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Western Préalpes Médianes Romandes: Timing and structure. A review.

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Key words: Préalpes Médianes, klippen, Briançonnais, folds, thrusts, tear faults, décollement, thin-skinned tectonics, synsedimentary tectonics, alpine tectonics, passive margin, active margin, sedimentation, transported metamorphism, internal deformation

ABSTRACT

Between the original position and their present day location as klippen, the Préalpes Médianes underwent a complex history of paleotectonics and alpine tectonics. Due to the opening of the Piemont ocean the Briançonnais sedimentation realm of the Préalpes Médianes evolved as a rim basin of the northern passive margin during Jurassic to Eocene times. Different paleotectonic features (normal faults, synsedimentary growth structures, inversion structures) developed and were active above a basal detachment in evaporitic layers. The tectonic movements were a consequence of thermal events in the crust. Isolated from the Iberic continent at the end of the Late Cretaceous, the Briançonnais exotic terrain was incorporated into the accretionary prism of the closing Piemont ocean and the incipient alpine orogeny during the Lutetian-Bartonian. The Préalpes Médianes were detached from their homeland during the Bartonian-Priabonian and were transported onto the foreland. The tectonic style is one of a thin-skinned foreland fold and thrust belt. Fault associated fold development above a main décollement, together with internal deformation, represent the Préalpes Médianes main structural features. The very low-grade metamorphic conditions have their origin in the heat flux induced by tectonic burial by overriding nappes in the accretionary prism. After having been transported on top of the developing Helvetic nappes the Préalpes were emplaced in their present day position in front of the Alpine mountain belt during Oligocene times. Post-emplacement and out of sequence thrusting, possibly younger than Oligocene, is observed and can be related to thrusting in the sedimentary substratum and the basement.

RESUME

Entre leur position de départ et leur situation actuelle en tant que klippe tectonique les Préalpes Médianes ont subi une histoire complexe de paléo-tectonique et tectonique alpine. Suite à l'ouverture de l'océan Piemontais, le domaine de sédimentation des Préalpes Médianes se développe en forme de bassin frangeant le long de la marge passive nord du Briançonnais entre le Jurassique et l'Eocène. Différents types de structures paléotectoniques (failles normales, failles inverses, structures de croissance synsédimentaire) se développent au-dessus d'un décollement basal dans les niveaux évaporitiques à la base des Préalpes Médianes. Ces mouvements sont les conséquences de réajustements occasionnés par les événements thermiques crustaux. Une fois isolé du continent Ibérique par une faille transformante sénestre N-S durant le Crétacé terminal, le terrain exotique Briançonnais vient s'insérer dans le prisme d'accrétion qui voit le jour suite à la fermeture de l'océan Piemontais dès le Lutétien-Bartonien. Le métamorphisme faible résulte d'un réchauffement du à l'effet d'enfousissement tectonique des Préalpes Médianes dans le prisme d'accrétion pendant le Bartonien-Priabonien. Elles sont ensuite détachées de leur patrie et mises en place sur les nappes Helvétiques en pleine formation, puis transportées sur l'avant-pays alpin, où elles arrivent pendant l'Oligocène. Le style structural est celui d'une tectonique «pelliculaire» caractéristique d'une chaîne d'avant-pays plissée. La déformation interne des roches

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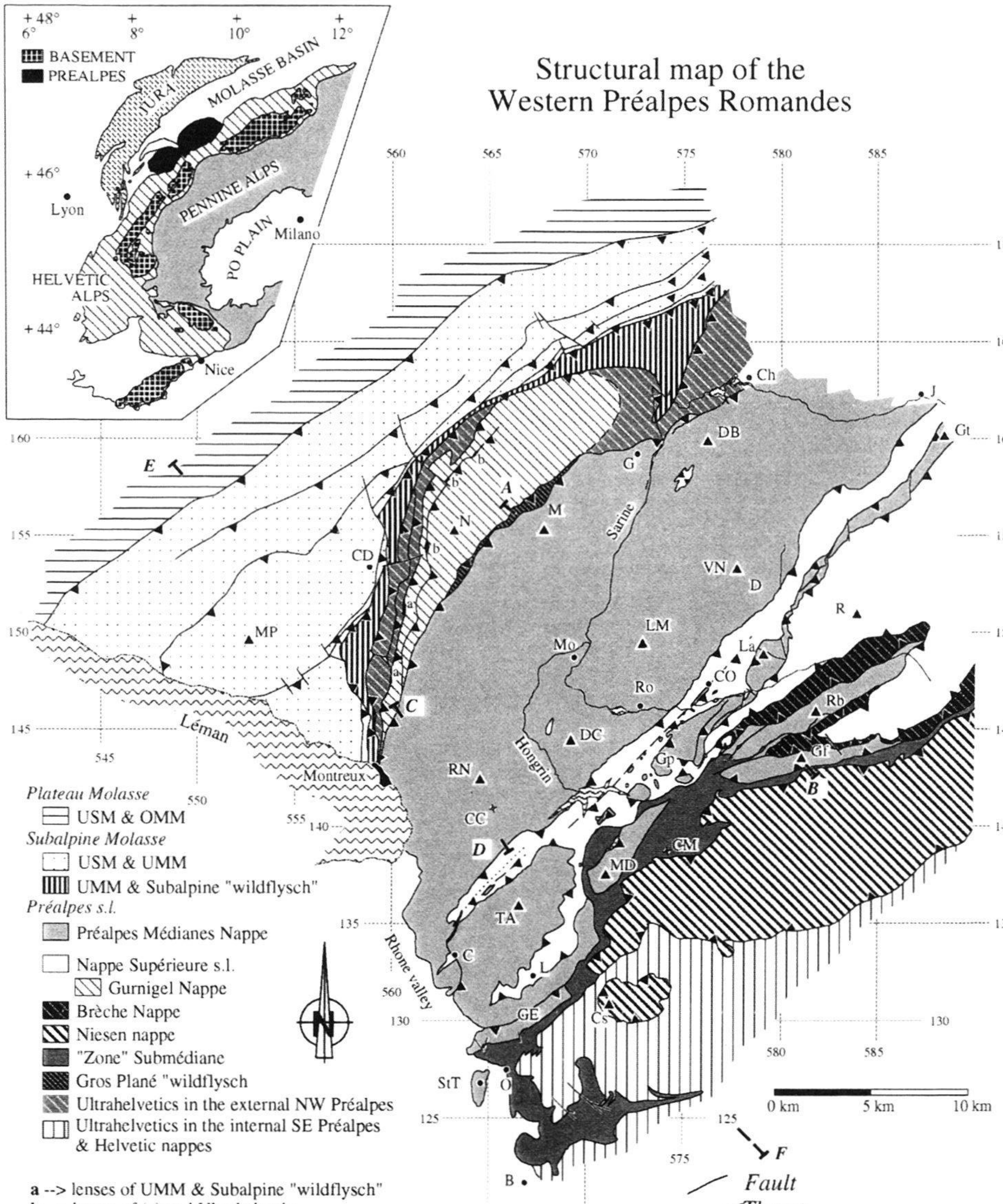
va de paire avec la formation de rampes, plis et plis-failles. Les chevauchements intervenus après la mise en place, probablement post Oligocène, sont associés aux déformations et à la tectonique intervenant dans les sédiments du substratum et de leur socle.

Introduction

The Préalpes are formed by several allochthonous tectonic klippen resting on the N and NW central European alpine foreland, in front of the Helvetic nappes and the external crystalline basements of the Alps (Schardt 1898; Jeannet 1922; Trümpy 1960; Badoux & Mercanton 1962; Caron 1973; Plancherel 1979; Fig. 1). Several klippen can be recognized from E of Lucerne (Mythen klippe) to Annecy (France) in the W (Annes klippe). The largest are the Préalpes Romandes NE of lake Geneva in Switzerland and the Chablais Préalpes S of Lake Geneva in Switzerland and France. Within the klippen several tectonic units with different paleogeographical origins can be identified. One can differentiate from top to bottom (Fig. 1): [i] the Nappe Supérieure which itself is subdivided into four different units: the Gets nappe, the Simme nappe, the Dranses nappe and the Gurnigel nappe (Caron 1972, 1976; Trümpy 1980); [ii] the Breccia nappe, resting on the trailing part of the Préalpes Médianes only (Lugeon 1896; Jaccard 1904; Schroeder 1939; Weidmann 1972; Steffen et al. 1993); [iii] the Préalpes Médianes nappe and [iv] the Niesen nappe which exists in the Préalpes Romandes only and which today forms the southernmost structural unit (McConnel 1951; Lombard 1971; Matter et al. 1980; Homewood et al. 1984; Ackermann 1986; Caron et al. 1989). At the base of the Préalpes Médianes and separating them from the Niesen nappe, is the "Zone Submédiane" structural unit (Weidmann et al. 1976). Elsewhere the sole of the Préalpes is in contact with the underlying units (the Helvetic nappes in the S and the Subalpine Molasse and flysch to the N) by means of the "Ultrahelvetics" (Badoux 1963; Homewood 1977; Jeanbourquin 1991, 1992, Jeanbourquin & Goy-Eggenberger 1991; Jeanbourquin et al. 1992; Lempicka-Münch & Masson 1993) which are characterized by mélanges and cornieules (Rauhwacken) associated with anhydrites.

It was Schardt (1884; 1893a; 1898) who first clearly demonstrated that the Préalpes were allochthonous (see also Lugeon 1902). He also recognized and described the fold and thrust style of the Préalpes Médianes (Favre & Schardt 1887), and concluded that there was a genetic link between thrusts and folds. Historical accounts of the development of ideas and geologic research in the Préalpes are given in Jeannet (1912–1913), Bailey (1935), Masson (1976) and Lemoine (1988); more than 800 references on the Préalpes can be found in Mosar & Borel (1995).

In terms of paleogeography the Préalpes Médianes formed part of the Subbriançonnais and Briançonnais sedimentation realm (Trümpy 1960; Caron 1972, 1973; Bernoulli et al. 1979; Caron et al. 1980a, 1980b; see general introduction Boillot et al. 1984; Lemoine et al. 1986; Debelmas 1989). Equivalent stratigraphic units have been found both in the Préalpes Médianes and the Pennine nappes south of the Rhône valley. In these units of the Grand Saint Bernard nappe, the Siviez-Mischabel nappe has been recognized as homeland for the Médianes Rigides and the Pontis nappe for the Médianes Plastiques (Schardt 1907; Ellenberger 1952; Baud & Septfontaine 1980; Sartori 1987, 1990; Escher et al. 1993; Sartori & Marthaler 1994). The Préalpes Médianes nappe was detached from its basement and underwent thin-skinned tectonics during the Alpine



B = Bex; C = Corbeyrier; CC = Col de Chaude; CD = Châtel St. Denis; Ch = Charmey; CM = Col des Mosses; CO = Château d'Oex; Cs = Chamossaire; D = Dorena; DB = Dent de Broc; DC = Dent de Corjon; G = Gruyère; GE = Grande Eau; Gf = Gummfluh; Gp = Gorges du Pissot; Gt = Gastlosen; J = Jaun; L = Leysin; LM = Les Millets; M = Moléson; MD = Mont d'Or; Mo = Montbovon; MP = Mont Pélerin; N = Niremont; O = Ollon; R = Les Rodomonts; Rb = Rübli; RN = Rochers de Naye; Ro = Rossinière; StT= Saint Triphon; TA = Tours d'Aï; VN = Vanil Noir

Fig. 1. Tectonic map of the western Préalpes Romandes and their neighbouring structural units with simplified location-map of the Chablais and Romandes Préalpes (in black) in the Alpine mountain belt. Although the Nappe Supérieure of the Préalpes is made of four distinct tectonic units, only the Gurnigel nappe has been shown with a different pattern. UMM = Lower Marine water Molasse; USM = Lower Fresh water Molasse; OMM = Upper Marine water Molasse; OSM = Upper Fresh water Molasse.

orogeny. The basal décollement occurred in evaporites located at the base of the Middle and Late Triassic. The Zone Submédiane and Niesen nappe paleogeographic homeland is on the northern European margin of the Valais ocean (Stampfli 1993; Stampfli & Marchant in press). The Breccia nappe has its origin on the north Piemontais margin and represents mainly a synrift deposit of that margin. The Nappe Supérieure comes from the Piemontais oceanic domain (Dranses nappe; see also controversy in Hsü 1989) or the south Piemontais active margin (Gets, Simme and Gurnigel nappes).

