Key Points:
- Most mid-ocean ridge basalt glasses record apparent mantle potential temperatures of 1322°C ± 56°C (melting at 1334°C ± 55°C and 13.0 ± 5 kbars)
- We estimate that the ambient unmelted mid-ocean ridge potential temperature is ∼1350°C-1400°C with localized hot regions (∼1600°C) near hotspots
- Outlier primitive basaltic glasses from slow-spreading ridges and back-arc regions record shallow low-temperature peridotite melting (<10 kbars)

Supporting Information:
Supporting Information may be found in the online version of this article.

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Citation:
Krein, S. B., Molitor, Z. J., & Grove, T. L. (2021). ReversePetrogen: A Multiphase Dry Reverse Fractional Crystallization-Mantle Melting Thermobarometer Applied to 13,589 Mid-Ocean Ridge Basalt Glasses. Journal of Geophysical Research: Solid Earth, 126, e2020JB021292. https://doi.org/10.1029/2020JB021292

Received 2 NOV 2020
Accepted 5 MAY 2021

Abstract
We present a new algorithm, ReversePetrogen (RevPet), to infer mantle melting conditions (pressure, temperature, source composition) using evolved basalts that have experienced multiphase fractional crystallization. RevPet measures and minimizes the compositional distance between experimentally predicted phase saturation boundaries and an erupted basalt and the more primitive liquids that return it to a primary melt. We use RevPet to investigate mantle melting conditions at mid-ocean ridges (MORs) using a global data set of 13,589 basaltic glasses. We find that their average apparent mantle potential temperature (T_P^*) is 1322°C ± 56°C with melting pressures of 13.0 ± 5 kbar. Inferring the true initial (pre-melted) T_P from T_P^* requires knowing the style and degree of melting of the input basalts. If MORB glasses were entirely produced by near-fractional melting of a homogenous source, they would record the cooling of the mantle during melting with an initial T_P = ∼1380°C (∆T_P = 0°C) down to T_P = ∼1270°C. If, instead, they were all fully pooled near-fractional melts of the same source, they would record variations in ambient MOR T_P, from ∼1300°C to 1450°C (∆T_P = 150°C). However, because MOR basalts are thought to be both near-fractional and variably pooled melts of variable sources, MOR T_P must be intermediate between these two extremes. Our best estimate, consistent with MOR crustal thickness, is that ambient MOR T_P is homogenous (∼1350°C–1400°C) except near hotspots where T_P reaches ∼1600°C. Some primitive glasses found near slow-spreading ridges and back-arc regions record very low temperatures (T_P^* < 1250°C) and pressures of melting (<10 kbar) and reflect mantle cooling during melting and melt equilibration in the mantle lithosphere.

1. Introduction
The major, trace, and isotopic compositions of primary mantle melts (basalts) record the pressures, temperatures, and source compositions of mantle melting. While basalt composition is a valuable thermobarometer of mantle conditions, different methods fundamentally disagree on the temperature of the Earth’s mantle by hundreds of degrees (e.g., Dalton et al., 2014; Gale et al., 2014; Herzberg et al., 2007; Lee et al., 2009; Niu, 2016; Putirka et al., 2007). Differences arise, in part, because basalts must first be corrected to primary melt compositions, as primary melts are modified prior to eruption (Section 2.1), and methods take different approaches to this correction. For example, many basalt thermobarometers limit the input data set to rare Mg-rich basalts to avoid correcting for significant secondary processing such as multiphase fractional crystallization. Differences may also arise due to other choices in methodology and interpretation.

To determine the causes of the differences between different thermobarometer melting predictions, as well as utilize a wider range of basaltic whole rock and glass compositions to infer mantle temperature, pressure, and composition, we present a new method, ReversePetrogen (hereafter referred to as RevPet). RevPet includes multiphase fractionation and relies on principles of multiple saturation and optimization (Sections 2.2–2.4). RevPet predictions can be validated and improved by future high-temperature and high-pressure experiments. RevPet is, at present, calibrated for dry, tholeiitic, and alkaline melting and fractionation (Section 2.5). RevPet also recognizes when basalts were formed under source conditions that it is not currently calibrated for such as hydrous melts, highly carbonated melts, nephelinites, basanites, and extremely high degree melts in equilibrium with harzburgite (Section 2.5).

In Section 3 we apply RevPet to 13,589 mid-ocean ridge (MOR) basalts and a few global basalts and compare our results to Gale et al. (2014), Niu and O’Hara (2008), and PRIMELT3 (Herzberg & Asimow, 2015). Overall, RevPet finds that ambient MOR temperature is homogenous except near hotspots. We find that melting...
prediction discrepancies occur between methods due to choices in data selection and processing, correction methodology, and interpretation (Section 4). In particular, interpretation is critical because the mantle cools as it melts, and inverse methods such as RevPet only accurately determine apparent mantle potential temperature, not true mantle potential temperature (see Putirka et al., 2007). True mantle potential temperature depends on how melts were extracted from the melting column (Sections 2.6, 4.2, 4.6).

2. Methods

2.1. Reversing the Differentiation of Primary Melts by Tholeiitic Fractional Crystallization: Mg#_{OP} and Mg#_{OPA}

In nominally anhydrous tholeiitic differentiation, the appearance of mineral phases is progressive and well-known (Grove et al., 1992; Kinzler & Grove, 1992a; Klein & Langmuir, 1987). Basaltic liquids first crystallize and fractionate olivine (O), then olivine + plagioclase (OP), and finally olivine + plagioclase + augite/clinopyroxene (OPA). Saturation of additional phases beyond clinopyroxene in mid-ocean ridges is rare and distinct, but does occur in some locations such as the Galapagos (Grove et al., 1992). Cr-spinel is also a potential early crystallizing phase, but we do not include it in this version of RevPet (see Section S1).

The second important behavior of tholeiitic differentiation is that primary mantle melts always evolve along a path from an initially higher Mg# of Mg#_{P},M = 69–77 in equilibrium with the mantle to a melt with a much lower Mg# upon eruption (Hess, 1992) (Figures 1a and 1c) (Mg# = molar 100*MgO/(MgO + FeO_{total})). Because Mg# is a measure of differentiation, we can use the parameters Mg#_{OP} and Mg#_{OPA} to describe the transition from O to OP and OP to OPA. Mg#_{OP} and Mg#_{OPA} are variables that depend on melt composition. Mg#_{OP} and Mg#_{OPA} notably depend on melt alkali content, in which Mg#_{OP} increases at lower alkali contents (Grove et al., 1992; Kinzler & Grove, 1992b) (Figures 1a–1c). Mg#_{OPA} additionally depends on the pressure of fractional crystallization, in which clinopyroxene saturates earlier (higher Mg#_{OPA}) at higher pressures (Fisk et al., 1980; Villiger et al., 2007; Wanless & Behn, 2017; Yang et al., 1996).

