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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 Ferreira 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 (Ferreira 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 Ferreira Mählmann et al. (2012) and Warr and Ferreira 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 mWm⁻²) 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 (Ferreira 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.