Published in Clay Minerals 36, 159-170, 2001, which should be used for any reference to this work

Near vertical iso-illite-crystallinity surfaces cross-cut the recumbent fold structure of the Morcles nappe, Swiss Alps

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This paper was presented at a colloquium held at the University of Lausanne on 20th May 1999 in honour of Professor Bernard Kübler, who subsequently died on 16th September 2000

ABSTRACT: Metamorphic isograd surfaces are mapped within the Morcles nappe using illite crystallinity (IC) and (clay-) mineral parageneses in 268 samples. The diagenesis-anchizone and the anchizone-epizone boundaries are nearly vertical surfaces which crosscut the present-day recumbent fold nappe structure. Frontal parts of the nappe are diagenetic ($T_{\max}$ <200°C) whereas rear parts both in the normal and inverted limb are epizonal ($T_{\max}$ >300°C). We demonstrate that the calcite content of shales, marls or limestones has no influence on the average IC. Deviations of individual samples from the mean IC of any given diagenetic and lower anchizonal site are very large, however, without it being possible to associate deviations with any obvious rock parameter. The standard deviations of populations of IC values decrease strongly with increasing metamorphic grade (toward smaller IC values). Mapping the diagenesis-anchizone boundary requires a much larger sampling effort than the same exercise for the anchizone-epizone boundary.

KEYWORDS: iso-illite crystallinity, recumbent fold structure, Morcles nappe, Swis Alps.

The Morcles nappe of western Switzerland is well known for its spectacular large-scale recumbent fold structure. It represents the lowermost unit in a stack of three major Helvetic nappes of western Switzerland (Fig. 1) which comprise up to 2 km thick of mostly shallow marine carbonates and marls, deposited from Middle Triassic to Middle Cretaceous on the former passive margin of the Neo-Tethys ocean. After a period of non-deposition and slight erosion from Upper Cretaceous to middle Tertiary, some additional shallow water carbonates, sandstones and finally deeper water Flysch-type detrital sediments were laid down from middle Eocene to earliest Oligocene in a typical foreland basin environment. The entire series (Mesozoic and Neogene) was intensely deformed during the Oligo-Miocene continent-continent collision which resulted in thrusting and folding of successively more external units (Lugeon, 1914; Badoux, 1972; Masson *et al.*, 1980; Ramsay, 1981; Escher *et al.*, 1993). The large-scale structure of the Morcles nappe is very well known (Durney, 1972; Huggenberger, 1985; Langenberg *et al.*, 1987; Burkhard, 1988a; Escher *et al.*, 1993). The Morcles nappe in its Swiss part is characterized by a pronounced axial plunge of up to 35° to the northeast which permits insight into this apparently 4–7 km thick recumbent fold nappe (Fig. 1).

The very low-grade metamorphism has been documented by a series of studies (Durney, 1974; Burkhard, 1988b; Goy-Eggenberger & Kübler, 1990; Goy-Eggenberger, 1998) mostly involving IC. The presence of index minerals such as

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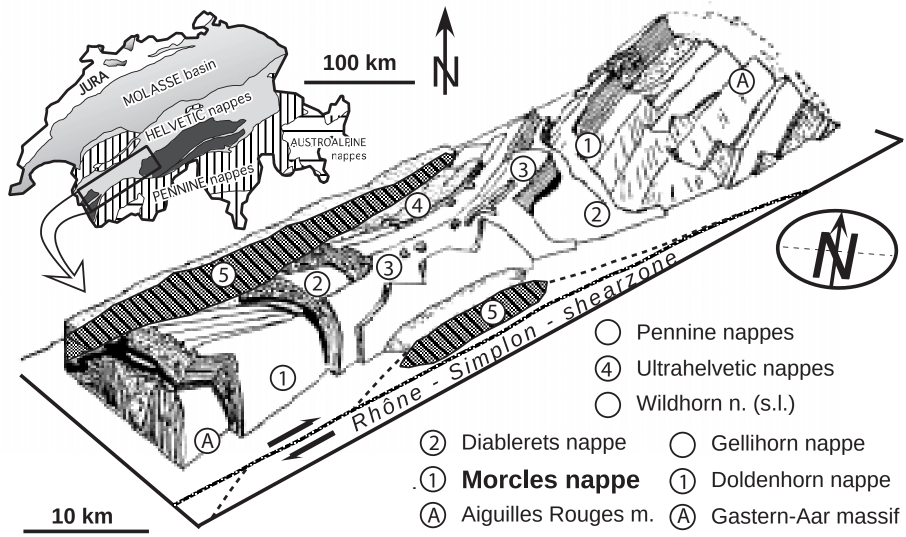

FIG. 1. Simplified tectonic map of Switzerland. The rectangle indicates the location of the block-diagram. The block-diagram of the Helvetic nappes of western Switzerland (Heim, 1921) illustrates the position and large-scale structure of the Morcles nappe with respect to the external crystalline massifs and higher Helvetic nappes. Note the culminations of the external crystalline massifs (Mt. Blanc-Aiguilles Rouges, Aar) and the important regional axial plunge to the NE within the Morcles nappe.

chloritoid, and fluid inclusion data, indicate epizonal conditions in rear parts of the nappe (estimated at ~330°C based on isotopic calcite-quartz oxygen (Burkhard & Kerrich, 1988; Kirschner *et al.*, 1995). The frontal part of the nappe, however, is diagenetic in grade, i.e. with estimated maximum temperatures of <200°C (Frey *et al.*, 1980). The lowest isotopic temperatures, measured at ~2 km in from the front of the nappe, are ~260°C (Kirschner *et al.*, 1995).

