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The Jurassic sequence of the Niesen nappe in the region of Le Sépey-La Forclaz (Switzerland): witness of the Piemont rifting in the Helvetic paleogeographic domain

by

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The Dogger *Couches à Posidonies de la Grande Eau* belongs to the front of the Niesen nappe (Western Switzerland). Detailed sedimentological/stratigraphical studies allowed to precise the age and to characterise the depositional environment as well as the petrology of these sediments. The geodynamic context can be related to the Piemont ocean rifting.

This formation was deposited in a deep-sea fan environment. Its base is of Aalenian age and reworked microfossils give a Bathonian age to the top of the formation.

The petrology of the displaced elements, current directions as well as a compilation of data on the Helvetic domain and the Alps in general, helped to reconstruct the paleogeography of the sedimentary sources. These were derived from a major topographic high, interpreted as the rift shoulder of the Helvetic margin. The sediments were deposited south of this rift shoulder in a proximal position.

If we compare the *Couches à Posidonies de la Grande Eau* with the contemporaneous deposits of the Brèche inférieure (Brèche nappe), it seems that these two formations are connected to the same event (the rifting of the Piemont ocean) and were

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laterally continuous in Middle Jurassic times. Their present position on the same cross-section in the western Alps implies a duplication of the Jurassic south European margin through the Cretaceous opening of the Valais domain.

Keywords: Niesen nappe, Dogger, deep-sea fan, Piemont ocean, Alpine Tethys, rift shoulder, Helvetic domain, Brèche nappe.

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Les Couches à Posidonies de la Grande Eau forment le Dogger du front de la nappe du Niesen. Une étude de sédimentologie et de stratigraphie détaillée a été entreprise afin de dater cette formation de manière plus précise, de caractériser l'environnement de déposition ainsi que la pétrologie des sédiments. Le contexte géodynamique peut être rattaché au rifting de l'océan Piémontais.

Cette formation s'est déposée dans un environnement de cône abyssal. Les microfossiles remaniés mais contemporains ont permis de donner un âge bathonien à une partie de la formation; la base étant constituée d'Aalénien.

L'étude de la pétrologie des éléments remaniés, des directions de courants ainsi que la compilation de diverses données sur le domaine Helvétique et les Alpes en général ont permis de reconstituer la paléogéographie de la source du détritisme, et d'établir que cette source constituait un haut-fond séparant le «rim basin» (ou bassin frangeant) Helvétique de l'océan Piémontais, haut-fond que nous interprétons comme l'épaulement de la marge Helvétique. Ces sédiments se sont déposés au sud de cet épaulement dans la partie proximale de la marge.

En comparant les Couches à Posidonies de la Grande Eau avec les dépôts contemporains de la Brèche inférieure (nappe de la Brèche), il semble que ces deux formations soient liées au même événement (le rifting de l'océan Piémontais) et se trouvaient en continuité latérale au Jurassique. Au vu de leur position actuelle sur une même transversale alpine, ceci implique une duplication de la marge sud-européenne jurassique due à l'ouverture du domaine Valaisan.

Mots clés: nappe du Niesen, Dogger, cône abyssal, océan Piémontais, Téthys Alpine, épaulement de rift, domaine Helvétique, nappe de la Brèche.

1. Introduction

The Niesen nappe is a Penninic nappe only found in the Swiss Prealps. It is oriented SW-NE and delimits a 50 km by 15 km area on the geological map. Tectonically, this nappe is overlapping the Lenk nappe (Lempicka Münch 1996) and is overthrusted by the «zone submédiane» to the NW (Fig. 1). The Niesen nappe is mainly composed by a thick Maastrichtian to Lutetian detritic serie (400 m-1300 m) called the Niesen Flysch (Ackermann 1986).

The pre-Cretaceous tectonic history can be understood looking at the rocks found at the base of the Niesen Flysch, and presenting a clear stratigraphic contact with the flysch. The Le Sépey-La Forclaz region (canton de Vaud) in the Prealps, contains in the core of the Niesen nappe front, a Dogger detritic formation called the *Couches à Posidonies de la Grande Eau* (Lugeon 1938,

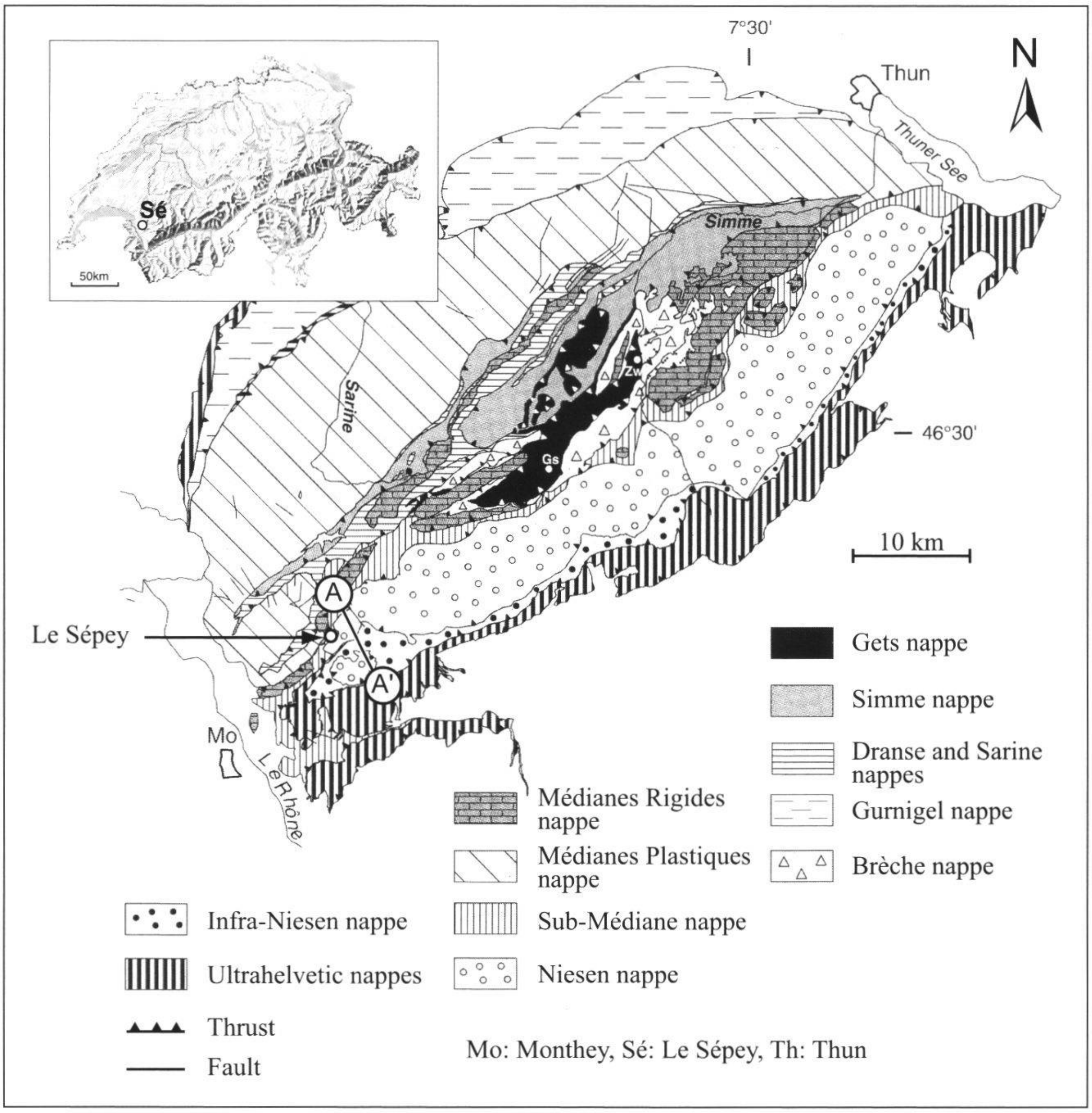

Figure 1a.–Geographical situation and Prealps general geological map modified from BILL (1998).

