LAVA FLOW MAPPING USING SENTINEL-1 SAR TIME SERIES DATA: A CASE STUDY OF THE FAGRADALSFJALL ERUPTIONS

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(1) INTRODUCTION

Lava flows can threaten populated areas, cause casualties and considerable economic damage. Therefore, understanding lava flows and their evolution is important because they can be linked to lava transport systems and eruption parameters. However, timely and accurate lava flow mapping in the field can be time-consuming and dangerous. **Earth observation (EO)** data plays an important role in improving lava flow mapping and monitoring. **Synthetic Aperture Radar (SAR)** data provide a unique opportunity to study lava flows, especially in areas with high cloud coverage during the year. Moreover, smoke and ash clouds can be partially penetrated by SAR data.

(2) MOTIVATION AND OBJECTIVE

The freely available **Sentinel-1 SAR data (C-band)**, with its high temporal and spatial resolution, opens new opportunities for studying lava flow evolution and lava morphology. However, Sentinel-1 data have mainly been used to study surface deformation using Differential Interferometric SAR (DInSAR) techniques. The aim of this study is to **determine the evolution of the lava flow extent for the 2021 Fagradalsfjall eruption using object-based image analysis (OBIA) and Sentinel-1 data.**

(3) STUDY AREA

The Fagradalsfjall volcanic system is located on the Reykjanes Peninsula in southwest Iceland (Figure 1). The eruption began on the 19th of March and lasted until the 18th of September 2021. The lava flows cover an area of 4.8 km^2 (Pedersen et al., 2022a). Figure 2 shows the lava flows resulting from the 2021 eruption, which produced pāhoehoe, ʻaʻā and a range of transitional morphologies.

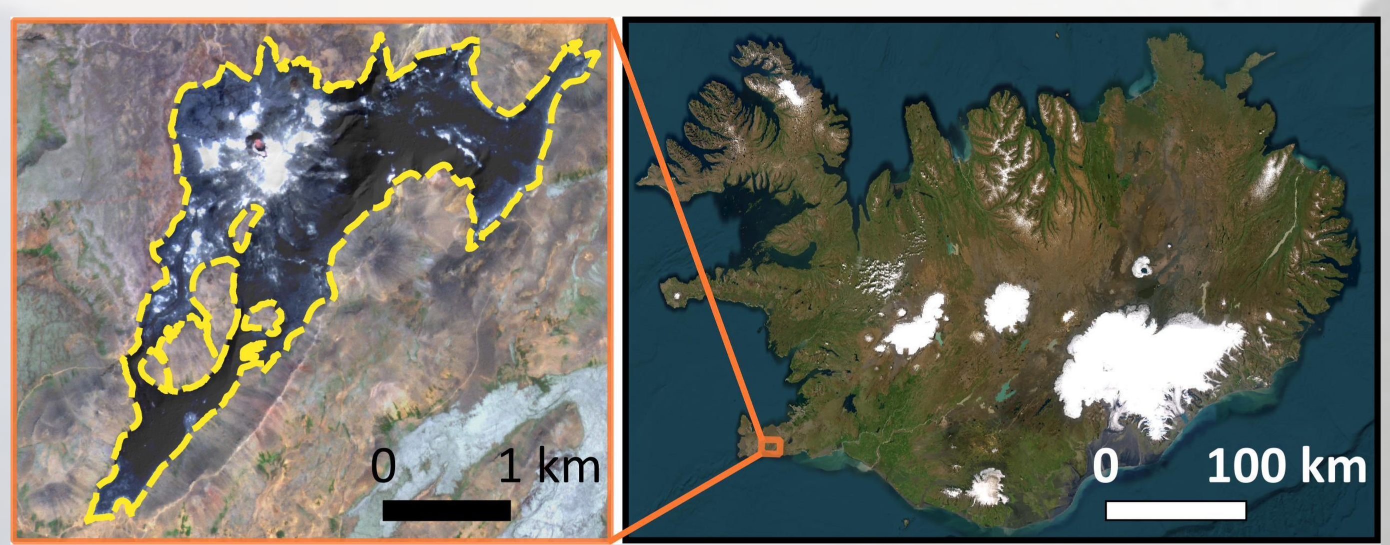

Figure 1. *Outline of the lava flows (yellow; Pedersen et al., 2022b) from the Fagradalsfjall 2021 eruption, which cover approximately 4.8 km², overlaid on a PlanetScope image from 30/09/2021 (left). Location of the Fagradalsfjall volcanic system in the southwest of Iceland (background data © ESRI; right).*

Figure 2*. Lava started infilling the Geldingadalir valley (© Birgir. V. Óskarsson; left). Impressions of the volcanic activity and lava flows (© Gro B.M. Pedersen; right).*

(4) DATA

We used pre-, syn- and post-event Sentinel-1 A & B dual polarisation interferometric wide swath Level-1 high-resolution ground range detected data. We selected an image per eruption phase as described by Pedersen et al. (2022a), one pre- and one post-event image for 2021 (Table1). The outlines of the Fagradalsfjall effusive eruption phases for 2021, provided by Pedersen et al. (2022b), were used as reference data for validation of the results.