The combined map of IC values and the occurrence of index minerals is a tool well-suited for analysing the metamorphic grade in very low-grade sedimentary series (Frey *et al.*, 1980; Frey 1987a,c; Kisch, 1980, 1990; Frey & Robinson, 1999). Large numbers of samples were analysed in order to obtain a sufficient area coverage. This is an essential requirement for the construction of reliable isocryst contours on the nappe scale. Provided some pitfalls inherent in the technique are avoided (Merriman & Roberts, 1985; Frey, 1987a,c) isocryst contour lines closely reflect lines of equal metamorphic grade or ‘isograds’. The occurrence or, ideally, the mapping of ‘first appearance’ or ‘disappearance’ of metamorphic index minerals (Fig. 2) such as stilpnomelane, kaolinite, pyrophyllite, chloritoid, rectorite, paragonite etc., requires the presence of suitable protoliths. The mapping of such minerals may not be sufficient for the construction of true reaction isograds on the map scale. Nevertheless, they are important pieces of information used to validate and ‘calibrate’ isocryst patterns.

VERY LOW-GRADE METAMORPHISM AND ANALYTICAL TECHNIQUES

Clay minerals are present in virtually all sedimentary rocks, either as a primary, detrital component and/or as a product of alteration and diagenesis. During burial, diagenesis and metamorphism, these clay minerals undergo progressive crystallographic and chemical changes and are involved in reactions between minerals. Monitoring these often subtle changes allows us to estimate the burial-metamorphic history (Kübler, 1964; Kübler, 1967a; Weaver & Broekstra, 1984; Hunziker, 1987; Frey & Robinson, 1999). In order to detect these changes by means of XRD analyses, clay minerals have to be separated physically from the whole-rock sample. This involves two steps: first, if necessary,

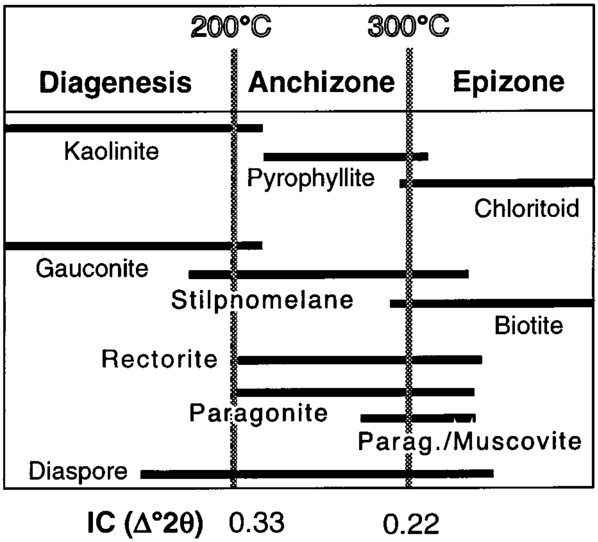

FIG. 2. Very low-grade metamorphism is subdivided into diagenesis, anchiizone and epizone based on an empirical IC scale (given in $\Delta°2\theta$) and the occurrence of 'index minerals'. The IC scale used here refers to a new calibration for the Scintag diffractometer at Neuchâtel and has no universal meaning. The well established occurrence of index minerals is indicated by thick black bars according to (Kübler, 1967a; Frey, 1987c). The temperatures (200 and 300°C) for the lower and upper limit of the anchizone are estimates.

carbonates are removed using dilute HCl, and second, clay minerals are enriched/isolated by means of grain-size fractionation.

Sample preparation and XRD measurements

Oriented clay mounts were prepared according to a standard method developed and used at the University of Neuchâtel (Kübler, 1967b). The following conditions were used for the measurement of XRD profiles: X-ray powder diffractometer (Scintag's XDS 2000); the spectral counter (KEVEX PSI1, PELTIER cooled silicon detector); wavelength of 1.5406 Å Cu-$K\alpha_1$; generator current of 45 kV and 40 mA; slits – emitter: 2 mm, 4 mm; receiver: 0.5 mm, 0.3 mm; goniometer speed of 1°/min; chopper increment of 0.03; continuous scan from 2° to 70°2θ; and circular glass plates (ϕ 2.5 cm), spinning about a vertical axis.

