A cautionary note on amphibole geobarometry

José F. Molina[1], Aitor Cambeses[1], Juan A. Moreno[2], Irene Morales[1], Concepción Lázaro[1], Pilar Montero[1], Fernando Bea[1]

1: Department of Mineralogy and Petrology, University of Granada, Spain

2: CICTERRA, CONICET, Universidad Nacional de Córdoba, Argentina

Introduction

The classical Al-in-hornblende geobarometer has been very successful in determining emplacement depths of metaluminous cordilleran granitoid plutons that bear the buffering assemblage at near solidus conditions: hornblende-biotite-plagioclase-orthoclase-quartz-sphene-two Fe-Ti-oxides (or one Fe-Ti oxide + epidote)-melt-vapor (e.g., [1-3]).

Ridolfi et al. [4] and Ridolfi and Renzulli [5] derived empirical amphibole-only barometric expressions that could be potentially applied to a larger number of phenocrystic assemblages from volcanic rocks. However, Erdmann et al. [6] claimed that these geobarometers are inaccurate and can give untenable estimates.

A graphical geobarometer based on the partitioning of Al and Si between amphibole and plagioclase was derived by Fershtater [7] using amphibole-plagioclase compositional pairs of rocks from the Urals. More recently, Molina et al. [8] calibrated an empirical expression based on experimental data that can be applied to igneous and high-grade metamorphic rocks.

In order to compare the reliability of amphibole-only and amphibole-plagioclase barometry, in this work, we test the performance of the expressions of Ridolfi and Renzulli [5] and Molina et al. [8], using an experimental data set compiled from the literature that has been recently published by Molina et al. [9].

Precision and accuracy of the amphibole-only geobarometers

Experimental data set

The experimental data set compiled from the literature by Molina et al. [9] contains 154 data that fulfill the requirements of use of the amphibole-only barometric expressions by Ridolfi and Renzulli [5]: atomic Mg-number, $Mg/(Mg+Fe^{2+})$ in amphibole greater than 0.5.

Temperature ranges from 650 to 1050ºC and pressure from ca. 0.5 to 15 kbar (**Fig. 1**).

Test of the expressions

The test carried out on the amphibole-only geobarometers from [5] reveals a poor performance, tending expressions 1A, 1B and 1C to underestimate pressures at $P > 5$ kbar (**Fig. 2**), whereas the expressions 1D and 1E tend to overestimate pressures (**Fig. 3**).

Test of the Al/Si amphibole-plagioclase geobarometer

Experimental data set

We tested the amphibole-plagioclase geobarometer from Molina et al. [8] using the experimental data set by Molina et al. [9]. We noted a better performance for Qz-Amp-Pl and Ol-free Cpx-Amp-Pl assemblages with the amphibole compositional limits (23O; normalisation to 13-CNK): total Al > 1, Ti: 0.05-0.27 and Fe^{3+}<1.07.

The number of amphibole-plagioclase compositional pairs in the selected data subset are 30 for Qz-Amp-Pl assemblages and 22 for Ol-free Cpx-Amp-Pl assemblages, with a total of 47 observations.

For the Qz-Amp-Pl assemblages, temperature ranges from 650 to 880ºC and pressure from ca. 2.5 to 13 kbar (**Fig. 4**), whereas for the Ol-free Cpx-Amp-Pl assemblages they ranges from 700 to 980ºC and from ca. 0.5 to 15 kbar.

Test of the expression

The test performed on the amphibole-plagioclase geobarometer for the for the Qz-Amp-Pl and Ol-free Cpx-Amp-Pl assemblages work well with a relations of calculated versus experimental pressures very close to the one-to-one line (**Fig. 5; Tables 1-3**).

The precision as estimated by the Root MSE parameter (see discussion in Molina et al. [8] and [9]) is close to ±1.7 kbar for the Qz-Amp-Pl assemblages and to ±1.4 kbar for the Ol-free Cpx-Amp-Pl assemblages (**Tables 1 and 2**); the expression yields an overall precision of ±1.6 kbar for the full data set (**Table 3**).

