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Folds and Thrusts in the Préalpes Médianes Plastiques Romandes

by

Jon MOSAR[1]

Abstract.–MOSAR J., 1997. Folds and Thrusts in the Préalpes Médianes Plastiques romandes (Switzerland). *Bull. Soc. vaud. Sc .nat. 84.4*: 347-384.
The western domain of the Swiss Préalpes Médianes Plastiques forms the frontal portion of the Préalpes Médianes nappe. This nappe is the most important of several structural units forming the Préalpes klippen at the NW front of the Alps. Detached over a basal décollement, the Préalpes Médianes were separated from the Briançonnais homeland during the Alpine orogeny. They underwent thin-skinned tectonics and now show the typical characteristics of a foreland fold-and-thrust-belt. A foreland propagating thrust sequence developed above a basal décollement and resulted in a series of large fault-related folds. The fold style can be compared to fault-bend and fault-propagation fold models, but other geometries such as detachment folds (box folds) also exist. Backthrusts developed at the ramp-flat transitions as well as by inversion of former normal, listric synsedimentary faults. Periclinal closures, en echelon relay structures, tear faults, lateral ramps and fold interference structures are commonly observed features.

Strong changes in fold axial dips and fold directions and important changes in the depth to the basal thrust, as well as W-directed thrust movements, most likely, indicate post-emplacement tectonics (post Oligocene) linked to thrusting in the external cristalline massifs and the development of new basement nappes.

Keywords: Préalpes Médianes Plastiques, fold-and-thrust-belt, décollement, thrusts, backthrusts, folds, geometry, kinematics.

Résumé.–MOSAR J., 1997. Plis et chevauchements dans les Préalpes Médianes Plastiques romandes. *Bull. Soc. vaud. Sc. nat. 84.4*: 347-384.
Les Préalpes Médianes constituent la nappe la plus importante de l'ensemble des klippes préalpines, distribuées le long du front NW des Alpes (fig. 1). Les Préalpes Médianes Plastiques étudiées dans cet article forment le segment frontal de cette nappe de chevauchement. Détachées le long d'un décollement basal, les Préalpes Médianes se sont séparées pendant l'orogenèse alpine de leur patrie. Cette dernière est restée en retrait et forme les unités tectoniques de Pontis et de Siviez Mischabel, au S du Rhône. Les Préalpes Médianes ont subi une déformation typique des régions d'avant-pays d'une

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chaîne de montagne. Elles ont acquis leur structures et leur faible métamorphisme lors de l'incorporation dans le prisme d'accrétion de la chaîne alpine naissante. Une suite de plis et de chevauchements se sont développés, de l'arrière-pays vers l'avant-pays, au-dessus du décollement basal le long des évaporites triasiques (fig. 1, 5). On y distingue du S vers le N, les Préalpes Médianes Rigides, formées de rampes de chevauchement et de plis sur rampes, les Préalpes Médianes Plastiques, caractérisées par une succession de grands plis, décrits ci-dessous et un domaine intermédiaire, les Gastlosen.

Dans la partie frontale (Préalpes Médianes Plastiques) plusieurs domaines tectoniques peuvent être distingués (fig. 2): une zone externe avec jusqu'à trois écailles tectoniques imbriquées; une zone appelée le «corps principal», formée de plis à grande échelle, dont le plus important est le synclinal d'Intyamon situé dans la vallée de la Sarine; un domaine formé par les hauts reliefs du chaînon du Vanil Noir-Rochers de Naye-Dorena-La Tinière. On y reconnaît trois grands plis du NW au SE (fig. 2, 4): l'anticlinal de Tsavas-Les Millets très développé dans le massif du Vanil Noir, mais très réduit plus au SW sous les falaises septentrionales des Rochers de Naye; le synclinal perché du Vanil Noir–Pointe de Paray (photo I) auquel fait suite plus vers le SW le synclinal de la Dent de Corjon et le synclinal des Rochers de Naye; et finalement l'anticlinal de Dorena (photo III, IV) relayé vers le Col de Chaude par l'anticlinal de la Tinière.

S'enracinant le long du décollement basal, une série de chevauchements avec des déplacements kilométriques forment des rampes et des plats (fig. 5). En association avec ces chevauchements se développent les plis des Préalpes Médianes Plastiques. Leur style peut être comparé aux modèles des plis de propagation ou des plis sur rampe, mais d'autres géométries par exemple du type plis coffrés (plis de détachement) s'observent. Des chevauchements en retour se sont formés en association avec les rampes principales, souvent en inversant d'anciennes failles normales synsédimentaires. Ces paléo-failles, associées à l'évolution du bassin frangeant de la marge passive de la Téthys, reflètent une aire de sédimentation à tectonique active et à reliefs marqués. Les dépôts des Préalpes Médianes Plastiques, composés essentiellement de calcaires de différents types et de marnes, montrent de grandes et rapides variations d'épaisseur (fig. 3).

La géométrie des structures tectoniques est bien reconnaissable dans le domaine principal des Médianes Plastiques. Fermetures périclinales, structures en échelon, décrochements, rampes latérales et structures d'interférences sont parmi les structures fréquemment observées (fig. 4, 5, 6). L'orientation et l'inclinaison des axes de plis changent le long des structures (fig. 4, 6). Ainsi les terminaisons périclinales occidentale de l'anticlinal de Dorena et orientale de l'anticlinal de la Tinière forment-elles un ensellement en échelon aux axes de plis plongeant de 30-40° (fig. 6). Avec sa terminaison périclinale prononcée vers l'E, l'anticlinal de Doréna disparaît très rapidement (fig. 4, photo II). Le synclinal de la Sarine est remarquable par son rapide plongement axial depuis la Dent de Jaman vers Montbovon (fig. 4) et sa remontée en direction de la Dent de Chamois (fig. 2). Le chevauchement basal se trouve ainsi à une profondeur d'approximativement –1100 m sous la vallée de la Sarine. Les imbrications frontales montrent une forte discontinuité latérale et la structure la plus importante se trouve dans l'écaille B avec le synclinal perché du Moléson (fig. 2, 5a). On y trouve également des plis couchés (fig. 5b) et des chevauchements orientés N-S avec un mouvement vers l'W (fig. 2, 5c).

Les importants changements d'orientation des axes de plis et la grande variation de profondeur du chevauchement basal, de même que des mouvements chevauchants vers l'W dans la région des écailles (fig. 1, 2, 4, 5), indiquent probablement une tectonique postérieure à la mise en place des Préalpes (post-Oligocène). Ces mouvements sont à relier aux chevauchements des massifs cristallins externes et au développement d'une nouvelle nappe de socle sous la partie E du Léman et sous les terminaisons W et E des Préalpes Romandes et du Chablais respectivement

Mots clefs: Préalpes Médianes Plastiques, plis, chevauchements, décollement, chevauchements en retour, géométrie, cinématique.

1. The Préalpes: location and brief historical

The Préalpes are formed by several klippen along the northern front of the Swiss and French Alps from east of the Mythen near Luzern (Switzerland) to the Klippe des Annes near Annecy (France). The two major lobes are formed by the Chablais Préalpes south of Lake Léman and the Préalpes Romandes between Lake Léman and Lake Thun. The Préalpes Médianes are the most important of several structural units now superposed (fig. 1), the most important of which are: (a) the Nappe Supérieure, (b) the Brèche Nappe, (c) the Préalpes Médianes nappe, (d) the "Zone Sub-médiane" and (e) the Niesen nappe.The Préalpes Médianes nappe has its paleogeographic origin in the Sub-Briançonnais and Briançonnais sedimentation realm (Trümpy 1960, Caron 1972, 1973, Boillot *et al.* 1984). Equivalent stratigraphic units have been found both in the Préalpes Médianes and the Siviez-Mischabel and Pontis nappes of the Pennine Alps south of the Rhône valley (Ellenberger 1950, 1952, Baud and Septfontaine 1980, Sartori 1987, 1990). The Préalpes Médianes nappe was detached along its Triassic evaporites from its basement during the Alpine orogeny. It was Schardt (1884, 1893, 1898) who first clearly demonstrated the allochthony of the Préalpes. He recognized and described the fold and thrust style of the Préalpes Médianes, and concluded that there was a genetic link between thrusts and folds: "*...nous arrivons à la conclusion que les plis qu'accusent les terrains à la surface, sont en partie compensés dans la profondeur par des failles; non par des failles verticales, mais des chevauchements des bancs compacts ..., au milieu de la masse de terrain plus plastique qui l'entourent*" (Schardt 1893). Subsequent workers further described the structures (Jaccard 1904, 1907, Mauve 1921, Wengen 1924, Bieri 1925, Revertera 1926, Nicol 1956), but many interpretations of the structural style made after the 1930's clearly lagged behind Schardt's understanding. Only recently attempts addressed the fold and thrust development in a quantitative and kinematic way (Badoux and Mercanton 1962, Plancherel and Weidmann 1972, Plancherel 1976, 1979, Müller and Plancherel 1982, Mosar 1989, 1991, 1994). A historical account is given in Bailey (1935), Masson (1976) and Mosar *et al.* (1996) and an extensive bibliography can be found in Mosar and Borel (1995).

In this paper I will present an investigation of fold geometry from the Préalpes Médianes Plastiques romandes (see also Plancherel 1976, 1979 and Mosar 1989, 1991 for an overview to the east and references therein). The fault-related folds analyzed belong to the frontal part of the Préalpes Médianes nappe: the Médianes Plastiques. Several cross sections will be analyzed and changes in structural style will be highlighted. Results from this study will be used to discuss tectonic and kinematic implication for the investigated area of the Préalpes Médianes Plastiques.

2. The Préalpes Médianes

2.1 *Regional structural geology of the Préalpes Médianes*

The Préalpes Médianes nappe is subdivided into the Médianes Plastiques, forming the frontal (NW) part of the nappe and Médianes Rigides, forming the trailing (SE) part of the nappe (LUGEON and GAGNEBIN 1941, fig. 1). A domain with intermediate characteristics exists between the Médianes Rigides and Plastiques: the Gastlosen range (LUGEON and GAGNEBIN 1941, BAUD 1972, PLANCHEREL 1979).

The Médianes Plastiques are composed of a succession of large-scale fault-related folds (fig. 2, 4, 5), whose trends vary from E-W in the eastern part of the nappe to NNE-SSW, and even N-S, in the western part of the nappe (GAGNEBIN 1922, JEANNET 1922, BADOUX *et al.* 1960, BADOUX and MERCANTON 1962, BADOUX 1965b , PLANCHEREL 1979, MÜLLER and PLANCHEREL 1982, MOSAR 1988a, 1988b, 1989, 1991, 1994, METTRAUX and MOSAR 1989, MOSAR and BOREL 1992, 1993, MOSAR *et al.* 1996). Folds and associated thrust planes die out along strike, resulting in the lateral transfer of displacement to other "en échelon" arranged fold-thrust structures.

The Médianes Rigides are formed by one major, in some places one or two minor, imbricated thrust slices dipping to the N/NW (fig. 1). These slices form fault-bend like folds that are cut by a large backthrust in their ramp portion. The imbrications dip gently to the north in the Simmental area of the eastern Préalpes Médianes and are steeply dipping in the western region near Châteaux-d'Œx.

2.2 *Transported metamorphism and internal deformation in the Préalpes Médianes*

Numerous studies in recent years (MOSAR 1988, ZAHNER and MOSAR 1993; JABOYEDOFF and THÉLIN 1995) showed that the Préalpes Médianes underwent a very low-grade metamorphism ranging from diagenetic conditions in the Médianes Plastiques to epizonal (300-400°C) conditions in the Médianes Rigides. Metamorphism in the Préalpes Médianes is a transported feature! since the epizonal conditions contrast with the diagenetic conditions preserved in the upper part of the underlying Niesen nappe.

Metamorphism of the Préalpes Médianes occurred during thrusting of the overlying nappes and subsequent burial in the accretionary prism of the developing alpine orogeny.

The internal deformation (MOSAR 1989) of the Médianes Plastiques is low (mainly pressure solution and week development of calcite twins). It corresponds to an «early» shortening parallel to bedding emphasized by the development of tectonic stylolites and an early rock cleavage. Subsequent folding sees the reorientation of these features, as well as the formation of a weak fold axial surface parallel cleavage. The strain increases going into the