These phase assemblage changes are recorded in residual liquid compositions (Bowen, 1928), especially in Mg# space (Figure 1). Olivine-only fractionation initially rapidly lowers the Mg# of the residual liquid until it reaches plagioclase saturation (Figures 1a and 1c). During OP and OPA crystallization, the Mg# of the residual liquid still declines but at a slower rate (Figures 1a and 1c). In FeO-Na,O space, olivine-only fractionation causes liquids to move to high Na,O at a roughly constant FeO (Figure 1b). By contrast, OP and OPA crystallization causes melts to evolve to high FeO at subparallel Na,O content (Figure 1b). OPA crystallization is similar to OP crystallization in FeO–MgO and FeO–Na,O space (Figure 1b), but OPA crystallization is distinct in spaces such as CaO–MgO (Figure 1d).

Reversing O->OP->OPA fractional crystallization is straightforward to compute mathematically given assumptions of Mg#_{OP} and Mg#_{OPA}. However, there are few constraints on Mg#_{OP} and Mg#_{OPA}. Most other methods (Section 4.1) use simplifying thresholds to determine Mg#_{OP} and Mg#_{OPA} that do not take into account the influence of bulk composition or pressure. RevPet determines Mg#_{OP} and Mg#_{OPA} differently by measuring the compositional distance (Section 2.3) to predicted OP and OPA phase boundaries that are specific to the composition of the liquid and pressure of fractional crystallization. OPA phase boundaries are predicted using the method of Yang et al. (1996). The predicted OP boundary is estimated by projecting the OPA boundary of Yang et al. (1996) onto the OP join (Grove et al., 1992; Yang et al., 1996).

2.2. Stopping the Reverse Fractionation Calculation at a Primary Melt: Mg#_{pri} and OPALM Points

In addition to deciding Mg#_{OP} and Mg#_{OPA}, the other challenge for reverse fractional crystallization methods is deciding when to stop the calculation. Most models, except for PRIMELT3 and RevPet, correct an erupted basalt to an imposed and constant Mg#_{P}, typically 70–73, or to an equilibrium olivine with Mg# between 89 and 90 (Section 4.1). There are, however, two problems (Sections 2.2.1 and 2.2.2) with assuming a constant Mg#_{pri} as the ending point. We overcome these in RevPet by allowing primary melts to have Mg#_{pri} within a user-defined range and including the additional criterion of multiple saturation.
2.2.1. The Mg# of Primary Mantle Melts is Variable

Primary mantle melts can span a range of Mg# (Figure 2 and Figure S4), so assuming a constant Mg#\textsubscript{pri} as the ending point is not realistic. This variability occurs because the Mg# of the mantle is variable, as is the Fe-Mg exchange equilibrium of olivine and melt (K\textsubscript{D}). In addition, both variables change continuously during melting. In particular, experiments show that primary lherzolitic mantle melts can have Mg#\textsubscript{pri} as low as 69 or even lower (Figure 1 and Figure S4), yet most models assume higher Mg#\textsubscript{pri} of \(\sim 72–73\).

Another complicating factor is that there are two ways to calculate Mg#. Some use Mg# = molar 100*MgO/(MgO + FeO), while others use Mg# = molar 100*MgO/(MgO + FeO\textsubscript{Total}), where FeO\textsubscript{Total} = FeO + 0.899*Fe\textsubscript{2}O\textsubscript{3}. The differences are significant. For example, primary basalt 82-72f has a reported FeO\textsubscript{Total} = 8.2 wt% and MgO = 10.5 wt% (Bartels et al., 1991) which corresponds to Mg# = 69.5 using FeO\textsubscript{Total}. If we assume 10% of this FeO is Fe\textsuperscript{3+}, as is common, then Mg# is found to be much higher, Mg# = 71.7. For consistency with experiments, we use FeO\textsubscript{Total} (see Section S2).

2.2.2. Mg# is Not the Only Criteria for Identifying a Primary Melt: Primary Melts Are Also Multiply Saturated

Primitive melts (erupted or calculated) that have Mg# equal to the assumed Mg#\textsubscript{pri} may not actually be in equilibrium with the mantle. This could occur, for example, if a reverse calculation used the incorrect
fractionating phase assemblage. Fortunately, primary mantle melts have the unique property that they are in equilibrium with their source residue when returned to their conditions of melting, and are therefore, multiply saturated on their liquidus with olivine (O), orthopyroxene (L, for low-CaO pyroxene) clinopyroxene (A for augite), and plagioclase/spinel/garnet (P). This thermodynamically constrained multiple saturation point is called the OPALM point, and OPALM points can be predicted by melting temperature ($T_M$), pressure ($P_M$), and melt composition by multiple linear regression on OPAL-saturated experiments (Table 1, Section S3, Figures S1–S3).

Evolved erupted basalts are typically initially far from OPALM points, but parental melts move closer as the correct fractionating phases are added back. The regressions in Table 1 can be used to judge if a basalt composition (or its more primitive parental melts) is in equilibrium with a mantle assemblage, as well as $T_M$ and $P_M$ if the melt is found to be multiply saturated. Manual thermobarometers use this principle to find a reverse fractional crystallization path (RFP) by hand that successfully returns a basalt back to a mantle equilibrated primary melt (Chatterjee & Sheth, 2015; Grove et al., 1992; Till, 2017). RevPet automates the process by calculating potential RFPs and minimizing the compositional distance between calculated potentially primary melts with Mg#$_{Pri}$ and their predicted OPALM points.

### 2.3. Compositional Distance and Recognizing Multiply Saturated Melts

All phase boundaries (OPALM, OPAM, OPM) in RevPet are defined in OLIV-CPX-PLAG-QTZ mineral component space (Grove, 1993), and so melts in oxide wt.% must first be transformed into component space for comparison to phase boundaries. The compositional distance in component space between the composition of a basalt and its predicted phase boundaries is given by the root mean square deviation (RMSD):

$$\text{RMSD} = \sqrt{\frac{\sum_{c=1}^{C} \left( \bar{\theta}_c - \theta_c \right)^2}{C}},$$

where $c =$ the mineral component OLIV, CPX, PLAG, and/or QTZ, $C =$ number of components, $\bar{\theta}_c =$ magnitude of the predicted component, $\theta_c =$ magnitude of the component in the liquid. The number of components depends on the specific phase saturation boundary (i.e., $C = 4$ for OPALM, $C = 3$ for OPAM, $C = 2$ for OPM). We define RMSD$_{OPALM}$, RMSD$_{OPAM}$, and RMSD$_{OPM}$, as the RMSD between a basalt and its predicted OPALM, OPAM, and OPM boundary, respectively.

