

Prebiotic synthesis of simple sugars by photoredox systems chemistry

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The Supplementary Information contains:

- Experimental Procedures
- Figs. S1 to S24

General Experimental

All reagents were purchased from commercial sources and used without further purification. ¹³C-labelled potassium cyanide had an isotopic incorporation of 99%. Photochemical reactions were carried out in a Spectrosil quartz screw-cap cuvette, purchased from Sigma-Aldrich, using a Rayonet RPR-200 photochemical chamber reactor, acquired from The Southern New England Ultraviolet Company. A Mettler Toledo SevenEasy pH Meter S20 was used to monitor pH and deoxygenation of solutions was achieved by sparging anhydrous argon through the desired aqueous solution for 15–20 min. ¹H and ¹³C-NMR spectra were acquired using a Bruker Ultrashield 400 Plus (at 400.1 MHz and 100.6 MHz respectively). Coupling constants (*J*) are given in Hertz and the notations s, d, br s represent the multiplicities singlet, doublet and broad signal. Deuterium oxide was purchased from Sigma-Aldrich.

General Procedure for Photochemical Reactions

A solution of K¹³CN (30 mg, 0.454 mmol) or KCN (30 mg, 0.461 mmol) was dissolved in H₂O (2.2 mL) and, optionally, D₂O (0.3 mL) then degassed. The cyanide solution was adjusted to pH 7.2–7.4 using degassed 1M HCl, CuCN (2 mg) was added then the mixture was transferred and sealed in a quartz cuvette fitted with a magnetic flea. The reaction was irradiated and stirred at a temperature of *ca.* 33 °C for the desired amount of time. At this point the UV source was turned off and an aliquot of

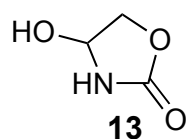
the reaction mixture was removed for NMR analysis, after which, the sample was returned to the cuvette and irradiation was continued.

To obtain an estimate of the yield of **13**, a solution of pentaerythritol, of known concentration in D₂O, was added to an NMR sample of a crude reaction mixture. A quantitative ¹³C-NMR spectrum was acquired over 5000 scans with a delay recycle of 20 s to ensure all nuclei relaxed fully and nOe build-up was removed. Normalization of the integrated signals then allowed a yield to be calculated.

General Procedure for Reaction with Cyanate

The substrate (**2**, **3**, or **16**, 0.3 mmol) was dissolved in D₂O (1.5 mL) and KNCO (4 eq) was added. The pH was adjusted to *ca.* 8 with DCl until it remained constant and then samples were taken for NMR analysis.

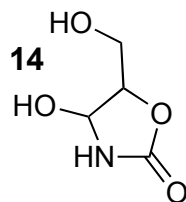
4-Hydroxy-1,3-oxazolidin-2-one (**13**) from glycolaldehyde (**2**)



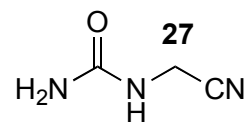
¹H-NMR (D₂O) δ 5.42 (1H, dd, *J* 6.1, 1.7), 4.50 (1H, dd, *J*, 10.3, 6.1), 4.18 (1H, dd, *J* 10.3, 1.7) (Fig. S1); ¹³C-NMR (D₂O) δ 161.0, 76.7, 73.7 (Fig. S2).

¹H-NMR (DMSO-*d*₆) δ 8.75 (1H, br s, NH), 5.44 (1H, br s, OH), 5.20 (1H, dd, *J* 6.0, 1.7), 4.34 (1H, dd, *J* 9.5, 6.0), 3.93 (1H, *J*, 9.5, 1.7). Lit.³³ ¹H-NMR (DMSO-*d*₆) δ 8.3 (1H, d, *J* 1.4), 6.25 (1H, d, *J* 6.9), 5.20 (1H, dd, *J* 6.0, 1.8), 4.34 (1H, dd, *J* 9.5, 6.0), 3.93 (1H, dd, *J* 9.5, 1.8) (Fig. S3).

4-Hydroxy-5-hydroxymethyl-1,3-oxazolidin-2-one (**14**) from glyceraldehyde (**3**)



2 Diastereoisomers A and B, 2.6:1 respectively. ¹H-NMR (D₂O) δ 5.40 (1H, B, dd, *J* 5.8, 3.1), 5.21 (1H, A, m), 4.65 (1H, B, m), 4.40 (1H, A, m), 3.89-3.64 (2H, A + B, m) (Fig. S4); ¹³C-NMR (D₂O) δ 160.2, 85.3 (A), 81.7 (B), 78.2 (A), 77.1 (B), 60.8 (A), 59.1 (B) (Fig. S5).

1-Cyanomethylurea (27) from glycine nitrile (16)

^1H -NMR (D_2O) δ 4.04 (2H, s) (Fig. S6); ^{13}C -NMR (D_2O) δ 160.6, 118.1, 28.5 (Fig. S7).

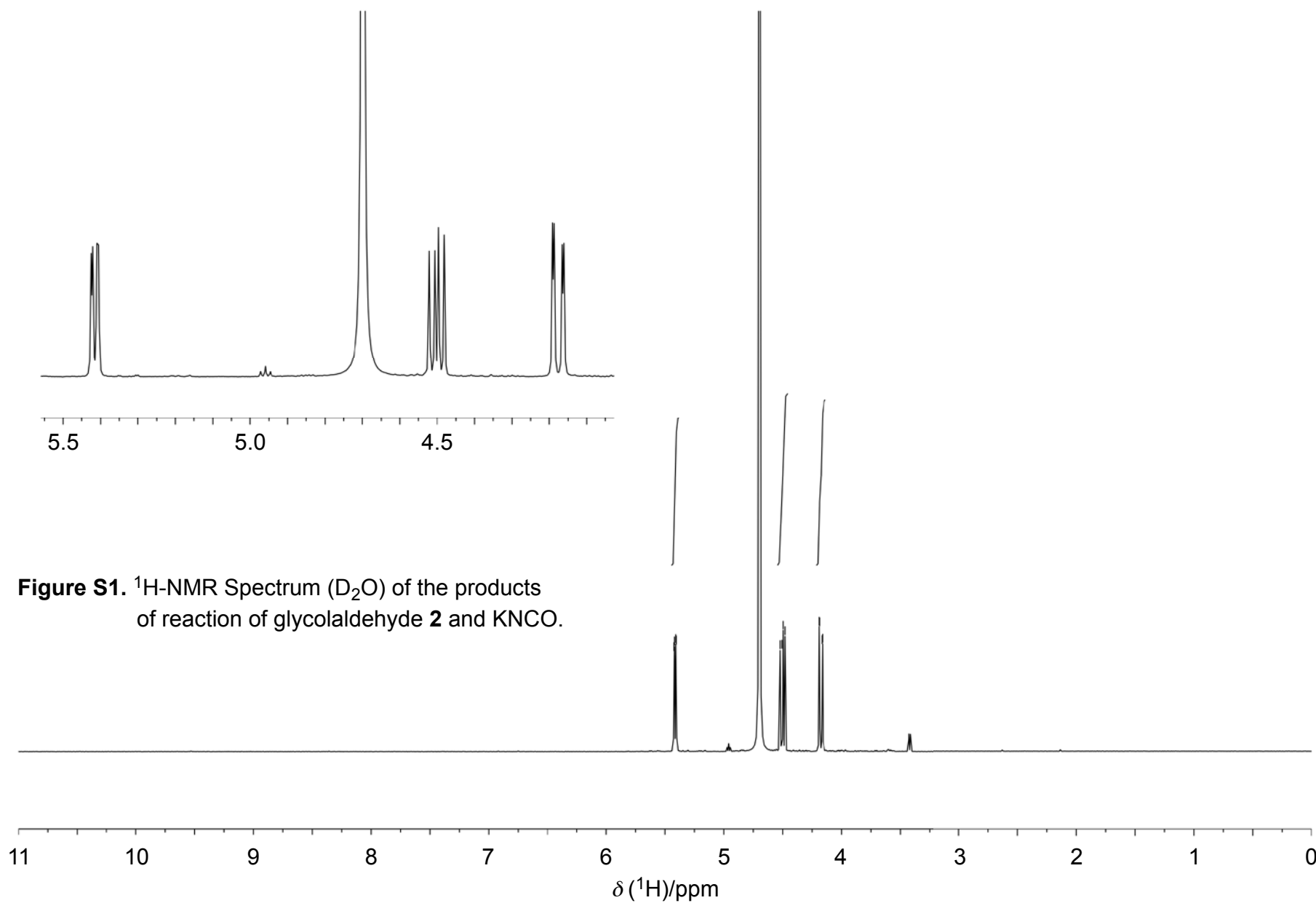


Figure S1. ^1H -NMR Spectrum (D_2O) of the products of reaction of glycolaldehyde **2** and KNCO .

Figure S2. ^{13}C -NMR Spectrum (D_2O) of the products of reaction of glycolaldehyde **2** and KNCO .