The files generated with SCINTAG are of raw data, which are routinely reduced to 'net intensity' by the application of a fast Fourier noise filter, background subtraction and $K\alpha_2$ stripping. All measurements were made on the 'net intensity' files using the SCINTAG DMS program. The IC measurements were made on the first (10 Å) mica reflection of oriented clay XRD patterns. The IC values were measured in the <2 μm and 2–16 μm grain size-fraction, both air dried and glycolated, thus leading to four different IC values per sample. In this study, we used the data from the <2 μm fraction of the air-dried sample to construct the isocryst patterns on the map scale.

Illite crystallinity

The empirical method of relating the shape of the 10 Å peak to metamorphic grade was first suggested by Weaver (1960) who used the ratio of the peak intensity at 10.5 Å and 10 Å. Kübler (1964) introduced the 'Illite Crystallinity' concept as it is used today, i.e. the measurement of the full width of the 10 Å peak at half of its maximum (FWHM) also called the Scherrer (1918) width (SW). For a review and a complete reference list see Frey (1987a). The IC measurements should be understood as a statistical means to determine the approximate very low metamorphic grade in sedimentary terrains. With increasing burial and very low-grade metamorphism, smectites, mixed-layer illite-smectite and illites tend to (re-)crystallize to larger crystal size and are progressively transformed to muscovite. Both transformations, however complex in detail, lead to a progressive decrease in the width of the 10 Å peak as measured on an XRD diagram. The IC measurements thus allow us to establish three subdivisions within very low-grade metamorphism: diagenesis, anchizone and epizone. The respective limits between these fields are defined as IC values, expressed in Δ°2θ. The absolute values of these limits are not fixed, however, because they depend on the XRD machine type and setting. Each laboratory (each XRD machine) yields slightly different values. Accordingly, calibrations are made using a set of standard rock slides provided by B. Kübler. This set of standards has remained identical since the very first days of IC work. At Neuchâtel, with the SCINTAG equipment, and using standard conditions as in this paper, the diagenesis-anchizone boundary is defined at 0.33 Δ°2θ whereas the anchizone-epizone limit is defined at 0.22 Δ°2θ.

These limits have been compared with a variety of other indicators of very low-grade metamorphism such as the progressive disappearance of smectites within the field of diagenesis, vitrinite reflectance, with the occurrence of indicative (clay-) mineral parageneses and with fluid inclusion studies (Kisch, 1980; Frey, 1987a,c; Kisch, 1987, 1990; Frey & Robinson, 1999).

Index minerals/mineral parageneses

The most sensitive mineral parageneses for the subdivision of very low-grade metamorphism are found within basic volcanic and volcaniclastic rocks (basalts, tuffs, greywackes, etc.). Volcanics are virtually absent from the Helvetics with the exception of one single stratigraphic horizon. The latest Eocene/earliest Oligocene Taveyannaz Flysch formation contains some andesitic rock debris (Bussy & Epard, 1984; Lateltin, 1988). For the rest of the Mesozoic sequence, carbonates and marls predominate, together with some detrital Flysch sequences and some black shale horizons. The most important index minerals encountered within these rocks are discussed below.

The clay size-fraction of the insoluble residue of the analysed limestones, marls, shales and sandstones is dominated by illite, muscovite and chlorite in variable proportions. Minor constituents include kaolinite, pyrophyllite, chloritoid, paragonite, paragonite/muscovite, rectorite, stilpnomelane, biotite, chamosite, diaspore, laumontite, prehnite, pumpellyite, actinolite, goethite, hematite and other ‘traces’. Some of these minerals are valuable indicators of very low metamorphic grade. The occurrence of most of these minerals is restricted to particular lithologies, however. Following such lithologies from the foreland into low-grade regions allows us to map the first appearance and/or disappearance of sensitive mineral parageneses, in ideal cases even the mapping of true reaction isograds. Figure 2 gives a summary of indicative phases as a function of metamorphic grade according to compilations by Kübler (1967a) and Frey (1987a,b).

RESULTS

The most important observations recorded from 268 samples from the Morcles nappe are summarized in Figs 3, 4 and 5. The entire data set was analysed in detail by Goy-Eggenberger (1998) and only the most relevant correlations are discussed below.

Illite crystallinities measured in this study vary from 0.11 to 0.85°2θ, with an arithmetic mean of 0.21 (±0.1, 1σ). From this it follows that our samples lie about half and half within the epizone and anchizone respectively. Only few samples are from the field of diagenesis.

In order to study the spatial relationship between isocryst surfaces and the internal structure of the recumbent Morcles fold nappe, we chose a horizontal cross-section of the Morcles nappe as a common map reference. The establishment of such a horizontal cross-section follows classical rules of 3-D geometry and cross-section construction (e.g. Ramsay & Huber, 1987). A datum of 1500 m a.s.l. was choosen because it provides many intersections between nappe structure and topography, the latter ranging from 450 to 3051 m a.s.l.

