Solid Earth Discuss., 7, C837–C844, 2015
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Solid Earth Discussions

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Interactive Comment

Interactive comment on "Magma mixing enhanced by bubble segregation" *by* S. Wiesmaier et al.

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Interactive comment on "Magma mixing enhanced by bubble segregation" by S. Wiesmaier et al. Anonymous Referee #2 — Received and published: 25 May 2015 'Magma mixing enhanced by bubble segregation' – S. Wiesmaier et al.

Referee #2: This is a very interesting manuscript that should be published following minor revision. I am impressed by the scholarly approach and detailed arguments that succeed in extracting the maximum information from the experiments. I have only three significant comments.

[Authors' comments:] We are glad to hear that the reviewer was impressed by our approach and arguments, and that according to them we succeeded in extracting the maximum information from our experimental work.

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Referee #2: First, I found some of the discussion to be rather long and repetitive, particularly the parts on the dynamic evolution of the melt filaments. The text on this could be shortened in order to make it more interesting and punchy to read.

[Authors' comments:] Comment accepted, and changes made thoughout the manuscript. (see also replies to comments 0 and 2 by reviewer #1).

Referee #2: Second, while I in no way deny the interest in studying mixing by this mechanism, I wonder how important it will be in nature. Bubble ascent through intermediate to silicic melt will be very slow – probably much slower than any bulk convective or advective motions. Are the mixing phenomena due to such motions not likely to overprint any generated by bubbles? Suppose that you put a layer of rhyolite in contact with a layer of basalt. It is hard for me to imagine that the thermally driven mingling at the interface will not occur faster, and potentially on a larger length scale, than any bubble-driven mixing. This is not to discredit the present study, but you may want to mention this issue.

[Authors' comments:] This question is indeed important. For this study, our aim was to isolate and constrain this process experimentally. In doing so, we demonstrated that bubbles have to be considered when discussing fluid mechanical agents for magma mixing mechanisms. Especially as we demonstrated the effect for a case of extremely high viscosity contrast. Coming from such a high viscosity contrast, it may be hard for the reviewer to imagine scenarios in which bubble mixing may become important. However, natural cases provide a wide range of extrinsic and intrinsic properties, which are specific to each magmatic setting. For example, a reduced initial viscosity contrast (with simultaneously reduced thermal and compositional effects) would tremendously enhance bubble mixing. Although this had already been discussed in the text, we take the reviewers comment seriously, as obviously, we have not clarified our view well enough so far. We therefore offer, along with a much shortened and condensed discussion, a reorganised section for relevance of bubble mixing in natural scenarios:

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5.4 Relevance for natural scenarios Is bubble mixing relevant in nature? Each natural case represents a unique combination of extrinsic and intrinsic properties, all of which influence whether bubble mixing comes into play during a system's magmatic history.In the following, we will lay out scenarios in which volatile content, thermal history and viscosity contrast may be favourable for bubble mixing. We then conclude with evidence from natural case studies that may show an influence of bubble mixing.

5.4.1 Effects of variable temperature conditions on bubble mixing Temperature contrasts between mafic and felsic magma are expected in nature. This merits the question whether or not a mechanism such as bubble mixing may be inhibited by quenching of one magma against another. Quench textures form when e.g. a hot basaltic magma is juxtapositioned on a much cooler, felsic magma and usually occur as mafic enclaves with chilled margins, as finely-grained dyke margins or even as mafic foam (e.g., Eichelberger, 1980; Coombs et al, 2003). The time-scales of interaction are short, because steep temperature gradients and small volume of individual enclaves cause the mafic enclave to rapidly solidify and quench. However, the presence of magmatic filaments in many outcrops worldwide testify to the potential of two magmas of contrasting composition to interact in fluid mechanical fashion (e.g. Perugini et al., 2002). In every one of these cases, thermal equilibration must have occurred to some degree, so as to inhibit quenching and permit magma mingling. Especially striking is the case of Montaña Reventada in Tenerife, Spain, where evidence for quenching and fluid-fluid interaction are simultaneously present in a composite lava flow from a single, monogenetic eruption. In the phonolite member of the Reventada flow, hybrid inclusions quenched to different degrees are observed, right next to hybrid filaments, which in turn are indicative of magma mingling. The variety of textures detected in the basanite inclusions and filaments has been interpreted to reflect a progressive thermal equilibration between mafic and felsic magma (Wiesmaier et al., 2011). As this thermal equilibration is thought to have occurred on a short time-scale just prior to eruption, the case of Montaña Reventada provides an example of how rapidly a natural system is able to move from production of quench textures to fluid-fluid interaction. Therefore, quenching of