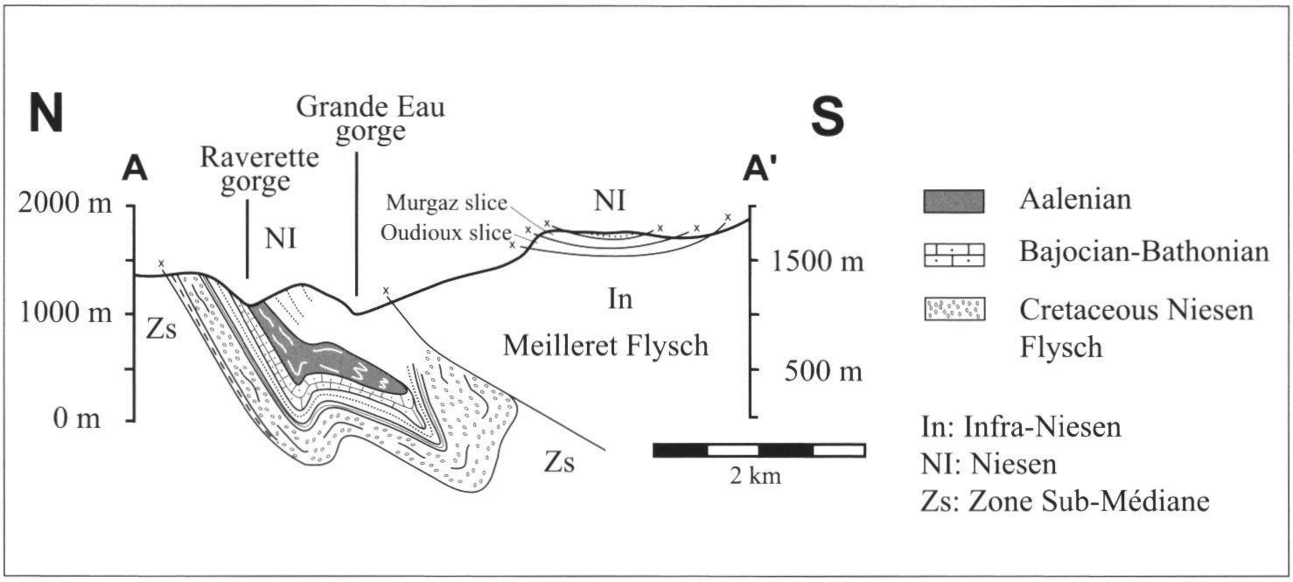

Figure 1b.–Cross-section of the Niesen nappe in the studied area (see fig. 1a for location).

BADOUX and HOMEWOOD 1978) and is in clear stratigraphic contact with the Cretaceous Niesen Flysch (Fig. 2). The main outcrop is located ESE of Le Sépey (map 1:25'000 n° 1265, Les Mosses) along Le Sépey-Les Diablerets main road. The eastern and western coordinates of the presented log (Fig. 3) are: 571'300/ 134'400 and 571'625/134'550 respectively. The formation is part of the Murgaz tectonic slice in which some series show the Cretaceous Flysch overlapping directly on the Triassic or on the Malm (MACCONNELL 1951). The pre-Flysch basement of the Niesen nappe also contains lower and upper Cretaceous series in some places (ACKERMANN 1986).

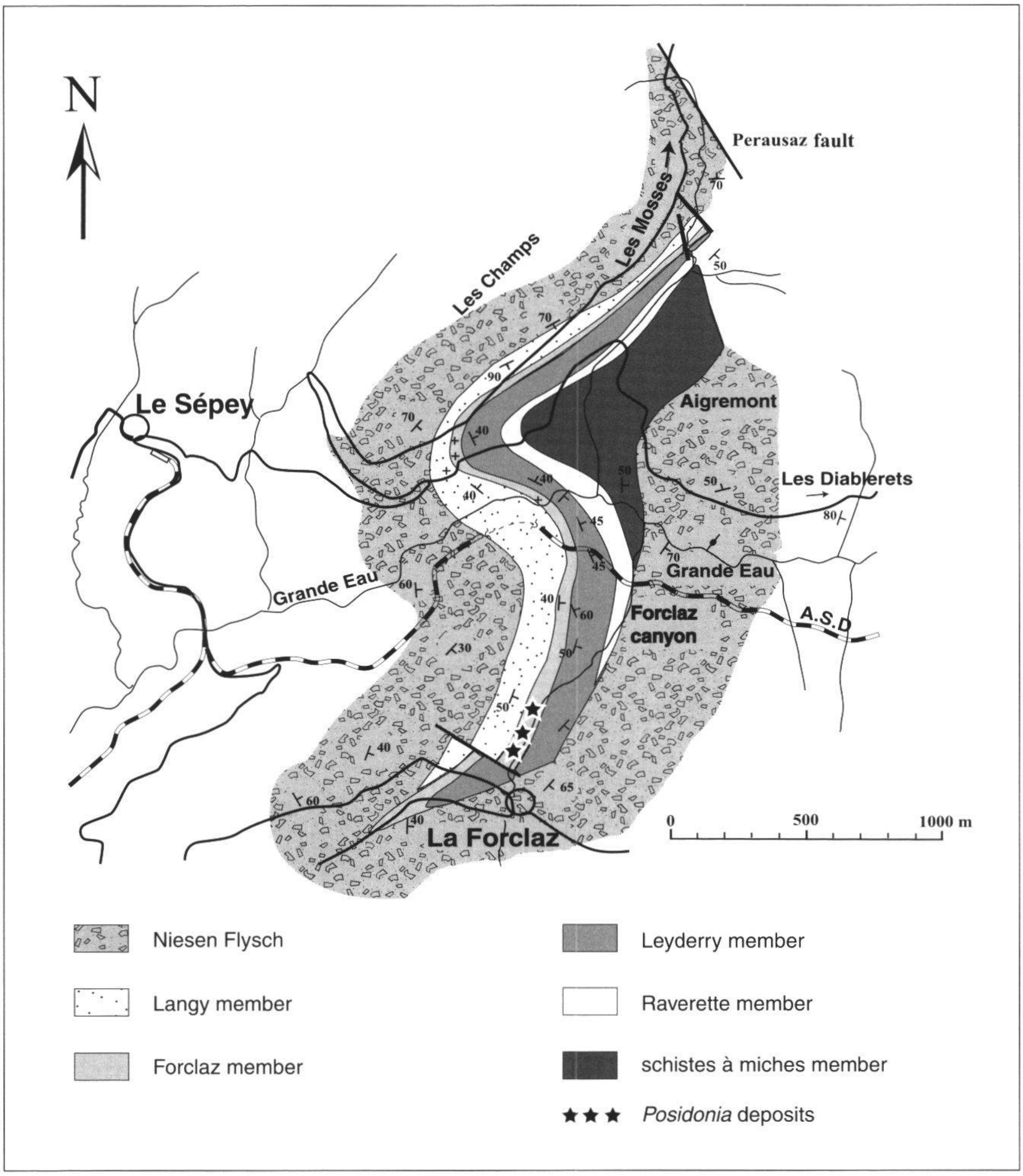

Figure 2.–Geological map modified from BADOUX and HOMEWOOD (1978).