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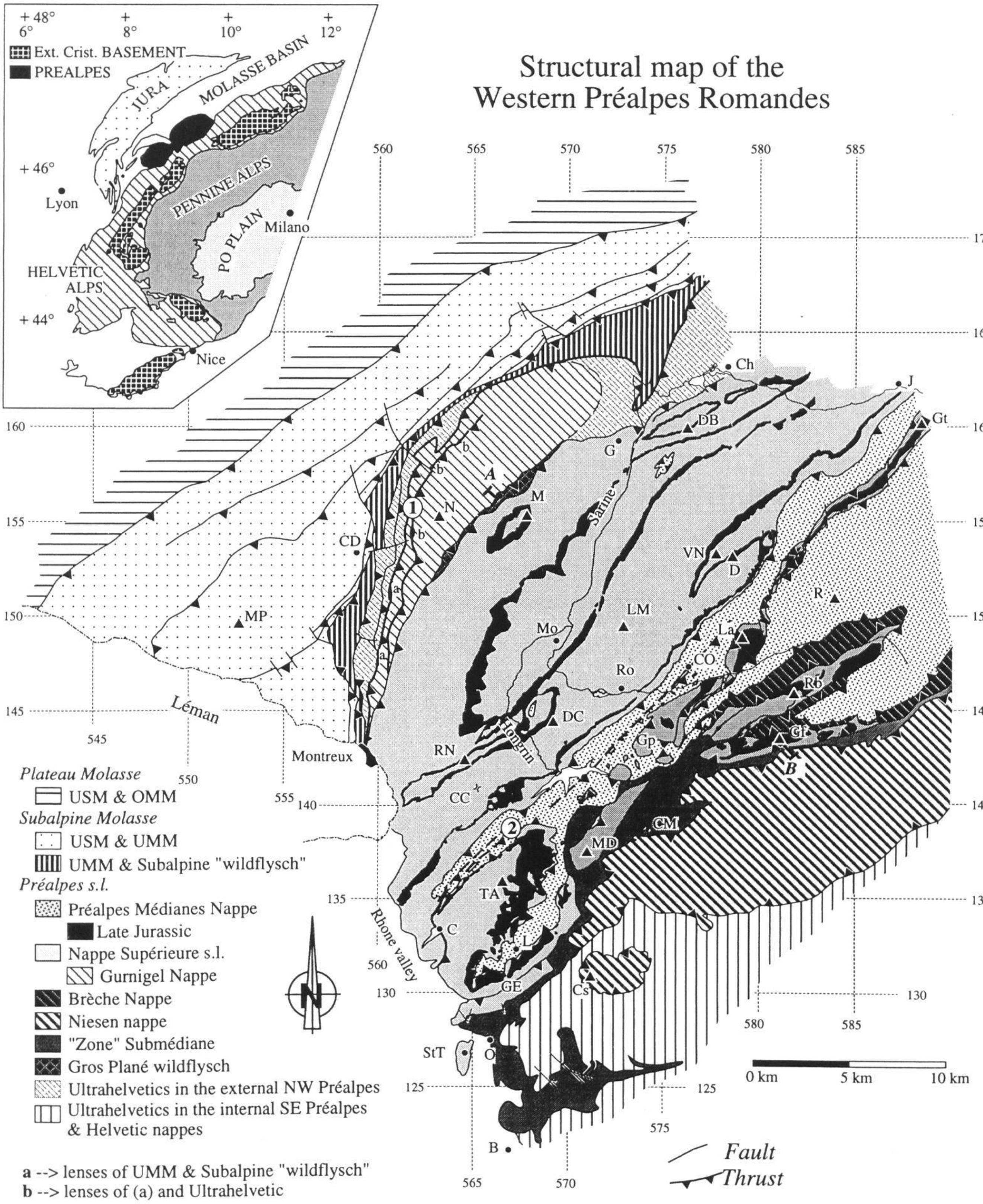
Figure 1.–(a) Simplified structural map of the Préalpes romandes fold-and-thrust belt and location map of the Préalpes klippen on a tectonic sketch of the Alps. Post-emplacement (out-of sequence) thrusts: (1) inside and at the base of the Gurnigel nappe, with lenses of Ultrahelvetic, Lower marine Molasse and Subalpine wildflysch material; (2) at the base of the Tours d'Aï anticline and inside the Château d'Oex syncline.
(a) Carte structurale simplifiée de la chaîne plissée et chevauchante des Préalpes romandes. Encadré: localisation des klippes des Préalpes sur une esquisse tectonique des Alpes. Chevauchements post-emplacement des Préalpes: (1) à l'intérieur et à la base de la nappe du Gurnigel, avec lentilles d'Ultrahelvétique, Molasse marine inférieure et flysch subalpin; (2) à la base de l'anticlinal des Tours d'Aï et dans le synclinal de Château d'Oex.



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 area; 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

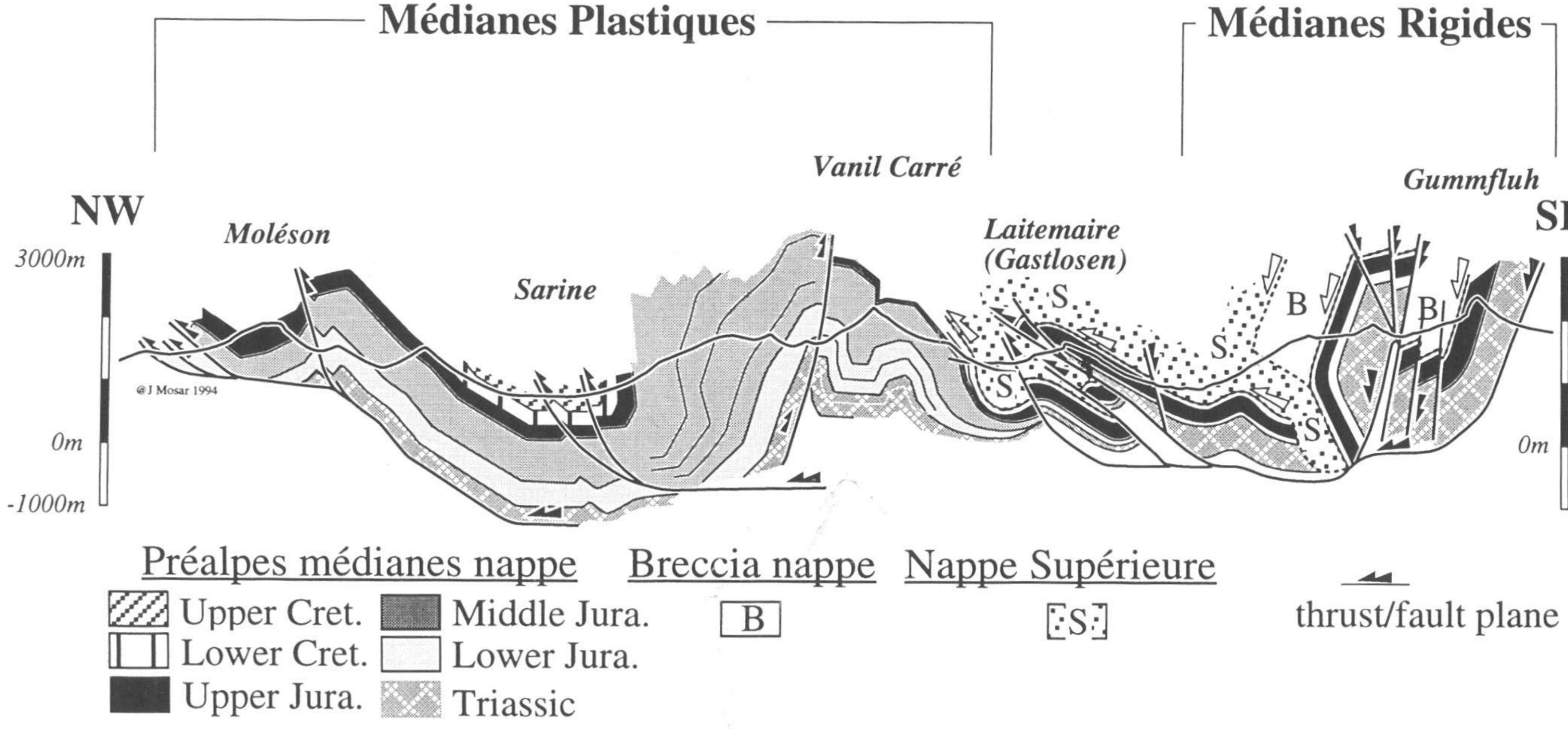


Figure 1.–(b) Simplified, NW-SE oriented cross section through the Préalpes Médianes romandes nappe with position of the overlying Breccia nappe and Nappe Supérieure. This map is compiled from published map as well as many unpublished research work (diploma).
(b) Coupe simplifiée, NW-SE, de la nappe des Préalpes Médianes romandes avec position de la Nappe Supérieure et de la nappe de la Brèche. Cette carte est compilée à partir de documents publiés ainsi que de nombreux travaux inédits (diplômes).

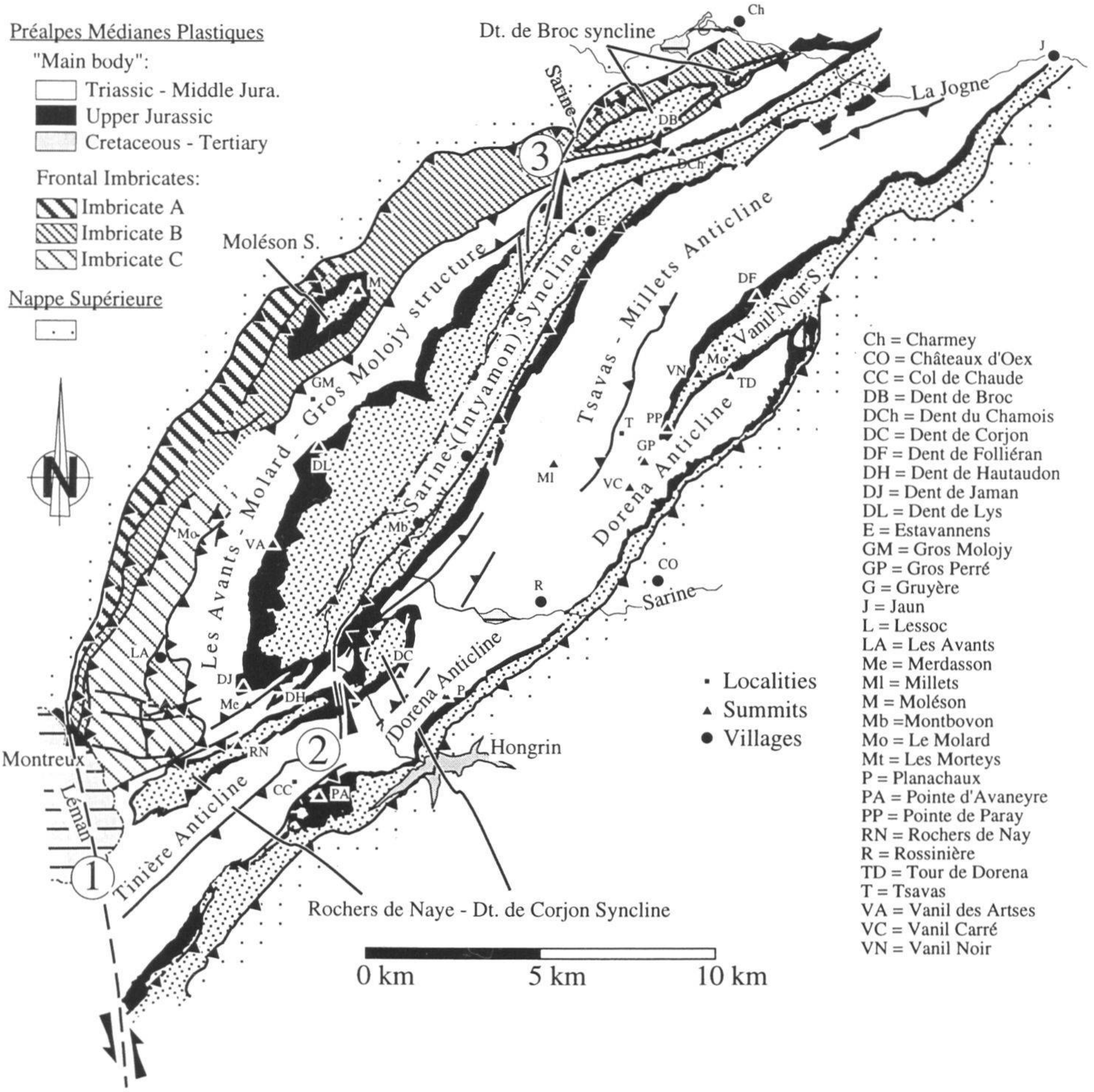


Figure 2.–Simplified tectonic map of the western part of the Préalpes Médianes Plastiques romandes. The different tectonic "domains" and the names of the various synclinal and anticlinal structures are indicated. Geographic localities are indicated with letters. Tear faults with left-lateral displacement grading into thrust fault towards the N are: (1) frontal imbricate thrust (combined thrust and left lateral displacement MOSAR and BOREL, 1992)-Rhône valley tear fault; (2) Laissallet thrust-Hongrin river tear fault; (3) Dent de Broc thrust-Sarine valley tear fault.

Carte tectonique simplifiée de la partie ouest des Préalpes Médianes Plastiques romandes. Les différents domaines tectoniques et les noms des différents synclinaux et anticlinaux sont indiqués. Les localités géographiques sont notées avec des lettres. Les zones décrochantes sénestres qui se relient vers le N à des chevauchements sont: (1) le chevauchement frontal des imbrications – décrochement le long de la vallée du Rhône (déplacement chevauchant-décrochant combiné: voir MOSAR et BOREL, 1992); (2) chevauchement de Laisallet–décrochement de l'Hongrin; (3) chevauchement de la Dent de Broc–décrochement de la vallée de la Sarine.

more internal Médianes Rigides (intense twinning and dynamic recrystallisation). 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 Brèche nappe.

2.3 *Sedimentology and paleo-tectonics*

The Préalpes Médianes are formed by limestone, dolomites, marls and shales ranging from Triassic to Tertiary in age (TRÜMPY 1960, 1980, BADOUX and MERCANTON 1962, PLANCHEREL 1979, 1990, BAUD and SEPTFONTAINE 1980, BAUD *et al.* 1989, BOREL 1995). Their sedimentation realm has been interpreted in terms of a rim basin located in the Sub-briançonnais domain to the N-NW of the Briançonnais upper plate rift shoulder of the N-Tethyan rift margin (STAMPFLI and MARTHALER 1990, STAMPFLI 1992, 1993, 1994, MOSAR *et al.* 1996). Two major sedimentation realms can be clearly differentiated since the Liassic and separated by two minor domains: 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 – that gives way to a platform and lagoonal environment in the Médianes Rigides. Detailed description and discussion of the various formations encountered in the Préalpes Médianes are in BOREL (1995) for subsidence curves, BAUD (1972, 1987) for the Triassic; METTRAUX (1989), METTRAUX et MOSAR (1989) and THURY (1973) for the early Jurassic (Lias); SEPTFONTAINE (1983), FURRER et SEPTFONTAINE (1977) et FURRER (1979) for the middle Jurassic (Dogger); WEISS (1949), ISENSCHMID (1983), HEINZ (1985) and HEINZ und ISENSCHMID (1988) for the late Jurassic (Malm); BOLLER (1963) for the early Cretaceous (Neocomian); CARON and DUPASQUIER (1989) and PYTHON-DUPASQUIER (1990) for the middle Cretaceous and GUILLAUME (1986) for the late Cretaceous-Tertiary.