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two magmas against each other has to be regarded as highly transient process. In turn, bubble mixing may occur soon after the onset of thermal equilibration, specifically when the temperature contrast is already too low for quenching. The problem then becomes one of a) potential onset of convection in the magma chamber and b) the initial viscosity contrast between the two magmas. Convection in a magma chamber depends on many variables in a natural system and, when occurring, certainly hinders bubble mixing. In the context of bubble mixing, we thus focus on the initial viscosity contrast in the following.

5.4.2 Initial viscosity contrast For our experiment, the furnace temperature was chosen to achieve a combination of feasible viscosity contrast, crystal-free melts and relatively short run time. Our experiment approximates the fluid dynamic behaviour of bubbles and attached filaments at an initial viscosity contrast γ of as high as 4 $\times$ 103. In nature, the initial viscosity contrast between two magmas may be much reduced. A lower viscosity contrast would cause more favourable conditions for bubble mixing, because of the reduced initial viscous resistance and also an increased buoyancy parameter β (see section 3.2.1), which implies less buoyancy loss for a bubble entering the upper body of melt. Because we chose an extreme viscosity contrast for the experiment, the qualitative notions hold fast, and may even be more pronounced, for systems showing smaller viscosity contrast between the initial end-member magmas. Rising bubbles that advect melt of more mafic composition will produce filaments of that melt in an overlying melt. A reduced initial viscosity contrast γ (e.g. between end-members basalt and andesite) will be yet more favourable for bubble mixing, because, with lower γ, the volume of entrained material and rise speed increase.

Referee #2: Third, it seemed to me that the nonlinearity of hybrid melt compositions on Fig. 5 was striking, but you barely mention it. Is this because it is discussed elsewhere? If not, I propose that you make more of this at the expense of the repetitive discussion on the filaments. I have only a few specific comments, as the manuscript generally reads very well.

[Authors' comments:] This is the same comment that reviewer 1 made on our Figure 5. Please refer to our answer there.

Detailed comments by reviewer #2

Referee #2: 1474 (5-10) – I don't follow this argument very well.

[Authors' comments:] Accepted and text changed: Among other scenarios that study dealt with a single bubble rising from low-viscosity to high-viscosity fluid, thereby entraining parts of low-viscosity fluid into the upper high-viscosity one. Numerical constraints from this study indicate the importance of the viscosity contrasts between a) fluid and gas and b) both fluids. The analogue studies of Thomas et al. (1993) and Manga & Stone (1995) argue strongly in favour of bubble-driven mixing scenarios. Nevertheless, experiments with analogue liquids are unable to replicate the diffusive equilibration of multi-component silicate melts, a fundamental feature in magma mixing.

Referee #2: 1474 (20-25) – This mechanism has, I think, been challenged in subsequent papers on the Bishop Tuff by Hildreth, Wilson and colleagues.

[Authors' comments:] Accepted and deleted from the manuscript. Also in section 5.4.3.

Referee #2: 1474 (6) – Remind me what the Bond Number is.

[Authors' comments:] Accepted and change made. See reply to comment 3) by reviewer #1.

Referee #2: 1474 (22) – Spell out TEMA.

[Authors' comments:] Accepted and change made.

Referee #2: 1476 (9) – By drop, do you mean bubble?

