

Trace elements in olivine fingerprint the source of 2018 magmas and shed light on explosive-effusive eruption cycles at Kīlauea Volcano

Adrien J. Mourey, Thomas Shea, Kendra J. Lynn, Allan H. Lerner, Sarah Lambart, Fidel Costa, Jeffrey Oalmann, R. Lopaka Lee, Cheryl Gansecki

▶ To cite this version:

Adrien J. Mourey, Thomas Shea, Kendra J. Lynn, Allan H. Lerner, Sarah Lambart, et al.. Trace elements in olivine fingerprint the source of 2018 magmas and shed light on explosive-effusive eruption cycles at Kīlauea Volcano. Earth and Planetary Science Letters, 2022, 595, 10.1016/j.epsl.2022.117769. insu-03776398

HAL Id: insu-03776398 https://insu.hal.science/insu-03776398

Submitted on 5 Mar 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Trace elements in olivine fingerprint the source of 2018 magmas and shed light on explosive-effusive eruption cycles at Kīlauea Volcano

Adrien J. Mourey¹, Thomas Shea¹, Kendra J. Lynn², Allan H. Lerner³, Sarah Lambart⁴, Fidel Costa^{5,6}, Jeffrey Oalmann⁵, R. Lopaka Lee, Cheryl Gansecki⁷

6	¹ Department of Earth Sciences, University of Hawai'i at Mānoa, Honolulu, HI, United States
7	² USGS Hawaiian Volcano Observatory, HI, United States
8	³ Department of Earth Sciences, University of Oregon, OR, United States
9	⁴ Department of Geology and Geophysics, University of Utah, Salt Lake City, UT, United States
10	⁵ Earth Observatory of Singapore, Nanyang Technological University
11	⁶ Asian School of the Environment, Nanyang Technological University
12	⁷ Geology Department, University of Hawai'i at Hilo

- 13 7221 words
- 14 10 figures
- 15 55 references

Corresponding author: Adrien J. Mourey, amourey@hawaii.edu

16 Abstract

Understanding magma genesis and the evolution of intensive parameters (temperature, 17 pressure, composition, degree of melting) in the mantle source of highly active volcanic 18 systems is crucial for interpreting magma supply changes over time and recognizing cyclic 19 behavior to anticipate future volcanic behavior. Major and trace elements in olivine are 20 commonly used to study variations in mantle lithologies and melting conditions (e.g., tem-21 perature, pressure, oxygen fugacity) affecting the mantle over time. Here, we track the 22 temporal evolution of primary melts through the most recent cycle of explosive and effusive 23 eruptions at Kīlauea (Hawai'i), which spans the last ~ 500 years. We report major and 24 trace elements in olivine from the last explosive period (~ 1500 -early 1820's Keanakāko'i 25 Tephra) and the most recent decade of the current effusive period (2018 LERZ, 2015-2018 Pu'u'ō'ō, 2008-2018 lava lake and 2020 eruption in Halema'uma'u). Scandium concentra-27 tions in olivine allow characterizing changes in mantle source between 1500 and 2018, and 28 suggest that the recent (2015-2018) magma feeding the $Pu'u'\bar{o}c\bar{o}$ cone did not significantly 29 interact with the magma that erupted in the LERZ in 2018. The evolution of olivine and 30 melt compositions over the past 500 years is not easily reconcilable with variations in mantle 31 potential temperature, pressure of mantle melt pooling and storage, or even oxygen fugac-32 ity conditions. Instead, Sc, Mn, and Co concentrations and Ni/Mg ratio in high forsterite 33 (Fo>87) olivine advocate for an increase in the proportion of clinopyroxene in the mantle 34 source associated with a slightly higher degree of partial melting from 1500 to 2018. Changes 35 in primitive melt compositions and degrees of mantle melting may well modulate magma supply to the crust and formation-replenishment of steady or ephemeral summit reservoirs, 37 and thereby control transitions between explosive and effusive periods at Kilauea. Analyz-38 ing trace elements in olivine at Kīlauea and elsewhere could therefore provide important 39 clues on subtle changes occurring at the mantle level that might herald changes in volcanic 40 behavior. 41

42 1 Introduction

Kīlauea is an active shield volcano located on the Island of Hawai'i (Fig.1), iconic
for its vigorous effusive activity over the last 200 years (Poland et al., 2014). However,
several centuries-long periods of explosive activity have also occurred over the past 2500
years (Swanson et al., 2014). Kīlauea's last explosive phase (~1500 - early 1820's) produced
the Keanakāko'i Tephra (KT), a period over which magma supply and eruption rates are

inferred to be low (5 x 10^{-4} km³/yr) compared to the 20^{th} (up to 0.1 km³/yr) and 21^{st} 48 centuries (0.1-0.2 km³/yr; Poland et al., 2014). The long-lived KT sequence was produced 49 by over ~ 320 years of dominantly explosive eruptions, following the collapse of the modern 50 Kīlauea caldera at around 1500 ± 30 C.E. (Swanson et al., 2012). The KT is composed of 51 explosive phreatomagmatic, phreatic, and high lava fountain deposits, as well as one lava 52 flow (McPhie et al., 1990; Swanson et al., 2012). During explosive periods at Kīlauea, magma 53 is thought to erupt with little to no processing in the crust (Sides et al., 2014; Lynn et al., 64 2017), whereas during the current effusive period, summit reservoirs are stable and steadily 55 replenished (Poland et al., 2014; Lynn and Swanson, 2022). Following the KT period, from 56 1840 to 1959, magma supply and the degree of partial melting remained low (Pietruszka and 57 Garcia, 1999). Since 1959 and through the present day, eruption rates and magma supply 58 have been steadily increasing (Poland et al., 2014; Wright and Klein, 2014). Between 2003 59 and 2007, a significant increase in the CO₂ emissions and inflation at Kilauea's summit also 60 suggested an additional surge in mantle-driven magma supply (Poland et al., 2012). Kilauea 61 is therefore currently undergoing a high magma supply period within a largely effusive cycle. 62

The transition between effusive and explosive periods is thought to be punctuated by 63 major caldera forming events, with smaller to moderate caldera collapse events in between 64 (<km in scale; Swanson et al., 2014). In addition to the caldera collapse in 1500, several 65 other collapses occurred in 1790 (inferred collapse event), 1832, 1840, 1868 (Brigham, 1909) and 1924. These collapse events are known to strongly perturb Kilauea's crustal plumbing 67 system (Anderson et al., 2019). The last significant caldera collapse occurred in 2018 during the lower East Rift Zone (LERZ) eruption, the largest eruption in the last 200 years of 69 activity (Neal et al., 2019). Prior to the 2018 crisis, Kilauea Volcano was erupting at two 70 locations, Pu'u'ō'ō on the East Rift Zone (ERZ), and within a lava lake inside Halema'uma'u 71 crater at the summit. The large cumulative volume of the Pu'u'ō'ō lavas between 1983-2018 72 $(>4 \text{km}^3)$ was sustained by a nearly continuous supply of mantle-derived magma that mixed 73 with large volumes of stored summit magmas (Neal et al., 2019). During this period, Kilauea 74 erupted near-continuously at the middle ERZ (Fig.1) at the Pu'u' \bar{o} , cone. On April 30th 75 2018, the configuration of the shallow magmatic storage system changed after complete 76 drainage of both the Halema'uma'u lava lake and the Pu'u'ō'ō vent (Neal et al., 2019). The 77 LERZ 2018 eruption was preceded by swarms of lower-crustal earthquakes 5-13 km beneath 78 Kilauea's summit area that started six months before the onset of the eruption that have 79 been interpreted either as an increase in magma supply and pressurization of the summit area 80

(Flinders et al., 2020), or as backing up of magma from a blocked shallow Pu'u'ō'ō plumbing 81 system (Patrick et al., 2020). The eruption was split into three main eruptive phases based 82 on field observations and lava geochemistry (Gansecki et al., 2019). Phase 3 (lavas from the 83 Ahu'ailā'au or fissure 8 vent) was by far the most voluminous (>92% of the total LERZ 84 2018 eruption volume) and the most destructive, emitting hot, low-viscosity mafic lavas (bulk 85 MgO \sim 7 - 9.5 wt.%, Gansecki et al., 2019). Highly variable bulk compositions between 86 different fissures showed that mixing between a volumetrically dominant mafic magma and 87 two more evolved magmas (high-Ti basalt and andesite) occurred. Although it is likely that 88 the evolved magmas were stored somewhere in the ERZ for decades (Neal et al., 2019), the origin of the mafic magma is still uncertain (summit reservoirs vs. Pu'u'ō'ō vs. deep East Rift Zone; Gansecki et al., 2019; Wieser et al., 2021; Lerner et al., 2021; Pietruszka et al., 91 2021). However, identifying the underground source(s) of magma that fed the 2018 Kilauea 92 LERZ eruption is critical for recognizing areas most prone to signs of pre-eruptive unrest. 93

Locating magma sources at Kilauea Volcano (Hawai'i) is challenging given the complex 94 and laterally extensive magmatic plumbing system. Mantle melts feed a suite of connected 95 deep (3-5 km) and shallow $(\sim 1 \text{ km})$ summit reservoirs, the South Caldera and Halema'uma'u 96 reservoirs respectively, which then distribute magmas to the Southwest and East Rift Zones 97 (Fig.1; Poland et al., 2014). Summit reservoirs and the upper/middle ERZ were activated 98 seismically and geodetically prior to and during the 2018 LERZ eruption (Neal et al., 2019). 99 Because the different Kīlauea reservoirs (Pu'u'ō'ō, Halema'uma'u, and phase 3 from the 100 LERZ 2018 eruption) have similar bulk and matrix glass major-element compositions (i.e., 101 glasses with ~ 11 wt.% CaO and $\sim 4.9 - 7.2$ wt.% MgO; Gansecki et al., 2019; Lerner 102 et al., 2021), and largely indistinguishable trace elements (i.e., same Nb/Y ratios between 103 2018 LERZ phase 3 and 21st summit and rift zone lavas; Pietruszka et al., 2021), iden-104 tifying the origin of the 2018 LERZ magma on the basis of geophysics and major/minor 105 element chemistry is difficult. The complete draining of lava from both the $Pu'u'\bar{o}'\bar{o}$ vent 106 and the Halema'uma'u lave lake shortly before and during the eruption support a well-107 connected plumbing system and thus a potential contribution from both summit reservoirs 108 and Pu'u'ō'ō. In addition, CO₂-H₂O vapor saturation pressures derived from olivine-hosted 109 melt inclusions from the 2018 eruption (Lerner et al., 2021; Wieser et al., 2021) indicate 110 relatively shallow trapping at 1-5 km depth, consistent with the location of the summit 111 reservoirs. These depths are, however, also consistent with crystallization of olivine under 112 $Pu'u'\bar{o}'\bar{o}$ or the rest of the ERZ. Moreover, total SO₂ emissions measured during the LERZ 113

