Trace element composition in olivine from the 2022 Meradalir eruption of the Fagradalsfjall Fires, SW-Iceland

Short Communication

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Abstract
This study focuses on determining the trace element composition in olivine from olivine tholeiitic basalts sampled in Iceland during the 2022 Meradalir eruption of the 2021-ongoing Fagradalsfjall Fires. The chemistry of Meradalir olivine is characteristic for a volcanic origin where olivine crystals represent the product of crystallisation. Olivine from the Meradalir basalt magma falls within the field characteristic for the melting of a dominantly peridotitic mantle source. However, the data show that the 2022 Meradalir olivine crystalized from a compositionally more evolved magma than olivine from the preceding 2021 Geldingadalir eruption of the Fagradalsfjall Fires.

Key words: olivine, Reykjanes Peninsula, Meradalir lava, LA-ICP-MS

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Introduction

On Wednesday, August 3, 2022, a new volcanic eruption in the Meradalir area on the Reykjanes peninsula (SW-Iceland) began. This took place less than a year after the end of the 2021 Geldingadalir eruption, which both belong to the 2021-ongoing Fagradalsfjall Fires (Fig. 1). Both eruptions took place within the Fagradalsfjall volcanic system, but in geological history, it has been active together with other volcanic systems on a trans-tensional structure referred to as the Reykjanes Volcanic Belt. It links the Western Volcanic Zone in the east to the Reykjanes Ridge in the west (*e.g.*, Peate et al. 2009, Sæmundsson et al. 2020, Bindeman et al. 2022).

In the magmas from the Reykjanes Peninsula, olivine is typically the first major phase to crystallise. Therefore, it provides an exceptional tool for deciphering the composition of mafic parental magmas from which the crystal grew and allows to glean information on the composition of their mantle source (*e.g.*, Thomson and Maclennan 2013, Demouchy and Alard 2021, Wang et al. 2022). The aim of this study was to present the initial results on the trace element composition of olivine from the lava that was sampled in August during the 2022 Meradalir eruption. We hypothesised that the analysis of trace would provide detailed information on magma origin and processes.

