Géoatelier alpin Grenoble, 12-13 novembre 1992

Thierry Dumont, Georges Mascle, Pierre Tricart

A. PECHER

GRENOBLE 1
UNIVERSITE
JOSEPH FOURIER
SCIENCES. TECHNOLOGIE. MEDECINE

GEOLOGIE ALPINE

EDITE PAR LE LABORATOIRE DE GEOLOGIE
DE L'UNIVERSITE I DE GRENOBLE

(Laboratoire de Géodynamique des Chaînes Alpines associé au CNRS)

SERIE SPECIALE "COLLOQUES ET EXCURSIONS" N°1

GEOATELIER ALPIN
RESUMES

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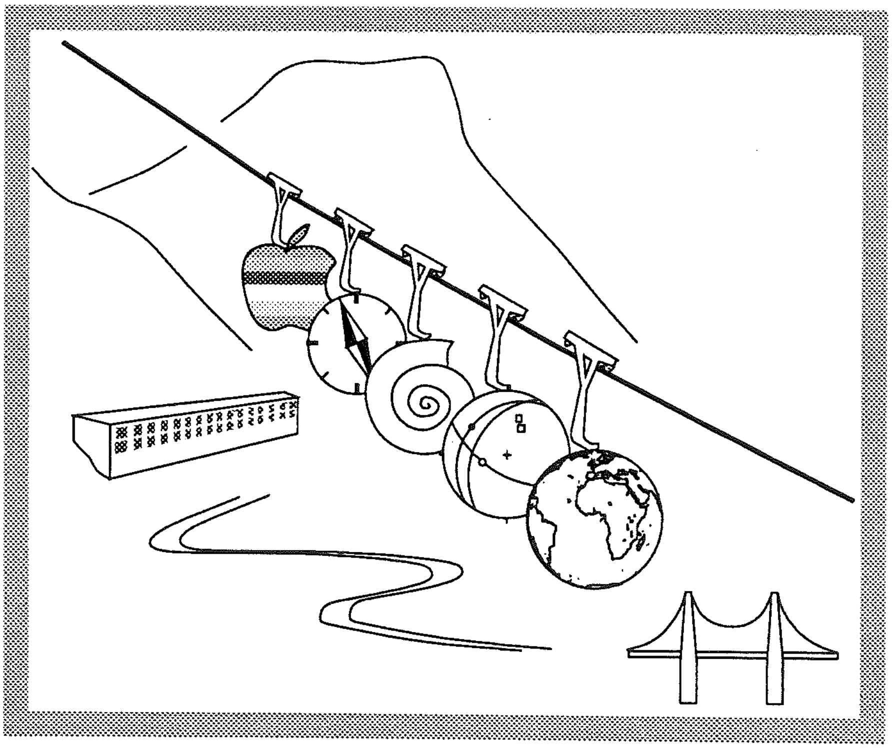
GEOATELIER ALPIN



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Organisation: Thierry Dumont, Georges Mascle, Pierre Tricart

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Géoatelier Alpin - 12/13 novembre 1992

Programme (communications)

JEUDI 12 NOVEMBRE

8h30 - Introduction.

9h00 - **Jouanne** François & Menard G. - Etude des mouvements verticaux actuels dans le Nord des Alpes françaises et le Sud du Jura par comparaison de nivellement.

9h20 - **Darmendrail** Xavier, Menard G. & Tardy M. - Resultats préliminaires de l'étude des marqueurs géomorphologiques des mouvements verticaux le long du sillon subalpin (Alpes occidentales, France).

9h40 - **Bogdanoff** Serge, Mansour M., Poupeau G., Michard A. & Tane J.L. - Apatite fission tracks dating and uplift of the Argentera Massif, Western Alps (France, Italy).

10h00 - Pause café/coffee break.

10h20 - **Pêcher** Arnaud, Barfety J.C. & Gidon M. - Structures Est-Ouest (anténummulitiques) à la bordure orientale du massif Ecrins-Pelvoux.

10h40 - **Ford** Mary - The tectonic emplacement of the SW Pelvoux massif, SE France.

11h00 - **Ferrandini** Jean & Loye Pilot M.D. - Tectonique en distension et décrochements au Burdigalien-Tortonien en Corse: l'exemple du bassin de Francardo-Ponte Leccia (Corse centrale).

11h20 - Pause/break.

11h30 - **Dietrich** Dorothee - Kinematics of the Helvetic nappes.

11h50 - **Mancktelow** Neil & Hubbard M. - Southwest-directed, orogen-parallel displacement during Neogene convergence in the Western and Central Alps.

12h10 - **Stampfli** Gérard - Le Briançonnais, terrain exotique dans les Alpes.

12h30 - Repas/lunch.

14h00 - 15h00: séance posters n°1/poster session n°1.

15h00 - **Desmons** Jacqueline & Radelli L. - Qu'est-ce que le Pennique?

15h20 - **Tricart** Pierre - Les calcschistes piémontais à l'Ouest du Mont Viso: esquisse structurale.

15h40 - **Fudral** Serge - Le massif péridotitique de Lanzo (Alpes italiennes nord-occidentales): cadre litho-structural et hypothèses sur les structures profondes.

16h00 - Pause café/coffee break.

16h20 - **Cotillon** Pierre - Contrôle tectono-eustatique de la sédimentation au Crétacé inférieur le long de la marge nord-provençale, de la montagne de Lure à l'arc de Castellane

16h40 - **Guillot** Stéphane & Ménot R.P. - Characteristics and signification of the deformations in the Paleozoic ophiolite of Chamrousse (Western Alps).

17h00 - **Vatin-Perignon** Nicole, Oliver R.A., Piboule M., Fabre J. & Guillot F. - Permian magmatism in the Briançonnais domain (Western Alps): new geochemical data and geodynamic implications.

17h20 - Pause/break.

17h30 -**Pairis** Jean-Louis, Audebaud E., Piboule M. & Bonhomme M. - Le volcanisme paléogène de l'unité des Aiguilles d'Arves. Le volcan du Goléon et la géodynamique alpine.

17h50 -**Lapierre** Henriette, Bernard V., Tardy M., Tricart P., Sennbier F. & Beck Ch.- Apports de la géochimie à la connaissance du cadre géodynamique du volcanisme calco-alcalin oligocène des Alpes externes (grès de Taveyannaz et brèches de Saint Antonin).

18h10 -Fin de la journée/end of the day.

VENDREDI 13 NOVEMBRE 1992

8h30 - **Steck** Albrecht & Hunzinker J. - Tectonique des Alpes de Suisse centrale: chronologie des événements structuraux et thermiques.

9h00 - **Baudin** Thierry & Marquer D. - Evolution tectonique des Alpes centrales: exemple de la nappe de Tambo.

9h20 - **Grujic** Djordje & Mancktelow N. - Structure of the Northern Maggia and Lebendun nappes.

9h40 - **Cosca** Michael, Desmons J., Hunziger J.C. - K/Ar and 40Ar/39Ar ages from the Grand Saint Bernard-Briançon Nappe (S.l.).

10h00 - Pause café/coffee break.

10h20 - **Porter** J.R. - Kinematics of the juxtaposition of the Combin and Zermatt-Saas units, the Piémont ophiolite nappe, Italian internal Western Alps.

10h40 - **Sandrone** Riccardo, Borghi A. & Compagnoni R. - Composite P-T path of the Gran Paradiso nappe: petrological constraints to the geodynamic evolution of the eclogitic continental crust of the Western Alps.

11h00 - **Henry** Caroline, Michard A. & Chopin C. - Geometry and structural evolution of ultra-high pressure and high-pressure rocks from the Dora-Maira massif, Western Alps, Italy.

11h20 - Pause/break.

11h30 - **Ramsbotham** Will - The structural setting of exhumed granulite and eclogite facies rocks in the Southern Sesia zone (internal Western Alps).

11h50 - **Postlethwaite** Emma - The Sesia zone: structural and metamorphic constraints on tectonic exhumation.

12h10 - Repas/lunch.

14h00 - 15h00 - Séance posters n°2/poster session n°2.

15h00 - **Castellarin** Alberto - Neoalpine compressional tectonics in the Southern Alps: relationships with the N-Apennines.

15h30 - **Schmid** Stefan - Geodynamic evolution of the Alps alog the EGT traverse. Part 1: Pennine units and deep structure.

15h50 - **Froitzheim** Niko - Geodynamic evolution of the Alps along the European Geotraverse. Part 2: the orogenic lid.

16h10 - Pause café/coffee break.

16h30 - **Schönborn** Gregor - Geodynamic evolution of the Alps along the European Geotraverse. Part 3: the Southern Alps.

16h50 - **Frisch** Wolfgang, Ratschbacher L. & Linzer H.G. - Transpression and lateral extrusion in the Eastern Alps.

17h10 - **Inger** Simon & Cliff R.A. - The age of metamorphism in the central and eastern Tauern window.

17h30 - **Bersezio** Riccardo, Gelati R., Fornaciari M., Napolitano A. & Valdisturlo A. - The signifiance of the upper Cretaceous to Miocene clastic wedges in the deformation history of the Lombardian Southern Alps.

17h50 - **Polino** Riccardo, Gelati R., Rossi P.M., Biella G. & de Franco R. - Crustal structures beneath the Southern Piemonte (Northwestern Italy): consequences on kinematics of the Alps/Apennine boundary.

18h10 - Fin de la réunion/end of the workshop.

Programme (posters) / Timetable (posters)

Séance poster n°1 (jeudi 12/11, 14h00 à 15h00):
Poster session n°1 (thursday 12/11, 14h00 to 15h00):

Aprahamian Jean, Tane J.L. & Uselle J.P. - Le métamorphisme à la base du Trias dans la région de Bourg d'Oisans. Réinterprétation du contact cristallin-sédimentaire.

Bussy François - Genetic implications for identical U-Pb ages of the Mont Blanc granites and its microgranular enclaves.

Cadoppi Paola, Sacchi R., Sandrone R. & Vialon P. - Thoughts on the Pre-Alpine evolution of the Dora-Maira massif

Hunziker J., Desmons J. & Hurford A.J. - Thirty-two years of geochronological work in the Central and Western Alps: a review on seven maps.

Huyges Pascale, Faucher T. & Mascle G. - Remobilisation ou préservation des diapirs précoces du domaine alpin: un problème d'alimentation?

Lardeaux Jean-Marc - Les témoins métamorphiques de l'amincissement lithosphérique anté-orogénique dans les Alpes occidentales.

Nziengui Jean-Jacques & Bonhomme M. - Excess radiogenic argon in fissure quartz from the French Western Alps in the Mesozoic black-shale unit. A new tool for K-Ar dating of epizonal metamorphism.

Venturini Guido & Hutzinker C. - Geology and geochronology of the central part of the Sesia-Lanzo zone: the state of the art.

Stampfli Gérard - Le Briançonnais, terrain exotique dans les Alpes.

Séance poster n°2 (vendredi 13/11, 14h00 à 15h00):
Poster session n°2 (friday 13/11, 14h00 to 15h00):

Blanc Eric, Beck C., Cousin M., Deville Eric, Tardy Marc - Tectonic activity recorded in sediments in front of a collision chain : between North Alpine foreland basin and Rhône basin, Chambery, Savoie, France.

Donzeau Michel, Gamond J.F. & Mugnier J.L. - Evolution et amortissement latéral d'une structure chevauchante: l'exemple du nord-Vercors

Epard Jean-Luc & Masson H. - The Morcles nappe SW of the Mont-Blanc massif.

Fry Norman - Implications of kinematics in the Western Alps for 3-plate solution.

Gosso Guido, Albini S., Forcella F., Spalla I. & Siletto G. - Pre-Alpine and Alpine deformations in the Orobic Alps, Southalpine belt.

Köhler Gabriele, Menot R.P. & Stein E. - Progressive mylonitization of rocks from amphibolite facies to semi-brittle conditions.

Sauer Joachim, Breuer G., Menot R.P. & Stein E. - The macro- and mesoscopic tectonics of the southern Belledonne massif: first results of a remapping. + Menot

Schönborn Gregor - Geodynamic evolution of the Alps along the European Geotraverse. Part 3: the Southern Alps.

Stanke Edith, Menot R.P. & Stein E. - History of deformation in Liassic sediments and balanced cross-sections in the Bourg d'Oisans area (SW Belledonne massif).

Steck Albrecht & Hunzinker J. - Tectonique des Alpes de Suisse centrale: chronologie des événements structuraux et thermiques.

Tallone Sergio & Cadoppi P. - Relationships between basement and Mesozoic covers in the Northernmost part of the Dora-Maira Massif.

Werner Joachim, Menot R.P. & Stein E. - Is the anisotropy of magnetic suceptibility (AMS) an useful cinematic criteria to determine the directions of nappe piling in the Belledonne massif?

Géologie Alpine. Série spéciale Résumés de colloques, n°1, 1992

PRE-ALPINE AND ALPINE DEFORMATIONS IN THE OROBIC ALPS, SOUTHALPINE BELT.

S. ALBINI , D. BATTAGLIA, G. BELLINI, C. BIGONI, E. CARMINATI, S. CERIANI , F. FORCELLA, G. GOSSO, A. OLIVA, G. REBAY, G.B. SILETTO, M.L. SPALLA

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The structural setting of the Southern Alps is related to the Alpine convergence. It consists in a southverging polyphased fold-and-thrust system that involves both basement and Permo-Mesozoic covers sheets.

In the eastern Orobic Alps, near the western border of the Adamello massif, the northernmost sheets consist mainly of metamorphic rocks affected by two preAlpine generation of ductile structures. These deformative events took place at different structural levels as evidentiated by the polyphase metamorphic evolution. The S_1 foliation is marked by the alignment of red-brown biotite and white-mica, while plagioclase, garnet, rutile (?) occur in the quartz-rich domains. After the amphibolitic stage a greenschist retrogradation

D_3 deformative event is related to a thrusting episode Alpine in age which involves both the basement and the Permo-Mesozoic sedimentary covers. This deformation produces a crenulation cleavage, locally evolving towards kink-bands development in basement rocks, and a penetrative cleavage in the sedimentary cover. S_3 orientation (330-350°/60-80°) is regionally consistent. In the sedimentary rocks chlorite, white-mica and stilpnomelane frequently grow on the cleavage planes.

Thrust geometries are outlined by large-scale cuspate synforms (up to 300 m wide, few kilometers long) of sedimentary rocks, locally boudinaged in pieces few meters wide along cataclastic zones (5-100 m wide) aligned along major thrust boundaries.

Isoclinal folds involving cover and basement rocks locally produce a pseudolayering at the meso-megascopic scale (10-100 m).

A second Alpine pervasive deformation (D_4) is observable in the sedimentary covers, where a crenulation cleavage and a fracture cleavage are developed in fine-grained (e.g. Collio arenites) and coarser clastic rocks (Collio and Verrucano Lombardo conglomerates) respectively.

The orientation of S_4 is 90-130° / 20-30° in the southernmcst sedimentary cover. No folds have been so far observed related to S4 cleavage in the area under discussion.

Shear planes (some decimeters to meters spaced-apart) dipping 30-40° toward North cut S_3 planes and are responsible for an overall south-verging deformation, also testified by kinematic indicators (foliation deflection, mineral fibers, striae, ...). Late deformative episodes (D_5), well observable in the southern sedimentary covers, are represented by fault planes (NW-SE / N-S trending) and joint sets that disrupt the belt into several blocks.

LE MÉTAMORPHISME À LA BASE DU TRIAS DANS LA RÉGION DE BOURG D'OISANS. RÉINTERPRÉTATION DU CONTACT "CRISTALLIN" - SÉDIMENTAIRE

J. APRAHAMIAN, J-L. TANE, J-P. USELLE et S. du CHAFFAUT

Institut Dolomieu, 15, rue Maurice Gignoux. 38031 GRENOBLE Cedex

Les Massifs cristallins externes de Belledonne et des Grandes Rousses encadrent l'hémigraben de Bourg d'Oisans, grossièrement allongé Nord-Sud. Le secteur de l'Armentier, auquel nous nous référons, est situé sur la remontée orientale de ce "fossé", côté Grandes Rousses.

Par ailleurs, la région est maintenant classiquement connue pour ses failles synsédimentaires, d'âge essentiellement liasique, liées à l'ouverture de la Téthys.

Un métamorphisme alpin a été signalé depuis fort longtemps en certains points de la couverture sédimentaire dauphinoise et plus particulièrement dans des niveaux détritiques attribués au Houiller, au Permien ou au Trias. L'utilisation des Indices de Cristallinité de l'Illite, permettant de définir l'anchizone, a montré que ce métamorphisme s'étendait plus largement et pouvait affecter des sédiments carbonatés et argileux. Cependant, les effets de ce métamorphisme, et donc son intensité, sont considérés comme faibles à très faibles, à tel point qu'on a tendance à le négliger.

On admet généralement, pour les distinguer, que les formations du socle (cristallin) sont celles qui ont subi l'influence d'un métamorphisme facilement identifiable d'âge hercynien, alors que les formations sédimentaires (couverture) n'auraient subi, éventuellement, que les influences d'un métamorphisme quasi-imperceptible: la limite supérieure du socle est communément placée là où, par l'observation de terrain, on ne retrouve plus les marqueurs habituels du métamorphisme (induration, recristallisation, foliation).

Sur le bord de la route d'Auris, au Sud du village d'Armentier, on voit les dolomies rousses du Trias, bien litées, reposer sur un substratum compact, induré, qui présente toutes les caractéristiques du "socle" (grain fin, couleur sombre, verdâtre, vague foliation), évoquant une amphibolite assez riche en quartz. Ce substratum n'est en fait pas homogène: par endroits, on trouve sous les dolomies litées des brèches à éléments cristallins seuls ou mêlés, en proportions variables, à des fragments eux-mêmes constitués de dolomie. Dans certains cas, ces éléments dolomitiques anguleux deviennent rares et sont dispersés dans une roche identique à celle qui est habituellement considérée comme le "socle".

L'examen des lames minces taillées dans les niveaux bréchiques et dans les niveaux massifs montre que l'on a affaire à des formations qui toutes sont détritiques, à éléments plus ou moins grossiers, et permet de mettre en évidence des cristallisations et recristallisations de muscovite et de quartz que l'on peut attribuer à un métamorphisme de faciès "schistes verts".

Nous sommes donc là en présence d'un niveau qui mime le socle (socle reconstitué); mais dans la mesure où, jusqu'à ce jour, aucun niveau dolomitique n'a été décrit dans le socle véritable, on peut se demander si l'âge de ce niveau n'est pas triasique, auquel cas le métamorphisme qui l'affecte serait lui-même d'âge alpin. A l'intérieur même des dolomies litées sus-jacentes, on observe de minces intercalations pélitiques transformées en fines lamelles à aspect séricíteux, qui montrent à leur tour des recristallisations de muscovite.

Au vu de ces indices, on peut se demander si l'intensité du métamorphisme dans les zones externes n'a pas été sous-estimée et si l'on n'a pas inclus dans le socle hercynien des niveaux détritiques du Trias. La limite traditionnelle socle/couverture, souvent fondée sur une brusque discontinuité apparente du métamorphisme, est sans doute trop schématique: il faut prendre en compte le fait que les formations du Trias sont majoritairement carbonatées et que pour cette raison, les symptômes du métamorphisme peuvent y être moins faciles à identifier que dans des matériaux détritiques.

EVOLUTION TECTONIQUE DES ALPES CENTRALES: EXEMPLE DE LA NAPPE DE TAMBO

Thierry BAUDIN, Didier MARQUER

Institut de Géologie, Emile Argand 11, CH 2007 Neuchâtel (Suisse)

Dans les Alpes centrales penniques, la nappe de Tambo, située entre les nappes d'Adula et de Suretta, constitue une écaille cristalline de 3.5 à 4 km d'épaisseur pour une longueur minimum de 25 km. Elle est surmontée par une couverture monométamorphique, attribuée pour une grande part au Permo-Trias, sur laquelle reposent des sédiments mésozoïques (Trias à Crétacé?) de type briançonnais (Baudin et al., 1991). Cette étude porte sur la structure interne de la nappe et sur les différents comportements rhéologiques du cristallin et de la couverture au cours des déformations alpines successives.

Les premières déformations alpines forment des zones de cisaillement cataclasiques à pendage nord qui recoupent l'ensemble de la nappe avec des jeux de failles normales. Celles-ci pourraient être liées aux extensions jurassiques résultant des ouvertures téthysienne et/ou ultérieurement valaisanne. Ces failles découpent des compartiments où les paragenèses reliques anté-alpines semblent montrer des degrés métamorphiques de plus en plus élevés vers le Sud. De plus, la limite méridionale du pennique est constituée par les migmatites de Gruf et les ultramafites de Chiavenna qui pourraient, dans cette nouvelle vision, représenter respectivement la croûte inférieure de Tambo et une pincée du manteau, "décoiffées" par les failles d'extension jurassiques.

La tectonique de convergence est marquée par 4 phases de déformation tertiaires :

- la phase D1 regroupe toutes les déformations progressives liées à l'empilement des nappes vers le NNW: (i) les premières structures d'accrétion sédimentaire frontale (dues à la subduction vers le SSE de la zone valaisanne sous le cristallin aminci de Tambo), (ii)l'empilement crustal avec le chevauchement final de Suretta sur Tambo à plus de 30 km de profondeur et en faciès métamorphique HP (13 kb) (subduction de type A), (iii) le plissement de la pile de nappes probablement dû au charriage du complexe austro-alpin qui marque le début du stade de collision continentale, à la fin de l'Eocène.

- la déformation ductile et hétérogène D2, quant à elle, n'est plus associée à aucun chevauchement majeur. Elle traduit un amincissement crustal (post-empilement D1) qui paraît synchrone des premiers chevauchements au front des massifs cristallins externes. Durant D2, le contraste rhéologique entre socle et couverture est devenu très faible. Un fort raccourcissement vertical associé à un cisaillement vers l'Est a provoqué le plissement des structures pré-existantes (foliations et interfaces). Ces plis montrent tous une vergence vers le SE et ont parfois été confondus avec un rétroplissement. Cette déformation a débuté sous des conditions HP qui ont rapidement évolué vers un gradient thermique normal (métamorphisme Lépontin; Deutsch & Steiger,1985) avec des pressions de 5 à 6 kb.

- les dernières déformations D3 et D4 sont mineures et se sont produites dans des conditions décroissantes du faciès schiste vert. La déformation D3, avec une géométrie de plis en escalier surtout développés dans le Sud , semble résulter d'un soulèvement différentiel de la partie sud de la nappe qui pourrait être dû à la remontée subverticale des Alpes centrales le long de la ligne insubrienne (Hurford, 1986 et Hurford et al., 1989). La dernière déformation D4 se signale par des couloirs de failles normales, en régime fragile/ductile, orientées NNW-SSE qui abaissent les compartiments est. Cette structure extensionnelle apparaît comme l'équivalent,symétrique par rapport au "dôme" simplo-tessinois, de la faille normale du Simplon (Mancktelow, 1985).

L'extrapolation des données tectono-métamorphiques acquises dans la nappe de Tambo suggère que la structure et le "style" particulier de la zone pennique suisse (Argand, 1909) résultent de l'enfouissement par subduction d'une croûte continentale, doublement amincie lors des ouvertures téthysienne et valaisanne (marge Sud-européenne et domaine briançonnais), puis de son accrétion en profondeur (30 à 50 km). Lors du stade suivant de collision continentale (fin Eocène à Oligocène) ce prisme d'accrétion crustal (zone pennique) a été d'une part, charrié sur la croûte européenne d'épaisseur normale et d'autre part, chevauché par le complexe austro-alpin, ce dernier étant probablement décollé en base de croûte. Le stade final de cette collision tertiaire est marquée par un amincissement et un soulèvement différentiel des zones sud-penniques, du fait du jeu sur la ligne insubrienne, pendant que, plus au Nord, les massifs cristallins externes chevauchaient la molasse.

Références.

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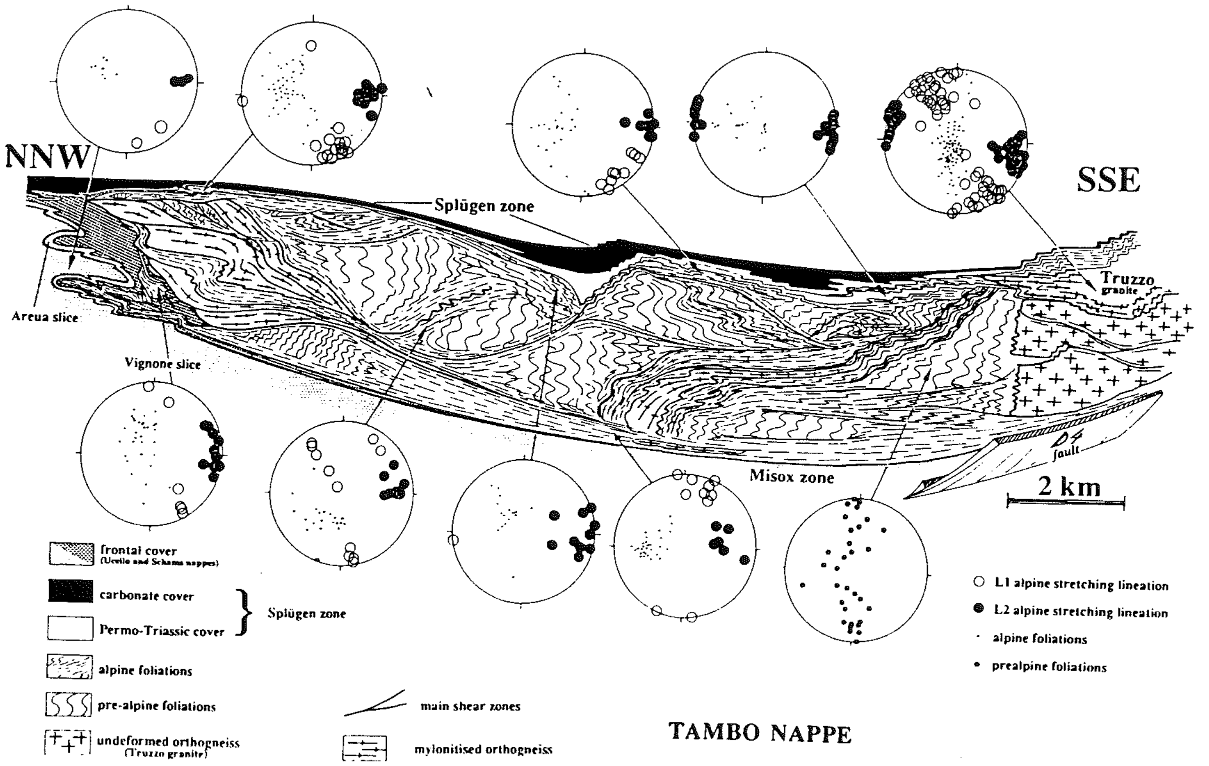

MIOCENE SYNTECTONIC SEDIMENTATION IN THE SOUTHERN JURA-NORTHWESTERN ALPS FORELAND BASIN (SAVOIE, FRANCE). IMPLICATIONS FOR HORIZONTAL SHORTENING AND VERTICAL FLEXURING VELOCITIES.

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The Chambéry-Aix-les Bains region, where the southern termination of the Jura mountains gets close to the western Alps front, corresponds to a junction area for the Jura and the northern Subalpine Chains (Bauges and Chartreuse massifs) Foreland basin.

In this complex area, the Oligocene-Miocene terrigeneous series (molasses) have been folded and overthrusted; these structures are a surficial consequence of a deeper decollement which removed mesozoic and tertiary formations (sediments from Dogger to Tertiary). We summarize the results of a detailed study of the syntectonic characters of the Oligocene-Miocene sets and especially of the Miocene siliciclastic coastal deposits. This analysis is based on :

- tridimensionnal geometry of molassic sedimentary sets and at the scale of sediments bodies;
- structural and sedimentological relationships between the Oligocene and Miocene terrigeneous series and their mesozoïc substratum;
- stratigraphic correlations established (especially using highly disturbed horizons) between two successive synclinal "infills" along a transverse profile.

It appears that, while keeping a marine coastal (subtidal to intertidal) depositional environment, the miocene sedimentation was migrating and changing upon each flat in relation with the activity of neighbouring "ramps". With espect to present days structures, two situations were observed :

-transversal (E-W) continuity of Miocene deposits (vertically deepening in eastern flanks of synclines) upon blind thrusts developped within oligocene clayey mudstone and desappearing westwards;
- shearing of miocene deposits by horizontal thrust-faults, with overthrusting of the western flanks of ramp anticlines on molassic series.

A shortening velocity above 1 mm per Year is proposed for the internal area of the Alpine Foreland basin during the Burdigalian-Serravallian period, so that a flexural subsidence of above 0.25 millimeters per year.

COMPOSITE P-T PATH OF THE GRAN PARADISO NAPPE: PETROLOGICAL CONSTRAINTS TO THE GEODYNAMIC EVOLUTION OF THE ECLOGITIC CONTINENTAL CRUST OF THE WESTERN ALPS.

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The internal Penninic massifs of the Western Alps (Monte Rosa, Gran Paradiso, Dora Maira) record a metamorphic evolution characterized by two main events: a Middle Cretaceous (eo-Alpine) event under LT eclogite facies (Grt I + Cld + Chl + Ph + Glf in metapelites) and an Upper Eocene (mesoAlpine) event under LP upper greenschist facies (Grt II + Bt + Olig + Ca-Amph) conditions. To better understand the P - T path at the transition between the two events, a detailed petrological study was performed on rocks from the Gran Paradiso nappe.

The Gran Paradiso nappe is a continental crust unit which consists of an upper polimetamorphic complex and a lower monometamorphic complex (Money Complex) of presumed PermoCarboniferous age.

In the Money Complex, two different garnet generations occur, which have markedly different chemical compositions.

Garnet I, developed during the early-Alpine event, shows a flat compositional pattern. The moderate Fe-enrichement and Ca- depletion at the rim is related to the overgrowth of the garnet II. Garnet I/ Phengite geothermobarometry gives T = 500 - 530 °C (Green & Hellman, 1982) and P = 11-13 Kbar (Massone & Schreyer, 1987).

Garnet II, developed during the meso-Alpine event, exhibits a clear bell-shaped growth zoning, characterized by a Mg/(Mg + Fe) increasing and Ca and Mn depletion from core to rim. Garnet II/ Biotite geothermometry (Perchuk & Laurent'eva,1983) shows T ranging from 420 °C (core) to 500 °C (rim), for P = 3 Kbar.

The thermodynamic GIBBS program (Spear & Menard, 1989) applied to the meso-Alpine zoned garnet, defines a prograde decompressive trajectory with a T increase of about 80 °C, coupled with a P decrease of about 2 Kbar.

Therefore, the whole P-T-t path recorded by the Gran Paradiso rocks is characterized by a significant near-isothermal decompression (ITD) stage postdating the climax eclogitic conditions, followed by a prograde decompressional trajectory and by a final marked cooling coupled with a moderate P fall. Consequently, the inferred P-T path is characterized by two metamorphic peaks at approximately the same T but significantly different P, which reflect distinct geothermal gradients and geodynamic conditions.

The prograde part of the eo-Alpine trajectory is consistent with a process of type-B subduction, whereas its decompressional part is compatible with a rapid continental crust uplift (rates > 2 mm/yr) occurring while subduction of cold oceanic crust was still active. The meso-Alpine trajectory is consistent with the thermal re-equilibration consequent to the continental collision of the Paleoeuropean margin (footwall) against the overridding eclogitic Insubric margin (hangingwall).

Therefore, the two main steps inferred for the Alpine P-T trajectory of the Gran Paradiso nappe may be referred to a first pre-collisional subduction stage characterized by a very low geothermal gradient and a second post-collisional stage characterized by a higher gradient, respectively.

Similar P-T-t trajectories were recently suggested for the polimetamorphic basement of the Dora Maira Massif (Sandrone & Borghi, 1992) and the Great St. Bernhard nappe (Desmons, 1992).

