-member is a Campanian age assigned since all my fossils happened to be collected within the extreme lower part of the Bi-member (1 m - 5 m from its base).
The occurrence of Navarella joaquini and Globotruncana stuarti in Van Elsberg's Bi-member may point to a MAASTRICHTIAN age to at least part of the higher strata of the Bi-member.

A MAASTRICHTIAN age may be assigned to the Bj- Bl- and Bm-members because of the following fossil association:
Navarella joaquini, Globotruncana stuarti, Siderolites calcitrapoides, Orbitoides apiculata, Lepidorbitoides socialis and Hellenocyclina visserae. (Hellenocyclina visserae only has been found in the Bm-member).

2.4. C-FORMATION

2.4.1. Introduction

The C-formation is about 130 m thick. In contrast to the yellowish-to-brown weathering colours of the B-formation, this formation is, in general, grey-weathered. Also in contrast to the B-formation is the absence of mica flakes and the occurrence of quartz and ferruginous material in few members only. The most characteristic deposits are : dolomites and dolomitic limestones at the base; limestones with *Lithothamium* in the middle part; and limestones with chert nodules in the uppermost part.

Following Van Elsberg (1968) the C-formation is divided into four informal members and, in one case, into informal beds:

(2.4.5.) Cq-member : well-stratified, bluish-grey-weathered limestones with chert nodules.

(2.4.4.) Cp-member :

- (2.4.4.4.) Cp_5-bed : well-stratified, grey-weathered limestones with silicified *Gryphea* s.p..
- (2.4.4.3.) Cp_4-bed : well-stratified, brownish-grey-weathered limestones.
- (2.4.4.2.) Cp_3-bed : non-stratified, grey-weathered limestones with *Lithothamnium*.
- (2.4.4.1.) Cp_{1-2}-bed : poorly stratified, grey-weathered limestones,.

(2.4.3.) Co-member : poorly stratified, light-grey-weathered dolomites and dolomitic limestones.

(2.4.2.) Cn-member : poorly stratified, dark-grey-weathered dolomites and dolomitic limestones.

Van Elsberg's subsivision into Cp_1- and Cp_2-beds is not followed. They have been included in one unit, the Cp_{1-2}-bed, a necessary consequence of the recognition of the Cp_3- Cp_4- and Cp_5-bed in both regions.

2.4.2. Cn-member

thickness : 15 m - 25 m
carbonate : 90%

The Cn-member is composed of poorly stratified, dark-grey- to violet-weathered dolomites and dolomitic limestones. Fresh colours vary from light- to dark-grey. At the base of the Cn-member the dolomites and dolomitic limestones are fetid and blackish weathered, probably owing to the preservation of organic material. Locally the dolomites and dolomitic limestones laterally grade into each other, which makes it probable that dolomitization is a secondary feature. Figure 20 shows a dolomitic limestone, composed of a structureless matrix and small, somewhat rounded pebbles. This microfacies is characteristic for the Cn-member. The same facies has been described of the same horizon in the Ordessa region (van Hillebrandt, 1962, Tafel I).

Fossil content:
'*Textularia*', Lagenidae and small Globigerinidae.

2.4.3. Co-member

thickness : 20 m - 30 m
carbonate : 90%

The Co-member is composed of dolomites and dolomitic limestones. In contrast to the dark-grey weathering colours of the Cn-member, the Co-member weathers light-grey. Similar to the Cn-member are the light- to dark-grey fresh colours, the absence of quartz, ferruginous material and mica; the poor fauna and the dolomitization as a secondary feature.

Locally oolitic limestone occurs (see figure 21). Because of the very small grain-size (0,06 mm - 0,25 mm), the oolitic limestone can be recognized only with the microscope, hence it is not possible to give the horizontal or vertical extension from these oolitic deposits. Oolitic limestone has also been described by Cuviller (1956) in the Lower Paleocene of the Aquitain Basin, as one of the facies of the Pyreneen piedmont.

Fossil content:
smaller foraminifera were found.

2.4.4. Cp-member

The Cp-member is divided into four informal beds:

2.4.4.1. Cp_{1-2}-bed

thickness : 15 m - 20 m
carbonate : 90%
The Cp_{1-2}-bed is composed of thickly layered, fine-grained organoclastic limestones. Fresh, and weathering colours vary from light to dark grey. In contrast to the Cn- and Co-members the Cp_{1-2} bed is not dolomitized and it contains small amounts of quartz and ferruginous material. Locally the limestones are recrystallized.
Fossil content:
Discocyclina sp., Operculina heberti Munier Chalmas, 'Textularia', Globigerina sp., Rotalia sp., 'Microcodium', Miliolidae, Lagenidae, other smaller foraminifera, Exogyra sp., Bryozoa, echinoderm- and mollusc fragments.
Exogyra sp. especially is found in a horizon, about two metres from the base of the Cp_{1-2}-bed.

2.4.4.2. Cp_3-bed

thickness : 20 m - 45 m
carbonate : 90%
This bed is composed of very fine-grained limestones.
Fresh and weathering colours vary from light- to dark-grey. The limestone consists of a calcipelitic matrix with fossil detritus. In general, this unit is not stratified and the entire bed is normally exposed in one massive unit. Ferruginous material occurs in small amounts. Quartz is absent.
Fossil content : (see figure 22)
Discocyclina sp., Operculina heberti Munier Chalmas, Alveolina sp., Globorotalia cf acuta Toulmin. 'Textularia', Fallotella sp., Rotalia sp., Bigenerina sp., Globigerina sp., Lagenidae, Rotaliidae, Miliolidae, other smaller foraminifera, Lithothamnium, Bryozoa, echinoderm- and mollusc fragments.

2.4.4.3. Cp_4- bed

thickness : 10 m
carbonate : 60% - 90%
This bed is composed of brownish-grey weathered, finegrained, organoclastic limestones (figure 23). Quartz grains are abundant especially at the base where irregular patches of small quartz grains are often present. These patches are clearly visible at the weathering surface. Ferruginous material occurs only in very small amounts. The abrupt increase in quartz has also been noted by Van Elsberg (1968), Van De Velde (1968), and Von Hillebrandt (1962).
Fossil content (see figure 23).
Discocyclina sp., Operculina heberti Munier Chalmas, Nummulites sp. (small and thick), Assilina sp., (thick), Fallotella alavensis Mangin, Alveolina primaeva Reichel, Anomalinoides grosserugosa Gümbel, 'Textularia', Hantkenina sp., Miliola sp., Globigerinidae and other smaller foraminifera, Bryozoa, Algae and mollusc fragments.

2.4.4.4. Cp_5-bed

thickness : 10 m
carbonate : 60% - 90%
This bed is composed of dark-grey weathered, fine-grained limestones (calcipelites). Locally, small patches of quartz grains occur, similar to those of the underlying Cp_4-bed. The most characteristic feature is the occurrence of silicified Gryphea sp., also described in the same horizon of the Ordesa region by Van De Velde, 1968,, Plate I, photo 4. The base of the Cp_5-bed is formed by a marly layer about one meter thick. This marl is highly fossiliferous:
Assilina, Nummulites, Operculi-

na and Discocyclina (see figure 24).
This easily recognizable key-bed has also been described in the same horizon of the Ordesa region by von Hillebrandt and Van De Velde. West of my region this marly layer is probably absent, for it is not mentioned by Van Elsberg (1968).
Fossil content (figure 24):
Discocyclina sp., Gypsina sp., Operculina sp., Assilina sp., Nummulites sp., Alveolina trempina Hottinger, 'Textularia', Miliolidae and smaller foraminifera.

2.4.5. Cq-member

thickness : 10 m - 15 m
carbonate : 85%
This member is composed of well-stratified, bluish-grey weathered, very fine-grained limestones (calcipelites). The most characteristic feature of this member is the occurrence of chert nodules in the middle of most of the layers. These limestones with chert nodules can easily be traced from the Aragón Subordan region (Van Elsberg) up to the Ordesa region (Van De Velde). Quartz and locally also ferruginous material are present in small amounts.
Fossil content:
Discocyclina sp., Gypsina sp., Operculina sp., Operculina cf. canalifera d'Archiac (figure 26), 'Textularia', Globigerinidae, Lagenidae and other smaller foraminifera, Bryozoa, echinoderm- and mollusc fragments.

2.4.6. Conclusions about the age of the C-formation

The limit between the B- and C-formation happens to coincide with the Cretaceous/Tertiary boundary. The Early Tertiary deposits of the Western Pyrenees are generally considered to be of Danian, Montian, Landenian and/or Ilerdian age (figure 5). In the present paper these names are not used since the determined faunae are too poor to give such a precise decission of the age. For this reason the Early Tertiary in this paper is devided into:

Late Paleocene (corresponding roughly to Landenian and Ilerdian).
Middle Paleocene (corresponding roughly to Montian and probably the early part of the Landenian).
Early Paleocene (corresponding roughly to the Danian of authors.

The same division has been used by Hottinger and Schaub (1960) with the exception of the Late Paleocene, for which they introduced the name Ilerdian.

To date the Cn- and Co-members (the dolomitic deposits of the lowermost part of the C-formation) is very difficult. In my region only Globigerinidae are found in the Cn-member, indicating a Tertiary age. Neither in the Ordesa region (Van De Velde, 1968), nor in my region and in the Aragón Subordán region (Van Elsberg, 1968· see figure 1) are index fossils found. Van De Velde and Van Elsberg attributed a Dano-Montian and Danian age respectively to these dolomitic deposits based entirely on its stratigraphic position.
Only Mangin (1958) assigned a Danian age to the lithostratigraphic correlative of these dolomitic deposits N. and NE. of Pamplona, by means of the determined fauna. He reports: Globigerina pseudobulloiddes Plummer, G. cf. Daubjergensis Bronnimann and Globorotalia compressa Plummer.
According to these findings an EARLY PALEOCENE age is assigned in this paper to the Cn- and Co-members, which is in agreement with their stratigraphic position.
The Cp_{1-2}- and Cp_3-beds are the lithostratigraphic correlatives of the limestones with Operculina and the limestones with Lithothamnium and Discocylina, which have been described in the Gallinera Formation by Van De Velde (1968, Ordesa

region). Van de Velde attributed a Danian-Montian age to these deposits. Von Hillebrandt attributed a Montian age to the same deposits.
Van Elsberg attributed a Montian age to the Cp_1- Cp_2- and Cp_3-beds of the Aragón Subordán region.
The MIDDLE PALEOCENE age assigned to the Cp_{1-2}- and Cp_3-beds in this paper is based on these lithostratigraphic correlations with deposits, east and west of my region and the occurrence of Operculina heberti, (cf. von Hillebrandt, 1962, page 301).

The MIDDLE PALEOCENE age assignment to the Cp_4-bed in this paper is based on the following fossil association: Fallotella alavensis and Alveolina primaeva, (cf. Hottinger, 1960).

The LATE PALEOCENE age assigment to the Cp_5-bed in this paper is based on the following fossil association:
Alveolina (Flosculina) cf. Triestina, Alveolina trempina (cf. Hottinger 1960).

The Cq-member is the lithostratigraphic correlative of the limestones with chert nodules of both the Ordesa region (Van De Velde, 1968) and the Aragón Subordán region (Van Elsberg, 1968). An Ilerdian and Landenian age have been attributed to these limestones respectively.
The LATE PALEOCENE age attributed to the Cq-member in this paper is entirely based on these lithostratigraphic correlations with deposits east and west of my region. However, the occurrence of Operculina cf. canalifera suggests and Early Eocene age (cf. Mangin, 1958 p.413 and Cuvillier, 1956 Plate LXXIII).
As one specimen has been found only and the conspecificity of this specimen with Operculina canalifera is uncertain, there is not sufficient base for an Early Eocene age assigment.

2.5. D - FORMATION

2.5.1. Introduction

The D-formation is mainly composed of Flysch-type deposits (1 km - 2 km thick). Only the lowermost part (Dr-member) has a different development and only this part of the D-formation has been studied. Following Van Elsberg (1968) the D-formation is divided into two members:

(2.5.3.)	Ds-member :	Flysch-type deposits
(2.5.2.)	Dr-member :	limestones with fracture cleavage.

2.5.2. Dr-member

thickness : 0 m - 50 m
carbonate : 75% - 85%
In the western area, southeast of the Mazico de Bernera this member is composed of 10 m marly limestones, which display well-developed fracture cleavage and contain chert and siderite concretions. The contact with the underlying cherty limestones (Cq-member) is, in some areas, difficult to determine.
In the Aragón Valley the limestones with fracture cleavage are overlain by coarse-grained, dark-grey weathered limestones (grain-size 0,2 mm - 0,5 mm), containing variable amounts of quartz and locally pebbles of sharp-edged light-grey limestone material. Within these limestones marine slope breccias occur as lense-shaped bodies, which have limestone-components varying in thickness from 0,1 m - 0,5 m. On this location the total thickness of the Dr-member has been estimated at 50 m. The exact figure could not be obtained because of the low angle of dip of the layers, the poor exposures and of several small fault zones.
Eastward up to the Río Gállego the Dr-member is absent. This suggests a stratigraphic noncomformity between the Flysch-type sediments (Ds-member) and the chert nodular limestones (Cq-member).
The Millaris Formation (Van De Velde, 1968) is the lithostratigraphic correlative of the Dr-member. Within the Ordesa region the Millaris Formation varies from west to east in thickness, from 5 m - 250 m. This thinning out suggest a noncomformity between the Millaris formation and the Flysch type sediments.

Fossil content:
Discocyclina sp., *Nummulites* sp., *Alveolina* sp., *Miscellanea* sp., and small Miliolidae.

2.5.3. Ds-member

No studies have been made of this member.

2.5.4. Remarks on the age of the D-formation

The lithostratigraphic correlative of the Dr-member in the Ordesa region, The Millaris Formation, has been dated by Van De Velde (1968) and by Von Hillebrandt (1962) as Late Ilerdian.
Van Elsberg (1968), to the west of my region, attributed a Landenian age to his Dr-member.
A LATE PALEOCENE age is assigned to the Dr-member, and is based entirely on these lithostratigraphic correlations with deposits to east and west of my region.
The lithostratigraphic correlative of the Dr-member, the Flysch type deposits in the Esca Valley (25 km west of my region) are dated by Mangin (1958) as Landenian. In the Ordesa region the Flysch type deposits have been dated by Van De VELDE (1968) and by von Hillebrandt (1962) as Cuisian. Based on these lithostratigraphic correlations a LATE PALEOCENE-EOCENE age is assigned to the Dr-member.

2.6. ENVIRONMENT OF DEPOSITION

2.6.1. Introduction

The lithologic features and the faunae of the A- B- and C-formations are indicative of a deposition in a shallow, warm, sometimes clear, marine environment. The facies changes in lateral direction suggest a supply of terriginous material from an easterly direction.
As only the lowermost part of the D-formation has been studied, no suggestions are given about the environment of deposition of the D-formation.

2.6.2. A-formation

The occurrence of rudistids and Algae in the A-formation indicate a deposition in a warm, shallow, marine environment. Probably the conditions became sometimes favourable for the development of rudistidreef-building, indicating a shallow, warm and clear, marine environment.
Quartz-gravel lenses are present in the eastern part of my region in the Ac- and Ae-members, suggesting a supply of terriginous material from an easterly direction.

2.6.3. B-formation

The occurrence of *Alectryonia*, *Inoceramus*, *Pinna*, Algae and the larger foraminifera *Orbitoides*, *Lepidorbitoides* and *Pseudosiderolites* in the B-formation indicate a deposition in a shallow marine environment. A deposition which, in general, evidently originated under uniform conditions of sedimentation. The sedimentation kept up with the rate of sinking of the sea bottom. The occurrence of intraformational conglomerates and fossil mudcracks in the B-formation even could indicate temporary emergence of the sea bottom. During such a period of emergence of the sea bottom, weathering caused a dehydratation of the present limonite, which resulted in the reddish colour of the layers with fossil mudcracks and of the intraformational conglomerates. Cracks were formed in the calcareous mud and a certain degree of induration followed. During subsequent flooding the layers were broken up along the fissures resulting in an intraformational conglomerate (cf. Pettijohn, 1949). Sometimes however, the layers were not broken up, and the fissures were filled with fine-grained ferruginous material, which is evidenced by the occurrence of fossil mudcracks. Van Elsberg (1968, figures 11 and 12) described the same features in the Aragón Subordán region. A supply from an easterly direction of terriginous material in the B-formation is evidenced by the increase from west to east of quartz and ferruginous material within the Bg- Bh- Bi- and Bl-members, and the increase in thickness and number of quartz-gravel lenses in the Bh-member in the same direction.

2.6.4. C-formation

With the beginning of the C-formation an abrupt halt of the supply of terriginous material is observed and the rich Cretaceous fauna also disappeared almost completely. The development of partly fetid dolomites and oolitic limestones (Cn- and Co-members), suggest deposition in a shallow, marine, perhaps a lagoonal, environment. The presence of the larger foraminifera Discocyclina, Operculina, Assilina and Alveolina again is indicative of a shallow, marine environment. Sometimes the conditions became favourable for the development of Lithothamium, suggesting a shallow, warm and clear marine environment. A supply from an easterly direction of terriginous material in the C-formation is evidenced by the following data: Van Elsberg (1968) reported absence of quartz within the lower part of the C-formation (Cp_1- Cp_2- and Cp_3-beds) In the Cp_{1-2}-bed of my region small amounts of quartz are found. The lithostratigraphic correlative of the Cp_{1-2}beds in the Ordesa region consists of quartzose sandstones and sandy limestones.

2.7. CORRELATION WITH NEIGHBOURING REGIONS

2.7.1. Introduction

A correlation is presented of the A- B- C- and D-formations with the rock stratigraphic units distinguished by other students of the university of Utrecht in neighbouring regions (see figures 1 and 6). Because of the close similarity of the previously described Cretaceous and Lower Tertiary deposits to those of the Aragón Subordán region, Van Elsberg's division in formations, members and beds is used

The writer had the opportunity to co-operate some time with Dr. J.N. Van Elsberg during his fieldwork in the easternmost part of his Aragón Subordán region. As no intensive study, similar to that of Van Elsberg's, of the rapid lateral lithologic changes of the Aa- and Ab-members has been made, these members are not divided in beds.

Moreover, Van Elsberg's subdivision in Cp_1- and Cp_2-bed is not followed, these two have been included in the Cp_{1-2}-bed, as a necessary consequence of the recognition of the Cp_3- Cp_4- and Cp_5-beds in both areas. The correlation of the A- B- C- and D-formations with lithostratigraphic units in the Tendeñera region (Van der Voo 1961, internal report) and in the Ordesa region (Van De Velde 1968) are given in the following paragraphs.