Conclusions

In accordance with Erdmann et al.[6], the test reveals unsustainable pressure estimates with the amphibole-only barometric expressions from Ridolfi and Renzulli [5]. Therefore we recommend to don't use the amphibole-only barometric expressions, calibrated for volcanic rocks, because of their very poor performance.

By contrast, the amphibole-plagioclase geobarometer from Molina et al. [8] works well for Qz-Amp-Pl and Ol-free-Cpx-Amp-Pl assemblages and yields a precision better than ±1.7 kbar. The good performance of the amphibole-plagioclase geobarometer when applied to these mineral assemblages suggests that the partitioning of Al and Si between amphibole and plagioclase buffered by reactions involving Qz+Amp+Pl and Cpx+Amp+Pl. However, it is important to emphasize that the expression should be used for amphibole having > 1 apfu total Al, 0.05-0.27 apfu Ti: and < 1.07 apfu Fe^{3+} to to ensure more reliable pressure estimates.

References

1. Hammarstrom, J.M., and Zen, E., 1986. Aluminum in hornblende, an empirical igneous geobarometer. American Mineralogist. American Mineralogist 71, 1297–1313.

2 Schmidt, M.W., 1992. Amphibole composition in tonalite as a function of pressure: an experimental calibration of the Al-in-hornblende barometer. Contributions to Mineralogy and Petrology 110, 304–310.

3. Anderson, J.L, and Smith, D.R., 1995. The effects of temperature and fO2 on the Al-in-hornblende barometer. American Mineralogist 80, 549-449.

4. Ridolfi, F., Renzulli, A., and Puerini, M., 2010. Stability and chemical equilibrium of amphibole in calc-alkaline magmas: an overview, new thermobarometric formulations and application to subduction-related volcanoes. Contributions to Mineralogy and Petrology 160, 45–66.

5. Ridolfi, F., Renzulli, A., 2012. Calcic amphiboles in calc-alkaline and alkaline magmas: thermobarometric and chemometric empirical equations valid up to 1130 °C and 2.2 GPa. Contributions to Mineralogy and Petrology 163, 877–895.

6. Erdmann, S., Martel, C., Pichavant, M., and Kushnir, A., 2014. Amphibole as an archivist of magmatic crystallization conditions: problems, potential, and implications for inferring magma storage prior to the paroxysmal 2010 eruption of Mount Merapi, Indonesia. Contributions to Mineralogy and Petrology 167, 1016

7. Fershtater, G.B., 1990. Empirical hornblende-plagioclase geobarometer. Geokhimiya 3, 328–335.

8. Molina, J.F., Moreno, J.A., Castro, A., Rodruiguez, C., and Fershtater, G.B., 2015. Calcic amphibole thermobarometry in metamorphic and igneous rocks: new calibrations based on plagioclase/amphibole Al-Si partitioning and amphibole-liquid Mg partitioning. Lithos 232 286–305.

9. Molina, J.F., Cambeses, A., Moreno, J.A., Morales, I., Montero, P., and Bea, F., 2020. A reassessment of the amphibole-plagioclase NaSi–CaAl exchange thermometer with applications to igneous and high-grade metamorphic rocks. American Mineralogist, in press, https://doi.org/10.2138/am-2020-7400

FIGURES

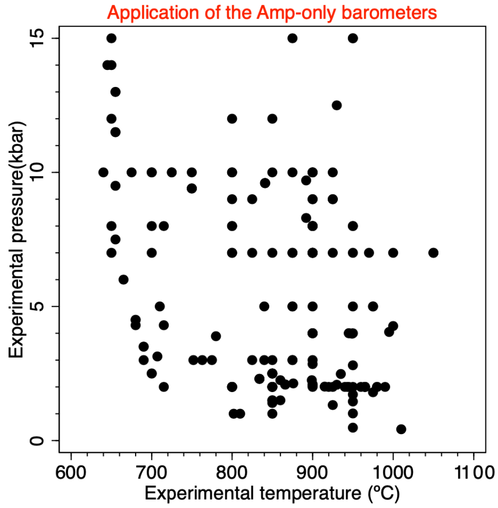

Figure 1. Experimental runs with amphibole having Mg/(Mg+Fe^{2+}) > 0.5. Data compiled from the literature by Molina et al. [9].

