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Numerical thermo-mechanical modelling of lava dome growth

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1. MOTIVATION

The thermo-mechanical structure of a lava dome interior (that is, a distribution of the temperature, the crystal content, and the viscosity) is critical for assessment of potential dome collapse and relevant hazards.

In this study we try to understand how cooling and different heat transfer mechanisms at the lava-air interface effect the lava dome formation and its morphology during long dome-building episodes.

We develop numerical models to analyse the lava dome growth at Volcán de Colima, Mexico during 2007-2009.

2. MODEL DESCRIPTION

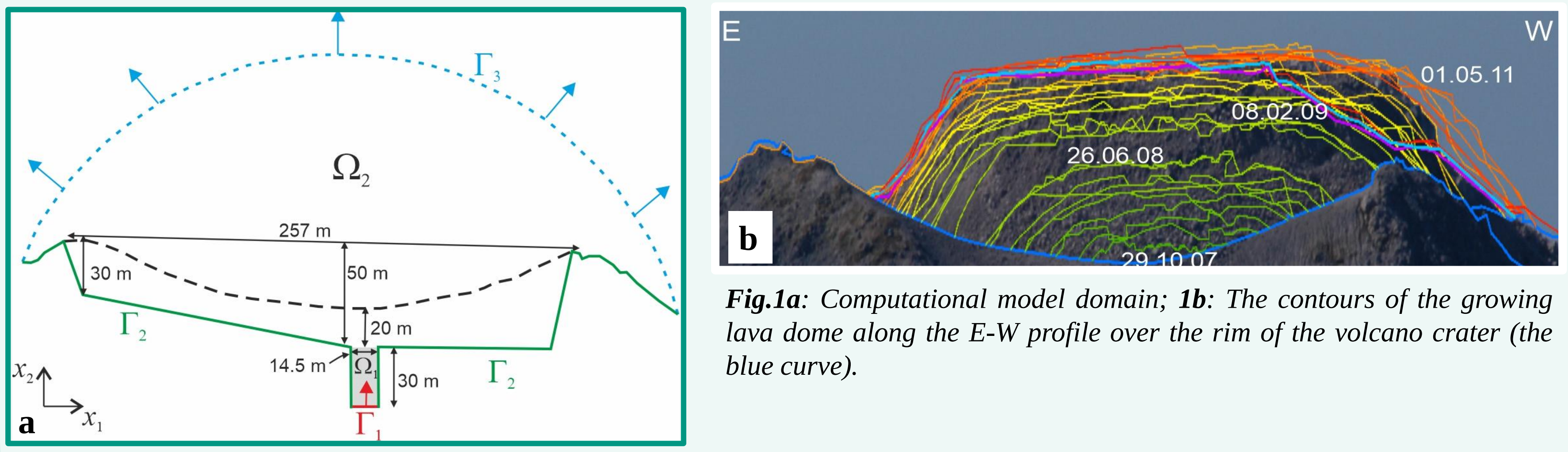

***Fig.1a**: Computational model domain; **1b**: The contours of the growing lava dome along the E-W profile over the rim of the volcano crater (the blue curve).*

We model an extrusion of the lava into the air on the surface of the crater. The geometry of the domain (Fig. 1a) approximates the horizontal spreading of the lava dome at Volcán de Colima across the E-W profile (Fig.1b).

The equations of motion, continuity, and heat transfer are solved with the relevant boundary and initial conditions in the assumption that the viscosity depends on the volume fraction of crystals and temperature.

To solve numerically the problem, we employ the Ansys Fluent software, where the finite volume method is used to solve the numerical models on HPC.