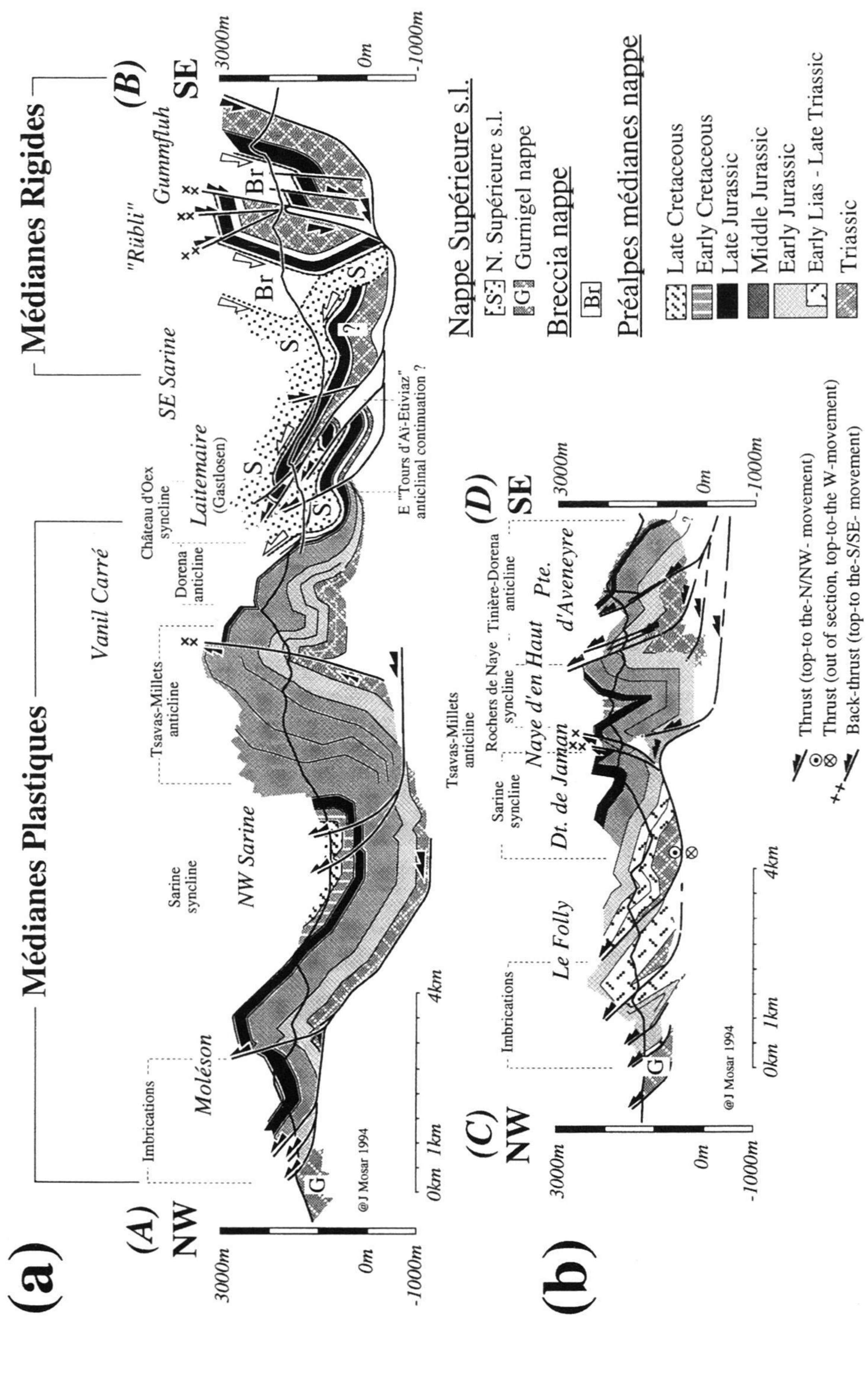
The Préalpes Médianes are subdivided into Médianes Plastiques, forming the frontal (NW) part of the nappe and Médianes Rigides, forming the trailing (SE) part of the nappe (Fig. 2; Lugeon & Gagnebin 1941). This subdivision is based on the large scale structural geometry (folds in the Médianes Plastiques and imbricates in the Médianes Rigides), internal deformation (strain) is on the contrary weak and brittle in the Médianes Plastiques and stronger and more "plastic" in the Médianes Rigides (Mosar 1989). In the Préalpes Romandes, a domain with intermediate structural and sedimentological characteristics exists between the Médianes Rigides and Plastiques: the Gastlosen range (Lugeon & Gagnebin 1941; Baud 1972; Plancherel 1979).

Before reaching their present day location the Préalpes Médianes experienced successive geologic events (Fig. 3). We will focus hereafter on two major families of structural and tectonic features: [i] those associated with syn-sedimentary deformation and tectonics, such as rift development, sedimentary growth faults, inversion structures etc., [ii] those associated with the alpine orogenesis s.str., starting during Late Eocene, after the Préalpes Médianes flysch sedimentation.

Paleo-tectonics and sedimentology

Sediments in the Préalpes Médianes range from Triassic to Paleogene (Eocene) in age (Fig. 4, Badoux 1962a; Plancherel 1979, 1990; Baud & Septfontaine 1980; Trümpy 1980; Baud et al. 1989). They are formed by limestones, dolomites, marls and shales. The only basement relics in the Préalpes themselves are Permo-Carboniferous sediments, thought to belong to the Préalpes Médianes. They are found in the SW Chablais Préalpes near Tanninges (Septfontaine & Wernli 1972; Wernli & Broennimann 1973). The Préalpes Médianes basement presently found in the Siviez-Mischabel and Pontis nappes (middle Pennine) is formed by polycyclic rocks as well as monometamorphic rocks (Thélin et al. 1993; Sartori & Marthaler 1994). The polymetamorphic basement is considered Proterozoic to early Paleozoic in age and has suffered ante-alpine metamorphism. The monometamorphic basement is Carboniferous to Early Triassic in age and is probably derived from several distinct basins (Thélin et al. 1993). The basement of both the Siviez-Mischabel and the Pontis nappes formed one single continuous substratum.

Fig. 2. Cross-sections through the western Préalpes Médianes Romandes. (a) The profile in the Sarine valley (A-B, location on Fig. 1) shows the formation of a trough-like structure (very deep syncline) beneath the Sarine syncline and the deepening of the basal décollement by some 2000 m. (b) The section along the Rhône valley (C-D, location see Fig. 1) shows the shallow depth of the basal décollement and top-to-the-W/WNW movements along thrusts surfaces in the frontal imbricates. In both sections backthrusts are remarkable (indicated by -xx-).


(a)
Médianes Plastiques
Médianes Rigides
(A)
NW
(B)
SE
3000m
0m
-1000m
Imbrications
Moléson
Sarine syncline
NW Sarine
Tsavas-Millets anticline
Vanil Carré
Dorena anticline
Château d'Oex syncline
Laitemaire
(Gastlosen)
SE Sarine
E "Tours d'Aï-Etiviaz" anticlinal continuation ?
"Rübli"
Gummfluh
G
S
Br
@J Mosar 1994
0km 1km
4km
(b)
(C)
NW
(D)
SE
Imbrications
Le Folly
Sarine syncline
Dt. de Jaman
Tsavas-Millets anticline
Rochers de Naye syncline
Naye d'en Haut
Tinière-Dorena anticline
Pte. d'Aveneyre
Nappe Supérieure s.l.
S N. Supérieure s.l.
G Gurnigel nappe
Breccia nappe
Br
Préalpes médianes nappe
Late Cretaceous
Early Cretaceous
Late Jurassic
Middle Jurassic
Early Jurassic
Early Lias - Late Triassic
Triassic
Thrust (top-to the-N/NW- movement)
Thrust (out of section, top-to-the W-movement)
Back-thrust (top-to-the-S/SE- movement)

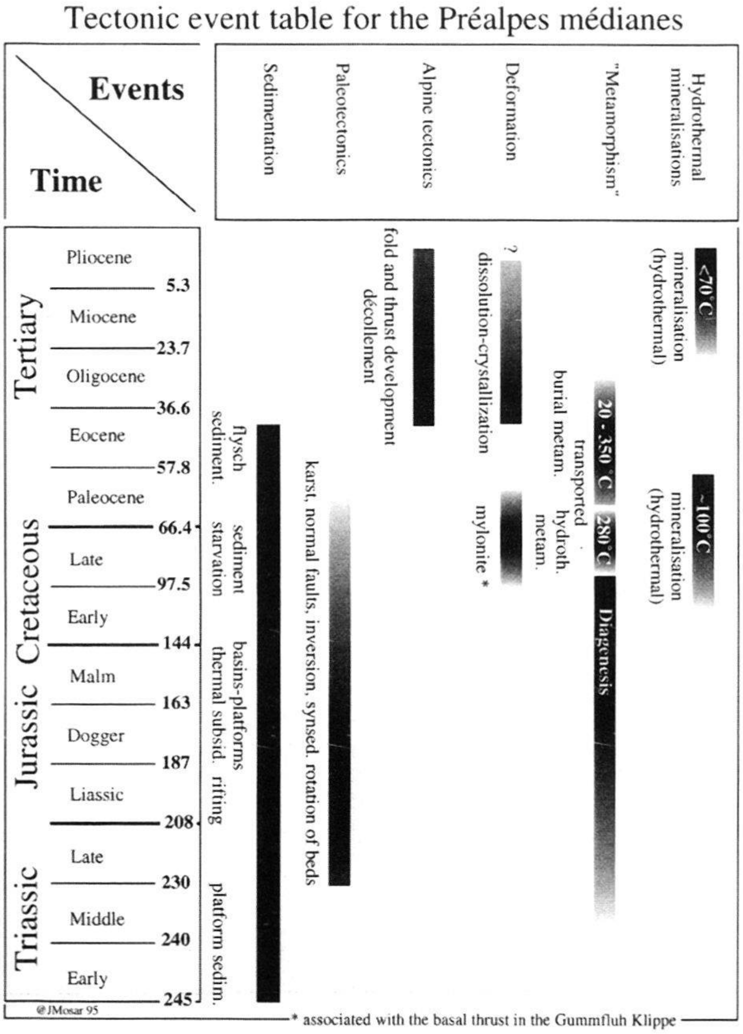


Fig. 3. Time table indicating the different tectonic (synsedimentary and alpine) and "metamorphic" events and their most likely development in time. Detailed discussion is provided in the text. Geological time scale by Odin (1994).

Two major sedimentation realms clearly differentiated since the Liassic: to the N-NW, in the Médianes Plastiques, a large basin is marked by an important thickness of sediments (Fig. 4). To the south this subsiding domain turns into a ramp (associated with a continuously active structural high, the Château d'Oche-Corbeyrier zone; Septfontaine 1983) that gives way since the Dogger to a platform and lagoonal environment in the Médianes Rigides (Baud & Septfontaine 1980). The sedimentary record is by no means complete nor continuous and is quite different in the two major domains. Sedimentary gaps are most important during Liassic times and in the Cretaceous-Tertiary period where hardgrounds may develop. The gaps may either reflect periods of non-deposition or of erosion. The reader can find more detailed descriptions and discussions of the various formations of the Préalpes Médianes in:

Baud (1972; 1984) for the Triassic;
Mettraux (1989), Mettraux & Mosar (1989) and Thury (1973) for the Early Jurassic (Lias);
Septfontaine (1983), Furrer & Septfontaine (1977) and Furrer (1979) for the Middle Jurassic (Dogger);

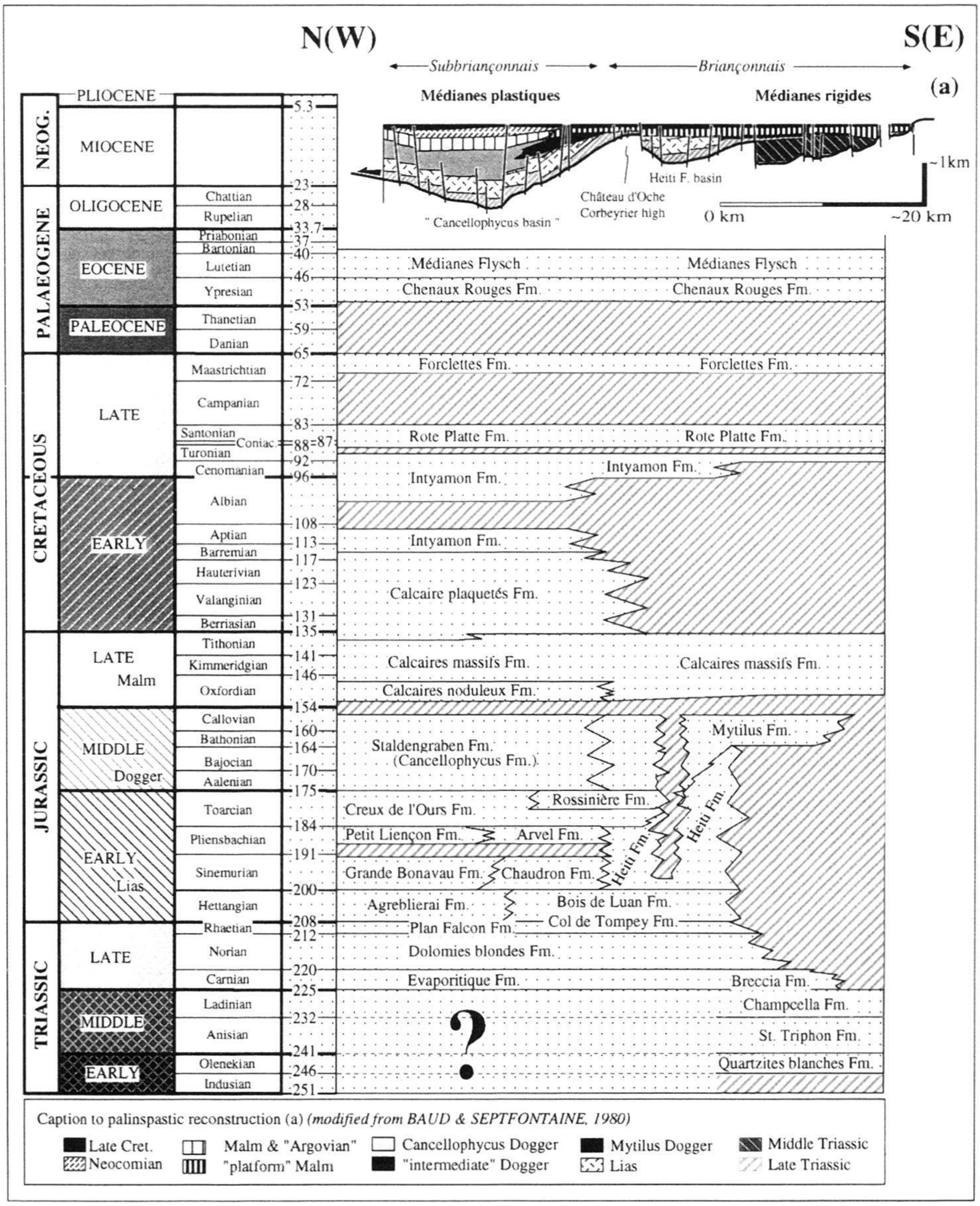


Fig. 4. Stratigraphic table showing the times of deposition and sedimentary gaps (non-deposition and/or erosion) in the Préalpes Médianes Plastiques and Rigides, with the different formation names (references given in the text). Geological time scale by Odin (1994). The simplified palinspastic reconstruction shows the main paleogeographic regions of the Préalpes Médianes (modified from: Baud & Septfontaine 1980).

