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Large scale progressive unconformities in Jurassic strata of the Prealps S of Lake Geneva: Interpretation as synsedimentary inversion structures; Paleotectonic implications

MICHEL SEPTFONTAINE[1]

Key words: Progressive unconformities, inversion, Jurassic, Prealps, paleotectonic

ABSTRACT

For the first time large scale Jurassic synsedimentary structures, interpreted as progressive unconformities between formations, have been recognized in the Préalpes Médianes nappe (Switzerland and France). Angular progressive unconformities up to 115° about an E-W horizontal axis have been recorded in a sedimentary pile of more than 650 m thickness (dated from Toarcian to Portlandian) at several locations. These paleostructures are associated with large scale synsedimentary folding which grew northward along the northern margin of the Briançonnais carbonte platform. This margin is about 120 km long in the Préalpes and is characterised by important sedimentary gaps, angular unconformities and emersions.

As a consequence the classical rift derived tilted blocks interpretation in a distensive "atlantic-type" passive margin setting, can no longer be simply applied to the Briançonnais domain, at least for the Middle to Late Jurassic interval.

A palinspastic reconstruction through the north-Briançonnais margin, constrained by field data (angular unconformities and synsedimentary structures) and sedimentary evolution in space and time, allows a new paleotectonic model to be proposed in a transpressive context.

After a period of rift-related extension during the Liassic, paleofaults were inverted in Toarcian times. Since then contractional movements affected portions of the N-Tethyan margin (during oceanic spreading) probably until the Early Cretaceous.

RESUME

Des discordances progressives à grande échelle ont été reconnues pour la première fois dans le Jurassique de la nappe des Préalpes Médianes. Les affleurements étudiés, au sud du Lac Léman (Suisse et France), présentent des structures tectono-sédimentaires en éventail dont la rotation peut atteindre 115° autour d'un axe horizontal E-W pendant 50 Ma. La série sédimentaire concernée mesure 650 m d'épaisseur entre le Toarcien et le Portlandien.

Sur la base d'arguments géométriques et sédimentologiques on montre que ces paleostructures sont probablement associées à un pli de propagation synsédimentaire qui s'est déplacé vers le nord au cours du Jurassique et du Crétacé inférieur. Ce pli se situe au dessous du rebord externe de la plateforme carbonatée briançonnaise au Dogger. Cette bordure septentrionale s'étend sur 120 km de longueur dans les Préalpes; elle est caractérisée par des lacunes sédimentaires importantes, des discordances angulaires et des émersions.

En conséquence le modèle classique «atlantique» de marge en extension, à blocs basculés sur paléofailles normales listriques, ne peut plus être retenu pour expliquer l'évolution paléotectonique du domaine briançonnais au Jurassique moyen et supérieur. Un nouveau modèle en transpression le long de la marge N-briançonnaise est proposé à partir d'un profil palinspastique et de son évolution tectono-sédimentaire. Après

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une courte période de rifting durant le Lias les paléofailles sont inversées dès le Toarcien. Depuis lors des mouvements de compression ont affecté une grande partie de la marge N-Théthysienne lors de l'expansion océanique jusqu'au Crétacé inférieur.

1. Introduction

1.1 Geographical and geological setting

The Préalpes Médianes nappe is situated south of lake Geneva, in France (Haute-Savoie) and in the Swiss cantons of Valais and Vaud (Fig. 1). This tectonic unit continues to the east in Switzerland to lake Thun. It forms a major part of the main Prealpine chain, following the southern border of the Molasse basin for a length of about 120 km. The geology and tectonics of this complex area are discussed in papers by Badoux & Mercanton (1962), Badoux (1962) and new insights are presented in papers by Mettraux & Mosar (1989), Mosar (1993), Mosar & Borel (1993).

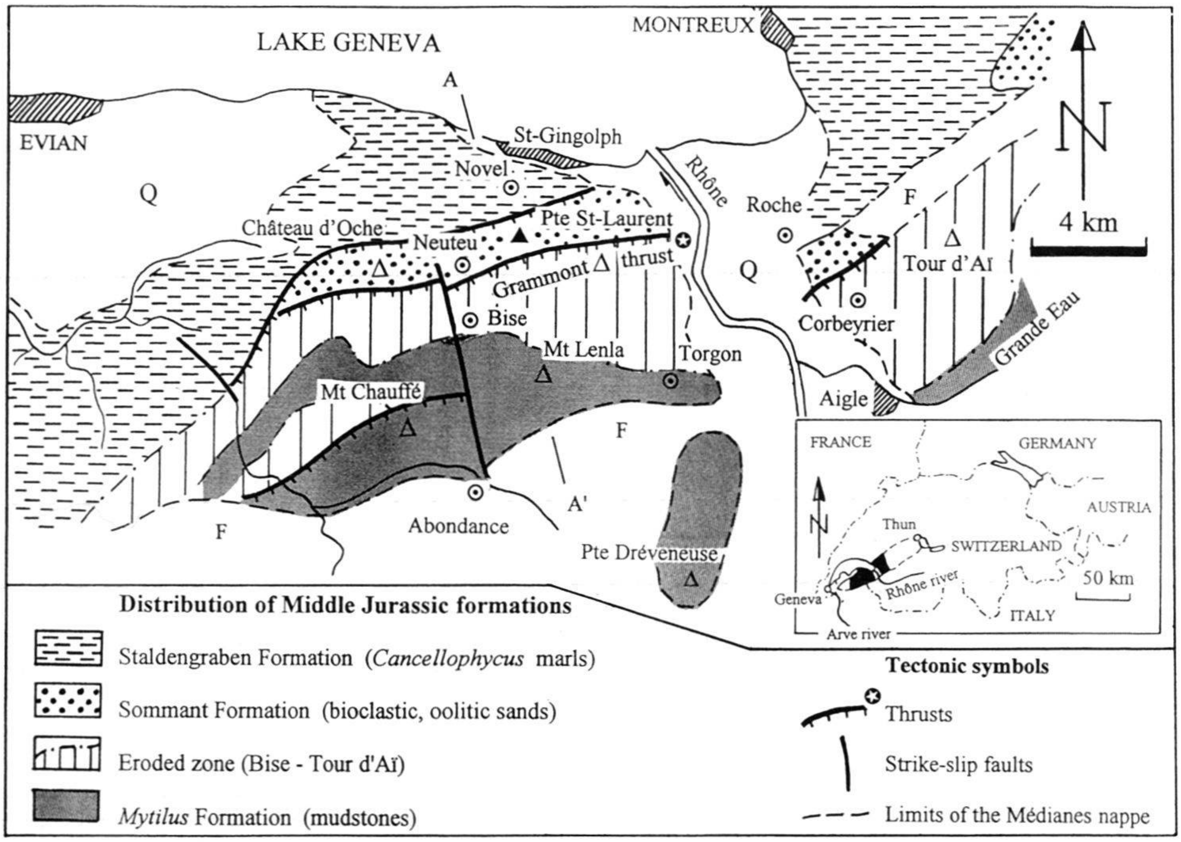

Fig. 1. Tectonic sketch and situation map of the Préalpes Médianes nappe south of lake Geneva. Middle Jurassic formations, representing different carbonate environments, are shown with recent Alpine tectonic lineaments. The northern limit of the platform (N-Briançonnais margin) is represented by the bioclastic sands of the Sommant Formation, bordering the pelagic *Cancellophycus* basin situated to the north. The complete lateral extension of isopic zones is of about 120 km from the Arve valley in the SW to lake Thun in the NE. Q = Quaternary sediments; F = Flysch Simme nappe s.l. (Late Cretaceous). AA' = situation of profile Fig. 2.

The Préalpes Médianes décollement nappe is of Middle Penninic origin, and consists mainly of Mesozoic carbonate rocks. The sediments of this nappe have undergone only very low grade metamorphism and show a relatively regular (paleogeographically coherent) spatial distribution on a surface of about 120 × 16 km, which allows for good correlations of formations for palinspastic reconstructions (Septfontaine 1979 & 1983; Baud & Septfontaine 1980).

1.2 Paleogeography

A carbonate platform developed along the north Briançonnais margin during the Dogger (Fig. 1). A shallow water lagoon to the south (*Mytilus* Formation) was separated from an open marine basin (Staldengraben Formation = *Cancellophycus* beds) by an outer shelf zone of bioclastic/oolitic sand accumulations (Sommant Formation). This last formation marks the northern limit of the N-Briançonnais margin, during Bathonian times.

These carbonate sediments have recorded parts of the history of the Tethyan oceanic opening (Piémontais domain) along the northern margin of the Alpine Tethys passive margin (Briançonnais s.l. domain). Equivalent sediments of the same age are found in the French Alps (Vanoise and Briançon area, Lemoine et al. 1986).

The Préalpes Médianes nappe remained, until the seventies, a poorly understood tectonic unit, especially with regard to the Jurassic and Lower Cretaceous stratigraphy and paleogeography of some complex areas (e.g. the Château d'Oche – Corbeyrier zone). As a consequence a revision of the available geological maps (Thonon-Châtel and Montreux, Badoux 1965) is now necessary to allow further palinspastic and paleogeographic reconstructions.

1.3 A review of paleotectonic interpretations

Formations are characterised by rapid vertical changes of sedimentary facies and abrupt horizontal changes of thicknesses in the Briançonnais realm. These variations were at first interpreted as the result of the migration of erosional and depositional sites (in a context of compressional movements) related to the pervasing growth of "geanticlinal" structures or recumbent Jurassic paleofolds, following the Argand model of embryotectonic (Argand, 1920). At that time no geometrical or sedimentological field arguments could support this interpretation. Following this model Peterhans (1926) interpreted the Briançonnais as a morphology of troughs and submarine swells persistent in a SW-NE direction. Lemoine (1953) has introduced a new insight in the paleogeography of the Briançonnais realm in the French Alps; according to him this contrasted topography could be better explained in terms of horst and graben-like structures. An historical review on this subject was later published by Trümpy (1960), who proposed a model of tilted blocks in a distensive regime for the Briançonnais and the Helvetic realm. Jurassic small-scale extensional features were locally described in the Prealps by Baud & Masson (1975). Later the extensional model was generalized by Alpine geologists all along the N-Tethyan passive margin during the Jurassic; this model was reinforced by our knowledge of the paleotectonic history of the Atlantic passive margin (Graciansky et al. 1979). Kelts (1981) proposed a model of oblique rifting (Gulf of California-type) for the

Briançonnais, in a strike-slip faulting regime, which has initiated a system of pull-apart basins, in an active margin setting.