2.4 *Transitions from the Préalpes Médianes to neighboring structural units*

The transition from the Préalpes Médianes nappe to the underlying and overlying structural units is marked by mélange units often termed wildflysch. The base of the Préalpes Médianes is in contact with the underlying units by means of the Ultrahelvetics and the Zone Submédiane (WEIDMANN *et al.* 1976) (fig. 1), which are characterized by mélanges and rauhwackes (cornieules; JEANBOURQUIN 1986, 1988, AMIEUX and JEANBOURQUIN 1989, JEANBOURQUIN and LUALDI 1994) associated with anhydrite.
The Ultrahelvetics and the Zone Submédiane have been interpreted in recent work as melanges resembling those formed in accretionary prisms. They have subsequently been strongly overprinted by Alpine tectonics (JEANBOURQUIN, 1991a, 1991b, 1994, 1992; JEANBOURQUIN *et al.* 1992; BADOUX 1963b, 1965a; LEMPICKA-MÜNCH *et al.* 1993).

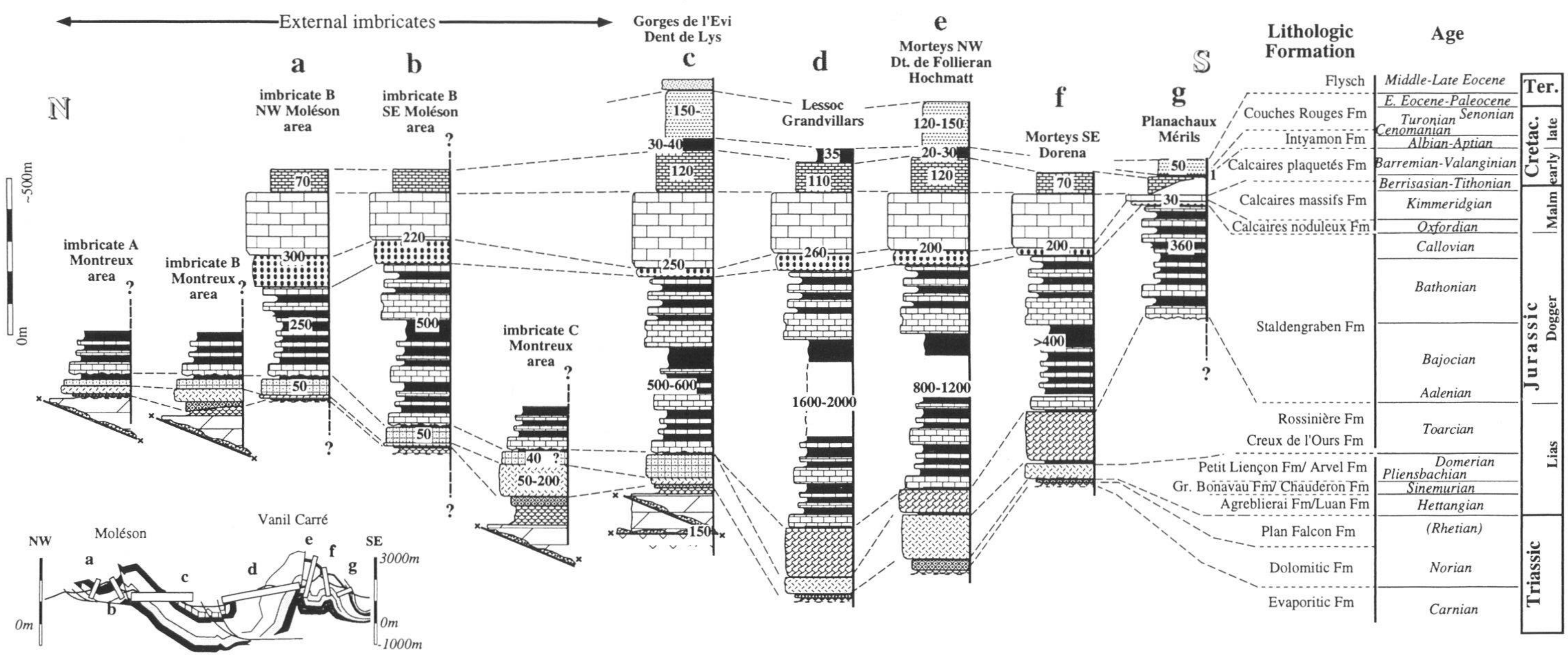
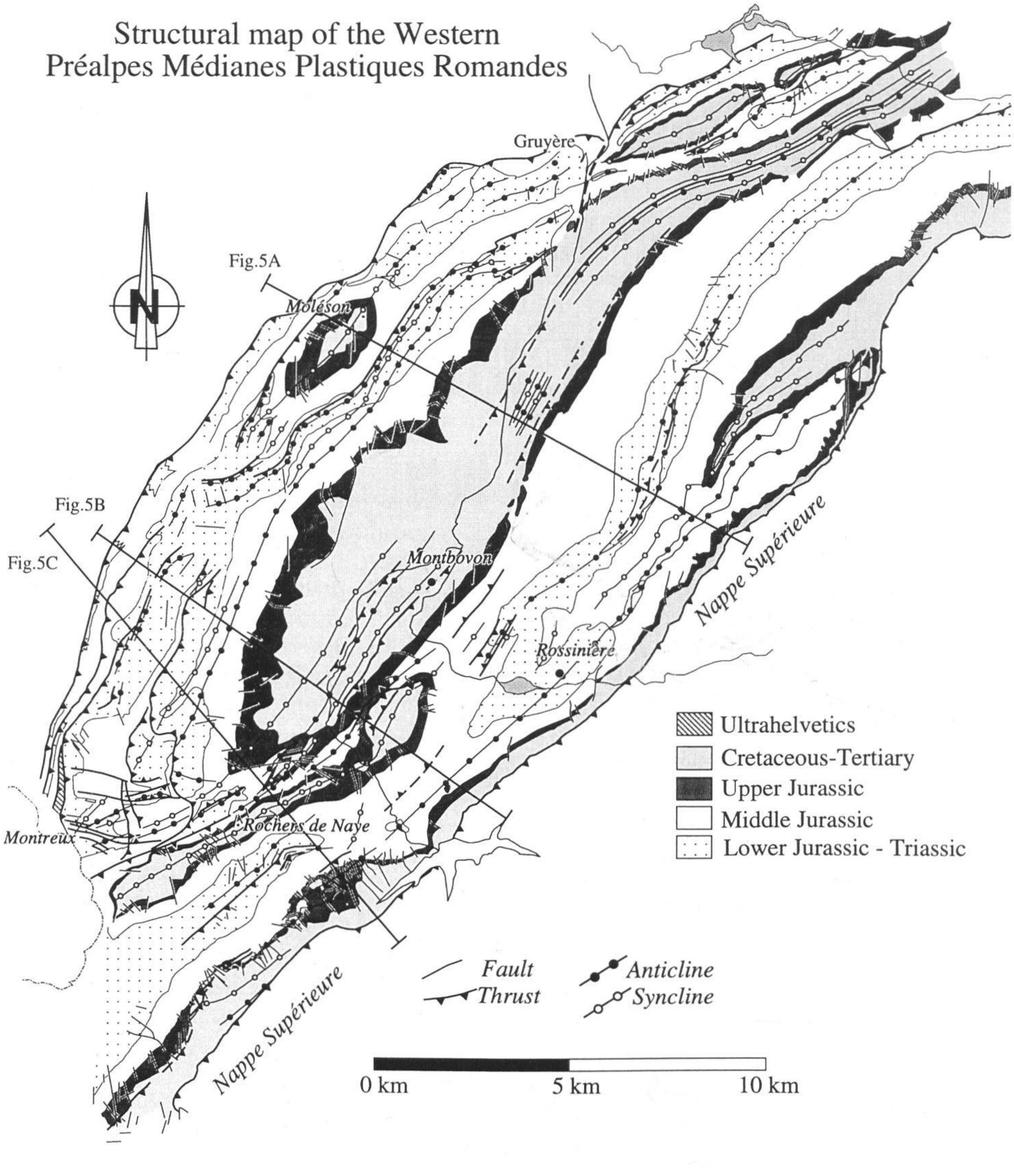


Figure 3.–Simplified stratigraphic columns from the Préalpes Médianes Plastiques romandes. Data have been compiled based on numerous published data and field work (see text for references). The different columns are located along the synoptic cross section in figure 1b. Indications for sediment thickness have been evaluated in the vicinity of the different columns.

Colonnes stratigraphiques simplifiées des Préalpes Médianes Plastiques romandes. La compilation des données est faite à partir de nombreux travaux publiés et de levés de terrain (les références sont dans le texte). Les différentes colonnes sont localisées sur la coupe synthétique de la figure 1b. Les indications d'épaisseur sont des moyennes des alentours de chaque profil.


Structural map of the Western
Préalpes Médianes Plastiques Romandes
Gruyère
Fig.5A
Moléson
Fig.5B
Fig.5C
Montbovon
Rossinière
Nappe Supérieure
Montreux
Rochers de Naye
Nappe Supérieure
Ultrahelvetics
Cretaceous-Tertiary
Upper Jurassic
Middle Jurassic
Lower Jurassic - Triassic
Fault
Thrust
Anticline
Syncline
0 km
5 km
10 km

3. Tectonics and structural domains in the Préalpes Médianes Plastiques

3.1 *Investigation techniques and cross section construction*

Using information compiled from literature and existing documents, together with newly collected data it was possible to construct new cross sections and draw new structural maps of the western part of the Préalpes Médianes Plastiques romandes. The geometric and kinematic constraints for the construction of cross sections arise largely from applying the laws of conservation of volume and the kink-method for constructing cross sections that are used here (Goguel 1952, Coates 1945, Laubscher 1962, Dahlstrom 1969, 1990, Faill 1973, Suppe 1983). These techniques apply to domains of the upper crustal, brittle deformation regime, where rocks have suffered little internal deformation under very low-grade or non-metamorphic conditions. They can appropriately be applied to the Préalpes Médianes where internal deformation of rocks is weak and metamorphic conditions never went beyond lowest greenschist facies. Furthermore, the large scale folds can be traced through large parts of the studied area and, when possible, fold axial surface traces have been mapped (fig. 4). It was thus possible to show that in many of these folds one has rather large domains with uniform dip. They form the fold limbs and are separated by proportionally small, rounded fold hinge zones. Since bed-thickness is, however, not constant in the Préalpes Médianes (important spatial variations in sediment supply and basin development yield thickness variations of 30-300 m in the Middle Jurassic limestones or 0-1800 m in the Early Jurassic marls and limestones) it is difficult to apply simple techniques of balancing.

Cross-sections (fig. 5) have been constructed parallel to presumed transport direction, which, in a first order approach, is supposed to be perpendicular to the general fold axis trend. Data have then been projected into the cross-section parallel to the fold axes calculated from bedding dip data and local small scale second-order folds.

3.2 *Fold and thrust geometry in the W Médianes Plastiques*

In the study area several distinct structural sub-units can be distinguished (fig. 1, 2, 4, 5). They are from the external NW border towards the SE in direction of the Médianes Rigides: (a) the external imbricates, divided into three different thrust slices forming the most frontal tectonic structures of the Médianes Plastiques (Schardt 1893, Jeannet 1922, Badoux 1965b, Mosar

◄———

Figure 4.–Detailed structural map of the western part of the Préalpes Médianes Plastiques romandes. Simplified stratigraphic units are used in order to highlight the different tectonic structures. Data have been compiled from published geologic maps and unpublished diploma and thesis work as well as from new field investigation on 1:25'000 scale.

Carte structurale détaillée de la partie ouest des Préalpes Médianes Plastiques romandes. Des unités stratigraphiques simplifiées ont été choisies afin de souligner les structures tectoniques. Les informations sont compilées à partir de cartes géologiques publiées, de travaux de thèse et diplôme, ainsi que de nouveaux relevés de terrain à l'échelle 1:25'000.

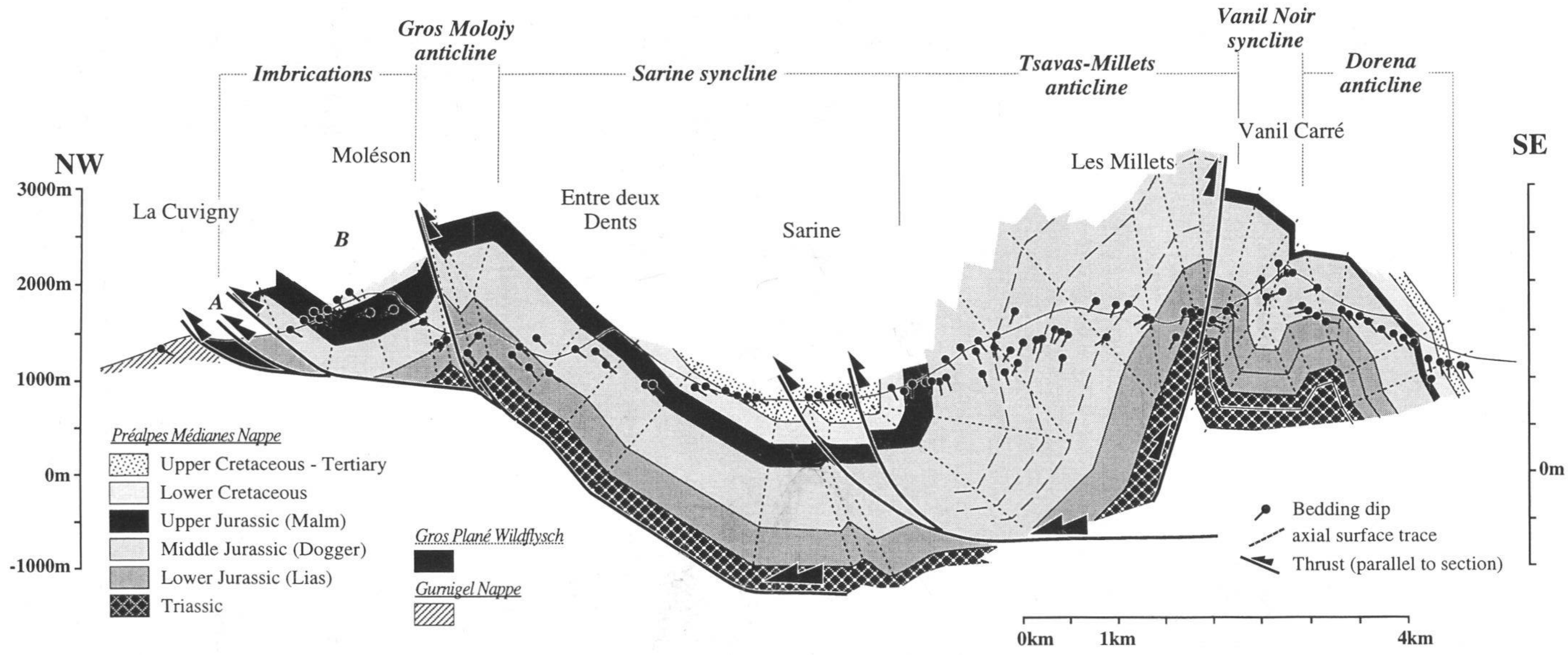


Figure 5a.–Detailed cross sections of the Préalpes Médianes Plastiques romandes. For location see figure 4. Axial surfaces do not necessarily bisect adjacent fold limbs, because of important changes in sediment thickness, rather they separate domains of varying dip. Moléson-Sarine-Vanil Carré section showing the frontal Moléson syncline developed as a lateral continuity of imbricate B. The deep Sarine syncline and the high structural relief of the Tsavas-Millets anticline/Vanil Noir syncline/Dorena anticline are clearly visible.