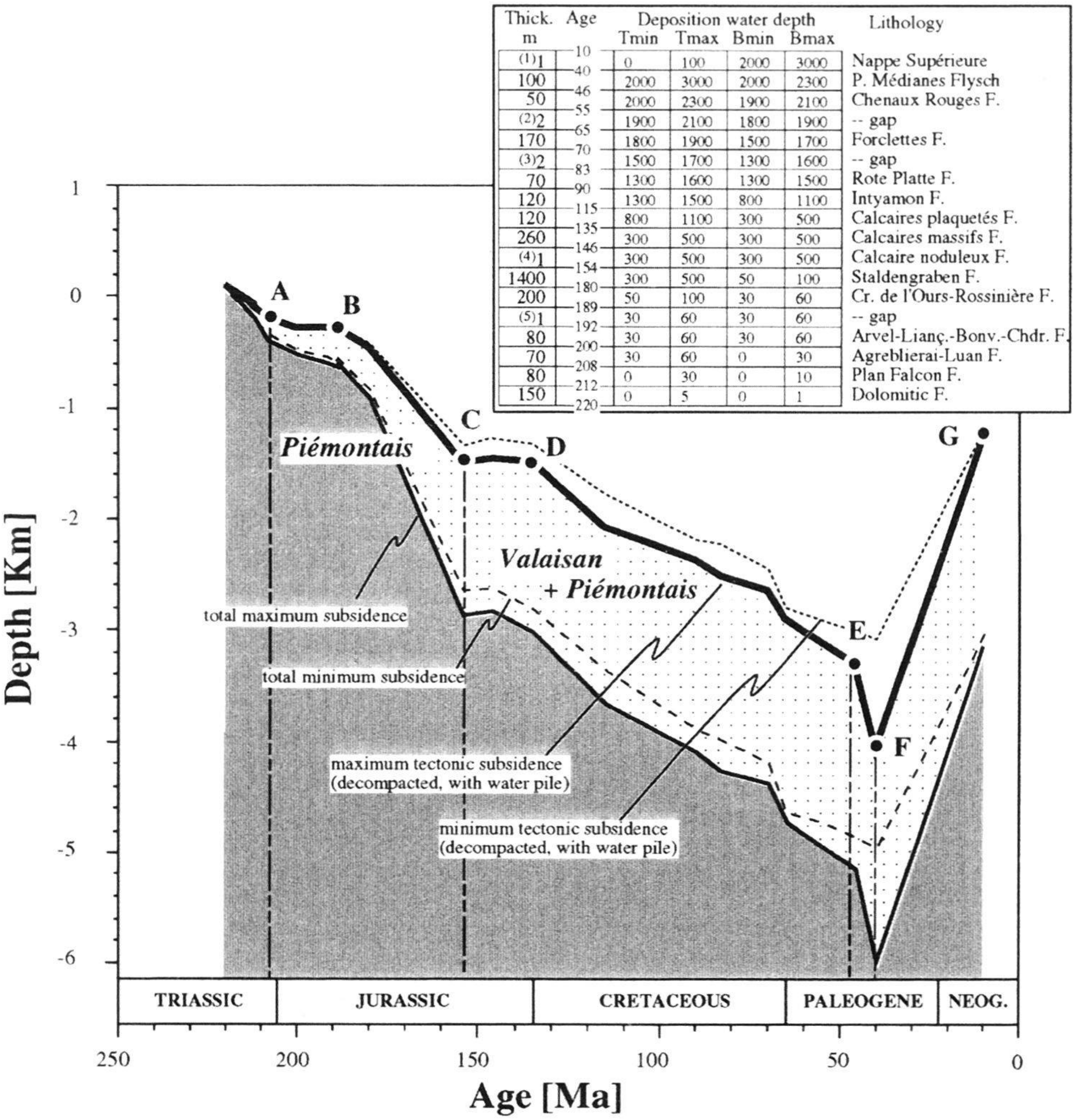
Weiss (1949), Isenschmid (1983), Heinz (1985) and Heinz & Isenschmid (1988) for the Late Jurassic ("Malm");
Boller (1963) for the Early Cretaceous (Neocomian);
Caron & Dupasquier (1989) and Python-Dupasquier (1990) for the "Middle" Cretaceous;
Guillaume (1986) for the Late Cretaceous-Tertiary and Flück (1973) and Caron et al. (1980b; 1989) for the Préalpes Médianes flyschs.

The Préalpes Médianes sedimentation realm has been interpreted in recent years in terms of a rim basin; the Sub-briançonnais (Médianes Plastiques p.p.) and the Briançonnais (Médianes Rigides and Médianes Plastiques p.p.) developing in this rim basin (Stampfli & Marthaler 1990). This basin was located to the N-NW of the Briançonnais upper plate rift shoulder which separated it from the Breccia nappe sedimentation domain to the south containing syn-rift deposits. This upper plate shoulder developed as a consequence of the breakup of Pangea which gave birth to the Alpine Tethys oceanic realm (Piemont ocean; Frisch 1979; Tricart 1984; Debelmas 1989; Favre & Stampfli 1992, 1993; Stampfli & Marchant in press). During the formation of the Valais ocean to the north in Late Jurassic-Early Cretaceous, the Briançonnais domain s.l. evolves as a micro-continent forming the eastern termination of the Iberic plate. Once detached from the Iberic plate, it will be incorporated as exotic Briançonnais terrane into the oblique closure of the Piemont ocean with its accretionary prism and mélange development into which the Nappe Supérieure is also included. The subsequent continental collision and alpine orogen will be discussed in the alpine tectonic chapter.

Based on a synthetic subsidence reference curve for the Médianes Plastiques (Girod 1995) we discuss the different stages of sedimentation and geodynamics (Fig. 5). This curve is based on the most complete and the thickest sediment record in the Préalpes Romandes (Sarine valley; Fig. 2a). The changes in slope of the subsidence curve are compared to geodynamic events occurring in the Tethyan area at a given time. These geodynamic stages are based mainly on thermal evolution except for the final stages of continental collision. Thermal heating due to asthenospheric upwelling, i.e. in a lithospheric fracture zone, will stop any previously ongoing progressive thermal subsidence. This is marked by a "plateau" (or even a slight bulge) in the subsidence curve. The possible oceanisation following this thermal expansion is thought to be expressed on the developing passive continental margins by an initially rapid and then a slower cooling. The subsidence curve will show a steeper slope. The ocean closure and the subsequent collision in an active margin cause a flexural response of the subducting plate in addition to the isostatic re-equilibration. On the subsidence curve this will show as steepening of the slope. General uplift results in a positive slope of the subsidence curve.

The different sedimentary facies and paleotectonic events can thus be integrated into a geodynamic **interpretation** (model) for the plate-tectonic evolution of the Briançonnais s.l. micro-continent. This interpretation is part of a larger scale attempt to re-evaluate the plate tectonics of the Tethyan domain. We chose to integrate data from the Préalpes into this model, aware of its debatable nature.

[i] The platform carbonates that develop during the Triassic period are associated with the thermal subsidence which may be seen as resulting from the opening of the Hallstatt-Meliata ocean (Fig. 5; Stampfli, this volume for references, Stampfli & Marchant in



Thick. m	Age	Deposition water depth Tmin	Tmax	Bmin	Bmax	Lithology
(1)1	10–40	0	100	2000	3000	Nappe Supérieure
100	40–46	2000	3000	2000	2300	P. Médianes Flysch
50	46–55	2000	2300	1900	2100	Chenaux Rouges F.
(2)2	55–65	1900	2100	1800	1900	-- gap
170	65–70	1800	1900	1500	1700	Forclettes F.
(3)2	70–83	1500	1700	1300	1600	-- gap
70	83–90	1300	1600	1300	1500	Rote Platte F.
120	90–115	1300	1500	800	1100	Intyamon F.
120	115–135	800	1100	300	500	Calcaires plaquetés F.
260	135–146	300	500	300	500	Calcaires massifs F.
(4)1	146–154	300	500	300	500	Calcaire noduleux F.
1400	154–180	300	500	50	100	Staldengraben F.
200	180–189	50	100	30	60	Cr. de l'Ours-Rossinière F.
(5)1	189–192	30	60	30	60	-- gap
80	192–200	30	60	30	60	Arvel-Lianç.-Bonv.-Chdr. F.
70	200–208	30	60	0	30	Agreblierai-Luan F.
80	208–212	0	30	0	10	Plan Falcon F.
150	212–220	0	5	0	1	Dolomitic F.

Fig. 5. Synthetic subsidence curves for the Préalpes Médianes sedimentation domain. The synthetic curve is based on data from the Médianes Plastiques basin in the Sarine valley area. The curve corresponds to the maximum tectonic burial curve after decompaction. Circled values refer to the different synsedimentary tectonic periods as described in the text. Geological time scale by Odin (1994).
Table shows the values used for constructing the subsidence curve with the program "Backstripp89" by R. Schegg. Thick. = sediment thickness in meters as observed or estimated. (x) indicate periods of eroded material (1) = 2000m eroded, (2) = 2m eroded, (3) = 0m eroded (no deposit), (4) = 10m eroded, (5) = 40m eroded; Tmin/max = minimum and maximum water depth of formation top; Bmin/max = minimum and maximum water depth of formation bottom. For age attribution and complete names of the different formations see Fig. 4.

press). Deposited in a steadily subsiding, stable shallow water environment, these sediments are the only ones in the Préalpes Médianes where a consistent signature of the interplay with eustatic variations is recorded (Baud 1984).

[ii] A break in the synthetic subsidence curve (Fig. 5-A) is shown by a "plateau" during the Rhetian-Liassic-Early Dogger period (Fig. 5A-B). This event is most likely associated with isostatic rebound related to the initial stages of rift development that eventually leads to the Piemont ocean opening. In our model the ongoing oceanic opening will be followed by extensive thermal subsidence, mainly during Dogger times.

At the beginning of the oceanic opening, during the Rhetian and Liassic, a series of synsedimentary normal faults develop. This ENE-WSW trending fault-system subdivides the Préalpes Médianes into several distinct ENE-WSW oriented sedimentation domains. They are associated with a N-S trending fault-system developing important scarps yielding breccias (Mettraux & Mosar 1989). Fast differential subsidence starts in the southern Préalpes Médianes during the Rhetian, with the associated depocenters subsequently migrating northward. The different small basins that develop are separated by structural highs (Fig. 4), the most remarkable of which is the Château d'Oche-Corbeyrier high (Septfontaine 1983). To the S of this structure develops a deep basin filled by the Sinemurian to Bajocian Heiti Formation (including the Tours d'Aï area) and further S is the Médianes Rigides platform domain. To the N two shallow highs separate three smaller basins. Further to the north three tectonic imbricates (located today in the frontal Médianes Plastiques) form three small domains associated with normal faults (Mosar 1994).

During this period we also see the formation of karst in the Liassic sediments (Mettraux 1989; Mettraux & Mosar 1989) and in the underlying Triassic limestones (Genge 1957; Baud & Masson 1975). Breccias of Late Liassic – Dogger age, indicative of strong erosion, form at the basin/platform transition (ramp) (Baud et al. 1989). Onlaps and erosion are common (Mettraux & Mosar 1989).

A generalized and continuous subsidence is well recorded in the Médianes Plastiques basin (Fig. 5B-C). These sediments are in excess of 1500–1800 m thickness (W of the Vanil Noir in the Sarine Valley, Préalpes Romandes). Important thickness changes occur both perpendicular to the E-W basin axis and along strike. Responsible for these variations are small en échelon synsedimentary listric normal faults. Because of the small size of the basins created by these faults (10 km^2) we suggest that the faults above which they originate are all linked to a "basal" décollement located in the Triassic evaporites. This detachment above which the Préalpes Médianes rim basin (and the listric normal faults) evolves is most likely gravity induced (Bally 1981) due to the small northward slope created by thermal expansion and related rift shoulder uplift to the S. According to this concept, the basement-rooted faults which controlled the Permo-Carboniferous troughs did not significantly affect local Préalpes Médianes paleo-tectonics, unlike proposed so far (Baud & Septfontaine 1980, Sartori 1987, 1990; Mettraux & Mosar 1989; Sartori & Marthaler 1994; Septfontaine 1995). The proposed "model" allows us to explain locally compressional synsedimentary structures such as progressively rotated (up to 100°) sedimentary unconformities (synsedimentary growth folds: Suppe et al. 1992; Septfontaine 1995) developing on a structural high to the N of an inverted listric fault of the Liassic Heiti Formation basin, without invoking reactivation of basement, when the general tectonics are extensional and the general trend is thermal subsidence. Growth structures on faults and folds, fan shaped sedimentary wedges, strong onlaps, slumps and resediments are but some of the more obvious sedimentation structures due to syndepositional tectonics during this period. Although interpreted as resulting from the combined movement along normal listric faults above a major décollement, the synsedimentary structural high of the Château d'Oche-Corbeyrier zone can be compared with the structural high described in the Schams nappe equivalent of the Briançonnais terrain in E Switzerland (Schmid et al. 1990). The authors describe this zone as resulting from transpressive movements forming a flower structure rooted in the basement. During this stage, synsedimentary tectonics are related to the progressive oceanisation with fault development during the Rhetian and Liassic followed by thermal subsidence and gravity induced basin development above shallow normal faults during the Dogger. Transpressive events could mark the onset of rifting in the Valais ocean in mid to late Jurassic times (Late Oxfordian; Stampfli 1993).