2.7.2. A-formation

The A-formation can be correlated with Van Der Voo's A-formation and Van De Velde's Estrecho Formation. However, a detailed correlation of its members is not possible.

2.7.3. B-formation

The B-formation can be correlated with Van Der Voo's B-formation. But his lowermost member (see figure 6) is the same nodular limestone as the uppermost member of my A-formation (Af-member).
The division into members by Van Der Voo allows the detailed correlation as indicated by figure 6.
The development of the Tozal Formation as reported by Van De Velde (Ordesa region) no longer permits a detailed correlation with the members, of the B-formation mentioned above. The Tozal Formation consits mainly of yellow-to brown weathered, hard, sandy limestones and dolomites. The marly deposits of the Aragón Subordán Valley change gradually, passing through the limy marls and marly limestones of my area, into the competent limestones of the Ordesa region. This is the major lateral change in facies.

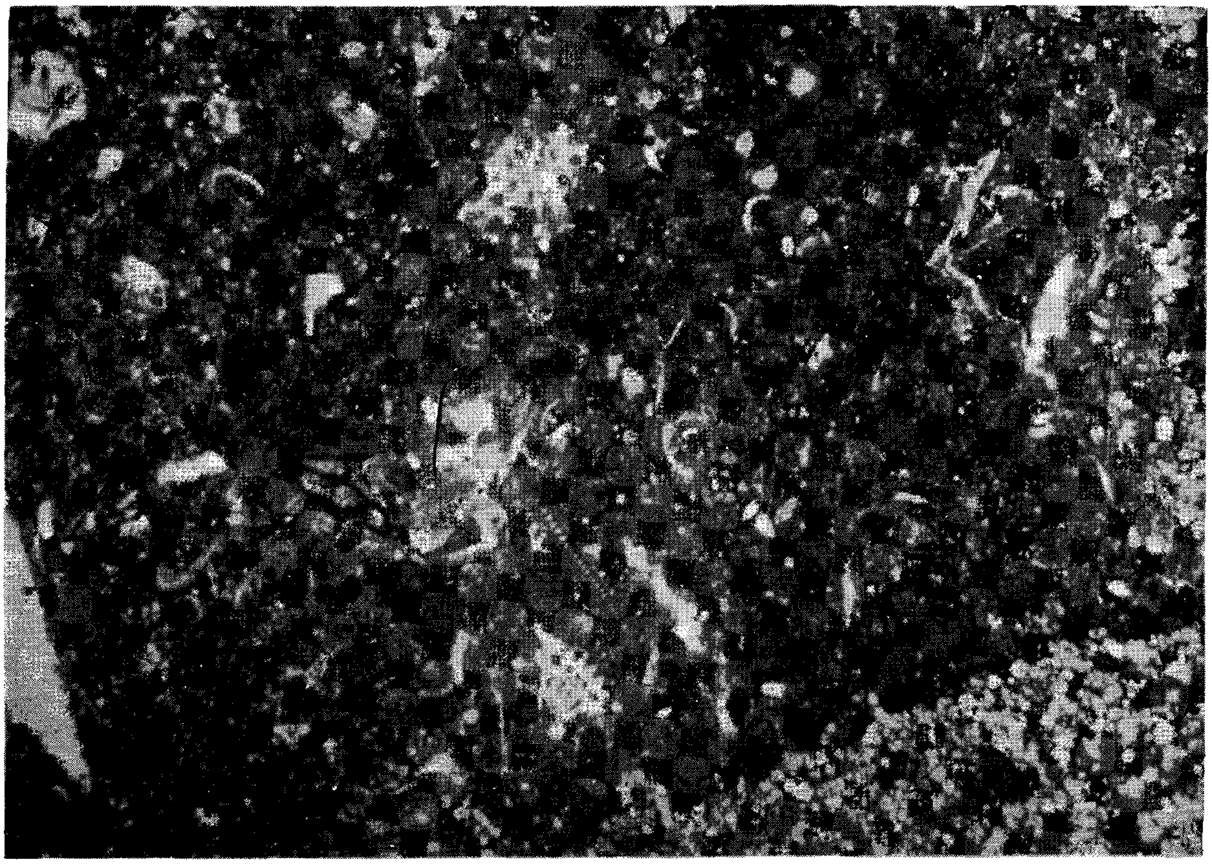


Fig. 9 Organoclastic limestone with Cyclolina sp., and Cuneolina pavonia d'Orbigny.
Locally, the limestone is completely dolomitized. CONIACIAN, (Ab-member, north of the Tortiellas, number A 392 g).

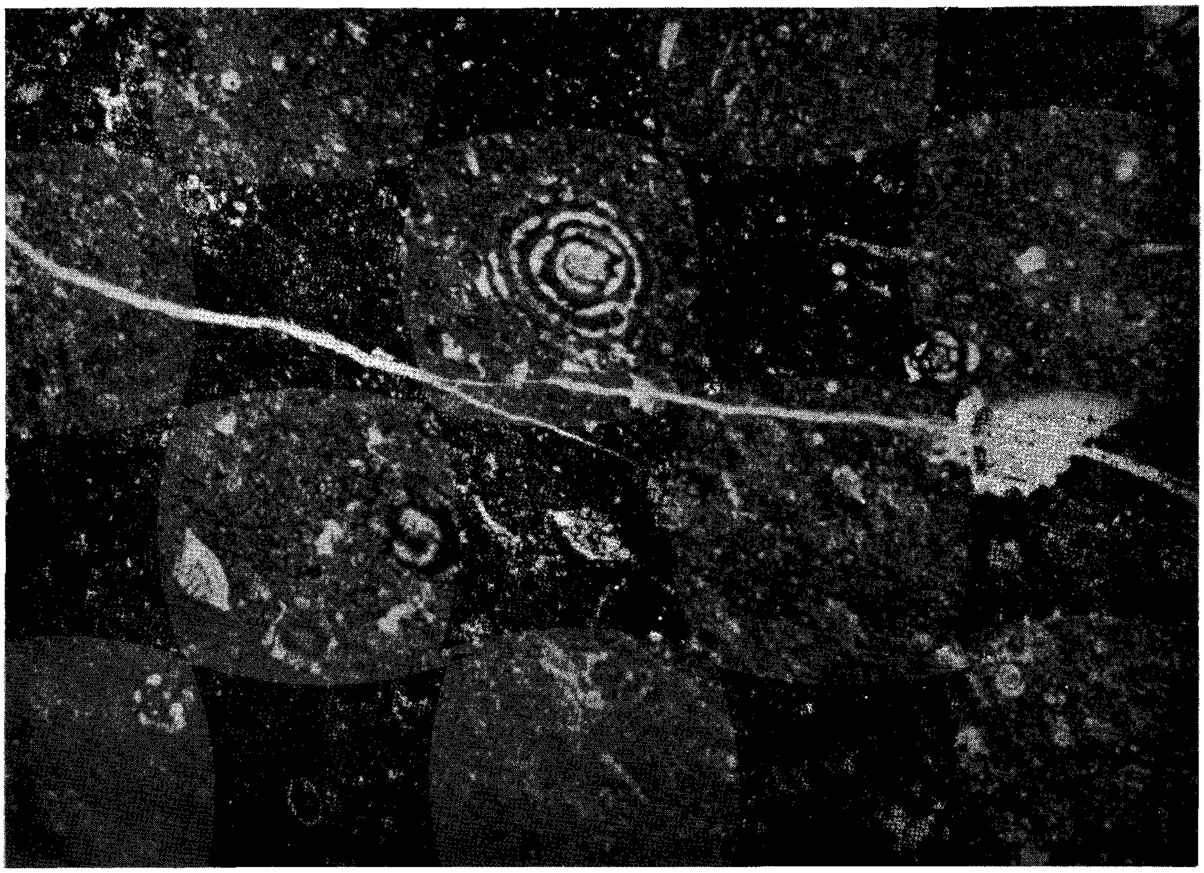


Fig. 10 Very fine-grained, dense, limestone (calcipelite) with Periloculina sp., Miliolidae and Rotaliidae. SANTONIAN (Ad-member, Barranco de Aspe, number C 195 c).

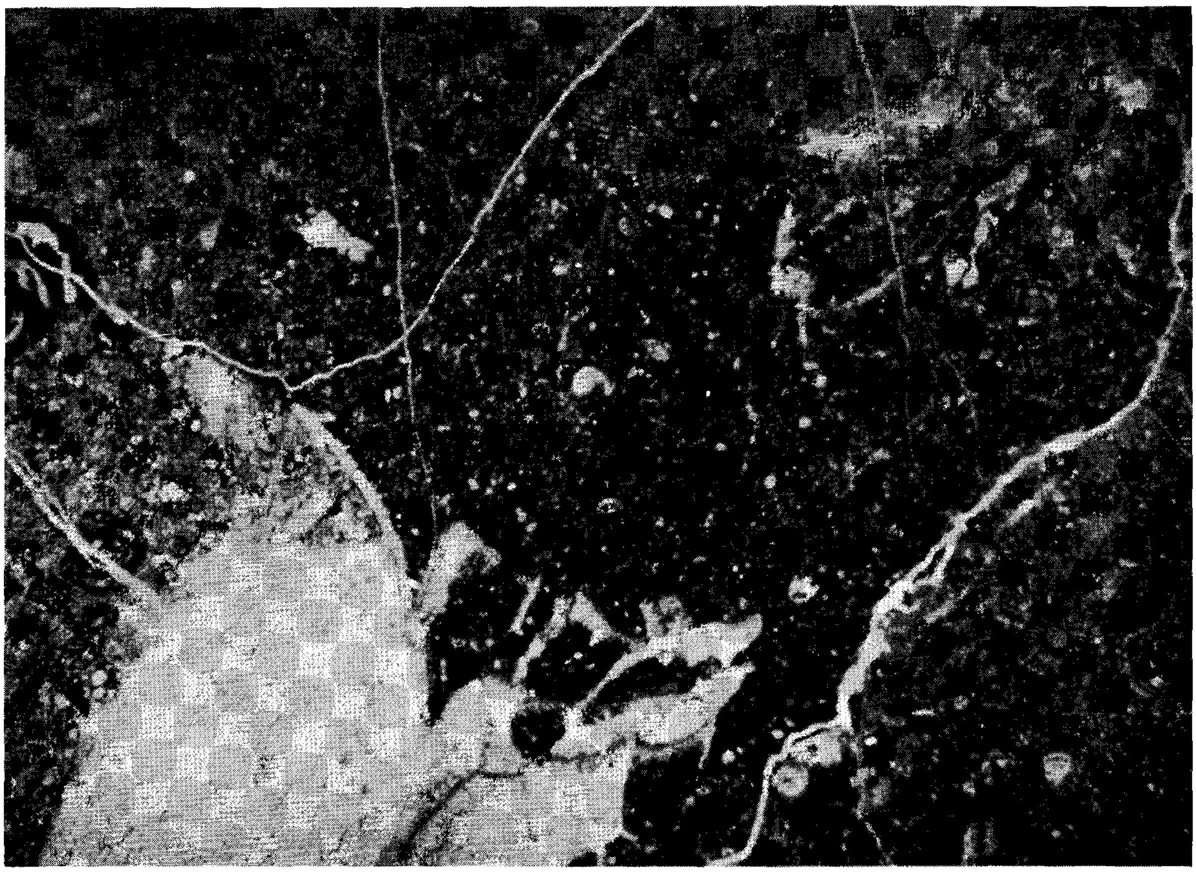


Fig. 11 Very fine-grained, dense, limestone (calcipelite) with Cuneolina pavonia d'Orbigny, Periloculina sp., and recrystallized mollusc fragments. SANTONIAN, (Ad-member, north of the Tortiellas, number A 391 a).

Fig. 12 Organoclastic limestone containing dolomite crystals in a specimen of *Monolepidorbis sanctaepelagiae* ASTRE.
SANTONIAN (Ae-member, north of the Tortiellas, number A 296 c).

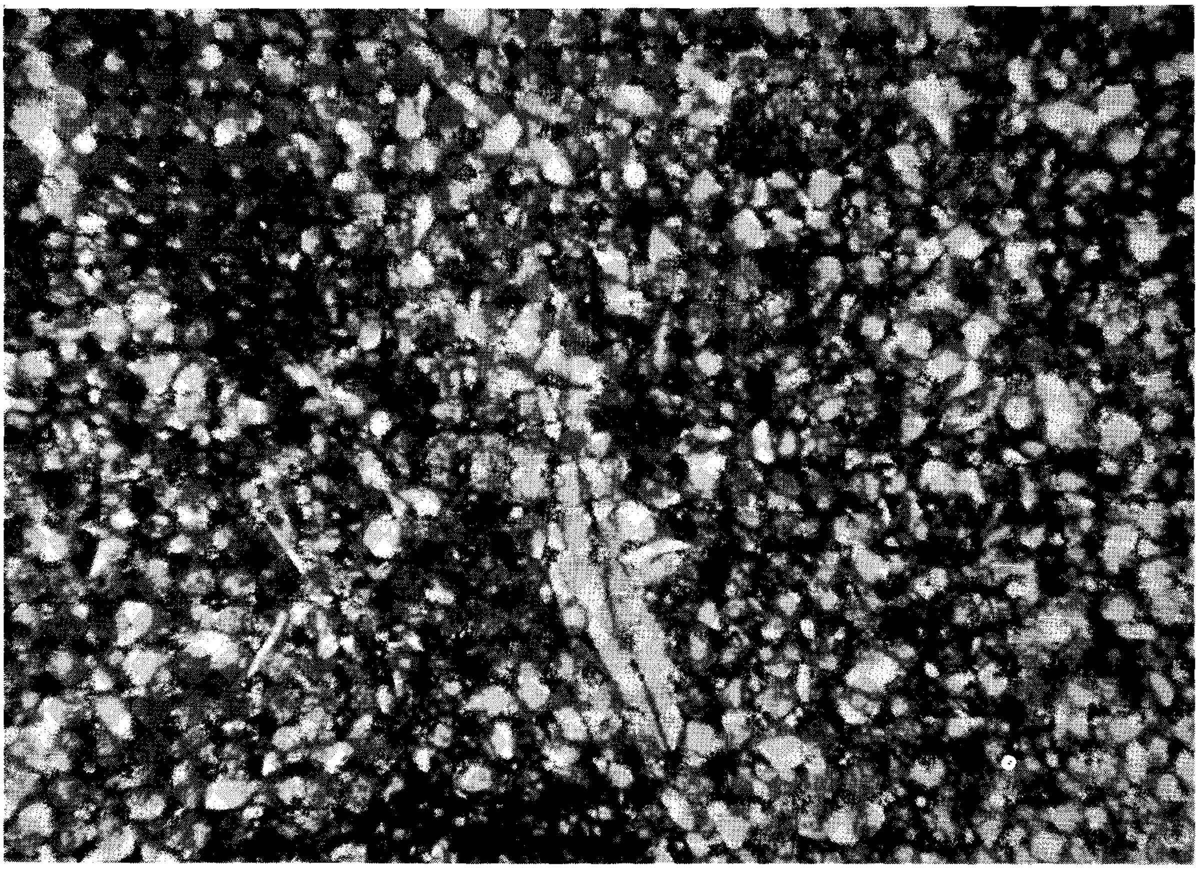


Fig. 13 Marly limestone containing abundant quartz grains (grain-size 0,3 mm - 0,7 mm) with Goupillaudina sp. CAMPANIAN (Bg-member, north of the Pena Collarada, number C 44 c).

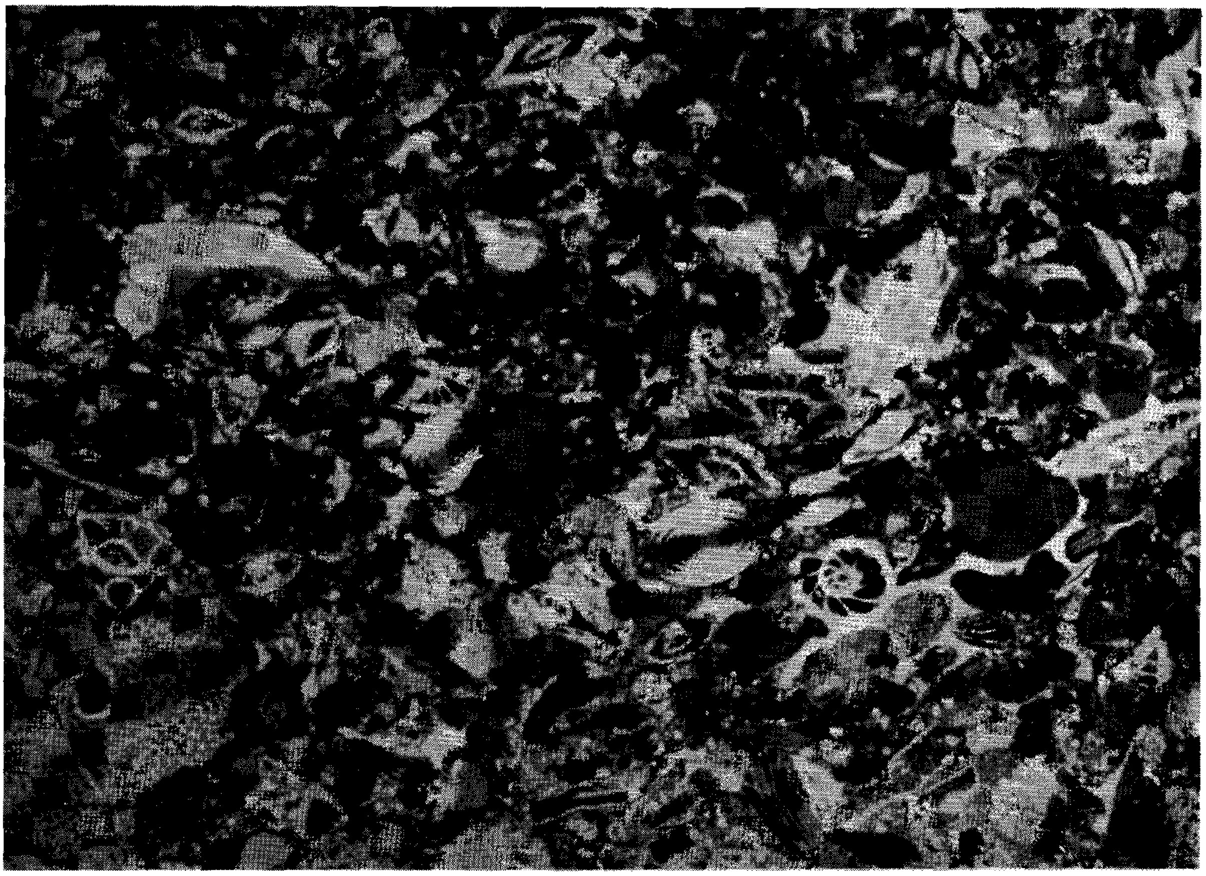


Fig. 14 Organoclastic limestone containing some quartz grains (grain-size 0,06 mm - 0,10 mm) with Nummofallotia sp., Orbitoides sp., Pseudosiderolites sp., and Rotaliidae.
The pore space is mainly filled with ferruginous material. CAMPANIAN (Bi-member, north of the Peña Collarada, number C 41 c).