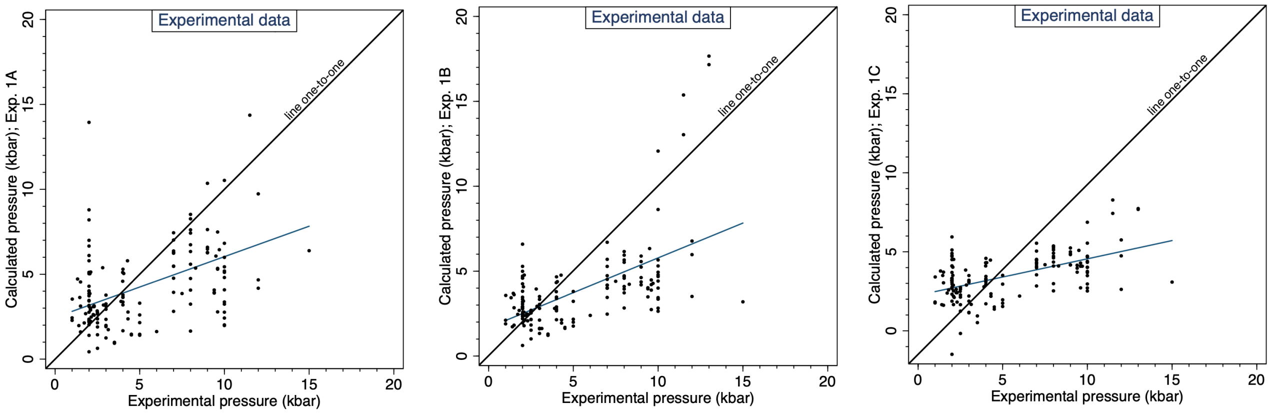

Figure 2. Calculated versus experimental pressures. Pressures estimated with the amphibole-only expressions 1A, 1B and 1C by Ridolfi and Renzulli [5]. Data compiled from the literature by Molina et al. [9].

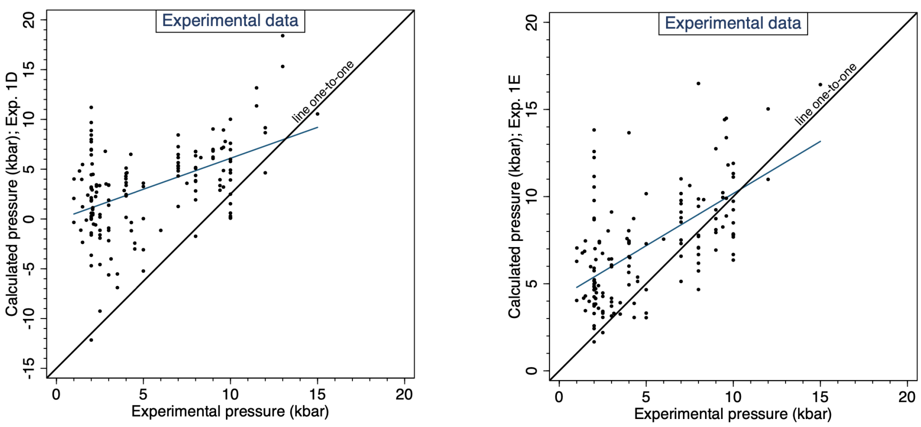

Figure 3. Calculated versus experimental pressures . Pressures estimated with the amphibole-only expressions 1D and 1E by Ridolfi and Renzulli [5]. Data compiled from the literature by Molina et al. [9].