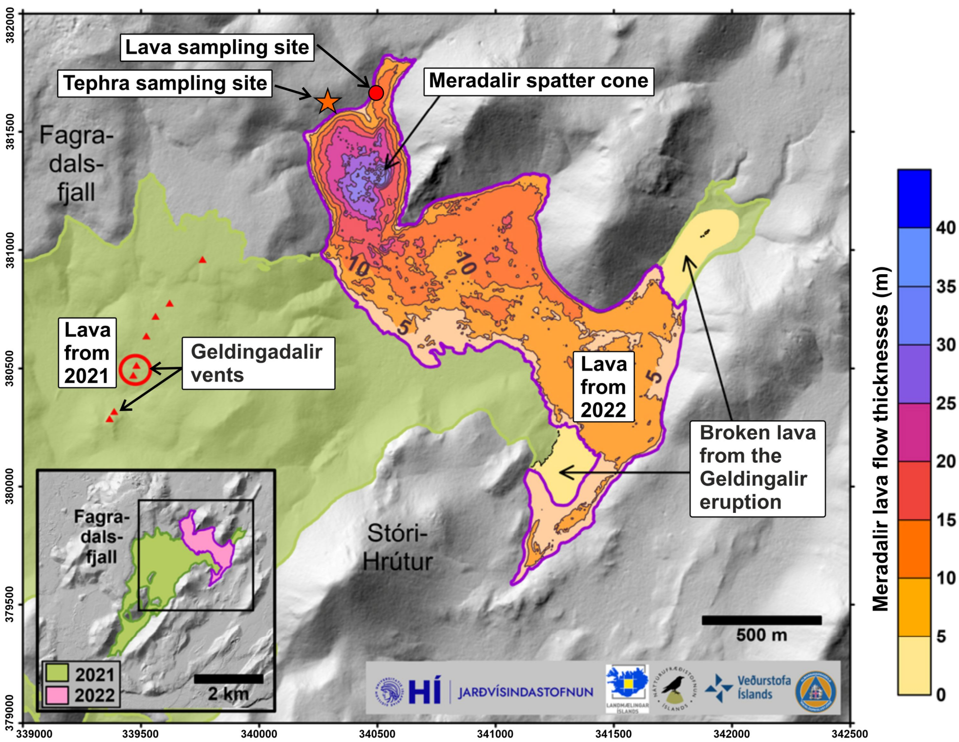

Fig. 1. Lava fields of the 2021 Geldingadalir and 2022 Meradalir eruptions with the location of the sampling sites. Map source adapted from [1] (Jarðvísindastofnun – Institute of Earth Sciences, University of Iceland).

The 2022 Meradalir eruption

Volcanic activity in Meradalir (located approximately 40 km from Reykjavík, 20 km from Keflavík International Airport, and 9 km from Svartsengi geothermal power plant), began at 13:18 GMT [2]. The actual eruption was preceded by an earthquake swarm that seismologists in the area have registered since the end of July. The largest earthquake had a magnitude of 5.5 [2]. The Meradalir eruption began with a curtain of Hawaiian-style lava fountaining along a 350-m-long NNE oriented volcanic fissure. In the first days of the eruption, the eruption products comprised tephra and a spectrum of lava types, including pāhoehoe and ‘a’ā lava textural types. These products were similar to those from the 2021 Geldingadalir eruption. On the first day of the 2022 eruption, the whole length of the erupting fissure was active and the magma discharge peaked at ~20 m^3 s^{-1} (dense rock equivalent; Krmíček 2022). A few hours after the onset, the very ends of the fissure became inactive and on the second day, the length of the fissure that fed eruptive activity was reduced by more than two-thirds of its original length to ~100 m with an outflow rate of ~15 m^3 s^{-1} (Krmíček 2022). In the following days, the activity on the fissure was confined to vigorous fountaining along the central segment of the fissure and with two smaller side vents. At this time the construction of what later became the main Meradalir spatter cone began (Fig. 2A). The vents within the growing cone were the main source of the lava outflow in the later stages of the eruption and the lava thicknesses produced proximal to the cone varied from 20 to 40 m. In the distal part of the lava flow field, the lava was thinner with a thicknesses of ≤ 15 m (Fig. 1). Intriguingly, a volcanological phenomenon began to occur in the vicinity of the volcano immediately after its formation, being that the surface crust of the 2021 lava was gradually broken up into the blocks of about 1 m length and was raised (and partially melted) by the pressure and temperature effect of the new lava flow (Fig. 2B, 2C). Finally, the eruptive activity in Meradalir then subsided in mid-August and eventually ceased on August 21, 2022.

Sampling of an active volcano

The fresh lava used in this study was collected during the active phase of the Meradalir eruption on August 12 (*see* Fig. 1 for sampling sites). Since the temperatures of the liquid lava could reach the temperature of up to 1200°C, together with the occurrence of dangerous volcanic gases that might have accompanied the eruption, special volcanological equipment consisting of a volcanological suit, head shield, gas mask and titanium steel sampling rod was used (Fig. 3A, 3B). The sampled lava was subsequently quenched in a steel bucket using deionised water. Apart from lava, our team also collected hundreds of fragments of unconsolidated pyroclastic material (tephra), which was ejected into its immediate surroundings during the eruption and which was deposited in the form of highly vesicular (and on occasion reticulite-like), golden-brown fragments of various sizes (Fig. 3C).

Fig. 2. Photos from the Meradalir area: A – newly built main volcanic cone, B – ropy lava of the 2021 Geldingadalir eruption broken into the meter-long blocks, C – Close-up view of a block of ropy lava.

