

Supplementary Information for: Vesto et. al. (2022), Condensed Phase Kinetic Studies of Hydroxynitrates Derived from the Photooxidation of Carene, Limonene, *trans*-Carveol, and Perillic Alcohol.

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S1. NMR Assignments

HN Structure	NMR Shift (ppm), multiplicity, #H
3-Car (4)	1.45, s, 3H
3-Lim (8)	3.70, bs, 1H
2-Lim (9)	4.90, bs, 1H
3-Per (10)	4.00, s, 1H
2-Per (11)	5.20, bs, 1H

Table S1. NMR shifts (ppm), multiplicity, and number of hydrogens for each of the starting HN studied in 25% D₂O/DMSO-*d*₆

S2. pH Measurements

Due to long equilibration times in a mixed aqueous/organic matrix, *in situ* measurements of pH were not feasible in this study. Instead, we measured changes to the pH of a single-phase mixed aqueous/organic solution upon titration with up to 1 equiv HNO₃. We chose 1 equiv HNO₃ to mimic the reaction taking place in our experiment as the nitrate group is released into solution. We titrated 10-mL of each solution with concentrated (16 M) HNO₃, such that the total volume added to achieve 1 equiv HNO₃ had negligible impact on the solution volume (0.03 mL added). The pH was measured using a glass IO Line triple junction pH probe (YSI). Each sample was allowed to equilibrate for 5 – 10 minutes with vigorous mixing with a teflon coated stir bar. Between each sample, the probe was rinsed with methanol, and deionized water, reconditioned with KCl (3M) for a minimum of 15 minutes, and the meter recalibrated with commercial standards.

Measurements were conducted in both 25% H₂O/DMSO and 25% H₂O/Ethanol, both without the addition of 5 equiv (150 mM) H₂SO₄ to assess changes to pH with the release of HNO₃ into solution. In 25% H₂O/DMSO we observed a dramatic decrease in the pH from 9.8 to 3.9 with only 0.03 equiv acid added, followed by further decrease to pH 3.2 when 0.2 equiv had been added. This is the range over which the initial rates were measured in our experiments. The pH continues to decline with added acid to 2.5 with 1 full equiv added. There was a slight buffering when 5

equiv H_2SO_4 was added, maintaining pH 1.7 until 0.2 equiv were added (the range over which the initial rates were measured). The pH then drops to 1.6 with one full equiv added.

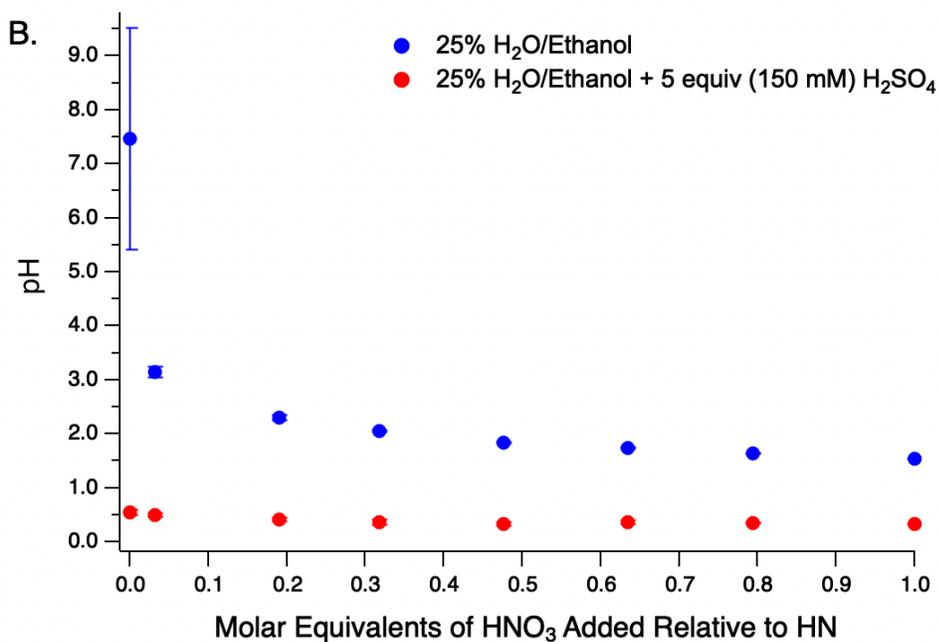
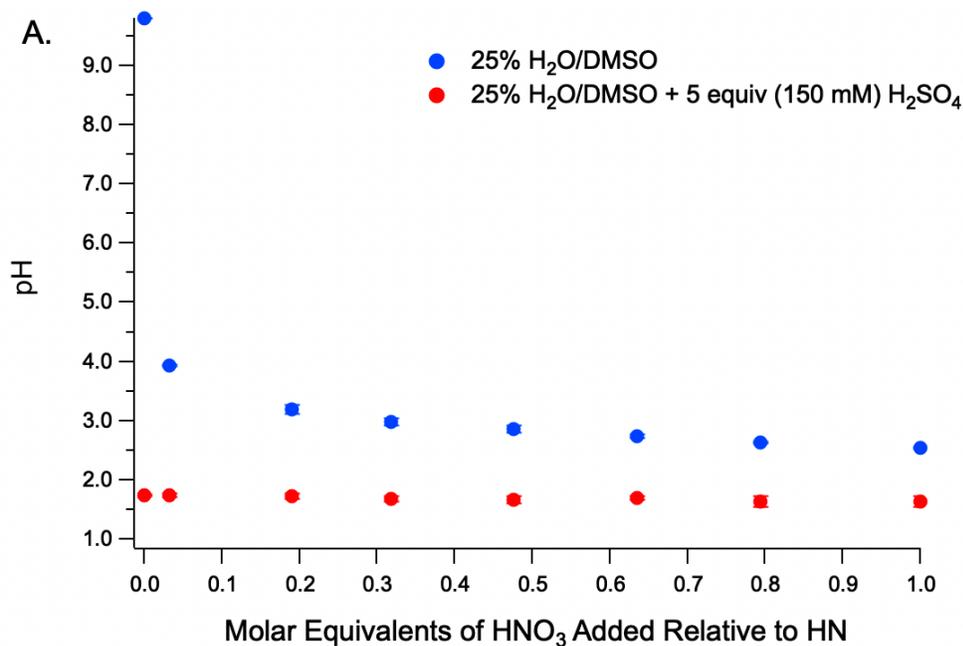


Figure S1. Solution pH as a function of HNO_3 addition to: A. 25% $\text{H}_2\text{O}/\text{DMSO}$ and B. 25% $\text{H}_2\text{O}/\text{Ethanol}$, with and without the addition of 5 equiv H_2SO_4 . Error bars represent one standard deviation from triplicate measurements.