Sample localities were projected onto this horizontal cross-section (Fig. 5) along vectors of the locally-determined fold axis plunge which varies between 5 and 30° towards the northeast (Langenberg *et al*., 1987; Burkhard, 1988a). This projection is an obvious choice in the Morcles nappe: it preserves the relative sample location with respect to the cylindrical nappe structure (cf. Fig. 1). The mean vertical component of this projection vector measures 485±370 m (1σ), the mean horizontal component is 1375±1260 m. Such a projection is further justified by the fact that large-scale tilting of the Morcles nappe was

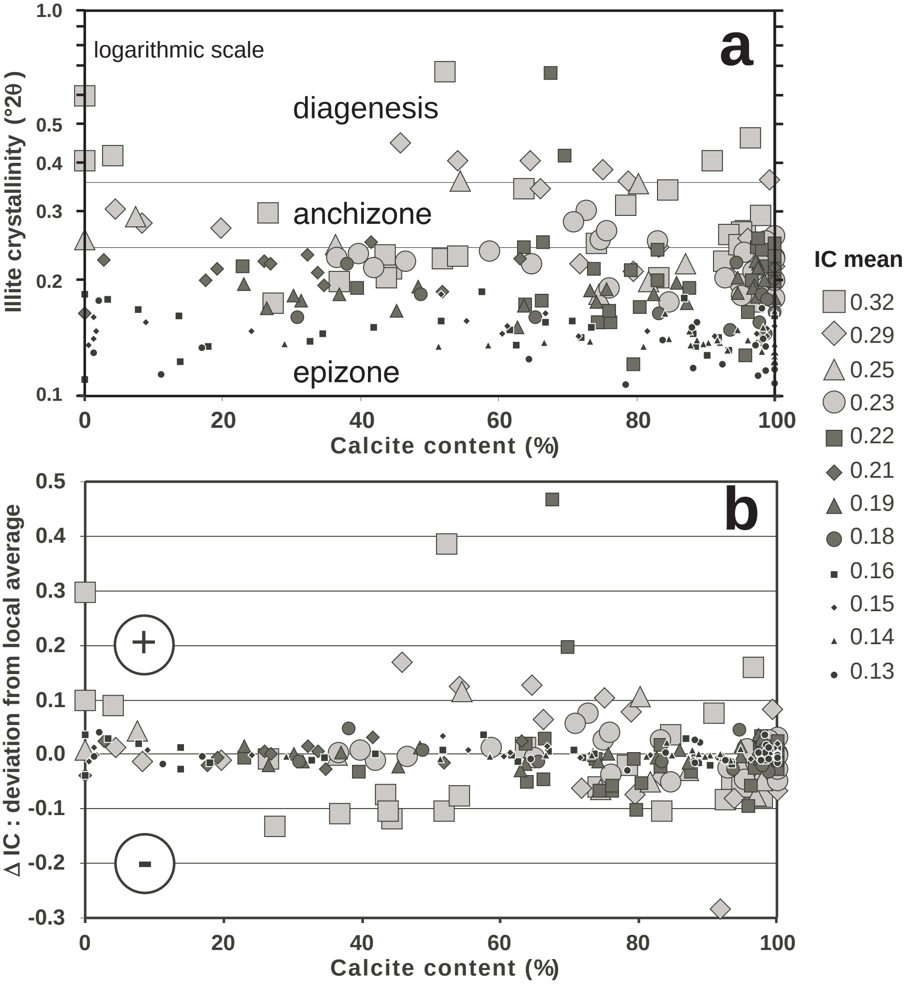

FIG. 3. Summary plots of IC values measured in the Morcles nappe; testing for an influence of lithology on IC. (a) Illite crystallinities (<2 µm, glycolated) *vs*. calcite content in a whole-rock sample as determined from XRD; note that the vertical scale is logarithmic for better distinction of the closely-grouped sample points within the epizone. (b) Individual samples with varying calcite content from a regional subset (sampling profile) are assumed to be of equal metamorphic grade – expressed as an average IC value (arithmetic mean). Deviations (ΔIC) from this average local value are plotted against calcite content. Average local IC values are coded by different symbols according to legend, each symbol covers 2−3 regional subsets.

achieved well after the peak metamorphism (Burkhard, 1988a,b), making any depth correction to the IC values unnecessary.

Index minerals are shown using various symbols whereas the IC values of all samples were used to map areas of diagenesis, anchizone and epizone as well as isocryst contours [Fig. 5]. This mapping was performed using the Unimap (UNIRAS) software package. Contouring by bi-linear interpolation of individual isocryst values on the basis of the projected sample localities yields an interpolated 'weighted arithmetic mean IC value' for any geographic coordinate on this horizontal cross-section 'map'. Similar maps were produced for both grain size-fractions (<2 µm, 2−16 µm) and for various sample treatments (air drying, glycolation) of the clay mounts prior to XRD analysis as well as separation for different lithologies. Despite some

