

DENSITY LIMITS IN METAPELITIC RECRYSTALLIZATION

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Abstract: Plotting densities (ρ^{ROCK}) versus atom packing of the metamorphic rocks (ϕ^{ROCK}) and their fused rock glasses gives the lines with the slope of $a=21.6\pm 0.28$. This extraordinary slope determines the recrystallization density changes influenced by original mineral composition and expresses the rock densification trajectory and density limits. The chemical composition and mineral assemblage approximates the fused rock glass density, rock density and their atom packing arrangements both on experimental and numerical basis.

Key words: rock glasses, density, atom packing, recrystallization.

Introduction

Metamorphic rock recrystallisation is, in first approximation, an isochemical process associated with appearance of new equilibrium phases, redistribution of chemical components and rock dehydration. Accompanied volume changes during metamorphic reaction progress attribute changes in metamorphic rock density.

French (1976) emphasised the importance of the relationship between silicate rock density and composition of igneous and metamorphic rocks. His empirical density formula $D_c^F = 2.6 [2 N_o / (4 N_{\text{Si}} + 3 N_{\text{Al}})]^{1/2}$ has been used as a factor equivalent to 'normative' rock density. Comparison of this calculated 'normative' density based on the chemical composition of a particular rock with its measured density offered the specific data for recrystallisation definition and interpretation of metamorphic pressures and temperatures. Changes of P-T parameters and the reaction recrystallisation progress cause the density change and the reaction products have eventually higher density with respect to the former mineral assemblage. Calculated empirical rock density using anhydrous basis remains however the same. Thus the densification of a metamorphic rock runs on its specific composition trajectory attaining consequently higher atom packing in the metamorphic reaction products.

In the present model, it has been presumed, that if chemical composition of metamorphic rock, its density and the reference density unit are known, the rock density change may be calculated and the specific densification rock trajectory numerically approximated. The non-crystalline solid (NCS) - fused rock glass, has been chosen as a density reference unit and its density compared with the density calculated from the molar volumes of the rock forming oxides. This approach allows to follow the specific empirical density range for a particular metamorphic rock and makes possible to expect the density limits based on the presumed atom packing index in the metamorphic rock.

Methods and results

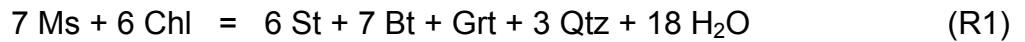
The powdered rock samples were melted in the quenching furnace in argon atmosphere for 4 hours at 1200 °C. No major chemical changes have been expected. The densities of fused rock glasses and rocks have been determined by sink-float method (see e.g. Proks, 1974; Fletcher, 1979). Liquid solution of bromoform and methanol with an ideal linearity between index of refraction and its density served for direct comparison with the density of the "swimming" solid phase. Reproducibility of a measurement was in the range of ± 0.006 to 0.01 g/cm^3 . Standard deviation (S) of 15 measurements represents consequently the rock sample homogeneity. The density data are given in Tab. 1. The density of the particular rock sample (ρ_{ROCK}), its fused rock glass equivalent (ρ_{GLASS}) and ion diameters given by Shannon and Prewitt (1969) were used as the basic enter data for packing index calculations of rock sample (ϕ_{ROCK}), fused rock glass (ϕ_{GLASS}) and calculated non-crystalline solid (NCS) equivalent (ϕ_{NCS}). As the uncertainty in co-ordination number for certain ions in rock and glass persists (e.g. Al^{IV} and Al^{VI}), the same ion volumes have been used for simplified comparison. For calculation of the non-crystalline solid density (ρ_{NCS}) the recalculated molar volumes of rock forming oxides and formula

$$\rho_{\text{NCS}} = \frac{\sum M_i X_i}{\sum V_i X_i} \quad (1)$$

of Bottinga and Weil (1970) have been used, where M_i stands for molecular weight, X_i for mole fraction and V_i for molar volume of the oxide i . The correlation between measured density of the fused rock glass (ρ_{GLASS}) and density of the NCS (ρ_{NCS}) calculated on the basis of its chemical composition is high ($r = 0.97$).

Thus the present model is based on the rock with corresponding calculated chemical composition. The model samples then resulted in the calculation of the model rock properties.

The reactants of the low grade metamorphic reaction



have overall density of 2.71 g/cm^3 . After the reaction has been completed the density change is $\Delta\rho = 0.62$ what corresponds to the volume reduction of 18.6 %. Reaction progress accompanied with water release represents significant volume change at the crossing of the isoreaction line. However, the extent of the volume change may not indicate the metamorphic grade as the original mineral assemblage has significant contribution to volume changes in rock.

