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Solid Earth
Discussions

Interactive comment on "Thermal conditions during deformation of partially molten crust from TitaniQ geothermometry: rheological implications for the anatectic domain of the Araçuaí belt, Eastern Brazil" *by* G. C. G. Cavalcante et al.

G. C. G. Cavalcante et al.

geanecarol@gmail.com

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Anonymous Referee #2

The paper includes an interesting dataset and well discussed consequences. The logic between the measurements and the topic8s) of the discussion is not easy to follow. A better connection between the data (T data) and the discussion (viscosities and geodynamic consequences) would be helpful. The paper uses well the TitaniQ approach to estimate the crystallization evolution of partially molten rocks. The data are

well measured, whereas some problems exist with the presentation and calculations. As shown by Thomas et al. (2010) the TitaniQ thermometer is pressure dependent and the Wark and Watson (2006) calibrations are well done mainly for 1 GPa. The general lower pressures of this study require a pressure correction (Thomas et al. 2010).

Answer: Following the suggestions of the reviewer we are modifying the section 4 (T° data) and the section 6 (discussion) to improve the connection between the temperature estimates, the viscosities and geodynamics consequences. Furthermore, as suggested by both reviewers, we have inserted new results using the calibrations of Thomas et al., (2010) and Huang and Audétat, (2012). In our revised version a new Table 1 containing temperature estimates using Wark and Watson, (2006), Thomas et al., (2010) and Huang and Audétat, (2012) calibrations are presented and a comparison between these results is discussed. More detailed comments on these new results are available in the answer to reviewer 1.

Question: Why are the TitaniQ temperatures so similar? Do you consequently select only the quartz grains crystallizing from a melt? What is about possible other quartz crytsals (relics of the metamorphic reaction described in your exchange thermometers)? In the case of concentrating only of the newly crystallizing quartz some words for the calibration of Huang and Audetat (2012) would be helpful.

Answer: The TitaniQ temperature is based on the content of the Ti into quartz. This content is temperature dependent. As already stated in our original manuscript we choose quartz grains of different migmatites (diatexite, metatexite, etc) with similar characteristics (page 8 line 4-6, "we have selected large and/or interstitial quartz grains ($\geq$ 0.3 mm) having similar aspects, no inclusions and nor evidence of intracrystalline deformation or microfracture"). The quartz grains do not show any evidence of zoning (CL images, Fig.7) suggesting that Ti content was homogenously distributed during the last thermal event, consequently, the TitaniQ temperatures are similar. The selected quartz grains from migmatitic granulite (sample Ar1296) that could represent relicts of the metamorphic reactions present lower temperatures than those of the others anatexites using Wark and Watson, 2006 calibration, but similar ones using Thomas et al. (2010) and Huang and Audétat (2012) calibrations. Since these quartz grains have an interstitial habitus and do not show evidences of solid-state deformation, and since films of quartz are observed between feldspar and/or biotite crystals, the temperature obtained from their Ti content probably reflects the temperature prevailing when they crystalized from the melt. As commented in the previous answer temperatures estimated using Huang and Audétat (2012) and Thomas et al (2010) calibration were inserted in our revised version of manuscript and the discussion section is going to be modified in order to take into account these pressure dependent calibrations.

Question: The nomenclature and description of the rocks are confusing. There are anatexites in the “anatectic-unit” versus migmatites. If I understand the text correct, the area does NOT have migmatites without partial melting. All described units are all anatextites, are they? The main differences are the type and amount of partial melting? You may followed the nomenclature given in Sawyer (2008).

Answer: Rewiever 2 is right, all rocks in the anatectic-unit are anatexites and the main differences between them are the composition and/or the amount of partial melting. Some of them have composition of kinzigite (Ar1083) or granulite (Ar1296). Considering this we prefer presenting the data differentiating these rocks. For classification of all the others rocks we followed Sawyer’s (2008) nomenclature (see page 13 line 16). Nevertheless, we have added some words in our new version of the manuscript to clarify that all the rocks are migmatites but with different amount of melts.

Question: The calculations for the viscosity are not clear to me. You calculate the solid/liquid pro- portion for a given P and T with a leucosome composition. All the following calculations are based on such a leucosome composition, are they? What is with the mesosome? The bulk viscosity of the migmatite will depend on the bulk rock behavior. The generation of the leucosome is part of the partial melting and segregation processes of the bulk system. The final viscosity of the segregated leucosome is only a part of the system.