2018 eruption suggest that the erupted volume was around twice the modeled volume loss 114 from the shallow Halema'uma'u reservoir (Anderson et al., 2019; Kern et al., 2020), im-115 plying that at least one other reservoir (potentially the South Caldera) contributed to the 116 eruption. The partial overlap in Fo (= Mg/(Mg+Fe) mol%) between the 2018 LERZ and 117 recent Pu'u'ō'ō olivine (Gansecki et al., 2019) may correspond to a transitional phase where 118 the Pu'u' \overline{o} ' \overline{o} magma was being flushed out from the rift system and then mixed with magma 119 arriving from the summit reservoir. High-Fo olivine (Fo_{87-89}) , however, was also erupted in 120 2018 (Fig. 2) and having not been seen in the East Rift Zone at Kilauea since the 1969-74 121 Maunaulu eruption (Gansecki et al., 2019; Lynn and Swanson, 2022), but high-Fo olivine is 122 sometimes found during the 2008-2018 Halema'uma'u lava lake period. Over the last 500+123 years, this high-Fo olivine population appears in the absence of a volumetrically significant 124 stable reservoir that do not mix efficiently recharge magmas after Kilauea caldera collapses 125 (Lynn and Swanson, 2022). Prior to the 2018 summit collapse, Pu'u'ō'ō had evolved olivine 126 (Fo₇₈₋₈₀) coming from a mature and buffered summit reservoir (Lynn and Swanson, 2022), 127 indicating that high-Fo olivine observed in phase 3 LERZ magmas in 2018 were generated 128 from at least one additional source other than Pu'u'ō'ō. 129

The first objective of this paper is to better constrain the origin of the voluminous 130 mafic magma from phase 3 of the 2018 LERZ eruption. Traditionally, bulk rock trace 131 element compositions are used to constrain the mantle melting conditions and its chemistry. 132 However, mantle melt composition and properties can be overprinted by magma mixing, 133 crystallization and assimilation during storage and ascent prior to an eruption. Therefore, 134 we use the chemical composition of olivine crystals from Pu'u'ō'ō, Halema'uma'u and 2018 135 LERZ lavas to fingerprint the different magmas and identify which magma reservoirs were 136 involved in the 2018 LERZ eruption. The renewed presence of high-Fo olivine in 2018 also 137 affords a longer-term analysis of potential changes in the characteristics of primitive magmas 138 over the last 500 years and the last explosive-effusive cycle. We leverage major and trace 139 elements from primitive (high-Fo) olivine macrocrysts from a low magma supply period (KT 140 1500-early 1820's) and from recent eruptions of the current high magma supply period (2018 141 LERZ, 2015-2018 Pu'u'ō'ō, 2008-2018 Halema'uma'u and 2020 Halema'uma'u eruptions) to 142 characterize long-term changes in primary melts at Kilauea. Thus, a second objective of 143 this work is to explore potential links between the nature of primitive melts in the mantle 144 and the occurrence of long-lived effusive or explosive cycles at Kilauea. 145

146 2 Methods

From 2008 to 2018, a lava lake was present within Halema'uma'u crater, located in 147 the southwest area of the summit caldera (Fig.1). We examined 9 samples from this lava 148 lake collected by scientists at the U.S. Geological Survey's Hawaiian Volcano Observatory 149 HVO (wafted Pele's hairs and tears, tephra) near the old Halema'uma'u parking lot between 150 2008 and 9 May 2018. On 20 December 2020, eruptive activity returned to Halema'uma'u 151 and limited tephra samples were deposited south of Halema'uma'u crater. We studied one 152 sample (in which only two microphenocrysts were large enough to analyze by laser ablation) 153 from this last summit eruption (sample KS20-525). All summit samples consist of juvenile 154 Pele's hair, tears, ash and lapilli that were naturally quenched in air. These samples are 155 glassy and the proportion of olivine phenocryst is <5 vol.% (bubble-free volume). 156

Olivine crystals were collected from juvenile material in deposits spanning the entire KT period (1500-early 1820's, see descriptions in Swanson et al., 2018). The KT units investigated (Fig. 1) include unit B (~1500 C.E., formerly the Basal Reticulite), unit D (two pumice-rich samples, formerly units 7 and 11 from S07-39, ~1500-1650 C.E.), unit E (~1650 C.E., formerly the layer 6 scoria, unit G (formerly unit 20 from S07-39, ~1650-1670 C.E., a pumice-rich layer), unit K1 (between 1790 and early 1820's, formerly the Golden Pumice), and unit K2 (between 1790 and early 1820's, formerly the Eastern Pumice).

Samples from the 2018 eruption are mainly spatter or rapidly quenched lavas that were collected from the early phase 1 (referred to as phase 1a, 3 to 9 May 2018; Gansecki et al., 2019), late phase 1 (referred to as phase 1b, erupted 12 to 18 May 2018), phase 2 (erupted 17 to 27 May 2018) and phase 3 (erupted 28 May to 4 August 2018).

Finally, we also study two samples from the $Pu'u'\bar{o}'\bar{o}$ eruption collected in 2015 during episode 61 and 2018. We chose to focus on the last stages of this eruption since they would be most relevant to the compositions possibly involved in the 2018 LERZ events.

171

2.1 Electron probe micro-analysis (EPMA)

¹⁷² Major and minor element composition of the matrix glasses and olivine were determined ¹⁷³ using a JEOL JXA-8500F Hyperprobe with five wavelength-dispersive spectrometers at the ¹⁷⁴ University of Hawai'i. Olivine spot analyses were done using a 20 keV accelerating voltage, ¹⁷⁵ 200 nA beam current, and with a diameter of 10 μ m. Peak counting times were 40 s for each ¹⁷⁶ element. San Carlos USNM 111312/444 and Springwater UNSM 2566 olivine were used as ¹⁷⁷ internal standards for Si, Fe and Mg, a CalTech Ni-ol for Ni, Kakanui augite USNM 122142

for Ca, Chromite USNM 117075 for Cr, Verma garnet for Mn and A99 basalt glass (USNM 113498/1) for P. For glass analyses, an accelerating voltage of 15 keV, a current of 10 nA and a beam diameter of 10 μ m were used. Peak counting time was 40 s for each element. A99 basalt glass (USNM 113498/1) was used for Si, Al, Fe, Mg, Ca, Sphene glass for Ti, Verma garnet for Mn, Amelia albite for Na, Orthoclase (OR-1) for K, fluor-apatite USNM 104021 for P. VG-2 was used as an external standard.

184

2.2 Laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS)

Trace element analyses were measured in olivine and matrix glass at the Earth Obser-185 vatory of Singapore using a Photon Machines Analyte G2 193 nm Ar-F excimer laser with a 186 two-volume ablation cell coupled to a Thermo-Scientific Element 2 ICP-MS. Sample aerosol 187 was transported from the ablation site in He gas with a total flow rate of 1 L/min and mixed 188 with 1.0 L/min of Ar gas ~ 15 cm upstream from the plasma using a glass mixing bulb. For 189 the 2008-2020 samples in this study, the ICP was sustained with an RF Power of ~ 1500 190 W. A spot size of 80 x 80 μ m (square), fluence of 3.55 J/cm², and a repetition rate of 10Hz 191 was used for matrix glass and olivine analyses. Total counting times were 5 ms for ²⁹Si 192 on olivine and ⁴⁴Ca on matrix glass and 10 ms for all other isotopes. For the KT olivine, 193 analyzed during a previous session, the laser was run at 70% output, 5.9 J/cm^2 fluence, 194 and frequency of 8 Hz with constant voltage with a spot size of 50 x 50 μ m (square). Data 195 reduction was performed using the Trace Elements IS data reduction scheme of Iolite v. 3.6 196 (Paton et al., 2011). For all 2008-2020 analyses, the synthetic basaltic glass GSD-1G was 197 used as the primary calibration standard, whereas NIST 612 was used for the KT analyses. 198 Precision and accuracy of secondary standards (BCR-2G, BHVO, NIST) are reported in the 199 Supplementary tables. 200

201

3 Results and discussion

202

3.1 Pathways of the magma supplying the 2018 Kilauea eruption: implications for the recent plumbing system of Kilauea Volcano

The 2018 LERZ lavas contain heterogeneous olivine core compositions (phase 1 with Fo₇₃₋₈₂, phases 2 and 3 with Fo₇₇₋₉₀), a much broader range than the lower-Mg, homogenous olivine compositions erupted in the last decade at Pu'u' \overline{o} ' \overline{o} (Fo₇₈₋₈₀) or Halema'uma'u (Fo₈₀₋₈₂, rarely to Fo₉₀) (Fig.2). Olivine core compositions in samples from all phases of

the 2018 eruption are generally out of Fe-Mg equilibrium with the host melt ($K_{Fe^{2+}-Mg^{2+}}^{ol/melt}$ ~0.33 with 'K' the crystal/melt distribution coefficient; Putirka, 2016; Matzen et al., 2011) (Fig.2). In contrast, recent Pu'u'ō'ō and some Halema'uma'u olivine crystals (with Fo₈₀) are nearly in equilibrium with their carrier melts. Most of the olivine from the 2018 LERZ eruption are normally zoned (decreasing Fo from core to rim; Fig.3). This zoning is inferred to have developed during incorporation and mixing of the higher-Fo olivine cargo with a more evolved melt either at the summit or in the ERZ (Gansecki et al., 2019).

