UPLIFT OF THE MALÉ KARPATY MTS. VARISCAN BASEMENT

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Abstract. The culmination reaction paths have steep slopes (dP/dT ≈ 89-121 bar/K) and later diffusion processes run during decompression cooling (dP/dT ≈ 62-68 bar/K). The annealing estimates indicate ca. 0.10-0.53 garnet mass fraction transfer during cooling. The depth and heating rate data ($4*10^{-5}$ ^{o}C/y) correspond to burial rate of 1-2 km/Ma. Cooling rates calculated from garnet diffusional zonality (~4.7-94 ^{o}C/Ma) approximate the exhumation rate at ca. 0.2-3.8 km/Ma. The data confirm different cooling scenarios for tectonicaly controlled rapid uplift end erosion.

Key words: reaction slope, cooling rate, uplift trajectories, West Carpathians.

The Malé Karpaty Mts. (M.K.) play a specific and important role in the Eastern Alpine and Western Carpathian relationship and correlation as they bear some typical geological features of both mountain systems, but they have a prevailing Carpathian influence (Maheľ, 1983). Recent petrological research indicates complex development of this core mountain mass (Dyda, 1994, 2000). This requires the assumption of several superimposed nappe units consisting of pre-Alpine crystalline basement with its Mesozoic cover (Plašienka et al., 1991). The reconstruction of the Hercynian orogenic cycle is complicated because of Alpine tectonic overprinting. Fragments of Hercynian structure were incorporated into new paleoalpine units (Bezák et al., 1998).

The major whole rock reactions encountered in the rocks represent terminal stability of staurolite which occurs at culmination temperature and pressure in sillimanite stability field. Staurolite remove from the assemblages is accompanied with progressive growth of garnet and sillimanite in the assemblage St+Ms+Bt+Grt+Sil+Pl+Qtz, where important kyanite rests are consumed and eventually disappear. During decompression stages kyanite → sillimanite reaction boundary is crossesd and kyanite presence is replaced by fibrolitic sillimanite. Kyanite is almost completely resorbed and significant unresorbed kyanite rests remain only in some assemblages.

To infer the P-T data of metamorphic thermal culmination and retrograde closing conditions different sets of calibrated mineral equilibria have been used to determine the position of the rock sample in the P-T coordinates. The lowest variance mineral assemblages of the studied paragneisses include St, Bt, Grt, Ms, Pl, Ilm, Sil, Qtz. The metamorphic whole rock reactions among these minerals are represented formally by a system of linear equations for components chosen. The mineral abundance in paragneisses and their compositions can thus be arranged in numerical form to express the whole rock metamorphic reactions. Reaction stoichiometry gives consequently a P-T vector determining the slope $dP/dT = \Delta S/\Delta V$ of the culmination reaction paths A1, A2 and specifies the reaction slopes of closing retrograde exchange processes (B1, B2).

Sample KB-5. Core

$$1\ St + 0.263\ Ms + 0.970\ Pl + 1.730\ Qtz = 8.135\ Sil + 1.398\ Grt + 0.223\ Bt + 0.156\ Ilm + 1.765\ H_2O \quad (A1)$$

reaction path - slope $dP/dT = 121.7$ bar/K

KB-5. Rim

$$1\ St + 985.1\ Sil + 427.4\ Ilm + 73.7\ Bt + 2889\ Qtz = 75.75\ Ms + 245.4\ Grt + 1133\ Pl \quad (B1)$$

reaction path - slope $dP/dT = 62.9$ bar/K

Sample KB-17. Core

$$1\ St + 0.323\ Ms + 0.555\ Pl + 2.431\ Qtz = 8.037\ Sil + 1.266\ Grt + 0.296\ Bt + 0.159\ Ilm + 1.773\ H_2O \quad (A2)$$

reaction path - slope $dP/dT = 89.3$ bar/K

KB-17. Rim

$$1\ St + 48.67\ Ms + 172.9\ Grt + 669.8\ Pl = 643.6\ Sil + 307.4\ Ilm + 50.67\ Bt + 1658\ Qtz \quad (B2)$$

reaction path - slope $dP/dT = 68.5$ bar/K

The rock decompression accompanied with heating gives a stoichiometric reaction with negative reaction slope and decompression during cooling is characterised by a positive one. The changes in modal abundance and textural features of mineral growth or reactant consumption along this P-T vector determine the reaction extent as well. Different whole rock reaction stoichiometry thus permits numerical solution for rock cooling along different reaction path on the post culmination metamorphic trajectories. The calculated reaction stoichiometry compared with microscopic study of the samples thus assures the resemblance to the calculated whole rock reaction that actually run in the rock. Both petrological approaches are consistent in the studied assemblages and the constraints are placed on the calculated P-T path. Processes that effect modal changes and element distribution among minerals are strictly path dependent and reflect P-T conditions along the reaction path.

The staurolite decomposition reactions and the rock mikrostructure confirm the progressive growth of Grt, Sil in the assemblages and thus form the important feature in the interpretation of the post culmination trajectory. Careful examination of garnet did not prove any important inclusions as they have been homogenised during culmination metamorphic process and existing chemical zonation is clearly related to diffusional processes that have occurred during retrogression. Thus the phase relations of the assemblages examined give reliable constraints on the culmination conditions and retrograde P-T path . The steep slopes of the whole rock reactions are consistent with their dehydration nature and water quantity released. The difference in entropy between structurally bound H_2O and H_2O in fluid phase is considerably large and thus the reaction paths A1 and A2 are quasi vertical (dP / dT = 121 bar/K and 89 bar/K respectively).

