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Autor: Rykken, Jack
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The Nummulitic of the Nappe de Morcles

BY

JACK RYKKEN [1]

Résumé

Le but de ce travail était d'élucider les conditions de sédimentation du Tertiaire de la Nappe de Morcles, basée sur une étude stratigraphique détaillée de ces terrains. A cette fin, huit coupes stratigraphiques composites furent étudiées dans le flanc inverse, la zone frontale et le flanc normal de la Nappe. Elles sont désignées comme suit : I. Petit Cor ; II. Torrent Sec (Dent de Morcles) ; III. Dent Rouge ; IV.Vallée de Nant ; V. L'Argentine ; VI. Col des Essets ; VII. Derborence ; VIII. Lizerne.

Dans le flanc renversé et dans la zone frontale, les séries nummulitiques commencent avec une séquence conglomératique massive : les « Couches conglomératiques du Roc Champion », qui alternent avec des schistes sapropéliques, des marnes à rares filets anthraciteux, cela dans les coupes I, II et III. On trouve, très rarement, des petites Nummulites et des *Borelis* dans ces conglomérats. Dans les coupes I à IV, les conglomérats sont séparés des couches nummulitiques susjacentes par une mince assise marneuse : les « Couches à Cérithes » ; *Cerithium diaboli* et d'autres espèces de gastéropodes et lamellibranches caractérisent ce niveau. Elles sont surmontées par une série de calcaires, les « Calcaires à Petites Nummulites » présents dans toutes les coupes. Les couches basales de cette série sont des calcaires gréseux à ciment carbonaté argileux ; elles contiennent les formes suivantes de foraminifères : quatre espèces de Nummulites, des Discocyclines, *Borelis* et d'autres genres de moindre valeur stratigraphique décrits dans le texte. Dans les coupes I et II, les « Calcaires à Petites Nummulites » contiennent des lits de dolomie et un épais complexe de brèches calcaires riches en éléments cristallins. Les coupes III à VIII montrent un calcaire essentiellement arénacé ou bioclastique avec des faciès conglomératiques subordonnés à la base. Les « Schistes à Globigérines» stratigraphiquement susjacents présentent une succession de schistes calcaires et de minces lits calcaires. Ce faciès passe au Flysch, dont les meilleurs affleurements sont visibles dans la vallée de la Lizerne. Là, le Flysch comprend au moins 40 m de grès lités pétrographiquement semblables aux « Grès de Taveyannaz ». La série nummulitique a été attribuée à l'Eocène supérieur, le Flysch est peut-être oligocène. Le flanc renversé de la Nappe repose en position inverse sur le Flysch parautochtone.

La reconstitution du bassin éocène obtenue en replaçant les coupes dans leurs positions primitives permet de dégager les conclusions suivantes : le nombre et la variabilité des faciès de la zone externe, ou NW, suggère un dépôt de mer peu profonde et particulièrement instable. Vers le SE, en direction de la partie interne du bassin, prédominent des faciès marins profonds et plus constants. Il est en outre évident que l'axe du bassin tertiaire s'est déplacé en direction du NW au cours du Nummulitique.

[1] Present address : Amoco Norway Oil Co., Oslo, Norway.

Abstract

This study has been undertaken to describe in detail the Tertiary stratigraphy of the Nappe de Morcles and in doing so to achieve some understanding of Nummulitic and Flysch sedimentation. To accomplish this end, a series of eight composite stratigraphic sections were measured on the reversed flank, frontal zone, and normal flank of the Nappe. These are designated as follows : I. Petit Cor ; II. Torrent Sec (Dent de Morcles) ; III. Dent Rouge ; IV. Vallée de Nant ; V. L'Argentine ; VI. Col des Essets ; VII. Derborence ; VIII. Lizerne.

On the overturned flank and frontal zone the Nummulitic series begins with a massive conglomerate sequence called « Couches conglomératicques du Roc Champion ». They are interbedded with sapropelic shale, marl and anthracite in sections I, II, and III. Very rarely, small Nummulites and *Borelis* are found within this conglomerate. In sections I through IV, the conglomerates are separated from the overlying Nummulitic limestone by a thin marl bed called the "Couches à Cérithes". *Cerithium diaboli*, plus other species of gastropods and pelecypods are characteristic of this level. A massive limestone series known as the "Calcaire à Petites Nummulites" follows stratigraphically and can be traced over the entire Nappe. Lithologically the basal layers are an arenaceous limestone with a muddy carbonate matrix. These beds contain the bulk of the Nummulitic microfauna which includes at least four species of small Nummulites, *Discocyclina* and *Borelis*. Other genera of less stratigraphic value are described in the text. In sections I and II, the "Calcaire à Petites Nummulites" contains beds of dolomite and a considerable section of limestone breccia with crystalline elements. In sections III through VIII, it is essentially an arenaceous or bioclastic limestone with a minor conglomeratic development at the base. The "Schistes à Globigérines" follow stratigraphically and are made up of calcareous shales with thin limestone interbeds. These grade upward into the Flysch series which is best exposed in the Lizerne Valley. Here, the Flysch includes at least 40 m of bedded sandstone petrographically similar to the "Grès de Taveyannaz". An Upper Eocene age has been assigned to the Nummulitic series, while the Flysch may be lowermost Oligocene. The overturned flank of the Nappe rests inverted on the autochthonous Flysch.

In reconstructing the Eocene basin (by attempting to replace the measured sections in their original positions), the number and variety of facies on the external or northwestern edge suggest a rather unstable shallow marine environment. Southeastward, towards the internal part of the basin, a more persistant deep marine regime prevailed. There is evidence that the axis of the Tertiary basin was migrating in a northwesterly direction.

Introduction

A detailed description of the stratigraphy and sedimentation of the Tertiary series of the Nappe de Morcles was undertaken as the subject of my thesis at Lausanne University in 1957 under the guidance of Professor H. BADOUX. Copies of the completed text, together with microphotographs, rock samples and thin sections have been deposited at the Institut de Géologie of the University. The following text has been abridged to facilitate publication.

I wish to express my debt of gratitude to Professor H. BADOUX who has so patiently awaited the results contained herein. Equally, Professor M. VUAGNAT, now at the University of Geneva, has been most generous with his help, especially with problems concerning the Flysch. Dr. H. SCHAUB at the University of Basel most kindly verified the determinations of the Nummulites

described in the text. I am also grateful to Professor P. BRÖNNIMANN of the University of Geneva for his review and helpful criticism of the other foraminifera from the Nummulitic of Morcles.

STRATIGRAPHY

1. Regional Setting

Structurally, the Nappe de Morcles is a large recumbent anticline the axis of which is oriented about N 40° E and is plunging at 20° to the northeast. The overturned flank of the Nappe extends from Saillon, in the Rhône valley, to the Dents de Morcles. The frontal zone is best illustrated by the vertical strata along the ridge of l'Argentine. The normal flank (with a few local folds), extends from the Col des Essets to Derborence and along the Valley of the Lizerne (see figure 1).

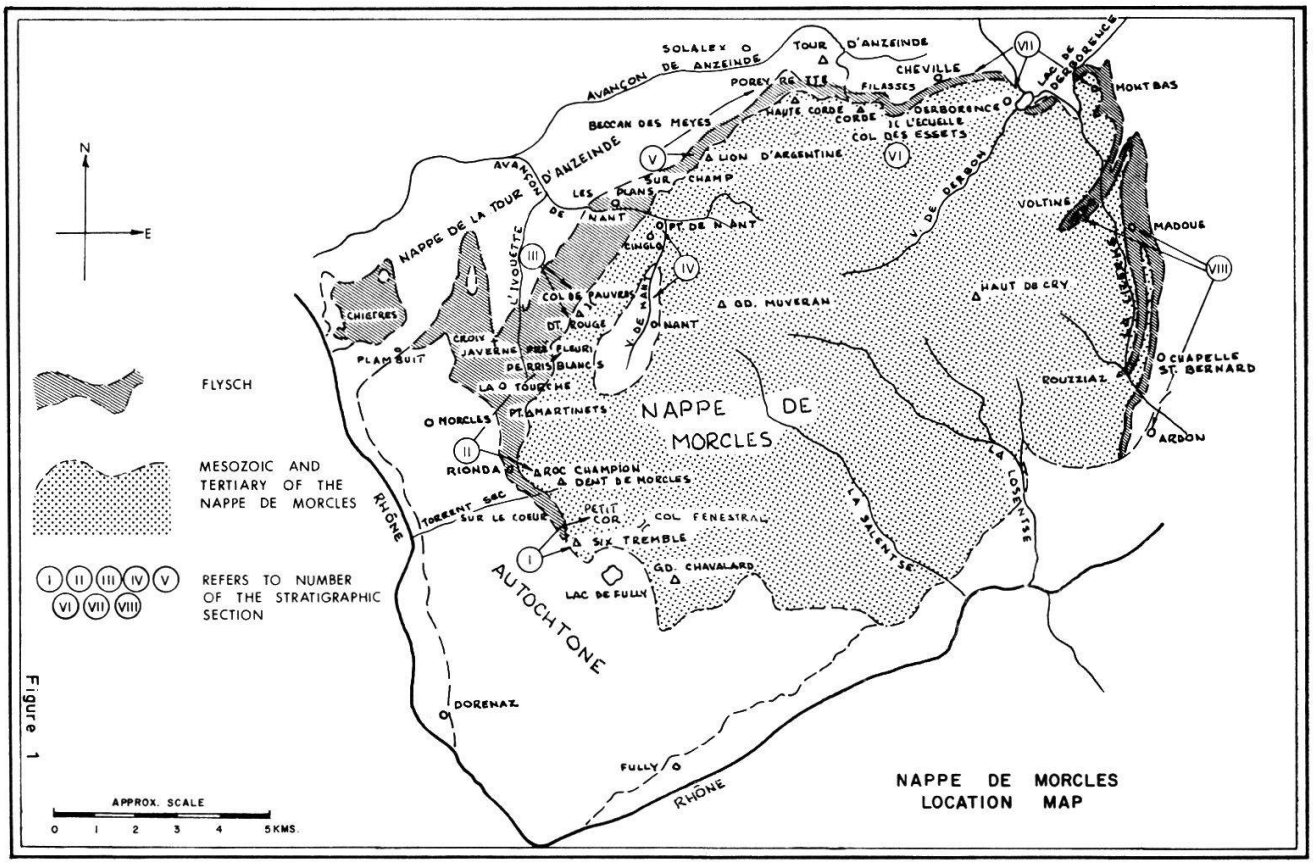


Figure 1.

Figure 1.

Situated directly below the Nappe are Tertiary, Mesozoic, Permian, Carboniferous and older crystalline rocks which comprise the autochthonous and para-autochthonous foundation of the Massif de Morcles. These general relationships are shown on figure 2. Further north, in the latitude of the

Avançon de Nant and Les Plans, the Nummulitic of Morcles rests in contact with the Ultra-helvetic Nappes (Nappe de la Tour d'Anzeinde and Nappe de la Plaine Morte).

Tertiary, Cretaceous, Jurassic and Triassic rocks are included in the folded strata of the Nappe de Morcles. The outcrop of the Nummulitic-Flysch series roughly delineates the exterior limits of the Nappe as shown on figure 1, while the core is composed of older Mesozoic rocks.

a) History

RENEVIER (1890), was the first geologist to study in detail the Nummulitic of Morcles and Diablerets. This author noted the following subdivisions within the Tertiary series :

(1) *Flysch.*
(2) *Nummulitique Supérieur*, including (from oldest to youngest) the "Couches à Cérithes", "Grès Nummulitique", "Calcaire à Petites Nummulites", and the "Schistes Nummulitiques Supérieurs" (Bartonian age).
(3) *Eocène d'eau douce*, which is subdivided into "Sidérolithique", "Marnes d'eau douce", and "Anthracite". This sequence was considered as Parisian (Lutetian) or Bartonian.
(4) *Nummulitique Inférieur*, composed of "Brèche à Gros Eléments", with large Nummulites *(Nummulites perforatus)*. The presence of *Nummulites perforatus* in these beds was denied by BOUSSAC (1912), and no mention of this species has been made by subsequent authors.

Further study by LUGEON (1937), enabled him to recognize eight subdivisions within the Nummulitic of Morcles. These are (youngest to oldest) :

(1) Flysch
(2) Schistes à Globigérines
(3) Calcaire à Petites Nummulites
(4) Couches à Cérithes
(5) Couches à Vivipares
(6) Couches de Champion
(7) Couches à *Chara* et *Helix*
(8) Sidérolithique

LUGEON considered the younger beds of this series as Priabonian, while the lower beds (Couches de Champion and Couches à *Chara* et *Helix*) were questionably placed in the uppermost Lutetian.

b) The Nummulitic Facies of the Nappe de Morcles

One of the principle objectives of this study has been the subdivision of the Nummulitic section of Morcles into facies which remain fairly consistant over the region between the Rhône valley and the Massif des Diablerets. These subdivisions (or facies) which are outlined below, and discussed in some detail in the following pages, are based on the system of LUGEON (1937).

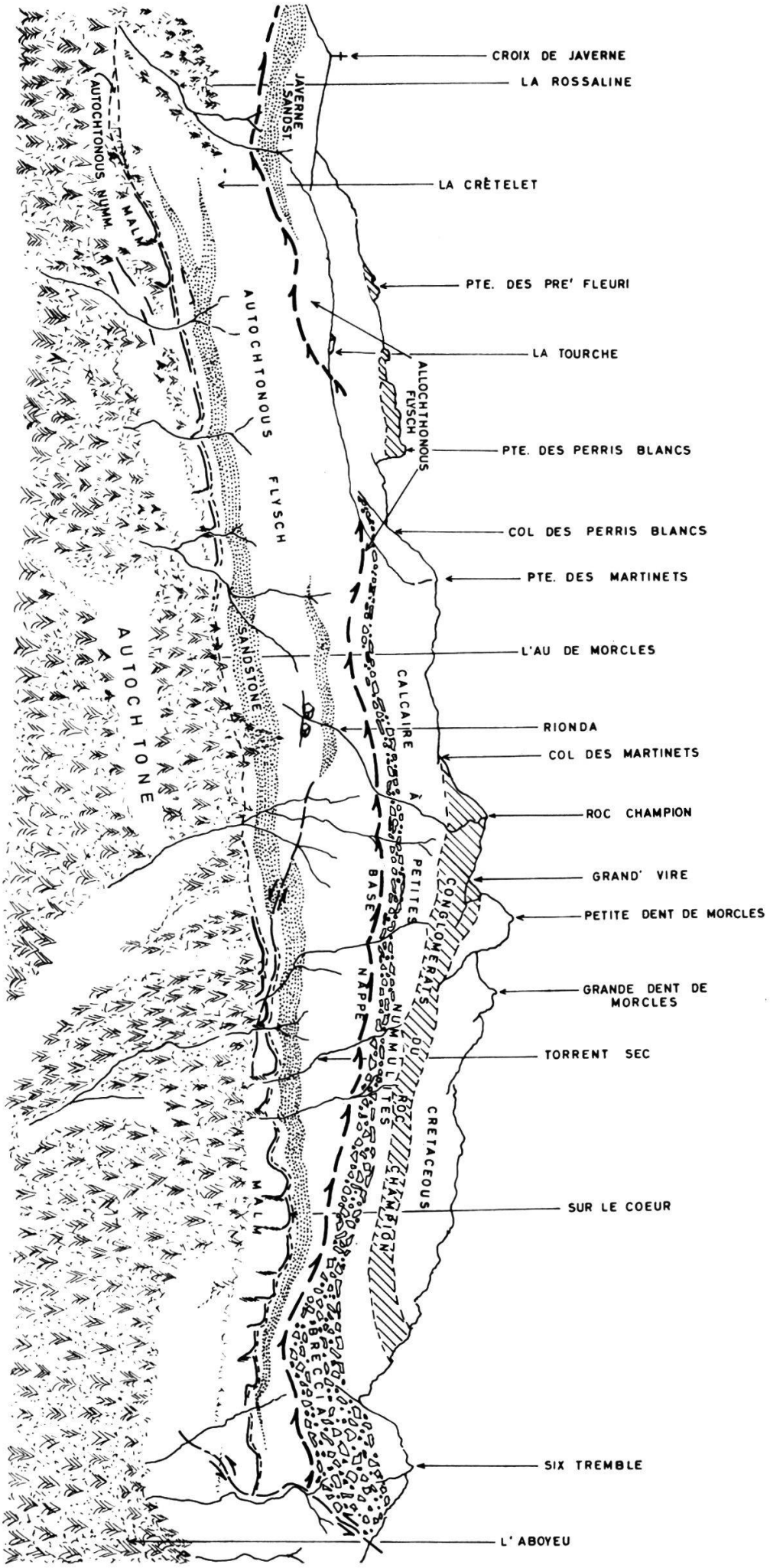


Fig. 2. — Structural sketch of the Massif de Morcles between the Croix de Javerne and Six Tremble.