Fig. 15 Marly limestone, containing abundant quartz (grain-size 0,03 mm - 0,06 mm) and small patches of ferruginous material with N a v a r e l l a sp. MAASTRICHTIAN, (Bj-member, Tortiellas, number B 138 b).

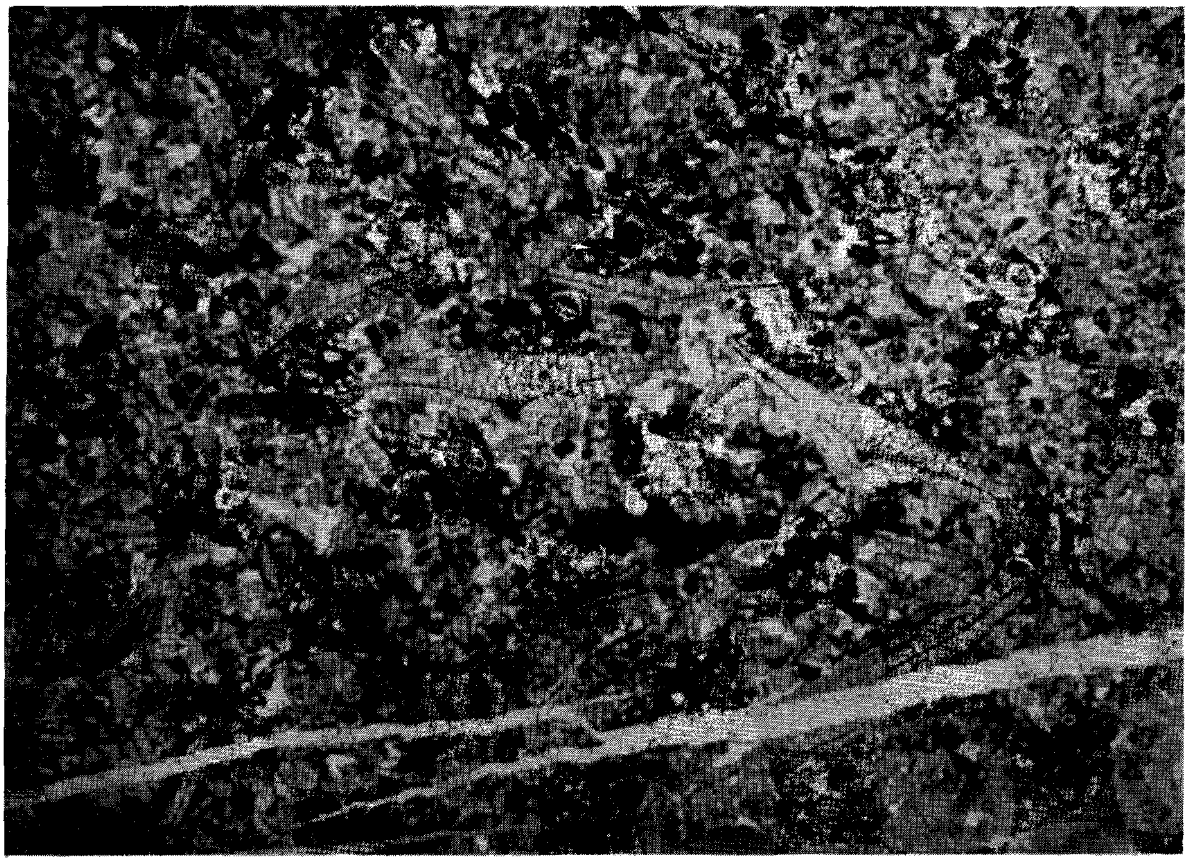


Fig. 16 Organoclastic limestone, containing very few quartz grains with *Clypeorbis mamillata* Schlumberger.
MAASTRICHTIAN, (Bk-member, Río Aurín, number B 193 a).

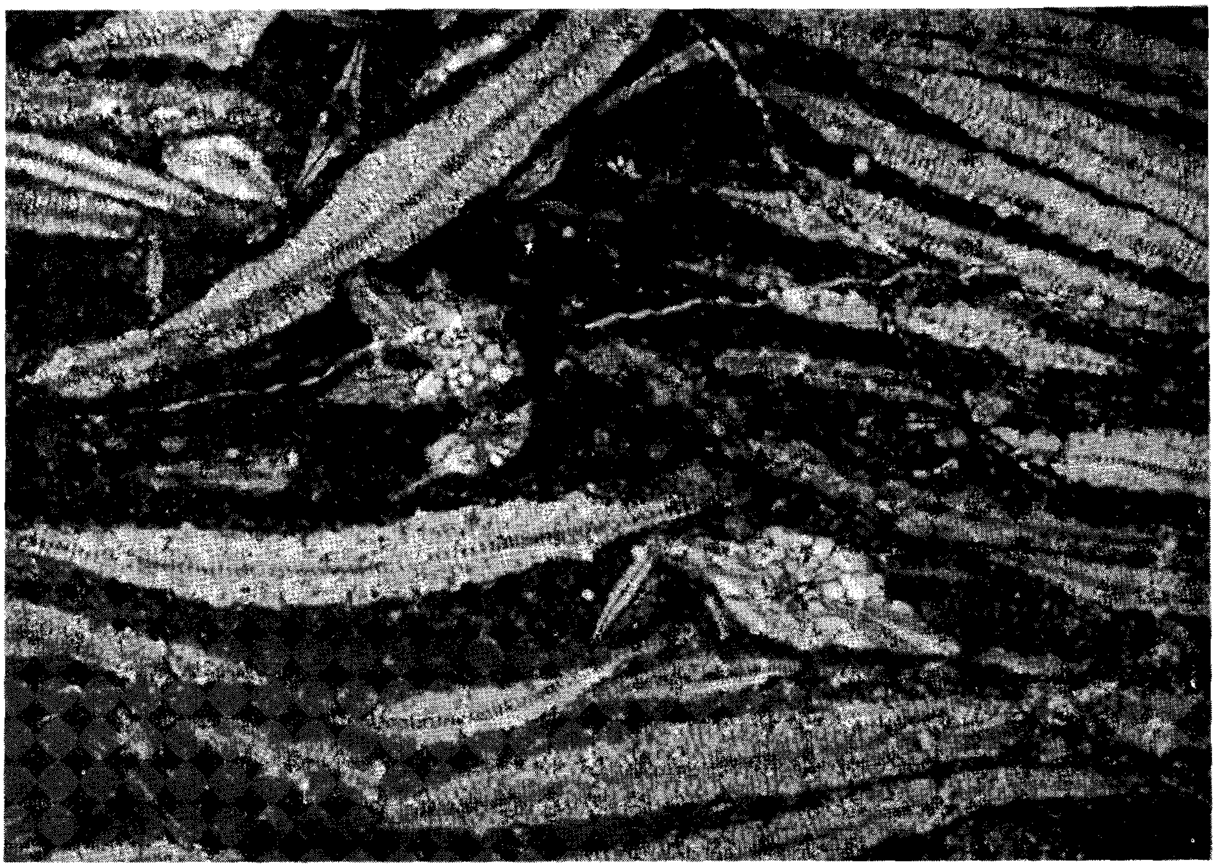


Fig. 17 Organoclastic limestone, containing abundant ferruginous material and small quartz grains (grains-size: 0,015 mm - 0,035 mm) with Lepidorbitoides socialis (Leymerie), Siderolites calcitrapoides Lamarck and Clypeorbis mamillata Schlumberger.
MAASTRICHTIAN, (BI-member, north of the Peña Collarada Number C 34 b).

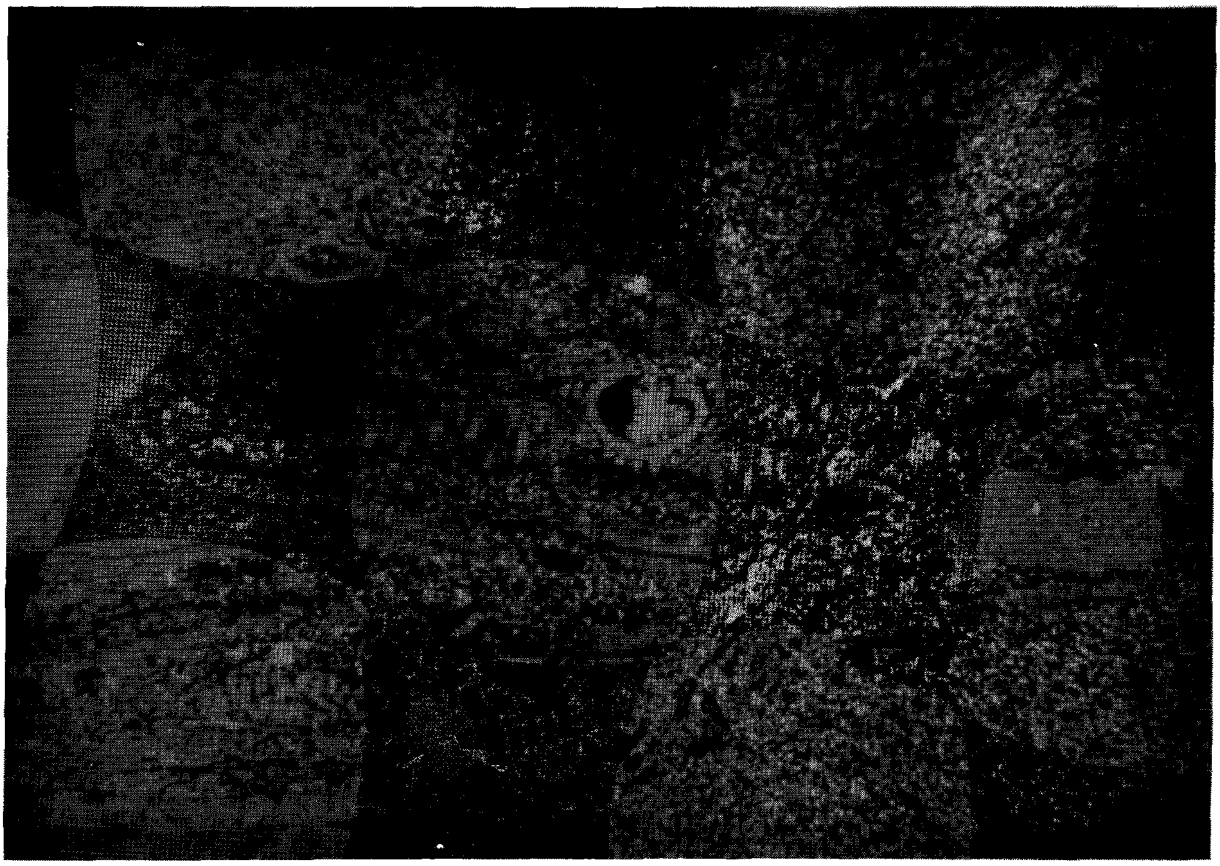


Fig. 18 Fine-grained marly limestone (calcipelite) containing abundant quartz grains and ferruginous material, with *Lepidorbitoides* sp., and *Orbitoides apiculata* Schlumberger.
MAASTRICHTIAN (Bl-member, Río Aurín, number B 192 e).

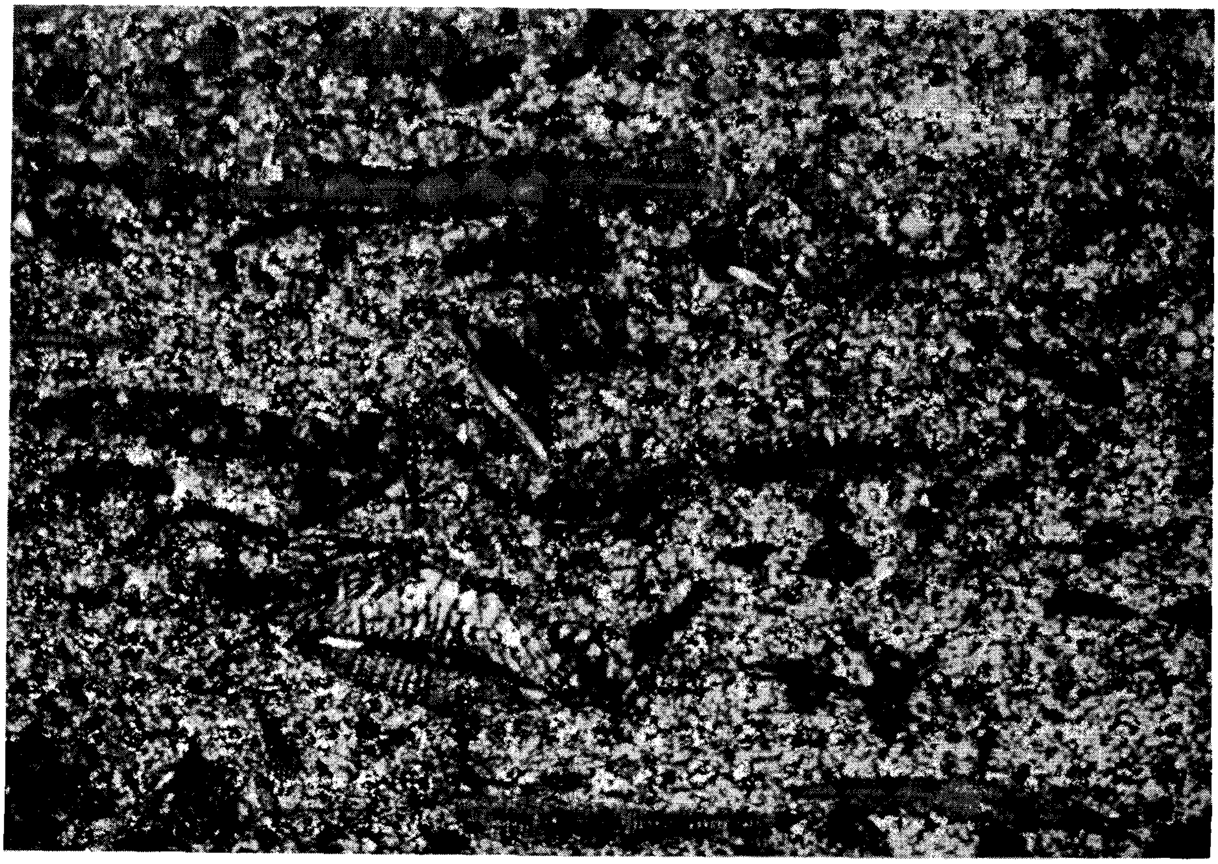


Fig. 19 Fine-grained limestone (calcipelite) containing abundant Quartz and ferruginous material with Lepidorbitoides sp., and a fragment of Orbitoides apiculata Schlumberger. (a).
MAASTRICHTIAN, (Bm-member, Tortiellas, number A 133 d).

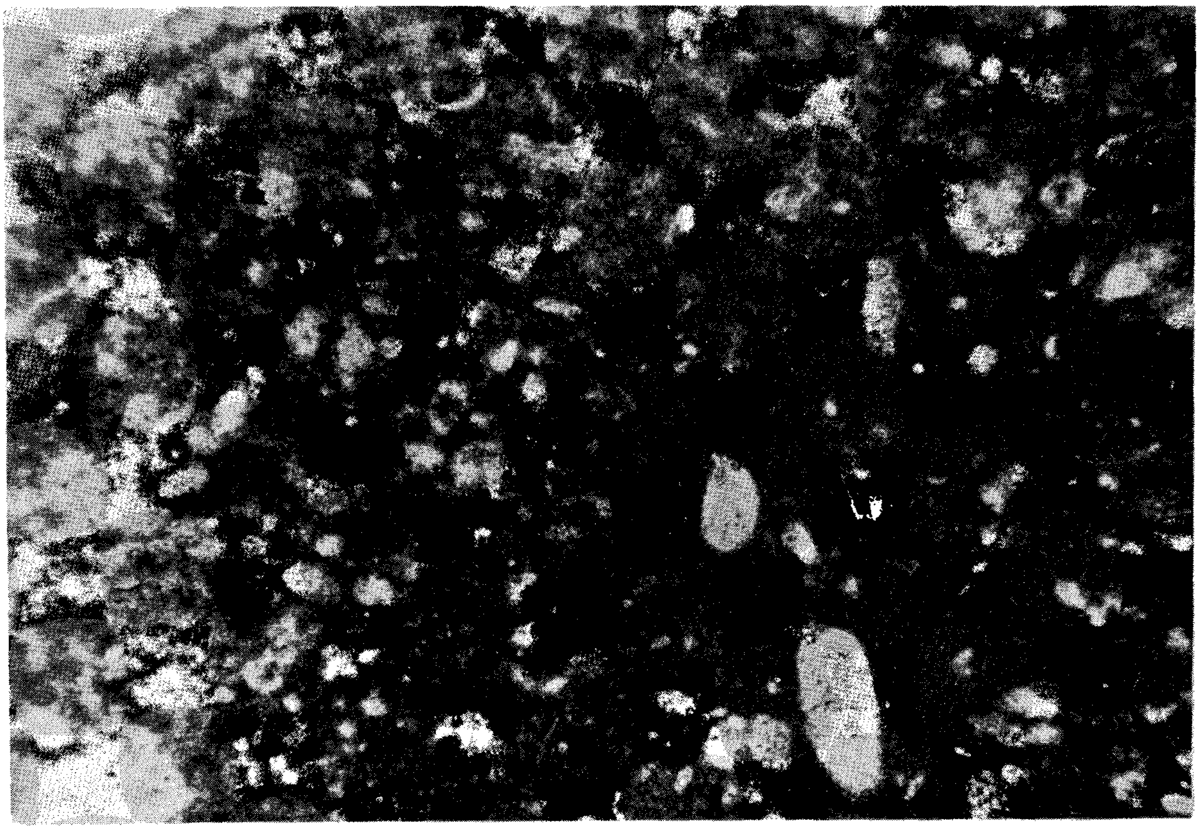


Fig. 20 Very fine-grained, dolomitic limestone (calcipelite) LOWER PALEOCENE, (Cn-member, Río Aurin, number B 185 a-2) Also described in the Ordesa region by von Hillebrandt, 1962, Tafel I.