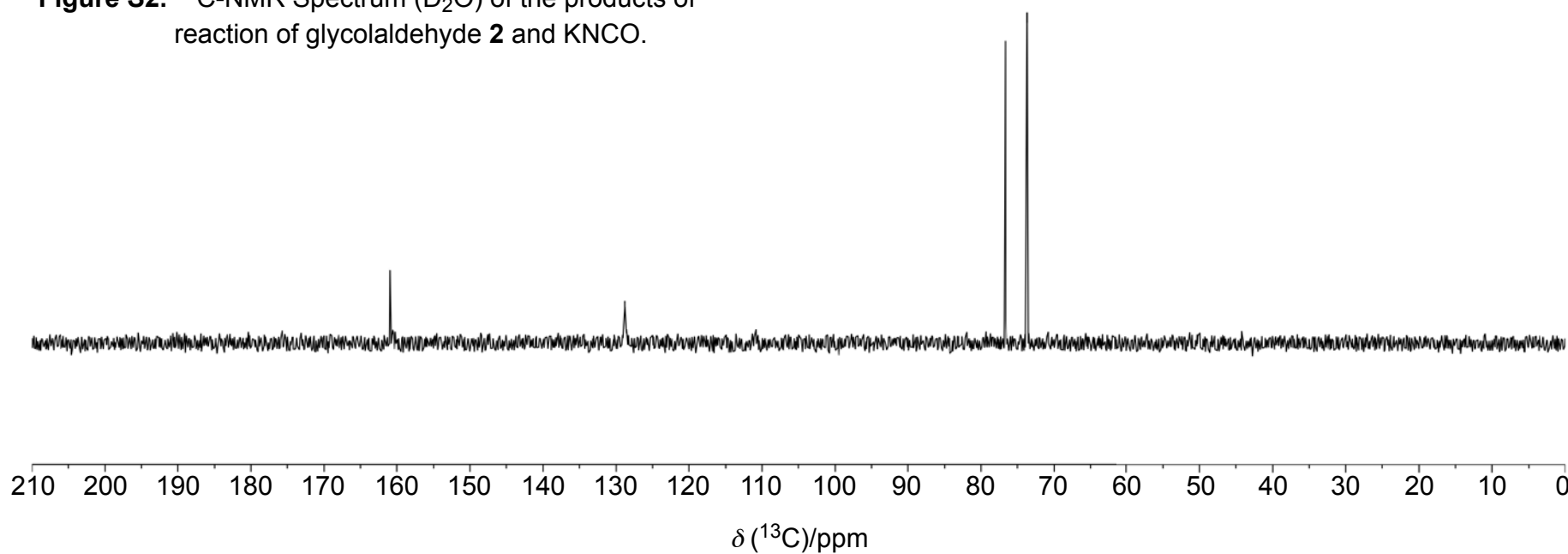
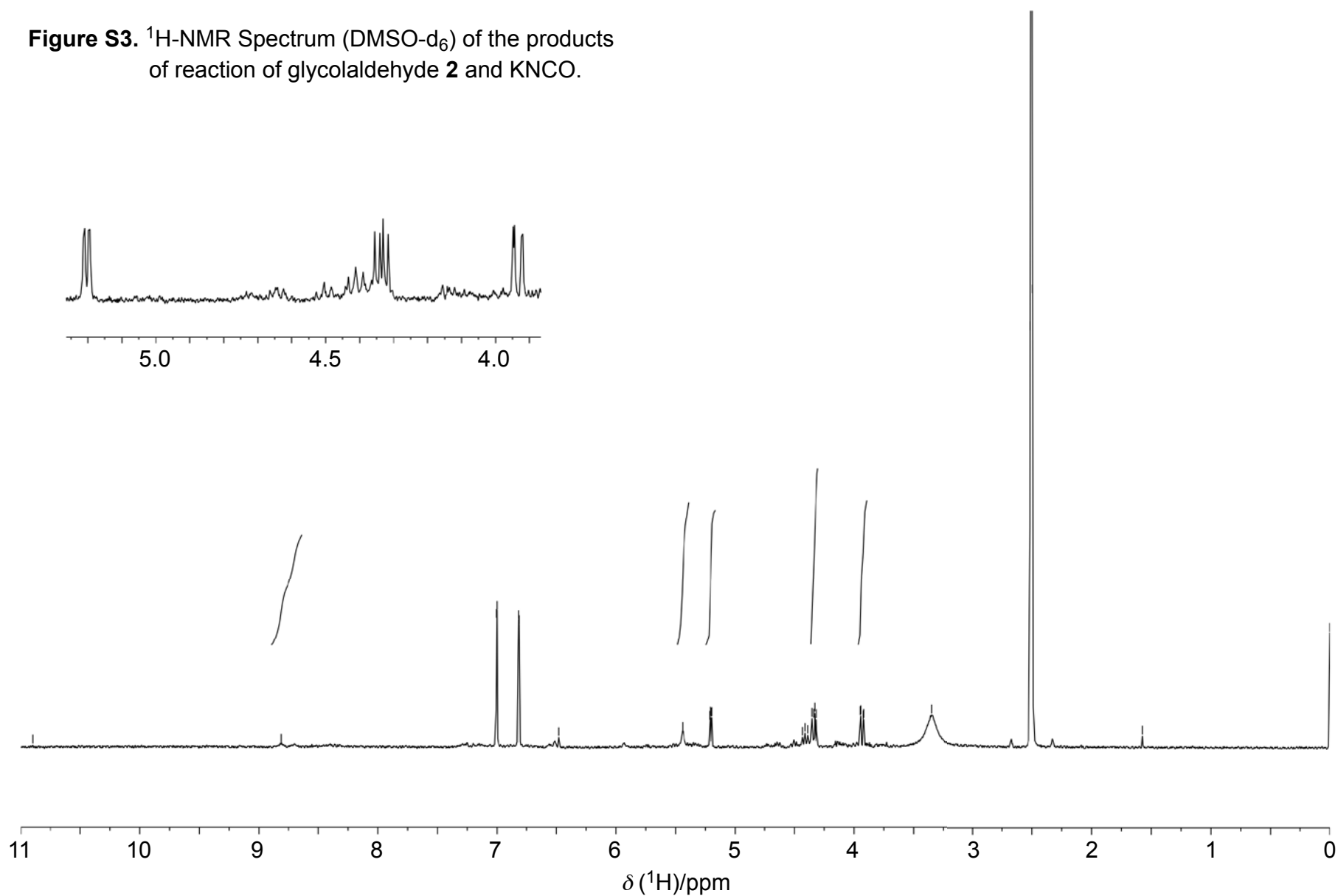


Figure S3. ^1H -NMR Spectrum (DMSO- d_6) of the products of reaction of glycolaldehyde **2** and KNCO .



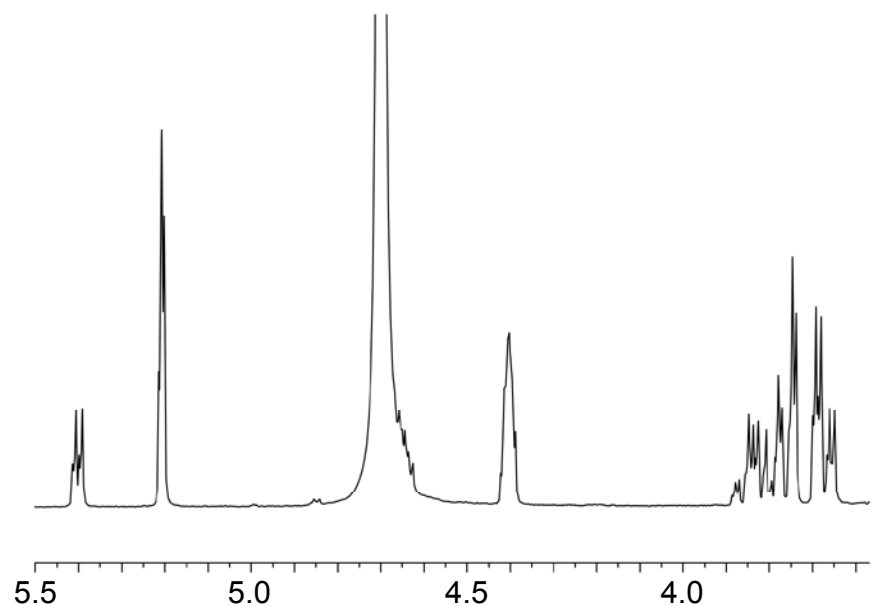


Figure S4. ^1H -NMR Spectrum (D_2O) of the products of reaction of glyceraldehyde **3** and KNCO .

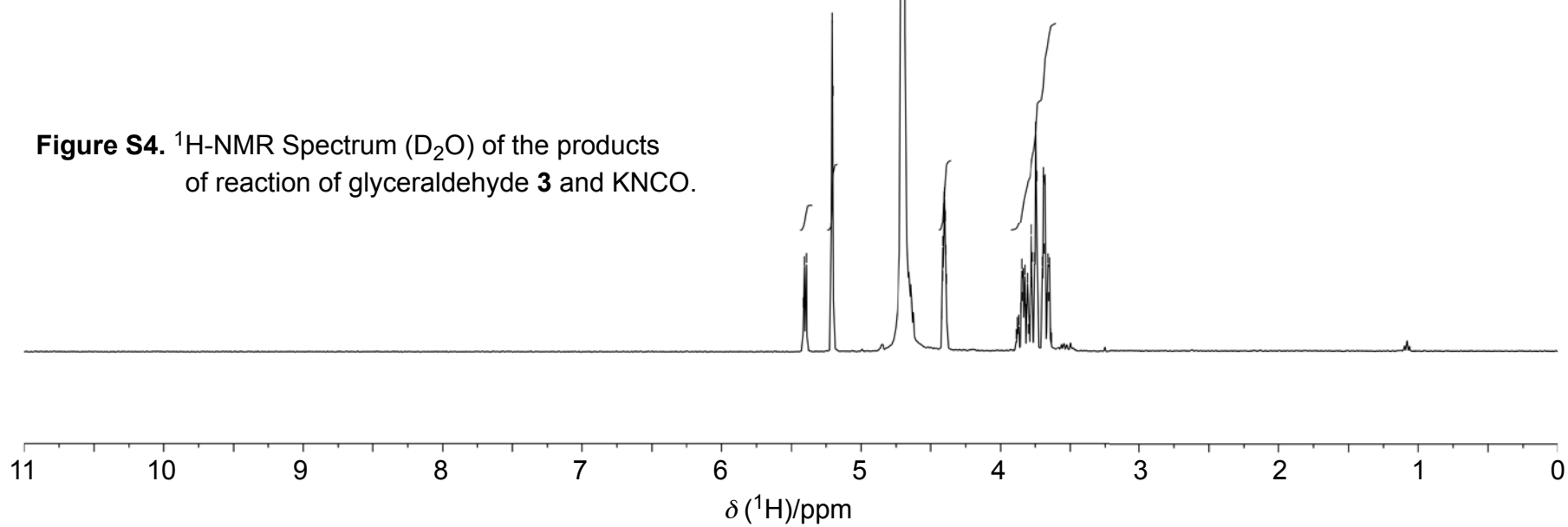


Figure S5. ^{13}C -NMR Spectrum (D_2O) of the products of reaction of glyceraldehyde **3** and KNCO .

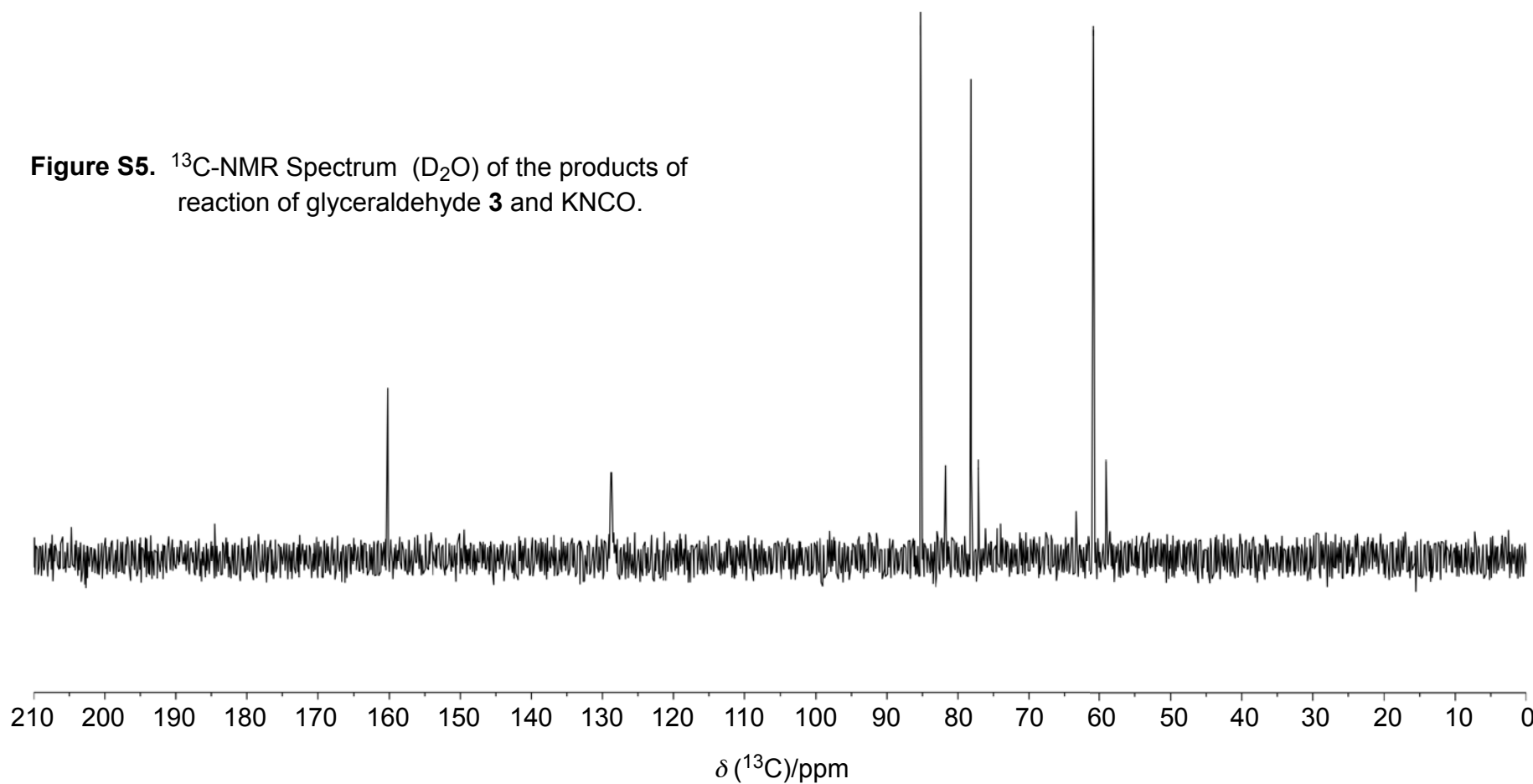


Figure S6. ^1H -NMR Spectrum (D_2O) of the products of reaction of glycine nitrile **16** and KNCO .