Septfontaine (1983) stated that the extensional model did not fit field geometrical data between formations during certain critical periods ("Callovo-Oxfordian phase") of the paleotectonic evolution of the Prealpine Briançonnais. The symmetrical truncation of Middle Jurassic formations on both sides of the Bise-Tour d'Aï zone pointed to some kind of large compressive movement that caused the emersion of this zone.

The Jurassic paleotectonic evolution of the Briançonnais domain (in the French Alpes and the Swiss Préalpes) seemed to be definitely settled in a paper by Lemoine et al. (1986): Distensive rifting activity, starting in Early Jurassic times lasted until Early Oxfordian, and was dominated by tilted blocks moving along straight normal paleofaults.

In recent papers the Briançonnais is interpreted as a rift margin associated with a rim basin (Subbriançonnais) to the north in a transtensive regime during Jurassic times (Stampfli & Marthaler 1990; Stampfli 1993).

But without convincing field arguments the question remained: what kind of tectonic constraints (extensional, compressional or both) have controlled, at smaller scale, the sedimentary basin evolution along the Briançonnais passive margin during Jurassic times?

The purpose of the present paper is to show that, based on stratigraphical and geometrical field arguments at different scales, the classical extensional model of rigid blocks limited by normal paleofaults cannot generally explain the paleotectonic evolution of the Briançonnais in the Préalpes, during Middle and Late Jurassic times.

2. Jurassic stratigraphy in the Préalpes Médianes nappe: a new approach of old problems

Misinterpretation of Dogger carbonate formations (below the main Callovo-Oxfordian unconformity no. 4, Fig. 6) considered by many authors to be of Late Jurassic age, has led to confusions for paleogeographic reconstructions. The classic "Malm coralligène" of Peterhans (1926) in the Château d'Oche area is but one example: it was redefined as Sommant Formation and dated Bathonian by means of foraminifera in eastern Chablais (Septfontaine 1983). At a larger scale in the Château-d'Oche-Corbeyrier zone, along the N-Briançonnais margin (Fig. 8), $^2/_3$ of the mapped "Malm" limestones belong to the Sommant Formation of Aalenian to Bathonian age (repartition on Fig. 1) and to the *Mytilus* Formation dated Bajocian to Callovian. The most significant discovery, for paleotectonic reconstitutions, was a major unconformity, with important stratigraphic gaps, below the pelagic (Malm) limestone. This unconformity (4, Fig. 8) was recognised throughout most of the Préalpes Briançonnais (Septfontaine 1983).

The new interpretation presented here is primarily due to progress in several fields of research:

1. Biostratigraphy by means of benthic Jurassic foraminifera (Septfontaine et al. 1991). This group of microfossils is a powerful tool for age determinations and correlations across the three paleogeographic domains (Fig. 1) of the Briançonnais s.l. realm and along the Tethyan margins.
2. Lithostratigraphy and depositional environment interpretations (based on microfacies). This method allowed us to distinguish between formations and members previously included into one cartographic unit or defined by an incorrect chronostratigraphic attribution (geological stage).

3. Sequence stratigraphy using evidence and description of unconformities (angular or parallel) in representative exposures, in order to find original (Jurassic) stratigraphical and geometrical relationships between formations.

3. Key exposures

The exposures discussed below are situated in a narrow tectonic zone of about 1.5 km width (in a N-S direction), but with a large lateral extension (about 120 km) from the Sommant area in the southwest (France) to the Stockhorn at the eastern end of the Préalpes (Switzerland). This zone (Château d'Oche-Corbeyrier zone on Fig. 8) displays a tectonic style of imbricated slices (Fig. 2 to 4) all along the chain (Peterhans 1926; Septfontaine 1983, Fig. 1, 2). It is characterised by important stratigraphic gaps (carbonates of Middle or Late Jurassic age rest stratigraphically on Late Triassic dolomites). The locally preserved Middle Jurassic sediments are mainly bioclastic/oolitic accumulations (Sommant and Vervine Formations) alternating with lagoonal mudstones of the *Mytilus* Formation. This zone is bordered to the south by an important paleofault (Mt Gardy-Grammont paleofault) which is not directly exposed in the field. The position of this Jurassic paleofault is obscured by the main alpine Mt Gardy-Grammont thrust plane and associated imbricated slices (Fig. 1, 2).

3.1 Western cliff of the St Laurent peak

3.1.1 Location and description

The St Laurent peak (summit 550.575; 134.325; alt. 1850 m) shown in profile AA' (Fig. 1, 2) is located near lake Lovenex south of St Gingolph. The St Laurent massif (Fig. 3, 4) is a slightly bent tectonic imbricate above a lower imbricate consisting of the same Early to Late Jurassic carbonate rocks. No major Alpine deformations are visible within the slices.

The St Laurent cliff is mainly N-S oriented, but the southern half shows a NW-SE orientation. In this dihedral (about 30°) the beds have an apparent dip to the south in the southern panel (Fig. 5), although their true dip is to the east.

At the base of the cliff, the Vervine Formation (Aalenian–Bajocian) dips 50° to the north 600 m above the village of Novel (Fig. 2). It is a bioclastic limestone with reworked oolites, crinoïds articles and bryozoans. Dolomitic gravels are conspicuous. Some spicules, cherts and *Cancellophycus* traces point to an open marine deposit. The grainstone beds show slumping figures and tectonic fracturing. A clear angular unconformity (2) of 15° is visible between the Vervine Formation and the Sommant Formation (Fig. 5 a-b).

Above the unconformity (2, Fig. 5, 6), the first beds of the Sommant Formation (Bathonian) show a similar petrographic composition compared to the Vervine Formation, although the oolites become more abundant higher up. The synsedimentary erosional surface 3, visible in oolitic beds (Fig. 5, 6), is important for the interpretation of the direction of paleotectonic constraints. The lower beds are cut by an upper bed with an unconformity of 40°. Some onlaps (affected by rotational movements?) towards the south are also recognisable on top of the thick oolitic bed below the unconformity 3. Some fifty meters

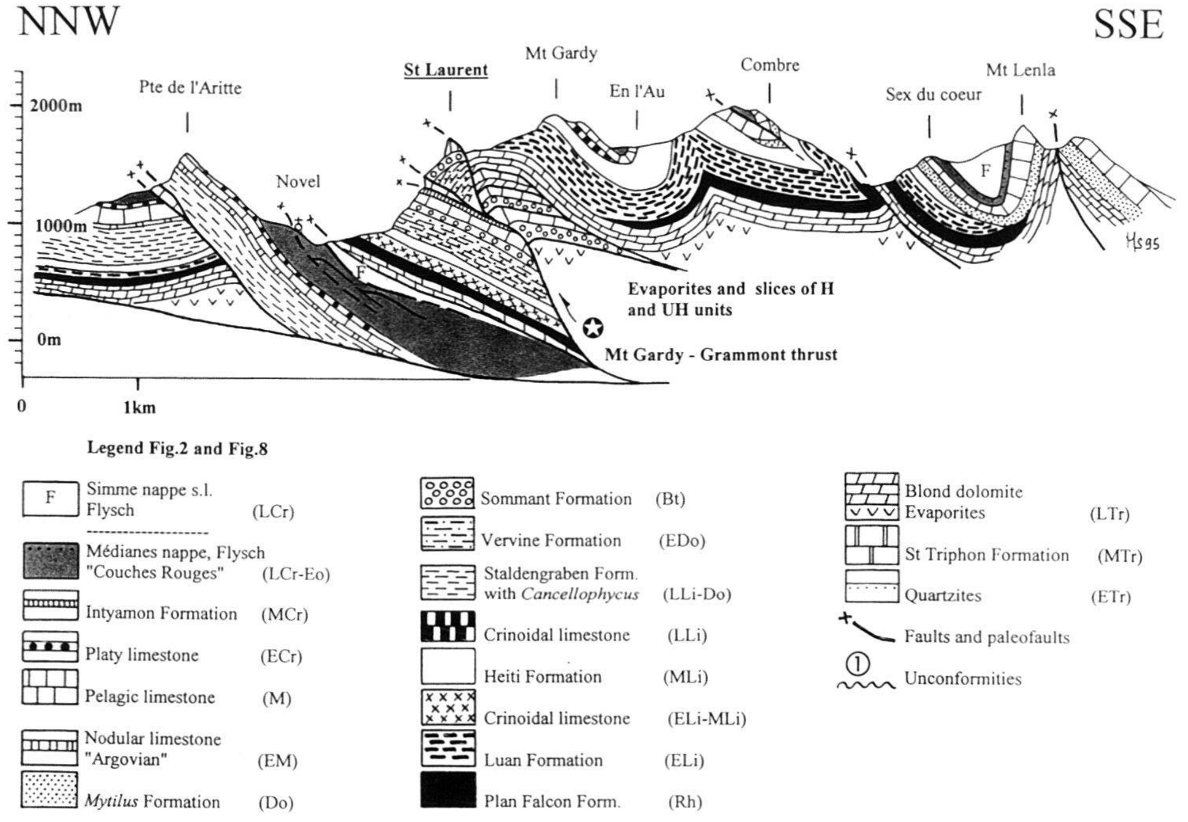

Fig. 2. Geological cross-section of the studied area (AA' profile on Fig. 1). The interpretation at depth is based on investigations in the Château d'Oche-Corbeyrier zone. Eo = Eocene; ECr, MCr, LCr = Early, Middle, Late Cretaceous; M = Malm; EM = Early Malm; Do = Dogger; EDo = Early Dogger; Bt = Bathonian; ELi, MLi, LLi = Early, Middle, Late Liassic; Rh = Rhetian; ETr, MTr, LTr = Early, Middle, Late Triassic. H = Helvetic nappes; UH = Ultrahelvetic nappes.

southward, the unconformity 3 joins with unconformity 2 at a low angle. The oolitic Sommant Formation (80 m thick) above is dated as Bathonian by means of foraminifera (*Archaeosepta* and Pfenderinids). Parallel bedding is visible between unconformities 3 and 4 (Fig. 5); beds onlap to the south on the eroded surface of unconformity 2.