The presence of primitive olivine $(Fo_{87-90}, Fig.2)$ at Kīlauea requires fluxes of MgO-rich 215 melts into the reservoirs (Helz et al., 2014). High-Fo olivine (Fo_{87-90}) has been infrequently 216 erupted during the modern high-effusion-rate period, mainly with Kilauea Iki 1959 and 217 Maunaulu 1969-1974 lavas. They were, by contrast, recurrent in tephra and lavas from 218 the KT period. F_{087-89} olivine is thought to form at mid-crustal levels, where water-poor, 219 primitive melts with densities of 2.8 - 2.9 g/cm³ are neutrally buoyant (Putirka et al., 220 2018). These primitive melts, and their high-Fo olivine cargo, would periodically intrude 221 the summit reservoirs, a scenario consistent with the normal Fe-Mg zoning in most (>95%)222 olivine erupted in 2018 (Fig.3). By contrast, low-moderate Fo olivine (Fo_{78-83}) typifies the 223 35 year-long Pu'u' \bar{o} ' \bar{o} period as well as the recent lava lake period at the summit. Even 224 though extensive processing within the crust over several years could obliterate high-Fo 225 cores to lower Fo (Gleeson and Gibson, 2020), the overall smaller size of Pu'u'ō'ō olivine in 226 comparison with the 2018 LERZ olivine indicate that these low Fo compositions may reflect 227 the volumetrically large and persistent set of summit reservoirs, where most of the recent 228 olivine crystallizes. Lower Fo₇₃₋₇₇ olivine would dominantly crystallize in more fractionated 229 and cooler magmas residing within the ERZ. 230

231

The origin of the 2018 LERZ mafic phase 3 magma cannot be easily determined using 232 only major elements (Fe-Mg) in olivine because of the large compositional overlap between 233 potential source reservoirs (Figs.2 and 3). Trace elements, particularly those that do not 234 vary significantly in olivine during fractionation, can shed more light on source character-235 istics. For instance, Sc is moderately incompatible in olivine and increases with decreasing 236 Fo (Fig.4a). Compared to Fe-Mg, Sc may also diffuse more slowly (i.e, tri- and tetrava-237 lent trace element diffusivities being lower than that of divalent elements; Putirka et al., 238 2018), although other data suggests Sc may diffuse at rates comparable to divalent cations 239 (Spandler and O'Neill, 2010; Bouvet de Maisonneuve et al., 2016). Alternatively, Sc may 240

be subject to trace element coupling (e.g. Lynn et al. 2020) and stay effectively locked in 241 the olivine lattice. In either case, initial Sc concentrations may be better preserved through 242 time. These characteristics (incompatible behavior, potentially slow diffusivity or perma-243 nency associated with coupling) make Sc an efficient tracer of liquid or source composition. 244 Sc concentrations in Fo_{78-80} Pu'u'ō'ō olivine (9 - 11 ± 0.3 ppm, Fig.4a) are significantly 245 higher than Fo_{78-80} olivine from the 2018 LERZ eruption (6 - 8 ± 0.3 ppm). Halema'uma'u 246 olivine have Sc concentrations slightly higher than the 2018 LERZ olivine (Fo_{88-90} with 247 Sc=5.5 - 6.6 ppm and Fo_{80-82} with Sc=6.4 - 9.3 ppm). Preliminary data in two Fo_{82} 248 olivine from the 2020 Halema'uma'u eruption yield Sc concentrations similar to previous 249 Halema'uma'u olivine (7.7 - 8.2 ppm) for the same Fo content. The partition coefficient 250 of Sc between olivine and the melt stays constant around 0.25 between FMQ -2 and +2251 (Mallmann and O'Neill, 2009). Hence, a change in the oxidation state cannot explain the 252 difference in Sc between $Pu'u'\bar{o}'\bar{o}$ and LERZ 2018 olivine (Fig.4a). Therefore variations in 253 parental melt compositions - brought about by changes in source composition, melting T 254 and P - are most likely the primary control over olivine Sc contents. 255

Fractional crystallization of Kilauea basaltic melts affects Sc concentration in olivine 256 only moderately and in a predictable fashion that cannot lead to the differences in Sc ob-257 served between recent $Pu'u'\bar{o}'\bar{o}$ and LERZ 2018. Instead, Sc data indicate that the magma 258 source of the Pu'u'ō'ō olivine must be richer in Sc than the summit source, and ultimately, 259 that the recent $Pu'u'\bar{o}'\bar{o}$ olivine cargo never made it to the LERZ 2018 eruption site. There-260 fore, magma feeding the Pu'u' \bar{o} ' \bar{o} vent in the years preceding 2018 did not interact signif-261 icantly with the magma erupting at LERZ, and was perhaps stored somewhere in the rift 262 zone after the collapse of $Pu'u'\bar{o}'\bar{o}$ in May 2018. The variations in Sc cannot be simply 263 related to clinopyroxene fractionation before olivine crystallization, since olivine is replaced 264 by orthopyroxene as the liquidus phase at greater depth (beyond 0.4 GPa; Lynn et al., 265 2017). The variations in Sc in olivine are therefore likely inherited from the mantle source. 266

 $\begin{array}{rcl} & Mn/Sc \ ratios \ (Fig.4d) \ provide \ a \ means \ to \ discriminate \ between \ lower \ Fo \ (Fo<83) \ olivine \\ & from \ Pu'u'\bar{o}'\bar{o}, \ Halema'uma'u \ or \ LERZ \ 2018. \ Mn/Sc \ ratios \ in \ Pu'u'\bar{o}'\bar{o} \ olivine \ vary \ between \\ & 180 \ to \ 240. \ Low-Fo \ olivine \ (Fo<83) \ from \ Halema'uma'u \ have \ similar \ Mn/Sc \ ratios \ (180 - \\ & 275) \ to \ Pu'u'\bar{o}'\bar{o} \ olivine. \ In \ contrast, \ Fo<83 \ olivine \ from \ the \ LERZ \ 2018, \ have \ higher \ Mn/Sc \\ & ratios \ (from \ 250 \ to \ 400). \ About \ 27\% \ of \ Fo<83 \ olivine \ from \ LERZ \ 2018 \ have \ Mn/Sc \ ratios \\ & overlapping \ with \ those \ from \ Halema'uma'u, \ but \ no \ LERZ \ 2018 \ olivine \ has \ the \ same \ Mn/Sc \\ & ratio \ as \ Pu'u'\bar{o}'\bar{o} \ olivine. \ The \ large \ variability \ of \ the \ Mn/Sc \ values \ in \ 2018 \ LERZ \ olivine \\ & Mn/Sc \ values \ in \ 2018 \ LERZ \ olivine \ Nn/Sc \ values \ in \ 2018 \ LERZ \ olivine \ Nn/Sc \ values \ in \ 2018 \ LERZ \ olivine \ Nn/Sc \ values \ in \ 2018 \ LERZ \ olivine \ Nn/Sc \ values \ in \ 2018 \ LERZ \ olivine \ 2018 \ lerZ \ 2018 \ l$

(Fig.4d) may arise from mixing of olivine from various periods in a complex mush pile,
partial diffusive re-equilibration and/or mixing between olivine crystallized from olivineonly magma (MgO >7 wt.%) and olivine from plagioclase and pyroxene-bearing magma
(MgO <7 wt.%).

Although magmas feeding Pu'u'ō'ō from the summit could have been erupted in 2018, 278 there's no evidence for magmas crystallizing at shallow depths immediately below $Puu'\bar{o}'\bar{o}$ 279 being drawn back into the plumbing system and erupted downrift. The fraction of $Pu'u'\bar{o}'\bar{o}$ 280 magma with olivine crystallizing at shallow levels potentially never reached the LERZ 2018 281 eruption site and may have instead been stored in a shallower part of the rift zone after 282 the vent collapsed, or filled in available space during unzipping of the rift zone. The 2018 283 LERZ mafic magma, with its compositionally diverse olivine cargo, most likely originated 284 from the summit reservoirs where primitive melts (up to 14 wt.% MgO; Gansecki et al., 285 2019; Lerner et al., 2021; Wieser et al., 2021) mixed with lower MgO (<7.5 wt. %) melts. 286 More specifically, several lines of evidence identify the deeper South Caldera reservoir as an 287 important source of mafic magma for the LERZ 2018 eruption. First, the summit caldera 288 collapse and geophysical modeling based on pre- and syn-eruptive deformation argue that 289 a large volume $(>1 \text{ km}^3)$ of magma was evacuated from one or both of the summit reser-290 voirs (Anderson et al., 2019). Second, pre-eruptive seismicity showed several swarms in the 291 months prior to May 2018 that are distributed around the inferred South Caldera storage 292 region and could correspond to arrival of high-Fo olivine bearing primitive melts (Fig. 5; 293 Flinders et al., 2020). Third, trace elements (Mn, Sc) in LERZ 2018 olivine only overlap with compositions from the summit reservoirs (Fig.4a,d). But because olivine from the 295 Halema'uma'u lava lake is, for the most part, different from LERZ olivine (>70% of Mn/Sc 296 values not overlapping), the most likely origin for the dominant fraction of LERZ 2018 297 olivine is the deeper South Caldera reservoir. This interpretation fits generally well with 298 storage configurations proposed based on melt inclusion entrapment depths. Lerner et al., 299 2021 and Wieser et al., 2021 found that most <Fo₈₆ olivine crystallized at shallow depths 300 (typical of the Halema'uma'u reservoir), and that Fo_{86-90} olivine could have formed in both 301 Halema'uma'u and South Caldera reservoirs. The notable difference in Sc concentration 302 between most of the LERZ 2018 olivine and Halema'uma'u 2008-2018 olivine provides an 303 additional information: both low- and high-Fo LERZ 2018 olivines were for the most part 304 sourced from South Caldera. This revised configuration contrasts slightly with the model 305 proposed by Wieser et al., 2021 where most of the high-Fo olivine is inherited from South 306

Caldera and low-Fo populations from the shallower Halema'uma'u system. Pietruszka et al., 307 2021 recently proposed, based on whole rock chemistry, that much of the LERZ 2018 mafic 308 magma was derived from an accumulation zone east of Pu'u'ō'ō. The general absence of 309 cumulate textures (e.g. kink bands, Gansecki et al., 2019) and the highly euhedral 'primary' 310 nature of LERZ 2018 olivine morphologies precludes involvement of old, cold, compacted 311 cumulate regions as suggested by Pietruszka et al., 2021. Thus, if the mafic magma had 312 originated from the ERZ, the high and low-Fo olivine cargo would have accumulated in 313 this region in the decade preceding the eruption, as the reservoir was accumulating enough 314 magma. Preservation of Fe-Mg in high-Fo olivine from diffusive re-equilibration for such 315 long periods, however, are unlikely at magnetic temperatures corresponding to a \sim 7-7.5 316 wt.% MgO melt (Thomson and Maclennan, 2013; Gordeychik et al., 2020), which precludes 317 long residence of those crystals in the ERZ. Alternatively, thermo-compositional gradient 318 in the ERZ conduit caused by olivine settling could produce low- and high-Fo crystals, and 319 where cooling at the floor and roof of the sill would create an asymmetric reservoir with 320 high-Fo crystals in equilibrium with MgO rich melts (Pankhurst et al., 2018). 321