Beginning with the Dogger only one large basin remains to the N of the Château d'Oche-Corbeyrier structural high (Fig. 4: "Cancellophycus basin"), separated by a sedimentary ramp from a lagoon and platform to the S (Médianes Rigides; Septfontaine 1983). Progressive onlaps of sediments from the N onto this platform (Malm onto Triassic and Late Cretaceous onto Malm) and the formation of cuestas (Septfontaine 1995) show that this domain has constantly suffered from erosion and non-deposition. This is indicative of the proximity to a rift shoulder in the south (S of Médianes Rigides domain; between Briançonnais and "Ultra-briançonnais" domains). To the S of this rift shoulder the Breccia nappe sedimentation is dominated by breccia deposits from Sinémurian to late Dogger (Jaccard 1904; Schroeder 1939; Gagnebin 1940; Weidmann 1972; Steffen et al. 1993).

[iii] Another important break in the subsidence curve (Fig. 5C) marks the beginning of the "Callovo-Oxfordian phase" of Septfontaine (1983). The "plateau" developing during the final Dogger and Malm and lasting for about 20 Ma indicates a period of little tectonic subsidence (Fig. 5C-D). Malm limestones vary in thickness between 30 and 300 m. Platform carbonates develop to the S in the Médianes Rigides, condensed facies are observed in the transition zone (sedimentary ramp; Château d'Oche-Corbeyrier zone) with the basinal sediments of the Médianes Plastiques (Isenschmid 1983; Heinz 1985; Heinz & Isenschmid 1988). During this period thickness changes in the Malm layers could be enhanced by differential compaction and be associated with listric faults (f.i. former Permian basins or Heiti Formation basin; Girod 1995).

The geodynamic change leading to the development of the Malm "plateau" in the subsidence curve may be explained by a thermal influx due to the opening of the Valais ocean. This rifting separates Europe to the N from the Iberian plate to the S, the Briançonnais domain thus becoming a peninsula. The thermal influence of the Valais ocean formation combined with the thermal subsidence associated with the Piemont ocean phase, lasts for most of the Cretaceous until the Campanian (Fig. 5D-E). The continuing basin infill in the Médianes Plastiques is documented by the 100–150 m thickness of the Early Cretaceous Calcaires plaquetés Formation (Boller 1963). Present in the Médianes Plastiques basin this formation pinches out towards the S in direction of the Médianes Rigides platform along a slope close to an ancient coastline. The pelagites and hemi-pelagites of the Middle Cretaceous Intyamon Formation (Caron & Dupasquier 1989; Python Dupasquier 1990) are followed by the Rote Platte Formation of Late Cretaceous age (Guillaume 1986). The latter is transgressive on the Calcaires plaquetés For-

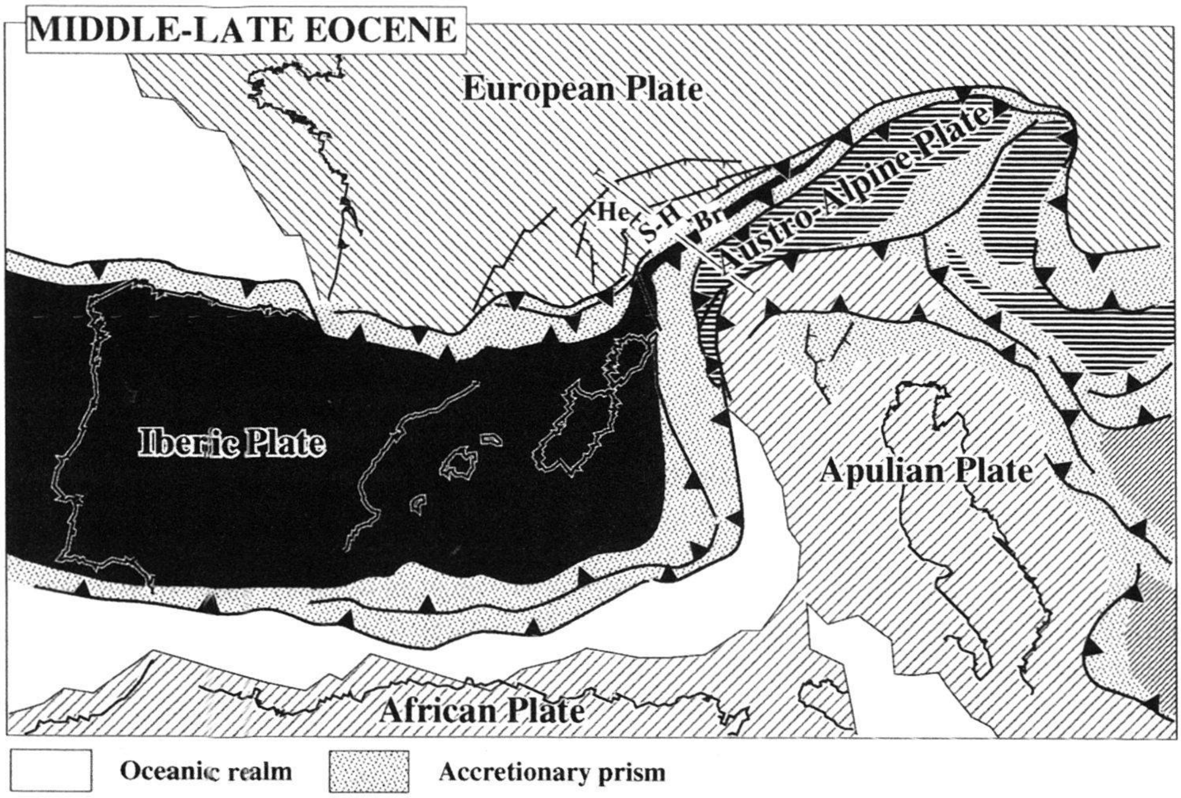
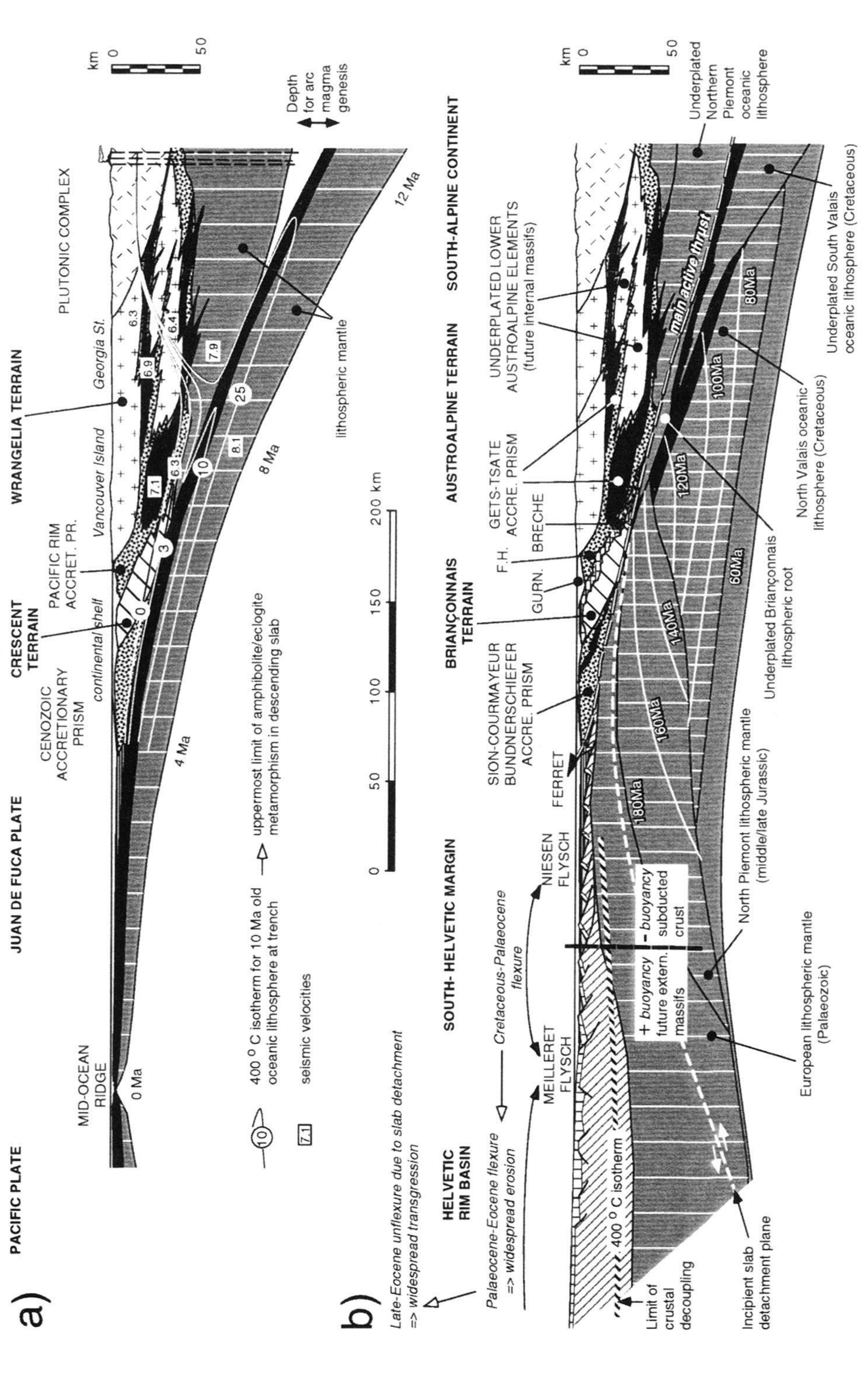


Fig. 6. Middle to Late Eocene palinspastic map of the Alpine region. The Briançonnais (Br) is becoming an isolated terrain being pushed onto the South-Helvetic (S-H) continental margin. The Helvetic domain (He) represents a rim basin along the European continental margin. The Austro-Alpine plate and its Carpatho-Dinaric continuation is being spliced into several segments or terrains incorporated into active margins. The Austroalpine terrain represents the former passive margin of the Apulian plate, already inverted in early Cretaceous. Subduction is also active under the Iberic plate.

Fig. 7. a) Present day cross-section of the N-E Pacific active margin modified from the Lithoprobe transect of southern Vancouver Island (Fuis & Clowes 1993). The 400 °C gradient is taken from van den Beukel (1990). The position of this gradient is indicated for different ages of oceanic lithosphere entering the accretionary prism (25, 10, 3 and 0 Ma). Widespread amphibolitic metamorphism and related hydrothermalism can be expected in the prism when young oceanic crust is being subducted (i.e. when 400 °C gradient crosses from the mantle to the crustal rocks of the descending slab).
b) Mid to Late Eocene (~45-40 Ma) pre-collisional stage of the Alpine orogen (location of cross-section in Fig. 6). For the upper plate the Vancouver Island transect has been used as an actualistic reference frame in order to compare the thermal behaviour of the subducted terrains. Size geometry and juxtaposition of the alpine elements in this upper plate is therefore schematic. In Eocene time the Briançonnais terrain has been detached from its lithosphere and lower crust substratum and pushed onto the North Valais ocean margin. The Briançonnais was first covered by flysch and then by the accretionary prism of the closing Piemont ocean (Gets-Tsaté prism). The Gurnigel flysch (GURN) is the witness of the obduction of this prism but was not necessarily located where shown in the figure. The lower plate represented by the Helvetic margin is affected mainly by changing flexuration behaviour related to the buoyancy of the lithosphere being subducted.


a)
PACIFIC PLATE
JUAN DE FUCA PLATE
CRESCENT TERRAIN
WRANGELIA TERRAIN
MID-OCEAN RIDGE
0 Ma
CENOZOIC ACCRETIONARY PRISM
continental shelf
PACIFIC RIM ACCRET. PR.
Vancouver Island
Georgia St.
PLUTONIC COMPLEX
4 Ma
8 Ma
12 Ma
lithospheric mantle
Depth for arc magma genesis
km 0 50
400 °C isotherm for 10 Ma old oceanic lithosphere at trench
uppermost limit of amphibolite/eclogite metamorphism in descending slab
seismic velocities
0 50 100 150 200 km
b)
Late-Eocene unflexure due to slab detachment => widespread transgression
Palaeocene-Eocene flexure => widespread erosion
Cretaceous-Palaeocene flexure
HELVETIC RIM BASIN
SOUTH- HELVETIC MARGIN
BRIANÇONNAIS TERRAIN
AUSTROALPINE TERRAIN
SOUTH-ALPINE CONTINENT
MEILLERET FLYSCH
NIESEN FLYSCH
FERRET
SION-COURMAYEUR BUNDNERSCHIEFER ACCRE. PRISM
GURN.
F.H.
BRECHE
GETS-TSATE ACCRE. PRISM
UNDERPLATED LOWER AUSTROALPINE ELEMENTS (future internal massifs)
main active thrust
+ buoyancy future extern. massifs
- buoyancy subducted crust
400 °C isotherm
180Ma
160Ma
140Ma
120Ma
100Ma
80Ma
60Ma
Limit of crustal decoupling
Incipient slab detachment plane
European lithospheric mantle (Palaeozoic)
North Piemont lithospheric mantle (middle/late Jurassic)
Underplated Briançonnais lithospheric root
North Valais oceanic lithosphere (Cretaceous)
Underplated South Valais oceanic lithosphere (Cretaceous)
Underplated Northern Piemont oceanic lithosphere
km 0 50

mation in the N, further S on the Intyamon Formation and in the Médianes Rigides on the Calcaires massifs Formation of the Malm.