2. Stratigraphy and lithology

The studied formation has been divided into 6 members («Schistes à Miches», «Grès et marnes de la Raverette», «Conglomérats du Leyderry», «Grès de passage», «Marnes et calcaires du torrent de La Forclaz», «Grès de Langy») by Badoux and Homewood in 1978. For the purpose of this paper we have adopted the following nomenclature for the formation and included members (Fig. 3):

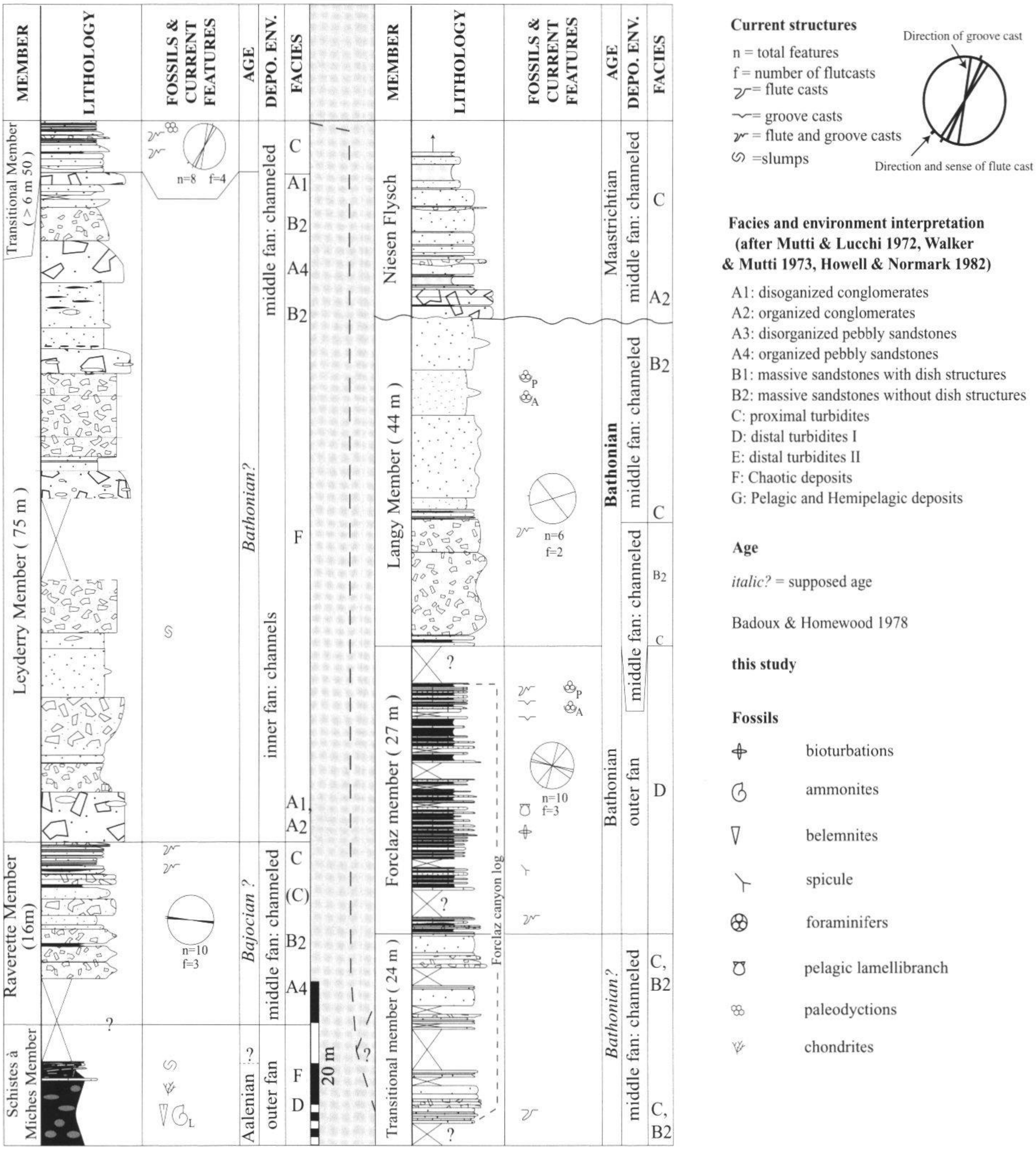

Figure 3.–Synthetic log of the Grande Eau Formation.

The *Couches à Posidonies de la Grande Eau* becomes the *Grande Eau formation* divided in 6 members:

– Raverette member
– Leyderry member
– Grès de Passage member
– Forclaz member
– Langy member

The «Schistes à Miches» is not considered as a member of the formation but as the base of the formation, it is in fact a characteristic facies of the «Zone des Cols» that can be found in many places.

2.1. *Lithological description and age determination*

2.1.1. *«Schistes à miches» member (Aalenian)*

It consists of black clays full of micas containing calcareous, cherty and pyritic concretions that gave sometimes ammonites and belemnites. HOMEWOOD and BADOUX (1978) have found a specimen of *Leioceras* giving an Aalenian age to the formation.

At the top of the series, one can find a 2 m chaotic level with a matrix similar to the rest of the «Schiste à Miches» and containing segmented beds of micaceous sandstones. It is interpreted as a mudflow or a slump.

The transition to the Raverette member is unexposed, but prior to the slump, there is a calcareous and micaceous polygenic bed of sandstone with chondrites that resembles the Raverette member. Therefore, the transition seems to be progressive and there is no reason to put a tectonic contact between those two members.

2.1.2. *Raverette member (Bajocian?)*

This member, which is 16 m thick along the Sépey-Diablerets road and around 40 m in the Grande Eau gorge, is composed at its base by calcareous microconglomeratic metric massflows with millimetric to centimetric elements, separed by thin layers of micaceous marls and calcareous sandstones. Going up in the series, the size and granulometry of the beds become finer, Tab Bouma (Bouma turbidites classification can be found in BOUMA 1962) sequences and graded beddings occur. We often found incorporated ductile clasts forming extensive lenses due to compaction.

In the matrix, all clasts are represented by: quartz (very often polycristalline), feldspars, black limestones with spicules (plate 1) and dolomite, there are two dominant size groups of clast ranging from mm to cm. The cement is dolomitic, probably of secondary origin.