The presence of compositionally distinct olivine populations between 2008 and 2018 322 within the South Caldera - Halema'uma'u summit reservoir system (Fig.4b) has additional 323 implications for the survival of multi-generational olivine populations in a mush pile (Thom-324 son and Maclennan, 2013). Wieser et al., 2019 postulated, based on the variability of trace 325 element ratios (Nb/Y) in melt inclusions from 20^{th} century eruptions, that mush piles in 326 summit reservoirs accumulate olivine from periods spanning decades to centuries. Scav-327 enging of these cumulates and mush piles would occur during most eruptions, yielding 328 compositionally variable melt inclusions. However, the relatively narrow Sc and Mn vari-329 ations in the summit-derived 2018 high-Fo olivine cores and their distinct composition to 330 2008 summit olivine rules out the notion that primitive olivine represents century-old cu-331 mulates/mush. Instead, the high-Fo olivine studied here largely represent recently formed 332 crystal cargo, with residence times of a decade or less, based on the time taken to diffusively 333 homogenize whole olivine grains. Even lower Fo olivine populations (Fo_{78-82}) appear to lie 334 on the Sc-Fo fractional crystallization trends outlined by their high-Fo counterparts, though 335 with more variability in the case of 2018 LERZ (Fig.4a). Hence, most low-Fo crystals are 336 younger than a few decades in the eruptions investigated. Based on the differences in Fo 337 and Sc contents observed in the Halema'uma'u, Pu'u'ō'ō, and 2018 LERZ olivine, we pro-338 pose a revised plumbing configuration that integrates petrological, geophysical and surface 339

observations for the period 2008-2018 with three different olivine populations and for the 340 syn-eruption period with three additional olivine populations (Fig.5). The concordant trend 341 in Sc in olivine from Halema'uma'u and Pu'u' \overline{o} ' \overline{o} over the period 2008-2018 (Fig.4a and b) 342 confirms that the two reservoirs were directly connected in the years preceding the 2018 343 crisis (Patrick et al. 2020). By contrast, South Caldera-derived olivine erupted at LERZ in 344 2018 show no overlap in Sc content with $Pu'u'\bar{o}\bar{o}$, implying that there was no direct connec-345 tion between the two systems without passing through Halema'uma'u reservoir. As a result, 346 before 2018, primitive magma (14 wt.% MgO, at equilibrium with Fo_{89-90} , and with 3.6-5.2 347 ppm Sc) was being fed from the deep crust to South Caldera where it likely mixed with a 348 large volume of relatively mafic magma (MgO \sim 7.5 wt.%, Fo₈₀₋₈₈, Sc=3.9-7.5 ppm). This 349 magma was transported towards $Pu'u'\bar{o}'\bar{o}$ (MgO ~ 6.5-7 wt.%, Fo₇₈₋₈₀, Sc=8.4-10 ppm) af-350 ter passage through Halema'uma'u (MgO \sim 7-7.5 wt.%, Fo₈₀₋₈₂, Sc=6.4-9.3 ppm). Finally, 351 the initial mixing event(s) between primitive melt and the LERZ 2018 mafic end-member 352 $(\sim 7-7.5 \text{ wt.\% MgO})$ was not preserved in the glass compositions of 2018 LERZ samples, 353 which only increase in MgO from 5.5 to 7.2 wt.% during the high effusion rate phase of the 354 eruption (Gansecki et al., 2019). Instead, syn-eruptive variations in MgO are chiefly asso-355 ciated with mixing of the \sim 7 - 7.5 wt.% mafic end-member and the two old evolved LERZ 356 end-members. The input of primitive magma (MgO $\sim 14 \text{ wt.\%}$) is only recorded as high-Fo, 357 euhedral olivine and their melt inclusions (Lerner et al., 2021; Wieser et al., 2021). Such 358 high-Fo olivine has occurred infrequently during the 20^{th} and 21^{st} centuries. We infer that 359 primitive melts, which intrude the summit region of Kīlauea at a rate of ~ 0.1 -0.2 km³/year 360 (Poland et al., 2014; Wright and Klein, 2014), are a small fraction of the whole magma 361 volume stored in the South Caldera reservoir, and thus are rapidly diluted into the much 362 larger volume of resident melt. The presence of a large volume of relatively differentiated 363 $(\sim 7 - 7.5 \text{ wt.}\% \text{ MgO})$ and primitive (up to $\sim 14 \text{ wt.}\% \text{ MgO}$, crystallizing high-Fo olivine) 364 magma in the South Caldera is thus a testament to the period of high magma supply and 365 persistent, voluminous magma storage defining Kilauea volcano since the 1950's (Wright 366 and Klein, 2014; Poland et al., 2014). 367

368

3.2 Variability of primitive melts during the period 1500 – 2018

Olivine trace element compositions allowed us to establish the configuration and connectivity of the magmatic plumbing system underneath Kīlauea during the recent, dominantly effusive, eruptive period. Comparing the 2018 LERZ data with trace element data from the

last explosive period (KT, 1500-1820), we next examine longer-term variations in olivine 372 trace element compositions to better understand changes in primitive melt composition 373 over the last explosive-effusive cycle. In particular, we evaluate processes underpinning the 374 chemistry of high-Fo olivine: (1) fractional crystallization, (2) changes in source melting con-375 ditions (P, T, fO_2) , (3) changes in the extent of melting (F), (4) changes in the composition 376 of primary melts in the mantle source. Although most of the melting source parameters (T, 377 P, F, X, fO_2 are not independent from each other, the next sections attempt to distinguish 378 their related influences based on available petrological and geochemical indicators. 379

380

3.2.1 Influence of fractional crystallization

The Sc concentration of high-Fo olivine progressively decreases from 1500 to 1820s 381 and from 2008 to 2018, with a clear time progression within the KT spanning 320 years 382 (8-13 ppm Sc in olivine; Fig.4). High-Fo olivine from unit K1 and unit K2 have similar 383 Sc contents. High-Fo olivine from the 2008 Halema'uma'u lava lake have slightly higher 384 Sc contents than those from the LERZ 2018 eruption (\sim 5.5 – 6.6 \pm 0.25 ppm and \sim 385 $3.6 - 5.2 \pm 0.2$ ppm, respectively). The substantial decrease in Sc contents in high-Fo 386 olivine (~ 13 to 4 ppm) between the KT era and the recent decade of eruptions cannot be 387 explained by fractional crystallization because Sc varies little with fractionation (Fig.4a). 388 In contrast, olivine Mn contents increased slightly from the 1500 to 2018 (Figs.4b and 4c). 389 Magma fractionation trends for Mn-in-olivine (as described in Putirka et al., 2018) with 390 a starting liquid concentration with MnO = 0.17 wt.% (peridotite type) with ${
m K}_{Mn}^{Ol/melt}$ = 391 -3.6 +4500/(T(°C)) for lower temperature (and lower Fo, with 'K' the partition coefficient), 392 and $K_{Mn}^{Ol/melt} = -6.2 + 7800/(T(^{\circ}C))$ for higher-temperature (1150–1400°C, higher Fo) can 393 reproduce most of the LERZ 2018 olivine (Fo_{72-90}) Mn data but cannot reproduce the lower 394 Mn contents of KT olivine (Fig.4c). Thus, while fractional crystallization can cause changes 395 in olivine Sc and Mn compositions for each individual eruption studied, variations between 396 different eruptive periods must be induced through a different mechanism. 397

398

3.2.2 Influence of oxygen fugacity in the magma source region

The oxidation state of primitive Kilauea magmas between 1500 and 2018 can be estimated using the V content in olivine and matrix glasses (Canil, 2002; Fig.6). Here, we consider only the most forsteritic olivine (Fo>88 mol.%) to estimate the oxidation state close to the source. Measured V contents in matrix glasses were corrected for olivine frac-

tionation using an initial primitive composition with 14 wt.% MgO (Lerner et al., 2021, see 403 calculations and V contents before and after corrections in the supplementary material). 404 The calculated oxidation state for the KT period varies between FMQ + 0.8 to +1.2. These 405 fO_2 values are slightly lower than the hypothetical oxidized mantle plume inferred by Mous-406 sallam et al., 2019 (FMQ +1.5 to +2.5), but are higher than those obtained from gases 407 and melt inclusions trapped at depth (FMQ +0.2 to +0.5; Moussallam et al., 2016), and 408 similar to values retrieved from $\mathrm{Fe}^{3+}/\Sigma\mathrm{Fe}$ and $\mathrm{S}^{6+}/\Sigma\mathrm{S}$ ratios in Mauna Kea glasses (up to 100 FMQ +0.9; Brounce et al., 2017). Vanadium-in-glass measurements of LERZ 2018 magmas 410 indicate large variations in the oxidation state of primitive magmas (FMQ +0.1 to FMQ 411 +1.0) consistent with recent measurements from melt inclusions (FMQ +0.5, Lerner et al., 412 2021) and are slightly more reduced than KT magmas. However, some of the variations in 413 the oxidation state in 2018 LERZ magmas could also reflect the influence of magma mixing 414 between the mafic and more evolved stored magmas (e.g., Gansecki et al., 2019) on the final 415 glass vanadium content used for our calculations. Thus, oxygen fugacity conditions may 416 have changed by 0.4 log units in the last 500 years, but additional work examining V in 417 high-Fo olivine hosted melt inclusions may be required to verify this. 418