S3. Arrhenius Analyses

Conversion of 2-Per (**11**) and 3-Per (**10**) and 2-Lim (**9**) proceeded too slowly at 30 °C to be observed in real time. Instead, Arrhenius plots were constructed for each at elevated temperatures and the activation energy (E_a) determined from the linearized Arrhenius expression (S1):

$$\ln(k_{obs}(T)) = -\frac{E_a}{RT} \quad (S1)$$

where R is the ideal gas constant (0.008314 kJ/mol K), T is the temperature (K), $k_{obs}(T)$ is the observed rate constant at a given T . The rate constant at 30 °C is then predicted from a rate constant ($k_{obs}(T_1)$) measured at an elevated temperature, T_1 , using expression S2:

$$k_{obs}(30^\circ C) = k_{obs}(T_1)e^{\frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{303K}\right)} \quad (S2)$$

The Arrhenius plots for each of the species measured are given below.

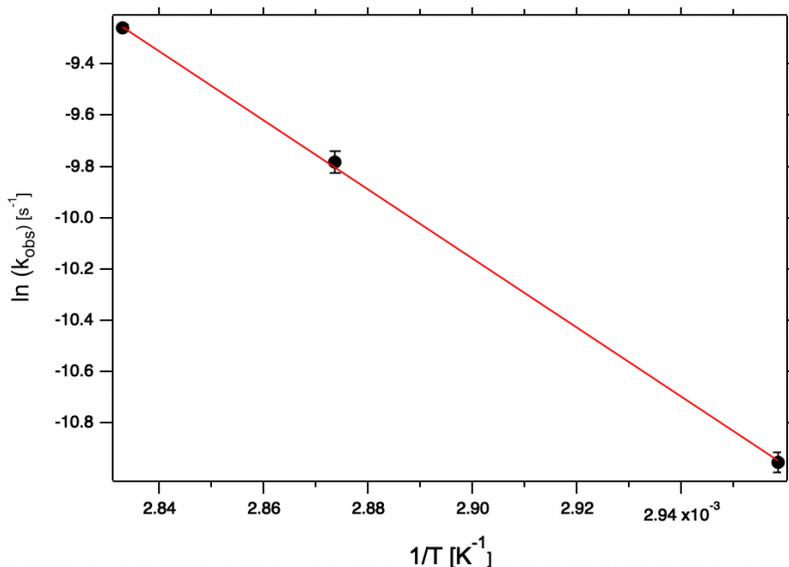


Figure S2. Arrhenius plot for 2-Lim (**9**) conversion. Error bars represent \pm one standard deviation from the mean from triplicate measurements. The line of best fit represents a least squares regression weighted by the standard deviation of each point: $\ln(k) = -13450 (\pm 300) (1/T) + 29 (\pm 1)$, $R^2 = 0.998$, $E_a = 112 \pm 2$ (kJ/mol).

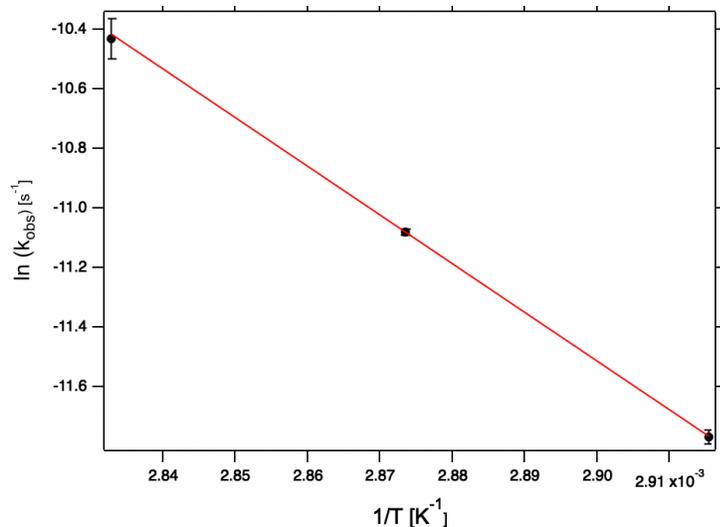


Figure S3. Arrhenius plot for 2-Per (**11**) conversion. Error bars represent \pm one standard deviation from the mean from triplicate measurements. The line of best fit represents a least squares regression weighted by the standard deviation of each point: $\ln(k) = -16368 (\pm 500) (1/T) + 36 (\pm 2)$, $R^2 = 0.998$, $E_a = 136 \pm 5$ (kJ/mol).

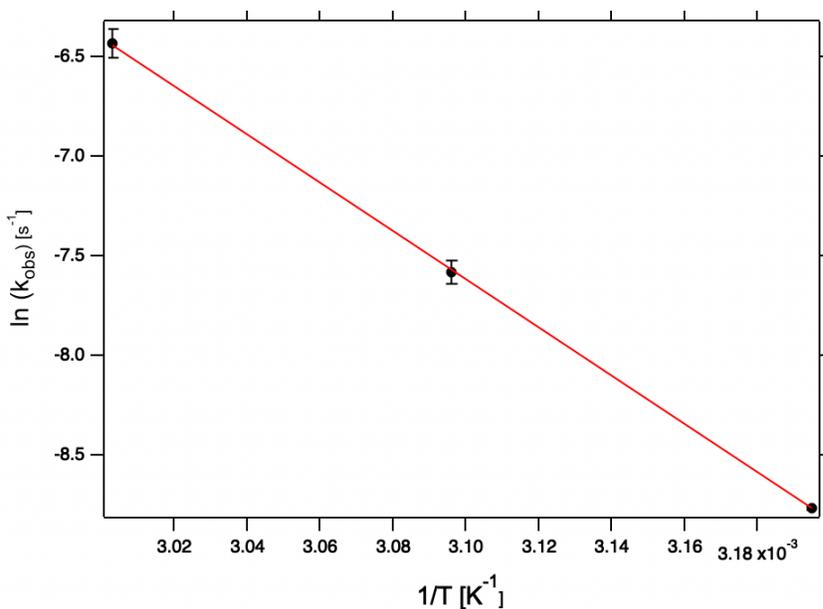
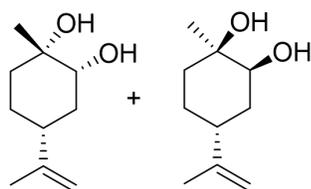


Figure S4. Arrhenius plot for 3-Per (**10**) conversion. Error bars represent \pm one standard deviation from the mean from triplicate measurements. The line of best fit represents a least squares regression weighted by the standard deviation of each point: $\ln(k) = -12111 (\pm 300) (1/T) + 30 (\pm 1)$, $R^2 = 0.999$, $E_a = 101 \pm 3$ (kJ/mol).

