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# Weathering of ignitable liquids at elevated temperatures: A thermodynamic model, based on laws of ideal solutions, to predict weathering in structure fires

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# HIGHLIGHTS

- An extended model to simulate the evaporation of a gasoline under different conditions.
- $\bullet\,$  Gasoline weathered at temperatures up to 210 °C.
- Raoult's law model fits to within  $\pm \sim 3\%$  root mean squared error of predictions (RMSEP).
- Henry's law model fits to within  $\pm \sim 2\%$  root mean squared error of predictions (RMSEP).

# ARTICLE INFO

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This manuscript provides experimental evidence and a strong theoretical basis that weathering at elevated temperatures (up to 210 °C) results in significantly different distributions of the weathered residues compared to room temperature weathering, especially when the extent of weathering is held constant. A nine-component artificial gasoline mixture enabled quantitative comparisons between the residues predicted by a mathematical model and those measured in temperature-controlled evaporations. The simple mathematical model employs iterative fractional losses (e.g. 5% each step) of the mixture components in proportion to their theoretical partial pressures. The partial pressures of the constituents are determined using either: 1) Raoult's law and Antoine constants from the literature, or 2) Henry's law.

The model supports the experimental observations in that the composition of weathered residues as a function of time—or extent of weathering—is significantly different at different temperatures. For example, toluene falls below the limits of detection at 90% weathering and 30 °C but is still readily observable at  $\sim$ 1% of the total ion chromatogram (TIC) at 98% weathering and 210 °C. Such behavior could help explain why ignitable liquids that are highly weathered at elevated temperatures in structure fires are likely to resemble those weathered in the laboratory to a lesser extent at room temperature. Given a chromatogram of a pristine ignitable liquid, the model based on Raoult's law predicts the peak area of each weathered compound with a root mean squared error of prediction (RMSEP) of  $\sim$ 3% when the liquid is weathered up to 98% and 210 °C.

# 1. Introduction

The remains of property fires provide a wide variety of interpretable evidence for fire investigators. When the extent of destruction is modest, the origin, fuel source and ignition source are generally discernable. However, when the fire scene is largely consumed, there may be little, if any, evidence for investigators to collect and interpret. When ignitable liquids are suspected, fire debris is often screened for the presence of ignitable liquid residues (ILRs) [1–3]. The identification of elevated levels of ILRs in a substrate—relative to comparison samples—is widely used to support a claim of deliberate intent, or arson [4]. Due to its widespread availability and effectiveness, gasoline is widely reported to be the most commonly used ignitable liquid for purpose-fully set fires, although the use of other classes of ignitable liquids is

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#### also documented [2,5].

When ignitable liquids are exposed to ambient conditions, the liquids may evaporate in a process termed weathering, and of all the components in the liquid mixture, the most volatile components, which have the highest vapor pressures, evaporate the fastest [6]. Weathering therefore alters the relative quantities of components in a mixture, and these changes make it difficult for an analyst to compare weathered residues to non-weathered ignitable liquids. The weathering process can occur at any temperature ranging from room temperature—for example before or long-after the fire is active—to temperatures exceeding 1000 °C during full-room involvement [7].

A standard procedure for the analysis of ILRs involves the generation of comparison samples of the suspected ignitable liquid that are weathered to varying extents in the hope that one of the weathered extents will provide a similar profile to that of the ILR [8,9]. Without the weathering process, the comparison of the neat ignitable liquids to the recovered ILRs would be near-impossible because the distribution of components in the two samples would be too disparate. Other frequent complications in the identification of ILRs include microbial degradation and matrix interferences present in the sample [10–18].

Ignitable liquids, specifically gasoline, have been the subject of numerous studies concerning weathering. One approach to understanding the weathering process is through mathematical modeling. For example, an advanced distillation curve model has been used to connect the evaporation rate with the retention time of each component using gas chromatography-mass spectrometry (GC/MS) [19-22]. Several chemometric approaches have been used to classify and discriminate pristine ignitable liquids [10,23-26] or ignitable liquids from casework [27]. In general, chemometric approaches struggle the most with associating liquids with weathered versions of themselves [28-33], and especially in the presence of background chemicals or pyrolysis products. Isotope ratio mass spectrometry (IRMS) has been proposed as way to link compounds pre- and post-weathering [34,35], but weathering and pyrolysis cause unpredictable changes in the isotope ratios of the residues, so IRMS is no more reliable than chemometric approaches for comparing liquids pre- and post-weathering [36-42]. Finally, several studies have sought to understand the effect of weathering conditions on the relative distribution of the chemical residues [43-45], but these studies are qualitative rather than quantitative in nature.