SENTINEL-1	Eruption Phase
22/08/2020	pre-event
31/03/2021	syn-event (phase 1; 19th March - 5th April 2021)
12/04/2021	syn-event (phase 2; 5th April - 27th April 2021)
18/05/2021	syn-event (phase 3; 27th April - 28th June 2021)
29/07/2021	syn-event (phase 4; 28th June - 2nd September 2021)
27/09/2021	post-event (phase 5; 2nd - 18th September 2021)

Table 1. *Time series Sentinel-1 data used to study the Fagradalsfjall eruption during 2021.*

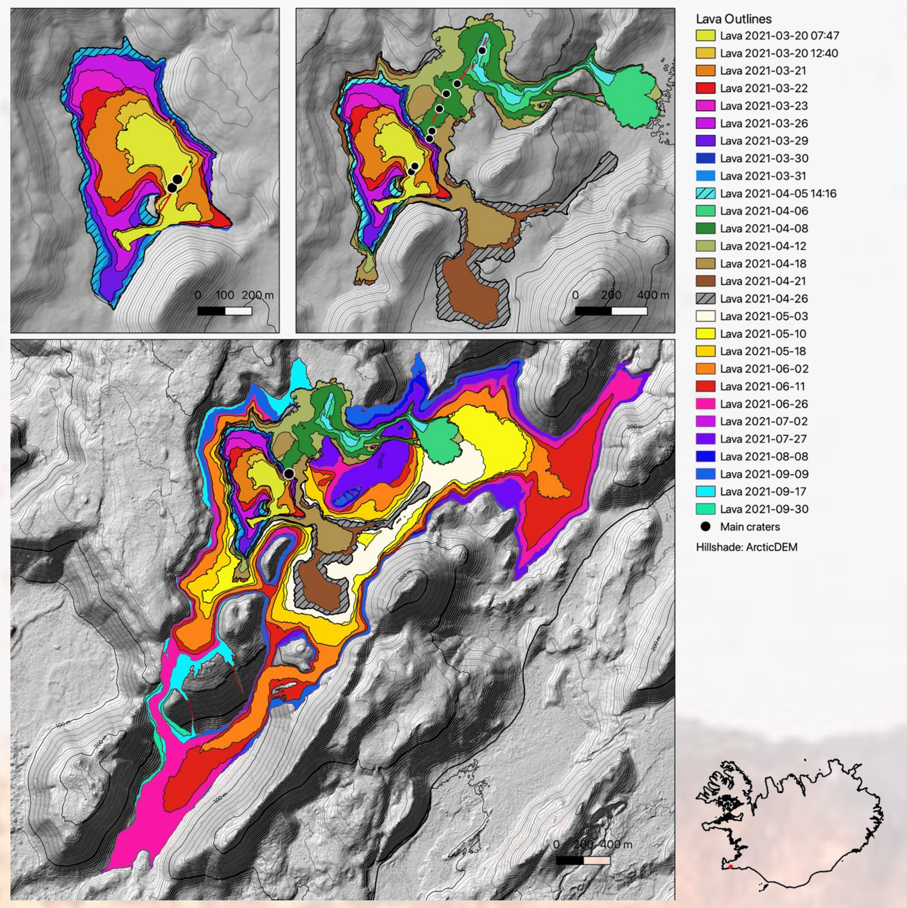

Figure 3. *Fagradalsfjall eruption outlines (Pedersen et al., 2022a). Dates close to Sentinel-1 data (Table 1) were used to validate the classification results.*

(5) METHODS

All Sentinel-1 data were pre-processed, using orbit-state vector correction, calibration, terrain flattening, Refined Lee speckle filtering and Range Doppler terrain correction to derive sigma and gamma nought polarisation data. These layers were used as input for the object-based mapping. Figure 4 shows the main steps applied to map lava flows, including multiresolution segmentation, and calculation of mean and standard deviation of the intensity layers per objects. A knowledge-based classification ruleset was developed using the backscatter information, spatial (e.g., size) and context information to map lava flows. Finally, refinement was performed using merging algorithms and considering the relationships between objects.