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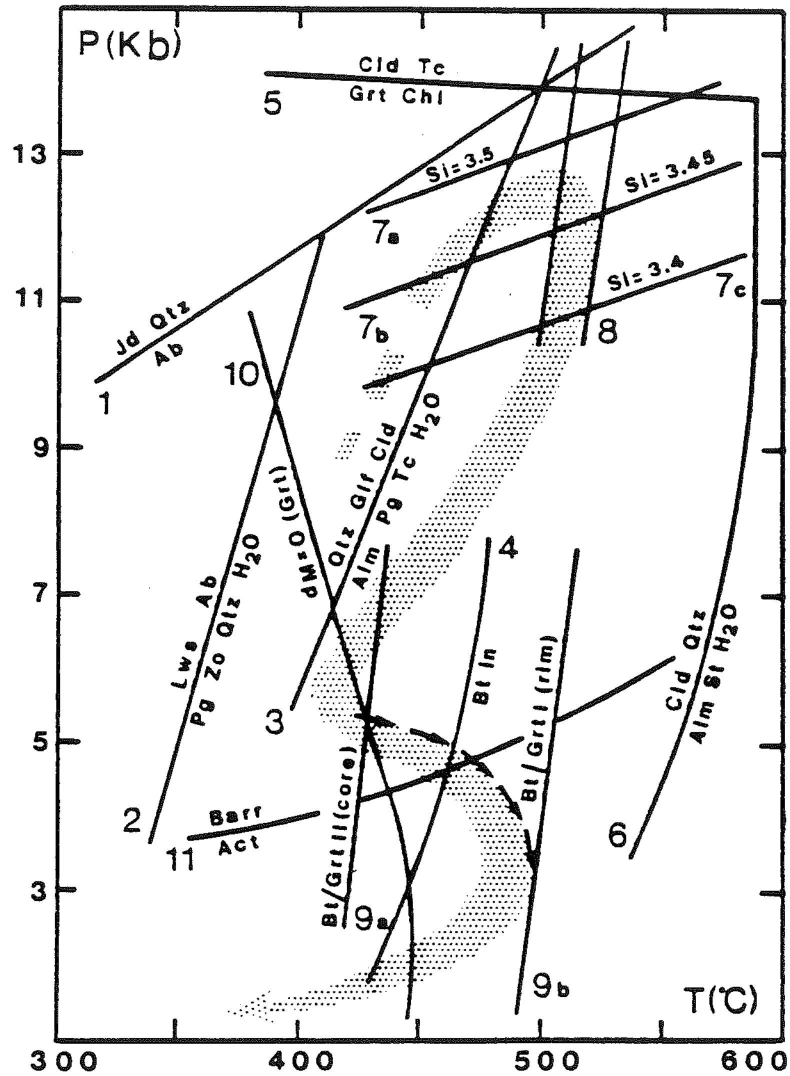

Alpine P - T path for the Gran Paradiso Nappe. 1 = Holland (1980), 2 = Heinrich & Althaus (1980), 3 and 6 = Holland & Powell (1990), 4 = Nitsch (1972), 5 = Chopin (1985), 7a and 7b = Massone & Schreyer (1987) calibration, 8 = Green & Hellman (1982) calibration, 9a and 9b = Perchuk & Laurent'eva (1983) calibration, 10 = Garnet-in curve for the meso-Alpine garnet (Spear & Menard ,1989), 11 = Ernst (1979). The arrows indicate the P-T path calculated for the meso-Alpine zoned garnet the GIBBS program (Spear & Menard, 1989).

GENETIC IMPLICATIONS FOR IDENTICAL U-PB AGES OF THE MONT-BLANC GRANITE AND ITS MICROGRANULAR ENCLAVES

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As are most of the calc-alkaline and alkali-calcic granites in the world, the Mont-Blanc granite (Mont-Blanc external massif, Western Alps) is rich in dark microgranular enclaves. These enclaves are composed of two contrasting types (an Fe-rich and a Mg-rich type) (Bussy, 1990). Microgranular enclaves are commonly interpreted as blobs of a more or less mafic liquid (s.l.) once coexisting with the granitic magma. This interpretation requires that both the host granite and its enclaves have the same crystallization age. In order to test this assumption, Rb-Sr whole rock analyses were performed on the Mont-Blanc granite. The results yielded similar ages of 311.6 ± 18.4 Ma for the granite and 316 ± 19.5 Ma for a group of mafic Mg-rich enclaves (Bussy et al., 1989). Because the large uncertainties of the data, a further attempt was made using the U-Pb isotope dilution technique on zircon. Three samples (a granite, an Fe-rich and a Mg-rich enclave) were processed. All contained a high proportion of crystals with inherited lead. Several analyses of each rock type, free of Pb inheritance, were obtained after selection of very small fractions (up to 7 mg) of gem-quality zircons. Zircons with a flat diamond shape, typical of a fast skeletal growth in an undercooled magma, have been selected within the enclave populations. The latter zircon morphologies are typically free of inheritance.

Results are as follows:
1) for the Mont-blanc granite, two concordant fractions give an age of 304 ± 3 Ma,
2) for the Mg-rich enclave, three discordant fractions define a discordia line with an upper intercept at 306 +5/-3 Ma,
3) for the Fe-rich enclave, a similar discordia line has an upper intercept at 305 ± 2 Ma.

All three ages overlap within errors and are interpreted as recording the crystallization of the Mont-Blanc granite. Enclave ages are slightly older than that of the granite, but considering the small errors and the few data available, no geological significance is currently attributed to this age difference. These results together with the occurrence of zircons of skeletal morphology are in good agreement with a magmatic origin for the microgranular enclaves.

The Mont-Blanc intrusion is one of several late-Variscan granites of the External Massifs of the Western Alps. Its rather young age agrees well with its ferro-potassic geochemical nature of late- to postorogenic affinity.

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THOUGHTS ON THE PRE-ALPINE EVOLUTION OF THE DORA-MAIRA MASSIF

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There are not many chronological landmarks in the pre-Alpine evolution of the Dora-Maira Massif, owing to lack of radiometric datings and to the superimposed Alpine orogeny which played havoc with pre-Cretaceous structures. Let's have a look.

1. In the earliest recognizable stage there was an amphibolite-grade basement prior to the early-Alpine, HP-LT metamorphism and therefore presumably Palaeozoic in age, primarily composed of metapelites (garnet-chloritoid micaschists with relics of muscovite, garnet and staurolite), diopside-bearing marbles, basic rocks, and granitoids (the "gneiss amygdalaires" of Vialon, 1966; Sandrone et al., 1986). Neither the age of the protoliths nor that of metamorphism (Variscan? pre-Variscan?) are known.

2. In a period which is generally assumed to be the Carboniferous, a detrital sequence rich in organic matter (Ensemble graphitique de Pinerolo, Vialon, 1966) was deposited on the eroded, already metamorphic basement.

3. Emplacement of granitic magmas - the soundest evidence of a Varisic event - occured at around 300 Ma (J.-L. Paquette, pers. comm. 1989 in Chopin et al., 1991).

The nature of the Variscan event is a major problem. The lack of a sequence of recognizable Devonian-Dinantian age makes it impossible, in fact, to gouge the Variscan effects as distinct from those of a hypothetical, earlier (?Lower Palaeozoic) orogeny.

As a consequence, there are two possible scenarios. The first one is inspired by the similarity of the Ensemble grafitique with the "Zone Houillère" (Briançonnais): the main metamorphism is Variscan; an uplift and erosion phase separates it from the deposition of a molasse (the Ensemble graphitique) old enough to record the thermal metamorphism induced by the post-kinematic Variscan granites and diorites.

In an alternative scenario the main, pre-Alpine metamorphism is pre-Variscan and was followed, after erosion, by deposition of a detrital sequence whose age could be Middle/Lower Carboniferous (the Ensemble graphitique once again) to Devonian (the fine grained gneiss of the Ensemble de Dronero, Vialon, 1966). This carries two assumptions. One is a relatively old age of the Ensemble graphitique, whose parallel would have to be found in certain sequences of the Taillefer (Belledonne). Second , the Variscan metamorphism somewhat disappears or rather is assumed to be low-grade and thus indistinguishable from, or obliterated by, the Alpine effects. The main Variscan feature is widespread emplacement of granite plutons.

Granite emplacement is a late- to post-Variscan event in both scenarios - in substance, the closing of a cycle. A problem on its own is the layered sequence containing granitic and other rocks variously referred to in the literature as "Lusema Stone" (commercial name), "Porphyroïdes Arkosiques" (Vialon, 1966), generally seen as the latest product by (questionable) field criteria. The metagranites are calcalkaline in nature (some with a peraluminous trend, e.g. the granitic body of Borgone in the lower Susa Valley, Cadoppi, 1990) in contrast with the mildly alkaline trend of some of the supposedly older ones (especially the "Freidour type", Borghi et al., 1984; "gneiss oeillés omogènes", Vialon, 1966).

We suggest that this sequence may have been laid down in a rift domain into which shallow granitic bodies (e.g. Borgone Granite and the granite facies of the "Porphyroïdes Arkosiques") intrude their volcanic and sedimentary cover.

This model is not exempt from problems. It need hardly be stressed, in fact, that the succession of the granite types does not fit well within the usual geodynamic patterns. On the other hand, Dora-Maira granitoids make an interesting comparison with the general arrangement for the Variscan magmatism put forward by Bonin (1988). According to the author, the key feature of the Variscan magmatism is a "critical period" at 270 Ma (Middle Permian) when a tensional regime set in, and the transition to an alkaline trend took place. In Dora-Maira the granite most resembling that of the "critical period" is the Freidour type. The Borgone-type granite and its associated volcanics find their equivalents respectively in Bonin's "Lower Permian anatectic" suite and the calcalkaline "Eo-Permian" magmatism near the Stephanian-Autunian boundary (Pitcher's Caledonian type, 1982): a hypothesis which represents a considerable upheaval. The puzzle of the Dora-Maira granitoids can be tackled only by sound radiometric datings, provided that some Palaeozoic isotopic system managed to survive homogenization in Alpine time.

It is even more difficult to insert the supposedly Permian dioritic magmatism ("diorite di Malanaggio", auct.; see e.g. Sandrone et al., 1988) which is thought to terminate the Variscan event, into any kind of arrangement. Some workers went as far as hypothesizing a Jurassic age (Borghi et al., 1989) within the compass of the model proposed by Lemoine et al. (1987) where a mantle magmatism in a thin crust is regarded as the product of the early opening phases of the Ligurian-Piedmontese Tethys.

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RELATIONSHIPS BETWEEN BASEMENT AND MESOZOIC COVERS IN THE NORTHERMOST PART OF THE DORA-MAIRA MASSIF

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Basement and cover lithological associations in the northernmost sector of the Dora-Maira Massif (Susa and Sangone Valley) are characterized by a high degree of structural and lithostratigraphic heterogeneity.
The pre-Mesozoic basement comprises at least three superposed, North-dipping units primarily distinguished by lithostratigraphical and structural features.The lower unit, extending in the right flank of the Sangone Valley, is mainly composed of meta-granites ("Freidour type" augen gneiss); their geochemical feature and zircon typology indicate a mildly alkaline character (Cadoppi, 1990). These granitoids are overlain by a monometamorphic detrital complex (made of garnet-chloritoid- and graphite-bearing micaschists, quartzites, fine-grained gneiss and metaconglomerates) of supposedly Carboniferous age ("Ensemble graphitique de Pinerolo", Vialon, 1966).
The middle unit, extending along the floor of the Sangone Valley, consists of granite-monzogranite orthogneisses with well preserved parageneses and magmatic fabric. Their geochemistry and zircon typology is similar to that of the underlying meta-granites, but with a smaller degree of differentiation. An intrusive relation to the overlying polymetamorphic complex, made of garnet-chloritoid micaschists with boudins of marbles and metabasites, is suggested by the presence of metapegmatites and aplitic gneisses along their contact.

The upper unit, mainly developed in the lower Susa Valley, comprises:

a) a "layered" sequence of phengite-bearing, leucocratic augen-gneiss, tourmaline-rich leucocratic gneiss and metagranitoids (Borgone Granite) with intercalations of decimetric to metric layers of "silvery micaschists". This sequence, similar to the well known "Pietra di Luserna" (Barisone et al., 1979) and interpreted by Vialon (1966) as the metamorphic product of a volcano-detrital complex (his "pophyroïdes arkosiques"), probably derived from the metamorphic transformation along shear zones of aluminous, crust-derived granites and their break-down products (Cadoppi, 1990; Cadoppi and Tallone, 1992).

b) A (?) Permian monometamorphic detrital sequence overlaying (a) mainly made of garnet-chloritoid micaschists with intercalations of crossite±garnet±phengite quartzites and scattered boudins of metabasites.
The three units display the same Alpine metamorphic evolution at least since the greenschist stages. An early-Alpine eclogitic stage is recorded in the middle and upper units (Cadoppi, 1990), whereas the pre-greenschist history of the lower unit cannot yet be identified.

The cover complex consists of two lithostratigraphically distinct metamorphic units (Tallone, 1990), which reciprocal relations are investigated. The more widespread lithostratigraphic sequence is the Molaras unit, located in the westernmost sector of the lower Susa Valley. This includes a Middle-Triassic basal metadolomitic complex with intercalations of calcareous-dolomitic marbles, cargneules and metapelites, followed by metric layers of banded grey-blue marbles (Malm?) and by a thick complex of calcschists and impure fillosilicate marbles (Early Upper Cretaceous; Marthaler et al. 1986). Blocks of metadolomites ranging from decimetre to hectometre in size, are frequently included in the calcschists. An association of basaltic metabasites tectonically overlays the marbles-calcschists complex.

The cover association of the easternmost sector is represented by a different quartzitic-carbonatic sequence (Pavaglione unit) of unknown age, characterized by a basal association of kyanite bearing quartzites, followed by a complex of banded calcareous-dolomitic marbles and a thin horizon of calcschists.

Three main folding phases are recognizable both in the basement and cover associations.

The first one (F1) displays intrafolial isoclinal folds, the axial planes of which are represented by a HP/LT metamorphic transpositive regional foliation.

The folds belonging to the second phase (F2), with E-W axial trending and North-dipping axial planes, range from millimetre to kilometre in size. These control the basement and cover structure on regional scale, deform the HP/LT fabrics and are associated to the development of greenschist parageneses.

The third phase, more developed in the cover than in the basement rocks, is characterized by folds ranging from millimetre to kilometre in size, with N-S trending axes and steeply dipping axial planes.
The structural and metamorphic evolution of the cover rocks is comparable with that of the basement, even

though the early-stage HP peak cannot be determined from the mineralogical associations in the cover. Parallelism between the HP transpositive foliations present in the basement and Molaras-unit cover rocks and their surface contact points to juxtaposition of the two complexes in the pre- to syn- HP stages. An allochthonous nature of the Pavaglione-type unit appears likely, though the contact is unexsposed.

Shear zones related to different stages of the structural and metamorphic evolution affect both the basement and cover rocks.

In the basement units the shear zone systems related to pre-greenschists metamorphic stages are mainly represented by the levels of "silvery micaschists".

The evidence in the cover rocks are more indirect. The presence in the calcschists of decimetric to hectometric metadolomitic blocks with margins deformed by the F2 folds and preserving the regional transpositive foliation, seems connected with the action of shear zones at some time between the transposition cycles and the second deformation phase.

The change in P, T and strain rate, associated with the transition to greenschist metamorphic stages, is recorded by the activation of kilometric-length ductile shear zones (mainly located in the cover sequences) in the form of mylonitic calcschists preserving basement and cover boudins.

Late low-angle N-NE dipping shear zone systems, concentrated in the anisotropy areas (basement - cover contact surfaces and old ductile shear zones), are responsible for the flaking of portion of the basement in the cover.

The pre- to syn- greenschists kinematics indicators (S-C mylonites and extensional crenulation cleavages) found in the basement and cover rocks, point to top-to-west sense of shear.

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ALPINE COMPRESSIONAL TECTONICS IN THE SOUTHERN ALPS. RELATIONSHIPS WITH THE N-APENNINES.

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The southern Alps orogenic development has been produced by non-cylindrical accretion of arcuated thrust belts. The western-northern sector of the chain is occupied by the "Orobic Arc", an Eoalpine to Mesoalpine structural system including the Grigna and Presolana overthrusts. The radiometric age of the dykes cutting the overthrusting contacts suggests Late Cretaceous age of the principal tectonic emplacement.

Apart from the Dinaridic influence in the eastern sector, the remaining parts of the Southern Alps were deformed mainly by the Oligo-Miocene, Miocene and Plio-Pleistocene events. The Chattian to Burdigalian tectonic phase (mainly Aquitanian in age) produced the backthrust system during the "Gonfolite" l.s. sedimentation. This WNW-trending compressional belt predominates in the Po Plain subsurface between the Piedmont and Lombardy regions. Prominent tectonic structures belonging to this system also outcrop in eastern Lombardy. The structures of "Dinaridic phase" in the Dolomites may be referred mainly to this event; in this picture the Mt. Parei conglomerate could be an equivalent of the Lombardian "Gonfolite".

The Middle-Late Miocene compressional events produced widespread deformation in the central and eastern regions of the Southern Alps with ENE trending prevailing structures, including the NNE trending thrusts of the Giudicarie region. The Messinian to Plio-Pleistocene compressional structures mainly affected the eastern regions of the Southern Alps along the southernmost border in the "Friuli external arc". This last belt is probably kinematically linked to the buried frontal Apennine chain. A comparison between the neoalpine tectonic accretion of the Southern Alps and the Northern Apennines is attempted in the frame of the geodynamic evolution of the Western Mediterranean domains.

K/Ar AND $^{40}Ar/^{39}Ar$ AGES FROM THE GRAND SAINT BERNARD-BRIANÇON NAPPE (S.L.)

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The Grand St. Bernard Napppe (S.l.) comprises several imbricate nappes. Taken together, these nappes represent a significant section of the Alps and although detailed mapping and structural data are availahle for some parts of theh Grand St. Bernard Nappe, little geochronological data has been puhlished. Over 40 samples have heen analyzed by the K/Ar and $^{40}Ar/^{39}Ar$ methods from rocks of the Grand St. Bemard Nappe (S.l.). These new data. mainly from samples of phengitic white mica. help constrain the tectonothermal history o f the Western Alps.

The white micas have K/Ar and $^{40}Ar/^{39}Ar$ ages ranging from 370 to 35 Ma, with the majority of Alpine cooling ages in the range 150 to 50 Ma. These ages are roughly correlated with geographic position, with slightly younger ages found in the more internal parts of the Alpine chain. The $^{40}Ar/^{39}Ar$ age spectra form broad age plateaus with no suggestion of extraneous argon, indicating these ages are a good measure of the time they cooled through argon closure. Only two samples show disturhed $^{40}Ar/^{39}Ar$ spectra, which are interpreted as having suffered partial argon loss during Eoalpine deformation.

The range of ages recorded in the white micas clearly indicates that the Grand St. Bernard Nappe has suffered a polymetamorphic history. Some of the samples indicate that little or no isotopic resetting took place in the micas since Carboniferous to Permian time. Of the samples showing signs of resetting, however, most of the K/Ar and $^{40}Ar/^{39}Ar$ cooling ages fall within the Eoalpine phase of orogenesis. Although no eclogitic assemhlages are ohserved in the samples studied, the parageneses observed in our samples offer indications of medium to high pressure metamorphic conditions. Detailed petrologic work is in progress in order to place consraints on the P-T conditions of metamorphism. Only a few samples record ages as young as 35 Ma, but as their position is more internal, they may record a thermal episode perhaps related to the margins of the Lepontine. Alternatively, these samples may record some aspect of localized uplift during the Tertiary.

CONTROLE TECTONO-EUSTATIQUE DE LA SEDIMENTATION AU CRETACE INFERIEUR LE LONG DE LA MARGE NORD-PROVENCALE DE LA MONTAGNE DE LURE A L'ARC DE CASTELLANE.

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Les enregistrements sédimentaires le long de la marge nord-provençale témoignent au Crétacé inférieur de phénomènes complexes et variés liés 1/ à des variations relatives du niveau marin, à l'origine d'une diversification des faciès et d'une géométrie particulière des corps sédimentaires; 2/ à la présence de pentes menant du bassin vocontien à ses plates-formes bordières; 3/ à une paléotectonique complexe polyphasée.

Les variations du niveau marin ont permis l'établissement de plates-formes carbonatées et de corps sédimentaires adjacents. Ainsi les calcaires de Lure, d'âge Hauterivien supérieur, représentent un prisme progradant bordant la plate-forme urgonienne (Fig. 1). La plate-forme des Calcaires blancs de Provence de l'arc de Castellane, fonctionnant jusqu'au Berriasien - Valanginien inférieur, se prolongeait vers le Nord par un prisme hémipélagique à calcaires roux (COTILLON 1992) (Fig. 2). Ces plates formes ont été ennoyées par des cortèges transgressifs Valanginien moyen-supérieur dans l'arc de Castellane, Barrémien inférieur dans la Montagne de Lure.

Les pentes ont bien souvent amplifié les condensations sédimentaires liées aux transgressions, d'où des lacunes importantes, surtout à l'Est, accompagnées de faciès glauconitiques et crinoïdiques. On note en outre des ravinements, des karstifications sous-marines et de spectaculaires resédimentations gravitaires, notamment dans le secteur de Lure. Un indice de pente est commun à toute la marge: une surface de banc calcaire, à terriers de Rhizocorallium, qui s'est établie à la limite Bédoulien inférieur- Bédoulien supérieur, c'est à dire juste avant le dépôt d'un cortège transgressif marneux.

L'ensemble de la marge a été affecté par une tectonique en blocs basculés qui s'est manifestée jusqu'à l'Albien moyen. Les failles de direction provençale limitant les blocs ont été reprises en failles inverses à vergence Nord (Lure) et Sud (arc de Castellane) au Miocène. D'autres accidents NW-SE, NE-SW, méridiens et subméridiens, N 70° à N 100°, la plupart décrochants, ont complété le découpage du secteur. Certains, hérités du rifting téthysien, sont des traits tectoniques majeurs plus ou moins permanents: failles du Var, de Castellane, de la Durance. Les autres ont eu une activité plus passagère; dans l'arc de Castellane, ces accidents ont participé à une évolution depuis un régime d'extension E-W (Valanginien-Hauterivien) jusqu'à un régime de décrochement E-W au Mésocrétacé (HIBSCH et al. 1992). Dans la région de Sisteron, les failles subméridiennes de l'anticlinal de Lure semblent liées au même décrochement sénestre N 40° responsable de la structuration du champ de Banon (JOSEPH et al. 1987); elles ont joué dès le Barrémien supérieur. D'autres accidents N 70 à N 100° se sont manifestés du Barrémien inférieur au Barrémien supérieur, d'abord en décrochements puis en distension. Cette activité polyphasée semble avoir dépendu des mouvements de translation et de rotation des blocs ibéro-corso-sarde et apulien (HIBSCH et al. 1992).

La sédimentation a enregistré partout le contrôle paléotectonique. Dans l'arc de Castellane, le basculement des blocs est à l'origine de la répartition des zones de subsidence définissant des bandes W-SW - E-NE alternativement résistantes et mobiles (COTILLON 1985). Les autres accidents ont joué un rôle important dans la délimitation des faciès et de leur épaisseur, dans l'ennoiement de la plate-forme des Calcaires blancs (COTILLON et GIRAUD 1992) et dans la topographie des fonds, elle-même responsable de la nature des bioturbations sur les bancs carbonatés. En outre, le relief sous-marin a contrôlé la répartition spatiale de l'espace disponible pour la sédimentation au même titre que les variations du niveau marin. Dans la zone de Lure, la tectonique barrémienne a marqué la topographie des pentes et localisé certaines unités stratigraphiques telles que le Barrémien supérieur, ce qui démontre la précocité des accidents subméridiens de ce secteur.

L'histoire de la région enregistre un tournant important à l'Albien supérieur avec la fin des mouvements de distension dont les accidents sont scellés sous une masse importante de matériaux siliciclastiques. Il s'agit de la première phase véritable de rétrécissement et de comblement du bassin vocontien par des prismes progradants de haut niveau marin.

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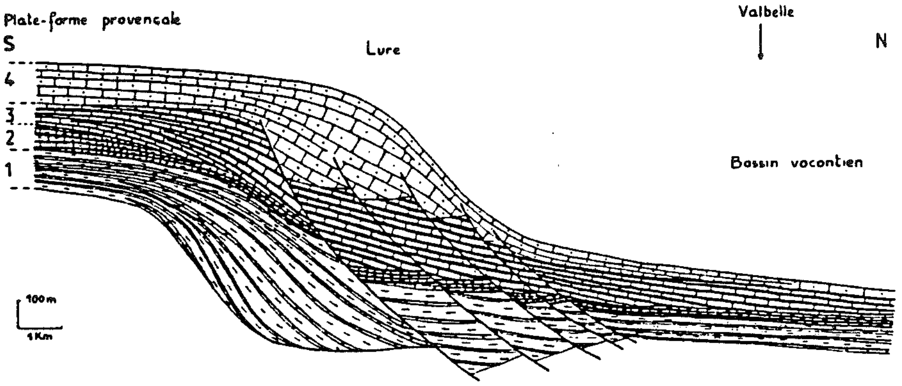

Fig. 1 - Coupe théorique de la marge provençale au niveau de la Montagne de Lure. La tectonique en blocs basculés est supposée ne pas encore affecter l'Hauterivien supérieur.
1 : Prisme de bas niveau Valanginien inférieur - 2 : Cortège transgressif Valanginien supérieur - Hauterivien inférieur - 3 : Prisme de haut niveau Hauterivien - 4 : prisme de bordure de plate-forme Hauterivien supérieur.

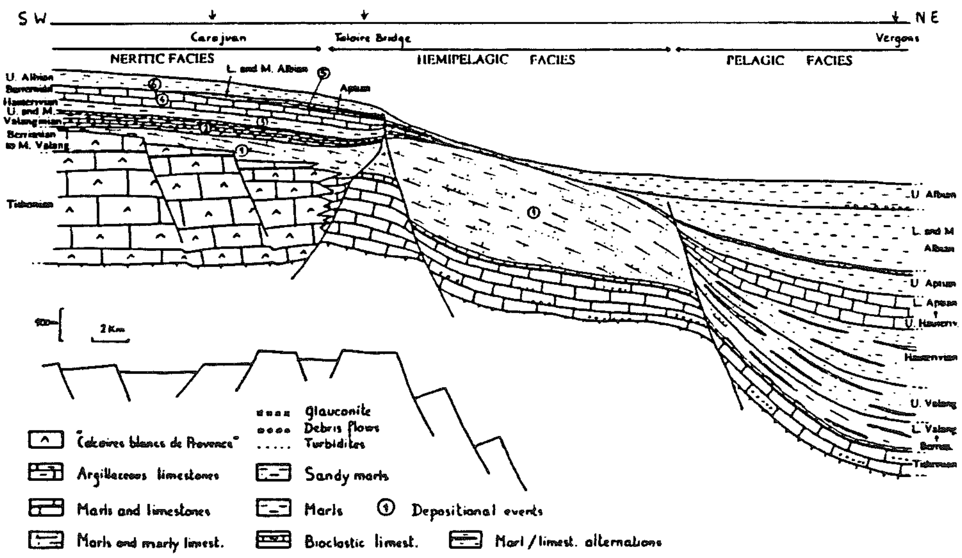

Fig. 2 - Coupe théorique de la plate-forme provençale au bassin vocontien dans l'arc de Castellane.
1 : Prisme de bas niveau Valanginien inférieur - 2 : Cortège transgressif Valanginien - 3 : Cortège transgressif et prisme de haut niveau Hauterivien - 4 : Prisme de bordure de plate forme Hauterivien à Bédoulien - 5 : Cortège transgressif Aptien à Albien moyen - 6 : Cortège de haut niveau Albien supérieur.

RESULTATS PRELIMINAIRES DE L'ETUDE DES MARQUEURS GEOMORPHOLOGIQUES DES MOUVEMENTS VERTICAUX LE LONG DU SILLON SUBALPIN (ALPES OCCIDENTALES, FRANCE)

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L'étude morphologique de la bordure orientale du sillon subalpin (moyenne vallée de l'Isère, Alpes occidentales), montre des irrégularités dans les tracés en carte et les profils en long de certains cours d'eau. Certaines de ces anomalies ont été attribuées à des phénomènes de captures de rivières (M. Lugeon, 1897; J.C. Fourneaux, 1975; G. Pappini, 1976). Ces captures étaient alors expliquées par des barrages dus à des langues de glaciers descendues du Massif de Belledonne. Si de tels barrages ainsi que l'érosion fluvio-glaciaire peuvent expliquer certaines anomalies morphologiques, une partie au moins du moteur des captures est d'origine tectonique (M. Lugeon, 1901; J. Masseport, 1955).

L'étude des profils en long des affluents en rive gauche de l'Isère montre des modifications de leur profil d'équilibre (reprises d'érosion), dues à une baisse du niveau de base, suggérant des mouvements verticaux de plus de 100 mètres. Ces mouvements verticaux sont interprétés comme la conséquence de deux tectoniques conjuguées:

- une tectonique gravitaire (glissement couche sur couche au sein du Lias), transverse par rapport à l'allongement de la chaîne, conséquence de la surrection du massif de Belledonne. Elle entraîne des affaissements qui expliquent la reprise d'érosion en amont du panneau affaissé.
- une tectonique longitudinale qui provoque le basculement d'un bloc vers le NE. Ce mouvement est déduit de la morphologie des interfluves, de la morphologie du substratum enfouie sous les alluvions récentes déduite d'une étude gravimétrique (ESSO R.E.P., 1967) et de l'étude des paléo-dépots lacustres eemiens (- 100 000 ans) (G. Nicoud, 1983).

Ces mouvements verticaux sont responsables des captures de rivières qui se succèdent du Sud vers le Nord. Une chronologie relative et des éléments de datation ont permis l'élaboration d'un modèle de captures successives, dont le moteur est la tectonique (X.Darmendrail, 1991, complété).

Les vitesses de ces mouvements verticaux donnés par la déformation finie pour les derniers 100 000 ans (pas de marqueurs datés au delà) sont de 1 à 3 mm / an. La comparaison de deux nivellements effectués à 55 ans d'intervalle (1901 et 1956) confirme ces vitesses en déformation instantanée, et suggère qu'une partie au moins de ces déformations est encore actuelle.

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QU'EST-CE QUE LE PENNIQUE ?

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Le Pennique, zone axiale du géosynclinal alpin pour Argand , ensemble des zones internes des Alpes occidentales et centrales (à l'exclusion de ce qui est appelé austro-alpin), a été subdivisé en Pennique inférieur (nappes simplo-tessinoises), moyen (Briançonnais - Gd-St-Bernard) et supérieur (massifs cristallins internes et zones piémontaises).

Le front pennique ou chevauchement pennique frontal, limite des zones internes du côté extérieur, est classiquement considéré comme une suture géotectonique majeure, quoique non ophiolitique dans sa moitié ouest et sud.

Les zones penniques appartenaient en grande partie non pas à la marge européenne, mais à la *marge gondwanienne* (Radelli & Desmons, 1987). Cette affirmation repose sur plusieurs arguments, notamment : les faciès sédimentaires du Trias, la similitude pétrographique des séries cristallines de socle dans le Pennique et les Alpes méridionales et orientales, les différences dans l'histoire varisque des socles externes et internes et les caractères particuliers de la zone houillère.

Les deux unités piémontaises, Zermatt et Combin, individualisées par Bearth et par Dal Piaz, proviennent de deux bassins différents (Desmons, 1989 ; Radelli et Desmons, 1989). Le critère de superposition permet de déduire que le bassin du Combin était situé en arrière de celui de Zermatt. Suivant le mécanisme de migration d'arc de Radelli (1987), nous voyons dans ces bassins des bassins arrière-arc, nés lors de la dérive successive des unités à partir de Gondwana. Mais qui dit migration, dit espace libre au devant de ces arcs : un océan. C'était là l'*océan téthysien*, en position intermédiaire entre Eurasie et Gondwana, avant qu'il disparaisse par subduction dans une zone de Benioff sans laisser de traces (ophiolites), comme c'est le sort d'un océan.

Nous appelons *domaine téthysien* l'ensemble formé par l'océan lui-même, les bassins plus ou moins océaniques qui en formaient les dépendances et les arcs, à l'époque îles et hauts-fonds.
La zone valaisanne (ou mieux les zones valaisannes, suisse plus externe et savoyarde plus interne) était une de ces dépendances téthysiennes, peut-être située à l'origine vers la marge européenne, sinon au bord le plus externe de la marge gondwanienne.

La notion de Pennique et celle de front pennique sont cohérentes pour une époque, celle des mouvements chevauchants dirigés vers les zones externes, mouvements d'âge éocène supérieur-oligocène *(le Méso-Alpin)*. Le front pennique est plutôt l'enveloppe des unités internes, sautant du Valaisan au Subbriançonnais, puis aux zones de flyschs à Helminthoïdes, et non pas la trace d'un grand chevauchement simple. A l'échelle lithosphérique cependant, celle des coupes sismiques profondes, le mouvement peut être considéré comme en bloc, les chevauchements entre unités n'en étant que l'expression à grande échelle.

Après le Méso-Alpin, c'est-à-dire au Miocène, lors de la tectonisation des zones externes entre autres, le Pennique est devenu un héritage. Auparavant, pendant les phases mésozoïques (l'Eo-Alpin tardif au Crétacé supérieur-Paléocène, l'Eo-Alpin précoce au Crétacé inférieur et les phases mésozoïques antérieures que nous ne faisons encore que soupçonner), les futures zones penniques n'avaient pas de cohérence et la notion de Pennique ne peut être appliquée comme telle.

