Low-grade metamorphism of the Gets nappe (Western Alps)

Autor(en): **Bill, Markus / Masson, Henri / Thélin, Philippe**

Objekttyp: **Article**

Zeitschrift: **Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie**

Band (Jahr): **81 (2001)**

Heft 2

PDF erstellt am: **20.05.2024**

Persistenter Link: https://doi.org/10.5169/seals-61690

SCHWEIZ. MINERAL. PETROGR. MITT. 81, 229–237, 2001

Low-grade metamorphism of the Gets nappe (Western Alps)

by *Markus Bill*[1,2], *Henri Masson*[1] and *Philippe Thélin*[3]

Abstract

The Gets nappe, a decollement cover nappe located at the top of the Prealps, is characterized by the occurrence of ophiolitic rocks. The metamorphic grade in the Gets nappe was determined using illite crystallinity and clay mineral assemblages. Samples from the same locality were analyzed to estimate variations in illite crystallinity values and in the parageneses of clay minerals, both in sedimentary elements of a breccia and in the embedding shaly flysch. For samples from one and the same locality, the range in illite crystallinity data between breccia elements and the shaly flysch is comparable to the variation between different shaly beds. Two S–N transects along the Gets nappe reveal the same metamorphic gradient, with the internal parts of the nappe being characterized by middle anchizonal metamorphism and the external parts showing diagenetic conditions. The metamorphic grade is higher within the Gets nappe than in its hangingwall (i.e. the Brèche and Simme nappes), suggesting that the metamorphism in the Gets unit is transported. The timing and conditions of thrusting of the Gets Nappe onto the Brèche and the Simme nappes is constrained by stratigraphic and metamorphic data.

Keywords: Low-grade metamorphism, illite crystallinity, accretionary prism, Western Alps, Tethys.

1. Introduction

The study of metamorphism and sedimentology in ophiolitic nappes of orogenic belts is a proxy to understand the processes of subduction and obduction of oceanic crust in convergent margins. In the Alps, relics of oceanic lithosphere occur in several ophiolitic nappes. Classically in the Alpine literature, a consensus exists that the majority of ophiolitic nappes composed of the stratigraphic trilogy "green rocks–radiolarites–limestones" originated from the Piedmont ocean, a segment of the Mesozoic Tethys ocean. Along a cross-section through the Western Swiss-Italian Alps, ophiolitic nappes of Piedmont origin occur in four tectonic nappes characterized by different metamorphic conditions (Fig. 1).

The *Antrona* and *Zermatt-Saas* ophiolitic nappes are found in a structurally low position. They are affected by high-P metamorphism (eclogite facies) followed by greenschist to amphibolite grade metamorphism (BEARTH, 1974; DAL PIAZ, 1974b; HUNZIKER, 1974; DAL PIAZ and ERNST, 1978; COLOMBI, 1989; STECK, 1989; VANNAY and ALLEMANN, 1990; REINECKE, 1991; AMATO et al., 1999).

The *Tsaté* nappe overthrusts the *Zermatt-Saas* nappe and is affected by blueschist to greenschist facies metamorphism. Ophiolitic rocks are represented by slices and lenses imbricated with calcschists (MARTHALER, 1984; LAGABRIELLE, 1987; KUNZ, 1988).

The *Gets* nappe is a decollement cover nappe situated in the front of the Alpine belt. This nappe was affected by very weak metamorphism, preliminary illite crystallinity data suggest anchizonal conditions (CARON and WEIDMANN, 1967).

While in the Western Alps the metamorphism of the *Antrona*, *Zermatt-Saas* and *Tsaté* nappes are relatively well known, the metamorphism of the Gets nappe is poorly known, and the P-T-t conditions during emplacement are not constrained. The aim of this paper is to present (a) a quantification of the metamorphism of the Gets nappe using data on the illite crystallinity and mineral assemblages, especially those involving

[1] Institut de Géologie et de Paléontologie, Université de Lausanne, CH-1015 Lausanne, Switzerland.
[2] Present address: University of California, Environmental Science, Policy and Management, 250 Hilgard Hall, Berkeley, CA 94720-3110, USA. <mbill@nature.berkeley.edu>
[3] Institut de Minéralogie et de Pétrographie, Université de Lausanne, CH-1015 Lausanne, Switzerland.