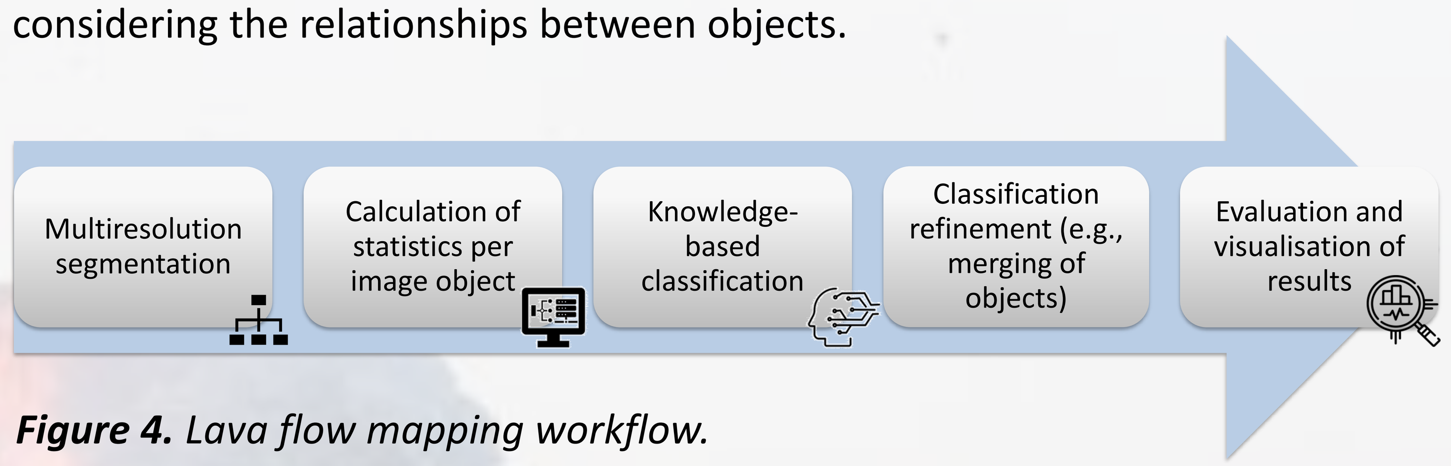

Figure 4. *Lava flow mapping workflow.*

(6) RESULTS

The results of the lava flow mapping using OBIA are shown in Figure 5. The pre-eruption image (0) was used as a base to compare how the area changed after the lava flow started to infill the neighbouring valleys within the Fagradalsfjall area. The images from 1 to 5 show the evolution of lava extent for the 2021 eruption.