Detail comments: Question: The Table 1 has no analytical errors. I think the table is not necessary in this detail. “0.0” occur in Table 3, which is not possible. You may either not measured this element or the concentration is below the detection limit of your method. Table 3 has no clear relations to the samples. The first âĹij20-30 rows are one sample? In this case the analysis are in analytical error and only one representative analysis per mineral would be enough. If these are different samples you have to shown it. Table 4 is important data set for the calculations, but it is not described how you measured it. How did you extract the leucosome?)? It has a lot of Fe2O3 and MgO for a pure leucosome. What is the reason for the 0.8 wt% LOI? Are the feldspars altered? Are many hydrous phases in the leucosomes? If yes, why?

Answer: We agree with the reviewer that the generation of the leucosome is only a part of the melting process; consequently its viscosity does not represent the viscosity of the bulk system (neosome + residuum). The viscosity of the leucosome represents the viscosity of the suspension (magma viscosity). The analyses come from the lighter-colored portions of the neosome, which we classified as “leucosome” following Sawyer’s (2008) classification. The Leucosomes are dominantly constituted by quartz and feldspar but often are rich in garnet (Fig. 3b; Page 6 line 5-9). Biotite, although more often in the malanosome portions (darker-colored part of the neosome), is occasionally observed in the leucosome (Fig. 4). Sillimanite and cordierite are frequent accessory minerals. This composition may explain the Fe2O3 and MgO content in whole rock analysis, although inclusion of small proportion of melanosome + residdum in the samples cannot be ruled out. In the field, the leucosomes configure a network of interconnected magma (as shown in the Fig.4) suggesting the presence of at least 30% melt (e.g., Sawyer, 2008). In the entire anatectic domain, pieces of malanosome and residuum are discontinuous and are always associated with a large proportion of leucosome. We therefore sampled magma-rich domains, which can reliably provide a good approximation of the magma viscosity in the anatectic domain. This probably was not enough clear in our original manuscript, so in the section 3 of our revised version we are adding some words to clarify it. The viscosities obtained from these domains are considerably lower (1010 to 109; see Page 2 line 15) that those required in numerical models to trigger gravity-driven deformation (1017 to 1019 Pa s; see Page 3-line 5). When the melts are interconnected ($\geq$ 7% melt fractions) the viscosity of the bulk system is closer to the magma viscosity than to the solid portion (e.g., Rosenberg and Handy, 2000). Many experiments have shown that the drop in viscosity from that of a solid rock to that of a liquid occurs over a restricted range of melt fractions ranging from 10 – 30 % (e.g., Arzy 1978; Rosenberg and Handy 2000). When the bulk viscosity is closer to the magma viscosity the rheological behavior of the rock is closer to the magma one. Thus, considering that the melt fractions in the anatectic crust are enough to produce interconnected network of melts, the calculated viscosities from the leucosomes compositions are closer to the viscosity of the bulk system. Furthermore, as the volume of melanosome + residuum is limited in the bulk system a viscosity increase of 6 or 7 orders of magnitude that could impede a gravity-driven deformation is quite unlikely.

Answer: In Table 3 we specified the name of each sample. For instance, for the sample Ar949 the Table shows the microprobe analysis of garnet, biotite, cordierite and plagioclase; subsequently, it shows the composition of garnet, biotite and plagioclase for the sample Ar1083 and so on to the others samples. As our goal is to estimate the P and T for each sample we think that is important to show a group of analysis representative of each mineral. To make the Table clearer we highlighted the names of the samples putting it in bold letters. As already commented there are some hydrous phases in the leucosome, especially biotite. However, its composition is dominated by quartz and feldspar, and it is often rich in garnet; the Fe and Mg content belong to the garnet-biotite bearing leucosome. Hydrous phases and/or liquid can be produced from partial melting of metasedimantary rocks through of melting reactions involving muscovite or biotite breakdown (e.g., Spear et al., 1999; Douce and Johnston 1991). We commented on page 13, line 1-3, that at least part of the anatexites are the result of the partial melting of metasedimantary rocks such as kinzigites (metamorphosed pelite)"…samples of migmatitic kinzigites from which derive, at least partly, the

anatexites…". Kinzigites have cordierite, garnet, biotite, sillimanite in their composition (page 6, line 14-15). Partial melting of such parent rock as kinzigites can produce melt/liquid and hydrous phases in the leucosome.

Answer: We extracted the leucosome using a driller (the same kind used for the AMS work), hammer and chisel. We have added some comments on section 3 (samples: location and description) to clarify how we extracted the leucosome and how the geochemisty analyses were realized.

Answer: The reason for 0.8% of the loss on ignition (LOI) is most probably due the presence of hydrous phases in the leucosome because most feldspars are not altered.

Interactive comment on Solid Earth Discuss., 6, 1299, 2014.