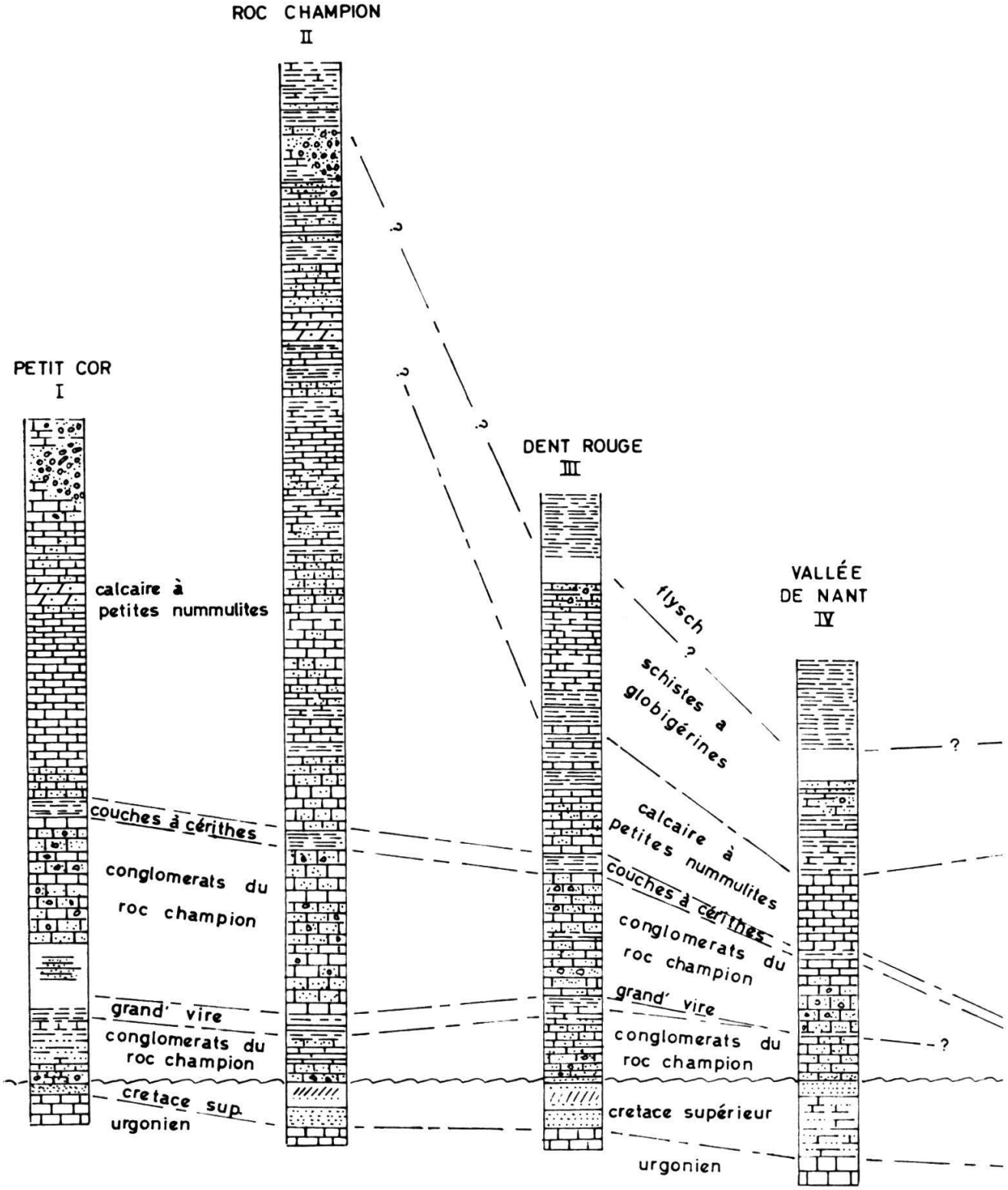
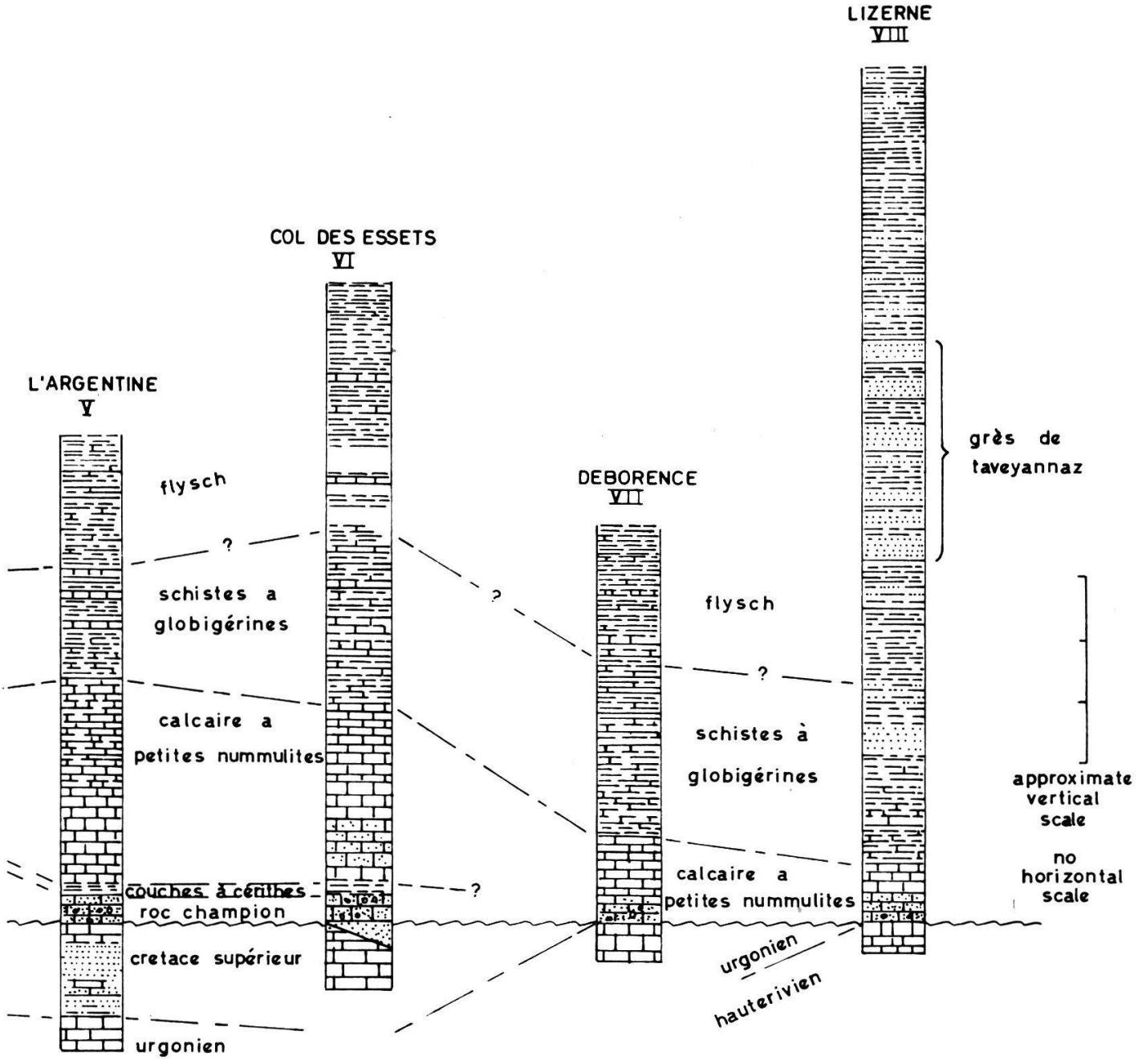


Fig. 3. — Correlation of Nummulitic sections,



Nappe de Morcles. Figured vertical scale : 30 m.

Age		Facies
Lower Oligocene (Lattorfian)		Flysch
		. . .
		Schistes à Globigérines
		. . .
		Calcaire à Petites Nummulites
Upper Eocene (Priabonian)		. . .
		Couches à Cérithes
		. . .
		Couches Conglomératiques du Roc Champion
	major hiatus	
Cretaceous		Red beds ; Cenomanian, Urgonian and Hauterivian limestone

c) Measured Stratigraphic Sections

In order to follow the sequence of Nummulitic facies over the area studied, and to maintain control on changes in thickness and lithology, a series of eight composite stratigraphic sections were constructed. These sections, measured on the reversed, front and normal flank of the Nappe, are designated as follows (see figure 1 for locations) :

I. — Petit Cor, Six Tremble, Col de Fenestral
II. — Torrent Sec, Roc Champion, Pré Fleuri, Pte Perris Blancs
III. — Dent Rouge, Col des Pauvres
IV. — Vallée de Nant, Avançon de Nant
V. — Lion d'Argentine, Sur Champ, Beccan des Meyes, La Poreyrettaz
VI. — Col des Essets, L'Ecuelle, Les Filasses
VII. — Cheville, Derborence, Montbas
VIII. — Ardon, Madoue, Voltine

The detailed description (lithology, thicknesses, samples, paleontology) of these sections is included in the unabridged copies of my thesis deposited at the Institut de Géologie, Université, Lausanne.

2. Description of Outcrops

a) Pre-Tertiary of the Nappe de Morcles

Between the Dents de Morcles and the Dent Rouge, basal Eocene conglomerates and limestones rest stratigraphically over a complex series of reddish, argillaceous siltstone and limestone. At the Dent Rouge, these red beds attain

a thickness of 15 m and are made up principally of alternating bands of brick red argillites, and dull reddish calcilutites which are often conglomeratic. The supposed contact with the overlying Eocene strata lies within a 6 m band of argillite and reddish limestone conglomerate which is well developed on the face of the Petite Dent de Morcles (see figure 4), and is also readily seen at the Dent Rouge. No diagnostic fossils were found within the red argillite series. However, their supposed mode of formation — as highly oxidized or weathered limestones — indicate that the red argillites of the Dent Rouge are related to the Cretaceous cycle of deposition and are of probable Upper Cretaceous age.

Above the chalet of Nant, these red argillites are still visible at the Cretaceous-Eocene contact. Slightly further north, in the Vallée de Nant at the point where the Eocene disappears under recent alluvium, the basal Nummulitic limestones are resting on reddish (hematitic) or greenish (glauconitic) quartzites. These quartzites are probably related to the Gault facies and occur stratigraphically below the red argillites of the Dent Rouge. The quartzites, in turn, overlay a 10 m bed of limestone and sandy argillite (often conglomeratic) which is resting over the Urgonien limestone. Figure 3 illustrates the above mentioned relationships.

Northward, at the massif of l'Argentine and at the Col des Essets, basal Eocene conglomerates are overlying Cenomanian limestone (with *Globotruncana*, sample 455), which are resting above the Gault quartzites. The quartzites attain a maximum thickness of 12 m between La Corde and Haute Corde, while at the Col des Essets proper, they are not present. Approximately 1 km eastward, below the Tête à Grosjean, the basal Nummulitic rests on dark gray greenish siltstones of Cenomanian (?) age, containing a rich ammonite fauna. Occasional siltstone cobbles (with ammonites) have been incorporated in the basal Nummulitic conglomerate.

Following the normal flank of the Nappe eastward, basal Eocene beds are overlaying progressively older Cretaceous rocks. At Derborence, Nummulitic beds are transgressive over Urgonien limestone (see figure 3). The Nummulitic-Urgonien contact is exposed just above the water catchment installation at Le Liapey and again at Montbas on the east side of the Lizerne Valley. Further southeastward, along the normal flank of the Nappe, at Voltine, Madoue, the basal Nummulitic beds are transgressive on Hauterivian limestones.

In summary, it appears that the initial Nummulitic transgression inundated an asymetrical, peneplained Cretaceous syncline. In the synclinal axis, pre-Cenomanian red beds, and Cenomanian limestones have been preserved.

b) Conglomerate of Roc Champion

LUGEON (1937), used the name Couches du Roc Champion in reference to the thick series of conglomeratic limestones which are typically exposed at the Roc Champion. In this study, the term "Couches du Roc Champion" is modified somewhat to include the entire conglomeratic series of the Roc

Champion, *plus* the black carbonate and sapropelic beds of the Grand'Vire Supérieure *and* the conglomeratic beds stratigraphically below the Grand'Vire which overlay Upper Cretaceous argillites. Figure 4, illustrates these relationships in the region of the Roc Champion.

On the face of the Petite Dent and the Roc Champion the total thickness of the conglomeratic beds reaches 45 m. The lowermost conglomerates contain well rounded pebbles 2 to 3 cm in diameter, the majority of which, are clear, gray Urgonien limestone. The conglomeratic elements are concentrated in layers 20 to 30 cm thick. The limestone matrix is composed, in a large part, of fine detritic material. Black chert, glauconite, and carbonate fragments are common. One thin band within the conglomeratic series along the Grand'Vire is oölitic (sample 475). A similar relationship (as outlined above) between the basal Eocene conglomeratic beds (Couches du Roc Champion), and the underlying Cretaceous argillites and quartzites, exists in the Petit Cor, at the Perris Blancs, Pré Fleuri, and at the Dent Rouge (sections I, II, III).