To enable analysts to compare residues in fire debris to reference ignitable liquid samples, the comparison ignitable liquid samples are usually weathered to some extent before comparing chromatograms of peak abundances. Anecdotally, casework samples frequently provide adequate quality matches when the comparison ignitable liquids are weathered between 50 and 75% [3,8,45,46]. Conventional wisdom predicts that the elevated temperatures of structure fires should cause more weathering than 50-75%, especially for more volatile ignitable liquids such as gasoline. One possible explanation for this phenomenon is entrapment, which assumes that a certain portion of the pristine liquid is trapped in the pores of the substrate, and these relatively unweathered residues are then extracted during the equilibrium conditions of headspace extraction. Our previous work showed that when an artificial gasoline simulant containing seven compounds was weathered to a certain extent at 90 °C, the proportion of volatiles in the residue was greater than when the liquid was weathered to the same extent at room temperature. A simple model based on Raoult's law was sufficient to explain the disparate changes in evaporation rates of each compound as a function of temperature and extent of weathering [47]. The present work compares the same model against the weathering of a ninecomponent artificial gasoline mixture weathered to between 30 and 210 °C, a much wider range of temperatures. The model's validity is supported by quantitatively describing the distribution of residues after the evaporation of this more complex mixture at temperatures closer to those anticipated in actual casework.

#### 2. Methods

#### 2.1. Artificial gasoline preparation

Due to the complexity of modeling the thousands of compounds present in commercial gasoline, an artificial version of gasoline was designed to replicate the quantity and classes of compounds found in commercial gasoline. The relative quantities of nine compounds were first measured in an unweathered commercial gasoline sample (Kroger, Morgantown, WV, USA) by dissolving the commercial gasoline 1:200 in pentane and analyzing the diluted sample in triplicate using GC/MS (see GC/MS section for details). In the commercial unweathered gasoline sample, hexadecane and eicosane were below the detection limits, so the concentration of these two compounds was artificially elevated in the artificial gasoline recipe to ensure that they were always quantifiable. The inclusion of compounds with boiling points up to C20 provides greater confidence that the model will be applicable to a wide range of ignitable liquids and not just gasoline.

A 200 mL stock solution of the artificial gasoline was prepared, and 1 mL aliquots of this stock solution were weathered to different extents at different temperatures (30, 90, 150, and 210 °C), as described below. The relative total ion chromatogram (TIC) peaks areas of the final artificial gasoline recipe were: toluene (46.6%), ethylbenzene (9.3%), oxylene (15.0%), nonane (2.8%), 1,2,4-trimethylbenzene (19.7%), indane (2.8%), naphthalene (3.8%), hexadecane (0.06%) and eicosane (0.05%). The theoretical basis of the model uses fractional molar ratios and the simulations are based on fractional GC peak areas; these fractions are modestly different in proportion to the relative sensitivity factors of each component quantified by the GC/MS. However, we have verified that, from a mathematical perspective, there is no significant difference between simply modeling GC peak areas directly and the cumbersome alternative, which would require first converting peak areas to molar ratios, then modeling the change in molar ratios before converting the molar ratios back to peak areas.

# 2.2. Weathered artificial gasoline sample preparations

Replicate 1 mL aliquots of the artificial gasoline sample were weathered at four different temperatures (30, 90, 150, and 210  $^{\circ}$ C) to various percentages (50–99%). By necessity, the extent of weathering was determined by mass, not volume, so the mass of the initial liquid and the mass of the residue were assessed differently. The initial mass of the liquid was established from the starting volume of 1 mL and the measured density. The average density of the artificial gasoline was established to be 0.853 g/mL by weighing five replicate aliquots of 1 mL transfers.