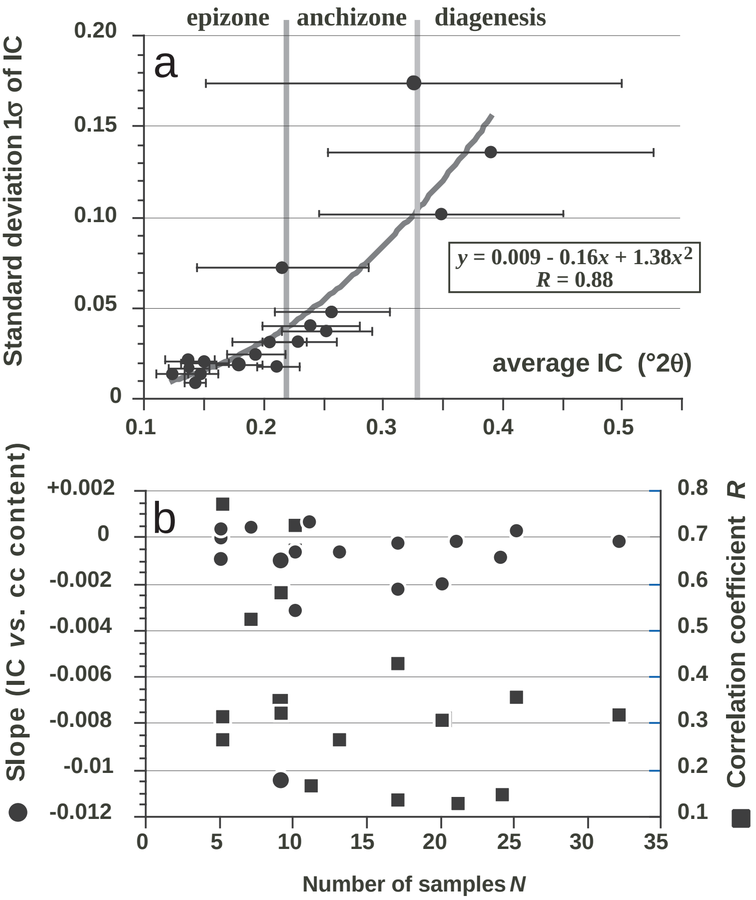

FIG. 4. (a) Standard deviations (1σ) are compared with the average IC (arithmetic mean) for 18 regional subsets with >5 individual samples: the standard deviations decrease rapidly with increasing metamorphic grade satisfying an empirical cubic regression. (b) Linear regressions have been calculated for the same 18 regional subsets as shown in Fig. 4a. Slopes, i.e. the relationship between the IC value and calcite content and the respective correlation coefficients (*R*) are plotted *vs*. the number of samples (*N*).

minor differences, all of these maps (Goy-Eggenberger, 1998) confirm the general isocryst patterns shown in Fig. 5.

Isocryst contours clearly crosscut the internal structure of the Morcles nappe. Diagenetic IC values are predominant in a small region at the nappe front, within Cretaceous, Tertiary and the overlying Ultrahelvetic thrust slices. This is confirmed by an additional set of >60 samples taken from Ultrahelvetic thrust slices in this region, but not used for contouring in Fig. 5 (Jeanbourquin & Goy-Eggenberger, 1991; Jeanbourquin, 1994) and from unpublished data. A large central part of the Morcles nappe lies in the field of the anchizone, whereas rear (SSE) parts, in the inverted limb, core and normal limb lie within the field of epizonal illite crystallinities. This epizonal degree is confirmed by the presence of chloritoid in Aalenian black shales.

The results obtained from 10 chlorite thermometry measurements (Goy-Eggenberger, 1998) vary between 187°C at the front of the nappe to 341°C at the rear (Fig. 5). These temperatures are in excellent agreement with previously published stable isotope thermometry data which gave temperatures of 260–350°C (Burkhard & Kerrich, 1988; Kirschner *et al*., 1995) in the southern half of the nappe (Fig. 5).