On the reversed flank of the Nappe de Morcles, from the Petit Cor to the Dent Rouge at the Vallée de Nant, a black argillaceous bed, varying from several cm to a maximum of 7 m in thickness, is found within the basal conglomeratic series. These black shale beds were called the Couches d'Eau Douce by RENEVIER, and the Couches à *Chara* et *Helix* by LUGEON. Structurally, they form the *Grand'Vire Supérieure* between the Petite Dent de Morcles and the Roc Champion. These beds can be traced southward from the Dents de Morcles to Six Tremble and the Petit Cor, and northward to the Perris Blancs, Pré Fleuri, Dent Rouge, and to the Vallée de Nant. Along the Grand'Vire, they are composed of black marls and shales at the base, overlain by a thin band of black, cryptocrystalline limestone (frequently with molds of minute gastropods and pelecypods) which are in turn overlain by black, sapropelic shales with occasional thin layers of anthracite.

Stratigraphically above the Grand'Vire, approximately 30 m of conglomeratic limestone make up the sharp ridge known as the Roc Champion (see figure 4). Here, the series becomes more conglomeratic with large rounded cobbles (up to 10 cm in diameter) of Urgonien limestone. The conglomerates are best seen on the traverse from the Grand'Vire along the east side of the Roc Champion to the Col des Martinets. The cobble sized elements are often flattened and elongated parallel to the bedding, due, presumably, to compression of the strata during emplacement of the Nappe. The carbonate matrix is black and argillaceous with considerable amounts of detritic quartz.

Moving northeastward, the Couches du Roc Champion are visible, although in somewhat reduced thickness, at the Pte des Perris Blancs and the Pte de Pré Fleuri. At the Dent Rouge, the conglomeratic beds are separated by a shale interval 2 to 3 m in thickness, containing molds of minute pelecypods and smaller unidentified foraminifera (samples 317 and 410). At the Col des Pauvres, the basal Nummulitic conglomerate contains Cretaceous limestone elements, with *Orbitolina* (sample 306 in Section III). In the Vallée de Nant,

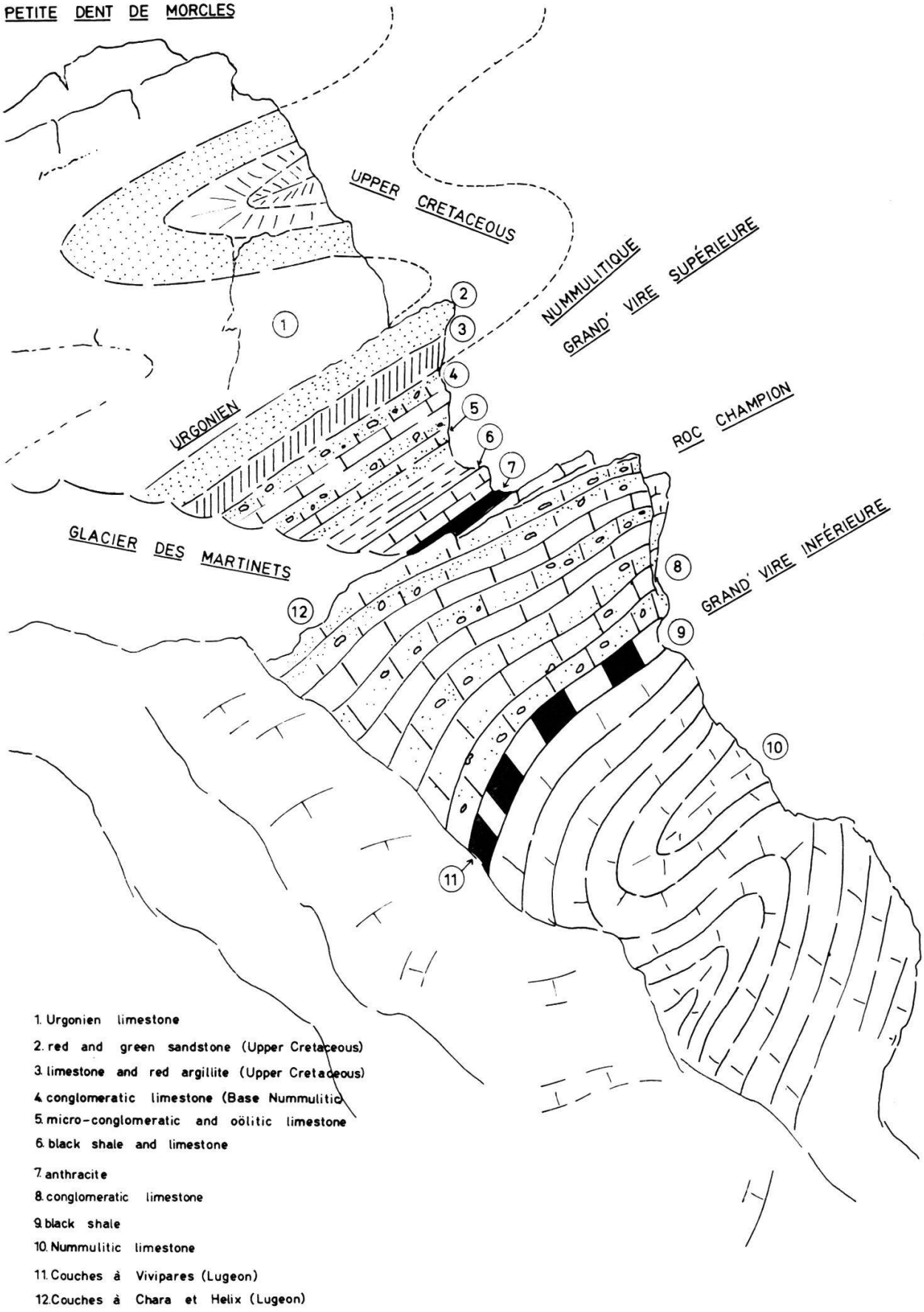


Fig. 4. — Structural section through the Petite Dent and Roc Champion.

from les Martinets to the point where the Nummulitic disappears under recent alluvium near the Pont de Nant, the conglomerates of the Roc Champion are present, but the thickness decreases to 12 m. A single Nummulite (sample 424), was found within the basal conglomerate just above the Chalet de Nant.

The Conglomerate of Roc Champion is considerably thinner along the frontal zone of the Nappe de Morcles. Typically seen at Sur Champ and above Solalex on the ridge of l'Argentine, these basal conglomerate beds are in the order of 5 to 7 m thick. Here, as at the Dents de Morcles, the elements are principally rounded and somewhat flattened Urgonien pebbles up to two cm in diameter. North of the Avançon de Nant, the shale and marl interbeds within the conglomerate series (Couches de la Grand'Vire or Couches à *Chara* et *Helix*) which are found in the Vallée de Nant and at the Dents de Morcles are no longer apparent. Hence, the basal conglomerates of the frontal zone form a homogeneous unit approximately 2 to 6 m thick, transgressive over Cenomanian limestone. In stratigraphic sections V and VI the basal conglomerates of Roc Champion are occasionally fossiliferous, containing rare Nummulites and *Borelis*. Just east of the Col des Essets, basal Nummulitic conglomerates are overlying soft ferruginous sandstones which may be the "Sidérolithique" referred to by LUGEON.

On arrival at the syncline of Derborence and continuing along the normal flank of the Nappe de Morcles, the conglomeratic beds of the Roc Champion are present only as a thin (50 to 100 cm) band incorporated within the base of the Calcaire à Petites Nummulites, and cannot be recognized as a separate facies within the Nummulitic. This relationship of the basal Nummulitic beds is illustrated on figure 3.

c) Couches à Cérithes

The Couches à Cérithes were originally described by RENEVIER (1890), as the basal Nummulitic shale and marl section from the "mine de houille" below the Pointe de la Houille in the Massif des Diablerets. RENEVIER recognized over 100 species of fossils from the Couches de Cérithes which were later restudied and classified by BOUSSAC (1912). As BOUSSAC has explained, the Couches à Cérithes are often present in the basal Nummulitic, but are not everywhere contemporaneous, i.e. they are a local facies occurring sporadically within the lower Nummulitic series. Below the Pointe de la Houille, the Couches à Cérithes are 30 m thick and apparently comprise the basal Nummulitic beds, while at La Corde and the Col des Essets they occur just above the Couches du Roc Champion and are equally fossiliferous although not more than 4 m thick.

On the reversed flank of the Nappe de Morcles, from the Petit Cor to the Vallée de Nant, a 2 m shale interval, equivalent to the Couches à Cérithes, occurs stratigraphically above the basal conglomerates of Roc Champion, and just below the Calcaire à Petites Nummulites. These shales contain *Cerithium*

diaboli, and *Cardium rouyanum*. Rarely, small Nummulites, herein identified as *Nummulites incrassatus*, are present in the upper few cm of the shaly beds (sample 402 from the Col de Pauvres). As shown on the section through the Dent de Morcles (figure 4), the Couches à Cérithes occur at the base (structural) of the Roc Champion where they form the Grand'Vire Inférieure of LUGEON. Also present along the Grand'Vire Inférieure (close to the military "abri" just south of the Col des Martinets) is a thin band of black sapropelic shale at the base of the Couches à Cérithes which was called the *Couches à Vivipares* by LUGEON. These beds are less than 1 m thick and were not found in any other locality in the Morcles area.

Along the frontal zone of the Nappe de Morcles, the Couches à Cérithes can be traced from the Lion d'Argentine to the Col des Essets. At La Corde and the Col des Essets the Couches à Cérithes form a lenticular bed not more than 3 to 4 m thick of brownish shale and marl. These beds contain *Natica vulcani*, plus other species of gastropods and pelecypods. Southeast of the Col des Essets, in the region of l'Ecuelle, the Couches à Cérithes disappear and are not found again along the normal flank of the Nappe.

d) Calcaire à Petites Nummulites

This name was created by RENEVIER (1890), and later employed by LUGEON (1937) to designate the thick series of limestones which make up the greater part of the Nummulitic series of the Nappe de Morcles. These beds are always characterized by the presence of small Nummulites, sometimes in great numbers, which are of Priabonian (Upper Eocene) age. These Nummulitic limestones have several different facies which are described separately below.

The Calcaire à Petites Nummulites of the reversed flank : As shown on sections I, II, III and IV, the Calcaire à Petites Nummulites commences with a bed ranging from 10 to 25 m thick of *arenaceous limestone*. The limestone (see sample 249) contains up to 50 % detritic quartz (averaging 0,2 to 0,5 mm in diameter), imbedded in a black mass of argillaceous and carbonate matrix material. Rarely the matrix has a sparry calcite structure. The percentage of detritic quartz material varies considerably, and perhaps occasionally this unit approaches a sandstone in composition. Hence, the name "Grès Nummulitique" used by LUGEON and RENEVIER for corresponding beds in the Nappe des Diablerets.

It is within this lower limestone unit of the Calcaire à Petites Nummulites that a considerable amount of the Priabonian fauna is found. Foraminifera tests can be concentrated to the extent that the rock becomes a true *foraminiferal limestone* (see sample 519). *Nummulites incrassatus*, *N. garnieri*, *N. striatus*, and *Discocyclina* are common within this zone.

In the Torrent Sec and continuing southeastward to Six Tremble and the Petit Cor, a dolomitic interval is sporadically present within the Calcaire à Petites Nummulites. These dolomite or *dolomitic limestone* beds are lenticular

in shape, usually 2 to 3 m thick and extending laterally for several hundreds of m. The freshly broken surface of the rock is light gray, and the weathered surface is a distinctive tan, while the entire bed has a brecciated structure. In thin section, samples 251 and 252 have an equigranular mosaic texture, apparently of anhedral dolomite crystals. Similar type dolomitic beds are found at : 1) in the cirque of the Petit Cor, 2) along the trail on the south side of Six Tremble near "Lui Crève", 3) in the Torrent Sec and extending southward along the flank of the massif of Morcles, 4) below (west) of the Pointe de Pré Fleuri and the Pointe des Perris Blancs, and also a large block (?) o dolomite is found along the trail from La Tourche to the Col des Perris Blancs.

Beginning just above (stratigraphically) the level of dolomitic limestone the aspect of the Calcaire à Petites Nummulites changes somewhat. As shown in Stratigraphic Sections I and II, the limestones above the dolomite become clastic, grading upward into *breccia*.

In the Torrent Sec this breccia is 30 to 35 m thick, while southward towards the massif of Six Tremble these beds are probably 70 to 80 m thick.

Along the trail from Rionda to the Dent de Morcles, the breccia may be divided roughly into three zones as shown below (from stratigraphic base to top) :

1) Limestone with breccia elements, fine texture towards base becoming coarser rapidly, with increase in proportion of crystalline elements towards top. Breccia elements angular and poorly sorted.
2) Zone composed entirely of large crystalline blocks with little or no carbonate binding material. Varies from 3 to 6 m thick.
3) Thin bedded to shaly limestone with fine, angular breccia elements.

Zone "2", best exposed just above Rionda, has been described as a "mylonite" by LUGEON (1937). However, this term is misleading and should be discontinued, as it infers a structural rather than a sedimentary origin.

Petrographically, a great majority of the breccia blocks are granitic type rocks (see samples 101, 103, 105), with abundant quartz, orthoclase, plagioclase feldspar (near oligoclase in composition), and mica. Sample 108 is of similar granitic composition, but contains biotite mica altered to chlorite. In thin section, samples 106 and 472 show a granitic composition, but have a noticeably finer (aplitic) texture. Sample 109 is a marble, with an abundance of calcite, idocrase, muscovite, a colorless garnet, and graphite. Marble very similar to this in composition has been described by LUGEON and JÉRÉMINE (1913), from the Massif des Aiguilles Rouges (near Alesse, Itroz, and between Forclaz and Arpille), where the marbles are found in lenticular bands associated with granites and aplites.

In the Torrent Sec and below the Pointe de Pré Fleuri rare small Nummulites resembling *Nummulites incrassatus* were found within the breccia zone (sample 414).

As indicated on the stratigraphic sections the zone of limestone breccia has a very definite "wedge" shape, thin, as mentioned above, in Sections III and IV (Dent Rouge and Vallée de Nant) and thickening noticibly towards the Dent de Morcles and Six Tremble (Sections I and II). Below the Dent de Morcles in the Torrent Sec, the breccia zone is at least 25 to 30 m thick, of which at least 5 m are made up completely of igneous and metamorphic elements without any limestone matrix ("complexe cristallin" of LUGEON). Following along the south flank of the Massif de Morcles towards Six Tremble, the zone of limestone breccia thickens to a maximum estimated at 75 to 80 m. Only the basal part was measured in the Petit Cor, as the upper half is buried under the moraine above the Lac de Fully. The approximate distribution of the breccia zone along the reversed flank of the Nappe is shown on figure 2.

The Calcaire à Petites Nummulites in the frontal zone : Perhaps the most striking change in the character of these beds (from the reversed flank) is their reduction in thickness, being only 35 m thick along the base of the massif of l'Argentine. The basal limit is well marked by the "Couches à Cérithes", while the upper limit grades imperceptibly into the "Schistes à Globigérines". Petrographically, these limestones differ from those of the reversed flank in that they contain a greater amount of organic debris and that the limestone frequently has a more "spathique" aspect. Bioclasts in the form of crushed shell material, foraminifera tests, echinoid spines, bryozoa and algal remains are common and make up a good percentage of the rock. Sample 431 from below the Lion d'Argentine contains large numbers of Nummulites and *Discocyclina* and might be more accurately described as a *foraminiferal limestone*. Sample 451 from La Poreyrettaz is loaded with Nummulite tests to such a degree that it could truly be called a *Nummulitic limestone*.