S4. Synthesis of Diols

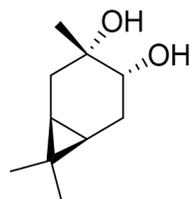
General Procedure (adapted from Lu and Lin 2011)

The starting material (1.1 mL) and $\text{Me}_3\text{NO} \cdot 2 \text{H}_2\text{O}$ (1.5 equiv) were suspended in a mixture of THF (11.2 mL), D.I. water (1.3 mL), and acetone (3.8 mL). Then, 1% OsO_4 (aq) (0.01 equiv) was added to the mixture, and it was microwaved to 120 °C for 15 minutes with 1.5 minutes of pre-stirring. The reaction mixture was concentrated in vacuo to remove the organic solvents, then diluted with saturated NH_4Cl (aq) (10 mL) and extracted into EtOAc (3 x 15 mL). The organic extracts were dried with anhydrous Na_2SO_4 , gravity filtered, and concentrated in vacuo.



Limonene Diol

(+)-Limonene was used as the starting material according to the general procedure above. The crude product was purified by column chromatography (40 g SiO_2 , 20% EtOAc/hexane for 5 CV, 20-30% over 5 CV, 30% for 15 CV), yielding the mixture of limonene diols as a white solid (0.479 g, 41% yield).



Carene Diol

3-Carene was used as the starting material according to the general procedure above. The crude product was purified by column chromatography (40 g SiO_2 , 0-100% EtOAc/hexane), yielding carene diol as a white solid (0.939 g, 79% yield): ^1H NMR (400 MHz, CDCl_3) δ 3.19 (dd, $J = 9.5, 7.3$ Hz, 1H), 2.09 (ddd, $J = 17.2, 15.1, 8.5$ Hz, 2H), 1.68 (ddd, $J = 14.6, 9.5, 8.1$ Hz, 1H), 1.24 (dd, $J = 15.6, 4.5$ Hz, 1H), 1.21 (s, 3H), 1.00 (s, 3H), 0.90 (s, 3H), 0.86 (t, 8.6 Hz, 1H), 0.63 (td, $J = 9.4, 4.5$ Hz, 1H); ^{13}C NMR (101 MHz, CDCl_3) δ 73.30, 70.35, 33.37, 28.69, 27.03, 25.52, 21.66, 17.61, 16.35, 15.50.

S5. NMR Scale Solubility Studies

2-Lim (9) and 3-Lim (8) in D₂O

A true solubility study was not able to be carried out on 2-Lim (9) and 3-Lim (8) because they react with water. Thus, this experiment was meant to demonstrate the solubility of the reaction mixture. The solubility of 2-Lim (9) and 3-Lim (8) was not quantified because it is likely that the reaction quickly became a complex mixture of compounds.

General Procedure. 2-Lim (9) and 3-Lim (8) (20 mg) was rinsed into an NMR tube using a solution of dimethyl-2-silapentane-5-sulfonate sodium salt (DSS, internal standard) in D₂O (1 mg in 1 mL). The mixture was mixed by vortexing for 2 minutes, then monitored by ¹H NMR for 5 hours.

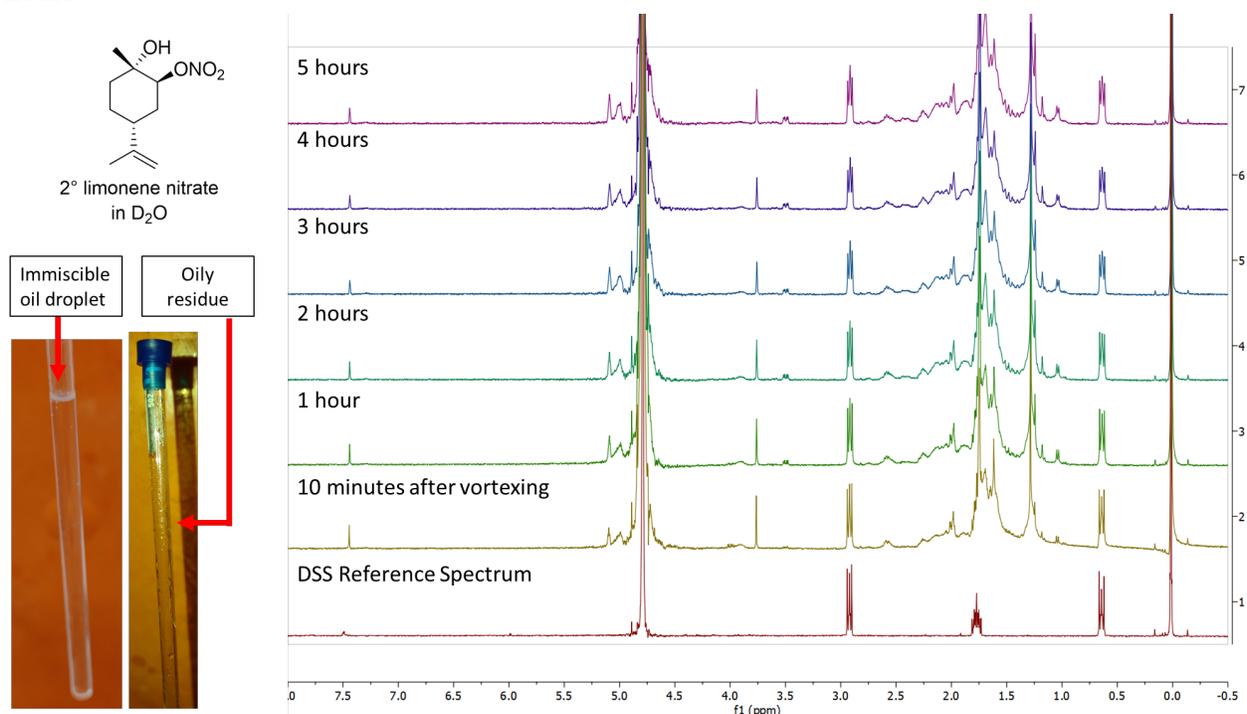


Figure S5. 2-Lim (9) dissolution in D₂O over 5 hours. Despite making up only 5% of the moles in the mixture, the DSS signal dominated the NMR spectrum. This indicates that the solubility of 2-Lim (9).