The contact between the Sommant Formation and the pelagic limestone is marked by a parallel erosional unconformity (4, Fig. 5). Above the unconformity, the Malm limestone shows a progressive "fan shaped" unconformity of 35° around a SW-NE striking axis, and a dip towards the SE. The total maximum thickness of the pelagic limestone is 80 m.

3.1.2 Interpretation

The structural relationships between bedding surfaces and unconformities are the result of interactions between paleotectonic movements and eustacy. Together with sedimentation rate variations, thermal subsidence and uplift they are responsible of the complex geometry observed between the sedimentary bodies.

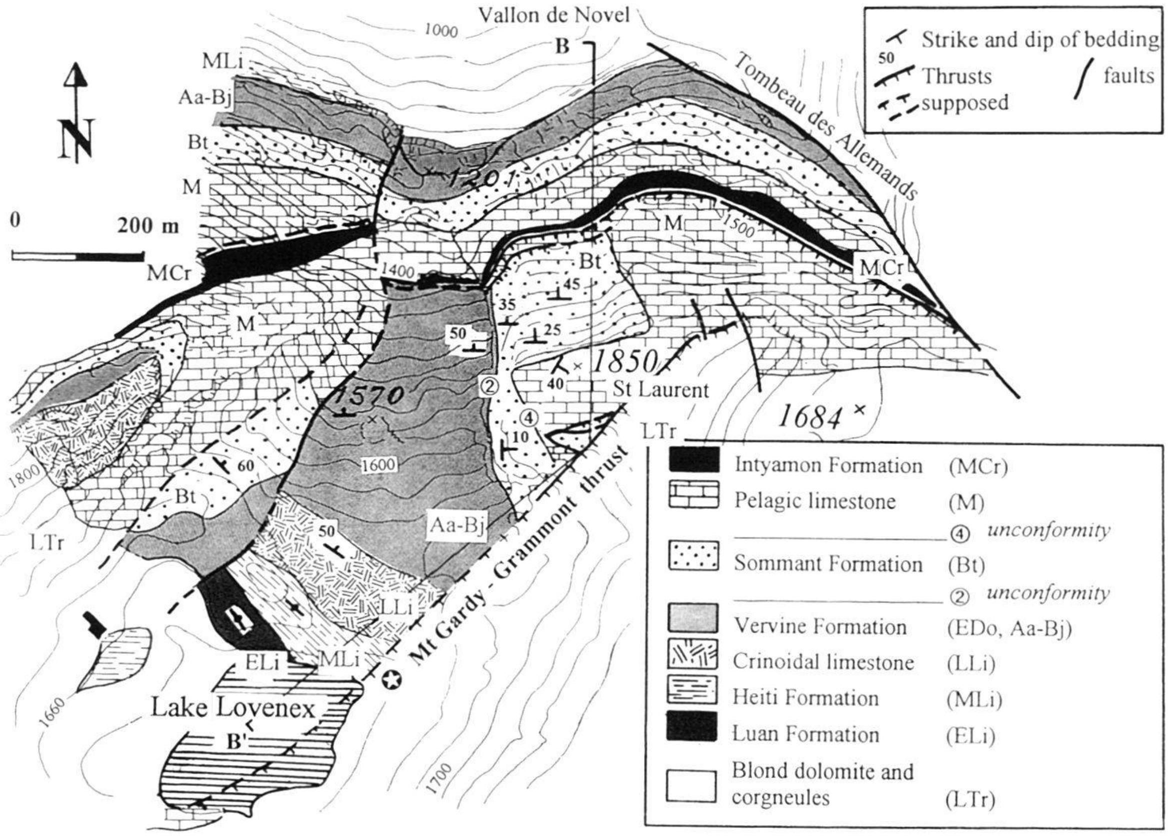

Fig. 3. Detailed geological map of the St Laurent massif and surrounding areas. The BB' profile is given in figure 4. Coord. top St Laurent: 550.575; 134.325 Alt. 1850 m (Atlas géol. suisse, 1264 Montreux 1 : 25,000)

The St Laurent exposure is a dihedral (NS-NW/SE). It belongs to a larger slice (around 800 m in a SW-NE direction) which has been thrusted and gently folded during Alpine deformation (Fig. 2–5). To get a true palinspastic view of the massif, two geometric corrections are needed. They reveal the original (pre-Late Malm) relationships between the Jurassic formations:

1. Prolongation updip of intersection points between structural lines (like point A in the NNW-SSE flank of the dihedral, Fig. 5) in the N-S plane of the profile (A becomes A' in the N-S plane; A' is not shown in figures). This operation corrects the apparent dip to the south (in the southern flank) due to the dihedral configuration of the cliff.
2. In the N-S profile, the frontal alpine bending of the St Laurent slice is of 35°. A clockwise rotation of that amount of the northern flank will restore the original planar bedding in the oolite of the Sommant Formation. The angular contrast between the Vervine Formation and the top of the pelagic limestone reaches 75° in the southern flank (Fig. 6). Then a general northward counter-clockwise tilting of 35° of the upper imbricate (Fig. 4) will restore the position of the paleostructures by reference to the top of Late Jurassic pelagic limestone (horizontal reference line in Fig. 6, 8). Point A' (not shown) rotates to a A" position (Fig. 6).

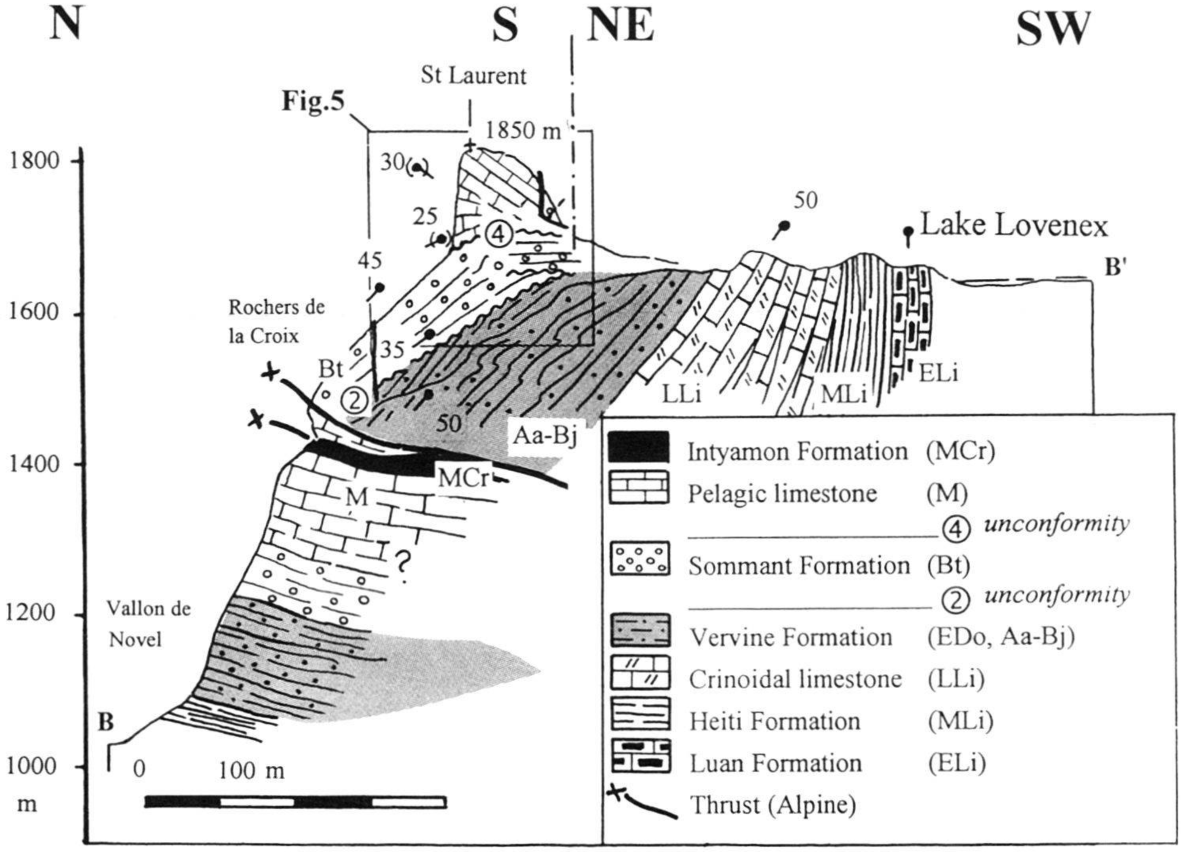

Fig. 4. Geological cross-section through the St Laurent massif (BB' in Fig. 3). The upper imbricate, above the thrust, shows a progressive unconformity recorded in Late Liassic to Late Malm sediments. The total tilting is estimated to be about 115° and lasted 50 Ma. Degree of tilting is based on direct visual observations (Fig. 5) and map interpretation.

At a larger scale, between the cherty limestones of the Heiti Formation and the bioclastic Vervine Formation a progressive unconformity of 40° can be beduced from the geological map (Fig. 3) and profile (Fig. 4). In addition to the 75° (Fig. 6) it makes a total progressive unconformity of 115° between the Middle Liassic Heiti formation and the top of the pelagic limestone.