Fig. 3. Meradalir volcano sampling: A – collection of a liquid lava sample for analysis, B – flow emplacement of the investigated lava type 'a'ā, C – example of highly vesicular tephra ejected during the active eruption.

Analytical methods

Polished thin sections were examined using conventional optical microscopy to evaluate the presence of individual olivine crystals. The composition of selected olivine grains was analysed using an electron probe micro-analyser paralleled by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). The LA-ICP-MS consisted of quadrupole-based ICP-MS (Agilent 7900) connected to the ArF* excimer laser ablation system Analyte Excite+ (Teledyne CETAC Technologies). The laser ablation system emits a laser beam at a wavelength of 193 nm and is equipped with 2-vol Cell HelEx II. The ablated material was carried by He flow (0.5 and 0.3 l min^{-1}) and mixed with Ar (~1 l min^{-1}) prior to entering the ICP mass spectrometer. The sample surface of individual spots was ablated for 60 s per spot by a 50µm laser beam diameter with the fluence of 3 J cm^{-2}, 10 Hz repetition rate and 60 s washout time. The monitored isotopes are as follows: $^{7}Li^{+}$, $^{11}B^{+}$, $^{23}Na^{+}$, $^{27}Al^{+}$, $^{29}Si^{+}$, $^{31}P^{+}$, $^{44}Ca^{+}$, $^{45}Sc^{+}$, $^{47}Ti^{+}$, $^{51}V^{+}$, $^{52}Cr^{+}$, $^{55}Mn^{+}$, $^{60}Ni^{+}$, $^{63}Cu^{+}$, $^{66}Zn^{+}$, $^{69}Ga^{+}$, $^{73}Ge^{+}$, $^{89}Y^{+}$, $^{90}Zr^{+}$, $^{93}Nb^{+}$, $^{118}Sn^{+}$, $^{181}Ta^{+}$, and $^{208}Pb^{+}$.

The ICP-MS was tuned using SRM NIST 612 with respect to the sensitivity and minimum doubly charged ions (Ce^{2+}/Ce^{+} < 5 %), oxide formation ($^{248}ThO^{+}/^{232}Th^{+}$ < 0.3 %) and mass response $^{238}U^{+}/^{232}Th^{+}$ ~1. The potential interferences were minimised via a collision cell (He 1 ml min^{-1}). The elemental contents were quantified using artificial glass standards SRM NIST 610 and 612, and Si as the internal reference element after baseline correction and integration of the peak area using HDIP software (Teledyne CETAC Technologies, Omaha, Nebraska, USA). The elemental content was also checked via ablation of MongOL Sh11–2 olivine standard (Batanova et al. 2019) as unknown material. Representative trace element olivine analyses are listed along with the average detection limits under operating conditions in Table 1.

	MDL1	MDL2	MDL3	MDL4	MDL5	MDL6	MDL7	MDL8	MDT	LOD	LOQ
Al	284	306	273	233	255	264	239	294	247	2.44	8.14
P	*160*	251	314	*160*	*161*	242	*117*	*154*	256	60.6	202
Ca	2187	2047	2197	2105	2201	2101	2106	2040	2233	140	466
Sc	8.99	8.89	10.1	8.06	8.99	9.17	8.44	8.00	8.93	0.44	1.46
Ti	45.4	49.0	49.3	39.4	48.2	46.3	38.6	38.1	49.7	1.41	4.71
V	13.4	9.11	12.1	11.5	13.2	11.3	11.0	10.3	8.19	0.18	0.59
Cr	203	304	299	212	246	264	248	262	278	0.77	2.56
Mn	2005	1578	1888	1693	1810	1788	1647	1610	1868	0.64	2.13
Ni	1417	1766	1679	1439	1521	1609	1743	1771	1603	0.64	2.14
Cu	5.61	7.83	5.55	4.60	6.28	5.67	4.79	5.31	6.45	0.53	1.75
Zn	122	92.0	113	116	117	120	107	92.0	125	0.83	2.76
Ga	0.17	0.18	0.15	0.14	0.15	0.18	0.17	0.12	0.18	0.03	0.09
Ge	2.51	*1.71*	2.29	1.89	2.25	2.25	2.27	*1.72*	2.24	0.52	1.74
Y	0.12	0.12	0.08	0.10	0.09	0.11	0.09	0.08	0.08	0.01	0.04
Zr	0.03	0.09	0.03	*0.02*	0.05	0.03	*0.02*	0.08	0.04	0.01	0.03