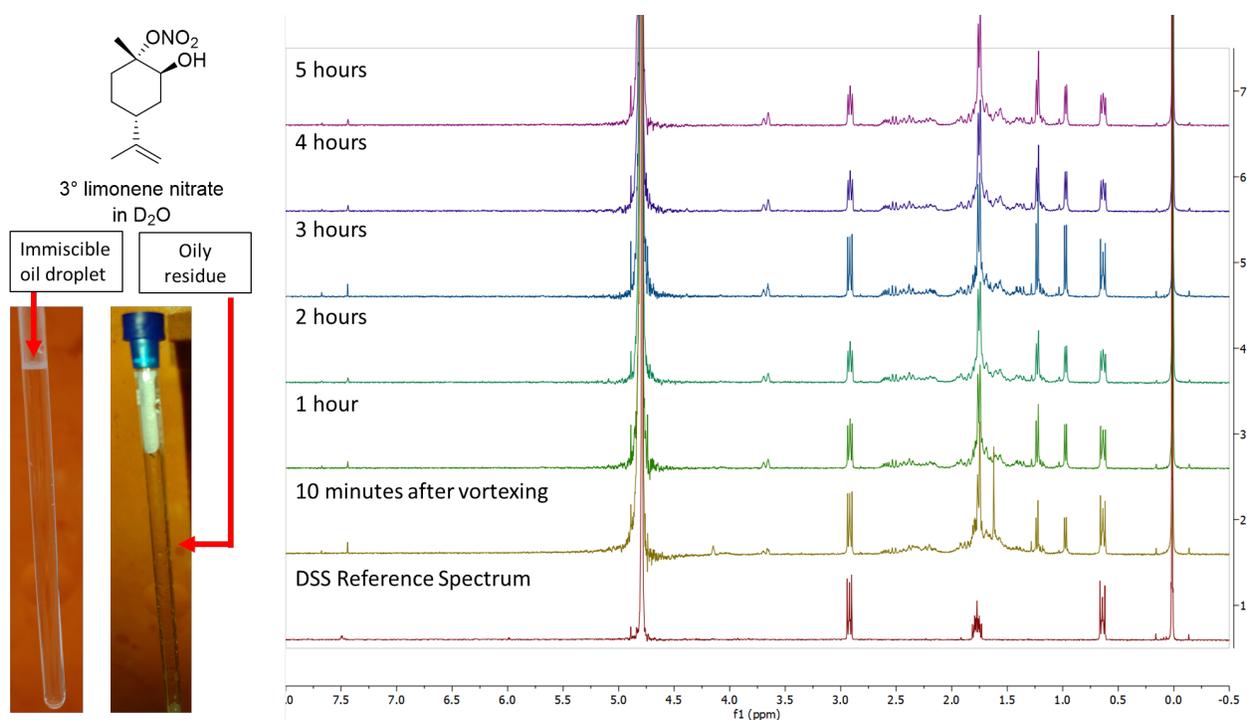
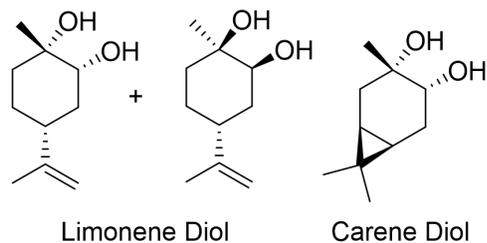


Figure S6. 3-Lim (**8**) dissolution in D₂O over 5 hours. Despite making up only 5% of the moles in the mixture, the DSS signal dominated the NMR spectrum. This indicates that the solubility of 3-Lim (**8**) is very low in D₂O.

Carene and Limonene Diols in D₂O



General Procedure. Carene or limonene diol (20 mg) was rinsed into an NMR tube using a solution of dimethyl-2-silapentane-5-sulfonate sodium salt (DSS, internal standard) in D₂O (1 mg in 1 mL). The mixture was mixed by sonication for 5 minutes, then a ¹H NMR spectrum was recorded. It was sonicated for 5 minutes again 1 hour after mixing, then a ¹H NMR spectrum was recorded. The mixture was sonicated for 10 minutes after 24 hours had passed since mixing, then a ¹H NMR spectrum was recorded. The concentration of diol in solution was determined by integration of a characteristic signal (3.29 ppm for carene diol, 1H and 3.70 + 3.50 ppm for limonene diol, 1H each) relative to the internal standard (2.92 ppm, 2H). The percent dissolved was quantified by comparing the calculated concentration of diol to the amount of diol actually added.

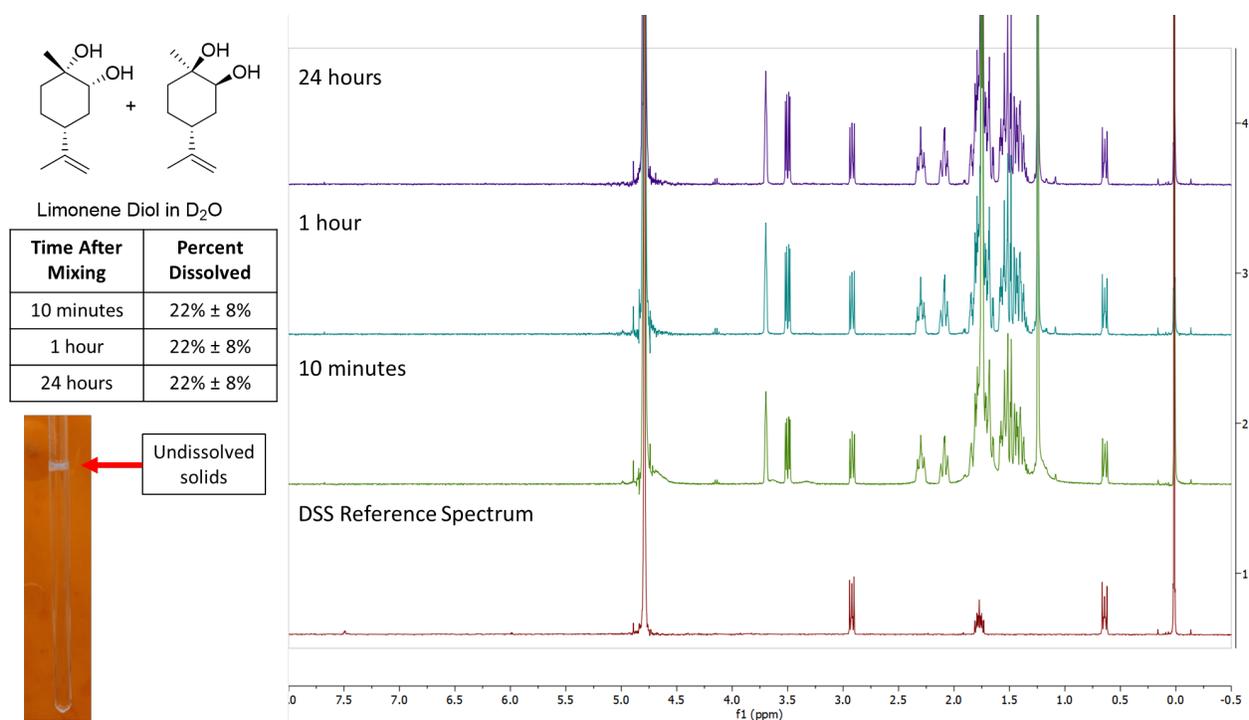


Figure S7. Limonene diol dissolution over 24 hours. Diols had limited solubility in D₂O, even with sonication and time.