While RevPet could minimize RMSD down to an infinitely small number, the regressions in Table 1 have uncertainty that we must consider. We therefore define ER$_{Pri}$ as the critical RMSD threshold error below which a melt is likely to be multiply saturated if we were to do an experiment on that composition. We constrain ER$_{Pri}$ to be the error of the regressed mineral components that predict the OPALM points. We also define similar errors ER$_{OPAM}$ and ER$_{OPM}$ for OPAM and OPM saturation, respectively. The regressions have maximum average absolute errors of 1.5%–1.7% (Table 1, Figures S1–S3). We tested different values of ER$_{Pri}$ from $10^{-4}$% to 2% and found that an ER$_{Pri} = 1.5$% best reproduces multiple saturation experiments not used to derive the regressions (Section 2.5). If ER$_{Pri}$ is made very small (e.g., ER$_{Pri} = 10^{-4}$%), we find that the melting predictions can be overfit.
| Table 1 | OPLAM Melting Pressure, Temperature, and Melt Composition Linear Regression Coefficients Used by RevPet (Section S3) to Identify if a Melt Equilibrated With Plagioclase (P), Spinel (S), or Garnet (G) Peridotite, and if so, the Pressure (P_M) and Temperature of Melting (T_M) |
|------|--------------------|----------------|----------------|----------------|----------------|----------------|-------------|--------------|----------------|
| Plagioclase lherzolite | Intercept | OLIV (melt) | Mg# (mol) | NaK# (wt%) | TiO₂ (wt%) | K₂O (wt%) | CaO/Al₂O₃ (wt%) | r² | Avg. er. | Eq# |
| P (kbar) | −43.59 | 136.90 | 24.54 | 37.55 | 2.11 | −0.773 | 1.636 | 0.95 | 0.79 | 1P-P |
| std. er. | 9.90 | 13.86 | 2.536 | 9.254 | 0.502 | 0.387 | 6.908 | |
| Spinel lherzolite | Intercept | OLIV (melt) | Mg# (mol) | NaK# (wt%) | TiO₂ (wt%) | K₂O (wt%) | CaO/Al₂O₃ (wt%) | r² | Avg. er. | Eq# |
| P (kbar) | −29.50 | 84.82 | 25.00 | 24.67 | 2.79 | −0.138 | −1.848 | 0.83 | 1.53 | 1S-P |
| std. er. | 4.05 | 4.60 | 2.45 | 4.34 | 0.75 | 0.30 | 3.52 | |
| Garnet lherzolite | Intercept | OLIV (melt) | Mg# (mol) | NaK# (wt%) | TiO₂ (wt%) | K₂O (wt%) | CaO/Al₂O₃ (wt%) | r² | Avg. er. | Eq# |
| P (kbar) | −77.53 | 139.90 | 46.44 | 28.72 | 1.52 | 3.25 | 18.62 | 0.97 | 1.26 | 1G-P |
| std. er. | 5.58 | 8.49 | 2.924 | 6.229 | 0.68 | 0.62 | 4.54 | |

| Plagioclase lherzolite | Intercept | P (kbar) | Mg# (mol) | NaK# (wt%) | TiO₂ (wt%) | K₂O (wt%) | CaO/Al₂O₃ (wt%) | r² | Avg. er. | Eq# |
| T (°C) | 1,074 | 11.86 | 65.55 | −138.2 | 20.55 | 5.855 | 79.02 | 0.95 | 11.50 | 1P-T |
| std. er. | 113.4 | 2.5 | 33.0 | 97.8 | 10.0 | 16.2 | 124.8 | |
| Spinel lherzolite | Intercept | P (kbar) | Mg# (mol) | NaK# (wt%) | TiO₂ (wt%) | K₂O (wt%) | CaO/Al₂O₃ (wt%) | r² | Avg. er. | Eq# |
| T (°C) | 1,049 | 12.71 | 63.47 | −3.325 | 2.658 | −12.03 | 117.8 | 0.93 | 14.28 | 1S-T |
| std. er. | 53.0 | 0.6 | 35.1 | 61.4 | 11.3 | 8.3 | 53.8 | |
| Garnet lherzolite | Intercept | P (kbar) | Mg# (mol) | NaK# (wt%) | TiO₂ (wt%) | K₂O (wt%) | CaO/Al₂O₃ (wt%) | r² | Avg. er. | Eq# |
| T (°C) | 1,136 | 8.739 | 184.9 | −19.48 | 29 | −23.42 | −22.48 | 0.93 | 18.72 | 1G-T |
| std. er. | 95.8 | 1.0 | 57.6 | 108.0 | 11.1 | 9.6 | 82.8 | |
2.4. The RevPet Algorithm

Using user-defined ranges of Mg#_{OP}, Mg#_{OPA}, and Mg#_{Pri}, RevPet calculates combinations of Mg#_{OP} and Mg#_{OPA} as unique reverse fractionation crystallization paths (RFPs) and then determines using a decision tree which RFP(s) best return an erupted basalt back to an OPALM point within the range of Mg#_{Pri} (Figure 3, for full details see Section S4). The identified primary melt compositions directly determine T_M, T_p, and T_p*p (Table 1 and Equation 2). The default ranges of Mg#_{OP}, Mg#_{OPA}, and Mg#_{Pri} are based on experiments (Section S4). See Section 4.5 for a discussion on changing Mg#_{Pri} (Section 2.2.1), which can strongly influence melting predictions.

Some RFPs fail to stay saturated in the phases they are crystallizing, for example, they move far from the OP phase boundary while crystallizing OP. Some RFPs entirely fail to reach an OPALM point, do not final an optimal solution within the set Mg#_{Pri}, or find other impermissible solutions (Section S4). These failed RFPs are excluded. Of the remaining viable RFPs, RevPet then finds the most likely primary melt along each RFP using logic determined by calibration with experiments (Section 2.5) (Figure 3). If the primary melts within the range of Mg#_{Pri} have RMSD_{OPALM} < Er_{Pri} the most likely primary melt for that RFP is the one with the lowest Mg#_{Pri} that first reaches Er_{Pri}. Instead, if they have RMSD_{OPALM} > Er_{Pri}, the primary melt is the one with the lowest RMSD_{OPALM}.

Some erupted basalts find multiple RFPs with primary melts that have RMSD_{OPALM} < Er_{Pri} and these multiple solutions can have different melting conditions. For this reason, RevPet identifies a unique maximum likelihood solution out of the viable primary melts (experimental calibration currently indicates the best RFP is the one that minimizes multiphase fractionation, see Section S5), as well as a consensus solution that averages the melting conditions of all the well-fitting primary melts (Figure 3). The average and standard deviation of the consensus solution will be small if the multiple solutions are similar and large if they contain significantly different RFPs.

2.5. RevPet Calibration

We evaluate and calibrate the performance of RevPet and determine its prediction limits by testing how well RevPet reproduces the melting temperature and pressures of basalts with experimentally determined (known) melting temperatures and pressures. We perform two validation steps: (a) experimentally determined primary lherzolite and non-lherzolite melts, including those in Figure 1 (Section S5) and (b) experimentally determined paths of fractional crystallization (Section S6). We find that RevPet accurately predicts known melting conditions when RMSD_{OPALM} errors are <2%–3%. RMSD_{OPALM} errors greater than ~3% indicate non-lherzolitic sources (pyroxenitic, hydrous, carbonated, or refractory). High RMSD_{OPALM} could also indicate complex secondary processing of primary melts (e.g., fractionating at multiple pressures or significant amounts of crustal assimilation) or significant Fe³⁺.