Table 1. Representative trace element compositions (in ppm) of Meradalir olivine. Values below limit of quantification are given in italics. The contents of Li, B, Na, Nb, Sn, Ta and Pb are below their detection limits. Abbreviations: MDL = Meradalir lava, MDT = Meradalir tephra, LOD = limit of detection, LOQ = limit of quantification.

Results

Fresh lava samples from Meradalir consisted of olivine tholeiite basalts characterized by abundant plagioclase and minor olivine macrocrysts that reside in a finely crystalline to glassy groundmass (Fig. 4).

Olivine macrocrysts were present as subhedral to euhedral stubby prisms with variable MgO contents [$Fo_{86–77}$, where Fo = Mg / (Mg+Fe) mol%]. Nickel concentrations correlated positively with Fo content and ranged between 1260 and 2210 ppm. Olivine also showed a variation in Mn concentrations between 1430 – 2005 ppm, whereas Ca contents ranged from 1830 to 2500 ppm at relatively low Ti (up to 50 ppm). Aluminium (232 – 344 ppm), Zn (86 – 125 ppm) and Ga (0.12 – 0.19 ppm) concentrations mostly overlapped the previously published data for Icelandic olivine (Rasmussen et al. 2020), while Sc concentrations (7.5 – 10 ppm) were elevated relatively to previously published work.

Mn/Zn value in the 2022 Meradalir olivine macrocrysts ranged from 14.6 to 17.8, and broadly overlapped the range known from the olivine from the adjacent Western Volcanic Zone (Fig. 5). On the other hand, olivine crystals from the Meradalir eruption clearly differed from those of the 2021 Geldingadalir eruption by showing systematically lower Mn/Zn ratios (Fig. 5).

