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BASALTIC LAVA FLOW CHARACTERIZATION AND MODELLING USING A GEOMORPHOLOGICAL APPROACH: INTEGRATION OF FIELD AND DRONE ACQUIRED DATA (KRAFLA, ICELAND)

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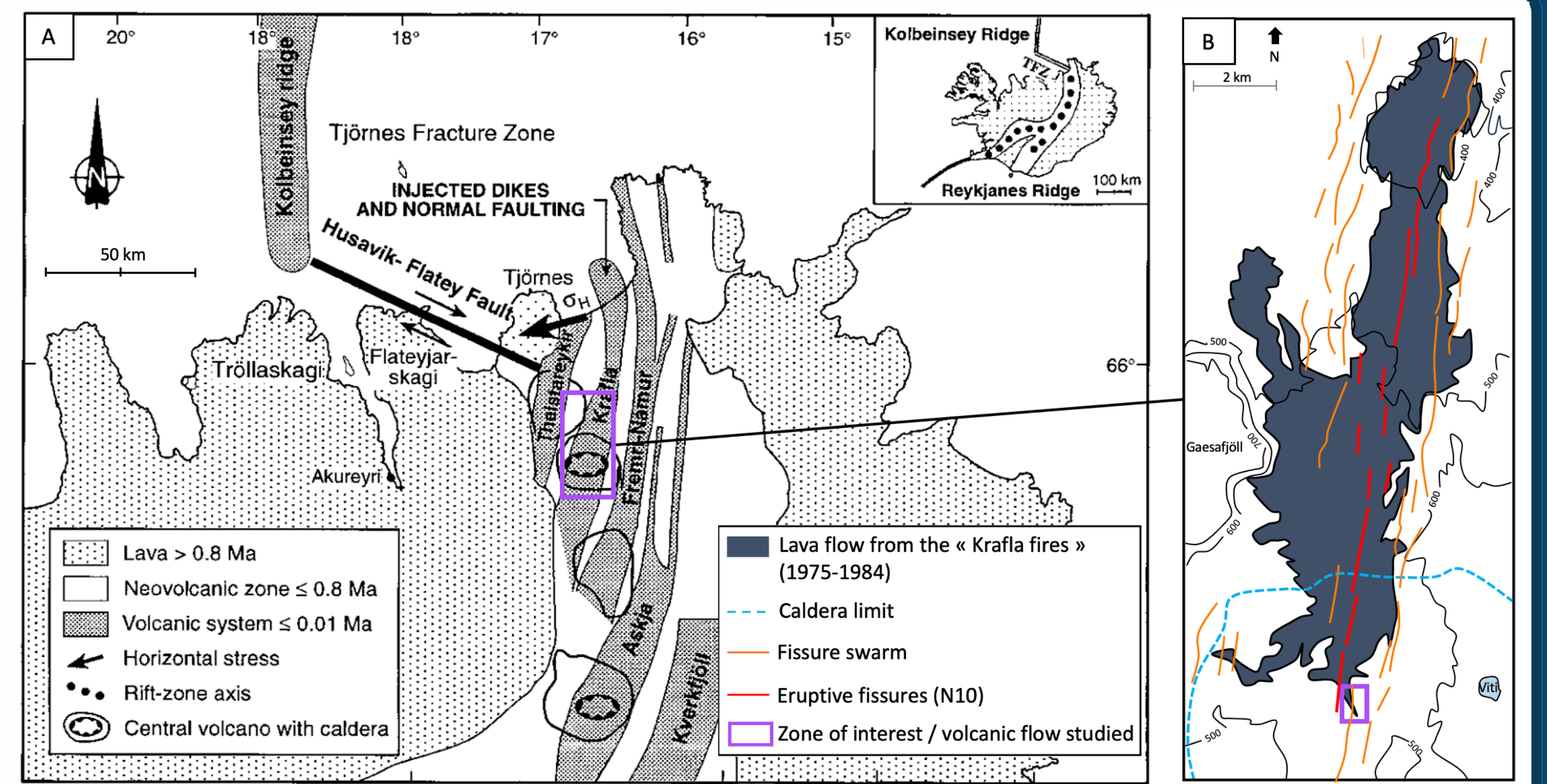


1 INTRODUCTION

The **Krafla volcanic system** is located in the axis of the Icelandic rift valley and is under the tectonic influence of the Tjörnes Fracture Zone and the **North Volcanic Zone** (Figure 1A), which delineates the active rift zone of the country. This zone comprises 5 fissure swarms arranged in echelons, accompanied by a central volcano (Gudmundsson, 2000). At its centre, Krafla has a caldera (Figure 1B) around 10 km in diameter and has a fissure swarm, oriented along the N10 axis, which is responsible for the **fissural eruptions** producing the **tholeiitic basaltic lavas** (Nicholson, 1990). The flow studied was the result of the last eruptive episode known as the **"Krafla fires"**, which took place between 1975 and 1984.

