Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry.

Supporting Information

Tailoring chemoenzymatic oxidation via *in situ* peracids

Rebecca Re,[a] Johanna C. Proessdorf,[a] James J. La Clair[a] Maeva Subileau,[a,b,*] and Michael D. Burkart[a,*]

[a]Department of Chemistry and Biochemistry, UC San Diego, 9500 Gilman Drive, La Jolla CA 92093-0358, United States and [b]Montpellier Supagro, UMR 1208 IATE, 2 Place Viala, 34060 Montpellier Cedex 2, France

Correspondence should be directed to

mburkart@ucsd.edu (M.D.B.) or maeva.subileau@supagro.fr

Contents **Page**

A. General experimental methods: Chemical reagents were purchased from Acros, Fluka, Sigma-Aldrich, or TCI. Deuterated NMR solvents were purchased from Cambridge Isotope Laboratories. All reactions were performed in a 1 dram vial with a PTFE lined cap and were stirred with a Teflon coated stir bars using an IKAMAG RCT-basic mechanical stirrer (IKA GmbH). Analytical Thin Layer Chromatography (TLC) was performed on Silica Gel 60 F254 precoated glass plates (EM Sciences). Preparative TLC (pTLC) was conducted on Silica Gel 60 plates (EM Sciences). Visualization was achieved with UV light and/or an appropriate stain (I_2 on SiO_2, $KMnO_4$, bromocresol green, dinitrophenylhydrazine, ninhydrin and ceric ammonium molybdate). Flash chromatography was carried out Geduran Silica Gel 60 (40-63 mesh) from EM Biosciences. Yields and characterization data correspond to isolated, chromatographically and spectroscopically homogeneous materials. ^{1}H NMR spectra were recorded on a JEOL ECA500 or a Varian VX500 spectrometer equipped with an Xsens Cold probe. Chemical shifts for ^{1}H NMR and ^{13}C NMR analyses were referenced to the reported values of Gottlieb (Gottleib H. E., Kotlyar, V.. and Nudelman A. *J. Org. Chem.* 1997, **62**, 7512-7515) using the signal from the residual solvent for ^{1}H spectra, or to the ^{13}C signal from the deuterated solvent. Chemical shift δ values for ^{1}H and ^{13}C spectra are reported in parts per million (ppm) relative to these referenced values and multiplicities are abbreviated as s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad. All ^{13}C NMR spectra were recorded with complete proton decoupling. FID files were processed using MestraNova 12.0.3. (MestreLab Research). Electrospray (ESI) mass spectrometric analyses were performed using a ThermoFinnigan LCQ Deca spectrometer and high-resolution analyses were conducted using a ThermoFinnigan MAT900XL mass spectrometer with electron impact (EI) ionization. A Thermo Scientific LTQ Orbitrap XL mass spectrometer was used for high-resolution electrospray ionization mass spectrometry analysis (HR-ESI-MS). Spectral data and procedures are provided for all new compounds and copies of select spectra have been provided.

B. Lipase Production. CALB, wt CpLIP2, CpLIP2 Y179F and other mutants of CpLIP2 were produced by recombinant expression in *Komagataella pastoris* X-33 using the expression vector pPICZαB. Briefly, the clones of K. *pastoris* X-33 transformed with the corresponding expression vectors were cultivated in synthetic medium to allow enzyme production and secretion at multigram per liter scale. Recombinant enzymes were obtained from the culture supernatant which was concentrated and diafiltered with ultrapure water before lyophilization and conservation at -20°C. Lyophilized proteins were then resuspended in water (2.5 mg mL^{-1}) and aliquoted in 160 µL samples (0.4 mg) for further use.

C. General procedure. The alkene or sulfide (0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol) were suspended on 500 mM sodium phosphate buffer at pH 6.5 (200 uL), 30% H_2O_2 (153 µL, 1.5 M) and water (350-450 µL, see individual procedures). A 2.5 mg/mL stock of enzyme (160 µL) in water was added to generate a total volume of 1 mL. After stirring for 12-24 h at rt, the mixture was extracted with EtOAc (3 × 2 mL), washed with $NaHCO_3$ and brine, dried over Na_2SO_4 and then evaporated to dryness by air or vacuum. The products were purified by chromatographic purification with gradients of hexanes to hexanes/EtOAc.

D. Exemplary substrates. The following sections provide the methods for the preparation of each of the analogues displayed in Figs. 2-3.

8-(3-hexyloxiran-2-yl)octanoic acid (1d). The reaction was conducted using the general procedure with alkene **1c** (25.4 µL, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (388 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 3:1 hexanes/EtOAc yielded 19.2 mg (71%) of **1d**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.91 (m, 2H), 2.34 (t, J = 7.5 Hz, 2 H), 1.62 (dd, J = 14.2, 7.0 Hz, 2H), 1.50 (m, 6H), 1.42 (m, 2H), 1.33 (m, 8H), 1.28 (m, 2H), 0.88 (t, J = 6.8 Hz, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 179.5, 57.5, 57.4, 34.1, 31.9, 29.4, 29.4, 29.3, 29.1, 28.0, 27.9, 26.7, 24.8, 22.7, 14.2; HRMS (ESI) *m/z* $[M-H]^+$ Calculated for $C_{16}H_{29}O_3$: 269.2117; Found 269.2122.

(3-Methyl-3-((4*R*,8*R*)-4,8,12-trimethyltridecyl)oxiran-2-yl)methanol (2b). The reaction was conducted using the general procedure with alkene **2a** (34.9 µL, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (378 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 3:1 hexanes/EtOAc yielded 17.1 mg (55%) of **2b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.84 (m, 1H), 3.67 (dd, J = 12.5, 6.8 Hz, 1H), 3.65 (d, J = 6.5 Hz, 1H, minor isomer), 2.97 (dd, J = 6.9, 4.2 Hz, 1H), 1.60 (m, 2H), 1.51 (m, 1H), 1.41 (m, 5H), 1.33 (s, 1H), 1.29 (s, 3H), 1.22 (m, 7H), 1.08 (m, 6H), 0.85 (dd, J = 12.0, 6.5 Hz, 12H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 63.0, 61.6, 61.4, 39.5, 38.9, 37.6, 37.5, 37.5, 37.4, 32.9, 32.9, 28.1, 25.0, 24.6, 22.9, 22.8, 22.7, 19.9, 19.8 (isomer), 19.8, 19.7 (isomer), 16.9; HRMS (ESI) *m/z* $[M+Na]^+$ Calculated for $C_{20}H_{40}O_2Na$: 335.2926; Found 335.2919.

Methyl (*E*)-5-(3,3-dimethyloxiran-2-yl)-3-methylpent-2-enoate (3b). The reaction was conducted using the general procedure with alkene **3a** (19.7 µL, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (394 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 4:1 hexanes/EtOAc yielded 15.2 mg (77%) of **3b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.71 (bs, 1H), 3.68 (s, 3H), 3.67 (s, 3H, minor isomer), 2.86 (ddd, J = 12.2, 9.3, 6.4 Hz, 1H, minor isomer), 2.78 (t, J = 6.3 Hz, 1H, minor isomer), 2.70 (dd, J = 6.8, 5.7 Hz, 1H), 2.29 (m, 2H), 2.18 (s, 3H), 1.91 (s, 3H, minor isomer), 1.71 (m, 2H), 1.64 (s, 2H, minor isomer), 1.30 (s, 3H), 1.29 (s, 3H, minor isomer), 1.27 (s, 3H, minor isomer), 1.26 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 167.2, 159.1 (minor isomer), 116.4 (minor isomer), 115.8, 64.1 (minor isomer), 63.7, 58.6, 51.0, 37.7, 30.2 (minor isomer), 29.8 (minor isomer), 27.8 (minor isomer), 27.1, 25.4 (minor isomer), 24.9, 19.0, 18.9, 18.8 (minor isomer); HRMS (ESI) *m/z* $[M+Na]^+$ Calculated for $C_{11}H_{18}O_3Na$: 221.1154; Found 221.1148.

(*E*)-*tert*-butyl((5-(3,3-dimethyloxiran-2-yl)-3-methylpent-2-en-1-yl)oxy)dimethylsilane (5b). The reaction was conducted using the general procedure with alkene **5a** (26.8 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (386 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 4:1 hexanes/EtOAc yielded 15.9 mg (56%) of **5b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.34 (t, J = 6.3 Hz, 1H), 4.19 (d, J = 6.3 Hz, 2H), 2.71 (t, J = 6.3 Hz, 1H), 2.14 (m, 2H), 1.65 (m, 5H), 1.30 (s, 3H), 1.26 (s, 3H), 0.89 (s, 9H), 0.06 (s, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 136.1, 125.0, 64.2, 60.4, 58.6, 36.2, 27.3, 26.2, 25.0, 18.9, 18.6, 16.5, -4.9; HRMS (ESI) *m/z* $[M+Na]^+$ Calculated for $C_{16}H_{32}O_2SiNa$: 307.2070; Found 307.2069.

***tert*-butyl((5-(3,3-dimethyloxiran-2-yl)-3-methylpent-1-en-3-yl)oxy)dimethylsilane (7b).** The reaction was conducted using the general procedure with alkene **7a** (26.8 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (386 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 4:1 hexanes/EtOAc yielded 19.6 mg (69%) of **7b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.82 (dd, J = 17.3, 10.7 Hz, 1H), 5.15 (ddd, J = 17.2, 3.6, 1.2 Hz, 1H), 4.99 (dt, J = 10.9, 1.4 Hz, 1H), 2.67 (t, J = 5.5 Hz, 1H), 1.56 (m, 4H), 1.30 (s, 3H), 1.30 (s, 3H, isomer), 1.29 (s, 3H), 1.29 (s, 3H, isomer), 1.25 (s, 3H), 1.25 (s, 3H, isomer), 0.87 (s, 9H), 0.07 (s, 3H), 0.05 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 145.5, 145.3, 112.3, 112.2, 75.4, 75.3,

64.8, 64.7, 58.6, 58.5, 40.4, 40.2, 27.7, 27.6, 26.1, 25.0, 23.8, 23.8, 18.8, 18.8, 18.5, -1.9, -1,9; HRMS (ESI) *m/z* $[M+Na]^+$ Calculated for $C_{16}H_{32}O_2SiNa$: 307.2070; Found 307.2062.

(1R,5S)-5-(2-hydroxypropan-2-yl)-2-methylcyclohex-2-en-1-ol (8c). The reaction was conducted using the general procedure with alkene **8a** (31.8 µL, 0.2 mmol), methyl hexanoate (148 µL, 1.0 mmol), water (794 µL), 500 mM sodium phosphate buffer pH 6.5 (400 µL), 30% H_2O_2 (306 µL) and 2.5 mg/mL CpLIP2 Y179F in water (320 µL). Flash chromatographic purification with 4:1 to 1:1 hexanes/EtOAc yielded 10.9 mg (32%) of **8c**.

^1H NMR ($CDCl_3$, 500 MHz) *δ* 5.58 (d, *J* = 4.2 Hz, 1H), 4.04 (s, 1H), 2.13 (d, *J* = 16.9 Hz, 1H), 2.01 (d, *J* = 13.4 Hz, 1H), 1.80 (s, 3H), 1.74 (m, 2H), 1.43 (m, 1H), 1.22 (s, 3H), 1.20 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) *δ* 134.6, 125.5, 72.4, 68.9, 39.0, 32.9, 27.8, 27.2, 26.8, 21.0; HRMS (ESI) *m/z* $[M-2H_2O+H]^+$ Calculated for $C_{10}H_{15}$: 135.1173; Found 135.1167.

(1*S*,7*R*)-3,8,8-trimethyl-4-oxatricyclo[5.1.0.0^{3,5}]octane (9b). The reaction was conducted using the general procedure with alkene **9a** (31.5 µL, 0.2 mmol), methyl hexanoate (148 µL,1.0 mmol), water (795 µL), 500 mM sodium phosphate buffer pH 6.5 (400 µL), 30% H_2O_2 (306 µL) and 2.5 mg/mL CpLIP2 Y179F in water (320 µL). Flash chromatographic purification with hexanes to 5:1 hexanes/EtOAc yielded 15.5 mg (51%) of **9b**.

^1H NMR ($CDCl_3$, 500 MHz) *δ* 2.83 (s, 1H), 2.30 (ddd, *J* = 16.3, 9.1, 1.6 Hz, 1H), 2.15 (m, 1H), 1.64 (dt, *J* = 16.4, 2.2 Hz, 1H), 1.49 (dd, *J* = 16.2, 2.2 Hz, 1H), 1.26 (s, 3H), 1.01 (s, 3H), 0.73 (s, 3H), 0.53 (td, *J* = 9.1, 2.2 Hz, 1H), 0.45 (td, *J* = 9.1, 2.0 Hz, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) *δ* 58.4, 56.1, 27.9, 23.5, 23.2, 19.4, 16.1, 14.8, 14.0; HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{10}H_{17}O$: 153.1279; Found 153.1275.

((7-oxabicyclo[4.1.0]heptan-3-yl)methoxy)-t*ert*-butyldimethylsilane (11b). The reaction was conducted using the general procedure with alkene **11a** (22.6 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (390 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 4:1 hexanes/EtOAc yielded 9.9 mg (41%) of **11b**.

^1H NMR ($CDCl_3$, 500 MHz) *δ* 3.49 (m, 1H, minor isomer), 3.43 (dd, *J* = 9.9, 5.8 Hz, 1H), 3.38 (dd, *J* = 9.8, 6.3 Hz, 1H), 3.35 (dd, *J* = 5.6, 2.4 Hz, 1H), 3.19 (m, 1H), 3.14 (m, 2H), 2.13 (m, 2H), 2.01 (m, 2H), 1.84 (m, 1H), 1.72 (m, 1H), 1.65 (m, 1H), 1.45 (m, 6H), 1.10 (td, *J* = 12.5, 4.6 Hz, 1H), 1.00 (m, 1H), 0.94 (s, 9H, minor isomer), 0.88 (s, 9H), 0.17 (s, 6H, minor isomer), 0.03 (s, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) *δ* 68.1, 67.6, 53.2, 53.0, 52.1, 51.7, 35.6, 32.6, 28.1, 27.3, 26.1, 26.1, 25.0, 23.8, 23.3, 21.1, 18.5, 18.5, -5.2, -5.2, -5.2, -5.3; HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{13}H_{27}O_2Si$: 243.1780; Found 243.1778.

((7-oxabicyclo[4.1.0]heptan-2-yl)oxy)-*tert*-butyldimethylsilane (13b). The reaction was conducted using the general procedure with alkene **13a** (21.2 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (390 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 4:1 hexanes/EtOAc yielded 9.8 mg (43%) of **13b**.

^1H NMR ($CDCl_3$, 500 MHz) *δ* 4.01 (ddd, *J* = 9.4, 5.6, 2.0 Hz, 1H, minor isomer), 3.96 (t, *J* = 6.6 Hz, 1H), 3.24 (t, *J* = 4.3 Hz, 1H, minor isomer), 3.21 (bs, 1H), 3.14 (bs, 1H, minor isomer), 3.01 (d, *J* = 3.8 Hz, 1H), 2.43 (t, *J* = 7.5 Hz, 1H, minor isomer), 1.97 (dt, *J* = 16.0, 4.8 Hz, 1H), 1.75 (m, 3H), 1.44 (m, 3H, minor isomer), 1.19 (ddd, *J* =11.3, 4.5, 2.2 Hz, 2H), 0.91 (m, 9H), 0.87 (m, 9H, minor isomer), 0.11 (s, 3H, minor isomer), 0.11 (s, 3H), 0.10 (m, 3H, minor isomer), 0.09 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) *δ* 69.6, 66.9, 56.9, 56.4, 54.8, 53.4, 32.1, 31.2, 30.3, 30.1, 29.9, 29.5, 28.3, 26.0, 26.0, 25.9, 24.3, 22.7, 18.3, 14.7, -4.3, -4.4, -4.6, -4.7; HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{12}H_{25}O_2Si$: 229.1624; Found 229.1617.