Weathering was conducted in aluminum weigh boats that were heated to 400 °C in a kiln (Paragon Digital High Fire Kiln, Paragon Industries Inc., Sapulpa, OK, USA) to remove residual organic lubricants and contaminants. The empty weigh boats were weighed and countersunk in a custom-made aluminum block, and both were preheated to the desired weathering temperature in a standard oven (Lindberg Blue M, Thermo Scientific, Waltham, MA, USA) before each weathering experiment. Once at the desired temperature, the hot block and weigh boat were transferred to a fume hood and 1 mL (0.853 g) of the artificial gasoline sample was spiked onto the hot weight boat. After reaching the desired extent of weathering, the weigh boat was transferred to a replicate aluminum block that was previously cooled to -20 °C in a freezer. The cold block immediately cooled the weigh boat and its residues thereby minimizing any additional weathering.

After weighing the weigh boat and its residues to quantify the extent of evaporation, the weigh boat was washed with five successive washes of 0.5 mL of pentane. The washings were transferred to a GC vial where they were combined. Because the pentane evaporates so quickly during the washing steps, the five combined replicates typically provided a total volume between 0.6 and 1 mL of washings. The weigh boats were weighed after the five replicate washes to ensure that all the residues were collected. The dissolved residues were then brought to a final volume of 1 mL. Because each weathering experiment resulted in a different mass of residue in the 1 mL of pentane washings, different volumes of each washing were subsequently diluted to provide final working solutions that were all 1:200 of weathered residue in pentane.

#### 2.3. Gas chromatography/mass spectrometry

All samples were analyzed using an Agilent Technologies 7890B GC/5977A MS with a 30 m  $\times$  250 µm  $\times$  0.25 µm film thickness HP-5 column (Agilent J&W Columns). The GC/MS parameters were as follows: 0.5 µL injection volume; 250 °C injection temperature; 20:1 split ratio; the initial oven temperature was 40 °C (3.0 min hold), which was ramped to 250 °C at 15 °C/min (3.0 min hold) and then ramped to 280 °C at 10 °C/min (3.0 min hold). The total run time for the GC/MS analysis was therefore 26.50 min. The carrier gas was ultra-high purity helium (Matheson, Fairmont, WV, USA) with a flow rate of 1 mL/min. The mass spectrometer was scanned from m/z 40–350 at a scan rate of 781 Da/sec after a 1.50 min solvent delay. The transfer line and ion source temperatures were 270 °C and 250 °C, respectively. A pentane blank and an n-alkane ladder were run with all samples. The resulting data was extracted and analyzed using Microsoft Excel version 15 (Microsoft Corporation, Redmond, WA, USA).

# 3. Results and discussion

# 3.1. Simulations

Table 1 shows the predicted vapor pressures for each pure compound at 30, 90, 150, 210, and 500 °C [48]. These vapor pressures were predicted using well-characterized Antoine coefficients. The Antoine coefficients are most accurate within certain established temperature ranges [48], and because the present model estimates vapor pressures outside of some of these well-defined regions, the calculated vapor pressures contain a certain degree of error. However, the magnitude of these uncertainties is expected to be negligible relative to the orders-ofmagnitude changes in the absolute vapor pressures at the different temperatures.

Toluene is the earliest eluting compound in the artificial gasoline and possesses the highest vapor pressure of  $5.0 \times 10^{-2}$  bar at 30 °C. Eicosane is the latest eluting compound and has the lowest vapor pressure of  $4.9 \times 10^{-8}$  bar at 30 °C. At 30 °C, their vapor pressures are different by six orders of magnitude. The vapor pressure increases with temperature for all compounds, but the magnitude of the increase is greatest for the latest eluting compounds. For example, at 210 °C, toluene has a vapor pressure of 9.2 bar whereas the vapor pressure for eicosane is  $2.6 \times 10^{-2}$  bar. Therefore, at 210 °C, toluene and eicosane are only different by a little more than two orders of magnitude. The range in vapor pressures of all the compounds is significantly smaller at elevated temperatures than at room temperature, and this similarity at elevated temperatures explains why the compounds evaporate at more similar rates at elevated temperatures relative to room temperature.

Fig. 1 compares chromatograms of fresh and weathered (79% at 90  $^\circ C)$  artificial gasoline with the hexadecane and eicosane peaks



Fig. 1. Examples of experimentally obtained chromatograms of the artificial gasoline mixture: a) unweathered and b) weathered to 79% at 90 °C.

increased by a factor of 20 for visualization purposes. The trend observed in the chromatogram of the weathered artificial gasoline is qualitatively consistent with conventional wisdom; the more volatile compounds evaporate faster than the less volatile compounds. However, when one is concerned with accurately quantifying and modeling these losses, the artificial gasoline makes quantitation considerably easier than dealing with a more complex mixture.