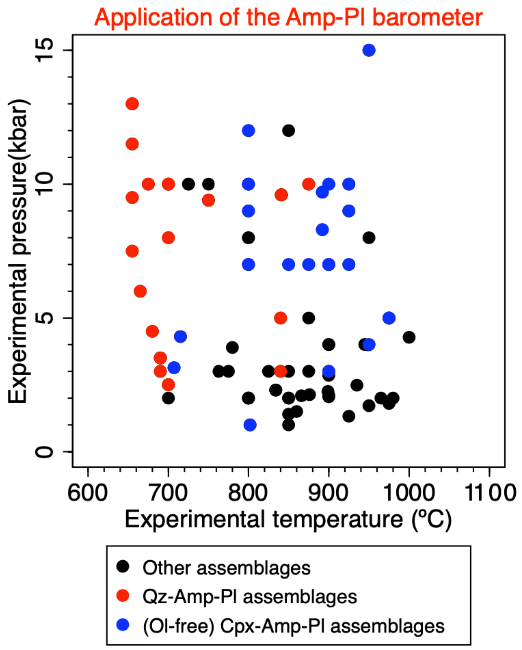

Figure 4. Experimental runs with amphibole having (apfu, 23O): total Al > 1, Ti: 0.05-0.27 and Fe^{3+}<1.07. Data compiled from the literature by Molina et al. [9].

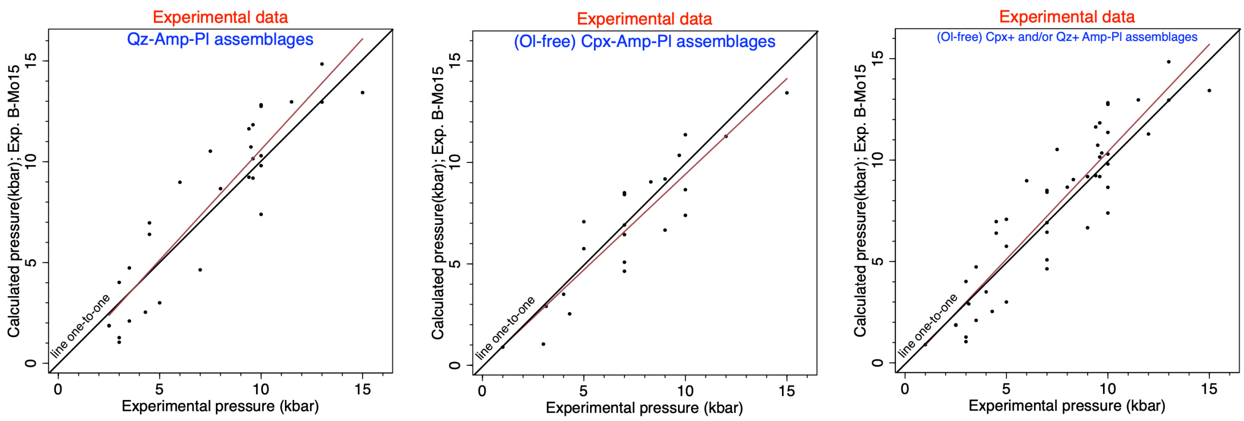

Figure 5. Calculated versus experimental pressures . Pressures estimated with the amphibole-plagioclase barometric expression B by Molina et al. [8]. Data compiled from the literature by Molina et al. [9].

TABLES

Table 1

Source	SS	df	MS
Model	2340.55665	1	2340.55665
Residual	88.5610976	29	3.05383095
Total	2429.11774	30	80.9705915

Number of obs	=	30
F(1, 29)	=	766.43
Prob > F	=	0.0000
R-squared	=	0.9635
Adj R-squared	=	0.9623
Root MSE	=	1.7475

pkbB_tc	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
pkbar	1.057755	.0382074	27.68	0.000	.9796117	1.135898

Table 2

Source	SS	df	MS
Model	1234.73641	1	1234.73641
Residual	41.2073201	21	1.96225334
Total	1275.94373	22	57.9974422

Number of obs	=	22
F(1, 21)	=	629.24
Prob > F	=	0.0000
R-squared	=	0.9677
Adj R-squared	=	0.9662
Root MSE	=	1.4008

pkbB_tc	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
pkbar	.9417183	.0375415	25.08	0.000	.8636465	1.01979

Table 3

Source	SS	df	MS
Model	3326.0934	1	3326.0934
Residual	115.031462	46	2.50068395
Total	3441.12486	47	73.2154226

Number of obs	=	47
F(1, 46)	=	1330.07
Prob > F	=	0.0000
R-squared	=	0.9666
Adj R-squared	=	0.9658
Root MSE	=	1.5814

pkbB_tc	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
pkbar	1.038719	.0284813	36.47	0.000	.9813893	1.096049