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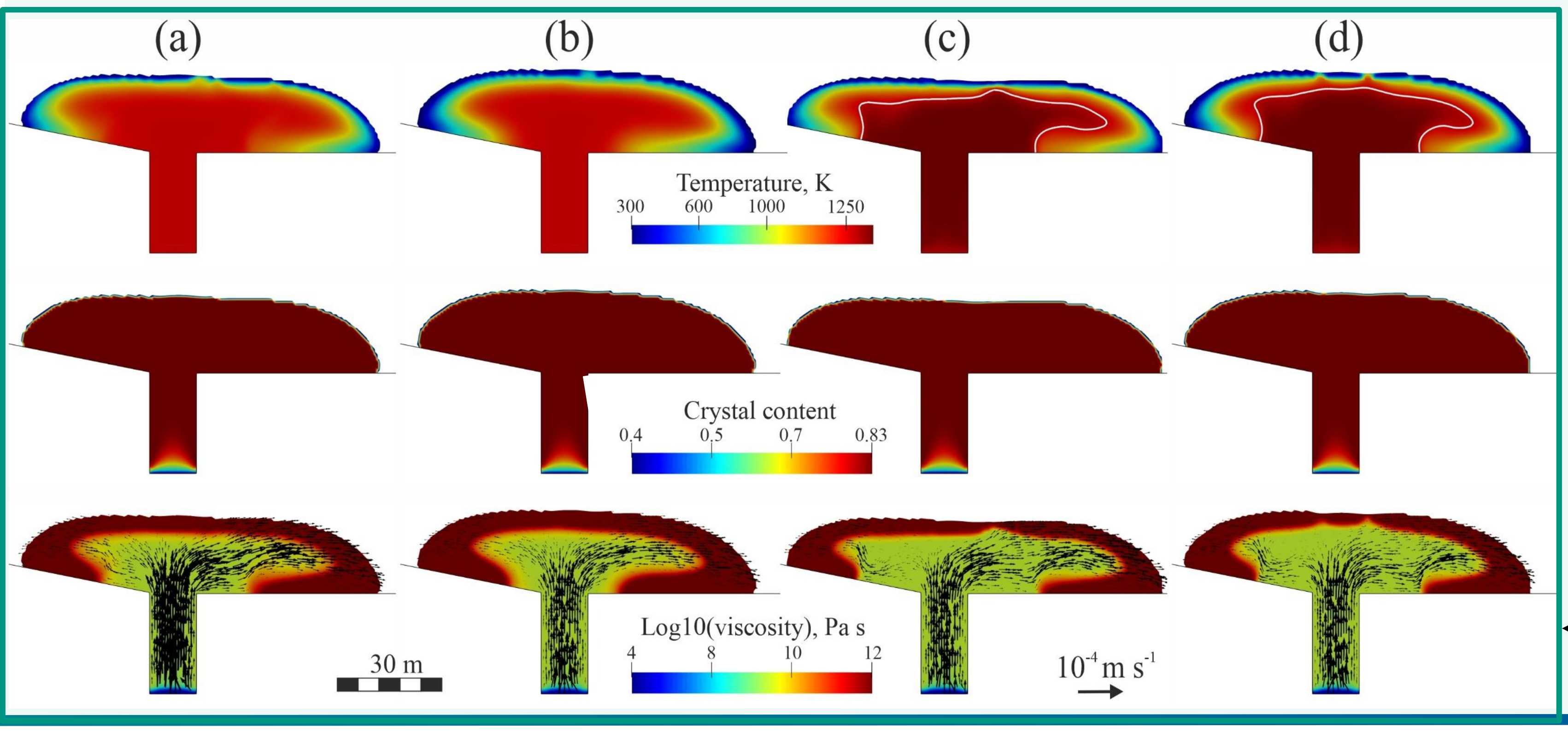
3. NUMERICAL RESULTS

3.1 The role of Heat Transfer and Latent Heat (Exp.1)

Here we presented the results of numerical experiments on the lava dome growth considering different heat transfer mechanisms at the interface between the lava and the air. We assume at this interface a convective heat flux in exp.1(a) and a convective-radiative heat flux in exp.1(b). Also, we run numerical experiments accounting for the latent heat of crystallization together with convective in exp.1(c) and convective-radiative in exp.1(d) heat fluxes.