419

3.2.3 Influence of primary melt source composition

First-row transition elements (e.g., Mn and Fe) in olivine are frequently used as tracers 420 of chemical heterogeneities in the mantle and of variations in melting temperature or pres-421 sure (Sobolev et al., 2007; Le Roux et al., 2011). Partial melting of an upper mantle with 422 olivine and orthopyroxene does not significantly fractionate Mn over Fe (Mallik et al., 2021). 423 In contrast, the melting of a pyroxenitic mantle source with clinopyroxene and garnet should 424 fractionate Mn from Fe. Hence, eclogite and pyroxenite melts have lower Mn/Fe compared 425 to peridotite melts (Humayun et al., 2004). Variable fractions of pyroxenite and peridotite 426 can also reconcile the different Mn/Fe ratios and transition metal contents (e.g., Mn or Ni) 427 in olivine (Sobolev et al., 2007; Wang and Gaetani, 2008). Our olivine data from the 1500-428 early 1820's KT and 2018 LERZ eruptions show variable Mn/Fe ratios at constant Ni/Mg 429 ratios (Fig.7a). Given that an increase in the olivine fraction in the melt source should 430 increase Ni/Mg values, we instead attribute variations in Mn/Fe to a variation of the modal 431 abundance of clinopyroxene in the source at the expanse of orthopyroxene between 1500 432 and 2018. The two minerals that could cause Sc to decrease in Mg-rich olivine and their 433 carrier primitive melts are garnet (representing 60% of the Sc budget of lherzolite; Chassé 434

et al., 2018) and clinopyroxene (the most Sc-enriched mineral after garnet, accounting for 435 10% of the Sc budget in lher zolite). However, Mn is highly compatible in garnet ($\mathbf{K}_{Mn}^{Gt/melt}$ 436 \sim 3, see supplementary for the references used for the choice of partition coefficients), while 437 it is slightly incompatible in clinopyroxene (${\rm K}_{Mn}^{Cpx/melt}$ \sim 0.7). Therefore, the decrease in 438 Sc in primitive olivine $(>Fo_{87})$ with increasing Mn also implies that the contribution of 439 clinopyroxene in the melt increased drastically (from 11 to 67% using simple batch melt-440 ing calculations, Fig. 8). Furthermore, Ni/Co values greater than 20 in olivine are often 441 thought to reflect a pyroxenite source component (Sobolev et al., 2007; Folev et al., 2013). 442 Primitive olivine (Fo>87) from KT have high Ni/Co values (Fig.7b) between 20 and 30 443 (and low $100^{\circ}Mn/Fe$ between 1 and 1.3) compared to the 2018 olivine (Ni/Co \sim 20-24), and, 444 to a first order, consistent with a higher proportion of pyroxenite in the source. However, 445 depletion in Co, rather than high Ni content, is responsible for the high Ni/Co observed in 446 the KT primitive olivine relative to the 2018 LERZ olivine (Fig.7d). This decoupling be-447 tween Co and Ni contents is not easily explained by a decreasing pyroxenite component with 448 time. Instead, the increase in Co since the KT period can also be successfully reproduced 449 by increasing the proportion of clinopyroxene that melted in the source over time relative 450 to the proportion of orthopyroxene (Co being less compatible in clinopyroxene compared 451 to orthopyroxene; $K_{Co}^{Opx/melt} = 1.3$ and $K_{Co}^{Cpx/melt} = 1.06$). Finally, an increase of the contri-452 bution of clinopyroxene at the expense of orthopyroxene is also consistent with the Zn-Mn 453 correlations in olivine (Fig. 8b) and the broadly constant Zn/Fe ratio (Fig.7c) as $K_D^{Zn/Fe}$ 454 are similar for orthopyroxene and clinopyroxene at a given temperature (Le Roux et al., 455 2011). 456

457

3.2.4 Influence of mantle melting temperature and pressure

The lower Mn (and Mn/Fe ratio) in high-Fo olivine in KT compared to recent Kilauea 458 eruptions could also result from an increase in the degree of partial melting at lower pressure 459 or higher temperature (Matzen et al., 2017; Putirka et al., 2018) from the KT to 2018 LERZ 460 eruptions. We tested these hypotheses using major element compositions of olivine hosted 461 melt inclusion. Mantle potential temperatures (Fig.9a) were calculated using primitive melt 462 inclusions with MgO >10 wt.% (after post-entrapment corrections). The melt inclusion 463 compositions include the KT period (Sides et al. 2014), some of the 20^{th} century Kilauea 464 eruptions (Kilauea Iki, Maunaulu; Sides et al., 2014) and the 2018 LERZ eruption (Lerner 465 et al., 2021; Wieser et al. 2021). Mantle temperature calculations were carried out using 466

the model from Lee et al., 2009 (with $K_{Fe^{2+}-Mg^{2+}}^{ol/melt} = 0.33$, Fo = 92 mol.% in the mantle 467 source and $\text{Fe}^{3+}/\text{Fe}_T=0.18$; Lerner et al., 2021). Because relative mean mantle temperature 468 variations can be subtle (absolute values are subject to large and complex uncertainties), 469 potential temperatures calculated for the 2018 LERZ eruption are statistically compared 470 to the other eruptions using one-way analysis of variance (ANOVA) tests (Fig.9a). The 471 primitive melts supplying the 2018 LERZ eruption are found to be statistically slightly 472 hotter (by around 10-15°C) than the melts from the 20^{th} century eruptions at Kilauea (p-473 values 2×10^{-3} to 2×10^{-6}). However, the increase in mean melting temperature is minor 474 and within the error bars ($\sim 40^{\circ}$ C uncertainty) associated with these models (Lee et al., 475 2009). Also, different choice of initial FeO concentrations for post-entrapment corrections 476 used in the studies (Sides et al., 2014; Lerner et al., 2021; Wieser et al., 2021) can explain 477 these differences in mantle potential temperature. Mantle melting pressures for the KT, 478 2008 Halema'uma'u eruption, and the 2018 LERZ eruption are calculated from the same 479 primitive melt inclusion compositions using the calibration from Lee et al., 2009 (Fig.9b). 480 We do not observe any major difference between the pressure calculated for the two eruptive 481 periods, with mean mantle melting pressures of $2.5 \pm 0.1 (1\sigma)$ GPa for the KT period and 2.6 482 $\pm 0.1 (1\sigma)$ GPa for the 2018 LERZ magmas. To summarize, neither a change in the melting 483 pressure or the mantle temperature can easily explain the clear variations observed in Sc, 484 Mn, as well as the Ni/Mg and Mn/Fe ratios in primitive olivine. Instead, we suggest that 485 these trace element variations are due to an increase in the fraction of clinopyroxene that 486 melts in the mantle source. However, an increase in the degree of mantle fertility recorded 487 within primitive melt compositions could also be associated with an increase in the degree 488 of partial melting (for any degree of decompression and any fixed temperature) between the 489 two eruptive periods (Hirschmann and Stolper, 1996). We next test this possibility using 490 high-Fo olivine compositions. 491

492

3.2.5 Influence of degree of melting

493

De Hoog et al., 2010 proposed that the Cr# (= Cr/(Cr+Al) in mol) in primitive olivine (Fo>87) can be used to calculate the degree of melting (% Fmelting = 14.5 x ln Cr#ol+26). 494 Only Fo>87 olivine cores (n=11 for Halema'uma'u 2008, n=111 for KT, n=147 for LERZ 495 2018) were used for these calculations to avoid issues related to diffusive re-equilibration of 496 Cr at the rims. Using Cr data collected in olivine from the 2008 Halema'uma'u lava lake, 497 2018 LERZ and the KT eruptions, we find that the average degrees of partial melting in 498

the source increased from 21.8% to 24% between 1500 and 2018 (i.e., a significant difference 499 considering the 0.3% analytical uncertainties on this calculations; Fig.10). Uncertainties 500 related to the calibration are greater than the calculated variations in the degree of melting, 501 but this is a more qualitative approach in which we focus on the relative variation in degree of 502 melting between the eruptive units. These degrees of partial melting are comparable to those 503 calculated by Putirka, 2016 (19%), but higher than those derived from incompatible trace 504 elements (5-10% melting for lavas from the 19^{th} and 20^{th} centuries; Pietruszka and Garcia, FOF 1999). Uncertainties related to the calibration are greater than the calculated variations 506 in the degree of melting, but this is a more qualitative approach in which we focus on the 507 relative variation in degree of melting between the eruptive units. Therefore, both degree 508 of partial melting and source fertility (fraction of clinopyroxene inherited in primary melts) 509 appear to have changed between the KT period and modern era. 510

511

3.3 Implications for eruptive cycles at Kilauea

The difference in trace element concentrations in high-Fo olivine between the KT, 2008 512 Halema'uma'u and 2018 LERZ eruption periods provide key new insights into the long-513 term evolution of magma supply, storage and eruption at Kilauea. Changes in the fraction 514 of clinopyroxene that melts in the source, combined with an increase in melt productivity 515 between 1500 and present day, are in excellent agreement with the observation that magma 516 supply and eruption rates appear to have increased since the end of the KT era (Swanson 517 et al., 2014; Wright and Klein, 2014). Clinopyroxene being the most fusible mineral in the 518 mantle source, the increase in the degree of mantle fertility between 1500 and 2018 at a 519 similar depth and temperature, may be explained by metasomatism (melt-rock interaction) 520 that produce clinopyroxene-rich rocks in the mantle over the past century. Trace elements 521 in melt inclusions and radiogenic isotopes (Pietruszka et al., 1999; Sides et al., 2014) also 522 underscore that magma supply from the mantle increased after the Kilauea Iki eruption 523 in 1959 in a trend that continued until 2018. Changes in the supply of primitive magma 524 to crustal reservoirs underneath Kilauea are closely linked to variations in eruption style. 525 Low magma supply tends to favor formation of ephemeral, less evolved, and perhaps more 526 scattered magma reservoirs that erupt more primitive magma with less stalling and crustal 527 interaction (Lynn et al., 2017) while high supply tends to promote formation of large, 528 steady and more evolved reservoirs (Lynn and Swanson, 2022). The change in the fraction 529 of clinopyroxene and associated increase in partial melting in the mantle source may have 530

contributed to the transition from dominantly explosive to dominantly effusive styles at 531 Kilauea. Higher magma supply during the 2008-present day effusive period at Kilauea is 532 characterized by efficient mixing of recharge and stored magmas in shallow magma reservoirs. 533 Shallow magma reservoirs may buffer ascending magmas and allow extensive degassing that 534 reduces explosivity. In contrast, the absence of established mature shallow reservoir fed by 535 lower magma supply during the Keanakako'i Tephra explosive period may have prevented 536 magma degassing and therefore increase explosivity. Petrologic monitoring of trace elements 637 in olivine (in particular Sc) could help to recognize a decrease of mantle source productivity 538 that might herald changes in magma supply and in the dominant eruptive style at Kilauea. 539 For instance, trends of increasing Sc in olivine with time could forewarn of a declining 540 magma supply and a possible transition to a more explosive style at Kilauea. 541

542 4 Conclusions

We compared olivine and olivine-hosted melt inclusion compositions from explosive Kīlauea eruptions (seven eruptions between 1500 and early 1820's from KT) and from effusive Kīlauea eruptions (Pu'u'ō'ō 2015-2018, Halema'uma'u 2008-2018, Halema'uma'u 2020 and LERZ 2018). This comparison revealed that:

- Olivine from late-stage Pu'u'ō'ō (2015 to 2018) has different trace element compositions than olivine from the 2018 LERZ eruption. Sc contents in Fo₇₈₋₈₀ Pu'u'ō'ō olivine are distinctly higher than Fo₇₈₋₈₀ olivine from the 2018 LERZ eruption. This suggests that magma feeding Pu'u'ō'ō shortly prior to May 2018 played little role in the LERZ eruption and potentially remained stored in the rift zone after the collapse of Pu'u'ō'ō.
- Mn and Sc contents in olivine indicate that most of the olivine cargo erupted in the
 2018 LERZ magma is also different from the Halema'uma'u 2008-2018 olivine cargo,
 with only ~25% of the olivine analyzed having a composition overlapping the earlier
 Halema'uma'u samples.
- The distinct Sc content of olivine erupted from the summit between 2008 and 2018 challenges the notion that multi-generational olivine cargo accumulated over centuries are amalgamated prior to major eruptions. Most of the LERZ 2018 olivine from the mafic magma end-member is likely decadal or less in age.