The top beds of the Vervine Formation are truncated by an erosional surface (2 on Fig. 6) during rotation. The resulting unconformity (2 on Fig. 6) may be related to an episode of low sea level. The surface is devoid of any paleokarstic deposit or features. It is interpreted as a soft submarine surface, on top of tilted and slumped bioclastic sand beds. This interpretation is supported by the fact that the overlying beds show a similar petrographic composition. There is no important time gap between the Vervine Formation below the unconformity and the Sommant Formation above. The Vervine Formation represents a facies of slope deposits and should be correlated to a more proximal (hypothetical) oolitic wedge eroded during Bajocian times. The oolite (base of the Sommant Formation) in the Neuteu area is probably a lateral equivalent of this outer platform wedge (of Bajocian age?) locally preserved from erosion.

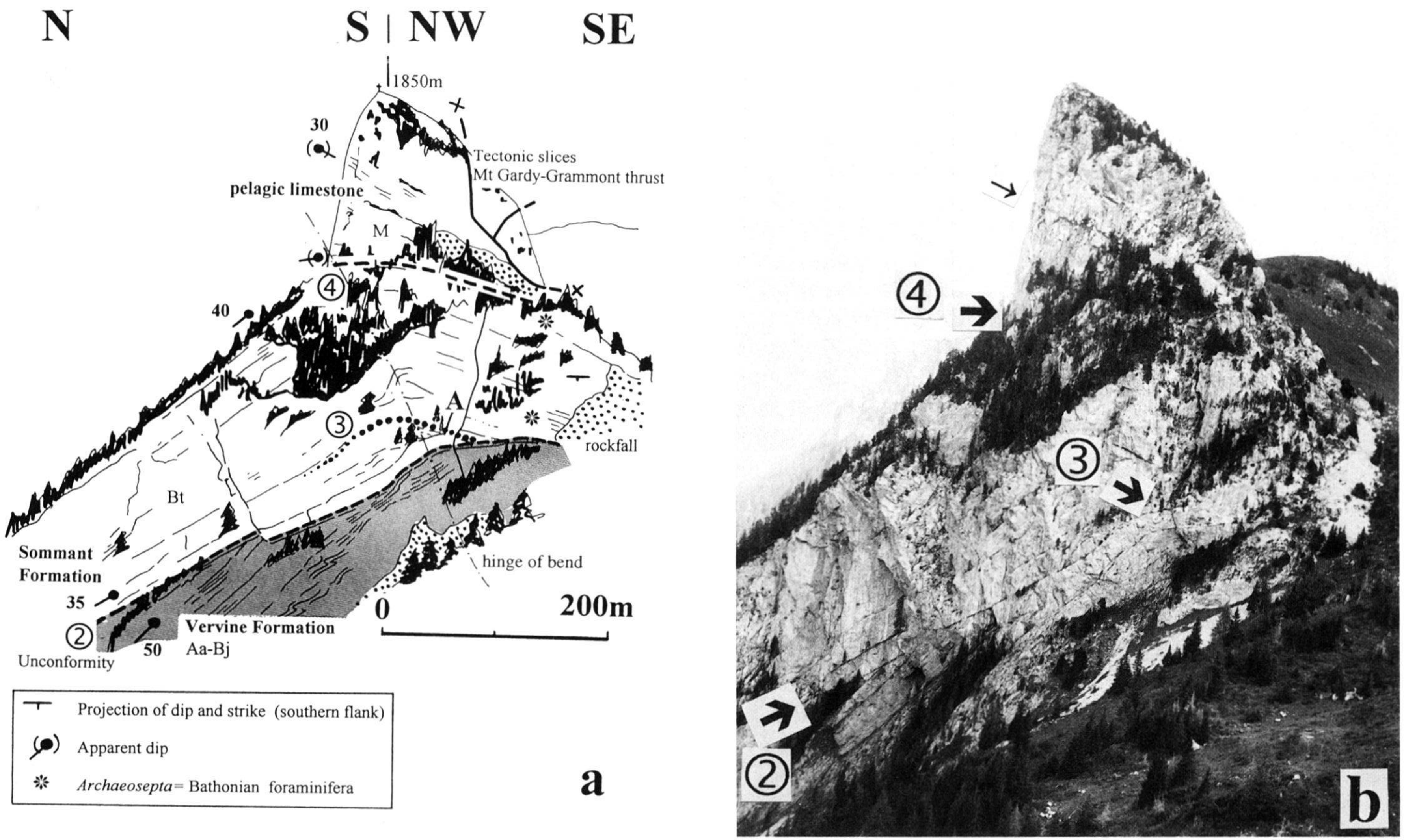

Fig. 5a. The St Laurent cliff (Upper imbricate in Fig. 4) about 200 m high, drawn from a photograph taken from the west (5b). The Middle Jurassic Sommant Formation (oolitic beds) has been slightly bent during Alpine thrusting; the trace of the axial surface (or hinge) is shown. In the southern flank the apparent dip of oolitic beds is to the south but the true dip is 10° to the east. Different unconformities (2 to 4 in circles) are visible. A is the intersection between unconformity 3 and the top of a truncated oolitic bed in the NW/SE oriented face. M = Malm; Bt = Bathonian; Aa-Bj = Aalenian-Bajocian. Coordinate: 550.575/134.325 Alt.: 1850 m. Atlas géologique suisse, 1264 Montreux 1 : 25,000

The next episode concerns the deformation of the surface 2 (Fig. 6), after deposition of a thick sequence (visible as a single bed of about 15 m thickness below A") of bioclastic sands. The unconformity 2 and the first bioclastic bed above are folded together northward, under a compressive tangential force trending approximately S-N (the paleostrike within the Dogger formation is E-W). The flexure was important as it created a 40° paleoslope. The next four overlying beds (below unconformity 3) prograde to the south on this tilted surface (onlapping). An episode of submarine erosion (unconformity 3) then truncated the thick bed (15 m) of bioclastic sands, close to point A" on Figure 6. This probably occurred during an episodic low stand of sea level. The next beds above unconformity 3 onlap the previously tilted surface of unconformity 2 in a southward direction.

Higher up in the Sommant Formation, there are 80 m of conformable horizontal oolitic beds which were deposited during Bathonian times. The lack of true angular unconformities is interpreted as the result of a high sedimentation rate and a rapid subsidence, which compete with a slow movement of folding.

Unconformity 4 represents the Callovo-Oxfordian phase, with strong erosion (Septfontaine 1983). Above the unconformity, the pelagic limestone (Malm) onlaps on this surface in a southeastern direction. These sediments record a new progressive wedge-shaped unconformity, which indicates that the paleotectonic tilt movement was still active during Late Jurassic times. The wedge opens to the northwest with an apparent angle of about 35° in the N-S profile. The true dip is 40 to 50° and directed to the SE, which is the onlapping direction of the pelagic limestone on the Sommant Formation. This transgression is due to general sea level rise, recorded along the whole European margin as far as Portugal (Haq et al. 1987). Its effects combined locally on the N-Briançonnais margin with large-scale folding.

As shown in Figures 6 and 8, Late Upper Jurassic limestones seal synsedimentary structures within Middle and Late Jurassic lithologic units. These ancient structures were not significantly deformed by Alpine orogenic movements.

Thus the St Laurent massif has recorded, in its sedimentary formations, a pervasive north-directed tilt movement, which began during deposition of the Late Liassic crinoïdal limestone. It probably ended during Late Jurassic or Early Cretaceous times. During Middle Jurassic sedimentation, the main axis of tilting was horizontal and E-W oriented (present-day orientation). This orientation changed during the Malm, becoming SW-NE. This continuous tilting affected about 650 m of carbonate sediments during 40 to 50 million years. An estimation of the total angle of progressive unconformity, due to the tilt movement, amounts to approximately 115° between Upper Liassic and Upper Malm formations. Such a peculiar synsedimentary deformation has so far not been described in Mesozoïc sediments of the Alpine domain. It is frequent in inverted Tertiary basins, during orogenic phases, like the margins of the eastern Ebro basin along the Pyrenean chain (Riba 1976; Anadon et al. 1986); or in the Neogene basin of Valensole near Dignes in southern France (Gidon 1987, Fig. G21).

Moreover, the onset of a shallow carbonate platform (Sommant Formation) during Bajocian times above tilted slope facies (Vervine Formation) is indicative of a quick progradation of outer-shelf sediments towards the open sea. Here sedimentation rate must have been higher than rate of relative sea level rise.