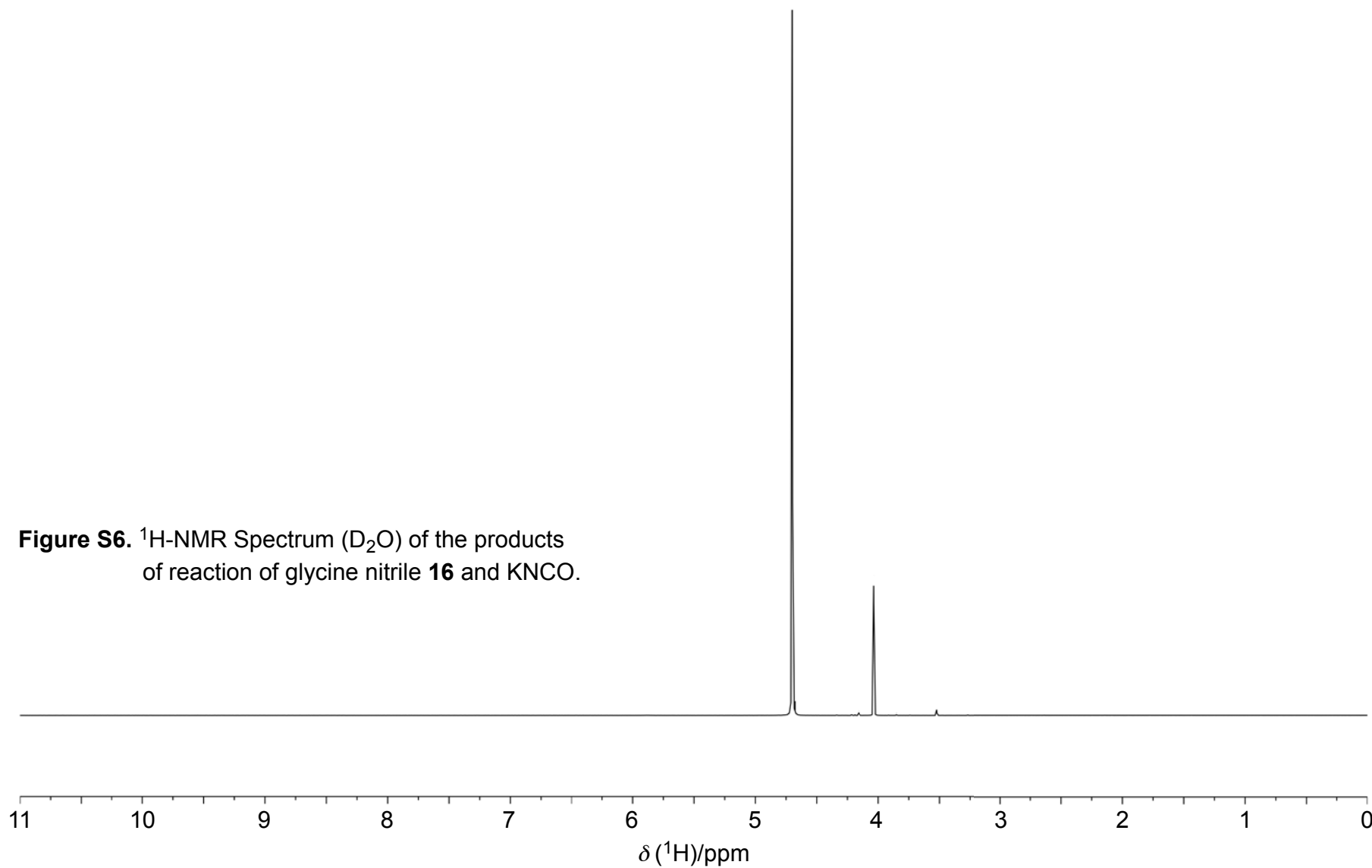


Figure S7. ^{13}C -NMR Spectrum (D_2O) of the products of reaction of glycine nitrile **16** and KNCO .

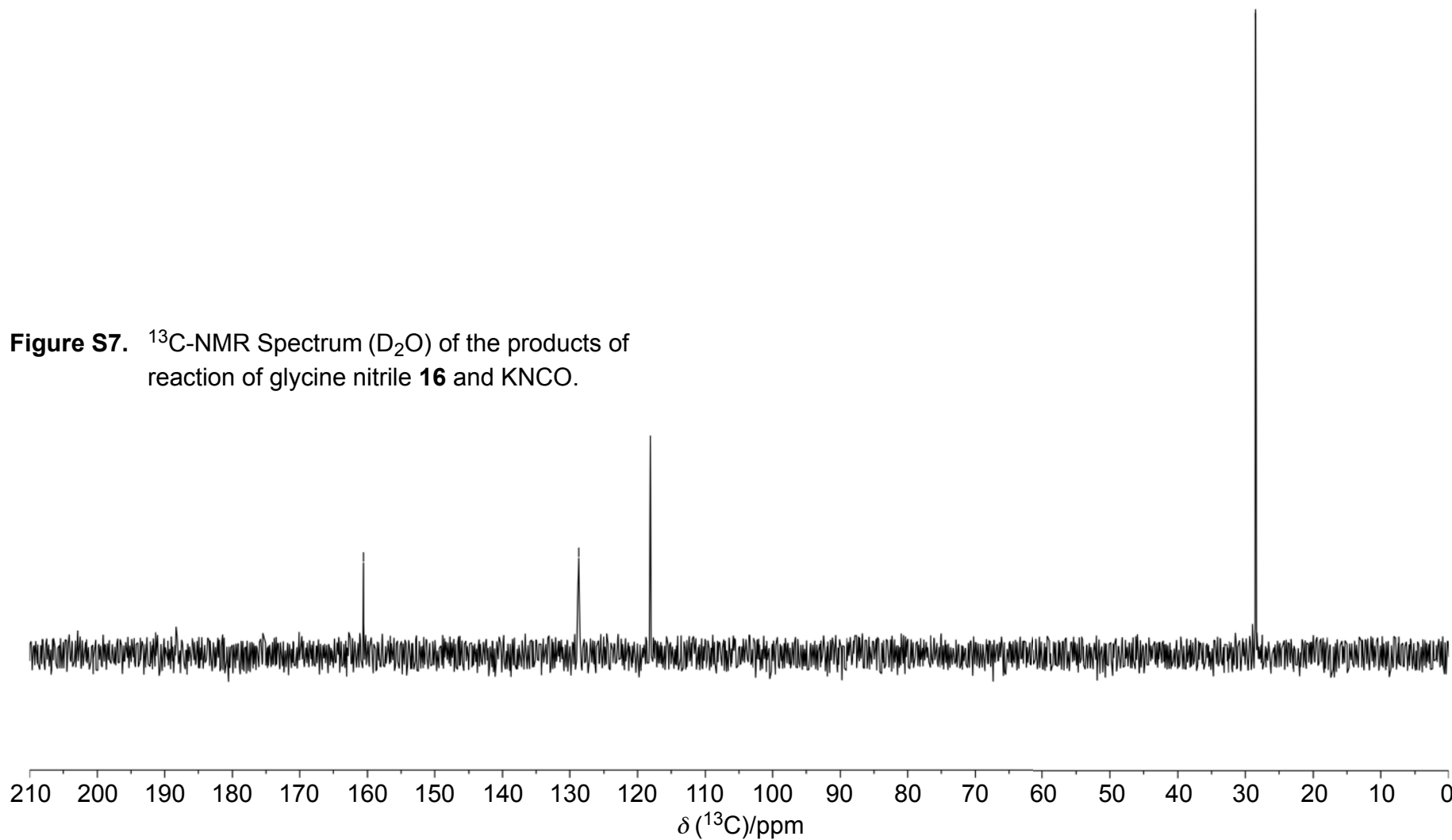


Figure S8. ^1H -NMR Spectrum (D_2O) of glycine nitrile **16**.

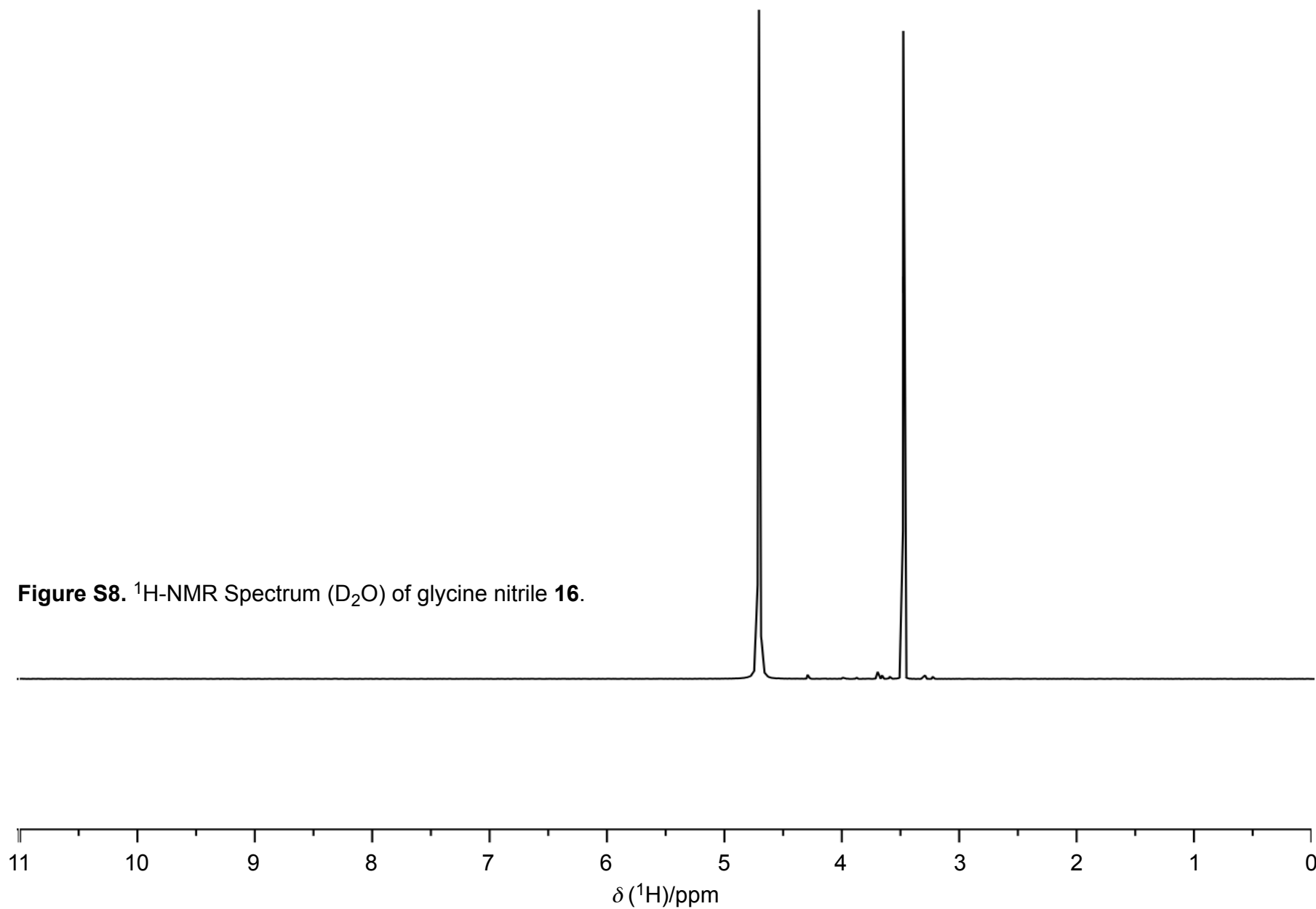


Figure S9. ^{13}C -NMR Spectrum (D_2O) of glycine nitrile **16**.