Les nappes *simplo-tessinoises*, qualifiées par Milnes (1974) de subpenniques, c'est-à-dire situées en dessous du Pennique, puis d'infrapenniques par Trümpy (1980) pour une raison d'euphonie, ont pris un sens de "Pennique inférieur", malgré l'attribution à l'Ultrahelvétique des unités les plus basses (Verampio, etc.). Séparées du Gd-St-Bernard et des autres unités par des "Bündnerschiefer" valaisans, les nappes simplo-tessinoises se trouvaient originellement en position plus externe que le Valaisan. Au sens tectonique elles peuvent cependant être considérées comme penniques car elles ont subi les mouvements méso-alpins. La limite externe des zones dites penniques ne coïncide donc peut-être pas avec la limite externe de la marge gondwanienne au Mésozoïque.

Dans la *fenêtre des Tauern* le socle rappelle tout à fait celui des nappes simplo-tessinoises et non pas le Briançonnais comme le pensait Termier, ni les massifs cristallins externes. Les "Bündnerschiefer" s'y sont révélés semblables à des Schistes lustrés valaisans (notamment Trümpy, Lemoine et Antoine, in Geyssant et Tollmann, 1966). Nous y voyons aussi du "subpennique".

Enfin, l'interprétation des coupes sismiques profondes montre l'allochtonie non seulement du Pennique et de l'Austro-Alpin, mais aussi des zones externes, à une autre échelle il est vrai. On ne peut pas identifier Pennique et allochtone.

Le Pennique s'est donc individualisé grâce à la naissance, au tout début du Mésozoïque, de bassins dans les marges téthysiennes. Il s'agit d'un ensemble de zones qui a été cohérent dans son mouvement tectonique à une époque, le Méso-Alpin. Le front pennique est la limite enveloppe, héritée, des zones internes méso-alpines.

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THE LATERAL DYING-OUT OF THE MOUCHEROTTE THRUST STRUCTURE (NORTH VERCORS)

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Two types of tectonic structures are induced by the initiation and propagation of a thrust zone: folds that accommodate dip variations of the thrust surfaces (ramp anticlines) as well as their frontal and/or lateral dying out (fault-propagation folds), and faults that branch on the thrust surface either as tear-faults if the thrust plane remains in the same stratigraphic level, or as lateral ramps if they transfer the displacement to a higher stratigraphic level. In either case, the function of the faults is to accommodate variations in the frontal displacement and the lateral dying out of the thrust zones .

Fault-propagation folds have been extensively studied from a theoretical viewpoint. Although well-documented examples showing 3D geometry and evolution are quite uncommon, some exist in the Subalpine fold belts of France. The Moucherotte thrust in Northeastern Vercors is a good example. This 15 km-long, N 20 -oriented structure has already been extensively studied either in itself, or in relation with the tectonic environment. More recently, the relationship between the Moucherotte thrust and the External Crystalline Massifs has been considered, and three different hypotheses have been put forward: (1) the thrust is rooted underneath the E. C. M., or the thrust glides over them, either (2) as a compressive structure or (3) as a gravitational one. The third interpretation was retained. Although this point is controversial, it has no bearing on the present study of the lateral dying-out of a thrust.

Our work on the Moucherotte thrust has consisted in a structural field study for the search of kinematic markers and in the making of a series of seven N110 -oriented cross-sections, drawn parallel to the thrust movement. These cross-sections are completed by two cross-sections oriented N 20 , parallel to the strike of the structure, and are complemented by a cut-off sketch-map of the Urgonian and Tithonian marker horizons by the Moucherotte thrust. In the course of our study, we were able to specify the geometric and genetic relationships between folds, faults and thrust plane. We show that fault-propagation folds, tear faults and lateral ramps can combine and mutually enhance their effects on the general displacement of the main thrust sheet .

The Moucherotte thrust seems to have been initiated as a fault-propagation fold that started on a structural heterogeneity induced by an early backthrust, and was subsequently cross-cut by the propagating thrust surface. The fault-propagation fold is preserved in the Southern part of the structure, were it is just overtaken by the thrust surface, whereas in the North, it is cross-cut and passively transported for 3 km. Small horses of Urgonian material are located on the thrust surface and mark out the dismantled short limb of the fault-propagation fold .

The ratio of the thrust displacement to the half-length of the thrust front has been shown to be 0.14 for simple cases where the lateral dying-out of a thrust zone is accommodated by fault-propagation folds only. In the Moucherotte thrust, this ratio is 0.3, i.e., twice as high. Here, the displacement induced by the thrust decreases along strike from the central part of the structure towards the South, in a step-like manner. The steps are bounded by tear-faults oriented N 100 -110 , parallel to the direction of displacement, that branch on the main thrust surface or on lateral ramps. They delineate blocks in the thrust sheet, accommodating a greater displacement for the central and thicker one.

Our study shows that, in a general manner, when the lateral dying-out gradient for a thrust front is high, the combination of tear-faults with fault-propagation folds is necessary. This enables a thrust front to be shorter than it would be if the lateral dying out was accommodated by fault-propagation folds only.

THE MORCLES NAPPE SW OF THE MONT-BLANC MASSIF

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Tectonic and stratigraphic investigations in the Mont Joly area located between the crystalline basements of the Mont-Blanc, Aiguilles-Rouges and Belledonne Massifs (French Alps, Savoie) made possible to define the following tectonic units (Epard 1990):

1) the Aiguilles-Rouges and the external part of the Belledonne Massifs together with their autochthonous sedimentary cover (Triassic, Lower and Middle Jurassic);
2) the parautochthonous Vervex unit which is a slice or an isoclinal anticline cored with Upper Carboniferous rocks ("Lame Houillère", Paréjas 1925), Triassic dolomites and evaporites ("Trias de Vervex", Paréjas 1925), or granite ("Coin Granitique de la Motte", Paréjas 1925);
3) the Morcles nappe which is divided into two units: the Sangle unit and the Mont-Joly unit. They form large recumbent anticlines linked by the Mont d'Arbois syncline;
4) the internal part of the Mont-Blanc massif, together with its sedimentary cover.

The Sangle unit and the Mont-Joly unit are extensions of the Morcles Nappe in France. The external part of the Mont-Blanc massif and the internal part of the Belledonne massif form the crystalline cores of these anticlines and therefore represent the homeland of these units.

The Mont-Joly unit corresponds to the Aravis massif (Middle Jurassic to Tertiary Subalpin Chain), the Sangle unit is correlated with the Bornes Massif (frontal part of the Subalpine chain). The Mont d'Arbois syncline can be related to the Thônes syncline. Therefore the Aravis and Bornes Massifs belong to one single tectonic element which corresponds to the Morcles Nappe. The Diablerets and Wildhorn Nappes are not present in the Subalpine Chain.

The hypothetical "Mont-Blanc Thrust" (Butler 1983) which should separate this crystalline massif from the Mesozoic rocks of the Chamonix zone, does not exist (Epard 1986). The vertical faults of N-S direction mapped by some authors (ie. Mennessier 1976) at the SW end of the Aiguilles-Rouges and Mont-Blanc massifs show no alpine movement.

The Roselette Nappe, which lies between the Mont-Blanc and Belledonne massifs does not belong to the Ultrahelvetics but could be a continuation of the helvetic Diablerets and Wildhorn Nappes.

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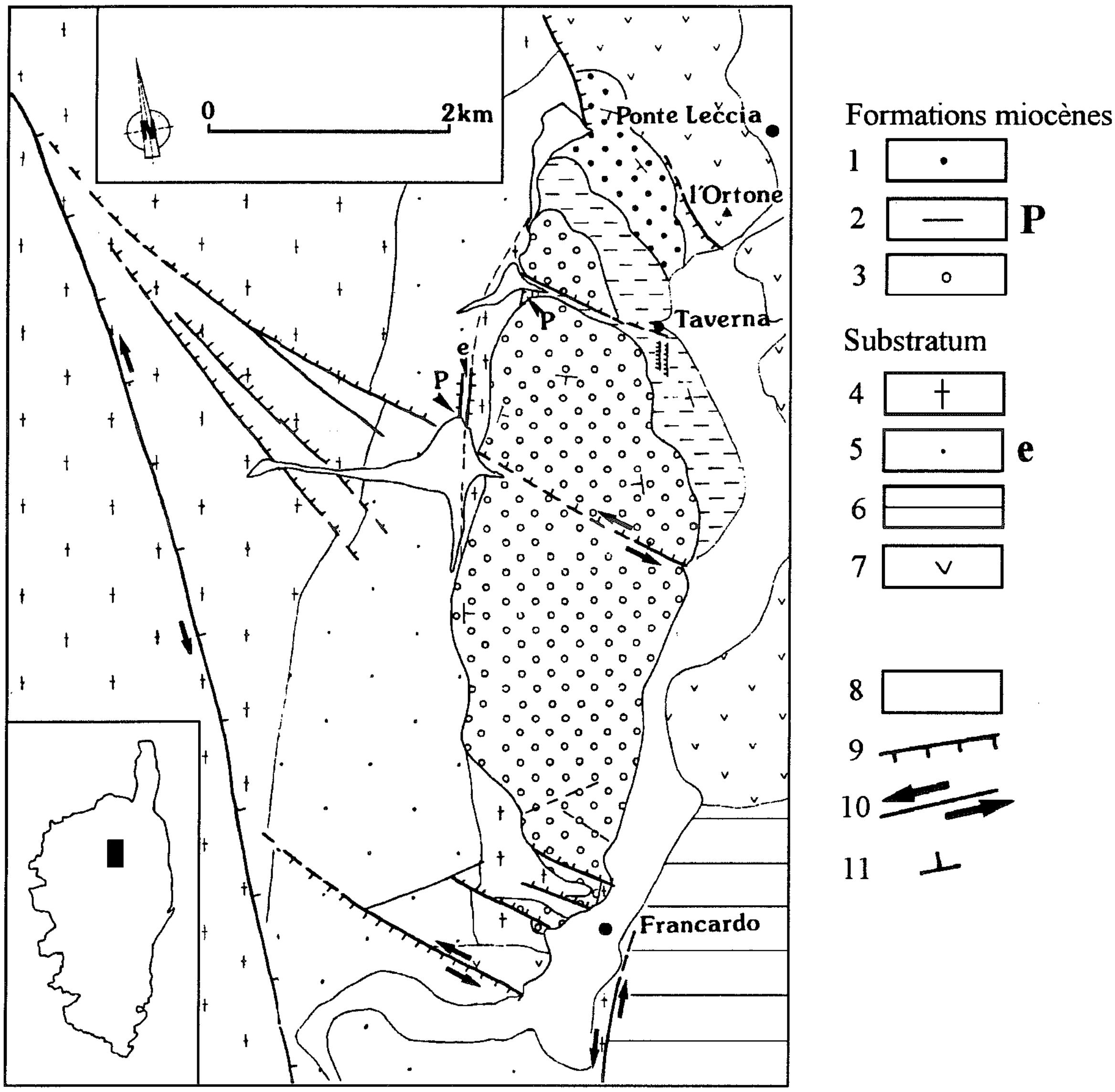

Le bassin miocène de Francardo-Ponte Leccia dans son cadre structural.
Formations miocènes
1:formation de l'Ortone; 2: formation de Taverna - P: paléosol; 3: formation de Francardo;
Substratum:
4: autochtone et parautochtone; 5: prépiémontais- e: Eocène; 6: unité prépiémontaise de Caporalino-Pedani; 7: unités ophiolitiques ligures;
8: Quaternaire; 9: faille normale; 10: décrochement; 11: pendage.

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TECTONIQUE EN DISTENSION ET DECROCHEMENT AU BURDIGALIEN-TORTONIEN EN CORSE: L'EXEMPLE DU BASSIN DE FRANCARDO-PONTE LECCIA (CORSE CENTRALE)

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Le bassin de Francardo-Ponte Leccia est allongé sur 7km selon une direction Nord-Sud dans la zone de contact entre la Corse hercynienne et la Corse alpine. De récentes observations montrent que ce bassin est constitué par trois formations lithostratigraphiques contrôlées par des mouvements en extension et en décrochement.

LITHOSTRATIGRAPHIE DU BASSIN

On distingue trois formations séparées par des discordances, avec de bas en haut:
- la formation de l'Ortone: elle est constituée par un ensemble de conglomérats peu évolué, granodécroissant vers le haut. Il s'agit d'une formation continentale, probablement de type cône alluvial.
- la formation deTaverna: elle est caractérisée par des niveaux de microconglomérats suivis par une série marno-silteuse et se terminant par des grés et de conglomérats. Les niveaux fins ont livré une macro et micro-faune marine (Alesandri et al., 1977) qui témoignent d'un milieu littoral.
- la formation de Francardo: il s'agit d'une formation conglomératique de type cône alluvial se terminant vers le haut par un système de chenaux.

L'épaisseur cumulée des trois formations est comprise entre 500 et 600 m. Le cortège pétrographique des éléments détritiques montre une alimentation en provenance de l'Ouest. La présence, dans la série marno silteuse de la formation de Taverna de *Miogypsina gr. intermedia* marque le Burdigalien supérieur (Alesandri et al. 1977). La formation de l'Ortone représente le début du comblement du bassin précédent vraissemblablement de peu la transgression marine. La formation de Francardo ne devrait pas dépasser le le Tortonien moyen en comparaison avec les dép6ts de la plaine orientale. En effet, les éléments de schistes lustrés et d'ophiolite, quasiment absents dans le bassin de Francardo, apparaissent en plaine orientale au Tortonien supérieur (Loye Pilot, 1990).

EVOLUTION TECTONO-SEDIMENTAIRE

- les failles normales et décrochantes dans le bassin:

.la formation de l'Ortone est contr6lée dans sa partie Ouest et Est par des failles normales de direction N125 0140°E à pitch for[, dessinant des hémigrabens,

.la formation de Taverna révèle quelques failles normales subméridiennes, à regard Ouest, à pitch fort et à caractère hydroplastique, en particulierdans la carrière de Taverna. Cette formation débute à l'ouest par des paléosols, structurés par des failles normales de direction subméridienne. Dans la partie centrale du bassin, un faisceau de failles normale N120° E limite cette formation vers le Sud.

.labasedelaformationdeFrancardoestaffectéepartoutunensembledefaillesnormalesN120°E. Dans lapartiecentraledubassin,desdéformationssynsédimentairessontvisiblesauvoisinageduplandefaille. Certaines des failles de direction N120° E ont fonctionné en décrochement senestre .

- les failles régionales:

Deux failles majeures encadrent le bassin de Francardo-Ponte Leccia:
.l'une à l'Ouest à l'Ouest, de direction N 1 65°E, dont on peut suivre le prolongement en Balagne, admet un mouvement normal sénestre,
l'autre au Sud Est, se développe vers le Sud, montre également un mouvement sénestre.

Les failles de direction N120° E décrites ci-dessus sont probablement en rapport avec ces accidents régionaux.

CONCLUSIONS

Les rapports entre la tectonique et la sédimentation montrent que le bassin de Francardo-Ponte Leccia peut s'interpréter comme une zone de relais en régime coulissant transtensif, la composante horizontale sénestre étant modeste. Des indices de même nature existent en plaine orientale et dans le bassin de St. Florent, montrant la présence d'une tectonique distensive et décrochante en Corse au Burdigalien-Tortonien .

THE TECTONIC EMPLACEMENT OF THE SW PELVOUX MASSIF, SE FRANCE.

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The Pelvoux basement Massif and the Devoluy foreland basin lie in a critical position within the Alpine arc where the SW transport direction of the Provençal thrust system merges with the W to WNW transport directions of the Vercors thrust system. Within the Pelvoux Massif itself overthrust directions vary between WNW and SW (Coward et al. 1991). Large scale Alpine models (eg. Vialon et al. 1990) suggest that the central Alpine tectonostratigraphical units were emplaced towards the NW during the Oligocene, confined to the SW by a NW-striking crustal sidewall. The orogenic pile then collapsed outward towards the southwest due to gravitational instability to form the late Alpine Provençal fold and thrust belt. Such models imply that the Pelvoux Massif lay NE of the crustal sidewall and should record a history of considerable NW transport with late southwestward thrusting. The development of the Devoluy basin which lies 10 km to the SW should be related to this emplacement history. These predictions are compared with detailed field observations from the SW regions of the Pelvoux Massif where Eocene Grès de Champsaur successions unconformably overlie basement overthrusted onto Liassic successions which lie in SW-facing folds. There is also evidence of horizontal shear deformation. These observations imply that there were considerable pre-Eocene movements in this region. The Eocene succession itself shows NW transport which may be related to the main emplacement of the central Alpine units (Fry 1990). Later SW transport is difficult to detect and may have been transferred at depth out to the foreland where it is clearly seen in the Devoluy region.

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Dans synclinal de Morges, comme Queyrel
transport direction sous Pic Queyrel ↖

See Fry 89 pour direction de transport

Thrust SW Pelvoux : top to SW

Plis EW à vergence S.

NW transport mid Oligocene.

TRANSPRESSION AND LATERAL EXTRUSION IN THE EASTERN ALPS

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Alpine orogeny in the Eastern Alps is characterized by Cretacous to Early Tertiary, highly transpressive contraction and Middle to Late Tertiary lateral extrusion (RATSCHBACHER et al. 1989, 1991 b). Cretaceous W-directed tectonic transport connected with subduction and crustal imbrication is revealed by ductile to semiductile shear phenomena in the Austroalpine basement complex and the underlying Penninic zone. The early kinematic indicators were oliterated in large parts of the Penninic windows during post-collisional heating and deformation.

Cretaceous motion was top-to-W and thus highly transpressive to the European foreland. It led to imbrication and the formation of tectonic mélange along the Austroalpine/Penninic boundary, the main Alpine suture. The Arosa zone mélange is a block-in-matrix structure with blocks of Penninic (ophiolite material and pelagic sedimentary rocks) and Austroalpine (continental basement and cover) derivation in a flysch (oceanic and trench sediments) or serpentinitic matrix (RING et al. 1989). Frontal imbrication with subduction along N-S stretches of the plate boundary alternated with strike-slip motion with longlived clastic sedimentation along E-W stretches (WAIBEL and FRISCH 1989).

In the Northern Calcareous Alps, a transpressional thin-skinned thrust and fold belt, WNW to NW directed thrusting is docmuented by the orientation of imbrication structures (frontal ramps), sets of tear and transfer faults, first-order fold axes, and paleostress orientations (LINZER et al., 1 991). West-directed tectonic transport in combination with north-directed gravity gliding off the rising Austroalpine basement or, alternatively, block rotations in the Northern Calcareous Alps (supported by paleomagnetic data) may be the cause for the divergent motion of the cover relative to the basement.

As a consequence of crustal stacking and underplating of the Penninic Tauern terrane (a separated crustal fragment in Briançonnais position) beneath the Adriatic plate (Austroalpine zone), unroofing occurred and caused extension mainly to the east of the Tauern window. This event is documented by low-angle extensional shear zones (e.g., Gurktal and Graz nappe systems) and the formation of the Upper Gosau basins (Campanian, ca. 80 Ma).

In a period of Eocene N to NNE directed convergence (suborthogonal to the European continental margin) the Rhenodanubian flysch trough was closed. The abrupt change in the motion direction is documented in the Arosa zone and adjoining units and occurred around 50 Ma (RING et al. 1989). Lateral extrusion (a combination of gravitational collapse and tectonic escape) governed the evolution of the Eastern Alps in the Miocene, a process which is responsible for the actual topographic pattern. In contrast to the Western and Central Alps, where foreland imbrication and backthrusting are important phenomena, Miocene plate convergence in the Eastern Alps produced a combination of compressional, extensional, and escape structures. An extrusion channel developed between the rigid South Alpine indenter and the European foreland (Bohemian Massif). In front of the tip of the indenter (western Tauern window, Ötztal-Silvretta mass), N-S compressional structures prevail (e.g., Ötztal pull-up with out-ofsequence thrusts). To the east of the Tauern window, E-W extension forms grabens and, approaching the Pannonian basin, a basin-and-range structural pattern. Escape is dominated by three crustal wedges migrating to the east and leaving incompatibility holes behind. The holes are filled by the Zentralgneis domes in the western and eastern Tauern window, and by thick Miocene sediments in the Fohnsdorf basin, where no buoyant Zentralgneis was lying beneath. The Zentralgneis domes experienced rapid uplift (up to 3.6 mm/a; v. BLANCKENBURG et al. 1989) and exhumation in the Miocene.

In the vertical profile, extrusion is partitioned into ductile flow (mainly in the thermally equilibrated Penninic zone) and brittle deformation (Austroalpine). Lateral extrusion, mainly active in the Miocene, was facilitated by the unconstrained eastern margin of the extrusion channel: the intra-Carpathian basin which experienced E-W extension driven by subduction roll-back at that time.

Scaled indentation experiments of lithospheric dimension are able to simulate lateral extrusion (RATSCHBACHER et al. 1991a). The conditions best reproducing the situation in the Eastern Alps are a narrow, deformable body between rigid foreland and indenter, and a weakly constrained lateral margin. Indentation generates thickening away from, and attenuation near the weakly constrained lateral margin. Attenuation is by spreading and the formation of a rhombohedral pattern of oblique and pure normal faults. High indentation velocity favours escape along strike-slip faults, a triangular shape of the indenter favours spreading, and lateral confinement limits lateral motion and favours thickening.

During stacking/imbrication the kinematics in the Eastern Alps were governed by the relative plate motion between Adriatic and Eurasian plate. The concept of coeval radial outward transport of nappes throughout the Alpine (-Carpathian) arc has to be abandoned due to the kinematic data and geometric incompatibility. In the collapse stage, kinematics were governed by the boundary conditions of the extrusion channel.

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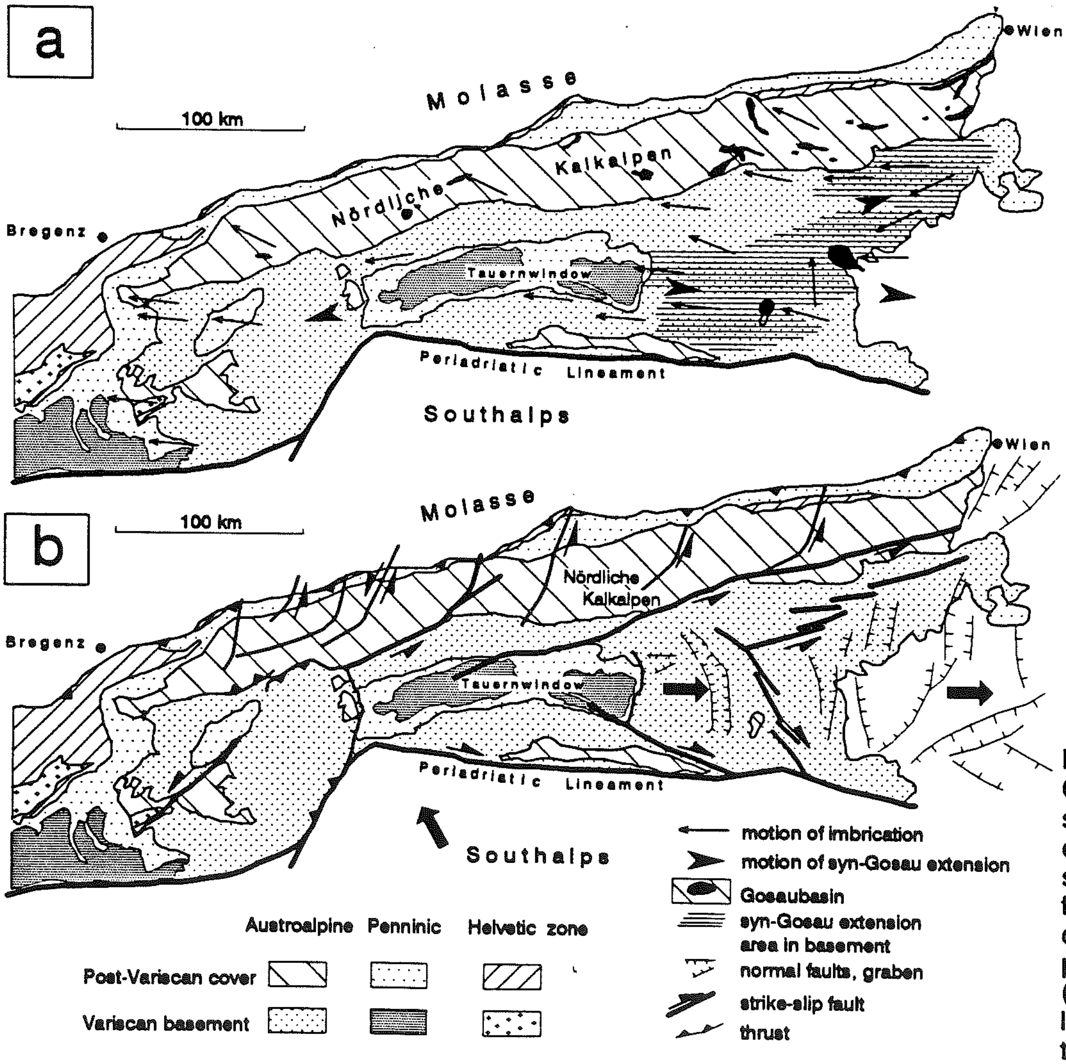

Fig. 1: Geological sketch map of the Eastern Alps for (a) Cretaceous transpression and (b) Tertiary lateral extrusion.

GEODYNAMIC EVOLUTION OF THE ALPS ALONG THE EUROPEAN GEOTRAVERSE. PART 2: THE OROGENIC LID

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The Austroalpine nappes of Eastern Switzerland record a multi-stage deformational history, including compressional as well as extensional phases of Cretaceous and Tertiary age. Here the pre-Tertiary evolution of the Central Alps can be studied, and the transformation of a Jurassic passive continental margin into a Cretaceous active margin and finally a Tertiary orogenic lid can be reconstructed.

Cretaceous deformation in the Austroalpine nappes of Eastern Switzerland

a. Formation of the nappe stack

Cretaceous convergence between Apulia and Europe resulted in shortening of the previously stretched Austroalpine continental margin, including imbrication of basement units and deformation under mostly low-grade (anchizonal to greenschist facies) metamorphic conditions. Thrusting was predominantly top-to-the-west (Schmid & Haas 1989). Anomalous thrust geometries (younger-on-older thrusting) can be explained by interference of Jurassic rift-related normal faults and Alpine thrusts. The nappe edifice was locally overprinted by transpressional deformation (apparently sinistral), resulting in east-west-striking "steep zones" (Albula pass zone, Samedan zone) where thrust faults and nappes were deformed by tight folds with steeply dipping axial surfaces.

b. Post-nappe extension

Kinematic analysis of mylonitic and cataclastic fault rocks along shallowly dipping tectonic contacts has revealed that part of these faults are not overthrusts, as generally assumed, but low-angle extensional faults, mostly top-east to top-southeast directed. Since they cut a preexisting nappe stack, the faults exhibit younger-on-older as well as older-on-younger geometries. Such extensional faults were found in the Bernina nappe (Corvatsch mylonite zone, Liniger,1992) and the Silvretta nappe (Fig.1, upper profile). Along the Silvretta basal thrust between Bergün and the Engadine valley, earlier, thrusting-related mylonites were overprinted by top-southeast directed low-temperature mylonites to cataclasites, indicating reactivation of the thrust as an extensional fault. Spectacular second-generation recumbent folds associated with top-east to -southeast extensional shear zones occur in the underlying Ela nappe and Err-Carungas nappe (Fig.1, lower profile). These recumbent folds are interpreted as "collapse folds" resulting from extension, vertical thinning and top-east to -southeast shear affecting steeply inclined layers within the earlier-formed transpressional "steep zones".

Top-west thrusting of the Oetztal nappe over the Engadine Dolomites is dated at about 90 Ma (age determinations by Thöni, cited in Schmid and Haas, 1989). The suture between south Penninic ophiliotes and Austroalpine basement was also formed in the Late Cretaceous (112-66.5 Ma ages from postkinematic hornblende, Deutsch 1983). For the extensional phase, a Late Cretaceous to earliest Tertiary age can be assumed because extensional faults and folds are deformed by younger folds probably related to final collision in the Eocene (see below). A correlation of the extensional phase with the rapid deepening of the Gosau basins in Austria at about 80 Ma , interpreted in terms of crustal extension by Ratschbacher et al. (1989) , is possible. However, the extensional collapse may be of different age in different parts of the Austroalpine.

The Austroalpine nappes in the Tertiary

After the Late Cretaceous to earliest Tertiary extensional phase, the Austroalpine nappes were thrust over the Middle and North Penninic, as indicated by occurrence of fossil-bearing Lower Eocene sediments underlying the Austroalpine in the Oberhalbstein area (Ziegler, 1956) and in the Engadine window (Rudolph, 1982). West-east to northwest-southeast trending folds refolding the whole Austroalpine nappe stack (in contrast to the older "collapse folds" which occur only in deeper levels of the nappe stack) are interpreted as related to this thrusting or to additional shortening after the thrusting. The north-directed thrust itself was probably located at the base of the South Penninic Platta ophiolites. Today, however, this position is kept by an east-dipping and top-east directed normal fault of Late Eocene to Oligocene age, the Turba mylonite zone (Liniger, 1992). It represents a second phase of east-west extension, postdating the emplacement of the Austroalpine/South Penninic lid on top of the Middle and North Penninic. After or in part already contemporaneously with the Turba extension, additional N-S shortening led to vertical extrusion of the wedge-shaped Gruf-Bergell block situated between the Engadine line to the northwest and the Insubric line to the south (see Schmid, part 1). Along the Engadine line, this vertical extrusion was accommodated by oblique sinistral slip and block rotation, resulting in different movement vectors along the strike of the line, and further complicating the structure of the Swiss Austroalpine.

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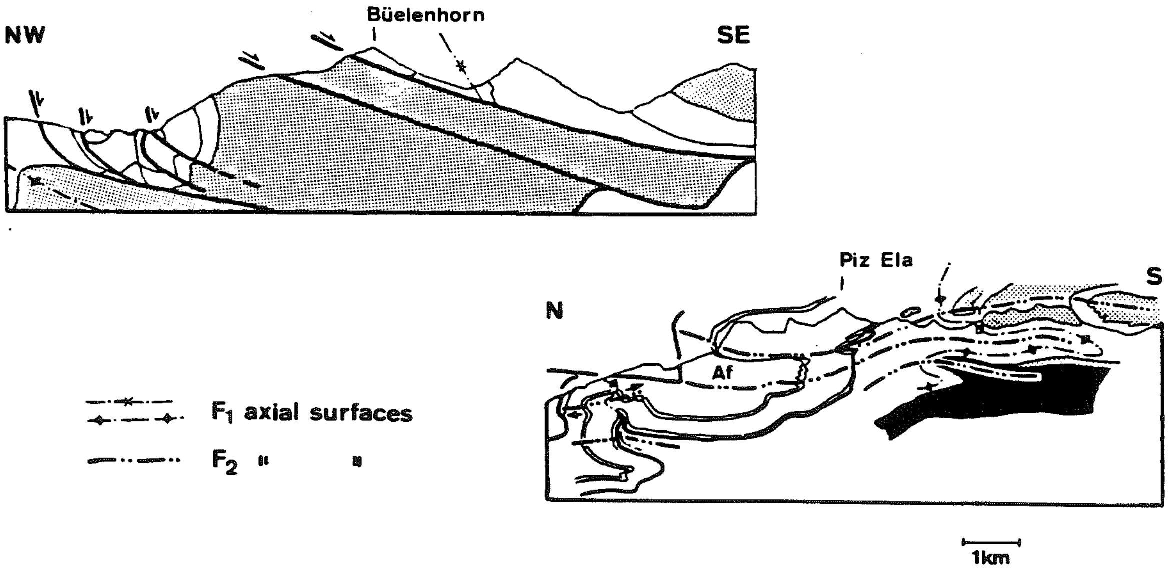

Fig. 1: Two cross-sections of the Austroalpine nappes near Bergün, Graubünden. Black: South Penninic ophiolites (Platta nappe), stippled: Austroalpine basement, white: Austroalpine Mesozoic sediments. Upper section shows Late Cretaceous to earliest Tertiary normal faults cutting and stretching the Silvretta nappe. Lower section shows recumbent second-generation folds refolding Ela, Err-Carungas, and Platta nappes. Both normal faulting in the Silvretta and recumbent "collapse folding" in the underlying Ela-, Err-Carungas, and Platta nappes are interpreted as resulting from Late Cretaceous crustal extension.