• The decrease in Sc content combined with the increase in Mn content in primitive olivine (>Fo₈₇) between 1500 and 2018 implies that the proportion of clinopyroxene in the source increased drastically (from ~11 to 67%). There is no clear evidence of a significant change in mantle melting pressure or oxygen fugacity conditions between the two periods, although mantle melting temperature may have increased by 10-15°C in the 21^{st} century. The increase in clinopyroxene fraction in the melting reaction may also have been accompanied by an increase in the degree of melting from 1500 to 2018.

Sc in olivine may provide one of the most robust non-isotopic tracers of mantle source composition to date in Hawaiian magmas. Future studies focused on characterizing the partitioning and diffusivity of Sc in olivine will provide key constraints on why Sc in olivine appears to more faithfully record the chemical characteristics of primary magmas.

Olivine trace element data are also needed for the 1820-2008 period to confirm the trend in Sc content established by the KT and 2008-2018 olivine. Tracking the temporal evolution of these key trace elements in olivine from Hawai'i and elsewhere will allow characterizing changes in mantle source and magma supply histories, thereby tracking the long-term (hundreds to thousands of years) evolution of volcanic systems.

- 579
- 580

Data Availability

All compositional data obtained in this study are included in the supplementary data tables.

583

CRediT authorship contribution statement

Adrien Mourey: Conceptualization, Investigation, Methodology, Data curation, Writing – original draft. Thomas Shea: Funding acquisition, Writing – review & editing. Kendra J.
Lynn: Data curation, Funding acquisition, Writing – review & editing. Allan H. Lerner:
Investigation, Writing – review & editing. Sarah Lambart: Investigation, Writing – review & editing. Fidel Costa: Funding acquisition, Writing – review & editing. Jeffrey Oalmann: Data curation, Writing – review & editing., R. Lopaka Lee: Resources. Cheryl Gansecki: Resources.

591

⁵⁹² Declaration of competing interest

The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

595

Acknowledgements

We acknowledge Rosalind Helz for comments on a previous version of the manuscript, David
Neave and an anonymous reviewer for critical reviews, and Jordan Lubbers for the internal
USGS review. This work was supported by the National Science Foundation through a NSF
EAR Grant 1725321 to TS and both an East Asia and Pacific Summer Institutes NSF grant
(OISE-1513668) and the Fred M. Bullard Graduate Fellowship at the University of Hawai'i
to KJL.

603 References

- Anderson, K.R. et al., 2019. Magma reservoir failure and the onset of caldera collapse at
 Kīlauea Volcano in 2018. Science 366:6470. https://doi.org/10.1126/science.aaz1822
- Bouvet de Maisonneuve, C., Costa, F., Huber, C., Vonlanthen, P., Bachmann, O.,
 Dungan, M.A., 2016. How do olivines record magmatic events? Insights from major
 and trace element zoning. Contrib. Mineral. Petrol.171, 1–20.
- Brounce, M., Stolper, E., Eiler, J., 2017. Redox variations in Mauna Kea lavas, the oxygen fugacity of the Hawaiian plume, and the role of volcanic gases in Earth's oxygenation.
 PNAS 114, 8997–9002. https://doi.org/10.1073/pnas.1619527114
- Brigham, W.T., 1909. The volcanoes of Kilauea and Mauna Loa on the island of Hawaii.
 Memoirs of the Bernice Pauahi Bishop Museum, Vol II, no 4. Bishop Museum, Honolulu, 222 pp. Reprinted in 1974 by Kraus Reprint Co., Millwood, NY
- Canil, D., 2002. Vanadium in peridotites, mantle redox and tectonic environments: Archean
 to present. Earth Planet. Sci. Lett. 195, 75–90. https://doi.org/10.1016/S0012821X(01)00582-9
- Chassé, M., Griffin, W.L., Alard, O., O'Reilly, S.Y., Calas, G., 2018. Insights into the mantle geochemistry of scandium from a meta-analysis of garnet data. Lithos 310-311, 409–421. https://doi:10.1016/j.lithos.2018.03.026
- Dasgupta, R., Jackson, M.G., Lee, C.-T.A., 2010. Major element chemistry of ocean
 island basalts Conditions of mantle melting and heterogeneity of mantle source.
 Earth Planet. Sci. Lett. 289, 377–392. https://doi:10.1016/j.epsl.2009.11.027
- De Hoog, J.C.M., Gall, L., Cornell, D.H., 2010. Trace-element geochemistry of mantle
 olivine and application to mantle petrogenesis and geothermobarometry: Chem. Geol.
 270, 196-215, https://doi.org/10.1016/j.chemgeo.2009.11.017.
- Flinders, A.F., Caudron, C., Johanson, I.A., Taira, T., Shiro, B., Haney, M., 2020. Seismic
 velocity variations associated with the 2018 lower East Rift Zone eruption of Kīlauea,
 Hawai'i. Bull.Volc. 82(6). doi:10.1007/s00445-020-01380-w
- Foley, S.F., Prelevic, D., Rehfeldt, T., Jacob, D.E., 2013. Minor and trace elements in olivines as probes into early igneous and mantle melting processes. Earth Planet. Sci. Lett. 363, 181–191. https://doi:10.1016/j.epsl.2012.11.025
- Gansecki, C., Lopaka Lee, R., Shea, T., Lundblad, S.P., Hon, K., Parcheta, C., 2019. The
 tangled tale of Kilauea's 2018 eruption as told by geochemical monitoring: Science 366,
 eaaz0147. https://doi.org/10.1126/science.aaz0147.
- Gleeson, M.L.M., Gibson, S.A., 2019. Crustal controls on apparent mantle pyroxenite signals in ocean island basalts. Geology 47, 321–324. https://doi.org/10.1130/G45759.1.
- Gordeychik, B., Churikova, T., Shea, T., Kronz, A., Simakin, A., Wörner, G., 2020. Fo
 and Ni relations in olivine differentiate between crystallization and diffusion trends. J.
 Petrol. 61, egaa083.1
- Helz, R.T., Clague, D.A., Sisson, T.W., Thornber, C.R., 2014. Petrologic insights into
 basaltic volcanism at historically active Hawaiian volcanoes: in eds. Poland and
 Kauahikaua, Characteristics of Hawaiian Volcanoes, USGS Prof. Pap. 1801, 6, 1-55,
 http://dx.doi.org/10.3133/pp1801

645	Hirschmann, M. M., Stolper, E. M., 1996. A possible role for garnet pyroxenite in the
646	origin of the "garnet signature" in MORB. Contrib. Mineral. Petrol. $124(2)$, $185-208$.
647	$\rm https://doi:10.1007/s004100050184$
648	Howarth, G.H., Harris, C., 2017. Discriminating between pyroxenite and peridotite
649	sources for continental flood basalts (CFB) in southern Africa using olivine chemistry.
650	Earth Planet. Sci. Lett. 475, 143–151. https://doi.org/10.1016/j.epsl.2017.07.043
651	Humayun, M., Qin, L., Norman, M.D., 2004. Geochemical Evidence for Excess Iron in
652	the Mantle Beneath Hawaii. Science 306, 91–94. doi:10.1126/science.1101050
653	Kern, C., Lerner, A.H., Elias, T. et al., 2020. Quantifying gas emissions associated with
654	the 2018 rift eruption of Kilauea Volcano using ground-based DOAS measurements.
655	Bull. Volc. 82, 55. https://doi.org/10.1007/s00445-020-01390-8
656	Lee, CT.A., , Luffi, P., Plank, T., Dalton, H., Leeman, W.P., 2009. Constraints on the
657	depths and temperatures of basaltic magma generation on Earth and other terrestrial
658	planets using new thermobarometers for mafic magmas. Earth Planet. Sci. Lett. 279,
659	20–33. https://doi:10.1016/j.epsl.2008.12.020
660	Le Roux, V., Lee, CT.A., Turner, S.J., 2010. Zn/Fe systematics in mafic and ultramafic
661	systems: Implications for detecting major element heterogeneities in the Earth's mantle.
662	Geochim. Cosmochim. Acta 74, 2779–2796. https://doi:10.1016/j.gca.2010.02.004
663	Le Roux, V., Dasgupta, R., Lee, CT.A., 2011. Mineralogical heterogeneities in the
664	Earth's mantle: Constraints from Mn, Co, Ni and Zn partitioning during partial melt-
665	ing. Earth Planet. Sci. Lett. 307, 395–408. https://doi:10.1016/j.epsl.2011.05.014
666	Lerner, A.H., Wallace, P.J., Shea, T., Mourey, A.J. et al., 2021. The petrologic and
667	degassing behavior of sulfur and other magmatic volatiles from the 2018 eruption of
668	Kīlauea, Hawai'i: melt concentrations, magma storage depths, and magma recycling.
669	Bull. Volc. 83, 43. https://doi.org/10.1007/s00445-021-01459-y
670	Lerner, A.H., Muth, M.J., Wallace, P.J., Lanzirotti, A., Newville, M., Gaetani, G.A.,
671	Chowdhury, P., Dasgupta, R., 2021. Improving the reliability of Fe- and S-XANES
672	measurements in silicate glasses: correcting beam damage and identifying Fe-oxide
673	nanolites in hydrous and anhydrous melt inclusions. Chem. Geol. 586, 120610.
674	https://doi.org/10.1016/j.chemgeo.2021.120610
675	Lynn, K.J., Garcia, M.O., Shea, T., Costa, F., Swanson, D.A., 2017. Timescales of
676	mixing and storage for Keanakāko'i Tephra magmas (1500–1820 C.E.), Kīlauea Volcano,
677	Hawai'i. Contrib. Mineral. Petrol. 172(9). doi:10.1007/s00410-017-1395-4
678	Lynn, K.J., Garcia, M.O., Shea, T., 2020. Phosphorus coupling obfuscates lithium geospeedo
679	-metry in olivine. Front. Earth Sci. 8, 135. https://doi.org/10.3389/ feart.2020.00135
680	Lynn, K.J., Swanson, D. A., 2022. Olivine and glass chemistry record cycles of plumbing
681	system recovery after summit collapse events at Kīlauea Volcano, Hawai 'i. J. Volc.
682	Geo. Res. 426, 107540.
683	Mallik, A., Lambart, S., Chin, E.J., 2021. Tracking the evolution of magmas from het-
684	erogeneous mantle sources to eruption. In Mantle Convection and Surface Expressions,
685	151–177. https://doi: 10.1002/9781119528609.ch6
686	Mallmann, G., O'Neill, H.St.C., 2009. The crystal/melt partitioning of V during mantle
687	melting as a function of oxygen fugacity compared with some other elements (Al, P, Ca,