Foraminifera, indigenous to the Calcaire à Petites Nummulites along the frontal zone of the Nappe de Morcles, are many and varied. Among the more distinctive species identified in thin section are : *Nummulites garnieri*, *N. incrassatus*, *N. striatus*, *N. fabianii*, *Borelis* cf. *vonderschmitti*, *Spiroclypeus granulosus*, *Heterostegina* sp. ind., *Discocyclina* cf. *discus*, *D.* cf. *chudeaui* and *Asterocyclina* sp. ind.

The *Calcaire à Petites Nummulites in the normal flank :* At the Col des Essets on the normal flank of the Nappe de Morcles the thickness of the Calcaire à Petites Nummulites varies between 25 and 30 m ; much the same as it does along the ridge of l'Argentine. At the Col des Essets, detritic quartz grains are concentrated within the basal layers to the extent that RENEVIER (1890) and LUGEON (1937) have called this band the "Grès Nummulitique". RENEVIER also mentions that this sand is better developed in the Nappe des Diablerets where it occurs just above the Couches à Cérithes. In the samples and thin sections examined during this study, the quartz content seems to average somewhat less than 50 % and it would probably be more accurate to refer to this zone as *arenaceous* or *sandy limestone*. These arenaceous limestones are, in turn, overlain by a series of dark argillaceous limestones extremely

rich in foraminifera tests and broken shell debris. Stratigraphically above, and interbedded with these bioclastic limestones are approximately 9 to 10 m of slightly more "spathique" limestone, grading upwards into a thin bedded or shaly limestone which also contains considerable amounts of fossil debris. Foraminifera identified in samples from the Col des Essets - L'Echelle area, are similar to those listed from the frontal zone.

The facies of the Calcaire à Petites Nummulites remains similar to that described above while moving eastward along the band of Nummulitic outcrops from L'Echelle, Les Filasses to Cheville where the Nummulitic momentarily disappears under recent alluvium northwest of Derborence. It is also in this area, that the Couches à Cérithes which are present along the reversed flank of the Nappe de Morcles from the Petit Cor to Cheville gradually thin and disappear loosing their identity within the Calcaire à Petites Nummulites.

Hence, starting in the region of l'Ecuelle and continuing east, the Calcaire à Petites Nummulites comprises the basal Nummulitic strata as shown on sections VII and VIII. Above the Chalets de Cheville, the basal Nummulitic beds are a pebble limestone, which grade upward into dark, argillaceous limestones containing the bulk of the Nummulitic fauna.

In the syncline of Derborence, the Calcaire à Petites Nummulites varies from 10 to 15 m in thickness. Here again, the basal layers are conglomeratic and contain occasional Nummulites (samples 481 and 482) which are interbedded with, and grade up into, a "spathique" limestone, typically lighter gray with a bluish white weathered surface.

A section similar to that described at Derborence may be observed at Montbas and in the syncline at Voltine along the Lizerne valley.

e) Schistes à Globigérines

From the Vallée de Nant northward towards l'Argentine, and from there eastwards along the normal flank of the Nappe de Morcles, the Calcaire à Petites Nummulites grades upward into a series of thin bedded limestones and calcareous shales. These shales were described by RENEVIER (1890) as the "Schistes nummulitiques", and by LUGEON (1937) as the "Schistes à Globigérines", whose occurrence was restricted to the "carapace" of the Nappe. Detailed examination of the upper part of the Calcaire à Petites Nummulites indicates that the shaly section (Schistes à Globigérines) described by LUGEON from the syncline of Rouzziaz, is also present at Derborence, the Col des Essets, l'Argentine, and in the Vallée de Nant. These relationships are shown on figure 3, and the approximate thickness and lithology of the Schistes à Globigérines are shown on stratigraphic sections III to VIII. The upper and lower limits are approximate, as the lithologic change from bedded limestone to shale is gradational, and the upper limit with the overlying Flysch shales is also arbitrary. In general the Schistes à Globigérines vary from 15 to 30 m in thickness, are composed principally of dark calcareous shales with a whitish

to light gray weathering surface, and are interbedded with thin beds (1 to 10 cm) of dark limestone. Above the Chalet de Nant, a microbreccia zone (with dolomitic elements) approximately 2 m thick is present within the shale.

In sample 428 (from the Avançon de Nant between Les Plans and the Pont de Nant), Nummulites were found in a thin limestone bed in the shale section.

f) The Helvétique Flysch

In the immediate vicinity of the Massif of Morcles, beds which have been referred to as Flysch belong to two distinct tectonic units. These are : 1) the Flysch deposited, displaced and folded in concordance with the Nummulitic of the Nappe ; and 2) a Flysch series locally folded and faulted, which originated in a more external position in the Alpine Basin and is related to the autochthonous and para-autochthonous zones of the Massif des Aiguilles Rouges. These units are discussed separately below.

The Flysch of the Nappe de Morcles : Along the normal flank, and the frontal zone of the Nappe, the "Schistes à Globigérines" grade upward (stratigraphically) into a thick series of shale and sandstone which have been described as Flysch by RENEVIER (1890), BOUSSAC (1912), LUGEON (1937) and VUAGNAT (1952). These beds are best seen along the valley of La Lizerne at Madoue, Voltine and Montbas, and in the syncline of Derborence. Along the Lizerne, this Flysch series includes a massive body of sandstone known as the "Grès de Taveyannaz" described in detail by VUAGNAT (1952).

West and southward of La Lizerne, along the frontal zone the Flysch is again exposed from the Tête de Filasses to the Col des Essets, La Poreyrette, below (west of) the massif of l'Argentine, and southward to the Cheval Blanc and the Avançon de Nant. Through this region the Flysch is made up of a monotonous series of shale, void of the massive sandstone layers found at the valley of La Lizerne.

South of the Avançon de Nant, the zone of allochthonous Flysch continues through Joux Ronde, Euzanne, and forms at least a part of the shale series exposed on the Chaux Commun, and below (west of) the Pointe de Pré Fleuri and the Pointe des Perris Blancs. From the Pointe des Perris Blancs southward, as shown in figure 2, the Flysch of the Nappe is composed of a thin band of shale (10 to 20 m thick) resting inverted over the autochthonous Flysch. Below the Nappe, the mass of shales and sandstone outcropping in the region from Six Tremble - Sur le Cour - Rionda - La Tourche - Croix de Javerne - La Druzine and Plambuit form the *autochthonous Flysch* and are discussed in the next section.

The precise outline of the "plan de chevauchement" forming the base of the Nappe de Morcles has not been mapped during the course of this study except in a generalized manner as on figure 2. Instead of a single major plane of movement over which the Nappe moved, it seems likely that there are several horizontal planes of displacement within the Flysch shales over which

movement occurred during the emplacement of the Nappe. Tracing the outline of these horizontal fault systems is encumbered by the vegetation cover which consistantly reaches upward to the base of the Nummulitic limestone cliffs. Therefore, good Flysch outcrops at the lower elevations are restricted to stream beds, road cuts, and occasionally along the foot paths.

The Flysch of the Nappe de Morcles — along the frontal zone and on the reversed flank of the Nappe — is essentially a *shale* unit. Only rare detritic beds, in the form of siltstone, sandstone, and fine micro-breccia are found in these areas. Characteristically, these shales are finely laminated to papery thin, and often calcareous. The fresh cleavage plane is usually silvery gray, and the weathered surface is a darker gray with a yellowish brown tinge. Often (for example along the trail leading from Rionda to the Grande Dent de Morcles), the schistosity *is not* parallel with what appears to be the original bedding plane. The bedding planes are marked by a dark brownish gray banded pattern probably due to oxidation of iron compounds in alternate layers of slightly different lithology.

The entire Flysch (both the autochthon and allochthon) series ends against a vertical fault in the stream canyon running up the west flank of the massif of Six Tremble (l'Aboyeu).

North of the Dent de Morcles, this band of Flysch shale (belonging to the Nappe) must continue and thicken, and it is probable that the greater part of the Flysch exposed at Euzanne and on the "Chaux Commun" belongs also to the Nappe. However, any trace of a major "plan de chevauchement" separating the Nappe from the autochthon in this region is not apparent in the outcrops. Further northward, on arriving at the latitude of the Avançon de Nant, *all* of the Flysch shales exposed between the Nummulitic of Morcles and the Ultrahelvetic Nappes belong to the Nappe de Morcles.

North and east of Les Plans, the Flysch beds of the Nappe are discontinously exposed along the trail going up the torrent d'Ayerne to the Cheval Blanc. Here, the Flysch is made up of black, slightly micaceous shale with some standstone interbeds at the base (towards Les Plans). These are the first occurrence of important sandstone developments within the allochthonous Flysch.

From the region of l'Argentine northward, towards Beccan des Meyes, the Flysch shales are easily traced between the beds belonging to the Nappe de la Plaine Morte, and the vertical Nummulitic limestones of the Nappe de Morcles. There is a minimum of 50 m of Flysch shale exposed in this band. Again, these shales are calcareous, dark to silver gray with brownish banding paralleling the bedding planes. The cleavage is developed at almost right angles to the bedding.

Elsewhere, along the frontal zone of the Nappe, and in the first folds of the normal flank, Flysch shales are exposed at La Poreyrette, and between the Col des Essets and the Tête des Filasses. In this vicinity, the section averages 50 m in thickness. The shales are very fissile to papery, micaceous, and cal-

careous. Just east of the Col des Essets, one finds thin (1 to 2 cm) bands of hard siliceous limestone within the Flysch shales.

In the syncline of Derborence, approximately 20 m of Flysch shales similar to those described above are found along the southeast flank. There are no traces of sandstone associated with the Flysch shales in this area.

Between the Chapelle St Bernard, and Madoue, along the Valley of the Lizerne (and on the normal flank of the Nappe), the Nummulitic is overlain by a much more complete section of Flysch than found elsewhere in the Nappe de Morcles. (See Stratigraphic Section VIII.)

The section is as follows :

From base to top (oldest to youngest)

17 m — *shale*, black to grey, brownish weathering, calcareous to carbonaceous, finely laminated rare thin interbeds of micaceous *siltstone*.
6 m — micaceous *siltstone* and very fine grained *sandstone*, thin interbeds of shale.
12 m — *siltstone* alternating with papery thin carbonaceous *shales*. Rare *sandstone* beds, 20 to 50 cm thick.
35 m — *shale*, silvery grey with yellowish weathering, very fissile and slightly calcareous. Thin *silt* and *sandstone* interbeds. Poor outcrops towards the top of this zone (along road).
15 m — *sandstone*, interbedded with and grading into *siltstone* and *shale*. The sandstone is medium grained, dark grayish in color with a distinctive greenish coloration, rare carbonate specks, beds between 20 cm and 2 m thick. The outcrops along the road to Madoue are tightly folded.
8 m — principally *siltstone* and *shale*.
25 m — *sandstone*, massive beds 1 to 2 m thick, micaceous, grey with greenish coloration.
9 m — *shale*, alternating with thin *siltstone* and *sandstone* beds.
40 m — (possibly more) — *shale*, black, micaceous carbonaceous, papery thin cleavage, interbedded with thin sandstone beds. Poor exposures in upper parts along road.

In total, there are at least 170 m of Flysch shale and sandstone composing the section in the Lizerne valley. The sandstones are the "Grès de Taveyannaz", and have been described in detail by VUAGNAT (1952). According to VUAGNAT, their composition may be summarized as follows :

1) more than 50 % volcanic fragments (up to 95 % max.) mostly spilites, with albitic feldspar, and chlorite ;

2) lesser amounts of miscellaneous igneous and sedimentary rocks, such as : quartz, chert, granitic fragments and rarely carbonate rocks.

In addition to the more or less complete section described above, Flysch beds are present above the Nummulitic at Montbas (east side of La Lizerne), and in the syncline at Voltine (west side of La Lizerne). Near Voltine, along the trail where it traverses the southeast flank of the syncline at least 30 m of Flysch sediments are present. The basal 15 m is composed of finely laminated to papery thin shales, with rare, thin (2 to 10 cm) sand and siltstone interbeds, while the upper 15 m are made up of silvery grey shales, becoming black and

carbonaceous at the top. There are no massive bands of sandstone and micro-breccia at either Voltine or Montbas.

The Autochthonous Flysch : Along the reversed flank of the Nappe de Morcles, from Six Tremble to roughly Javerne, the overturned Flysch of the Nappe (described in the preceeding section) is overlying (structurally) a thick series of black shale and sandstone known as the autochthonous Flysch. While there is good evidence that a major fault plane separates the Flysch of the Nappe from that of the autochthone along the southwest side of the Massif de Morcles (from Six Tremble to Pointe des Martinets), north of this area the actual base of the Nappe is not clearly defined. Outcrops in this area are poor, often covered by talus or grassy pasture, and a close examination of all the stream beds traversing the Flysch series just below Pré Fleuri and Perris Blancs has not disclosed any evidence of an important structural division within the Flysch series. However, it seems likely that somewhere between the Chalets de Javerne and the "Chaux Commun" there must be (probably buried beneath the recent alluvium) a continuation of the "plan de chevauchement" at the base of the Nappe.

A generalized picture of the arrangement of the autochthonous Flysch and the distribution of the main sandstone bodies found between Six Tremble and the Croix de Javerne, is illustrated on fig. 2. Whereas north of Rionda, towards La Tourche and the Croix de Javerne the Flysch section is structurally very complex, and as VUAGNAT (1952) has pointed out *repeated* through folding and faulting, to the southeast at Sur le Cœur (Bella Crêta) a normal Flysch series is found.

A representative section of the autochthonous Flysch between Rionda and Sur le Cœur would be as follows :

from base to top (oldest to youngest)

80 m — *shale*, typically black often weathering brownish, interbedded with *siltstone* and rarely fine grained *sandstone*.
40 m — *sandstone*, medium to coarse grained occasionally micro-breccia texture, with considerable carbonate constituants.
10 m — *shale*, with thin interbeds of fine grained *sandstone*.
25 m — *sandstone*, micro-breccia texture.
40 m — *shale*, with some *siltstone* and medium grained *sandstone* at base.
45 m — *sandstone*, medium grained to micro-breccia, calcareous, massive beds ; forms main body of sandstone by Rionda.
65-85 m — *shale*, dark grey to black, calcareous, often fractured with calcite vein filling.

The massive sandstone beds concentrated in the middle of this sequence, can be readily traced southeastwards along the flank of the Massif de Morcles. Southeast of Sur le Cœur, the sandstone beds thin, are of somewhat finer texture, and are concentrated in the lower third of the Flysch section. Further southeast, on arriving just below Six Tremble, the sandstones grade into a series of thin silty beds, interbedded with Flysch shales. As mentioned

before, the Flysch terminates against a nearly vertical fault running up the canyon of the torrent l'Aboyeu.