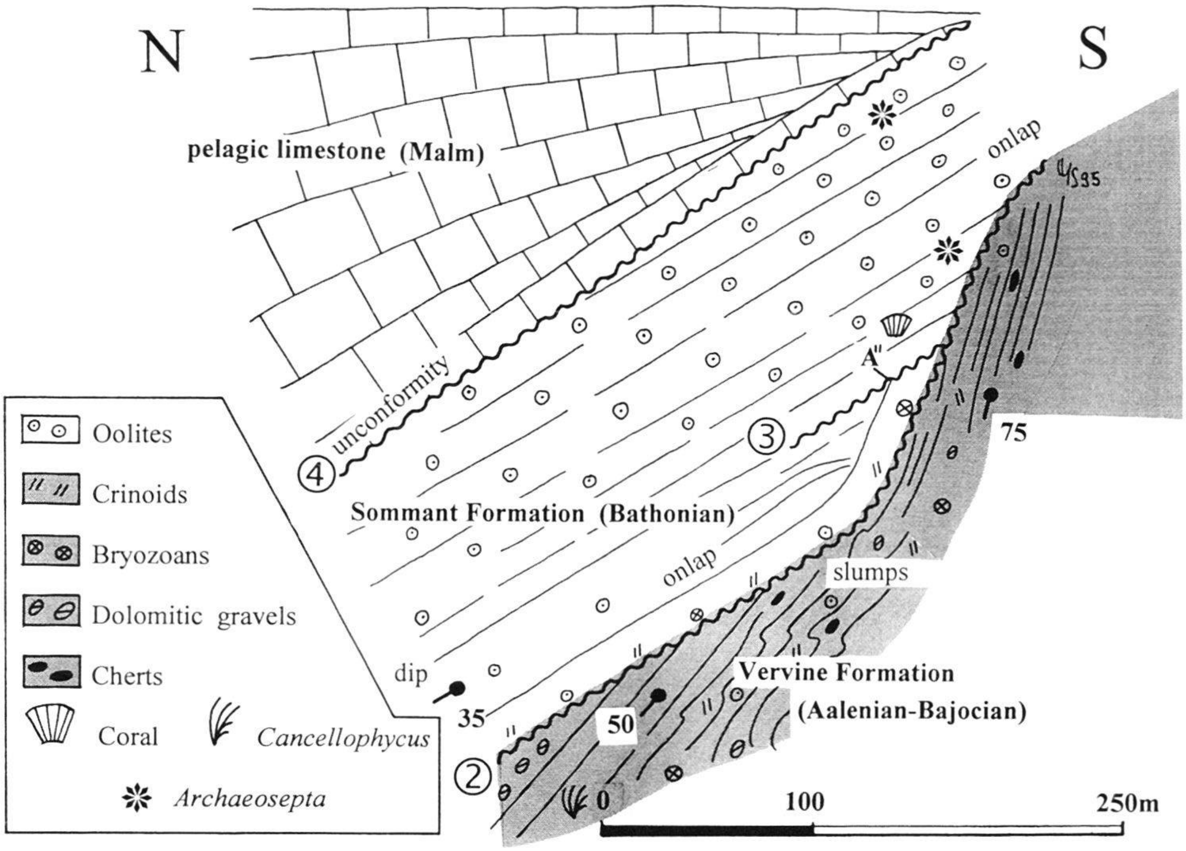

Fig. 6. Interpretation of the St Laurent exposure showing geometric relationships of stratigraphic contacts between Middle and Late Jurassic formations below the top of the pelagic limestone as horizontal reference line. Reworked dolomitic gravels are of Late Triassic age.
After correction of alpine deformation (bending of 35°, see Fig. 4) the synsedimentary angular progressive unconformity deduced from this reconstruction is of about 75° in the southern flank. A'' corresponds to the position of point A in Fig. 5 after two geometric corrections (see text).

3.2 The Chalets de Neuteu area

3.2.1 Location and description

This small locality is situated 2,5 km west of the St Laurent Peak in the same SW-NE trending tectonic and paleogeographic zone of Château d'Oche-Corbeyrier. The Chalets of Neuteu (1700 m) are built on Triassic dolomite along the Mt Gardy-Grammont main thrust surface (Fig. 1). The E-W oriented scarps immediately north of the chalets, are made of Middle Jurassic oolitic limestone (Sommant Formation), coals, conglomerates (Château d'Oche Formation), and micritic limestone of the *Mytilus* Formation. These challow water carbonate formations are about 50 to 100 m thick and show a rather constant dip to the south with an average inclination of 45°. These Middle Jurassic sediments rest stratigraphically on Late Liassic crinoïdal limestone at the eastern end of the scarp and on Middle Liassic cherty limestone (Heiti Formation) at the base of the scarp, below

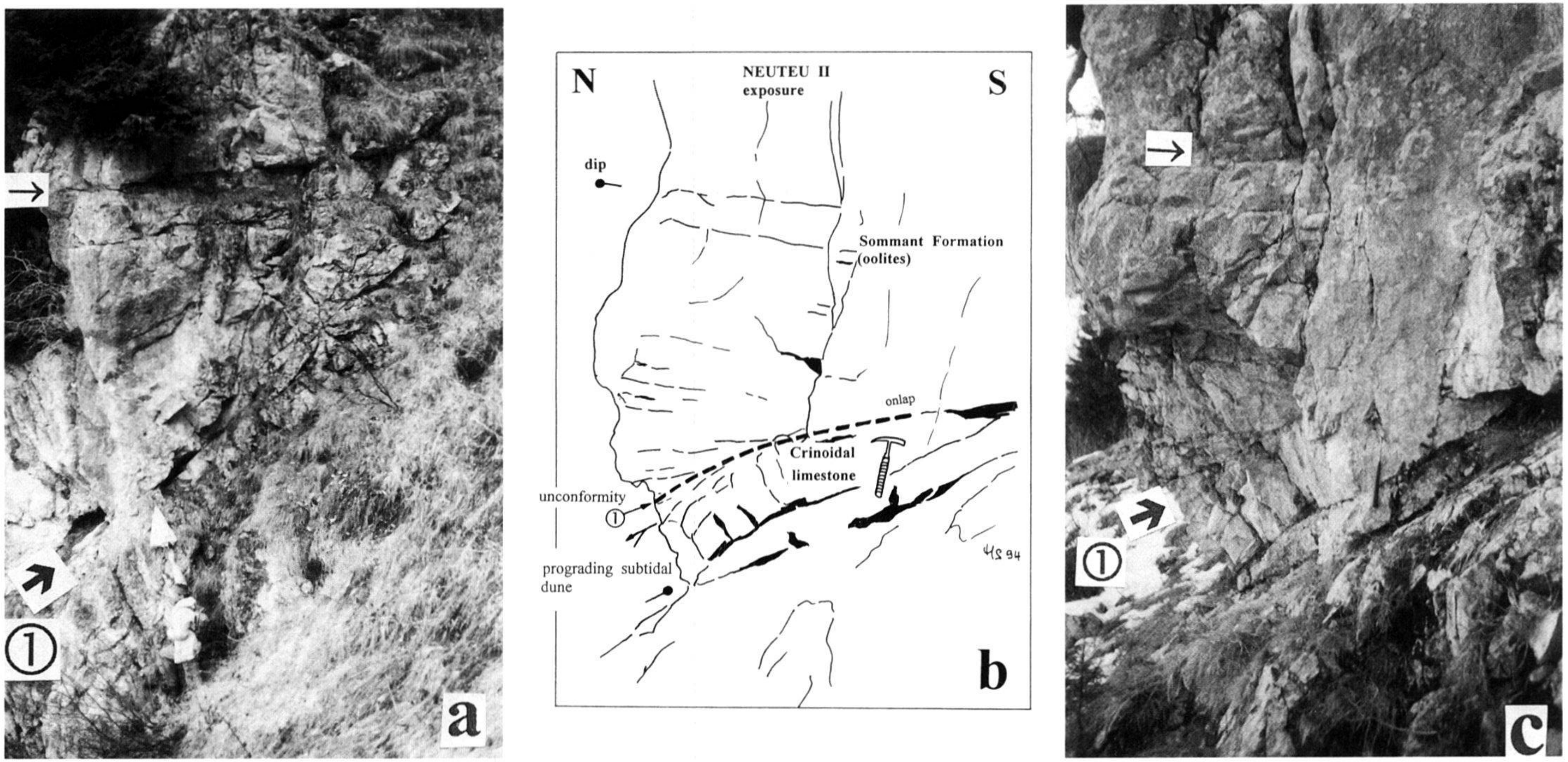

Fig. 7a-b-c. Wedge-shaped stratification and onlap of Middle Jurassic oolitic beds on a paleosurface (unconformity 1) of crinoïdal sand dunes of Late Liassic age. Outcrop is in the Neuteu I (a) and II (b-c) area.
Coordinates Neuteu I: 940.90; 159.80 Alt.: 1600 m
Neuteu II: 940.95/159.90 Alt.: 1560 m. Thonon-Châtel 1 : 50,000 (Topographic map of France)

the Chalets of Neuteu. The scarp is composed of at least five tectonic slices laterally imbricated and separated by WNW-ESE trending alpine strike-slip faults. Key exposures (I to III) show significant angular or progressive (wedge-shaped) unconformities (Fig. 7), which confirm the synsedimentary tilting movement to the north as observed in the St Laurent cliff.

*Neuteu I (coord.: 940.90/159.80; alt.: 1600 m) is the first outcrop visible in a cliff, 30 m east of the trail which joins the Novel valley to the Neuteu chalets, just before it crosses the base of the main E-W scarp. A sedimentary wedge open to the north is clearly visible in the N-S oriented cliff (Fig. 7a). It belongs to a progressive unconformity developing in the lowest part of the oolitic unit of the Sommant Formation. Some cross-stratification is also visible in oolitic beds, which I interpret to be oolitic (tidal?) sand dunes.

The oolitic wedge rests on an erosional surface of crinoïdal limestone dipping 45° to the north. The overlying oolitic beds conform to the dip on that surface (parallel unconformity). An angular progressive unconformity develops in the oolite above and the total angle of the sedimentary wedge is about 40 to 50°. On top of the hill, 50 m higher, the oolitic beds dip 30° to the south below the *Mytilus* Formation. This indicates a wedge with an angle of 80° open to the north. However, the limestone on the crest is separated from the Neuteu I outcrop by vertical alpine faults, and this rotation value may not be realistic.

*Neuteu II (coord.: 940.95/159.90; alt.: 1560 m) belongs to the same tectono-sedimentary system as Neuteu I. It is situated below the first outcrop at an altitude of 1560 m, about 100 m further east. It can be reached following the base of the N-S cliff to the east on the structurally dipping surface of crinoïdal limestone, above a rockfall. At this place a sedimentary wedge, opening to the north, is visible in the oolite of the Sommant Formation (Fig. 7 b–c). The base of the wedge is made of thin decametric beds of oolite onlapping to the south on the previously eroded surface of crinoïdal limestone. The visible synsedimentary wedge is opening to the north with an angle of 30°. The thickness is about 3 m.

*Neuteu III (coord.: 940.65/159.90; alt.: 1580 m) is located about 150 m west of the trail, still at the base of the E-W scarp of oolitic limestone; it shows a different structural pattern, although related to the same paleotectonic mechanism as above: a north-directed tilting around an E-W axis. Here the Middle Liassic beds of cherty limestone (Heiti Formation) are tilted 25° northward below an erosional surface and transgressed by the oolite of the Sommant Formation. The oolite shows a wedge-shaped sedimentary structure opening to the north with an angle of about 10°. Thus, the complete tilting of the siliceous limestone is 35° to the north, relative to the top of the Sommant Formation.

