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article in press

Zircon geochronology and geochemistry reveal a young, cold, wet trans-crustal reservoir beneath Dominica, Lesser Antilles

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Abstract

20 Dominica has experienced multiple voluminous explosive intermediate eruptions within the last 250 kyrs. We present >175 U-Th ages and trace element compositions from ignimbrite zircon surfaces to characterize eruptive history and reservoir evolution. Zircon crystallization appears periodic and ranges from secular equilibrium to near eruption age. There is no discernible island-wide time progression of eruptions and there is an apparent volcanic hiatus between ~200 ka and 70 ka. We establish a new youngest constraint on northern volcanism of ~18 ka.

25 Calculated Ti-in-zircon temperatures (570-620°C) sit near or below the wet granite solidus. Hf concentrations range from 2200-18,000 ppm. The low temperatures and low Hf can only be reconciled if zircon crystallized in a less evolved melt at high water concentrations (e.g., 8 wt% H₂O) and lower crustal depths (e.g., 28 km, 750 MPa). Discrepancies between low zircon crystallization temperatures and high Fe-Ti oxide eruption temperatures (700-890°C) require rapid entrainment of zircon from a long-lived trans-crustal mush reservoir.

Non-technical summary

Dominica has a large number of volcanoes, an active hydrothermal system, and experiences periodic swarms of earthquakes across the island, so it has a high likelihood of erupting in the future. Many of the past eruptions have been quite large and explosive, so we investigated the timing of the eruptions across the island to better inform hazard potential. To constrain the eruptive history, we analyzed the surfaces of zircon, a robust mineral that could be found in volcanic deposits and dated. We determined that explosive volcanism in northern Dominica was much younger than previously known by ~25,000 years. We also found evidence of older volcanism in northern Dominica (>200,000 years) and that there was a long period of time (>100,000 years) in which no eruptions occurred anywhere on the island. When eruptions resumed, there were explosive eruptions from many different vents. We were also interested in the magma system beneath the volcano and where the magmas grew and were stored. Their zircon is consistent with an origin that was deep and wet.

Introduction

In volcanic arc systems, there is abundant evidence for trans-crustal, vertically protracted magma reservoirs, consisting of crystal-rich, near sub-solidus temperature lenses or sills/dykes that get remobilized and mixed prior to eruption (e.g., Annen et al., 2015; Cashman et al., 2017; Edmonds et al., 2019). Geothermometry, barometry, hygrometry, and melt inclusions are often used to assess the depth, temperature, and volatile content of these systems and provide a snapshot of conditions at a particular time. Zircon can provide a complementary thermochemical record to assess magma chamber dynamics, particularly with respect to crystallization history. ^{238}U - ^{230}Th disequilibrium dating of zircon, coupled with trace element and/or temperature information, can yield insight into reservoir longevity, protracted crystal growth, and processes of arc systems (Charlier et al., 2005; Claiborne et al., 2010; Klemetti & Clynne, 2014; Rubin et al., 2017; Schmitt et al., 2010; Stelten & Cooper, 2012). By targeting the unpolished surfaces of zircons, we can extract information about the conditions under which the zircon last grew prior to transport to the surface and eruption and constrain a maximum eruption age. Heterogeneous zircon surface ages and chemistry can provide evidence for unique thermal histories and crystallization prior to mobilization and mixing en route to the surface e.g., Claiborne et al., 2010, 2018; Frey et al., 2018; Howe et al., 2015; Schlieder et al., 2025; Storm et al., 2012).

We previously reported ^{65}U -Th zircon surface dates for ignimbrites within the Roseau Valley of Dominica (Frey et al. 2018), the most populous region in the country. We documented multiple eruption events, including a Holocene eruption, and established that there were discrete crystallization events punctuated by hiatuses. In this study, we present 116 new U-Th ages of zircon surfaces, which help to refine (or define) the eruption age(s) of several other ignimbrites across the island, as well as periods of crystallization in the magmatic system beneath Dominica. We also report trace element compositions of zircons from both datasets, which allow us to interrogate the temperature and evolution of the plumbing system, complementing prior work which suggests repeated partial melting events and magma storage at different depths.

Geologic background

70 The Lesser Antilles in the Caribbean has been the site of significant historic volcanism, including effusive-explosive eruptions on St. Vincent from 2020-2021 and the current unrest and 1995-2013 eruptions in Monserrat. In 1902, ~31,000 people perished from the devastating eruptions of Mt. Pelee, Martinique and Soufriere, St. Vincent. However, the island with the highest volcanic hazard potential is Dominica, with some volume estimates of individual explosive eruptions on Dominica up to 10 km³, an order of magnitude larger than those on neighboring
75 islands (Boudon et al., 2017; Lindsay, Smith, et al., 2005; Wadge & Shepherd, 1984). The volcanism in Dominica is also young, with nine volcanic centers that are Pleistocene or younger in age (Fig. 1; Lindsay, Trumbull, et al., 2005).

As a result of the underlying young magmatic system (<Pleistocene), Dominica features more than 30 hydro/geothermal areas (Smith et al., 2013) and experiences frequent seismic activity. Since continuous
80 instrumental monitoring of earthquakes began in 1953 by the Seismic Research Center of the University of the West Indies (UWI-SRC), there have been numerous significant seismic swarms of shallow, small earthquakes (M<4.0), predominantly in southern Dominica (e.g., Morne Plat Pays region; (Lindsay, Smith, et al., 2005)), with more recent additional activity in the northern Morne aux Diaboles region and in central Dominica between Morne Trois Pitons and Morne Watt (Pers. Comm, Joseph). The recent unrest has been attributed to magmatic movement,
85 although pressure changes related to magma crystallization or degassing (or some combination thereof) are also plausible. The magmatic system underlying Dominica is active and presents an ongoing hazard to the island and region.

In 2005, a series of Dominica volcanic hazard assessment maps were published (Fig. 1), based on past volcanic activity, seismicity, and geothermal activity (Lindsay, Smith, et al., 2005). Six eruptive scenarios were
90 explored, with a phreatic eruption in the Valley of Desolation deemed the most probable. Least likely was a dome forming eruption in northern Dominica at Morne aux Diaboles, presumably owing to older (>1.5 Ma) measured lava

dome K-Ar ages (Bellon, 1988; Monjaret, 1985). Previous interpretation of the geochronology of the lava domes on Dominica suggested that crystallization/magmatic foci migrated from north to south over time (Howe et al., 2015). However, since that time, there have been additional geochronology studies (Boudon et al., 2017; Frey et al., 2018; Howe et al., 2014, 2015), including this work, and recent seismic swarms that may warrant a reevaluation of hazard assessments, particularly in northern Dominica.

Eruptive History

Dominica is comprised nearly entirely of volcanic material and many of the towns, including the capital city of Roseau (pop. ~15,000) in central Dominica and Portsmouth (pop. ~3600) and the Ross University School of Medicine (pop. ~3500) in northern Dominica, are built on old intermediate composition (andesite-dacite) pyroclastic flow deposits associated with different volcanic centers/vents across the island. The older centers are restricted to the north and include the lava domes of Morne aux Diabes (MAD) and the stratovolcano of Morne Diablotins (Howe et al., 2015; Smith et al., 2013) (Fig. 1). Morne Trois-Pitons and Micotrin dominate the central portion of the island, with several smaller domes/vents located to the south. The southernmost and youngest lava dome complex is Plat Pays, with Morne Patetes dated at 510 ± 93 yrs BP (Roobol et al., 1983).

There are explosive deposits (predominantly from pyroclastic density currents) associated with each of these volcanic centers and their eruption ages have been variously constrained in previous studies from charcoal within the deposits (or overlying stratigraphy) by ^{14}C accelerator mass spectrometry (AMS) dating and U-Th and (U-Th)/He dating of zircons (Table 1; Fig. 2). Minimum ages of the northern ignimbrite deposits include >46 ka for Morne aux Diabes (Smith et al., 2013); >22 ka for Grande Savane (Sparks et al., 1980) and >40 ka for Layou (Wadge, 1989). The eruption age of the Layou ignimbrite was further refined to 65 ± 5 ka by a (U-Th)/He zircon age (Howe et al., 2014) and a ^{14}C age of $50,598 \pm 5590$ BP (Boudon et al., 2017). More extensive work has been done on the >200 m thick deposits within the Roseau valley of central Dominica, origin of voluminous eruptions (>58 km³) that blanketed nearby Caribbean islands and the eastern Caribbean Sea in ash (Carey & Sigurdsson,

115 1980; Sigurdsson, 1972). The “Roseau Tuff” is now recognized to be comprised of multiple events, spanning ~40
kyr (Boudon et al., 2017; Frey et al., 2018; Howe et al., 2014; Smith et al., 2013). The youngest reported U-Th/He
zircon age was 24.5 ± 2 ka (Howe et al., 2014), but significantly younger U-Th zircon (2.6 ± 8 ka; Frey et al. 2018)
and ^{14}C dates (~9-12 ka BP; Boudon et al, 2017) have since been reported. These younger ages appear to be
restricted to smaller volume ($<1 \text{ km}^3$) airfall deposits (Boudon et al., 2017). The southernmost ignimbrites, found
120 near Grand Bay along the coast near Berekua, have yielded ^{14}C ages between 30 and 39 ka (Lindsay, Trumbull, et
al., 2005), whereas Howe et al. (2014) reported an older eruption age of 62.6 ± 4 ka via apatite (U-Th)/He. The
most recent eruptions in Dominica were phreatic eruptions in the Valley of Desolation in 1880 and 1997 (Lindsay,
Smith, et al., 2005), which also experiences periodic drastic changes in the level of Boiling Lake, owing to an active
hydrothermal system (Joseph et al., 2011, 2019).

125 **Source of Ignimbrites**

The origin of the various ignimbrites (Fig. 2) has been explored by several researchers on the basis of field
observations, geochemistry, and mineral assemblages. The eruptive sequences in northernmost Dominica
associated with Morne aux Diabls have been broadly mapped as Lower to Upper Pleistocene and interpreted as
emanating from a distinct small magma reservoir, whereas the other ignimbrites have been proposed to originate
130 from an island-wide batholith underlying central and southern Dominica (Smith et al., 2013). The Pointe Ronde
deposits on the northwest coast have not been explored in detail, but have been inferred to be from Morne Diablotins
based on geographical constraints (Sparks et al., 1980). Deposits from Grande Savane represent two distinctive
eruptions (one amphibole-bearing), but both are also attributed to Morne Diablotins (Smith et al., 2013; Boudon et
al., 2017). The Layou ignimbrite was once considered part of the Roseau Tuff (Carey and Sigurdsson, 1980), but
135 later determined to be a separate eruptive sequence based on geochemistry (Smith et al., 2013; Howe et al., 2014).
Owing to the lack of definitive up-valley outcrops and the presence of significant amphibole (similar to one of the
Grande Savane units), Boudon et al. (2017) suggested an origin of Morne Diablotins for the Layou Ignimbrite. The

various eruptions in the Roseau Valley have been attributed to a buried caldera (by Micotrin volcano) at Wotten Waven proposed by Demange et al. (1985), and supported by subsequent studies (Lindsay et al., 2005; Smith et al., 2013). Boudon et al. (2017) confirmed an origin within the Morne Trois Pitons-Micotrin summit region. The southern ignimbrite sequences at Grand Bay were initially associated with the Plat Pays complex on the southern coast based on mineralogy and topography (Lindsay et al., 2003), but was later attributed to the buried Wotten Waven caldera (Lindsay, Smith, et al., 2005; Smith et al., 2013) and/or Morne Trois Pitons-Micotrin region (Boudon et al., 2017).

145 **Magma plumbing system**

The source of magma feeding the crystal-rich andesite-dacite effusive lava dome eruptions and explosive deposits has been hypothesized as a two-magma chamber system beneath Dominica, consisting of an Upper Pliocene/Lower Pleistocene smaller, shallower chamber beneath Morne aux Diabes in the north and an Upper Pleistocene/Holocene mid-crustal batholith beneath the rest of the island (Smith et al., 2013). The main batholith is suggested to have formed from an amalgamation of smaller reservoirs based on the homogeneity of bulk rock major and trace element chemistry, coupled with heterogeneous mineral chemistry and crystal cargo (Smith et al., 2013). Prior to the andesite-dacite magmatism that has proliferated over the last several hundred thousand years, effusive mafic (basalt to basaltic-andesite) lavas were dominant from ~7-2 Ma (Bellon, 1988; Monjaret, 1985). The younger basalts (~2.2 Ma) are restricted to the Foundland Center in the southeastern tip of the island, whereas older mafic lavas are found beneath intermediate ignimbrite deposits on the eastern and western sides of the island.