Sc, Ti, Cr, Fe, Ga, Y, Zr and Nb), J. Petrol. 50, 1765–1794. https://doi.org/10.1093/ 688 petrology/egp053 689 Matzen, A.K., Baker, M.B., Beckett, J.R., Stolper, E.M., 2011. Fe-Mg Partitioning be-690 tween Olivine and High-magnesian Melts and the Nature of Hawaiian Parental Liquids. 691 J. Petrol. 52, 1243–1263. https://doi:10.1093/petrology/egq089 692 Matzen, A.K., Wood, B.J., Baker, M.B., Stolper, E.M., 2017. The roles of pyroxenite and 693 peridotite in the mantle sources of oceanic basalts. Nat. Geosci.10, 530-535. McPhie J., Walker J.P., Christiansen R.L., 1990. Phreatomagmatic and phreatic fall and 695 surge deposits from explosions at Kilauea volcano, Hawaii, 1790 A.D.: Keanakakoi Ash 696 Member. Bull. Volc. 52, 334-354. https://doi:10.1007/BF00302047 697 Moussallam, Y., Edmonds, M., Scaillet, B., Peters, N., Gennaro, E., Sides, I., Oppen-698 heimer, C., 2016. The impact of degassing on the oxidation state of basaltic mag-699 mas: a case study of Kilauea Volcano. Earth Planet. Sci. Lett. 450, 317–325. 700 https://doi.org/10.1016/j.epsl.2016.06.031 701 Moussallam, Y., Longpré, M.-A., McCammon, C., Gomez-Ulla, A., Rose-Koga, E.F., 702 Scaillet, B., Peters, N., Gennaro, E., Paris, R., Oppenheimer, C., 2019. Mantle plumes 703 are oxidised. Earth Planet. Sci. Lett. 527, 115798. 704 Neal, C.A., et al., 2019, The 2018 rift eruption and summit collapse of Kilauea volcano: 705 Science 363, 367-374. https://doi.org/10.1126/science.aav7046. 706 Nikkola, P., Guðfinnsson, G.H., Bali, E., Rämö, O.T., Fusswinkel, T., Thordarson, T., 707 2019. Signature of deep mantle melting in South Iceland olivine. Contrib. Mineral. 708 Petrol. 174(5). doi:10.1007/s00410-019-1580-8 709 Pankhurst, M.J., Morgan, D.J., Thordarson, T., Loughlin, S.C., 2018. Magmatic crystal 710 records in time, space, and process, causatively linked with volcanic unrest. Earth 711 Planet. Sci. Lett. 493, 231–241. https://doi.org/10.1016/j.epsl.2018.04.025. 712 Paton, C., Hellstrom, J., Paul, B., Woodhead, J., Hergt, J., 2011. Iolite: Freeware for the 713 visualisation and processing of mass spectrometric data. J. Anal. Atomic Spec. 26, 714 2508. https://doi:10.1039/c1ja10172b 715 Patrick, M.R., Houghton, B.F., Anderson, K.R. et al., 2020. The cascading origin of the 716 2018 Kilauea eruption and implications for future forecasting. Nat. Comm. 11, 5646. 717 https://doi.org/10.1038/s41467-020-19190-1 718 Pietruszka A.J., Garcia M.O., 1999. A rapid fluctuation in the mantle source and melting 719 history of Kilauea Volcano inferred from the geochemistry of its historical summit lavas 720 (1790-1982). J. Petrol. 40, 1321-1342. https://doi.org/10.1093/petroj/40.8.1321 721 Pietruszka, A.J., Garcia, M.O., Rhodes, J.M., 2021. Accumulated Pu'u 'O'ō magma fed 722 the voluminous 2018 rift eruption of Kilauea Volcano: evidence from lava chemistry. 723 Bull Volcanol 83, 59. https://doi.org/10.1007/s00445-021-01470-3 724 Poland, M.P., Miklius, A., Jeff Sutton, A., Thornber, C.R., 2012. A mantle-driven surge 725 in magma supply to Kilauea Volcano during 2003–2007. Nat. Geosc. 5(4), 295–300. 726 https://doi:10.1038/ngeo1426 727 Poland, M.P., Miklius, A., and Montgomery-Brown, E.K., 2014. Magma supply, storage, 728 and transport at shield-stage Hawaiian volcanoes: USGS Prof. Pap. 1801, 179-234. 729 https://doi.org/10.3133/pp18015. 730

- Putirka, K., 2016. Rates and styles of planetary cooling on Earth, Moon, Mars, and Vesta,
 using new models for oxygen fugacity, ferric-ferrous ratios, olivine-liquid Fe-Mg exchange, and mantle potential temperature. Am. Mineral. 101, 819–840. https://doi:10.
 2138/am-2016-5402
- Putirka, K., Tao, Y., Hari, K.R., Perfit, M.R., Jackson, M.G., Arevalo, R., 2018. The mantle source of thermal plumes: Trace and minor elements in olivine and major oxides of primitive liquids (and why the olivine compositions don't matter). Am. Mineral. 103, 1253–1270. https://doi:10.2138/am-2018-6192
- Sides, I.R., Edmonds, M., Maclennan, J., Swanson, D.A., Houghton, B.F., 2014, Eruption
 style at Kilauea Volcano in Hawai'i linked to primary melt composition: Nat. Geosc.
 740 7, 464–469. https://doi.org/10.1038/ngeo2140.
- Sobolev, A.V. et al., 2007. The amount of recycled crust in sources of mantle derived melts. Science 316, 412–417.
- Spandler, C., O'Neill, H.S.C., 2010. Diffusion and partition coefficients of minor and trace
 elements in San Carlos olivine at 1300°C with some geochemical implications. Contrib.
 Mineral. Petrol. 159, 791–818.
- Swanson, D.A., Rose, T.R., Fiske, R.S., McGeehin, J.P., 2012. Keanakāko'I Tephra
 produced by 300 years of explosive eruptions following collapse of Kīlauea's caldera
 in about 1500 CE. J. Volcanol. Geotherm. Res. 215–216:8–25. https://doi:10.1016/
 j.jvolgeorres.2011.11.009
- Swanson, D.A., Rose, T.R., Mucek, A.E., Garcia, M.O., Fiske, R.S., Mastin, L.G., 2014.
 Cycles of explosive and effusive eruptions at Kilauea Volcano, Hawai'i. Geology 42, 631–634. https://doi:10.1130/G35701.1
- Swanson, D.A., Houghton, B.F., 2018. Products, processes, and implications of Keanakāko'i
 volcanism, Kılauea Volcano, Hawai'i. In: Poland MP, Garcia MO, Camp VE, Grunder
 A (eds) Field volcanology: a tribute to disting career Don Swanson, Geol. Soc. Am.
 Spec. Pap. 538, 159–190.
- Thomson, A., Maclennan, J., 2013. The distribution of olivine compositions in Icelandic
 basalts and picrites. J.Petrol.54, 745–768.
- Wang, Z., Gaetani, G.A., 2008. Partitioning of Ni between olivine and siliceous eclogite partial melt: experimental constraints on the mantle source of Hawaiian basalts.
 Contrib. Mineral. Petrol. 156, 661–678. https://doi:10.1007/s00410-008-0308-y
- Wieser, P.E., Edmonds, M., Maclennan, J. et al., 2019. Crystal scavenging from mush piles
 recorded by melt inclusions. Nat Commun 10, 5797. https://doi.org/10.1038/s41467-019-13518-2
- Wieser, P.E., Lamadrid, H., Maclennan, J., Edmonds, M., Matthews, S., Iacovino, K.,
 Jenner, F.E., Gansecki, C., Trusdell, F., Lee, R.L., Ilyinskaya, E., 2021. Reconstructing
 magma storage depths for the 2018 Kılauean eruption from melt inclusion CO2 contents:
 the importance of vapor bubbles. Geochem. Geophys. Geosystems 22:e2020GC009364.
 https://doi.org/10.1029/2020GC009364
- Wright, T.L., Klein, F.W., 2014. Two Hundred Years of Magma Transport and Storage at Kilauea Volcano, Hawaii, 1790–2008. USGS Prof. Pap. 1806, 1-240. https://doi.org/ 10.3133/pp1806.



Figure 1: Map of Kilauea Volcano with the studied eruptions. Inset: Map of the Island of 774 Hawai'i. Letters B, D, E, G, K1 and K2 correspond to the unit name for the KT eruptions. 775 Red circle inside the caldera is the Halema'uma'u lava lake before the 2018 eruption.