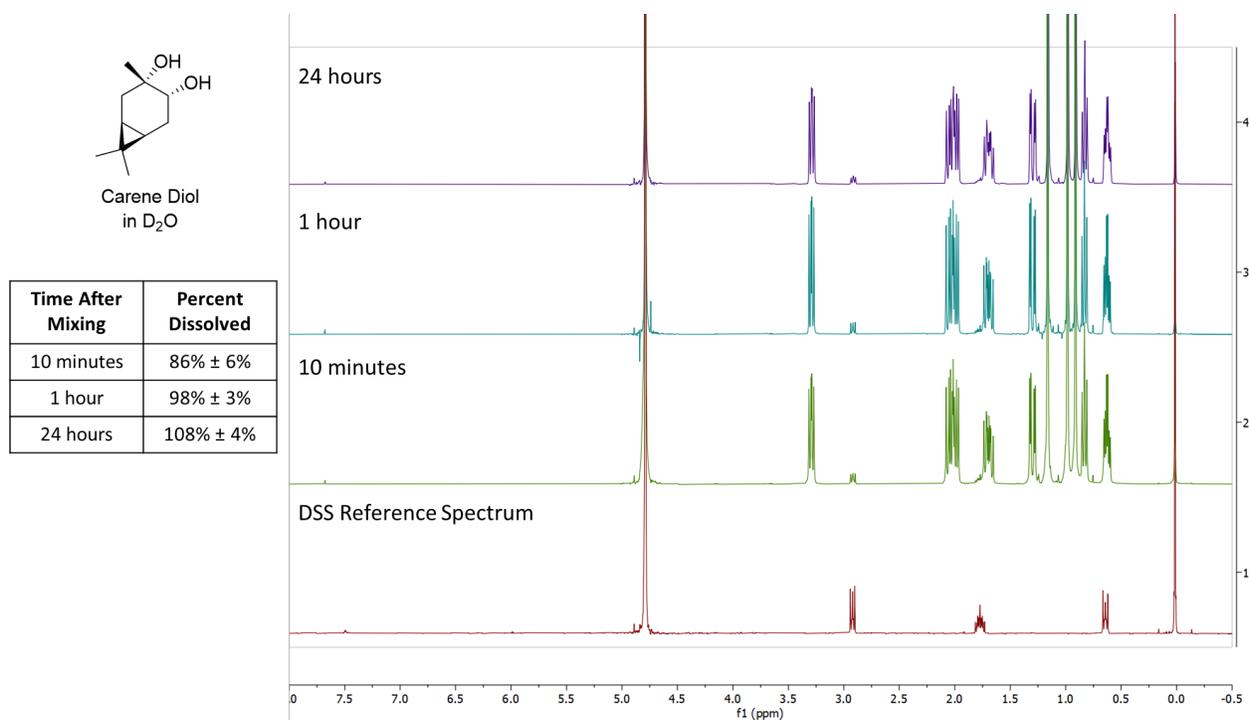


Figure S8. Carene diol dissolution over 24 hours. Diol was relatively well soluble in D₂O.

S6. Time Series for 3-Car (4) Conversion in 8.4% D₂O/DMSO at 30 °C

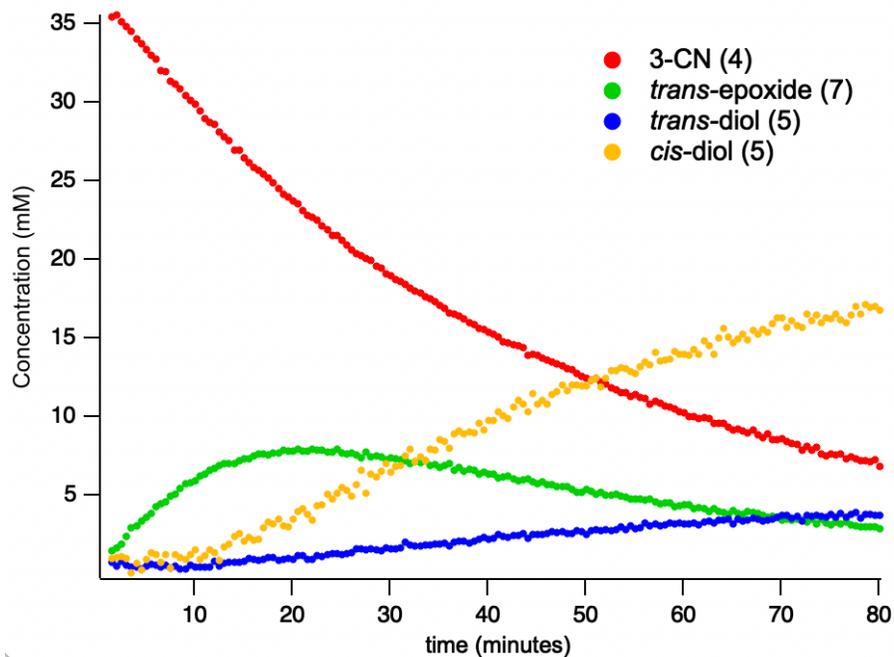


Figure S9. A. Substitution and rearrangement reaction products from 3-CN (4); **B.** Time series for the conversion of 3-Car (4) and the formation of the major products in 25% D₂O/DMSO-*d*₆.

Figure S10. ^1H NMR spectra over time showing the reaction progression of 3-Car (**4**) in 10% (v/v) $\text{D}_2\text{O}/\text{DMSO-}d_6$ at 30 $^\circ\text{C}$.