2.6. Mantle Potential Temperature (T_p), Apparent (T_p*), and Variations in T_p (ΔT_p and ΔT_p*)

The ultimate goal of RevPet is to use primary melt compositions to determine absolute mantle potential temperatures (T_p) and significant variations in mantle potential temperature (ΔT_p) on a regional to global...
scale, where \( T_r \) is the adiabat on which the mantle first beings to melt, and \( \Delta T_p \) is the difference between the maximum \( T_p \) and minimum \( T_p \) of two or more basalts samples. The problem in calculating \( T_{PM} \) and \( \Delta T_{PM} \) is that inversion-based thermobarometry methods typically predict apparent mantle potential temperature \( (T_{PM})^* \) unless degree of melting \( (F) \) is estimated and used to determine \( T_{PM} \) as done by Putirka et al. (2007).

\[
T_{PM} = T_{PM}^* - dT / dP_{adiabat} * P_M
\]

where here we use an adiabatic slope, \( dT/dP_{adiabat} \) of 1.5°C/kbar (Section S7).

Figure 3. The RevPet Algorithm. RFP = reverse fractional crystallization path. Pipeline: An evolved erupted basalt (EB) is returned to its primary composition by passing through boxes b–d to boxes f (the single best solution) and g (the consensus solution). Example 1: calculation of compositional distance \( (RMSD_{OPALM}) \) for two basalt compositions and their nearest OPALM points, as well as the \( P_{PM}, T_{PM} \) and \( T_{PM}^* \) of the two predicted OPALM points using Table 1.

A melting prediction is only applicable if \( RMSD_{OPALM} \) is small. Examples 2 and 3: Mg# melt versus \( RMSD_{OPALM} \) for two different EB used by PRIMELT3 and discussed in Section 4.3 and 4.4. Both EBs are already within error of an OPALM point without correction. With increasing reverse fractionation, D-20-15 first moves closer to an OPALM point and then further away—but because all 3 RFPs for D-20-15 have \( RMSD_{OPALM} < Er_{Pri} \) within Mg#Pri, the most likely primary melt for each RFP is the one with the min Mg#Pri. The overall max likelihood primary melt for D-20-15 is the one that minimizes multiphase fractionation (the black path). By contrast, 1187-8 moves away from an OPALM point with increasing reverse fractionation. When Mg# reaches the minimum Mg#Pri, \( RMSD_{OPALM} \) is \( \sim 2.5\% \), which makes this the most likely primary melt. In this case, because \( RMSD_{OPALM} > Er_{Pri} \), the overall max likelihood path is the one with the lowest \( RMSD_{OPALM} \), which does experience multiphase fractionation (the green path).
For example, in this forward melting simulation (Krein et al., 2013; Spiegelman & Kelemen, 2008), the only melts that record the unmelted mantle cool as it melts (Figure 4), yet \( T_{p}^{*} \) requires knowing the relevant F for two or more basaltic sources. \( \Delta T_{p}^{*} \) only equals \( T_{p} \) if all erupted basalts in a group were produced by the same degree and style of melting of the same source. For example, \( \Delta T_{p}^{*} = \Delta T_{p} \) if all basalts in the group were fully pooled melts of the same source, or if they were all first near-fractional melts of the same source. If the basalts in the group were instead extracted from different parts of the same melting column, then \( \Delta T_{p}^{*} \) could be much larger than \( \Delta T_{p} \) (up to \( \sim 220^\circ \text{C} \), see Figure 4). If multiple sources were involved, then \( \Delta T_{p}^{*} \) would be even larger, even if melting entirely occurred at the same \( T_{p} \) \( (\Delta T_{p} = 0) \).

It is unlikely that basalts are produced by the same degree and style of melting of the same source. In particular, Mid-Ocean Ridge Basalts (MORBs) are thought to represent both variably pooled and near-fractional melts (Elliott & Spiegelman, 2014; Johnson et al., 1990; Jull et al., 2002; Spiegelman & Elliott, 1993; Spiegelman & Kelemen, 2003). Therefore, some variation recorded by \( \Delta T_{p}^{*} \) likely reflects the cooling of the mantle as it melts instead of real variation in initial \( T_{p} \). Future work combining \textit{RevPet} with forward melting models of major and trace elements and isotopic constraints will be needed to rigorously determine the relevant degree and style of melting for a basalt or a group of basalts. We discuss preliminary approaches and results using simplifying assumptions in Sections 4.2 and 4.6.

## 3. Results: \textit{RevPet} Melting Predictions

### 3.1. Mid-Ocean Ridge Basalts (MORBs)

We compiled a MORB glass data set by combing the 12,527 glasses from Gale et al. (2013) with an additional 1,006 EarthChem glasses from locations not represented in Gale et al. (2013). \textit{RevPet} finds that 9,679 of 13,589 MORB glasses have RMSD\({}_{\text{OPALM}}\) less than or equal to \( \text{ERR}_{\text{PSI}} \) (1.5%) with average maximum likelihood melting pressures of 13.0 \( \pm \) 5 kbars, \( T_{p}^{*} = 1323 \pm 56^\circ \text{C} \), and a \( \Delta T_{p}^{*} \) of \( \sim 400^\circ \text{C} \) from \( T_{p}^{*} = 1200^\circ \text{C} \)–1600°C (results for Gale et al., 2013 glasses shown in Figure 5). By contrast, \textit{RevPet} finds that the 22 binned and averaged Niu and O’Hara (2008) com-
positions have average melting pressures of 11.5 ± 0.6 kbars, average $T_p^*$ of 1303°C ± 11°C, and a $\Delta T_p^*$ of 53°C from 1262°C–1315°C. Both data sets, therefore, predict similar average MORB melting conditions (∼1310°C), but different temperature and pressure standard deviations, and different $\Delta T_p^*$.

The average consensus solutions are similar to the maximum likelihood solutions but shifted to slightly lower pressures and temperatures of melting. For example, the average consensus melting pressures for the 9,679 well-fit MORB glasses is 11.0 ± 5 kbars, $T_p^*$ = 1303°C ± 31°C, and $\Delta T_p^*$ of ∼400°C from $T_p^*$ = 1200°C–1600°C.