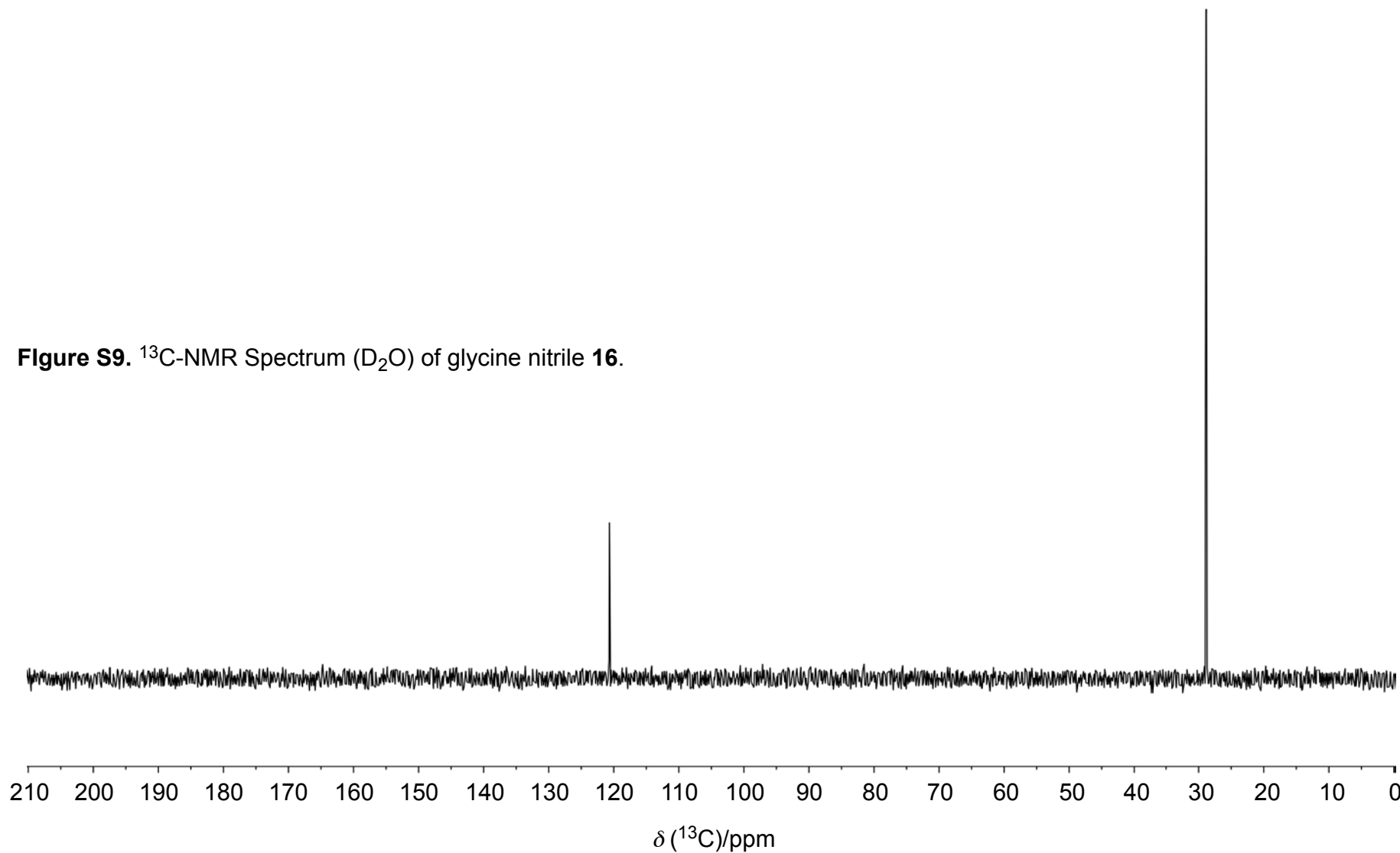
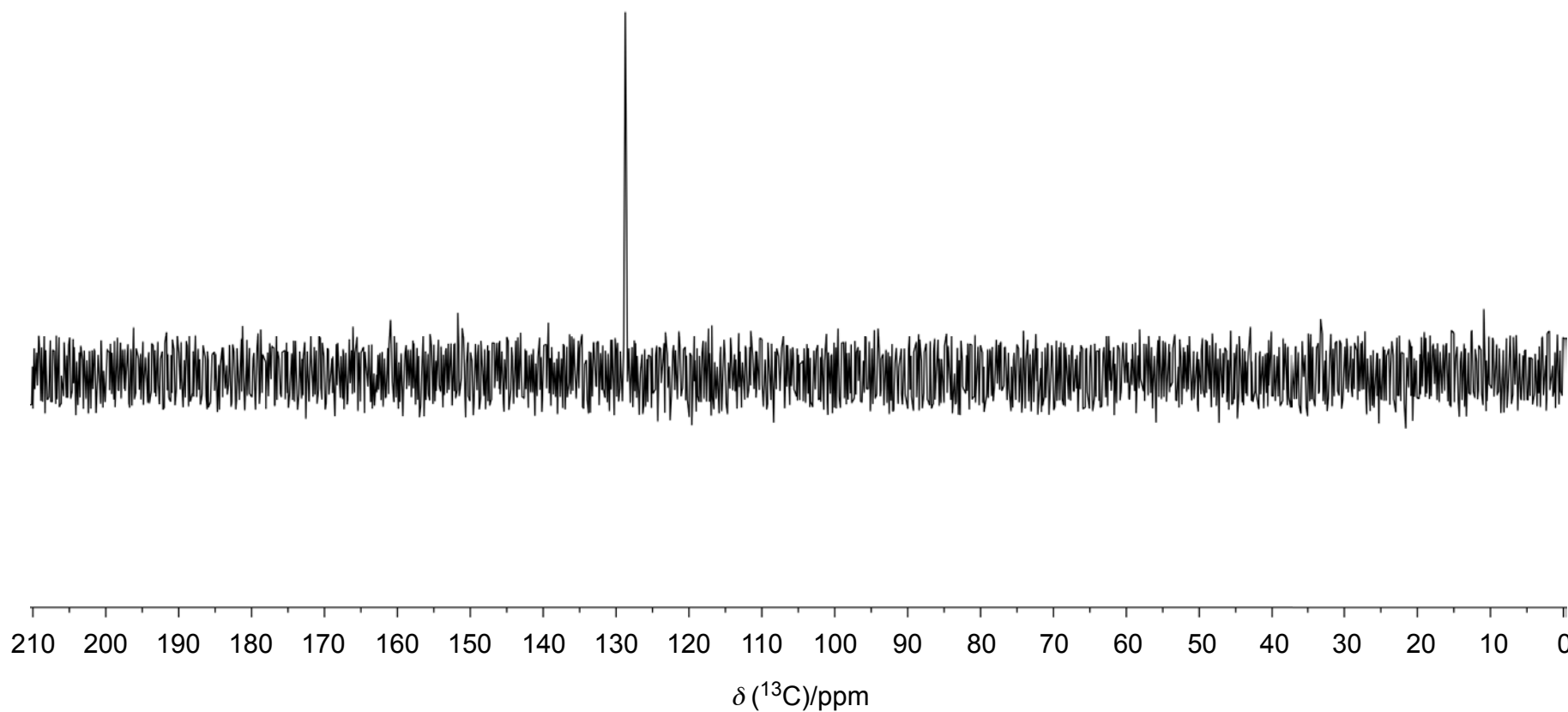
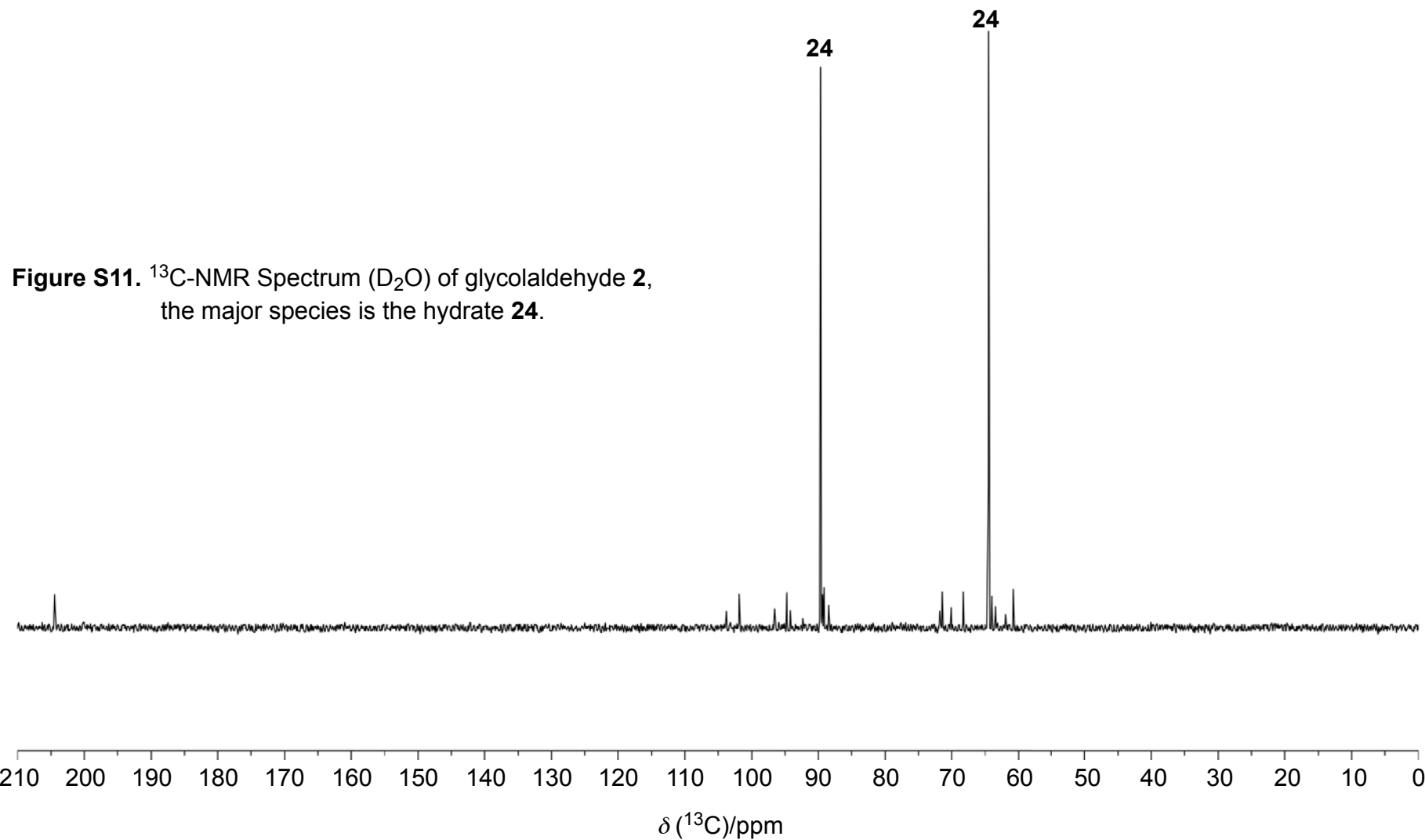


Figure S10. ^{13}C -NMR Spectrum (D_2O) of potassium cyanate at pD = 8. This serves as a standard for the cyanate anion of **20** and cyanate anion conjugate base of **18**.