At the very end of this stage follows a period mainly marked by non-deposition and/or erosion that ends only with the Forclettes Formation of the very final Late Cretaceous. Due to the ongoing geodynamic development of the Valais ocean and the Briançonnais peninsula development, the Préalpes Médianes sedimentation realm is cut from its regular sediment supply and is both starving and drowning. Variations in the subsidence curve steepness indicate changes in thermal subsidence rate as for example around 70 Ma (Fig. 5).

It is during this period that the Briançonnais peninsula is separated to the W from its Corso-Sardinia-Iberia motherland and evolves into an isolated terrain (Maury & Ricou 1983; Ricou & Siddans 1986). At the same time the northern Valaisan margin receives sediments (Niesen nappe flysch) from an uplift located along the southern European margin, possibly related to inversion structures developing in the margin (Figs. 6, 7).

The fact that the Forclettes Formation sediments are deposited during a general period of starvation (period related to an "elevation" by Guillaume 1986) is most likely connected to combined effects of the complex geodynamic situation at that time. The isolation of the Briançonnais terrane may result in some isostatic uplift; the thermal influx caused by the possible subducting towards the S of the still warm Valais ocean may also cause some uplift and a new source of sediments might come from the uplifting of the shear zone between the Briançonnais and Corsica. Eustatic sea level changes as a cause for the sedimentation of the Forclettes Formation may be excluded.

[iv] Following a new 15 Ma sedimentation gap the Briançonnais microcontinent is finally incorporated into the Tsaté accretionary prism (Fig. 6, 7) developing at the expense of the closing Piemont ocean (Marthaler & Stampfli 1989). The load of the thrusted units coming from the S causes the subducting plate to flex (Fig. 5E-F). It is during this period, starting in Early Eocene, that the Chenaux Rouges Formation is deposited (pelagic limestones and clays). This formation begins in the Ypresian and grades into the Préalpes Médianes flysch formation. These are the youngest sediments preserved in the Préalpes Médianes sedimentation realm. The portion of the synthetic subsidence curves associated with this last stage has a steeply inclined concave shape. The great depth is suggested by the fact that the red clays at the transition between carbonates and flysch were deposited below the CCD.

Except for a N-S and an ENE-WSW trending normal fault system with small displacement, no local tectonic disturbances are known from this period. The small faults (Guillaume 1986; Python Dupasquier 1990) cause local and small changes in depositional thickness. Occassionally breccias along fault scarps may be expected. These breccias become quite important in the Briançonnais domain in France (Chaulieu 1992).

[v] The final stage is represented as a steep positive slope between 40 Ma and 10 Ma (Fig. 5F-G). This portion of the synthetic subsidence curve is based on the eroded sediments of the thrust Nappe Supérieure whose thickness is estimated to about 2000 m (based on studies of very low-grade metamorphism, Mosar 1988a). The Préalpes Médianes plus the supported Nappe Supérieure and Breccia nappe were subsequently uplifted during continental collision. The uncertainties in timing of the thrusting (events taking place between 40 and 10 Ma) allowed only to construct one single straight segment for the subsidence curve during these post-sedimentation events.

Alpine tectonics

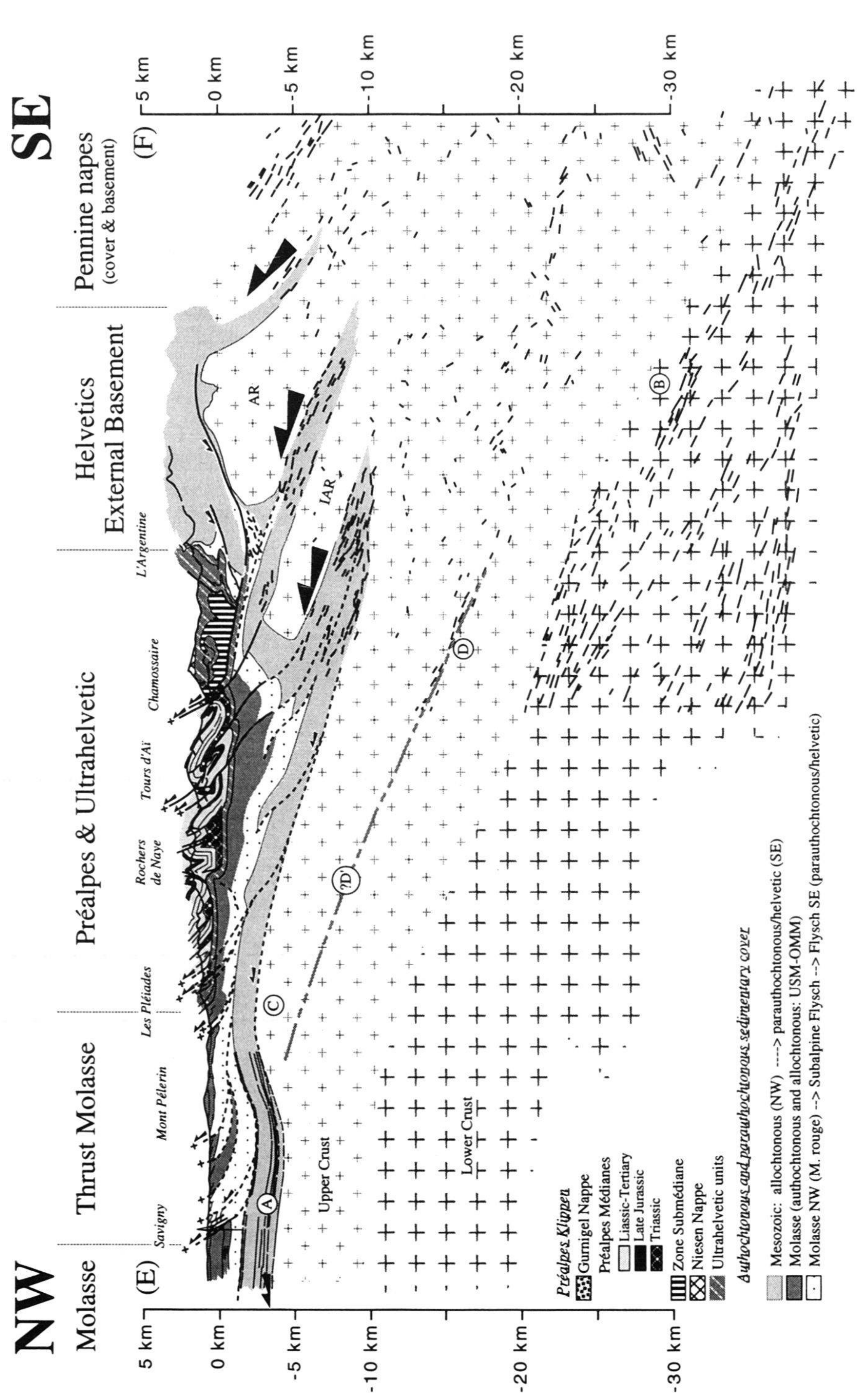
Alpine tectonics in the Préalpes Médianes start with the end of sedimentation during Late Eocene (Bartonian) and their complete involvement in the active accretionary prism at the front of the developing Alpine mountain belt. This corresponds to the beginning of the continental collision stage resulting from the final closure of the Piemont ocean. The Valais ocean is at this stage almost closed (hence largely subducted) and the European continental plate starts subducting beneath the accretionary prism. While most of the Briançonnais terrain suffers intense thick-skinned deformation (with basement involved) and high-grade metamorphism during this Meso-alpine phase (Steck & Hunziker 1994), the Préalpes Médianes are detached from their substratum and suffer thin-skinned tectonics. Although these cover nappes may reach a total of some 10 km no basement is involved, they represent "cover nappes" according to the definition of Escher et al. 1993. This décollement occurs where evaporite series were present near the base of the sedimentary cover (Fig. 4). The areas devoid of this evaporite formation, such as the Barrhorn series (considered as the lateral equivalent of the Médianes Rigides) stick to their Pennine homeland (Trümpy 1955; Sartori 1990; Sartori & Marthaler 1994). Consequently a thick-skinned tectonic regime develops "basement nappes" (Escher et al. 1993). The differences in distribution of the evaporite series is thought to be controlled by N-S trending syn-sedimentary paleofaults. Thus the Médianes Rigides and the Médianes Plastiques were detached from the Siviez-Mischabel nappe basement and from the Pontis nappe, respectively. They have been substituted by a new "cover": the Mont Fort nappe (Sartori 1990; Escher et al. 1993). The main detachment is thought to occur after the arrival of the Nappe Supérieure onto the Préalpes Médianes during the Bartonian-Priabonian, coeval or slightly postdating the cessation of sedimentation (Bartonian).

In the following we will discuss the formation of the Préalpes Médianes fold and thrust belt first from the perspective of large-scale structural development, then from the point of view of internal rock deformation associated with the larger scale structures and finally in a more general environment of alpine tectonics.

Structural geology

Three distinct structural domains can be recognized in the Préalpes Médianes (Lugeon & Gagnebin 1941; Plancherel 1979; Mosar 1991): the Médianes Plastiques to the N are formed by a series of large fault-related synclines and anticlines, the Médianes Rigides to the S by several sets of large imbricates and in between lies a unit with intermediate features, the Gastlosen–Tours d'Aï chain (Fig. 1, 2a, 8).

[i] The Médianes Plastiques are bordered to the North and the South by the Nappe Supérieure (Gurnigel nappe to the N and Simme nappe in the Corbeyrier-Château d'Oex-Simmenthal syncline). The external, northernmost zone sees the characteristic development of several, mostly three, imbricates. The fault-bend fold style is dominant although some open upright folds, as in the Moléson (Gruyère) area (Mauve 1921) and even tight overturned folds may form (Gagnebin 1922, 1924; Peterhans 1923; Mosar 1991, 1994; Weidmann 1992). The thrust ramps often terminate with one or several splays. The southernmost part of the Médianes Plastiques, along the N limit of the Corbeyrier-Hongrin-Châteaux-d'Oex syncline, forms the transitional Dt d'Oche – Sex de la Sarse zone from the Médianes Plastiques to the Médianes Rigides sedimentation domain.


NW
SE
Molasse
Thrust Molasse
Préalpes & Ultrahelvetic
Helvetics
External Basement
Pennine napes
(cover & basement)
(E)
(F)
Savigny
Mont Pélerin
Les Pléiades
Rochers de Naye
Tours d'Aï
Chamossaire
L'Argentine
5 km
0 km
-5 km
-10 km
-20 km
-30 km
Upper Crust
Lower Crust
AR
IAR
A
B
C
D
?D'
Préalpes Klippen
Gurnigel Nappe
Préalpes Médianes
Liassic-Tertiary
Late Jurassic
Triassic
Zone Submédiane
Niesen Nappe
Ultrahelvetic units
Authochtonous and parauthochtonous sedimentary cover
Mesozoic: allochtonous (NW) ---> parauthochtonous/helvetic (SE)
Molasse (authochtonous and allochtonous: USM-OMM)
Molasse NW (M. rouge) --> Subalpine Flysch --> Flysch SE (parauthochtonous/helvetic)

The basinal Cancellophycus Formation series from the Dogger are thinning and by means of a transitional facies (Sommant Formation, Septfontaine 1983) turning into lagoonal facies of the Mytilus Formation; the Early Cretaceous Calcaires plaquetés Formation is missing (Fig. 4).

Folds and thrusts are oriented E-W in the eastern Médianes Plastiques Romandes and have a more NE-SW, and even N-S, orientation in the western part (Jeannet 1922; Plancherel 1979). The Jaun-lac Noir N-S to NNE-SSW sinistral strike-slip zone is the dominant structural feature separating these two domains (Jeannet 1922; Plancherel 1976, 1979). A similar change in trend of the main structures of the Médianes Plastiques can also be observed in the Chablais Préalpes.

Fault-propagation and/or detachment type folds seem to prevail, though synclinal and anticlinal breakthrough thrusts are common. Box-fold shaped structures are another frequently observed fold style, such as in the Dent de Broc anticline (Chassé 1924) or in the Rochers de Naye-Vanil Noir synclines (Wengen 1924; Revertera 1926). Folds and associated thrust planes die out laterally, resulting in the lateral transfer of displacement to other "en échelon" arranged fold-thrust structures (Bieri 1925; Nicol 1956; Mettraux & Mosar 1989; Mosar & Borel 1993). These transfer zones are locally associated with tear faults, which are kinematically linked with the fold-associated thrust planes (Mosar & Borel 1992). Displacements are left-lateral along N-S to NNE-SSW oriented tear faults and right-lateral along NW-SE to WNW-ESE oriented faults. Stress directions associated with thrusts and tear faults were calculated using fault/striae analyses and show a general NW-SE orientied compression direction. Fold interference structures, giving way to very tight folds, result from the simultaneous development of neighboring anticlines, as in the Col de Chaude area of the Tinière-Dorena anticline (Plancherel & Weidmann 1972).

Thrust surfaces are generally dipping towards the SE, as are fold axial planes. Only when closely spaced fault-related folds form imbricated stacks, are they overturned and dipping towards the NW such as in the Gantrisch area of the eastern Médianes Plastiques (Plancherel 1979; Mosar 1991). This type of overturning mechanism is related, in the Médianes Plastiques, to a thrust and fold development sequence progressively moving towards the N-NW foreland.