### 3.1.1. Outlier $T_p^*$ MORB Melting Predictions

The large $\Delta T_p^*$ of ∼400°C from $T_p^*$ = 1200°C–1600°C using the supplemented Gale et al. (2013) data set is pinned by ∼1200 outlier basalts that comprise ∼10% of the MORB glasses. The basalts with high $T_p^*$ have high primary melt MgO contents. Those with >16 wt% have an average $T_p^*$ of 1555°C ± 25°C and

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**Figure 5.** Top row: Maximum likelihood RevPet results for the 9,025 of the 12,527 mid-ocean ridge basalts (MORB) glasses from Gale et al. (2013) with RMSDOPALM of 1.5% or lower. Bottom row: Maximum likelihood RevPet results for the 22 averaged MORB glasses from Niu and O’Hara (2008) which all have RMSDOPALM ≤1.5%.
1551°C ± 21°C. These same basalts also consistently have higher predicted primary Mg#'s of ∼75 (Figures 5a and 5c red circles and triangles) and also require more olivine-only fractionation. When we examine this high Tp* group in more detail, we find that the erupted basalts have low Mg#s (Figure 5a red circles), and that their consensus solutions have high standard deviations in predicted Tp* that overlap the average 1323°C ± 56°C (Figure 6). Because RevPet parsimoniously defaults to minimizing multiphase fractionation (and therefore higher Tp*), the single best-fit maximum likelihood solution is the one with the highest Tp* (Section S4). This suggests that most of the highest Tp* basalts are less well-constrained than the basalts that predict lower Tp*, except for the MORB glasses in fuschia that have a standard deviation <30°C.

When we examine this high Tp* group in more detail, we find that the erupted basalts have low Mg#s (Figure 5a red circles), and that their consensus solutions have high standard deviations in predicted Tp* that overlap the average 1323°C ± 56°C (Figure 6). Because RevPet parsimoniously defaults to minimizing multiphase fractionation (and therefore higher Tp*), the single best-fit maximum likelihood solution is the one with the highest Tp* (Section S4). This suggests that most of the highest Tp* basalts are less well-constrained than the basalts that predict lower Tp* (Figure 6), and experiments are needed to constrain their origin further.

There are, however, a subset of the high Tp* basalts with consensus solutions that only have high Tp* (Figure 6, fuchsia triangles). These basalts more robustly predict high Tp* and are all from localized places on Earth that are often associated with hot spots (Iceland, the Azores, Easter Island, Galapagos, Juan De Fuca) (Figures 6 and 7).

The outlier basalts that predict low Tp* (<1250°C) and low pressures (<10 kbar) of melting are all near-primary MORB glasses with high Mg#s (67–68) that require little fractionation correction to reach a multiple saturation point (Figure 8a, blue circles and triangles). This means that, unlike the outlier high Tp* basalts, the outlier low Tp* basalts are well-constrained with RevPet (Figures 6 and 7, blue points and stars).

### 3.2. Global Basalts—Comparison of PRIMELT3 to RevPet

To compare PRIMELT3 to RevPet, we ran the same eight globally sourced basalt samples in the PRIMELT3 example spreadsheet in RevPet. Four of the eight are in good agreement with PRIMELT3 in that they require O-only fractionation and predict similar Tp* (Figure 8). The four samples that agree with PRIMELT3 and only require O fractionation (Hawaii, Iceland, Gorgona komatiite, and West Greenland) are sensible: they all have high erupted MgO for their given FeO contents (Figure 8a), they are not close to OP or OPA phase boundaries, and they are all from locations known to have high Tp*. RevPet does predict slightly lower Tp* by 10°C–70°C than PRIMELT3 (Figure 8c), but this difference is explained by the fact that RevPet predicts slightly lower Mg#pri (Figure 8d). The difference in Mg#pri is directly proportional to the difference in predicted Tp*, and likely occurs because PRIMELT3 assumes a constant mantle source composition.
Three of the four outliers are flagged by RevPet as being poor fits to OPALM points (Figures 8c and 8d). One is from the Archean Superior Craton, and RevPet fails to find any viable solutions for its primary magma (and it does not appear in Figures 8c and 8d). The other two (West Greenland, Ontong Java) have high RMSD_{OPALM} of ~2.5%. West Greenland is found by PRIMELT3 to require olivine subtraction to return it to a primary melt, and this picrite that has accumulated olivine cannot be easily compared to RevPet. The third sample with higher RMSD_{OPALM} is from the Ontong Java Plateau. The fourth sample is a Siqueiros Transform MORB from the East Pacific Rise (EPR) and is well fit by RevPet, but our melting predictions...
These last two samples (Ontong Java and the Siqueros MORB) are both predicted by RevPet to have \( T_P^* \) cooler by 150°C–75°C compared to PRIMELT3 (Figure 8c), respectively, and are good examples to explore why, in depth, the same samples have different melting predictions using different methods (Sections 4.5 and 4.6).

### 4. Discussion

Here, we discuss why previous studies have resulted in different estimates of global MOR \( T_P^* \) and \( \Delta T_P^* \) (Section 4.1), the RevPet estimate of MOR \( T_P \) and \( \Delta T_P \) (Section 4.2), and the low \( T_P^* \) and shallow \( P_M \) outlier basalts in the MORB data set (Section 4.3). We then address melt migration and melt-rock reaction (Section 4.4), melting prediction uncertainty, and mantle source heterogeneity by focusing on Ontong Java Plateau basalts (Section 4.5), and shallow melting at the Siqueiros Transform (Section 4.6). As needed, we describe future experiments that can resolve uncertainty in melting predictions.
| Method            | Dataset                                      | # Basalts | $T_p^*$ or $T_r^*$ (°C) | $\Delta T_p^*$ (°C) | $P$ (kbar) | Phases | Mg#$_{OPLA}$ | Mg#$_{OP}$ | Correction Endpoint | FeO$^+$ | Variables to predict T | Variables to predict P |
|-------------------|----------------------------------------------|-----------|------------------------|---------------------|------------|--------|--------------|------------|----------------------|---------|------------------------|------------------------|
| RevPet (this study) | MOR Gale et al. (2013) glasses + EarthChem glasses | 12,527 + 1,062 = 13,589 | $T_p^*$ = $T_r^* = 1323±56$ (1200–1600) | 400 | 13.0±5 | O, OP, OPA | phase equilibria | phase equilibria | closeness to OPLA point | FeO$_T$ | Pressure, Mg#, NaK#, TiO$_2$, K$_2$O, CaO/Al$_2$O$_3$ | Oivine melt component, Mg#, NaK, TiO$_2$, K$_2$O, CaO/Al$_2$O$_3$ |
| RevPet (this study) | Niu and O'Hara (2008) MORB averages | 22 | $T_p^*$ = 1303±11 (1262–1315) | 53 | 11.5±0.6 | " | " | " | " | " | " | " |
| Niu & O'Hara (2008) | MORB glasses >400 m | 22 | $T_p^*$ = 1277–1345 | 68 | 11.3–17.4 | O, OP, OPA | Uses local slope or OP slope | OP-sat when <8.5 wt.% MgO | Mg#$_{OPLA}$ = 72 | Fe$^{2+}$ | P (Langmuir et al., 1992) | FeO (Langmuir et al., 1992) |
| Gale et al. (2014) | All MORBs > 1 km | 9,076 | $T_p^*$ = 1421±64 (1162–1659) | 497 | 1.43–5.23±6 | O, OP, OPA | Uses local slope or OP slope | OP-sat when <8.5 wt.% MgO | Mg#$_{OPLA}$ = 90 | FeO$_T$ | Visual comparison to DMM pMELTs model | NA |
| Gale et al. (2014) | All MORBs > 1 km | 9,076 | $T_p^*$ = 1421±64 (1162–1659) | 497 | 1.43–5.23±6 | O, OP, OPA | Uses local slope or OP slope | OP-sat when <8.5 wt.% MgO | Mg#$_{OPLA}$ = 90 | FeO$_T$ | Visual comparison to DMM pMELTs model | NA |
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| Dalton et al. (2014) | All MORBs | 16,694 | $T_r^*$ = 1300–1500 | 250 | O, OP | Not discussed | OP-sat when <8.5 wt.% MgO | Mg#$_{OPLA}$ = 90 | Fe$^{2+}$ | Na$_2$O, ridge depth, and shear wave velocity calibrated to pMELTS | NA |
| Dalton et al. (2014) | MORBs >1 km | not given | $T_r^*$ = 1314–1464 | 150 | O, OP | Filters for low CaO liquids | Not discussed | Finds F consistent between forward and corrected melts | Fe$^{2+}$ | MgO | NA |
| PRIMELT3 (Herzburg & Astmow, 2015) | EPR | 1 | $T_r^*$ = 1344 | NA | O | Filters for >8.5 wt.% MgO | Filters for >8.5 wt.% MgO | Mg#$_{OPLA}$ = 90 | Fe$^{2+}$ | MgO, SiO$_2$, H$_2$O, SiO$_2$, FeO, CaO, H$_2$O, T | NA |
| Lee et al. 2009 | MAR and EPR | 100 | $T_r^*$ = 1300–1400 | 7–17 | O | Filters for >8.5 wt.% MgO | Filters for >8.5 wt.% MgO | Mg#$_{OPLA}$ = 90 | Fe$^{2+}$ | MgO, SiO$_2$, H$_2$O, SiO$_2$, FeO, CaO, H$_2$O, T | NA |
| Behn and Grove (2015) | All MARB glasses | 12,527 | $T_r^*$ = 1300–1450 | 150 | O, OP, OPA | phase equilibria | phase equilibria | NA | FeO$_T$ | Visual comparison to melting model (crustal thickness and composition) | NA |
| Putirka et al. (2007) | PetDB MORBs | 22,591 | $T_r^*$ = 1454±78 | 140 | assume 8 kbars | O | Not discussed | OP-sat when <9.5 wt.% MgO | Mg#$_{OPLA}$ = 91.5 | Fe$^{2+}$ | Pressure, SiO$_2$, Na$_2$O, K$_2$O, MgO, FeO, CaO, MgO, Al$_2$O$_3$, TiO$_2$, H$_2$O, Mg#$_{OPLA}$ | assume 8 kbars |