Coupes détaillées des Préalpes Médianes Plastiques romandes. Localisation sur la figure 4. Les surfaces axiales ne sont pas nécessairement bissectrices des flancs adjacents, car l'épaisseur des couches est variable; elles séparent des domaines à pendages différents. Coupe Moléson-Sarine-Vanil Carré montrant le synclinal perché frontal du Moléson qui constitue la continuation latérale de l'imbrication B. Le synclinal profond de la Sarine et les reliefs structuraux élevés de l'anticlinal Tsavas-Millets/synclinal du Vanil Noir/anticlinal de Dorena sont clairement visibles.

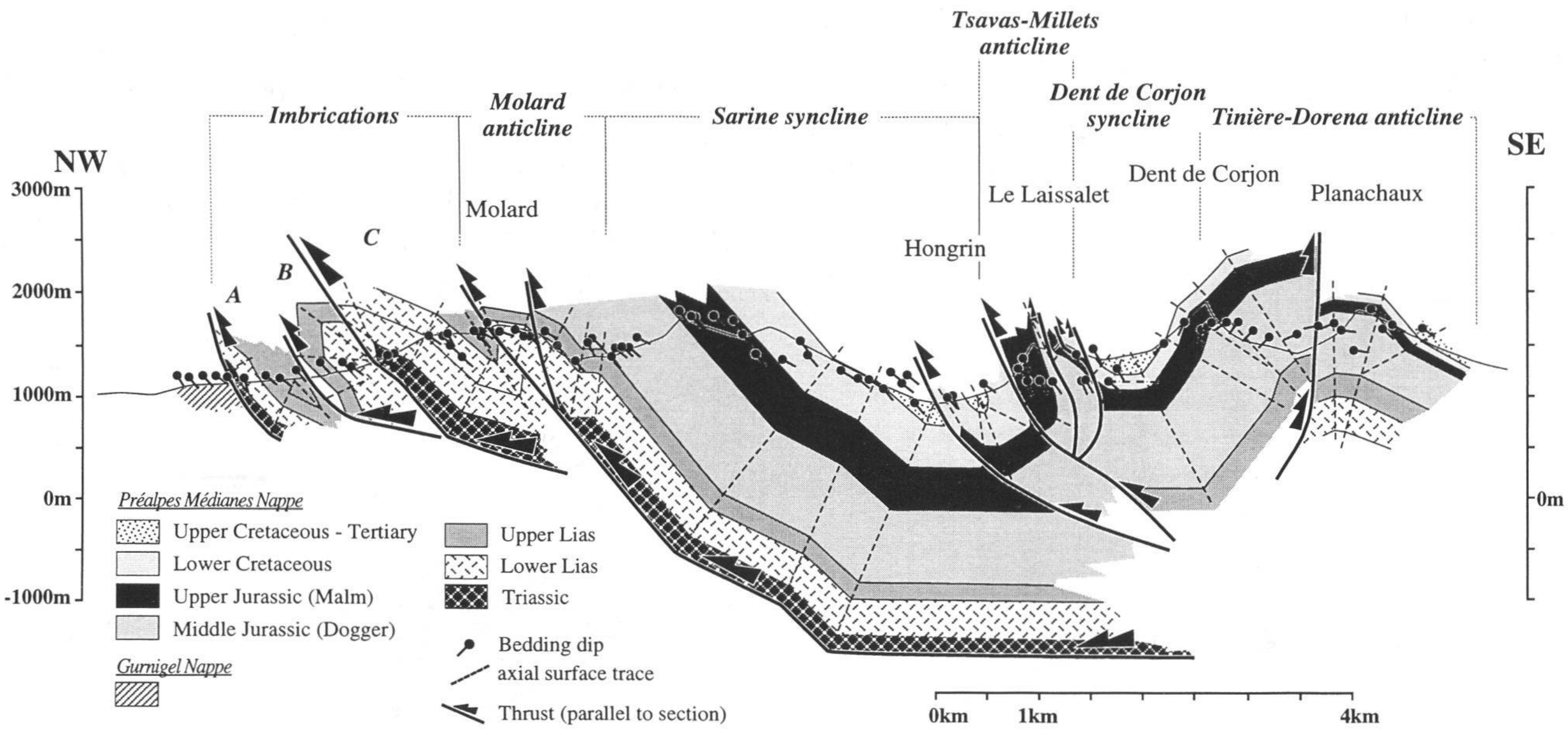


Figure 5b.–Detailed cross sections of the Préalpes Médianes Plastiques romandes. For location see figure 4. Axial surfaces do not necessarily bisect adjacent fold limbs, because of important changes in sediment thickness, rather they separate domains of varying dip. Molard-Sarine-Planachaux section illustrating the three frontal imbricates. The Tsavas-Millets anticline is very tight and slightly overturned.

Coupes détaillées des Préalpes Médianes Plastiques romandes. Localisation sur la figure 4. Les surfaces axiales ne sont pas nécessairement bissectrices des flancs adjacents, car l'épaisseur des couches est variable; elles séparent des domaines à pendages différents. Coupe Molard-Sarine-Planachaux montrant les trois imbrications frontales. L'anticlinal de Tsavas-Millets est très serré et légèrement renversé.

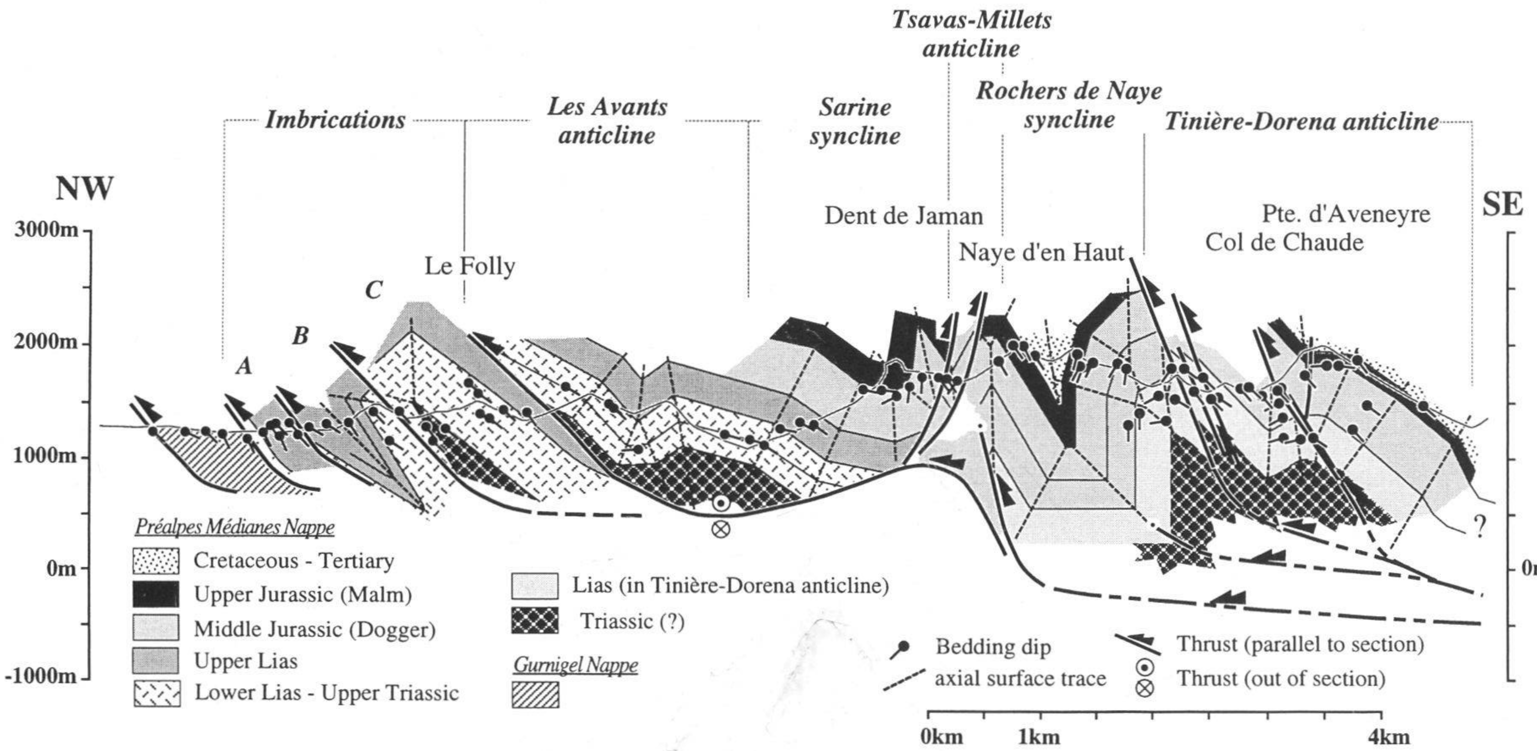


Figure 5c.–Detailed cross sections of the Préalpes Médianes Plastiques romandes. For location see figure 4. Axial surfaces do not necessarily bisect adjacent fold limbs, because of important changes in sediment thickness, rather they separate domains of varying dip. Le Folly-Dent de Jaman-Pointe d'Aveneyre section. The Sarine syncline rises and culminates at the Dent de Jaman. The development of the neighboring Tinière and Dorena anticlines leads to the formation of interference structures. Note in all three sections the backthrusts developed along the Tsavas-Millets anticline, but also in the SW position of the Dorena anticlinal as well as in the SE portion of the imbricates.

Coupes détaillées des Préalpes Médianes Plastiques romandes. Localisation sur la figure 4. Les surfaces axiales ne sont pas nécessairement bissectrices des flancs adjacents, car l'épaisseur des couches est variable; elles séparent des domaines à pendages différents. Coupe Le Folly-Dent de Jaman-Pointe d'Aveneyre. Le synclinal de la Sarine remonte pour culminer à la Dent de Jaman. Le dévelopement voisin des anticlinaux de Tinière et Dorena produit des structures d'interférences. Dans les trois coupes on peut remarquer les chevauchments en retour développés le long de l'anticlinal de Tsavas-Millets, mais aussi dans la partie SW de l'anticlinal de Dorena, ainsi que dans la partie SE des imbrications frontales.

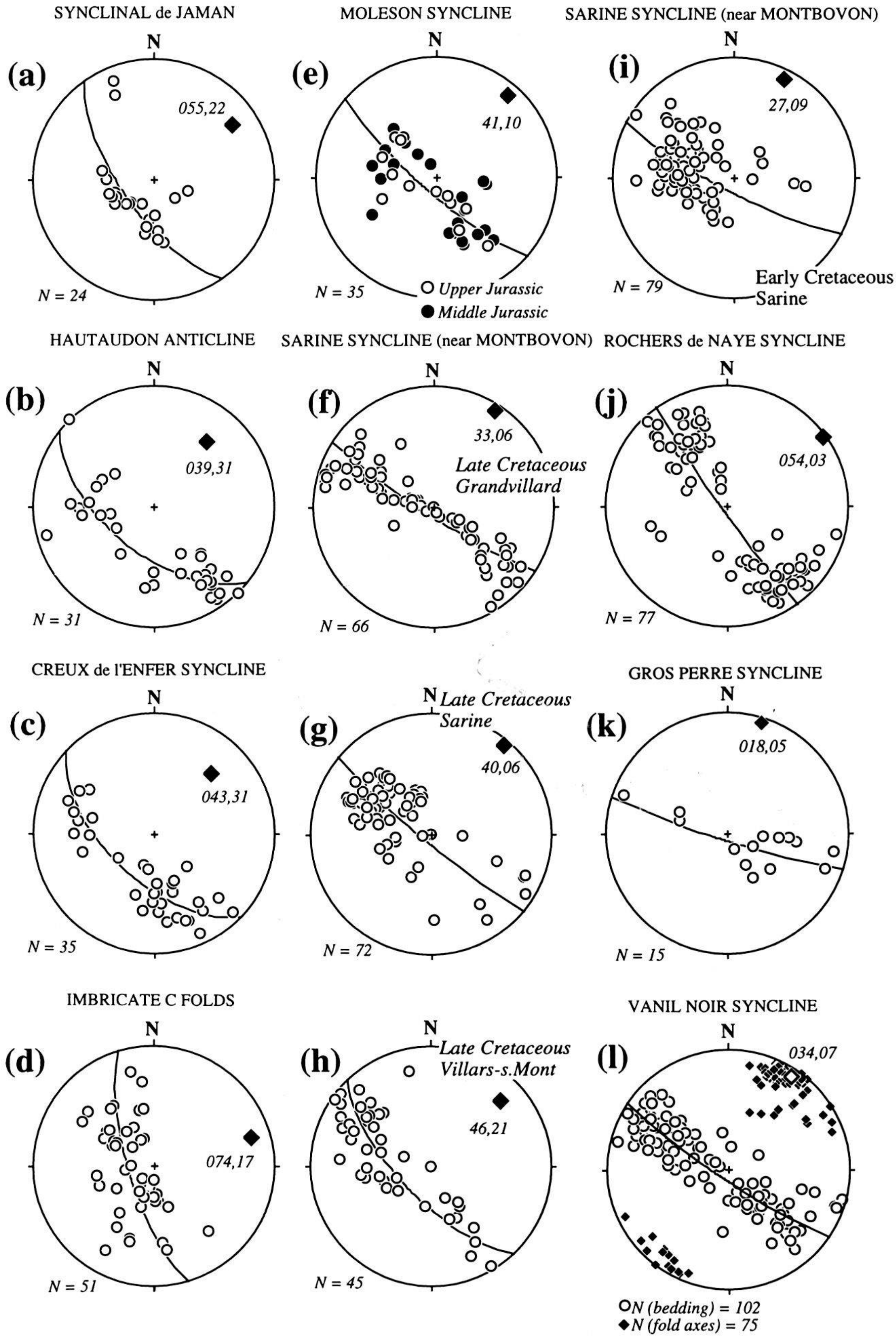
1994). (b) The Gros Mology-Molard-Les Avants anticlinorium that forms the transition from the external imbricates to the «main body» of the Médianes Plastiques. (c) The broad and deep Sarine or Intyamon syncline. (d) The Tsavas-Millets anticline that runs on the NW flanks of the mountains dominated by the Vanil Noir summit. (e) The Vanil Noir-Dent de Corjon-Rochers de Naye syncline forms a high mountain ridge that runs SE of the Sarine valley and extends till Lake Léman. (f) The Dorena and Tinière anticlines are a most prominent feature in the Médianes Plastiques bordering to the N the (g) Châteaux d'Œx syncline and further S the intermediate Médianes (Gastlosen-Tours d'Aï) which further S is followed by the Médianes Rigides. These different structures, their geometry and relation with faults and thrusts will be discussed hereafter.