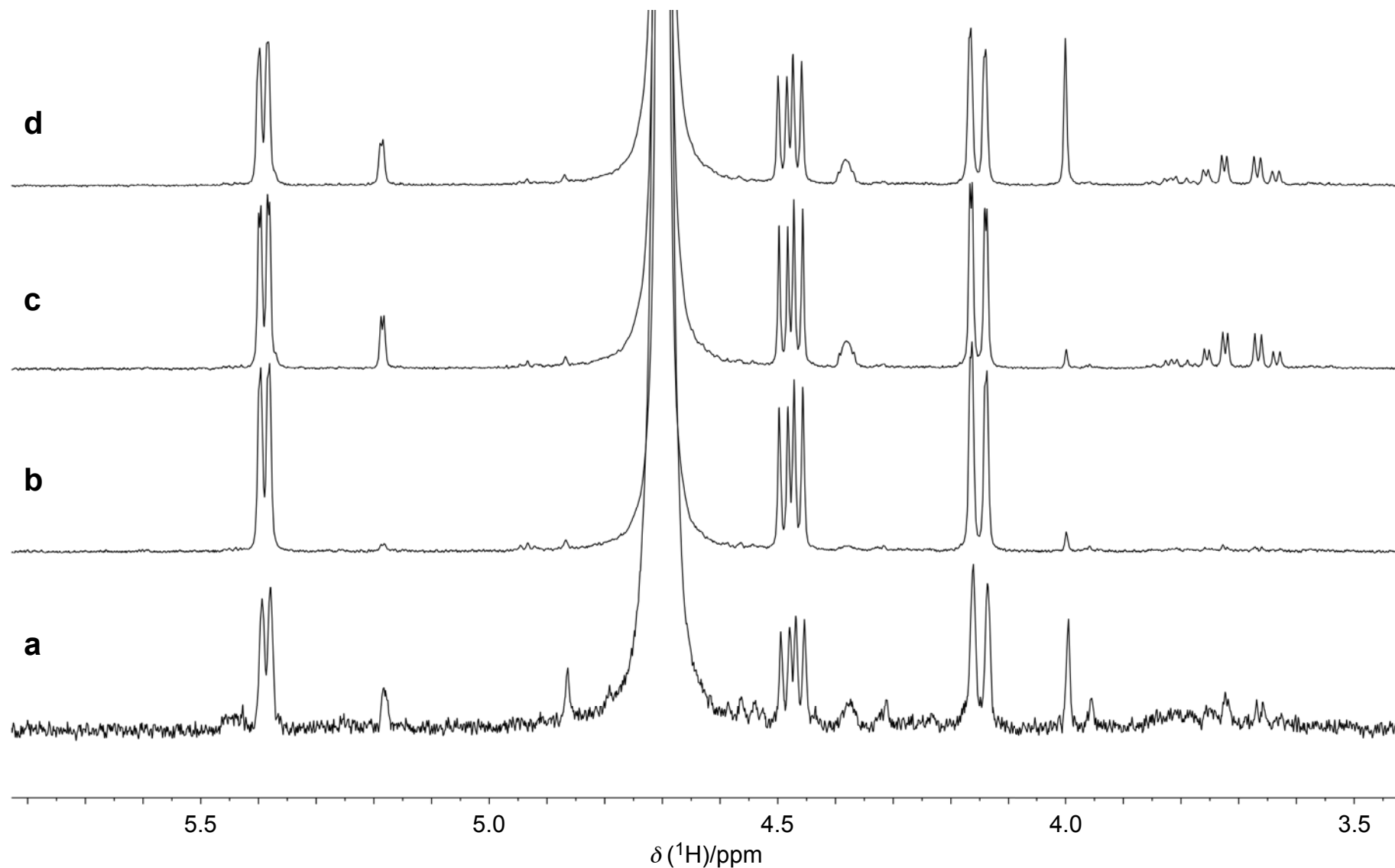


Figure S12. ^1H -NMR Spectra (D_2O) from a sequential spiking experiment: **a**, crude soluble photochemical reaction products; **b**, as **a**, spiked with **13**; **c**, as **b**, spiked with **14**; **d**, as **c**, spiked with **27**.

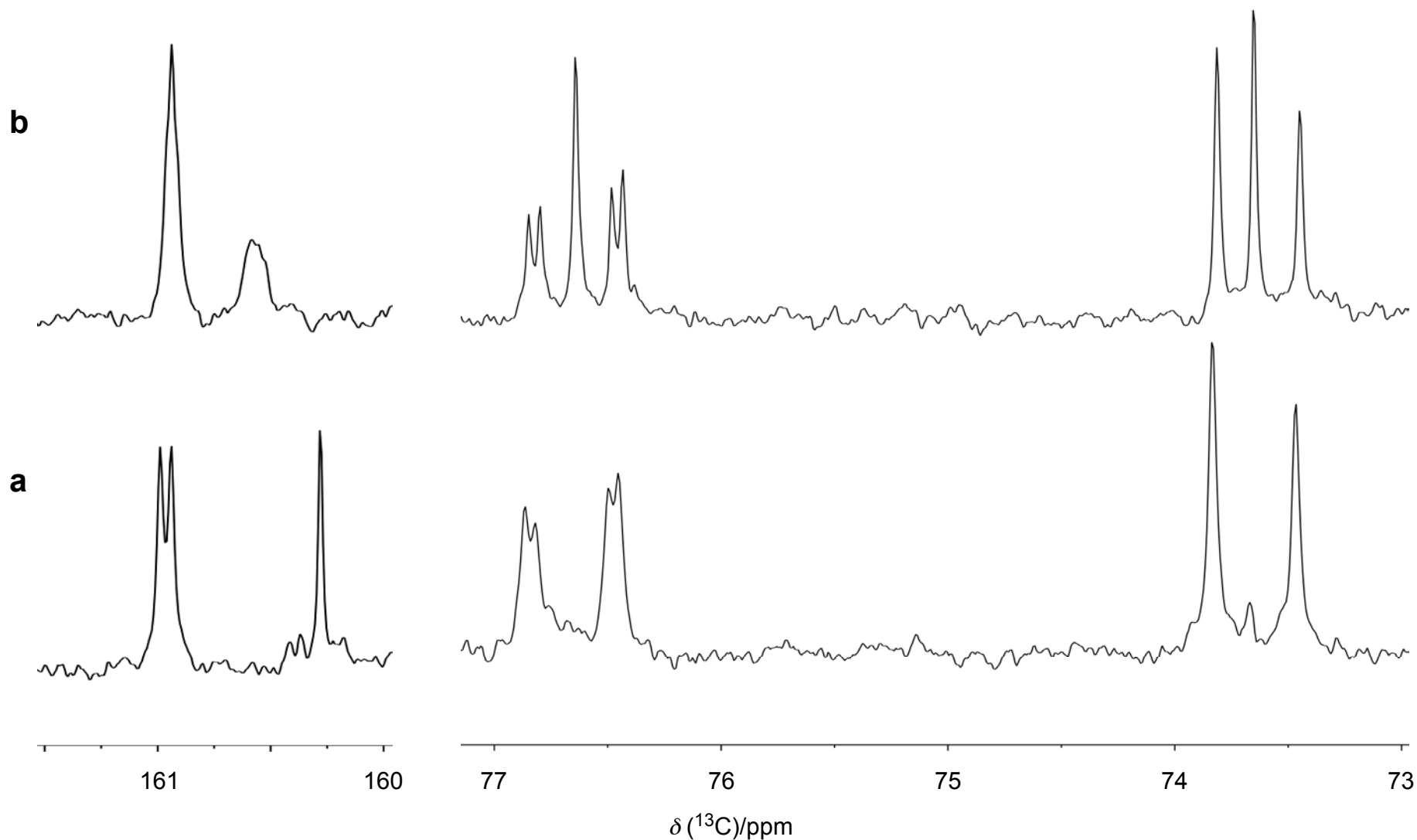


Figure S13. ^{13}C -NMR Spectra ($\text{H}_2\text{O}/\text{D}_2\text{O}$ (9:1)) from a spiking experiment using crude soluble photochemical reaction products derived from K^{13}CN : **a**, enlargement to show signals derived from ^{13}C -labelled **13** (singlet at $\delta = 160.25$ is due to **30**); **b**, as **a**, spiked with unlabelled **13** (signal due to **30** has broadened and shifted presumably due to change in pD).

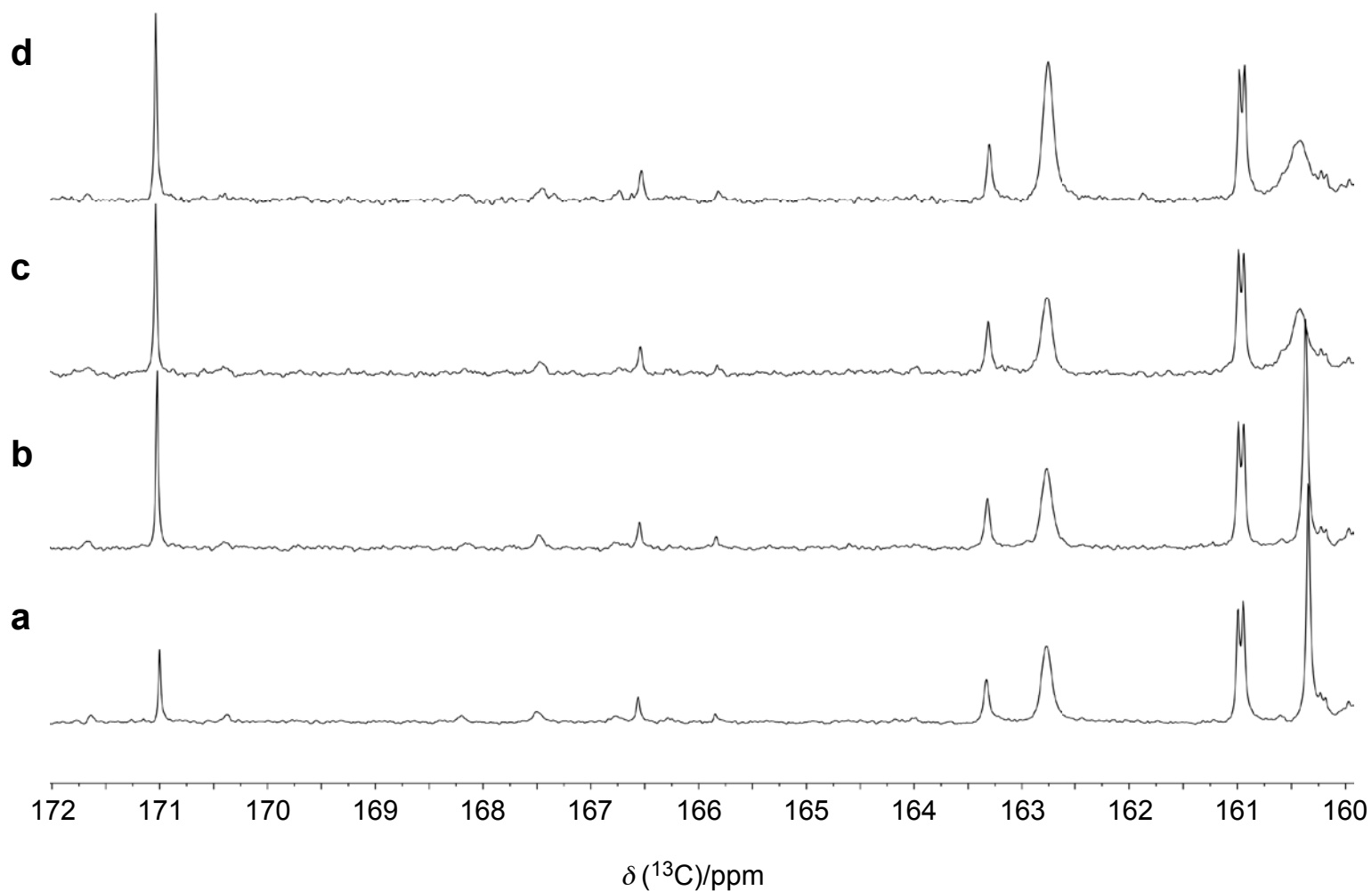


Figure S14. ^{13}C -NMR Spectra ($\text{H}_2\text{O}/\text{D}_2\text{O}$ (9:1)) from a sequential spiking experiment: **a**, crude soluble photochemical reaction products; **b**, as **a**, spiked with **29**; **c**, as **b**, spiked with **30** (note shift and broadening of signal as in Figure S13); **d**, as **c**, spiked with **31**.