As a result of lower temperatures and higher viscosity, a carapace forms due to both the convective and convective-radiative heat fluxes at the lava-air interface. Meanwhile, the carapace becomes thicker in the case of the convective-radiative heat flux, which slightly retards the horizontal advancement of the lava dome (Fig. 2b)) and promotes the growth of the dome upwards.



The latent heat released during the crystallization influences the conduit and lava dome temperature, and contributes to variations in the lava viscosity by increasing the temperature in the dome interior (Fig. 2c, d; the area of the elevated temperature is marked by a white curve) compared to the case with no latent heat (Fig. 2a, b). The higher temperature within the dome interior promotes further dome flattening.

Exps.1 (a) -(d) show that the heat exchange between lava and air play a significant role in lava dome carapace development during the long dome-forming eruptions.

← ***Fig.2** The temperature (upper panels), crystal content (middle panels), and viscosity overlain by velocity vectors (lower panels) at day 300 . White curves indicate the area of elevated temperatures due to the release of the latent heat of crystallization.*

3.2 Application to Volcán de Colima, Mexico (Exp.2)

In this experiment, we assume the convective heat transfer at the lava-air interface. The increased viscosity of the carapace due to cooling restrains the lateral advancement of the dome (Fig.3a).

The modelled dome develops steep flanks, and its morphology fits observations at Volcán de Colima with a few meter differences in the length of the dome (Fig.3a).

The dome heights (Fig.3b) agree with the observations and fit the heights of the lava dome modelled by Zeinalova *et al.* (2021).

The thicker carapace (in exp.2, fig.5b) constrains the lava dome advancement despite its viscosity in one order of magnitude lower than in the case with the modelled artificial carapace by [1] (Fig.5a).