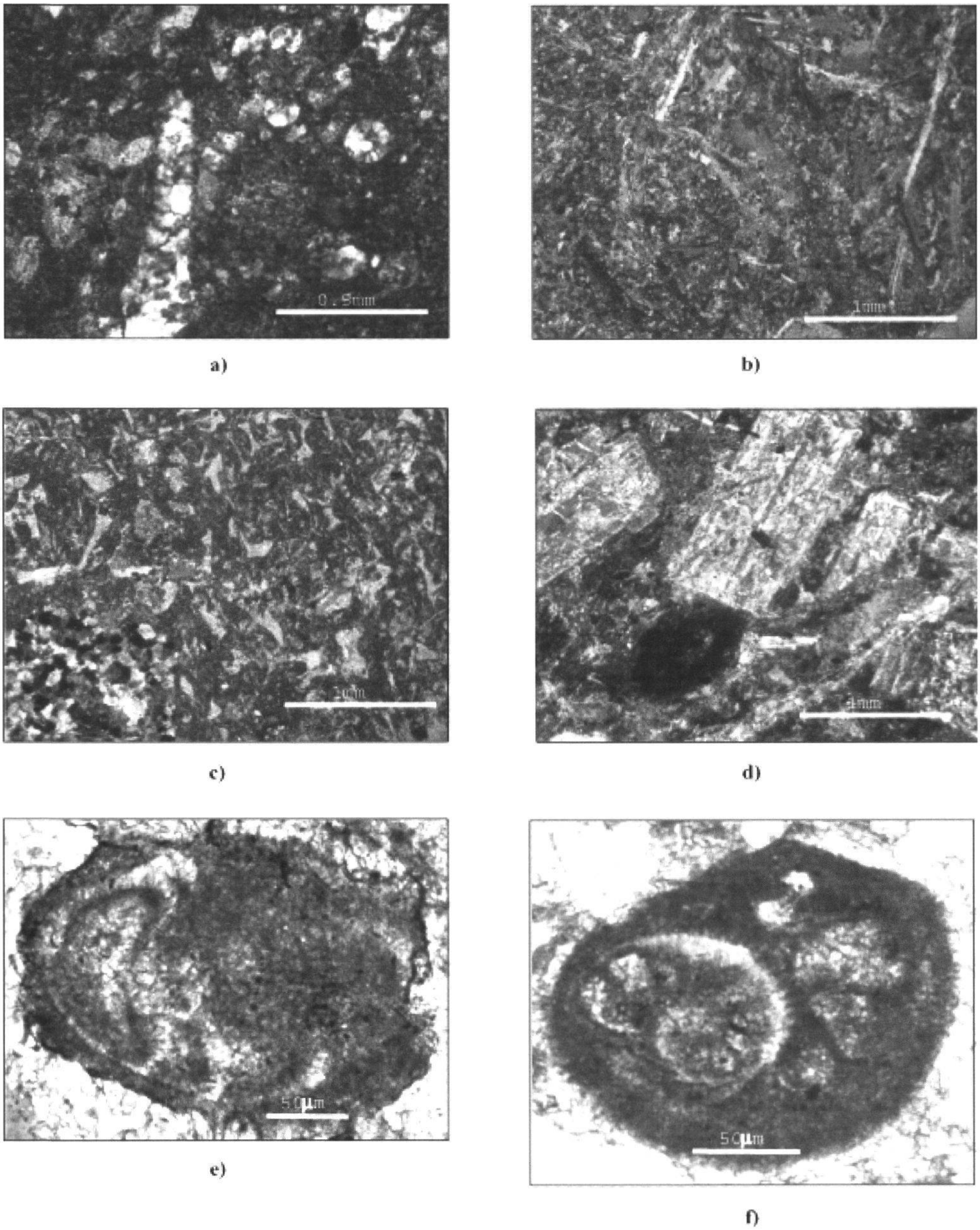

Plate 1.–Thin-sections of some clasts and characteristics foraminiferas found in the Grande Eau Formation.
a) Liassic black limestones with silicified spicules found in the Raverette member;
b) dolerite fragment found in the Leyderry member;
c) welded tuff fragment found in the Leyderry member;
d) dacite fragment found in the Leyderry member;
e) *Archeosepta platierensis* found in the Langy member;
f) *Protopeneroplis striata* found in the Langy member.

2.1.3. *Leyderry member (Bathonian?)*
These polygenic conglomerates are 50 m thick along the Sépey-Diablerets road and less than 25 m in the Grande Eau gorge. They have no internal structures (disorganized conglomerates) and elements are decimetric. The main elements are dolomites, gneiss, quartzites, black limestones, rhyodacites, dolerites, rhyolites, green sandstones, volcanoclastic rocks and green rocks of probable metamorphic origin. The calcareous gritty matrix looks like the Raverette member but we can find contemporaneous resedimented ooliths from the base to the top of the member.

Based on an analogy with the findings of LEMPICKA MÜNCH (1996) on the Infra-Niesen Fm, in which ooliths are of Bathonian age, we assumed that ooliths described herein are also of Bathonian age. Therefore, a Bajocian age is assumed for the underlying Raverette member, in which no ooliths are found.

2.1.4. *Grès de Passage member (Bathonian?)*
This member forms the transition between the Leyderry and the Forclaz members. It is around 6 m thick on the Sépey-Diablerets road and 26 m in La Forclaz gorge. It is formed by metric and decimetric calcareous turbidites, which consist of quartz, feldspars and many micritic clasts containing echinodermic fragments, spicules, foraminifers (*Lenticulina*, *Trocholina* and *Syphovalvulina*) and ooliths with quartz and feldspar cores. As in the Raverette member, the granulometry of the beds become finer and their thickness decreases upward. Tabd Bouma sequences can be identified.

2.1.5. *Forclaz member (Bathonian)*
Good outcrops of this member are only found in La Forclaz stream (map 1:25'000 n°1285, Les Diablerets, geographic coordinates: 571'600/133'325 to 571'775/133'650). It is 30 to 50 m thick and composed of turbiditic sandy limestones which alternate with marls. The proportion sand/marls is 1:1 and Tabc sequences are present. The detritic elements point to a more basinal environment than for the other members: limestones with little quartz, feldspars and white micas but a lot of spicules, recrystallized echinoderms, *Lenticulina*, *Nodosoaria* and little or no resedimented platform fragments. Marls interbeds are sometimes full of *Posidonia bronni* or *bositra* and ichnofossil imprints. HOMEWOOD and BADOUX (1978) found *Protopeneroplis striata* (WEYNSCHENK) and *Archeosepta platierensis* (WERNLI) which indicate a Bathonian age. The transition to the Langy member is gradual, the bed thickness and the detritic fraction increase upward.

2.1.6. *Langy member (Bathonian)*

The base and the middle part of this member consist of decimetric beds of coarse calcareous sandstones and argillaceous intercalations. The rest is made of metric to decametric grain flows of coarse calcareous sandstones and calcareous microconglomerates without intercalations. The elements are quartz and feldspars and contain up to 30% of limestone clasts, mainly ooliths with quartz and feldspar cores but also echinodermic fragments and foraminifera (*Protopeneroplis striata* and *Archeosepta platierensis*) which indicate a Bathonian age. In the microconglomerates, the detritic fragments are very diversified: gneiss, quartzites, dolomites, black limestones, volcanoclastic rocks and some rhyolites.

Plate 1 shows thin sections of clasts and two important foraminiferas (*Protopeneroplis striata* and *Archeosepta platierensis*). Identification was confirmed by M. Septfontaine from the Geological Museum in Lausanne.

3. Sedimentological interpretation

The depositional environment interpretation has been defined according to the models of Mutti and Lucchi (1972), Walker and Mutti (1973) and Howell and Normark (1982) based on a description of the turbiditic facies and their classification. Seven facies ($A_{1,4}$; $B_{1,2}$; C; D; E; F; G) have been defined according to the above classification and are reported and explained on Figure 3. As shown on Figure 4, each member characterises a given area in a deep-sea fan environment.

3.1. *«Schistes à Miches»*

These clays have been deposited in an anoxic environment above the CCD. they can be interpreted as resulting from the dissolution of the emerging Triassic and Liassic platforms in Toarcian time (Stampfli 1993). The top of the series is characterized by some turbiditic events and slumping of the upper beds, marking the onset of coarser detritic activity.

3.2. *Raverette member*

The detritic event initiated at the top of the «Schistes à Miches» became more important with the deposition of decacentimetric to metric massflow (facies A4 and B2) and turbidites (facies C). The transition from B2 to C indicates a thining- and fining-upward sequence which is typical of a middle fan (channeled suprafan from Walker and Mutti 1973). This implies the installation of a deep-sea fan.