VUAGNAT (1952), has made a detailed study of the petrography and origin of the autochthonous Flysch sandstones in this region. Briefly, this author has described them as follows :

1) High percentage of the detritus is of sedimentary origin. Chert, quartz, limestone and dolomite are common.
2) Acid eruptive and other volcanic rocks are relatively scarce.
3) Carbonate cementing material.

They approach a true greywacke in composition. And, as VUAGNAT has demonstrated, these sandstones are closely related to the *Grès du Val d'Illiez*.

Generally, the grain sorting is poor and the sand grains are sub-angular to angular. Occasionally, there is evidence of graded bedding, going from coarse at the base to fine at the top, and also conversely. Rarely, large erratic blocks are found within the shale. For example, along the "lower" trail from Rionda to Sur le Cœur, a block of Nummulitic limestone over 30 cm in its longest dimension can be seen imbedded in the Flysch shales.

Going generally northeastward from Rionda towards the Croix de Javerne, La Drusine and Plambuit, the precise stratigraphy of the Flysch is difficult to comprehend. Repetition of the section through faulting and tight folding has resulted in at least 1500 m (vertical distance) of Flysch shale and sandstone beds cropping out on the steep cliffs between the Croix de Javerne and Plambuit. Further complicating the stratigraphy are remnants of tightly folded beds belonging to the Ultrahelvetique Nappes included within the Helvetique Flysch shales.

Before continuing with the description of the Flysch outcrops in this area, it might be useful to summarize briefly certain relationships which have already been established by VUAGNAT (1952) and LUGEON and VUAGNAT (1948). These authors have proposed that :

1) a relationship exists between the composition of the sandstone beds and its stratigraphic position within the Flysch series, i.e., older sandstones contain a greater percentage of volcanic detritus, while the progressively younger beds contain lesser amounts of volcanic material and *greater* amounts of sedimentary origin ;
2) a relationship exists between the composition of the sandstone beds and their position of deposition within the Flysch basin, i.e., from southeast to northwest the sandstones show a gradual decrease in their volcanic constituants and a simultaneous increase in the percentage of sedimentary detritus.

In short, clastic beds within the Flysch are becoming more "molassiques" towards the periphery of the basin. Both points 1) and 2) (above), are related to each other as the Flysch series was transgressive from the southeast.

In the autochthonous Flysch series of the Nappe de Morcles, massive bodies of sandstone (or micro-breccia) are concentrated in three different zones. These are :

1) the Plambuit - Les Monts - Chièbres region ;
2) a more or less continuous band exposed between La Rosseline, Rionda and Sur le Cœur (see figure 2) ;
3) a large outcrop just below the Croix de Javerne (see figure 2).

A detailed examination of these outcrops in the field indicates (as VUAGNAT has suggested) that the sandstone masses of Plambuit and la Rosseline - Rionda, Sur le Cœur are essentially the same unit, occurring near the base of the Flysch series and often overlying a thin band of Nummulitic limestone. This relationship is confirmed by VUAGNAT and LUGEON (1948) even though there is a very slight variation from La Rosseline to Rionda in 1) the amount of volcanic material, 2) the ratio of porphyrites to total volcanic constituants, and 3) the quantity of carbonate material. In fact, for each parameter, the constituants of the sandstones would indicate a slightly younger and more external origin for the Plambuit sandstones than those at Rionda. Although Plambuit is separated by only 3 or 4 km from Rionda and Sur le Cœur, it *was* actually in a more external position in the Flysch basin.

The composition of the Javerne sandstones strongly indicates a considerably more internal (and older) origin for these beds. The field evidence for this is not clear. However, the structure between the Croix de Javerne, La Tourche, and the first Nummulitic limestones below the Pointe des Martinets is *extremely complex*. Crushed, fractured, and tightly folded shale beds are typical of the outcrops along the crest leading from the Croix de Javerne to the Pointe des Martinets. In absence of any evidence to the contrary, it appears that the Javerne sandstones belong to a separate structural packet, which was displaced over a "plan de chevauchement" not readily perceptible in the field.

g) Autochthonous Nummulitic

To complete the Tertiary history of the Massif de Morcles one must mention the outcrops of autochthonous Nummulitic limestone present in a thin sporadic band at the base of the Flysch section. Outcrops of this sort were examined between Rionda and Sur le Cœur, and at La Rosseline. This limestone represents the initial Tertiary transgression across the Massif des Aiguilles Rouges.

A typical section of the basal Tertiary autochthonous sediments outcrops along the Morcles-Rionda road at La Rosseline (just a few m past the military road barrier). In this locality, the following section is exposed :

(base to top) :

1. *Malm :* massive limestones.

2. *Nummulitic limestone :* 4-5 m of conglomeratic limestone, very similar to the Conglomerate of Roc Champion, rounded pebbles of Urgonien limestone. One Nummulite was found in sample 359 from this locality.
3. Calcareous shales reminiscent of the *Schistes à Globigérines*, about 10 m thick.
4. Dark, *Flysch* shales.

VUAGNAT and LUGEON (1948) have also noted an occurrence of autochthonous Nummulitic limestone just south of Rionda.

PALEONTOLOGY

1. The Nummulitic Fauna of the Nappe de Morcles

The following list records all the fossils identified during the course of this study. There are many other microfossils present, particularly foraminifera. However, only the more common species are described below. No mention is made of planktonic foraminifera, but it is worth noting that *Globorotalia cerro-azulensis* (COLE) occurs in the Calcaire à Petites Nummulites (slide 419 B).

With the exception of certain species of Nummulites, no other type material was available to compare with the specimens from Morcles. A complete list of references on which specific determinations were based is included in the bibliography.

FORAMINIFERA

LITUOLIDAE
Placopsilina sp. ind.

ALVEOLINIDAE
Borelis cf. *vonderschmitti* (SCHWEIGHAUSER), 1952

ASTERIGERINIDAE
Asterigerina rotula KAUFMANN, 1867

ROTALIIDAE
Rotalia sp. ind.
Chapmanina gassinensis (SILVESTRI), 1905

NUMMULITIDAE
Nummulites incrassatus DE LA HARPE, 1883
Nummulites striatus (BRUGUIÈRE), 1792
Nummulites fabianii PREVER, 1905
Nummulites garnieri DE LA HARPE, 1896
Operculina sp. ind.
Heterostegina sp. ind.
Spiroclypeus granulosus BOUSSAC, 1905

ACERVULINIDAE
Sphaerogypsina cf. *globulus* (REUSS), 1848

CYMBALOPORIDAE
Halkyardia minima (LIEBUS), 1911

HOMOTREMATIDAE
Sporadotrema cf. *cylindricum* (CARTER), 1880

DISCOCYCLINIDAE
Discocyclina cf. *discus* (RÜTIMEYER), 1850
Discocyclina cf. *chudeaui* (SCHLUMBERGER), 1903
Asterocyclina sp. ind.

OTHER FOSSILS

LAMELLIBRANCHES
Meretrix villanovae DESHAYES
Pecten infumatus LAMARCK
Cardium rouyanum D'ORBIGNY
Ostrea sp. ind.

GASTROPODS
Cerithium diaboli BRONGNIART
Natica vulcani BRONGNIART

ALGAE
Lithothamnium spp.

The Nummulitic of the Nappe de Morcles represents an Upper Eocene transgression over the western fringes of the Alpine Basin. Each Upper Eocene facies of the Nappe is, in turn, characterized by a particular faunal assemblage. These are summarized below, and are also shown more completely on the stratigraphic range chart (figure 5).

1) Conglomérats du Roc Champion : contains rare, small Nummulites, *Borelis*, *Rotalia*, and *Asterigerina*.

2) Couches à Cérithes : with *Cerithium diaboli*, best development below the Petite Dent de Morcles. These beds have generally been described as Upper Eocene throughout the Western Alps. However, their stratigraphic position is not fixed. At Vicenza they are found at the base of the Priabonian series just above the beds containing large Nummulites (Couches de Ronca with *Nummulites aturicus*), while at Morcles they are found within the Priabonian limestones. This phenomenon has been noted by both RENEVIER and BOUSSAC. BOUSSAC (1912), says the following :

> "Il (RENEVIER) chercha avant tout à préciser la situation de la couche à Cérithes. Il remarqua qu'aux Diablerets elle est à la base de la série, tandis qu'à La Cordaz la couche à grosses Natices qui la représente est intercalée entre deux couches à Nummulites dont la supérieure est de beaucoup la plus épaisse. Il y a donc intercalation véritable, continue-t-il, de la couche à Cérithes entre des couches à Nummulites, ainsi que l'avait déjà pressenti ... M. Studer, et, comme il le pensait aussi, cette couche n'est qu'un faciès local, car sur plusieurs points de La Cordaz, ainsi qu'à l'Ecouellaz, elle manque complètement, et la grande masse de calcaire à Nummulites repose directement sur le Gault. Du moment que cette couche à Cérithes n'est qu'un faciès du terrain nummulitique, elle peut, dans d'autres localités, se trouver superposée à une plus grande épaisseur de Nummulites et ainsi se trouvent expliquées toutes les divergences d'opinion sur la position relative de ces couches."

3) Calcaires à Petites Nummulites : These beds contain several species of Nummulites, plus *Operculina*, *Heterostegina*, *Spiroclypeus*, *Discocyclina*,

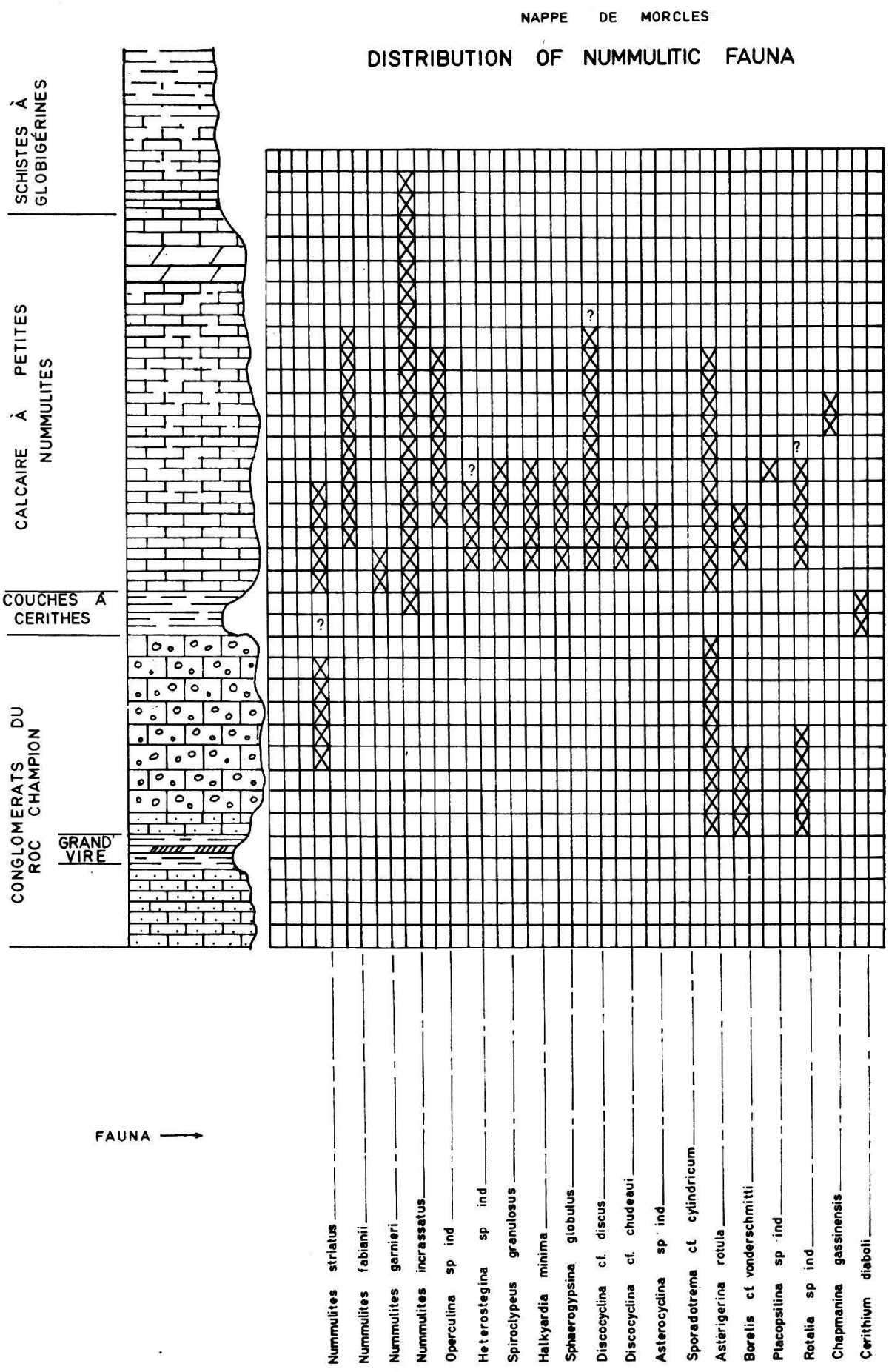

FACIES
NAPPE DE MORCLES
DISTRIBUTION OF NUMMULITIC FAUNA
SCHISTES À GLOBIGÉRINES
CALCAIRE À PETITES NUMMULITES
COUCHES À CERITHES
CONGLOMERATS DU ROC CHAMPION
GRAND VIRE
FAUNA
Nummulites striatus
Nummulites fabianii
Nummulites garnieri
Nummulites incrassatus
Operculina sp ind
Heterostegina sp ind
Spiroclypeus granulosus
Halkyardia minima
Sphaerogypsina globulus
Discocyclina cf. discus
Discocyclina cf. chudeaui
Asterocyclina sp ind
Sporadotrema cf. cylindricum
Asterigerina rotula
Borelis cf. vonderschmitti
Placopsilina sp ind
Rotalia sp ind
Chapmanina gassinensis
Cerithium diaboli

Figure 5.

Asterocyclina, *Chapmanina*, and others. *Lithothamnium* frequently occurs with these forms.

4) In the shale samples from the Schistes à Globigérines, rare, broken tests of Globigerinas were noted.

5) No fossils were found in the Flysch. The only conclusion that can be drawn regarding the age of these beds is that they are *younger* than the Nummulitic limestones, and *older* than the alpine orogenic phase during which the Nappe de Morcles was displaced. BOUSSAC (1912), and VUAGNAT (1952) consider the bulk of the Helvetique Flysch (including the Grès de Taveyannaz in the valley of La Lizerne, and the Grès du Val d'Illiez at Plambuit and Rionda) to be of lowermost Oligocene age (Lattorfian).

The Nummulitic of Morcles correlates rather closely with the type Priabonian. It is of Upper Eocene age and is younger than the Upper Lutetian and the Auversian of BOUSSAC, and the Biarritzian of SCHAUB and HOTTINGER.

2. Systematic Paleontology

LITUOLIDAE DE BLAINVILLE, 1825
PLACOPSILINAE RHUMBLER, 1913
Placopsilina D'ORBIGNY, 1850
Placopsilina sp. ind.