IMPLICATIONS OF KINEMATICS IN THE WESTE~N ALPS FOR 3-PLATE SOLUTIONS

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Two questions which have been addressed by recent work on the evolution of the AlpineMediterranean region are: (1) The sense ot asymmetry of the spreading of the Piemont-Ligurian ocean margin; and (2) Whether independent motion of a third lithospheric component (microplate, perhaps) is required in addition to African-European plate convergence. The lack of concensus on these questions is noteworthy; it suggests that they can only be answered together, and perhaps in the context of other, as yet unspecified, constraints. This contribution argues that these questions cannot be satisfactorily answered by detailed consideration of the syn-rifting and syn-spreading paleogeography until full account has been taken of knowledge already gained about (1) the marginparallel component of the total relative motion of the African and European plates, and (2) the geological record, on the orogenic margins, constraining timing and directions of convergent motions.

On the basis of wide-ranging synthesis of evidence, Polino et al. (1990) argue the case for European lower plate and Adrian upper plate during asymmetrical extension, while Stampfli & Marthaler (1990) argue the opposite, at least for the western Alps. The latter authors admit the possibility that extensional margins have different sectors, with reversal of the sense of asymmetry across their boundaries. However, both these papers (used here as examples of a wider debate) assume that the two sides of the western Alpine suture have derived from the same sector. This assumption is not only unjustified, but contradicts models of the constraining plate motions.

The need for a third lithospheric plate is assumed by many field geologists, though disputed as unnecessary on the basis of paleomagnetism. The geophysical evidence from the European geotraverse locates a separate lithospheric element at depth within the Alpine ediface, but leaves open the question whether this derived by convergent orogenic processes from African or European margin, or whether it had a longer independent plate history. Is it possible to provide evidence for the independence of the effects of African convergence and third-plate convergence upon the geological record of the European margin, even though it may indeed remain impossible to confirm the independence of plate motion of a third plate in any other, more direct, way?

Work on the SW Alps, in the sector between the Durance and the Arc de Nice (Fry 1989, 1991), indicates that the response of the Alpine foreland to different convergent components of the tectonic regime differs in both style and timing. Convergence-related block tilting is initiated mid-Cretaceous, at the onset of northward convergence of Africa with Europe, and reverses in Oligocene or Miocene at a time when the divergent phase, which led to separation of Corsica-Sardinia, had disengaged the European margin from African encroachment. This long, slow block-tilting and tilt-reversal overlaps in time with the migration of the Tertiary Alpine foredeep, which is first recorded in the Eocene in this sector of the Alps, and elsewhere is seen to extend well into the Neogene. If the Alpine foredeep results from lithospheric loading of the European margin by an over-riding plate, occurring even when African convergence was disengaged from the European margin, the independence of the over-riding plate from the African is established. Furthermore, the estimated directions of convergence northwards for Africa, northwestwards to westwards for the foredeep - are not only different but they are independent from the southwesterly direction of the more superficial tectonic transport in this sector of the Alps.

While this author believes that the case for a third plate is established by the geological evidence in the western Alps, others may be more sceptical. How may such a hypothesis be tested? The answer may lie with the synthetic studies of margin paleogeography which have recently developed on the basis of spreading models, or with matching of pre-rift geology. Modelled motions of the African plate based on Atlantic spreading data (e.g. Dewey *et al.* 1989) include a total sinistral margin-parallel displacement of about 2000 km relative to Europe. The "African" side of the Alpine suture in the western Alps should, on a 2-plate model, provide a paleogeographical match for somewhere on the European margin to the west, in Iberia, not in southeast France. On the other hand, most proponents of an independent Adrian plate would postulate gross westwards movement relative to Europe. The "Adrian" side of the Alpine suture in the western Alps should, on a 3-plate model, provide a paleogeographical match for somewhere further east along the European margin, unfortunately without good constraint on distance. This distinction, east or west, may already be known or suspected by workers at the *GeoatelierAlpin,* without realisation of its significance for plate models. At the very least, admission of the possibility of relative margin-parallel motions, bringing together elements from different asymmetrical-spreading sectors, allows explanation of some of the irregularity of the convergent orogen.

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LE MASSIF PERIDOTITIQUE DE LANZO (ALPES ITALIENNES NORD-OCCIDENTALES) : CADRE LITHO-STRUCTURAL ET HYPOTHESES SUR LES STRUCTURES PROFONDES

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Le massif de Lanzo domine la plaine du Pô au Nord-Ouest. Formé de lherzolites à spinelles rééquilibrées dans le faciès à plagioclase (Nicolas et Jackson, 1972), il représente l'un des plus grands massifs lherzolitiques recensés. La serpentinisation n'affecte en outre que la frange du massif, sur 1km d'épaisseur environ.

Appartenant à la bordure interne de la ceinture métamorphique des Alpes occidentales, il offre à l'affleurement des assemblages minéralogiques HP alpins dont le pic métamorphique se situe vers 450-500° pour des pressions minimales de 12 à 13 kbar (Compagnoni et Sandrone, 1979 ; Pognante et Kiénast, 1987). Structuralement lié au massif cristallin de Sesia selon un système de plis E-W serrés (Blake et al., 1980 ; Spalla et al., 1983) et supportant localement une couverture de Schistes lustrés, le massif de Lanzo présente des conditions litho à tectono-métamorphiques similaires à celles des Schistes lustrés à ophiolites des Alpes occidentales (Fudral et Deville, 1986; Lagabrielle et al., 1989). En définitive, les péridotites de Lanzo représentent un fragment du paléo-plancher océanique téthysien, plissé et métamorphisé avec sa couverture de Schistes lustrés. Appartenant aux nappes ophiolitiques elles sont donc dépourvues de "racines".

Le massif de Lanzo appartient aussi à une frontière de paléoplaques lithosphériques - européenne et sud-alpine (ou apulienne) - soulignée ici par la célèbre ligne ou faille Insubrienne. Cette limite particulière est le siège d'anomalies géophysiques importantes et connues depuis longtemps d'une part, mais toujours d'interprétations discutables d'autre part . Ainsi le Corps d'Ivrée des géophysiciens (ou "l'anomalie d'Ivrée") présumé responsable de cet état de choses, a souvent été raccordé au massif de Lanzo. Dans ce secteur ont en effet été mises en évidence :

- **une anomalie sismique**. Vers 10km de profondeur apparaissent des vitesses d'ondes longitudinales voisines de 7,4 km/sec alors que peu à l'Ouest elles n'atteignent que 6 km/sec (Closs et Labrouste, 1963). Le récent profil ECORS-CROP Alpes a mis aussi en évidence un réflecteur de forte énergie en ces points. D'extension limitée et légèrement concave vers le haut, ce réflecteur avait également été repéré par la sismique réflexion grand angle, à la même place et à la même profondeur (ECORS-CROP DSSG, 1989). Une telle anomalie implique l'existence d'un corps rapide, peu profond. Parfois nommée "Ivrea body reflector" on assimile généralement cette limite à un Moho.
- **une anomalie gravimétrique**. Positive et dépassant 100 mgal, elle déborde un peu à l'Est, le massif de Lanzo. Les calculs permettent de supposer l'existence d'un corps lourd, de 12 à 25 km d'épaisseur dont le gisement serait celui d'une lame de manteau assez fortement inclinée vers le sud-est. Depuis Berckhemer (1968) certains auteurs assimilent cette lame à un coin de manteau apulien. Le massif de Lanzo pouvant être encore relié à ce coin de manteau profond.
- **enfin, une anomalie du champ magnétique**. Cette dernière n'est pas exactement superposable géographiquement à la précédente. Localisée un peu plus à l'Est, elle est généralement rapportée à une écaille de matériaux riches en magnétite (socle cristallin apulien de type zone Ivréa-Verbano ou serpentinites de la frange de Lanzo ?), peu profonde (inférieure à 5 km) et d'épaisseur discutable. On trouvera dans Lanza (1982) et Ménard et Thouvenot (1984), un résumé et une discussion des modèles explicatifs possibles pour cette anomalie.

La confrontation des données litho-structurales et géophysiques impose de séparer le gisement des péridotites de Lanzo de celui des différents corps géophysiques individualisés. Et une nouvelle organisation des structures profondes doit être recherchée pour ce secteur.

Deux modèles peuvent servir de base de réflexion : celui de Roure et al., (1989) et celui de Tardy et al., (1990), qui s'appuient tous deux sur le concept de l'écaillage lithosphérique. Dans le modèle de Tardy et al., ce sont des lames de manteau européen qui sont responsables du corps lourd, rapide et peu profond nommé "Corps d'Ivrée". En revanche, le modèle de Roure et al., rapporte à ce corps l'essentiel d'un poinçon ultrabasique, d'origine apulienne, d'architecture comparable à celle proposée pour expliquer la structure générale de la chaîne pyrénéenne (Roure, Choukroune et al., 1989). Des données géologiques indirectes confirment l'existence de matériel riche en chrome à des profondeurs restant modestes (les andésites tertiaires de Biella, Vitally, 1980).

Le modèle du poiçonnement ultrabasique apulien paraît plus adapté à l'ensemble des contraintes. Un forage hyper-profond (10 km) apporterait sans aucun doute d'utiles informations sur les problèmes structuraux superficiels et profonds de ce secteur.

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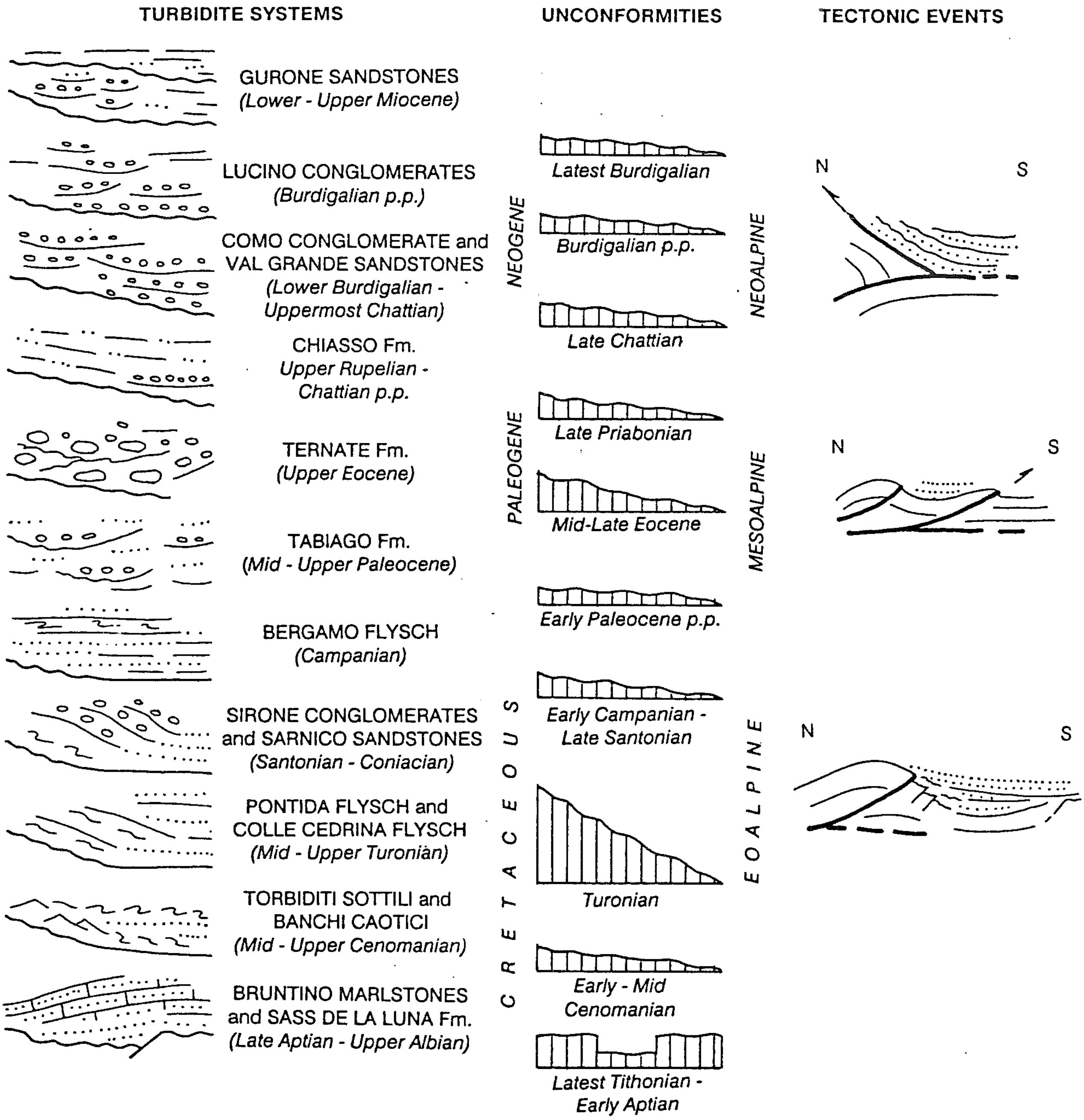

Fig.1 - Late Cretaceous to Miocene turbidite systems of Lombardy and their tectonic interpretation.

THE SIGNIFICANCE OF THE UPPER CRETACEOUS TO MIOCENE CLASTIC WEDGES IN THE DEFORMATION HISTORY OF THE LOMBARDIAN SOUTHERN ALPS (NORTHERN ITALY)

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The Cretaceous to Miocene turbidite systems of the Lombardian Southern Alps form two main composite clastic wedges which characterize the synorogenic basins developed at the southern border of the Alpine chain (Fig.1).

Within the lower wedge, the Late Cretaceous turbidite systems consist of 5 tectonically controlled depositional sequences. Each sequence contains one main longitudinal turbidite system, fed by erosion of the basement and cover units of the Austroalpine and Southalpine domains. The extrabasinal sediments interfinger within mass gravity deposits supplied by the basin margins. Each sequence is bounded by a marginal unconformity which progressively developed northeastwards during the deposition of the longitudinal turbidite systems. Therefore a close relationship is documented between Late Cretaceous upfolding and possible southward thrusting in the Southern Alps of Lombardy and the coeval Eoalpine orogenic stages in Central and Eastern Alps.

The Paleogene turbidite systems mostly consist of coarse-grained clastics supplied by erosion of the local Southalpine cover, mixed with penecontemporaneous shelf biota, bathial Foraminifera and some fine-grained siliciclastics. Clasts of the Campanian Flysch of Lombardy have been found into the Late Eocene turbidites (Herb, 1976).Each turbidite system is bounded by a lower unconformity of local extension. The Paleogene basins might have developed within a tectonically mobile belt. The Late Cretaceous deep water sediments were involved into the upfolded marginal areas.

The Oligo-Miocene turbidite systems form the upper wedge, which consists of at least 4 main synorogenic depositional sequences. These are bounded by unconformities which progressively develop over the northern basin margin. The Oligo - Miocene turbidite systems were fed by erosion of the Southalpine basement and cover and of the rapidly uplifted northalpine nappes and Tertiary intrusive bodies (younger pebbles of the Bergell tonalite are 31 Ma old). Their deposition has been strongly controlled by the synsedimentary growth of the frontal Southalpine structures in western Lombardy, which determined the northward thrusting of the Oligo-Miocene deep water sequences as a result of progressive wedging of the mesozoic carbonate units into the Jurassic/Cretaceous succession.

The southernmost thrust fronts are shown to be sealed in the Po plain subsurface by onlapping clastic sediments of Late Miocene age, deposited in the alpine-apennine foreland basin (Dalla et al., 1991).

On the basis of the stratigraphic data the Eo-, Meso-, and Neoalpine (i.e. "insubric") tectonics can be recognized in the Lombardian Southern Alps. The neoalpine deformation must have involved and strongly modified the Eo- and Mesoalpine structural framework of the whole fold and thrust belt. Recent geophysical data (CROP, NFP20 and EGT projects) shows that the neoalpine thrusts involved the basement and cover starting from the internal areas (Orobian Prealps) and reaching the buried foothills of the Milano belt (Castellarin and Vai, 1986), as an out-of-sequence foreland propagation.

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STRUCTURE OF THE NORTHERN MAGGIA AND LEBENDUN NAPPES

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The Basòdino-Cristallina-Campolungo area provides the key to understanding the geology of the Lower Pennine Nappes. In this area, several regional-scale Alpine structures of various generations meet. The elucidation of the space and time relationships of these structures within the study area thus provides crucial evidence for determining the tectonic history of the Pennine zone in the Central Alps.

The large scale fold structures and related small scale structures can be divided into four generations. Folds from each phase of deformation show characteristic profile geometry which can vary depending on local conditions of lithology, pre-existing deformation geometry and metamorphism. The structures formed during each phase of deformation also have characteristic orientations. Superposition of structures of different deformation phases resulted, therefore, in characteristic interference patterns: the northern Maggia region is one of the classic textbook examples for the development of the full range of fold interference patterns (Types 1, 2 and 3, e.g. Ramsay and Huber 1987).

Linear and planar structural elements, related to each of the four deformation phases have been measured and this data has been combined with that from previous published and unpublished work. For clarity, data for each of the structural elements were selected and plotted separately. Interpretation of the compilation maps, together with field mapping, has allowed the axial traces of major folds assigned to each fold generation to be delineated.

First phase folds are related to the main nappe development. They are large recumbent isoclinal folds with cores of pre-Triassic basement surrounded by a more or less unbroken envelope of dolomitic marbles and quartzites. In outcrop, first phase folds are tight to isoclinal, with very elongate limbs. In the pre-Hercynian paragneisses, it is often difficult to distinguish between pre-D2 folds of Alpine age (i.e. D1) or pre-Alpine folds of probable Hercynian age.

The second deformation phase tightly refolded the interleaved Penninic basement-cover nappe sequence on a regional scale and produced the regionally dominant schistosity. Second phase folds show a strong penetrative axial plane foliation, and also a marked elongation lineation, which is generally parallel to small scale fold hinges. Several major D2 folds can been followed over long distances (> 50 km), and were mapped by earlier workers as distinct fold nappes (e.g. the "Antigorio nappe", whose antiformal core is a D2 fold). Some D2 folds previously mapped as distinct structures have been found to be part of a single large structure, and several structures previously described as due to later deformation phases have been reinterpreted as hinge zones of large second phase folds with a weak axial plane foliation. The regional pattern of Mesozoic-cored synforms (e.g. Tegglio, Campolungo, Piora and Molare) and intervening basement-cored antiforms is largely due to large-scale D2 folds.

The third phase structures have developed obliquely to the trend of earlier structures and to the Pennine zone as a whole. Third phase folds are more open and have a characteristic chevron or corrugated style, with much lower limb to hinge ratios than folds of the first two deformation phases. A new crenulation cleavage is variably developed parallel to the axial planes of folds, particularly in more micaceous lithologies. In the northern Maggia area, this deformation phase is coeval with the thermal peak of Tertiary metamorphism and with the main period of porphyroblast growth. Superposition of second and third phase folds resulted in Type 1, 2 and 3 interference patterns on all scales. Third phase folds have much greater regional importance than has previously been assumed (e.g. Simpson 1982): the main structures related to this deformation phase are the Campo Tencia synform and the Maggia Steep Zone.

Fourth phase folds developed in a more or less continuous deformation process with third phase folds: some third phase structures were reactivated in the process or continued to develop under slightly different P and T-conditions. When the third phase folds were refolded they produced different interference patterns in different regions due to variations in their initial orientation. The main structures of this latest ductile deformation phase are the backfolds of the northern steep zone and the Wandfluhhorn Fold. In addition, some structures in the Maggia Steep Zone are also related to the fourth deformation phase.

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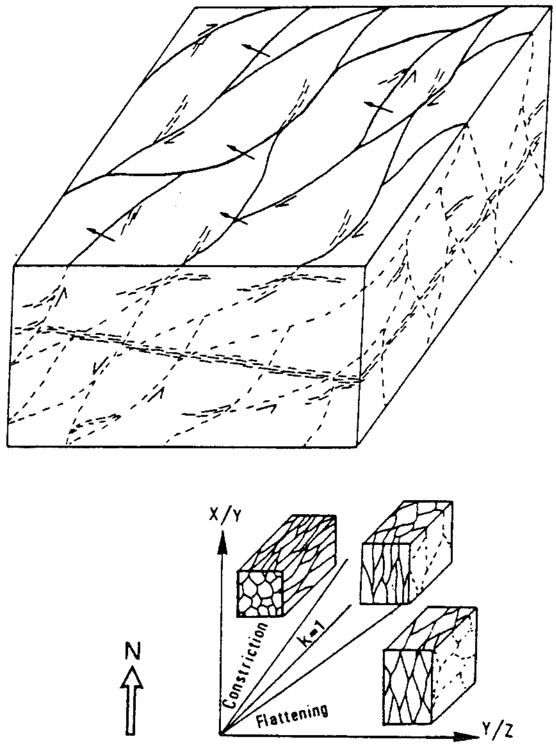

Géométrie des déformations intra-océaniques dans les gabbros inférieurs de l'ophiolite de Chamrousse. Comparé à la géométrie des zones de cisaillement en fonction du type de déformation, la déformation 2 s'approche d'un régime encisaillement simple, normal et progressif.

CHARACTERISTICS AND SIGNIFICATION OF THE DEFORMATIONS IN THE PALAEOZOIC OPHIOLITE OF CHAMROUSSE (WESTERN ALPS)

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One of the rare preserved Lower Palaeozoic ophiolitic sequence outcrops in the Chamrousse massif, just East of Grenoble, in the Belledonne massif.

The layered gabbros and peridotites display preserved early structures of deformations. The intra-oceanic nature of such tectonics is supported by the time-relationship with the ophiolitic magmatism and by the HT-LP conditions of the related metamorphic recrystallizations (Guillot et al., 1992). The superposition of two S-L fabrics allow us to characterize two successive events of deformation. The S1 foliation corresponds to a penetrative planar structure, well-developped near the boundary between the mafic and ultramafic cumulates. It results to foliated and striped amphibolites. Above this zone, rocks are more weakly deformed and the S1 foliation is close to the S0 magmatic layering. The S2 plane corresponds to the main regional foliation in the ophiolite. It results in the development of shear zones in the whole cumulate sequence and displays a nearly regular orientation at around N25 45°W, the associated mineral lineation strikes N90-N120 dipping 10 to 30° towards the west.

The two successive deformational events are considered to be respectively related to lithospheric stretching during an earliest rifting stage and to the development of listric faults due to thermal subsidence of the oceanic crust during its cooling. The structural and geochemical features of the Chamrouse complex suggests an origin in a slow spreading ridge maginal basin (Ménot et al., 1988).

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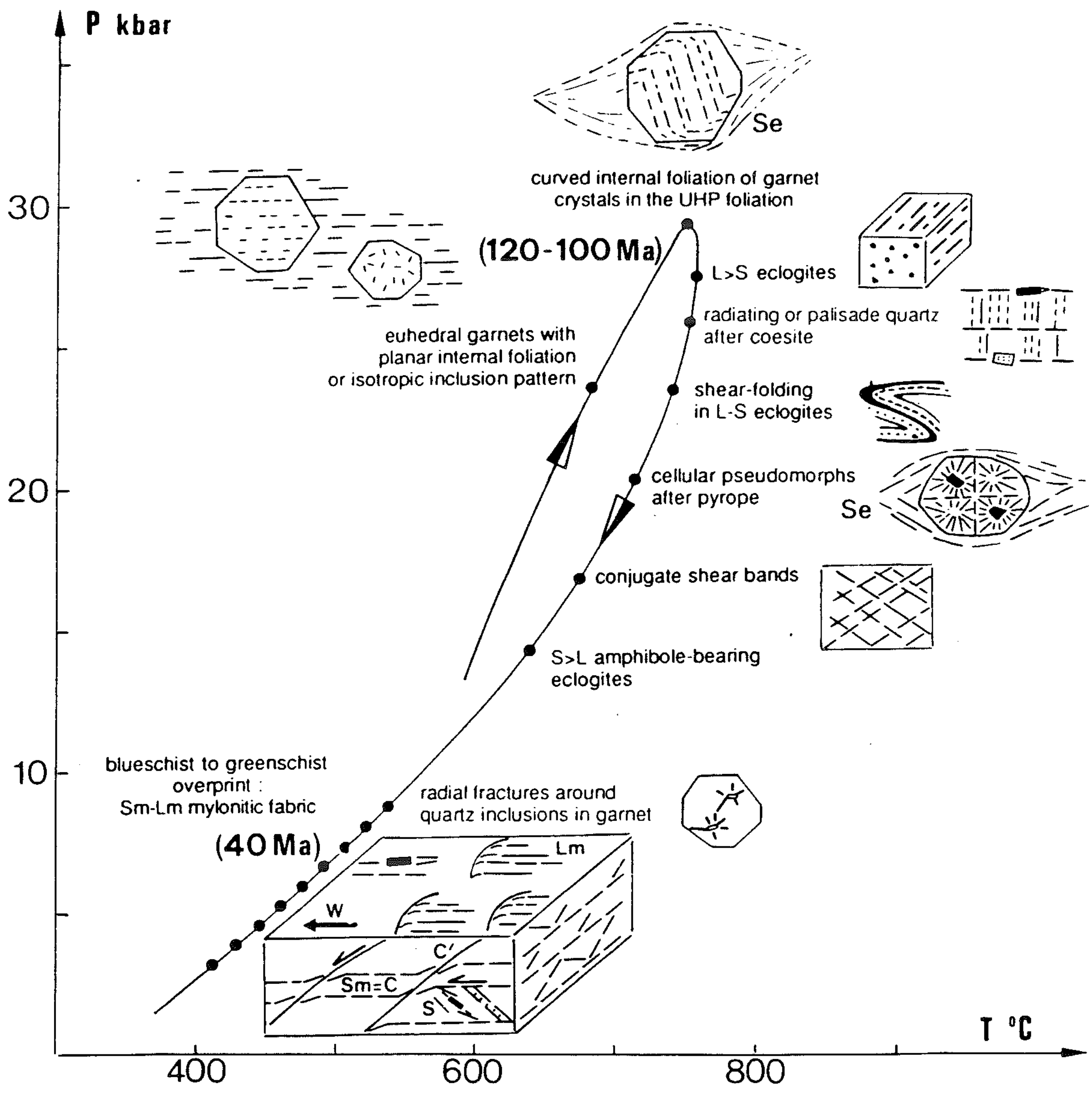

Sketch of the (P, T, t) path with superimposed microstructural evolution for the Dora-Maira UHP rocks (unit I), after Henry et al. 1992.

GEOMETRY AND STRUCTURAL EVOLUTION OF ULTRA-HIGH-PRESSURE AND HIGH-PRESSURE ROCKS FROM THE DORA-MAIRA MASSIF, WESTERN ALPS, ITALY.

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The crystalline nappes of the Dora-Maira massif, Western Alps, essentially made of continental material from the upper crust, show petrological relics of an ultra-high-pressure (UHP) to high-pressure (HP, "cold" eclogite) Eoalpine metamorphism. They also display relics of UHP-HP structures, preserved in boudins and/or within large UHP porphyroclasts, in a retrograde, greenschist-facies regional deformation fabric.

The greenschist-facies overprint has the character of a shallow-dipping mylonitic foliation (Sm), bearing a penetrative stretching lineation (Lm) which roughly parallels the axes of coeval, isoclinal folds. Shear sense markers indicate a west-verging overthrust mechanism.

The UHP and HP relic structures are of variable nature. The coexistence of equant and inequant, either symmetric or asymmetric fabrics, indicates that the deformation at UHP-HP conditions was strongly heterogeneous and partitioned. This is also supported by the local preservation of Hercynian, magmatic fabrics. The UHP and HP deformation involved, at least locally, rotational components, although less intensive than during the later retrograde stage. Kinematics during the UHP-HP metamorphism remains unconstrained due to the sparseness and late rotation of the UHP-HP structural relics.

The regional structural evolution is envisaged as follows : i) the Eoalpine subducted crust was subdivided into lenticular bodies surrounded by UHP-HP shear zones. As for the main part of the exhumation processes (from 100 km up to 30 km-depth), conflicting models are possible depending on the interpretation of the early sense of movement (normal versus reverse) along the faults that limit the lens-shaped units ; we favour a forced flow, or extrusion tectonics of imbricate slices in the subduction wedge ; ii) the late, heterogeneous, regional greenschist deformation can be attributed to the Eocene collapse of the Alpine orogenic wedge.

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SOUTHWEST-DIRECTED, OROGEN-PARALLEL DISPLACEMENT DURING NEOGENE CONVERGENCE IN THE WESTERN AND CENTRAL ALPS

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Although major deformation in the Western Alps is clearly the result of northwest-directed thrust tectonics, there is evidence to suggest that orogen-parallel displacements have also been important in the late tectonic history of the Western Alps. Deformation features related to these movements are: 1) southwest-directed normal fault movement along the Simplon Fault Zone in the Simplon Alps; 2) a diffuse zone of northeast-striking dextral strike slip deformation along the Rhone Valley in Switzerland, continuing between the Mont Blanc and Aiguilles Rouges massifs, and through the Belledonne massif; and 3) southwest-directed thrusting in the Embrunais-Ubaye and Digne nappe systems of southeastern France. The linking of these three broad regions of deformation is based on their contiguity, similar amounts of minimum displacement, consistent kinematics, and the timing of deformation.

Direct evidence for coeval folding related to northwest-directed convergence and normal faulting related to extension parallel to the Alpine chain is provided by the Simplon Fault Zone (SFZ) relationships around the Simplonpass. The SFZ in this region is a major, low-angle (25° dip) normal fault associated with WSW-ENE-directed extension. Movement began around 18 Ma and continued until at least 3 Ma, accumulating a total vertical throw of around 15 km, corresponding to 35 km displacement parallel to the fault. This displacement is partitioned between a broad zone of ductile mylonites in the footwall and a more discrete cataclastic "detachment fault" (the Simplon Line). In the region of the Simplonpass, a broad zone of earlier-formed, greenschist-facies retrograde mylonitic foliation in the footwall of the SFZ is folded about large amplitude "backfolds" (the Glishorn antiform and Berisal synform) coaxial with the displacement direction of the fault zone itself. These folds are truncated by a narrower zone of mylonites of similar microstructural aspect and kinematics to those mylonites folded about the backfolds. This younger, narrower, transecting mylonite zone is overprinted by a very narrow (generally less than a few metres) zone of cataclasites which forms the discrete Simplon Line detachment between the footwall and hanging wall. The cataclastic Simplon Line, together with the concordant adjacent mylonites, is itself weakly folded about the same backfolds, but with much lower fold amplitude. The parallelism between the stretching lineation associated with WSW-directed extensional shearing and the fold axes of the backfolds, the sequential interplay between shearing and folding (with mylonitic shear fabrics being folded, the folds being truncated by mylonites and cataclasites, and these fabrics in turn being further folded), together with the similarity in microstructure between folded and transecting mylonites are suggestive of a continuous history of NNW-directed shortening and WSW-directed extension, rather than of a series of separate deformation "phases". Two coeval and competing processes were active: folding leading to shortening in the direction NNW-SSE and near vertical extension, and normal faulting producing crustal thinning and extension in the direction WSW-ENE.

The Simplon Fault Zone can be followed to the northwest into the Rhone Valley, where there is abundant evidence of stretching in a WSW-ENE direction (late fibres on pyrite, stretched belemnites at Leytron etc. e.g. Badoux 1963, Dietrich and Durney 1986). The fault zone containing the stretching direction is steeper in this region (the so-called "northern steep zone" or "Helvetic root zone") and clear sense of shear indicators demonstrate a dominantly dextral sense of shear (with a smaller vertical normal fault component). At least a part of this major fault zone can be followed into the Chamonix Zone between the Mont Blanc and Aiguilles Rouges massifs, as indicated by late stepped fibre growth on old foliation planes, from calcite crystallographic preferred orientation fabrics, and from asymmetric folds (e.g. Gourlay and Ricou 1983). The zone can be followed further into the Belledonne Massif, where late retrograde mylonite zones and en-echelon fault geometries (Mugnier and Gidon 1988) are further evidence of dextral shear.

The rapid swing in orientation of the Alpine structures around the Pelvoux massif, through ~ 90° from SW-NE to NW-SE, transforms the SW-directed movement of the southern hanging wall side of this diffuse displacement zone into a thrust geometry, to produce the SW-directed Neogene thrusting in the Embrunais-Ubaye and Digne nappe systems of Haute Provence, in southeastern France.