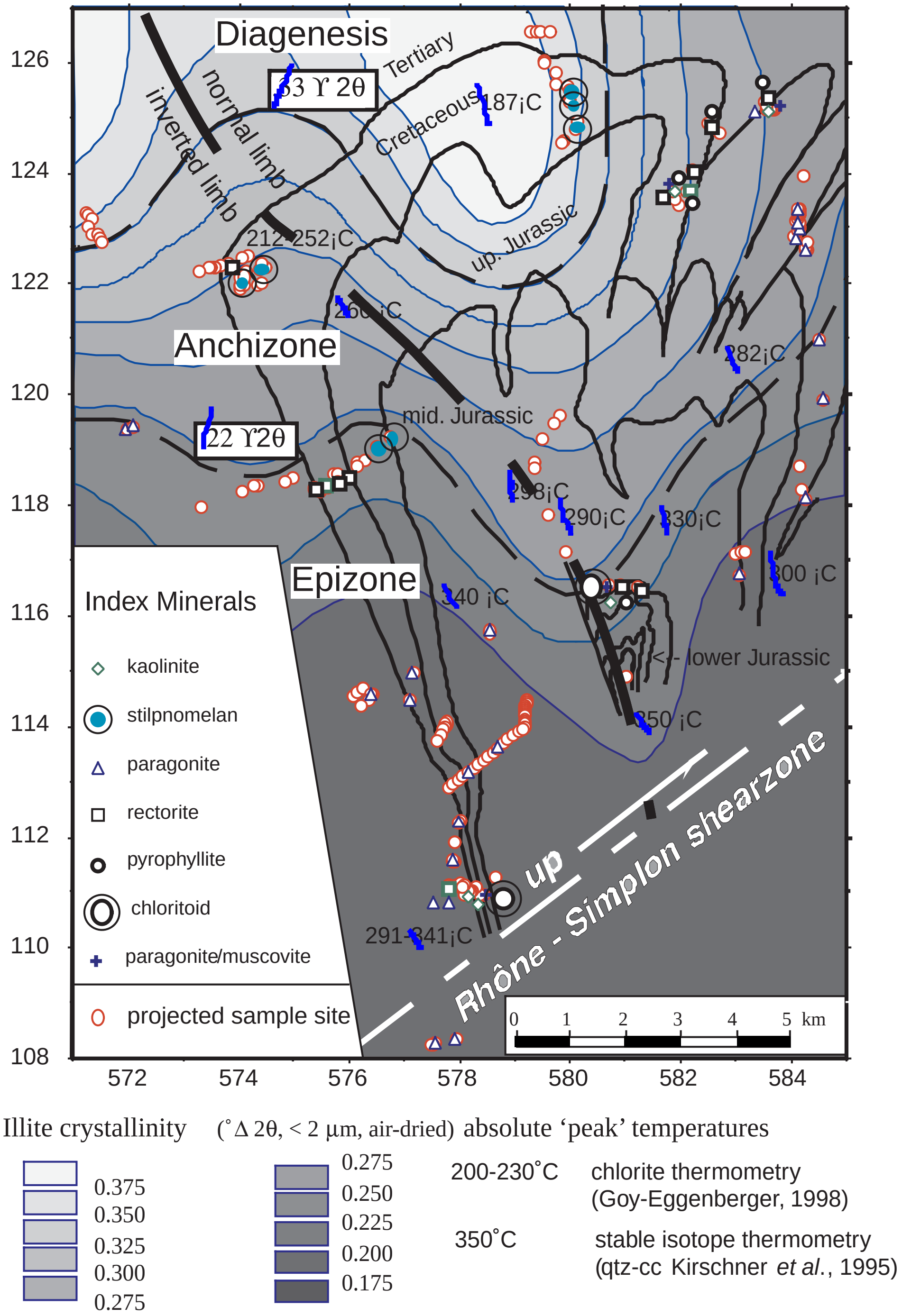

FIG. 5. Sample localities and the occurrence of index minerals within the Morcles nappe, projected onto a simplified horizontal cross-section of the nappe at 1500 m a.s.l. The ICs of the air-dried <2 µm clay fraction were used to calculate isocryst contours obtained by linear interpolation between points with contour intervals of 0.025 Δ°2θ.

The anchizone-epizone boundary cuts at a high angle through all lithologies of the inverted limb, seems to be deflected to the south within the mid-Jurassic, and cuts again at a high angle through the normal limb of the nappe. This deflection of the anchizone-epizone boundary is mirrored by the diagenesis-anchizone boundary at the nappe front. Both limits seem to indicate a lesser metamorphic grade in the core of the nappe when compared with either the normal or inverted limb vertically above and below.

DISCUSSION AND CONCLUSIONS

Illite crystallinity = maximum thermometer?

Among the many factors theoretically influencing IC, namely: protolith composition, integrated time-temperature history, strain intensity, fluid-rock interaction, porosity/permeability, etc., the peak temperature attained during burial metamorphism is generally regarded as the single most important parameter. Many authors have detected, or suspected an influence of protolith composition on IC, however. Pure, micritic limestones, for instance, have been suspected to 'retard' the crystallization of illites as compared with shaly and sandy horizons during diagenesis (Persoz, 1982).

The recumbent fold geometry of the Morcles nappe allows us to test for some of the above-mentioned influences. Individual lithologies can be followed over ~10 km from the normal limb to the frontal part of the nappe and back to the inverted limb at the rear. Tertiary, Cretaceous and Upper Jurassic formations all show very clearly an increase in IC from the front to the rear of the nappe, in both the inverted and the normal limbs. This overall relationship is therefore certainly independent of 'protolith composition'. Furthermore, isocryst contours do not show any deflection at formation boundaries at least with regard to Tertiary, Cretaceous and Upper Jurassic formations. This alone is another strong argument against an influence of protolith composition. However, the same cannot be claimed as easily for the Lower Jurassic. This formation occupies the core of the Morcles nappe and its areal extent (cf. Fig. 5) is insufficient to reveal any significant differences in IC between normal and inverted limb. On the map scale, however, this core region, made up entirely of Lower Jurassic formations, displays slightly larger IC values than the normal limb above and the inverted limb below. This leads to a conspicuous deflection of IC contours, which appear to be 'folded' in an opposite direction with respect to the overall nappe structure. The question arises if this trend reflects a true isograd (line of equal metamorphism) or, alternatively, if it represents an artifact due to an influence of protolith composition on IC values. The suspicion is that IC values might, on average, be larger within the marly and shaly Lower Jurassic series (including the Aalenian black shales) than within the more limestone-dominated normal and inverted limbs respectively (the Malm and Urgonian formations are dominated by very pure carbonates (>95% calcite).