In two specimens the tests measure 7.0 mm and 4.25 mm respectively in length, and both are approximately 2.5 mm in width. The arrangement of the neanic chambers is not clear, but they appear to be in a linear series. The test wall is divided into three distinct layers. The outer coarsely granulated layer, composed largely of quartz grains averages about 0.17 mm in thickness. The intermediate fine granular layer is about 0.12 mm thick. The thickness of the inner pseudochitinous layer is in the order of 0.013 mm. The pseudochitinous layer extends over the floor of the chamber where it is attached to the substratum. The wall thickens internally around the edge of the aperture. The specimens seen in thin section are most often attached to *Lithothamnium*.

Placopsilina sp. ind. is associated with *Nummulites incrassatus* and *N. fabianii*. It is present in samples 406 and 250 (slides 406 A-C, and 250 A).

ALVEOLINIDAE EHRENBERG, 1839
Borelis DE MONTFORT, 1808
Borelis cf. *vonderschmitti* (SCHWEIGHAUSER), 1952
(Plate III, figures 1, 2, 4.)

Ellipsoid shaped tests with a diameter between 0.7 mm and 0.9 mm in the tangential sections measured in slides 445 C-D, 446 A-C, and 448 C. One specimen measured 1.4 mm along the axis and 1.2 mm equatorial diameter, in a section which is off center. Figures 1 and 2 show clearly the development of a preseptal canal. The septula subdividing the meridional chambers are

in alignment from one chamber to the next (figure 4). It appears that the axis of enrollment changes during ontogeny. These specimens are larger than the type species of *Borelis vonderschmitti* (SCHWEIGHAUSER) from Vicenza. *Borelis* cf. *vonderschmitti* is found in samples 445 and 446 from the very basal Nummulitic conglomerates. Although it occurs in one thin section with *Nummulites fabianii* (448 C), *Borelis* cf. *vonderschmitti* is more characteristic of the Eocene beds lying below the first Nummulitic limestones.

ASTERIGERINIDAE D'ORBIGNY, 1839
Asterigerina D'ORBIGNY, 1839
Asterigerina rotula KAUFMANN, 1867

This species is present in abundance throughout the Calcaire à Petites Nummulites. The test is biconvex in axial section with the spiral side somewhat flatter than the ventral. The average test is 1.2 to 1.4 mm in diameter and made up of 3 to 4 whorls. The wall consists of finely laminated, radially textured layers and has an average thickness of 0.058 mm on the ventral side. These examples correspond very closely with the type description of *Asterigerina rotula* by KAUFMANN. Sections 448 and 451 show many examples of this species.

ROTALIIDAE EHRENBERG, 1839
ROTALIINAE EHRENBERG, 1839
Rotalia LAMARCK, 1804
Rotalia sp. ind.

The chambers are arranged in a trochoid spiral. In a ventral section cutting close to the axis (slide 430 B) the principal dimensions are as follows : diameter of test, 1.49 mm ; height from apex to tip of ventral plug, 0.88 mm ; width of outside chamber (internal dimension), 0.41 mm ; thickness of test wall near ventral periphery, 0.07 mm. A test composed of 3 whorls has 8 to 9 chambers in the outer whorl. A specific identification is not possible with the present material.

Rotalia sp. ind. is found in samples 419 A-B and 430 A-B, from the Calcaire à Petites Nummulites. It is associated with *Nummulites incrassatus* and *N. fabianii*.

CHAPMANINAE THALMANN, 1938
Chapmanina SILVESTRI, 1931
Chapmanina gassinensis (SILVESTRI), 1905

An oblique axial section is illustrated in slide 419 B showing the rectangular cortical chambers along the flanks of the cone, and the umbilical region composed of horizontal laminae supported by hollow vertical pillars. The height of the cone is 0.8 mm and its basal diameter is 1.2 mm. Dimensions and internal features compare closely with the type description of *Chapmanina gassinensis* (SILVESTRI).

Chapmanina is found in slide 419 B and is associated with *Nummulites incrassatus*, *N. fabianii*, and *Discocyclina*.

NUMMULITIDAE DE BLAINVILLE, 1825
NUMMULITINAE DE BLAINVILLE, 1825

In this study, the following species of Nummulites have been identified in samples from the Nappe de Morcles :

1) *Nummulites fabianii* (micro- and megalospheric forms)
2) *Nummulites incrassatus*
3) *Nummulites striatus*
4) *Nummulites garnieri*

Some confusion has arisen in the differentiation of *Nummulites fabianii* from *N. fichteli*. Probably DE LA HARPE was the first author to call this small reticulated Nummulite from the Nappe de Morcles, *Nummulites fichteli*. In 1877, he described a small Nummulite accompanying *N. striatus* at Anzeindaz, Cordaz, l'Argentine, and the Dent de Morcles, and identified it as *Nummulites garansensis* JOLY and LEYMERIE. Later in 1880, he grouped *Nummulites garansensis* with *N. fichteli*. Describing the Nummulitic section of the Val d'Illiez and l'Argentine, DE LA HARPE observed that the form he called *N. fichteli* is found at a slightly higher stratigraphic level than *N. striatus*. This relationship is, in effect, true as can be seen on figure 5. *N. striatus* is present from the base of the Nummulitic limestones, while what is actually *N. fabianii* appears at a slightly higher level.

Nummulites LAMARCK, 1801
Nummulites fabianii PREVER 1905
(Plate I, figures 1, 2, 3)

The lenticular shaped test varies between 2.5 mm and 4.0 mm in diameter, and is normally from 1.0 to 1.5 mm thick. The perforate spiral sheet is noticeably thicker on the periphery of the test than over the poles. The spiral sheet is 0.09 mm thick near the periphery decreasing to 0.04 mm over the sides. In an equatorial cut the wall measures approximately 0.08 mm thick. The inner, imperforate layer doubles to form the septa. The septa are considerably thinner than the spiral sheet (less than one half). Figure 2 on plate I, shows the pillar structure which manifests in granulations on the surface of the test. In the equatorial section, the chambers are quite regularly longer than high. The heavy spiral line on the exterior of the test is caused by the concentration of pillars along the periphery of the preceding whorl (see figure 3, plate I). The septal filaments are disposed in a generally radiating pattern from the center of the test to its borders. The filaments are irregular and bifurcating. The combination of these two patterns (the spiral line and the radiating septal filaments) forms a crude rectangular pattern on the surface of the test.

Nummulites fabianii is common in the Calcaire à Petites Nummulites. It is present in great numbers in samples 448 and 451.

Nummulites incrassatus DE LA HARPE, 1883
(Plate II, figures 3, 4)

The test is usually between 2.5 and 3.3 mm in diameter. It is slightly inflated over the poles averaging 1.4 mm in thickness. The spiral walls meet in a thin relatively sharp periphery. In axial section (figure 3), a well developed central pillar is visible which manifests as a whitish pustule on the poles of the test. Consequently, the spiral sheet is noticeably thicker over the poles (0.16 mm in figure 3) than towards the edge of the test (0.08 mm on figure 3). The regular, radiating pattern of the septal filaments is shown on figure 4.

A comparison of the average size of *Nummulites incrassatus* with that of *N. striatus* and *N. garnieri* is shown on the figure 6.

Nummulites incrassatus is very common throughout the Calcaire à Petites Nummulites, especially in samples 431, 448, 451 and 507.

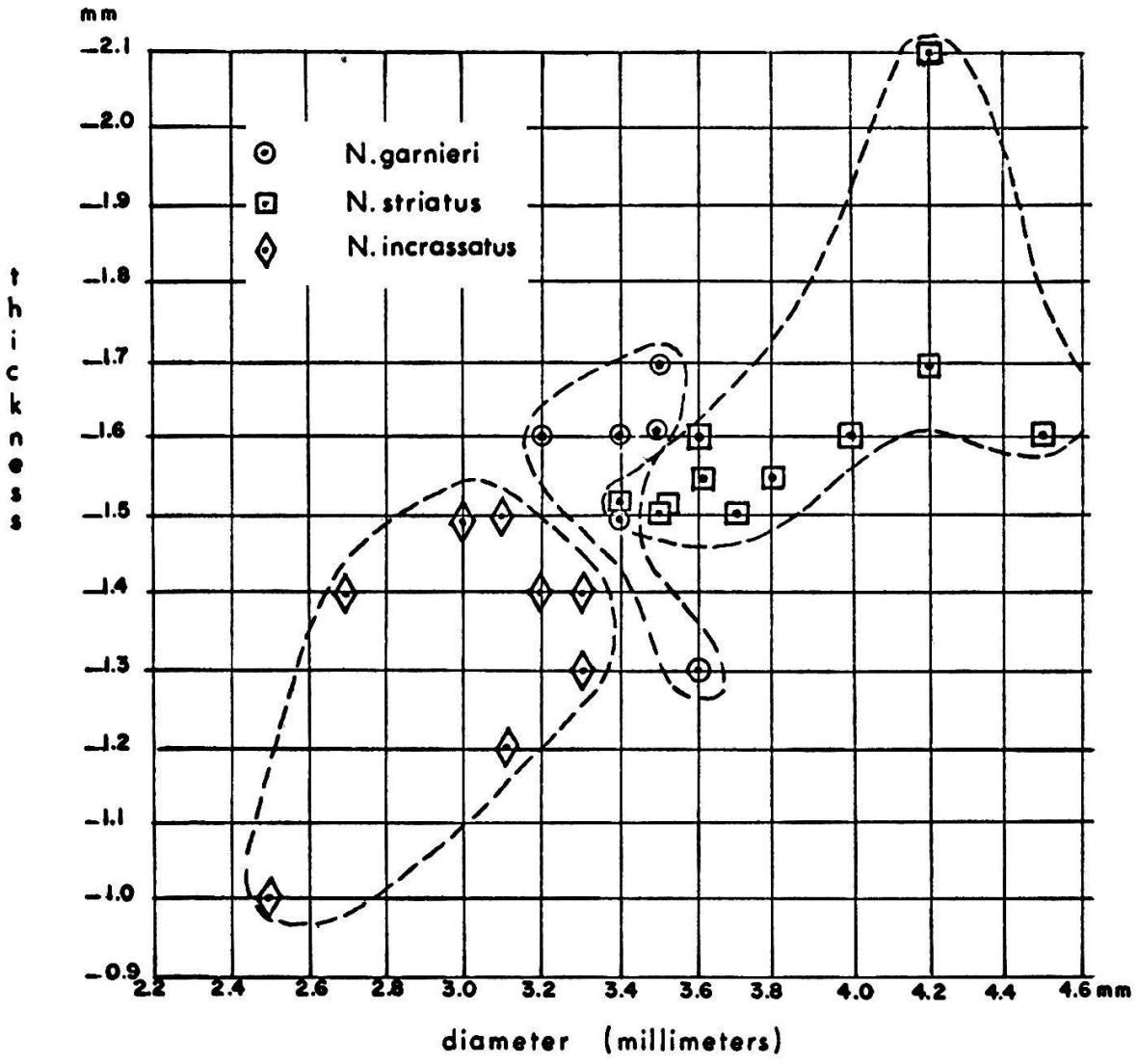


Fig. 6. — Size relationships of Nummulites with radiating septal filaments.

Nummulites striatus BRUGUIÈRE, 1792
(Plate I, figure 5 and plate II, figure 5)

Figure 5, plate I shows the symmetrical lenticular aspect of the test which varies between 3.5 mm and 4.5 mm in diameter, and between 1.5 and 1.7 mm in thickness. The axial section shows a spiral wall which is around 0.19 mm thick, and thins slightly over the poles. The central pillar is poorly developed and is less apparent than in *Nummulites incrassatus*. The equatorial section (figure 5, plate II) shows a spiral composed of 5 to 6 whorls. The septa, which are slightly inclined to the spiral sheet, are 0.03 mm thick. The septal filaments are arranged in a radiating pattern and undulate slightly over the poles. *Nummulites striatus* is found in sample 459 from the Couches Conglomératiques du Roc Champion, and in samples 328 and 329 from the Calcaire à Petites Nummulites. In samples 431 and 507 *N. striatus* is found with *Discocyclina*, and in sample 329 it is with *Nummulites fabianii*. *Nummulites striatus* seems restricted to the basal Nummulitic conglomerates and limestones in the Nappe de Morcles.

Nummulites garnieri DE LA HARPE, 1896
(Plate II, figures 1, 2)

The specimens examined average 3.4 mm in diameter and vary from 1.3 to 1.7 mm in thickness. The perforate spiral sheet is thickest over the poles reaching 0.18 mm. The septal filaments are disposed in a radiating pattern, but they are masked by heavy granulations over the poles of the test. Figure 1 shows the pillar structures which form the granulations. The average specimen has a test composed of 5 to 6 whorls with chambers which are consistantly higher than long.

Nummulites garnieri is found in sample 519 and 352 from the Calcaire à Petites Nummulites. It is associated with *Nummulites incrassatus*, *Discocyclina* and rarely with *Borelis*.

Operculina D'ORBIGNY, 1826
Operculina sp. ind.

The flattened evolute test is 5.0 mm in diameter and 0.5 mm thick. There appear to be light granulations over the sides. In an equatorial section, the rapidly increasing height of the whorls and the strongly arched aspect of the septa can be noted.

Operculina sp. ind. is found with *Nummulites incrassatus* and *N. fabianii* in samples 451, 328, and 329 from the Calcaire à Petites Nummulites.

CYCLOCLYPEINAE BÜTSCHLI, 1880
Heterostegina D'ORBIGNY, 1826
Heterostegina sp. ind.

An incomplete axial section measured 3.0 mm in diameter, and 0.9 mm thick. In tangential sections, the subdivision of the chambers into chamberlets

is occasionally visible. The dimensions and general aspect of the spiral of these specimens fit closely to the description of *Heterostegina helvetica* described by KAUFMANN (1867) from the Upper Eocene Flysch in the Pilatus (Switzerland).

Heterostegina sp. ind. is found in sample 431 with *Discocyclina*, *Nummulites striatus*, *N. incrassatus*, and *Spiroclypeus*.

Spiroclypeus DOUVILLÉ, 1905
Spiroclypeus granulosus BOUSSAC, 1905

In an off-center axial cut, the diameter of the test is 2.8 mm, and the thickness 0.9 mm. The spiral wall is subdivided into irregular chambers. Pillars are clearly visible in the axial section which form granulations on the surface of the test.

Spiroclypeus granulosus occurs in the basal part of the Calcaire à Petites Nummulites with *Nummulites fabianii*, *N. incrassatus* and questionably *N. striatus*. It is present in samples 328 and 431.

ACERVULINIDAE SCHULTZE, 1854
Sphaerogypsina GALLOWAY, 1933
Sphaerogypsina cf. *globulus* (REUSS), 1848

In thin section, the test appears as a mass of semi-rectangular chambers arranged in radiating rows. The specimens from the Calcaire à Petites Nummulites have an average diameter of 1.0 mm and are somewhat smaller than *Ceriopora globulus* REUSS (2 to 4.5 mm). However, in other respects, they fit closely the description of *Gypsina globulus* by HANZAWA (1957).