3.3. *Leyderry member*

This member comprises conglomerates of A1 facies, a chaotic slump of F facies that can be interpreted as the infill of an inner fan channel. At the top, thickness and grain size decrease, and graded bedded pebbly sandstones can be found (facies A4). This progessive removal of the sediments source could be explained by a relative highstand which could correspond with the main Bathonian highstand (HAQ *et al.* 1986). This trend of thining and fining upward continued until the deposition of La Forclaz member, which are almost basinal.

3.4. *Grès de Passage member*

The classical turbidites (facies C) of this member shows a lot of graded bedding and current features. We also have found *Paleodyction* traces which characterize a deep environment (around 2000 m) and the member shows a thining- and fining-upward sequence. All those elements allow the Grès de Passage Member to be placed in the channeled suprafan.

3.5. *Forclaz member*

Here, distal turbidites alternate with hemipelagic marly intercalations (facies D). This implies a suprafan depositional lobe position. Actually, the important calcareous proportion, the low detritic fraction and the absence of platform resediments show clearly that this member is more distal. This fits well with the Bathonian highstand which could have completely drowned the source of influx. At the top, turbidites become more sandy and less calcareous before the transition to the Langy member which comprises a lot of platform resediments.

3.6. *Langy member*

The base and the middle part is formed by classical turbidites (facies C). The rest are massive grain flows (facies B2) with no clay. This member could be placed in the channeled suprafan.

3.7. *Current features*

As shown in figure 3 the main current features are N-S and E-W, the sense is from NNE to SSW or from E to W. Regarding the general situation of the Helvetic margin, we assume that NNE-SSE is the main direction of influx and the E-W directions are due to the channeling dispersal.

3.8. *Source stratigraphy*

The petrological study of the clasts allows the following stratigraphy for the source area to be proposed:

Bathonian: carbonate platform
Liassic: black limestones with spicules
Triassic: dolomitic, calcareous and white quartzites
Permo-Carboniferous: volcanic (rhyolites, rhyodacite, dolérite, welded tuff), green sandstones
Pre-alpine basement: gneiss fragments

4. Discussion

The Grande Eau Formation has been sedimented in a deep-sea fan environment (Fig. 4).

The erosion of layers from basement to Dogger show that the source of detrital influx was a submarine rise which has been uplifted for a long time before being colonized by a Bathonian platform. Furthermore, the reworked elements of this platform (echinoderms fragments, ooliths, foraminiferas) can

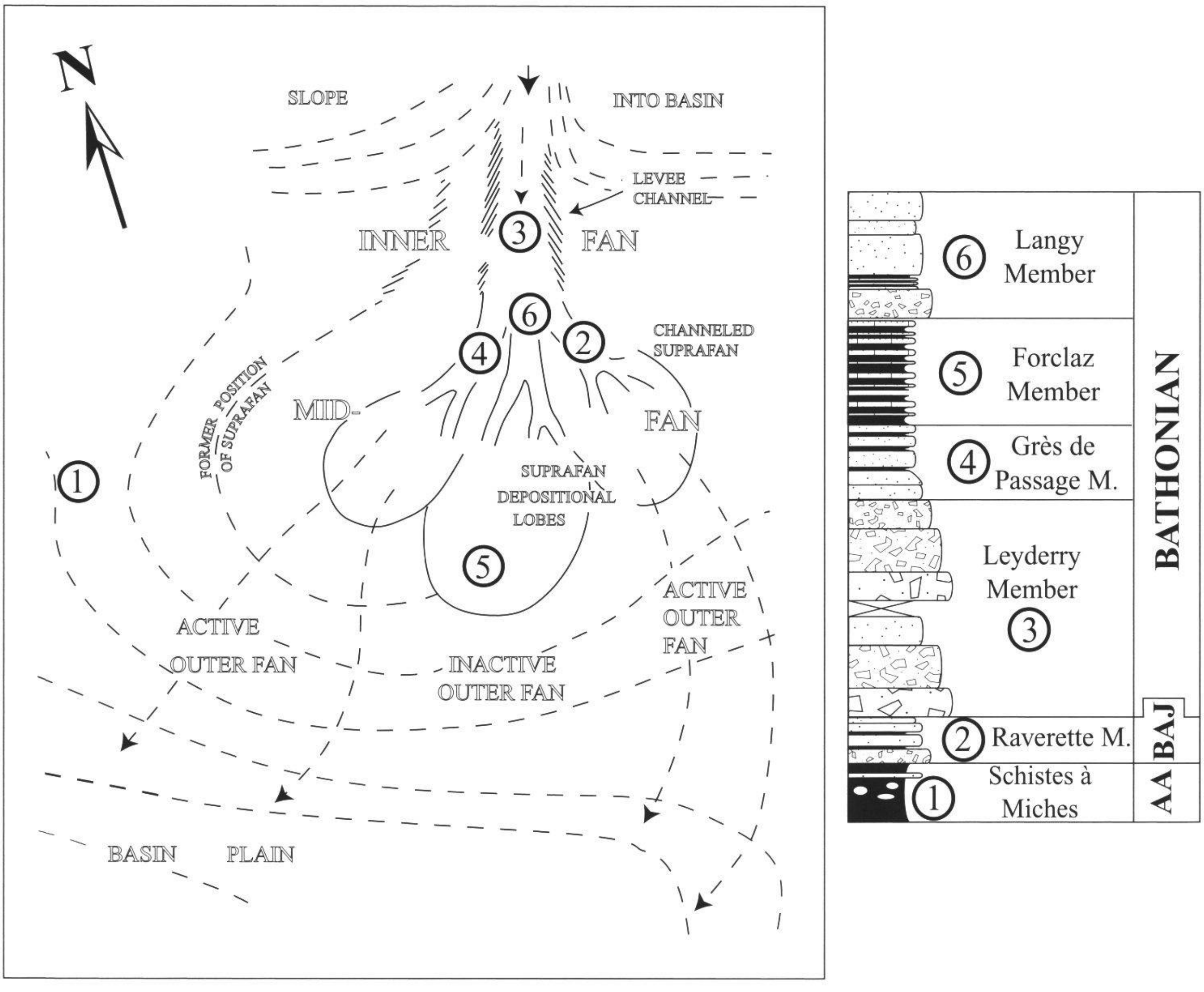

Figure 4.–Interpretation of the depositional environments (modified from Walker and Mutti 1973).

be found in the Grande Eau formation and in the Infra-Niesen domain (Lenk nappe, LEMPICKA MÜNCH 1996). The stratigraphy of the Lenk nappe (Blaue Schüpfe and Mulkerblatten series) shows 20-50 m of fine argillaceous sandstones (Bajocian), 30-60 m of sandy limestones (Bathonian) with 3 m of microconglomerate at the top. Therefore, the submarine rise separated two distinct environments, a shallow one to the north represented by the Infra-Niesen with some detritic and organogenic influx and another one, much deeper to the south, represented by the Grande Eau Formation. Therefore this submarine rise can be considered as the separation between the Helvetic rim basin domain to the north and a south facing rifted margin, and interpreted as the Helvetic rift shoulder.

As seen above, the Bathonian of the Grande Eau formation ends with microconglomerates, then an erosional surface takes place (probably submerged, H. Masson oral communication) followed by Oxfordian shales. The Callovian starvation is more likely due to the final drowning of the rift shoulder following important thermal subsidence. The Oxfordian shales corresponding then to the distal progradation of the Helvetic shelf. However starvation would perdure as the larger part of the progradation was trapped in the rim basin and the shelf edge never reached the rift shoulder area.