The aim of this study is to determine the internal parameters (temperature, yield strength, etc.) and more specifically the viscosity of a basaltic lava flow using a **morphological approach** (field study and very high-resolution numerical model) and a **chemical approach**. The finality is to fix the internal parameters of a basaltic lava flow in order to be able to simulate it as close as possible to the reality of the field. The focus of this study is an auxiliary flow, 605 m long and covering 0.04 km², positioned at the southern end of the main Krafla flow of the "Krafla fires" episode (Figure 1B). It erupted during the end period of the event, in 1984.

Figure 1 : A) Volcanic and tectonic systems of the North Volcanic Zone (Gudmundsson, 2000). B) Location of the flow studied in relation to the general flow of the "Krafla fires" eruptive episode, modified from Cooper et al. (2016).



2A GENERAL METHODOLOGY

FIELD STUDY

- Measure of flow/channel width/thickness, slope angle (regular intervals)
- High resolution drone image acquisition
- Facies recognition

CHEMICAL ANALYSIS

- Viscosity calculation program (Giordano et al., 2008) for:
 - New chemical analysis
 - 3 chemical analysis by Nicholson (1990)

NUMERICAL SIMULATIONS

- Viscosity and yield strength representation
- Impact of the parameters : slope, vent's geometry, effusion rate

MORPHOLOGICAL APPROACH :

- evaluation of the viscosity for the upstream part of the flow
- identification of the specific morphologies associated

CHEMICAL APPROACH :

- viscosity for a specific temperature
- confrontation with the morphological approach

Hierarchy of the parameters

2B PARAMETERS CALIBRATION

The aim of using the **3 calculation methods** is to assess whether there can be **variations in viscosity** within the part considered as upstream of a flow (first 100 meters from the vent) and to check whether these variations can reflect specific surface morphologies. The slope measurements (Figure 2B) are taken at every slope discontinuity and the dimensional measurements are taken at each major dimensional change in the flow (Figure 2A).