Crustal structure and potential reservoir depths beneath Dominica was reconstructed using an inversion of seismic receiver functions and petrology of crustal xenoliths to create a seismic velocity profile (Melekhova et al., 2019). Total crustal thickness is ~38 km, with a mid-crustal discontinuity ~13 km depth (Melekhova et al., 2019), as constrained by geobarometry of olivine hornblende gabbro crustal xenoliths that yielded a pressure of 200-350 MPa (Zibera et al., 2017). In contrast, melt inclusions in orthopyroxenes from northern and central ignimbrites

had volatile contents 4.5-7.6 wt% H₂O and calculated pressures up to 750 MPa or ~28 km (Balcone-Boissard et al., 2018). Experimental studies which reproduced phase assemblages and compositions of Layou and Roseau pumice samples yielded pressures of ~400 MPa (~16 km depth) and 7-8 wt% melt H₂O (Solaro et al., 2019). Studies of volatiles in melt inclusions from younger (<20 ka), smaller Plinian eruptions in central Dominica estimated storage pressures ~50-200 MPa, corresponding to a depth of 2-8 km in the upper crust (d'Augustin et al., 2020). Collectively, these studies support a trans-crustal magmatic reservoir, with magmas originating in the lower crust and being stored at variable depths at potentially subsolidus conditions, requiring reheating and remobilization prior to eruption.

Methods

In the field, pumice clasts were collected from 12 unconsolidated ignimbrite deposits and 2 welded tuffs from throughout the island for zircon extraction (Fig. 2). Due to low zircon yield, multiple pumice clasts from each unit were processed in a jaw crusher and disc mill to liberate crystals from the groundmass. A water table was not used for density separation, owing to the scarcity of zircons and high glass content of the samples, but all samples were decanted in water prior to magnetic separation and density separation by heavy liquids (tetrabromoethane and methylene iodide). From the extracted zircons, crystals were handpicked from each sample under a binocular microscope, and grains with a euhedral morphology were preferentially targeted as some ignimbrites have rare xenocrystic, detrital zircons (Frey et al., 2024). Since crystal surfaces were being targeted for analysis, cathodoluminescence imaging of the zircons was not done.

All zircons were analyzed for age and trace element analyses by sensitive high resolution ion microprobe reverse geometry (SHRIMP-RG) at the Stanford-USGS Microanalytical Center, following procedures defined in Claiborne et al., 2010; Klemetti & Clynne, 2014 and summarized in the supplementary material. Zircons were rinsed in dilute HF for 10-15 seconds to remove adhering glass and pressed into indium metal mounts for unpolished surface analyses. Given the presumed young age of the samples, ²³⁸U-²³⁰Th analyses were performed.

Care was taken to analyze flat surfaces close to the terminus of the crystal to capture the youngest age recorded by the zircon and the surface that was in contact with the melt. More than 200 zircons were analyzed, with a small fraction (~15 %) yielding ages in secular equilibrium (>350 ka), particularly from the northern units. These older units and additional zircons were further investigated by U-Pb dating at University of Arizona's Laserchron Center and discussed in Frey et al. (2024). A sub-set of the young zircons from the Roseau Valley was previously reported by Frey et al. (2018).

Model ages were calculated using the whole-rock $^{238}\text{U}/^{232}\text{Th}$ and $^{230}\text{Th}/^{232}\text{Th}$ ratios reported by Howe et al. (2015) for Dominica, with $^{230}\text{Th}/^{238}\text{U}$ ratio between 0.99 and 1.03 for six samples island-wide. We assumed a constant melt composition and that the zircons were derived from the melt. The veracity of such an assumption was tested by Moser et al. (2026) who compared calculated U-Th model ages using a constant melt composition to using a constant zircon-melt U/Th fractionation factor. Their study recommends that one should evaluate whether the whole rock represents the glass forming melt by comparison with the youngest isochron intercept on the secular equilibrium line. Because our youngest isochrons overlapped with the whole rock isotopic composition (e.g., Fig. 3A and 3G), we used a constant melt composition to anchor the calculated isochrons. In Figure 2, model ages are plotted in standard rank file form with a kernel density estimate created using Mathematica's "SmoothHistogram" function. Model age errors are determined based on the analytical uncertainty of isotope ratios used in generating the slope of the isochron, so U-Th model age errors are not symmetric and should not be treated as such for accurate modeling. In Fig. 2, isochron slope values have been converted to age. Populations (denoted as vertical black lines with gray 1-sigma error bars in Fig. 2) are derived from mixing models as described in Frey et al. (2018), based on the work of Sambridge & Compston (1994). The minimum number of populations within a given dataset is determined if adding an additional population does not improve the relative model misfit by more than 2% (Frey et al., 2018).

Fig. 3 features additional data visualizations for select samples made in IsoplotR (Vermeesch, 2018), including isochron plots and radial plots, with all sample age visualizations available in the supplementary material. In the isochron plots, age is a function of the slope, anchored by the initial U-Th composition of the melt, with steeper slopes approaching secular equilibrium. In the radial plots, the age is also a function of slope, but analyses are weighted by their errors; more precise analyses plot further from the origin. By incorporating the errors, we can statistically determine whether datapoints are consistent with a single age population or represent a more complex crystallization history, as described in the supplementary material. The relatively large errors on the model ages are a consequence of U-poor (<200 ppm) zircons. Isochron, radial, and kernel density plots as output from IsoplotR for all samples are in supplementary Figure 1. Complete analytical results of the U-Th analyses and uncertainties, as constrained by zircon standard Early Bishop Tuff (EBT), are compiled in the supplementary data tables.

Trace elements were analyzed in a separate analytical session on the SHRIMP-RG on the crystal surfaces of nearly all zircons that were dated, adjacent to each U-Th age spot, irrespective of whether a viable U-Th age was obtained. Analyses included measurements of $^{48}\text{Ti}^-$, $^{49}\text{Ti}^-$, $^{56}\text{Fe}^-$, $^{89}\text{Y}^-$, $^{139}\text{La}^-$, $^{140}\text{Ce}^-$, $^{141}\text{Pr}^-$, $^{146}\text{Nd}^-$, $^{147}\text{Sm}^-$, $^{153}\text{Eu}^-$, $^{155}\text{Gd}^-$, $^{179}\text{DyO}^-$, $^{182}\text{ErO}^-$, $^{188}\text{YbO}^-$, $^{196}\text{HfO}^-$, $^{248}\text{ThO}^-$, and $^{238}\text{U}^-$. Complete analyses and analytical uncertainties of trace element measurements, as constrained by zircon standard MAD-559, are provided in the supplementary material.

The Ti-in-zircon thermometer (Ferry & Watson, 2007) is used to constrain the crystallization temperature of the zircons (Table 2). Since quartz is not present in the samples, $a_{\text{SiO}_2} < 1$ and we assign a value of 0.8. The a_{TiO_2} used is 0.65-0.7, based on $f\text{O}_2$ calculated from co-existing Fe-Ti oxides (Ghiorso & Evans, 2008) analyzed by Frey et al. (2018). An error of 0.2 in the activity estimates would affect zircon crystallization temperatures $\sim 30^\circ\text{C}$, but the relative temperatures between individual units and zircons would remain unchanged, as the melt is saturated with a Ti-bearing phase (titanomagnetite).

Zircon saturation temperatures (Table 2) were calculated using the approach detailed in Boehnke et al. (2013) and glass compositions analyzed at Union College by scanning electron microscopy. Details are in the supplementary material.

Results

U-Th model age geochronology

We report 116 new U-Th model ages for five andesite-dacite ignimbrites across the island, from north to south, coupled with 65 U-Th ages for the Roseau Ignimbrites (Frey et al., 2018). All analyses were done on crystal surfaces, and thus represent the last crystallization of the zircon prior to eruption. An additional 35 zircons were analyzed, but ages were either in secular equilibrium (>350 ka) or there was too little ^{230}Th to calculate a meaningful age. Like many zircons in arc systems, concentrations of U in Dominican zircons are relatively low, (25 to 778 ppm; average = 135 ppm, median = 111 ppm), thus little ^{230}Th is present in young crystals and the ^{230}Th signal to background noise can be significant, resulting in large errors. Collectively, the data set ranges from ca. 18 ka to secular equilibrium (at ca. 350 ka), with the youngest ages often overlapping eruption ages previously determined by (U-Th)/He and ^{14}C . Data is shown in rank file and kernel density plots (Fig. 2) and isochron and radial plots (Fig. 3). Some of the units display polymodal age distributions, with hiatuses apparent in kernel density plots and/or significant age dispersion which suggest a complex crystallization history prior to eruption. Populations within each unit were determined with mixing models (Frey et al., 2018), as described in the methods and supplementary materials. Unlike the age progression observed in the lava domes (Howe et al., 2015), there is not a spatial-temporal crystallization trend from north to south and each unit displays a unique crystallization history.

Morne aux Diables (MAD)

Twenty-one zircons were dated from this unit, with 14 yielding viable ages between 18 and 125 ka, forming a broad kernel density peak with a median age of ~ 70 ka (Fig. 2A). The distribution of the age data could reflect

250 relatively continuous crystallization or two periods of crystallization (~50 ka and ~107 ka), given the error on the analyses. Five crystals are in secular equilibrium (Supplemental Fig. 1), which is unsurprising, as this unit has a documented preponderance of older and xenocrystic zircons (Frey et al., 2024). A ^{14}C age of >46 ka (Lindsay, Smith, et al., 2005) was the only previous age for this ignimbrite, so our young zircon age of 18.2 (+7.4/-7.0) ka is a significant addition to the eruption history in the north.

255 *Pointe Ronde (PR)*

Although this coastal unit emanating from Morne Diablotins has been mapped (Smith et al., 2013), the only previous age constraints are U-Pb zircon ages, which show a significant population of older volcanic zircons up to 8 Ma, as well as older xenocrystic zircons >50 Ma (Frey et al., 2024). We attempted to date 10 zircons, and four yielded ages >200 ka with errors >70 ka, and the population was defined as 280 ± 95 ka (Fig. 3A). The
260 remaining four crystals were in secular equilibrium (Fig. 3A). Collectively, the data suggest that this unit is the oldest ignimbrite in this study, with no ages <200 ka.

Grande Savane (GS)

Also emanating from Morne Diablotins, like the Pointe Ronde ignimbrite, Grande Savane is known to contain older volcanic and xenocrystic zircons (Frey et al., 2024) and was constrained to be older than 22 ka by ^{14}C
265 dating (Sparks et al., 1980). Our U-Th dating of zircons yielded two ages >200 ka (± 100 ka), with three more crystals in secular equilibrium (Fig. 3B). Like Pointe Ronde, the Grande Savane Ignimbrite is an older explosive unit >200 ka. A second locality (GS-8) was initially thought to be a Grande Savane deposit based on geographic location, but its zircon age distribution and chemistry suggests an affinity for the Layou Ignimbrite instead, as described below.

270 *Layou (LV)*

In contrast to the more northern ignimbrites, nearly all of the 51 U-Th zircon ages associated with three

deposits from Layou are <150 ka (Fig. 2B-D). Zircons from the northernmost deposit (GS-8), located near the town of Salisbury, span an age range of 43-166 ka, with a broad kernel density distribution that peaks at ~90 ka, with no discernible hiatuses at the resolution of our data (Fig. 2B). However, the age dispersion could also be explained by multiple periods of crystallization at ~72 ka and ~118 ka (Fig. 3F). Within the Layou valley, zircons from an up valley welded tuff (LV-7) span a narrower range, from 70-108 ka, with a comparable peak ~89 ka (Fig. 2C). Zircons from an unconsolidated deposit (LV-1) at the mouth of the Layou River show a slightly broader distribution, with zircon ages ranging from 46-99 ka, with a peak at ~72 ka and a single older crystal at 187 ka (Fig. 2D). The zircon distributions for these deposits are all unimodal on the KD plots, with a single broad peak of crystallization, but with long tails from older and younger zircons. This could reflect continuous crystallization over 40-50 kyrs or multiple (two) periods of crystallization for the Layou ignimbrites.

Roseau (RI)

In previously published U-Th zircon model ages from seven locations within the Roseau Valley (Frey et al, 2018; Howe et al., 2014), zircons ranged in age from ~6 ka to secular equilibrium and plots are shown in Fig. 2 for comparison with ignimbrites in this study. In contrast to the Layou deposits, the Roseau zircon kernel density distributions are distinct between units and feature polymodal distributions and apparent crystallization hiatuses within units (e.g., Fig 2I, Fig 3H). Several of the Roseau flows feature a peak crystallization episode ~110-125 ka, as well as older and younger populations (Fig. 2) as fully described in Frey et al. (2018) and shown in the supplementary Figure 1.

Grand Bay (GB)

Zircons from three unconsolidated deposits in the Grand Bay area yielded 42 young zircon ages, ranging from 43-250 ka, with an additional six crystals with ages >250 ka, and 14 that did not generate a viable result. Like the Roseau Ignimbrites, these southern deposits have distinctive, complex polymodal age distributions (Fig. 2E-F)

and periods of crystallization. GB-10 has a preponderance of crystals <150 ka, with an average age of ~96 ka, with
295 a smaller fraction of crystals yielding an older, broader peak ~194 ka (Fig. 2E; Supplementary Fig. 1). GB-11 was
a zircon-poor sample and yielded a well constrained young zircon at $67 +14/-12$, and three older crystals (~150-
200 ka; Supplementary Fig. 1). GB-12 has the most complex distribution, with a population between 49-95 ka (9
zircons) and average age of 71 ± 11 ka, a second population 126-208 ka (8 zircons) with an average age of $161 \pm$
26 ka, and a third population (5) in secular equilibrium (Fig. 2F and Supplementary Fig. 1). The Grand Bay units
300 produce very broad multi-humped distributions, not unlike the Roseau Ignimbrites, which likely emanate from the
same location near Morne Micotrin.