Different statistical analyses were performed in order to test for any such lithology-related bias in the map-scale isocryst patterns, particularly the influence of calcite content on IC. First, samples were grouped into regional subsets which correspond to sampling profiles across different lithologies conducted in different parts of the Morcles nappe (Fig. 5). Given the typical alternation of limestones and marls on a dm- to m-scale, many different rock types were sampled in each profile varying from very pure limestones to marls and, in places, even shales. Given the small distances of generally <100 m among individual samples in such a subset, they are *a priori* assumed to be of equal metamorphic grade, despite variable IC values. Our data set of 268 samples was thus grouped in 27 regional subsets with an average of 10 individual samples each (±6).

Test 1. Test 1 consisted of calculating linear regressions of IC *vs.* calcite content for each regional subset containing at least 5 individual samples. The calcite content of each sample was determined by XRD peak heights from the whole-rock sample. The overall trends of IC *vs.* calcite content are shown in Fig. 3a. Individual samples in this graph are coded according to the arithmetic mean IC value of the subset to which they belong. Each symbol stands for 2–3 subsets. The calculation of linear regressions for each regional subset with >5 samples of variable calcite content did not reveal any significant influence of calcite content on IC (Fig. 4b). Although the correlations ('slopes') calculated are more often negative than positive, these slopes are very small, and the correlation coefficients (R) for these linear regressions are very poor (often due to small sample size). The above-mentioned nappe scale trend, if interpreted as related to lithology, should lead to a negative correlation between IC and calcite content but Test 1 failed to show any such trend.

Test 2. Test 2 consisted of calculating an ‘average IC’ for each regional subset and subsequently comparing the difference (Δ IC = IC sample − average IC) for each individual sample *vs*. the calcite content in this sample. This test compares differences, and not absolute values (as did Test 1), and should be even more sensitive to lithological differences than Test 1. In addition, Test 2 has the advantage of allowing a simultaneous analysis of all samples of the entire nappe, regardless of metamorphic grade. The results of Test 2 are shown graphically in Fig. 3b. Any systematic correlation between IC and calcite content should be revealed clearly in this graphic representation. For instance, if black shales had a general tendency to show higher IC values in comparison to limestones of the same metamorphic degree, the data points of Fig. 3b should be arranged along a line or curve with a positive slope. No such tendency is visible and we conclude that the calcite content has no influence on the IC values.

Tests 1 and 2 failed to confirm any such trend and we therefore conclude that the southward deflection of the anchizone-epizone boundary in the nappe core is not an effect of different lithologies but reflects a true ‘metamorphic isograd’.

If anything, the calcite content might have a slight influence on the homogeneity among different samples, expressed as an increasing spread of points toward high calcite percentages in Fig. 3b. This tendency, however, is due entirely to a few regional subsets with large average IC values, close to the diagenesis-anchizone boundary. Most of the remaining anchizonal and epizonal subsets fail to confirm any such trend.

Figure 3 also illustrates two other important facts: (1) our sampling of the Morcles nappe covers an entire range of lithologies varying from black shales (0% calcite content) to very pure limestones (‘100%’ calcite content) and even within regional subsets, a large spread of lithologies is present; (2) for any given regional subsets, IC values display considerable variation, expressed clearly as vertical spread in Fig. 3b. Ideally, all points in this graph should plot along the zero line, indicating minimal deviations. This clearly is not the case, as the deviations are large, especially for samples of subsets with large average IC values. Standard deviations decrease considerably with increasing metamorphic grade, to be almost ideally distributed for regional subsets of epizonal degree (Fig. 4a, Fig. 3b). This means that large numbers of samples are required in order to determine meaningful regional IC values in regions near the diagenesis-anchizone boundary. Therefore, for future research in very low-grade metamorphism, in order to map IC value contour patterns, sampling efforts (sample density) should be inversely proportional to the (anticipated) metamorphic grade.

Further tests (large-scale correlations, comparisons with quartz-bearing lithologies, etc.) have been performed and discussed elsewhere (Goy-Eggenberger, 1998). As a general conclusion, no correlation between IC and lithology could be detected. The IC values display large scatter, especially in the diagenesis and lower anchizone region without it being possible to relate the IC value to any obvious lithologic parameter such as calcite, clay or quartz content. Consequently, large numbers of samples are required in order to obtain meaningful ‘average’ IC values for any given region and for mapping isocryst patterns.