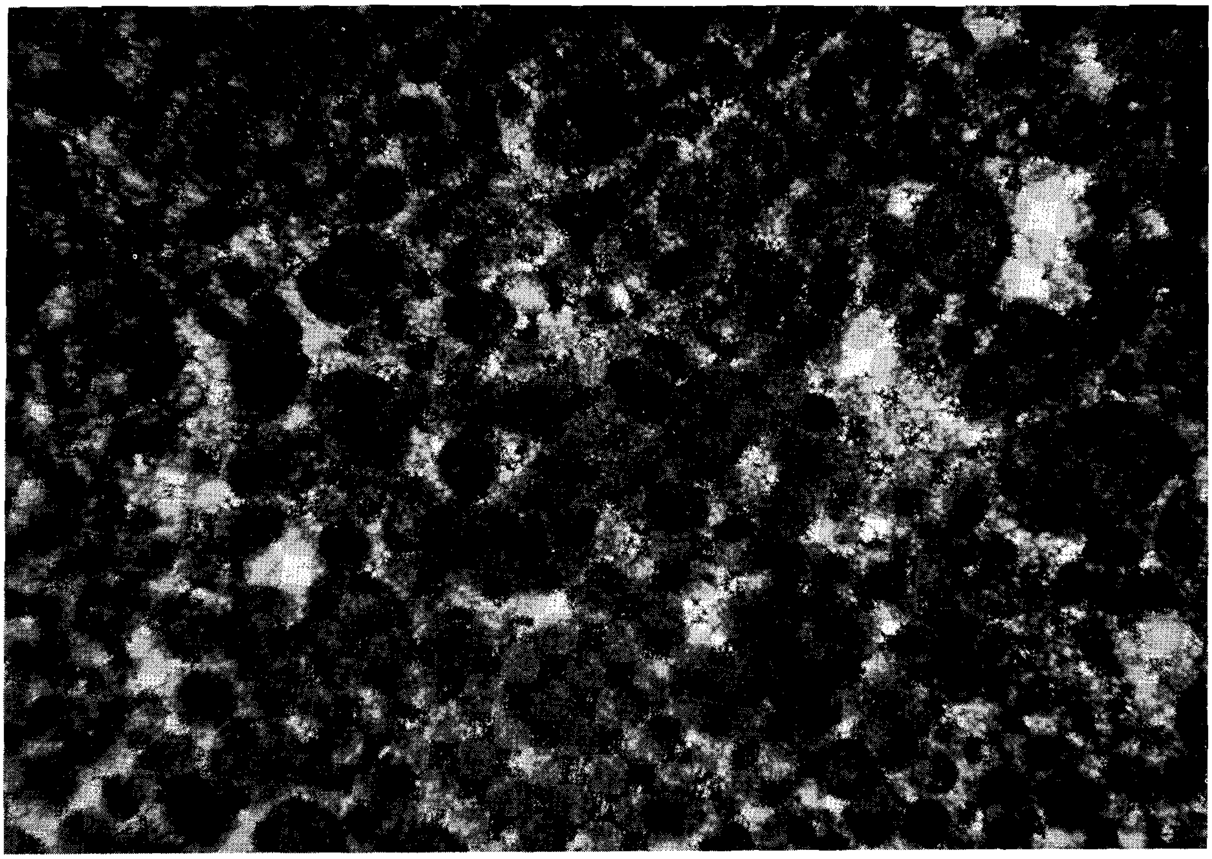


Fig. 21 Oolitic limestone (grain-size: 0,06 mm - 0,25 mm). The pores between the grains are filled with dolomite, displaying mozaïc structure.
LOWER PALEOCENE, (Co-member, Río Aurín, number B 185 - a-1) Also described in the Danian of the epicontinental zone of the Aquitain Basin, by Cuvillier, 1956, Plate LXVI.

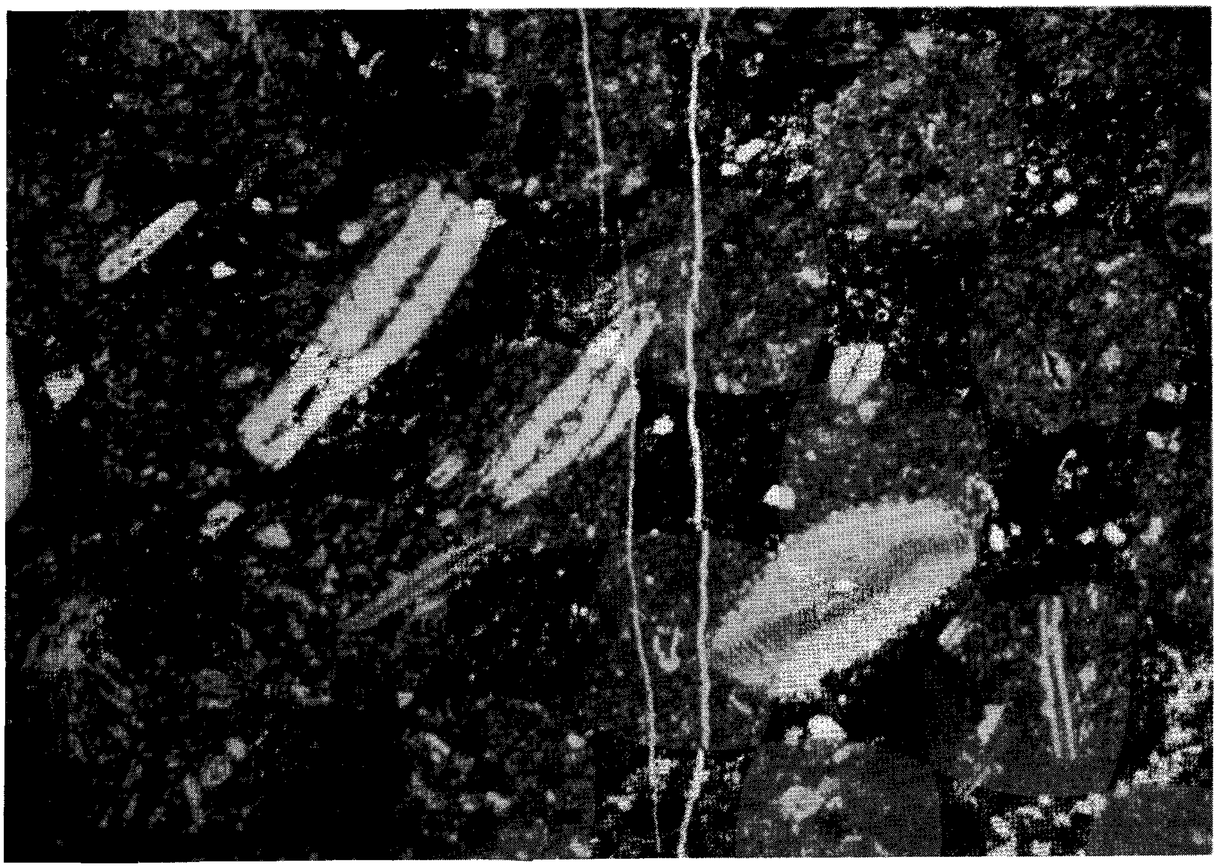


Fig. 22 Lithothamnium limestone (calcipelite) with Operculina sp., Discocyclina sp.
MIDDLE PALEOCENE, (Cp3-bed, Gállego Valley, number B 257 b). Also described in the Ordesa region by von Hillebrandt, 1962, Tafel I.

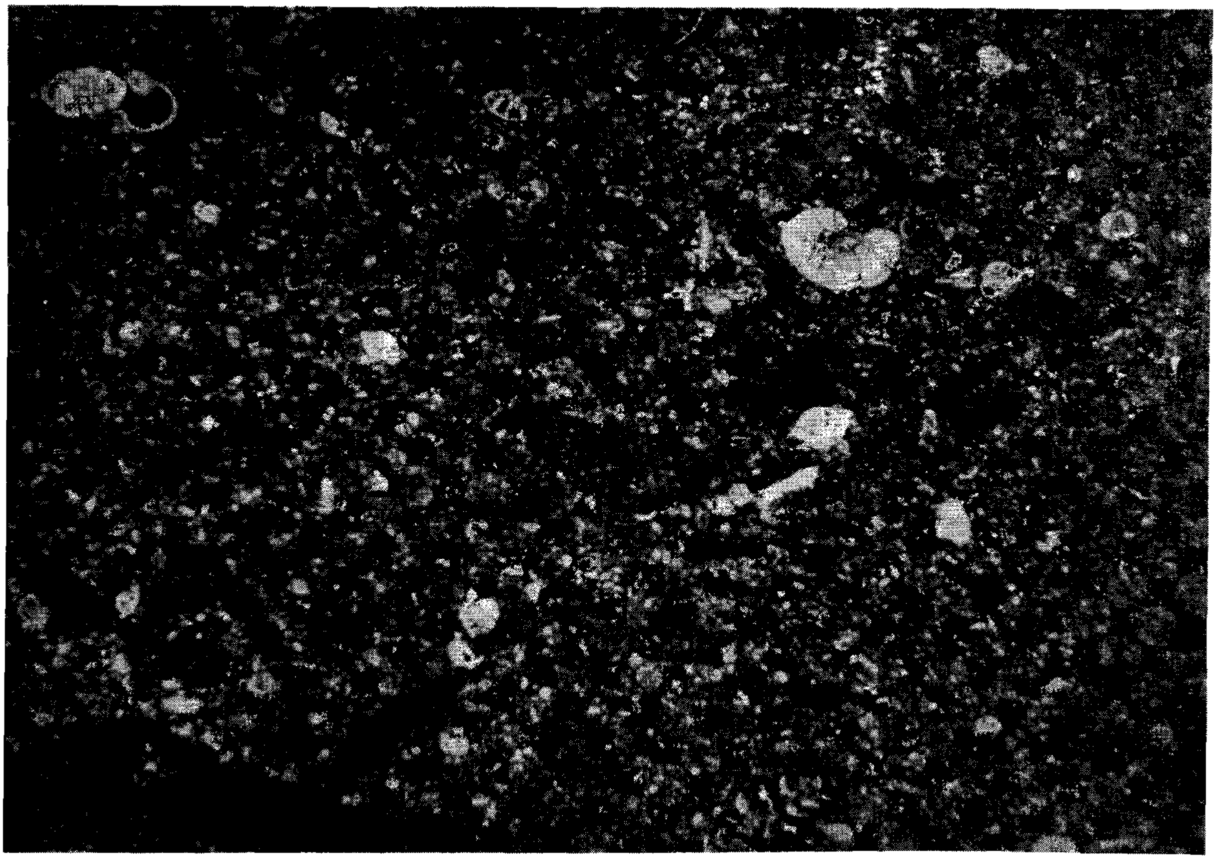


Fig. 23 Organoclastic limestone (calcipelite) with Anomalinoides grosserugosa (Gümbel) Fallotella alavensis Mangin, (vaguely visible on the left side of the photograph) and 'Textularia'. MIDDLE PALEOCENE, (Cp_4-bed, Gállego Valley, number B 257 a-2)

Fig. 24 Highly fossiliferous marly limestone which has a calcipelitic matrix, containing abundant small quartz grains and ferruginous material, with Assilina sp., Nummulites sp., Operculina sp., and Discocyclina sp. UPPER PALEOCENE, (Cp_5-bed marly deposit; Río Aurín, Number B 189 c).

Fig. 25 Organoclastic limestone with *Discocyclina* sp., *Assilina* sp., *Nummulites* sp., and *Operculina* sp.
UPPER PALEOCENE, (Cp_5-bed, Río Aurín, number B 189 b).

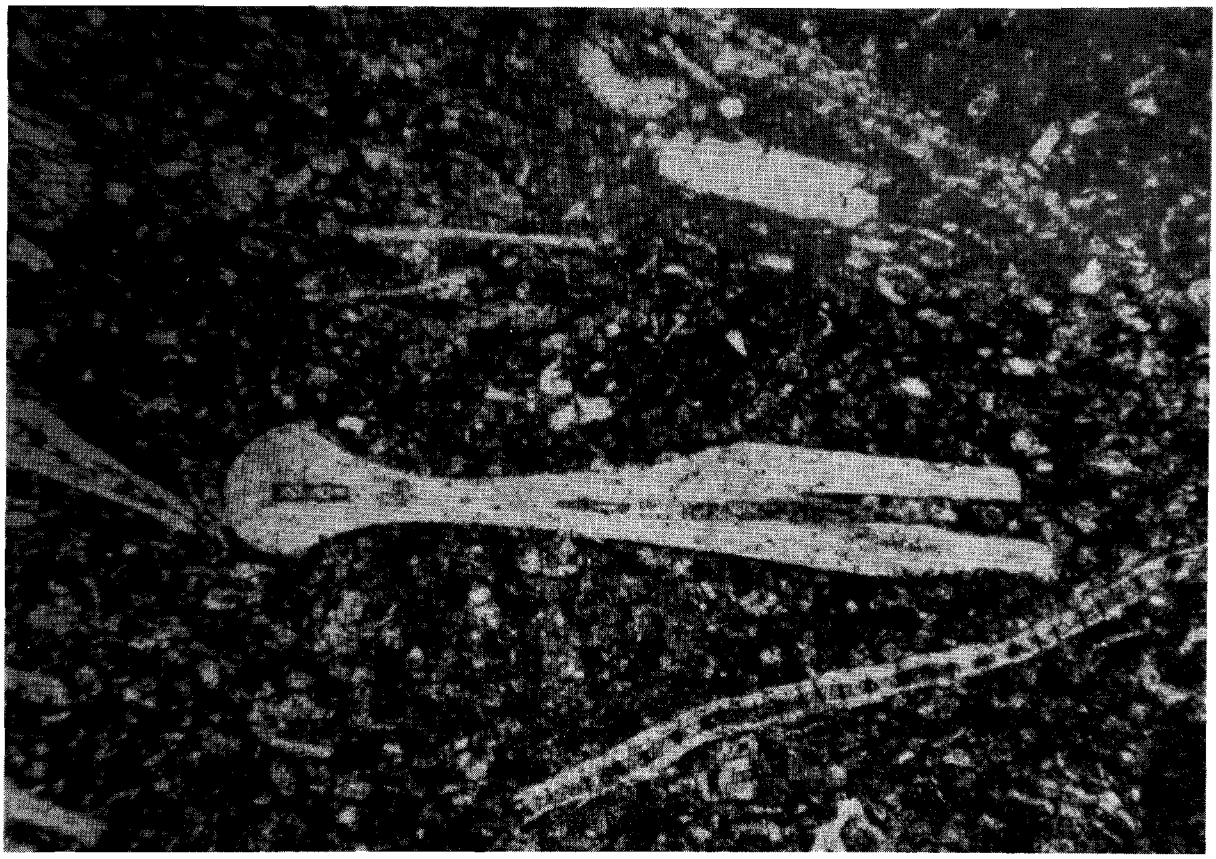


Fig. 26 Fine-grained limestone (calcipelite) with Operculina canalifera d'Archiac.
UPPER PALEOCENE, (Cq-member, south of the Pico de Aspe, number C 131 h).

2.7.4. C-formation

The base of the C-formation (Cn- and Co-members) has the same development in all the regions. The lithostratigraphic correlatives of these members (dolomitic deposits) are the Salarons Formation (Van De Velde, Ordesa region) and the C-formation (Van der Voo, Tendenera region).
The overlying Cp- and Cq-beds can be correlated with Van der Voo's D- and E-formation and Van de Velde's Gallinera Formation.

2.7.5. D-formation

The base of the D-formation (Dr-member) is similar to Van de Velde's Millaris Formation. Van der Voo did not mention this deposit, it is therefore probably absent in his area.
The lithostratigraphic correlatives of the overlying Ds-member are the F-formation (Van der Voo) and the 'Flysch-type-deposits' (Van de Velde).

3. STRUCTURAL GEOLOGY

3.1. INTRODUCTION

3.1.1. Structural Setting

Jacob (1930) and Rutten (1967) divide the Western Pyrenees simply into an axial zone consisting of pre-Alpine rocks and external zones towards the north and the south consisting of Mesozoic and Tertiary strata. Following this division, the region discussed in this thesis is situated in the southern, external zone (north of Jaca).
De Sitter (1964) presented the Pyrenees as a more or less structurally symmetric mountain chain. He distinguishes the following units:

(1) An axial zone predominantly consisting of Paleozoic rocks.
(2) A northern and southern external zone separated from the axial zone by the Northern and Southern Pyrenean Fault and characterized by folded Mesozoic rocks locally surrounding domes of Paleozoic rocks.
(3) A northern and southern sub-Pyrenean zone; marginal zones filled with Mesozoic to Eocene sediments. However, there are no external zones similar to De Sitter's in this part of the Western Pyrenees. Along the northern boundary of the area of study the Upper Cretaceous sediments immediately cover, in general, Paleozoic rocks of the southern flank of the axial zone.

3.1.2. Structural History

The Pyrenees originated by the Hercynian and the Alpine Orogeny. The Hercynian Orogeny embraces several phases which all have occurred within the Carboniferous. During this orogenetic period folding and induration of Carboniferous and older rocks took place. In present time these Hercynian folded rocks mainly form the axial zone of the Pyrenees. After these orogenetic movements a period of peneplainization and subsequent sedimentation occurs, resulting in a sedimentary cover of Mesozoic to Tertiary strata. New orogenetic movements of the Alpine Orogeny affect both the Hercynian folded core and the sedimentary cover. The rigid core reacts mainly by faulting and only locally by folding (cf. Wensink, 1962). The sedimentary cover, however, is strongly folded by the Alpine Orogeny. According to most writers this orogeny consists of two phases: An older phase between the Late and Early Cretaceous (Austrian Phase) and a younger phase at the end of the Eocene (Pyrenean Phase) (cf. De Sitter, 1964). The Austrian Phase, however, is not a true folding phase (according to Mattauer and Sequret, 1966 and Rutten, 1967): only epirogenetic movements took place during this time (see 3.4.).

As in most part of the Western Pyrenees there is a stratigraphic hiatus of Upper Triassic, Jurassic and Lower Cretaceous. Thus the structural features to be discussed concerning the Upper Cretacecous to Eocene sediments originated during the Pyrenean Phase only.