Zircon trace element chemistry

Overall, trace element concentrations in the analyzed zircons (n=220; Supplementary Table 2) span broad
ranges, with little correlation with respect to location/ignimbrite and age (Fig. 4) or grains that did not produce
305 viable ages. Concentrations of uranium in Dominican zircons are relatively low, 25 to 778 ppm, with an average
of 149 ± 155 ppm (Fig. 4A). Hafnium, which is correlated with the extent of magma fractionation (Claiborne et al.,
2010), spans a broad range from ~2200 to ~18,000 ppm (Fig. 4B). Morne aux Diables is the only unit to display a
restricted range, ~10,000 ppm, with an average 10620 ± 1281 ppm. Ti concentrations are very low, ranging from
0.4-8.4 ppm, with the bulk ranging from 1-3 ppm (Fig. 4C). There is no apparent correlation of Ti with unit, age or
310 U concentration. Yb/Gd (vs. Th/U) which has been used as a proxy for basaltic input (Barth et al., 2012; Klemetti
& Clynne, 2014) ranges from ~10-65 (Fig. 4D), with lower values more indicative of interaction with mafic
material. There is again no apparent correlation with this compositional parameter and unit or age, but the high
values suggest limited basaltic input. Eu/Eu*, which is a proxy for the extent of plagioclase crystallization prior to
zircon crystallization (Claiborne et al., 2010), ranges from 0.2 to 0.7 (Fig. 4E), with a value of 1 indicative of no
315 plagioclase fractionation.

Chondrite-normalized REE abundances of zircons have broadly similar patterns of steeply rising slopes from

LREE to HREE, with variable positive Ce anomalies and negative Eu anomalies (Fig. 5). These patterns are typical of crustally derived zircons formed under oxidizing conditions (Hoskin & Schaltegger, 2003). The older Morne Diablotins ignimbrites (Pointe Ronde and Grande Savane) display the most variation between zircons and have variable slopes and relative REE abundances (Fig. 5A). Some of the crystals may be in secular equilibrium and/or xenocrysts that did not yield a U-Th age (grey lines). The younger Morne Diablotins deposits (Layou) exhibit the most restricted compositional range and parallel trends between zircons (Fig. 5B). Parallel trends typically are indicative of fractionation from a common source. However, there is no correlation with age and degree of fractionation, as the oldest zircons in the Layou deposits have a moderate abundance of REEs. The various samples from Roseau (e.g., KH-4 in Fig. 5C) and Grand Bay have some zircons with parallel REE trends, but several outliers.

Thermometry

Within each deposit, we can compare temperature estimates which reflect the conditions in the magma reservoir at different stages of magma evolution. Using the Ti-in zircon thermometer (Ferry and Watson, 2007), we calculate the final crystallization temperature of the zircon prior to eruption. Owing to the very low Ti concentrations (most <4 ppm), Ti-in-zircon temperatures range from 540 to 810 °C, with the majority at 570-620°C (Fig. 6), or temperatures typically considered subsolidus, as explored in the discussion.

Two-oxide thermometry is based on the temperature dependent partitioning of Fe and Ti into co-existing ilmenite and magnetite and reflects the temperature at which the eruption occurred. Previous studies estimated Fe-Ti oxide temperatures ~700-880 °C for the various ignimbrites, with most >800°C (Frey et al., 2018; Howe et al., 2014). Pre-eruptive storage temperatures may be even higher, based on opx-cpx and cpx-melt thermometers which suggested temperatures of 860-890 °C (d'Augustin et al., 2020; Gurenko et al., 2005; Lindsay, Trumbull, et al., 2005).

Zircon saturation temperatures are the predicted temperature at which zircon will start to crystallize, calculated using measured matrix glass composition and Zr abundances estimated from whole-rock geochemistry and mass balance (Boehnke et al., 2013). Zircon saturation temperatures are between 677-733°C, reflecting broad similarity in calculated Zr concentration and measured rhyolitic glass chemistry (73-77 wt% SiO₂) between ignimbrites across the island (Table 2). Clasts within deposits are nearly indistinguishable with respect to silica content and zirconium concentration, but there are subtle differences between the deposits, even from the same volcanic center. Overall, for every ignimbrite, the Fe-Ti oxide (eruption) temperatures are significantly higher than the zircon saturation temperatures, which are higher than the Ti-in zircon crystallization temperatures (Fig. 6), sometimes by >100°C.

Discussion

Updated Eruption Chronology

We interpret the youngest zircon in each sample as a potential eruption age, as the surface represents the last crystallization event. With the new ages for the northern ignimbrites (MAD, Pointe Ronde, and Grande Savane), we can better describe the eruptive history of Dominica and demonstrate that the explosive eruptions do not correlate with the time progressive nature of the lava domes from north to south (Fig. 1, 2; Howe et al., 2015). Following the eruptions of the older Morne Diablotins ignimbrites (>200 ka), there appears to have been a quiescence of >100 kyrs before explosive activity resumed ~70 ka (Fig. 7A). This may reflect a “flare-up” of explosive volcanism after thousands of years of intermittent zircon crystallization (Fig. 7B). Within the error estimates, eruptions could be separated by tens of kyrs, but there *could* have been *simultaneous* eruptions from different vents across the island, which suggests that the plumbing system was primed for explosive eruption during that time period.

Despite the lack of a progressive spatial-temporal trend and variability between samples within the same unit, the ignimbrites associated with each volcanic center have characteristic kernel density distribution patterns

and age spectra. Geochronology studies of ^{14}C (Boudon et al., 2017) and (U-Th)/He zircon (Howe et al., 2015) refined the eruption ages of the central and southern ignimbrite deposits on Dominica and our youngest U-Th zircon surface model ages are within error of these ages (Table 1; Fig. 2). However, until now, the ages of the northern ignimbrites have been largely unconstrained and the relationship between the timing of lava dome extrusion and explosive eruptions has not been explored. The proto-Morne aux Diabls dome was previously dated at 1.7 – 2.0 Ma by K/Ar (Monjaret, 1985), with subsequent Morne aux Diabls lava domes yielding a (U-Th)/He age of 170 ± 14 ka (Howe et al., 2015). Overlying block and ash flows yielded ages of >46 ka and $43,710 \pm 1590$ yr B.P. from ^{14}C dating (Lindsay, Smith, et al., 2005; Smith et al., 2013). Our U-Th zircon surface ages were between 18 and 125 ka, with several crystals <50 ka (Fig. 2A). Therefore, explosive volcanism in the north post-dates the Morne aux Diabls lava dome extrusion and was contemporaneous with explosive eruptions from the other volcanic centers of Morne Diablotins (Layou) and Morne Trois Pitons-Micotrin (Roseau and Grand Bay) and is significantly younger than previously suggested.

The explosive eruptions sourced from the Morne Diablotins vent both pre- and post-date the Morne Diablotins lava dome, which was dated at 75 ± 4 ka by (U-Th)/He (Howe et al., 2015). The eastern ignimbrite, variably referred to as Wesley and Londonderry, was dated at 80 ± 7 ka (Howe et al., 2015), whereas the northern ignimbrite, Bense, only yielded older (>350 ka) zircons (Frey et al., 2024). Little has been published about the northwestern ignimbrite, Pointe Ronde, beyond an outcrop description and stratigraphy (Smith et al., 2013) and the presence of xenocrystic zircons (Frey et al., 2024). In this study, a few zircons yielded ages ~ 200 ka with large errors, with additional crystals near secular equilibrium, so we can constrain the likely eruption age of Pointe Ronde to >200 ka. The southwestern ignimbrite from Morne Diablotins, Grande Savane (GS-7), also yielded zircon ages near ~ 200 ka, as well as secular equilibrium, with previous estimates only broadly constrained as >22 ka by ^{14}C dating (Sparks et al., 1980). Our results establish that there was an older period of explosive volcanism in northern Dominica, >200 ka, that produced extensive pyroclastic flow fans that traveled down the western valleys and

385 predated the Morne Diablotins lava dome extrusion by >100 kyrs.

Previous studies of the Layou Ignimbrite report an eruption age of 65 ± 5 ka (U-Th)/He zircon age; (Howe et al., 2014)) and $50,598 \pm 5590$ BP (^{14}C age (Boudon et al., 2017)). Zircons from the welded Layou tuff (LV7) we dated ($69.5 + 11.3/-10.3$ ka) are consistent with the older estimate, whereas the unwelded Layou deposit (LV1) ($45.7 + 7.5/-7.0$ ka) and young Grande Savane deposit ($42.7 + 18.3/-15.7$ ka) are more consistent with the younger ^{14}C age. Thus, the Layou ignimbrite may be comprised of multiple flows/eruptions like the Roseau ignimbrite sequence (Boudon et al., 2017; Frey et al., 2018; Howe et al., 2014; Smith et al., 2013), in which pumice clasts from different deposits have similar bulk andesite-dacite chemistry and phase assemblages, but unique eruption ages and periods of zircon crystallization. All three Layou ignimbrites post-date the eruption of Morne Diablotins at ~ 75 ka by 10-20 kyrs.

395 The southernmost ignimbrites (Grand Bay) yielded ^{14}C ages between 32 and 41 ka (Lindsay, Trumbull, et al., 2005), whereas Howe et al. (2014) reported an older eruption age of 62.6 ± 4 ka via apatite (U-Th)/He. The youngest Grand Bay U-Th zircon age from this study was $43 + 13/-12$ ka, which is consistent with previous eruption ^{14}C age determinations, within error. In central Dominica, the Morne Trois Pitons lava dome has a young eruption age (26 ± 3 ka) and the Morne Micotrin dome is younger than detection limits of (U-Th)/He (Howe et al., 2015), 400 but has a calibrated ^{14}C age of 868 ± 68 (Lindsay et al., 2005). Both the Roseau and Grand Bay ignimbrite sequences display polymodal age distributions, with zircons that are predominantly older than the lava domes of Morne Trois Pitons, but younger than the eruption of Morne Micotrin.

Utility of U-Th zircon surface analyses

In addition to constraining eruption ages for the northern ignimbrites (MAD, Pointe Ronde, and Grande Savane), our results demonstrate the viability of using U-Th zircon surface analyses to estimate eruption ages. 405 Although our errors are larger, all of our youngest U-Th zircon ages are within error of ^{14}C and (U-Th)/He age determinations (Fig. 2). The overlap between zircon surface analyses and eruption ages has been documented for 18

several volcanic systems, including the Taupo Volcanic Zone, NZ (Charlier et al., 2005; Storm et al., 2012; Rubin et al., 2016), St. Lucia (Schmitt et al., 2010), the Bükkalja Volcanic Field, Hungary (Lukács et al., 2015) and the
410 Rockford tephra from Mt. Lassen, CA (Coble et al., 2017) among others, in addition to Dominica. However, other systems do not have eruption-age zircons, and zircon crystallization pre-dates eruption by tens of thousands years, as documented at Mount St. Helens, WA (Claiborne et al., 2010), Okataina Volcanic center, NZ (Danišík et al., 2020), Mount Lassen, CA (Klemetti & Clynne, 2014) and Ciomadul, Romania (Harangi et al., 2015). In these latter
415 to eruption. In Dominica, the diverse zircon populations may reflect both pre-extraction storage at depth and near-eruption crystallization.

Age distribution patterns and crystallization periods

The zircon surfaces represent the last stage of zircon growth within a melt and produced a large range of zircon ages, which span from eruption to secular equilibrium, but peak between 50-200 ka (Fig. 7). Using mixing
420 models (Frey et al., 2018), we can distinguish different zircon populations for several of the ignimbrite deposits (e.g., Roseau and Grand Bay), as shown in the Supplementary figure 1. The model age kernel density plots from each sample display a variety of distribution patterns, including 1) relatively tightly-constrained and unimodal (Fig. 2C), 2) broad multi-humped peaks spanning tens of kyrs (Fig. 2A), and 3) complex distributions with multiple peaks and hiatuses (Fig. 2 – Roseau and Grand Bay). The various distribution patterns could reflect a sampling bias
425 or small sample size, but the reproducibility of patterns from different ignimbrites emanating from each volcanic center suggests there are fundamental differences in the plumbing systems beneath them.

Zircon model ages from the northernmost ignimbrite (MAD-2) span a broad range from ~18-125 ka (Fig. 2A), but it is difficult (although not impossible) to resolve any peaks or populations given the errors on the age determinations. The majority of zircons are 10s of kyrs older than the youngest crystal, suggesting a protracted
430 period of zircon growth prior to eruption. The younger ignimbrite from Morne Diablotins (Layou) is characterized

by narrower kernel density plots (Fig. 2B-D), with the majority of crystallization ~80 ka, or ~40 kyr prior to eruption. Each Layan deposit has a similar distribution shape suggesting similar histories, but the crystallization may have been prolonged or episodic (two pulses), given the error on the U-Th analyses (Kent & Cooper, 2017) and statistical analysis (Supplemental Fig. 1).