3.2.2 Interpretation

The shallow water oolitic beds of the Sommant Formation in the Neuteu area belong to a wedge-shaped system (progressive unconformity) tentatively correlated with the more distal Vervine Formation (oolitic-bioclastic sands containing open marine fossils) described in the St Laurent massif. This Aalenian-Bajocian (?) oolite, present in the Neuteu area, has been truncated below unconformity 2 in the St Laurent massif before deposition of the Upper part of the Sommant Formation (Bathonian). Conversely, the Vervine Formation of deeper water facies is absent in the Neuteu area. This repartition suggests that the tectonic imbricates in the Neuteu-Château d'Oche zone were situated paleogeographically south of the St Laurent massif, as shown on Figure 8, and represented the outer carbonate shelf during Dogger times.

The angular relations between Jurassic lithologic units as in Neuteu III and the intraformational progressive unconformities within the Sommant Formation are almost exclusively the result of local paleotectonic activity. They confirm the north-directed tilting movement observed in the St Laurant exposure, but during a shorter time interval. These ancient deformations are sometimes combined with sea level variations: the erosional surface (1, Fig. 7) on top of the crinoïdal limestone is probably related to the drastic sea level drop at the very base of the Aalenian (Haq et al. 1987) and the onlap of the oolitic beds on this north-tilted surface could be correlated with the rising of the sea level during Early Dogger times.

4. Large scale synsedimentary compressive deformations in the Jurassic of the Prealpine Briançonnais realm?

4.1 Further arguments for a new interpretation

1 km north of Mt Lenla there is a cartographic angular unconformity (below surface 1–2) between Liassic and Late Triassic formations and the Middle Jurassic *Mytilus* Formation at the southern end of the Bise-Tour d'Aï zone (Fig. 8). The paleodip of this unconformity was to the north. The basal continental beds of the *Mytilus* Formation are progressively transgressive towards the north on younger formations of the emerged Mesozoic substratum, and this occurs over a large part (40 km) of the Briançonnais platform (Badoux & Mercanton 1962; Septfontaine 1983, Fig. 26). At other localities, like the Grande Eau valley (Fig. 1) in the Préalpes Vaudoises east of the Rhône valley, paleodips of 24 to 28° have been described in the Liassic or Triassic substratum (Weiss 1949) below the *Mytilus* Formation. They all indicate a constant paleostrike (SW-NE) with a northward dip along the southern border of the Préalpes Médianes nappe.

In the Cornettes de Bise massif (Combre, Fig. 8, coord.: 132.000/551.100) the Liassic cherty Heiti Formation dips gently to the N-NE below unconformity 1 (F. Giraud pers. comm.). In the Mt Gardy massif the N-tilt of the Late Liassic crinoïdal limestone below the Malm limestone is also consistent with an Early Dogger uplift movement. South of this zone the transgressive contact between the Middle Jurassic *Mytilus* Formation and the Late Triassic beds is conformable (Mt Lenla). This parallel unconformity persists

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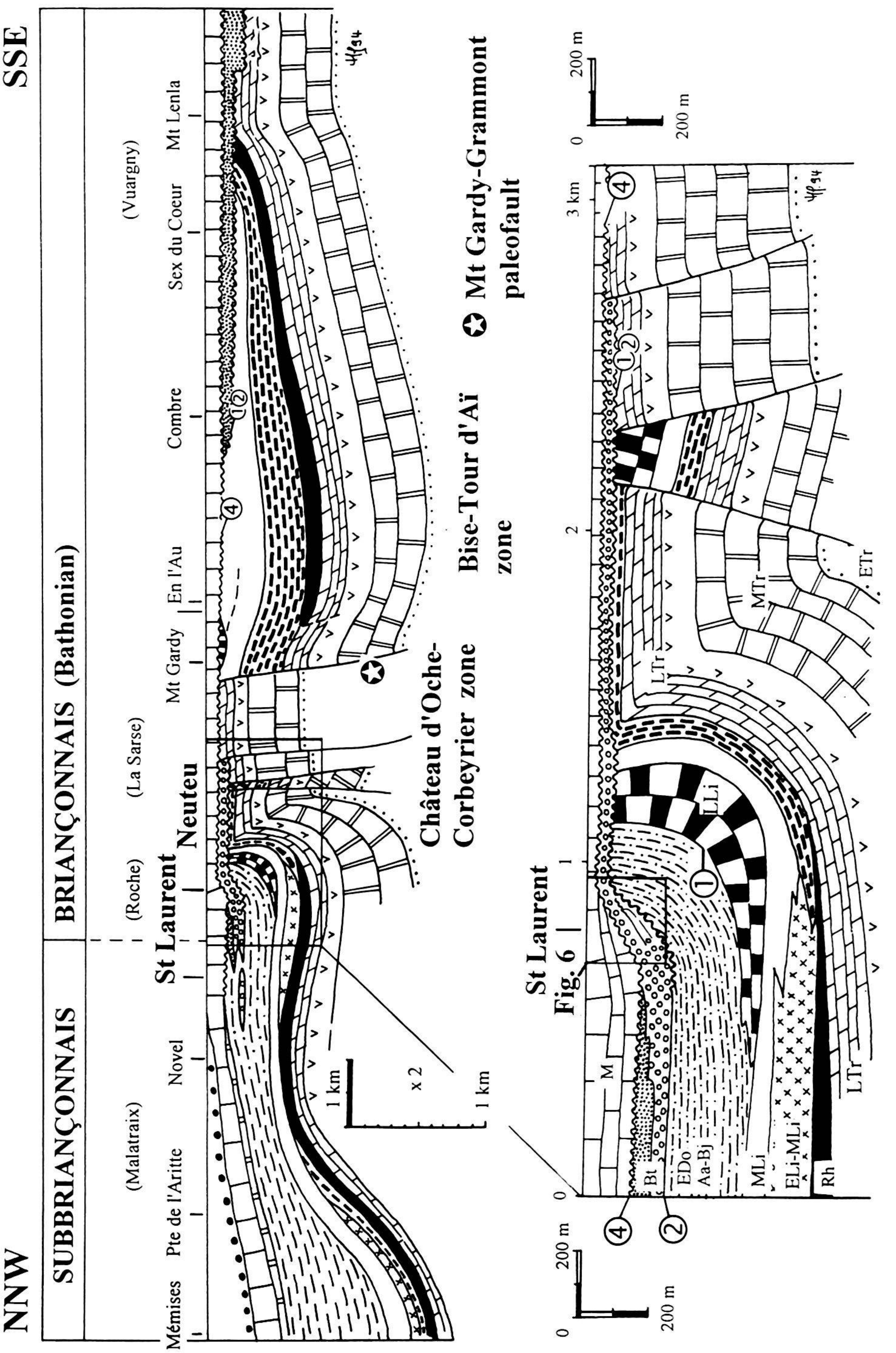
Fig. 8. Above: Palinspastic cross-section obtained by unfolding the geological profile Fig. 2. Formations are shown with their present compacted thicknesses. Horizontal reference line represents the Mid-Cretaceous sea-bottom. This palinspastic profile is constrained by field data (formations thicknesses, angular unconformities and stratigraphic gaps).
Stratigraphic legend as in Fig. 2.
Below: Detailed profile in the St Laurent-Neuteu-Château d'Oche area (rectangle in profile above). The St Laurent exposure (Fig. 6) is situated in the rectangular window. Numbers in circles refer to main unconformities. M = Malm; Bt = Bathonian; EDo = Early Dogger; Aa-Bj = Aalenian-Bajocian; ELi, MLi, LLi = Early, Middle, Late Liassic; Rh = Rhetian; ETr, MTr, LTr = Early, Middle, Late Triassic.


NNW
SSE
SUBBRIANÇONNAIS
BRIANÇONNAIS (Bathonian)
(Malatraix)
(Roche)
(La Sarse)
(Vuargny)
Mémises
Pte de l'Aritte
Novel
St Laurent
Neuteu
Mt Gardy
En l'Au
Combre
Sex du Coeur
Mt Lenla
④
①②
1 km
x 2
1 km
Château d'Oche-Corbeyrier zone
Bise-Tour d'Aï zone
Mt Gardy-Grammont paleofault
St Laurent
Fig. 6
0
1
2
3 km
200 m
200 m
M
Bt
EDo
Aa-Bj
MLi
ELi-MLi
Rh
LTr
LLi
MTr
ETr
①
②
④

eastward up to the village of Torgon. The Late Triassic dolomitic beds are also cut by a paleorelief of about 30 to 50 m, oriented SW-NE (Fig. 8, 9a).

In front of the Château d'Oche-Corbeyrier zone the presence of Jurassic progressive unconformities is suspected on the E side of the Rhône valley above Roche (work in progress). To the SW, in the Sommant area (Septfontaine 1983) the Jurassic Sommant Formation is transgressive on a northward tilted Late Triassic substratum. To the NE, the Stockhorn massif (Préalpes of canton Bern) is characterised by important sedimentary gaps (Thury 1973) and should be revised too.