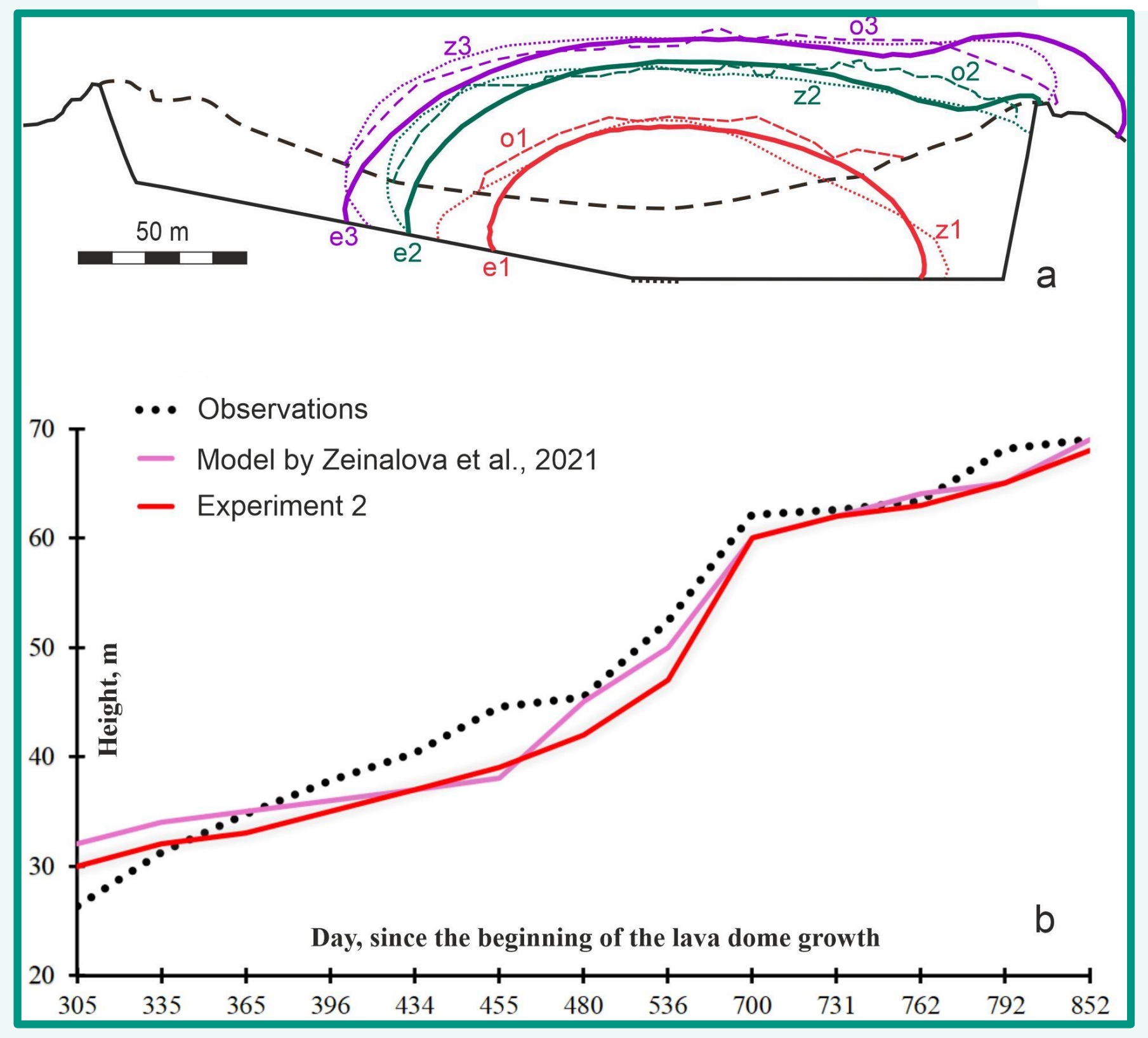


***Fig.3** (a) Comparison of the morphological shapes of the modelled dome (index e) with those developed by [1] (index z) and with observed shapes (index o) on 1/05/2008 (red curves), 4/12/2008 (green curves),and 1/05/2009 (violet curves). The black dashed line is the crater rim.*
(b) Comparison of the observational maximum heights at the center of the lava dome with those of the modelled dome (exp.2) (red curve) and the ones in [1] (pink curve).