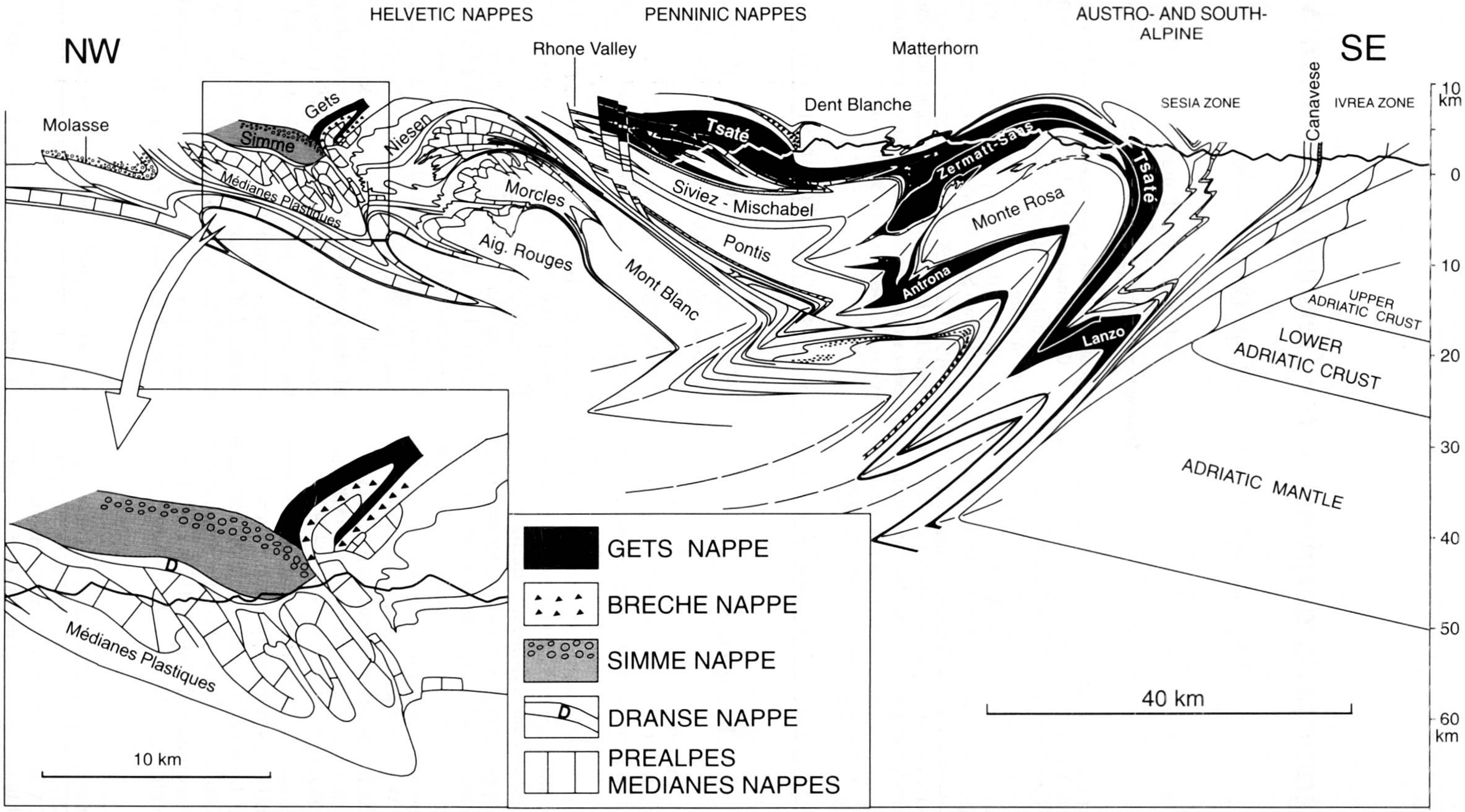


Fig. 1 Tectonic cross-section through northern part of the western Swiss Alps and tectonic position of the Gets nappe (modified from ESCHER et al., 1997).

clay minerals, (b) a discussion of the data and tectonic implications for the subduction system of the Piedmont ocean.

2. Geological setting

Geographically the Gets nappe outcrops from the Gets (French Prealps) to Zweisimmen (Swiss Prealps). The Gets nappe is the highest nappe of the Prealps, which is made up of a thick stack of decollement cover nappes situated in the front of the Western Alps. Internal parts of the Gets nappe overthrust the Brèche nappe, and external parts were emplaced onto the Simme nappe (Fig. 1). The Gets nappe is composed of two series (CARON, 1972): the base of the nappe (Perrières series) essentially comprises a composite wildflysch containing ophiolitic material (serpentinite, gabbro, basalt and diabase), deep marine deposits (radiolarite, pelagic limestone, manganiferous shale), and Palaeozoic granite, all embedded in a shaly matrix (Fig. 2). The disrupted oceanic crust, the melange of ophiolitic rocks and the chaotic sedimentation are characteristic of an accretionary prism sequence (e.g. MASCLE et al., 1988; PICKERING et al., 1989). Isotopic dating, trace element data and Sm–Nd isotopes of the gabbros and basalts of the Gets nappe, together with structural and stratigraphic evolution of the northwest shoulder of the Piedmont rift indicate that, at least in part, the ophiolitic material of the Gets nappe is a remnant of the onset of the Piedmont ocean spreading (BILL et al. 1997, 2000, 2001). The composite wildflysch is overlain by the Hundsrück series, composed mainly of turbiditic sandstones and polygenic conglomerates of Upper Cretaceous age.

3. Method and Sampling

Samples were crushed to millimeter size, in order to extract the clay fraction. Carbonates were then removed from crushed samples by dissolution in 2M HCl for 20 min; the residue was neutralized to pH 5.6 with distilled water. The size fraction < 2 µm was separated by centrifuging at pH 7.5 and then saturated with Ca^{2+} using 1M $CaCl_2$ for 36 hours. Clays were washed until they were defloculated. By pipetting, 3 ml of clay suspension were sedimented onto a glass slide. To measure illite crystallinity, we only used the slides with more than 2.5 mg/cm^2 of material, following the recommendations by FREY (1988) and the experiment by JABOYEDOFF and THÉLIN (1996) which suggest that very thin preparations lead to an underestimate of the illite crystallinity (i.e. the Scherrer width). We used a Rigaku-Rotaflex diffractometer with a rotating Cu anode at 40kV and 30mA, a nickel filter, 0.5° divergence and scatter slits, 0.15 mm receiving slit and 5° Soller slits. Finally, the full width at half-maximum (FWHM) of the first illite basal reflection at 10Å on an X-ray diffractogram was obtained using step scanning with 0.01° 2θ steps and a counting time of 2 s per step. This FWHM measurement represents the so-called illite "crystallinity" or "Kübler index" or "Scherrer width". Limits to estimate the low grade metamorphism are 0.39° Δ2θa (CuKα) for the boundary between diagenesis and anchizone, and 0.22° Δ2θ (CuKα) for the boundary between anchizone and epizone, as calibrated by JABOYEDOFF and THÉLIN (1996). For precise measurements of the FWHM on diffractograms we used the software "QUICK WIDTH" (©JABOYEDOFF, 1997) without any smoothing or Kα2 stripping.