If the model rock with different modal ratio Ab / Qtz

I1	Ab 20	Qtz 80	→	Qtz 85.4	Jd 14.6	$\Delta V = 3.6$
I2	Ab 40	Qtz 60	→	Qtz 70.9	Jd 29.1	$\Delta V = 7.7$
I3	Ab 60	Qtz 40	→	Qtz 56.3	Jd 43.7	$\Delta V = 10.8$

is subjected to recrystallization according to the reaction



the different modal composition gives different volume reduction in the rock expressed in Fig.1. as the density and packing index change. The more complex metapelitic assemblage with modal composition 58 mod.% Chl, 36 mod.% Ms and 6 mod.% Qtz corresponds with the reactants of the reaction



After completing the reaction the density changes from 2.73 to 2.81 g/cm^3 . With increased pressure cordierite may decompose to 61 mod.% Alm, 27 mod.% Sil and 12 mod.% Qtz and the volume decrease is 32 %. In presence of Bt, cordierite decomposition may proceed according to reaction



and from the previous Chl+Ms+Qtz assemblage a new one with Alm+Kfs+Sil is produced. The relevant volume change is 20.4 %. However, these progressive reactions are far more complex in nature determined by original mineral assemblages and leading to the reduction of the empty space in the rock. Clearly, rocks with simple mineral compositions are less suitable in this approach than the polyphase mineral assemblages. More suitable are the rocks with complex mineral reaction changes and solid solution phenomena during progressive recrystallization that brings the rocks to significant empty space reduction and denser mineral rock structures that may be limited by high ion space filling.

Tab. 1. Densities of the Malé Karpaty Mts. metapelites (ρ_{ROCK}), their fused rock glasses (ρ_{GLASS}), non crystalline solid (ρ_{NCS}) units and their corresponding packing indices (ϕ). D_c^F is density calculated according to French (1976) formula $D_c^F = 2.6 [2 N_o / (4 N_{\text{Si}} + 3 N_{\text{Al}})]^{1/2}$.

Sample	ρ_{ROCK}	S	ρ_{GLASS}	ρ_{NCS}	D_c^F	ϕ_{ROCK}	ϕ_{GLASS}	ϕ_{NCS}
2.	2.757 ± 0.023		2.48	2.50	2.72	60.8	54.9	55.3
4.	2.809 ± 0.024		2.57	2.55	2.74	61.2	56.0	55.7
5.	2.700 ± 0.017		2.47	2.49	2.73	59.7	54.6	55.1
6.	2.690 ± 0.024		2.49	2.48	2.70	59.7	55.2	55.1
7.	2.765 ± 0.027		2.57	2.57	2.77	60.0	55.7	55.8
8.	2.742 ± 0.010		2.54	2.55	2.75	59.8	55.5	55.7
9.	2.805 ± 0.054		2.59	2.60	2.77	60.5	55.9	56.1
11.	2.747 ± 0.028		2.49	2.52	2.71	60.4	54.4	55.4
12.	2.750 ± 0.016		2.61	2.62	2.77	59.1	56.1	56.3
14.	2.798 ± 0.013		2.56	2.56	2.73	60.9	55.8	55.7
17.	2.862 ± 0.046		2.55	2.54	2.74	62.5	55.7	55.7
18.	2.757 ± 0.016		2.54	2.55	2.77	60.2	55.5	55.7
19.	2.690 ± 0.030		2.40	2.42	2.70	60.5	54.0	54.4
KB-1.	2.787 ± 0.038		2.55	2.55	2.73	60.8	55.7	55.7
KB-2.	2.792 ± 0.080		2.56	2.57	2.75	60.7	55.8	55.9
KB-3.	2.727 ± 0.024		2.56	2.55	2.73	59.5	55.8	55.7
KB-4.	2.758 ± 0.016		2.59	2.60	2.76	59.6	56.0	56.1
KB-5.	2.825 ± 0.036		2.62	2.63	2.78	60.5	56.3	56.4

The basic assumption of the present model was that the given rock approaches on its specific trajectory its density maximum that is given by original mineralogical composition and its atom packing index. The minimum density of a rock is defined by non-crystalline solid units (NCS) where ρ_{NCS} is obtained numerically from chemical composition using recalculated molar volumes of the rock forming oxides in formulation of equation (1). Densities of synthetic diopside, akermanite and anorthite glasses are in good agreement with the calculated density values. Measured densities of fused rock glasses (Tab.1.) with those calculated from composition have high correlation approving the reliability of the calculated ρ^{NCS} . The NCS value and the determined densification trajectory slope ($a = 21.6 \pm 0.28$) in density and packing index coordinates determine the density changes in metamorphic assemblages.. If dense rock structure with $\phi \approx 0.7$ is taken to be the limit and the density minimum is given by ρ^{NCS} then rock density limits may be approximated by calculation.

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