5. JURASSIC PALEOGEOGRAPHY OF THE HELVETIC DOMAIN

The reconstruction of the Helvetic margin in Jurassic time is conditioned by extensional tectonic due to the rifting of the Alpine Tethys. This rifting is composed of two distinct phases: first, a late Triassic-early Liassic transtensive phase affecting a large area with an extentional factor of 1.03-1.25 (STAMPFLI *et al.* 1998). This phase is already well developed in Liassic times, defining distinct sedimentation domains characterised by submarine rises and basins development in the Helvetics and South Helvetics (Ultrahelvetic tectonic unit) domains (e.g. «Lias des Mines», «Lias d'Oudioux», «Lias de Murgaz» for the Ultrahelvetics, HOMEWOOD 1974), furthermore, microbreccias reworking Triassic material are found in the Sinemurian of Murgaz (MACCONNELL 1951). During the second phase the constraints affected a more limited area where the final break up took place. Asymmetric rifting at upper crustal level defines an upper plate flexural margin and a lower plate tilted blocks margin. The European Helvetic margin is interpreted as a lower plate margin with tilted blocks. Laterally, in the Briançonnais domain, this lower plate margin becomes an upper plate (STAMPFLI and MARCHANT 1997). In our model (FRISCH 1979, STAMPFLI 1993) the Briançonnais domain was not located to the south of the Helvetic margin in Jurassic times, but was the lateral continuation of this margin westward.

Figures 5 and 6 show an Oxfordian reconstruction and a zoom on the Helvetic zone modified after STAMPFLI *et al.* (1998). The Helvetic rim basin is represented with its main faults delimiting distinct sub-basins (Morcles, supernappes of Wildhorn and Ultrahelvetic) and the Helvetic rift shoulder characterised by an uplift in Late Liassic-Dogger times (this paper). The faults position is constrained by stratigraphical and tectonic data (BURKHARD and SOMMARUGA 1998, WILDI *et al.* 1989, PFIFFNER *et al.* 1997, TRÜMPY 1980). The eastern end of the basin has been determined taking into account the following facts:

–The Jurassic sediments thickness decreases towards the east

–Between the Bohemian massif and the Tauern gneiss there is no real equivalent of the Helvetic rim basin (e.g. GWINNER 1971, TOLLMANN 1985). This implies a change in the extensional pattern between west and east during the Piemont rifting, probably due to crustal thickness and pre-rift inherited rheology.

–The zone affected by the transtensive phase of rifting is bordered to the NW by a longitudinal structure emerged during Liassic and Dogger times situated between the Souabe basin to the north and the Helvetic domain to the south (Alemanic land of TRÜMPY 1980), this zone can be extended toward the Aiguilles Rouges massif. This structure could be due to unroofing along major border faults of the rift which can lead to an uplift of 10-15% of the footwall (JACKSON and MCKENZIE 1983).

The paleogeographical position of the Niesen nappe is constrained by:

Its Lower Penninic structural position in the Alps; this nappe comes from a transition zone between a basinal area (Piemont ocean) and the Helvetic platform (rim basin).

As seen above the Grande Eau Formation has been deposited south of a major submarine rise interpreted as the Helvetic part of the Alpine Tethys rift shoulder. The continuation of this shoulder to the East could be represented by the lower Penninic nappes of Verampio and Antigorio (SPRING *et al.* 1992).

In France (Moûtiers unit) the Quermoz zone (Permian, middle Liassic, Jurassic Brèches du Grand-Fond and Cretaceous Flysch) is considered as equivalent to the Niesen nappe (HOMEWOOD *et al.* 1984, ACKERMANN 1986). These two units were in lateral continuity between the Cretaceous «Cordillère Tarine» and the Helvetic rift shoulder within the Piemont margin until their differential incorporation in the Alpine accretionary prism (ACKERMANN 1986).

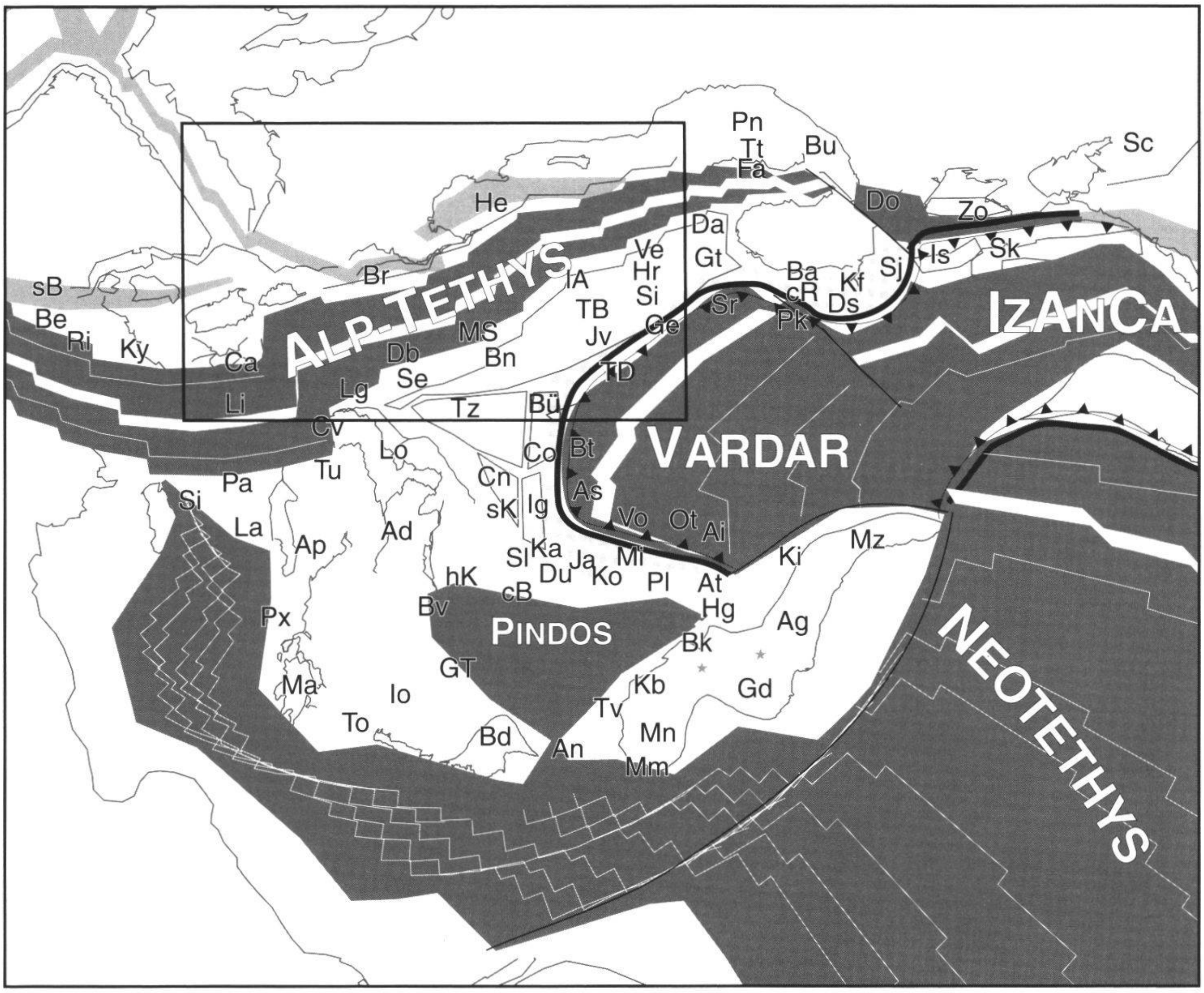

Figure 5.–Plate tectonics scheme of the western Tethyan region in Late Oxfordian (modified from STAMPFLI and BOREL (2001). Rectangle shows the location of Figure 6.