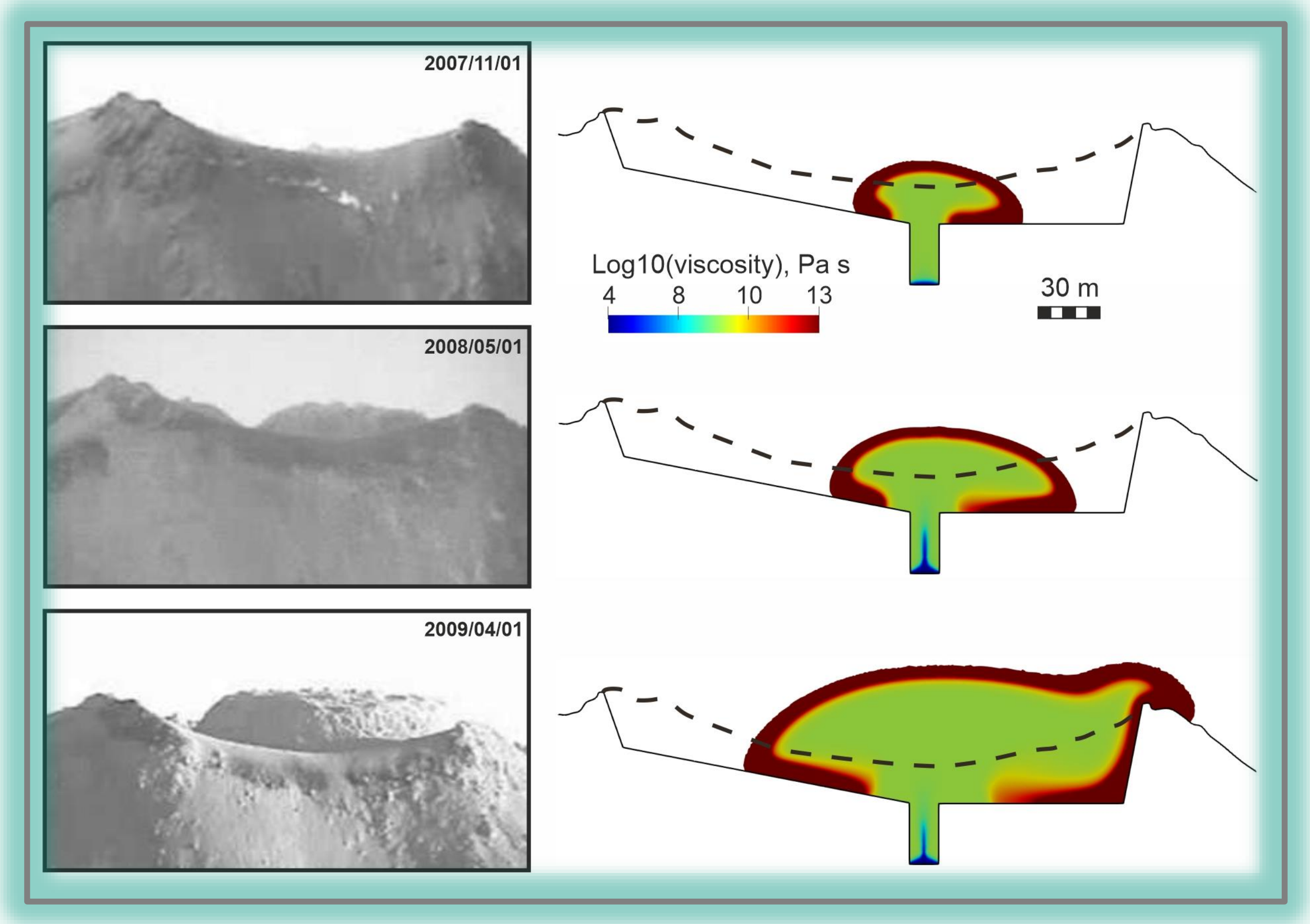


***Fig. 4** Images of the lava dome evolution at Volcán de Colima (left column:[2]) versus modelled lava dome growth (right column; exp.2, presenting lava viscosity) at times of 1/11/2007 (upper panels), 1/05/2008 (middle panels), and 1/04/2009 (lower panels). The black dashed line is the crater rim.*

