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Introduction to the special issue: Diagenesis and Low-Grade Metamorphism

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This special issue of the Swiss Bulletin of Mineralogy and Petrology grew out of contributions to a symposium entitled "Diagenesis and Low-Grade Metamorphism", held in April 2001 at EUG XI in Strasbourg. This topical meeting was to commemorate two eminent Swiss Earth scientists: Martin Frey (1940–2000[†]), late Professor at the University of Basel, and Bernard Kübler (1930–2000[†]), late Professor at the University of Neuchâtel. Internationally known as pioneers and enthusiastic promoters of research into diagenesis and low-grade metamorphism, both these scientists recognized the importance of rock-forming processes near the Earth's surface and the broad value of scientific investigations in the archives of diagenesis and low-grade metamorphism. Martin Frey and Bernard Kübler were prominent in the International Geological Correlation Program IGCP Project 294 "Low-Grade Metamorphism" (1989–92), which initiated a very active decade of focussed research worldwide, with meetings and field excursions in Europe, New Zealand, the USA and Chile. Results of this decade of research were published in the book "Low-grade Metamorphism" edited by FREY and ROBINSON (1999), a sequel to the classic book on "Low Temperature Metamorphism" edited by FREY (1987).

Building on these foundations, the present issue once again presents advances in our understanding of diagenetic and low-grade metamorphic processes and the rock archives resulting from these. The seventeen contributions address a wide spectrum of topics, from theoretical principles and the presentation of new techniques, to comparative efforts and case studies in various tectono-metamorphic contexts.

An important debate in low-grade metamorphic studies is whether equilibrium is attained and at what scale; the validity of pressure and temperature estimates depends on such criteria. The equilibration and homogenization of minerals during low-temperature metamorphism is a complex and difficult process to quantify. Addressing this problem, LIVI et al. present three models of homogenization that explore the consequences of variable solid/fluid diffusivities. Progress towards equilibrium is estimated by means of the Fourier transforms of compositional transects of minerals. These yield, for the first time, a quantitative measure of the degree and nature of homogenization in low-grade metamorphic rocks. KISCH proposes a new method to detect calcite lattice preferred orientation (LPO) by use of the intensity ratios of reasonably strong near-basal and near-prismatic calcite X-ray reflections. This provides information on the development of a calcite LPO fabric during incipient cleavage development in low-grade metamorphic rocks rich in phyllosilicates and thus the intensity of rock deformation. Deformation plays an important role on the evolution of some very low-grade metamorphic parameters to determine P-T conditions.

One of the principal research topics in the field of diagenetic and low-grade metamorphic

[†] Obituaries in Schweiz. Mineral. Petrogr. Mitt. vol. 80, p. 351-355 (M. Frey) and vol. 81, p. 139-142 (B. Kübler).

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rocks is the study of illite, a dominant mineral phase in low-grade metapelites. XRD measurement of the "illite crystallinity" (KÜBLER, 1964; 1967a, b; 1968) or the determination of the full width at half-maximum intensity (FWHM) of the basal illite reflection (KÜBLER, 1990) are now formally referred to as the Kübler index or KI (GUGGENHEIM et al., 2002). Developed during the early 1960s as an exploration tool for the petroleum industry, the KI was initially used to recognize the geologically relevant window for oil generation. Subsequently, Bernard Kübler and Martin Frey, with their co-workers introduced and applied the KI to determine the grade of the diagenetic to low-grade metamorphism of argillaceous rocks. Although this empirical and pragmatic approach lacked a precise theoretical background and relates to many crystal-chemical changes in illite, the KI has since been widely and successfully applied in low-temperature metamorphic studies, particularly once computerized X-ray diffraction equipment became available. Current research by BRIME et al. shows that decomposition of X-ray diffraction data of illitic assemblages can be used to reveal more details of the complex metamorphic history. In their study in the Cantabrian Zone in Spain, where authigenic illite formed during low-grade metamorphism mixed with relics of altered detrital mica, decomposition of the illitic assemblage allows the recognition of several phases. There is some disagreement as to whether or not X-ray scattering domain sizes of clay minerals may be used to obtain information about crystal growth mechanism of clay minerals. In this volume conflicting views are represented and addressed. The contribution of BRIME and EBERL applies this concept to Paleozoic rocks of the Cantabrian Zone. Based on illite thickness distributions they postulate an early growth stage characterized by nucleation and growth and a later growth stage, which is surface controlled, without nucleation. In contrast, WARR and PEACOR caution that it is difficult to test models of crystal growth mechanism in natural systems on the basis of X-ray diffraction derived data. In addition to methodological problems, they emphasize that before being able to discuss crystal growth models, the effect of other variables such as temperature and strain need to be considered. JABOYEDOFF and THÉLIN introduce software called PATISSIER, which uses the "illite crystallinity" measurements to calculate a series of parameters, such as the number of consecutive illite layers or the swelling interlayer content. This program makes it possible to retrieve new information from X-ray diffractograms of previously analyzed samples.