***tert*-Butyl((3,3-dimethyloxiran-2-yl)methoxy)dimethylsilane (15b).** The reaction was conducted using the general procedure with alkene **15a** (20.0 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (393 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 2:1 hexanes/EtOAc yielded 9.0 mg (42%) of **15b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.73 (dd, J = 5.3, 3.0 Hz, 2H), 2.90 (t, J = 5.3 Hz, 1H), 1.33 (s, 3H), 1.28 (s, 3H), 0.90 (s, 9H), 0.09 (s, 3H), 0.08 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 64.2, 62.5, 58.3, 26.0, 24.9, 19.0, 18.5, -5.0, -5.2; HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{11}H_{25}O_2Si$: 217.1624; Found 217.1620.

2,3-Diphenyloxirane (16b). The reaction was conducted using the general procedure with alkene **16a** (17.8 µL, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (395 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 2:1 hexanes/EtOAc yielded 8.0 mg (41%) of **16b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.16 (m, 10H), 4.37 (s, 2H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 134.4, 127.9, 127.6, 127.0, 59.9; HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{14}H_{13}O$: 197.0966; Found 197.0963.

2,3-dihydro-1*H*-indene-1,2-diol (17b). The reaction was conducted using the general procedure with alkene **17a** (23.3 µL, 0.2 mmol), methyl hexanoate (148 µL, 1.0 mmol), water (803 µL), 500 mM sodium phosphate buffer pH 6.5 (400 µL), 30% H_2O_2 (306 µL) and 2.5 mg/mL CpLIP2 Y179F in water (320 µL). Flash chromatographic purification with hexanes to 3:1 hexanes/EtOAc yielded 11.4 mg (38%) of **17b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.43 (m, 1H), 7.26 (m, 3H), 5.00 (d, J = 4.9 Hz, 1H), 4.50 (m, 1H), 3.12 (dd, J = 16.3, 5.8 Hz, 1H), 2.95 (dd, J = 16.3, 3.5 Hz, 1H), 2.63 (bs, 2H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 142.0, 140.2, 129.0, 127.4, 125.5, 125.2, 76.1, 73.6, 38.8; HRMS (ESI) *m/z* $[M-H]^+$ Calculated for $C_9H_9O_2$: 149.0603; Found 149.0607.

2,2-Dimethyl-1a,7b-dihydro-2*H*-oxireno[2,3-*c*]chromene-6-carbonitrile (18b). The reaction was conducted using the general procedure with alkene **18a** (27.8 mg, 0.15 mmol), methyl hexanoate (111 µL, 0.75 mmol), water (592 µL), 500 mM sodium phosphate buffer pH 6.5 (300 µL), 30% H_2O_2 (230 µL) and 2.5 mg/mL CpLIP2 Y179F in water (240 µL). Flash chromatographic purification with hexanes to 3:1 hexanes/EtOAc yielded 9.9 mg (33%) of **18b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.66 (d, J = 2.1 Hz, 1H), 7.53 (dd, J = 8.5, 2.1 Hz, 1H), 6.87 (d, J = 8.5 Hz, 1H), 3.92 (d, J = 4.3 Hz, 1H), 3.54 (d, J = 4.3 Hz, 1H), 1.60 (s, 3H), 1.29 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 156.6, 134.6, 133.9, 121.2, 119.2, 118.9, 104.4, 74.8, 62.5, 50.0, 25.6, 23.2; HRMS (ESI) *m/z* $[M-H]^+$ Calculated for $C_{12}H_{10}NO_2$: 200.0712; Found 200.0716.

3,4,6-Tri-O-acetyl-α,β-D-glucopyranose (19b). The reaction was conducted using the general procedure with tri-*O*-acetyl-D-glucal **(19a)** (27.2 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (391 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with 3:2 to 1:2 hexanes/EtOAc yielded 14.7 mg (48%) of **19b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.44 (m, 1H, minor isomer), 5.34 (d, J = 3.6 Hz, 1H), 5.29 (t, J = 9.7 Hz, 1H), 5.11 (m, 1H), 5.04 (m, 1H), 4.95 (t, J = 9.7 Hz, 1H, minor isomer), 4.88 (bs, 1H, minor isomer), 4.80 (dd, J = 10.1, 3.6 Hz, 1H, minor isomer), 4.71 (m, 1H, minor isomer), 4.24 (m, 2H), 4.15 (m, 1H, minor isomer), 4.11 (d, J = 10.5 Hz, 1H), 3.71 (dd, J = 9.8, 3.7 Hz, 1H), 3.56 (dd, J = 15.1, 7.1 Hz, 1H, minor isomer), 2.17 (m, 3H, minor isomer), 2.13 (bs, 6H, minor isomer), 2.09 (s, 6H), 2.04 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 171.6, 171.3, 171.1, 171.0,

170.9, 170.3, 170.2, 169.8, 169.8, 96.7, 95.3, 93.9, 93.8, 92.3, 91.7, 90.2, 75.6, 74.5, 73.2, 73.0, 72.9, 72.0, 71.8, 71.4, 70.8, 69.4, 69.4, 69.3, 68.4, 68.2, 68.0, 67.9, 66.2, 65.6, 62.6, 62.5, 62.4, 62.2, 62.1, 62.1, 21.0, 21.0, 20.9, 20.9, 20.8, 20.8, 20.8. 20.7, 20.7, 20.7, 20.6, 20.6 (anomeric isomers complicated the ^{1}H and ^{13}C spectrum); HRMS (ESI) *m/z* $[M+Na]^+$ Calculated for $C_{12}H_{18}O_9Na$: 329.0849; Found 329.0839.

3,4,6-Tri-O-acetyl-α,β-D-galactopyranose (20b). The reaction was conducted using the general procedure with tri-*O*-acetyl-D-galactal **(20a)** (27.2 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (391 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with 3:2 to 1:2 hexanes/EtOAc yielded 11.9 mg (39%) of **20b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.40 (m, 2H), 5.18 (dd, J = 10.4, 3.3 Hz, 1H), 4.93 (dd, J = 10.3, 3.4 Hz, 1H, minor anomer), 4.71 (d, J = 7.7 Hz, 1H, minor anomer), 4.42 (t, J = 6.6 Hz, 1H), 4.13 (dd, J = 6.5, 2.8 Hz, 1H), 4.09 (dd, J = 6.5, 3.8 Hz, 1H), 3.96 (m, 1H), 3.78 (dd, J = 10.2, 7.7 Hz, 1H, minor anomer), 3.72 (bs, 1H), 2.14 (s, 3H), 2.06 (s, 6H), 1.78 (bs, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 170.5, 170.3, 170.0, 169.1, 89.8, 77.2, 68.9, 67.5, 67.5, 61.4, 21.0, 20.8, 20.8, 20.8, 20.7 (anomeric isomers complicated the ^{1}H and ^{13}C spectrum); HRMS (ESI) *m/z* $[M+Na]^+$ Calculated for $C_{12}H_{18}O_9Na$: 329.0849; Found 329.0844.

6-O-(*tert*-Butyldiphenylsilyl)-α,β-D-glucopyranose (21b). The reaction was conducted using the general procedure with 6-*O*-(tert-butyldiphenylsilyl)-D-glucal **(21a)** (38.4 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (386 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with 3:2 to 1:2 hexanes/EtOAc yielded 28.0 mg (67%) of **21b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.66 (m, 4H), 7.39 (m, 6H), 5.14 (s, 1H), 4.68 (s, 1H, minor anomer), 4.31 (m,1H), 3.93 (m, 5H), 3.58 (m, 1H), 3.39 (m, 1H), 2.79 (bs, 4H), 1.05 (s, 9H), 1.04 (s, 9H, minor anomer); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 135.8, 135.7, 132.9, 132.8, 132.6, 123.5, 130.2, 130.1, 130.0, 128.1, 128.0, 127.9, 94.4, 94.0, 79.2, 74.2, 73.7, 72.7, 71.5, 71.2, 70.7, 70.6, 70.5, 65.7, 65.6, 60.6, 27.0, 19.3, 19.3 (anomeric isomers complicated the ^{1}H and ^{13}C spectrum); HRMS (ESI) *m/z* $[M+Na]^+$ Calculated for $C_{22}H_{30}O_6SiNa$: 441.1710; Found 441.1706.

3,4,6-Tri-O-benzyl-α,β-D-glucopyranose (22b). The reaction was conducted using the general procedure with tri-*O*-benzyl-D-galactal **(22a)** (41.7 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (377 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with 3:2 to 1:2 hexanes/EtOAc yielded 10.8 mg (24%) of **22b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.32 (m, 15H), 5.34 (d, J = 3.7 Hz, 1H), 4.86 (dd, J = 11.5, 4.4 Hz, 1H), 4.67 (m, 2H), 4.50 (m, 4H), 4.15 (m, 1H), 3.94 (d, J = 1.8 Hz, 1H), 3.89 (dd, J = 6.2, 3.3 Hz, 1H), 3.73 (dd, J = 9.9, 2.6 Hz, 1H), 3.56 (m, 2H), 3.47 (dd, J = 9.4, 6.2 Hz, 1H), 3.41 (dd, J = 9.8, 2.7 Hz, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 138.4, 138.3 (minor isomer), 138.1, 137.9 (minor isomer), 137.8, 137.7 (minor isomer), 128.7 (minor isomer), 128.7, 128.6 (minor isomer), 128.6, 128.4, 128.4 (minor isomer), 128.2, 128.1 (minor isomer), 128.1 (minor isomer), 128.0, 128.0, 127.9 (minor isomer), 127.9, 97.4 (minor isomer), 92.9, 82.0 (minor isomer), 82.0 (minor isomer), 79.2, 74.7 (minor isomer), 74.7, 73.9 (minor isomer), 73.8, 73.7 (minor isomer), 73.7, 72.9 (minor isomer), 72.7 (minor isomer), 72.5 (minor isomer), 72.4, 69.9, 69.3, 69.0, 68.8 (minor isomer) (anomeric isomers complicated the ^{1}H and ^{13}C spectrum); HRMS (ESI) *m/z* $[M+Na]^+$ Calculated for $C_{27}H_{30}O_6Na$: 473.1940; Found 473.1929.

3-(3-((4-Hydroxy-6-methoxy-7-methyl-3-oxo-1,3-dihydroisobenzofuran-5-yl)methyl)-2-methyloxiran-2-yl)propanoic acid (23b). The reaction was conducted using the general procedure with alkene **23a** (32.0 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water

(381 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with 1:2 to 1:9 hexanes/EtOAc yielded 19.1 mg (57%) of **23b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.23 (s, 2H), 5.15 (s, 2H, minor isomer), 3.97 (s, 3H, minor isomer), 3.92 (m, 1H), 3.83 (s, 3H), 2.97 (dd, *J* = 13.8, 2.4 Hz, 1H), 2.81 (dd, *J* = 13.8, 10.3 Hz, 1H), 2.67 (ddd, *J* = 9.2, 7.1, 4.0 Hz, 2H), 2.54 (m, 1H), 2.51 (m, 1H), 2.18 (s, 3H), 2.06 (s, 3H, minor isomer), 1.97 (ddd, *J* = 12.9, 9.3, 6.9 Hz, 1H), 1.52 (s, 3 H), 1.42 (s, 3H, minor isomer); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 177.0, 172.7, 164.0, 153.7, 145.3, 119.3, 117.3, 106.9, 88.4, 75.8, 70.3, 61.2, 29.3, 28.8, 25.8, 22.4, 11.9; HRMS (ESI) *m/z* $[M-H]^+$ Calculated for $C_{17}H_{19}O_7$: 335.1131; Found 335.1135.

(1*R*,4*R*,6*R*,10*S*)-4,12,12-trimethyl-9-methylene-5-oxatricyclo[8.2.0.0^{4,6}]dodecane (24b). The reaction was conducted using the general procedure with alkene **24a** (22.6 µL, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (388 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 2:1 hexanes/EtOAc yielded 14.8 mg (67%) of **24b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 4.97 (s, 1H), 4.85 (s, 1H), 2.88 (dd, *J* = 10.6, 4.2 Hz, 1H), 2.62 (q, *J* = 9.5 Hz, 1H), 2.33 (ddd, *J* = 12.7, 8.2, 4.4 Hz, 1H), 2.25 (ddd, *J* = 16.8, 8.2, 4.3 Hz, 1H), 2.10 (m, 2H), 1.76 (t, *J* = 9.9 Hz, 1H), 1.67 (m, 2H), 1.62 (m, 1H), 1.42 (m, 1H), 1.32 (dddd, *J* = 12.6, 10.8, 8.2, 4.4 Hz, 1H), 1.20 (s, 3H), 1.00 (s, 3H), 0.98 (s, 4H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 151.9, 112.9, 64.0, 60.1, 50.7, 48.9, 39.8, 39.2, 34.2, 30.4, 30.0, 29.8, 27.3, 21.7, 17.2; HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{15}H_{25}O$: 221.1905; Found 221.1897.

(3*S*,6a*S*,6b*S*,9*R*,9a*R*,11a*S*,11b*R*)-3-Chloro-9a,11b-dimethyl-9-((*R*)-6-methylheptan-2-yl)hexadecahydrocyclopenta[1,2]phenanthro[8a,9-*b*]oxirene (25b). The reaction was conducted using the general procedure with alkene **25a** (40.5 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (377 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with 2:1 to 1:2 hexanes/EtOAc yielded 24.8 mg (59%) of **25b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 4.10 (tt, *J* = 12.1, 4.6 Hz, 1H), 3.86 (tt, *J* = 12.6, 4.1 Hz, 1H, minor isomer), 3.06 (d, *J* = 2.2 Hz, 1H, minor isomer), 2.92 (d, *J* = 4.4 Hz, 1H), 2.39 (t, *J* = 12.6 Hz, 1H), 2.14 (m, 1H), 2.06 (m, 1H, minor isomer), 1.93 (m, 3H), 1.81 (m, 1H), 1.72 (dt, *J* = 13.6, 3.5 Hz, 1H), 1.61 (dd, *J* = 16.0, 2.5 Hz, 1H, minor isomer), 1.49 (m, 3H), 1.44 (m, 6H, minor isomer), 1.33 (m, 6H), 1.21 (m, 4H), 1.12 (m, 3H), 1.08 (s, 3H), 1.03 (m, 2H), 0.95 (m, 3H), 0.88 (d, *J* = 6.6 Hz, 3H), 0.86 (dd, *J* = 6.7, 2.4 Hz, 6H), 0.63 (s, 3H, minor isomer), 0.60 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 66.1, 63.8 (minor isomer), 63.2 (minor isomer), 59.7, 57.2, 56.9, 56.3 (minor isomer), 56.3 (minor isomer), 56.0, 51.6 (minor isomer), 43.4 (minor isomer), 42.6, 42.4, 42.4 (minor isomer), 41.6, 39.9 (minor isomer), 39.6, 39.4, 39.2 (minor isomer), 36.2, 35.9, 35.9 (minor isomer), 34.9 (minor isomer), 34.9, 34.3, 32.9, 32.7 (minor isomer), 32.6 (minor isomer), 29.9, 29.9 (minor isomer), 28.9, 28.3 (minor isomer), 28.2, 28.2, 24.3 (minor isomer), 24.2, 24.0, 23.9 (minor isomer), 23.0, 22.7, 22.0 (minor isomer), 20.6, 18.8 (minor isomer), 18.8, 17.1 (minor isomer), 16.0, 12.0, 11.9 (minor isomer); HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{27}H_{46}ClO$: 421.3237; Found 421.3227.