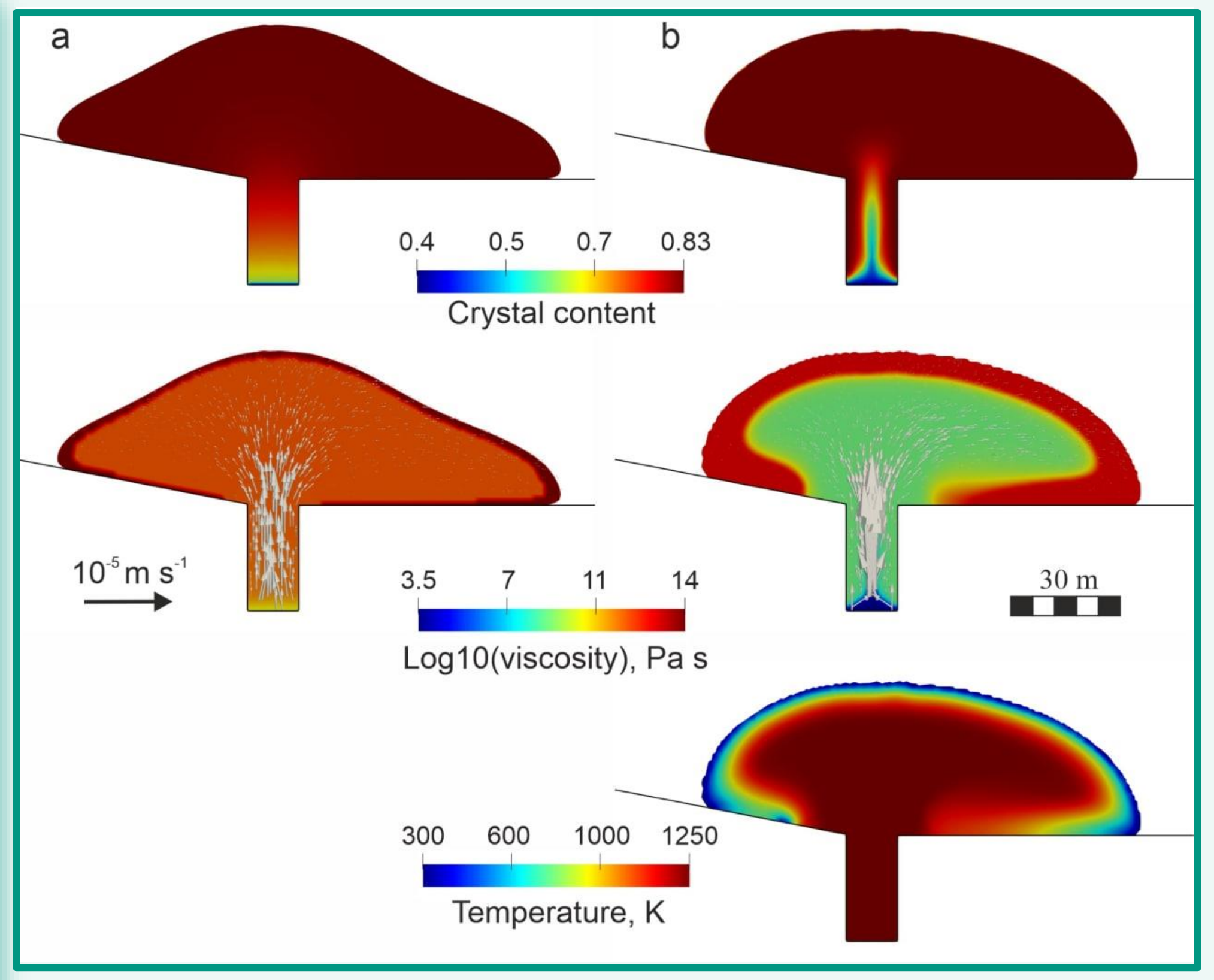


***Fig.5** Comparison between two models of the lava dome growth at Volcán de Colima at day 480 : (a) the crystal content and lava viscosity in the model by [1], and (b) the crystal content, lava viscosity, and temperature in exp.2.*

4. CONCLUSION

(i) The dome carapace becomes thicker in the case of a convective-radiative heat transfer at the interface between the lava and the air.
(ii) The latent heat of crystallization leads to elevated temperature in the conduit and in the lava dome interior and flatten further the dome.
(iii) The cooling at the interface of the lava dome and the air is identified to be a dominant parameter influencing the dome morphology during long episodes of its building.
(iv) The developed thermo-mechanical model of the lava dome evolution can be used at other volcanoes during effusive eruptions, long episodes of lava dome building, the dome carapace formation, and its potential failure, which may lead to pyroclastic flow hazards.

References
[1] Zeinalova, N., Ismail-Zadeh, A., Melnik, O., Tsepelev I. & Zobin V., 2021. Lava dome morphology and viscosity inferred from data-driven numerical modeling of dome growth at Volcán de Colima, Mexico during 2007-2009, Front. Earth Sci., 9, 735914, doi: 10.3389/feart.2021.735914
[2] Bretón-Gonzalez, M., Campos, A., Leon, Z., Plascencia, I. & Ramírez, J.J., 2013. The 2007-2012 lava dome growth in the crater of Volcán de Colima, México, derived from video monitoring system, in Complex Monitoring of Volcanic Activity, pp. 153–169, ed. Zobin, V.M., Nova Science Publishers Inc., New York.