3.1.3. Main structural features of the region of study

The sedimentary epidermis of Upper Cretaceous and Lower Tertiary sediments (A-B-C- and D-formations) forms part of the southern external zone of the Western Pyrenees. In general an ESE-WNW strike and an southern dip is present in these sediments.

The following structural features could be observed:

(1) A basal detachment fault.
(2) Internal low angle faults in combination with thrust folds.
(3) Bedding plane faults in combination with disharmonic folds.
(4) Transverse high angle faults.

The superficial epidermis consisting of the A-B-C- and D-formation moved over the basal detachment fault. However, the fault plane is only locally exposed, along the northern boundary of the region of study.

At these localities the fault plane coincides with the lower boundary of the sedimentary cover, and separates gently S-dipping and WNW-ESE striking Upper Cretaceous sediments from N-dipping and E-W- striking Devonian and Carboniferous deposits. Only locally across the French frontier on the northern side of the Aspe Unit (fig. 27), do Upper Cretaceous sediments uncomformably overlie WNW-ESE striking and S-dipping Permo-Triassic deposits. The Permo-Triassic and older Paleozoic rocks belong to the southern flank of the axial zone, which form the basement of the Upper Cretaceous to Eocene sediments (Van Der Lingen, 1960 and Wensink, 1962) Although not corrobated by field evidence, the basal detachment fault may locally not coincide with the lower boundary of the Upper Cretaceous. The detachment of the epidermis might also in places have stripped parts of the top of the basement complex. In the western wall of the Aragón Valley the basal strata (Aa-member) are locally stripped off. Van Der Voo (1967) described a thinning of the lowermost formation (A-formation) from 110 m to 5 m in the Tendeñera region (see fig. 27), owing to the fact that the lowermost strata were probably stripped off or extended in thickness during the movements along the basal fault plane.

The direction of movement of the Upper Cretaceous to Eocene epidermis over the basal detachment fault could not be established with certainty. However, we conclude to a southward movement since all internal movements along low angle fault planes and along swarms of bedding planes are established to be southwards, which movements are considered to have originated by the same orogenetic forces. Moreover, Van Lith (1968) established Southward movement along the same fault plane in the Cinca Region (see hereafter part 3.3.2.)

Apart from the movement along the basal detachment thrust fault, internal movements along low angle thrust planes have taken place within the superficial epidermis. These movements occur mainly in the upper part of the B-formation and in the C-formation. The southern part of each of these fault planes cuts the beds of the C-formation at an acute angle, whereas towards the north the fault plane disappears between the layers of the B-formation (mostly Bj-member), thus passing into a bedding plane thrust fault. A similar feature, however, in relation with much larger displacements, has been described by Gwinn (1964) for the Central Appalachians. In contrast to the basal detachment thrust plane the low angle thrust planes are well exposed, especially their southern parts. These internal movements resulted in an imbricated structure of thrust slices. The observed overlap without exception show a southward movement. The most striking example of

this imbricated structure is found in the Bernera Unit (section XII).
The southern frontal parts of the thrust slices generally consist of a well-developed thrust fold. The best examples of these thrust folds are found in the western part of the region.

Besides these important movements over major internal low angle fault planes also smaller differential movements along swarms of bedding planes do occur. The alternation of marly limestone either with limy marls or with still more competent pure limestones in the B-formation made such movements possible. These movements are evidenced by locally observed down-dip striation on the bedding planes, which indicates southward movements. Both the internal movements along major low angle thrust planes and the smaller movements along bedding planes are directed southward. In combination these movements resulted in tectonic structures in which the higher strata have advanced farther southward than the lower ones. For this mecha-

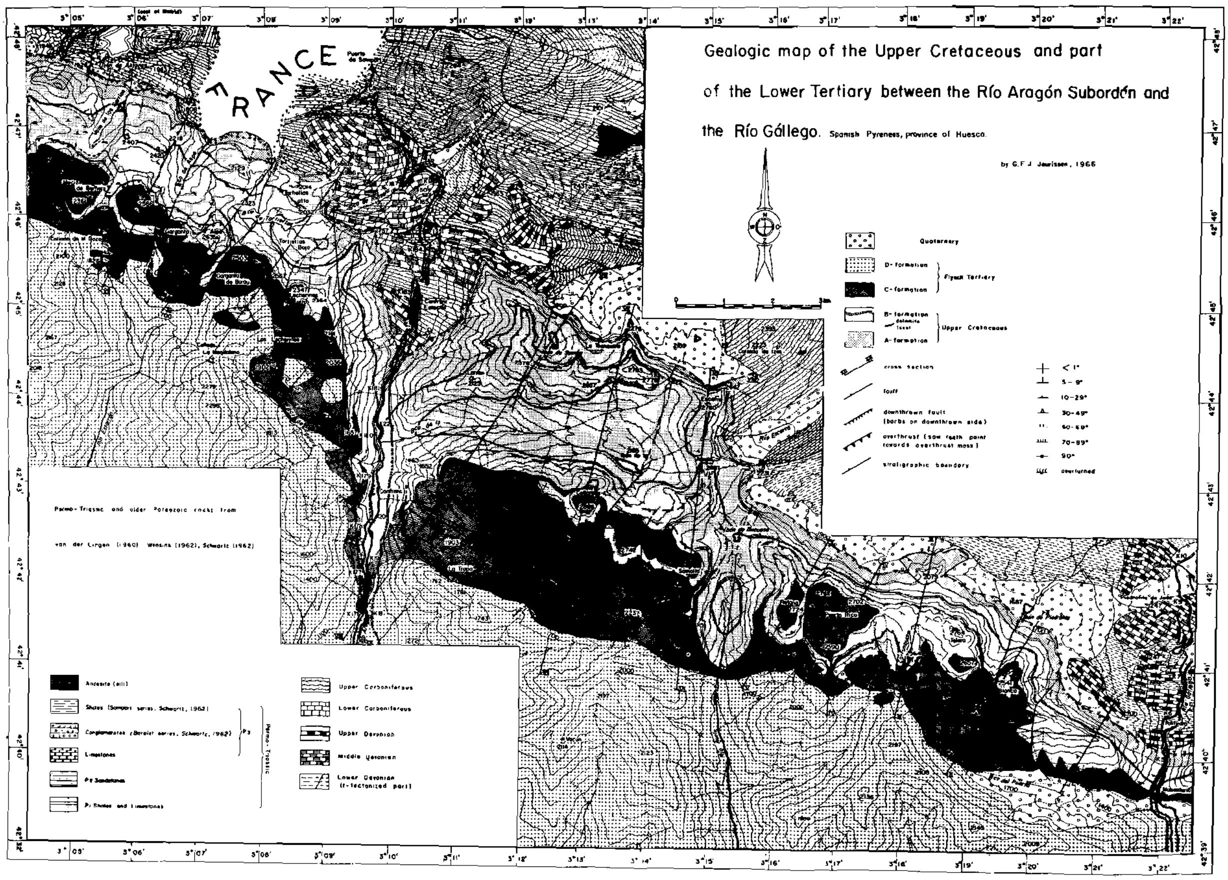


Fig. 27 Location of the tectonic units.

nism the German coined the expression: 'Das voraneilen der jüngere Schichten'. Accompanied by the internal movements along swarms of bedding planes disharmonic folds are present. These folds are stratigraphically located within the B-formation and topographically in the northern parts of the entire region with the exception of the eastern units (Retona- Telera- and Blanca Unit).
The axial planes of these folds have a northern dip (German: S-vergenz). In general an increase of tectonic deformation from below upward is observed. This mechanism is clearly demonstrated in the Somolla Unit (section VI).

The fourth important tectonic element that has to be discussed is formed by the transverse high angle faults. The orientation of these faults ranges from N to N 30^{o} E and the dip from vertical to 60^{o}E. They are found in the epidermis, consisting of the A-B-C- and D-formations only. They do not penetrate into the basement.
These faults separates parts of the sedimentary cover which have a different tectonic structure. On account of this fact the region could be divided into nine tectonic units (fig. 27). The stratigraphic throw observed along the transverse high angle faults generally indicates a (stratigraphic) lower position of the eastern unit. However, the stratigraphic throw changes in magnitude along the strike of one and the same fault. For instance the stratigraphic throw measured between the counterparts of the boundary A/B-formation along the extreme northern part of the transverse fault immediately east of the Collarada amounts about 10 metres. The throw between the counterparts of the boundary B/C-formation observed in the highest possible part of the Collarada mass and beneath the highest low angle fault, amounts to 150 m. The throw between the counterparts of the same stratigraphic boundary B/C-formation in the extreme southern part amounts again to some 10 metres. The origin and the complex character of these transverse high angle fault will be discussed in part 3.3.

3.2. TECTONIC UNITS

3.2.1. Blanca Unit (section I and II)

The Blanca Unit is bounded in the west by a transverse high angle fault immediately west of the Peña Blanca. The eastern boundary is formed by the Río Gállego which cuts the unit in a narrow transverse valley. The data as found along the road of the Gállego Valley have been projected in section I. The overall structure of the Blanca Unit is composed of gently S-dipping strata of the northern part (concordantly with the basal fault plane) and undulating strata of the southern (frontal) part. This structure is found also in the following more westerly units (Telera and Retona Units). The Blanca Unit forms the most simply structured unit. Apart from the basal detachment plane only one major internal low angle fault plane is present. In the eastern part a steeply tilted succession composed of the A-B-C- and D-formation, dipping southward from 15^{o} - 75^{o} has been left by erosion. This succession (section I) which overlies the basal fault plane, represents the lower, main thrust slice.
In the western part of the Blanca Unit a second thrust slice is found. At an elevation of about 2400 m the C-formation is cut a major low angle fault plane (figure 28, section II). The overlying mass, consisting of the upper part of the B-formation, has been moved southward.
The minimum overlap is roughly estimated at 1 km - 2 km.

3.2.2. Telera Unit (section III and IV)

The eastern and western boundary of this unit is formed by a transverse high angle fault.
In the Telera Unit three thrust slices can be distinguished:
A lower main thrust slice; a large jammed wedge; and an upper thrust slice.
The lower mass is composed of gently undulating strata of the A-B- and C-formation, similar to the structure of the Blanca Unit.

The upper thrust slice in itself forms a shallow syncline and is composed of strata of the B- and C-formation (figure 29). The overlap, which is the minimum amount of displacement, is 2 km (southward). Between the lower and the upper thrust slice a jammed wedge is found. The upper boundary of this wedge is formed by the important major internal low angle fault plane of the upper thrust slice; the lower boundary concerns an internal fault plane of minor importance. The jammed wedge forms a large mass which is stripped from the underlying main thrust slice. The minimum amount of displacement of this wedge is estimated at 300 m southward. The stratigraphic series taking part in this wedge differs along the strike, owing to the change in stratigraphic level of both the upper and the lower internal fault plane. In the eastern part of the Telera Unit the situation is rather complex, as the single fault plane of the base of the wedge is replaced by several smaller fault planes which show inbricated structure. In section III (figure 30) across the Peña Zarrambucho, the wedge is composed of the whole C-formation with the exception of its uppermost member (Cq-member). In section IV (figure 31) across the Puerto Rico the wedge is composed of the upper part of the B-formation (Bm-member) and the lowermost part of the C-formation (Cn-member). In the extreme western part of the Telera Unit the wedge peters out; the lower and the upper internal fault plane joining each other here.

In section IV a frontal part of the upper thrust slice is shown. It slid down and now forms the most southern part of the Puerto Rico mass. The lower part of it is composed of steeply S-dipping to overturned N-dipping strata (Cq-member and Cp-member). This structure gradually passes into a synformal anticline (Co-Cn- and upper part of Bm-member), which forms the upper part of the down-slid frontal nose (see fig. 31).

3.2.3. Retona Unit (section V)

To the east and west this unit is bounded by a transverse high angle fault. The western transverse fault follows the middle part of the broad Aurín Valley.

In the Retona Unit three thrust slices may be distinguished: A lower main thrust slice; a middle and probably an upper thrust slice. The lower thrust slice is composed of a broad anticline with a 70° - 80° S-dipping southern flank and a subhorizontal to slighty N-dipping northern flank, passing northwards into a shallow syncline with a 10° - 20° S-dipping northern flank. This lower, main thrust slice is cut off by a major internal low angle fault plane of which the southern part is clearly exposed (figure 32). The minimum southward displacement is 2 km. At higher elevations another internal fault plane is probably present. Although not actually found, the stratigraphic succession above the clearly recognizable Bk-member (figure 32) is too thick to represent the normal succession of the Bl- and the Bm-members only. Hence tectonic doubling is very likely.

3.2.4. Somolla Unit (section VI)

In the east the Somolla Unit is bounded by the transverse fault which follows the Aurín Valley. The western boundary is formed by a transverse fault immediately east of the Collarada.

The Somolla Unit is composed of a lower main thrust slice; a middle and an upper thrust slice. In contrast to the afore-mentioned units the lower main thrust slice still shows a large northern non-eroded part, which is also present in all the more westerly units.
The structure of the southern part is similar to the structure as found in the Retona Unit.
The northern part is composed of a gently folded A-formation overlain by intensely folded series of the B-formation. The difference of folding in the northern part between the lowermost part of the epidermis (A-formation) and the middle part (B-formation), may be related to the bedding plane slip in the B-formation already

mentioned (3.1.3.).
The folding has a southward direction (German: 'Vergenz'), with N-dipping axial planes. The amplitude of these folds increases from below upward. This disharmonic folding is generally found in all the northern parts of the lower main thrust slice throughout the entire region with the exception of the eastern units (Blanca-, Telera- and Retona Unit).

In the southern part of the Somolla Unit two major internal low angle fault planes are present higher up in the series. They are clearly exposed along the western flank of the Peña Somolla (figure 33). The minimum distance of displacement of the lower and the upper major internal fault plane are 1.5 km and 1 km respectively. Towards the north both major internal low angle fault planes disappear between the layers of the B-formation, probably passing into a bedding plane fault.

3.2.5. Collarada Unit (section VII and VIII)

This unit is bounded in the east by the transverse high angle fault immediately east of the Peña Collarada. The transverse valley of the Río Aragón forms the western boundary.

Apart from the basal fault plane and an accompanying internal fault plane of minor importance in the A-formation (northern part of section VII and VIII), three major internal low angle fault planes are found. Section VII shows the middle and the upper, section VIII the middle and the lower major internal low angle fault plane. The upper internal fault plane is encountered at an elevation of about 300 m beneath the top of the Collarada (section VII, figure 34). The next lower internal fault plane is, in contrast to the upper, exposed along the southern flank of the Collarada only. The lower internal fault plane is badly known. It is exposed over a small distance along the eastern valley wall of the Río Aragón only.
The overlap of the upper, the middle and the lower internal fault plane is 1,2 km, 0,25 km and 0,25 km respectively.
The stratigraphic succession of the upper part of the B-formation near Ibón the Samán (northern part of the Collarada Unit) is too thick to represent the normal succession only. Tectonic doubling is very likely and a major internal low angle fault plane is supposed to be present (dashed line in sections VII and VIII). The connection with the middle, internal low angle fault plane in the southern part of the Collarada Unit is rather speculative.

3.2.6. Lecherines Unit (section IX)

This unit is bounded in the east by the transverse valley of the Río Aragón. The western boundary is formed by a transverse high angle fault immediately west of top 2347 m, accompanied by a second fault of minor importance which join southwards.

Three internal low angle fault planes are found en échelon in the Lecherines Unit, beside the basal fault plane. They are all of minor importance since the minimum distance of overlap vary from 100 m to 200 m. The data as found in the western valley wall of the Río Aragón are represented in section IX, which clearly shows the three internal fault planes and the basal fault plane. Above each internal fault plane a well developed thrust fold has been formed during the southward movements.

In contrast to all other tectonic units the Lecherines Unit is locally covered by deposits of the D-formation (the Lowermost part of the Flysch formation).

The lower main thrust slice above the basal fault plane shows a simply structural succession of the A-B- and C-formation. In the northern part strata of the A-formation, dipping subhorizontally to 20°S, overlie with an angular unconformity strata of Paleozoic age, dipping 30°N to subvertical (figure 4).

3.2.7. Garganta unit (section X)

The eastern and western boundary is formed by a transverse high angle fault.

The Garganta Unit is composed of a lower, main thrust slice in which a minor internal fault plane is present on the southern part; a jammed wedge and an upper thrust slice.

The structure of the lower thrust slice is similar to that described in the Lecherines unit.

The upper thrust slice consists of strata of the C-formation and part of the B-formation (upper part of the Bm-member A well-developed thrust fold, which has a S-dipping axial plane, forms the southern part of the upper thrust slice.

The jammed wedge enclosed between the upper and the lower thrust slice has a rather complex structure. For the greater part it is composed of intensely folded strata of the Flysch deposits of the D-formation (Ds-member). The minor northern part, underneath top 2567 m consists of highly tectonized strata of the C-formation. In contrast to what is generally found the major internal low angle fault plane below the jammed wedge does not cut the strata of the C-formation. The southward movement of the upper thrust slice together with the wedge has taken place on the stratigraphic boundary C-formation/D-formation. However, the lowermost part of the D-formation (Dr-member) is absent. Strata of the Flysch deposits (Ds-member) probably have lubricated these southward movements. The minimum displacement of the upper thrust slice is 2 km towards the south.

3.2.8. Aspe Unit (section XI)

This unit is bounded on the east side by a transverse high angle fault mentioned already in the preceding paragraph. The western boundary is formed by two parallel transverse faults, which are accompanied by several minor faults in the region in between.

The Aspe Unit can be divided into three thrust slices: A lower main thrust slice, a middle and an upper thrust slice.

The lower thrust slice is composed of intensely folded strata of the B-formation (figure 36). The underlying A-formation forms a recumbent fold with a slightly N-dipping axial plane. The disharmonic folding of the B-formation which is present in all northern noneroded parts of the lower thrust slice, is especially developed in the Aspe Unit.

The lowermost major internal low angle fault plane is exposed along the northern side of the Aspe Unit only. The minimum overlap is 2 km. The southern part of the overlying (middle) thrust slice is composed of a thrust fold of which, in general, the overturned N-dipping part has been preserved (figure 38).

At higher elevations another major internal thrust fault is present which has a minimum overlap of 0,8 km.
The upper and lower internal thrust plane are clearly shown in figure 37.