4.2 Interpretation of the paleotectonic history

a. In Figure 8, south of the Bise-Tour d'Aï zone, the angular unconformity (1–2) below the *Mytilus* Formation is interpreted as a constant flexure along a SW-NE paleoaxis, parallel to the Château d'Oche-Corbeyrier paleohigh. The parallelism between the axis of the flexure and the rotation axis of the Neuteu-St Laurent progressive unconformities must be emphasized. These paleostructures are related to the same paleotectonic machanism within the same time interval. Thus I interpret the paleoflexure south of the Bise-Tour d'Aï zone as resulting from a compressive (tangential) force acting in a S-N direction, probably related to a SW-NE strike-slip movement within the Château d'Oche-Corbeyrier zone during Late Liassic times. This event would have triggered the inversion of the Bise-Tour d'Aï graben filled by 300 to 500 m of basinal spongolitic limestone of Liassic age (Luan and Heiti Formations). The inversion is marked by uplift and flexuring of non-competent Liassic formations (not yet lithified) and strong erosion at the Lias-Dogger boundary. It is coeval with thermal uplift of the rift shoulder (Briançonnais and Prépiémontais domains, south of the studied area, see Stampfli 1993). The general sea-level drop at the beginning of the Aalenian stage also played a role during this first emersive event.

b. During Dogger times, the Bise-Tour d'Aï zone was covered by a shallow sea that progessively transgressed southward in the direction of the rift shoulder (Septfontaine 1983), and northward on the Château d'Oche-Corbeyrier paleohigh. This event marked the installation of the first Jurassic carbonate platform along the N-Briançonnais margin. It lasted approximately 20 Ma, within the Bajocian to Callovian time interval. Carbonate deposits (100 to 200 m) of the *Mytilus* Formation (inner platform) and of the Sommant Formation (sand bars and mudmounds) cover the Briançonnais domain (Fig. 9a). This turnover of the subsidence history can be correlated with the general thermal subsidence along the rift border and inside the subbriançonnais rim basin (Stampfli 1993) where deep water basinal conditions persisted during the whole of the Middle Jurassic (Staldengraben Formation with *Cancellophycus* beds). The general sea-level rise at the beginning of the Middle Jurassic was also coeval with the transgression of the *Mytilus* Formation. The progressive unconformity in the St Laurent-Neuteu area was still active during that period, in front of the N-Briançonnais carbonate margin.

c. Callovo-Oxfordian times were characterised by a new episode of emersion in the Briançonnais domain of the Préalpes. The Bise-Tour d'Aï zone was again uplifted and the *Mytilus* Formation slightly tilted southward. The carbonates (mainly lagoonal mud-

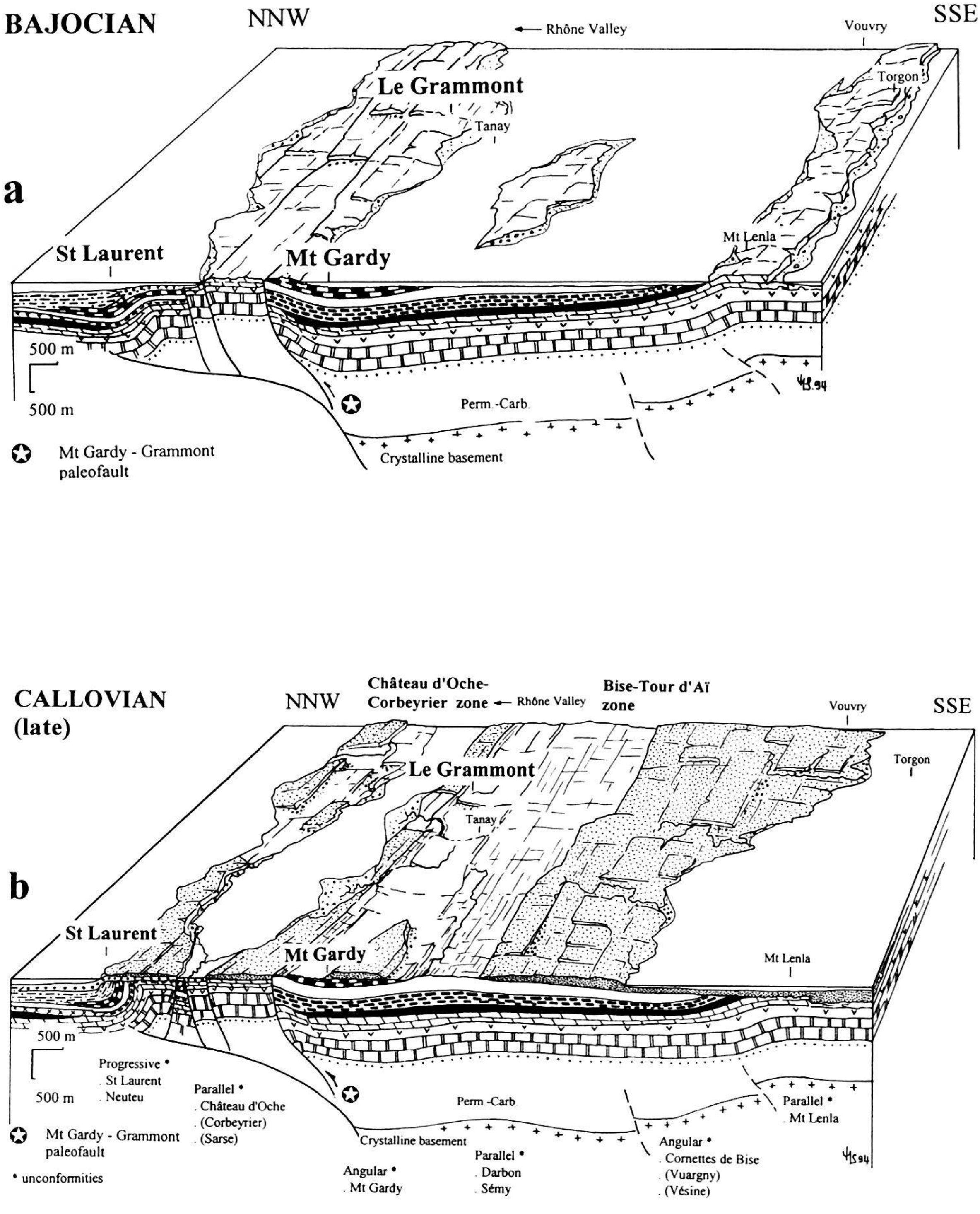


Fig. 9a. Block diagram of the studied area (eastern Chablais) during Bajocian times, showing relations between paleostructures at depth and superficial relief evolution.

b. Block diagram of the same area during Late Callovian times. Compressive movements trigger the uplift of the central part of the Briançonnais carbonate platform (Bise-Tour d'Aï zone) with emersion and erosion in the Château d'Oche zone. The Middle Jurassic *Mytilus* Formation (stippled) is strongly eroded by karstic dissolution. Along the northern coast, rivers brought coarse sediments coming from Middle Liassic outcrops of the Bise-Tour d'Aï zone. This paleotectonic event has been previously called the Callovo-Oxfordian phase by Septfontaine (1984)

Block diagram b is slightly enlarged compared to a. Legend of lithologic symbols on figures 2 and 8.

stones) were strongly eroded by karstic dissolution and truncated; the coastline of the lagoon migrated to the south.

The *Mytilus* Formation and the Sommant Formation deposits were also eroded on the Château d'Oche-Corbeyrier paleohigh. This episode of general emersion (Fig. 9b) was locally marked by coarse deposits of conglomerates and coal of the Château d'Oche Formation in a torrential and fluviatile environment. The wedge-shaped stratification in the St Laurent pelagic limestone above unconformity 4 indicates that the tilt movement was still active in a NW direction probably during Late Oxfordian or Kimmeridgian times. The Callovo-Oxfordian emersion can hardly be interpreted in terms of eustatic sea-level drop, as the curve of Haq et al. (1986) shows a constant elevation of sea level during this time interval. Neither can it be explained by thermal uplift during this period, because thermal subsidence induced a general drowning of the Tethyan domain at that time (Favre & Stampfli 1992).

4.3 Discussion

The sedimentary evolution on the Château d'Oche-Corbeyrier zone (Fig. 8, 9) and the subsidence history in the Bise-Tour d'Aï zone allows me to interpret the uplift movements in a compressive regime along the N-Briançonnais margin. During Early and Middle Liassic times the Château d'Oche-Corbeyrier zone and nearby areas were under deep water conditions as proved by the presence of the locally preserved spongolitic limestone of the Heiti Formation. This is supported by the fact that the Heiti Formation in the adjacent Bise-Tour d'Aï graben does not contain any reworked lithoclast of Triassic dolomite. Obviously, if the Château d'Oche paleohigh was already emerged during Middle Liassic times, the presence of fault scarp breccias in the Mt Gardy-Grammont chain would be expected (as it is commonly the case during Dogger times along the N-Briançonnais paleorelief). Thus, the Château d'Oche-Corbeyrier paleohigh is not a Liassic heritage in terms of uplifting movement and emersion. Rather the thin sedimentary cover of spongolitic limestone (Heiti Formation) in this zone, below Late Liassic crinoïdal limestone, is due to a relatively low synsedimentary subsidence movement compared with the Bise-Tour d'Aï zone which is characterised by a high subsidence rate. The water depth, during deposition of the Heiti Formation, was constant over the entire Briançonnais domain of the studied area.

During Late Liassic times, characterised by thermal uplift of the rift shoulders, the N-Briançonnais margin had emerged and was affected by the inversion of the Mt Gardy-Grammont paleofault. Emersion resulted in numerous sand or pebble sized reworked dolomitic grains in the crinoïdal limestone, being deposited on both sides of the paleohigh. The progressive movement along the unconformity of St Laurent began at that time.

These events and the Late Middle Jurassic uplift movement cannot be explained in a context of extensional deformation. Tilted blocks in extension cannot generate important uplift and emersions, especially during the Late Dogger thermal subsidence. Inversion along the N-Briançonnais margin appears to offer a better explanation.