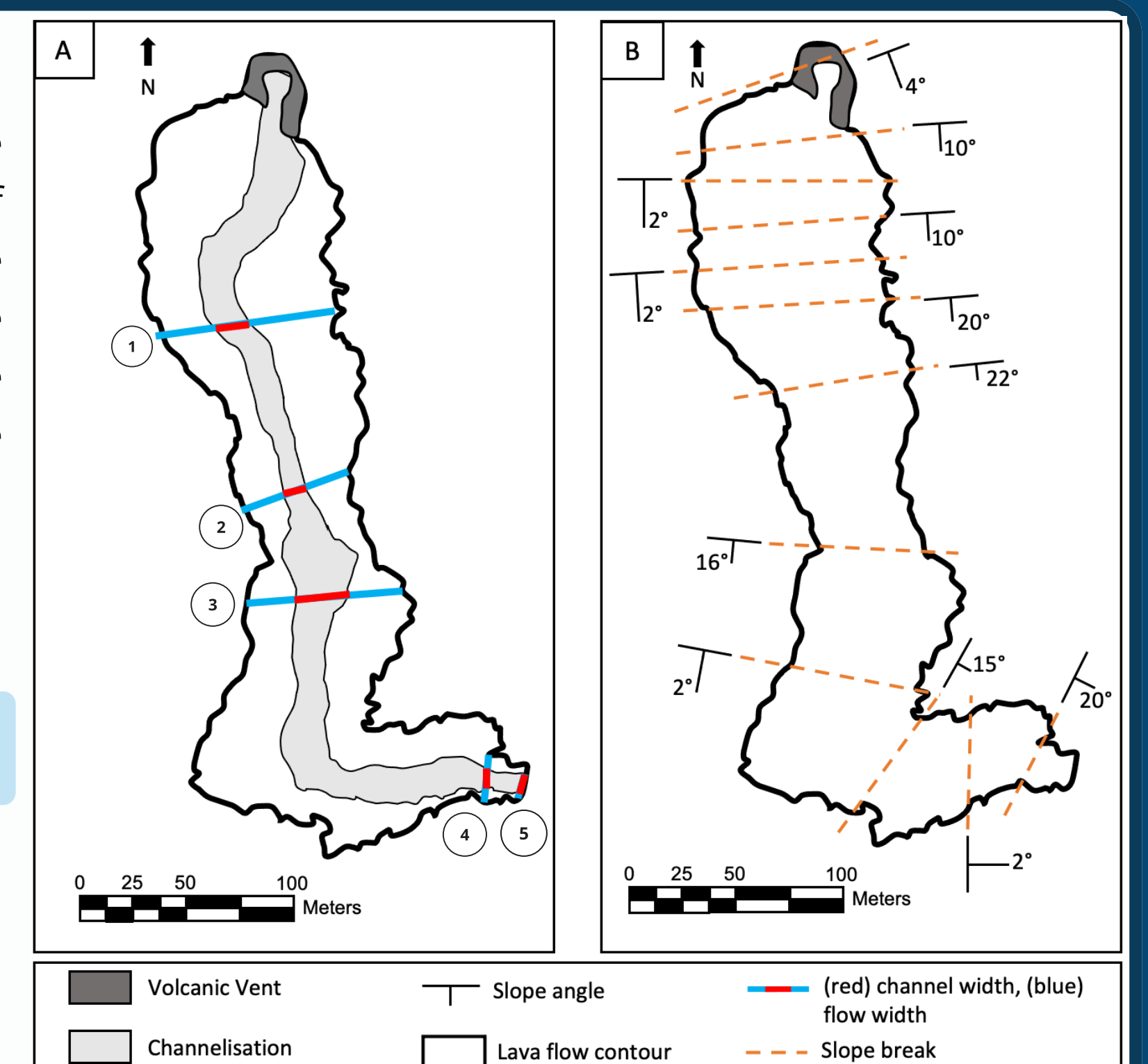
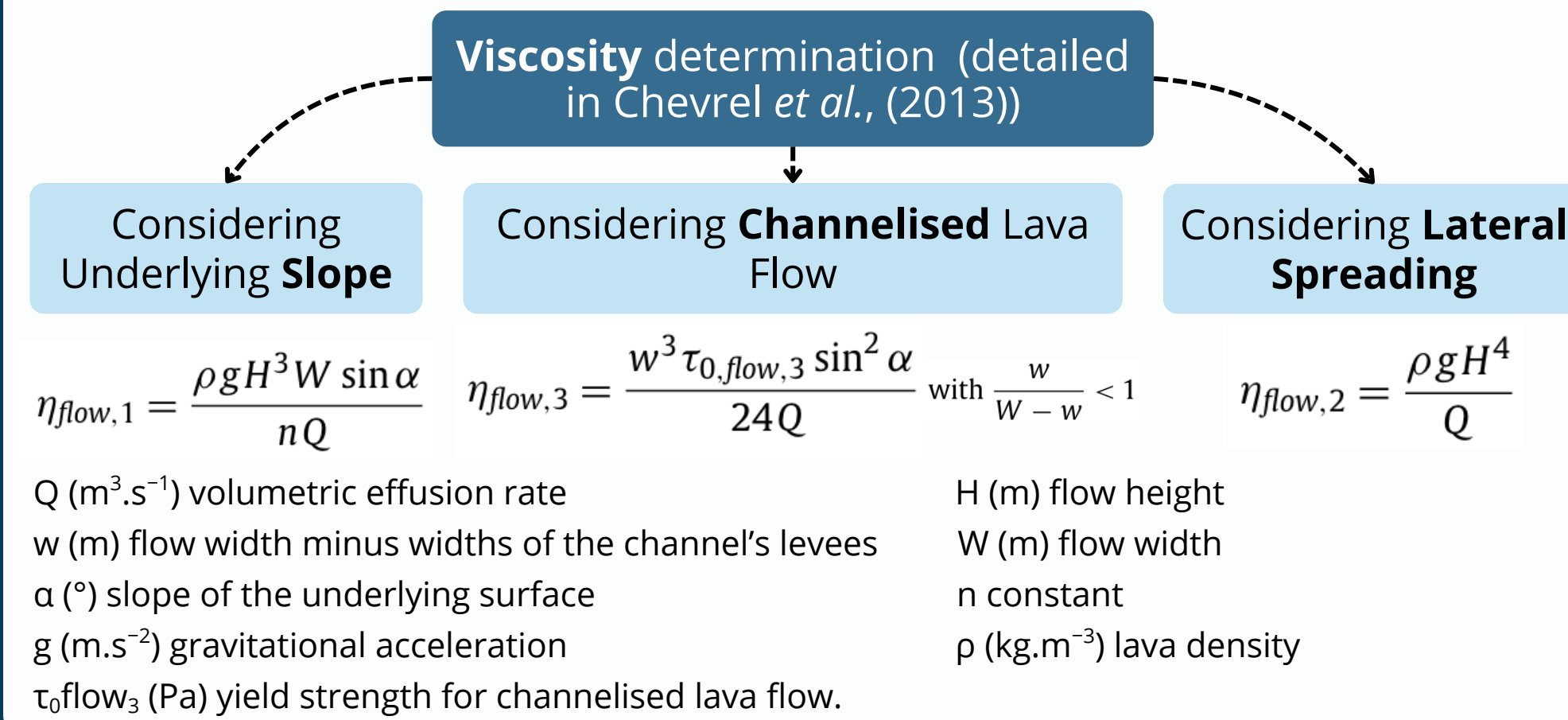