Note: Gray and white rows denote unique models (one model can be used on different MORB data sets). Mg#$_{OPLA}$ = how a given model determines the Mg# of olivine + plag + augite saturation. Mg#$_{OP}$ = how a given model determines the Mg# of olivine + plag saturation. Correction Endpoint = reports how a model ends the reverse fractional crystallization calculation (i.e., Mg#$_{Prim}$ = 72 means the model calculation ends when the primary melt has an Mg# = 72, Mg#$_{OPLA}$ = 90 means the model calculation ends when the primary melt is in equilibrium with Mg# = 90 olivine). FeO$^+$ = reports if model uses Fe$^{2+}$ or FeO$_T$ to calculate Mg# (Section 2.2.2). The last two columns report the regressed variables or techniques used to estimate melting temperature and/or pressure. Note that Putirka et al. (2007) estimate F and use it to calculate $T_r$. Abbreviation: MORB, Mid-Ocean Ridge Basalts.
4.1. RevPet Perspectives on MOR $\Delta T_P^*$

Numerous studies (Behn & Grove, 2015; Dalton et al., 2014; Gale et al., 2014; Kinzler & Grove, 1992b; Klein & Langmuir, 1987; Niu & O’Hara, 2008) have used global variations in mid-ocean ridge basalt (MORB) chemistry to infer the melting conditions under mid-ocean ridges, but with inconsistent methods and results (Table 2).

In particular, Niu and O’Hara (2008) and Gale et al. (2014) disagree in MOR $\Delta T_P^*$ by at least ~200°C (Section 58). Niu and O’Hara (2008) predict smaller $T_P^*$ and $\Delta T_P^*$ compared to Gale et al. (2013), Gale et al. (2014), and Dalton et al. (2014) because they use a small number of averaged compositions. It is interesting, however, that the Gale et al. data set predicts an average range in $T_P^*$ of ~1270°C–1380°C, which is roughly similar to the total range of 1262°C–1315°C predicted by the 22 averaged basalts of Niu and O’Hara (2008). So, on average the two different data sets predict similar results, with the important difference that Gale et al. predicts slightly higher temperatures, likely due to their predicting more O-only correction.

Given depth-averaged MORBs, as done by Niu and O’Hara (2008), RevPet finds that ocean ridge $\Delta T_P^*$ is small (~110°C) and consistent with Niu and O’Hara (2008). Instead, given individual, localized basalts, RevPet finds that ocean ridge $\Delta T_P^*$ varies by ~400°C from 1200°C–1600°C, which is consistent with Gale et al. (2014) and Dalton et al. (2014). Yet, while our maximum range in $\Delta T_P^*$ is more similar to Gale et al. (2014) and Dalton et al. (2014), the locations of the high T MORBS are different (Figure 7). We do not find evidence for high $T_P^*$ along large tracts of ocean ridge as they do (e.g., along the southern East Pacific Rise, the Marion Rise, and the South East Indian Ridge) (compare our Figure 7 to their Figure 3). In particular, we find cooler temperatures where the Dalton et al. (2014) paper noted that their model was overpredicting mantle potential temperature (e.g., the Azores and the Marion Rise).

Furthermore, we can consider that oceanic crustal thickness is largely constant on a global scale, with the exception of ultraslow spreading ridges and plume-affected crust (Chen, 1992; White & Klein, 2014). Because crustal thickness is largely a function of mantle potential temperature (Klein & Langmuir, 1987), we can infer that mantle potential temperature should be relatively constant on a global scale for slow to fast spreading ridges unaffected by mantle plumes. RevPet is most consistent with this assumption when comparing individual basalts on a global scale (Figure 7).

4.2. RevPet Perspectives on MOR $T_P$ and $\Delta T_P$

Inferring $T_P$ from $T_P^*$ requires knowing the style of melting that the input MORB compositions experienced (Section 2.6, Table 1). If MORB glasses are near-fractional melts of a single depleted MORB mantle (DMM) source, then an average $T_P^*$ from 1322°C ± 56°C could record the cooling of an entirely initially isothermal mantle ($\Delta T_P = 0°C$) during melting from an initial $T_P = ~1380°C$ down to a $T_P = ~1270°C$ during a maximum degree of melting, F, of ~15% with a mean F of ~7% (Figure 4, Table 1, Equation 3). If MORBs are instead pooled melts of a single DMM source, 1322°C ± 56°C could reflect variations in $T_P$ of 50°C–100°C, where $\Delta T_P$ depends on pooling geometry (Section 57). Narrowly to fully pooled melts require larger $\Delta T_P$ of 100°C, and absolute $T_P$ of ~1350°C–1450°C, while column pooled melts require smaller $\Delta T_P$ of 50°C, and absolute $T_P$ of ~1350°C–1400°C (Section 57). If we were to also include major element mantle source variability, $\Delta T_P$ estimates from melting models would be even lower.