Two basic models could be invoked to explain the Neogene kinematics of the Western Alps: oblique convergence and dextral transpression (e.g. Steck 1984, 1990) or lateral continental extrusion (e.g. Ratschbacher et al. 1991). Simple lateral extrusion implies a symmetric detachment of the mountain belt from both the foreland and the hinterland (i.e. the "indenter" in the models referred to above). This does not seem to be the case in the Western Alps: detachment along a right-lateral "transfer-zone" can be documented between the more internal Upper Pennine zone and the external Sub-Alpine massifs, but there is little evidence for significant detachment on the other side of the mountain belt against the Southern Alps (Schmid, et al. 1989). Instead, the right-lateral component is transferred, via the Simplon Fault Zone "pull-apart", from the Pelvoux-Belledonne-Rhone Valley zone to the Periadriatic Line, further to the southeast, in an overall dextral transpressive regime. This, together with other regional kinematic arguments (e.g. Choukroune et al. 1986, Platt et al. 1989), suggests that convergence during the Neogene was oblique, with the Southern Alps moving in a WNW direction relative to the European foreland. The oblique convergence itself may be related to the continued Neogene opening of the Western Mediterranean and Tyrrhenian sea, which produces an anticlockwise rotation of mainland Italy relative to the European foreland during the general NW-SE convergence of Africa and Europe (e.g. Gratier 1989, Vialon, et al. 1989).

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THIRTY-TWO YEARS OF GEOCHRONOLOGICAL WORK IN THE CENTRAL AND WESTERN ALPS : A REVIEW ON SEVEN MAPS

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This paper represents a review of the last 32 years of geochronological work in the Central and Western-Alps. Some of these data, distributed in over 230 papers, are poorly accessible, thus starting to fade away from the view of Alpine geologists. The data have been represented on 7 maps, 3 of which, in a scale of 1:1000 000, cover the area from the Alpine/Appennine boundary near Genova, throughout to the western Silvretta. Map I contains Rb-Sr data, map II summarizes the K-Ar and Ar-Ar mineral data.Map III shows U-Pb and whole rock data, therefore represents our knowledge of the pre-Alpine history. The ages on maps I and II are represented by a colour code,the symbol on the maps represents the mineral concerned. A number, printed near the symbol leads to the references, that are given both in numerical and alphabetical order. 4 maps of the Central Alps show a scale of 1:666 666. Maps IV and V give the fission track data for apatite and zircon respectively. On map VI and VII the K-Ar and Rb-Sr data are given once more in the same scale for direct comparison. The interpretation of the mineral data is presented in the light of the cooling and blocking temperature concept, discussed in detail. All ages are calculated using the new constants.

The present compilation of joint geochronological research in the Central and Western-Alps reveals astonishing inhomogenieties, both in regional and temporal distribution. The Western-Alps contain practically no Rb-Sr and U-Pb data. A majority of the data deals with the Alpine metamorphism and with the cooling after the Alpine orogeny. From pre-Variscan times, little can be said with certainty, no pre-Variscan mineral ages have been found so far. Widespread Variscan granitoids, which become more acidic with time, intruded a pre-Variscan polymetamorphic basement of generally lower crustal origin, with maximum sedimentation ages between 1000 and 500 Ma. Around 300 Ma, before present calcalkaline magmatism, both intrusive and effusive started, and lasted until mid Permian, the onset of Verrucano sedimentation. These late Variscan magmatic phases, mark the onset of continental thinning and rifting , with high heat flow and concomitant hydrothermalism, along preferred lystric planes, geochemically completely altering the adjacent rocks, and thus lowering their radiometric ages. In the Austroalpine/Southalpine units, mica ages between 240 and 140 Ma mark the slow uplift and cooling of these zones, from lower to upper crustal conditions.

The Eoalpine orogeny has been subdivided into an early eclogitic stage (140-85 Ma) and a later blueschist and cooling stage (85-60 Ma). The coincidence of two or more different chronometers facilitates the interpretation of the Eoalpine age data.
The Tertiary has been subdivided into 4 phases, the +- 30 Ma calcalkaline magmatism, subdividing the Cenozoic era into the Mesoalpine and Neoalpine.

1) The period between 60 and 45 Ma.is characterized by relative quiescence (Trümpy's 1961 restoration phase). These ages can be interpreted in different ways. For example, as mixed pre-Alpine/Tertiary ages, mixed Eoalpine /Tertiary; as ages from regions without a pronounced break in the P-T-conditions between the Eoalpine and Tertiary evolution.

2) 45-30 Ma marks the Mesoalpine metamorphic phase, found dominantly outside and around the Lepontine area, therefore the term Lepontine phase, for this age range has been dropped.

3) Ages between 30 and 0 Ma mark the Neoalpine event, subdivided (arbitrarily at 15 Ma - a more or less quiet period) into early and late Neoalpine.

The Alpine movements of major tectonic lines, such as the Insubric line, the Simplon line, and the Aosta-Ranzola line, have been dated both during their ductile as well as their brittle movements, by means of mineral ages. Thus periods of polyphase Alpine movements, ranging from as early as Jurassic, and lasting throughout the whole Tertiary have been identified. Also Jurassic, Cretaceous, and Miocene movements along major thrust planes of nappes have been dated with success, principally by the K-Ar and Ar-Ar methods on K-white micas. Cooling curves for a great variety of different regions in the Central Alps have been established.

REMOBILISATION OU PRESERVATION DES DIAPIRS PRECOCES DU DOMAINE ALPIN : UN PROBLEME D'ALIMENTATION ?

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Comme la plupart des marges passives ou des bassins intraplaques contenant des évaporites, le bassin du Sud-Est a été le siège de diapirisme dès les premiers stades de son évolution syn-rift au Jurassique.
Dans le domaine alpin, les arguments en faveur d'une halocinèse jurassique sont cependant rares en raison de la remobilisation fréquente des diapirs. Cette dernière efface notamment les arguments se basant sur les relations structurales de l'encaissant par rapport aux évaporites.

Les recherches que nous avons menées sur les affleurements de gypse triasique de Lazer-Upaix et du Haut soleil (Hautes Alpes et Alpes de Haute Provence) montrent que les seules preuves d'injection de gypse dès la période d'ouverture du bassin vocontien proviennent des petites structures diapiriques. Il s'agit de relations structurales particulières entre encaissant et évaporites et de paquets de gypse interstratifiés dans les Terres Noires mis en évidence par des relevés cartographiques détaillés.

En revanche, lorsque les structures diapiriques sont de plus grande taille et toujours alimentées, elles ont été remobilisées lors de chaque événement tectonique, effaçant toute trace de diapirisme antérieur (cas du diapir de la Platrière aux environs de Lazer et de celui du massif du Haut Soleil).

Il semble donc que le volume de sel mobilisé et surtout les possibilités d'alimentation en profondeur jouent un rôle important. La préservation des rapports structuraux gypse/encaissant en faveur d'un diapirisme syn-rift dans les structures de petite taille pourrait résulter d'un isolement précoce de la masse de sel ascendante avec le niveau évaporitique l'alimentant. Dans ce cas, le diapir formé n'est pas susceptible de s'écouler à chaque nouvelle phase d'instabilité tectonique mais tend au contraire à s'immobiliser.

Enfin, nous avons mis en oeuvre des méthodes géochimiques qui nous ont permis de déceler la présence d'éléments-traces caractéristiques des fluides salifères (Sr) dans les formations encaissantes des évaporites, notamment dans les Terres Noires contemporaines de la mise en place précoce des diapirs.

THE AGE OF METAMORPHISM IN THE CENTRAL AND EASTERN TAUERN WINDOW

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The Tauern Window of the Eastern Alps exposes pre-Alpine basement of the Pennine zone with its allochthonous Mesozoic cover. Existing geochronological studies have largely concentrated on the metagranitoid and metasedimentary rocks of the basement complex, and have consequently suffered from incompletely reset isotope systematics in Hercynian precursors. The lowermost levels of the cover sequence in the Eastern Tauern have been metamorphosed up to upper greenschist facies in the Alpine and present the opportunity to ascertain the age of the Alpine thermal peak at these crustal levels in rocks whose metamorphic history is well-characterised (Droop, 1985). Micaschists in this area show petrographic evidence of an early-Alpine blueschist event which was overprinted by the Alpine regional metamorphism, both events believed to be related to overthrusting of the Austroalpine nappes in the Alpine collision. Isotopic ages cannot be obtained for the blueschist event, but petrological studies place it in the latest Cretaceous, between two major phases of thrust-related deformation. The age of the thermal climax in higher structural levels has been determined by Rb-Sr and K-Ar on micas to be 35-40Ma, whereas previous data from the base of the cover sequence indicated near-peak conditions at 25Ma, which Cliff et al (1985) suggested might reflect diachronous metamorphism at different crustal levels. Having separated extremely lead-enriched allanites from garnet-micaschists mantling the Hochalm basement dome, we present U-Pb ages on allanite and sphene from the base of the cover sequence which (so far) indicate peak metamorphism at 35-40Ma, whereas well-constrained white mica Rb-Sr ages from the same rocks cluster at 25Ma and 30Ma. These preliminary data may be interpreted in terms of differential cooling rates and isotopic closure, or mixing of isotopic signatures during a polyphase thermal history.

In the Central Tauern, the basement and cover complexes are separated by an allochthonous sequence of variably-retrogressed metasediments and metabasites which have been metamorphosed under eclogite facies conditions. These are commonly thought to be part of the Mesozoic Pennine domain, and show evidence of an early blueschist mineralogy transforming to eclogite, which was overprinted by the Alpine blueschist to greenschist metamorphism. Many of the micaschists are thoroughly retrogressed, but mineral chemistry in both eclogites and metasediments preserves high pressure equilibria (20kb, 620°C, Holland, 1979 & K.Eremin pers.comm.) No isotopic ages are yet available for the pristine eclogites, but the Rb-Sr systematics in white-micaschists appear to be comprehensively reset at 29-31Ma, which may represent a Tertiary high-pressure phase as has been proposed elsewhere, or more probably records thorough retrogression under greenschist facies conditions. Titanian phases that can be reliably related to the paragenesis in these rocks are seen as potential U-Pb thermochronometers which may record the high-pressure history or the thermal peak of the overprint, although suitably uranium-rich separates have so far proved elusive.

In general, Rb-Sr white mica ages (representing cooling through ~550°C) get younger from west to east at equivalent structural levels in the Mesozoic Tauern, but there are hints of diachroneity that need to be unravelled within a more tightly constrained geochronological framework in order to elucidate further the tectonic history of the Eastern Alpine Pennine zone and the rates of metamorphic processes in the collision belt.

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ETUDE DES MOUVEMENTS VERTICAUX ACTUELS DANS LE NORD DES ALPES FRANCAISES ET LE SUD DU JURA PAR COMPARAISON DE NIVELLEMENTS.

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En France deux réseaux de nivellements ont été successivement établis: le N.G.F réalisé de 1886 à 1907 dans la region et l'I.G.N 69 observé de 1965 à1979. La bonne précision de ces nivellements, dont l'erreur probable kilométrique est estimée de 1 à 3mm, permet la détection et la localisation de mouvements verticaux relatifs.

La comparaison des différences de niveau entre les repères mesurés lors des deux nivellements précités met en évidence des déplacements verticaux relatifs entre deux repères communs successifs.
Une fois cette opération effectuée sur les profils de premier, de second et de troisième ordre il est nécessaire, d'une part de donner une origine commune à toutes les comparaisons de nivellement pour avoir une vision globale des mouvements verticaux, d'autre part d'estimer la significativité des mouvements obtenus. Pour ces deux raisons, nous avons décidé de compenser (imposer que la somme des différences de dénivellés soit nulle sur une boucle en répartissant les écarts par moindres carrés) simultanément les **différences de niveaux** mises en évidence sur les profils de premier, second et troisième ordres. En fait, étant donné que les époques de mesures fluctuent un peu selon la région et l'ordre du profil nous avons compensé les **vitesses relatives (seconde methode de Holdahl) (Holdahl, 1975)** entre repères voisins (hypothèse de mouvements continus). Pour effectuer la compensation nous avons choisi une loi d'écart type fonction de la distance entre repères successifs dont les coefficients tirés des études de l'IGN prennent en compte l'ordre et l'époque de réalisation.

Les principaux résultats sont :
- la caractérisation del '**activité du front du Jura** marquée par une surrection en un siècle de 2 à 3cm.
- présence d'une **surrection relative importante du sud du Bugey interne** par rapport au sud du Bugey externe.
- **effondrement des rives du Lac du Bourget** par rapport à la Cluse des Hopitaux et au Bassin Molassique.
- **activite complexe dans la région de Nantua.**
- présence d'une **importante surrection relative entre d'une part la cluse de Nantua, le bassin molassique et le Jura externe, et d'autre part le Jura interne au nord de la Cluse de Nantua.**

Ce type d'étude apparaît être le meilleur outil pour mettre en évidence les mouvements verticaux et pour préciser le caractère localisé ou non de la déformation, étant donnée la forte densite de l'information disponible (1024 repères dans cette étude). Nous avons pu ainsi confirmer et affiner les grandes tendances mises en évidence sur des profils de premier ordre par Fourniguet (1977,1978).

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PROGRESSIVE MYLONITIZATION OF ROCKS FROM AMPHIBOLITE FACIES TO SEMI-BRITTLE CONDITIONS

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The Belledonne massif belongs to the pre-triassic basement of the Western Alps; it is one of the crystalline external massifs, whose structural development is widely controlled by the Variscan orogeny, with a small overprint of the Alpine tectonometamorphic development. This tectonic imprint is mainly characterized by a polyphase folding of at least three more or less homoaxial fold generations. These ductile deformations are followed by numerous cataclastic deformations whose age may either be late Variscan or Alpine.

In the working area which is situated N of the village of Allemont in the mountain range of the Clapiere des Crouzes folds are only very scarce. The overall deformation is developed as a strong mylonitzation which started allready under amphibolite conditions. In orthogneisses you can observe feldspar phenocrysts which are deformed to s-clasts in cm scale, furthermore there are strong mineral lineations consisting of biotite and feldspars. The recrystallisation of k-feldspars and of plagioclase give rise for minimum temperatures during this deformatins of about 450° C. The mylonitic s-planes show a flat (20°) to moderate (50°) inlination and a NE-SW strike direction In some discrete layers internal folds with a proposed non-cylindricity are developed. All the mentioned kinematic markers as well as a pronounced sc-fabric show a transport of the hanging wall to the WSW. These amphibolite facies mylonites are folded, you can observe small scale folds with wavelengths and amplitudes of some cm to some dm. A relaated crenulation cleavage without polygonization or recrystallization of micas point to decreasing temperatures. These folded areas are bound by discrete shear zones which show a retrograde mineral assemblage with chlorite and white mica These shear zones show the same orientation and the same material transport. This is a wellknown fact that shear zones in rocks become more and more discrete during decreasing temperatures. As already mentioned above a lot of cataclastic faults are crosscutting all the older inventory. Subject to further investigations it is at the moment still unclear wether they are Variscan or Alpine in age.

APPORTS DE LA GEOCHIMIE A LA CONNAISSANCE DU CADRE GEODYNAMIQUE DU VOLCANISME CALCO-ALCALIN OLIGOCENE DES ALPES EXTERNES (GRES DE TAVEYANNAZ ET BRECHE DE SAINT ANTONIN)

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Au Paléogène, alors que le processus de collision continentale entamé au Crétacé supérieur se poursuit, les Alpes occidentales et centrales connaissent une activité magmatique. Ses principaux témoins sont des séries calco-alcalines, ultrapotassiques et shoshonitiques, situées au coeur de l'arc et datées du milieu de l'Oligocène (autour de 30 Ma). D'autres témoins, comme les andésites calco-alcalines des Grès de Taveyannaz, des Grès du Champsaur ou de Saint Antonin, présents dans la zone externe, sont légèrement plus anciennes (Oligocène inf.) Le volcanisme andésitique des Grès de Taveyannaz et du Champsaur n'apparaît que sous forme de galets et d'éléments minéraux; celui de Saint Antonin est, par contre, autochtone. La source des andésites de Taveyannaz et du Champsaur est encore discutée; cependant la fraicheur des amphiboles et des clinopyroxènes isolés et celle des fragments d'andésite est telle qu'on envisage que ce volcanisme se soit mis en place dans le bassin flexural de flysch oligocène, vraisemblablement par l'intermédiaire d'explosions phréato-magmatiques comme en témoignent des structures décrites. Parmi les autres éléments des Grès de Taveyannaz, on signale des micas blancs et orthoses perthitiques provenant du démantèlement du socle hercynien, des fragments de roches issues des zones alpines internes et, enfin, des clinopyroxènites blastomylonitiques d'origine mantellique, enclaves remontées par le magma andésitique. Ces grès peuvent être affectés par un métamorphisme léger à laumontite, prehnite et smectites, à l'origine de l'aspect moucheté de leurs surfaces altérées.

Les **andésites de Taveyannaz** sont à phénocristaux de plagioclases, clinopyroxènes (augites, salites) et amphiboles qui varient en composition depuis des pargasites ± ferrifères jusqu'aux édénites. Les plagioclases quand ils ne sont pas albitisés, montrent un coeur d'andésine (An_{48-32}) et une bordure d'oligoclase (An_{25}). Ces laves, fractionnées (Cr = 25ppm; Zr = 72ppm), présentent les caractères classiques des séries calco-alcalines potassiques ($K_2O \leq 3,5$ %; La/Nb = 1,53; La/Th = 1,28) : spectres enrichis en terres rares légères $[La/Yb)_N = 6]$, enrichissement plus ou moins marqué en éléments lithophiles et appauvrissement en éléments à forte charge ionique par rapport aux MORB. Les rapports isotopiques εNd, recalculés à T = 40 Ma, des amphiboles et des clinopyroxènes, séparés dans deux échantillons de grès, sont compris entre -1,05 et -0,62 (Fig. 1). Les rapports isotopiques εSr(T = 40 Ma) des mêmes minéraux varient un peu plus. Le clinopyroxène et l'amphibole provenant d'un échantillon de grès non métamorphisé (TV38) ont des valeurs εSr(T = 40 Ma) comprises entre +6,45 et +8,50, alors que celles des clinoyroxènes et amphiboles, prélevés dans un échantillon de grès métamorphisé (TV 43), sont beaucoup plus élevées et comprises entre +12,54 et +19,73. Cette augmentation du Sr radiogénique est vraisemblablement liée au métamorphisme d'enfouisssement à zéolites qui a provoqué une légère mobilisation de l'élément. Ces valeurs isotopiques montrent que le magma andésitique dérive d'une source mantellique contaminée par un composant crustal. Le socle hercynien des zones externes pourrait représenter ce contaminant crustal, car des feldpaths potassiques, provenant de l'érosion de granites hercyniens, prélevés dans ces mêmes grès, se caractérisent par des rapports εNd(T = 40 Ma) = - 7, 65 et εSr(T = 40 Ma) = +85,88.

Le faciès le plus commun de **la brèche de Saint Antonin** est une andésite basique porphyrique (40 % de phénocristaux) à plagioclases, amphiboles brunes et clinopyroxènes. Sont aussi présentes des dacites et des andésites fluidales à hornblende verte, clinopyroxène et biotite. Plus rarement, on trouve des faciès basiques (GSA47), à texture proche des lamprophyres, riches en hornblende pargasitique, biotite magnésienne et titanomagnétite. Les plagioclases xénomorphes forment le fond de la roche. Les andésites renferment fréquemment des enclaves gabbroïques à diopside et amphibole. Les clinopyroxènes, toujours fortement zonés, présentent deux compositions distinctes. Les diopsides (Wo_{45-47}, En_{43-48}, $Fs_{6-9,5}$) sont présents dans les enclaves grenues et les coeurs des agrégats gloméroporphyriques des laves, alors que les augites (Wo_{38}, En_{43}, Fs_{19}) et salites (Wo_{17}, En_{36}, Fs_{17}) auréolent les coeurs de diopside ou sont en microphénocristaux isolés. Les microlites et bordures des clinopyroxènes des faciès les plus différenciés, comparés aux coeurs des cristaux, montrent un enrichissement en MgO, TiO_2, Cr et MnO. Ceci suggère l'influence de mélanges magmatiques entre liquides acides et basiques. Les amphiboles présentent les mêmes compositions que celles des andésites de Taveyannaz. Les plagioclases, fortement zonés, varient comme ceux des enclaves gabbroïques, depuis l'anorthite (An_{95}) jusqu'au labrador (An_{38}). Ces andésites calco-alcalines sont comparables à celles de Taveyannaz ($K_2O \leq 2$ %; Nb (6-7 pmm). Cependant, elles sont plus enrichies en terres rares légères $[(La/Yb)_N = 14\text{-}17]$. Les rapports isotopiques εNd(T = 40Ma), obtenus sur les andésites et leurs minéraux constitutifs, et les diopsides et amphiboles des enclaves gabbroïques sont compris entre +0,95 et +1,70 (Fig. 1). Il en est de même pour les rapports de l'εSr(T = 40 Ma) qui s'échelonnent +16,66 à +17,72 (Fig. 1). Les rapports εNd(T = 40 Ma) et εSr(T = 40 Ma) du faciès basique (GSA 47) indiquent que cette roche est plus enrichie en Nd et Sr radiogéniques que les andésites et leurs enclaves, et donc ne dérive pas de la même source.

Ainsi, il apparait que les magmatismes de Taveyannaz et de Saint Antonin, bien que tous deux calco-alcalins, ne sont pas cogénétiques.

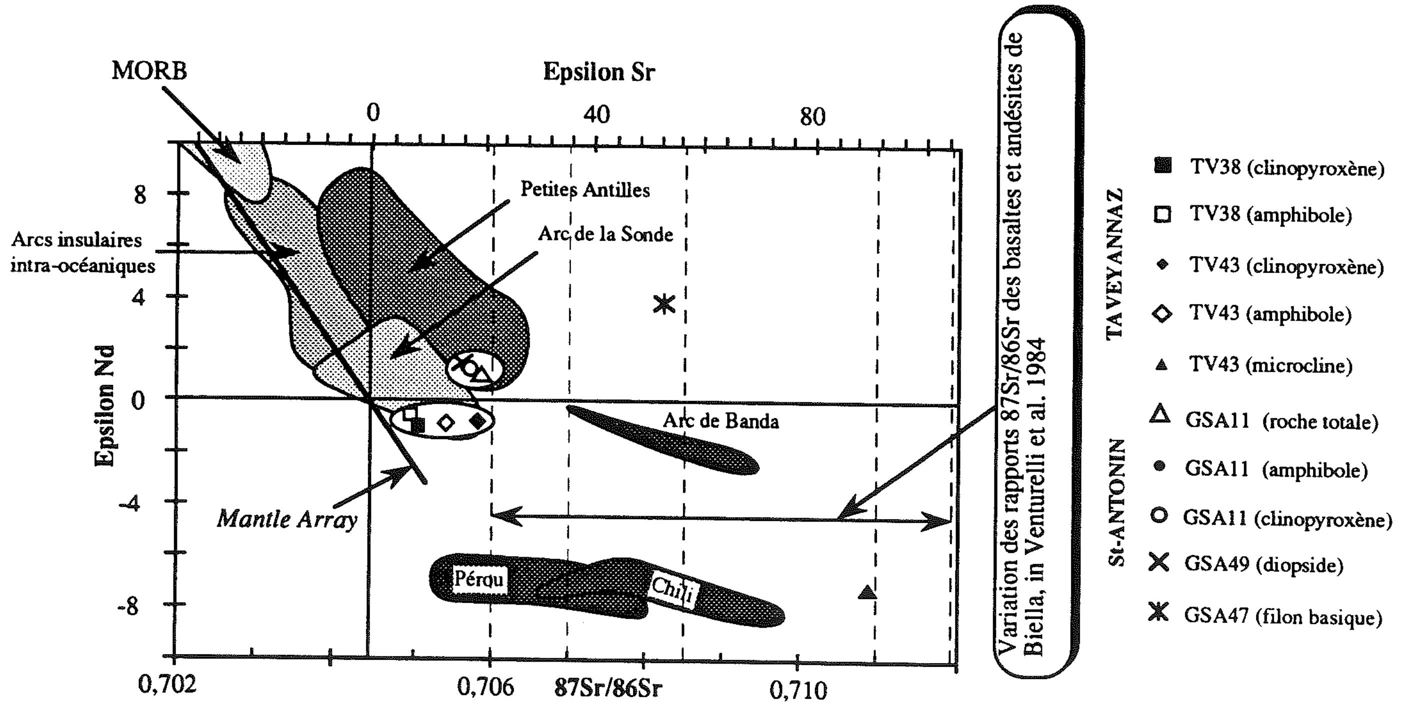
Dans les Grès de Taveyannaz, la présence d'enclaves mantelliques remontées par les andésites déjà différenciées, pétrographiquement et géochimiquement homogènes, situent leur origine à proximité du Moho dans le manteau supérieur. Les rapports isotopiques du Sr et du Nd des minéraux et des roches indiquent que la contamination crustale du magma calco-alcalin s'est produite vraisemblablement au niveau de la source mantellique.

Les laves calco-alcalines de Saint Antonin diffèrent des andésites de Taveyannaz. Les variations chimiques des clinopyroxènes et des plagioclases évoquent des mélanges magmatiques acides-basiques qui, par ailleurs, pourraient expliquer les rapports élevés εSr, observés dans ces minéraux et les roches qui les contiennent. Leur source mantellique, enrichie en Nd radiogénique, apparaît moins contaminée par un composant crustal que celle des laves de Taveyannaz.

En dépit des différences constatées sur les roches et minéraux volcaniques paléogènes de Taveyannaz et de Saint Antonin, il apparait difficile d'envisager pour la genèse de ces deux suites calco-alcalines des contextes géodynamiques totalement opposés. Déposés vers la limite Eocène-Oligocène (environ 35 Ma), les flyschs qui constituent les Grès de Taveyannaz et du Champsaur témoignent d'une subsidence rapide au front de l'arc alpin, en cours de progression vers l'Ouest; là, le régime tectonique local est clairement distensif; cela a guidé la montée des magmas, en particulier si des décrochements majeurs hérités ont été réactivés. Le contexte du volcanisme andésitique de Saint Antonin, au milieu de l'Oligocène (environ 30 Ma), est légèrement différent puisqu'il accompagne le rifting précédant l'ouverture océanique liguro-provençale; c'est à dire la naissance d'un bassin arrière-arc dans une dynamique apennine distincte de la dynamique alpine évoquée ci-dessus.

Nos analyses montrent que la source de ces magmas calco-alcalins de la zone alpine externe ne peut être qu'un manteau océanique métasomatisé (type éclogite) par des subductions anciennes et contaminé par de la croûte continentale. La fusion partielle de ce manteau éclogitique serait survenue durant sa remontée adiabatique en contexte distensif, le contaminant crustal dérivant de l'anatexie de la partie supérieure de la lithosphère européenne.

Se pose encore le problème de l'origine du manteau éclogitique. Il existe un quasi consensus pour admettre que la lithosphère océanique (Téthys ligure), puis la lithosphère continentale amincie sud-européenne (ancienne marge nord-téthysienne) aient été subduites sous l'Afrique (du moins son promontoire apulo-adriatique), loin au SE de la zone alpine externe envisagée ici. Ainsi, la lithosphère océanique jurassique ne peut représenter la source de ces magmatismes calco-alcalins.



LES TEMOINS METAMORPHIQUES DE L'AMINCISSEMENT LITHOSPHERIQUE ANTE-OROGENIQUE DANS LES ALPES OCCIDENTALES

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Dans la Chaîne Alpine, les témoins stratigraphiques, sédimentologiques et magmatiques de l'ouverture océanique Téthysienne sont particulièrement bien connus. Leur étude a conduit à des reconstitutions, parfois contradictoires, du domaine océanique Liguro-Piémontais. Jusqu'à présent les conséquences métamorphiques d'une telle extension dans la croûte continentale n'ont jamais été prises en considération. Pourtant des témoins d'un métamorphisme, d' âge Permo-Triasique, associé à l'extension ont été reconnus dans le domaine Sud-Alpin (Brodie et al. 1989; Zingg et al. 1990 ; Diella et al., 1992) comme dans les nappes de socle internes (Lardeaux et Spalla, 1991).

Nous présentons une revue des données actuellement acquises sur l'évolution métamorphique des croûtes continentales au Permo-Trias. Le régime thermique anormalement élevé déduit de ces évolutions métamorphiques est confronté aux modélisations thermiques des zones en extensioll et permet de discuter la dynamique du rifting ante-orogénique.

APATITE FISSION TRACK DATING AND UPLIFT OF THE ARGENTERA MASSIF, WESTERN ALPS (FRANCE, ITALY).

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The Argentera-Mercantour massif is one of the External Cristalline Massifs (ECM) of the Western Alps, consisting of pre-alpine basement. In order to document its exhumation history, 16 samples were taken along a SW-NE transect across the massif for fission track (FT) dating on apatite. Altitude of sampling varied from 900 to 2400 m.

FT apparent ages (t app) were obtained by the population method of Naeser (1967), after the calibration of two nuclear reactors used for irradiation of the apatite concentrates. While the lowest samples of the transect show t app ages close to 2.5 Ma, this value increases linearly with altitude for the samples above 1200 m (SW side) and 1400 m (NE side) and reaches 7.5 Ma at 2400 m. This pattern is interpreted with the help of the Partial Annealing Zone (PAZ) concept of Wagner (1972) and Wagner et al. (1989). A corrected tf age of crossing the upper limit of the PAZ ($T < 65°C$) is calculated taking into account the variation of the track length distribution with the altitude. From the tf/altitude relationships, exhumation rates of 0.6 mm/year and 0.9 mm/year is obtained respectively for the SW and the NE sides of the massif, in the interval 2.59 - 0.31 Ma.

The t0 age of crossing the base of the PAZ (cooling down to 130° C) varies from 9.5 Ma (highest samples) to 2.8 Ma (lowest ones), this indicates an exhumation rate of ca 0.2 mm/year all over this period. The part of the massif above the 1200-1400 m level corresponds to a Mio-Pliocene PAZ rapidly exhumed during the Plio-Quaternary interval. Like the other studied ECM, the Argentera massif started its uplift and exhumation about 10 Ma ago, but the exhumation rate sharply increased 3 Ma ago.

EXCESS RADIOGENIC ARGON IN FISSURE QUARTZ FROM THE FRENCH WESTERN ALPS IN THE MESOZOIC BLACK-SHALE UNIT. A NEW TOOL FOR K - AR DATING OF EPIZONAL METAMORPHISM.

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Strong amounts of excess ^{40}Ar have been discovered during normal processing of fissure quartz for conventional K - Ar dating. The composition of those quartz shows that the best candidates for the location of that excess radiogenic argon are the fluid inclusions. The thermodynamic features of the fluid inclusions lead to the conclusion that they trapped the metamorphic fluids including regional anomalies in the ^{40}Ar / ^{36}Ar ratios. The date of the trapping corresponds to the beginning of the regional cooling after the metamorphism peak. As the K - Ar dating of metamorphic newly formed or transformed fine phyllosilicates during metamorphism also corresponds to the same moment, we have tried to substract the amount of excess radiogenic argon found in the quartz from the amount detected in those phyllosilicates. The results give the assumed age of the metamorphism.

The main feature of the Lower and Middle Mesozoic units of the French Western Alps overlying the external crystalline massives is the impermeability. In these conditions any metamorphic event affecting such rocks releases the previously accumulated radiogenic argon. But, this argon cannot escape totally or partially and remains dissolved or related to the fluids formed during the metamorphism. This fluids are then occluded by the quartz during their growth.

This process allows for a systematic seeking of the excess ^{40}Ar in the quartz to determine more accurately the age of the metamorphic event through K - Ar dating of fine phyllosilicates.

LE VOLCANISME PALEOGENE DE L'UNITE DES AIGUILLES D'ARVES LE VOLCAN DU GOLEON ET LA GEODYNAMIQUE ALPINE

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Le volcanisme paléogène des Alpes occidentales et des régions périalpines se manifeste par des produits grauwackeux ou lahariques le plus souvent, laviques ou intrusifs quelquefois, répartis de manière très discontinue de la Suisse à la Méditerranée dans diverses formations éocènes et oligocènes. Donné comme calco-alcalin depuis l'étude détaillée des Grès de Taveyanne (VUAGNAT, 1958 ; MARTINI et VUAGNAT, 1967 ; MARTINI, 1968 ; SAWATZKI, 1975), il a été qualifié ensuite d'orogénique (MAURY et VARET,1980). Durant longtemps aucun centre d'émission volcanique n'avait été clairement mis en évidence dans les bassins de sédimentation paléogènes des Alpes, de sorte que ces produits ont été tour à tour donnés comme pouvant provenir de l'érosion d'un arc volcanique andésitique actif (LATELTIN, 1988; WAIBEL, 1990) aujourd'hui disparu, ou bien d'un volcanisme implanté *in situ*, dans le bassin lui-même ou sur ses limites (GIRAUD, 1983; DIDIER et LAMEYRE,1978; PAIRIS, 1988), avec des bouches volcaniques non encore clairement identifiées.