Figure 2 : A) Position of the measures and of the channel in the lava flow ; B) Inventory of the slope breaks and the slope angle along the lava flow

3 RESULTS

MORPHOLOGICAL APPROACH :

Table 1 : Flow studied viscosity results using the approaches detailed in Chevrel et al., (2013)

	Considering underlying Slope $\eta_{flow,1}$		Considering lateral Spreading $\eta_{flow,2}$		Considering channelled lava flow $\eta_{flow,3}$	
	Pa.s	log η (Pa.s)	Pa.s	log η (Pa.s)	Pa.s	log η (Pa.s)
1	13 131 ± 0.1	4.1 ± 0.1	8 402 ± 0.1	3.9 ± 0.08	-	-
2	9 882 ± 0.5	4.0 ± 0.01	-	-	434 ± 0.2	2.64 ± 0.07
3	3 996 ± 0.6	3.6 ± 0.01	3 442 ± 0.6	3.5 ± 0.03	-	-
4	4 642 ± 0.5	3.7 ± 0.4	-	-	47.5 ± 0.4	1.68 ± 0.02
5	1 086 ± 0.5	3.0 ± 0.03	-	-	8.21 ± 0.3	0.91 ± 0.06

Drone acquisition (Figure 3) and field observations indicate a range of thicknesses from 35 cm to 3.5 m, with a range of width from 16 m to 76 m and slope angles varying from 4° to 21°. Moreover, facies tend to become rougher and more **disturbed as they approach the flow terminations**.

The approaches considering maximum spreading and slope show viscosity values of the order of 3.5 - 4 Pa.s (Table 1), a value much higher than those usually found in the literature for this type of lava. The channelling approach gives values of the order of 2 Pa.s (Table 1). The difference between these 3 approaches reflects a **chronology in the emplacement** of the lava and suggests that other factors, are involved in the emplacement and that might be explained with the chemical approach.



Figure 3 : Digital Elevation Model (DEM) of the upper part of the lava flow (2cm resolution).

CHEMICAL APPROACH :

The use of the chemical methodology defined by Giordano et al. (2008) is intended to support the estimation of viscosity values and to estimate the **evolution of temperature during the eruption**. The chemical analysis obtained for the studied lava flow (Table 2) is consistent with the chemical analysis of 3 samples collected shortly after the eruption by Nicholson (1990). Comparison with recent Icelandic eruption (2021) values estimated by Ylvassdotter (2024) (Figure 4) shows negligible variation in Icelandic lava chemistry.

Table 2: Chemical analysis of the "Krafla fires" lava from (Nicholson, 1990) and from the lava flow studied (Figure 3)

	Krafla Lava			Krafla 1984
	Nicholson, 1990	84-19	84-05	
SiO ₂	48.76	49.63	49.96	49.48
TiO ₂	1.47	2.05	1.17	2.11
Al ₂ O ₃	14.79	13.12	13.86	13.50
FeO(T)	11.58	14.51	11.04	15.08
MnO	0.20	0.24	0.19	0.25
MgO	8.66	5.86	7.57	5.92
CaO	11.65	10.14	12.32	10.40
Na ₂ O	2.08	2.29	2.03	2.46
K ₂ O	0.20	0.33	0.13	0.33
P ₂ O ₅	0.14	0.21	0.11	0.21
Total	99.53	98.38	98.38	99.99