1-((3*S*,6a*S*,6b*S*,9*S*,9a*S*,11a*S*,11b*R*)-3-hydroxy-9a,11b-dimethylhexadecahydrocyclopenta-[1,2]phenanthro[8a,9-*b*]oxiren-9-yl)ethan-1-one (26b). The reaction was conducted using the general procedure with alkene **26a** (31.6 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), , water (381 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with 2:1 to 1:2 hexanes/EtOAc yielded 12.9 mg (39%) of **26b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.91 (m, 1H), 3.70 (m, 1H, minor isomer), 3.07 (d, J = 2.5 Hz, 1H, minor isomer), 2.91 (d, J = 4.4 Hz, 1H), 2.50 (t, J = 8.8 Hz, 1H), 2.15 (m, 1H), 2.10 (s, 3H), 2.08 (m, 1H, minor isomer), 2.05 (s, 1H, minor isomer), 2.04 (m, 1H, minor isomer), 2.02 (m, 1H, minor isomer), 1.99 (m, 1H), 1.97 (dd, J = 4.4, 3.1 Hz, 1H), 1.93 (m, 1H), 1.82 (m, 1H, minor isomer), 1.67 (m, 3H), 1.60 (bs, 1H), 1.57 (m, 3H, minor isomer), 1.49 (m, 3H), 1.38 (m, 3H), 1.27 (m, 3H), 1.14 (m, 3H), 1.06 (s, 3H), 0.99 (s, 3H, minor isomer), 0.59 (s, 3H, minor isomer), 0.55 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 209.7, 209.6 (minor isomer), 69.5 (minor isomer), 68.8, 65.8, 63.8 (minor isomer), 63.7 (minor isomer), 63.5, 63.0 (minor isomer), 59.2, 57.1, 56.4 (minor isomer), 51.3 (minor isomer), 44.1, 44.0 (minor isomer), 42.6, 42.3 (minor isomer), 39.9, 38.9 (minor isomer), 38.6, 37.4 (minor isomer), 35.0 (minor isomer), 35.0, 32.6 (minor isomer), 32.5, 31.7, 31.7 (minor isomer), 31.2, 31.1 (minor isomer), 30.0, 29.9 (minor isomer), 28.8, 24.5 (minor isomer), 24.4, 22.9 (minor isomer), 22.8, 22.1 (minor isomer), 20.8, 17.2 (minor isomer), 16.0, 13.4, 13.3(minor isomer); HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{21}H_{33}O_3$: 333.2429; Found 333.2421.

(3*S*,6a*R*,6b*S*,9a*S*,11a*S*,11b*R*)-3-hydroxy-9a,11b-dimethyltetradecahydrocyclopenta[1,2]-phenanthro[8a,9-*b*]oxiren-9(2*H*)-one (27b). The reaction was conducted using the general procedure with alkene **27a** (28.8 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.1 mmol), water (384 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with 2:1 to 1:2 hexanes/EtOAc yielded 16.4 mg (54%) of **27b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.91 (m, 1H), 3.71 (m, 1H, minor isomer), 3.13 (d, J = 2.5 Hz, 1H, minor isomer), 2.95 (d, J = 4.4 Hz, 1H), 2.43 (dd, J = 19.4, 8.1 Hz, 1H), 2.21 (dt, J = 14.2, 3.4 Hz, 1H, minor isomer), 2.11 (d, J = 2.6 Hz, 1H, minor isomer), 2.09 (bs, 1H), 2.05 (m, 2H), 1.94 (m, 2H), 1.78 (m, 1H), 1.71 (dt, J = 13.4, 3.4 Hz, 1H), 1.65 (d, J = 4.8 Hz, 2H, minor isomer), 1.62 (d, J = 4.2 Hz, 1H), 1.60 (d, J = 4.2 Hz, 2H), 1.54 (m, 2H), 1.48 (m, 1H), 1.41 (d, J = 4.2 Hz, 1H, minor isomer), 1.38 (d, J = 4.3 Hz, 3H, minor isomer), 1.32 (m, 3H), 1.25 (m, 3H), 1.09 (s, 3H), 1.02 (s, 3H, minor isomer), 0.85 (s, 3H minor isomer), 0.82 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 220.8, 68.7, 65.8, 58.9, 52.0, 47.8, 42.9, 39.9, 35.9, 35.2, 32.5, 31.2, 31.2, 29.6, 27.9, 21.8, 20.1, 16.1, 13.7; HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{19}H_{29}O_3$: 305.2116; Found 305.2111.

Benzo[b]thiophene 1,1-dioxide (28b). The reaction was conducted using the general procedure with sulfide **28a** (26.8 mg, 0.2 mmol), methyl hexanoate, 799 µL of water (148 µL, 1.0 mmol), 500 mM sodium phosphate buffer pH 6.5 (400 µL), 30% H_2O_2 (306 µL) and 2.5 mg/mL CpLIP2 Y179F in water (320 µL). Flash chromatographic purification with hexanes to 3:1 hexanes/EtOAc yielded 8.3 mg (25%) of **28b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.73 (d, J = 7.2 Hz, 1 H), 7.55 (m, 2H), 7.37 (dd, J = 6.6, 1.3 Hz, 1H), 7.23 (d, J = 6.9 Hz, 1H), 6.73 (d, J = 6.9 Hz, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 136.8, 133.8, 132.5, 131.3, 131.0, 130.8, 125.5, 121.6; HRMS (ESI) *m/z* $[M+Na]^+$ Calculated for $C_8H_6O_2SNa$: 188.9987; Found 188.9982.

(Methylsulfinyl)benzene (29b). The reaction was conducted using the general procedure with sulfide **29a** (23.5 µL, 0.2 mmol), methyl hexanoate (148 µL, 1.0 mmol), water (803 µL), 500 mM sodium phosphate buffer pH 6.5 (400 µL), 30% H_2O_2 (306 µL) and 2.5 mg/mL CpLIP2 Y179F in water (320 µL). Flash chromatographic purification with 2:1 to 1:1 hexanes/EtOAc yielded 18.8 mg (67%) of **29b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.65 (m, 2H), 7.52 (m, 3H), 2.73 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 145.9, 131.2, 129.5, 123.6, 44.1; HRMS (ESI) *m/z* $[M+H]^+$ Calculated for C_7H_9OS: 141.0374; Found 141.0371.

5-((*R*)-((*R*)-*sec*-Butyl)sulfinyl)-1-phenyl-1*H*-tetrazole (30b). The reaction was conducted using the general procedure with sulfide **30a** (23.4 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (390 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 3:1 hexanes/EtOAc yielded 12.3 mg (47%) of **30b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.69 (m, 2H), 7.66 (m, 2H), 7.62 (m, 6H), 3.85 (m, 1H, minor isomer), 3.65 (m, 1H), 2.06 (dqd, *J* = 15.1, 7.5, 4.0 Hz, 1H, minor isomer), 1.80 (m, 1H), 1.70 (ddt, *J* = 14.6, 9.0, 7.4 Hz, 1H, minor isomer), 1.61 (m, 1H), 1.42 (d, *J* = 6.8 Hz, 3H), 1.21 (d, *J* = 6.9 Hz, 3H, minor isomer), 1.09 (t, *J* = 5.5 Hz, 3H, minor isomer), 1.06 (t, *J* = 5.5 Hz, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 156.0, 155.8 (minor isomer), 133.3, 133.3 (minor isomer), 131.3, 131.3 (minor isomer), 130.0 (minor isomer), 129.9, 125.4, 125.3 (minor isomer), 60.3, 59.3 (minor isomer), 24.0, 22.6 (minor isomer), 12.7 (minor isomer), 12.0, 11.4, 10.5 (minor isomer); HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{11}H_{15}N_4OS$: 251.0966; Found 251.0960.

5-((*R*)-((*R*)-Heptan-2-yl)sulfinyl)-1-phenyl-1*H*-tetrazole (31b). The reaction was conducted using the general procedure with 27.6 mg (0.1 mmol) of sulfide **31a**, methyl hexanoate (74 µL, 0.5 mmol), water (386 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 153 µL of 30% H_2O_2 and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 3:1 hexanes/EtOAc yielded 18.4 mg (63%) of **31b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.68 (m, 2H), 7.65 (m, 2H), 7.61 (m, 6 H), 3.86 (dqd, *J* = 9.4, 6.9, 4.0 Hz, 1H,minor isomer), 3.68 (m, 1H), 1.96 (m, 1H, minor isomer), 1.71 (m, 2H, minor isomer), 1.62 (m, 1H), 1.52 (m, 2H, minor isomer), 1.44 (m, 2H), 1.41 (d, *J* = 6.8 Hz, 3H), 1.28 (m, 8H), 1.22 (d, *J* = 6.9Hz, 3H), 0.87 (m, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 156.0, 155.8 (minor isomer), 133.3, 133.3 (minor isomer), 131.3 (minor isomer), 131.3, 130.0 (minor isomer),129.9, 125.4, 125.3 (minor isomer), 58.8, 58.1 (minor isomer), 31.6 (minor isomer), 31.5, 30.6, 29.3 (minor isomer), 26.4, 25.8 (minor isomer), 22.5 (minor isomer), 22.5, 14.1 (minor isomer), 14.0, 13.2 (minor isomer), 12.4; HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{14}H_{21}N_4OS$: 293.1436; Found 293.1432.

1-Phenyl-5-((*S*)-((*R*)-1-phenylethyl)sulfinyl)-1*H*-tetrazole (32b). The reaction was conducted using the general procedure with sulfide **32a** (28.2 mg, 0.1 mmol), methyl hexanoate (74 µL, 0.5 mmol), water (385 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). Flash chromatographic purification with hexanes to 3:1 hexanes/EtOAc yielded 14.6 mg (49%) of **32b**.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.72 (d, *J* = 8.1 Hz, 1H, minor isomer), 7.61 (m, 2H, minor isomer), 7.58 (m, 1H, minor isomer), 7.52 (t, *J* = 7.6 Hz, 1H), 7.44 (t, *J* = 8.2 Hz, 2H), 7.38 (t, *J* = 7.6 Hz, 2H, minor isomer), 7.33 (t, *J* = 7.3 Hz, 2H, minor isomer), 7.29 (m, 1H), 7.22 (t, *J* = 7.8 Hz, 2H), 7.06 (d, *J* = 7.1 Hz, 2H), 7.01 (d, *J* = 8.0 Hz, 2H), 6.93 (d, *J* = 8.4 Hz, 2 H, minor isomer), 5.05 (q, *J* = 7.2 Hz, 1H), 4.74 (q, *J* = 7.3 Hz, 1H, minor isomer), 1.91 (d, *J* = 7.2 Hz, 3H), 1.85 (d, *J* = 7.3 Hz, 3 H, minor isomer); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 133.2, 132.7, 131.2 (minor isomer), 131.1, 130.9 (minor isomer), 130.4 (minor isomer), 130.3 (minor isomer), 129.7, 129.5, 129.3, 129.3 (minor isomer), 129.0, 129.0, 128.9, 125.4, 125.1, 124.5 (minor isomer), 121.4 (minor isomer), 65.5, 65.2 (minor isomer), 15.3, 13.5 (minor isomer); HRMS (ESI) *m/z* $[M+H]^+$ Calculated for $C_{15}H_{15}N_4OS$: 299.0966; Found 299.0962.

E. Co-catalyst screening. The following sections provide the methods for the co-catalyst screening efforts. The crude product of these reactions were evaluated by ^{1}H NMR and reported in Fig. 4.

α-Decalactone. The reaction was conducted using the general procedure with β-caryophyllene (22.6 µL, 0.1 mmol), α-decalactone (54 µL, 0.3 mmol), water (430 µL), 500 mM sodium

phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). After stirring for 24 h, the mixture was extracted with EtOAc (3 × 2 mL), washed with sodium bicarbonate and brine, dried over Na_2SO_4 and dried by rotary evaporation.

Caprolactone. The reaction was conducted using the general procedure with β-caryophyllene (22.6 µL, 0.1 mmol), caprolactone (33 µL, 0.3 mmol), water (431 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). After stirring for 24 h, the mixture was extracted with EtOAc (3 × 2 mL), washed with sodium bicarbonate and brine, dried over Na_2SO_4 and dried by rotary evaporation.

α-Methylbutyrolactone. The reaction was conducted using the general procedure with β-caryophyllene (22.6 µL, 0.1 mmol), α-methylbutyrolactone (29 µL, 0.3 mmol), water (436 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). After stirring for 24 h, the mixture was extracted with EtOAc (3 × 2 mL), washed with sodium bicarbonate and brine, dried over Na_2SO_4 and dried by rotary evaporation.

β-Butyrolactone. The reaction was conducted using the general procedure with β-caryophyllene (22.6 µL, 0.1 mmol), β-butyrolactone (24 µL, 0.3 mmol), water (440 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). After stirring for 24 h, the mixture was extracted with EtOAc (3 × 2 mL), washed with sodium bicarbonate and brine, dried over Na_2SO_4 and dried by rotary evaporation.

δ-Valerolactone. The reaction was conducted using the general procedure with β-caryophyllene (22.6 µL, 0.1 mmol), δ-valerolactone (28 µL, 0.3 mmol), water (436 µL), 500 mM sodium phosphate buffer pH 6.5 (200 µL), 30% H_2O_2 (153 µL) and 2.5 mg/mL CpLIP2 Y179F in water (160 µL). After stirring for 24 h, the mixture was extracted with EtOAc (3 × 2 mL), washed with sodium bicarbonate and brine, dried over Na_2SO_4 and dried by rotary evaporation.