Fig. 8. Crustal cross-section of the frontal Alps along the N side of the Rhône valley (Fig.1 for location). The section has been constructed based upon existing surface (Badoux et al. 1960; Badoux 1965; Weidmann 1988; Badoux et al. 1990; Weidmann 1992; Mosar 1994) and subsurface data (Escher et al. 1993). (A) data from Sommaruga (pers. comm.) from the S Molasse, work in progress at Neuchâtel University, see also: Gorin et al. 1993; Marchant 1993; (B) seismic data and original interpretation are to be found in Steck et al. in press. The cross-section is not balanced at depth due to lack of information. Thrusts and imbricates beneath the Préalpes are to be considered as possible solutions that may help explain surface structures and a way in which the present day mountain front evolves. Thus the out of sequence thrusts that cut the whole Préalpes nappe pile are thought to be related to these thrusts at depth and the developing basement imbricates. (C) refers to "basement high" that may be explained in different ways: imbrication and duplexes in the sedimentary cover, inversion of a former permo-carboniferous trough or antiform developing above a newly developing basement imbricate whose basal thrust or rather shear zone (D') may connect to the seismic reflectors indicated by (D).

Overturned to recumbent large-scale folds are found in the Chablais Médianes Plastiques. With its isoclinal geometry and its axial surface dipping at a shallow angle to the S, the Cornettes de Bise syncline is but one of the most spectacular ones (Chamot 1961; Badoux 1962a; Girod 1995).

Although described very early, backthrusts (top-to-the-S movement) appear to be a widespread structural feature (Schardt 1893a; Wengen 1924; Revertera 1926). They appear to develop in two distinct types of situations. Associated with ramps between two flats of a fault-bend fold, or together with breakthrough thrusts near the core of fault-propagation type anticlines thus forming pop-up structures in a crestal position. A second type is linked to anticlines showing important thickness changes between two adjacent limbs. Those changes are thought to be due to former synsedimentary normal faults, that are later inverted to form backthrusts. The most prominent of these backthrusts is in the Tsavas-Millets anticline along the E slopes of the Sarine valley (Fig. 2a). The Dogger series change thickness from 2000 m on the W limb to 500 m on the E limb.

The general thrust direction is to the N-NW (Mosar 1988b, 1991) except for some thrusts found in the western termination of the Médianes Plastiques near Montreux (Mosar 1994). This area forms a structural high above the Rhône valley and the Léman lake, with its structures steeply plunging towards the NE into the Sarine valley. From their geometry and their intersection of strata in the hangingwall it appears that some of the N-S trending thrusts indicate a movement towards the W (Fig. 2).

[ii] The Gastlosen-Tours d'Aï structure is located to the S of the transitional zone from the Médianes Plastiques to the Médianes Rigides sedimentation domain. In this domain the series of Malm age may rest directly on top of the Liassic Heiti formation or even the Triassic in the Tours d'Aï area (Fig. 4a).

To the N as well as to the S this structure is bordered by the Nappe Supérieure units (Chenevart 1945; Page 1969; Müller & Plancherel 1982). As between the E termination of the Tours d'Aï anticline (Jeannet 1912–1913) and the Laitemaire imbricate (Campana 1943), virtually all of the structure is "buried" underneath the Nappe Supérieure. Some small imbricates, that we propose to group with the Gastlosen-Tours d'Aï structure, can be seen in isolated outcrops N of the main structure in the Corbeyrier-Hongrin-Château d'Oex syncline. Based on stratigraphic criteria the Gastlosen-Tours d'Aï domain has been subdivided into two different zones (Baud 1972): a) the Gastlosen zone between the Laitemaire to the W and the Mittagflue near Boltigen to the E (Médianes Rigides externes) and b) the Tours d'Aï – Grande Eau valley – Etivaz (Gorges du Pissot) area and the imbricates N and E of Boltigen along the Simme valley in the E Préalpes Médianes (Médianes Plastiques internes).

The tectonic imbricates or folds form above thrusts dipping to the S-SE. In the central Gastlosen-Laitemaire portion of the Préalpes Médianes Romandes we observe a large imbricate sometimes with one or two small splays (Fig. 2). In the eastern part, in the Simmental area this structure is found as far east as Boltigen and is absent further east (Bieri 1946). It has been speculated that its equivalent might be hidden below the Médianes Rigides south of the Simme valley (Mosar 1991).

In the western part in the Tours d'Aï and the Etivaz (Gorges du Pissot) area, the structure forms a large anticline with a vertical, thinned northern limb. To the S, the Tours d'Aï anticline connects to the Leysin syncline which is cored by the Nappe Supérieure. The Tours d'Aï anticline has a periclinal closure dipping by some 20° towards the NE and disappears beneath the Nappe Supérieure S of lake Hongrin, only to be seen again in the Etivaz window. NE of here he fold "transforms" into several imbricates.

The subdivision of the Tours d'Aï-Gastlosen zone, based on sedimentological criteria is also reflected by the differences in structural geology: large fold (possibly fault-propagation type) in the Tours d'Aï-Etivaz portion and imbricate (probably fault-bend fold type) in the Laitemaire-Gastlosen portion. However, unlike the N-S juxtaposition proposed by paleogeographic criteria, we suggest here that the two zones form a lateral continuity with the original paleogeographical trends oblique to them.

[iii] The trailing part of the nappe, the Médianes Rigides, is a N/NW-dipping thrust sheet, although locally there are one or two minor imbricate thrusts (Fig. 2a). The imbricates are gently north-dipping in the east (Spillgerten-Niederhorn area; Jaccard 1904; Rabowski 1912, 1920), while in the west (Rübli-Gummfluh) they dip more steeply (Jaccard 1907; Dubey 1962; Dousse 1965; Lonfat 1965). The major thrust sheets form fault-bend like folds that are cut by a large backthrust through the layers in the hangingwall of their ramps. Because the fault-bend fold structure has been tilted to the NW (its present day position), the backthrust and associated splays suffered a rotation and hence appear as normal faults with the southern compartment downthrown by 200–400 m (Jaccard 1904, 1907; Mosar 1991). The backthrusts cut not only through the Médianes Rigides but also through the overlying Breccia nappe and Nappe Supérieure. Thus these two nappes have been emplaced on the Médianes Rigides before the fault-bend fold and the associated backthrust developed (Mosar 1991). In the Mont d'Or and the Grande Eau, the Médianes Rigides are reduced to slices consisting of series of Triassic age only (Fig. 1). Moreover, these slices (embedded in the Zone Submédiane) are overturned and dipping to the S-SE. A similar slice in the Rhône valley, the Saint Triphon klippe, is in an upside down position and completely detached from the rest of the Préalpes Médianes. Because of its isolated position the connection of the Saint Triphon klippe with the Médianes Rigides has remained speculative and several solutions, from a lateral or frontal portion of the inverted Médianes Rigides folded imbricate (Weidmann et al. 1976; Escher et al. 1993), to a detached slab torn off during Late Tertiary to Quaternary times and emplaced independantly of the structural evolution of the Préalpes Médianes (Badoux 1962b) have been proposed.

The different Médianes Rigides imbricates are mostly surrounded by terrains belonging to the Zone Submédiane, except where covered by the Breccia nappe. Between the Gummfluh-Rübli imbricates and, to the N and W, of the Mont d'Or inverted imbricate the Zone Submédiane (called locally "Petite fenêtre mitoyenne" as opposed to the "Grande fenêtre mitoyenne" for the major part of the Zone Submédiane, Lombard 1975; Weidmann et al. 1976) is in contact with the Nappe Supérieure (Fig. 1). Between the Grande Eau valley and the Hongrin lake this contact has a N-S direction (it juxtaposes Zone Submédiane to both the Nappe Supérieure in its N portion and to the Préalpes Médianes in its S section) suggesting thrusting of the Zone Submédiane onto the Nappe Supérieure and the Préalpes Médianes, probably in a westerly direction.

Especially in the Gummfluh-Rübli imbricate the large faults and thrusts are numerous and form a number of small slices. Next to inverse and normal displacements, strike-parallel movements, along more or less NE-SW oriented fault zones, appear to be more important than previously thought.

Internal deformation

The internal deformation of limestones from the Préalpes Médianes was measured using the distortion of pellets as well as twinning of sparitic calcite (Mosar 1989). The strain intensity in the frontal Médianes Plastiques is very low and dominated by transgranular deformation mechanisms, mainly pressure solution, with weak development of calcite twins. The weak slaty cleavage is parallel to the fold axial surface (Mosar 1989, 1991). This deformation corresponds to an "early" shortening parallel to bedding emphasized by the development of tectonic stylolites and an early rock cleavage. Due to the shearing induced by the arrival of the Nappe Supérieure on top of the Médianes Plastiques, small scale metric folds developed near the basal thrust in the Late Cretaceous marls and limestones (Mosar & Borel 1993). These folds are aligned on a great circle (on the stereonet projection) subparallel to the thrust surface and indicate a transport direction towards the NW.

The strain increases going into the more internal Médianes Rigides where intragranular deformation mechanisms, such as twinning (numerous large, curved and twinned twins) and dynamic recrystallisation, prevail. The most intense strain is associated with large scale shearing due to thrusting on the basal décollements of the Préalpes Médianes nappe and of the overlying Breccia nappe. The calculated finite extension is parallel to the general NW transport direction in the vicinity of the thrust planes. This is corroborated by the flat lying rock cleavage, mainly in the Late Cretaceous rocks at the top of the Médianes Rigides (Mosar 1989, 1991). Elsewhere in the Médianes Rigides nappe the extension direction is oriented at a high angle to the thrust planes, reflecting early shortening similar to that recognized in the Médianes Plastiques.

In the Gummfluh klippe a mylonitic layer has been described at the base of the imbrication above the underlying Zone Submédiane and Niesen Nappe (Baud & Masson 1976; Cosca et al. 1992). Intense folding (cm to dm scale folds in Triassic limestones) has not been studied yet, but appears to be associated with intense thrust-induced shearing at the basal décollement of the Médianes Rigides.

A strong cm to m thick cataclasis and locally a crenulation cleavage developed along some of the larger strike-slip faults as well as in the ramp-associated backthrust in the Médianes Rigides or along thrust surfaces (Mosar 1988b; 1989; 1991; 1993).

Veins with calcite filling are ubiquitous, but only rarely are regular and well developed systems recognized, even more rarely two systems with cross-cutting relationship enabling relative chronological dating. One such example in the Dogger formation from the Médianes Plastiques seems to have formed before and during folding (Mosar 1988b).

Anhydrites and gypsum from the Zone Submédiane have suffered strong deformation during the different tectonic events. Field observations and measurements from well log data have shown the existence of two directions of small scale fold axes: one N-S the second NE-SW (Zahner & Mosar 1993). They may be explained in terms of two superposed tectonic events; one associated with NW directed thrusting of the Préalpes Médianes, the other possibly related to W directed movements most likely after the Préalpes were emplaced in their present day position. The actual timing of these events remains speculative due to the uncertainty of the structural relationship between the Préalpes Médianes and the Zone Submédiane.

Because of their controversial origin and their ubiquity in the Préalpes, cornieule (also called cargneules or Rauhwacke (Weidmann 1971)) deserve a brief review. They are chemical breccias with honeycomb aspect due to preferred dissolution of dolomite clasts with respect to the calcite cement. Mainly three possible origins for this type of breccia have been proposed: i- a sedimentary Triassic or Tertiary origin (Schardt 1884; Brunnschwiller 1948), ii- a chemical genesis by dissolution and de-dolomitization during the Late Tertiary and the Quaternary (Brückner 1941; Jeanbourquin 1988), iii- a tectonic origin (Leine 1971; Masson 1972). The latter hypothesis proposes a mechanism of hydraulic fracturing in Triassic dolostones, which creates a high pressured fluid mush weakening and lubricating thrust surfaces (Masson 1972; Masson et al. 1980).

Recent studies in the Alps (Müller 1982, Jeanbourquin 1986, 1988; Amieux & Jeanbourquin 1989; Jeanbourquin & Lualdi 1994, Schaad 1995) clearly demonstrate that the cornieules are chemical or collapsed breccia formations evolving either directly or indirectly from evaporite sequences during Tertiary or Quaternary times. These transformations testify to high amounts of fluids circulating in these sheared Triassic sequences during the telogenesis.

The fact that most occurrences of cornieule are associated with or result from the transformation of Triassic dolostones is readily explained because major décollement levels are precisely located in evaporite layers (base of Middle and Upper Triassic in the Préalpes Médianes). The deformed evaporites, and the accompanying fault gouge (breccias and cataclasites) resulting from the important heterogeneous deformation imposed by thrusting, make these sequences prone to "cornieulisation". Thus, in the end several processes may have operated within the very same material. This renders their comprehension difficult.

Tectonics at the scale of the Alps

In order to discuss the position and tectonics of the Préalpes in their larger present-day tectonic setting we constructed a cross-section extending from the autochthonous Molasse to the N, through the western termination of the Préalpes, to the external basement massifs of the Aiguilles Rouges (Fig. 8). This cross-section on a crustal scale is based on surface data along the profile as well as subsurface data from seismic investigations (petroleum prospection under the thrust Molasse and NFP20 survey below the Helvetics). No subsurface data are available below the Préalpes in this area. Classical cross-sections through this portion of the Alps (Escher et al. 1993) rely on projection of information into the section datum plane from distances up to 25 km. Except for the 10–12 km projection of the seismic data under the Helvetic from the Chablais Préalpes, the construction of Fig. 8 did not use long distance projections. The cross-section shows a rather flat sole of the Préalpes Médianes close to sea-level (Mosar 1991; Vollmayr 1992). The folds and thrusts shown at depth beneath the Préalpes in the parautochthonous sedimentary cover (Jurassic and Molasse) are speculative and meant to highlight a kinematic process that can be related to structures observed in the Préalpes cover nappes and the thrust Molasse.

Pebbles in the Subalpine Molasse of the Mont Pélerin area find their origin in the Nappe Supérieure (Trümpy & Bersier 1954). These sediments of Chattian age are deposited on arrival of the Préalpes on the alpine foreland. Folding and thrusting of the Subalpine Molasse units thus can be considered post-Préalpes Médianes and hence post-Nappe Supérieure emplacement.