Thrusts

Common in the Préalpes Médianes, they are generally buried under Quaternary sediments and can be studied in few outcrops only. A hierarchical sequence of thrusts of different importance and structural significance can be distinguished. The main thrust surface is formed by the basal décollement along the Triassic evaporites (BAUD 1972) of the Préalpes Médianes. It can be seen in the external imbricates, elsewhere it is buried below a folded hangingwall. From cross section construction (fig. 5) we see that this surface appears curved (folded ?). It is along this décollement that the Préalpes have been detached from their basement and partly carried over the Helvetic units onto the N-NW Alpine foreland. Other thrust surfaces show less displacement and are associated with small imbricates and folds. Some may be overturned, steeply dipping towards the N due to stacking of several thrust slices (PLANCHEREL 1979, MOSAR 1989, 1991). They are all splays of the main décollement. In turn smaller thrusts (reverse faults) branch off from these surfaces near their termination, in fold cores e.g. Besides these foreland-vergent thrusts a series of hinterland-vergent or backthrusts have been recognized and described (REVERTERA 1926). Those thrusts exhibit a top-to-the S-SE movement opposed to the general transport direction towards the NW onto the Molasse basin. They may originate on décollement and thrust ramps, as in the Médianes Rigides (Niederhorn E Préalpes; Gummfluh-Rübli W Préalpes south of Châteaux d'Œx (MOSAR 1989, 1991), or may result from inverted former synsedimentary faults (Tsavas anticline). In other places still, they may be the result of triangle zones developing in response to space accommodation problems in fold cores (as is suggested in the case of the Dorena anticline; photo III, IV).

Strike-slip Faults (tear-faults)

An important and prominent structural feature in the Préalpes Médianes are vertical to sub-vertical faults or fault zones with horizontal displacement (PLANCHEREL 1976, 1979). They are mostly oriented N10 with a sinistral displacement and N110 with a dextral displacement. These zones separate domains with different orientations of fold axis directions, as well as areas where individual folds terminate and form en échelon relay structures. These faults have been interpreted as strike-slip faults rooting in the basement and affecting thus both the overlying and underlying structural units. Movement along these strike-slip fault systems would then be responsible for the fold-and-thrust development in the Préalpes Médianes Plastiques. A different


SYNCLINAL de JAMAN
N
(a)
055,22
N = 24
MOLESON SYNCLINE
N
(e)
41,10
N = 35
Upper Jurassic
Middle Jurassic
SARINE SYNCLINE (near MONTBOVON)
N
(i)
27,09
Early Cretaceous
Sarine
N = 79
HAUTAUDON ANTICLINE
N
(b)
039,31
N = 31
SARINE SYNCLINE (near MONTBOVON)
N
(f)
33,06
Late Cretaceous
Grandvillard
N = 66
ROCHERS de NAYE SYNCLINE
N
(j)
054,03
N = 77
CREUX de l'ENFER SYNCLINE
N
(c)
043,31
N = 35
N
Late Cretaceous
Sarine
(g)
40,06
N = 72
GROS PERRE SYNCLINE
N
(k)
018,05
N = 15
IMBRICATE C FOLDS
N
(d)
074,17
N = 51
N
Late Cretaceous
Villars-s.Mont
(h)
46,21
N = 45
VANIL NOIR SYNCLINE
N
(l)
034,07
N (bedding) = 102
N (fold axes) = 75

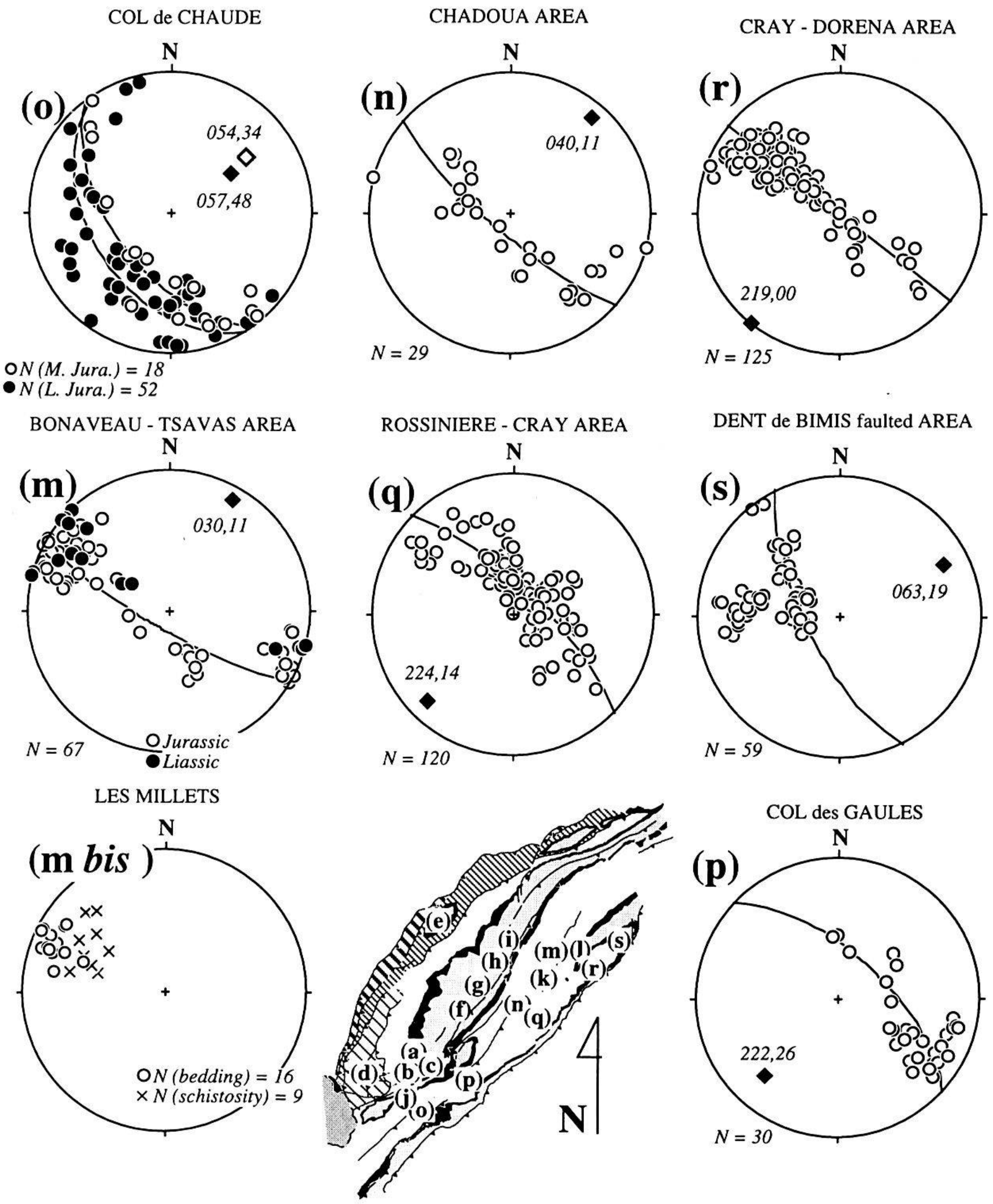


Figure 6.–Stereonet equal area lower hemisphere projections of bedding dip plane and small scale fold axes. Best fit great circles and corresponding fold axis have been calculated using Stereoplot™ program (N. Mancktelow). Simplified tectonic maps indicate the areas where data for the different stereonet projections have been sampled. *Projection stéréographique de Schmidt, hémisphère inférieur, des plans de stratification et des axes de plis de petite échelle. Les meilleurs grands cercles et axes de plis correspondants ont été calculés avec le programme Stereoplot™ (N. Mancktelow). Sur la carte tectonique simplifiée sont indiquées les régions où les mesures ont été faites.*

explanation, favored here, associates these faults with individual thrust and fold structures of the Médianes Plastiques only (MOSAR and BOREL 1992). They are considered to be tear faults kinematically linked to the fold-associated thrust planes. In other places they form lateral ramps. Thus these faults can be considered transfer zones between two adjacent tectonic features. An example is formed by the western termination of the Dent de Broc syncline. By means of a tear fault that runs in the Sarine river valley (mostly hidden under Quaternary sediments) it is juxtaposed to the W with the complex anticlinal structures of the Gruyères area (fig. 2 and 4). Another such tear fault separates the Dent de Corjon syncline from the Rochers de Naye syncline and runs in the Hongrin river valley (fig. 4). In the Montreux area the external imbricate thrusts trend NNE-SSW and show a strong sinistral displacement component. They can be interpreted as lateral ramps. Further south this zone turns into a larger sinistral tear fault zone affecting the whole of the western termination of the Médianes Plastiques. The Laitemaire-Gastlosen imbricate, between the Médianes Plastiques and Médianes Rigides, is cut into several distinct lobes by such tear faults merging laterally with the thrust of the affected imbricate.

Folds

The Médianes Plastiques are characterized by large-scale folds, but numerous smaller decametric to centimetric folds can be observed in multilayer lithologies such as the Early and Late Cretaceous or the Middle Jurassic. These folds are too numerous and too small to be represented in our cross sections.

Different tectonic domains can be recognized in the western Médianes Plastiques:

1.-Three distinct units can be distinguished in the zone of external imbricates. With local variations they can be found all along the front of the Médianes Plastiques nappe and are predominantly developed in rocks of Triassic and Early Jurassic age. In the occidental region studied here, the most external (northwestern) is imbricate A (BADOUX 1965b). Imbricate B is mainly developed in the northern part in the Moléson-Gruyères area and includes the Moléson syncline as an outstanding feature (MAUVE 1921, fig. 4, 5a, 6e). We can find the complete stratigraphic series, except the Middle and Late Cretaceous. Imbricate C only exists in the southern part of the external imbricate zone, near Montreux (MOSAR 1994). The northern area between the NE termination of the Moléson syncline and Gruyères is poorly understood. Outcrops are of rather poor quality and the bedding dip data coverage is week. From former mapping (MAUVE 1921, PUGIN 1952, VON DER WEID 1961) we can construct a series of folds associated with thrusts affecting rocks of Triassic, Early and Middle Jurassic age only. Evaporites (gypsum) can be found in fold cores in some places in this region (WEIDMANN 1992). The continuation across the Sarine valley remains unclear. Structures east of the N-S running Sarine valley are more E-W oriented than on the western side of this frontal portion of the Médianes Plastiques. They are separated by a set of N10 oriented vertical faults that seem to be tear faults associated with the thrusts on the east side of the river. With respect to the Sarine syncline further S, the Dent de Broc syncline can tentatively be correlated with imbricate B and thus would form the continuation of the Moléson syncline.

2.–The transition from the external imbricates to the main body of the Médianes Plastiques is formed by the Gros Mology-Molard-Les Avants anticlinal structure. It is formed by two small anticlines separated by a small syncline and has a very long SE limb (see Sarine syncline). It is always associated with an important thrust forming the base of the Médianes Plastiques main body. The anticlines develop at the tip of this thrust. The thrust may develop splays, as in the Molard portion of the anticline and cut at the base of one of the two anticlines. East of the Sarine river this structure forms one well developed box fold shaped anticline, located between the Dent de Broc and the Dent de Chamois (CHASSÉ 1924, CHATTON 1974, CHENEVART 1945). A periclinal closure dipping towards the E terminates this structure just NE of the Jogne river (fig. 1, 4).