3.2.9. Bernera Unit (section XII)

On the east side the Bernera unit is bounded by a system of transverse high angle faults already described. On the west side the boundary is formed by a transverse valley, lying in Van Elsberg's region, west of the Macizo de Bernera.
This structural unit represents a most striking example of a piling up of a series of thrust slices. A lower main thrust slice which has a similar structure as found in the Aspe Unit, is overlain by a series of four thrust slices. Each slice has a southward displacement which amounts for the upper one to the lower one range to: 0,5 km; 0,5 km; 2 km and 0,8 km. Between these major internal low angle fault planes well developed thrust folds are present.

3.3. TECTONICAL CONSIDERATIONS

3.3.1. Introduction

The movements along the basal fault plane, along the major internal low angle fault planes and along swarms of bedding planes are southward movements. Similar southward movements of the Upper Cretaceous to Eocene deposits in the Spanish Western Pyrenees have been described also by Van Elsberg (1968) Schwarz (1962), Van Der Lingen (1960), Wensink (1962), Van Der Voo (1967), Van De Velde (1968) and Van Lith (1968), all students of the geological institute of the state University of Utrecht. To give a clear insight into the structural evolution of the region of this thesis the described main structural features reported in some of these papers will be discussed in relation to the tectonics of the region of discussion. It will be shown that the region of study structurally forms the transition from a region in which no important movement has taken place (Aragón Subordán region, Van Elsberg, 1968) to regions in which considerable movements are established (Ordesa region, Van De Velde, 1968 and the Cinca region, Van Lith, 1967). In this paper four main structural features are distinguished:

(1) A basal detachment fault along which the Upper Cretaceous to Eocene epidermis moved southward.
(2) Internal low angle faults in combination with thrust folds. Along these major internal low angle faults parts of the epidermis moved southward, resulting in an imbricated structure of thrust slices.
(3) Bedding plane faults in combination with disharmonic folds. These bedding plane slips made possible differential southward advance of the epidermis, particularly the B-formation.
(4) Transverse high angle faults. These faults allowed a differential southward movement of the epidermis along the basal fault, along the internal fault planes and along the bedding planes.

3.3.2. Basal detachment fault

Few data are available about the movement along the basal thrust plane in the region of study, since the contact is only locally exposed (along the northern boundary). The direction and the amount of displacement could not be established, as no tectonic doubling is found. However, in the Aragón Valley a clear fault plane is exposed whereby part of the basal layers of the A-formation are stripped off.

To the west of the region Van Elsberg (1968) reported in the Aragón Subordan region that there was no displacement at all along the contact between the Upper Cretaceous sediments and the Permo-Triassic and older rocks. He supported this statement by pointing out that a close lithological relationship can be observed between the coarse components of the basal layers of the Upper Cretaceous and the underlying Permo-Triassic and older rocks.

In the Gállego Valley, Wensink (1962) described Hercynian folds in Middle Devonian limestones immediately underneath the contact, which have been bended downwards as a result of the Alpine movements.

In the Tendeñera region, Van Der Voo (1967) observed a tectonic wedging out of the A-formation from 110 m to a few metres only, owing to the fact that the lowermost strata were stripped off or extended and reduced in thickness during the movements along the basal detachment thrust fault.

Van De Velde (1968) and Van Lith (1968) reported important southward movement along the same thrust plane. This important southward movement could be established in the Cinca region (Van Lith) since strata of allochthonous Upper Cretaceous rest upon strata of autochtonous Upper Cretaceous, forming the top of the basement.

From these observations it may probably be concluded that an increase of the southward movement along the basal detachment fault occurred.

3.3.3. Major internal low angle faults

More data are known about the amounts of displacement along major internal low angle fault planes. These internal southward movements cause repetitions of the stratigraphic sequences, by forming piles of thrust slices. These thrust slices are

in fact minor scale nappes of the Helvetian type. The maximum amounts of the minimum southward overlap along such low angle fault planes range from 0,5 km in the Aragón Subordán region (Van Elsberg, 1968) via 2 km in the region of study to about 10 km in the Ordesa and Cinca region (Van De Velde, 1968).
Moreover in the western part of the Aragon Subordán region (Van Elsberg, 1968, see fig. 1) the imbricate structure of thrust slices laterally change into piles of superimposed recumbent folds.
From the above mentioned facts it is concluded that evidently the amounts of southward movement along major internal low angle faults increase twentyfold from west to east over a distance of 60 km in the direction of the strike.

3.3.4. Bedding plane faults

Nothing can be said about the total amount of displacement along the swarms of bedding plane faults. The southward movement could be established by observed down-dip striation. In the region of study these bedding plane slips are generally accompanied by disharmonic minor scale folds. Bedding plane faults are also observed in the neighbouring region. No indication was found from which we may conclude that there is an increase from west to east of the southward movement along such bedding plane faults.

3.3.5. Transverse high angle faults

The transverse high angle faults separates parts of the fold belt in which the tectonic structures are different. Compare e.g. the Aspe Unit (section XI) with the Bernera Unit (section XII). Field evidence generally shows a stratigraphic and topographic lower position of the eastern unit, which is locally indicated in the geologic map by barbs on the downthrown side. However, these topographic and stratigraphic lower positions of the eastern unit do not reflect vertical movements originating from the basement, since these roughly N-S directed transverse faults do not extend towards the north into the Paleozoic rocks. In the picture of the increasing southward movements of the Upper Cretaceous to Eocene sediments from west to east, we may deduce from the lower position of the eastern unit, a relative southward displacement of this unit. These faults obviously made possible a differential southward movement of the epidermis in semi-independantly advancing tectonic units and they are in fact dextral strike-slip faults. These transverse faults are also reported by Van Elsberg (1968) to the west, and by Van Der Voo (1967) to the east of the region of study. Van Der Voo (personal communication) supports the dextral character of these faults in as much as he observed a (small) relative southward displacement of the eastern unit in the Tendeñera region (see fig. 1), by means of aerial photographs. Unfortunately the present writer had not the disposal of aerial photographs of the region dealt with in this thesis.
Van Elsberg (1968) described the importance of transverse faults or fractures with little or no displacement.
To establish the amount of displacement along a transverse fault is not possible. These faults are too complex to define them with merely one figure for the horizontal off-set since three types of differential southward movements have been active along the fault planes: along the basal detachment fault; along major internal low angle faults and along swarms of bedding plane faults. This complex character is reflected by the observed change in magnitude of the stratigraphic throw along the strike of one and the same fault. For instance in the Blanca Unit (section II) three observations were done, along the extreme northern part, along the extreme southern part and along the middle part of the transverse fault immediately west of the Blanca: the stratigraphic throw between counterparts of the boundary A/B formation along the northern part of the fault plane amounts to about 10 m; between counterparts of the boundary B/C formation (middle part of the fault) amounts to about 80 m. The amount of 10 m may probably

reflect the differential southward movement along the basal detachment plane. The amount of 80 m may be the result of both, differential southward movement along the basal fault plane and differential movements along the swarms of bedding plane faults in the B-formation.
However, the stratigraphic throw observed between counterparts of the boundary C/D formation along the extreme southern part of the transverse fault plane, again amounts to some 10 m. This small amount may be explained by a fading out of the bedding plane slip movements towards the south, by forming the large thrust fold which forms the southern dipslope of the Blanca mass. This explanation, however, is rather speculative since no special studies were made of the bedding plane slips.
The faults show a striking similarity with the 'lineaments' described by Gwinn (1964) in the Central Appalachians: 'Some of the northwest trending lineaments in the sedimentary cover of the Central Appalachian Plateau are tear faults produced by differential anvance of rectilinear thrust blocks; other appear to mark zones of change of stratigraphic level of the thrust'.
Another example of such transverse fault zones are the 'déchrochements horizontaux' at least in the interpretation of Aubert (1959) in the Jura Mountains. The horizontal translation of these décrochements horizontaux is small and moreover change in magnitude along the strike of one and the same déchrochement, and they are only known from the superficial, folded, sedimentary cover.

3.3.6. Conclusion

From the data reported in part 3.3.3. it is concluded that evidently the amounts of southward movement over major low angle thrust faults increase twentyfold from west to east over a distance of 60 km. Probably the amounts of southward movement over the basal detachment fault increase also from west to east, which is supported by the observations of Van Elsberg in the Aragón Suborđán region, who assumes no displacement, and the observations of Van Lith in the Cinca region who established considerable southward displacement.
No data are available to conclude to an increase in the same direction of the southward movements over bedding plane thrust faults.
Apparently there occurred a general eastward increase of the southward movements of the Upper Cretaceous to Lower Tertiary epidermis. This can most probably be explained by an increase in the same direction of the Alpine uplift of the axial zone of the Pyrenees, which resulted in an increase from west to east of the potential relief energy. It is this gravitational energy accumulating during the vertical uplift, which was the cause of the tectonic movements of the sedimentary epidermis and which gave rise to the structures of the Upper Creataceous to Lower Tertiary sediments, nowadays exposed in the southern flank of the Western Pyrenees.

3.4. GRAVITATIONAL ORIGIN OF THE TECTONIC STRUCTURES

During the arching up of the axial zone of the Pyrenees in mid-Tertiary time (see herafter III-5) the sedimentary cover of Upper Cretaceous to Eocene sediments slid towards the adjacent depressed belts at its northern and southern side. These lateral movements occurred owing to the growing energy of the regional relief and they represent the epidermal type of gravity tectonics (secondary tectogenesis, Van Bemmelen, 1955).
That the southward movements of the sedimentary epidermis studied in this paper, were the result of the potential (gravitational) relief energy is supported by the following observations:

(1) In all instances the higher units appear to have advanced farther downslope towards the south than do the lower ones. For this tectogenetic mechanism the German coined the expression: 'Das Voraneilen der jüngere Schichten'.
(2) The presence of semi-independantly advancing tectonic units along the strike of the region (part 3.2.), separated by transverse high angle faults.

(3) The locally observed increase of tectonic deformation from below upward of the disharmonic folds (section VI).
(4) The southward movements along bedding planes within the B-formation (Cloos 1964).
(5) The presence of a propable area of provenance.

An alternative explanation for the origin of the tectonic structures might be sought in tangentional compressive forces in the basement complex. This, however, seems improbable since the Alpine orogeny only slightly affected the Hercynian basement in the region of study (Schwartz, 1962, Van Der Lingen, 1960, Wensink, 1962).

3.5. DATING OF THE ALPINE OROGENATIC MOVEMENTS.

The Upper Cretaceous sediments of the region of study, along their northern boundary immediately cover, in general, Devonian and Carboniferous deposits. Only across the french frontier, on the northern side of the Aspe Unit, do the Upper Cretaceous sediments unconformably overlie Permo-Triassic deposits. To the west this (slight) unconformity is exposed over large distances in the Aragón Subordán Region (Van Elsberg, 1968). A slight tilting must have affected the Permo-Triassic before sedimentation of the Upper Cretaceous took place. This tilting may, or just as well may not, be related to the Austrian Phase.

The Pyrenean Phase is dated by most writers at the end of the Eocene. However, an unconformity between the Millaris Formation (Late Paleocene) and the Flysch deposits (Eocene) in the Ordesa region (Van De Velde, 1968) and the absence of the Millaris Formation in the Tendeñera region (Van Der Voo, 1967) and in most parts of the region under discussion (Millaris Formation = Dr-member, see figure 6), suggests vertical movements at the end of the Late Paleocene or in the beginning of the Eocene. The downsliding of the Upper Cretaceous and Lower Tertiary deposits must have occurred later than Late Paleocene or Early Eocene, since the Flysch deposits (Ds-member, see figure 6) have been influenced by the downsliding movements. These Flysch deposits have been dated by Van De Velde (1968) and von Hillebrandt (1962) as Cuisian.

Whether the gilding phase has actually occurred in the Late Eocene or is even younger can not be established from my investigations since only the lowermost part of the Eocene sediments has been studied.

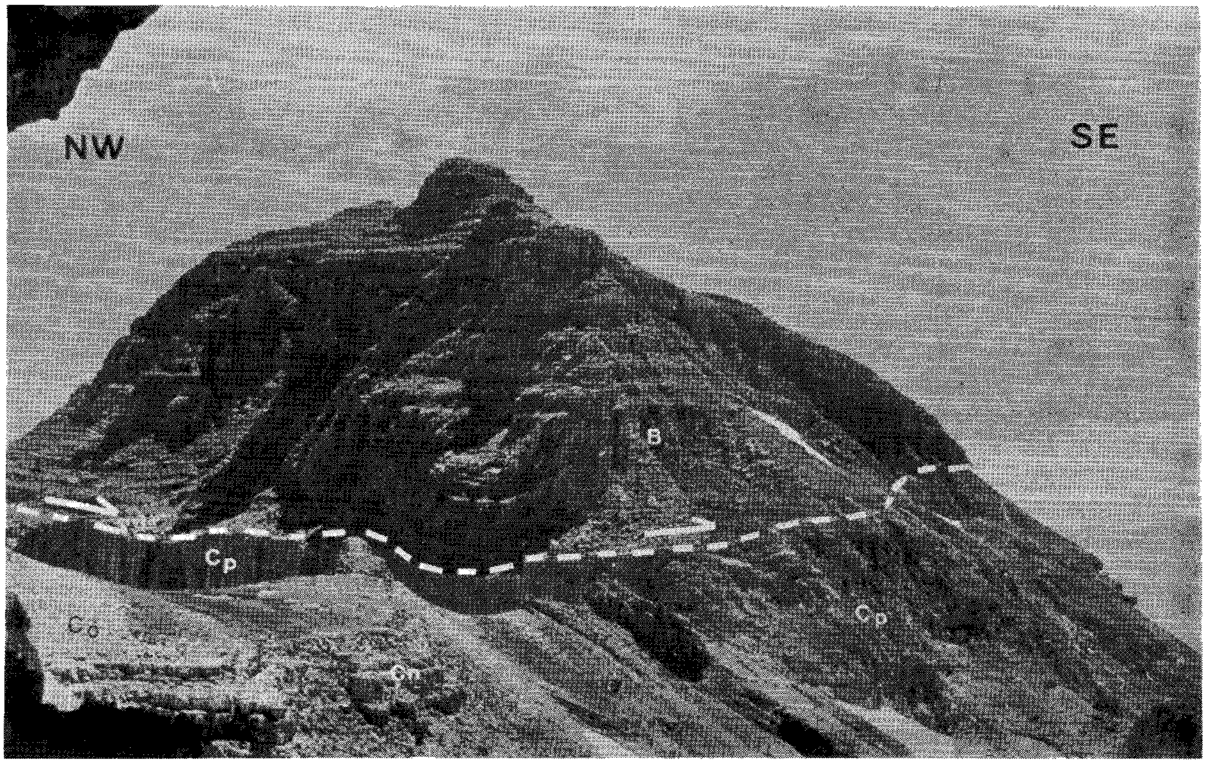


Fig. 28 View of the Peña Blanca from the southwest which clearly shows a major low angle fault plane.

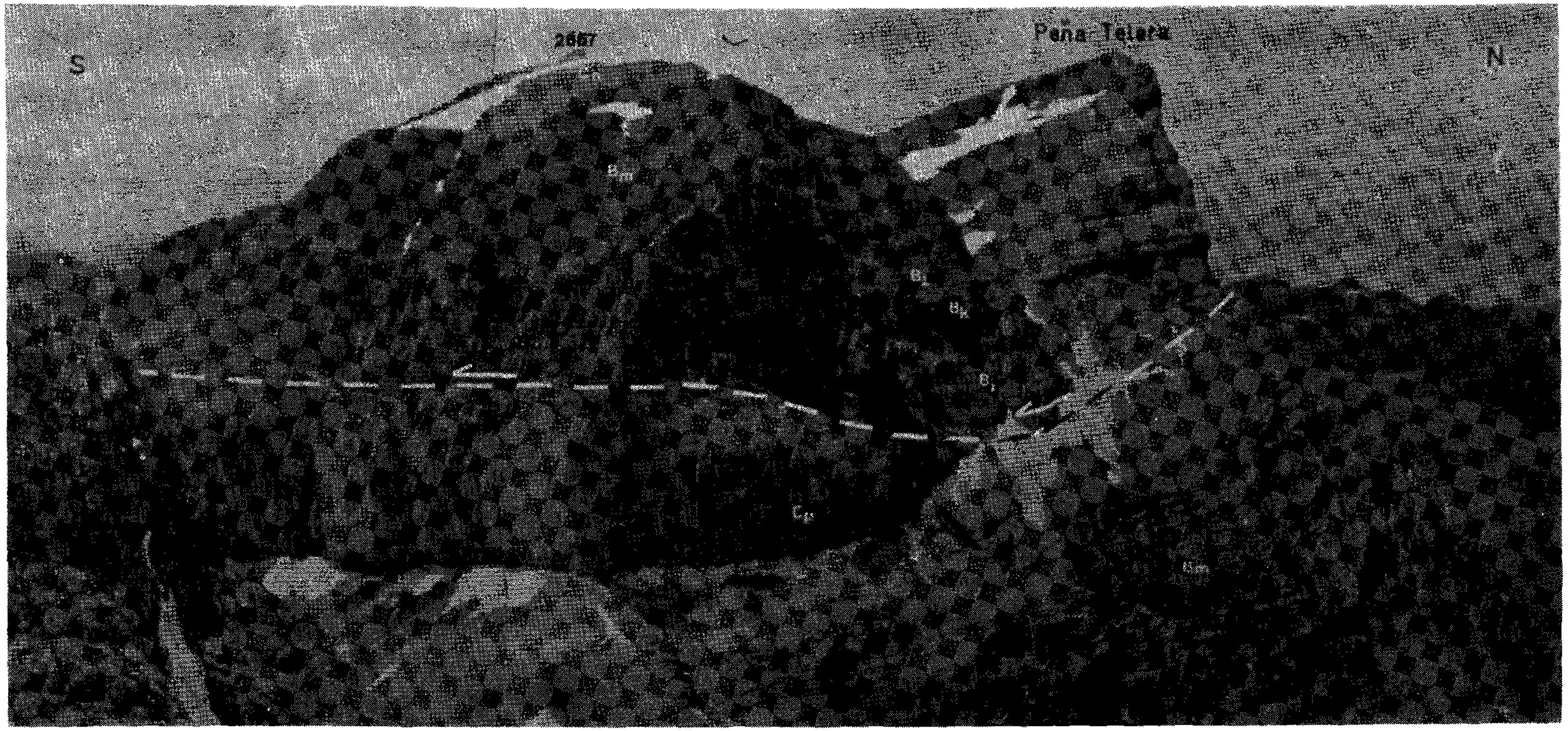


Fig. 29 The upper major low angle fault plane of the Telera Unit on the NE-slope of the Telera mass.