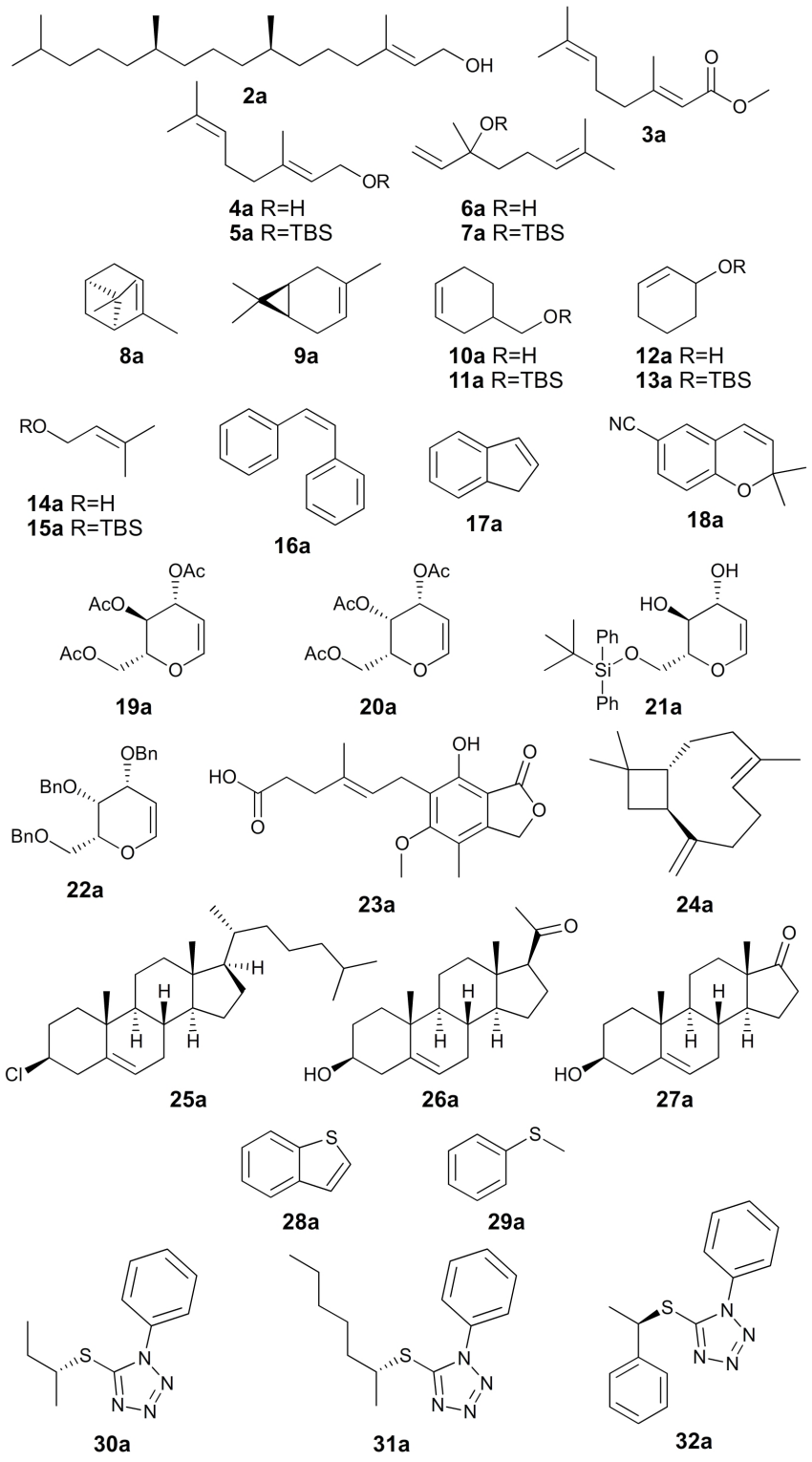
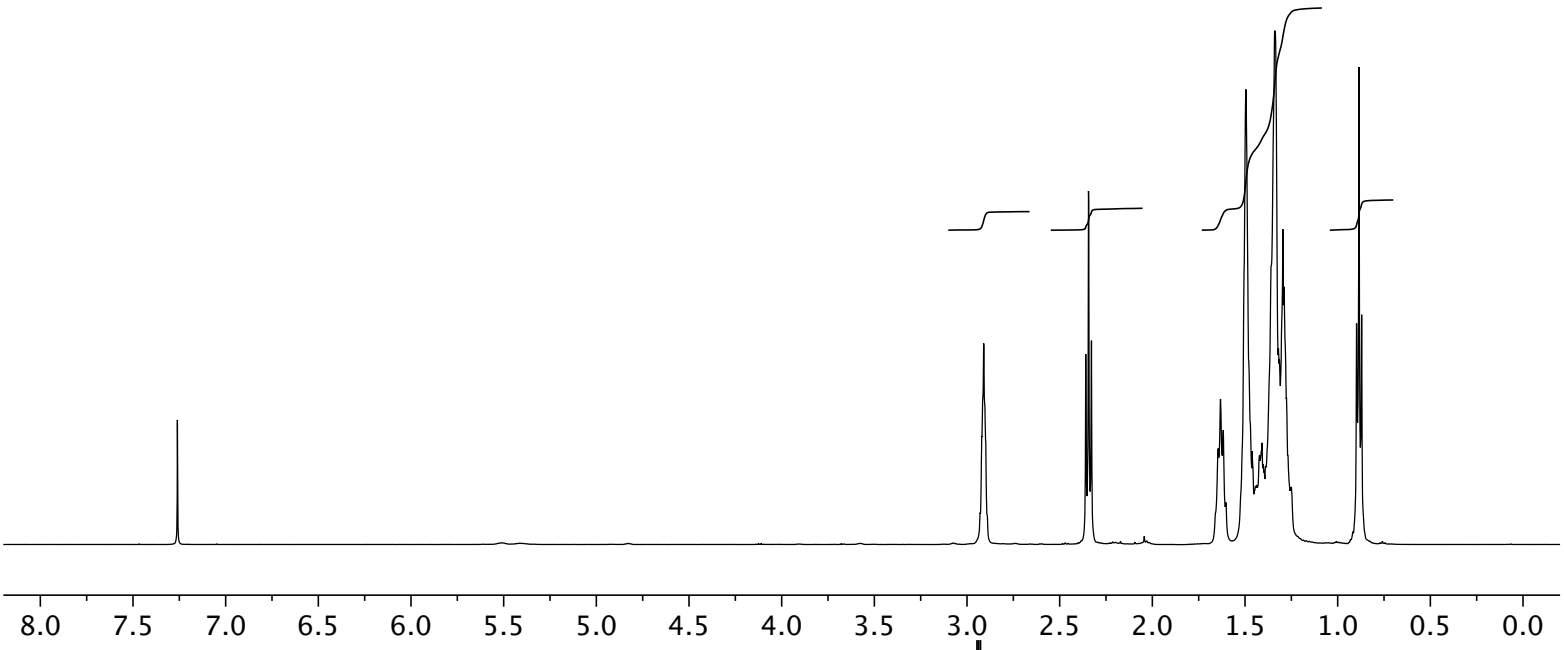
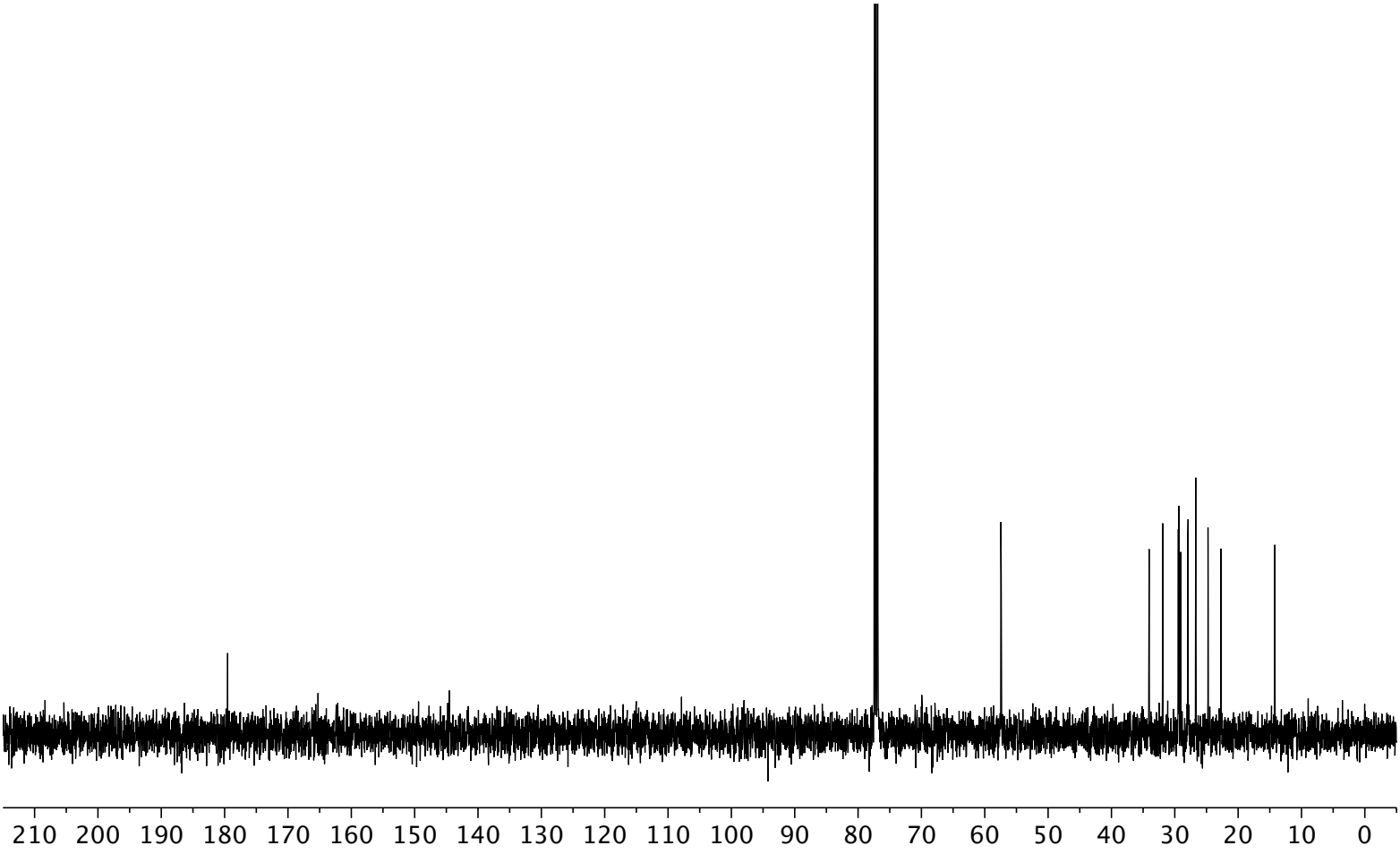


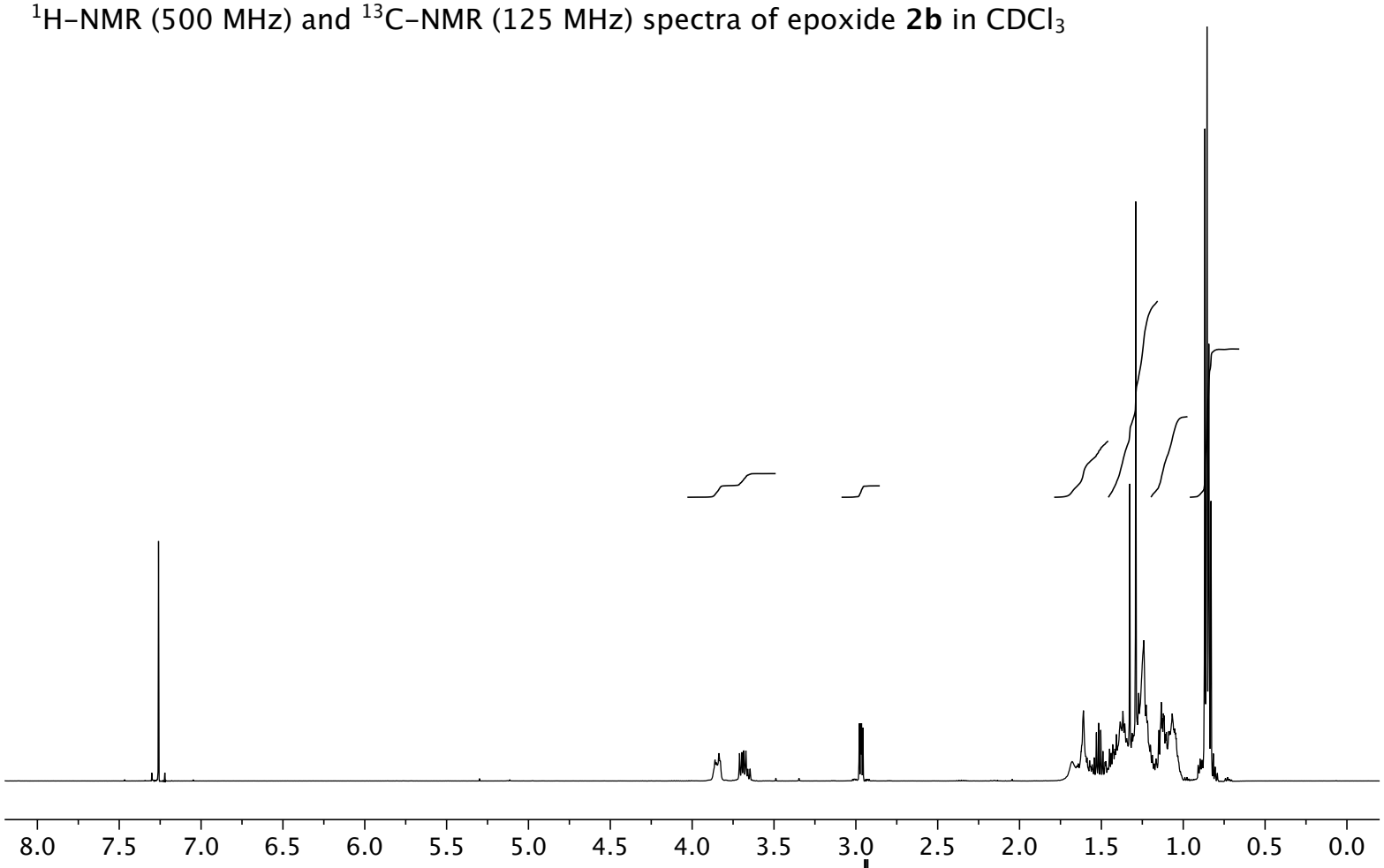
Figure S1. Structures of the starting materials used in this study.

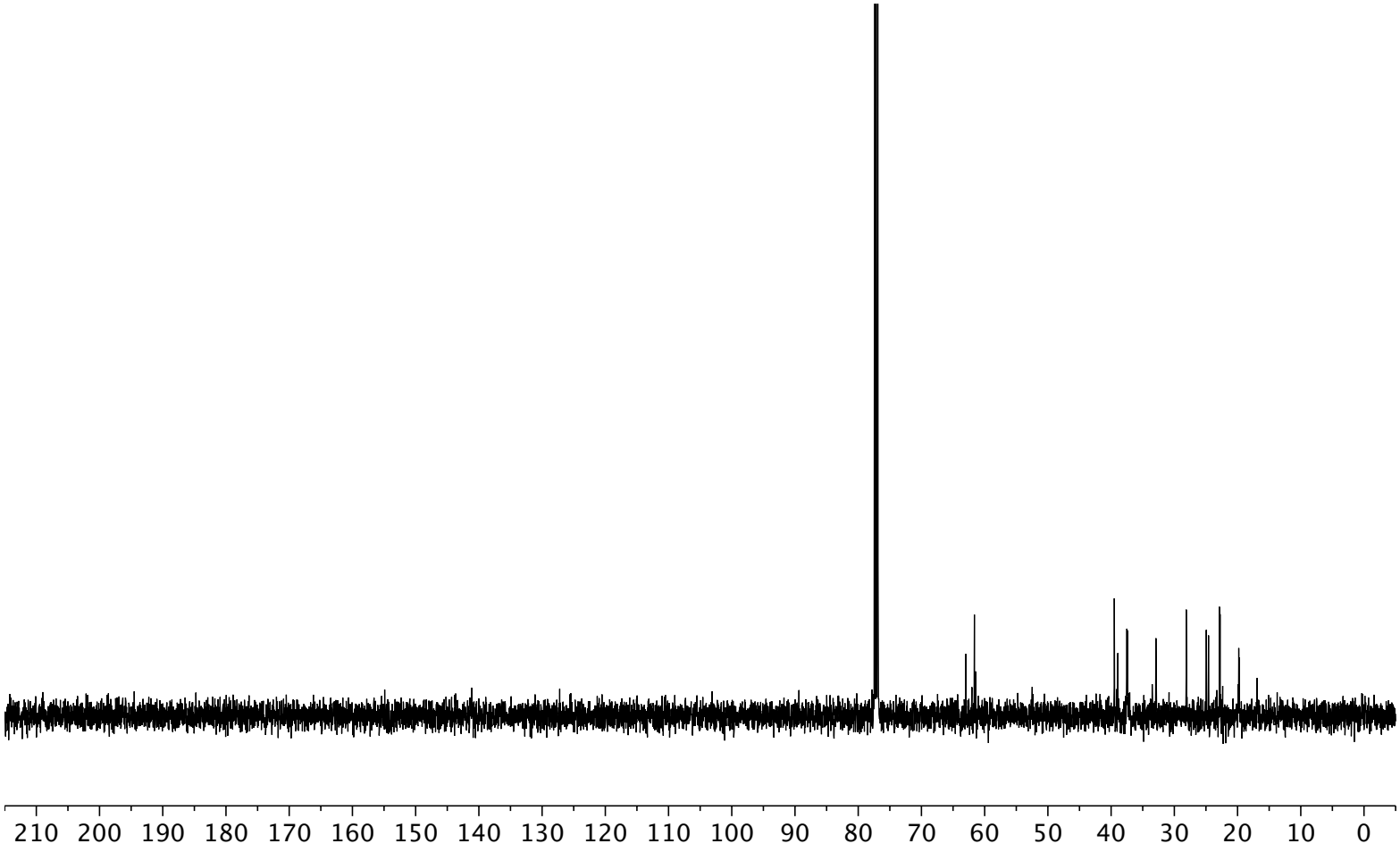
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **1d** in $CDCl_3$