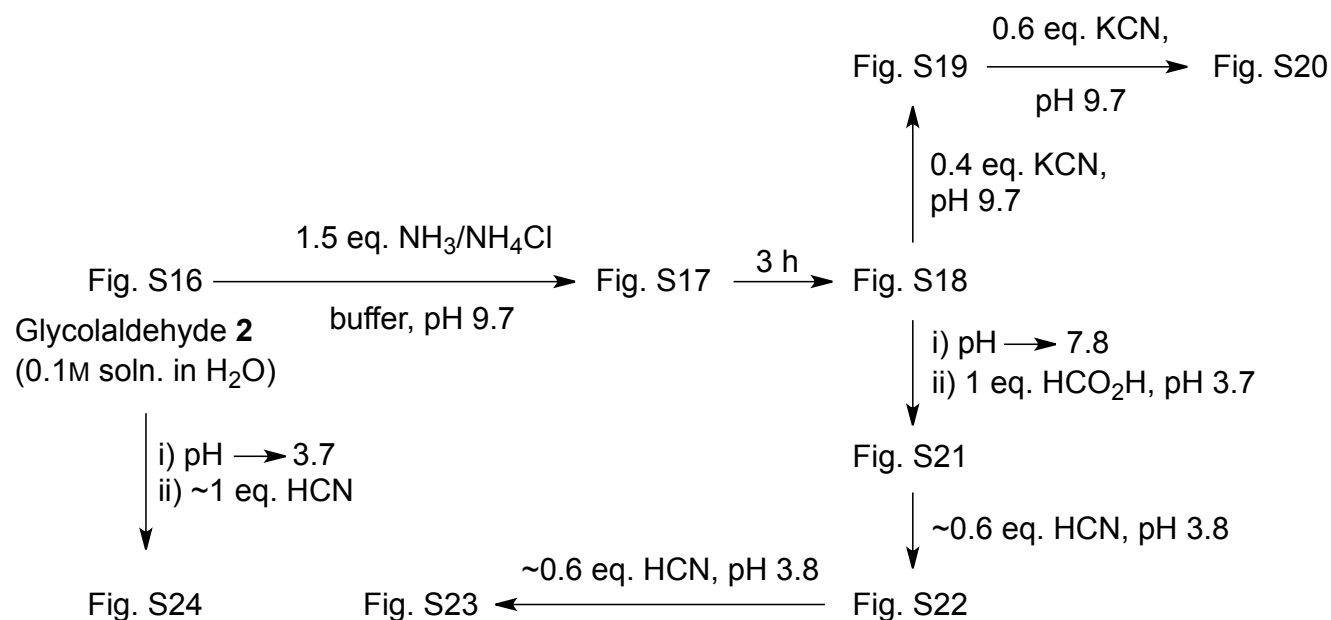


Figure S15. Reaction scheme to demonstrate the existence of the various equilibria shown in Fig. 5b. The additional figures referred to show ¹³C-NMR spectra of the solutions obtained at the various stages of this scheme along with the major species therein.

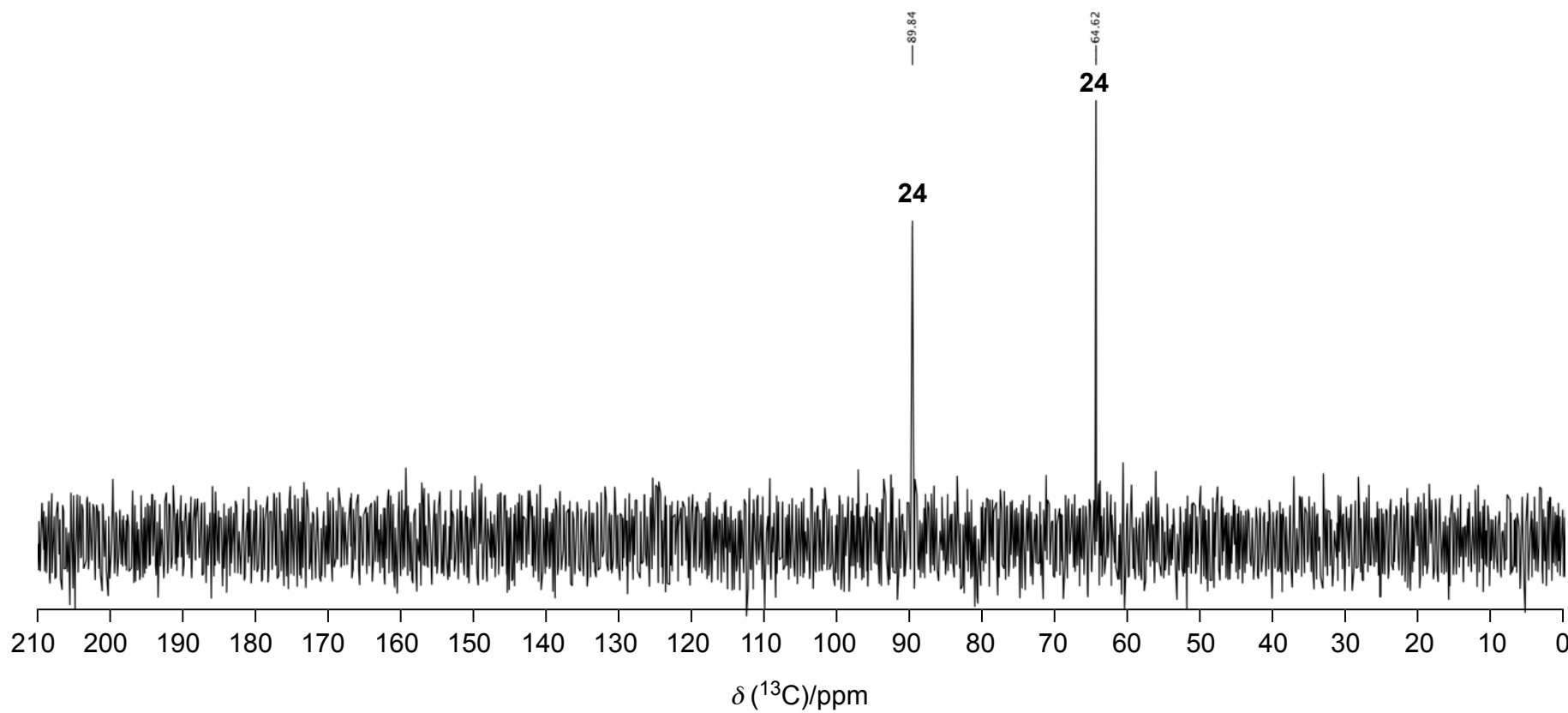
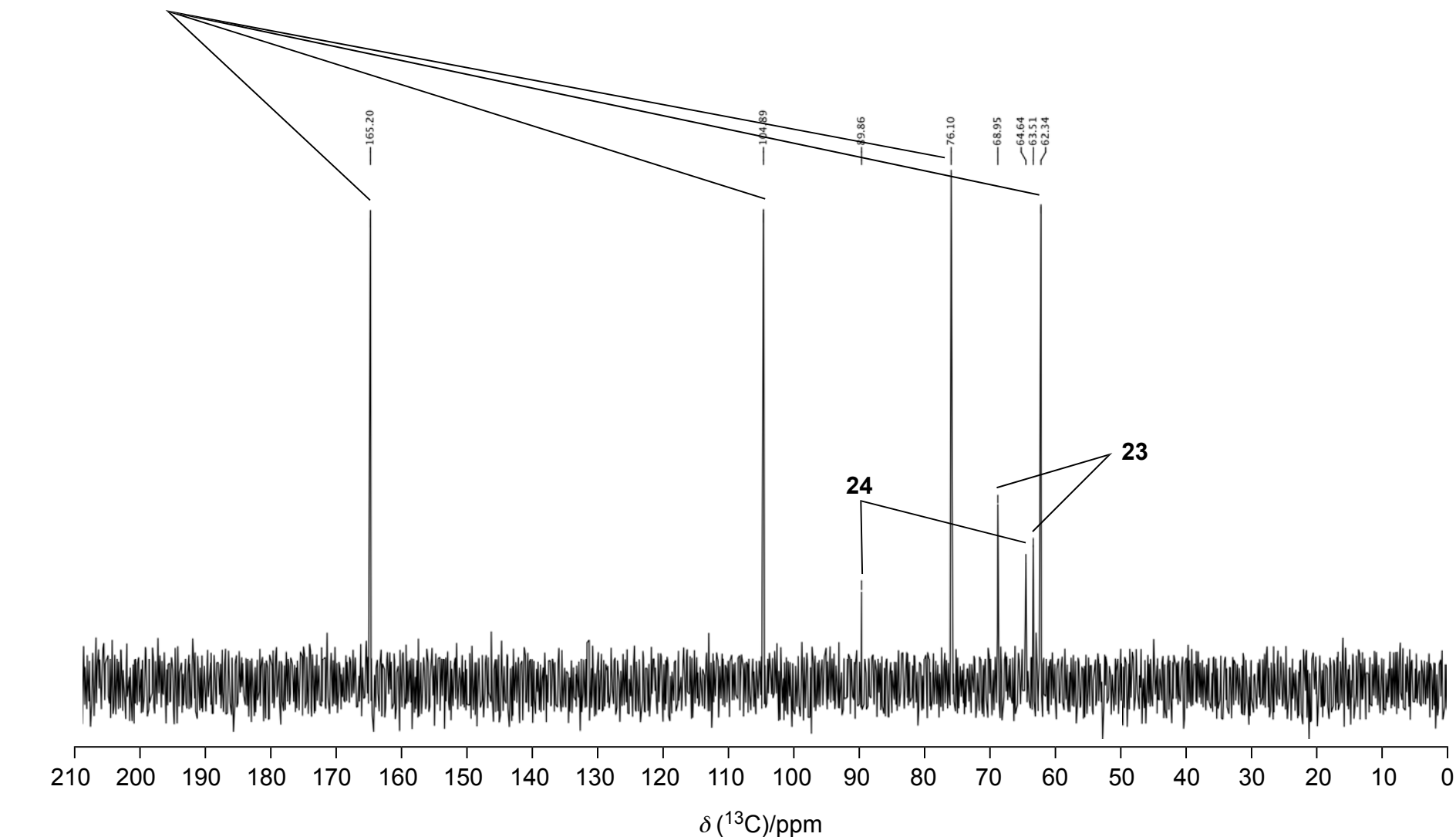
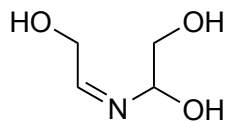
Figure S16.

Figure S17.