3.–The Sarine valley (Intyamon) syncline runs from the Dent de Jaman east of Montreux along the lower Hongrin river towards the NE. It widens to a width of almost 5 km in the Sarine valley (fig. 3, 6f, 6g, 6h, 6i). From Estavannens to the northeast, its orientation changes to a more E-W direction and the structure runs towards the ENE past the Dent de Chamois towards the Jogne river. By its dimensions the Sarine or Intyamon syncline forms the most important structure N-NE of the Rochers de Naye syncline. The topographic culmination of the Late Cretaceous rocks is around 2000 m. In the center of this syncline this limit is around 700 m, whereas the basal thrust reaches the a depth of about -1 km. The western limb of the syncline is dipping with 30-40° towards the SE and brings the Late Jurassic-Cretaceous limit from an elevation of 1800-2000 m in the Vanils ridge down below the 750 m high bottom of the Sarine valley. Drill holes and studies of the thickness of Quaternary sediments (PUGIN 1988) show that the top of the Cretaceous-Tertiary sediments is at an altitude of about 400 m in the center of the synform, between Montbovon and Lessoc. The Jurassic-Cretaceous boundary can thus be put at 200-300 m, assuming a 100-200 m thick sediment pile for the whole Cretaceous-Tertiary. Inside the syncline two topographic relief culminating around 840 m are formed by a series of tight folds in the Late Cretaceous layers. The eastern limb of the Sarine syncline is subvertical. The Late Jurassic-Cretaceous limit outcrops again beyond the adjacent Tsavas-Millets anticline at an altitude of 2200 m in the Vanil Noir syncline.

East of the Sarine river, the NE continuation of the Sarine syncline extends beyond the Dent de Chamois. The syncline clearly splits into two distinct smaller synclines separated by a thrust-associated anticline (CHENEVART 1945, CHATTON 1974). Beginning E of the Sarine river the synclinal bottom (Cretaceous-Jurassic boundary) raises to an altitude of about 1200 m south of the Dent de Chamois. To the SW too the syncline splits up into two minor 30-40° NE dipping synclines (fig. 6a, 6b, 6c). The Jurassic-Cretaceous boundary plunges from a height of about 2000 m at the Dent de Hautaudon towards the Sarine valley center, where fold axis have shallow to subhorizontal plunges (fig. 6f).

In the northern part of the syncline a small klippe of Nappe Supérieure can be found. Thus this large structure forms a deep synform bordered on each side by steeply dipping panels. At the center this basin reaches a depth of about -1 km.

The center and the lower part of the eastern limb are cross cut by two thrusts that uplift the southeastern area. These thrusts die out when approaching the Dent de Jaman where the main syncline splits into two minor synclines.

4.–The Tsavas-Millets anticline (fig. 6m, n) forms the slopes W of the Dent de Folliéran-Vanil Noir-Vanil Carré ridge (WENGEN 1924). It has a very important vertical to slightly overturned NW limb, as shown from the cleavage-bedding relationship (fig. 6m bis), that forms the lower half of the slopes. The meridional limb (some 600 m of Middle Jurassic limestones) is inclined to the SE and merges rather quickly into the southerly adjacent syncline. The Tsavas-Millets anticline has a slightly box-shaped fold core with two axial surfaces that can be mapped in the field. The fold core is cut by a steeply northward dipping thrust with top to the south displacement. This backthrust is associated with important changes in sediment thickness from one limb portion to the other.

In the Laisallet and Chamot Sale area further to the SW (above Lake Léman), this backthrust splits into two separate thrusts. In the Laisallet portion the whole structure is slightly overturned towards the NW (the overturned backthrusts thus exhibit a normal displacement on steeply SE dipping faults).

The northwestern limb thickness is in excess of 2000 m in the central Sarine valley section (1800 m of Middle Jurassic limestones) and thins along strike towards the NE as well as to the SW. In its external (NW) portion, beds are vertical (mainly in the Late Jurassic layers) whereas further SE (more internally, in the Middle Jurassic horizons) bedding is overturned. Rock cleavage-bedding relation clearly indicate the overturning of those beds. Further SE still the beds have an steep dip to the NW again (Early Jurassic layers).

When rotated back into its original position with bedding of the Late Jurassic dipping gently to the NW one can clearly recognize a synsedimentary unconformity indicating a northwestward opening fan (this deposition direction is corroborated by the presence of re-sediments also known W of the Sarine valley indicating the presence of a slope and a high further S-SE (HEINZ and ISENSCHMID 1988).

Towards the SW the anticline narrows and is thrusted, along a steeply dipping fault plane, to the N. In the Laisallet area the tightness is such that the synclines to the NW and SE become adjacent. This same situation is encountered further SW, above Lake Léman in the Chamot Sale and Merdasson area, before the anticline abuts against the thrust surface at the base of the "main body" of the Médianes Plastiques (fig. 4, 5b, 5c).

Further to the east this anticline is correlated with the Stockhorn anticline of the eastern Médianes Plastiques (JEANNET 1922, WENGEN 1924, PLANCHEREL 1979, MOSAR 1991).

5.–The Vanil Noir-Dent de Corjon-Rochers de Naye syncline forms a large, though discontinuous structure (fig. 6j, 6k, 6l). The three names stand for three distinct portions (from NE to SW) of a larger structure separating the Tsavas-Millets anticline and the Dorena-Tinière anticline. The Vanil Noir-Vanil Carré segment is the longest and extends from the Morteys area in the NE towards Rossinière N of the Sarine river (SCHARDT 1881-1882, 1884, WENGEN 1924, REVERTERA 1926). S of the Sarine river lies the Dent de Corjon portion, followed, further towards Lake Léman, by the Rochers de Naye segment. In the Sarine valley near Rossinière the northern and southern segments are not in line, but rather show a right lateral offset along a east-westerly trending line. This area: the Rossinière area, also shows a very complicated structure in the Tsavas-Millets anticline (PLANCHEREL 1979). Bedding is very steep to vertical and axial surfaces are difficult to trace. Possibly an en échelon structure links the Tsavas-Millets anticline to the Dorena-Tinière anticline and causes this offset in the synclinal structure.

Overall these synclines have a tight (Rochers de Naye) to open (Dent de Corjon) box fold geometry with a flat bottom. Many small scale, metric folds develop in Early Cretaceous horizons. Fold limbs are steep and the small scale folds are both symmetric or asymmetric depending on their location in the fold core or along the fold limbs, respectively. Because of axial surfaces merging in the fold core at higher structural levels the fold becomes isoclinal as in the Vanil Carré, Gros Perré or Pointe de Paray area (REVERTERA 1926, photo I). Fold hinges are very small compared to the limbs and confer a kink-like aspect to these structures.

Fold axial plunge varies throughout the different sections of these three synclines (fig. 6j, k, l). The central portion is horizontal whereas the extremities show significant plunges to the NE in the eastern termination and to the SW in the western termination. This is especially well developed in the Dent de Corjon and Rochers de Naye portions of the syncline. In a NE-SW direction the overall structure is one of crests and saddles.

All three portions of the Vanil Noir-Dent de Corjon-Rochers de Naye syncline form in there central section topographically elevated features. This type of inverted relief is typical in this part of the Médianes Plastiques.

6.–The Dorena and Tinière anticlines: located in the Vanil Noir-Châteaux d'Œx-Hongrin-Tinière area and trending NE-SW, these two major anticlines form an important and continuous structure in the meridional Médianes Plastiques (fig. 4, 5, 6 o-p). They develop an en échelon relay structure in the Hongrin river area (METTRAUX and MOSAR 1989, MOSAR and BOREL 1992, 1993). Both anticlines have a steep northern limb and a flat to gently southeastward dipping central part. The moderately to steeply dipping meridional limb forms a dip slope which extends continuously for almost 25 km. This dip slope surface is close and parallel to the major thrust contact with the overlying nappe Supérieure (MOSAR 1991, MOSAR and BOREL 1993). Thrust movements of the Nappe Supérieure have induced a dispersion of the small scale fold axes on the Late Cretaceous beds of the Médianes Plastiques along a surface parallel to the thrust surface and indicating a northwest transport direction.

The Dorena anticline (S of the Vanil Noir) can be subdivided into several structurally distinct segments. From NE to SW we can distinguish a periclinal fold termination dipping to the NE (fig. 6s, photo II) followed by a subhorizontal central fold segment (fig. 6r, photo III) complicated by a minor fold. This second order fold develops along the north-western hinge zone and shows a vergence towards the SE, opposite to the general NW direction. It is persistent along strike the major fold, although it changes its geometry, with occasionally two or three smaller folds forming (SCHARDT 1881-1882, FAVRE and SCHARDT 1887, REVERTERA 1926). The NE periclinal termination of the Dorena anticline is cut by a series of vertical faults perpendicular to the fold axes (photo II). They mainly seem to have normal offset. This is well documented by a set of large faults at the very NE end of the Dorena anticline. Due to the normal movement of these faults, bedding orientation is rotated from a rather flat position to steeper SE dips (fig. 6s).

The Dorena anticline progressively dies out towards the SW in a gentle SW dipping periclinal fold closure (fig. 6p) and is relayed en échelon by the Tinière anticline (fig. 6o). In subsurface, however, the fold extends along the meridional limb of the Tinière anticline and its surface expression is reduced to a small tight anticline cut by several thrusts, as observed in the Malatraix area. This tight fold results from the interference of two closely spaced anticlines: the Tinière anticline to the N and the Dorena anticline to the S (MOSAR 1994, for detail). In this western portion the Dorena anticline is cut in its core by a thrust with a top-to-the-NW displacement.

NE of the Rhône valley, along the Tinière valley the Tinière anticline forms an inverted relief. This large anticline has an axial plunge towards the NE. At the Col de Chaude this plunge reaches 35-45°, to form a steep periclinal fold closure. The fold dies out in the transverse Hongrin river valley. The core of the anticline is cut by a thrust with a top-to-the NW displacement. In the area between the Col de Chaude and the Hongrin river we can observe the en échelon transfer zone formed by the eastern termination of the Tinière anticline and the western termination of the Dorena anticline (MOSAR and BOREL 1992).

7.–The Châteaux d'Œx synclinorium is a complex zone located to the south of the investigation area and to the north of the Tour d'Aï-Gastlosen structural unit. This large synclinorium forms a topographic low that is filled with rocks belonging to the Nappe Supérieure. The latter has been thrusted on top of the Médianes Plastiques and both are folded together. Between Châteaux d'Œx and Lake Hongrin several outcrops of Cretaceous sediments belonging to the Médianes Plastiques indicate the existence of folded and thrusted structures at shallow depth beneath the surface. In the area above the Rhône valley two synclines can be clearly differentiated. This area corresponds to a former paleogeographic high bordered by sedimentary basins to the N and the S (BAUD and SEPTFONTAINE 1980, SEPTFONTAINE 1983). The inversion of this paleotectonically complex region has led to an even more complex alpine structure (SEPTFONTAINE 1995).

8.–South of the Châteaux d'Œx synclinorium we enter the realm of the Gastlosen-Laitemaire-Tours d'Aï structure. Developed as large fold in the Tours d'Aï area to the west, this tectonic structure changes to a SE dipping imbricate in the east. Another important syncline formed by the Nappe Supérieure forms the transition to the southern most portion of the Préalpes Médianes: the Médianes Rigides imbricates (PLANCHEREL 1979, MOSAR *et al.* 1996).

4. INTERPRETATIONS AND DISCUSSION

1.–From the regional description it arises that the three domains of the Médianes Plastiques Romandes show very distinct tectonic features: (a) the most external part of the thrust-belt is characterized by a series of sometimes three imbricates. They are associated with folds developing above thrust-ramps in a fault-bend fold style, but locally also with tight, recumbent folds. These imbricates can be found all along the NW-W front of the Préalpes Médianes Plastiques, both in the Swiss and the French lobe (PETERHANS 1923). (b) The second structural realm, further to the E-SE, forms the main "body" of the Médianes Plastiques. Its is formed by a series of large scale well developed folds, of which the Sarine or Intyamon syncline. This large open syncline forms a trough with its lowest point in the center of the Sarine valley. The basal detachment of the Médianes Plastiques is thus located at a depth of about -1100 m (vicinity of Lessoc-Granvillard). This area forms a structural low bound by fold limbs to the W and E and by the plunging fold axes at the NE and SW termination of the Sarine syncline. In these structural highs, the basal detachment rises to an altitude around 0 m. (c) The third distinct structural feature is the high ridge of the Vanil Noir-Rochers de Naye with the Tsavas-Millets anticlines, the Vanil Noir-Dent de Corjon-Rochers de Naye syncline and the Dorena-Tinière anticline. The whole forms an arch shaped structure with high structural relief. Because of its very straight and continuous southern limb (more than 20 km along strike) we can consider this structure as a reference line that suffered the same overall displacement above the main décollement of the Préalpes Médianes. We thus can use this reference line to evaluate the differential displacement involved with folds and thrusts developing further to the N-NW.

2.–Different categories of thrusts may be distinguished: (a) the basal décollement surface along which the Préalpes Médianes have been detached and transported from their origin to the present position; (b) thrusts associated with and responsible for the development of folds with displacements in the km range; (c) minor thrusts (reverse faults) in fold cores or developed as splays at the termination of larger thrusts with displacements in the order of 200 m or less; and (d) backthrusts with a top-to-the S-SE displacement.

The Préalpes Médianes were detached from their substratum above a basal décollement along evaporite layers at the base of the Late Triassic in the Médianes Plastiques (along the base of the Middle Triassic and partly the Early Triassic as indicated by quartzite lenses found at the base of the décollement, in the Médianes Rigides; see BAUD 1972, MOSAR 1988b, COSCA *et al.* 1992). Strong deformation in the Triassic limestones in the vicinity of the thrust surface have only been described in the Médianes Rigides. After they were detached, the Préalpes Médianes were emplaced on the Ultrahelvetics and Zone Submédiane. Thus developed a mélange zone, often highlighted by the development of cornieules, above which the Préalpes rode towards their present day emplacement. The depth to the basal detachment in the Médianes Plastiques is rather shallow, around 0 m to 500 m above sea level, except in the Sarine valley trough, where it deepens to -1km. It thus shows a rather strong topographic low in the central portion and a strong rise towards the W which can also be seen in the eastern portion of the Chablais Préalpes Médianes S of Lake Léman (work in progress, see also GIROD 1995, BADOUX 1963a). From recent seismic investigation it appears that a new basement imbricate is developing below the western termination of Lake Léman (ESCHER *et al.* 1993, MOSAR *et al.* 1996, SOMMARUGA 1995, 1997, PFIFFNER *et al.* 1997). The changes in depth of the basal décollement in this area correspond to the eastern lateral termination of this basement high.