Given the geological emphasis of this study, theoretical considerations related to illite growth within very low metamorphism, involving smectite contents and the size of coherent diffraction domains, are not discussed here. Details on these aspects were taken into account according to the studies of FREY (1987), KÜBLER (1990), JABOYEDOFF and THÉLIN (1996), NIETO and SANCHEZ-NAVAS (1994) and JABOYEDOFF et al. (2000).

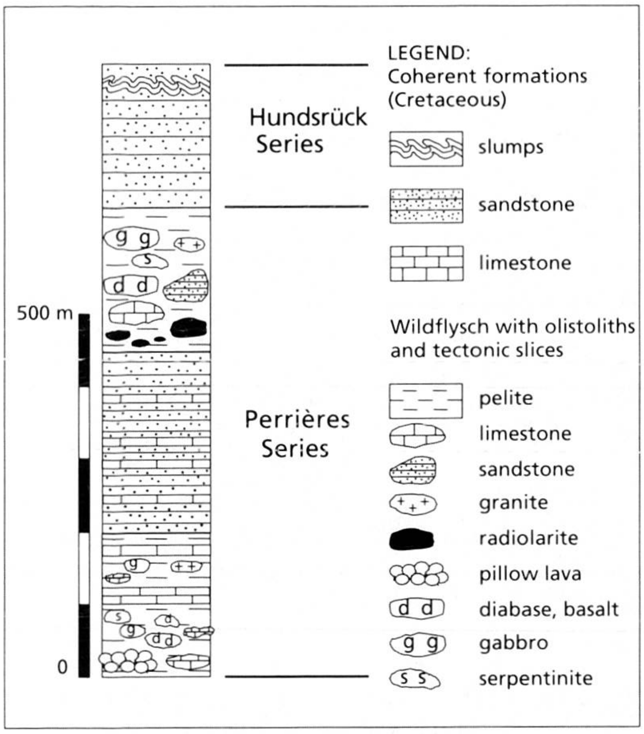


Fig. 2 Simplified stratigaphic section of the Gets nappe (modified from CARON and WEIDMANN, 1967; CARON, 1972; FLÜCK, 1973).

Illite crystallinity values are given for air dried samples (size fraction < 2 μm). Glycolated and heated samples were also considered to estimate the expandable layer effect. Samples were collected along two S–N transects in the Gets nappe (Fig. 3) to investigate a possible metamorphic gradient from internal to external part of the nappe and E–W metamorphic variations. Illite "crystallinity" measurements were carried out on metasedimentary blocks to examine whether these differ in metamophic grade from the embedding flysch.

4. Results

4.1. CLAY MINERALS

Independent pure smectite has not been found, instead smectite always occurs associated with illite or chlorite within mixed-layer phases. In the external parts of the Gets nappe the amount of interstratified smectite decreases and thus becomes difficult to estimate precisely from XRD patterns. Chlorite minerals are present in most of the clay samples and persist from diagenesis to middle anchizone. Fe-chlorite is revealed by the inversion of intensity of its basal peak (001 and 002) as detected in heated samples (MOORE and REYNOLDS, 1997). Fe-chlorite persists from low diagenesis to middle anchizone. No indication was found of a ternary mixed-layered phase with smectite-illite-chlorite.

Corrensite, a regular mixed-layer trioctahedral chlorite/smectite mineral, is observed in the NW part of the Gets nappe (Fig. 1, Tab. 1, Plenay section). Limestone elements of the wildflysch contain corrensite associated with chlorite and traces of illite. The embedded shaly limestone shows corrensite associated with chlorite and detrital illite. This observation suggests that the growth of corrensite does not depend on the degradation of detrital illite. The occurrence of corrensite in this part of the Gets nappe wildflysch is explained by locally abundant detrital elements of dolomite, which is the most obvious source for magnesium to produce corrensite in diagenetic processes.

Talc is found in the NE part of the Gets nappe (Jaunpass). This mineral occurs in limestones enclosed in a polygenic breccia composed of basalts, granitoids and limestones.

4.2. VARIATIONS OF ILLITE CRYSTALLINITY IN THE SAME LOCATION

In order to test the variation of illite crystallinity between sedimentary elements of breccia and surrounding shaly flysch, samples from the same locality within the basal wildflysch were analyzed (Tab. 1, Fig. 3). A breccia block located in the internal part of the Gets nappe offers this opportunity (Zweisimmen area Swiss coord. 593900, 154050). The breccia blocks is composed of basaltic, radiolaritic and calcareous elements within a pelitic matrix embedded in shaly flysch. The metapelitic matrix within this block shows Scherrer widths spreading from 0.29 to 0.33° $\Delta 2\theta$ (CuKα), corresponding to conditions from the middle to low anchizone. This range is comparable to variations observed in different shaly beds from the same locality (Tab 1.), indicating no discernable gradient between the breccia block and the matrix.