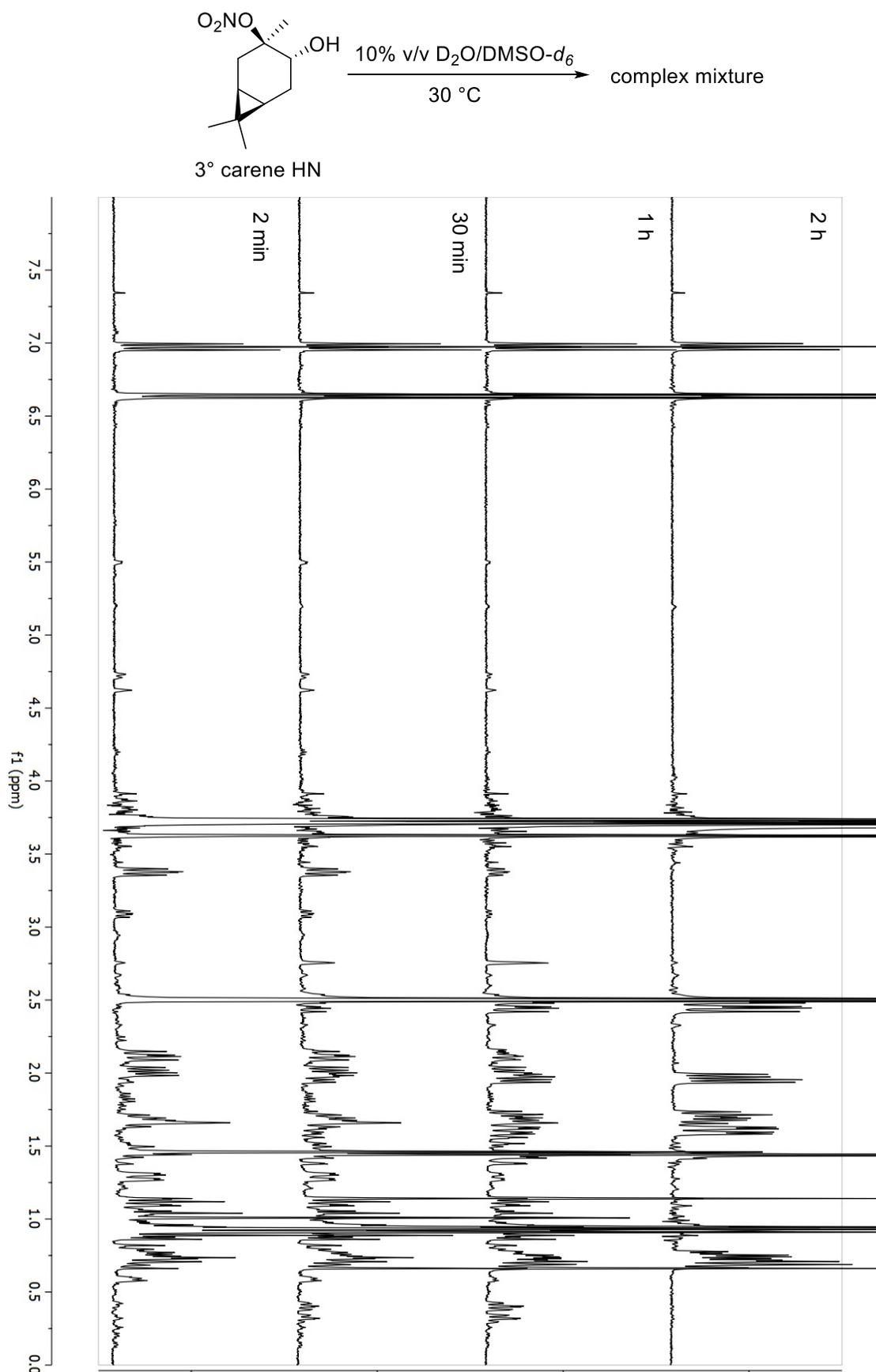


Figure S11. ^1H NMR spectra over time showing the reaction progression of 3-Car (**4**) with 5 equiv D_2SO_4 in 25% (v/v) $\text{D}_2\text{O}/\text{DMSO-}d_6$ at 30 °C.