L'examen de l'affleurement des volcanites du massif des Aiguilles d'Arves (MICHEL et BARBIER,1958; PAIRIS *et al.* 1990) sur le versant nord de l'Aiguille du Goléon (cotes 2900 à 2950), montre des tufs volcanogènes souvent massifs, verdâtres et rougeâtres, qui recoupent ou s'interstratifient dans des brèches volcano-sédimentaires polygéniques (blocs de Trias à Malm pouvant dépasser $1m^3$, et éléments de matériel éruptif en débris centimétriques vitreux, aphanitiques ou porphyriques dispersés et en blocs émoussés de roches massives variées (rhyodacites, dacites ou latites-andésites quartzifères). Par ailleurs, dans cet ensemble, et plus particulièrement dans la partie haute de l'affleurement, des laves massives d'épaisseur plurimétrique s'interstratifient dans les brèches : on peut les interpréter comme du matériel lavique en place.

PETROGRAPHIE : Les matériaux volcano-clastiques montent une grande variabilité texturale; leur débit planaire est surtout l'héritage d'une texture litée des matériaux tuffacés, acquise lors de leur sédimentation. Le caractère hyaloclastique de nombreux éléments est le plus souvent affirmé. Un second type d'éléments des tufs offre un cachet ignimbritique, avec des fantômes de "flammes" (généralement épigénisées par des carbonates cryptocristallins), associées à des structures axiolitiques, qui impliquent un régime éruptif localement subaérien.

Par ailleurs, une diversité des liquides magmatiques initiaux peut être relevée, ainsi que l'ubiquité des traces des phénomènes de mélanges. Des éléments à texture doléritique sont souvent emballés dans une lave à mésostase microlitique. Les contacts lobés ou suturés entre les produits laviques distincts sont également très fréquents. Il faut noter aussi une spilitisation, caractérisée par une albitisation des plagioclases et une chloritisation partielle des verres qui atteste d'une interaction avec l'eau de mer et/ou des influences un peu plus tardives de fluides hydrothermaux liés à des circulations syngénétiques dans les dépôts volcano-sédimentaires.

COMPOSITION CHIMIQUE : Les échantillons choisis pour analyse parmi les plus frais, offrent des compositions à majorité andésito-dacitique et rhyolitique, sauf un qui correspond à un matériel basaltique hautement alumineux. En raison de l'oblitération spilitique des caractères chimiques originaux, on accordera ici plus d'importance aux oxydes ou aux éléments moins susceptibles d'être mobiles que la chaux ou la soude.

Les comportements de l'alumine, du fer et du magnésium s'accordent clairement avec une évolution calco-alcaline des magmas parentaux qui s'exprime par un fort enrichissement relatif en aluminium, témoignant principalement d'une surcharge plagioclasique des matériaux andésito-basaltiques. Par ailleurs cette tendance est identique à celle que l'on peut noter pour les laves du Paléogène des domaines alpins et de la façade méditerranéenne (Thônes, Taveyanne, Champsaur, Saint-Antonin, Estérel...).

Les lanthanides offrent deux spectres distincts pour ces matériaux. Le matériel andésitique (échantillon AW9) montre une pente très forte des terres cériques et un spectre plat pour les terres yttriques. Le matériel rhyolitique (AW3) offre en plus, une forte anomalie négative en europium, probablement induite par un fractionnement plagioclasique. Par ailleurs le spidergramme montre un spectre très incliné comme celui des terres rares : il est enrichi en lithophiles de grande taille (Rb, Ba, Th, U, K), ce qui implique une contamination du matériel, vraisemblablement à la faveur de son transit dans la croûte continentale ou héritée de son histoire antérieure. Notons enfin que le spectre de terres rares de l'échantillon andésitique (AW9) présente une forte analogie avec les dacitoïdes tertiaires et les estérellites de l'Estérel.

A fin de comparaison, nous avons examiné d'autres secteurs alpins et périalpins : les analyses effectuées dans les Aiguilles d'Arves présentent de fortes analogies de composition avec celles des laves intermédiaires et acides du volcanisme paléogène connu dans le Sud-Est (Grès de Taveyanne, Champsaur, Saint-Antonin, Biot et même les estérellites) : toutes ces volcanites présentent des tendances géochimiques générales communes. Cette analogie se retrouve particulièrement dans les spectres de répartition des lanthanides qui offrent les mêmes caractéristiques pour des roches équivalentes. Toutefois, les éléments volcaniques des Grès de Taveyanne, qui ont été spécialement examinés aux abords du col de la Croix -Fry (route du Merdassier) et à l'est de Thônes, offrent une nette dérive dans le diagramme Al^2O^3-FeO-MgO vers FeO, attestant probablement d'importantes modifications chimiques des laves consécutives à l'altération sous-marine, à un remaniement et peut-être, pour certains échantillons, à l'empreinte d'un métamorphisme tardif. Il en est de même pour les Grès du Champsaur - homologues des Grès de Taveyanne (analyses publiées par A.F.WAIBEL, 1990).Si on place ces roches dans un diagramme Zr-Zr/Nb (CABANIS, à paraître), on voit qu'elles se regroupent en un nuage situé aux confins des termes différenciés par un magmatisme de subduction et de matériaux syncollisionnels; elles ne sont pas des andésites de vraie subduction et trahissent une collision continentale en cours.

AGE DES FORMATIONS RENFERMANT LES PRODUITS VOLCANIQUES : Le flysch qui fait suite stratigraphiquement aux conglomérats des Aiguilles d'Arves est d'âge priabonien; les formations détritiques à débris volcaniques du SE de la France sont du Priabonien terminal et/ou de l'Oligocène. On voit se manifester une migration centrifuge des venues volcaniques durant le Paléogène, en même temps que se dégage nettement le caractère ponctuel de toutes ces manifestations éruptives (PAIRIS, 1988). Des essais de datation K-Ar sur roche totale et sur plagioclase ont été effectués. L'ambiance régionale montrant des excès d'argon, variables mais généralisés, n'a pas permis d'atteindre ni l'âge réel de ces formations, ni celui de leur métamorphisme (NZIENGUI, 1992).

CONCLUSION : En conséquence, la migration centrifuge de ce volcanisme, sa localisation ainsi que la brièveté de la période d'activité des diverses zones éruptives, tour à tour apparues puis éteintes, nous conduisent à relier ce magmatisme, non pas à la subduction d'un résidu de plaque océanique qui se serait ainsi résorbée sous le domaine externe (GIRAUD, 1983) mais simplement à une reprise de fractures majeures (PAIRIS, 1988), très probablement crustales, tour à tour ouvertes par un mécanisme de distension qui reste à préciser dans le contexte de collision continentale dans lequel on se trouvait alors, puis plus ou moins rapidement refermées au cours de l'évolution de l'orogène. Cette distension peut être due 1.-à une obliquité du mouvement de collision par rapport aux lignes structurales de la plaque européenne, héritées de l'histoire antérieure, qui avec des décrochevauchements aurait pu avoir tendance à ouvrir des pull-aparts ou en tout cas des fractures majeures; 2.- ou bien, le bourrelet limitant du côté externe le bassin d'avant-pays marin puis continental creusé en avant des unités internes en cours de mise en place, a développé sur sa voussure une distension localisée. La migration centrifuge de cette zone de distension restreinte, au fur et à mesure de l'avancée des nappes internes, serait responsable à la fois du déplacement des émissions volcaniques dans le même sens au cours du temps et de la brièveté de l'activité de ces dernières.

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STRUCTURES EST-OUEST ANTENUMMULITIQUES À LA BORDURE ORIENTALE DU MASSIF DES ECRINS-PELVOUX (ALPES FRANÇAISES)

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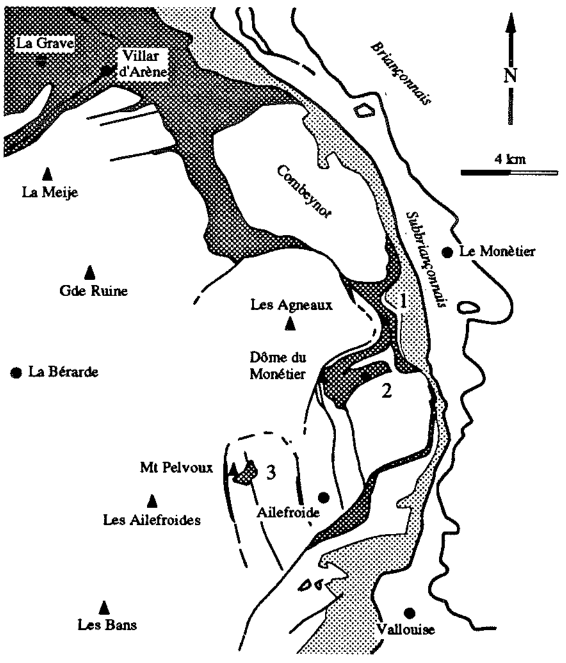

Figure 1 - Carte shématique de la bordure orientale du Massif des Ecrins-Pelvoux.
Grisé clair : nummulitique, grisé sombre : Mésozoïque.

La bordure orientale du massif des Ecrins-Pelvoux, au front des nappes briançonnaises et subbriançonnaises (zone dauphinoise), est une zone où sont imbriqués (fig. 1)

- le soubassement cristallin hercynien, fait de granites et de migmatites,
- la couverture mésozoïque (Trias et Jurassique montant jusqu'à l'Oxfordien), dolomies, grès et calcaires, calcschistes,, préservée soit en chapeau perché sur le cristallin (Mont Pelvoux), soit prise dans des écaillages de socle (région du Dôme du Monêtier),
- la couverture nummulitique (calcaires à la base, puis "flysch" grèseux), discordante sur le Cristallin ou sur le Mésozoique.

Des travaux déjà anciens, portant sur cette région (Barbier, 1963), ou plus géné-ralement sur les rapports entre les massifs cristallins (Pelvoux et Taillefer)et leur couverture (par ex. Gidon, 1979; Barféty et Gidon, 1990), ont souligné le caractère polyphasé de la déformation de la couverture : existence de structures transverses éo-alpines (orientées E-W, axes cinématiques orientés N-S) , reprises dans les plis et écaillages alpins, post nummulitiques, de direction cinématique ESE-WNW.

Certains travaux récents (Butler, 1992) interprètent au contraire la structuration de la bordure orientale du Pelvoux (crête des Grangettes, Rocher de l'Yret) uniquement en termes de tectonique de chevauchement ("thrust tectonic") post nummulitique, avec une direction de transport (marquée par les linéations d'étirement syn-cisaillement où le) compartiment supérieur va vers l'WNW.

Nos observations récentes dans le Mésozoique de l'Est Pelvoux confirment qu'il faut séparer deux étapes tectoniques majeures :

- Une tectonique anténummulitique (fig. 2), marquée par des plis ou des chevauchements à vergence nord. En rive droite du vallon du Grand Tabuc (fig.1, site 1), il s'agit de plis jusqu'à pluridécamétriques, orientés N100°E, associés à une schistosité ancienne dont l'existence est surtout attestée par une linéation d'intersection parallèle aux axes P1. Dans le vallon de l'Eychauda (site 2), il s'agit des plis de la Crête des Grangettes et du Dôme du Monétier, à vergence nord, orientés environ N80°E, chevauchés au S par le cristallin (chevauchement vers le nord des Rochers de l'Yret sur le Mésozoique de la Crête de la Montagnolle). Le Pelvoux (site 3), avec sa grande dalle structurale des Rochers Rouges (paleosurface jurassique supérieur, Barféty et al., 1986), repose par un plan E-W penté au sud (Gidon, 1954) sur le Jurassique de la vire d'Ailefroide. Cette structure pourrait aussi correspondre à un chevauchement vers le Nord.

- Une tectonique post-nummulitique (fig. 3), à direction cinématique vers l'WNW. Dans l'Eocène, elle est marquée par les structures imbriquées (Gidon, 1954) reétudiées par Butler (1992). Dans le Mésozoïque, elle est marquée par quelques plis d'axes environ N-S, et par une reprise vers l'ouest des chevauchements qui avaient joué précédemment à vergence nord.

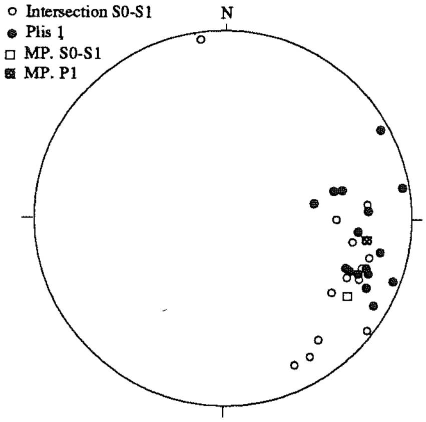

Fig. 2 : Structures ante-nummulitiques. Meilleurs poles : axes P1 = N98°E, 25°SE, intersections S0-S1 : N122°E, 24°E

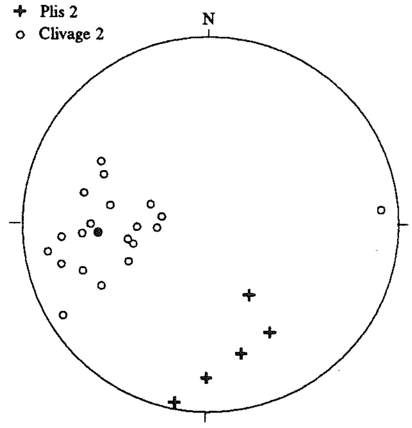

Fig. 3 - Structures post-nummulitiques. Meilleur pôle des schistosités S2 (carré noir) : N176°E, 49°E.

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CRUSTAL STRUCTURES BENEATH THE SOUTHERN PIEMONTE (NORTH-WESTERN ITALY): CONSEQUENCES ON KYNEMATIC OF THE ALPS/APENNINE BOUNDARY.

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Crustal structures at the alpine/apennine boundary are characterized by an anomalously shallow Moho, deepening from 22 to 30 km toward north, and by multiple wedging of the crust that show a crocodile type pattern. A peculiar character is a north vergent structure where the alpine metamorphic (HP/LT) basement overthrusts onto the Apennines at the upper crustal level, and the apenninic basement overthrusts onto the padane foredeep at a deeper one. Also the mantle shows similar features with strong indentation into the crust.

In this complex sutured boundary three main crustal domains (alpine, apenninic and padane) can be recognized:

- in the upper (alpine) domain piggyback basins (Torino Hills and Tertiary Piemonte Basin s.s.) form on alpine crust. Inversion of structural trend and backward migration of depocenters are the most prominent features.
- in the intermediate (apennine) domain a series of intramontane and piggyback basins (Monferrato) develops on the top of Apennine Liguride Nappes; they are strongly dismembered by syn- to post-sedimentary tectonic events;
- the lowest domain gently deepens toward south below the alpine/apennine domains. It is formed by the padane Tertiary/Quaternary molasses and acted as Apennine foredeep since Burdigalian.

A post-Messinian deformation reworks previous structures and is responsible of the formation of piggyback basins at the backside of the Apennine fronts.

The main lithostratigraphic and structural topics of these domains are as follows.

TORINO HILL

The stratigraphic succession range from Eocene to upper Miocene without clear unconformities. The basin deepens trhough time from platform conditions (lower Oligocene: fan-deltas conglomerates) to basinal conditions (upper Oligocene to Tortonian: siliciclastic turbidites and channellized coarse conglomerates). Turbiditic infillings show fining upward trends.

The deformation of the basin starts from upper Messinian. The present structure is a large asymmetric anticline interpreted as a ramp anticline related to the westward prolongation of the north-vergent apenninic thrusts in Plio-Quaternary time.

PIEMONTE TERTIARY BASIN s.s.

The proper Piemonte Tertiary Basin develops as a piggyback basin on both alpine basement and ligurides upper Cretaceous flysch.

In upper Eocene-lower Oligocene, continental or shallow water conditions develop to the west, whereas basinal condition are present to the east.

In the upper Oligocene the basin topography dramatically changed, with a migration of depocenter from east to west. In the East platform conditions set in; in the west a thick (up to 4000 m) succession of siliciclastic turbidites infilled a deep basin of Miocene age.

This deformation is strictly related to the evolution of thrust planes:

a) until the lower Oligocene the trusting of the alpine basement onto the Ligurian nappes along the Sestri Voltaggio Line is responsible of the formation of a foredeep basin in the eastern part of this structural domain;

b) since upper Oligocene thrusting of alpine domain onto Apennines moves forward and develops troughout the Ottone-Levanto/Villalvernia Varzi system.

The thrusting along this plane is responsible for tilting of the older thrust (now vertical) and backward migration of the depocenter.

MONFERRATO

The Monferrato range corresponds to the superficial expression of the main alpine/apennine boundary. Here a series of intramontane/piggyback basins rapidly evolves onto and at the front of the Apennine external liguride nappes moving toward north-east. The basins are strongly dismembered by syn- to late-sedimentary tectonic events.

In these short-lived basins tectonosedimentary signatures are represented by unconformities and stratigraphic gaps. The more significative are the lower Oligocene and the Burdigalian unconformities and the Serravallian gap.

PADANE FOREDEEP

The infillings of the Po plain gently deepen toward South below the Monferrato domain. Here the padane Tertiary/Quaternary molasses have been deposited in the Apennine foredeep basin since Burdigalian.

Finally Plio-quaternary sediments either infill piggy-back basins developed at the top of the upper element (to the south of the main thrusts), or seal the north vergent Plio-Quaternary thrusts that do not merge at surface as reverse fault, as in most overthrust belt.

Also crustal and mantle structures are in accordance with surficial trends; Fig. 1 shows a depth transformed geological interpretation of a seismic experiment undertaken in 1991 in this region. Crustal structures are characterized by important discontinuities that merge at the surface to delimit the previously described superficial structural domains. Peculiar features are the large overthrusts of basement onto Tertiary sediments and the presence of mantle slices strongly indented into the crust at intermediate depth . A similar disrupted geometry of Moho reflector have already been evidenced by EGT and CROP/ECORS experiments.

CONCLUSION

Crustal deformation was active during Tertiary time in the southern Piemonte region and played an important role in the evolution of sedimentary basins at shallow crustal level.

The boundary between the Alpine and the Apennine chains is not to be considered as fixed , but moved in time and space and was strongly influenced by kinematics of crust/mantle indentations developed during Tertiary time.

Some major events affected the whole crust:

- since Eocene-Oligocene time the opening of the Gulf of Lion, the consequent rotation and the eastward drift of the Corso-Sardinian block caused compressions in the Apennine crust;
- this deformations superimposed on south-vergent Cretaceous-Paleogene thrustis at the backside of the alpine chain and dramatically changed older geometries and vergences;
- also the already disrupted mantle slivers of the Alpine chain were involved in the orogenic chain and rose to shallow crustal levels.

The resulting structural style at the upper crustal level is dominated by the outward migration of the major thrusts acting since Cretaceous/Paleogene up to Present.

The main steps of this evolution at the surface are:

- along the Sestri-Voltaggio Line HP/LT metamorphic alpine elements overthrusts apennine elements (external ligurides, non metamorphic) up to the Oligocene: a consequent foredeep basin (eastern part of the Piemonte Tertiary basin) develops out of the thrust front:
- the outward migration of the thrusting along the Ottone-Levanto/Villalvernia-Varzi system during Miocene causes the tilting of the alpine upper crust and the backward migration of depocenters in the western part of the Piemonte Tertiary Basin;
- at the same time thrusting inside and at the front of the Apennine nappes strongly influences the life and the evolution of:
  - short-lived piggyback basins in the Monferrato region and
  - the Apennine foredeep in the Padane domain;
- finally, the thrusting along the external Apennine Fronts in Plio-Quaternary time extends westward to affect the Torino Hill basin and causes the formation of piggyback basins at his backside.

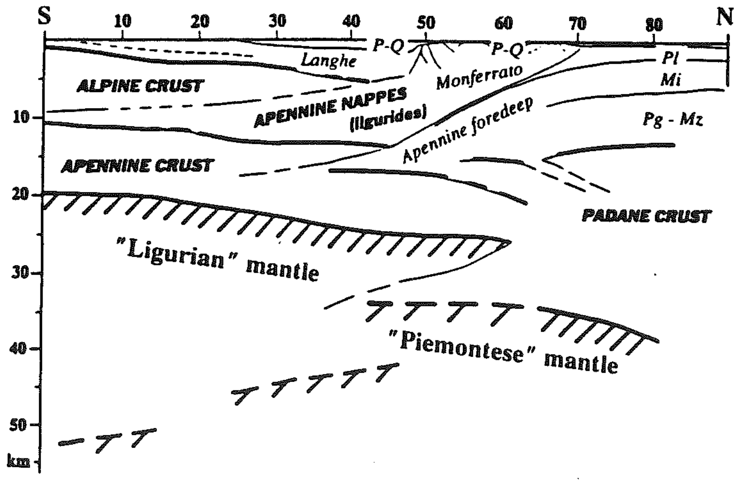

Fig. 1 - Crustal structures at the Alps/Apennine boundary.
Heavy lines: reflection and refraction surfaces from Deep Seismic Sounding; thin lines: superficial structural, shallow seismic and borehole data.
Plio-Quaternary piggyback basins of the Alpine and Apennine domains: P-Q.
Apennine foredeep (= Padane domain): Pliocene (Pl), Miocene (Mi) and Paleocene-upper Mesozoic (Pg-Mz) infillings.

KINEMATICS OF THE JUXTAPOSITION OF THE COMBIN AND ZERMATT-SAAS UNITS, THE PIÉMONTE OPHIOLITE NAPPE, ITALIAN INTERNAL WESTERN ALPS

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The Piémonte Ophiolite Nappe lies tectonically interposed between the underlying crystalline basement massifs (Monte Rosa, Gran Paradiso, Dora Maira) and klippe of the overlying Austroalpine nappe system. Classically, in canton Valais (CH) and the Haut Valtournanche (I), the Piémonte Nappe is subdivided into two tectonostratigraphically distinct elements which have enjoyed substantially different tectonometamorphic histories (Bearth, 1967; Dal Piaz, 1965; Dal Piaz & Ernst, 1978).

The structurally lower element, the so-called Zermatt-Saas Unit, exhibits variably preserved relics of Eoalpine (HP/LT) metamorphism whereas the upper element, the Combin Unit, generally only bears witness to the later Lepontine greenschist facies metamorphic overprint.

Palinspastic restorations have routinely ascribed the Zermatt-Saas Unit to a more internal position within the Ligurian Tethys than the majority of the Combin Unit. Given this palæogeographic context and the general scheme of NW-directed Alpine thrusting, one would expect the Zermatt-Saas unit to overlie the Combin Unit and not *vice versa* as observed. Therefore the kinematics of the boundary between the two units are clearly of considerable significance to the understanding of the tectonic evolution of the internal Alps.

This contribution considers the nature of the enigmatic contact between the Combin and Zermatt-Saas units, based on detailed observations from the Haut Valtournanche. Particular emphasis is placed on the resolution of complex patterns of shear-sense indicators from lithological units adjacent to the contact. A consistent kinematic model is developed and its significance within the broader Alpine framework is discussed.

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THE SESIA ZONE: STRUCTURAL AND METAMORPHIC CONSTRAINTS ON TECTONIC EXHUMATION

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Valchiusella, located approximately 60km north of Turin, provides a 15km long transect through the Sesia Zone, the lowermost Austro-Alpine unit of the Internal Western Alps. Structural and metamorphic research is being carried out from the Oligocene diorite intrusion at Traversella in the South East, through the Eclogitic Micaschist (EMS) and Gneiss Minuti (GM) units, to the structurally lower Piemonte Zone in the Northwest, at Piamprato (Valsoana), to constrain the exhumation of high pressure low temperature mineral assemblages.

The Eclogitic Micaschists, forming the Central and Eastern portions of the Sesia Zone, consist of micaschists, metaaplites, metagranitoids, marbles and metabasic pods and layers , all with eclogite facies mineral assemblages. Limited static greenschist facies overprinting is developed on a microscopic scale, but towards the west of the EMS it becomes more pervasive, within an approximately 2km wide Transition Zone. In the west of this Transition Zone the overprinting is complete, adjacent to the Gneiss Minuti. The Gneiss Minuti is characterised by banded metagranitoids, micaschists, metabasic layers and minor amounts of marbles and calcschists. These lithologies display greenschist facies mineral assemblages and fabrics, totally lacking evidence of having experienced an earlier higher pressure event. Similarly, the Piemonte Zone appears to consist of solely greenschist facies mineral assemblages, developed in variably graphitic calcschists and prasinites.

Initial structural data indicates that the Western most region of the Transition Zone may have been an oblique shear zone, uplifting and juxtaposing the EMS to its present position with respect to the GM. Field mapping is currently underway (summer '92) to clarify the existence of any such structure. The contact between the Sesia and Piemonte Zones at Piamprato consists of approximately three slices of (folded?) GM metagranitic rocks, within top to the South East sheared calcschist. The contact between the Monte Emilius Austro Alpine Klippe and Piemonte Zone, exposed around Grauson to the North of Cogne is also being examined. Unlike at Piamprato, the assemblages in both the Klippe and Piemonte rocks record early eclogitic then blueschist facies events, followed by a greenschist overprint. Structurally the contact at Grauson appears to consist of a zone of repeated Emilius and Piemonte lithologies which have been openly infolded together, the folds having shallowly East plunging hinges and postulated subvertical South dipping axial planes. More precise and extended metamorphic and structural data is currently being obtained in order to determine the grade of juxtaposition of the units and the fabrics developed in them.

OCEANIC TO CONTINENTAL EVOLUTION OF MAGMATISM AND DEPOSITIONAL SETTING IN THE INNER ZONE OF THE BETIC CORDILLERA DURING THE ALPINE CYCLE.

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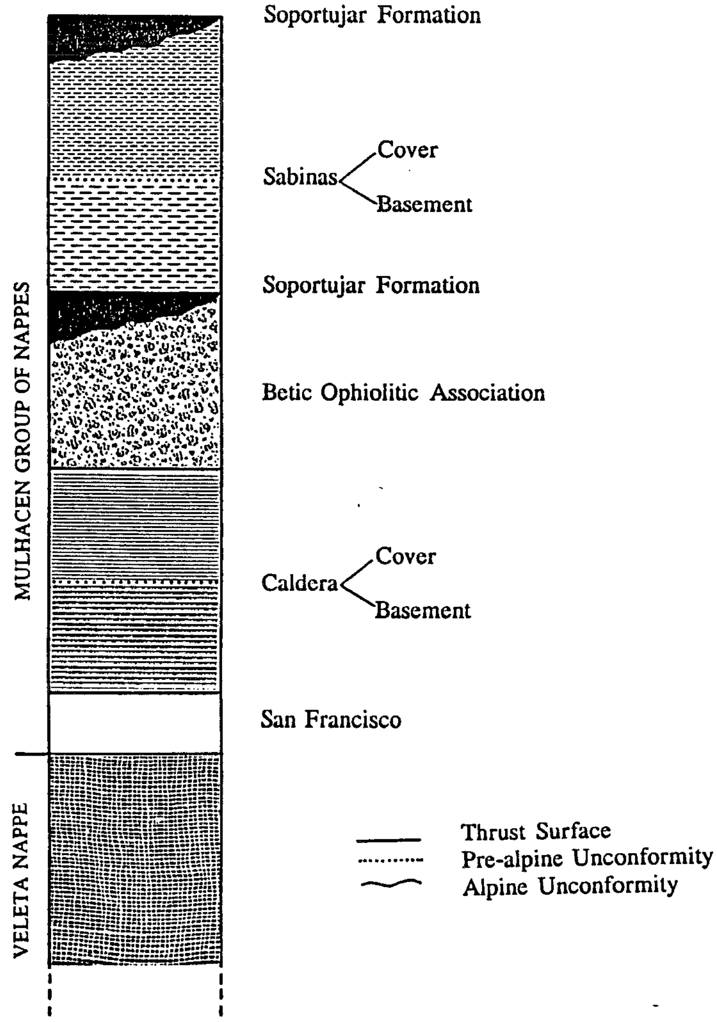
As can be seen in the Figure the schematic tectonic succession of the Nevado-Filabride Complex (NFC) (the deepest complex of the Betic Cordillera) consists of the Veleta nappe, metamorphosed in Ab-Ep Amphibolite facies, with very scarce remains of pre-alpine metamorphism, overthrust by the Mulhacen Group of nappes, affected in the most of its units by metamorphism in Eo-Alpine Eclogite facies overprinted by MesoAlpine Ab-Ep Amphibolite facies. The overlapping of the Mulhacen over the Veleta units ocurred, at the earliest, later than the Eo-Alpine, high-pressure, metamorphic event.

From bottom to top the tectonic units in the NFC, according to the nomenclature of Puga and Diaz de Federico (1976 a,b) and Diaz de Federico et al. (1980, 1990), are: the Veleta nappe, made up mainly by graphitic micaschists and quartzites; the San Francisco nappe, a discontinuous alumina-rich, pelite-psammitic formation; the Caldera nappe, with clear remains of pre-Alpine metamorphism in Amphibolite facies and Permo-Triassic calc-alkaline magmatism; the Betic Ophiolitic Association (BOA); the Soportujar Formation; and the Sabinas nappe, bearing some similarities to the Caldera nappe, and also overlayered by the Soportujar Formation.

The most widely discussed of these units, as far as their genetic conditions are concerned, are the Ophiolitic Association (Puga, 1990) and the Soportujar Formation (Puga et al, 1984), the main characteristics of which we describe helow.



Schematic succession of units in the NFC

The Ophiolitic nappe represents a slice of oceanic floor, made up of ultramafic, gabbroic and basaltic rocks, overlayered by metasediments containing some basaltic levels, and tectonically sandwiched between the Caldera and the Sabinas continental units. These ophiolites are locally overlayered by the continental-evaporitic, vulcano-sedimentary Soportujar Formation.

The magmatism that generated the ophiolites began under continental rift conditions at the TriassicJurassic boundary and continued under ocean-floor distensive conditions throughout the Jurassic (Hebeda et al, 1980; Portugal et al, 1988; Puga et al., 1991). The geochemical characteristics of the igneous protoliths in the BOA are typical of oceanic magmatism developed onto a hot and wet spot caused by the insertion of an astenospheric plume similar to those originating the P-type magmatism at numerous points along the MidAtlantic Ridge. This is manifest not only in the LILE-enrichment of the MORB-type magmas, but also in the strong oceanic hydration of the ultramafic rocks of this association, which highly favored the rodingitization of their enclosed basic dykes and the secondary development of spinifex-like textures in the harzburgites (Puga et al., in press; Bodinier et al., in prep.). According to their oxygen and carbon isotope signature (Puga et al., 1992) the rocks making up the sedimentary cover of the BOA are marine in origin, and their foraminifera remains date them probably to the Cretaceous (Tendero et al, this issue).

The metamorphism of the BOA developed during two subduction events (Eo-Alpine and Alpine s.str.) separated by a partial surrection period during which the overlying Soportujar Formation was deposited. This intra-orogenic formation contains some blocks of the underlying and previously eclogitized rocks and has only been affected by late Alpine metamorphism. The igneous rocks in this formation are mainly pyroclastic andesites, probably related genetically to the Eo-Alpine subduction process. Its carbonatic rocks, locally tuffitic, are continental-evaporitic in origin, according to the presence of primary gypsum and metamorphic scapolite, and the evidence of their stable-isotope signature (Puga et al., 1992).

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THE STRUCTURAL SETTING OF EXHUMED GRANULITE AND ECLOGITE FACIES ROCKS IN THE SOUTHERN SESIA ZONE, INTERNAL WESTERN ALPS.

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In the southern Sesia-Lanzo Zone (SLZ) a metamorphic and structural discontinuity separates 'pre-Alpine' granulite and Alpine high-pressure/medium-temperature eclogites from a suite of heterogenous lithologies at greenschist facies grade.

In the Valle dell'Orco transect the *western region* of the SLZ is composed of imbricated slices of albite-chlorite-mica-quartz schists (the 'Gneiss Minuti'), graphitic calc-schists (of probable Piemonte affinity) and minor orthogneisses, metabasites and metacherts that are all characterised by greenschist mineral assemblages. A similar architecture for this domain is described in the region around Lago di Monastero, south of Vall dell'Orco (Spalla et al, 1983), but a simpler, less imbricated, Gneiss Minuti/Piemonte contact is evident further north near Piamprato(pers. obs.). This hydrated *western region* forms a structural footwall to a *central region* which locally preserves granulite facies rocks (Pognante et al, 1988) and eclogite facies rocks. This *central region* is characterised metamorphically by incomplete static to syn-tectonic greenschist recrystallisation and in a structural sense by partial reworking of pre- to early-Alpine fabrics. The *eastern region* of the SLZ exposes well-preserved Eclogitic Mica Schists and associated eclogites and marbles, with little metamorphic or structural re-working in the greenschist facies.

In specific cases for deformed rocks, where the orientation of the strain ellipse can be estimated in the field, and where the flow can locally be shown to approximate progressive simple shear, asymmetries in the rock fabric may be adequate to determine the sense of shear (Hanmer and Passchier, 1991). Such observations have been made at a variety of scales within and between the subunits of the study area in an attempt to understand their relative movement - given that individual sub-units have similar, but slightly disparate, P/T paths (Pognante et al, 1987).