Despite our awareness of many complexities in the crystal-chemical evolution of clay mineral species, which lie behind "illite crystallinity", the Kübler index as such has certainly not lost its attractiveness. This method is applied, along with numerous other tools, to evaluate the conditions of low-grade metamorphism in case studies from the South Portuguese Zone of the Iberian Variscan Belt (ABAD et al.), the Swiss Alps (ÁRKAI et al. and MULLIS et al.), the Eastern Taurus in Turkey (BOZKAYA et al.), and the Chilean Coastal Range (BELMAR et al.), or using the Weber index in the study from the Montagne Noire in France (WIEDERER et al.).

In addressing low-grade metamorphic conditions of metabasalts, the wide compositional variations of the minerals pumpellyite, chlorite and epidote is a major concern. Various parameters have been suggested to be responsible for the chemical variation of these minerals. By calculating phase equilibria diagrams for whole rock composition, POTEL et al. address this problem and demonstrate that the chemical composition of these minerals is controlled by the assemblage in which they occur, as well as the temperature and oxygen fugacity. Their results question in part the facies division of subgreenschist facies rocks, which is largely based on mineral assemblages.

Based on TEM observations, FERREIRO MÄHLMANN et al. show that coalification and graphitization of carbonaceous material in Bündnerschiefer of Switzerland proceeds in several continuous steps that are characteristic of diagenetic and low-grade metamorphic rocks. They emphasize that strain has a catalytic effect on the evolution of organic matter and that it can locally be more important than temperature. The role of strain on phyllosilicate properties and organic matter is also emphasized by ÁRKAI et al. in their case study in the Helvetic Alps. Strain and/or hydrothermal fluids are recognized as major factors that locally control vitrinite reflectance, "illite crystallinity", mean crystallite thickness and lattice strain data along thrust planes. The paper by ABART and RAMSEYER also stresses the importance of deformation on oxygen isotope exchange between quartz and a fluid during low-grade metamorphism. In a case study from the Glarus thrust, dehydration of the footwall resulted in an oxygen isotope exchange in deformed areas above the thrust. ABAD et al. demonstrate that the Kübler index and other clay mineral data from sandstones and shales provide important information on the role of fluids and the time factor relevant to the metamorphic reactions in various lithologies. Over a limited temperature range, MULLIS et al. investigated the relationship between the "illite crystallinity", homogenization temperatures of fluid inclusion, and the Na-K contents at the high diagenesis-anchizone boundary of the Central Swiss Alps; this study emphasizes the role of bulk rock composition on the Kübler index. BOZKAYA et al. use several methods to detect stratigraphic hiati in low-grade metamorphic profiles in the Taurus mountains in Turkey, with implications on the regional tectono-metamorphic history.

Low-grade metamorphic processes are important also in shallow hydrothermal and contact metamorphic aureoles, where it can be difficult to distinguish them from regional low-grade metamorphism. In a metabasitic sequence of the western Sierra Nevada in California, the regional low-grade burial metamorphic history and the local hydrothermal event could be discriminated by SPRINGER and DAY who carefully studied textural and chemical differences between amphiboles. BELMAR et al. show that the effects of contact metamorphism and hydrothermal alteration in the metapelitic series of the Coastal Range of Chile can be discriminated when Kübler index and organic matter reflectance data are compared with the background data on the regional low-grade metamorphism.

WIEDERER et al. describe the evolution of a low-grade metamorphic core complex in the Montagne Noire in France and its consequences on the tectonic evolution of this area. The conodont alteration index is used and compared with "illite crystallinity" data. Finally this special volume reconsiders a question Martin Frey had pursued for years: Is chloritoid in the Bündnerschiefer of Switzerland the result of a prograde reaction or a break-down (retrograde) reaction of a former high-pressure mineral assemblage? RAHN et al. show that chloritoid formed in the Helvetic and Penninic domain of the Central Alps due to late-Alpine greenschist facies metamorphism as a result of continent-continent collision.

We would like to see this special issue and commemorative volume as a snapshot of the advancing knowledge of low-grade metamorphism. We hope that this collection of contributions will stimulate further research into low-grade metamorphic processes, just as the pioneering work of Martin Frey and Bernard Kübler has done over the past four decades.

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