Inside the Préalpes Médianes several thrusts clearly hint at late post-emplacement movements. Thus the Tours d'Aï fault-propagation fold has developed a breakthrough thrust that brings it on top of the northerly adjacent isoclinal Corbeyrier syncline which is cored with Nappe Supérieur sediments. At the base of this syncline another late thrust can possibly be traced all the way along the Châteaux d'Oex syncline up to a position W of the Laitemaire imbricate. The transition from the Médianes Rigides to the Médianes Plastiques is mostly hidden under the Nappe Supérieure cover (Simme and Sarine valleys). A thrust juxtaposes the overturned Grande Eau Médianes Rigides imbricate to the Leysin syncline of the Médianes Plastiques in the Col des Mosses – Grande Eau area (Baud 1972). To the N of the overturned Mont d'Or slice the transition is by means of the Zone Submédiane, assimilated here to a broad and diffuse shear zone. The movement along these thrusts or shear zones (Fig. 8) is thought to be post-emplacement (post-Oligocene) and may possibly be linked at depth to the imbrications developing in association with basement thrusts such as the Infra Aiguilles-Rouges slice (Caron et al. 1989; Escher et al. 1993).

Along the base of the Médianes Rigides, at the contact with the underlying Niesen Nappe, we always observe the Zone Submédiane. The presence of at least two fold axial directions in the evaporites possibly indicates a multiphase deformation history for this zone, one of which may be associated with the post-emplacement movements. NE-SW trending fold axes may have developed during the fold and thrust development and the emplacement of the Préalpes Médianes, while a N-S trending set of folds may be linked to later west-directed movements. The N-S oriented contact of the Zone Submédiane directly on top of the Tours d'Aï periclinal closure (Zone Submédiane against Nappe Supérieure) may be linked to late thrusting thus further substantiating the existence of such west-directed movements. These W-directed movements, probably post-Oligocene in age, are not without recalling the large W and SW directed Oligocene to Quaternary movements in the Central and SW (French) Alps (Steck 1990; Mancktelow 1992; Seward & Mancktelow 1994; Steck & Hunziker 1994).

Further evidence for post-emplacement thrusting is found in the western termination of the Médianes Plastiques E of Montreux (Fig. 1, 2b). Thrusts with a top to the W movement have been identified in this area. They are related to the structural high developing in the western termination of the Médianes Plastiques Romandes. Indeed between this area and the central Sarine valley syncline the base of the Médianes Plastiques plunges to the E-NE and drops from an altitude around +500 m to –1200 m (Fig. 2). This structural high appears to be related to a doming in the basement as indicated by seismic profiles (Fig. 8; Marchant 1993). This high is especially noticable in the Chablais Préalpes Médianes and we think is at the origin of the westward thrusting and the development of a structural high in the western termination of the Médianes Plastiques Romandes. This structure is no longer visible further E than the Montreux area. The origin of the structural doming in the basement remains controversial. Thus an inverted Permo-Carboniferous trough has been invoked (Gorin et al. 1993). Alternatively it could represent the frontal part of a newly developing basement thrust whose detachment horizon could correspond to a shear zone possibly represented by a set of reflectors in the crust under the Infra Aiguilles-Rouges nappe (Escher et al. 1993; Steck et al. in press). Similar basement imbricates are described under the Alpine foreland SE of the Chablais Préalpes beneath the Annes and Sulens klippen (Guellec et al. 1990). A further possibility could imply the development of a duplex structure in the sedimentary cover. Only further detailed seismic investigation may help resolve this problem.

Post-emplacement thrusting is also recognized in the neighbouring structural units (Fig. 1, 8):

- thus the Gurnigel nappe is found north of the Médianes Plastiques which indicates that when the Nappe Supérieure was emplaced on top of the Médianes Plastiques this transport went beyond the N edge of the Préalpes Médianes nappe. The fact that the Gurnigel nappe is overturned in its S portion and overridden by the Médianes Plastiques indicates thrusting after the Préalpes were emplaced in front of the Helvetic nappes.
- inside the Gurnigel nappe lenses of Molasse and Ultrahelvetic rocks are located along a thrust plane that brought them to the surface from underneath thus indicating, in our opinion, a late post-emplacement thrusting.
- a similar feature of a breaching thrust surface along with Molasse lenses transported from underneath the Préalpes nappe stack, is found at the tectonic contact between Gurnigel nappe and the Ultrahelvetic unit at the front of the Préalpes, thus indicating that this tectonic contact is a post-emplacement thrust.
- the outermost N Préalpes are in contact with the Subalpine Molasse by means of a belt of "wildflysch" and Lower Marine Molasse. The northern thrust bounding this zone cuts the existing thrusts in the Subalpine Molasse indicating yet another post-emplacement thrusting.

The orientation of the three latter thrust surfaces is NNE-SSW to N-S hinting to a possible westward movement similarly to the late movements and thrusts described in the Préalpes Médianes.

Evidence for late thrusting postdating the development of folds and thrusts in the Molasse substratum, is found in the E Chablais area. Here Molasse bedding and structures do not have the same orientation as those in the overlying Médianes Plastiques by which they appear to be cut.

Work in progress in the Chablais Préalpes Médianes shows the importance of large strike-slip faults cutting the existing fold and thrust structures. This system of conjugate faults trending N-S and WNW-ESE thus postdates the main folding and thrusting event and corresponds to a late post-emplacement event.

Structural development and chronology

The alpine "deformation" in the Préalpes Médianes starts with the final closure of the Valais and the Piemont oceans. Relevant information about the timing of this event come from the depositional age of the youngest flysch sediments of the different Préalpes nappes (Caron et al. 1980a, 1989; Winkler 1984; Wildi 1985; Homewood & Lateltin 1988). Indeed, these deep marine sediments of detrital and orogenic character, are directly related to the mountain building process of the Préalpes and Alps (Studer 1827; Schardt 1893b; Tercier 1948; Homewood & Lateltin 1988; Caron et al. 1989). The Préalpes Médianes flyschs range in age from Middle to Late Eocene (Lutetian-Bartonian). In the Nappe Supérieure the oldest flyschs are of Turonian to Maastrichtian age, while the youngest ones, found in the Gurnigel nappe, are Maastrichtian to Bartonian in age. In the Niesen nappe the oldest flyschs are Maastrichtian in age and the youngest ones Lutetian. The most recent orogenic deposits of the Préalpes are the Ultrahelvetic flyschs with their Lutetian to Bartonian age.

We thus suggest a tectonic convergence that first reaches the Nappe Supérieure sedimentation domain (with the Gurnigel nappe being involved later than the rest of the Nappe Supérieure units). The Préalpes Médianes are second, while the Niesen nappe and finally the Ultrahelvetic units register the youngest sedimentary development of the Préalpes.

In the Médianes Rigides, the Nappe Supérieure is emplaced on top of the Breccia nappe which itself rests on top of the Médianes Rigides. Because a large backthrust associated with the Médianes Rigides ramp fold formation cuts these three units, their emplacement has to be prior to the fold and thrust development in the trailing Préalpes Médianes. Since the Nappe Supérieure is folded with the Médianes Plastiques, its emplacement had to predate the fold and thrust development in this portion of the Préalpes Médianes. The arrival of the Nappe Supérieure and the Breccia nappe on top of the Médianes Plastiques caused strong shearing at the contact thus developing a strong deformation with a finite extension parallel to the transport direction. The very northern portions of the Nappe Supérieure (mainly the Gurnigel nappe) have traveled further than the present day northern limit of the Préalpes Médianes, since we find them resting on top of Ultrahelvetic beyond the northern and northwestern edge of the Médianes Plastiques.

We thus can propose an emplacement sequence as follows: Nappe Supérieure on Breccia nappe and Médianes Rigides (possibly also on Médianes Plastiques); Breccia nappe (carrying the N. Supérieure) on Médianes Rigides and Nappe Supérieure on Médianes Plastiques.

It is only after this emplacement during Bartonian times that the Préalpes Médianes detach from their homeland and undergo thin-skinned tectonics in the shallower part of the accretionary prism active at the front of the growing alpine orogeny. The undetached homeland cover, such as the Siviez-Mischabel or the Pontis nappes sedimentary series and the basement are incorporated in the deeper part of the forming mountain belt and suffer high-grade metamorphism and strong deformation. The basement is subducted and underplated to form the eclogitic root zone of the orogen (Marchant & Stampfli in press).

The emplacement on top of the Ultrahelvetic units, the Helvetic nappes and the Niesen nappe development (Steck 1984) are so far poorly understood. Investigation in the Ultrahelvetic mélanges (Jeanbourquin et al. 1992; Jeanbourquin 1994), however, reveal evidence for "early" (Tertiary) deformation developed in the accretionary prism below the overriding Pennine nappes.

In the Préalpes Médianes layer-parallel shortening indicates a general compression and deformation just prior to folding and thrusting. The thrust-related fold development appears to be foreland migrating (Mosar 1991).

Imbrication and backthrusting in the Médianes Rigides develops before the intermediate Gastlosen-Tours d'Aï zone forms. It is in this latter zone that the basal décollement steps up from the basal Middle Triassic to the base of the Late Triassic. In the Médianes Plastiques overturned folds and fold axial surfaces with a S-SE dip are found south of normal and upright folds. This is another indication of a foreland (N-NW) propagating sequence of fold and thrust development. Internal deformation is associated to the general fold and thrust development (Mosar 1989).

The progressive steepening and overturning of the Médianes Rigides from E to W is linked to the differences in development of the underlying Helvetic nappes. Thus in the W part, the present day position of the Médianes Rigides imbricates has been interpreted as belonging to the frontal and overturned limb of a large scale fold involving the Helvetic, Ultrahelvetic, Niesen and Médianes Rigides nappes. This fold refolds intra-Préalpes thrusts and develops above a thrust surface rooted in the basement (Caron et al. 1989; Escher et al. 1993). The structure is thought to develop upon or after the arrival of the Préalpes in their present position. It will later develop a breakthrough juxtaposing the Médianes Rigides of the Grande Eau area with the S Médianes Plastiques.

The final emplacement in front of the Helvetic nappes and the external basement massifs is associated with the formation of several thrusts cutting the Préalpes Médianes (see prior discussion). We propose that these thrusts root in the present day Préalpes substratum, that is the Mesozoic and Tertiary cover where they may be linked to thrust surfaces going all the way down to the crystalline basement (see also: Caron et al. 1989; Escher et al. 1993). Structural features such as large conjugate strike-slip systems (f.i. in the Chablais Préalpes Médianes) are records of this late tectonic event. It is also during this period that we believe the W-directed movements occur.

Metamorphism s.l.

Numerous studies (see references in Kübler et al. 1979; Mosar 1988a; Zahner & Mosar 1993) showed that the Préalpes underwent low-grade metamorphism ranging from diagenetic to epizonal (300–400 °C) conditions. These studies, covering most of the Préalpes units with a varying density, applied a variety of techniques such as illite crystallinity, the evolution of the clay mineral parageneses (Mosar 1988a; Jaboyedoff & Thélin in press), maturation of different types of organic material (Kübler et al. 1979; Burkhard & Kalkreuth 1989; Borel 1991), fluid inclusions in quartz crystals (Stalder & Touray 1970; Mullis 1979) and oxygen isotopes (Cosca et al. 1992).

This metamorphism varies from diagenesis in the north (i.e. in the Médianes Plastiques) to epizone in the south (i.e. in the Médianes Rigides). This zonation also exists from top to bottom in the southern part of the Préalpes nappe stack (Masson et al. 1980; Baud 1984; Mosar 1988a). The uppermost Nappe Supérieure and the upper part of the Breccia nappe are diagenetic, and metamorphic grade increases towards the lower part of the Breccia nappe. In contrast the diagenetic stage is preserved in the upper part of the underlying Niesen nappe (Dortmann 1982; Mosar 1988a). Thus metamorphism in the Préalpes Médianes, Breccia nappe and Nappe Supérieure is transported. Discontinuous metamorphic gradients also occur between the Niesen nappe and the underlying Ultrahelvetic units, and between the Ultrahelvetic units and the underlying Helvetic nappes (Burkhard 1988; Burkhard & Kalkreuth 1989; Goy-Eggenberger & Kübler 1990) as well as amongst different units of the Ultrahelvetic.

Since the frontal parts of the Préalpes Médianes have not evolved beyond diagenesis, the very low-grade metamorphism of this portion of the Préalpes Médianes begins with the deposition and compaction of the sediments. The main metamorphism, especially in the trailing Préalpes Médianes, the Breccia nappe and the Nappe Supérieure, however, occurred during thrusting of the overlying nappes and subsequent burial since Late Eocene (Bartonian) times. It would require the Médianes Rigides to be buried to a depth of 10 km during some stage of the Alpine orogeny to explain the epizonal temperatures above 300 °C (gradient of ~30 °C/km, Mosar 1988a; Jaboyedoff & Thélin in press).

Because this burial occurred in the geodynamic context of an accretionary prism a lower geothermal gradient may be expected for the Préalpes, at least during the beginning of their involvement in the accretionary prism (Fig. 7). Thus the Préalpes Médianes might find their way as cold material along the subduction zone and reach greater depths than normal.

The burial metamorphism of the Préalpes Médianes by the superposition of the Nappe Supérieure and the Breccia nappe is corroborated by syn-metamorphic internal deformation mechanisms associated with the arrival of the latter nappes (Mosar 1989, 1991).

The peak metamorphism is attained before the arrival of the Préalpes Médianes onto the Niesen, Ultrahelvetic and Helvetic domains, as shown by the discontinuous metamorphic gradients between these units.