[Authors' comments:] In section 2.2, we stayed with the exact terminology of Manga & Stone for reference. We clarified already in the introduction (page 1474-line 2) that Manga & Stone (1995) used the terms bubbles, drops and particles somewhat inter-

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changeably in their study. As a solution, we offer to repeat this clarification in 1476(9), if deemed helpful by the topical editor.

Referee #2: 1477 (12) – Did you test for Na loss by varying the beam size on glass standards? This is important, since you present the Na data in Fig. 5.

[Authors' comments:] As mentioned in section 2.4, we used a defocussed beam to counter alkali loss. This procedure has been established and verified in-lab to produce the least alkali loss possible. We included the following sentence: To counter alkali loss, Scherrer (2012) found a defocused 10μm beam as best solution for that instrument.

Referee #2: 1478 (21) – Where did you take the diffusivities from?

[Authors' comments:] The diffusivity value is constant in our calculations to ensure comparability of the different model curves. Only diffusion time was varied and the diffusivity was set to 1 $\times$ 10-11 m^2.s-1 arbitrarily. We included this sentence in section 3.6: The diffusivity D is kept constant in the calculation and has been arbitrarily set to 1 $\times$ 10-11 m^2.s-1.

Referee #2: 1481 (10) – Maybe show ALL the profiles described in the paper?

[Authors' comments:] We are happy to show all profiles in the paper. Maybe the topical editor can indicate whether he wishes us to do so, because of space issues and production cost?

Referee #2: 1495 (5-19) – I didn't follow the argument here very well, particularly pertaining to the Tenerife example.

[Authors' comments:] The Mna Reventada outcrop in Tenerife demonstrates that magmas of different composition AND temperature may equilibrate thermally and interact fluid mechanically (as opposed to just quench against each other).

Referee #2: 1497 (0-29) – As I said, the Bishop example has been challenged. Moreover, the Lican example that you cite is completely unconvincing. The bubble content in

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these products (just like other mafic scoria) is due to decompression and vesiculation upon eruption. It has nothing to do with your process.

[Authors' comments:] Apparently, our view on this was not sufficiently clear. We make a distinction between decompression-induced vesicles now present in the deposit and vesicles responsible for bubble mixing (which are likely not preserved anymore). The reason to invoke this mafic ignimbrite as potential example for bubble mixing is because of a) two crystal populations (hard evidence for mixing), b) the volatile-rich and low viscosity nature of the magmas involved and c) the proposed short time-scales of mixing, which are difficult to explain by standard convective mechanisms (cf. Lohmar et al., 2012). We therefore suggest this is a natural setting in which conditions were potentially favourable for bubble mixing. We now clarified this in the text: The Licán mafic ignimbrite, erupted from Villarica volcano, Chile, was potentially affected by a free volatile phase. Despite the homogeneity of this basaltic andesite, Lohmar et al. (2012) observed two distinct crystal populations with stark disequilibrium textures and overgrowth rims as hard petrological evidence for magma mixing. Mineralogical data and thermodynamic modelling indicate an increase of $\sim 200\ ^{\circ}$C during petrogenesis, interpreted as mafic recharge and subsequent thermal equilibration. Additionally, the deposit features an extremely high vesicularity of 53 vol%. The vesicularity of the deposit, uncommon in pre- and post-Licán deposits, is most certainly related to decompression-induced degassing. However, as the final vesicularity of the Licán mafic ignimbrite is unusually high for Villarica, the magma must have been very volatile-rich prior to eruption. In combination with a relatively small temperature and viscosity contrast between the initial end-members, the conditions in the Licán magma reservoir prior to eruption were thus highly favourable for mixing of the two magmas aided by bubbles. However, as the final deposit is very homogenous (apart from crystal populations), clear textural evidence pro or contra bubble mixing has probably been obliterated by the completion of mixing.

Referee #2: Figures – the captions for 6 and 7 are inversed.

[Authors' comments:] Accepted and change made.

Please also note the supplement to this comment:
http://www.solid-earth-discuss.net/7/C837/2015/sed-7-C837-2015-supplement.pdf

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Interactive comment on Solid Earth Discuss., 7, 1469, 2015.