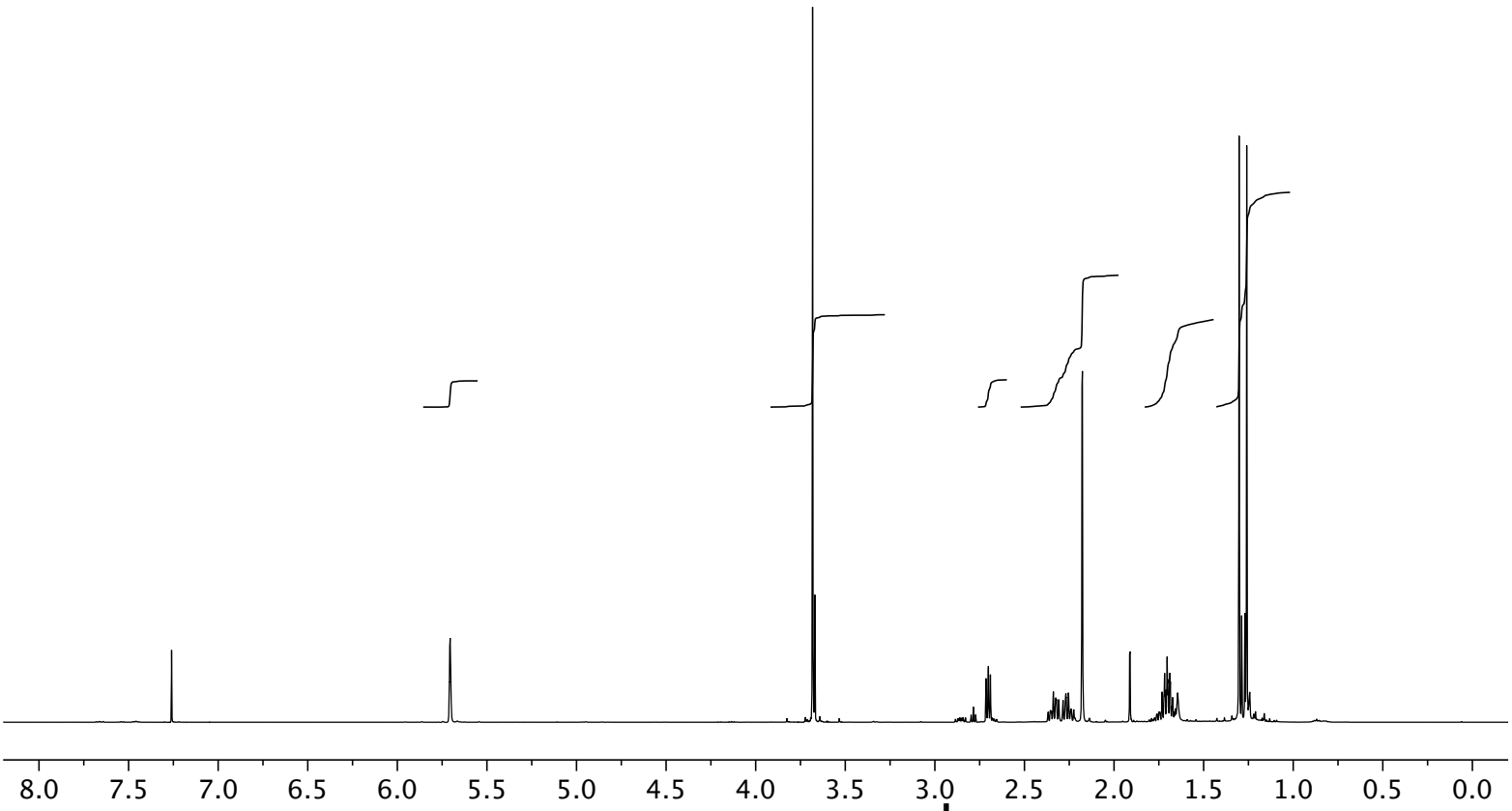


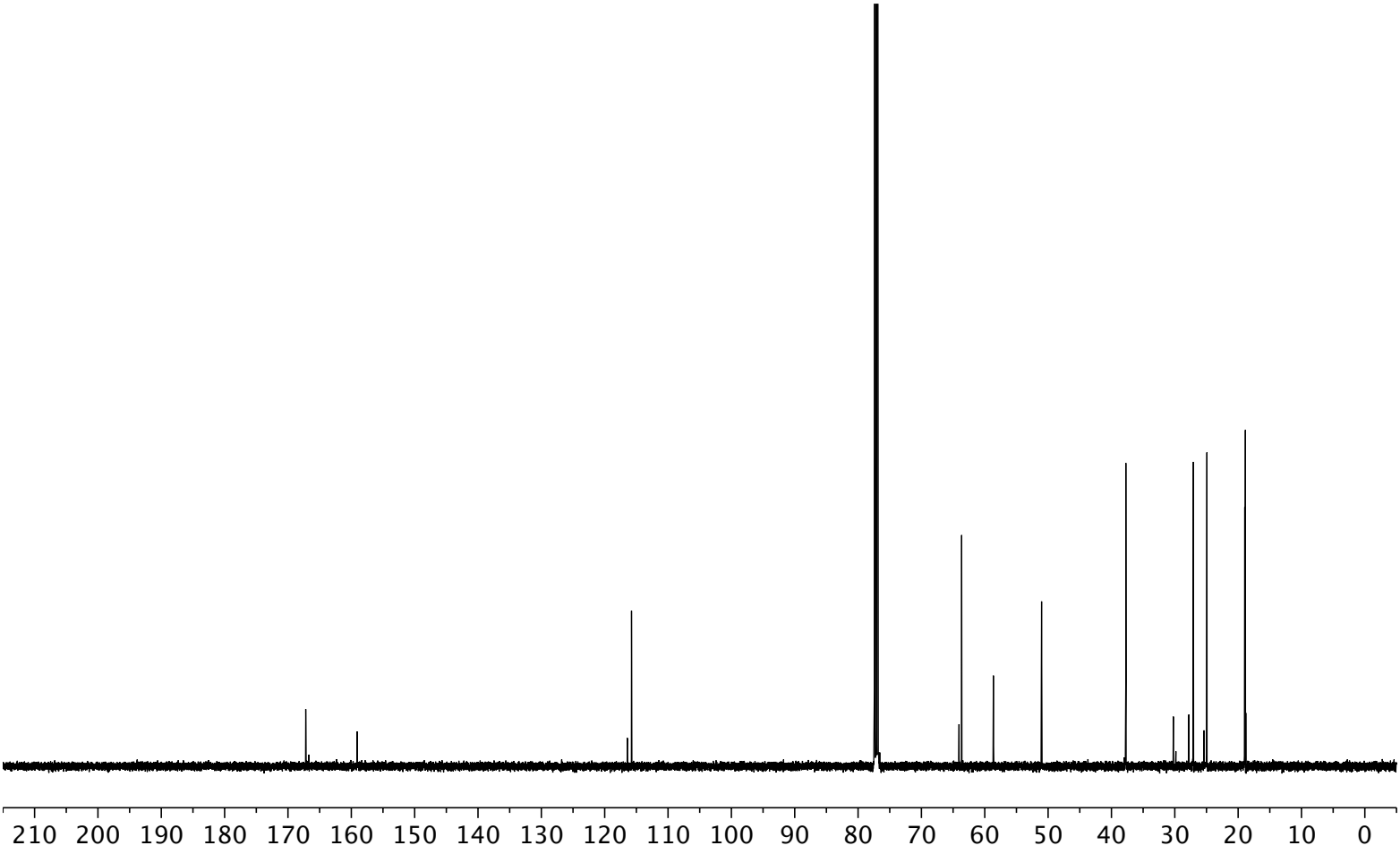
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **2b** in $CDCl_3$



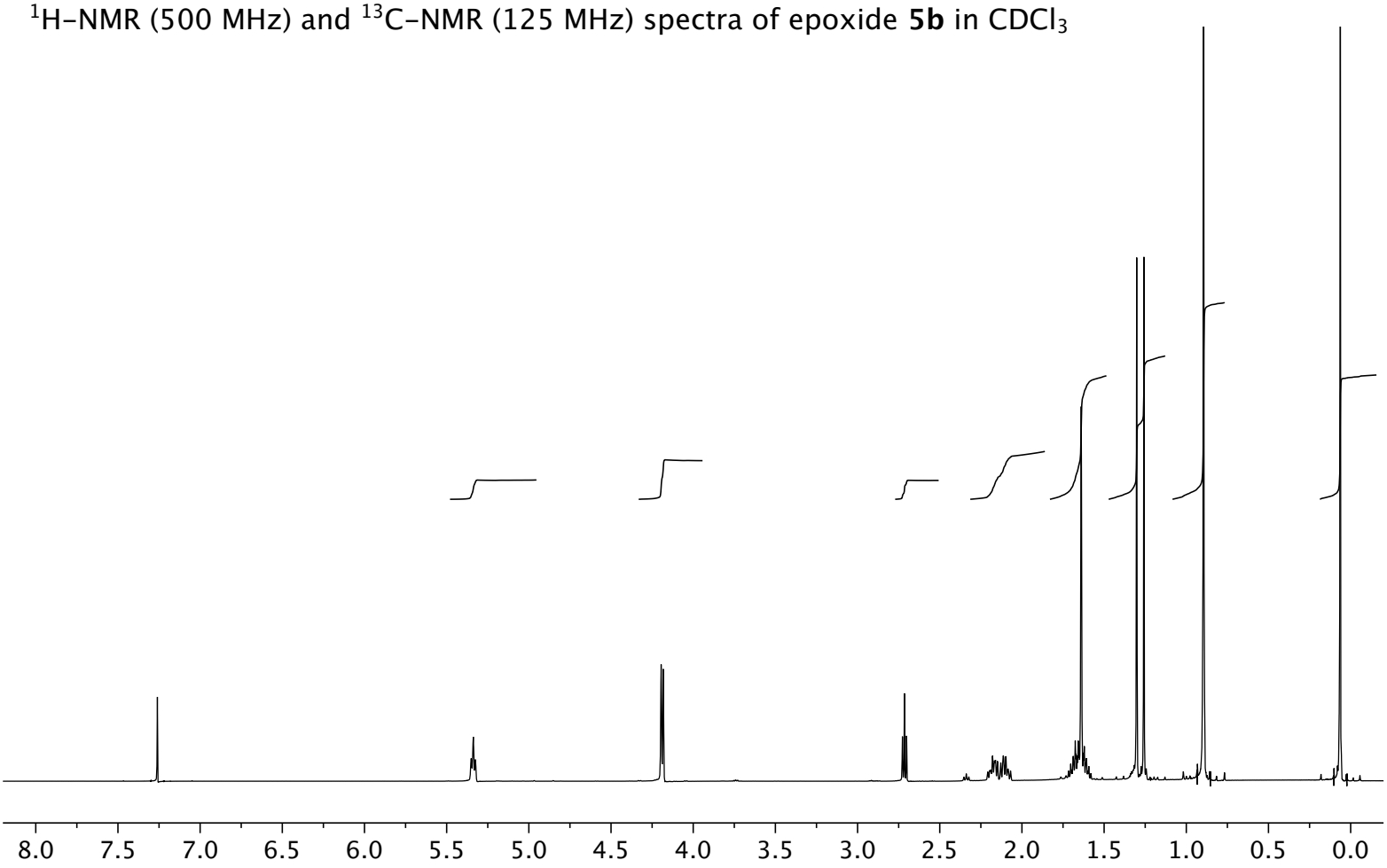


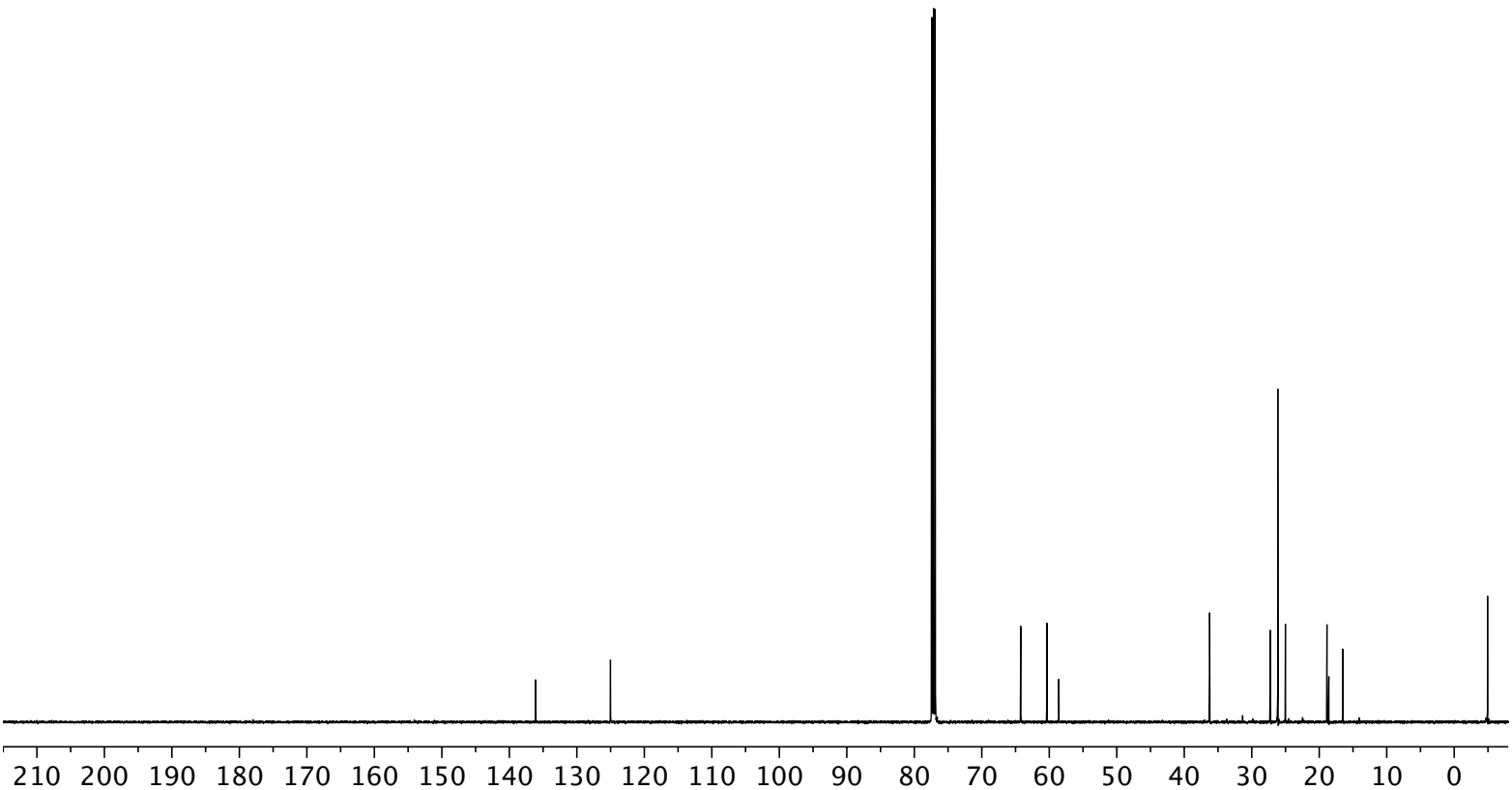
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **3b** in $CDCl_3$