435 In contrast, many of the southern ignimbrite sequences from Morne Trois-Piton - Micotrin are consistent with episodic crystallization. The complex, polymodal age spectra of the Roseau Ignimbrites were discussed in Frey et al. (2018), and show periods of peak crystallization (e.g., ca. ~10 ka, 60-70 ka, 110-125 ka), separated by hiatuses >10 kyrs. The southern Grand Bay Ignimbrites (Fig. 2E-F) display similar complex, polymodal distributions to Roseau, albeit with different and older periods of peak crystallization (e.g., ~80 ka; ~170 ka; ~210
440 ka). The episodic crystallization of the Roseau and Grand Bay ignimbrites suggests that the reservoir beneath Micotrin may have reached subsolidus conditions and rheological lock-up multiple times over the last 200 kyrs. Each unit within these ignimbrites shows a distinct, complex age distribution (Fig. 2).

Zircon chemistry

REE patterns and kernel density plots

445 The compositions of the zircons from the ignimbrites span a broad range (e.g., Hf), but there does not appear to be any pattern with respect to age (Fig. 4B), suggesting that magmatic conditions have not changed systematically over the last 200 kyrs. A geographic or spatial trend with composition also appears to be lacking, and is thus consistent with similar crystallization environments across the island which have produced intermediate composition lavas and tephras since ~2 Ma.

450 Despite the lack of correlation with individual elements and age/unit, the REE patterns (Fig. 5) appear to reflect the complexity observed in the zircon age distributions (Fig. 2 and 3). The older Morne Diablotins units (Pointe Ronde and Grande Savane), show inconsistent slopes and variable REE abundances (Fig. 5A). These zircons are >200 ka and include many zircons in secular equilibrium, as well as xenocrystic zircons. Therefore, it
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is not surprising that the zircons do not show similar REE patterns, as they are derived from different sources
455 (including potentially South America; Frey et al., 2024) with distinct crystallization histories.

In contrast, the younger Morne Diablotins ignimbrites (Layou) have nearly identical REE patterns between
samples and zircons (Fig. 5B), differing only in abundance, which is typically a sign of crystal fractionation.
However, there is not an age progression with elemental abundance, which would suggest similar crystallization
environments, but not fractionation from a single magma batch. The magmatic system feeding the more recent
460 ignimbrites from Morne Diablotins (<200 kyrs) could be a zoned, mushy reservoir or melt lenses of similar
composition. Such an origin seems plausible given the simpler, unimodal zircon population (Fig. 2B-D) displayed
by the three different deposits.

The Roseau and Grand Bay ignimbrites, which have polymodal zircon age distributions, display REE
variation between some zircons within units (Fig. 5C). This suggests that although these southern ignimbrites may
465 be contemporaneous with the Layou ignimbrites, their crystallization history is more complex and may reflect more
magma mingling/mixing or successive partial melting. On the basis of zircon chemistry, the mingled magmas could
have evolved in separate magma batches or lenses.

Ti concentrations, T_{Zir} and water content

The Ti concentrations in the Dominica zircons are extremely low, mostly <4 ppm, which is more typically
470 seen in highly evolved rhyolitic/granitic systems and porphyry copper deposits (Nathwani et al., 2024). The low Ti
concentrations yield low calculated T_{Zir} of 540 to 810 °C, with the majority of T_{Zir} at 570-620°C (Fig. 6). Although
the Ti concentrations and temperatures recorded by the Dominican zircons are low, similar values have been
documented in evolved magmatic systems, including the Taupo Volcanic Zone (NZ) (Barker et al., 2014; Rubin et
al., 2016, 2017; Schlieder et al., 2025) the Sierra Nevada Batholith (USA) (Schoonover et al., 2024), Adamello
475 Batholith (Italy) (Broderick et al., 2015) and the Altiplano Puna Volcanic Complex (Bolivia) (Kern et al., 2016).
Calculated T_{Zir} in these systems approach or are below the historically accepted wet granitic solidus of 650-700°C

(Luth et al., 1964), with lower range of temperature projected at ~4 kbars. Temperatures calculated from Ti in quartz thermometry in studies of the Tuolumne Intrusive Suite, CA (Ackerson et al., 2018) and experiments on the granite water-saturated solidus (Rufledt et al., 2024) also yield temperatures below the presumed wet granite
480 solidus. Collectively these studies and our results suggest that the temperature of the wet granite solidus may be significantly lower than currently accepted and may need revision. Therefore, although the Ti concentrations in zircon and T_{Zir} in Dominican ignimbrites are low, such conditions are not unprecedented in more evolved systems.

A recent study by (Nathwani et al., 2024) suggests that zircon crystallization is sensitive to the amount of dissolved H_2O (wt%) in the melt, and to a lesser extent the depth of crystallization. They demonstrated that magmas
485 with higher water content will crystallize zircon at lower temperatures due to lowering the liquidus temperature and increasing zircon solubility due to melt polymerization. Based on the matrix glass composition and whole rock Zr concentration, we calculated zircon saturation temperatures in the Dominican ignimbrites between 677-733°C, which is very low, but consistent with MELTS modeling results for Zr concentrations <100 ppm at high water contents >8 wt%, as shown by Nathwani et al. (2024). They also demonstrated that very low Ti concentrations (<5
490 ppm) could only be achieved at pressures >600 MPa, showing the interdependence of water solubility and depth on Ti in zircon concentrations. The low Ti in zircon concentrations in this study are therefore consistent with ‘super-wet’ magmas (>6 wt% H_2O) and zircon crystallization in the lower crust (>600 MPa) at temperatures below the wet granitic solidus. Such water and pressure conditions are similar to those extracted from melt inclusions in phenocrysts studies of the northern/central ignimbrites, which yielded up to 8 wt% H_2O and crystallization
495 pressures up to 750 MPa (Balcone-Boissard et al., 2018).

Reconciling Hf concentrations with low temperature

In many systems, low T_{Zir} has been correlated with high degrees of fractionation and elevated Hf concentration (Claiborne et al., 2006, 2018; Hoskin & Schaltegger, 2003), as Zr is preferentially incorporated over Hf into zircon, thus increasing Hf in the residual melt. In the rhyolitic/granitic systems with low T_{Zir} noted earlier

500 (e.g., Taupo, Sierra Nevada, Tuolumme), the zircons are associated with late-stage eutectic melts that are highly evolved and record Hf concentrations of mostly >10,000 ppm in zircon. Therefore, the anomalously low Hf concentrations (<7000 ppm) coupled with low T_{Zir} in many Dominican zircons are paradoxical (Fig. 8). One possible explanation is that the very high water contents and depolymerized melt promotes early zircon crystallization, which is further enhanced at high pressures (Sánchez-Navas et al., 2024). At these conditions, the melt is not yet strongly fractionated and the zircons would reflect the lower abundance of Hf in the melt. However, given the range of Hf concentrations up to 18,000 ppm (Fig. 4B, Fig. 8), zircons likely crystallized in more evolved melts as well. With the exception of the Morne aux Diables ignimbrite, Hf concentrations in each unit span >5000 ppm and have no correlation with age (Fig. 4B), and therefore do not reflect an evolving melt composition over time. It is more likely that the zircons are part of a complex crystal cargo, derived from different remobilized melt pockets, with slightly different compositions and evolutionary histories, within the trans-crustal magmatic system that may have intermittently experienced subsolidus conditions. The low temperatures and low Hf (Fig. 8) can only be reconciled if zircon crystallized in a less evolved melt at very high water concentrations (e.g., 8 wt% H₂O) and lower crustal depths (e.g., 28 km, 750 MPa).

Zircon crystallization and remobilization

515 The eruption temperatures recorded by Fe-Ti oxides and pyroxene thermometry (d'Augustin et al., 2020; Frey et al., 2018; Gurenko et al., 2005; Howe et al., 2014; Lindsay, Trumbull, et al., 2005) are much higher (700-890°C; Fig. 6) than T_{Zir} . Therefore, zircons formed predominantly in the lower crust from various melts and were likely entrained in a hotter carrier melt en route to the surface. Additional evidence for mixing and crystal mush remobilization is found in melt inclusions (in plagioclase and orthopyroxene) that were more evolved than the matrix glass in several Dominican ignimbrites and inferred to have formed at lower temperatures (Balcone-Boissard et al., 2018).

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The preservation of zircons over long time scales (up to 100s of kyrs) suggests that mush rejuvenation episodes either did not reach temperatures high enough to melt zircon, or did not maintain high temperatures for a long enough period of time to dissolve previously crystallized zircons. Frey et al. (2018) suggested that a 30 mm
525 zircon in the Roseau Ignimbrite would dissolve within 1100-2500 years, given the degree of zircon undersaturation and modeled zircon dissolution rates (Watson, 1996). Short remobilization time scales beneath Dominica are further supported by recent crystal systems analysis (CSA) and mineral diffusion studies of orthopyroxene which suggest magmas were stored in reservoirs at 12-16 km and 2-8 km depth and underwent mingling/mixing in the decades prior to eruption (Ostorero et al., 2021; Solaro et al., 2020).

530 **Model of magma plumbing system**

Since Smith et al. (2013) proposed an island-wide batholith as the source of most of the magmatism on Dominica, subsequent studies have refined this hypothesis. Geophysical and petrologic evidence support a trans-crustal magmatic system, with storage in both the upper crust (~2-8 km) and middle/lower crust boundary (~12-16 km) (Balcone-Boissard et al., 2018; d'Augustin et al., 2020; Melekhova et al., 2019; Solaro et al., 2019). This
535 study provides additional evidence for deep crustal magma genesis at very hydrous conditions, given the extremely low Ti concentrations (<4 ppm) observed in most zircon. The heterogeneous age distributions and zircon surface chemistry within each unit is consistent with prolonged storage and crystallization in geochemically isolated melts, with amalgamation of multiple magma batches that did not have sufficient time to re-equilibrate en route to the surface. These conclusions are similar to the proposed deep, wet trans-crustal reservoir beneath Montserrat
540 (Edmonds et al., 2016). This is not surprising given the proximity of the islands and their similar crustal structures (Melekhova et al., 2019).

Conclusions

Our zircon U-Th and trace element surface analyses from ignimbrites across Dominica provide new insights into the eruptive and crystallization history over the last ~250 kyrs. The surfaces capture the magmatic

545 environment and when the zircons crystallized, recording peak periods of activity and extraction from hydrous, cold, deeply-sourced, and variously evolved melts. Where known, the U-Th zircon ages are within error of eruption ages determined by ^{14}C and zircon (U-Th)/He. The oldest units, previously poorly-constrained, are the Pointe Ronde and Grande Savane ignimbrites, which emanate and flowed west from the Morne Diablotins region in northern Dominica. They contain abundant xenocrystic zircons, as well as many in secular equilibrium, but the
550 youngest may be 200-250 ka. These eruptions were followed by a period of apparent quiescence of that may have lasted between 78 and 273 kyrs based on uncertainties in our age determinations. This apparent volcanic hiatus was flowed by an island-wide flare-up of volcanism that peaked ~ 70 -30 ka. During this time interval, ignimbrites erupted from all of the major volcanic centers/vents on the island, but there was no spatial-temporal pattern, unlike the north to south (younging) extrusion of lava domes from the same vents. One of the most important findings
555 with respect to hazards and future risk assessment is the young age ($18.2 \pm 7.4/-7.0$ ka) of the Morne aux Diablies Ignimbrite in northern Dominica, which was previously thought to be >46 ka. This is younger than most of the more voluminous ignimbrite sequences (Layou, Roseau, Grand Bay) to the south. These ignimbrites are characterized by multiple eruptions (Boudon et al., 2017; Frey et al., 2018; Howe et al., 2014; Smith et al., 2013), but it is not possible to resolve their precise timing or length of hiatuses between eruptions given the uncertainties
560 in the geochronology. It is conceivable that many of the eruptions were occurring near simultaneously, suggesting that the magmatic system may have been primed for eruption after a long apparent volcanic hiatus, during which zircon was continuing to crystallize at depth. Given this history and the widespread seismicity and periodic earthquake swarms in Dominica, the next eruption could be associated with any of the volcanic centers/vents and continued island-wide monitoring is warranted.

565 Unlike many magmatic systems, the zircon trace element chemistry did not show a “fingerprint” for various units or evolution over time, suggesting that the ignimbrites have a complex crystal cargo and crystallization history. Previous work has suggested that like Montserrat, Dominica has a deep, wet, trans-crustal reservoir and

crystals record varying depths of crystallization. Such low Ti concentrations yielded low T_{Zir} , with many zircons recording temperatures below the wet granitic solidus. The simplest explanation would be that the zircons crystallized in a very late-stage eutectic melt, but this is not consistent with the hafnium concentrations, which extend as low as ~2200 ppm. The low temperatures and low Hf (Fig. 8) can only be reconciled if zircon crystallized in a less evolved melt at very high water concentrations (e.g., 8 wt% H_2O) and lower crustal depths (e.g., 28 km, 750 MPa). Therefore, the zircon chemistry lends increased support to previous models of a deep trans-crustal magmatic reservoir beneath Dominica. The broad range of zircon compositions and lack of discernible patterns with respect to unit or age is further evidence of multiple melt lenses and mixing of different populations of crystals.