Sphaerogypsina cf. *globulus* is rather common in the Calcaire à Petites Nummulites. It is found in thin sections 328 C, 329 B, 406 A, 448 A, and 451 C. It is associated with *Nummulites striatus*, *N. fabianii*, *N. incrassatus*, *Discocyclina* and *Asterocyclina*.

CYMBALOPORIDAE CUSHMAN, 1927
Halkyardia HERON-ALLEN and EARLAND, 1918
Halkyardia minima (LIEBUS), 1911
(Plate I, figure 4)

The oblique axial section in figure 4 (slide 329) illustrates the relationship of the dorsal lamellar cover, radial central chambers, and the umbilical plug. The maximum diameter of the test is 0.8 mm and the height 0.48 mm. These forms agree exactly with the type description of *Cymbalopora radiata* var. *minima* LIEBUS, 1911.

Halkyardia minima is found in the Calcaire à Petites Nummulites with *Nummulites incrassatus*, *N. fabianii* in slides 329 and 451 A, and with *Globorotalia cerro-azulensis* in slide 419 B.

HOMOTREMATIDAE CUSHMAN, 1927
HOMOTREMATINAE CUSHMAN, 1927
Sporadotrema HICKSON, 1911
Sporadotrema cf. *cylindricum* (CARTER), 1880
(Plate III, figure 5)

One fairly complete specimen of this species is found in slide 250 A (figure 5). This section, which is near vertical, illustrates the coarsely pitted nature of the wall. The pits are in communication with the chambers by means of fine pores. The inner wall doubles forming the septa. Dimensions of the specimen shown in figure 5, are as follows : height, 2.8 mm ; width, 1.7 mm ; thickness outer wall, 0.13 mm ; thickness inner wall, 0.033 mm ; thickness of septa, 0.066 mm.

The illustrated specimen is considerably smaller than *Polytrema cylindricum* CARTER, and is only slightly smaller in size and with thinner walls than the specimens described by HANZAWA (1957) ; HANZAWA describes his *Sporadotrema* cf. *cylindricum* (CARTER) from the Metansa limestone (Upper Eocene) of Micronesia.

Sporadotrema occurs in slides 250 A, B and C, commonly with Nummulites.

DISCOCYCLINIDAE GALLOWAY, 1928
Discocyclina GÜMBEL, 1870
Discocyclina cf. *discus* (RÜTIMEYER), 1850

This species has a large flattened test, the maximum measured diameter being 16.0 mm and the thickness, 1.1 mm (in slide 431 C). The embryonic chambers are bilocular, very large, and flattened. In axial section the lateral chamber wall appears very thick in relation to the height of the chamber, and the chambers are distinctly offset from one layer to the next. The principal dimensions are given on figure 7.

Although the type description of *Orbitolites discus* RÜTIMEYER does not include precise data on the internal structure, these specimens from the Calcaire à Petites Nummulites are very similar to *Discocyclina discus* described by NEUMANN (1958). Rarely, pillars are visible in the axial sections and these forms have been grouped with *Discocyclina* cf. *discus*. However, it is possible that the forms with pillars represent a distinct species.

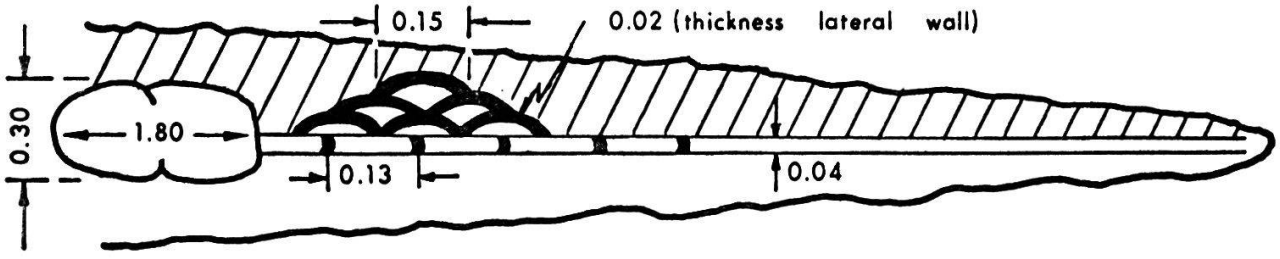


Fig. 7. — Dimensions of internal structure *(Lepidocyclina)* ; dimensions in mm.

Discocyclina cf. *discus* is found with *Discocyclina* cf. *chudeaui*, *Asterocyclina*, *Nummulites incrassatus*, *N. striatus*, and *N. fabianii* (see for example slides 431 and 328).

Discocyclina cf. *chudeaui* (SCHLUMBERGER), 1903
(Plate III, figure 3)

The specimen illustrated in figure 3 is 2.1 mm in diameter and 0.9 mm thick. It is not precisely a central cut, hence the true diameter is somewhat larger. The lateral chambers are arranged in radiating rows and increase regularly in size from the center towards the surface of the test. Near the surface, the size of the lateral chambers averages 0.025 mm by 0.06 mm. The walls of the lateral chambers are relatively thin compared to the height. The equatorial chambers measure 0.03 mm high near the center of the test, increase in height towards the periphery and become rectangular to slightly rounded in outline.

The specimens in slides 431 A and D, are smaller than the type specimens described by SCHLUMBERGER *(Orthophragmina chudeaui)*. However the axial section (figure 3) corresponds closely with the type material figured by SCHLUMBERGER (ref. NEUMANN, 1958). *Discocyclina* cf. *chudeaui* is found in the Calcaire à Petites Nummulites with *Discocyclina* cf. *discus*, *Asterocyclina*, *Nummulites incrassatus*, *N. fabianii*, and *N. striatus*.

Asterocyclina GÜMBEL, 1870
Asterocyclina sp. ind.

At least one species of *Asterocyclina* is found in slides 431 A, B, C, and D. Very little can be said concerning the size of the test as the apparent dimensions vary with the orientation of the section. The lateral chambers are arranged in radiating rows and the chamber wall is relatively thick. The pillars form heavy granulations on the surface of the test. No specific determination is possible.

Asterocyclina sp. ind. occurs with *Discocyclina*, *Nummulites incrassatus*, *N. fabianii* and *N. striatus* in the Calcaire à Petites Nummulites.

SEDIMENTATION

A geologic section through the Tertiary basin has been constructed by attempting to replace the measured stratigraphic sections (I through VIII) in their original positions during the time of deposition. This section, A-B, is illustrated by plate IV. The intermediate lithology has been sketched in between the sections. The calculated distance from section I to section VIII is 27 km.

To the northwest (position A on plate IV), tectonic instability of the foreland initiated minor fluctuations in the strandline which, in turn, are reflected in the number and variety of sedimentary facies in this direction (northwest).

The various facies (numbers 1 through 6 on the cross section) are discussed below :

1) Starting at the base of the Eocene transgression there was an initial phase of clastic deposition (poorly sorted, polygenic detritus in a carbonate matrix) probably in a littoral environment. No marine fauna is found in these sediments.

2) The black sapropelic shales and anthracite represent a change in the sedimentary environment, with entrapment of stagnant brackish water perhaps in coastal swamp areas. Euxenic conditions prevail. Brackish or fresh water fauna of gastropods and small pelecypods.

2) The thick conglomeratic series indicates a strong elevation of the source area and erosion of the Urgonien limestones. Simultaneous water borne transportation of coarse detritus and deposition along a subsiding shoreline. Still in shallow water environment with rate of fill and subsidence in equilibrium. Very *rare* occurrence of first marine fauna.

4) Period of quiescence, indicating a change in the source area, and also a brackish to very shallow marine environment along a low coast. Muddy carbonate deposition perhaps over tidal flats within shallow embayments. Contain rich marine fauna.

5) The massive Nummulitic limestones indicate a marked transgressive impulse over the region. At the same time, the shoreline was displaced to the northwest. Shallow water shelf conditions prevail supporting a rich fauna of foraminifera, algae, pelecypoda, echinoides and other bottom dwelling organisms. Carbonate deposition in clear, warm, freely circulated sea water, probably not in excess of 80 m deep. Biostromal type deposits common, whereas no true reef structures are known. Some disseminated quartz sand grains still transported by tidal or long-shore currents into this region. Wave and current action on bottom caused abrasion and re-working of organic remains. The fetid odor of some of these limestones indicates periods of more restricted water circulation.

6) The environment was generally similar to that outlined in facies 5, but probably occurred in a slightly more basinward position. The water was somewhat deeper indicating a continued subsidence. Sediments are mostly micro-crystalline carbonate ooze. This facies is characterized by the presence of erosional debris within the limestone section. These debris indicate a probable sub-sea fault scarp with accompanying landslides and talus deposits. This type of deposit has been called "chaotic breccia" by LONGWELL (1951). It seems likely that the breccia had its origin to the northwest on the Massif des Aiguilles Rouges.

Following the cross-section from A southeastwards towards B, the relationship of the various facies and their thicknesses can be followed. Generally

speaking, the southeast area reflects a more static environment. Rock facies in the stratigraphic section are less varied and more persistant than to the northwest.

The facies characteristic of the internal region are :

1) Carbonate sedimentation with conglomeratic intervals is restricted to the basal transgressive series. A marked reduction in the amount of the coarse clastic deposition is apparent.

2) Shelf type limestone and shale deposition followed. The limestone is characterized by large benthonic foraminifera and the shale by pelagic forms. This indicates a gradual increase of water depth with a static marine type environment.

3) The Flysch series which was measured in the more internal sections (nos. IV to VIII) indicates a distinct change in sedimentation. Generally speaking, the Flysch shales seem characteristic of marine deposition probably in an euxenic, semi-barred basin. Wave action was negligible, however, weak current action has resulted in faint bedding of the clastic layers. Two features of the Flysch are in striking contrast with Nummulitic beds. They are :
   a) Absence of a marine fauna which again is indicative of a semi-restricted, poorly aereated basin with a low oxidation potential over the sea floor.
   b) Substantial accumulations of sandstone and micro-breccia are restricted to Flysch deposits. It seems likely that the origin of these sands are related to turbidity flows. These flows were triggered when the equilibrium of water saturated, loosely packed sediments was upset. Submarine slumps or earthquakes characteristic of unstable tectonic environments could easily produce such a reaction.

The deposition of the Flysch marks the end of the Alpine orthogeosyncline. It represents the final phase of Tertiary sedimentation over the area now folded into Nappe de Morcles. At the same time, the Flysch marks the incipient phase of the orogenic paroxysm during which the Helvetic Nappes were emplaced.

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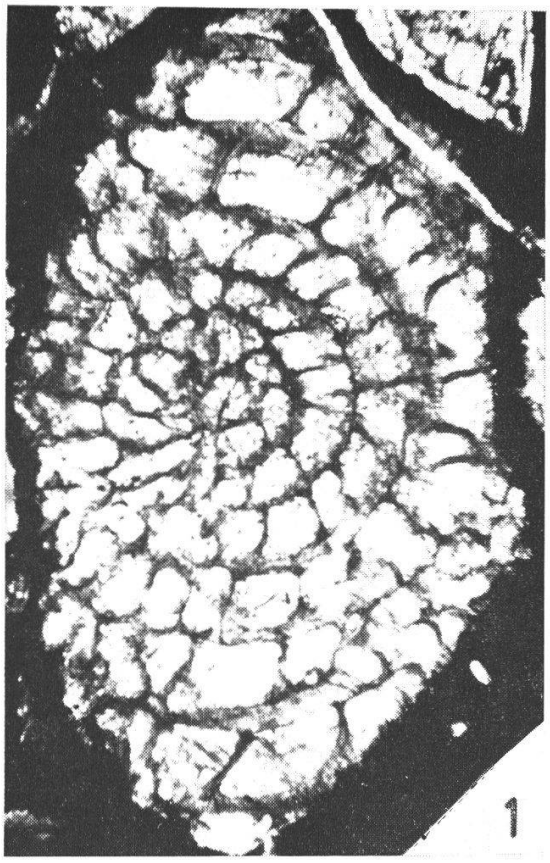
PLATE IV