4.3. VERTICAL VARIATION OF ILLITE CRYSTALLINITY

The vertical variation of illite crystallinity across the Gets nappe was tested in the same stratigraphic section, more precisely on the North side of the Hundsrück mountain (Fig. 3). Similar pelitic flysch from the Perrières series and from the Hundsrück series were analysed. The chaotic basal Perrières series and the upper Hundsrück series have contrasting illite crystallinity values. The basal series have Scherrer widths of 0.53 to 0.58° $\Delta 2\theta$ (CuKα), corresponding to middle diagenesis, whereas the Hundsrück series have slightly higher IC values (Fig. 3; 0.68 to 0.78° $\Delta 2\theta$ CuKα). The illite cristallinity difference between the two series is much higher than the illite cristallinity variation within the same locality.

4.4. REGIONAL VARIATION OF ILLITE CRYSTALLINITY

The eastern S–N traverse of the Gets nappe (Fig. 3) is included in the Romandes Prealps (Switzerland). Analyzed samples include pelitic rock components of the flysch and limestone blocks or pelitic matrix within blocks of wildflysch from its basal part. In the internal portion of the Gets nappe, Scherrer width values lie between 0.29 and 0.37° $\Delta 2\theta$ (CuKα), corresponding to a range from middle to low anchizone. The samples from the external part of the Gets nappe show that illite/smectite (I/S) mixed-layer phases are involved; very large Scherrer widths between 0.47 to 0.82° $\Delta 2\theta$ (CuKα) are measured, corresponding to low diagenetic conditions. In fact, at these conditions of very low grade, FWHM measurements cannot be used reliably, and it is the occurrence of the I/S

Tab. 1 Scherrer width and estimated modal composition for clay phases < 2 μm for different lithology within the same locality. CH = Swiss coordinates, F = French coordinates, abundance of clay phases; ••• = high, •• = medium, • = low, Fe = Fe chlorite, R = Reichweite parameter, R0 = random distribution, RI = ordered distribution.

Locality coordinates	Rock sample	Illite crystallinity Air dried < 2μ (Δ2θ° CuKα)	Other clay phases: Chl	C/S (Ro)	Illite	I/S	Sme
Kleine Simme CH 593900/154050	KSb 9a Limestone element of breccia block	0.34	•	–	•	–	–
CH 593900/154050	KSb 9b Pelitic matrix within element of block	0.30	Fe ••	–	••	–	–
CH 593900/154050	KSb 11 shaly matrix within block	0.29	••	–	••	–	–
CH 593900/154050	KSb 12 Shale embedded blocks	0.32	••	–	•••	–	–
Vorderi Schneit CH 587095/153880	VS 7 Black shale	0.65	••	–	••	•	–
CH 587120/153820	VS 8 Shale	0.54	••	–	•••	•	–
CH 587020/153500	VS 10 Shale	0.83	•	–	•••	•	–
Gruebe CH 588610/155260	GR 1 Limestone	0.47	Fe ••	–	••	•	–
CH 588610/155260	GR 2 Shaly limestone	0.54	Fe •	–	•••	•	–
CH 588610/155260	GR 3 Limestone	—	Fe •	–	•	–	–
Le Vuargne F 322980/5111440	V 3 Shale	0.28	–	–	•	–	–
F 322980/5111440	V 5 Shale	0.27	•••	–	••	–	–
F 322980/5111440	V 6 Shale	0.31	•••	–	•	–	–
Le Plenay F 321980/5115480	P5 Limestone element of breccia block	–	•••	RI ••	–	–	–
F 321980/5115480	P6 Black limestone	–	•••	RI ••	•	–	–
F 321980/5115480	P8 Limestone element	–	•••	RI ••	–	–	–
F 321980/5115480	P10 Shaly limestone (flysch)	–	•••	RI ••	•	–	–