Figure 2: Olivine compositions and olivine-melt equilibrium. Olivine Fo composition for 777 the KT (cores), 2008-2018 Halema'uma'u (cores), 2020 Halema'uma'u (cores, n=2), 2015-778 2018 Pu'u'ō'ō (cores), and 2018 LERZ (cores and rims) samples. Equilibrium olivine Fo 779 content is calculated with the matrix melt composition and a melt-olivine Mg/Fe exchange 780 coefficient (K_d) of 0.33 (Putirka, 2016). Fe³⁺/Fe_T was fixed at 0.18 to calculate Mg# of 781 matrix glasses (Moussallam et al., 2016; Lerner et al., 2021). KT olivine and glasses major 782 compositions are from Lynn et al., 2017. Other Kilauea olivine and matrix glasses data 783 (except for the 2018 LERZ eruption) are from Sides et al., 2014. 784



Figure 3: Forsterite content in olivine (rims and cores) of recent Kilauea eruptions. The 1:1 line represents olivine with no zonation. Most of the olivine (>95%) from the 2018 LERZ eruption have normal zoning. Olivine from the Halema'uma'u lava lake have rims slightly higher in Fo (Fo₈₂₋₈₅) compared to the olivine from LERZ 2018. Pu'u'ō'ō olivine are unzoned or slightly normally zoned.



Figure 4: Major (Fe-Mg) and trace (Mn, Sc) elements in olivine from the KT units, 790 2015-2018 Pu'u' \overline{o} ' \overline{o} , 2008-2018 Halema'uma'u, 2020 Halema'uma'u, and the 2018 LERZ 791 eruption at Kīlauea. (a) Sc versus Fo content. Melts in equilibrium with Fo_{81-90} olivine 792 only fractionate olivine (Sc is incompatible in olivine). The black curve models olivine 793 compositions in equilibrium with 5–40% melts of peridotite (Nikkola et al., 2019) evolving 794 with the degree of partial melting in percent (F%) and melt aggregation pressures in GPa. 795 Higher Sc contents in olivine from the KT units cannot be modeled with the same mantle 796 composition as for the 2018 LERZ olivine and require a change in the source composition. 797 Fractional crystallization models (blue, orange and green curve) show changes in Sc and Fo 798 in olivine during fractional crystallization as a function of Sc concentration in the starting 790 melt. Higher Sc concentration (up to 50ppm) in primitive melts could explain the measured variations in Sc. The model is based on that presented in Lynn et al., 2017 where Fe-Mg 801 partitioning is calculated using a $K_d = 0.33$ and a partition coefficient D_{Mg} from Putirka et 802 al., 2008. The melt-olivine Sc partition coefficient is taken to be 0.25 (Beattie et al., 1991; 803 Spandler and O'Neill, 2010). (b) Sc vs. Mn in primitive olivine (Fo>87). Mn increases 804 during magma fractionation. (c) Mn vs. Fo content in olivine cores. Mn in-Ol fractionation 805 trends for low and high-Fo olivine are from Putirka et al., 2018. The trends cannot reproduce 806 the lowest Mn-in ol data, arguing for different primitive melt compositions during the KT 807 period. (d) Cumulative frequency plot of Mn/Sc values in Fo<83 olivine. This ratio helps to discriminate olivine from the recent Pu'u'ō'ō (2015-2018) or Halema'uma'u (2008-2020) 809 from the LERZ 2018 olivine. The red and blue areas for the LERZ 2018 olivine highlight 810 the potential contribution from $Pu'u'\bar{o}'\bar{o}$ and Halema'uma'u (<10%), and from the South 811 Caldera reservoirs (>90%), respectively. 812



Figure 5: Summary of key components of the plumbing system under Kilauea (modified 813 from Wieser et al., 2021) before (a) and during (b) the 2018 LERZ eruption, and the range 814 in olivine composition (Fo=forsterite and Sc content) in the different magmatic reservoirs. 815 The olivine populations are based on differences in Fo and Sc contents. Sc content in 816 olivine implies that the low- and high-Fo populations are present in both the shallow and 817 deep summit reservoirs, but have significant differences in Sc contents (lower Sc contents 818 in the South Caldera reservoir). Earthquakes (black dots; all magnitudes earthquakes from 819 the HVO database) in the six months prior to the 2018 LERZ eruption suggest magma 820 intrusions preceding the 2018 eruption. Earthquake clusters at 5-13 km depth, below the 821 deeper South Caldera reservoir and East Rift Zone regions, and at 1-3 km depth, around the 822 shallower Halema'uma'u reservoir, precede the 2018 LERZ eruption. The red arrows show 823 the possible magma overturn at the summit and the transport in the LERZ during the dike 824 intrusion. The question marks highlight the possible storage of the $Pu'u'\bar{o}'\bar{o}$ olivine in the 825 East Rift Zone during the 2018 LERZ eruption and possible connections in the ERZ. The 826 moderately mafic melts ($\sim 7 - 7.5 \text{ MgO}$ for Halema'uma'u shallow reservoir) fractionate 827 progressively in the ERZ (~ 6.5 MgO at Pu'u'ō'ō prior to 2018; Gansecki et al., 2019). 828 Older stored magmas with lower Fo olivine (Fo_{70-75}) were involved during the phase 1 of 829 the 2018 LERZ eruption. 830



Figure 6: Variations in oxygen fugacity reported as log units above the FMQ reaction buffer 831 calculated from the V contents of primitive olivine (Fo>88) and V content in matrix glasses. 832 The dashed lines are derived from the calibration in Canil, 2002. The V content in the 833 matrix glass is corrected for olivine fractionation (see supplementary data for corrections), 834 so that matrix glasses are plotted in equilibrium with the primitive olivine. Conditions 835 were slightly more oxidized during the KT period than in 2008 at the Halema'uma'u lava 836 lake. Slightly more reduced conditions are inferred for the LERZ 2018 eruption but could 837 also reflect magma mixing during the eruption or greater sulfur degassing. Horizontal error 838 bars correspond to the uncertainties on the eruption age for the KT units (from Swanson 839 et al., 2012). Note that the calibration from Canil, 2002 of $K_V^{olivine/melt}$ is also function of 840 temperature, melt composition and olivine composition. A lower temperature for a given 841 fO_2 results in a higher 'K' value. 842



Figure 7: Composition of Mg-rich (Fo>87) olivine phenocrysts for the 2018 LERZ, 2008 843 Halema'uma'u lava lake and ~1500-1820 KT period. (a) 100*Mn/Fe versus 100*Ni/Mg 844 for primitive olivine (Fo>87) and fields for olivine in equilibrium with peridotite melts and 845 pyroxenite melts (Sobolev et al., 2007). KT olivine are depleted in Mn compared to other 846 Kilauea olivine. (b) 100*Mn/Fe versus Ni/Co of primitive olivines (Fo>87). Ni/Co values 847 >20 suggest a pyroxenitic component in the mantle source and Ni/Co ~ 20 (value for the 848 Bulk Silicate Earth) with 100*Mn/Fe between 1.6-1.8 would indicate a peridotite component (e.g., Sobolev et al., 2007; Foley et al., 2013). (c) 10000*Zn/Fe versus 100 Mn/Fe of primitive 850 olivine (Fo>87). Fields of olivine in equilibrium with peridotite melts and pyroxenite melts 851 are from (Le Roux et al., 2010; Howarth and Harris, 2017). (d) Ni versus Co content in 852 Fo>87 olivine. Dashed line represents Ni/Co=20 that distinguish olivine compositions due 853 to mantle melting and magma crystallization (Sobolev et al., 2007). Black arrows in panel 854 (a), (b) and (d) are illustrative trends for olivine crystallization. 855



Figure 8: Batch melting calculations for selected transition metals concentrations in 856 forsteritic olivine (Fo>87). Best fit mantle lithology that participated in melting for KT 857 magma is 6% olivine, 75% orthopyroxene, 11% clinopyroxene, 8% garnet. Best fit mantle 858 lithology for 2018 LERZ magma is 4% olivine, 13% orthopyroxene, 67% clinopyroxene, 12% 859 garnet, 4% spinel. This does not mean that these eruptions are necessary sourced from py-860 roxenites but means that the proportion of pyroxene that melted changed between 1500 and 861 2018. Full-color symbols are the averages for each eruption, faded background ones are all 862 Fo>87 olivine data. (a) Sc versus Mn. Note that Sc is highly incompatible in spinel, while 863 is highly compatible in garnet. Therefore, the decrease in Sc between 1500 and 2018 cannot 864 be only explained by a switch from garnet- to spinel-field melting, since spinel counteract 865 the contribution of clinopyroxene; (b) Zn versus Mn; (c) Ni versus Co; (d) Ni versus Mn. 866



Figure 9: Mean potential mantle temperatures and pressures calculated from KT and 867 2018 LERZ primitive melt inclusions (MgO >10wt.%). (a) Potential mantle temperature 868 (T_p) calculated with primitive (MgO >10 wt.%) olivine-hosted melt inclusions composi-869 tions from different Kilauea eruptions between 1500 and 2018. T_p were estimated using 870 the parametrization from Lee et al., 2009. Melt inclusion data from KT, Kilauea Iki and 871 Maunaulu eruptions are from Sides et al., 2014 and melt inclusions from the 2018 LERZ 872 eruption (fissure 8 'phase 3') are from Lerner et al., 2021 and Wieser et al., 2021. The 873 temperatures calculated for the 2018 LERZ eruption are compared with the other eruptions 874 using one-way analysis of variance (ANOVA tests; white circles represent the average and 875 the bars represent the first and last quartile). The P- and F- values for the ANOVA tests are 876 reported in supplementary data. (b) Pressures calculated from KT and 2018 LERZ primi-877 tive melt inclusions (MgO > 10wt.%). Temperatures and pressures calculated for Hawaiian 878 shield basalts are from Lee et al., 2009. Curved dashed lines represent melting adiabats ('F' 879 is the melting fraction; from Lee et al., 2009). Red lines are average pressure and tempera-880 ture. Lithosphere-Asthenosphere Boundary (LAB) depth is from Dasgupta et al., 2010. 881



Figure 10: Estimated degree of mantle partial melting for the 1500-early 1820's KT period, 2008 Halema'uma'u and 2018 LERZ magmas. The degree of partial melting (F) is estimated using the equation in De Hoog et al., 2010: $F_{melting} = 14.5 \times \ln(Cr\#ol) + 26 (Cr\#, molar$ ratio Cr/(Cr+Al)). Only high-Fo (Fo>87) olivine are used for these calculations. The 1500-early 1820's KT period was supplied by a lower degree of partial melting (F ~ 21.7%) compared to the 2008 Halema'uma'u olivine (F ~ 23.7%) or 2018 LERZ olivine (F ~ 24%). One sigma analytical error (related to Cr# measurements) on $F_{melting}$ is ~ 0.3%. Calculated F values are only qualitative.