#### 3.2. Mathematical simulations

The simulations are based on sequential, irreversible, stepwise losses of each component in proportion to its partial pressure at a given temperature. The first step of the simulation is to assess the initial molar ratios in the liquid phase. As described above, one can simply substitute fractional peak areas for fractional molar ratios without the need to calibrate for relative sensitivity factors of each compound. The equilibrium partial pressures were derived from the combination of Raoult's law, Dalton's law and Antoine constants for each compound in the mixture, as described previously [47,49]. Raoult's law dictates that the partial vapor pressure  $p_A$  of A is proportional to the product of the mole fraction  $\chi_A$  and the vapor pressure of the pure liquid  $p_A^*$ :

$$p_A = x_A p_A^* \tag{1}$$

This law makes a fundamental assumption that the intermolecular interactions between unlike compounds are equal to the intermolecular interactions between like compounds. The assumption is never strictly true but given the relative similarity of the intermolecular forces of all the hydrocarbons in this mixture, the assumption is reasonably valid.

Table 1

Retention times and calculated vapor pressures of each compound in the artificial gasoline mixture (bar).

			-		*				
Temp	Toluene	Ethyl benzene	o-xylene	Nonane	1,2,4-TMB	Indane	Naphthalene	Hexadecane	Eicosane
t <sub>r</sub>	2.62 min	4.24 min	4.76 min	4.95 min	6.28 min	6.81 min	8.51 min	12.22 min	15.02 min
30 °C	5.0E - 02	1.8E - 02	1.2E - 02	8.8E - 03	4.4E - 03	3.0E - 03	1.6E - 04	3.4E - 06	4.9E-08
90 °C	5.4E - 01	2.4E - 01	1.8E - 01	1.5E - 01	8.2E - 02	6.2E - 02	1.1E - 02	5.5E - 04	3.3E - 05
150 °C	2.8E + 00	1.5E + 00	1.2E + 00	9.9E - 01	6.0E - 01	4.8E - 01	1.4E - 01	1.4E - 02	1.8E - 03
210 °C	9.2E + 00	5.3E + 00	4.5E + 00	3.9E + 00	2.6E + 00	2.1E + 00	8.3E - 01	1.3E - 01	2.6E - 02
500 °C	1.9E + 02	1.4E + 02	1.3E + 02	1.2E + 02	1.0E + 02	8.5E + 01	5.0E + 01	2.6E + 01	1.1E + 01

Dalton's law applies similar logic to the vapor phase and asserts that partial pressures are additive. The partial pressures at different temperatures were calculated from tabulated Antoine constants of Antoine plots, which are a semi-empirical form of the Clausius-Clapeyron equation that relates a substance's vapor pressure to the temperature.

Once the equilibrium partial pressures were calculated for the original, unweathered artificial gasoline, a total of 5% of the mixture was then subtracted to represent an irreversible evaporative loss, as would be expected from the weathering of volatile components. The 5% loss was distributed unevenly among the nine components in direct proportion to each components' partial pressure. Therefore, the most volatile components experienced the largest proportional losses and the least volatile components experienced the smallest proportional losses.

After the simulated stepwise loss, the remaining molar ratio of each component changes, so the new partial pressures must be recalculated. The fractional losses and equilibrium partial pressures were calculated in an iterative process until the mixture was weathered to the desired extent. Because each step represented a 5% evaporative loss, the fraction remaining after each iteration followed an exponential decrease as a function of the number of iterations. Step sizes of 2%, 1% and 0.5% per step provided higher resolution data, but did not provide meaningfully different results. However, step sizes larger than 5% per step provided significantly different and unrealistic proportional losses. The mathematical simulations of the artificial gasoline were completed using Microsoft Excel version 15 (Microsoft Corporation, Redmond, WA, USA).

## 3.3. Effect of temperature

As demonstrated in our previous work [47], the extent of weathering has such a large effect on the distribution of components in the residues of artificial gasoline that the weathering extent must be fixed to be able to easily observe the influence of temperature. When samples are weathered such that only 10% of the original mass of the ignitable liquid remains (i.e. 90% weathered by mass), the temperature at which weathering occurred has a significant effect on the distribution of the remaining compounds.