While RevPet inherently considers variable mantle source composition, determining the exact nature of the sources also requires knowing F. Constraining F for each MORB is beyond the scope of this study, however, we can provide some estimates on MOR $T_P$ given that MORBS are thought to reflect both near-fractional melts and pooled melts of variable initial sources. Given that RevPet finds that ~10% of MORB glasses are outliers that either record high-temperature ($T_P^* > 1450°C$) high-pressure melting near hotspots, or low temperature ($T_P^* < 1250°C$) low pressure melting near slow-spreading ridges and back-arc, we propose that the high temperatures near hot spots are real, while the low temperature basalts from slow-spreading rates and back-arc are likely near-fractional melts or narrowly pooled melts that reflect mantle cooling during melting and melt equilibration with shallow mantle lithosphere. Thus, our best estimate is that the ambient MOR $T_P$ is ~1350°C–1400°C ($\Delta T_P = ~50°C$), while MORs influenced by hot spots reach up to $T_P = ~1600°C$. Further resolution, including identifying distinct mantle sources, requires a case-by-case analysis as discussed in Sections 4.5 and 4.6.
4.3. **Low \( T_p^* \) Shallow MORB Glasses**

The low \( T_p^* \) MORB glasses deserve special attention. These erupted basalts have high Mg#s (67–68), overall low FeO and MgO, and a large spread in erupted and corrected Na\(_2\)O content (Figure 5, blue points). They also tend to be restricted to slower spreading ridges and back-arc spreading centers (Figure 7, blue stars). These characteristics suggest that these melts are near-fractional or narrowly pooled melts of variably enriched and depleted mantle from or within the base of the lithosphere. Notably, these melts tend to have melting pressures that suggest they have equilibrated with a plagioclase-bearing peridotite.

Additional evidence of melting in the plagioclase stability field can be obtained from multiple saturation experiments and U-series disequilibria. Experimental evidence supports our result of melting in the plagioclase stability field (e.g., Kushiro, 1973), but more experiments are needed on higher Mg# basalts. In addition, some features of U-series disequilibria may be more easily produced by equilibrium with plagioclase (Krein et al., 2020). Trace element signatures (such as negative Eu anomalies), however, less clearly constrain a role of residual plagioclase. Strongly negative Eu anomalies are only expected for the first near-fractional melts of plagioclase peridotite. Higher extent melts have weak to non-existent negative Eu anomalies because the residue develops a positive Eu anomaly as it melts (Figure 8 in Krein et al., 2020). In addition, the magnitude of the Eu anomaly strongly depends on the mantle source composition, which is unknown and likely variable (Krein et al., 2020; Niu & O’Hara, 2009). Combined with other processes such as re-fertilization and melt-rock reaction (Dygert et al., 2016; Müntener et al., 2004), Eu anomalies are unlikely to be clearly correlated with predicted pressures of melting.

4.4. **Melt Migration, Melt-Rock Reaction, and Melting P-T Estimates**

MOR melt migration occurs at different porosities in which a low-porosity, reactive porous flow matrix supplies melt to high-porosity channels (Elliott & Spiegelman, 2014; Spiegelman & Kelemen, 2003, and references therein). The melt in the low-porosity matrix continuously equilibrates with the peridotite it is moving through, and so this melt remains multiply saturated and in equilibrium with a mantle assemblage throughout the melting column. Only if the melt reaches a high enough porosity such that the residual mantle phase assemblage changes would the melt move away from an OPLAM point (Mitchell & Grove, 2016). Melts modified by reactive porous flow thus record the final (the shallowest and coldest) pressures and temperatures of melting and melt reaction. By contrast, the melts that move into higher-porosity channels stop reacting with the mantle and are preserved near-fractional melts that do not mix with other melts. Therefore, channelized melts record their true pressures and temperatures of melting. Because both types of melt (reactive and nonreactive) are multiply saturated, both can be predicted by RevPet. The challenge, as discussed in Section 2.6 and is beyond the scope of this paper, is determining if the melts in question are better described as near-fractional (channelized) melts, reactive porous flow melts, or pooled melts (which could be mixtures of both types of melt).

4.5. **Mantle Source Heterogeneity and Mg#\(_{PRI}\): Ontong Java Sample 1187-8**

RevPet and PRIMELT 3 predict different melting conditions for Ontong Java sample 1187-8 (Mg# = 64, a glass). Assuming Mg#\(_{PRI}\) = 69–76, RevPet predicts a primary melt with Mg#\(_{PRI}\) = 69 and melting conditions of \( P_M \approx 12 \text{kbar} \) and \( T_p^* = 1344^\circ \text{C} \), while PRIMELT3 predicts Mg#\(_{PRI}\) = 75 and much hotter \( T_p^* = 1483^\circ \text{C} – 1533^\circ \text{C} \). Notably, the RevPet melting prediction has a moderate \( \sim 2.5\% \) RMSD\(_{\text{OPALM}} \) that could indicate a unique source composition or higher melting temperatures consistent with PRIMELT3.
If we reduce the minimum Mg# to 63, we find that the erupted sample is closer to a 6.7 kbar–1260°C OPALM point than any potential primary magma with higher Mg#. This behavior is similar as found for the high-iron olivine websterite melting experiments by Hirose and Kushiro (1993) that were well predicted by RevPet once the minimum Mg# was lowered (Figure S7). One possibility then, is that the source region for this Ontong Java basalt has a high-iron content and is potentially an olivine pyroxenite instead of a peridotite and last equilibrated at shallow pressures (<12 kbars).

However, if we instead increase the maximum Mg# to 82, we find that RevPet predicts hot and deeper melting of ~40 kbars and ~1550°C, similar to PRIMELT3. Thus, the other possibility, consistent with PRIMELT3, is that the Ontong Java primary melt last equilibrated at high pressures under hot T_P* conditions.

These two different solutions (low or high T_P* and Mg#) for the single sample 1187-8 can be tested by conducting multiple saturation experiments on the predicted primary melt compositions as well as 1 atm liquidus crystallization experiments on the erupted basalt: If 1187-8 is saturated with OPA or OP instead of only olivine on its liquidus, then the lower Mg# and lower pressure and temperature melting conditions are more likely to be accurate.