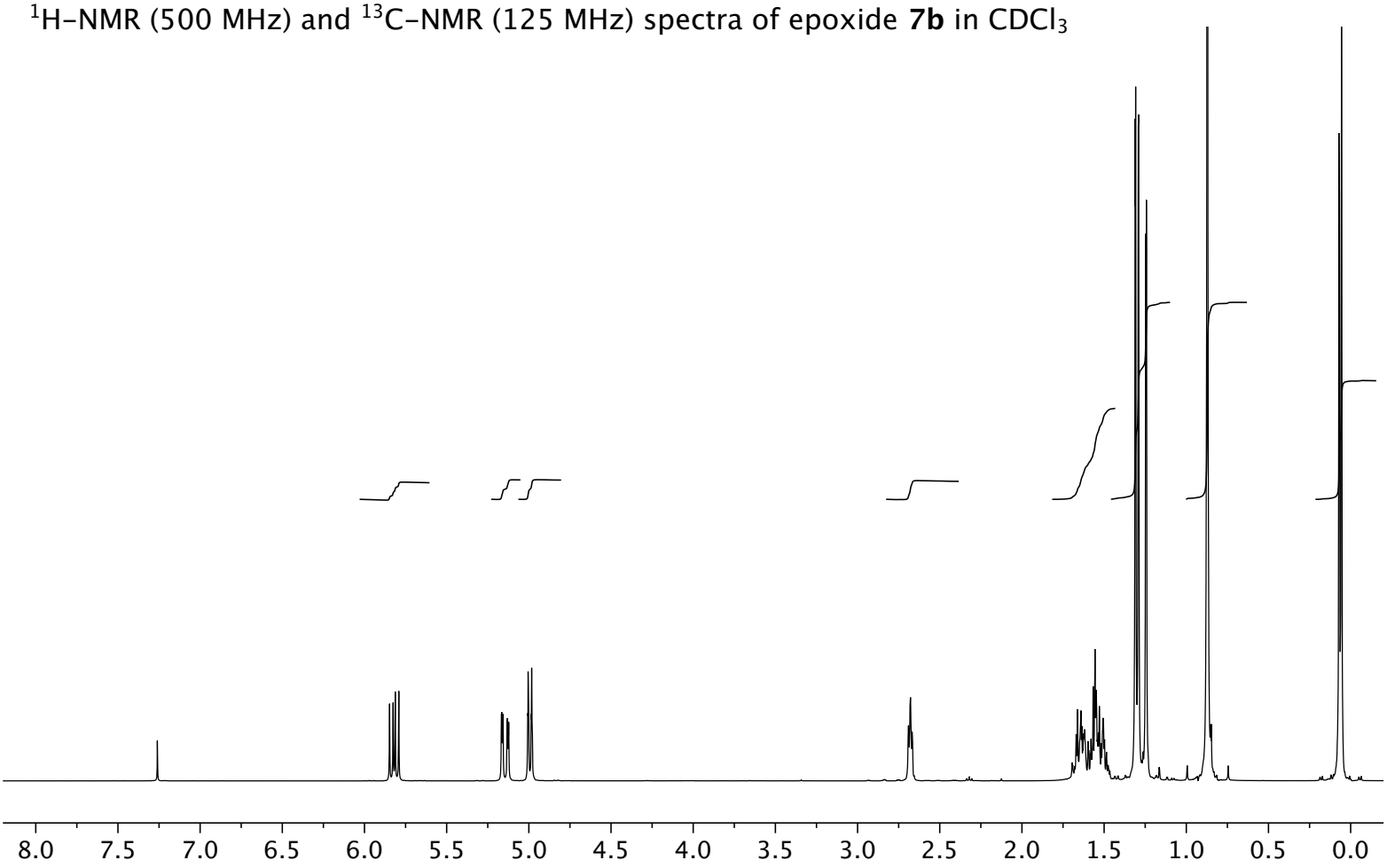


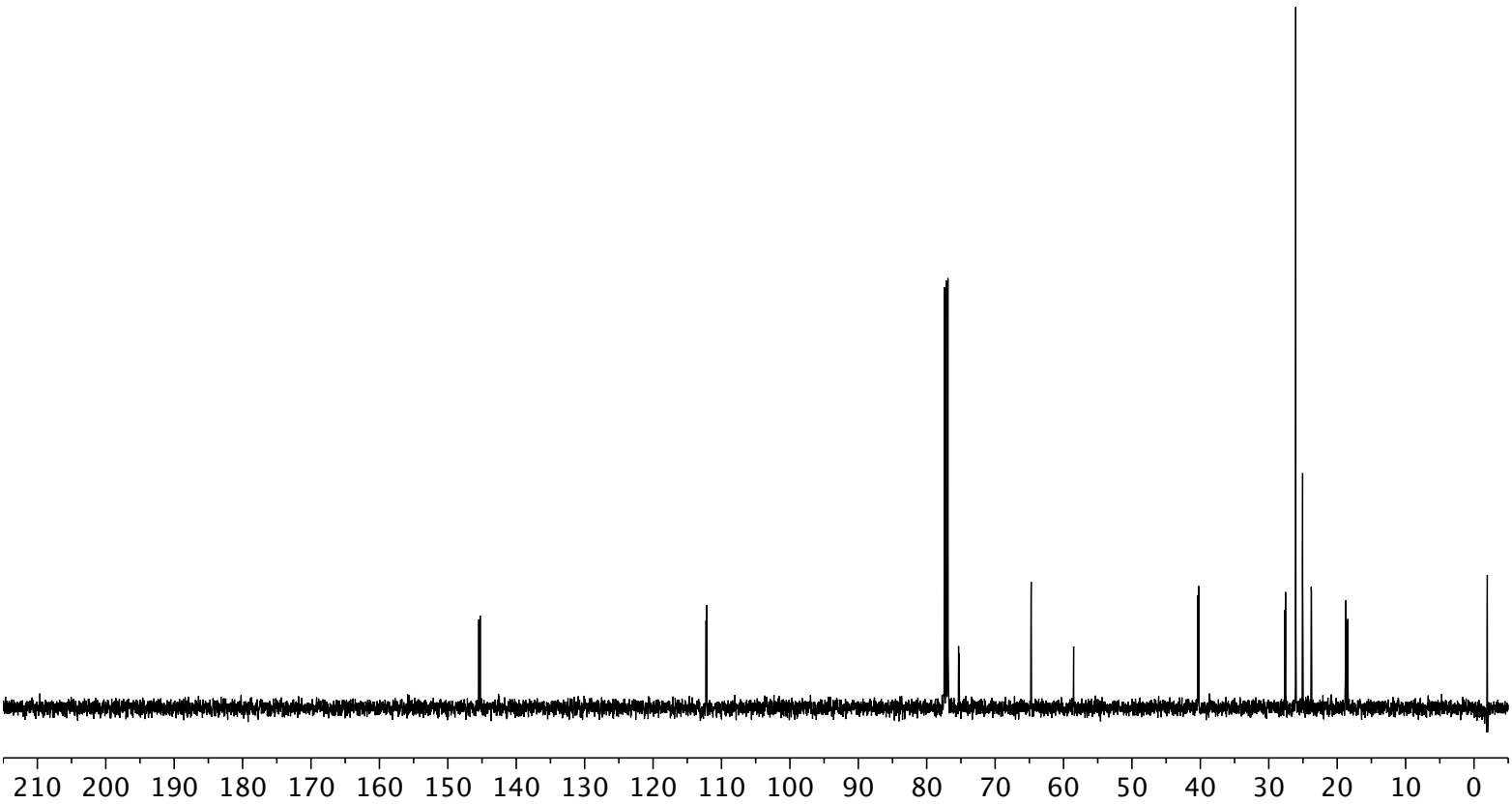
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **5b** in $CDCl_3$



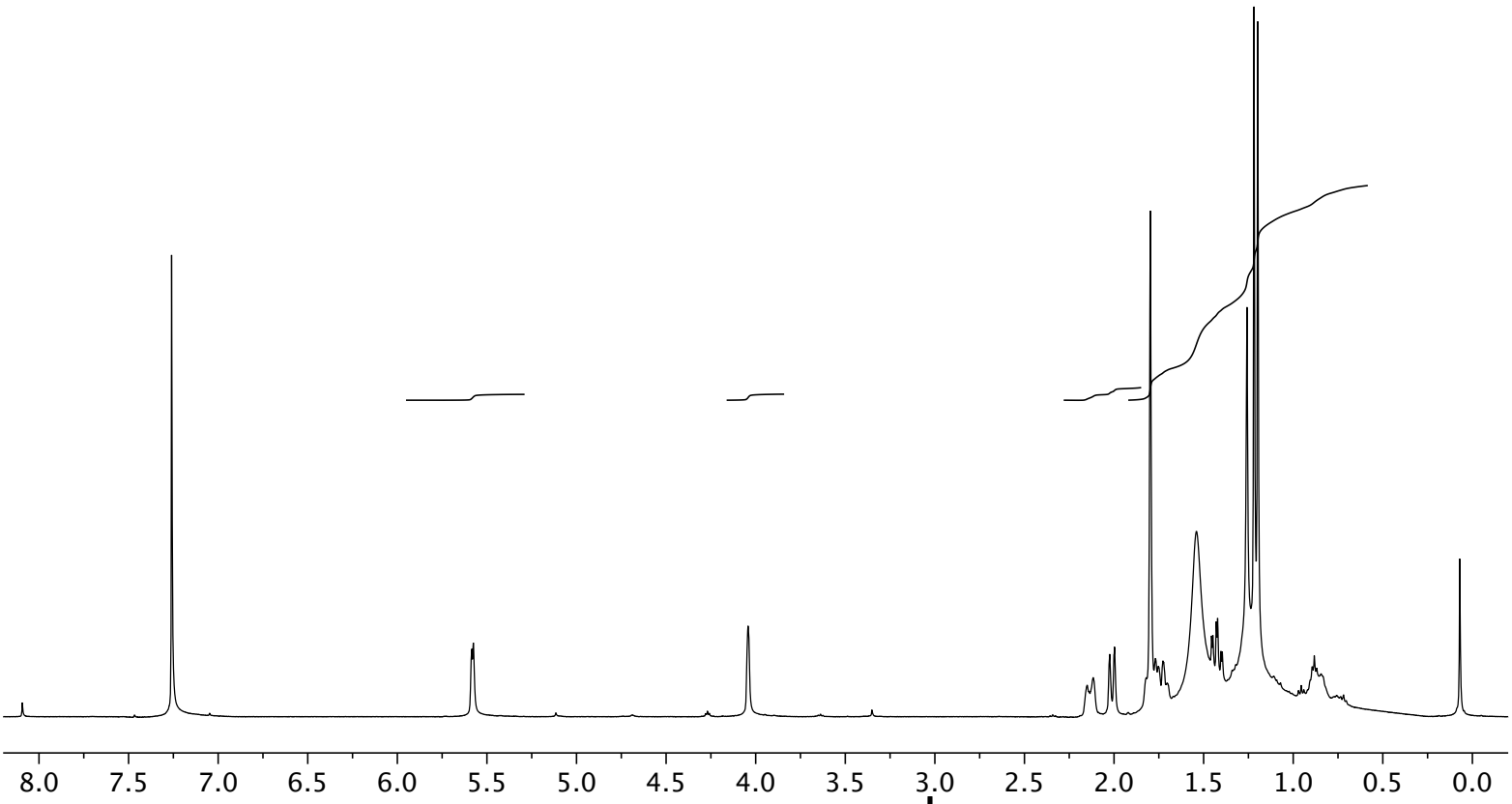


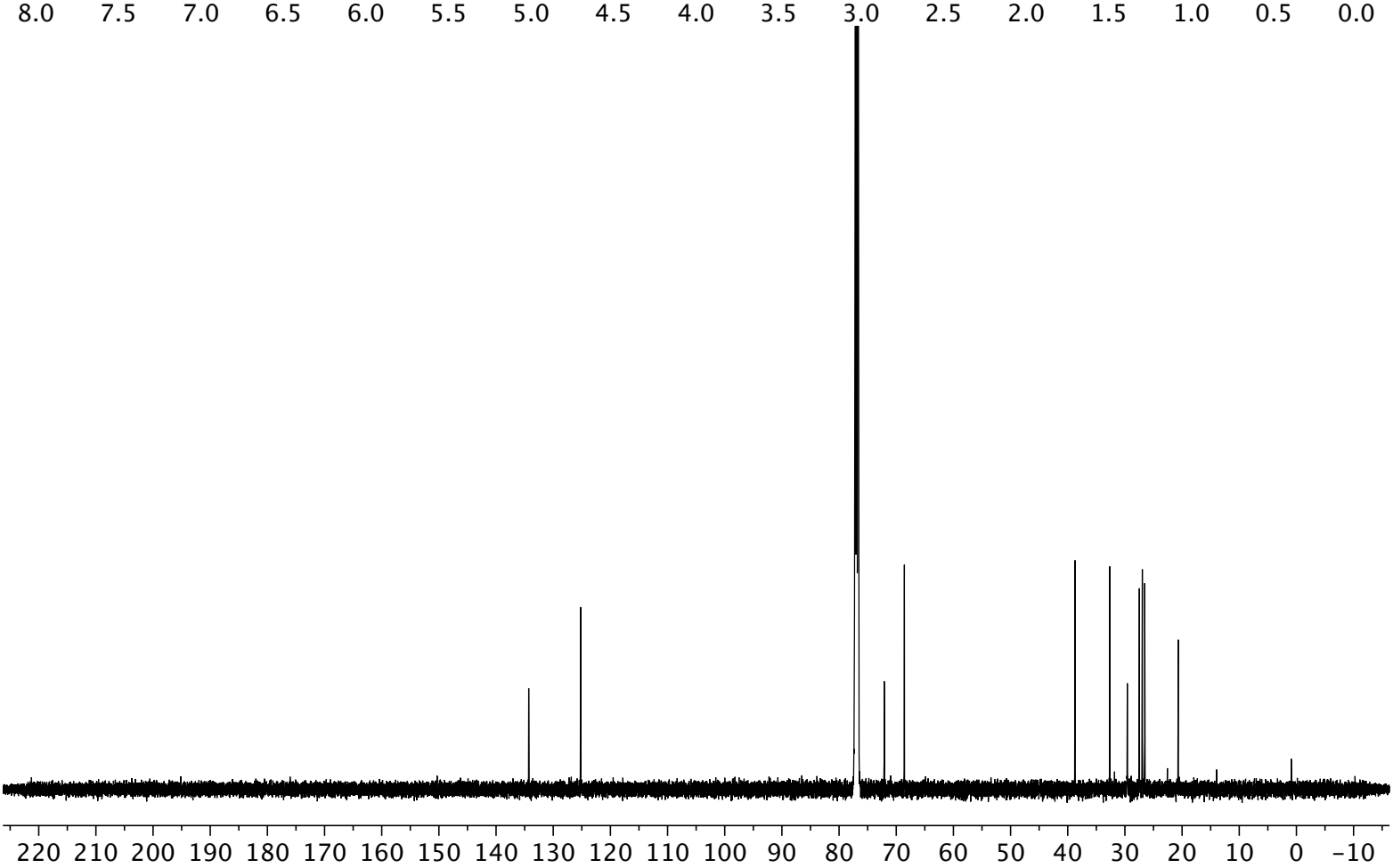
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **7b** in $CDCl_3$