Fig. 2 shows the mathematically simulated weathering data overlaid with the experimentally observed weathering data for each component of the artificial gasoline. One can use the residual differences between the measured and predicted fractional compositions to assess the fitness of the model. For example, based on 117 measurements (9 compounds at 13 different extents of weathering), the root mean squared error of predictions (RMSEP) was 3.4% at 90 °C and 2.3% at 210 °C. The RMSEP could be reduced by about 20% by emperically 'optimizing' the predicted vapor pressures of each compound. For example, for the model at 90 °C, reducing the calculated vapor pressures of toluene and 1,2,4-TMB by 10% and increasing the vapor pressure of naphthalene by 30% reduced the RMSEP from 3.4 to 2.5%, which is a 26% relative improvement in the model. For the model at 210 °C, reducing the calculated vapor pressures of toluene and o-xylene by 10% and increasing the vapor pressure of naphthalene by 10% reduced the RMSEP from 2.3 to 2.0%, or a 13% relative improvement in the model.

These empirical optimizations were performed using the guess feature in Excel. Each vapor pressure was altered in a univariate manner to obtain a vapor pressure that minimized the RMSEP for the model. The guess feature was repeated a second time for each compound. The vapor pressures obtained in the second round of optimizations were typically within 5% of the first round of optimization, so the process was not repeated a third time.

The empirical optimizations required to minimize the RMSEP can be interpreted as corrections for non-ideal behavior in the liquid or gas phase, or to compensate for errors caused by extrapolating the Antoine curves beyond their calibrated ranges. Alternatively, these empirical optimizations to Raoult's law could be interpreted as the mathematical solution obeying Henry's law rather than Raoult's law. In both laws, a plot of mole fraction of A ( $x_A$ ) in a mixture versus the partial pressure of A ( $p_A$ ) is proportional. However, in Raoult's law, the constant of proportionality is the standard vapor pressure of the pure substance A (see Eq. (1)) and in Henry's law, the constant of proportionality,  $K_A$ , is an empirically derived constant with dimensions of pressure such that the line of best fit is tangent to the experimental curve at  $x_A = 0$  [49].

$$p_A = x_A K_A \tag{2}$$

Although Raoult's law can be used to estimate the partial pressures during the modeled evaporation process with a RMSEP of  $\sim 3\%$ , empirical adjustments to each component's vapor pressure—to provide estimates of the Henry's law constant for each component—results in superior predictions of the experimental weathering with a RMSEP of  $\sim 2\%$ . This improvement is modest, but the ability to use empirically derived constants of proportionality for each component instead of known vapor pressures enables the model to be extended to more complicated solutions in which the vapor pressures of each substance cannot be known *ab initio*. For example, the Henry's law constants of a few model compounds with known retention indices could be interpolated to predict Henry's law constants of any substance in a chromatogram, just as Smith and McGuffin have done for the evaporation rate constants of different components of complex mixtures in their kinetic model of evaporation [21,22].

One contrast between the kinetic model of Smith and McGuffin [21,22] and the thermodynamic model described here is that the kinetic model currently does not take into account the fact that molar ratios can change as a function of time (or extent of weathering). Hypothetically, changes in molar ratios as a function of weathering could affect the evaporation rates in real time. The empirically derived evaporation rate of a substance over the course of a weathering experiment, but probably not the instantaneous rate at a given time. However, the sheer complexity of the samples in the work of Smith and McGuffin implies that every component is present at a relatively small molar ratio, so the changes in partial pressure as a function of weathering are likely to be modest. In other words, the complexity of their model.

One important feature of the simulations in Fig. 2b, d, and f is the relative quantity of volatile components such as toluene remaining beyond 80% weathering. At 30 °C, the model predicts toluene to disappear at around 83% weathering, a conclusion that is supported by the experimental data. Likewise, at 210 °C, the model predicts toluene to become undetectable at about 97% weathering, again supported by the experimental weathering data. Ethylbenzene is predicted to reach the baseline around 89% weathering at 30 °C but not until ~99% weathering at 210 °C. At 30 °C, naphthalene accounts for about 30% of the residue at 90% weathering, whereas at 210 °C, naphthalene only accounts for roughly 25% of the residue at 90% weathering. These comparisons support the qualitative and quantitative accuracy of the uncorrected model.