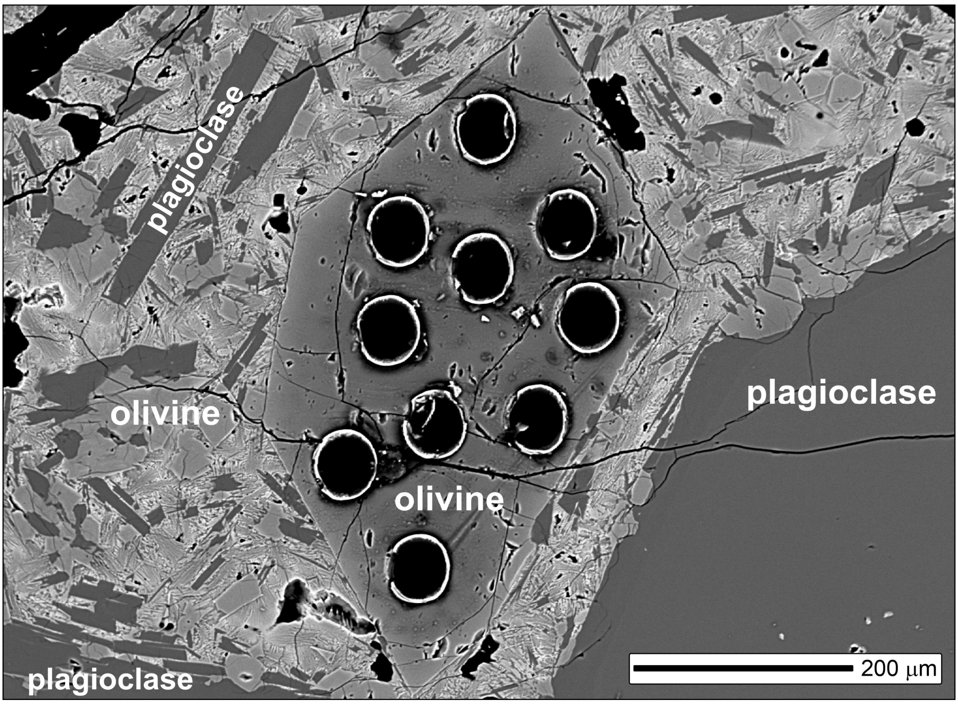

Fig. 4. Meradalir lava samples are characterised by plagioclase and olivine phenocrysts and microphenocrysts sitting in a finely crystalline to glassy groundmass. The circular holes in olivine are laser ablation pits. Back-scattered electron image.

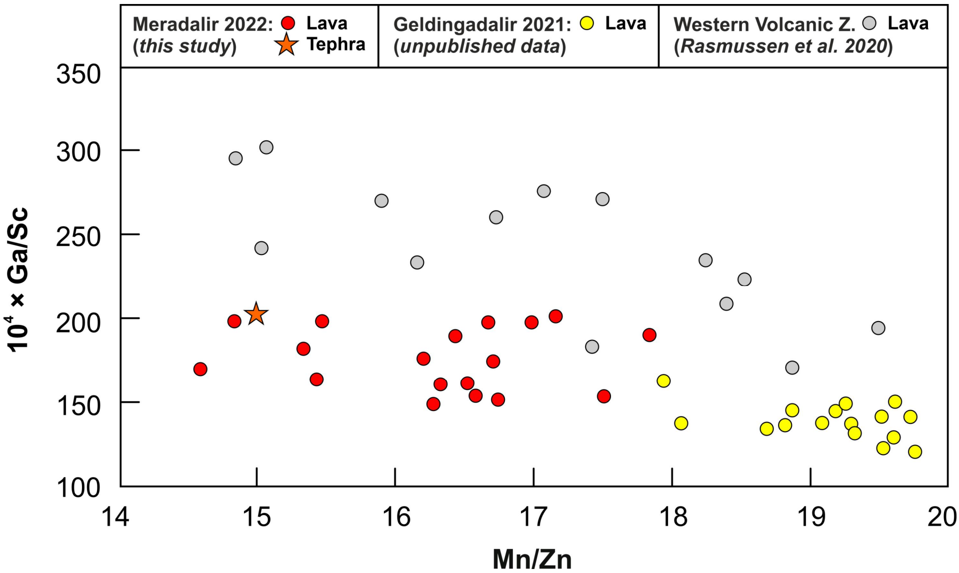

Fig. 5. The position of the studied samples in Ga/Sc *versus* Mn/Zn diagram supplemented by the data for olivine from the Geldingadalir eruption (unpublished data) and the Western Volcanic Zone (Rasmussen et al. 2020).

