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Pathways of volatile migration in the crust beneath Harrat Lunayyir (Saudi Arabia) during the unrest in 2009 revealed by attenuation tomography

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Harrat Lunayyir is a relatively young basaltic field in Saudi Arabia located at the western margin of the Arabian Peninsula. In April–June 2009, strong seismic activity and ground deformations at this site marked the activation of the magma system beneath Harrat Lunayyir. In this study, we present new three-dimensional models of the attenuation of P and S waves during the unrest in 2009 based on the analysis of t*. We measured 1658 and 3170 values of t* for P and S waves, respectively, for the same earthquakes that were previously used for travel time tomography. The resulting anomalies of the P and S wave attenuation look very similar. In the center of the study area, we observe a prominent high-attenuation pattern, which coincides with the most active seismicity at shallow depths and maximum ground deformations. This high-attenuation zone may represent a zone of accumulation and ascending of gases, which originated at depths of 5–7 km due to the decompression of ascending liquid volatiles. Based on these findings and previous tomography studies, we propose that the unrest at Harrat Lunayyir in 2009 was triggered by a sudden injection of unstable liquid volatiles from deeper magma sources. At some depths, they were transformed to gases, which caused the volume to increase, and this led to seismic activation in the areas of phase transformations. The overpressurized gases ultimately found the weakest point in the rigid basaltic cover at the junction of several tectonic faults and escaped to the surface.