As previously discussed in Frey et al. (2018), the polymodal zircon crystallization distribution patterns in the Roseau Ignimbrites suggest subsolidus storage conditions and intermittent rheological lock-up. Similar age distributions were observed for the Grand Bay zircons and both of these units show broad ranges in zircon composition and dissimilar REE patterns between crystals. In contrast, the Layou zircon age distributions were unimodal and compositions were slightly more restricted, and REE plots showed parallel patterns between crystals. Taken together, the complexity in the age distribution plots appears to be mirrored by the complexity in the zircon chemistry. This would suggest that the southern ignimbrites may have experienced more rheological lock-ups and rejuvenations of mush compared to the central ignimbrites. However, crystallization conditions across the island were likely similar and rejuvenation episodes must have been short-lived to preserve the zircons, as eruption temperatures are much higher than zircon saturation temperatures.

Author Contributions

Holli M. Frey: Writing – original draft, Writing – review and editing, Investigation, Formal analysis, Supervision, Project administration, Funding acquisition, Conceptualization, Sample collection. **Matthew R. Manon:** Writing – review and editing, Visualization, Formal analysis, Data curation. **Sarah K. Brehm:** Writing – review and

590 editing, Investigation, Sample collection, Data acquisition. **Sarah M. Hickernell:** Writing – review and editing,
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Data Availability

All data and additional method details are available in the supplementary materials.

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article in press

References

- Ackerson, M. R., Mysen, B. O., Tailby, N. D., & Watson, E. B. (2018). Low-temperature crystallization of granites and the implications for crustal magmatism. *Nature*, 559(7712), 94–97.
605 <https://doi.org/10.1038/s41586-018-0264-2>
- Annen, C., Blundy, J. D., Leuthold, J., & Sparks, R. S. J. (2015). Construction and evolution of igneous bodies: Towards an integrated perspective of crustal magmatism. *Lithos*, 230, 206–221.
<https://doi.org/10.1016/j.lithos.2015.05.008>
- Balcone-Boissard, H., Boudon, G., Blundy, J. D., Martel, C., Brooker, R. A., Deloule, E., Solaro, C., & 610 Matjuschkin, V. (2018). Deep pre-eruptive storage of silicic magmas feeding Plinian and dome-forming eruptions of central and northern Dominica (Lesser Antilles) inferred from volatile contents of melt inclusions. *Contributions to Mineralogy and Petrology*, 173(12), 101.
<https://doi.org/10.1007/s00410-018-1528-4>
- Barker, S. J., Wilson, C. J. N., Smith, E. G. C., Charlier, B. L. A., Wooden, J. L., Hiess, J., & Ireland, T. 615 R. (2014). Post-supereruption magmatic reconstruction of Taupo Volcano (New Zealand), as reflected in zircon ages and trace elements. *Journal of Petrology*, 55(8), 1511–1533.
<https://doi.org/10.1093/petrology/egu032>
- Barth, A. P., Feilen, A. D. G., Yager, S. L., Douglas, S. R., Wooden, J. L., Riggs, N. R., & Walker, J. D. (2012). Petrogenetic connections between ash-flow tuffs and a granodioritic to granitic intrusive 620 suite in the Sierra Nevada arc, California. *Geosphere*, 8(2), 250–264.
<https://doi.org/10.1130/GES00737.1>

- Bellon, H. (1988). Reconnaissance chronologique des deux premières phases d'activité volcaniques en Dominique (Petites Antilles). *Comptes rendus de l'Académie des sciences. Série 2, Mécanique, Physique, Chimie, Sciences de l'univers, Sciences de la Terre*, 306(20), 1487–1492.
- 625 Boehnke, P., Watson, E. B., Trail, D., Harrison, T. M., & Schmitt, A. K. (2013). Zircon saturation re-revisited. *Chemical Geology*, 351, 324–334. <https://doi.org/10.1016/j.chemgeo.2013.05.028>
- Boudon, G., Balcone-Boissard, H., Solaro, C., & Martel, C. (2017). Revised chronostratigraphy of recurrent ignimbritic eruptions in Dominica (Lesser Antilles arc): Implications on the behavior of the magma plumbing system. *Journal of Volcanology and Geothermal Research*, 343, 135–
630 154. <https://doi.org/10.1016/j.jvolgeores.2017.06.022>
- Broderick, C., Wotzlaw, J. F., Frick, D. A., Gerdes, A., Ulianov, A., Günther, D., & Schaltegger, U. (2015). Linking the thermal evolution and emplacement history of an upper-crustal pluton to its lower-crustal roots using zircon geochronology and geochemistry (southern Adamello batholith, N. Italy). *Contributions to Mineralogy and Petrology*, 170(3), 28.
635 <https://doi.org/10.1007/s00410-015-1184-x>
- Carey, S. N., & Sigurdsson, H. (1980). The Roseau ash: Deep-sea tephra deposits from a major eruption on Dominica, Lesser Antilles arc. *Journal of Volcanology and Geothermal Research*, 7, 67–86.
- Cashman, K. V., Sparks, R. S. J., & Blundy, J. D. (2017). Vertically extensive and unstable magmatic systems: A unified view of igneous processes. *Science*, 355(6331), eaag3055.
640 <https://doi.org/10.1126/science.aag3055>
- Charlier, B. L. A., Wilson, C. J. N., Lowenstern, J. B., Blake, S., van Calsteren, P. W., & Davidson, J. P. (2005). Magma generation at a large, hyperactive silicic volcano (Taupo, New Zealand) revealed

by U–Th and U–Pb systematics in zircons. *Journal of Petrology*, 46(1), 3–32.

<https://doi.org/10.1093/petrology/egh060>

645 Claiborne, L. L., Miller, C. F., Flanagan, D. M., Clynnne, M. A., & Wooden, J. L. (2010). Zircon reveals
protracted magma storage and recycling beneath Mount St. Helens. *Geology*, 38(11), 1011–
1014. <https://doi.org/10.1130/G31285.1>

Claiborne, L. L., Miller, C. F., Gualda, G. A. R., Carley, T. L., Covey, A. K., Wooden, J. L., & Fleming,
M. A. (2018). Zircon as Magma Monitor. In *Microstructural Geochronology* (pp. 1–33).

650 American Geophysical Union (AGU). <https://doi.org/10.1002/9781119227250.ch1>

Claiborne, L. L., Miller, C. F., Walker, B. A., Wooden, J. L., Mazdab, F. K., & Bea, F. (2006). Tracking
magmatic processes through Zr/Hf ratios in rocks and Hf and Ti zoning in zircons: An example
from the Spirit Mountain batholith, Nevada. *Mineralogical Magazine*, 70(5), 517–543.
<https://doi.org/10.1180/0026461067050348>

655 Coble, M. A., Burgess, S. D., & Klemetti, E. W. (2017). New zircon (U–Th)/He and U/Pb eruption age
for the Rockland tephra, western USA. *Quaternary Science Reviews*, 172, 109–117.
<https://doi.org/10.1016/j.quascirev.2017.08.004>

d’Augustin, T., Balcone-Boissard, H., Boudon, G., Martel, C., Deloule, E., & Bürckel, P. (2020).
Evidence for an active, transcrustal magma system in the last 60 ka and eruptive degassing
660 budget (H₂O, CO₂, S, F, Cl, Br): The case of Dominica. *Geochemistry, Geophysics,*
Geosystems, 21(9), e2020GC009050. <https://doi.org/10.1029/2020GC009050>

Danišík, M., Lowe, D. J., Schmitt, A. K., Friedrichs, B., Hogg, A. G., & Evans, N. J. (2020). Sub-
millennial eruptive recurrence in the silicic Mangaone Subgroup tephra sequence, New Zealand,

- from Bayesian modelling of zircon double-dating and radiocarbon ages. *Quaternary Science Reviews*, 246, 106517. <https://doi.org/10.1016/j.quascirev.2020.106517>
- Demange, J., Leborne, H., Traineau, H., & Westercamp, D. (1985). Histoire volcano-structurale de la Region sud de la Dominique. *Bureau de Recherches Geologiques et Minieres (BRGM), Institut Mixte de Recherches Geothermiques, Rapport*, 85.
- Edmonds, M., Cashman, K. V., Holness, M., & Jackson, M. (2019). Architecture and dynamics of magma reservoirs. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 377(2139), 20180298. <https://doi.org/10.1098/rsta.2018.0298>
- Edmonds, M., Kohn, S. C., Hauri, E. H., Humphreys, M. C. S., & Cassidy, M. (2016). Extensive, water-rich magma reservoir beneath southern Montserrat. *Lithos*, 252–253, 216–233. <https://doi.org/10.1016/j.lithos.2016.02.026>
- Ferry, J. M., & Watson, E. B. (2007). New thermodynamic models and revised calibrations for the Ti-in-zircon and Zr-in-rutile thermometers. *Contributions to Mineralogy and Petrology*, 154(4), 429–437. <https://doi.org/10.1007/s00410-007-0201-0>
- Frey, H. M., Manon, M. R. F., Brehm, S. K., & Babiak, R. N. (2018). Episodic crystallization in young explosive eruptions in Dominica, Lesser Antilles, revealed by U-Th dating of zircons. *Geology*, 46(10), 887–890. <https://doi.org/10.1130/G45217.1>
- Frey, H. M., Manon, M. R. F., Kittross, S., Pope, M. D., & Brehm, S. K. (2024). Magmatic and rare Eocene to Precambrian xenocrystic zircons in Dominica reveal discrete crystallization episodes and multiple sediment sources. *GSA Bulletin*, 136(7–8), 3169–3187. <https://doi.org/10.1130/B37238.1>

- 685 Ghiorso, M. S., & Evans, B. W. (2008). Thermodynamics of Rhombohedral Oxide Solid Solutions and a
Revision of the FE-Ti Two-Oxide Geothermometer and Oxygen-Barometer. *American Journal
of Science*, 308(9), 957–1039. <https://doi.org/10.2475/09.2008.01>
- Gurenko, A. A., Trumbull, R. B., Thomas, R., & Lindsay, J. M. (2005). A Melt Inclusion Record of
Volatiles, Trace Elements and Li–B Isotope Variations in a Single Magma System from the Plat
690 Pays Volcanic Complex, Dominica, Lesser Antilles. *Journal of Petrology*, 46(12), 2495–2526.
<https://doi.org/10.1093/petrology/egi063>
- Harangi, S., Lukács, R., Schmitt, A. K., Dunkl, I., Molnár, K., Kiss, B., Seghedi, I., Novothny, Á., &
Molnár, M. (2015). Constraints on the timing of Quaternary volcanism and duration of magma
residence at Ciomadul volcano, east–central Europe, from combined U–Th/He and U–Th zircon
695 geochronology. *Journal of Volcanology and Geothermal Research*, 301, 66–80.
<https://doi.org/10.1016/j.jvolgeores.2015.05.002>
- Hoskin, P. W., & Schaltegger, U. (2003). The composition of zircon and igneous and metamorphic
petrogenesis. *Reviews in Mineralogy and Geochemistry*, 53, 27–62.
- Howe, T. M., Lindsay, J. M., Shane, P., Schmitt, A. K., & Stockli, D. F. (2014). Re-evaluation of the
700 Roseau Tuff eruptive sequence and other ignimbrites in Dominica, Lesser Antilles. *Journal of
Quaternary Science*, 29(6), 531–546. <https://doi.org/10.1002/jqs.2723>
- Howe, T. M., Schmitt, A. K., Lindsay, J. M., Shane, P., & Stockli, D. F. (2015). Time scales of intra-
oceanic arc magmatism from combined U–Th and (U–Th)/He zircon geochronology of
Dominica, Lesser Antilles. *Geochemistry, Geophysics, Geosystems*, 16(2), 347–365.
705 <https://doi.org/10.1002/2014GC005636>

- Joseph, E. P., Fournier, N., Lindsay, J. M., & Fischer, T. P. (2011). Gas and water geochemistry of geothermal systems in Dominica, Lesser Antilles island arc. *Journal of Volcanology and Geothermal Research*, 206(1), 1–14. <https://doi.org/10.1016/j.jvolgeores.2011.06.007>
- 710 Joseph, E. P., Frey, H. M., Manon, M. R., Onyeali, M.-M. C., DeFranco, K., Metzger, T., & Aragosa, C. (2019). Update on the fluid geochemistry monitoring time series for geothermal systems in Dominica, Lesser Antilles island arc: 2009–2017. *Journal of Volcanology and Geothermal Research*, 376, 86–103. <https://doi.org/10.1016/j.jvolgeores.2019.03.010>
- Kent, A. J. R., & Cooper, K. M. (2017). How well do zircons record the thermal evolution of magmatic systems? *Geology*, 46(2), 111–114. <https://doi.org/10.1130/G39690.1>
- 715 Kern, J. M., de Silva, S. L., Schmitt, A. K., Kaiser, J. F., Iriarte, A. R., & Economos, R. (2016). Geochronological imaging of an episodically constructed subvolcanic batholith: U-Pb in zircon chronochemistry of the Altiplano-Puna Volcanic Complex of the Central Andes. *Geosphere*, 12(4), 1054–1077. <https://doi.org/10.1130/GES01258.1>
- 720 Klemetti, E. W., & Clynne, M. A. (2014). Localized rejuvenation of a crystal mush recorded in zircon temporal and compositional variation at the Lassen Volcanic Center, northern California. *PLOS ONE*, 9(12), e113157. <https://doi.org/10.1371/journal.pone.0113157>
- Lindsay, J. M., Smith, A. L., Roobol, M. J., & Stasiuk, M. V. (2005). Dominica. In *Volcanic Hazard Atlas of the Lesser Antilles*, Seismic Research Unit, The University of the West Indies (pp. 1–48). Seismic Research Unit.