Ad, Adria s.str.; Ag, Aladag; Ai, Argolis ophiolites; An, Antalya; Ap, Apulia s.str.; As, Apuseni-south, ophiolites; At, Attika; Ba, Balkanides, external; Bd, Beydaghlari; Be, Betic; Bk, Bolkardag; Bn, Bernina; Br, Briançonnais; Bt, Bator-Szarvasko ophiolites; Bu, Bucovinian; Bü, Bükk; Bv, Budva; Ca, Calabride; cB, central Bosnia; Cn, Carnic-Julian; Co, Codru; cR, circum-Rhodope; Cv, Canavese; Da, Dacides; Db, Dent Blanche; Do, Dobrogea; Ds, Drimos ophiolites; Du, Durmitor; Fa, Fatric; Gd, Geydag; Ge, Gemeric; GT, Gavrovo-Tripolitza; Gt, Getic; He, Helvetic rim basin; Hg, Huglu; hK, high karst; Hr, Hronicum; IA, Izmir-Ankara ocean; Ig, Igal trough; Io, Ionian; Is, Istanbul; Ja, Jadar; Jv, Juvavic; Ka, Kalnic; Kb, Karaburun; Kf, Kotel flysch; Ki, Kirshehir; Ko, Korab; Ky, Kabylies; La, Lagonegro; Lg, Ligerian; Li, Ligurian; Lo, Lombardian; Ma, Mani; Mi, Mirdita autochton; Mm, Mamonia accretionary complex; Mn, Menderes; MS, Margna-Sella; Mz, Munzur dag; Ot, Othrys-Evia ophiolites; Pa, Panormides; Pk, Paikon intra oceanic arc; Pl, Pelagonian ; Pn, Pienniny rift; Px, Paxi; Ri, Rif; sB, sub-Betic rim basin; Sc, Scythian platform; Se, Sesia (western Austroalpine); Si, Sicanian; Sj, Strandja; Sk, Sakarya; sK, south-Karawanken fore arc; Sl, Slavonia; Sr, Severin ophiolites; TB, Tirolic-Bavaric; TD, Trans-Danubian; To, Talea Ori; Tt, Tatric; Tu, Tuscan ; Tv, Tavas+Tavas seamount; Tz, Tizia; Ve, Veporic;Vo, Vourinos (Pindos) ophiolites; Zo, Zonguldak.

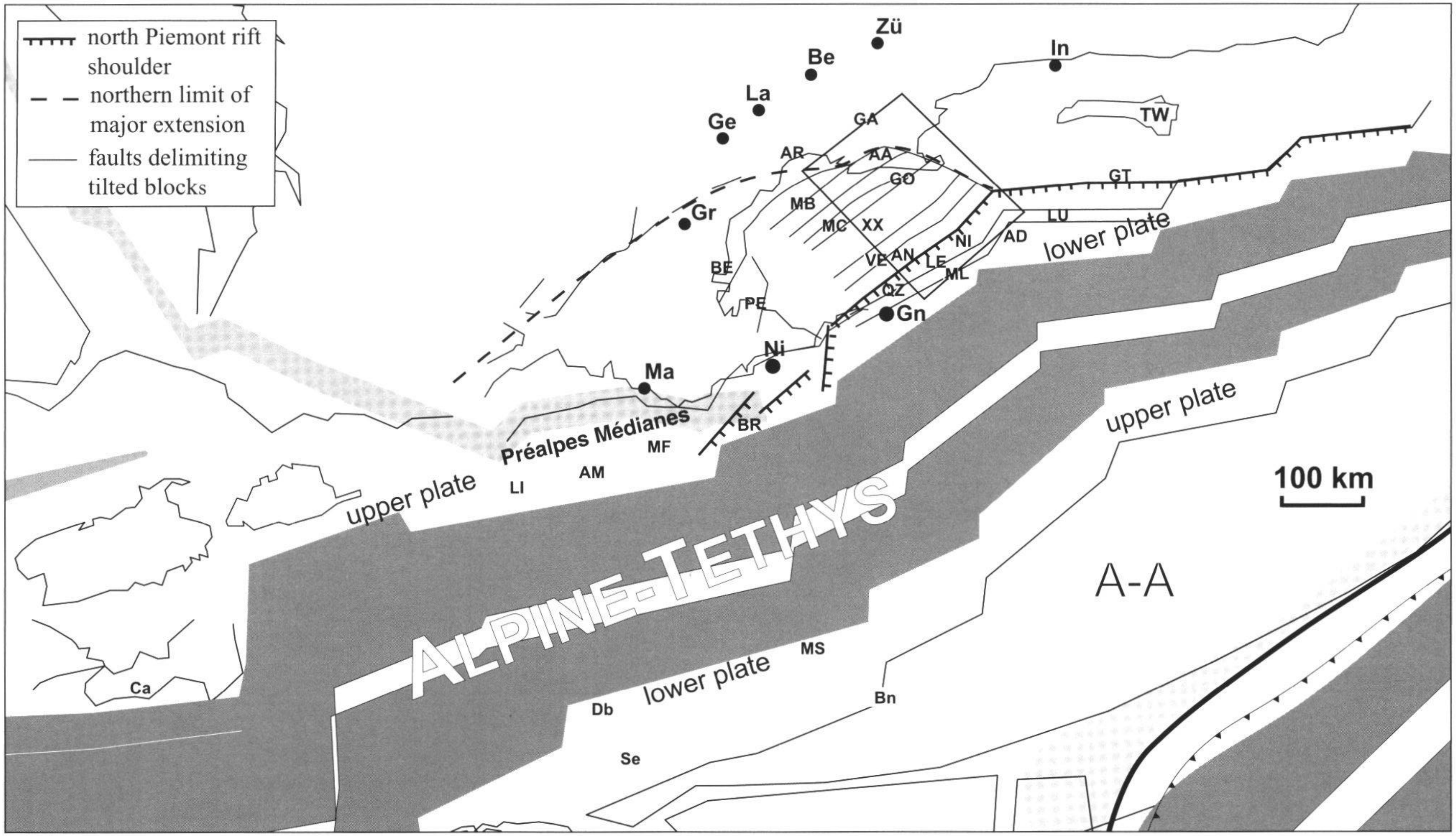

Figure 6.–Reconstruction of the north Piemont margin in Oxfordian times including Helvetic rim basin, Médianes rim basin, Piemont ocean and Austro-alpine margin (modified from STAMPFLI and BOREL 2001). Rectangle shows location of Figure 7.
Be-Berne, Ge-Geneva, Gn-Genova, Gr-Grenoble, In-Innsbruck, La-Lausanne,Ma-Marseille, Ni-Nice, Zü-Zürich
A-A-Austro-Alpine terrane, AA-Aar, AD-Adula, AM-Ambin, AN-Antigorio, AR-Aiguilles Rouges, BE-Belledone, Bn-Bernina, BR-Brèche, Ca-Calabre, DB-Dent-Blanche, GA-Gastern, GO-Gothard, GT-Tauern Gneiss, LE-Lebendum, LI-Briançonnais ligure, LU-Lucomagno, MB-Mont Blanc, MS-Margna-Sella, MC-Mont Chétif, MF-Mont-Fort, ML-Monte Leone, NI-Niesen, PE-Pelvoux, QZ-Quermoz, Se-Sesia, TW-Tauern Window, VE-Verampio, XX-basement recognized on seismic data (PFIFFNER *et al.* 1997).