Corrigendum : Invert the figured values of vertical scale and horizontal scale.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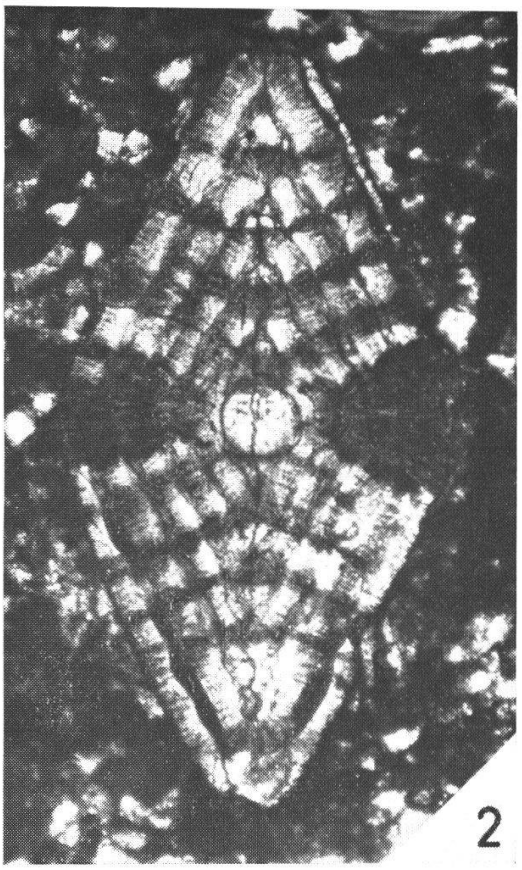
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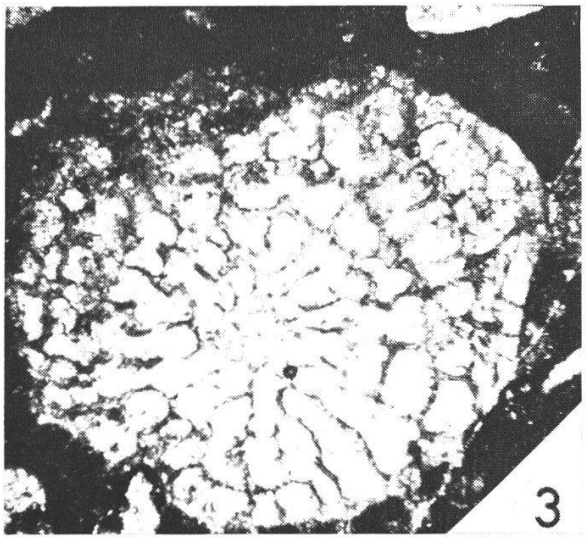
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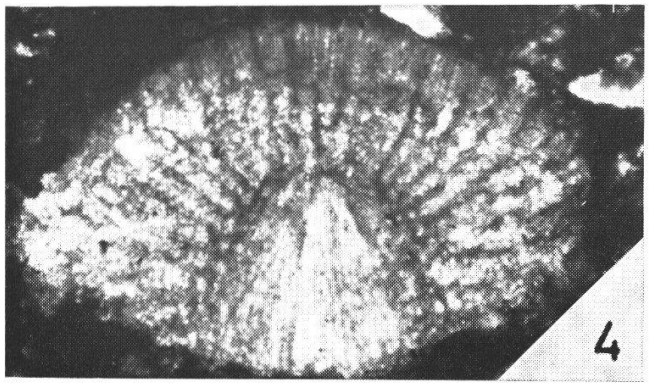
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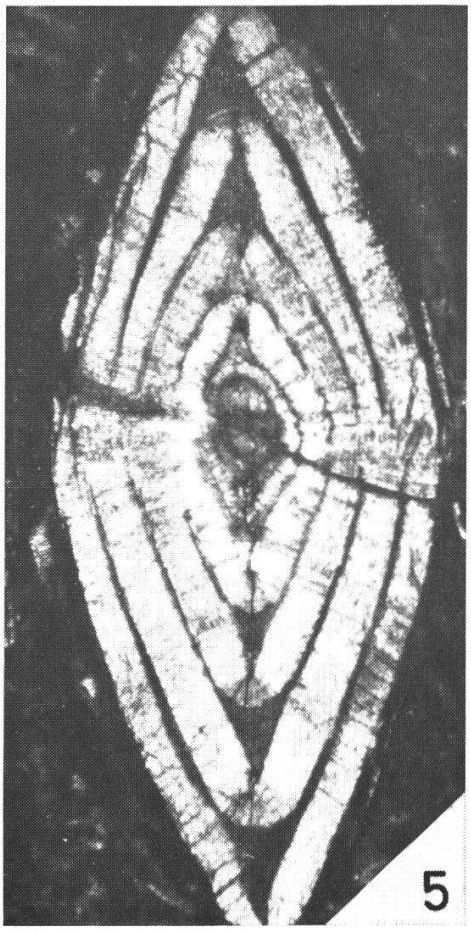
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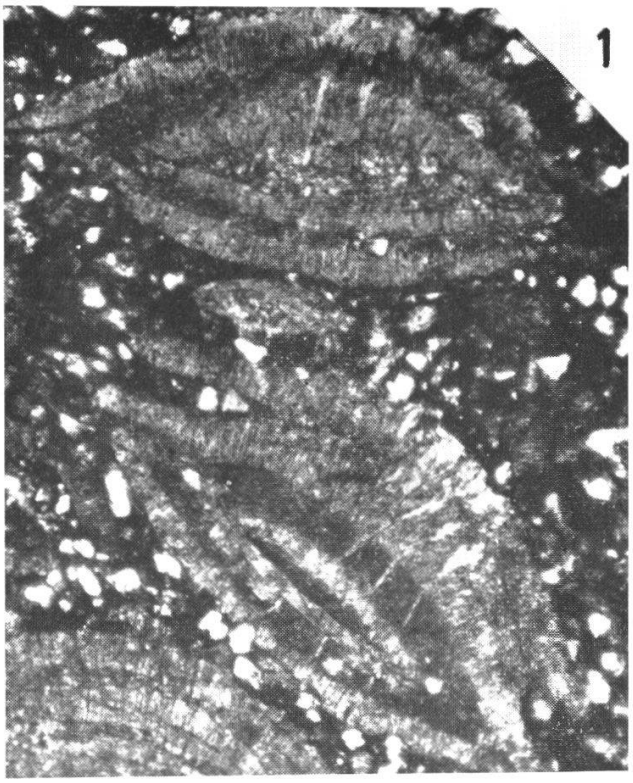
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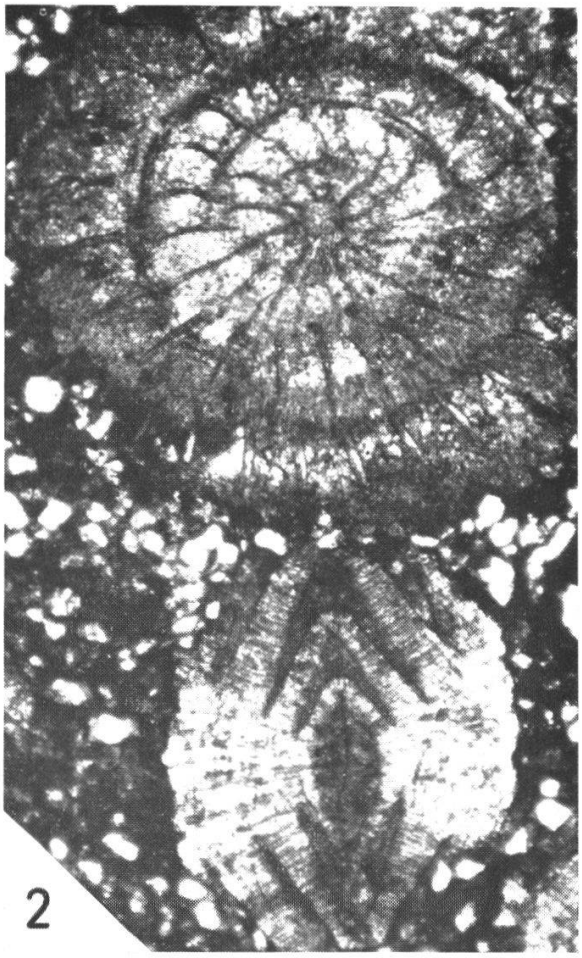
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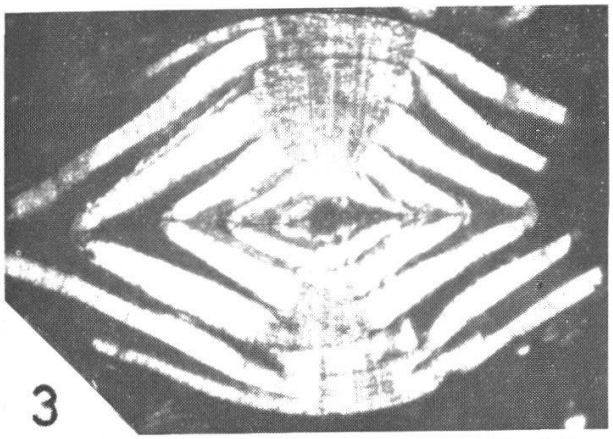
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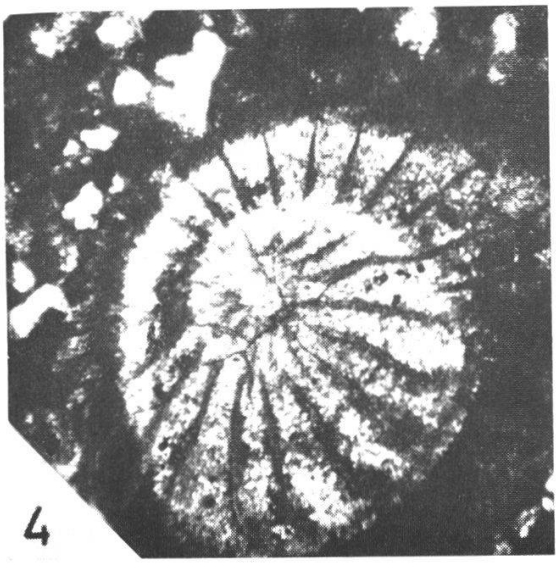
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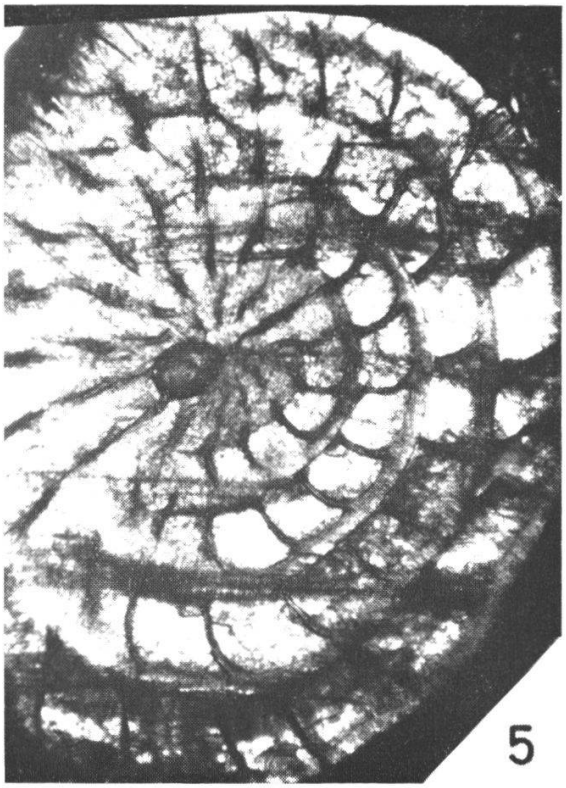
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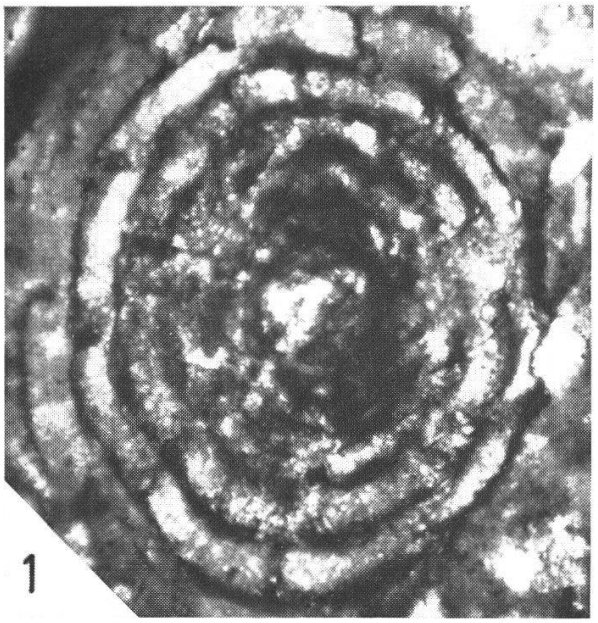
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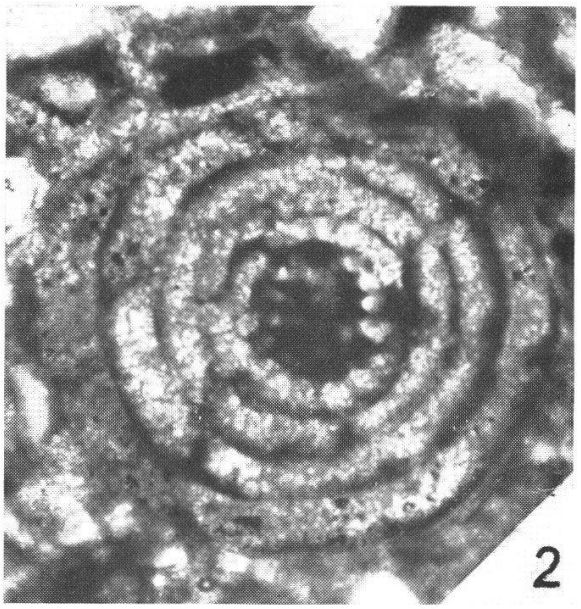
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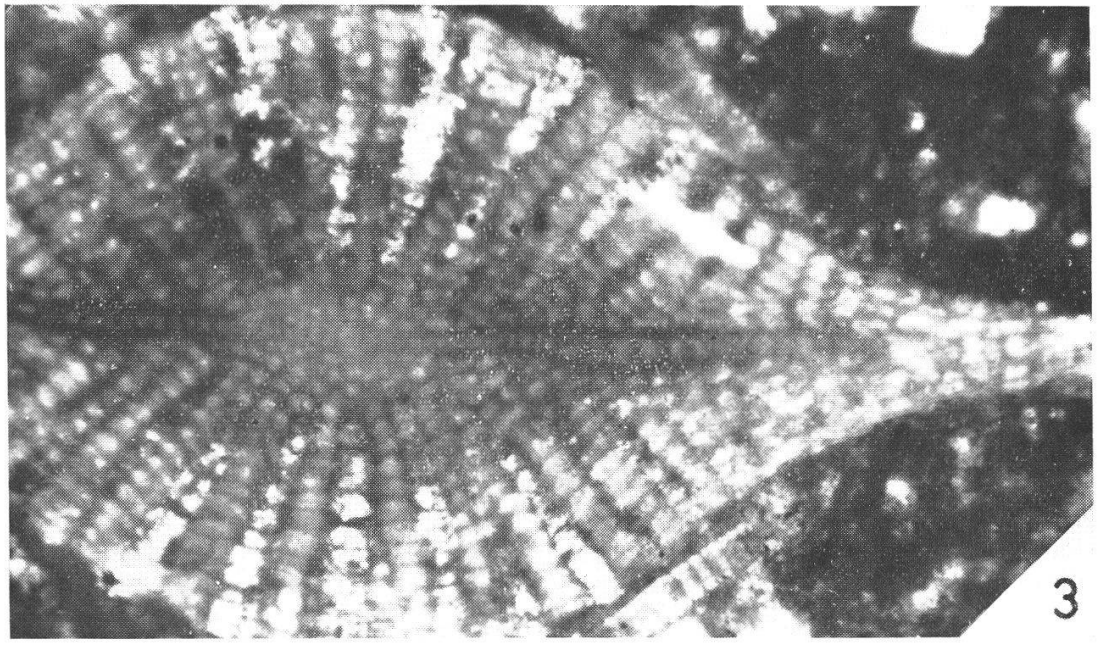
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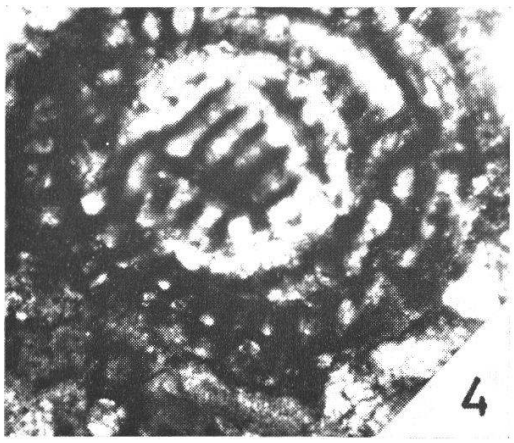
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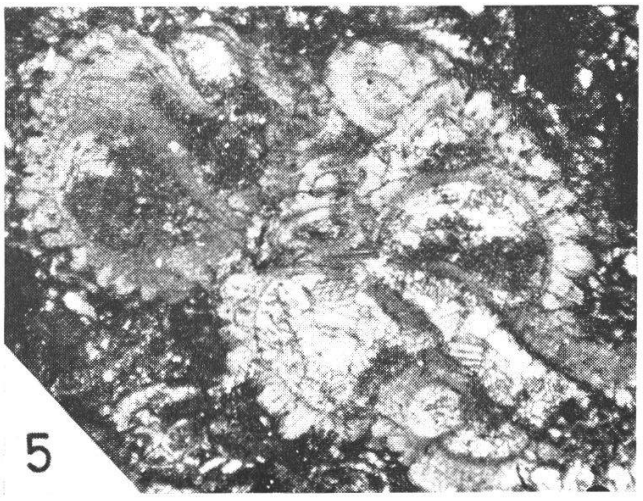
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reconstructed section through nummulitic basin showing relative position of stratigraphic sections