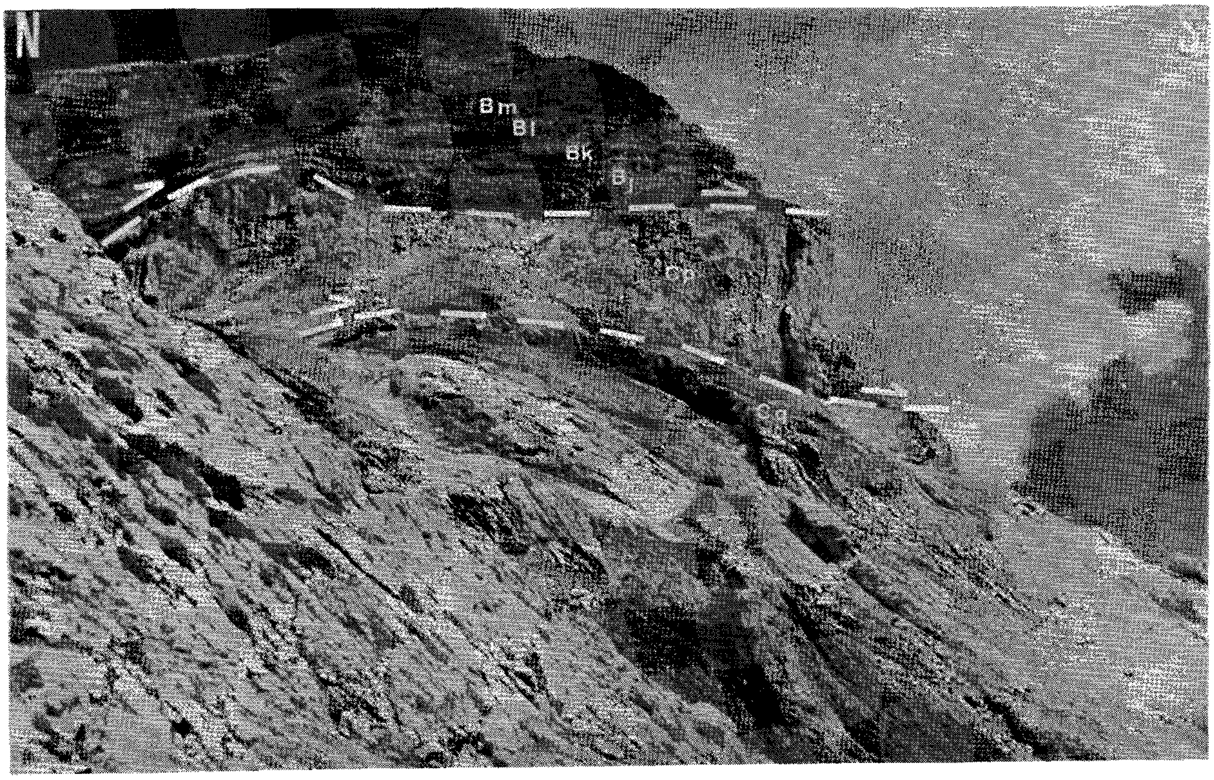


Fig. 30 The two major low angle fault planes of the Telera Unit in the southern part of the Zarrambucho mass.

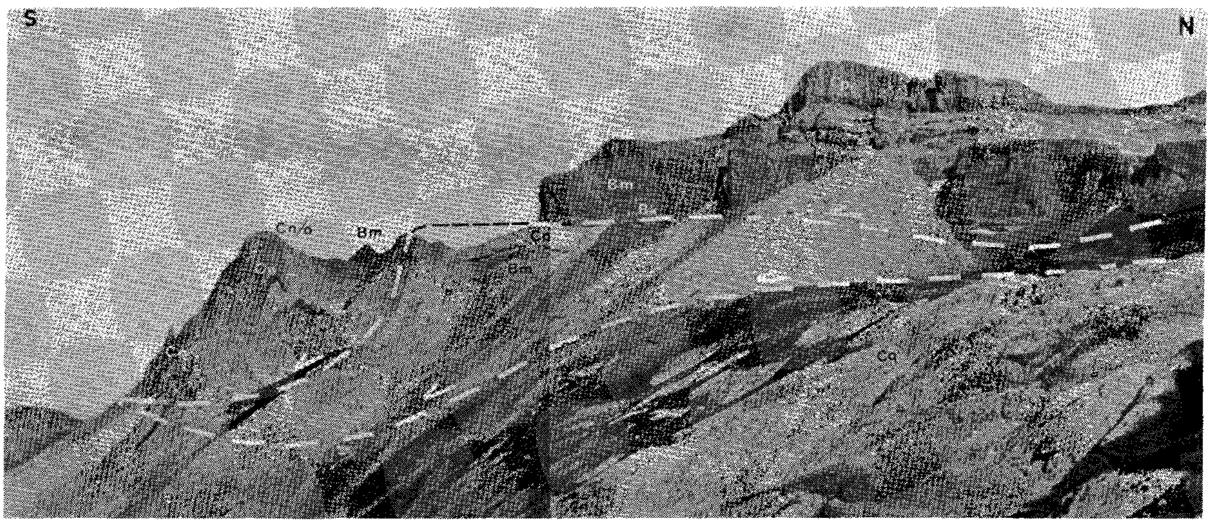


Fig. 31 The two major low angle fault planes of the Telera Unit in the southern part of the Puerto Rico mass: and the down-slid frontal nose of the upper thrust-slice.

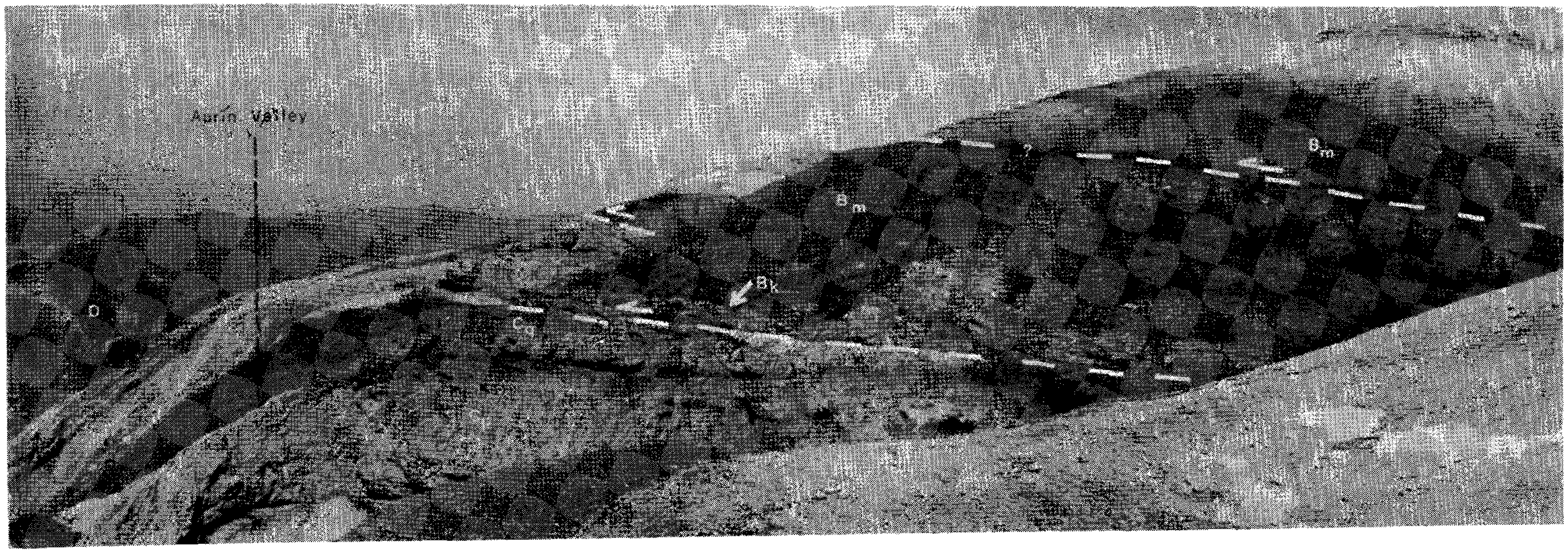


Fig. 32 Two major low angle fault planes in the southern part of the Peña Retona. In the background the southern part of the lower major low angle fault plane in the Somolla Unit.
Between fore- and background lies the transverse valley of the Río Aurín.

Fig. 33 Two major low angle fault planes on the eastern slope of the Peña Somolla, viewed from the eastern valley wall of the Río Aurín.

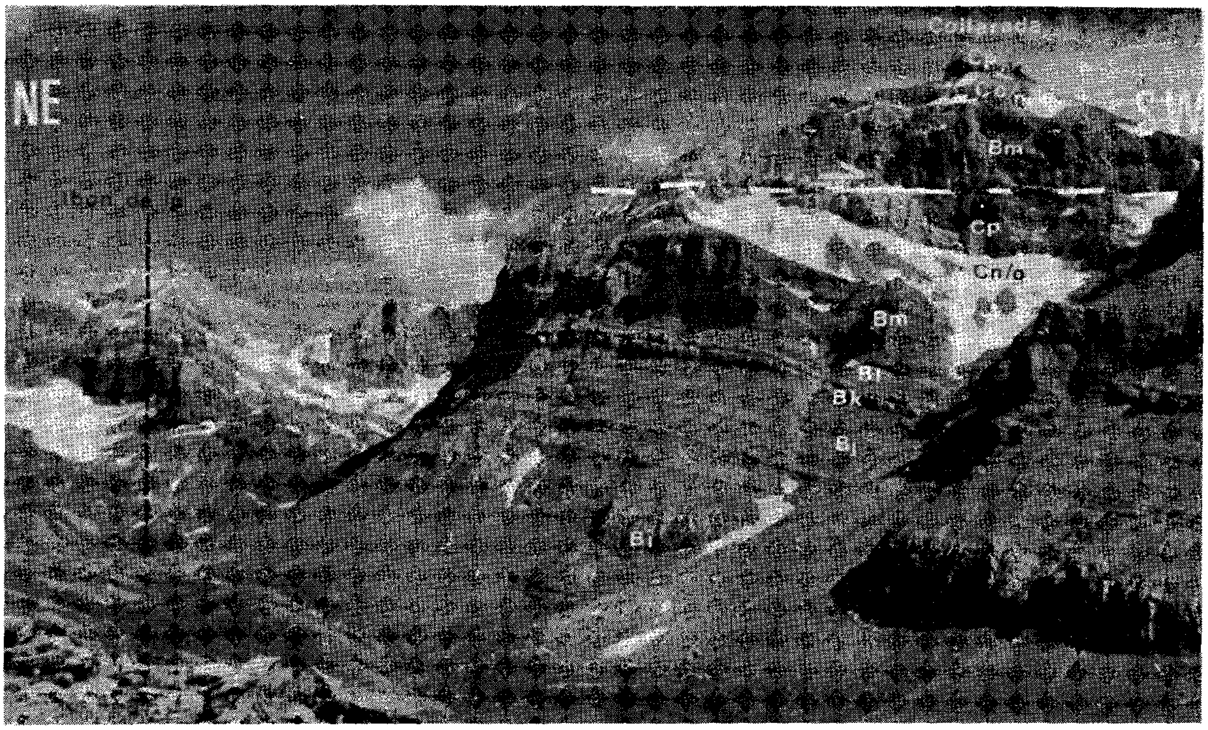


Fig. 34 The upper major low angle fault plane on the northwest-slope of the Collarada mass.

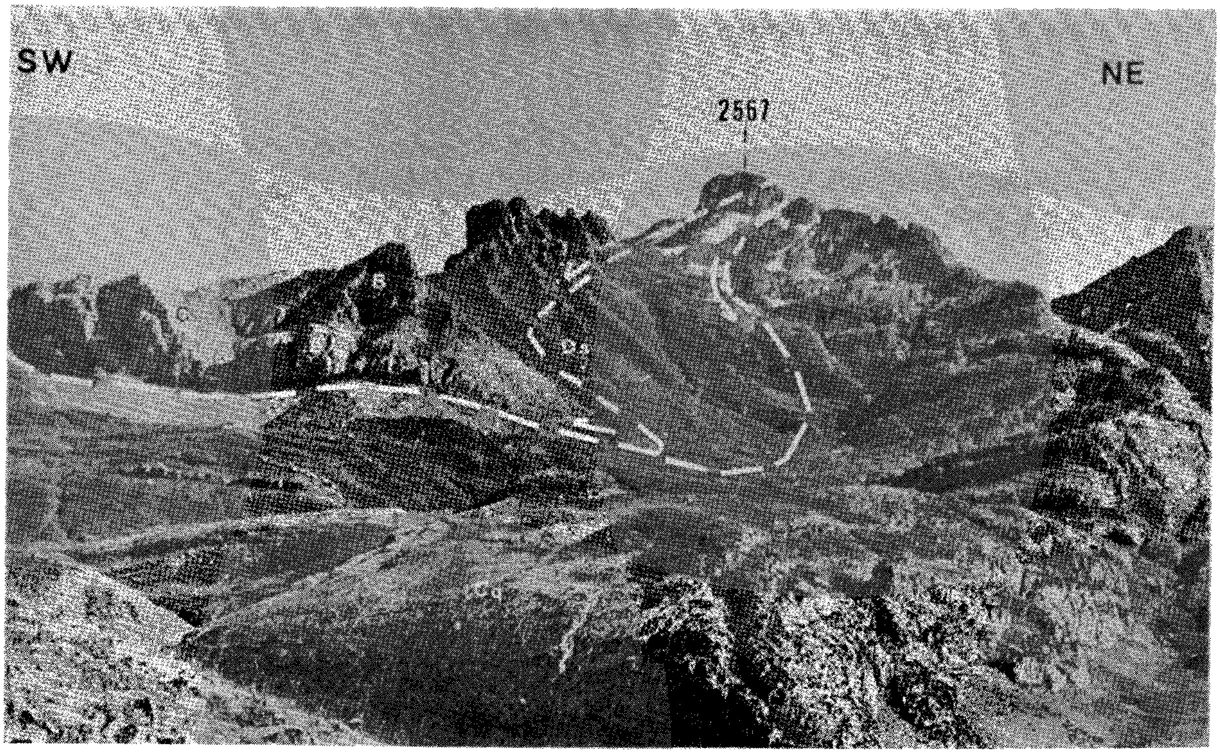


Fig. 35 The two major low angle fault planes of the Garganta Unit. In the foreground, in the upper right hand, a thrust fold of which the upper strata are composed of limestone with chert nodules (black dots).

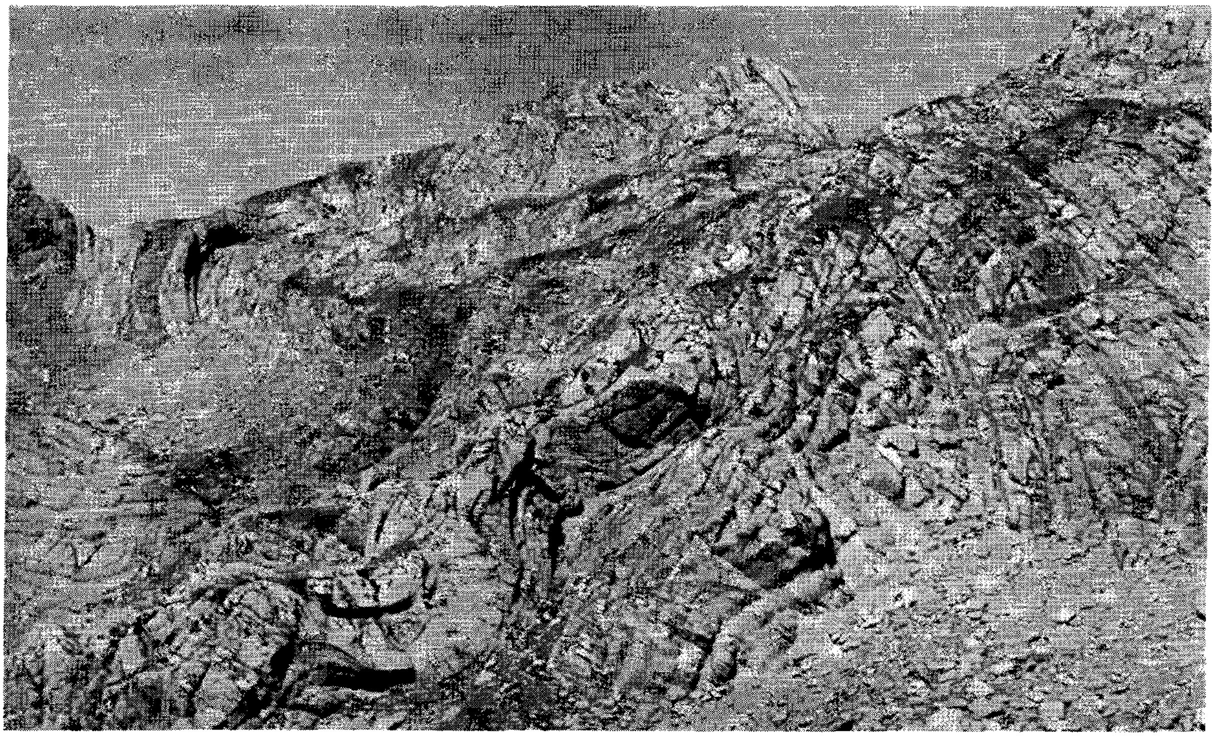


Fig. 36 Intensely folded strata of the B-formation north of the Aspe mass.