- 725 Lindsay, J. M., Trumbull, R. B., & Siebel, W. (2005). Geochemistry and petrogenesis of late Pleistocene
to Recent volcanism in Southern Dominica, Lesser Antilles. *Journal of Volcanology and
Geothermal Research*, 148(3), 253–294. <https://doi.org/10.1016/j.jvolgeores.2005.04.018>
- Lukács, R., Harangi, S., Bachmann, O., Guillong, M., Danišík, M., Buret, Y., von Quadt, A., Dunkl, I.,
Fodor, L., Sliwinski, J., Soós, I., & Szepesi, J. (2015). Zircon geochronology and geochemistry
730 to constrain the youngest eruption events and magma evolution of the Mid-Miocene ignimbrite
flare-up in the Pannonian Basin, eastern central Europe. *Contributions to Mineralogy and
Petrology*, 170(5), 52. <https://doi.org/10.1007/s00410-015-1206-8>
- Luth, W. C., Jahns, R. H., & Tuttle, O. F. (1964). The granite system at pressures of 4 to 10 kilobars.
Journal of Geophysical Research (1896-1977), 69(4), 759–773.
735 <https://doi.org/10.1029/JZ069i004p00759>
- Melekhova, E., Schlaphorst, D., Blundy, J., Kendall, J.-M., Connolly, C., McCarthy, A., & Arculus, R.
(2019). Lateral variation in crustal structure along the Lesser Antilles arc from petrology of
crustal xenoliths and seismic receiver functions. *Earth and Planetary Science Letters*, 516, 12–
24. <https://doi.org/10.1016/j.epsl.2019.03.030>
- 740 Monjaret, M. C. (1985). *Contribution a l'étude de l'arc des Petites Antilles. Le Volcanisme de la
Dominique. Données chronologiques, mineralogiques et geochimiques*. Unpublished thesis,
Université de Bretagne Occidentale.
- Moser, Z., Guillong, M., Nathwani, C., Iwahashi, K., Popa, R.-G., & Bachmann, O. (2026). Improving
crystallization and eruption age estimation using U-Th disequilibrium dating of young volcanic
745 zircon. *Geochronology*, 8(1), 63–84. <https://doi.org/10.5194/gchron-8-63-2026>

- Nathwani, C., Blundy, J., Large, S. J. E., Wilkinson, J. J., Buret, Y., Loader, M. A., Tavazzani, L., & Chelle-Michou, C. (2024). A zircon case for super-wet arc magmas. *Nature Communications*, 15(1), 8982. <https://doi.org/10.1038/s41467-024-52786-5>
- Ostorero, L., Boudon, G., Balcone-Boissard, H., Morgan, D. J., d'Augustin, T., & Solaro, C. (2021). Time-window into the transcrustal plumbing system dynamics of Dominica (Lesser Antilles). *Scientific Reports*, 11(1), 11440. <https://doi.org/10.1038/s41598-021-90831-1>
- Roobol, M. J., Wright, J. V., & Smith, A. L. (1983). Calderas or gravity-slide structures in the Lesser Antilles island arc? *Journal of Volcanology and Geothermal Research*, 19(1), 121–134. [https://doi.org/10.1016/0377-0273\(83\)90128-2](https://doi.org/10.1016/0377-0273(83)90128-2)
- Rubin, A., Cooper, K. M., Leever, M., Wimpenny, J., Deering, C., Rooney, T., Gravley, D., & Yin, Q. (2016). Changes in magma storage conditions following caldera collapse at Okataina Volcanic Center, New Zealand. *Contributions to Mineralogy and Petrology*, 171(1), 4. <https://doi.org/10.1007/s00410-015-1216-6>
- Rubin, A., Cooper, K. M., Till, C. B., Kent, A. J. R., Costa, F., Bose, M., Gravley, D., Deering, C., & Cole, J. (2017). Rapid cooling and cold storage in a silicic magma reservoir recorded in individual crystals. *Science*, 356(6343), 1154–1156. <https://doi.org/10.1126/science.aam8720>
- Rufledt, C., Thomas, J. B., & Ackerson, M. R. (2024). Granites are cooler than expected: An experimental study locating the granite water-saturated solidus. In AGU Fall Meeting Abstracts (Vol. 2024, No. 3037, pp. V31B-3037).

- 765 Sambridge, M. S., & Compston, W. (1994). Mixture modeling of multi-component data sets with application to ion-probe zircon ages. *Earth and Planetary Science Letters*, 128(3), 373–390. [https://doi.org/10.1016/0012-821X\(94\)90157-0](https://doi.org/10.1016/0012-821X(94)90157-0)
- Sánchez-Navas, A., Melchor, S., Ortega-Castro, J., Vidal-Daza, I., & Castro, A. (2024). A case study of depolymerization in silicates: Melting of quartz and zircon crystallization at high pressure. *Chemical Geology*, 661, 122156. <https://doi.org/10.1016/j.chemgeo.2024.122156>
- 770 Schlieder, T. D., Cooper, K. M., Kent, A. J. R., Gravley, D., Deering, C., Rubin, S., & Johnson, A. (2025). Insights into the construction of the Oruanui magma reservoir from a comparison of zircon hosted in plagioclase and whole-rock. *Earth and Planetary Science Letters*, 666, 119495. <https://doi.org/10.1016/j.epsl.2025.119495>
- 775 Schmitt, A. K., Stockli, D. F., Lindsay, J. M., Robertson, R., Lovera, O. M., & Kislitsyn, R. (2010). Episodic growth and homogenization of plutonic roots in arc volcanoes from combined U–Th and (U–Th)/He zircon dating. *Earth and Planetary Science Letters*, 295(1–2), 91–103. <https://doi.org/10.1016/j.epsl.2010.03.028>
- Schoonover, E. J., Ackerson, M. R., Garber, J. M., Smye, A. J., Kylander-Clark, A. R., & Reimink, J. R. (2024). Snapshots of magmatic evolution revealed by zircon depth profiling. *Earth and Planetary Science Letters*, 647, 118987. <https://doi.org/10.1016/j.epsl.2024.118987>
- 780 Sigurdsson, H. (1972). Partly-welded pyroclast flow deposits in Dominica, Lesser Antilles. *Bulletin Volcanologique*, 36(1), 148–163. <https://doi.org/10.1007/BF02596987>
- Smith, A. L., Roobol, M. J., Mattioli, G. S., Fryxell, J. E., Daly, G. E., & Fernandez, L. A. (2013). *The Volcanic Geology of the Mid-Arc Island of Dominica*. Geological Society of America.
- 785

- Solaro, C., Balcone-Boissard, H., Morgan, D. J., Boudon, G., Martel, C., & Ostorero, L. (2020). A System Dynamics Approach to Understanding the deep Magma Plumbing System Beneath Dominica (Lesser Antilles). *Frontiers in Earth Science*, 8.
<https://doi.org/10.3389/feart.2020.574032>
- 790 Solaro, C., Martel, C., Champallier, R., Boudon, G., Balcone-Boissard, H., & Pichavant, M. (2019). Petrological and experimental constraints on magma storage for large pumiceous eruptions in Dominica island (Lesser Antilles). *Bulletin of Volcanology*, 81(9), 55.
<https://doi.org/10.1007/s00445-019-1313-x>
- 795 Sparks, R. S. J., Sigurdsson, H., & Carey, S. N. (1980). The entrance of pyroclastic flows into the sea I. oceanographic and geologic evidence from dominica, lesser antilles. *Journal of Volcanology and Geothermal Research*, 7(1–2), 87–96. [https://doi.org/10.1016/0377-0273\(80\)90021-9](https://doi.org/10.1016/0377-0273(80)90021-9)
- Stelten, M. E., & Cooper, K. M. (2012). Constraints on the nature of the subvolcanic reservoir at South Sister volcano, Oregon from U-series dating combined with sub-crystal trace-element analysis of plagioclase and zircon. *Earth and Planetary Science Letters*, 313–314, 1–11.
800 <https://doi.org/10.1016/j.epsl.2011.10.035>
- Storm, S., Shane, P., Schmitt, A. K., & Lindsay, J. M. (2012). Decoupled crystallization and eruption histories of the rhyolite magmatic system at Tarawera volcano revealed by zircon ages and growth rates. *Contributions to Mineralogy and Petrology*, 163(3), 505–519.
<https://doi.org/10.1007/s00410-011-0682-8>

- 805 Vermeesch, P. (2018). IsoplotR: A free and open toolbox for geochronology. *Geoscience Frontiers*,
SPECIAL ISSUE: Frontiers in Geoscience: A Tribute to Prof. Xuanxue Mo, 9(5), 1479–1493.
<https://doi.org/10.1016/j.gsf.2018.04.001>
- Wadge, G. (1989). A Preliminary Analysis of Volcanic Hazards in Dominica. *Seismic Research Unit: St.*
Augustine, Trinidad.
- 810 Wadge, G., & Shepherd, J. B. (1984). Segmentation of the Lesser Antilles subduction zone. *Earth and*
Planetary Science Letters, 71(2), 297–304. [https://doi.org/10.1016/0012-821X\(84\)90094-3](https://doi.org/10.1016/0012-821X(84)90094-3)
- Watson, E. B. (1996). Dissolution, growth and survival of zircons during crustal fusion: Kinetic
principles, geological models and implications for isotopic inheritance. *Transactions of the*
Royal Society of Edinburgh: Earth Sciences, 87, 43–56. [https://doi.org/10.1017](https://doi.org/10.1017/S0263593300006465)
815 /S0263593300006465.
- Ziberna, L., Green, E. C. R., & Blundy, J. D. (2017). Multiple-reaction geobarometry for olivine-
bearing igneous rocks. *American Mineralogist*, 102(12), 2349–2366. [https://doi.org/10.2138/am-](https://doi.org/10.2138/am-2017-6154)
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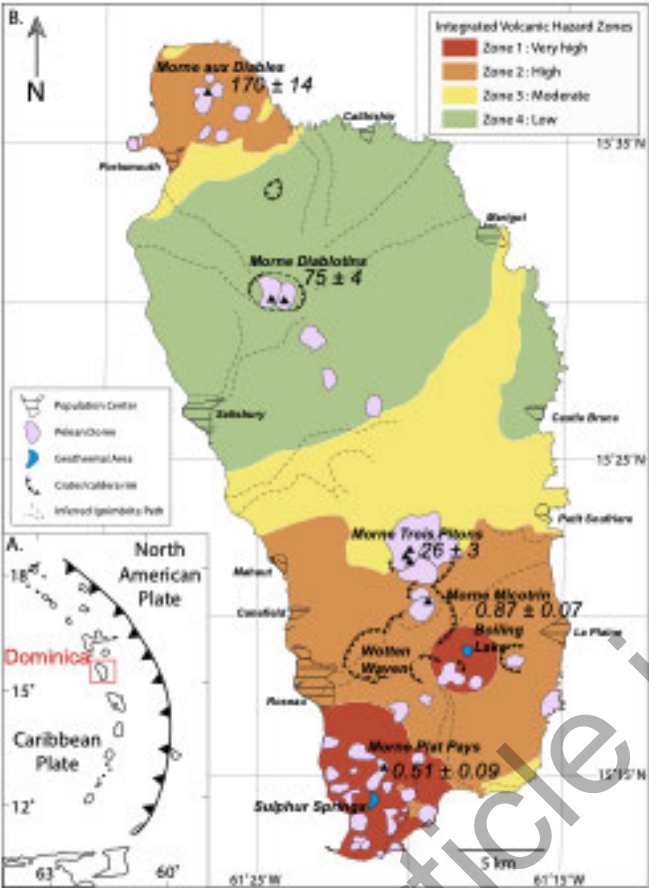


Figure 1: [A] Overview of the Lesser Antilles arc. [B] Integrated volcanic hazard map of Dominica from Lindsay et al. (2005). Volcanic centers as mapped by Smith et al. (2013) are in light purple. Ages for the lava domes/vents are given in ka and display a N-S progression of ages. Ages for Morne aux Diablos, Morne Diablotins, and Morne Trois Pitons are zircon (U-Th)/He ages (Howe et al., 2015) and Micotrin and Morne Patates are calibrated ¹⁴C ages (Lindsay et al., 2005; Roobol et al., 1983).