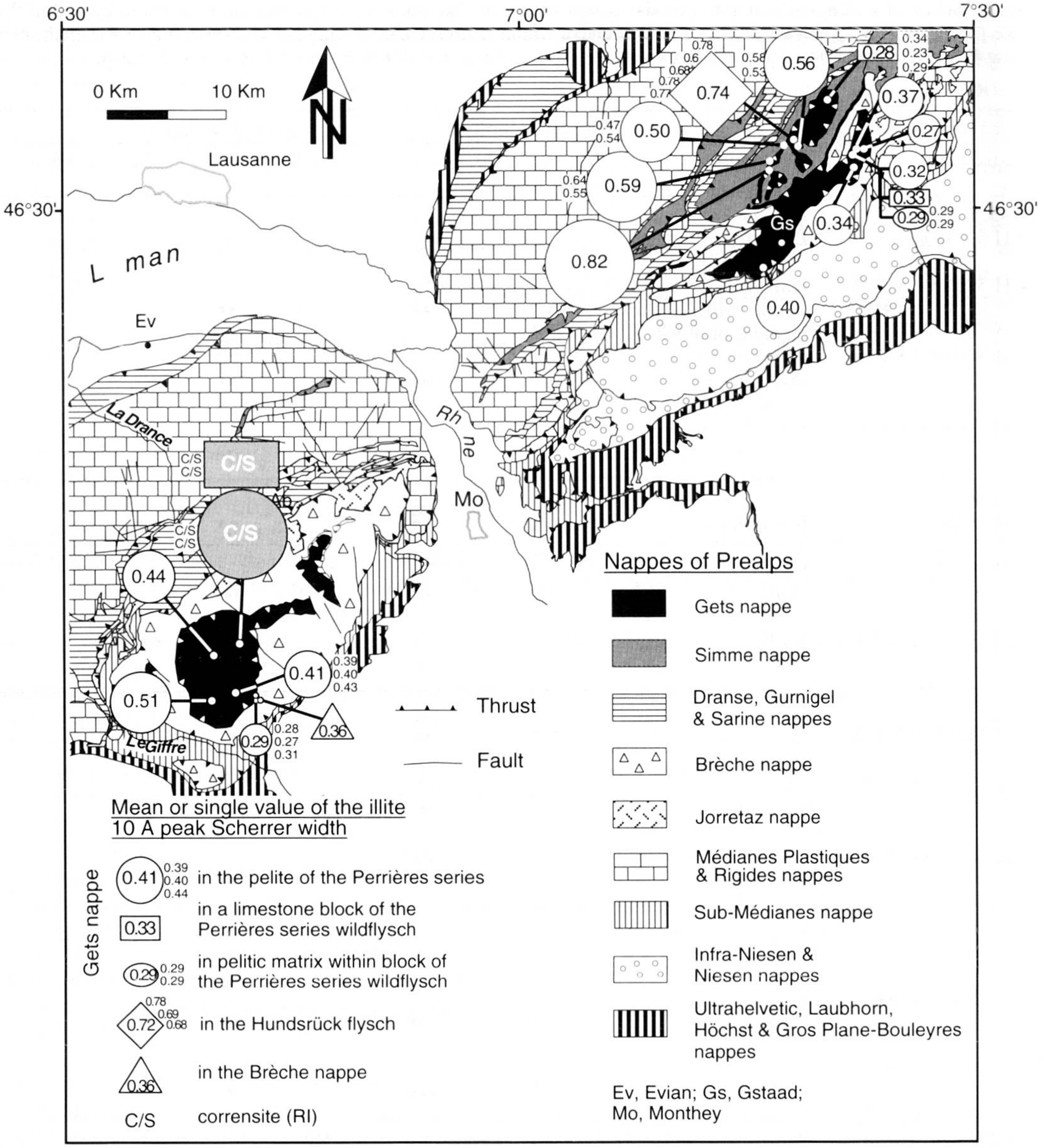


Fig. 3 Tectonic map of the Prealps showing the distribution of Scherrer widths in the Gets nappe and occurrence of corrensite (C/S) within different lithologies.

phases that indicates diagenetic conditions. In summary, illite crystallinity measurements regionally reveal a clear increase in metamorphic grade from internal parts (middle anchizone) to external parts (diagenesis) within the Gets nappe.

The western S–N traverse of the Gets nappe is included in the Chablais Prealps (France) (Fig. 3). Samples are from the shaly matrix of gabbro, basalt, diabase, radiolarite and granitic blocks (sample P6). Scherrer widths of the samples from the internal part of the Gets nappe show values ranging from 0.27 to 0.31° $\Delta 2\theta$ (CuKα), expressing middle anchizonal conditions. Samples showing the higher metamorphic grade occur some 20 m above the thrust separating the Gets nappe from the Brèche nappe; the underlying Brèche nappe shows weaker metamorphic conditions (anchizone). The external part of the Gets nappe shows lower metamorphic grade than the internal part. The presence of true corrensite mixed-layer minerals (glycolated "superstructure" peak at 31.31 Å) and Scherrer widths indicate low diagenetic conditions.

The same metamorphic gradient has been found along two transects: the internal part is characterized by middle anchizonal metamorphic conditions and the external part by diagenetic conditions (Fig. 3).

5. Discussion

5.1. METAMORPHIC FIELD GRADIENT

The grade of metamorphism increases from the internal to external parts of the Gets nappe. The internal part shows illite crystallinity of middle anchizone (Fig. 3) corresponding to metamorphic temperature of about 250–300 °C (e.g. KIRSCHNER et al., 1994; JABOYEDOFF and THÉLIN, 1996). The external part of the nappe show diagenetic conditions characterized by the presence of smectite in the I/S mixed-layered phases and Scherrer width > 0.39° Δ2θ (CuKα). The metamorphic temperature difference between the external part and the internal part is estimated to 100–150 °C.