In the *western region* where the dominant foliation dips to the E/SE, final re-crystallisation in the Gneiss Minuti was often static, but in many examples syn-tectonic fabrics are preserved which indicate the local x direction of the strain ellipse. Observation of shear-sense indicators in accompanying xz sections generally indicates top-to-the-W shear. However, important top-to-SE extensional shear bands are observed locally in the graphitic calc-schists (in cases where good stretching lineations are also preserved). The conclusion may be that deformation in the western region was dominantly top-to-W (or foreland propagating) but with a significant component of bulk pure shear at the Km scale; ie the *western region* represents a zone that was deforming, hydrating and thinning during continued late alpine compression.

In the *central region,* high-grade lithologies preserving granulite assemblages have been likened to the IIDK of the northern SLZ (Minnigh, 1977). The incomplete blueschist re-equilibration shown by this sub-unit is thought to be controlled by slow reaction kinetics (due to lower peak temperatures than further east) and resistance to deformation and,in particular, to fluid infiltration (Pognante et al, 1988). Similar slices of high-grade rocks occupy the same tectonic position further north (Williams and Compagnoni, 1983).

In the *eastern region* Eclogitic Mica Schists are well preserved with a relatively consistant foliation (dipping towards the E/SE) that is defined by minerals of, or just later than, the high-pressure metamorphism. In special case studies, where either

(i)the fold axial plane of intrafolial folds can be seen to rotate towards the shear plane (with closure of the interlimb angle), or

(ii)where a population of asymmetric intrafolial folds are not hinge parallel to the local x (but do have consistent vergence), the sense of internal shear-strain is top-to-E. In such situations the probability that the unit containing the fold population is parasitic on a larger structure is small. The conclusion might be that the intrafolial folds are evidence that the hanging-wall to the eclogitic rocks was extensional relative to the Alpine tectonic setting at depth. The internal region of the SLZ zone has experienced a regional tilting about a sub-horizontal axis trending NE-SW (Lanza, 1977). This event apparently occurred later than c.33Ma and may be associated with vertical displacement on the Canavese Line; the application of such a late tilting event on the internal SLZ does not affect the geometrical implications of top-east kinematics in the deep Alpine subduction setting.

In summary: the granulitic and eclogitic rocks of the southern Sesia-Lanzo Zone zone are in the hanging wall of a 5Km-wide zone of shearing characterised by west-directed greenschist facies deformation - a testimony to Eocene-Oligocene hydration and crustal shortening/thinning. Metamorphic retrogression and deformational reworking sharply decreases across the contact with the western and central regions, and then is progressively less pervasive towards the eastern region. An early record of the state of stress in the most internal region suggests that, soon after eclogite conditions, the hanging wall was extensional to the east relative to the underlying Eclogitic Mica Schists.

The observation of continuing foreland-propagating deformation in the footwall, and extensional deformation in the hanging-wall, is in empathy with the geometries predicted by current models that describe the return of pips or sheets of deeply-buried continental units within a subduction zone (Wheeler, 1991). No low-grade facies structures have been observed that relate to the higher-level structural unroofing of the SLZ eclogites.

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THE MACRO- AND MESOSCOPIC TECTONICS OF THE S´ BELLEDONNE MASSIF.-FIRST RESULTS OF A REMAPPING.

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The Belledonne massif as part of the pre-triassic basement of the Western Alps today builds up one external crystalline massif within the helvetic realm of the Alpine chaine. According to MENOT (1987) the Belledonne massif is subdivided in three main lithological and tectonic units which were juxtaposed by late orogenic strike slip movements: - Domain A which means the rameau externe, mainly consisting of lower paleozoic, metapelitic series, - Domain B which means the NE-part of the rameau interne charactrized by gneissic and amphibolitic basement rocks which are intruded by numerous orthogneisses and granites as well as by green and black schists and - Domain C forming the SW part of the rameau interne which is interpreted as a huge nappe pile built up of at least five different units according to their tectono-metamorphic developments to their ages and to their geodynamic significance (MENOT 1988).

The working area is part of Domain C; it is situated N´ to the Romanche valley, in between the La Pra-Livet fault to the W and the mountain range Grand Pic de Belledonne and Grande Lance d´Allemont to the E. At least three units with different compositions as well as different tectonic fabrics and different metamorphic evolutions can be seperated. One unit is characterized by a rock succession of micaceous gneisses, micaschists and amphibolites interlayered with leptinitic gneisses. They form the wall rocks for a lot of siliceous intrusions and for numerous acid as well as basic metavolcanics. According to these lithologies this unit is part of the Riouperoux- and Livet formations (MENOT 1987). Especially in the wall rocks you can identify a polyphase deformation history at refolded folds as well as at folded and refolded cleavage planes. At least three ductile deformations due to crustal shortening develop different types of folds. Rootless, isoclinal folds with a well developped axial plane foliation are scarcely to observe. They are overprinted by ubiquitious monoclinic folds from micro- to macro scale with different interlimb angles reaching from open to close. A second cleavage is related to this folding event. The latest folding is characterized by gentle to open folds with a related crenulation cleavage. The deformation history continues with a lot of normal- and reverse faults which are due to brittle dformations The second unit consists of medium grade metamorphic rocks like migmatic gneisses, micaschists and amphibolites which best fit into the Allemont-Rochetaillee formation. Again these rocks show a polyphase deformation history which is characterized by planar fabrics which developped under ductile as well as brittle conditions. The third unit is built up of various sedimentary rocks which are associated with volcanics. According to lithostratigraphy it may be a N´ outlayer of the Taillefer unit which is wellknown from the area S of the Romanche valley.

Summarizing, the poster will show the different types of deformations within the different main units of the working area.

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GEODYNAMIC EVOLUTION OF THE ALPS ALONG THE EUROPEAN GEOTRAVERSE. PART 1: PENNINE UNITS AND DEEP STRUCTURE

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North of the Insubric line the section of the Central Alps of Eastern Switzerland and northern Italy reveals complex wedging of crustal slices, detached from the European and Apulian plates respectively (e.g. ETH Working Group on deep Seismic Profiling 1991, Schmid et al. 1990). Unit 1 (see figure attached) consists of Austroalpine nappes, representing Apulian upper crust acting as an orogenic lid during Tertiary orogeny. Unit 2, the Pennine nappes, is formed by a viscously refolded stack of predominantly European upper crustal slices (including the Brianconnais ribbon continent), interleaved with a North Penninic ophiolitic suture (2b) and separated from unit 1 by the South Penninic ophiolitic suture (2a). Unit 3, representing Apulian lower crust, underplates a large portion of unit 2, while overriding European lower crust (unit 4). Undoubtedly, rheological stratification plays a key role in understanding such dramatic wedging. Here, however, we put emphasis on the fact that the present day configuration is the result of a longlasting multi-stage evolution starting in the Cretaceous and ending at the Miocene-Pliocene boundary. Note that extremely important movements occurred out of section (W-directed thrusting in the Cretaceous, dextral transpression in the Neogene) which are not discussed here.

<u>Cretaceous orogeny</u>:

Unit 1 acts as an orogenic lid only during the Tertiary orogeny, strictly separated from the Cretaceous orogeny by an important extensional event of Late Cretaceous age (see Froitzheim, part 2), overprinting a preexisting Austroalpine nappe stack. While suturing with the ophiolitic slice 2a is also of Cretaceous age, 2a and unit 1 override Tertiary sediments (Lower Eocene Arblatsch Flysch) over a distance of at least 50km towards the N along a thrust immediately below the ophiolitic slice 2a. Hence Cretaceous suturing of unit 1 with unit 2 is followed by Tertiary thrusting in the immediate footwall of the former Cretaceous suture.

<u>Final collision in the Tertiary</u>:

Deformation and metamorphism (local high p as well as Lepontine amphibolite facies metamorphism) within unit 2 are essentially the result of Tertiary orogeny, resulting in Late Eocene suturing between the Tambo-Suretta pair (Brianconnais) and the high-p Adula unit (European foreland) in a first stage (final collision) followed by a second stage (postcollisional deformation in the sense of additional shortening after complete closure of oceanic domains). Only the topmost tectonic units (possibly the Tambo-Suretta pair and certainly the Avers Bündnerschiefer in the hangingwall of the Suretta nappe) have been previously affected by Cretaceous orogeny. Tentatively it is proposed that suturing and collision during the Late Eocene resulted in high pressure metamorphism in the Adula nappe, followed by amphibolite grade overprint along a single p-T path. Within large parts of the Lepontine area peak temperatures are reached during the post-collisional stage, immediately following collision.

<u>Post-collisional shortening</u>:

Postcollisonal shortening during the Neogene may be conveniently divided into two steps.

<u>Step 1</u> led to complex post-nappe refolding (e.g. Schmid et al. 1990) within unit 2 (i.e. "backfolding" in the roof of the Suretta nappe). This post-nappe refolding is roughly contemporaneous with Lepontine amphibolite grade metamorphism, intrusion of the Bergell batholith and migmatization within the highest grade parts of unit 2 (in particular within the Gruf unit, representing the southern continuation of the Adula unit). Unroofing of anatectic units such as the Gruf unit is associated with crustal melt formation (Novate granite, not depicted in the attached figure for simplicity). Magma ascent within deeper parts of unit 2, not exposed at the earth's surface exept in the Bergell area, is considered to be an important heat source for high grade Lepontine metamorphism immediately to the N of the Insubric line.

The initial stages of the very substantial uplift of the Bergell-Gruf block (about 20km at its southern margin and more than 10km at its nothern margin) are associated with the syntectonic intrusion of the Bergell batholith (30-32m.a.) in a transpressive scenario. However, the orogenic lid (unit1) is differentially uplifted by only 7km across the Late Oligocene-Early Miocene Engadine line. This suggests that large portions of the differentially uplifted volume (vertical extrusion) are deflected into horizontal "intrusion" of the Tambo-Suretta-pair leading to post-nappe refolding of the Schams nappes (Merle and Guillier 1989). Only at a later stage during this step 1 does the Engadine line accommodate additional differential uplift in respect to tectonic units further to the N. Differential uplift in repect to unit 3 occurs along the Insubric line, appearing as a steeply inclined backthrust. The angle of dip of this backthrust is given by surface data and is in agreement with very prominent reflectors parallel to the projected dip of these mylonites, but located to the N of the Insubric mylonites.

Step 2: While the Insubric backthrust formed during step 1, crustal wedging of unit 3 between units 2 and 4 must have occurred at a later stage (during the Middle and Late Miocene). This is indicated by 3 independent lines of evidence: (1) Wedge 3 would have prevented the ascent of the Bergell intrusion from a mantle source, (2) the geometry of wedge 3 is incompatible with differential uplift of the Bergell-Gruf block, and (3) post-Middle Miocene shortening within the Southern Alps (Schönborn, part 3) asks for an appropriate volume of basement belonging to unit 3, only to be found below unit 2. Backfolding within the northern steep belt of unit 2, affecting the Gotthard and Lucomagno units, is probably contemporaneous with this step 2 of post-collisional shortening and results in uplift of the external massifs in the form of a pop-up in front of wedge 3.

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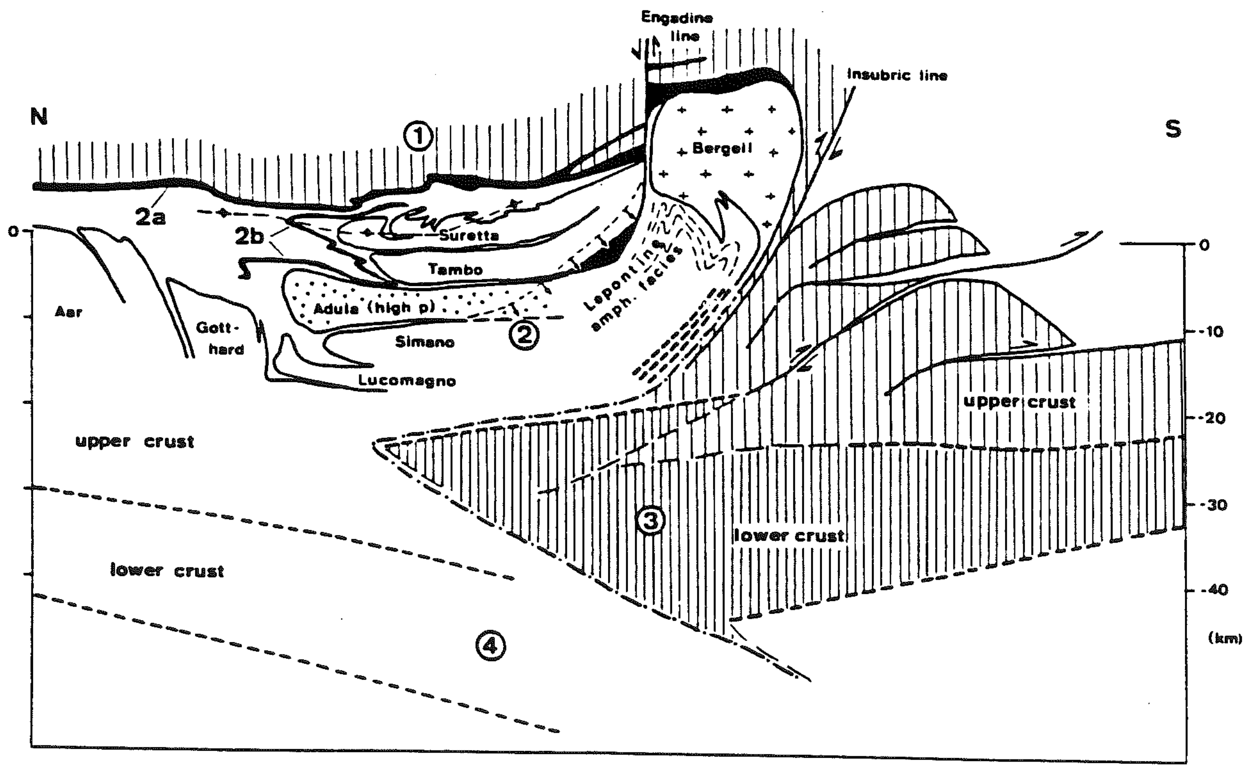

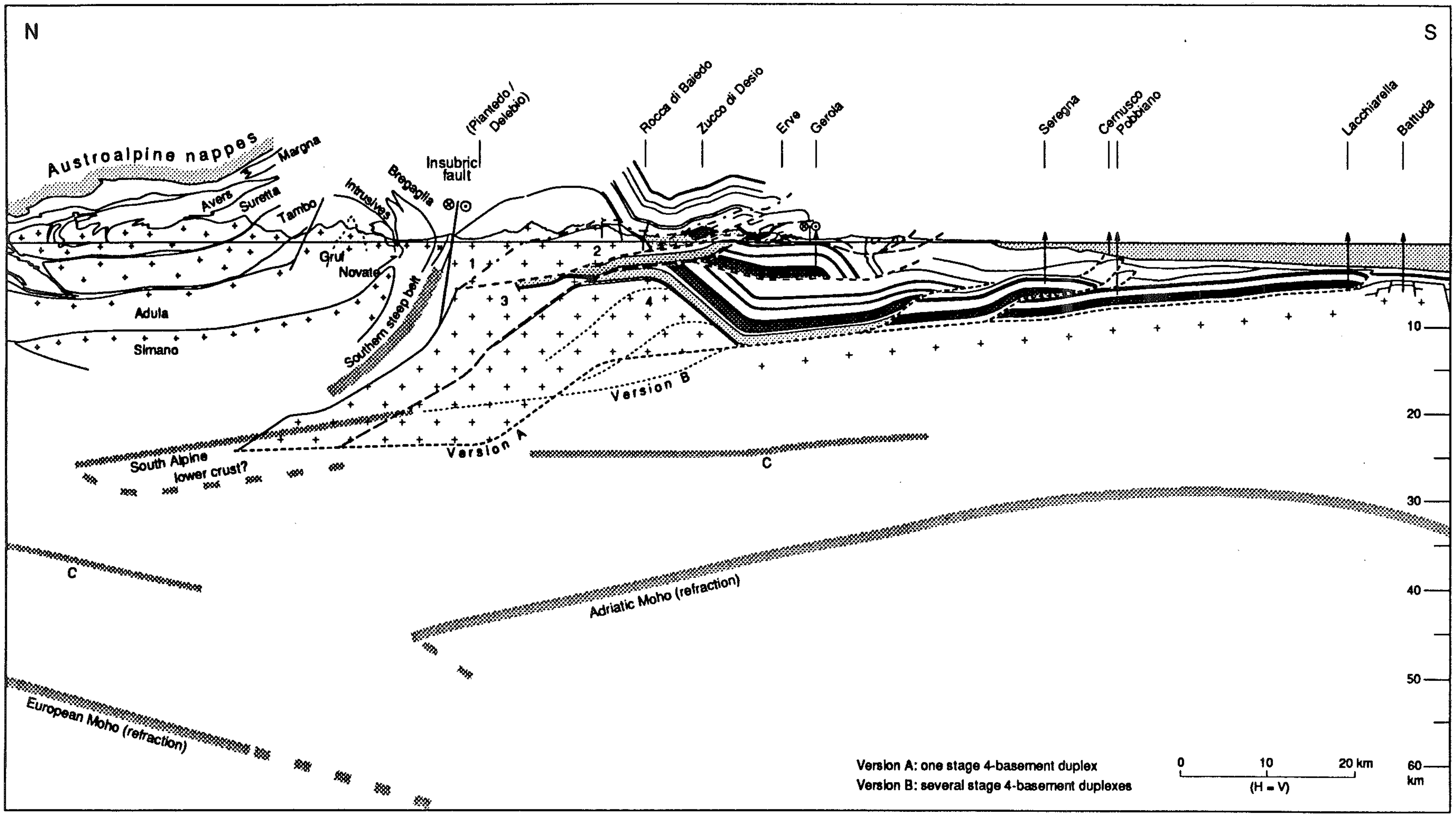

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Géologie Alpine. Série spéciale Résumés de colloques, n°1, 1992

GEODYNAMIC EVOLUTION OF THE ALPS ALONG THE EUROPEAN GEOTRAVERSE. PART 3: THE SOUTHERN ALPS

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The central Southern Alps are a mainly brittely deformed south verging fold-and-thrust belt. At least three thrust sheets are piled above each other, each consisting of a crystalline basement part in the north and a sedimentary part farther south.

The area of todays Southern Alps has been affected by transtensional faulting during the Permian and by extensional faulting during the early Mesozoic, preceding the opening of the Tethys. During Alpine thrusting the Permian troughs were scooped out below the basement thrusts or they were imbricated by numerous small thrusts that replaced the large basement thrusts. The Permian faults were reactivated as strike-slip faults or as thrusts. Inherited Mesozoic faults approximately parallel to the transport direction lead to distinct transverse zones and lateral ramps during Alpine thrusting. Inherited structures oblique to the transport direction triggered Alpine thrusting, and ramps in different thrust sheets above each other developed along the same lineaments. The inherited, oblique faults were linked by Alpine transverse structures. This way several triangular tips in map-view formed during thrusting. They acted as indenters, deflected the transport directions in their front and lead to rotation of blocks, lateral escape, lateral transtension and transpression.

Although the thrust sheets are not cylindrical but segmented by transverse zones, they can be correlated laterally from the Adamello area in the east to at least Lake Como in the west with the aid of balanced cross-sections (Geosec-20). These sections are all quantitatively compatible with each other and retrodeformable during each of the four steps of thrusting. This was achieved by complete foreward modelling constrained by the postulate of lateral continuity of shortening. The cross-sections were linked with map-view considerations, and a stepwise retrodeformed block mosaic revealed the amount of transport in the third dimension (E-W).

The existence of a deep seated thrust sheet (Milan belt) below the Po plain was shown by industrial seismic surveys (Pieri and Groppi, 1981). These data can be extrapolated to the north with the help of the NFP-20 results. Quantification of shallow thrusting enabled the localization of the basement-sediment contact within the deep seated thrust sheet and gave constraints concerning the overall geometry of this thrust sheet (Schönborn, in press).

Two deformational phases can be distinguished in the central Southern Alps. The structures of the first are sealed by the Adamello intrusions (Late Eocene to middle Oligocene), the structures of the second cut the pluton. Sedimentological and radiometric evidence suggests the first phase to be rather Late Cretaceous in age than Paleocene-early Eocene. Sedimentological, seismic and borehole data document the second phase to be Middle-Late Miocene (Burdigalian to Tortonian, sealed by the Messinian). In the central Southern Alps no evidence has been found for Eocene-Oligocene compression till now. Late Oligocene to early Miocene (Aquitanian) deformation seems to be limited to the area near the Insubric lineament.

Three major thrust sheets can be distinguished in the Lombardic Alps. The uppermost exposed (now eroded allochthonous units farther up are likely) was emplaced during the pre-Adamello phase, the lowermost (3 and 4 in the figure, Milan belt) during the post-Adamello phase (Miocene). Thrust sheet 2 in between is essentially post-Adamello, however, it seems to incorporate also a pre-Adamello portion that subsequently was reactivated. The youngest deformation is related to a large out-of-sequence thrust system cutting the entire nappe pile. It is also sealed by Messinian deposits.

The shortening in the model is between 80 km in the west and 110 km in the east. Some 25 km of these numbers can uniformly be attributed to pre-Adamello thrusting, the remaining 55 (west) to 85 km (east) to post-Adamello deformation. This suggests Miocene clockwise rotation of both the thrust sheets and the Tonale segment of the Insubric line which was transported piggy-back like the Adamello pluton. Retrodeformation places the Tonale segment into a position adjacent to the Pustertal segment of the Insubric line during the time of their activity (Oligocene-Aquitanian), before they were dissected by the Giudicarie line. The Miocene shortening obtained in the model is compatible with and supported by the findings of the deep seismic survey NFP-20 indicating approximately the border between the Central and the Southern Alps.

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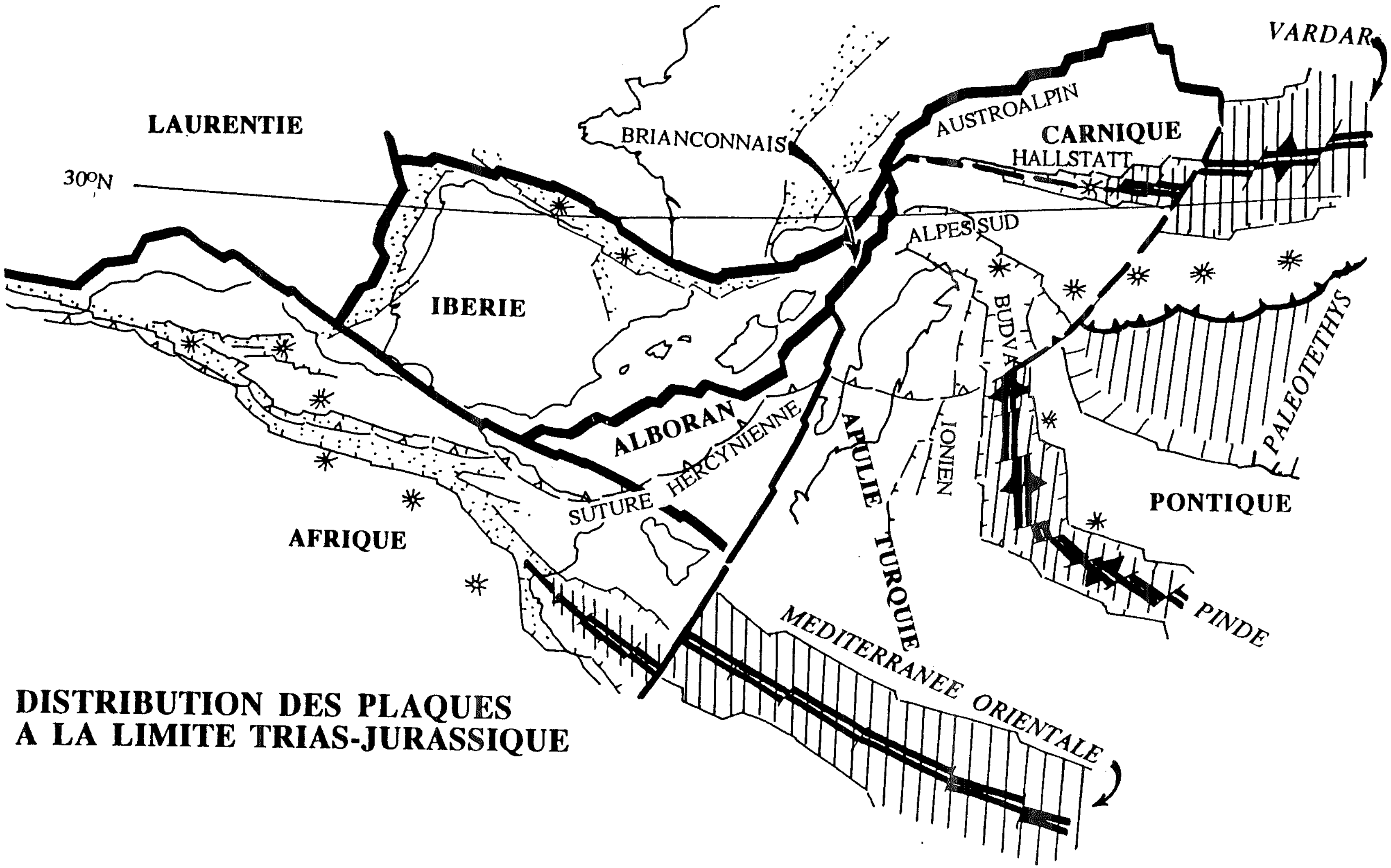

DISTRIBUTION DES PLAQUES A LA LIMITE TRIAS-JURASSIQUE

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LE BRIANÇONNAIS, TERRAIN EXOTIQUE DANS LES ALPES

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Le domaine briançonnais est un terrain exotique ayant été séparé de la marge européenne par la dérive de la plaque ibérique au Crétacé. Le long de la bordure nord de cette plaque des domaines océaniques vont apparaitre, le golfe de Gascogne à l'Ouest et le Valaisan à l'Est. La fracturation accompagnant l'ouverture de ces océans se marque par la présence de brèches et de discordance à partir de l'Oxfordien.

La péninsule briançonnaise va venir s'insérer dans le domaine océanique piémontais préexistant, déterminant deux zones de sutures ophiolitiques dans les Alpes occidentales:

- la zone de suture piémontaise est affectée par un métamorphisme HP/BT à partir du Crétacé inférieur et le bord oriental du Briançonnais est impliqué dans cette suture, on peut donc voir une relation directe entre l'ouverture du Valaisan et la fermeture du Piémontais. La suture piémontaise est une zone complexe de collision oblique où les unités continentales et océaniques sont imbriquées les unes dans les autres.
- la suture Valaisanne diffère dans sa partie occidentale (Valaisan s.str.) et sa partie orientale (Bündnerschiefer). A l'Ouest la suture comprend essentiellement des éléments de l'océan valaisan crétacé, à l'Est ces éléments crétacés sont dominés par des éléments d'océan et de pied de marge piémontais piégés au Nord de l'ouverture crétacée.

La subduction du Valaisan, du Crétacé supérieur à l'Eocène, se fait de façon classique et non décrochante comme celle du Piémontais. Cette subduction sera donc accompagnée d'un volcanisme andésitique de type arc que l'on retrouve sous forme de resédiments dans certains flyschs et sous forme de dykes recoupant les zones internes.

Les reconstructions proposées reposent sur plusieurs types d'observations, il y a tout d'abord celles indispensables effectuées sur le terrain par de nombreuses générations de géologues et les observations indirectes concernant la distribution des masses continentales en profondeur. La sismique profonde et la tomographie permettent de préciser ces structures profondes, cependant elles ne peuvent être comprises que si leur histoire antérieure est connue. Les conditions de départ, c'est à dire la période de rifting, jouent un grand rôle dans la compréhension du futur orogène. Pour connaître ces conditions de départ on doit pouvoir fixer les limites de plaques avec une certaine précision ce qui peut être obtenu grâce aux données géophysiques. Ainsi les données récentes de tomographie sismique apparaissent comme essentielles puisqu'elles permettent de fixer ces limites à un niveau lithosphérique et non seulement crustal.

D'autre part la géométrie des marges continentales, issues du rifting liguro-piémontais ou valaisan, permet d'expliquer la distribution non uniforme des empilements de nappes ainsi que leur nature; si une approche structurale cylindriste des Alpes a une certaine valeur, elle est à éviter lorsque l'on approche des problèmes paléogéographiques.

THE DEFORMATIONS OF JURASSIC ROCKS AND THEIR QUANTIFICATIONS WITH THE MEANS OF BALANCED CROSS SECTIONS IN THE BOURG D'OISANS AREA, SW ' BELLEDONNE MASSIF

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The working area is situated in the Bassin de Bourg d' Oisans. This basin is characterized by an alteration of finegrained pelitic and coarser grained psammitic sediments, jurassic in age. It is bound by crystalline basement complexes, the Belledonne massif to the W and the Rousse massifs to the E.These sediments show just an anchimetamorphic imprint combined with deformations which developed under conditions in the brittle- ductile transition field, clearly Alpine in age.

The oldest fabric is the sedimentary bedding (ss), which is the most important reference for the comparison of the deformations in different outcrops. The preservation of this bedding depends more on the initial lithological development of the sediments and their thickness than on the later metamorphic and tectonic overprinting. In more variegated lithologies which are characterized by very different grainsizes and different thicknesses of the layers, sedimentary bedding is the most important planar system. Sedimentary markers like graded bedding are abundant. In some other outcrops this bedding can just be observed as a weak lamination of different colours, composed of dark, very finegrained layers and somewhat lighter, somewhat coarser grained planes. Here the younger foliation is the best developed planar structure.

This bedding is folded from mm-scale to map scale. The flexural slip folds are generelly isopach, open with interlimb angles of about 90°, mostly upright to slightly SE verging, with orthorhombic or monoclinic symmetry. Contemporaneously a related axial plane cleavage developed, steeply inclined to the NW with an NE-SW strike direction. Due to the lithologies one can observe the refraction of the cleavage planes. In highly anisotropic rocks like the extremely finegrained liassic blackshales no sedimentary bedding can be observed at all. In these rocks a second cleavage system can be identified with the same steep inclination but with a slightly different WNW strike direction. The angle between both systems is about 20°. This is more interpreted as one conjugate system - for example described by WATKINSON & COBBOLD (1981) - than in the sense of GRATIER & VIALON (1975) who observed two distinct folding phases in these rocks.

In the same structural level developed discrete faults up to some ten meters in thickness with a hanging wall movement to the SE. All these structures are due to crustal shortening during the Alpine orogeny. It is now very important to quantify these Alpine deformations to determine these effects within the Variscan basement.

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TECTONIQUE DES ALPES DE SUISSE CENTRALE: CHRONOLOGIE DES EVENEMENTS STRUCTURAUX ET THERMIQUES

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L'OROGENESE CRETACEE (phase éoalpine).

Des vestiges d'un métamorphisme de haute pression éoalpin, daté du Crétacé supérieur (110-80 Ma) caractérisent les nappes du Pennique moyen et supérieur. Un étirement synmétamorphique parallèle à des chevauchements vers l'W s'observe dans la nappe d'Adula (LÖW , 1987) et la Zone Zermatt-Saas au Täschtal (STECK, 1989). Il est de même orientation que des structures de même type et âge dans les Alpes autrichiennes (RATSCHBACHER et al. 1989). L'absence de paragenèses indiquant un rééquilibrage du gradient thermique après la subduction montrent que ces roches sont remontées très rapidement vers la surface avant le métamorphisme de l'orogenèse tertiaire.

L'OROGENESE TERTIAIRE (phases méso- et néoalpines).

LA PHASE MESOALPINE (40 - 30 Ma).

- La mise en place des nappes: Le sous-charriage de la croûte européenne sous la croûte adriatique provoque un métamorphisme régional du type disthène-sillimanite (NIGGLI & NIGGLI,1965, gradient thérmique moyen de 25°C/km, FRANK, 1983, HAMMERSCHLAG, 1985), dont la culmination thermique est atteinte tout d'abord au S (nappes du Mont Rose, de Siviez-Mischabel et de Suretta) à la limite Eocène-Oligocène (~38 Ma) et ensuite au N (massif du Gothard et nappe de Glaris, vers 35 - 30 Ma) (HUNZIKER, 1970, HUNZIKER et al. 1986). Les plis de gneiss et les nappes-plis se forment dans une zone de cisaillement ductile d'une épaisseur de 10-20 km située sous le "traîneau écraseur rigide" de TERMIER (1903), formé par les nappes penniques supérieures et austroalpines, d'une épaisseur supérieure à 10 km. Dans les nappes-plis, à déformation ductile, se sont créés deux schistosités et un étirement X_I parallèle au transport des nappes vers le NW. Ils sont caractérisés par une cristallisation syncinématique prograde du métamorphisme tertiaire (zonage prograde des minéraux syncinématiques, HAMMERSCHLAG, 1985). Les isogrades du métamorphisme tertiaire sont à la fois discordantes au limites des nappes et transportées et plissées (voire réplique de MILNES, 1975 à STRECKEISEN et al. 1974). Dans les Alpes méridionales, cette phase mésoalpine se manifeste par un soulèvement accéléré depuis environ 50 Ma (HURFORD, 1986), probablement provoqué par la remontée vers le N de l'écaille de croûte inféreure de la zone d'Ivrée (GIESE, 1968).