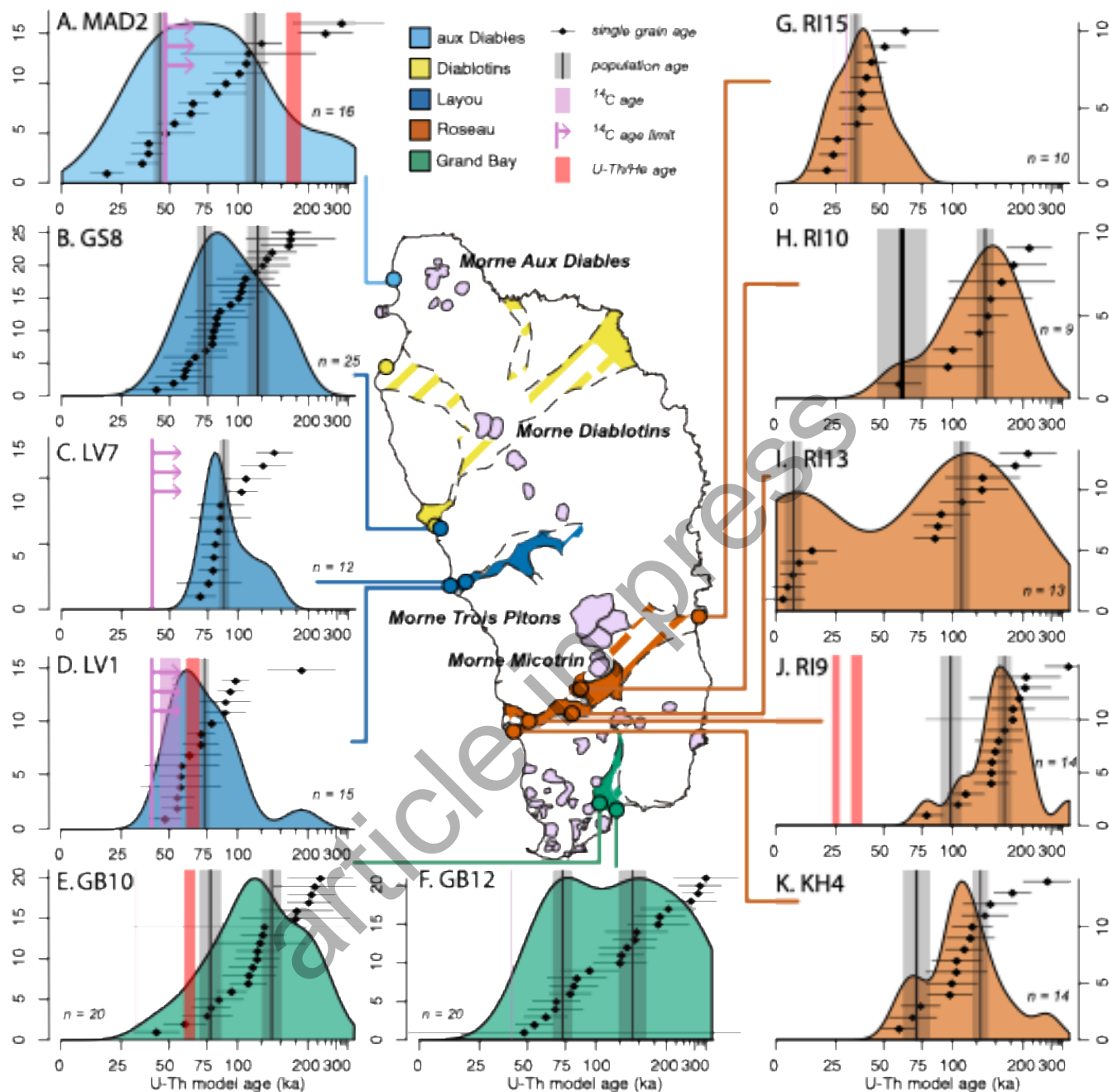
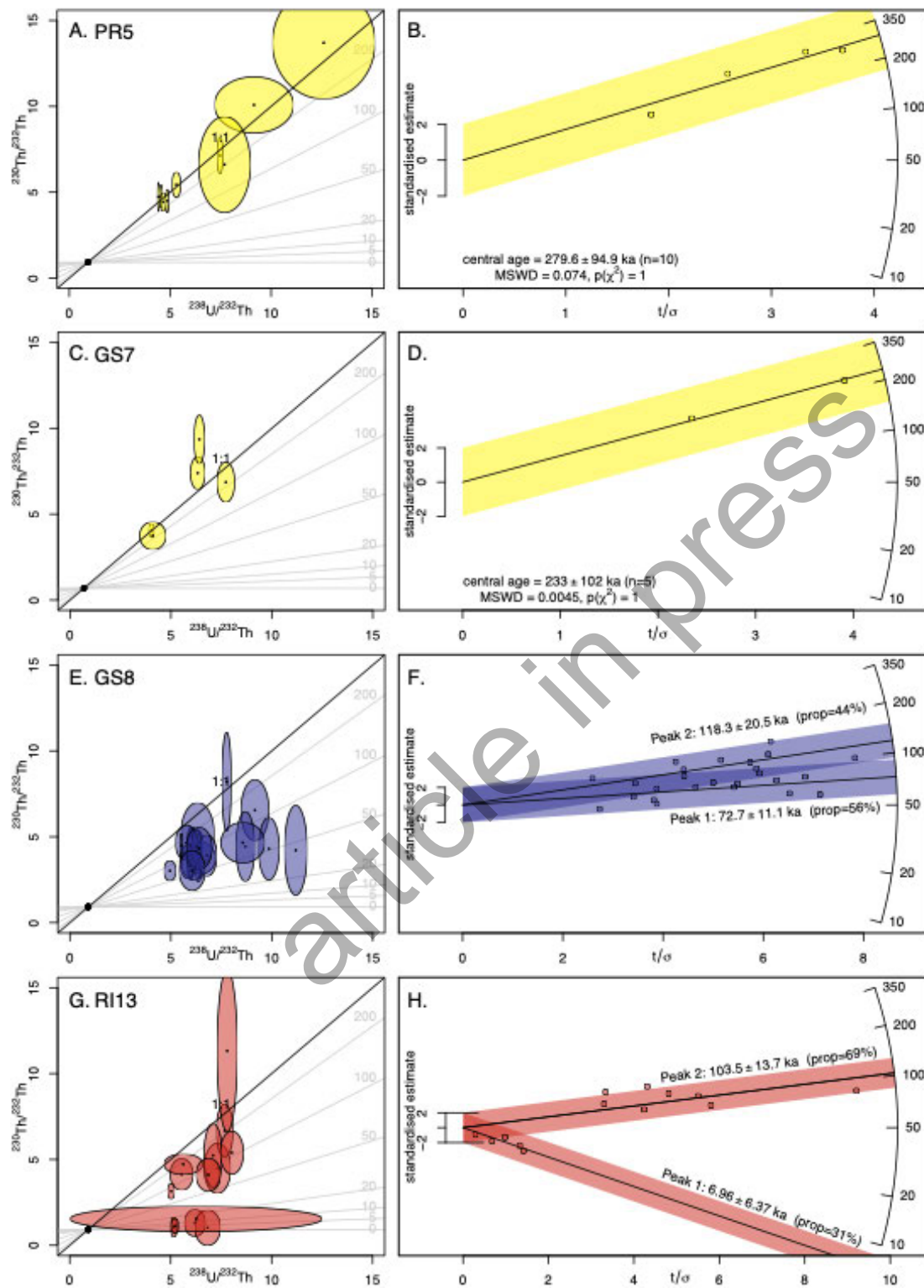


Figure 1: Simplified geologic map of volcanic deposits <100 ka (modified from Smith et al., 2013), with sample locations indicated by circles. Lava domes are in light purple and ignimbrites denoted in colors keyed in the legend; dashed regions are inferred flows. Each fill color corresponds to an ignimbrite sequence (modified from Smith et al., 2013). Each lettered panel show U-Th model ages from ignimbrites across the island. Ages are shown as rank-file

845 plots with 1-sigma errors and kernel density plots of model ages determined by two-point isochrons. Zircons in
secular equilibrium are not plotted. Populations as determined by mixing models (Frey et al., 2018) are shown as
black vertical lines with 1-sigma grey error bars. Purple vertical lines are eruption ages from ^{14}C and red vertical lines
are U-Th/He zircon studies (see Table 1 for references). Ignimbrites and samples are as follows: [A] Morne aux
Diabls (MAD2); [B] Layou (GS8); [C] Layou (welded; LV7); [D] Layou (unwelded; LV1); [E] Grand Bay (GB10); [F]
850 Grand Bay (GB12); [G] Roseau - Rosalie (RI15); [H] Roseau - Trafalgar (RI10); [I] Roseau - Casso (RI13); [J] Roseau - St.
Aromont (RI9); [K] Roseau - King's Hill (KH4).

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855 Figure 3: Isochron and radial plots for select samples created with IsoplotR. For isochrons, model ages were
calculated using a two-point isochron and the whole-rock $^{238}\text{U}/^{232}\text{Th}$ and $^{230}\text{Th}/^{232}\text{Th}$ ratios reported by Howe et al.
(2015). The age is calculated from the slope and error ellipses are 2-sigma. The dark solid line is secular equilibrium
(350 ka). [A] Pointe Ronde (PR5); [C] Grande Savane (GS7); [E] Layou (GS8); [G] Roseau (RI13). The radial plots show
the dispersion and populations of the calculated ages. [B] Pointe Ronde (PR5); [D] Grande Savane (GS7); [F] Layou
(GS8); [H] Roseau-Casso (RI13). Pointe Ronde [B] and Grande Savane [D] are characterized by a single >200 ka
860 population with large errors, whereas GS8 [F] has two populations with some overlap and RI13 [H] has two tightly
constrained distinct populations.

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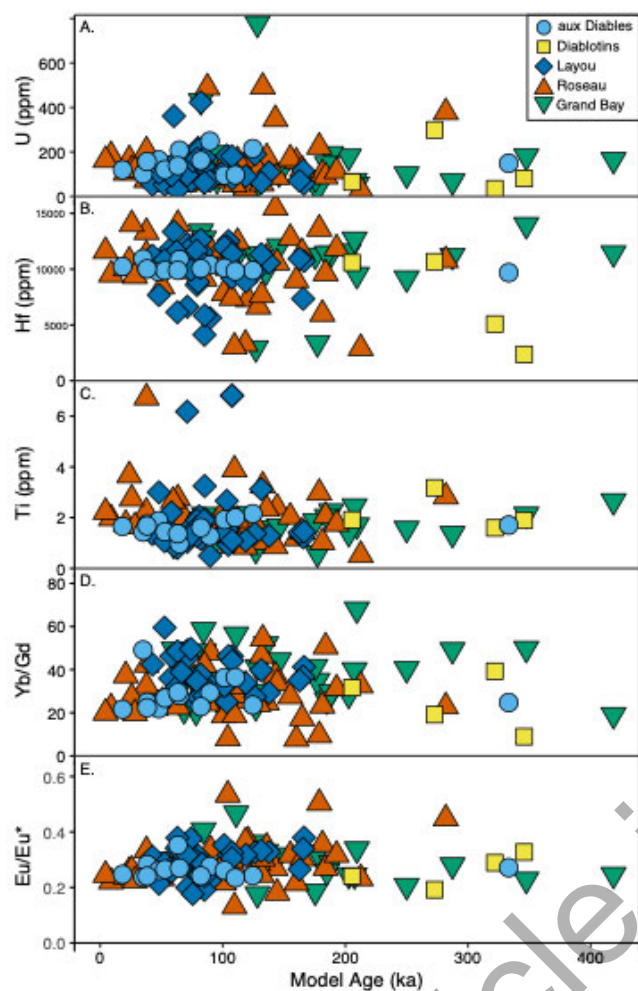


Figure 4: U-Th model age of Dominica zircons versus [A] uranium, [B] hafnium, [C] titanium [D] Yb/Gd, and [E] Eu/Eu*.

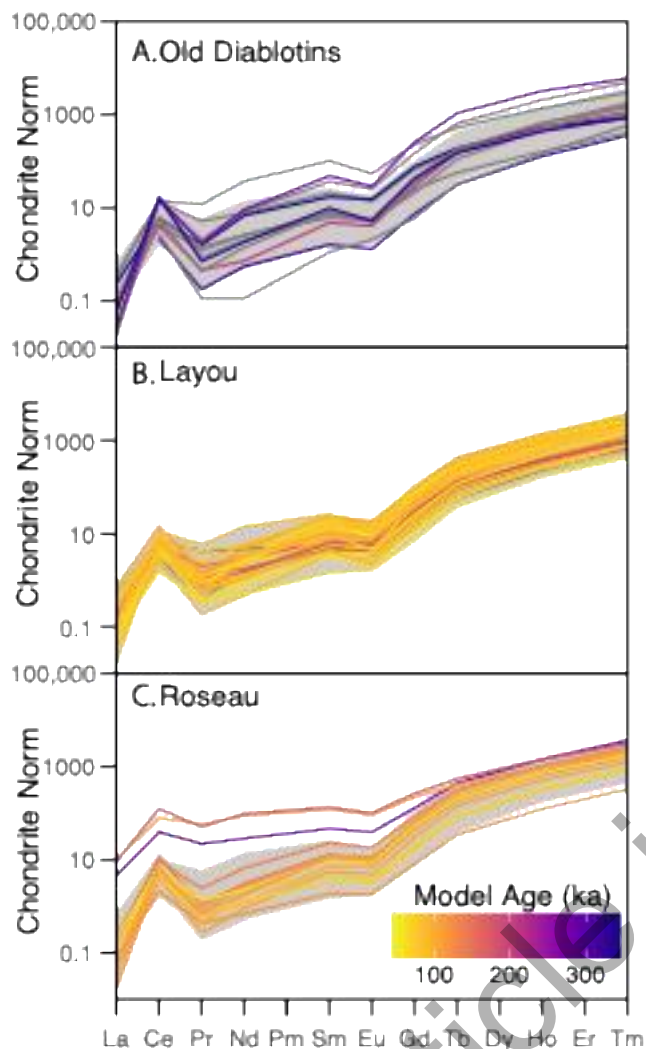


Figure 5: Representative chondrite normalized rare earth element (REE) plots of zircon for several ignimbrites. Data are color mapped by ^{238}U - ^{230}Th model age, with warmer colors representing older ages and gray representing ages in secular equilibrium. [A] Older Diablotins ignimbrites (Pointe Ronde and Grande Savane); [B] Layou (GS8, LV1, and LV7); [C] Roseau Ignimbrite (KH4). The shaded gray region in each panel is the range of the Layou samples for comparison.