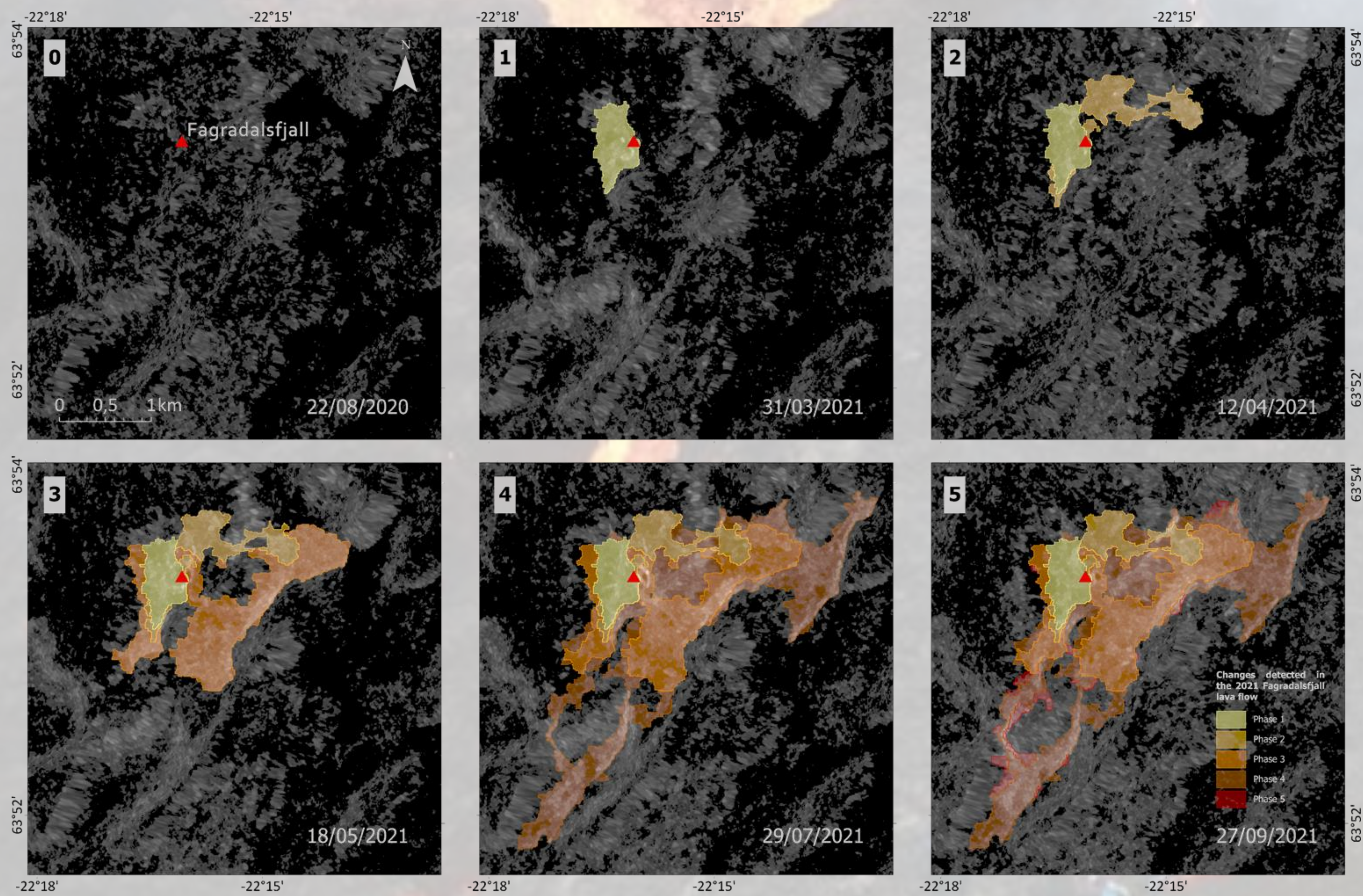

Figure 5. *The evolution of Fagradalsfjall lava flow extent derived from time series of Sentinel-1 data using OBIA. Each lava extent corresponds to the lava eruption phase as described by Pedersen et al. (2022a).*

(7) VALIDATION

We evaluated the accuracy of the results obtained from the OBIA mapping with the reference lava flow outlines (Table 2), where the overlapping areas show the correctly classified lava extent, the producer's accuracy represents the ratio between the overlapping area and the OBIA delineation, and the user's accuracy represents the ratio between the overlapping area and the reference delineation.

SENTINEL-1 DATA	OBIA (km²)	REFERENCE (km²)	DIFFERENCE (%)	OVERLAP (km²)	PRODUCER'S ACCURACY (%)	USER'S ACCURACY (%)
31/03/2021	0,32	0,30	6,74	0,26	81,62	87,12
12/04/2021	0,73	0,74	-2,12	0,64	88,45	86,58
18/05/2021	2,07	2,06	0,35	1,89	91,59	91,91
29/07/2021	4,10	4,28	-4,37	3,80	92,83	88,78
27/09/2021	4,32	4,85	-10,82	4,15	96,01	85,61

Table 2. *The accuracy of the results obtained from the OBIA classification compared with the reference lava extent provided by Pedersen et al. (2022b).*

(8) DISCUSSION & CONCLUSION

The object-based lava flow mapping results based on Sentinel-1 SAR backscatter data show high coincidence with the reference data. However, it should be considered that the OBIA approach is sensitive to the image objects derived from segmentation, which are used as a foundation for classification. Moreover, the spatial resolution of the Sentinel-1 data was a limiting factor for lava mapping when compared with the detailed delineation based on the very high-resolution imagery which was used to create the reference data. The side-looking geometry of the SAR sensor may cause foreshortening, layover, and shadow effects, which can influence the quality of the results. Nevertheless, using terrain correction gamma nought reduced the geometric distortion by decreasing the angle dependency of the radar backscatter.

The results demonstrate the potential and challenges of utilising SAR backscatter information from Sentinel-1 data for studying the spatio-temporal lava flow evolution and mapping lava flow morphology, especially when the applicability of optical EO data is limited.

REFERENCES

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ACKNOWLEDGEMENTS

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