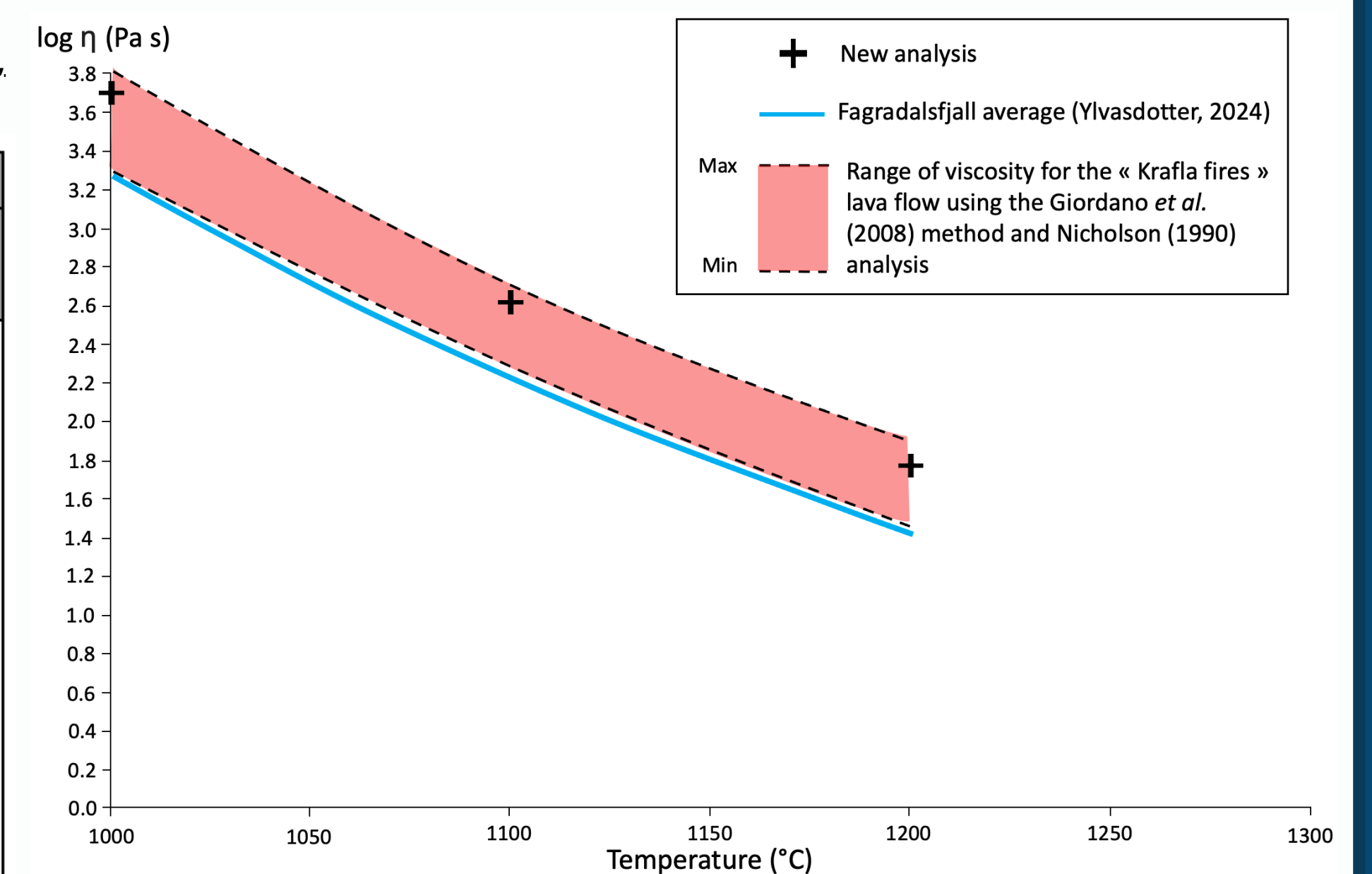


Figure 4: Viscosity evolution according to the temperature for the "Krafla fires" based on the literature and on the field results, modified from Ylvassdotter (2024)

4 INTERPRETATION & DISCUSSION

Estimation of viscosity using the morphological method revealed a **variation in viscosity as a function of apparent morphology** (spreading, channelling) associated in part with slope but also with variation in parameters internal to the lava. This method also indicates a chronology in the emplacement: spreading occurs early in the emplacement (high temperature and low viscosity), while channalisation occurs later (drop in temperature and higher viscosity).