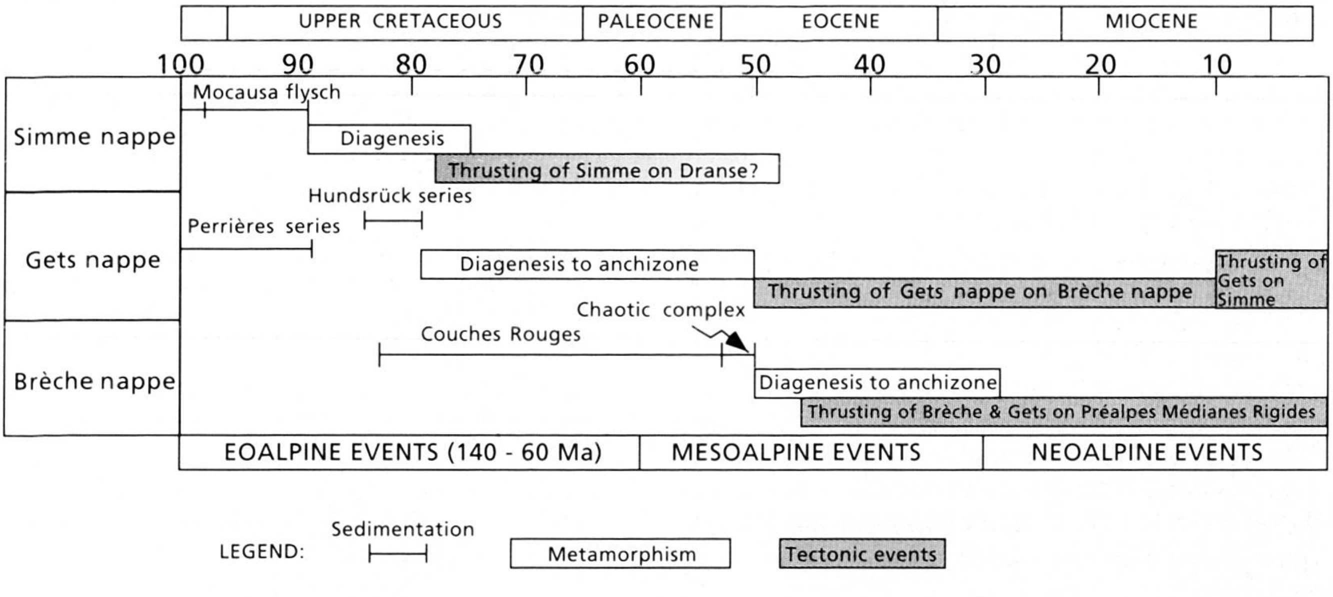
From a structural point of view the parts with the higher and the lower metamorphism are separated by about 4.2 km, with samples belonging to the same stratigraphic series. The interpretation of the metamorphic field gradient is strongly dependent on the paleoposition of the *proto* Gets nappe within an accretionary system, the geometry of isotherms and the velocity of transport through the isotherms. Furthermore, internal overthrusts and advective heat transport by fluids in accretionary prisms are common. For all these reasons it is not possible to conclude that the observed field gradient is representative of the overall thermal structure in the accretionary prism during metamorphism.

The underlying Breccia and Simme nappes are characterized by lower metamorphic grades. Illite crystallinity data on the Brèche nappe show anchizone (Fig. 1) (SAUDAN, 1986), whereas the Simme nappe shows an increase in the very low grade metamorphism (diagenetic conditions) from the internal to the external parts and from the SW to the NE (WICHT, 1984). This contrast of metamorphic conditions suggests that the Gets nappe was affected by metamorphism before its translation onto the Brèche and the Simme nappes.

5.2. THE HUNDSRÜCK SERIES, A HUNDSRÜCK NAPPE?

The Hundsrück series constitutes the upper stratigraphic unit of the Gets nappe. The shales of the Hundsrück series have higher Scherrer Width (0.74° Δ2θ, CuKα) than underlying shales from the Perrières series (0.56° Δ2θ, CuKα; Fig. 3). The stratigraphic thickness separating samples from the Perrières series to the Hundsrück series is about 100 m. The lithological similarity of the analyzed shaly samples indicate that the observed

Tab. 2 Ages of youngest deposits on the top of Brèche, Gets and Simme nappes constraining their metamorphic age. Intensity of metamorphism and ages of deposits constrained nappe translations. Metamorphic intensity based of clay mineral assemblages and illite crystallinity.



variations in illite crystallinity cannot be explained by a difference in mineralogical and/or chemical composition inducing differential chemical activity. With regard to the distance separating the samples, a strong difference in fluid pressure between these two series is also unrealistic to explain the illite crystallinity variation of 0.2° $\Delta 2\theta a$ (CuKα).

We proposed instead to explain the shift in illite crystallinity by the superposition of two tectonic units, the Hundsrück nappe and the Gets nappe, having different thermal histories.

The discrepancy in the metamorphic grade between these two units is explained by the translation of the Hundsrück nappe onto the Gets nappe represented by the Perrières series. These two units reveal contrasting thermal histories, differential lithological compositions, and different ages.

5.3. AGE OF METAMORPHISM AND TRANSLATION OF THE GETS NAPPE

The age of metamorphism is constrained by the younger age of sediments at the top of the Gets nappe (Tab. 2). If the Hundsrück series is not regarded as part of the Gets nappe, the youngest rocks in the Perrières series are Aptian in age (CARON, 1972; FLÜCK, 1973). Therefore, the metamorphism of the Gets nappe is post Aptian. The Hundsrück series is composed essentially of turbiditic sandstone and polygenic conglomerates. Calcareous nannoplankton show Late Santonian to Early Campanian age, i.e. Upper Cretaceous (MATTER et al., 1980). In that a case the metamorphism is post-Campanian.

The superposition of the Gets nappe onto the Brèche nappe can be constrained by the age of the youngest rocks in the top of the Brèche nappe, which is composed of a chaotic wildflysch with lenses of deep marine red shaly limestone, the so-called *"Couches Rouges"*, Campanian to Maastrichtian in age. The wildflysch overlies red shaly limestones of Paleocene age, therefore the maximum age of this wildflysch is Paleocene (CARON, 1965; CARON and WEIDMANN, 1967). These data suggest that the Gets nappe was translated onto the Brèche nappe after the Paleocene.