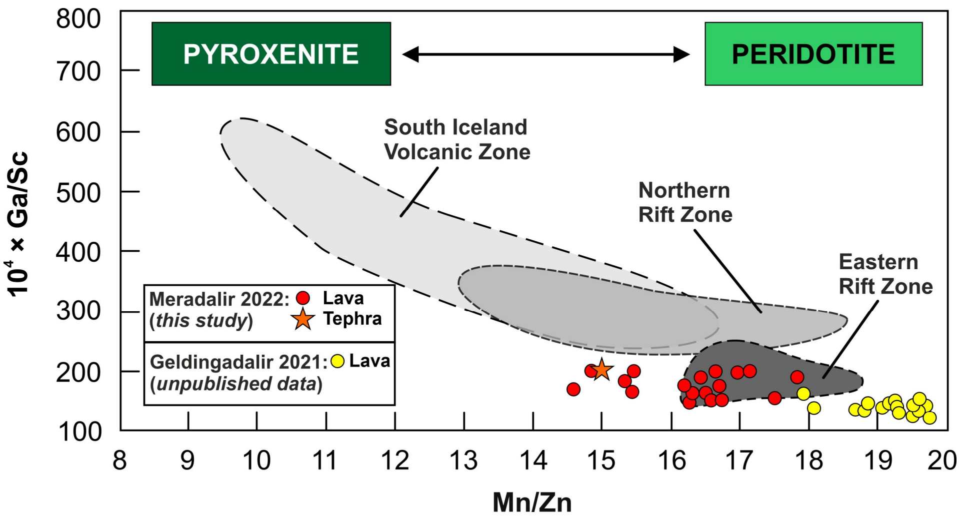

Fig. 6. The position of the studied samples in Ga/Sc *versus* Mn/Zn diagram supplemented by the data for olivine from the Geldingadalir eruption (unpublished data) and various Iceland zones as described in paper by Rasmussen et al. (2020). Peridotite and pyroxenite fields according to Howarth and Harris (2017).

Discussion

Mantle (xenocryst) olivine can be distinguished from volcanic olivine by lower concentrations of Ca (<700 ppm; Foley et al. 2013). Trace element compositions of olivine from our study provided evidence that all investigated macrocrysts qualify to be considered as high-Ca (and low-Ti) volcanic olivine. The olivine crystals from fresh lava samples from the 2022 Meradalir event thus represented the product of crystallisation from magma, but a compositionally more evolved magma compared to olivine from the 2021 Geldingadalir eruption, which is characterised by higher MgO contents (Fo_{90-81}; Halldórsson et al. 2022).

Howarth and Harris (2017) suggested the use of Mn/Zn ratios for distinguishing between pyroxenite and peridotite as the prevailing source lithology, with an approximate border at Mn/Zn ratio of 14. Olivine from the axial rift, including the Meradalir samples from the Reykjanes Volcanic Belt and samples from the Western Volcanic Zone fall within the field indicating melting of a dominantly peridotitic mantle source (Fig. 6). Contrastingly, the trace element composition of olivine from the southeast propagating Eastern Volcanic Zone (South Iceland Volcanic Zone *sensu* Rasmussen et al. 2020), fall mostly within the pyroxenitic field.

Both olivine from the 2022 Meradalir and 2021 Geldingadalir eruptions shows lower Ga/Sc ratios, compared to the Western Volcanic Zone olivine (Fig. 5). The lower Ga/Sc ratios were related to elevated Sc contents of 2022 Meradalir and 2021 Geldingadalir olivine groups. It is known that partial melting of fertile spinel peridotite could produce Sc-rich primary melts, whereas magmas derived from garnet peridotite are generally characterised by low Sc concentrations (Wang et al. 2021). For this reason, we cannot exclude an option that the observed differences in Sc contents of the studied samples may imply that Reykjanes Volcanic Belt olivine and those of the axial rift in Iceland might be controlled by different abundance of garnet *versus* spinel in the peridotite mantle source. Thus, they relate to the variations in the depth of the partial mantle melting. However, this hypothesis needs to be verified by further detailed analytical study, because the generally low Sc concentrations were affected to varying extent by a $^{29}Si^{16}O$ polyatomic interference on mass-45.

Conclusions

Based on our research, the following principal conclusions can be drawn: (1) Trace element compositions of Meradalir olivine provide evidence that all investigated macrocrysts of olivine are of volcanic origin and not xenocrystic. (2) Volcanic olivine from fresh lava samples from the 2022 Meradalir event represents a product of crystallisation from compositionally more evolved magma portion compared to olivine from the 2021 Geldingadalir eruption. (3) Olivine from the 2022 Meradalir samples falls within the field characteristic for the melting of a dominantly peridotitic mantle source.

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