Correlating the two approaches, the estimated temperature values with the viscosity values determined morphologically are not consistent with the chemically obtained viscosity values: Morphological method leads to a theoretical eruption temperature of about 1000°C, much lower than the known eruption temperatures for this type of lava (1200°C), bearing in mind that the measurements were taken close to the vent. Therefore, **this change of viscosity can't be explained only by a decrease of the temperature**.

Microscopic analysis (Figure 5), to understand the difference in values obtained by the morphological method and the chemical method, suggests that **other factors are involved in the variations in viscosity during flow**, which are not taken into account in the morphological method: the vacuole rate and/or the crystal rate. The lava studied shows a high proportion of vacuoles (40-45 %) compared with the proportion of phenocrysts (3-4 %). The strong increase in viscosity could be explained in part by the high proportion of gas present in the lava in a perimeter very close to the vent.

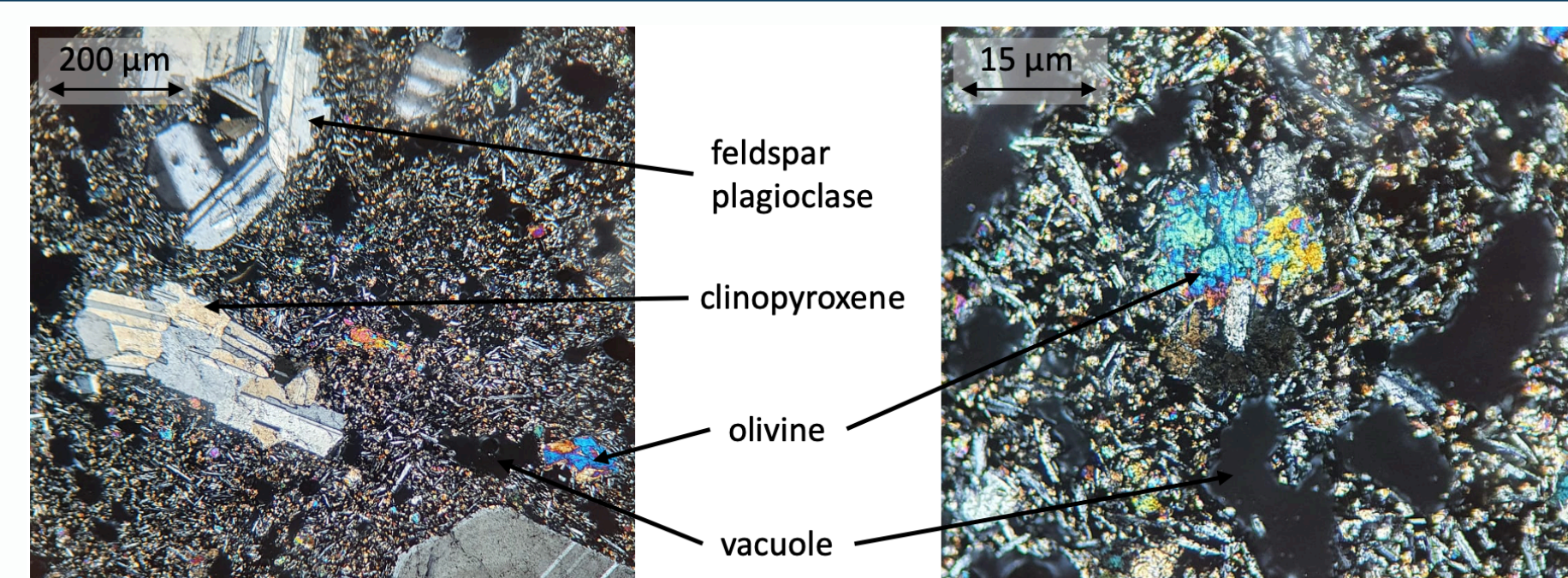


Figure 5 : Pictures of the thin-section of the tholeiitic lava in LPA. The phenocrysts are in decreasing proportion : plagioclase, olivine, pyroxene.

5 CONCLUSION

Discrepancies between the results of viscosity obtained by the morphological and chemical methods could be explained by the influence of other parameters (vacuole, phenocrysts), not currently taken into account in the various equations, on the viscosity during the flow. **Exploratory simulations** would enable refinement of the model's parameters in order to assess and prioritize their relative influence on emplacement behavior. These simulations **cannot be over-simplified** as there is a risk that they will not take into account the parameters' variations through time and therefore won't be representative of the reality on the field.

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