The Gueyras wildflysch contains large blocks of a radiolaritic sequence typical of the southern margin of the Alpine Tethys realm of Middle Jurassic to Early Cretaceous age (CLÉMENT, 1986; BILL et al. 2001). The youngest deposits on the top of the Simme Nappe are the Mocausa wildflysch dated by calcareous nannoplankton and planktonic foraminifera as Middle or Late Turonian to Middle Coniacian (CARON et al., 1989). The Mocausa flysch contains a conglomerate composed of pebbles of arenite, limestone, dolomitic elements, metamorphic and granitic elements (ELTER et al., 1966). Both the radiolaritic sequences and pebbles indicate a South Alpine affinity. The more internal paleogeographic position of the Simme nappe, the structural position between the Gets and Brèche nappes, and the very low metamorphism of the Simme nappe, all suggest that the tectonic contact between the Simme and the Gets nappe was probably produced during a late orogenic phase (Miocene). This interpretation is supported by seismic profiles, in which a thrust between the external and internal Prealpine nappes is observed (ESCHER et al., 1997).

6. Concluding remarks

The Gets nappe in its internal part overthrusts the Brèche nappe, in its external part the Simme nappe. Both footwall units show lower grade of metamorphism than the Gets nappe. This observation indicates that the metamorphism of the Gets nappe was transported from its original location situated in the active SE margin of the Piedmont ocean to the highest position in the Prealpine nappes. The distance of transport of the metamorphism is estimated to several hundred kilometers. The age of metamorphism of the Gets nappe can be bracketed between upper Cretaceous and Paleocene. This suggest that a subduction system was active in the Piedmont basin at least since the Upper Cretaceous producing low grade metamorphism.

Acknowledgements

This work forms part of the results obtained in research projects 20-40756.94 and 21-45789.95 funded by the Swiss National Foundation. We thank M. Engi, M. Jaboyedoff and two anonymous reviewers for helpful reviews and recommendations that improved the manuscript. We also thank L. Dusfresne for XRD analyses assistance.

References

AMATO, J.M., JOHNSON, C.M., BAUMGARTNER, L.P. and BEARD, B.L. (1999): Rapid exhumation of the Zermatt-Saas ophiolite deduced from high-precision Sm–Nd and Rb–Sr geochronology. Earth Planet. Sci. Lett. 171, 425–438.

BEARTH, P. (1974): Zur Gliederung und Metamorphose der Ophiolithe der Westalpen. Schweiz. Mineral. Petrogr. Mitt. 54, 385–396.

BILL, M., BUSSY, F., COSCA, M.A., MASSON, H. and HUNZIKER, J.C. (1997): High-precision U–Pb and $^{40}Ar/^{39}Ar$ dating of an Alpine ophiolite (Gets nappe, French Alps). Eclogae geol. Helv. 90, 43–54.

BILL, M., NÄGLER, T.,F. and MASSON, H. (2000): Major, minor, trace element, Sm–Nd and Sr isotopic compositions of mafic rocks from the earliest oceanic crust of the Alpine Tethys. Schweiz. Mineral. Petrogr. Mitt. 80, 131–145.

BILL, M., O'DOGHERTY, L., GUEX, J., BAUMGARTNER, P.,O. and MASSON, H. (2001): Radiolarite ages in Alpine-Mediterranean ophiolites: Constraints on the oceanic spreading and the Tethys-Atlantic connection. Geol. Soc. Am. Bull. 113, 129–143.

CARON, C. (1965): L'appartenance tectonique des flyschs du Kalberhöni (Préalpes romandes, Suisse); Considérations sur la nappe de la Simme. Bull. Soc. géol. France, 7. série. 7, 921–928.

CARON, C. (1972): La nappe Supérieure des Préalpes: subdivisions et principaux caractères du sommet de l'édifice préalpin. Eclogae geol. Helv. 65(1), 57–73.

CARON, C., HOMEWOOD, P. and WILDI, W. (1989): The Original Swiss Flysch: A reappraisal of the type deposits in the Swiss Prealps. Earth Sci. Rev. 26, 1–45.

CARON, C. and WEIDMANN, M. (1967): Sur les flysch de la région des Gets (Haute-Savoie). Eclogae geol. Helv. 60(2), 357–398.

CLÉMENT, J.-P., (1986): Les sédiments pélagiques de la Nappe de la Simme (Préalpes Romandes) Ph.D. thesis. Univ. Fribourg, Switzerland, 138 pp.

COLOMBI, A. (1989): Métamorphisme et géochimie des roches mafiques des Alpes ouest-centrales (géoprofil Viège–Domodossola–Locarno). Mémoires de Géologie (Lausanne). Vol. 4, Lausanne, 216 pp.

DAL PIAZ, G.V. (1974): Le métamorphisme alpin de haute pression et basse température dans l'évolution structurale du bassin ophilitique alpino-apenninique: 2e partie. Schweiz. Mineral. Petrogr. Mitt. 54, 399–424.

DAL PIAZ, G.V. and ERNST, W.G. (1978): Areal geology and petrology of eclogites and associated metabasites of the Piemonte ophiolite nappe, Breuil-St. Jacques area, Italian Western Alps. Tectonophysics. 51(1/2), 99–126.