Recent studies have shown two events that appear to be related to hydrothermal fluid circulation, but whose interpretation is still open to discussion. The first study shows an unusually high concentration of barium, present under the form of barite scattered through the rock, in Cretaceous sediments of the Préalpes Médianes (Meisser, Musée géologique, Lausanne, work in progress). This type of mineralisation is thought to have a geothermal, syn-depositional origin. A cupriferous mineralisation associated with fossils in Late Cretaceous rocks is thought to develop in hydrothermal environments in the 100 °C range during sedimentation (Meisser 1992). Other mineralisations in veins (Meisser 1992) and in country rock seem to be associated with low temperature hydrothermal circulation possibly during the alpine orogenesis (Zingg 1984; Oberhänsli et al. 1985).

The second study also includes Rb/Sr, K/Ar and $^{40/39}$Ar dating of white micas from Triassic and Middle Jurassic limestones that yield ages of ~60 to 80 Ma in the trailing part of the Médianes Rigides in the western Préalpes Médianes (Masson et al. 1980; the Gummfluh imbricate: Huon et al. 1988; Cosca et al. 1992; the Amselgrat imbricate: De Coulon 1990). The "mylonitic rocks" described at the base of this imbrication, in the vicinity of the basal thrust (Baud & Masson 1976; Cosca et al. 1992), are thought to be heated up to 280 °C, as shown by oxygen isotope measurements. The ages are interpreted by the authors as strong evidence for a Cretaceous tectonic and/or thermal event that was probably related to the initial stages of closure of the Alpine Tethys. The synchronous heating of the basal layer is thus explained by the authors of that study, by hydrothermal fluid circulation during thrusting towards the S-SE in a transpressive continental collision environment in Late Cretaceous/Paleocene times. The conspicuous coincidence of these events with the sedimentation gaps during the Paleocene and Late Cretaceous as well as the rather continuous sedimentation during the Late Maastrichtian (Forclettes Formation) has still to be explained. The temperature range given by oxygen isotopes is similar to the one from the Eocene anchizonal to epizonal burial metamorphism (T ~300–350 °C) and would thus explain why the older temperatures have not been reset by the younger burial metamorphism.

Discussion

The chronology and structural interpretation of the Préalpes Médianes given here, though based on firmly established observational data, have been the subject to several controversies:

[i] Synsedimentary tectonics have so far always been linked to faults rooted in the underlying basement. They thus reflect active basement tectonics; either normal faults, inversions along former normal faults or transpressional movements resulting in flower structures. Most authors tried to explain synsedimentary structures in terms of local or regional structural highs and lows (basins) related to extensional or compressional tectonic regimes. Alternatively we propose that the whole of the Préalpes Médianes sedimentation realm develops above an evaporite décollement and that the structures in the hanging-wall are the result of large-scale sliding outward with respect to an uplifting rift-shoulder. The developing structures are the result of the interplay of faults (nomal and inverted) in an overall extensional passive margin tectonic regime.

[ii] Since the Bartonian the development of the very low-grade metamorphism is attributed mainly to burial by overriding tectonic nappes during the involvement of the Préalpes Médianes in the accretionary prism after the closure of the Piemont ocean (Fig. 7). Radiometric ages around 80–60 Ma and associated isotopic temperatures around 280 °C have so far been explained by hot fluid circulation along thrust planes active during the Late Cretaceous/Paleocene. We do not think however that these observations are to be linked to a Cretaceous orogeny in the Préalpes. We rather propose to integrate these data, together with the information on hydrothermalism, in the geodynamic context of an accretionary prism s.l. (Fig. 6, 7). The Briançonnais micro-continent underwent two major tectonic events: first it is breaking off the Iberic plate in Late Cretaceous and subsequently evolves as an exotic terrain detached from its lithospheric substratum; secondly it is integrated into the accretionary prism between the convergent Adriatic and European plates during Late Eocene (Fig. 6, 7). We propose that the 80–60Ma year radiometric ages and the associated hydrothermal fluid circulation are linked to the "inclusion" of the Briançonnais exotic terrain between the accretionary prism of the closing Valais ocean to the N and the closing Piemont ocean to the S. This thermal event might also be linked to the delamination of the Briançonnais from its lithospheric substratum and the subsequent heat influx. Further investigation especially on the microtectonics of the thrust zone at the base of the Médianes Rigides will help to obtain more detailed information on the geodynamic context.

[iii] The dynamics of the Préalpes emplacement have long thought to be dominated by gravity gliding (Schardt 1898; Lugeon 1943; Campana 1963; Debelmas & Kerckhove 1973). Thus models like the "diverticulation" (Lugeon 1943) have been proposed in order to explain the superposition and imbrication of the different tectonic units such as the Ultrahelvetic units. But since the 1970's it appeared that gravity gliding could not be the sole mechanism active in the Préalpes (Lemoine 1973). It appears now that the Préalpes evolved in a classic mountain building environment of plate collision (Mosar 1991; Stampfli 1993) such as described for example by tapered or non-tapered wedge models (Davis et al. 1983; Willett et al. 1993; Beaumont et al. 1994; Beaumont & Quinlan 1994).

[iv] Two major end-member models explaining the fold and thrust development in the Préalpes Médianes have been proposed to date: in a first model, folds and thrusts

may result from post- to syn-emplacement tectonics after the Préalpes Médianes were transported over the Helvetic nappes (Plancherel 1979); in a second model their development may be explained by "early" tectonics before their arrival on top of the Helvetic nappes (Mosar 1991). In the first model alpine structures are induced by strike-slip faults rooted in the autochthonous basement. These faults would affect the whole tectonic nappe pile of the present day klippen. In the second possibility the main deformation is considered to develop before, together or shortly after the detachment of the Préalpes Médianes from their homeland. Thus beginning with their involvement in the accretionary prism of the closing Piemont ocean, the Préalpes Médianes, the Breccia nappe and the Nappe Supérieure are superposed by thrusting. The subsequent metamorphism is associated with the main fold and thrust development. It is the impingement of the Adriatic plate on the Briançonnais and European plate as well as the isostatic rebound (flexural effect) following the detachment of the deeper portions of the subducted Valaisan and Piemont crust that caused the necessary change in mountain belt dynamics. This in turn alters the critically tapered wedge shape of the accretionary prism. In order to recover a stable configuration, shallow depth thrusting in the frontal part of the dynamic wedge (including the Préalpes thrust sheets) would explain why the Préalpes were not underplated (Marchant & Stampfli in press).

We strongly favour this latter interpretation. The transport on top of the Helvetic nappes was not a passive one (meaning without reactivation of former thrust and development of new thrusts and folds), neither is the emplacement in front of those nappes and the external massifs. Several tectonic events and structures can be attributed to those periods with the passage on top of the Helvetics remaining the more uncertain.

Topographic and geomorphologic criteria may help prove very recent basement uplift due to the development of a new basement imbricate underneath the Préalpes (Fig. 8). Thus there is a step in mean elevation between the autochthonous Molasse and the thrust Molasse/Préalpes area. This "plateau" is located, in our opinion, above the potential basement imbricate developing at depth. Detailed analyses of topography and of geomorphologic criteria such as valley incision and pass height, may help us understand this process and the timing of the uplift (tectonically induced).

[v] Strike-slip faults s.l. (possibly tear faults) are an important structural feature in the Préalpes and especially in the Préalpes Médianes (Plancherel 1976, 1979). Typically, the western edges of the Chablais and Romandes Préalpes Médianes are formed by such fault zones; but also within the Préalpes Médianes important vertical fault zones may develop such as the Jaun-Lac noir zone (see chap. "Structural geology"). Their importance and role has been variably appreciated and incorporated into the tectonic evolution of the Préalpes Médianes. Plancherel (1979) links the motion of N/NNE-S/SSE oriented, left-lateral strike-slip faults to the fold and thrust development of the Préalpes Médianes. These faults would root in the basement and were active after the emplacement of the Préalpes in front of the Helvetic nappes. They are also involved in the deformation of the underlying subalpine and autochthonous Molasse (see also: Pavoni 1987; Sambeth & Pavoni 1988).

Similar ideas of large scale strike-slip deformation have been applied to the Briançonnais and Sub-briançonnais domains of the western French Alps (Maury & Ricou 1983; Ricou 1984; Ricou & Siddans 1986). For these authors those strike-slip faults are, however, not only active in Oligocene to present times, but already existed in the

Briançonnais s.l. paleogeographic realm (active since Late Cretaceous) where they played an important role in structuring the sedimentation domains (see also discussion herein and: Sartori 1990).

Investigations in the Préalpes Médianes Romandes also show that some of the major strike-slip faults are in fact tear faults (that do not root in the present day substratum) associated with the fold and thrust development (Mosar & Borel 1992; Mosar 1994). It thus appears that the strike-slip faults s.l. of the Préalpes Médianes probably originated in the paleogeographic realm (true strike-slip faults rooted in the basement). These structures have subsequentely been reactivated as tear faults during the main fold and thrust development after the Bartonian. No conclusive evidence, however, shows that they are still active in the NW-SE oriented compressional stress regime of the alpine foreland (Deichmann 1990).

[vi] Although considered to be derived from one paleogeographic sedimentation domain, the connection between the Médianes Plastiques – Médianes Rigides is nowhere clear in the Préalpes. Especially the connection between the Médianes Rigides and the intermediate Tours d'Aï -Gastlosen structure is always buried under the overlying Nappe Supérieure. This led to the hypothesis that they might have been separated already during Cretaceous times. The continuous sedimentation and the lack of tectonic markers (for a potential tectonic separation during the Cretaceous), however, leads us to discard this possibility. The present day discontinuity between the two tectonic domains results from their involvement in folding of the Helvetic nappes and thrusting after their emplacement.

Conclusions

From data and discussions presented, keeping in mind that the structural evolution appears to be continuous and progressive, we propose to differentiate four main stages in the tectonic history of the Préalpes Médianes, each of which saw the development of different and specific structural features.

[i] A passive margin period (mainly Jurassic) during which we see the formation of normal faults, subsidence-induced basins above extensional faults associated with a basal décollement in evaporites. NE-SW trending basins are separated by structural highs resulting from local tectonics. Inversion structures are sealed by synsedimentary growth features. These structures formed in a rim basin bordered to the S by a rift shoulder issued from the Piemont oceanisation. The different types of structures observed during the sedimentation history can be related to thermal events linked to the development of the different Alpine oceanic domains, mainly the opening of the Piemont ocean but also the development of the Valais domain.

[ii] An active margin period (starting in Middle to Late Eocene: Lutetian-Bartonian) during which the Briançonnais flysch sedimentation marks the location of the Préalpes Médianes at the front of the Alpine orogeny. Finally, during Bartonian to Priabonian the now exotic terrain is incorporated into the accretionary prism of the closing Piemont ocean.

Continental collision during Late Eocene to present sees the development of the main structural features of the Préalpes Médianes fold-and-thrust belt. The Breccia nappe and the Nappe Supérieure are thrust on top of the Médianes Rigides and Plastiques and the metamorphism develops by tectonic burial. Thrust movements are recorded by internal deformation along the nappe contacts. It is after this emplacement that the Préalpes Médianes are detached from their substratum to undergo thin skinned tectonics in the brittle domain. Internal rock deformation registers pre- and synfolding and -thrusting deformation. The fault-related folds (fault-propagation folds, fault-bend folds), box-shaped folds, imbricates, imbricated fans and en échelon structures associated with tear faults develop in sequence, progressively migrating towards the foreland. Backthrusts and breakthrough thrusts are frequent.

[iii] The arrival of the Préalpes on the European continent, that is on top of the Ultrahelvetic units during final Eocene – beginning Oligocene and on the Helvetic units during Oligocene (probably Rupelian) times. By then the Préalpes Médianes have achieved most of their deformation and structural development. The transport on top of the deforming Ultrahelvetic and Helvetic nappes caused renewed large-scale deformation in the Préalpes Médianes nappe. Thus the Médianes Rigides, at least their western portion, and the basal décollement are involved in the folding of the frontal portion of those nappes, which confers them their present day steeply inclined or overturned position.

The arrival of the Préalpes on the Molasse basin (in subaerial conditions?) is recorded by the deposition of the conglomerates of the Mont Pélerin of Lower Chattian age. These sediments largely result from the erosion of the Nappe Supérieure.

[iv] A final period of thrusting, probably Chattian to younger in age, occurs in the Préalpes at the front of the still active mountain belt. Thus out of sequence thrusting occurs inside the Préalpes Médianes (such as between the Médianes Rigides and the Médianes Plastiques). These thrusts are associated with the development of the external crystalline massifs of the Alps. Similar thrusts are also active in the Subalpine Molasse and we propose they are also linked to the development of imbrications in the basement and in the allochthonous sedimentary substratum. Westward directed thrusting occurs in the Préalpes Médianes (frontal imbricate, Zone Submédiane) and is linked with a basement high developing underneath the western termination of the Préalpes Romandes and extending into the Chablais Préalpes. It may not be excluded that these movements towards the W are related to the large scale W to SW directed displacements in the central and southwestern Alps. Since these movements are of Oligocene to Quaternary age, hence also contemporaneous to the Jura folding, the lastest tectonic "activity" in the Préalpes may be of the same age.

Unlike most of the Pennine units the Préalpes Médianes thus succeeded in escaping an untimely reshaping (overheating and awful deformation) in the accretionary prism due to changes in the plate tectonic regime and the subsequent changes in thrust dynamics. Since then they enjoyed the unbearable lightness of thin-skinned tectonics and have been surfing the frontal "wave" of the alpine orogeny.

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BOREL, G. 1996: Préalpes médianes: courbes de subsidence et implications géodynamiques. Bull. Soc. vaud. Sci. nat. 83, 293–315.
SOMMARUGA, A. 1995: Tectonics of the Central Jura and the Molasse Basin. New insights from the interpretation of seismic reflection data. Bull. Soc. neuchât. Sci. Nat. 118, 95–108.