Branching off from the basal décollement are a series of thrusts that propagate towards the surface. They form ramps and flats above which fault-related fold geometries develop (e.g. fault-bend and fault-propagation folds). The majority of the structures in the Préalpes Médianes Plastiques developed as a consequence of displacement of hangingwall material along these thrust surfaces. Some of them may also have been active during different periods as e.g. suggested by superposed generations of slickenfibres. Several closely spaced, shallow ramp and flat thrusts are responsible for the development of the frontal imbricates along the outer, N-NW, Médianes Plastiques. Some of these thrusts, now oriented more or less N-S, acted as lateral ramps oriented oblique to the general direction of displacement (considered here to be to the NW in absence of conclusive kinematic evidence), such as E of Montreux. Thrust movements are coeval with strike-slip movements along these faults (MOSAR and BOREL 1992).

Some of the N-S oriented thrust surfaces in the area E of Montreux cut up-section, both in the frontal and the trailing part (fig. 5c), which is an indication of displacement directions top to the W (MOSAR 1994).

Elsewhere in the Préalpes there is also strong evidence that some of these thrusts cut the basal décollement and may root in the present day substratum (Molasse, autochthonous Mesozoic sediments, basement) of the Préalpes. Thus the lenses of Ultrahelvetics, Lower marine Molasse and Subalpine flysch found along thrust surfaces at the base and in the Gurnigel nappe (fig. 1a) are examples that may indicate such post-emplacement movements associated with shortening in the substratum. Another example is the thrust surface that brings the Tours d'Aï anticline on top of the Château d'Œx syncline (pinched Corbeyrier syncline, with its Nappe Supérieure flysch overthrust by Préalpes Médianes material).

This late thrusting at the Alpine front may be corroborated with the uplift of the external crystalline massifs and shortening in the foreland (also linked décollement of the Jura mountains), of which they would thus be out of sequence thrusts.

Backthrusts appear to be widespread, not only in the Médianes Plastiques, but also in the Médianes Rigides. Though recognized early during the geologic exploration of the Préalpes Médianes, their importance has been underestimated. Different types of backthrusts have developed: large backthrusts resulting from the inversion of former normal listric, syn-sedimentary faults; backthrusts associated with pop-up structures developed in large scale fold cores and backthrusts developed at the transition between ramps and flats in thrusted hangingwall blocks.

Large backthrusts such as in the Tsavas-Millet anticline, NW of the Vanil Noir crest, or in the Dorena-Tinière anticline, are associated with important variations in sediment thickness between adjacent fold limbs.

Because these thickness changes result from the lasting activity of synsedimentary normal listric faults, the backthrusts are interpreted here as resulting from the inversion of these faults. Further to the W, in the Laisallet area, N of Dent de Corjon, a series of such backthrusts has developed. Like the adjacent northern fold limb, they are here slightly overturned, probably due to progressive and strong tightening of this anticline.

Ramp-associated thrusts in the Médianes Plastiques are well developed in the area between Montreux, Les Avants and to the N of the Rochers de Naye syncline. Several E-W trending fault sets show top-to-the South movements that can be linked to the formation of two thrust-ramps which are associated, in this area, with the development of the frontal imbricates. Other important ramp-backthrusts, with a displacement exceeding 200-400 m, are recognized in the Médianes Rigides (MOSAR 1989, 1991).

3.–The development of various fold geometries in the Médianes Plastiques can be explained in terms of different kinematic and geometric models. Most of the folds described are associated with thrusts (or reverse faults), either in a fault-bend folding style with anticlines and synclines developing over thrust ramps or in a fault-propagation fold style with synclines developing at thrust tips and anticlines growing over the thrust ramp. Detachment folds are yet another type of folds that may, for instance, explain the development of box fold type geometries as observed in the Dent de Broc (CHENEVART 1945, CHATTON 1974). Detachment folds may evolve into fault-propagation folds with the development of a thrust ramp and subsequently continue to evolve by forming breakthrough thrusts. The transition from one fold type to another, e.g. from detachment fold to fault-propagation fold is most likely a function of the thrust propagation kinematics, the fault steepness and the different amounts of displacement along any one thrust surfaces.

Fault-bend folds are mainly developed in the Médianes Rigides where the thick, competent limestone series of Triassic and Malm prevail (MOSAR 1991). Examples of folds developed over ramps are found typically in the frontal imbricates. One of the best examples, where the thrusts surface below the ramp anticline is well exposed, is found in the Grammont-Derotchia-Tannay region of the Chablais Préalpes (BADOUX 1962).

More commonly in the Médianes Plastiques, folds developed synchronously with propagating faults to form fault-propagation or detachment type folds. They are dominant where the lithology is dominated by interbedded series of marl, shales and limestones (PLANCHEREL 1979). Those folds characteristically have higher structural (topographic) relief in comparison with fault-bend folds. Examples are the Tinière, Dorena, and Tsavas-Millets anticlines. The thrust may be blind or break through to the topographic surface. In the Médianes Plastiques Romandes, the thrust surfaces are exposed only due to erosion down to deeper structural levels of a fold core as in the Tinière anticline, whereas in the Dorena anticline the thrust remains buried.

4.–The strike-parallel evolution of the fold and thrust geometries is marked by periclinal fold terminations, en échelon relay structures, tear faults (accommodating strike-slip displacement above a basal décollement only), fold interference patterns and lateral ramps.

En échelon relay structures develop where two folds terminate and merge with their periclinal closures plunging in opposite sense (fold axial plunges vary between 20-40°). The transition from the Tinière anticline to the Dorena anticline is a typical example of such a relay structure (Fig. 4). They accommodate the different amounts of displacement associated with two anticlines forming on either side of the transfer zone. Associated with the en échelon structure we often observe the development of tear faults, that help accommodate the lateral (along strike) offset of the two adjacent structures (fig. 2). Some of these faults are well developed along the Hongrin river between the Rochers de Naye and the Dent de Corjon synclines (Fig. 4) at the northern continuation of the Tinière-Dorena anticlines relay. Another tear fault system separates the folds across the Sarine Valley, between Gruyères and the Dent de Broc, in the frontal part of the Médianes Plastiques and accommodates both a change in displacement and a change in fold axial direction from NE-SW to more E-W.

Closely spaced, neighboring folds, that form simultaneously, will develop interference structures, which, for example, may result in very tight folds between two major anticlines. Thus a very tight fold develops in the Malatraix area (S of the Tinière anticline) as a result of the development of the Tinière anticline to the N and the S-SW, lateral termination of the Dorena anticline (Fig. 4; see Mosar and Borel 1993). Due to the tightness of the structure, thrusts develop to accommodate space problems (see thrusts in the Col de de Chaude and Malatraix areas, Fig. 4, 5c).

Besides fold interference structures, space problems resulting from fold tightness also lead to the development of small scale folds (1-10 m wavelength) such as those found in the synclines (especially well developed in the interlayered marls and limestones from the Cretaceous-Tertiary: Sarine syncline, Vanil Noir-Rochers de Naye synclines), as well as out of the syncline thrusts or thrust related folds developing at fold hinges.

The small fold along the Dorena anticline may be linked either with an out of the syncline thrust of the NW adjacent Vanil Noir syncline or with the blind thrust of the Dorena fault-propagation fold. The additional displacement generated by a developing breakthrough thrust at the tip of the Dorena fault-propagation fold, may be consumed by forming a layer parallel (most likely) backthrust on the front limb of the main fold-propagation fold, but with an opposed vergence. A triple junction or wedge structures thus forms in the front limb. The displacement along this new décollement level is in turn consumed by the development of a minor fault-propagation fold.

5.–Besides the obvious geological structures due to the alpine deformation s.l., there are a number of paleo-tectonic or synsedimentary tectonic structures that can be observed or indirectly inferred in the Médianes Plastiques, as well as in the Médianes Rigides. Thus faults (normal, listric) have long since been invoked to separate domains with a varying thickness and/or nature of sediments (Trümpy 1960, Badoux and Mercanton 1962, Baud and Septfontaine 1980, Septfontaine 1983). During alpine deformation s.l. these structures were reactivated and inverted.

Progressive sedimentary unconformities create wedge-shaped structures that can be observed for example in the Dent de Jaman area, in the Tsavas-

Millet anticline or along the southern limb of the Dorena-Tinière anticline (fig. 5; see also SEPTFONTAINE 1995, for examples of progressive unconformities associated with actively growing folds related to synsedimentary inversion of older normal faults in the Chablais Préalpes Médianes). In the external imbricates sediment thickness progressively increases from the outer to the internal imbricate. This has been related to an increasing basin depth, itself associated with normal listric faults. These faults would have been reactivated as thrusts, separating the different imbricates during the alpine orogeny (METTRAUX and MOSAR 1989, MOSAR 1994).

Important thickness changes occur both perpendicular to the E-W basin axis and along strike. Fan shaped sedimentary wedges, strong onlaps, slumps and re-sediments are but some of the more obvious sedimentary structures due to syndepositional tectonics. Responsible for these variations are small en échelon synsedimentary listric normal faults that develop basins of typically 10 km^2 extension. Their development is related to thermal expansion and the associated rift shoulder uplift to the S (STAMPFLI 1993, MOSAR *et al.* 1996, BOREL 1995, BOREL in prep.).

6.–Correlation with structural features in the Médianes Plastiques further to the E have already been proposed by many authors (JEANNET 1922, PLANCHEREL 1979). Thus the large Stockhorn anticline can be traced to correspond with the Tsavas-Millets anticline. The western termination of this anticline does however not connect to the Tinière anticline (as proposed by the op. cit. authors) but rather to the Dent de Jaman-Merdasson area N of the Rochers de Naye syncline. In this we follow unpublished data by SCHARDT (1881-1882), who also shows that the Tinière anticline is relayed by the Dorena anticline.

The Sarine (Intyamon) syncline can be seen as the equivalent in the E Médianes Plastiques of the Gantrisch syncline (MOSAR 1991).

The structural style in the Préalpes romandes (the Pays d'Enhaut) is quite different from that in the Chablais Préalpes, across the Rhône valley and S of Lake Léman. Though sedimentary facies can be compared and show similar geometries and facies across the two lobes of the Préalpes Médianes (BAUD and SEPTFONTAINE 1980, SEPTFONTAINE 1983, 1995), the geometry of the tectonic features is different. Inclined synclines, with overturned limbs and breakthrough thrusts are frequent. The general style is more one resulting from thrusting over ramps and flats; thrust imbrications are common (SCHARDT 1898, GIROD 1995, SEPTFONTAINE 1995). Also the structural relief in the E Chablais (Valais) portion is higher than in the Préalpes romandes. This can be related to basement imbricate developing at depth.

7.–The tectonic development of the Médianes Plastiques and its alpine connection, cannot be inferred from the kinematic and geometric study of the folds and thrusts only. Thus the age of the youngest sediments of the Préalpes Médianes (Lutetian-Bartonian) and the age of the sediments eroded off the Préalpes and deposited in the Molasse basin (Chattian conglomerates of the Mont Pélerin), only give a time bracket in which the structural evolution occurred. A discussions based on structure, metamorphism, internal deformation sedimentation and geodynamics of all the Préalpes nappes is beyond the scope of this paper and is proposed elsewhere (MOSAR *et al.* 1996). It appears that the fold development is associated with the formation of thrusts (ramps and flats) that can all be linked to the basal décollement. A progressive foreland developing thrust and and fold sequence has been suggested for the Préalpes Médianes (MOSAR 1991).

However, many out of sequence thrusts, associated with thrusting in the Préalpes substratum and only observed in the external Préalpes nappes or in the trailing part of the Préalpes Médianes, are related to post-Oligocene and post-emplacement (out-of sequence thrusting) tectonics. The depth to the décollement changes both parallel and perpendicular to the general structural trend (of the fold axes). The fold axial trend also strongly varies from W to E in the studied area (Fig. 6). These changes, both in depth and in trend, confer to the Préalpes Médianes their particular geometry and they are most likely related to a changing topography of the substratum, which in turn appears to be the result of basement-footwall tectonics. The W-directed movements in the external imbricates and the changing axial directions, are another piece of evidence suggesting late W-directed movement in the Préalpes Médianes.