ELTER, G., ELTER, P., STURANI, C. and WEIDMANN, M. (1966): Sur la prolongation du domaine ligure de l'Apennin dans le Montserrat et les Alpes et sur l'origine de la Nappe de la Simme s.l. des Préalpes romandes et chablaisiennes. Bull. Lab. Géol. Min. Géophys. Musée géol. Univ. Lausanne. 167, 279–377.

ESCHER, A., HUNZIKER, J.C., MARTHALER, M., MASSON, H. and SARTORI, M. (1997): Geologic framework and structural evolution of the western Swiss-Italian Alps. In: PFIFFNER, O.A., LEHNER, P., HEITZMANN, P., MUELLER, S. and STECK, A. (eds): Final report of the PNR-20 project, Birkhäuser, Basel, 205–222.

FLÜCK, W. (1973): Die Flysche der präalpinen Decken im Simmental und Saanenland. Mat. Carte géol. Suisse (N.S.). 146, 1–88.

FREY, M. (1987): Low temperature metamorphism. Chapman and Hall, New York, 351 pp.

FREY, M. (1988): Discontinuous inverse metamorphic zonation, Glarus Alps, Switzerland: evidence from illite "crystallinity" data. Schweiz. Mineral. Petrogr. Mitt. 68, 171–183.

HUNZIKER, J.C. (1974): Rb–Sr and K–Ar age determination and the alpine history of the Western Alps. Mem. Ist. geol. Reale Univ. Padova. 31, 54.

JABOYEDOFF, M. and THÉLIN, P. (1996): New data on low-grade metamorphism in the Briançonnais domain of the Prealps, Western Switzerland. Europ. J. Mineral. 8, 577–592.

JABOYEDOFF, M., KÜBLER, B. and THÉLIN, P. (2000): Basis for meaningful illite crystallinity measurements: an example from the Swiss Prealps. Schweiz. Mineral. Petrogr. Mitt. 80, 75–83

KÜBLER, B. (1990): "Cristallinité" de l'illite et mixed-layer: brève révision. Schweiz. Mineral. Petrogr. Mitt. 70, 89–93.

KUNZ, P. (1988): Ophiolites penniques et sédiments associés dans la région d'Arolla (Val d'Hérens, Valais, Suisse). Eclogae geol. Helv. 81, 115–124.

LAGABRIELLE, Y. (1987): Les ophiolites: marqueurs de l'histoire tectonique des domaines océaniques. Le cas des alpes franco-italiennes (Queyras, Piémont), comparaison avec les ophiolites d'Antalya (Turquie) et du Coast Range de Californie. Ph. D. thesis. Univ. Brest, 350 pp.

MARTHALER, M. (1984): Géologie des unités penniques entre le Val d'Anniviers et le Val de Tourtemagne (Valais, Suisse). Eclogae geol. Helv. 77, 395–448.

MASCLE, A., MOORE, C.J., TAYLOR, E. and PARTY, S.S. (1988): ODP Leg 110 at the Northern Barbados Ridge: an introduction and explanatory notes. In: MASCLE, A. and others (eds): Proc. ODP, Init. Repts (Part A), Ocean Drilling Program, College Station, TX. 5–25.

MATTER, A., HOMEWOOD, P., CARON, C., RIGASSI, D., VAN STUIJVENBERG, J., WEIDMANN, M. and WINKLER, W. (1980): Flysch and molasse of Western and Central Switzerland. In: Geology of Switzerland: a guidebook. Part B. Schweiz. Geol. Kommission. Wepf and Co, Basel, 261–293.

MOORE , D. M. and REYNOLDS, R.C. (1997): X-ray diffraction and the identification and analysis of clay minerals. Oxford University Press, 2nd edition, 378 pp.

NIETO, F. and SANCHEZ-NAVAS, A. (1994): A comparative XRD and TEM study of the physical meaning of the white mica "crystallinity» index. Europ. J. Mineral. 6, 611–621.

PICKERING, K.T., HISCOTT, R.N. and HEIN, F.J. (1989): Active convergent margins. In: PICKERING, K.T., HISCOTT, R.N. and HEIN, F.J. (eds): Deep-marine environments: clastic sedimentation and tectonics. Unwin Hyman, London, 291–341.

REINECKE, T. (1991): Very-high-pressure metamorphism and uplift of coesite-bearing metasediments from the Zermatt-Saas zone, Western Alps. Europ. J. Mineral. 3, 7–17.

SAUDAN, F. (1986): Etude des nappes de la Brèche et des Préalpes Médianes Rigides: région de la Videmanette. Unpublished Diploma thesis, Univ. Lausanne, Switzerland, 122 pp.

STECK, A. (1989): Structures des déformations alpines dans la région de Zermatt. Schweiz. Mineral. Petrogr. Mitt. 69, 205–210.

VANNAY, J.C. and ALLEMANN, R. (1990): La zone piémontaise dans le Haut-Valtournanche (Val d'Aoste, Italie). Eclogae geol. Helv. 83, 21–39.

WICHT, J.M. (1984): Les flysch de la nappe de la Simme dans les Préalpes romandes. Ph.D. thesis. Univ. Fribourg, Switzerland, 166 pp.

Manuscript received September 8, 2000: revision accepted June 17, 2001.