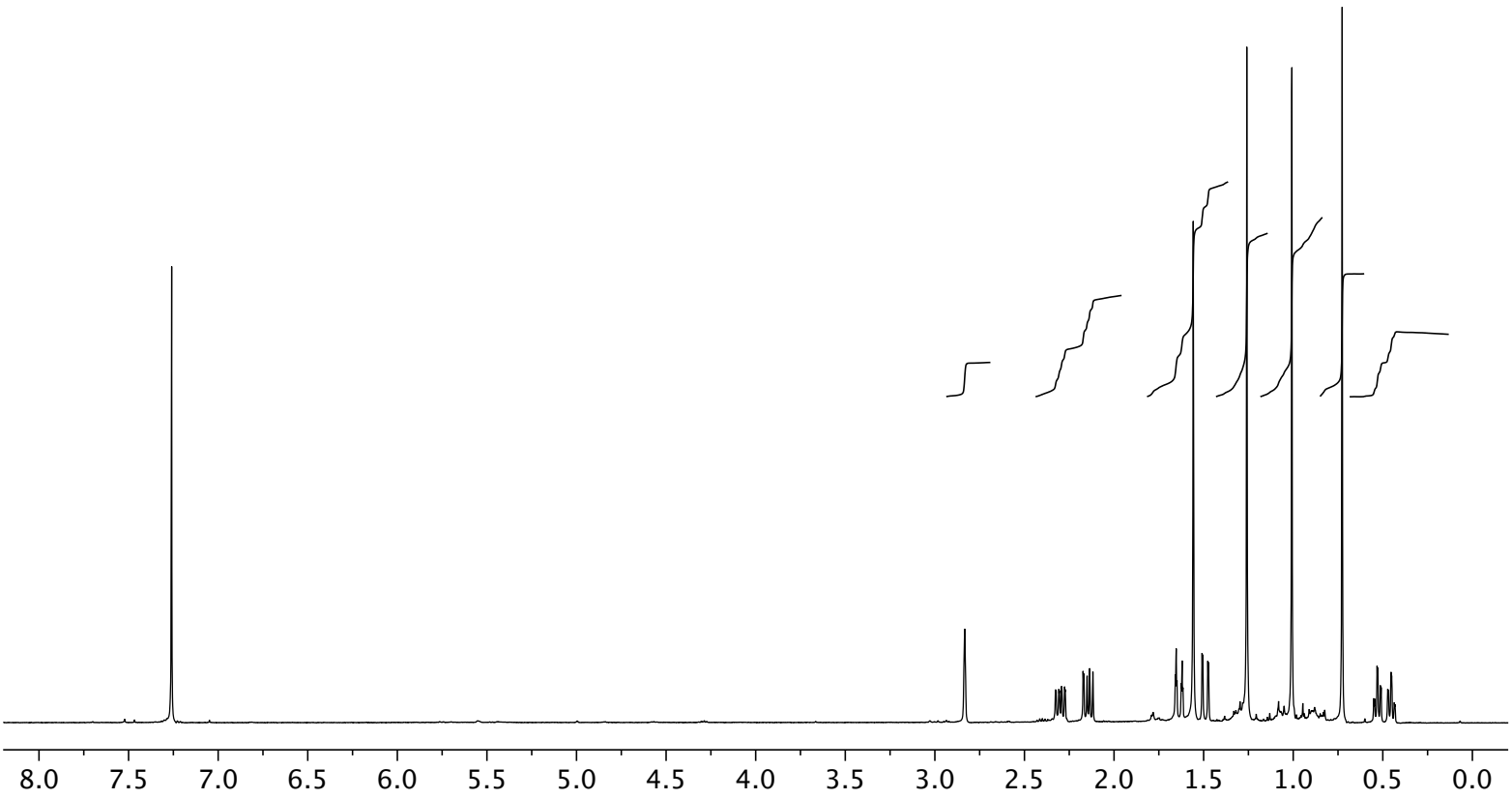


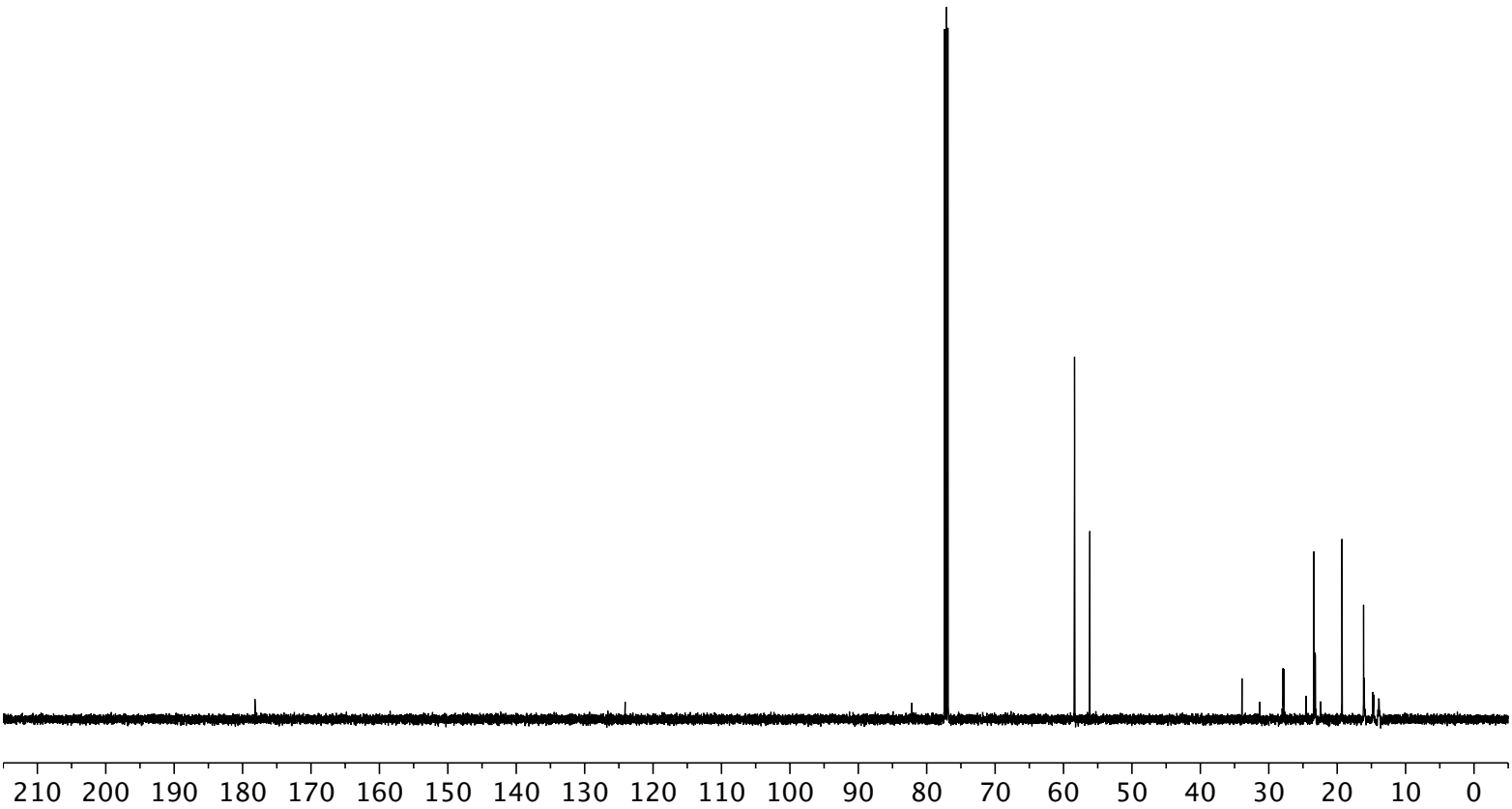
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of **8c** in $CDCl_3$



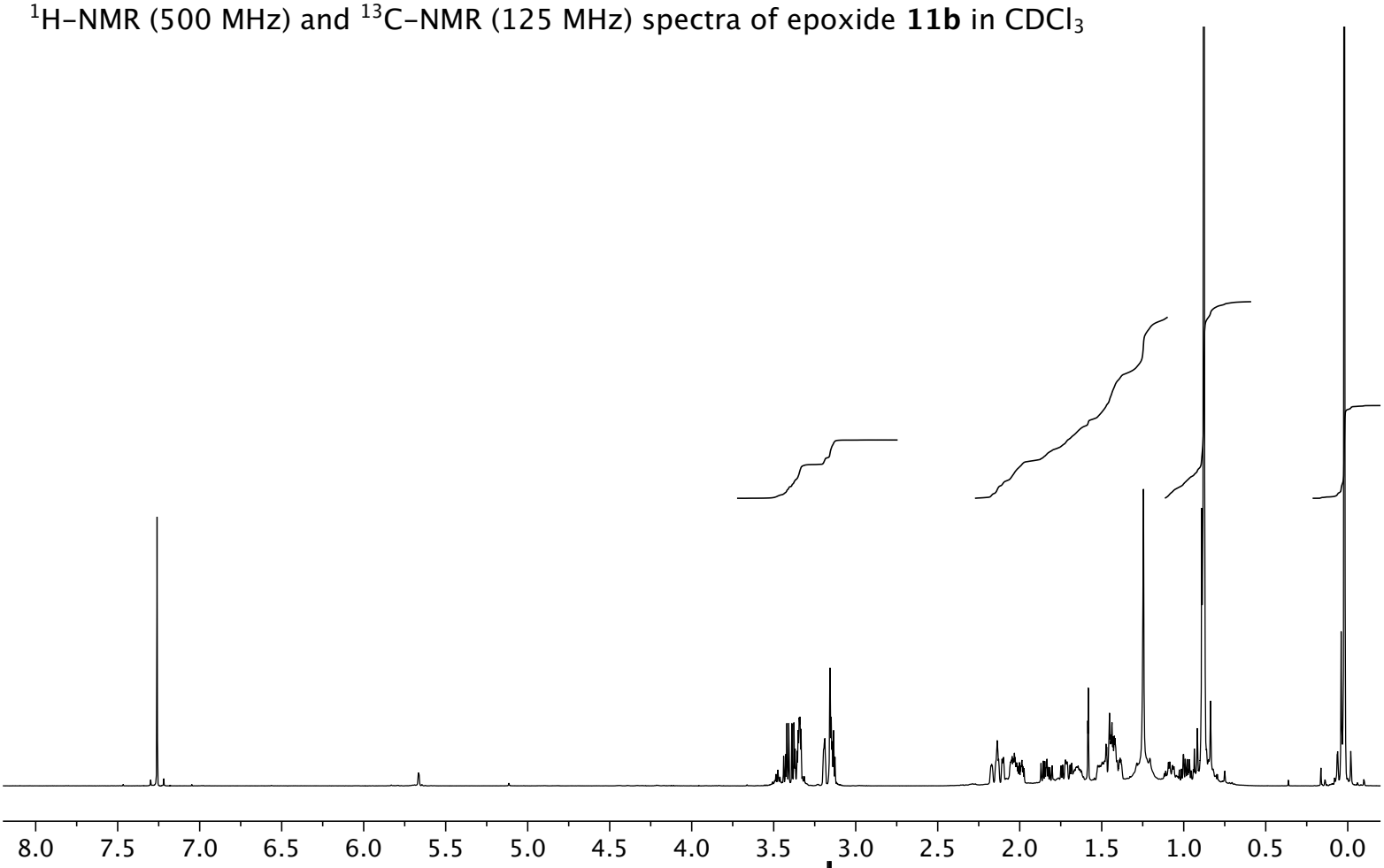


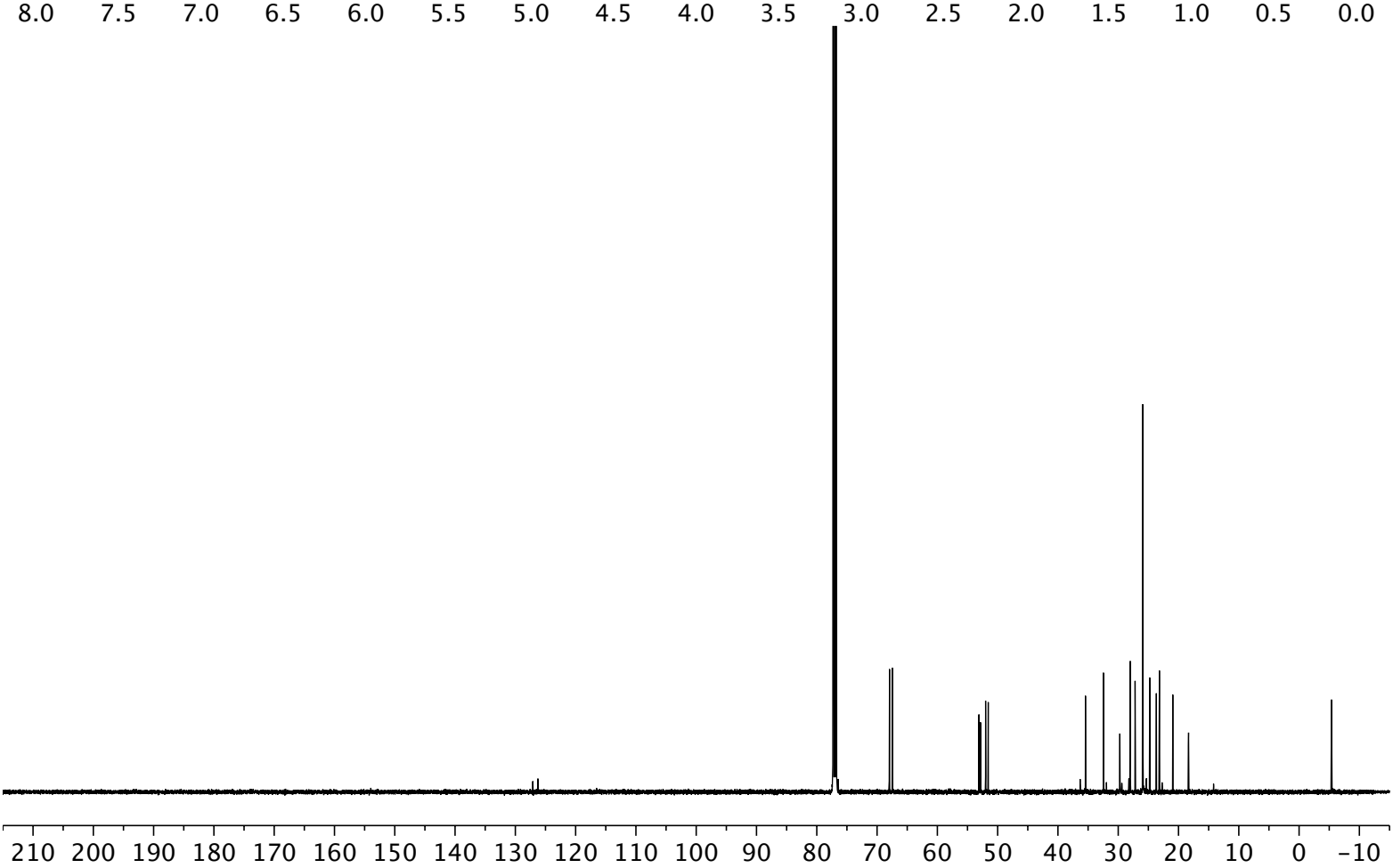
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of **9b** in $CDCl_3$