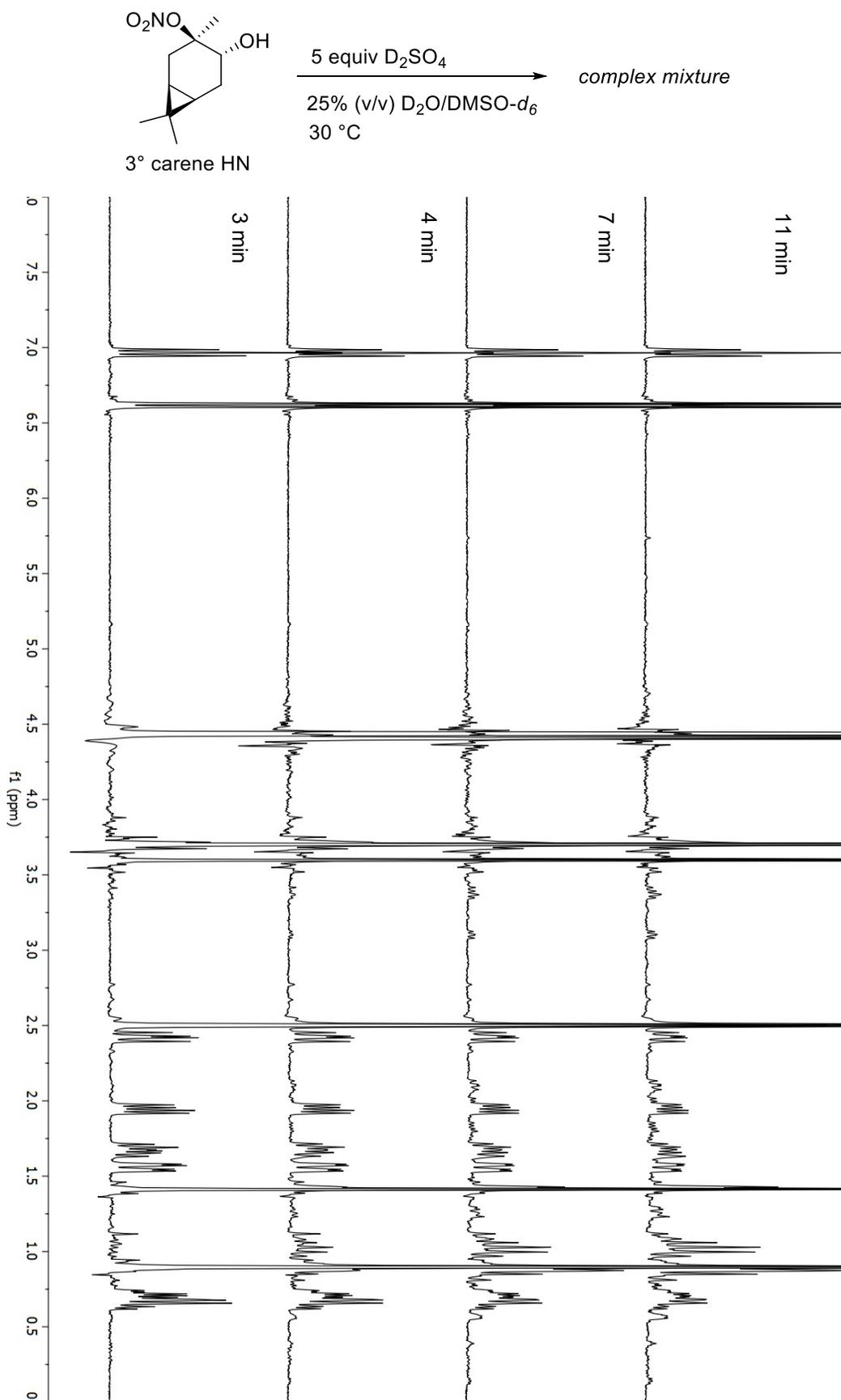


Figure S12. ^1H NMR spectra over time showing the reaction progression of 3-Lim (**8**) with 5 equiv D_2SO_4 in 25% (v/v) $\text{D}_2\text{O}/\text{DMSO-}d_6$ at 30 °C.

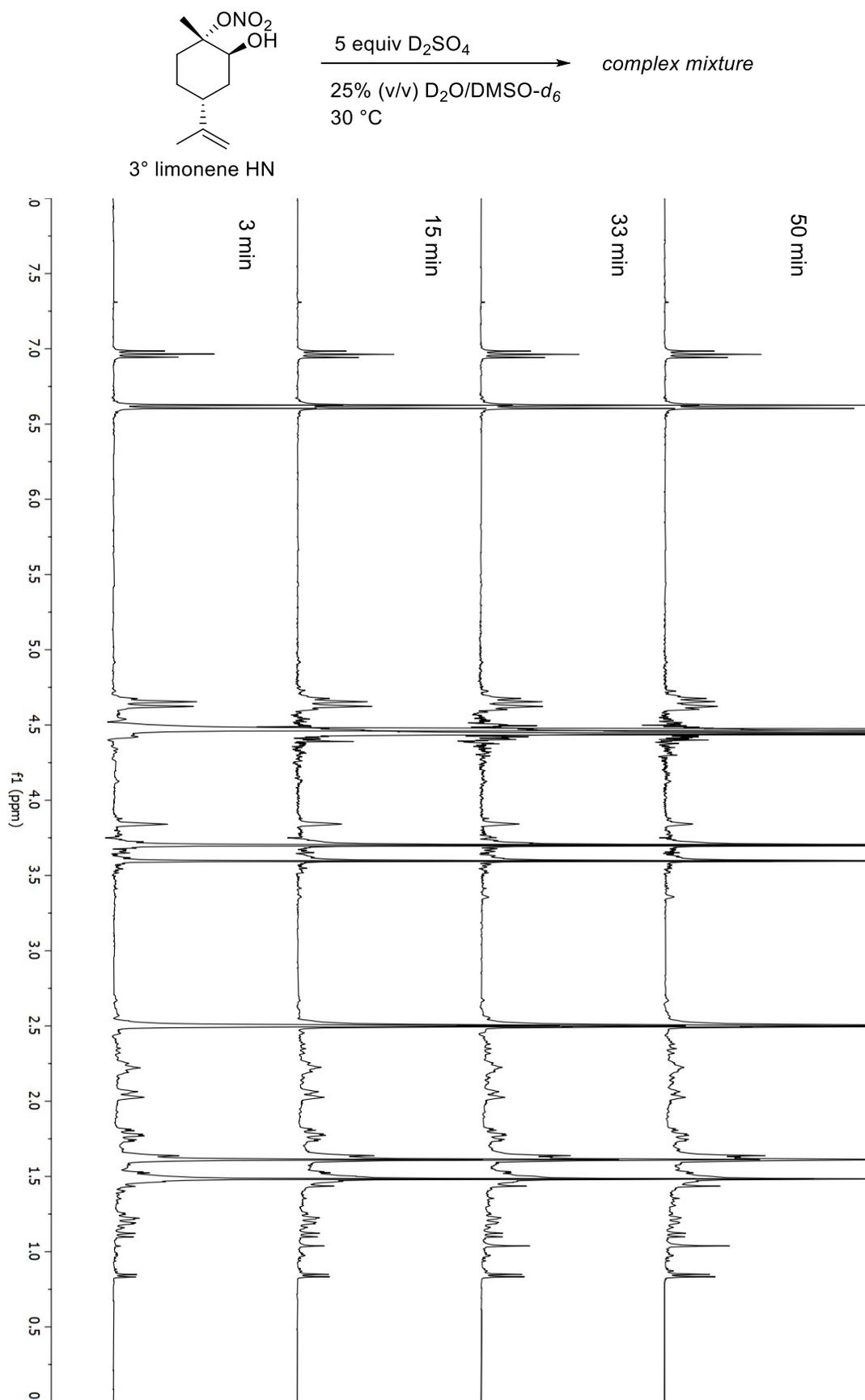


Figure S13. ^1H NMR spectra over time showing the reaction progression of 2-Lim (**9**) with 5 equiv D_2SO_4 in 25% (v/v) $\text{D}_2\text{O}/\text{DMSO-}d_6$ at 70°C .