4.4 Reappraisal of the classical "in extension" model

Field observations in the Préalpes do not fit with the classical extensional model proposed by previous authors (Trümpy 1960; Bourbon et al. 1976; Lemoine et al. 1986 and Lemoine 1988). They concluded that the Jurassic paleotectonic history in the Briançonnais was one of a horst and graben system composed of tilted blocks. Lemoine et al. (1986, Fig. 19) used arguments taken from our palinspastic profile (Septfontaine 1979, Fig. 3; 1983, Fig. 36–37; Baud & Septfontaine 1980, Fig. 1) without citation of references. But the truncated wedge (tilted to the south) of the Middle Jurassic *Mytilus* Formation was omitted by Lemoine et al. (1986) on the southern half of their palinspastic scheme. Thus, the Callovo-Oxfordian uplift of the N-Briançonnais margin could not be documented. Field data bring new arguments against the classical "in extension" tilted blocks paradigm:

- The St-Laurent progressive unconformity cannot be interpreted as part of a rollover fan belonging to a hypothetical northward tilted paleoblock, along a listric paleofault. This interpretation would imply the presence of a paleofault scarp north of the structure (St Laurent slice Fig. 4) along the proximal zone of the Subbriançonnais basin. But no indication of a paleohigh has ever been observed in that part of the *Cancellophycus* basin. Rather, it is well known that the transition from outer shelf carbonate sediments (Sommant Formation) to slope and basinal deposits (Staldengraben Formation) occured in a sedimentary ramp-like system (Furrer 1979, Septfontaine 1983). In a tilted block interpretation (related to an extensional regime) the synrift coarse sediment transport should have come from the north, that is from this hypothetical plaeofault scarp. In this case the turbidites would be shed away from the fault scarp (from the north) onto the bedrock dipping towards the fault (Eberli 1987; Schmid et al. 1990; Conti et al. 1994). In the St-Laurent area and more generally along the N-Briançonnais margin we observe the reverse situation. Sediment transport (carbonate particles and quartz grains) was roughly in a S-N direction or parallel to the SW-NE carbonate margin, in the same general direction as the one of the tilted bedrock. In other words the bedrock was tilted away from the source area, the Château d'Oche-Corbeyrier zone (Fig. 8). Such a geometry is incompatible with the classical situation of a domino-type extensional basin (Schmid et al. 1990).
- A pervasive tilting of 75° in the Middle to Upper Jurassic interval (Fig. 6) or at a larger scale of 115°, as deduced cartographically (Fig. 4) between the crinoïdal limestone (Toarcian) and the top of the pelagic limestone (Malm) is not known in a context of tilted paleoblocks in a distensive context, particularly in a rim basin situation. Other progressive unconformities implying rotations of more than 40° in the Sommant Formation (Neuteu area) confirm the important rotation movement of the Liassic substratum in the St Laurent massif.
- The uplifting of the Briançonnais carbonate margin during Callovo-Oxfordian times caused a roughly symmetrical tilting of Middle Jurassic sediments on both sides of the Bise-Tour d'Aï zone (Fig. 8, 9). This geometry points to some kind of compressional or transpressional mechanism, responsible for uplift, emersion and strong erosion on the margin.

4.5 Towards a new model of paleotectonic evolution of the N-Briançonnais margin in the Préalpes

– In the Mesozoic sedimentary cover

The above discussion points to an alternative model for the classical "in extension" model introduced by Alpine geologists during the sixties in the Préalpes Briançonnais realm. After a rather short period of extension the Liassic Bise-Tour d'Aï sedimentary basin was affected by inversion forces (Fig. 10b) triggered during Late Liassic times by a convergent SW-NE oriented strike slip system. These transpressional movements were responsible for the uplift and karstic erosion in this zone during the Dogger. North of the Mt Gardy-Grammont paleofault the N-Briançonnais margin developed a large scale synsedimentary paleofold (Fig. 10c) growing northward in front of a "flower structure" (Crowell 1985; Sylvester 1988), which was active during Middle and Late Jurassic times in the Château d'Oche-Corbeyrier zone. The length of the paleofold axis was greater than 10 km (from Neuteu to Roche, east of the Rhône valley, Fig. 1).

The mechanism responsible for the deformation in the Mesozoic sedimentary cover has been tentatively attributed to the progressive development of a synsedimentary "fault-propagation fold" (Suppe et al. 1991). This paleostructure creates rotations and truncations of beds (Fig. 10c–d) at its front through time (Mitra 1990). This type of model suggested to me by Jon Mosar (pers. comm.) fits well with field observations and explains the north-directed migration through time of the progressive unconformity (Fig. 9a–b) in the St Laurent area. This paleofold was probably relayed in the Château d'Oche massif by ejected blocks between straight reverse paleofaults, since only parallel unconformities have been observed in this area.

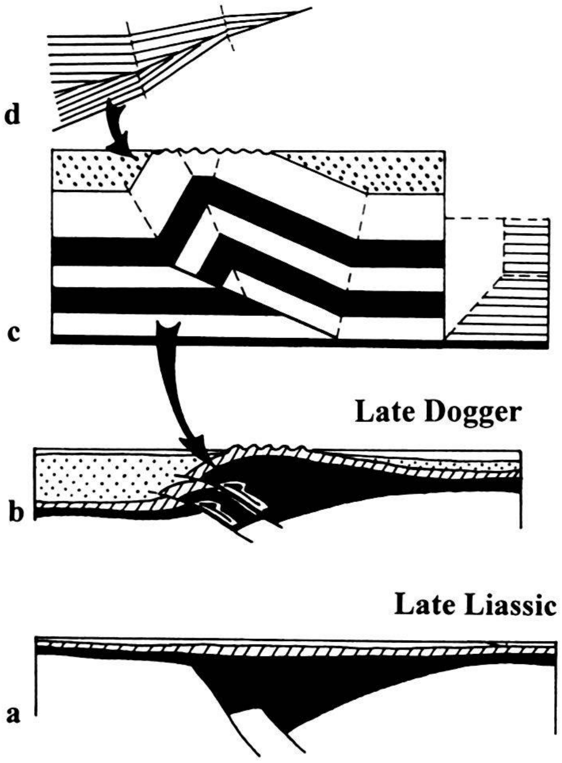


Fig. 10. Conceptual models related to the inversion of a half-graben (Bise-Tour d'Aï) redrawn with slight modifications from:
a-b: Letouzey (1990); c: Mitra (1990), "fault propagation fold" in front of the Château d'Oche zone; d: Van Mount et al. (1990), progressive unconformity, onlaps and erosions as observed in the St Laurent cliff.

The platy limestone of Early Cretaceous age shows a cartographic sedimentary wedge open to the north up to the Mémises area (left end of profile Fig. 8). The rotation axis could have been situated below the village of Novel at that time. This would mean a lateral migration of the paleofold hinge to the north until Early Cretaceous times.

– In the basement

The main fault at depth could be an ancient (Late Paleozoic?) normal paleofault affecting the basement. A similar paleofault has been described by Sartori (1987) in the Siviez-Mischabel nappe (internal Briançonnais in the canton of Valais, Switzerland). It is proposed (Fig. 9) that such a paleofault has been flattened and tilted to the north during the Late Liassic inversion. Since then it functioned as a tectonic ramp, below the propagation paleofold and associated ejected paleoblocks in the Château d'Oche-Corbeyrier zone.

– At a Tethyan scale

At a larger scale compressional movements during Jurassic times were also recorded along the N-Briançonnais margin in the Schams nappe (Schmid et al. 1990), in eastern Switzerland. These authors proposed a transpressive scenario related to an overall E-W directed major strike-slip movement acting over a long period, from Late Liassic to Early Cretaceous (in Vizan Breccia Formation), as in the Préalpes. The dip of blocks toward the basin (as in the St Laurent-Neuteu area) is typical for push-up ranges or flower structures (Crowell 1985), but not for extensional basins. Our model (Fig. 8 to 9) fits well in the general paleotectonic sketch of the central Alps proposed by Schmid et al. (1990, Fig. 10). The latter shows compression in "en échelon" basins generated in an overall sinistral transtensional system during oceanic spreading.

At the western end of the Tethyan realm, in Morocco, the High Atlas trough can be, to some extent, considered an ancient analogue of the Briançonnais rim basin. Its geodynamic history and position regarding the Atlantic rift shows some striking similarities (Favre & Stampfli 1992). After the Liassic rifting period related to the opening of the central Atlantic, the High Atlas trough was inverted during Toarcian times. Compressional deformations, such as progressive unconformities, reverse paleofaults and associated scarp breccias, were recorded by Studer & Du Dresnay (1980), Jenny et al. (1981) and Jossen (1990). These events coincided with the beginning of oceanic spreading in the Atlantic roughly at the same time as the spreading in the Piémont-Ligurian domain and the inversion of the N-Briançonnais margin in the Préalpes.

5. Conclusions

Based on geometric field relationships between formations and a general stratigraphic revision of Jurassic sediments in the Préalpes Médianes nappe, a new paleotectonic model is proposed. The presented arguments are deduced from the tectono-sedimentary evolution of selected areas.

1. A progressive unconformity has been recognised in front of the N-Briançonnais margin. It shows a continuous tilting of about 115° recorded in Jurassic sediments of the St Laurent massif. Such important tilting is not known in an extensional regime of paleoblocks, in a rim basin situation.

2. Angular unconformities and fan shaped sedimentary structures visible in the Neuteu area, as well as observations of angular unconformities on the east side of the Rhône valley (above Roche) suggest that this setting has a lateral extension greater than ten kilometers.
3. Further west and east of the studied area (on a distance of 120 km) the N-Briançonnais carbonate margin is characterised by important stratigraphic gaps. They are due to strong erosion on top of ejected tectonic blocks along reverse faults since the Late Liassic. Scarp breccias and dolomitic gravels are displaced northward, that is in the same general direction as the bedrock rotation (St Laurent, Neuteu). Such a geometry is not compatible with a situation of a domino-type extensional basin.
4. The Bise-Tour d'Aï zone was uplifted and eroded at the end of the Middle Jurassic, during a period of high sea level and thermal subsidence. This event must have resulted from contraction in the sedimentary cover. This is supported by the roughly symmetrical truncation of Middle Jurassic sediments on both sides of the E-W tilt axis of that erosional zone.

These observations and a palinspastic reconstruction through the Préalpes Médianes nappe constrained by field data, as well as a kinematic reconstruction in the Château d'Oche-Corbeyrier zone, point to an alternative model to the tilted blocks paradigm in an extensional regime. It is proposed that a large scale transpressive strike-slip movement along the N-Briançonnais margin has triggered tectonic inversion during the Late Liassic. This movement was responsible for rotations and flexuring of beds in the Briançonnais of the Préalpes. It induced reversal of previous Liassic normal paleofaults, creating locally a large synsedimentary "fault propagation" type of fold at depth below the N-Briançonnais margin associated or relayed by ejected tectonic paleoblocks, in a context of flower structure. This inversion coincides with the onset of sea floor spreading in the Alpine Téthys.

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