With the relatively high concentration of glycolaldehyde **2** employed in this series of control experiments (to enable ^{13}C -NMR spectra to be acquired at natural abundance), this dimeric species dominates over the hemiaminal **23**. The dimer (an adduct of imine **7** and **2**) is formed reversibly from **2** and ammonia, like **23**, and on acidification (which causes protonation of ammonia to ammonium ions), both revert to **2** which exists predominantly as the hydrate **24** (Figure S21)





See note on Figure S19.

Figure S18.

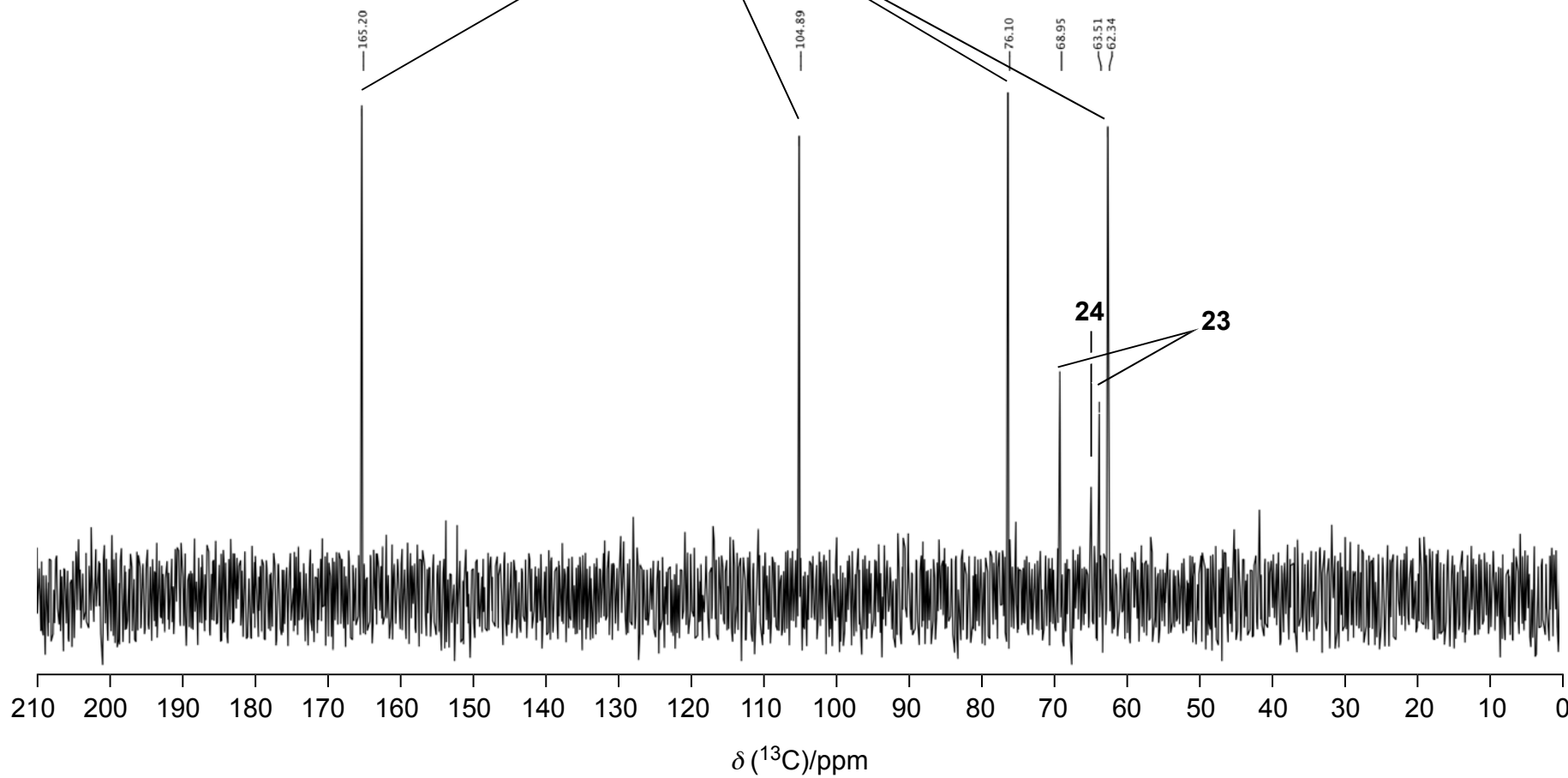


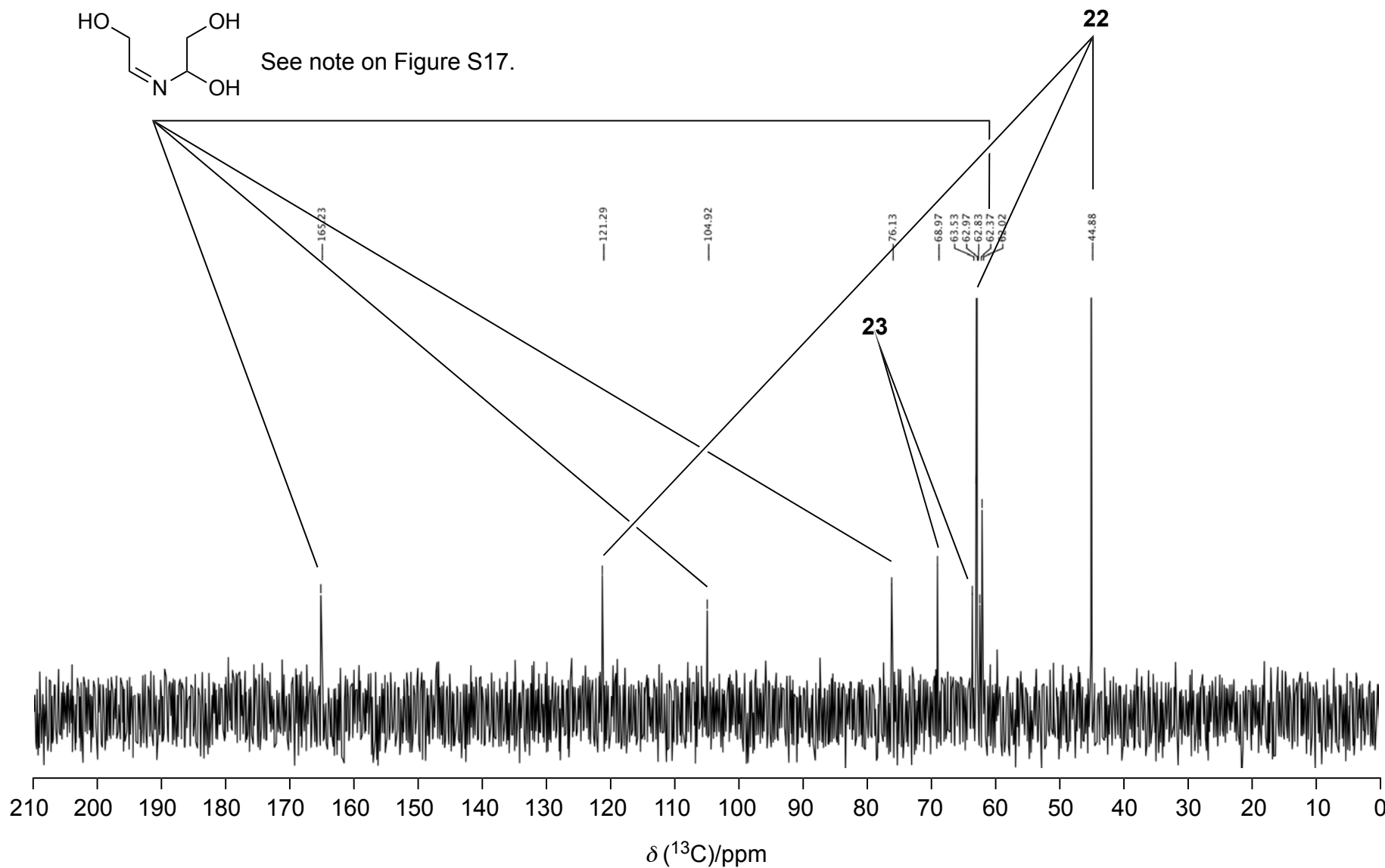
Figure S19.

Figure S20.

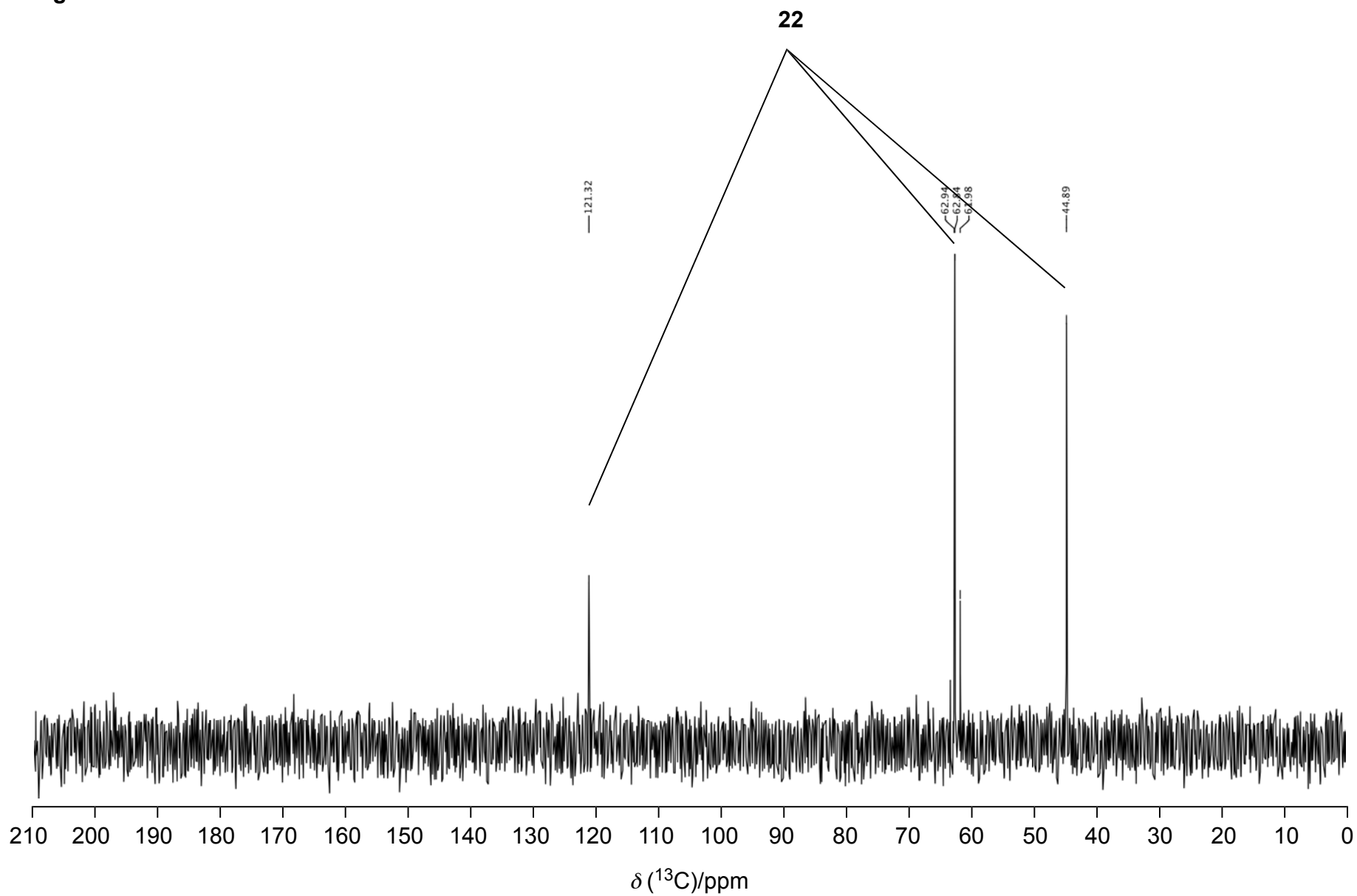


Figure S21.