- Une première génération de plis de vergence S à SW: Dans le domaine des gneiss lépontins, l'empilement de nappes est déformé pendant la culmination du métamorphisme par des plis de vergence S à SW (plis de Cima Lunga (s = synclinal), Verzasca (a = anticlinale), Maggia (s), Salmone (a) et Wandfluhhorn (s, en partie en position d'antiforme). L'isograde An 50 des amphibolites enveloppe le synclinale de la Maggia. Cette relation géométrique suggère une diffusion thérmique élevée dans cette zone à schistosités subverticales du pli (WENK & KELLER, 1969, WENK & WENK, 1984).

- La zone de cisaillement ductile Rhône - Simplon: Un cisaillement ductile dextre de l'empilement des nappes, parallèle à une seconde linéation d'étirement X_{II} orientée vers le SW crée une zone de cisaillement ductile d'une épaisseur finale de 10 km. Il s'agit des premières structures de cette zone, résultant de mouvements de transpression dextre entre les blocs adriatiques et européens (STECK, 1980,1990, MERLE et al. 1989). Cette zone de cisaillement dextre s'enracine entre Domodossola et Locarno dans la zone à sillimanite du métamorphisme tertiaire. Près de Locarno elle est tranchée par la jeune ligne du Tonale (phase néoalpine).

Lors de la phase mésoalpine les unités les plus élevées et les plus internes (Sesia, Mont Rose, Siviez-Mischabel, Adula, Suretta) subissent un refroidissement suite au soulèvement et à l'érosion (culmination du métamorphisme à 38 Ma, Rb-Sr- micas blancs, HUNZIKER, 1969).

LE MAGMATISME CALCOALCALIN DE LA LIGNE INSUBRIENNE.

A l'Oligocène, une phase d'extension affecte l'ensemble du continent européen avec l'ouverture des fossés rhénans, de la Saône et de Limagnes (BERGERAT, 1987). Dans les Alpes, des fissures suivies d'intrusions de magmas calcoalcalins d'origine mantellique (Biella, Bergell, etc., datées de 32 à 29 Ma), sont concentrées à proximité de la ligne insubrienne. Des pégmatites à muscovite, biotite et grenat des Centovalli, provenant de fluides métamorphiques, sont datées de 26 Ma (U-Pb, Monazite, SCHÄRER, communication orale).

LA PHASE NEOALPINE (30 - 0 Ma).

La phase néoalpine est caractérisée par des plis de vergence S et SE et la continuation des mouvements décrochants dextres dans les Alpes penniques (phase insubrienne d'ARGAND, 1916) et la formation de nappes de vergence S dans les Alpes méridionales, tandis que simultanément au N le chevauchement vers le N du front helvétique et des Préalpes continue. L'intrusion du Bergell commence à être plissée, soulevée et erodée immédiatement après sa mise en place. Le décrochement dextre de la ligne du Tonale crée une queue d'extension des tonalites d'environ 50 km (HEITZMANN, 1987). La zone de cisaillement ductile du Simplon est réactivée et se déplace dans les parties externes, plus profondes et restées plus chaudes (faciès amphibolite-schistes verts, ligne du Simplon du modèle de MANCKTELOW, 1985, 1990). Un rapide refroidissement des Alpes centrales entre 26 et 19 Ma (HURFORD, 1986, HUNZIKER et al. 1992, sous presse) est expliqué par le soulèvement, la dénudation tectonique et l'érosion en relation avec les mouvements dextres et en faille normale de la zone de cisaillement du Rhône-Simplon et les décrochements dextres et les rétrocharriages de la ligne Insubrienne. Le refroidissement sous 300°C des roches (ages Rb-Sr biotite) se propage progressivement entre 30 et 12 Ma du Bergell au Simplon (JÄGER et al. 1967). Ainsi se crée dans la grande zone de transpression dextre des Alpes centrales une structure de "pull apart" avec la dépression Rawil-Valpelline à l'W et le massif de l'Aar et le grand dôme des gneiss lépontins à l'E du Simplon (SCHMID et al,1989, STECK, 1990). Les plis de vergence S du Glishorn et de Berisal déforment tardivement le contact helvétique - pennique et la surface des massifs cristallins externes (STECK et al. 1979). Sur la carte des âges Rb-Sr biotites, ces plis déforment d'une manière évidente l'isochrône de 12 Ma. D'autre part, ces plis sont coupés par la ligne discrète du Rhône - Simplon (ligne du Simplon, BEARTH, 1956), dont l'isograde chlorite-biotite dans les mylonites est datée de 11 Ma. Le serrage des plis du Glishorn et de Berisal continue et l'accident du Simplon est à son tour plissé (STECK, 1984, MANCKTELOW, 1990). Ainsi dans la région du Simplon, on observe, entre environ 35 et 11 Ma (ou moins), l'interférence d'une zone de cisaillement dextre, tout dabord large puis de plus en plus discrète, et une succession de plis de vergence S à SE. D'après les âges traces de fission de l'apatite (SOOM, 1990), des mouvements de soulèvement du compartiment N (massifs du Simplon, de l'Aar, zone du Rawil, massifs du Mont Blanc et des Aiguilles Rouges) ont réactivé la ligne Rhône-Simplon depuis 3 Ma. Des mouvements de soulèvement de 1,5 mm/a, les plus élevés des Alpes suisses (WIGET & GUBLER, 1988) et une activité sismique élevée, avec un mécanisme au foyer indicant des mouvements décrochants dextres (PAVONI, 1980) caractérisent actuellement la Zone Brig-Sierre.

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DISCOVERY OF CRETACEOUS MARINE FAUNA IN THE METASEDIMENTARY COVER OF THE BETIC OPHIOLITICASSOCIATION (NEVADO-FILABRIDE COMPLEX, BETIC CORDILLERA, SE SPAIN). PRELIMINARY PALAEOGEOGRAPHIC AND PALAEOTECTONIC IMPLICATIONS.

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One of the most important problems that the geology of the Betic Cordillera poses concerns the palaeogeographical evolution of the Internal Zones from the Jurassic to the Oligocene. The major gap in the knowledge of the geological history of the westernmost European Alpine chain is essentially due to an absence of biostratigraphic data concerning this interval of geological time. Most authors have considered, following Fallot (1948), that the lack of post-Triassic sediments in the Nevado-Filabride and Alpujarride complexes is a real fact, and that this can be put down to a generalized emersion at the end of the Triassic, and that this wide area has remained a continent since the beginning of the Jurassic. Nevertheless, the Betic Ophiolitic Association (BOA) (Puga, 1990 and references therein), the westernmost outcrop of the Mediterranean ophiolite belt, has been dated as having developed from the Triassic-Jurassic boundary (Puga et al., 1991) until the Upper Jurassic (Hebeda et al., 1980; Portugal et al., 1988; Puga et al., 1991). Furthermore, the supra-ophiolitic metasedimentary cover, well exposed in many Nevado-Filabride ophiolitic outcrops, and generally composed (from the bottom to top) of the following units: 1) thin bedded quartzites, 2) alternating calcschists and pelitic-quartzitic marbles, 3) black schists and quartzites, 4) thin to thick bedded upper quartzitic marbles, and 5) green amphibole-bearing micaschists to calcschists, has some microscopic ankeritic spots within its Unit 2, which by their shape and size, closely resemble mid-cretaceous planktonic foraminifera. Specifically, we have noted the presence of a section very similar to the profile of a planktonic foraminifera characteristic of the Middle-Turonian (Helvetica, see figure 1). Similar ankeritic objects have also been interpreted as being planktonic foraminifera, and have been used, together with lithostratigraphy and correlation with nonmetamorphic successions, for the chronostratigraphy of metamorphic "schistes lustrés" type formations (Marthaler, 1981; Crespo, 1984; Lemoine et al., 1984; Marthaler, 1984; Deville, 1986; Marthaler et al., 1986; Fudral et al., 1987; Lagabrielle, 1987). The discovery ot foraminifera in the sedimentary ophiolitic cover forces us to reconsider the problem of the age and depositional environment of the covers belonging to the different units of the Nevado-Filabride complex, which has been considered to be essentially Triassic and continental-evaporitic (Gomez-Pugnaire and Camara, 1990; De Jong and Bakker, 1991, and references therein) or else marine throughout the Mesozoic, evolving to continental-evaporitic in the overlying intraorogenic Soportujar Formation, radiometrically dated as Paleocene-Eocene (Puga et al., 1984; Puga et al., 1988 and Puga et al., 1992). The geochronological characterization of the unit 2 as mid-cretaceous and the complete lithostratigraphical succession allow us to make the correlation with ophiolitic covers in Penninic units .

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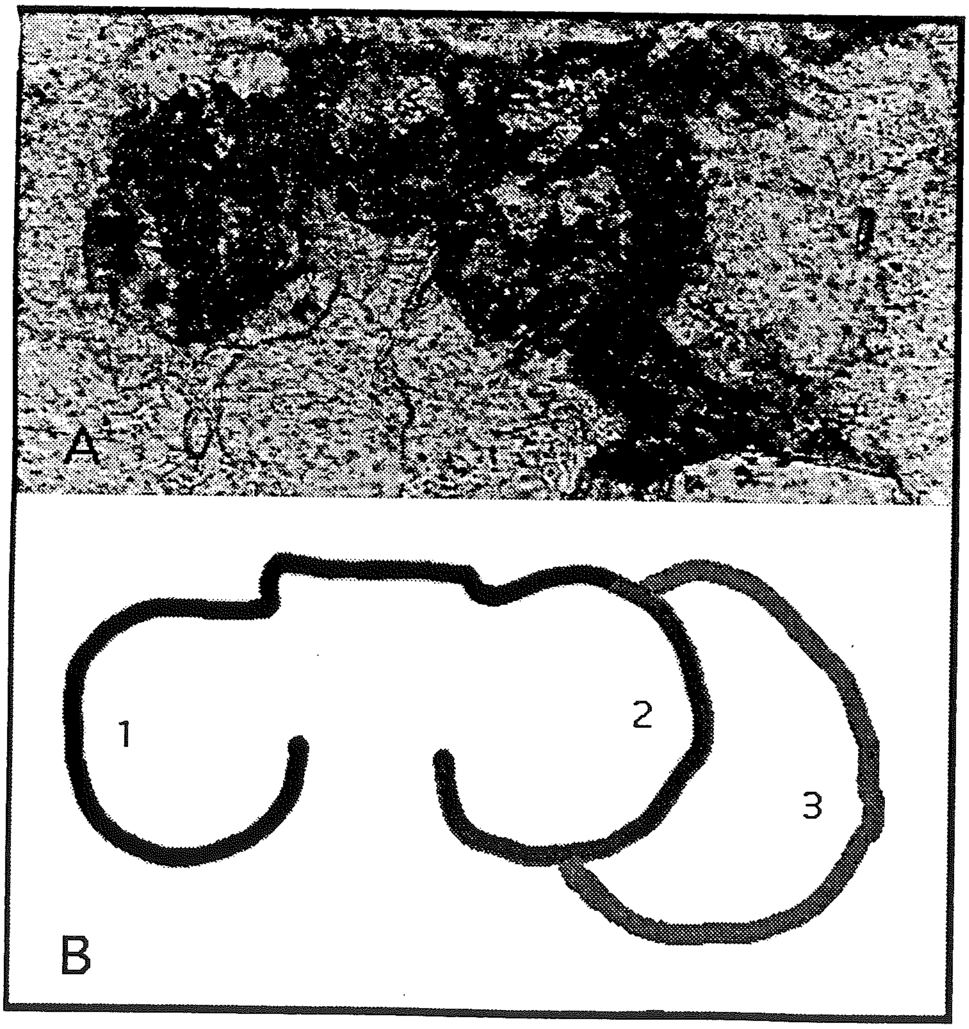

Figure Caption

Figure I. A: Possible Helvetoglobotruncana Helvetica, Middle-Turonian. Size 0.3 mm. One polarized light. B: 1) (black), characteristic profile of Helvetica ; 2) (dark grey), wall preserving the original thickness ; 3) (light grey), last lodge with two polarized light.

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LES CALCSCHISTES PIEMONTAIS A L'OUEST DU MONT VISO : ESQUISSE STRUCTURALE

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A l'Ouest du Mont Viso, les hautes vallées de l'Ubaye, du Cristillan, du Queyras et de la Cerveyrette offrent un paysage typique de "Schistes lustrés" piémontais : un énorme volume de métasédiments monotones dans lequel sont dispersées des masses hétéroclites d'ophiolites et de dolomies ; l'ensemble, très tectonisé, évoque certaines zones de mélanges, d'où l'hypothèse que pourrait être enregistré ici un stade précoce de la fermeture téthysienne ; les relevés cartographiques récents ou en cours (feuilles Aiguille de Chambeyron, Briançon, Aiguilles, Col Saint-Martin) conduisent au contraire à souligner l'importance des structures nées durant la collision alpine, sous la forme de nappes très repliées sur elles-mêmes.

I. - Deux types de nappes sont étroitement imbriquées : (1) des unités de marge, provenant du domaine piémontais (anciennement "prépiémontais"), interprété comme la partie distale de la marge Nord-téthysienne et (2) des unités à ophiolites, issues du bassin océanique ligure (ou liguro-piémontais) de la Téthys. Ces dernières, bien plus développées que les unités de marge, constituent l'essentiel de l'édifice.

II.- Le matériel des unités de marge. Lors du charriage initial, le décollement est intervenu suivant les évaporites du Carnien ; la série-type débute par plusieurs centaines de mètres de dolomies noriennes (Hauptdolomit) que surmontent des dépôts de plus en plus marins, datés du Rhétien puis du Lias ; viendraient ensuite différents termes attribués au reste du Jurassique puis au Crétacé. Des structures faillées en extension, localement conservées, des variations latérales de faciès, l'enchaînement des types de dépôt, illustrent un rifting débutant au Lias inférieur et s'achevant à la fin du Dogger par une subsidence rapide, conformément au schéma évolutif reconnu pour l'ensemble de la marge.

III.- Le matériel des unités océaniques. Ces nappes, essentiellement constituées de sédiments, ont été le plus souvent décollées suivant la limite socle-couverture, localement à l'intérieur même du socle.

- *le socle océanique* est principalement formé de péridotites mantellaires à structures de tectonites, entièrement serpentinisées ; des intrusions basiques (surtout des gabbros magnésiens) présentent des formes et dimensions variées, mais leur volume total reste modeste. Au toit de ce socle une surface d'érosion sous-marine est plus ou moins tapissée de brèches sédimentaires variées ; les plus abondantes remanient des péridotites serpentinisées (ophicalcites, épaisses de quelques dizaines de mètres, au plus, mais d'une grande extension latérale). Très localement, des coulées sous-marines de basaltes tholéiitiques surmontent ces brèches ; leur épaisseur caractéristique n'est que de quelques dizaines de mètres, exceptionnellement quelques centaines de mètres.

- *les sédiments pélagiques* recouvrent le complexe bréchique et ses basaltes ou même, directement, le socle ultramafique et ses intrusions basiques. Les dépôts débutent par des radiolarites lenticulaires, datées en deux endroits, de la fin du Dogger et du début du Malm. Les termes suivants de la série ne sont identifiés qu'au vu de leur faciès : calcaires pélagiques du Malm, alternances argilo-calcaires du Crétacé inférieur, "black shales" médio-crétacé, marnes du Crétacé supérieur. Cette série présente d'importantes variations latérales de faciès (y compris le développement local de faciès flysch), interprétées en terme de resédimentation en milieu abyssal. Surtout, on peut y trouver, remaniées sous des formes variées, les différentes composantes du socle océanique sous-jacent : niveaux clastiques ou olistolites, parfois géants. Localement, ce détritisme apparaît lié à des mouvements de blocs faillés kilométriques, en extension. Le détritisme ophiolitique concerne surtout les termes du Crétacé inférieur et moyen, parfois du Malm ; il ne concerne pas les marnes du Crétacé supérieur. Tout suggère ici un détritisme associé à l'expansion de l'océan ligure, entre son ouverture initiale, vers 160 Ma et le milieu du Crétacé (vers 90- 100 Ma ?). Les olistolites associés participent à l'allure chaotique de certains paysages de Schistes lustrés.

IV.- L'édifice de nappes initial. Dans les limites de la région étudiée, on reconstitue une nappe de marge portant une ou plusieurs nappes océaniques. Le tout repose sur les nappes briançonnaises.
Les nappes océaniques, pelliculaires, ont une grande extension latérale (plusieurs dizaines de km) en regard de leur épaisseur (quelques centaines de mètres). Leur niveau de décollement basal est une shear zone chlorito-

talqueuse dérivant des brèches sédimentaires à l'interface socle océanique-sédiments pélagiques, particulièrement les ophicalcites. Quelques témoins de ce socle, charriés avec la couverture, dérogent à cette règle : ils pourraient dériver de reliefs, tronqués. Au total, les nappes d'origine océanique sont surtout constituées de sédiments pélagiques, plus particulièrement crétacés : très replissés, ils sont à l'origine de la plus grande masse des actuels "Schistes lustrés".

V.- Les mégaboudins. Les fragments de socle charriés avec la série sédimentaire océanique ont subi un boudinage à l'échelle régionale : en témoignent les massifs hectométriques-kilométriques de péridotites, gabbros et/ou basaltes peu déformés qui semblent parsemer au hasard la région mais jalonnent en fait la base des nappes océaniques (et sont bien distincts des olistolites). Il en est de même pour les dolomies noriennes à la base de la nappe issue du pied de la marge. Ce méga-boudinage des ophiolites et des dolomies est intervenu tôt durant la collision, probablement durant la première phase de plissement intrafoliaire affectant l'ensemble de la zone piémontaise. On peut montrer localement que ce boudinage a été guidé par des fractures téthysiennes (marge et océan).

VI.- Les plis intrafoliaires initiaux. Là où existent de bon repères lithostratigraphiques et des critères de polarité (par exemple les marbres du Malm), la cartographie de détail fait apparaître de multiples répétitions de séries dans les flancs de plis isoclinaux à charnières effilées dont l'amplitude dépasse la dizaine de km. Il leur correspondrait la première foliation régionale (S1), associée au métamorphisme HP-BT dans le faciès Schistes bleus (travaux en cours).

VII.- Les replissements successifs. A toutes les échelles, l'analyse fait ressortir une accumulation de plis polyphasés déformant les structures précédentes :
- des plis P2 transverses à la chaîne (proches d'E-W), dont l'axe est souligné par une forte linéation d'étirement. Le style dominant est celui de chevrons fermés, pluri-kilométriques, couchés vers le Nord ; il leur correspondrait le passage à un métamorphisme dans le faciès Schistes verts.
- des plis P3 quasi-coaxiaux des précédents mais déversés vers le Sud ; ils présentent des charnières arrondies. La déformation associée est dominée par un cisaillement subhorizontal à vergence sud qui localement s'exprime par des chevauchements kilométriques vers le Sud.
- des plis P4 subméridiens, déversés vers l'Est, à charnières également arrondies. La déformation est dominée par un cisaillement horizontal à vergence Est. Localement se développent des chevauchements vers l'Est (rétrochevauchements) qui sont les seuls qui soient vraiment visibles dans le paysage (troncatures) ; c'est lors de ce dernier plissement que les couches acquièrent leur pendage quasi-uniforme vers l'Ouest, manifestation la plus visible des classiques rétrodéversements.

VIII.- La fracturation tardi-orogénique traduit surtout une extension horizontale multi-directionnelle. Elle ajoute à la complexité structurale en fragmentant les flancs de plis.

En conclusion, dans cette partie externe de la zone piémontaise, la structure complexe actuelle résulte principalement du plissement répété d'une pile de nappes pelliculaires ; chaque génération de pli est géométriquement et cinématiquement cohérente ; *cette structure illustre avant tout les effets de la collision alpine*.
D'autres causes de complexité sont, à l'intérieur de ces nappes (1) les variations latérales au sein des séries de marge et d'océan et (2) le détritisme ophiolitique, localement chaotique. Une cause supplémentaire réside dans le boudinage régional de la semelle ophiolitique ou dolomitique des nappes, rigide dans les conditions du métamorphisme Schistes-bleus.
Reste à discerner dans les charriages pelliculaires initiaux ainsi reconstitués ce qui pourrait résulter d'un décollement intra-océanique de type *obduction*, ce qui pourrait illustrer le fonctionnement d'un *prisme d'accrétion* ou encore ce qui pourrait marquer le début de la *collision alpine* proprement dite.

PERMIAN MAGMATISM IN THE BRIANCONNAIS DOMAIN (WESTERN ALPS): NEW GEOCHEMICAL DATA AND GEODYNAMIC IMPLICATIONS.

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During Carboniferous and Permian times, the Hercynian in Europe was marked by an important maqmatic activity, especially in the Western Alps from the Ligurian or the Mediterranean Provençal zone to the Swiss Valais. Several authors still have a tendancy fo confuse the old massifs of the external Alps, which are included in the Variscan oroaenic event in Europe, with those of the internal Alps, including the Pennic Alps, which althouqh they have affinities with Gondwanaland, should most probably be included in the intermediate Insubric Plate. This mix-up is due in part to the onset of the Aloine orogeny which has brouaht these massifs In close contact.

It has been shown (Greber, 1965; Cortesoano et al., 1984, 1986; Cabella et al., 1988) that the evolution during Permo-Carboniferous times was much different on either side of the Frontal Pennine Thrust (FPT). Both lower Palaeozoic volcano-sedimentary formations and Permo-Carboniferous magmatism are usually present in the External Crystalline Massifs (ECM's) and these have been largely affected by the Variscan orogeny (Vivier et al., 1987; Laurent, 1992). The earliest Carboniferous basins in the ECM's were lower Stephanian and especially middle Stephanian in age (Greber, 1965). However, there is to date, no radiometric evidence for the existence of lower Palaeozoic formations (excepted perhaps some Upper Cambrian granophyric plutons, Guillot et al., 1991) and no convincing arguments can be made for a Variscan orogenic overprint in the Briançonnais domain. In addition, the Carboniferous sedimentary succession was deposited between the Namurian and the end of the lower Stephanian, starting some 20 to 25 Ma before the beqinning of the Carboniferous sedimentation in the External Zones. The Permo-Carboniferous magmatic activity in the Briançonnais s.s. is represented by a series of homogeneous sequences disrupted by strike-slip displacements along the FPT, a major discontinuity of the Alplne Chain (Ricou and Siddans, 1986; Fabre et al., 1987). These relations do not appear to be entirely fortuitous. An important problem is concerned with the exlstence of a large deep crustal cleavaqe plane, revealed by the ECORS Project and superficially expressed by the FPT.Was this cleavage due iust to the Alpine oroaenic event, or has it been determined by preexisting-Variscan crustal or deep faults, occasioned by the collision of plates durlng the Variscan and reactivated during the Alpine orogeny? Treatment and discussion of the geochemical data from the Briançonnais magmatism may shed some light, not only on the types of magma~ism and there geodynamical context but may also be a useful contribution in answering this auestion .

Following the work of several authors (Fabre, 1962; Feys, 1964; Ellenberqer, 1966; Piantone, 1980; Schade, 1989) three magmatic associations have been defined for the Permo-Carboniferous within the Briançonnais s.s., Early rhyolites, earlv andesites from the Ponsonnière series associated with lacustrine sediments in the Stephano-Permian (the middle and late Stephanian plus the EoPermian), andesites and andesitic ignimbrites representing 90% of the Ponsonnière series in the NeoPermian, late K-rhyolites as pebbles in the Verrucano. The ages of the microaranitic dykes, microdioritic and dioritic plutons have not been determined from stratigraphic relations. From these formations 35 new samples have been analysed for both major and trace elements.Preliminary results indicate a bimodal magmatism with the majority of the Early Permian having calc-alkaline affinities. However, the presence of a limited number of samples with tholeiitic affinities indicates their possible source in an island or even back island arc domain. The Late Permian rocks show calc-alkaline to shoshonitic affinities and here their provenance is attributed to a destructive continental arc domain.

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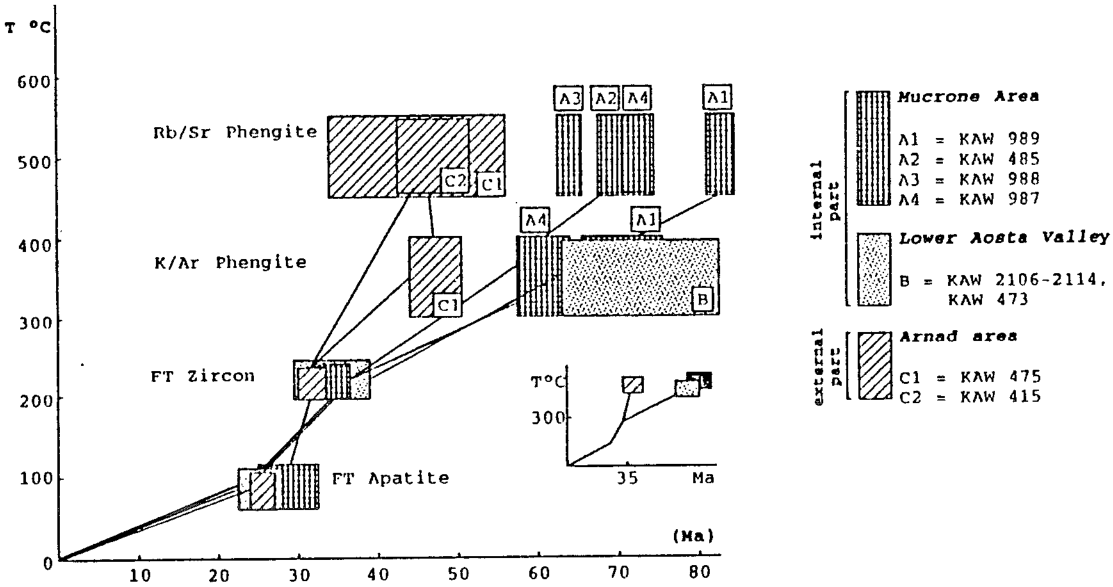
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C2
C1
B
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300
35
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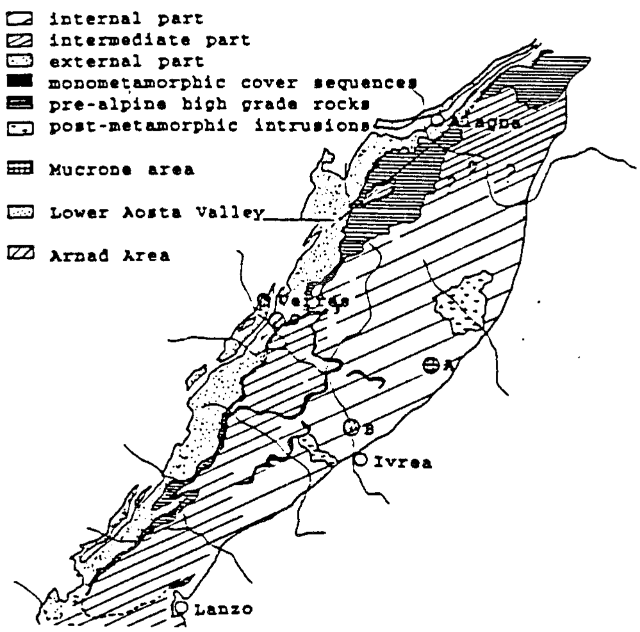
internal part
Mucrone Area
A1 = KAW 989
A2 = KAW 485
A3 = KAW 988
A4 = KAW 987
Lower Aosta Valley
B = KAW 2106-2114, KAW 473
external part
Arnad area
C1 = KAW 475
C2 = KAW 415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pre-alpine high grade rocks
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Lanzo
B
A

GEOLOGY AND GEOCHRONOLOGY OF THE CENTRAL PART OF THE SESIA- LANZO-ZONE: THE STATE OF THE ART.

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In the last three years, the geological interpretation of the Sesia-Lanzo-zone has undergone significant changes. An earlier model (Dal Piaz et al.,1972) depicted the Sesia zone as a slice of continental crust with PreAlpine HT metamorphic assemblages which were subsequently overprinted by HP metamorphism of Eoalpine age. This HP belt was later overthrusted by a sheet of pre-Alpine continental crust which was only partially affected by Alpine metamorphism. The external part of this HP belt (Gneiss Minuti) was then overprinted under greenschist condition of Mesoalpine age, while the internal part (Micascisti Eclogitici) preserves the HP Eoalpine assemblages.

Recent extensive field work has shown that (1) it is possible to distinguish between a Variscan and possibly older basement, and a post-Variscan monometamorphic cover series, (2) the different units are separated by tectonic contacts.

The monometamorphic cover series (Venturini *et al.*, 1991) is composed of gabbroic rocks, basalts and pillow breccias, covered by a volcanodetrital sequence which laterally grades into a carbonatic sequence of presumed upper-Triassic age. This carbonatic sequence consists of manganese-bearing calcschists and coarse grained dolomites, which in turn is overlain by a carbonatic breccias of presumed Liassic age. The whole cover series shows an Eoalpine HP-overprint.

Our mapping has confirmed the same subdivisions for the polymetamorphic basement complex as proposed by Dal Piaz and others (1972), although an intermediate rock sequence was found. This intermediate sequence is composed of retrogressed HP gneiss, as well as a series of Prealpine high grade rocks (upper amphibolite to granulite facies) of the 11 DK. This intermediate sequence was only partially overprinted during Alpine times, yielding both 180 Ma and 50 Ma ages. The monometamorphic cover series is always structurally related to the intermediate block. The extension of these two series, cover rocks and Prealpine HT rocks outcrops over at least 80 km from Lanzo to the Toce.

The contact of the intermediate sequence with the external greenschist part is tectonic and is probably of Mesoalpine age, as shown by the different cooling curves which were constructed from data collected in this and other studies (Hurford *et al.*,1991; Stockhert *et al.*, 1986).

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IS THE ANISOTROPY OF THE MAGNETIC SUSCEPTIBILITY (AMS) AN USEFUL CINEMATIC CRITERIA TO DETERMINE THE DIERECTIONS OF NAPPE PILING IN THE BELLEDONNE MASSIF ?

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The SW ´ part of the Belledonne massif is interpreted as a Variscan nappe complex, consisting of at least five units different in age, tectono-metamorphic development and in their geodynamic significance. The nappe character of these rock units can clearly be derived from the inversion of metamorphism because the mesozonal formations of Chamrousse and Allemont are overlying the epi- to mesozonal Riouperoux and Livet formations (MENOT 1988). A brief description of the geology of the Belledonne massif is given by SAUER et al (this volume). The unit´s boundaries - where they are best exposed, - are characterized by strong mylonitic deformations with characteristic fabrics like sheath folds, mineral stretching lineations and shear sense criteria like sc-fabrics, s- and d-clasts.The first evaluations of these kinematic markers give rise for a SW dircted transport of the upper nappes, whereas in the lower parts an E directed transport may be interpreted. In widespread areas shear sense criteria are absent, therefore the transport direction of the nappe units respectively of the overall nappe piling cannot be determined. In such a case RATHORE (1985) and BORRODAILE et al. (1989) suggested to use magnetic fabrics.for that purpose. According to BORRODAILE et al. (1989) the magnetic fabrics provide a powerful way of determining the shape and the orientation of a special ellipsoid which describes the anisotropy of magnetic susceptibility. The ability of a substance to magnetize in a presentday applied magnetic field is called the magnetic susceptibility. This susceptibility depends on the rock fabrics. Most of the sedimentary rocks as well as metamorphic rocks show a pronounced anisotropy like sedimentary bedding resectively metamorphic banding or tectonic foliation. Such an anisotropy causes an anistropy of the magnetic susceptibility as well, which forms an ellipsoid similar to the strain ellipsoid. KLIGFIELD et al (1981), HIRT et al. (1988), and BORRODAILE (1988) and BORRODAILE et al. (1989) have shown that AMS.- and strain ellipsoids correspond in form and orientation. Therefor the authors interpreted the AMS as a reliable method determining the strain. BORRODAILE et al. (1989) described the magnetic susceptibility fabrics as good indicators of the sense of shear even in the country rocks to a fault. Based on this the nappe contacts as well as the seperating shear zones in the SW ´ part of the Belledonne massif are investigated to reconstruct the overall nappe piling in this area.

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