We can also learn about melting conditions at Ontong Java by examining all 81 samples in the Godfrey Fitton and Godard (2004) data set. The raw data set alone suggests that shallower pressures of melting are required to generate all trends in the Ontong Java sample suite. In particular, the basalts with 8–9 wt% MgO and FeO primary melts (panel AB). If these glasses are related by a near-fractional melting path, then the maximum T_P* and deepest point of melting predicted by RevPet of ~1330°C is the T_P and 15% adiabatic decompression melting cools the mantle down to a T_P of ~1260°C, which would generate the primary melts with lower melting temperatures, pressures, and MgO contents.

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4.6. Siqueiros Transform: Comparing Melting Predictions From RevPet, PRIMELT3, Niu and O’Hara (2008), and Gale et al.(2014)

RevPet and PRIMELT 3 also predict slightly different melting conditions for Siqueiros Transform MORB glass D-20-15 (Mg# = 68.4). RevPet finds a multiple saturation point at ~9 kbar, 1280°C, and T_P* = ~1270°C.
(1% olivine addition to Mg\# = 69). PRIMELT3 by contrasts predicts a hotter $T_P^*$ by ~70°C of 1344°C and a higher Mg\# = 71.6 and 5% olivine addition (Figures 10a and 10b, compare dark red triangles). D-20-15 is, incidentally, very close in composition to a Siqueiros Transform MORB glass that Perfit et al. (1996) used for a high-pressure experimental study. The sample they studied (ALV2384-001) is near-primary with an Mg\# = 68.8. The experiments on ALV2384-001 provide only an upper limit on melting pressure (~13 kbars) (Figure S3). However, this experimental result is more consistent with the shallower RevPet prediction than the deeper PRIMELT prediction. If the sample used by Perfit et al. (1996) is already very close to being multiply saturated, then it is unnecessary to add another 4% of olivine back to D-20-15 for it to be in equilibrium with the mantle.

The differences, however, between RevPet and PRIMELT predictions, are small, and both are consistent with the depth-appropriate average melting predictions of Niu and O’Hara (2008) (Figure S11). In contrast, using the expressions of Langmuir et al. (1992), Gale et al. (2014) predict >~100°C hotter $T_P^*$ of ~1450°C (Figures 10a and 10b, gray circles and triangles). One reason for their hotter estimate is that their method of correction prevents OP crystallization at MgO > 8.5wt% (Figure 1). The second reason is that the Gale et al. (2014) filtering method left out important MORB compositions: their data set does not include any Siqueiros Transform samples with Mg\# > 63. If they had included any of the very high Mg\# samples from Perfit et al. (1996), such as D-20-15, they would likely have predicted similar primary melts as PRIMELT3.

If we use RevPet to correct all of Perfit et al. (1996) glasses from the Siqueiros Transform, we find that the predicted primary melts record melting of $P_M$ = 8–14 kbars, $T_M$ = 1270°C–1350°C, and $T_P^*$ = 1260°C–1340°C (Figure 10). These primary melts are consistent with near-fractional melting trends or accumulated near fractional melting trends (e.g., melting in the spinel lherzolite field produces deeper melts with higher Na2O). If true, then experiments would find that the RevPet predicted primary melts of D-20-15 and ALV2384-001 have shallower multiple saturation points (~8 kbars) than the samples predicting higher pressures and higher alkali contents (e.g., ALV2376-003 and ALV2376-007 at ~12 kbars). Such an experimental result can also be used to constrain mantle source heterogeneity using the experimentally determined compositions and proportions of equilibrium minerals.

If the deepest and hottest 1340°C $T_P^*$ melts (ALV2376-003 and ALV2376-007) were the first-near fractional melts of the melting column, then $T_P = 1340°C$. However, if there were other hotter and deeper, lower-degree, near-fractional melts that formed prior to the primary melts of ALV2376-003 and ALV2376-007, or if the primary melts of ALV2376-003 and ALV2376-007 were mixed or pooled in any way, then $T_P$ would be hotter. $T_P$ as well as estimates of degrees of melting, can be confirmed and improved upon by combining the proposed multiple saturation experiments with an in-depth study of the major element, trace element, and isotope (long-lived and U-series) characteristics of all known Siqueiros Transform basalts, especially the E-MORBs (Lundstrom et al., 1999), which are not in the Perfit et al. (1996) data set.

$$ F = \left( T_P^{\text{Deep}} - T_P^{\text{Shallow}} \right) / \left( L_H / C_F \right). $$

5. Conclusions

RevPet allows for more robust correction of a larger number of evolved basalts to better understand mantle melting and melt migration. Using RevPet we find that global data sets of MORB glasses record an average $T_P^* = 1322°C ± 56°C$, but a much larger range in minimum to maximum $T_P^*$ from 1200°C–1600°C ($\Delta T_P^* = 400°C$) based on a small number of outliers. Our predicted average MORB $T_P^*$ is consistent with the small $\Delta T_P^* = 50°C$ estimate by Niu and O’Hara (2008), who used average MORB compositions binned by depth. Our larger predicted range in $T_P^*$ of ~400°C is, by contrast, more consistent with the $\Delta T_P$ and $\Delta T_P^*$ predicted by Gale et al. (2014) and Dalton et al. (2014), who used individual basalt compositions. Unlike Gale et al. (2014) and Dalton et al. (2014), we find that the location of the MORB glasses that predict $T_P^*$ greater than ~1450°C–1500°C are found close to hotspots. Our initial analysis of inferring true mantle potential temperature ($T_P$) from apparent mantle potential temperature ($T_P^*$), which takes into account the cooling of the mantle as it melts, indicates that ambient MOR $T_P$ is ~1350°C–1400°C, with hot outliers near hotspots of $T_P > ~1600°C$. Our result is consistent with observation of MOR crustal thickness (White & Klein, 2014). More rigorous constraints on $T_P$ require identifying the relevant degree and style of melting of each MORB.
Some basalt compositions have nonunique and significantly different melting predictions. Because each melting temperature and pressure prediction has its own unique path of reverse fractionation and primary magma composition, these nonunique cases (e.g., Ontong Java, Siqueros) can be tested by future experiments. Thus, further resolution on the long-standing controversies on the extent of mantle temperature and compositional heterogeneity using modern MORBs and basalts of all ages can be established by future experiments on the basalt compositions that pin predicted maximum and minimum $\Delta T^*$.

Data Availability Statement

The software for this research (ReversePetrogen) is available in the following Harvard Dataverse data citation reference: Krein et al. (2021), [MIT license], https://doi.org/10.7910/DVN/VWYCMY. The software package includes a tutorial video on how to use ReversePetrogen and ImportPlot. ImportPlot reformatstags geochemical data from different sheets in Excel and then creates customizable variation plots and ternary diagrams.

Acknowledgments

The authors gratefully acknowledge the thoughtful comments of the reviewers Rong Xu and Olivier Namur and the Associate Editor Susanne Straub whose comments greatly improved this paper. The authors would also like to thank Oliver Jagoutz for encouraging this work, as well as Emiilie Bowman and Susana Hoyos for their help, discussions, and patience with using early versions of RevPet as it was being developed. Support for this work was provided through the National Science Foundation from grants OCE-1457916 and EAR-1551321 to T.L.G.

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