From contour map to nappe profile

The tectonic interpretation of the IC contour map (Fig. 5) requires projection of the data onto a classical, fold-axis perpendicular profile. As with the projection of folds and other structures, this construction is straightforward in principle: isocryst contours are projected with the same projection vectors as the nappe structures, leading to the isocryst patterns illustrated in Fig. 6. This simple projection method may introduce some artifacts in the projected isocryst pattern. The projection method assumes a cylindrical relationship between metamorphic grade and nappe structure. There is no possible test for this parallelism, however, since all evidence has been removed by erosion. On a much larger scale, it seems obvious, that neither isograd surfaces nor the nappe structures are cylindrical. To the west, the Morcles nappe can be correlated with rear parts of the Chaînes subalpines − a thrust nappe without any inverted limb and with significantly lower metamorphic grade than the Morcles nappe (Moss, 1992). Despite this uncertainty, and the observation that isocryst surfaces were not perfectly parallel to the nappe structure along strike, we assume such parallelism for the

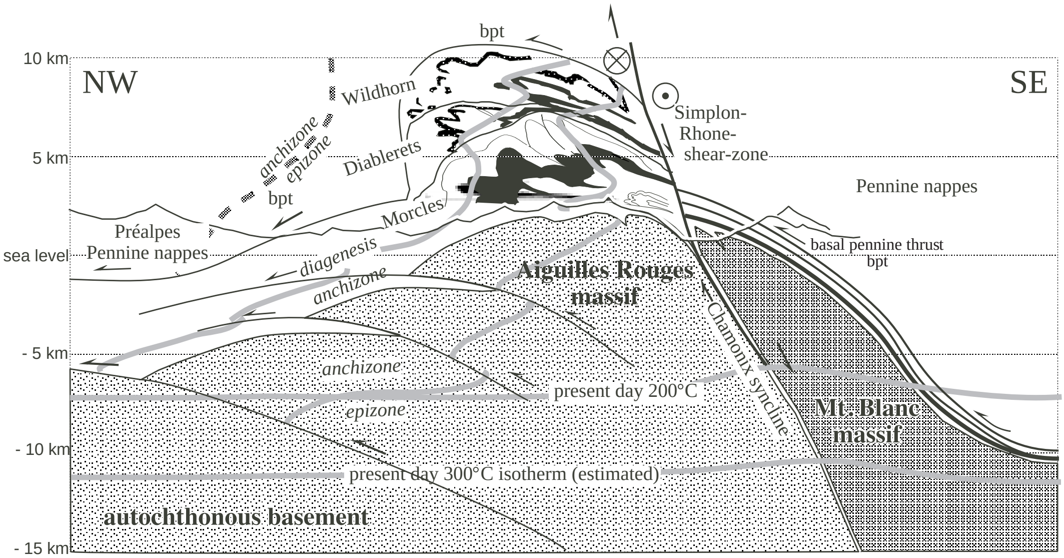

FIG. 6. Present-day geometry of the Morcles nappe and surrounding tectonic units. The Diablerets and Wildhorn nappes are modified from (Dietrich & Casey, 1989). Measured and extrapolated (at depth) 200 and 300°C isograd surfaces and hypothetical present-day isotherms are indicated. Note that this profile is constructed in the lower Rhone valley (Burkhard & Sommaruga, 1998), west of the out-cropping Morcles nappe, where the entire stack of Helvetic nappes projects above the topography, (cf. Fig. 1). This projection, however, has no influence on the relationship between nappe structures and isograd surfaces, which are all projected cylindrically along the same plunging fold-axis trend.

limited horizontal distances (~13 km) involved in projecting the nappe structure and isograd surfaces of the Morcles nappe.

Illite crystallinity vs. strain intensity

It is well known that plastic deformation is strongly favoured by an increase in temperature. In naturally-deformed limestones, intracrystalline deformation mechanisms are observed to be efficient and increasingly dominant at temperatures estimated between 200 and 300°C (Schmid, 1982; Groshong, 1988; Burkhard, 1990). It is no surprise therefore, that a very good overall correlation exists between IC and strain intensity: high plastic strains in the Helvetic nappes are restricted to areas lying within the epizone (Burkhard, 1986). This close correlation should not be used to infer that IC values depend on strain intensity, however (Flehmig, 1973; Flehmig & Langheinrich, 1974). Rather, both strain intensity and IC are strongly dependent on temperature.

Testing the potential influence of strain intensity on IC is not an easy task. Despite a large number of existing quantitative strain analyses in the Helvetic nappes (Durney, 1972; Ramsay & Huber, 1983; Siddans, 1983; Huggenberger, 1985; Burkhard, 1986; Ramsay & Huber, 1987), very few samples exist where both finite strain and IC have been measured, and there are no publications where these data are recorded. Samples suitable for strain analysis are restricted to a few specific stratigraphic horizons. For the case of an Eocene Breccia horizon (Burkhard & Badertscher, 2001), we are able to show that there is no correlation between IC and finite strain in the inverted limb of the Morcles nappe at Salanfe.

ACKNOWLEDGMENTS

Greatest thanks to m^3 (maître Küb.) are in order! Indeed, Bernhard Kübler followed this project with great interest as it evolved over the years. Our ideas were shaped in the course of innumerable hours of hard labour in his lab and seemingly endless disscussions, mostly at rue Emile Argand 11- rez. We take this opportunity to apologize for not following all his advice – we still believe in the Kübler Index as an

extremely useful, albeit not very precise, maximum thermometer.

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