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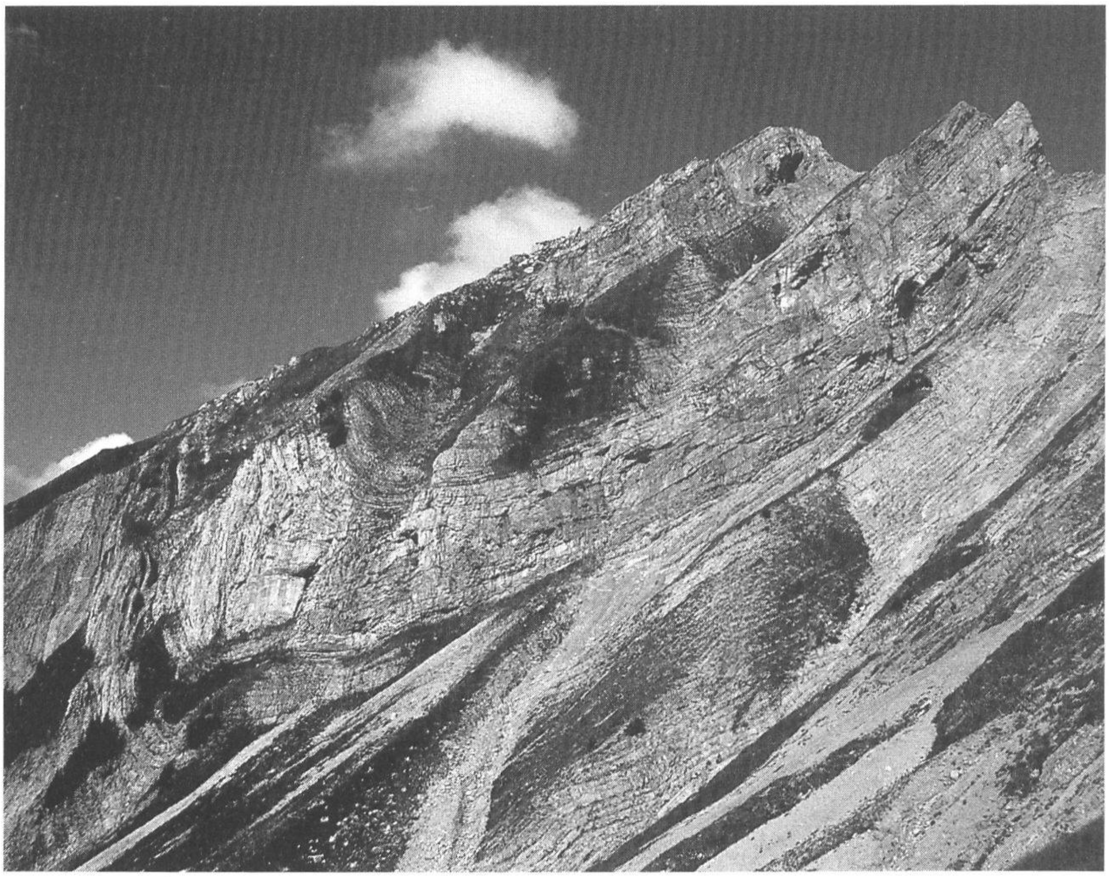

Photo (I).–View to the N-NE, towards the Pointe de Paray, showing the core of the Vanil Noir syncline. Fold core is formed by massif limestones of the Late Upper Jurassic (Malm). The well developed layers forming the external envelope of this syncline are formed by the alternating limestones and marls of the Middle Jurassic (Dogger-Cancellophycus formation).
Vue vers le N-NE en direction de la Pointe de Paray et montrant le coeur du synclinal du Vanil Noir. Le coeur de pli est formé par les niveaux de calcaires massifs du Malm. Les alternances bien marquées de marnes et calcaires formant l'enveloppe externe du pli sont d'âge Jurassique moyen (Dogger-Formation à Cancellophycus).

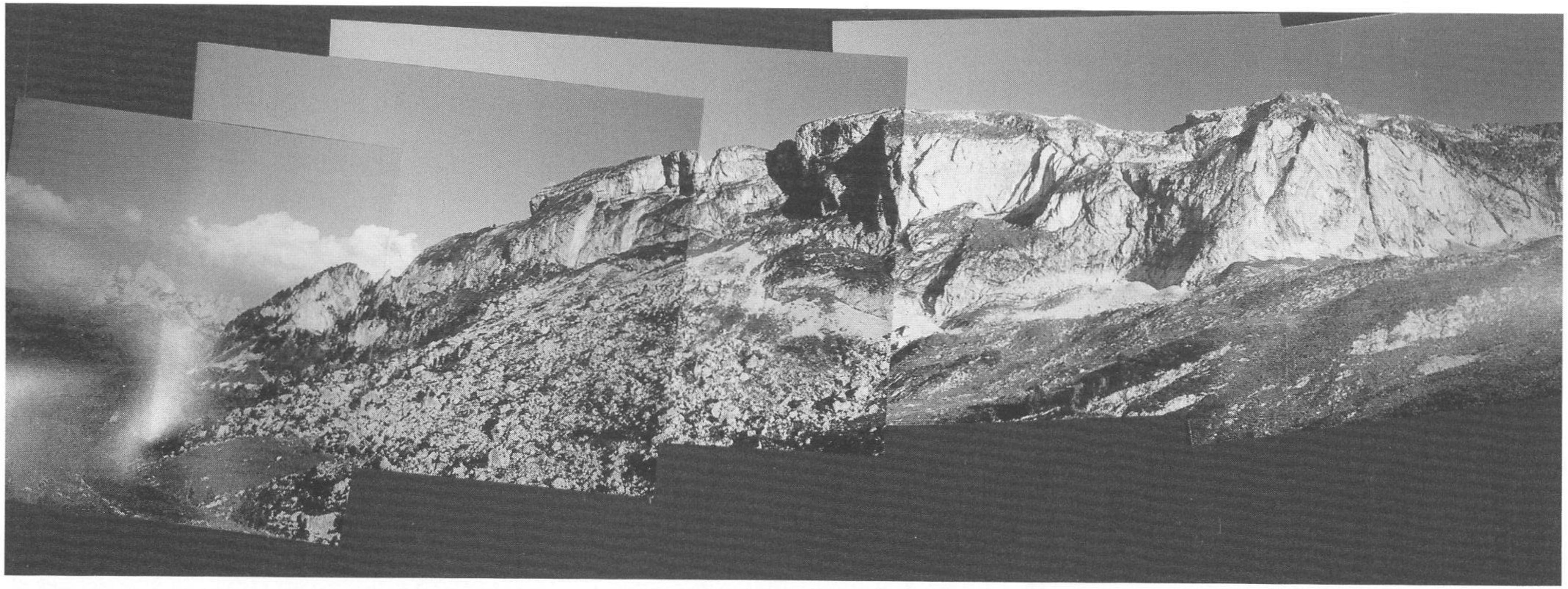

Photo (II).–View towards the S showing the eastern periclinal termination of the Dorena anticline (E of the Tour de Dorena). The crest of the cliffs is representative, in this area, of the anticlinal hinge zone and highlights the 30-40° plunge of the fold axes towards the E. To the W (to right of the picture) the fold core is exposed due a large rockslide. The "envelope" of the fold seen on the photo belongs to the massif limestones of the Late Jurassic (Malm). The slopes in the foreground belong to the Vanil Noir syncline, which in this portion has a box-fold geometry.

Vue vers le S montrant la terminaison périclinale orientale de l'anticlinal de Doréna (à l'E de la Tour de Doréna). La crête des falaises coïncide dans ce secteur avec la charnière du pli et met en évidence le plongement axial de 30-40° vers l'E. A l'W (côté droit de l'image) le coeur du pli est mis à nu par un éboulement. L'enveloppe du pli visible sur cette photo est formée par les calcaires massifs du Jurassique supérieur (Malm). Les pentes au premier plan appartiennent au synclinal du Vanil Noir, qui dans cette partie a une géométrie de type pli coffré.

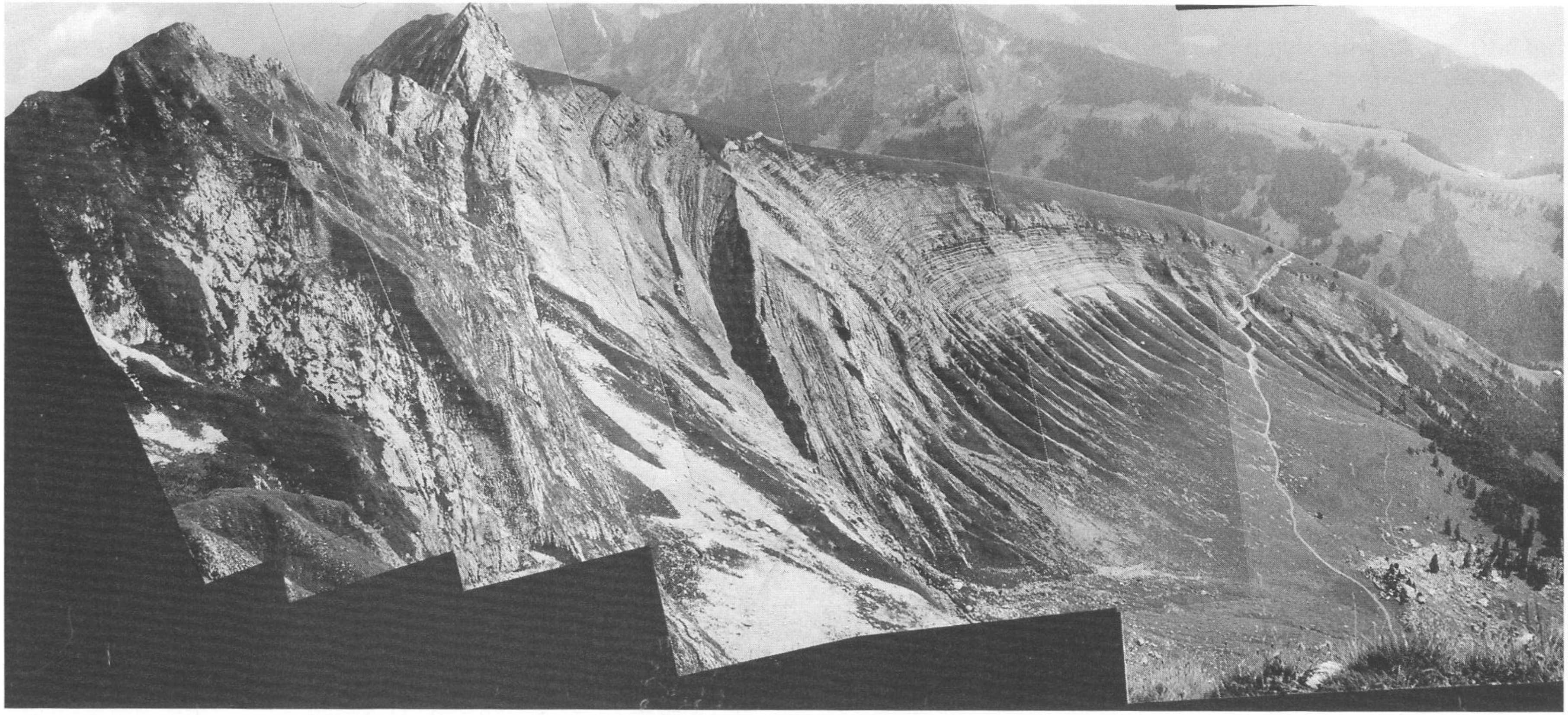

Photo (III).–View towards the E-NE into the large Dorena anticline. In the hinge zone between the steep northern limb and the gently SE dipping crestal portion of the anticline develops a small scale fold (see photo IV). Rocks exposed mainly belong to the interlayered marls and limestones of Middle Jurassic age (Dogger-Cancellophycus formation).
Vue vers l'E-NE dans le coeur de l'anticlinal de Doréna. Dans la zone charnière entre le flanc N raide et le flanc méridional à faible pendage vers le SE, se développe un pli secondaire (voir photo IV). Les roches affleurantes appartiennent essentiellement aux alternances calcaires-marnes du Jurassique moyen (Dogger-Formation à Cancellophycus).

Photo (IV).–Small scale fold along the northern hinge zone of the Dorena anticline. The geometry of this fold suggest a fault-propagation fold type indicating a movement towards the SW. View towards the E-NE. Location of the fold is to the SW of the Tour de Dorena (see also photo III).
Pli décamétrique le long de la zone charnière de l'anticlinal de Doréna. La géométrie de ce pli suggère un pli du type «pli de propagation» à mouvement vers le SW. Vue vers l'E-NE; localité au SW de la Tour de Doréna (voir aussi photo III).

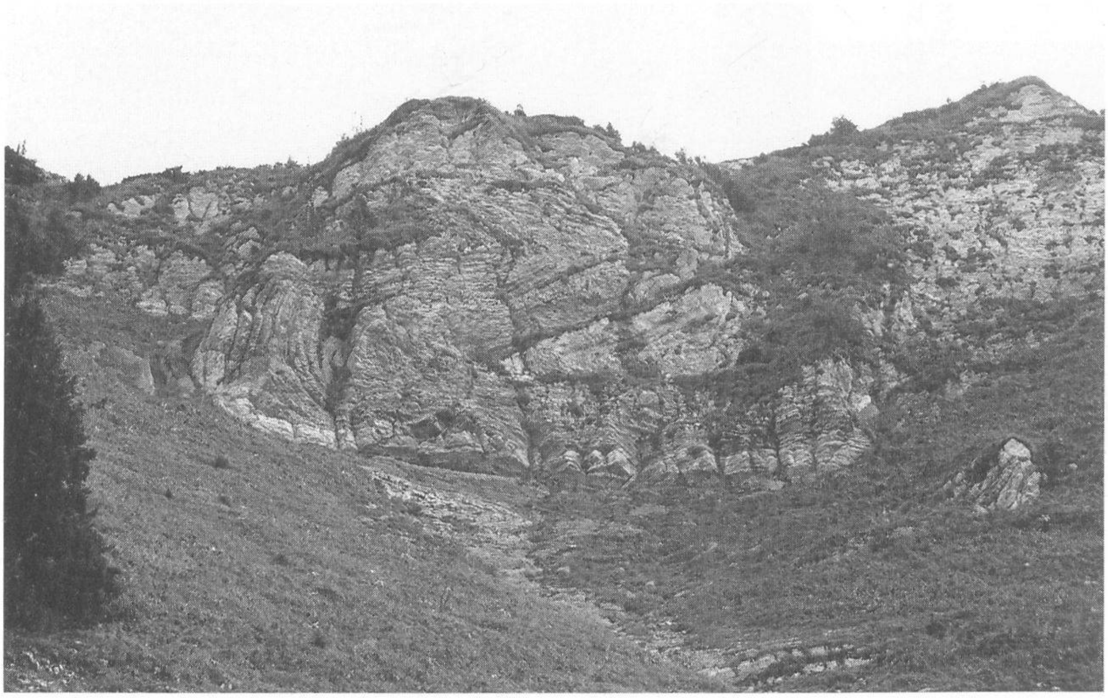

Photo (V).–Succession of folds with flat lying axial surface traces, and a box fold geometry, located towards the crest of the S limb of the Dorena-Tinière anticline. The fold is associated with the overthrusting of the Nappe Supérieure. Location near the summit of Malatraix in the vicinity of Lake Léman; view towards the S-SE. The multilayers are formed by limestones and marls of Late Cretaceous-Tertiary age.
Succession de plis avec une trace axiale de pli subhorizontale et une géométrie de type pli coffré dans la crête du flanc S de l'anticlinal de Doréna-Tinière. Le pli est associé au chevauchement de la Nappe Supérieure. La localité est à proximité du sommet de Malatraix dans la région du Lac Léman. Les couches sont formées par des alternances de calcaires et de marnes d'âge Crétacé supérieur-Tertiaire.

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