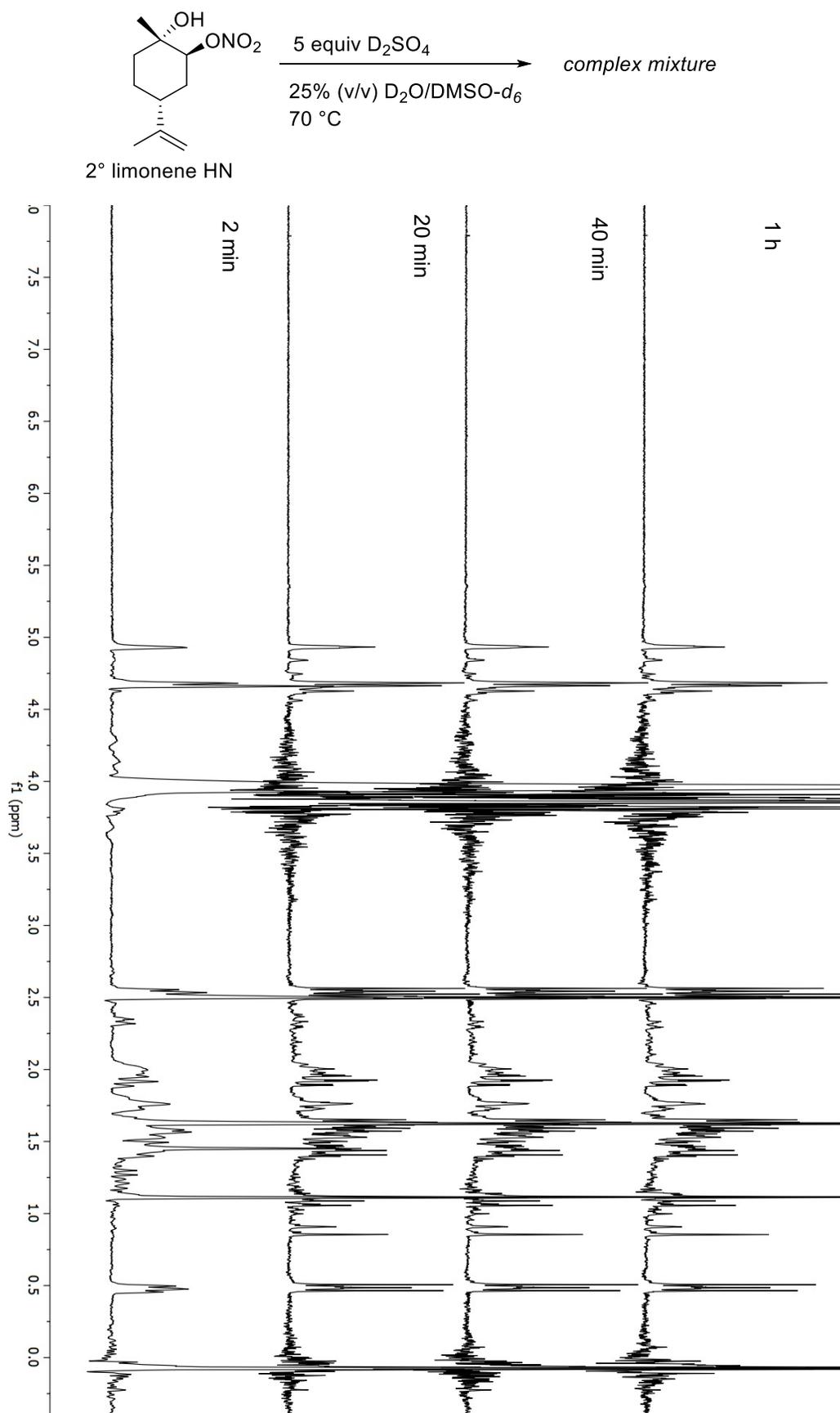


Figure S14. ^1H NMR spectra over time showing the reaction progression of 4-Per (**10**) with 5 equiv D_2SO_4 in 25% (v/v) $\text{D}_2\text{O}/\text{DMSO-}d_6$ at 40°C .

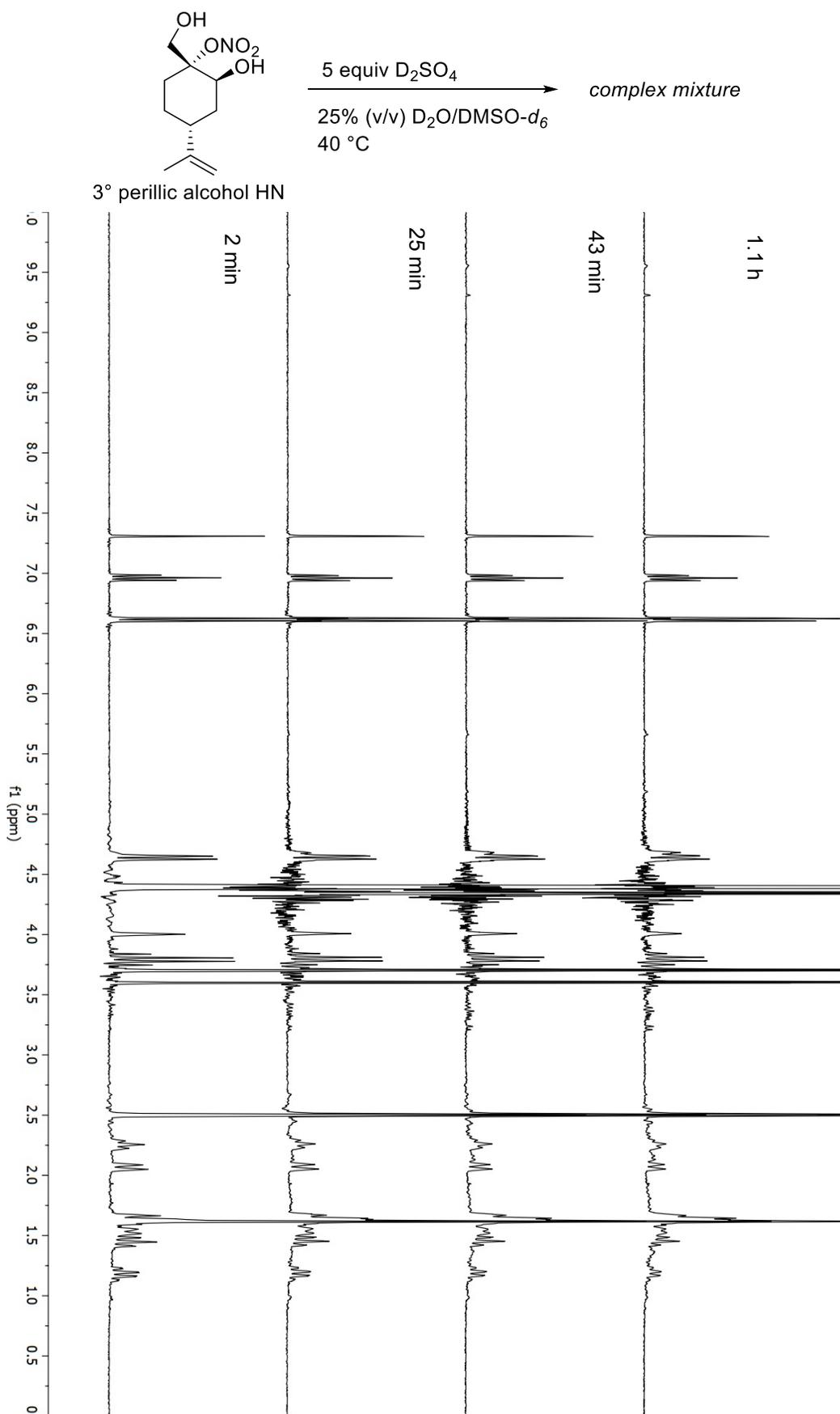


Figure S15. ^1H NMR spectra over time showing the reaction progression of 2-Per (**11**) with 5 equiv D_2SO_4 in 25% (v/v) $\text{D}_2\text{O}/\text{DMSO}-d_6$ at 80°C .