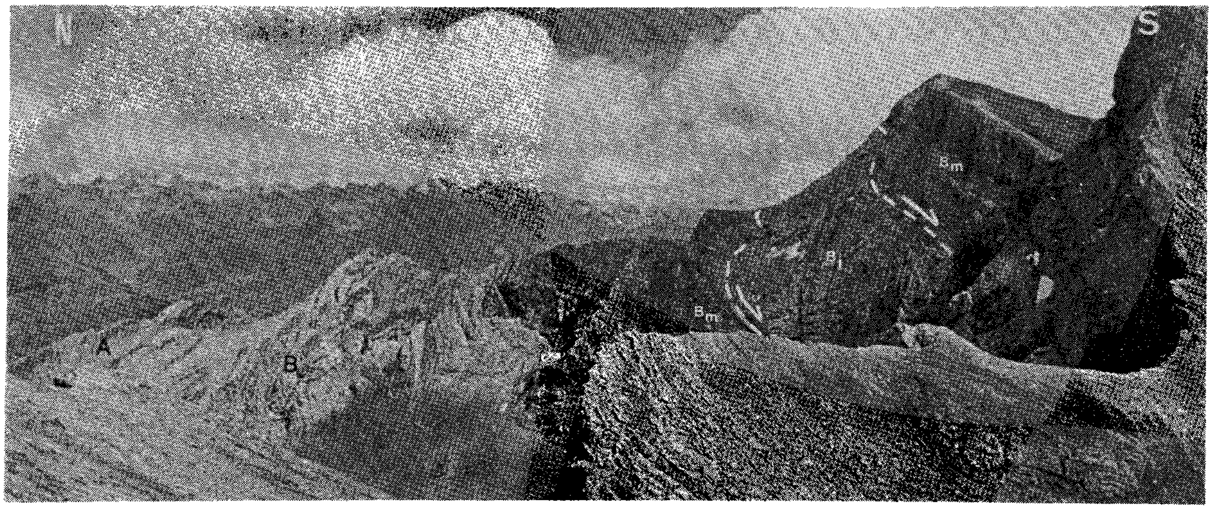


Fig. 37 View on the northern part of the Aspe Unit.
Left side : N-dipping strata of the A-formation and intensely folded strata of the B-formation.
Right side: Two major low angle fault planes.

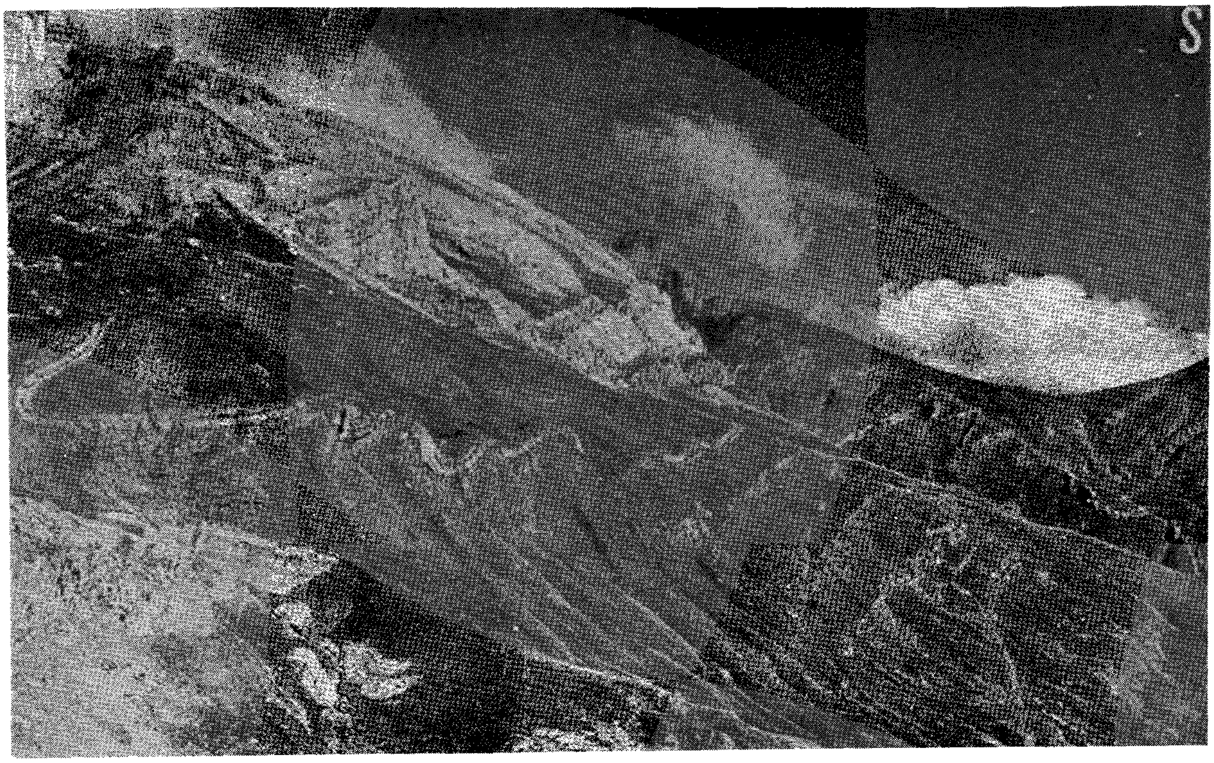


Fig. 38 Cascade folds in the D-formation (Flysch deposits) south of the Aspe Unit.

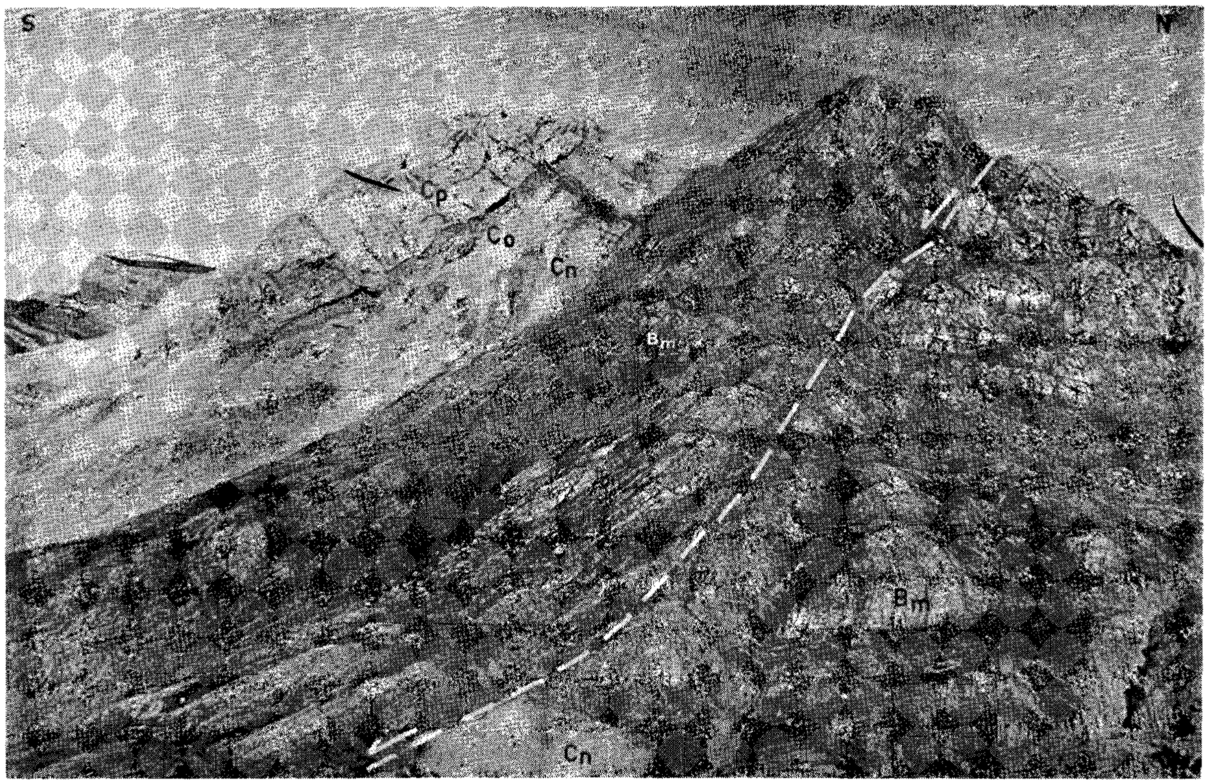


Fig. 39 View on the eastern slope of the Bernera mass, showing the upper major low angle fault plane.

BIBLIOGRAPHY

Amferer, O., 1934. Ueber die Gleitformung der Glarner Alpen. Sitzungsberichten Ac. Wissensch. Wien, Mathem.- naturw. kl. Abt.I, 143, Band, 3 und 4.

Alastrue, E., Almela, A., Rios, J.M. 1957. Explicación al mapa geológico de la provincia de Huesca, 1 : 200000., Mem. del Inst. Geol. y Min. de Esp. Tomo 58.

Aubert, D., 1959 Le déchrochement de Pontarlier et l'orogenèse du Jura. Mem. Soc. vaudoise Sci. Nat., nr. 76, vol 12 : 93 - 152.

Aubert, D. et Badoux, H., 1959. Notice explicative feuille 1, Neuchâtel, Carte Géologique de la Suisse. Kümmerly und Frey, Bern, 27 pp.

Bemmelen, R.W. van, 1953. Problemen van alpiene gebergtevorming. Geol. en Mijnb. nr. 4 : 99 - 102.

Bemmelen, R.W. van, 1955 Tektogénèse par gravité. Bull. Soc. belge Géol. Pal. Hydr. 44: 95 - 123.

Bemmelen, R.W. van, 1960. New views on east-alpine orogenesis, Int. Geol. Congr. Copenhagen part XVIII : 99 - 117.

Bemmelen, R.W. van, 1964. Phénomènes géodynamiques. Mem. Soc. belge Geol. Pal. Hydr. 8 : 1 - 127.

BOUMA, A.H., 1962. Sedimentology of some flysch deposits. Elsevier publishing company, Amsterdam/New York.

Cloos, E., 1964. Wedging, bedding plane slips, and gravity tectonics in the Appalachians. 'Tectonics of the Southern Appalachians' V.P.I. Dept. Geol. Sci. Mem. 1.

Cuvillier, J., 1956. Stratigraphic correlations by microfacies in Western Aquitain. E.J. Bril, Leiden.

Cuvillier, J., Henry, J., Ribis, R., Villanova, M. 1964. Microfaunes cénomaniennes et santoniennes dans le 'Calcaire des cañons' Bull. Soc. géol. Fr., (7), VI : 273 - 277.

Dalloni, M., 1910. Etude géologique des Pyrénées de l'Aragon. Ann. Fac. Sci. Marseille, 26/3: 1 - 444.

Elsberg, J.N. van, 1968 Geology of the Upper Cretaceous and part of the Lower Tertiary North of Hecho and Aragues del Puerto, Spanish Pyrenees, province of Huesca, Estud. geol. Inst. Mallada, in press.

Gwinn, V.E., 1964. Thin-skinned Tectonics in the Plateau and Northwestern Valley and Ridge Provinces of the Central Appalachians. Bull. Geol. Soc. Am. vol. 75 : 7 - 12.

Hillebrandt, A. von, 1962. Das Alttertiär im Mont Perdu Gebiet. Ecl. geol. Helv., 55 : 285 - 295.

Hinte, J.E. van, 1965. The type Campanian and its planktonic foraminifera. Kon. Ned. Akad. Wetensch., Proc., Series B., 68, nr. 1.

Hinte, J.E. van, 1966. Orbitoides from the Campanian type section. Kon. Ned. Akad. v. Wetensch. Amsterdam, Series B, 69, nr. 1.

Hottinger, L. und Schaub, H., 1960. Zur Stufeneinteilung des Paleocaens und des Eocaens. Einführung der Stufen Ilerdien und Biarritzien. Ecl. geol. Helv., 53 : 453 - 479.

Hottinger, L., 1960. Über Paleocaene und Eocaene Alveolinen. Ecl. geol. Helv. vol.53, nr. 1 : 265 - 284.

Jacob, Ch., 1930. Zone axiale, versant sud et versant nord des Pyrénées. Libre jubilaire, Centenaire Soc. géol. Fr., : 389 - 410.

Krumbein, W.C. and Sloss, L.L., 1963. Stratigraphy and sedimentation. W.H. Freemand and Company, San Francisco, California.

Lingen, G.J. van der, 1960. Geology of the Spanish Pyrenees north of Canfranc, Huesca province. Estud. geol. Inst. Mallada, 16 : 205 - 242.

Lith, J.G.J. van, 1968. Geology of the Spanish part of the Gavarnie Nappe (Pyrenees) and its underlying sediments near Bielsa (Province of Huesca). Geologica Ultraiectina, nr. 10, Utrecht.

Mangin, J.Ph., 1954. Etude sur Operculina heberti, Munier Chalmas. Bull Sc. de Bourgogne T. XV.

Mangin, J.Ph., 1957a. Remarques sur le terme Paléocène et sur la limite Crétacé - Tertiaire. C.R. Soc. géol. France, 14 : 319.

Mangin, J.Ph., 1957b. La limite Crétacé - Tertiaire sur le versant des Pyrénées occidental. C.R. Ac. Sc. 244 : 1227 - 1229.

Mangin, J.Ph., 1958. Le Nummulitique sud-pyrenéen à l'ouest de l'Aragón. Thèse, Dyon, Libr. General, Zaragoza, 620 pp.

Mangin, J.Ph., 1958a. Note préliminaire sur les 'calcaires à Alveolines et Nummulites' du versant Sud des Pyrénées. C.R. Acad. Sci. Paris, 246 : 1234 - 1237.

Mangin, J.Ph., 1958b. Note préliminaire sur la Stratigraphie du Nummulitique dans le domaine pyrénéen occidental (versant espagnol).

C.R. Acad. Sci. Paris, 246 : 3479 - 3481.
Mangin, J.Ph., 1958c. Remarques sur l'orogénèse pyrénéenne pendant la période Nummulitique. C.R. Acad. Sci. Paris, 246 : 3652 - 3654.
Mangin, J.Ph., 1958d. Hypothèse sur l'histoire Nummulitique du domain Pyrénéen. Cahier du laboratoire de géologie université de Dyon.
Mangin, J.Ph., 1959. Données nouvelles sur le Nummulitique Pyrénéen. Bull. Soc. géol. Fr., (7) 1 : 16 - 30.
Mangin, J.Ph., 1960. Réflexions sur la limite Crétacé - Tertiaire à propos du domaine Pyrénéen. Int. Geol. Congr. 21, Norden, 5 : 145 - 149.
Mangin, J.Ph., 1961. Remarques sur la notion d'étage, à propos de 'L'Ilerdien et du Biarritzien, C.R. Soc. géol. Fr.: 212 - 213.
Mattauer, M. and Seguret, M., 1966. Sur le style des déformations Tertiaires de la zone axiale hercynienne des Pyrénées. C.R. Soc. Géol. Fr. 1 : 10 - 13.
Mengaud, L., 1929. Quelques points de la géologie des environs de Canfranc (massif du Peña Collarado, du Somport et du Pic d'Anie).
C.R. Soc. géol. France : 36 - 37.
Mirouse, R. and, Souquet, P., 1964, Présence du Cénomanien au sommet du Pic Balaïtous (Hautes Pyrénées). C.R. Soc. géol. Fr., : 308 - 309.
Misch, P., 1934. Der Bau der mittleren Südpyrenaen. Abh. Ges. Wiss. Göttingen, Math. Phys. Kl. III, 12 : 1 - 168.
(Beitr. Geol. Westl. Mediterrangeb. : 1597 - 1764).
Oomkens, E. and Terwindt, J.H.J., 1960. Inshore estuarine sediments in the Haringvliet (Netherlands). Geol. en Mijnb., : 701 - 710.
Pettijohn, F.J., 1948. Sedimentary rocks. Harper's geoscience series. New York.
Rutten, M.G., 1955. Nota preliminar sobre la Geología de los Pirineos de la provincia de Huesca; Notes on the Pyrenees of Huesca. Estud. geol. Inst. Mallada, 11 : 19 - 26.
Rutten, M.G., 1967. Geology of Western Europe. (in press.)
Schwarz, E.J., 1962. Geology and paleomagnetism of the valley of the Río Aragón Subordán North and East of Oza, Spanish Pyrenees, Prov. of Huesca. Estud. geol. Inst. Mallada, 18 : 193 - 240.
Seguret, M., 1966. Sur les charriages de la zone des Nogueras (versant sud des Pyrénées) C.R. Soc. Géol. Fr. 1 : 17 - 19.
Selzer, G., 1934. Geologie der südpyrenaïschen Sierren in Oberaragonien. Neues Jb. Min. Abh., Beil. Bd. 71, Abt. B : 370 - 406.
Sitter, L.U. de, 1954. Gravitational gliding tectonics. An essay in comparative structural geology. Amer. J. Sci., 252 : 321 - 344.
Sitter, L.U. de, 1956a. A cross section through the central Pyrenees. Geol. Rdsch., 45 : 214 - 233.
Sitter, L.U. de, 1956b. Structural Geology, McGraw-Hill, New York, 552 pp.
Sitter, L.U. de, 1961. La phase tectogénique pyrénéenne dans les Pyrénées méridionales. C.R. Soc. géol. Fr., : 224 - 225.
Sitter, L.U. de, 1965. Hercynian and alpine orogenies in northern Spain. Geol. en Mijnb. nr. 11 : 373 - 384.
Souquet, P., 1964a. Extension du Cénomanien dans la zone sud-pyrénéenne et en- bordure de la zone primaire axiale dans les Pyrénées centrales.
C.R. Soc. géol. Fr.: 209 - 211.
Souquet, P., 1964b. Précisions stratigraphiques sur le Crétacé de la couverture méridionale de la zone primaire axiale pyrénéenne. C.R. Soc. geol. Fr., : 334 - 335.
Souquet, P., 1964c. Sur la structure de la vallée d'Arazas, au Sud du massif du Mont Perdu (Pyrénées Aragonaises, Espagne). C.R. Acad. Sci. Paris, 258 : 6491 - 6493.
Souquet, P., 1964d. Corrélations stratigraphiques dans l'Albien et le Cénomanien de la zone sud-pyrénéenne et de la couverture de la zone primiaire axiale dans les Pyrénées centrales. C.R. Acad. Sci. Paris, 259 : 4746 - 4749.
Straaten, L.M.J.U. van, 1950. Environment of formation and facies of the Waddensea sediments. Tijdschr. Kon. Ned. Aardr. Gen., 67, afl. 3 : 94 - 108.
Szots, E. 1961. Remarques critiques sur l''Ilerdien' et sur le 'Biarritzien' nouveaux étages introduits par Hottinger et Schaub. C.R. Soc. géol. Fr.: 24 - 25.
Velde, E.J. van de, 1967. Geology of the Ordesa overthrust mass, Spanish Pyrenees, province of Huesca. Estud. geol. Inst. Mallada., vol. 23, p. 163-201.
Voo, R. van der, 1966. Geology of the Sierra de Tendenera region, Spanish Pyrenees, province of Huesca, Estud. Geol. Inst. Mallada, Vol. XXII,: 61-64.
Wensink, H., 1962. Paleozoic of the upper Gállego and Ara valleys, Huesca province, Spanish Pyrenees. Estud. Geol. Inst. Mallada, 18 : 1 - 74.

Internal report : Voo, R. van der, 1961.