Calculated approximative P-T trajectories, in the range of 570-650 ^{o}C and 3.5-6.1 Kbar, express the first order tectonic motion and represent specific uplift conditions of the particular tectonic blocks. Some of the samples express uplift trajectories determined dominantly by decompression during cooling while the others may present more isothermal, probably rapid decompression during tectonicaly driven uplift period. The microscopic appearance of garnets and no occurrence of significant retrograde mineral domains, all confirm the individuality of these basement tectonic blocks.

These trajectories are consistent with regional metamorphic environment. The maximum pressure experienced by the rocks implies that the overburden immediately following the metamorphic culmination stage was of the order of 16 - 20 km. Intrusion of the granodioritic rocks during metamorphic culmination and later might have heated the rocks to different temperatures because of their different ambient geological positions. It is worth emphasising that not all rock samples studied reveal the same P-T histories and confirm exceedingly complex geological development of the area.

The culmination temperatures produced the equilibrium mineral assemblage with uniform Fe-Mg distribution. The compositional changes in the profile of garnet at the biotite-garnet couple interface served as a primary source of data for petrological cooling rate estimates. As the post culmination cooling starts, the equilibrium conditions change with decreasing temperature and drives the diffusion exchange of mobile components at the grain interface boundaries. The diffusion process continue till the retrograde closure temperature froze in the compositional changes in garnet realised during cooling. The diffusion garnet profiles were then normalised for Mg concentrations as a function of normalised distance from the Bt-Grt edge to obtain the shape of the garnet compositional profile. Diffusion

formalism and equations of Lasaga (1983), Lasaga et al. (1977) served as the methodical tool and computation basis for petrological cooling rates estimates. Using pre-exponential factor D_0 and activation energy for diffusion Δ E* (Elphic et al., 1985; Lasaga, 1983), cooling rates in the range from 4 to 94 ^{o}C/Ma.have been calculated.

Korikovskii et al., (1984) present for the whole M.K. metamorphic region the pre culmination trend as isobaric heating recrystallisation process characterized by pressures ca. 3.3 Kbar and temperatures extent of ca. 350-550 ^{o}C. Thus the isobaric heating presupposed by these authors runs in progressive pre culmination metamorphic stages even in the And stability field and the P-T trends would be typical of contact metamorphic terrane where crust has had considerable heat added by the addition of magmas. Isobaric heating might have been confirmed by garnet zonality development, reaction sequences and reaction slopes in equilibrium assemblages. Anyhow, the crucial contact metamorphic assemblages are missing in the Bratislava massive basement area Although there is some scatter in the studied P-T paths, most of the paths show simultaneous decompression and cooling, consistent with the P-T data, whole rock reaction paths their slopes and the reaction sequence.

The regional metamorphism in the area has been documented earlier (Dyda, 1994, 2000) by slow rate of garnet nucleation 2.9 $*10^{-8}$ cm^3/s - $1.0*10^{-7}$ cm^3/s, the reaction temperature overstep of ca. 0.15 ^{o}C/y and the modeled progressive heating rate trends of $4*10^{-5}$ ^{o}C/y, they are in good agreement with the characteristics of the regional metamorphic thermal regime.

The regional recrystallisation products are usually subjected to prolonged cooling after thermal culmination ceased and processes of the assemblage ripening and diffusion adjustment operate. The diffusion processes and the annealing mass transfer are temperature and time dependent mineral changes. The calculated values of the post culmination garnet mass transfer (X = 0.10-0.53) are in particular samples significantly different documenting thus different annealing processes that lasted after the thermal culmination was attained and completed (Dyda, 2000).

The metamorphic trajectories represent “clockwise” post culmination decompression cooling , that is typical of regions that have undergone crustal thickening followed by thermal relaxation and are principally different from isobaric heating regime trajectories. The early part of the trajectory is a heating phase through the kyanite stability field and is interpreted to result from regional metamorphism. The pressure peak was followed by slightly

heating period and decompression cooling. As there is no reheating or significant retrogression signs the major Variscan orogeny is believed to have been caused by collision of the continental fragments. The differences in peak temperatures, pressures and cooling might show approximate position of the units along P-T at various stages of convergence followed by thermal relaxation and are not considered to represent some major fundamental differences in the tectonic setting.

Metamorphic grade increased to the peak metamorphic assemblages post-dating and eradicating earlier metamorphic assemblages and fabrics and thus the culmination mineral assemblage document single Variscan metamorphic event with different intensity of post culmination retrograde changes on the scale of metamorphic crystalline core. The Alpine tectono deformation processes destroyed and displaced the crystalline basement units and emplaced previously assembled complexes into new tectonic structural positions.

The differences in peak temperatures, pressures and cooling rates predict discontinuities in P and T in crustal depths and are considered to form an additional evidence that the post metamorphic faulting juxtaposed the rock blocks of different P-T characteristics and the fragmented basement area was a locus of major tectonic activities.

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