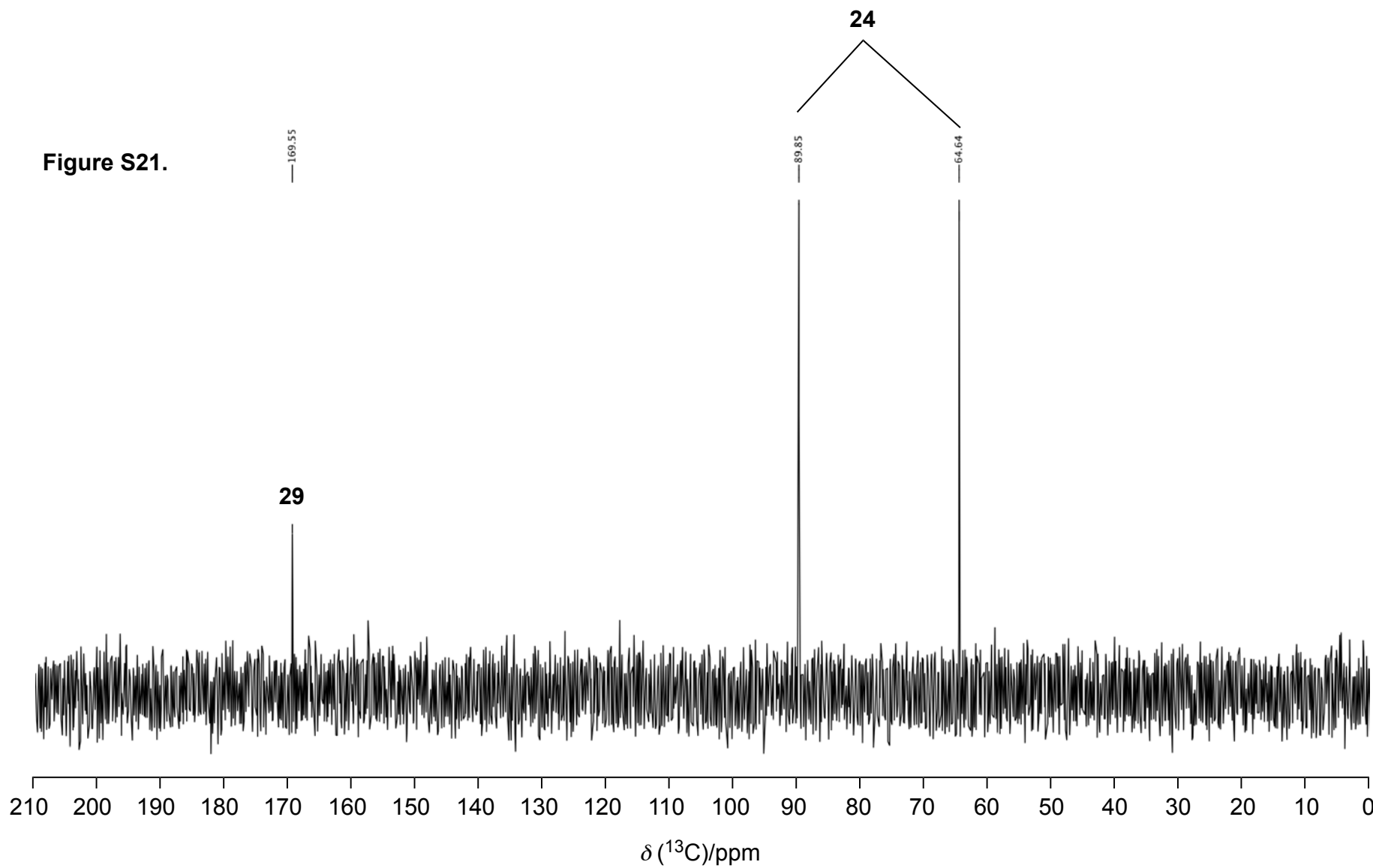


Figure S22.

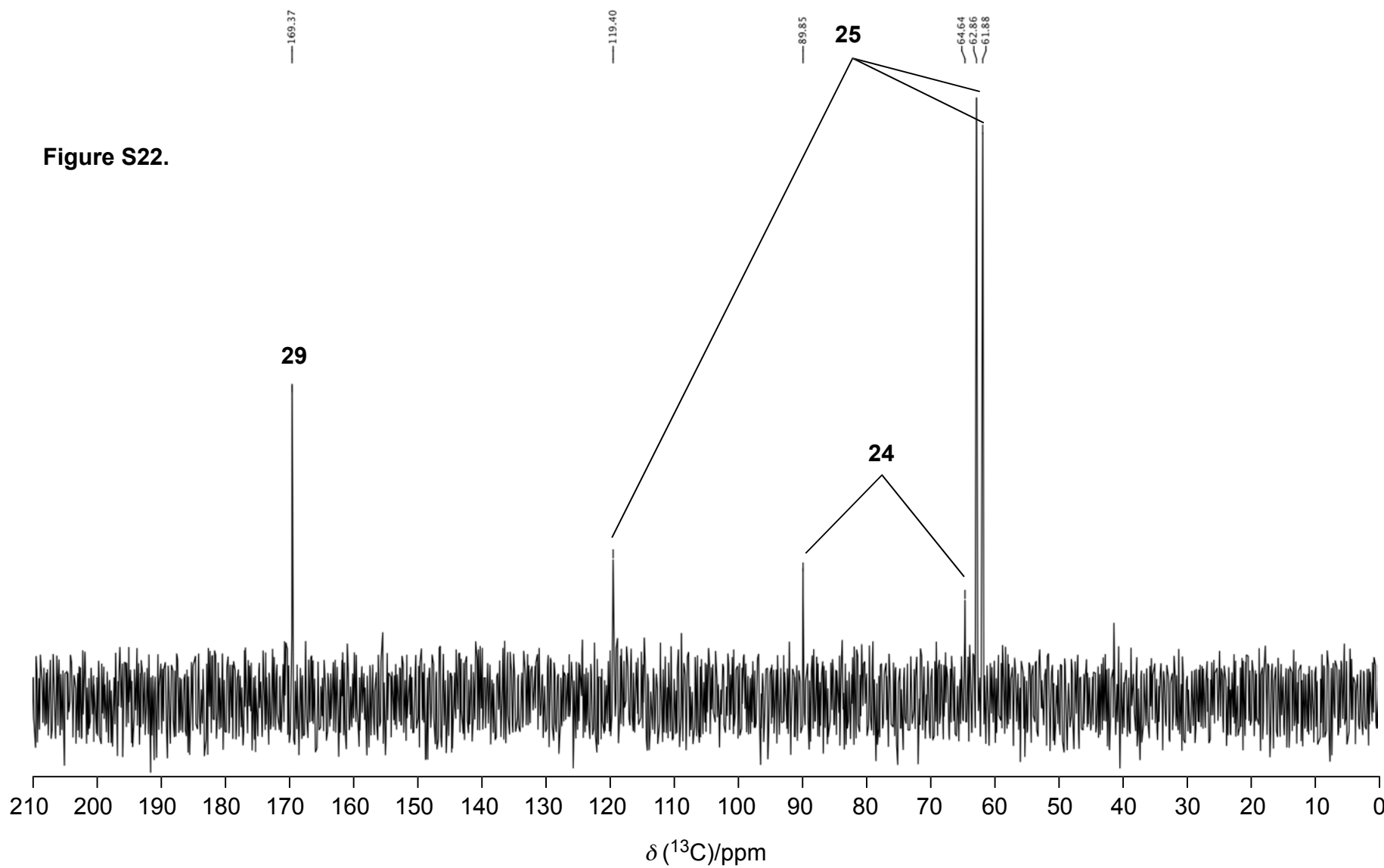


Figure S23.

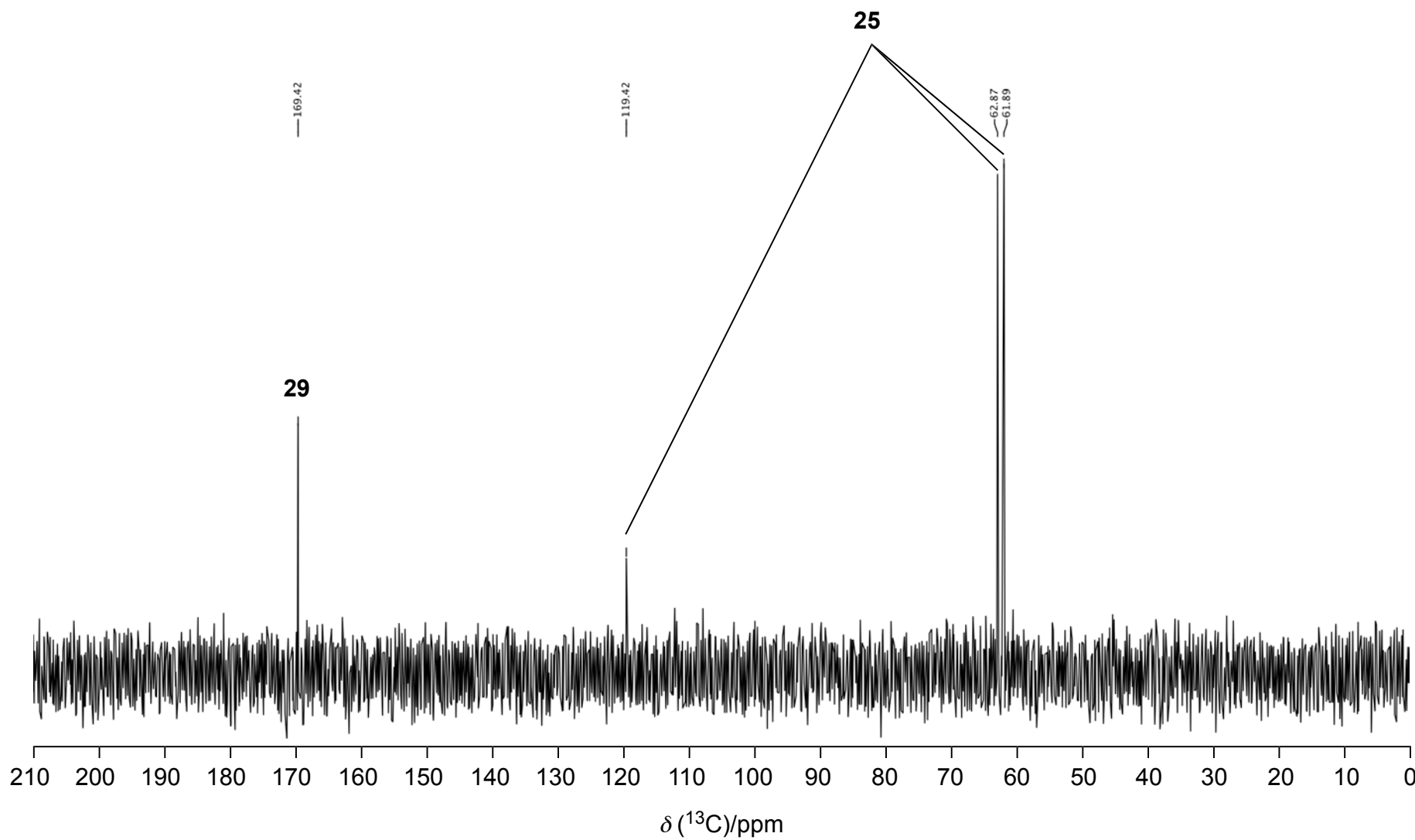


Figure S24.