6. Geodynamics of the Helvetic margin

We saw that in Liassic time, distinct sedimentation areas are present in the Helvetic s.l. domain (Fig. 7). Then, extension is going on in Toarcian and Aalenian to create the Helvetic rim basin. At the same time, subsidence curves (Stampfli 2000) show a thermal uplift whose paroxysm is placed in Late Toarcian. The two phenomena have to be taken into account to explain the shoulder uplift. One is the classical thermal uplift due to asthenospheric diapirism, the other is related to the movement along the major shoulder border fault («Niesen fault») which has a throw in the range of 2-3 kilometers (presence of Paleodyction traces in a deep-sea fan environment) and induced important unroofing. The consequences of this uplift are:

–The emersion of a carbonate platform (Liassic and Triassic layers) whose erosion started in Sinemurian times and dissolution gave the material for the Aalenian schists deposits.

–Then the acceleration of uplift of the «Niesen fault» footwall, with the erosion of the whole series from Liassic to basement.

It not easy to quantify this uplift but taking the approximation for unroofing of Jackson and McKenzie (1983) of a 15% fault throw, we can imagine an uplift of at least 200-400 m for the shoulder, confirmed by the thickness of the eroded pre-rift series of the same order of magnitude.

The erosional surface between the Langy member and the Cretaceous Niesen Flysch remains difficult to explain. Some arguments can also be found in the Infra-Niesen and in the other pre-flysch sequences of the Niesen nappe:

As mentioned in the introduction, the pre-Flysch sequences in the Niesen nappe comprise series from basement to upper Cretaceous. Therefore it seems clear that all these series were deposited in the «Niesen basin» and the differential erosion of the sequences is due to a pre-Maastrichtian tectonic event (Lugeon 1938, 1949; Homewood 1974). A pre-Maastrichtian tectonic phase (or event) is quite plausible looking at the geodynamic situation: in Turono-Senonian times, the closure of the Valais trough (Stampfli *et al.* 1998) generated the first movement of inversion in the French external Alps (Devoluy region, Huyges and Mugnier 1995) and major clastic input in Provence (La Ciotat conglomerates, Philip *et al.* 1987), therefore these first inversion movements could also have affected the Helvetic margin before the main Campanian-Maastrichtian inversion, submitting some parts of the pre-Flysch basement to erosion. These first relief could be linked with the «Cordillère Tarine» (Barbier 1948) which represents the inverted parts of the Helvetic rifted margin, source of sediments supply for the upper Cretaceous-lower Tertiary Niesen flysch.

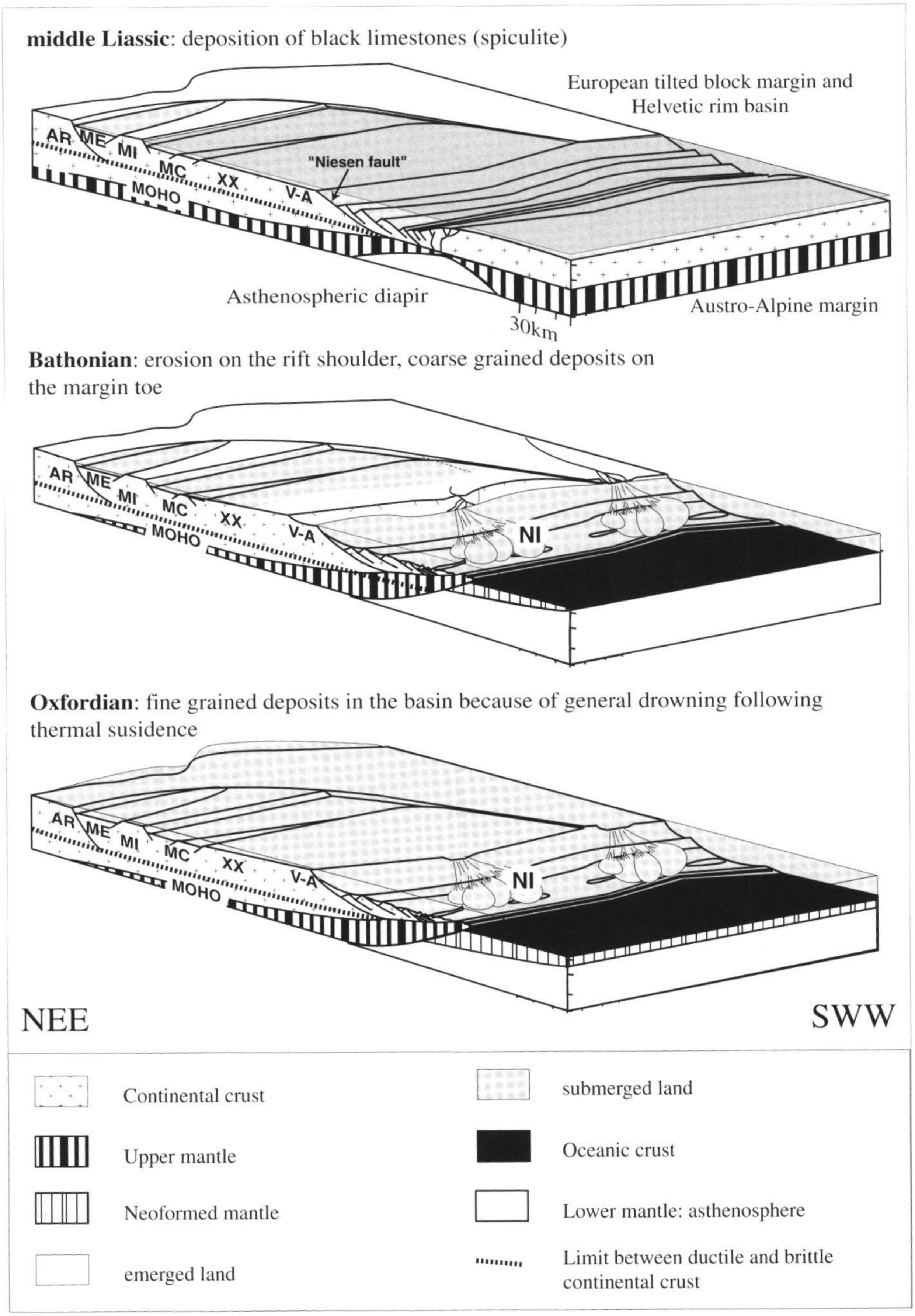

Figure 7.–Block diagrams of the north Piemont margin in Jurassic times.
AR-Aiguilles Rouges, MC-Mont Chétif, ME-Mont-Blanc externe, MI-Mont-Blanc interne, NI-Niesen, V-A-Verampio-Antigorio, VE-Verrucano, XX-Basement recognized on seismic data (PFIFFNER *et al.* 1993).

7. Conclusion

The sedimentological/stratigraphical interpretation allowed the Grande Eau Formation to be replaced in a deep-sea fan environment at the foot of the Helvetic margin, resulting from the erosion of the Helvetic part of the north Piemont rift shoulder. From a geodynamical point of view, the deposition began in a transitional period between the thermal uplift and the thermal subsidence of the Alpine Tethys and continued during this subsidence phase. Inversion processes related to the Pyrenean-Alps system began in the Middle-Late Cretaceous generating local erosion (e.g. pre-flysch sequence of the Niesen nappe), then major movements gave birth to flysch deposits like the Niesen Flysch.

Looking at the age, sedimentation and petrology of the Brèche inférieure, we can observe some common points: first, the Brèche inférieure is Lias-Dogger (Steffen *et al.* 1993) and, furthermore, was deposited in a deep-sea fan environment during the Alpine Tethys rifting, the sediments being the erosional product of the Briançonnais shoulder (Steffen *et al.* 1993). The conclusion is that these two formations were in a lateral continuity during Jurassic times. The present position of these two formations on the same cross-section in the Alps is an argument for the European margin duplication as proposed by Stampfli (1993).

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