Fig. 3 presents the same data as Fig. 2 but illustrated differently. Here, the fractional composition of each component is plotted as a function of percent weathering. The plots include comparisons of the model and experimental data up to 210 °C and the modeled behavior at 500 °C. The similarity between the experimental data and the modeled data highlights how well the model describes the observations up to 210 °C. The accuracy of the model at 210 °C provides some confidence in the extrapolated behavior at the elevated temperature of 500 °C.

In Fig. 3, toluene, the most volatile component, only decreases with the extent of weathering, and this decrease is more pronounced at lower temperatures. For o-xylene, the composition stays constant until  $\sim$ 50% weathering, at which point its composition decreases between 50 and 95% weathering at each temperature. For naphthalene, the model and experimental data show that at every temperature, the composition increases slightly between zero and 75% weathering. The relative



Fig. 2. Overlay of experimentally collected weathering data (circles) and the mathematically modeled predictions (lines) for the artificial gasoline mixture for a) 30 °C, b) 30 °C expanded, c) 150 °C, d) 150 °C expanded, e) 210 °C, and f) 210 °C expanded.

increase is caused by the loss of the more volatile components, which evaporate at a faster rate. In both the model and the experimental data, 1,2,4-TMB more than doubles in fractional composition between zero and 90% weathering before decreasing in composition above 90% weathering. 1,2,4-TMB reaches its largest fractional compositions of ~0.55 at the lowest temperatures, and only reaches a fractional composition of ~0.45 at the highest temperature studied (210 °C). The least volatile components, which elute last in the GC, show steep increases in composition in the later stages of weathering (e.g. above 85% weathering).

The accuracy of the uncorrected model is notable, especially when two of the requisite assumptions are taken into account: 1) that there are no differences in intermolecular interactions between like and unlike compounds, and 2) that vapor pressure predictions based on Antoine plots can be extrapolated beyond their intended limits. To provide a broad summary of these observations; for weathering around room temperature, the differences in partial pressures of the components are different by around six orders of magnitude, so the components evaporate at vastly different rates. The result is a sequential-like evaporation of components in order of their GC elution times. When the same mixture is evaporated at elevated temperatures (e.g. 210 °C), the partial pressures are only different by two orders of magnitude, so the evaporation rates are much more similar than at room temperature, and one observes a more uniform evaporation of all the components. This phenomenon helps explain why gasoline recovered from fire debris anecdotally appears to be weathered to a lesser extent than one might expect after exposure to the elevated temperatures of a structure fire. This effect of temperature has recently been supported by McIlroy et al. [22], who used a kinetic-based model to describe the evaporation of complex mixtures at different temperatures. Although



Fig. 3. Comparison of the fractional composition of residue as a function of percent weathering for six of the nine compounds in the artificial gasoline. Open circles represent experimentally obtained data points and solid lines show the compositions predicted by the model. The dashed gray line shows the compositions predicted at 500 °C to simulate evaporation in a more realistic structure fire.

their data and model were only compared between 0 and 35  $^{\circ}$ C, their results are in agreement with the trends described above.

# 4. Conclusions

Whereas the extent of weathering is still a significant factor when considering the relative distribution of residues in weathered ignitable liquids, the role of temperature cannot be ignored. When the extent of evaporation is kept constant, weathering at higher temperatures leaves greater quantities of volatile components in the residue. This phenomenon is supported by a simple model based on fundamental properties of matter, including Raoult's law and Dalton's law. When the composition of a liquid is known, the composition of each component in the residue can be predicted with a root mean squared error prediction of around 3%, even up to 98% weathering. There are at least two ways in which one could make practical use of this knowledge. First, the model could be applied to databases of pristine ignitable liquids to provide laboratories with huge in-house databases of weathered samples. This capability would circumvent their need to perform any experimental weathering of ignitable liquids and thereby save time, money, environmental impact, resources and chemical waste. Second, this model might be able to distinguish between liquids that have been weathered at room temperature, in the absence of fire, versus liquids that have been weathered at elevated temperatures. To enable this benefit, one would also need to assess the effects of temperature variations during the simulated weathering. Such modifications to the model are relatively straightforward, but the variety of temperatures and times that require modeling might require impractical computational power.

#### **Declaration of Competing Interest**

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

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