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► **To cite this version:**

Rafael Ferreiro Mählmann, Sébastien Potel, Lan Nguyen-Thanh, Rainer Petschick, Meinert Rahn. Determination of a normal palaeo–geothermal gradient comparing the reaction progress of clay minerals calibrated with organic maturity indices Dedicated to the 90 th birthday of Hans Krumm. EURO-CLAY 2019 International conference on clay science and technology, Euroclay 2019 committees & Clay Minerals Society, Jul 2019, Paris, France. hal-04297140

HAL Id: hal-04297140

<https://hal.science/hal-04297140>

Submitted on 5 Dec 2023

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Determination of a normal palaeo-geothermal gradient comparing the reaction progress of clay minerals calibrated with organic maturity indices

Dedicated to the 90th birthday of Hans Krumm

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Based on the large data set of the authors from different orogenic belts, geodynamic setting with a normal geothermal gradient were selected. In these studies clay mineral versus organic matter correlations show in the vitrinite reflectance (VR)/Kübler Indices (KI) plot from Ferreiro Mählmann et al. (2012) gradients with “moderate (normal) geotherm” conditions. Using maturity modelling and clay mineral reaction progress studies a normal temperature gradient of 25 to 35 °C was estimated.

In the Lower Austroalpine (Eastern Switzerland) a 20 myr lasting metamorphic overprint caused a clay mineral (CM) – organic matter (OM) thermal equilibrium among the indices used (Ferreiro Mählmann, 2001) establishing a significant gradual sensitive correlation. For New Caledonia, an identical correlation has been published (Potel et al., 2006). There, prior to re-equilibration of the CM/OM sediments underwent a high-pressure subduction event as detected by studying the indices to determine maturity, temperature and grade of diagenesis to incipient metamorphism. The CM/OM indices are in equilibrium or close too it, showing nearly identical thermal estimations despite being subject of a pluri-facial metamorphic history. In the eastern Helvetic Alps (Rahn et al., 1995) and Northern Calcareous Alps (Petschick, 1989, Krumm et al., 1988) similar correlations were found. Comparison between different regions became possible using KI standardization and data discrimination as recommended by Ferreiro Mählmann et al. (2012) and Warr and Ferreiro Mählmann (2015). In both parts of the Alps a poly-thermal history of short durations (5 to 10 Ma) caused similar CM/OM trends, but dis-equilibrium is shown by lower significant regression statistics.

Compiling the results, the following correlations can be calculated for a moderate geotherm (55 to 75 mWm²) at normal temperature gradient condition (25 to 35 °Ckm⁻¹):

$VR R_{max}\% = 1.445 KI^{-0.885}$, $KI = \Delta^{\circ}2\Theta$, $r^2 = 0.88$ (limited to values between 0.2 to 0.6 $\Delta^{\circ}2\Theta$).

This result confirms the correlation published for normal gradients from the Lower Austroalpine (Ferreiro Mählmann, 2001) between KI grades of 0.19 to 0.48 $\Delta^{\circ}2\Theta$:

$VR R_{max}\% = 8.6 - 17.7 (KI) + 11.1 (KI)^2$, $r^2 = > 0.8$ (between 0.80 to 0.95 for different areas)

With increasing depth (z) a VR gradient of $1.4 \pm 0.2 R_{max}\%km^{-1}$ is determined and a KI gradient of $0.09 \pm 0.002 \Delta^{\circ}2\Theta km^{-1}$ is observed. The methodical limit is given by VR at $9.1 R_{max}\% = KI$ at $0.125 \Delta^{\circ}2\Theta$ (representing the technical limit of the XRD measurement device).

It is to conclude that a normal geotherm can be described by the VR/KI correlation, while even different heating episodes may cause the same VR/KI regression. For detection of a poly-phase or pluri-facies thermal history many CM/OM indices with very different kinetics have to be used. This is e.g. demonstrated by the strongly differing amount of smectite content at equal VR/KI values versus structural depth.