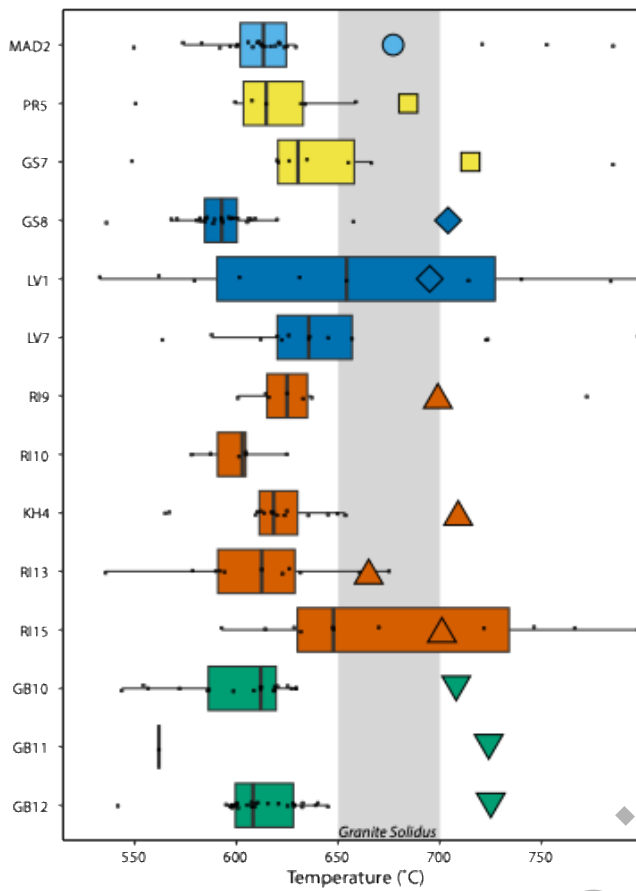
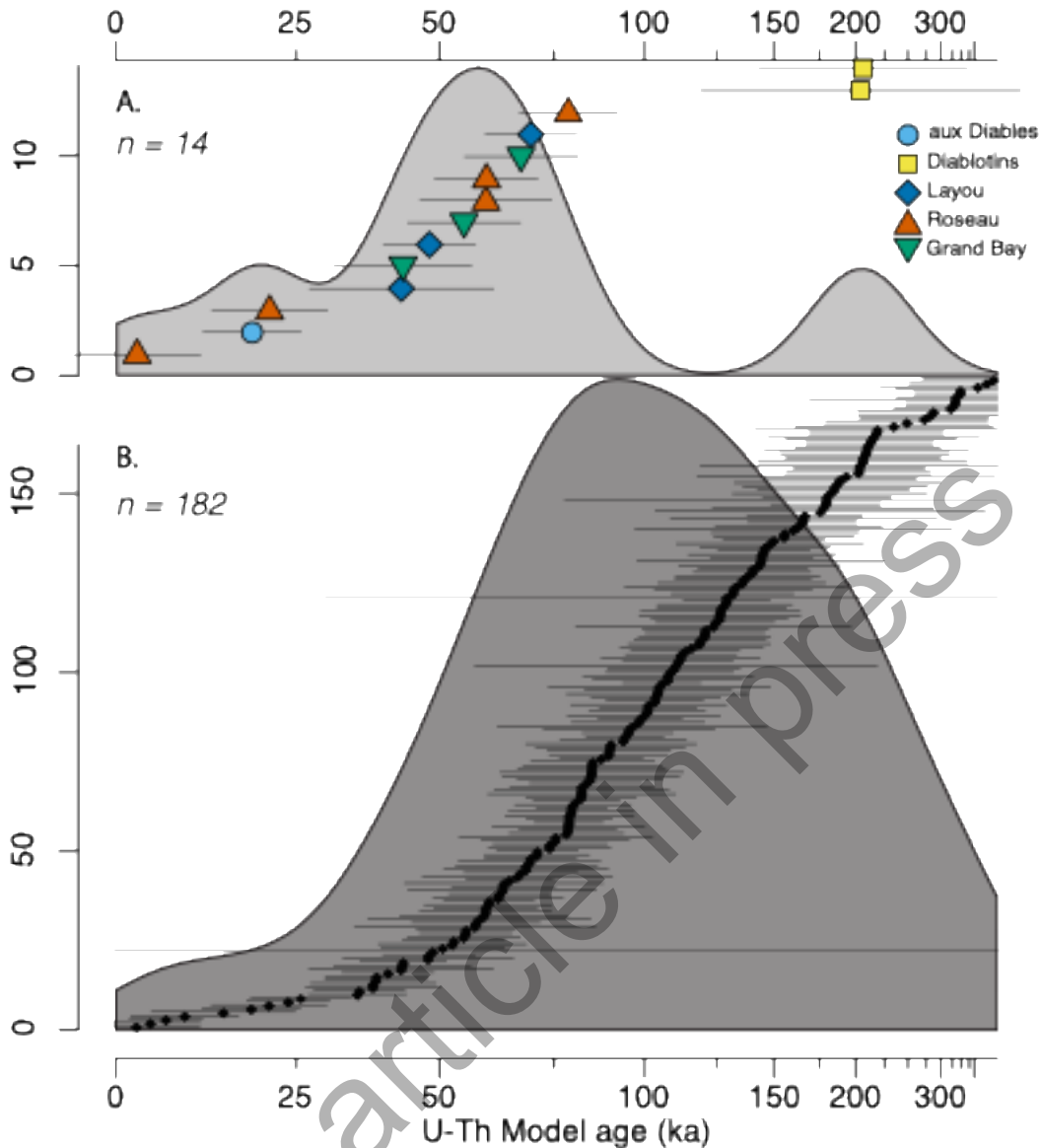


Figure 6: Ti in zircon temperatures calculated using methods in Ferry and Watson (2007) are shown as box and whisker plots, with individual analyses shown as black dots. Zircon saturation temperatures (calculated using Boehnke et al., 2013 and listed in Table 2) are shown as solid symbols. The wet granite solidus from Luth et al. (1964) is also noted.



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Figure 7: Rank file plots (1-sigma error) and kernel density plots of zircon surface U-Th model ages in Dominica [A] The youngest zircon analyzed in each unit. The Morne Diablotins (PR5 and GS7) ignimbrites show eruptions ~200 ka followed by a >100 kyr quiescence before an island-wide eruption “flare-up” begins ~70 ka; [B] All zircon surfaces analyzed in this study and Frey et al. (2018) shows that crystallization spans from secular equilibrium to eruption, but is more concentrated between 50-200 ka.

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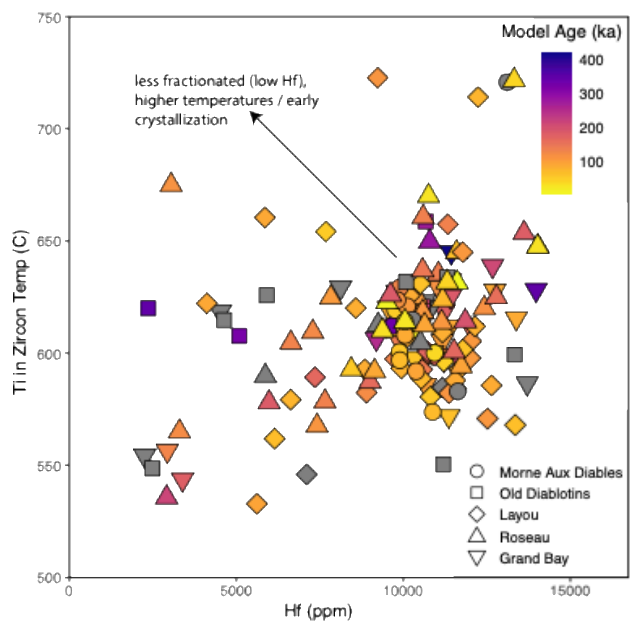


Figure 8: TZir vs Hf. The temperatures and Hf are positively correlated which is not consistent with the more typical relationship of highly evolved (high Hf) melts formed at lower temperatures, i.e., late-stage eutectic melts. Grey symbols indicate crystals in secular equilibrium.

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Table 1. Comparison of ^{14}C ages and (U-Th)/He ages from previous studies and the youngest zircon ages from this study. (U-Th)/He ages are the inferred eruption ages of the deposits.

Eruptive Center	Ignimbrite Unit	Sample name	Coordinates (N and W)	Calibrated ^{14}C ages (ka BP)	(U-Th)/He zircon age (ka) ⁸	Youngest U-Th zircon age (ka)
Morne aux Diabes	Morne aux Diabes	MAD2	15° 36.474 61° 27.848	>46 ¹		18.2 (+7.4/-7.0)
Morne Diablotins	Pointe Ronde	PR5	15° 32.682 61° 28.450			203.4 + >350/-84.5
	Grande Savanne	GS7	15° 26.390 61° 26.415	>22 ²		205.3 + 164.1/-62.9
	Layou	GS8	15° 26.847 61° 26.83			42.7 + 18.3/-15.7
	Layou	LV1	15° 23.865 61° 25.610	>40 ³ ; 51 +/-6.6 ⁷	65 +/- 5	45.7 + 7.5/-7.0
	Layou	LV7	15° 24.716 61° 22.861	>40 ³		69.5 + 11.3/-10.3
Morne Trois Pitons-Micotrin	Roseau	GW	15° 18.533 61° 23.033	31 +/-0.8 ⁴ ; >46 ⁴ ; 18 +/-0.2 ⁷	62 +/-8	
	Roseau	RI9/Link flow 3	15° 18.291 61° 22.628		25 +/-2	28.3 +18.2/-15.6 ⁹
	Roseau	Link flow 1	15° 18.245 61° 22.519		35 +/-3	
	Roseau	RI10	15° 19.610 61° 20.118			59.3 +15.1/-13.2 ⁹
	Roseau	RI13	15° 18.803 61° 21.207			2.6 + 8.4/-7.8 ⁹
	Roseau	KH4	15° 17.975 61° 22.816			59.4 +11.6/-10.5 ⁹
	Rosalie/Grand Fond	RI15	15° 21.948 61° 15.302	+/- 0.5 ⁵ ; 24 +/- 0.4 ⁷		20.9 +9.0/-8.3 ⁹
	Grand Bay	GB10	15° 14.969 61° 19.028	32 +/-0.17 ¹	62.8 +/-4*	43.0 +13.4/-11.9
	Grand Bay	GB11	15° 14.461 61° 18.725	41 +/-0.6 ⁶		67.2 + 13.8/-12.3
	Grand Bay/St. John	GB12	15° 14.665 61° 16.967	41 +/-0.6 ¹		48.7 +>350/-106.4

¹ Lindsay et al. (2005); ² Sparks et al. (1980); ³ Wadge (1989); ⁴ Sigurdsson (1972); ⁵ Carey and Sigurdsson

Table 2. Zircon saturation temperatures in Dominica ignimbrites						
	Whole-rock SiO₂ (wt%)	Whole-rock Hf (ppm)	Matrix glass SiO₂ (wt%)	% Glass	Whole-rock Zr (ppm)	Zircon Saturation T (°C)
MAD2	60.1	2.2	72.6	62	71	677
PR5A	61.9	3.0	74.0	80	95	684
PR5B	61.1	3.0	73.6	80	100	686
GS7	61.3	2.8	76.2	65	92	715
GS7B	60.7	3.1	75.8	65	102	733
GS8A	62.0	2.7	76.9	75	89	704
LV-1	64.5	2.6	75.4	72	91	695
LV-1 rep	64.5	2.6	75.6	72	91	696
RI9	62.7	3.3	76.0	70	94	699
RI9B	62.6	3.1	76.4	70	90	700
RI13	59.8	2.4	65.5	56	74	665
RI15	61.8	2.8	74.9	65	89	701
RI15B	62.5	2.8	74.9	65	92	702
KH4	61.8	2.6	76.1	65	89	709
KH4B	62.3	2.5	76.7	65	89	713
GB10A	63.4	2.9	76.3	67	95	708
GB11B	62.0	2.8	77.1	65	91	724
GB12B	61.5	3.4	73.6	65	110	725
Zr saturation calculated using Boehnke et al. (2013)						