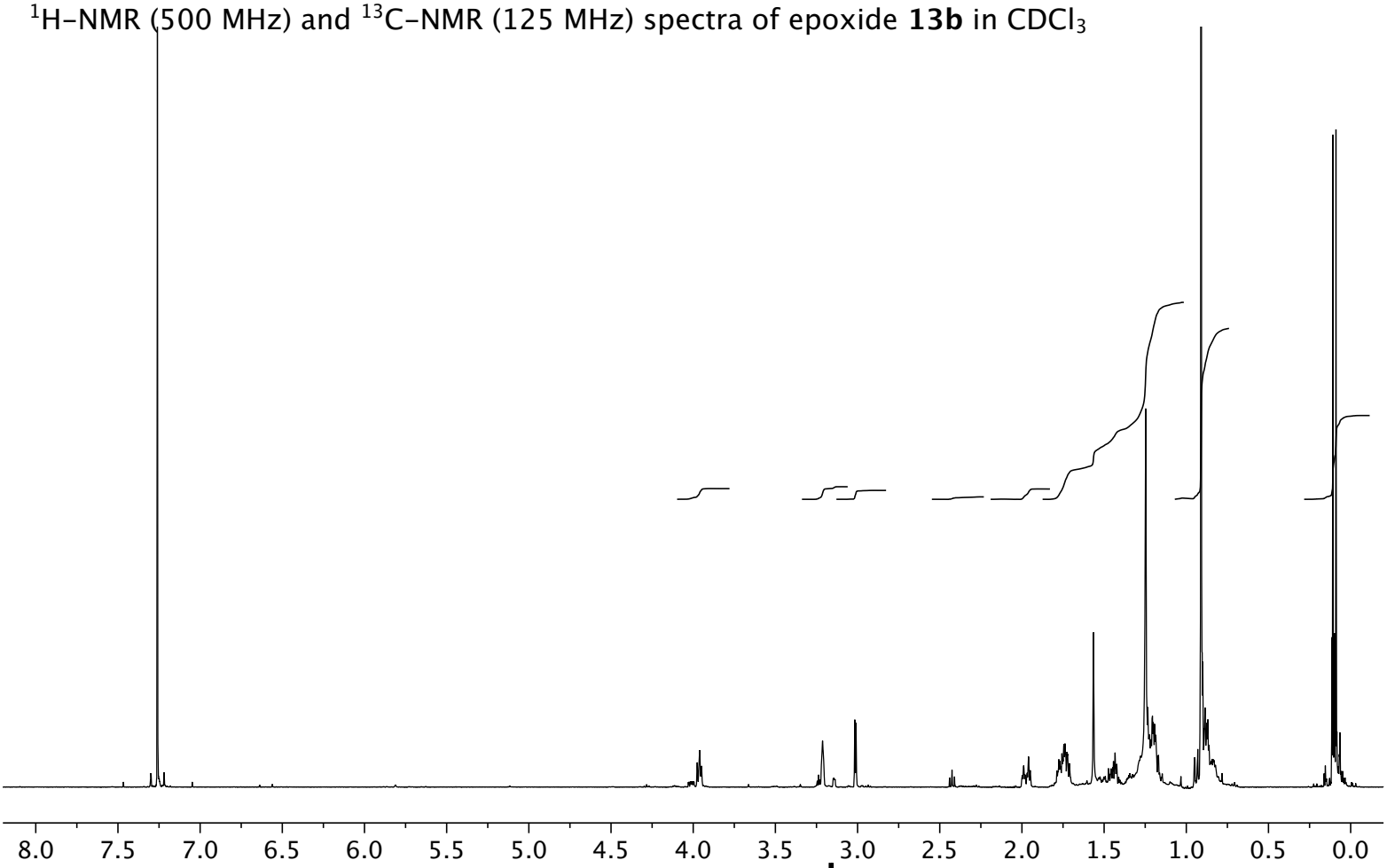


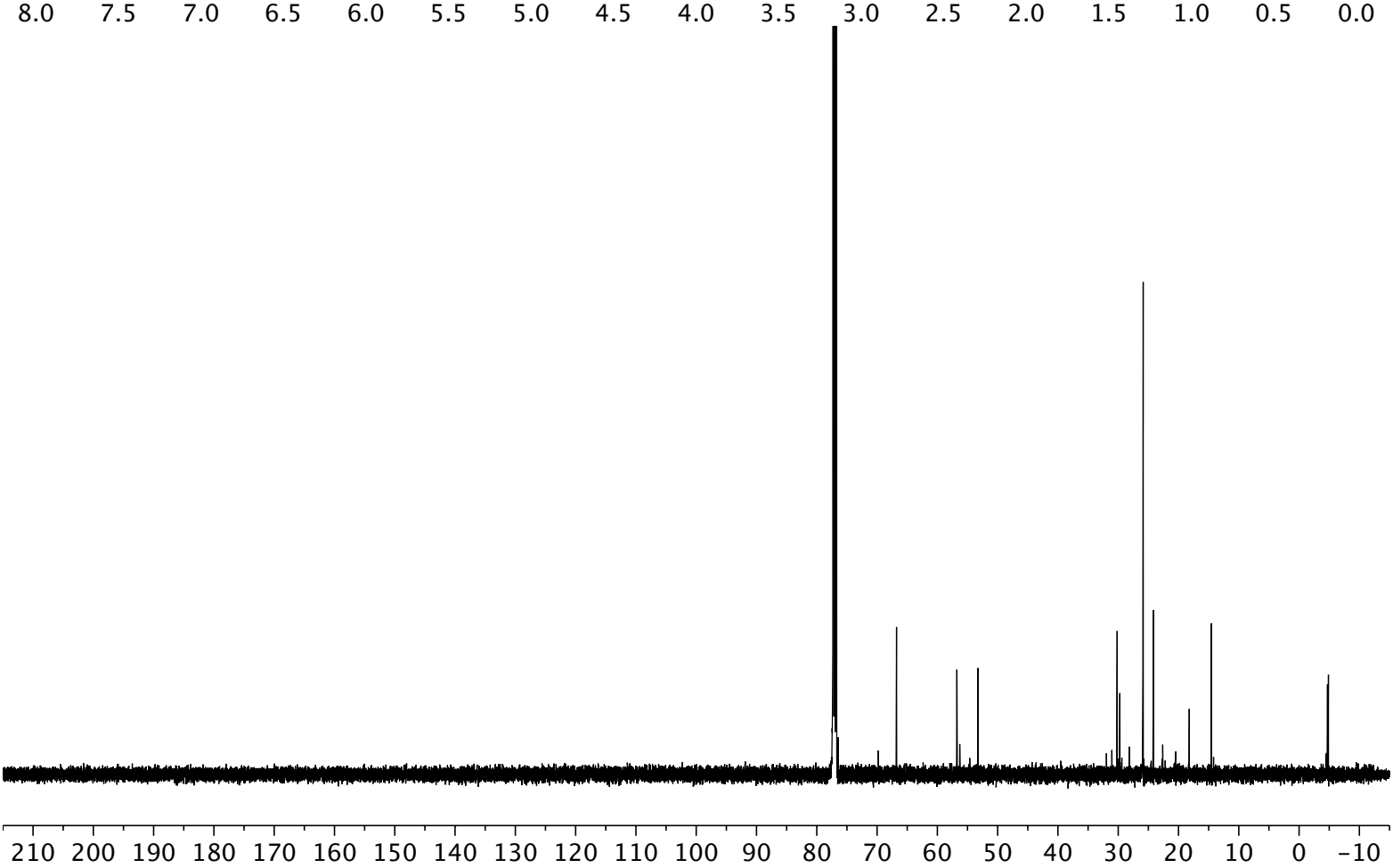
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **11b** in $CDCl_3$



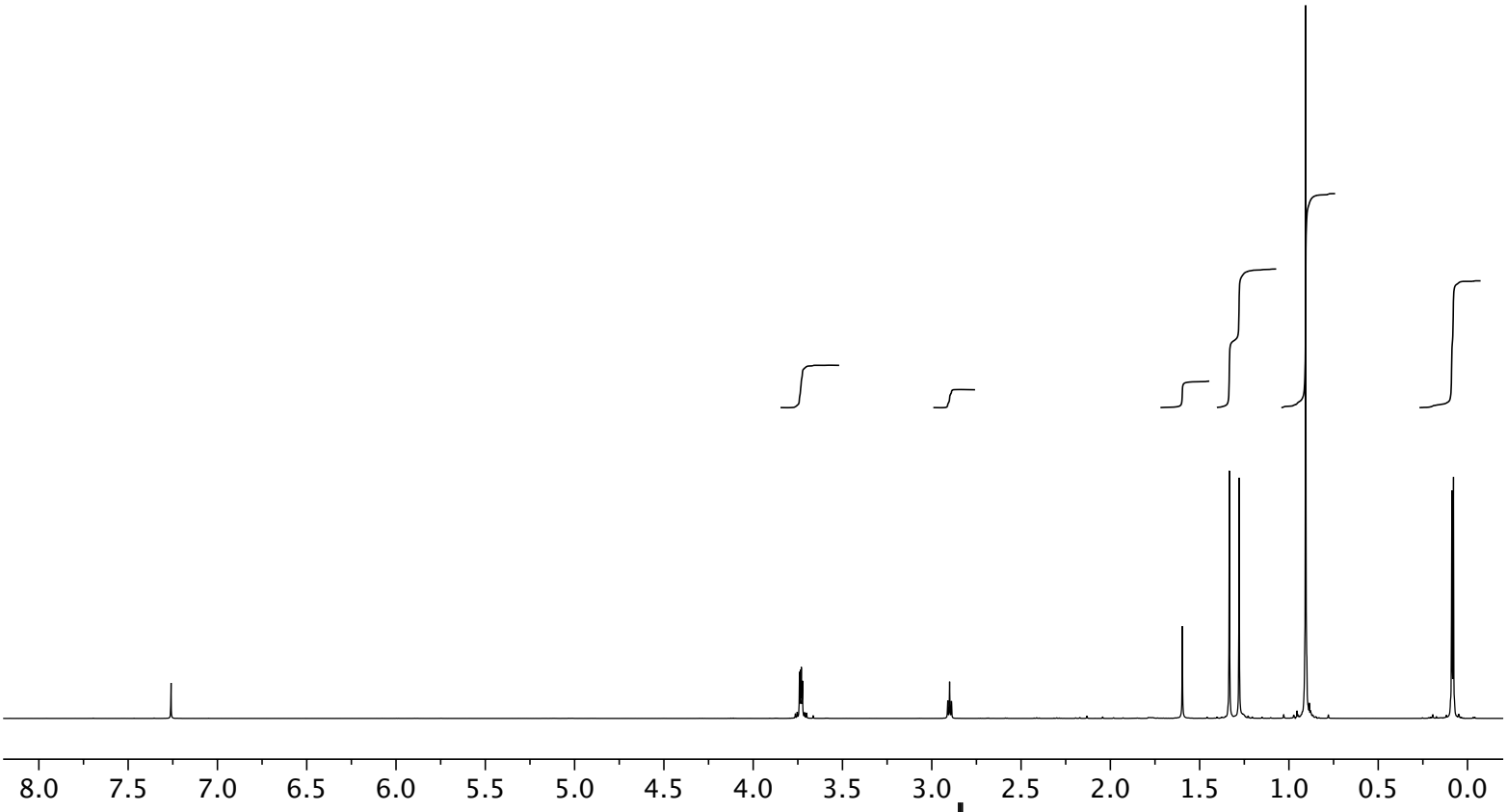


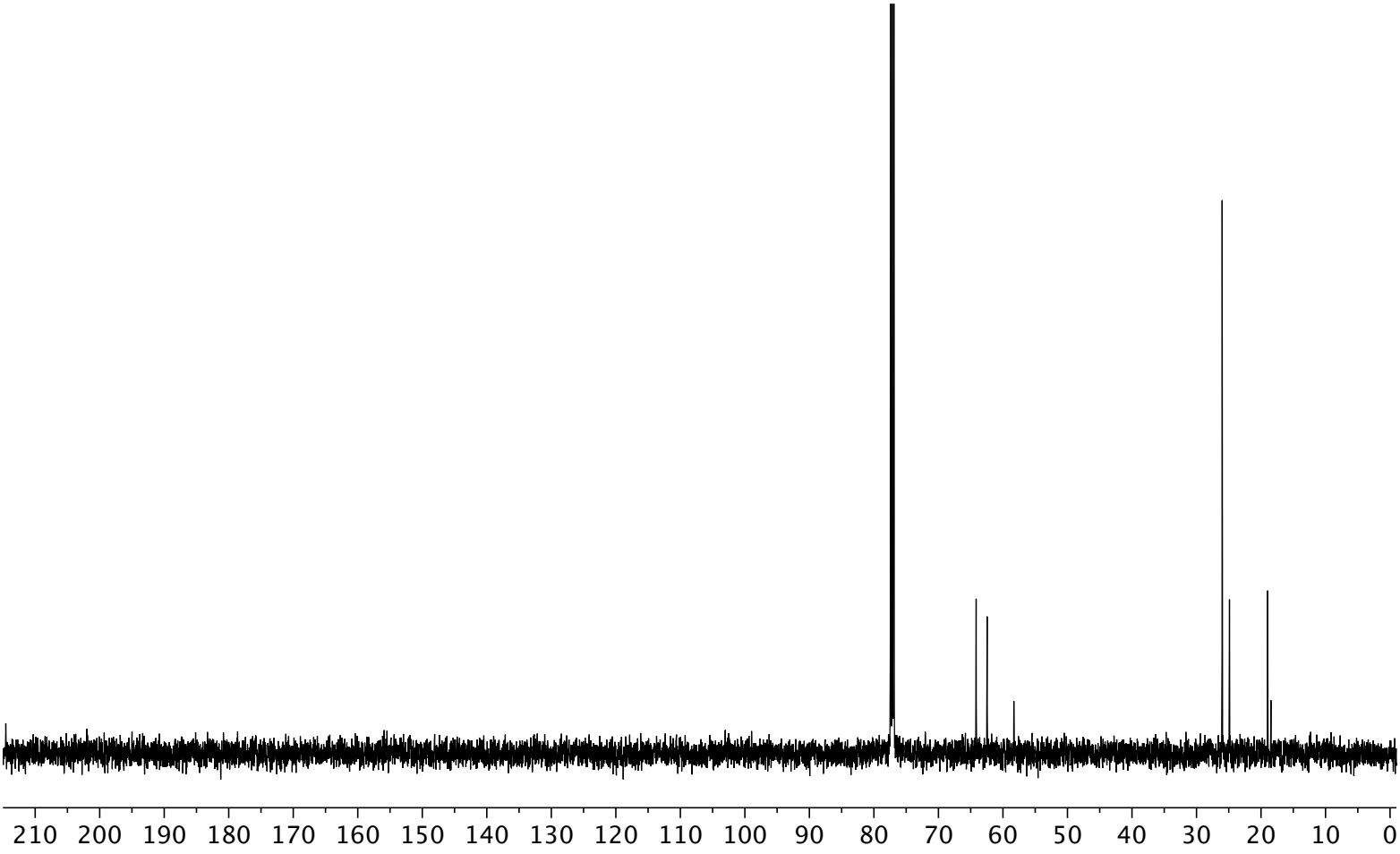
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **13b** in $CDCl_3$



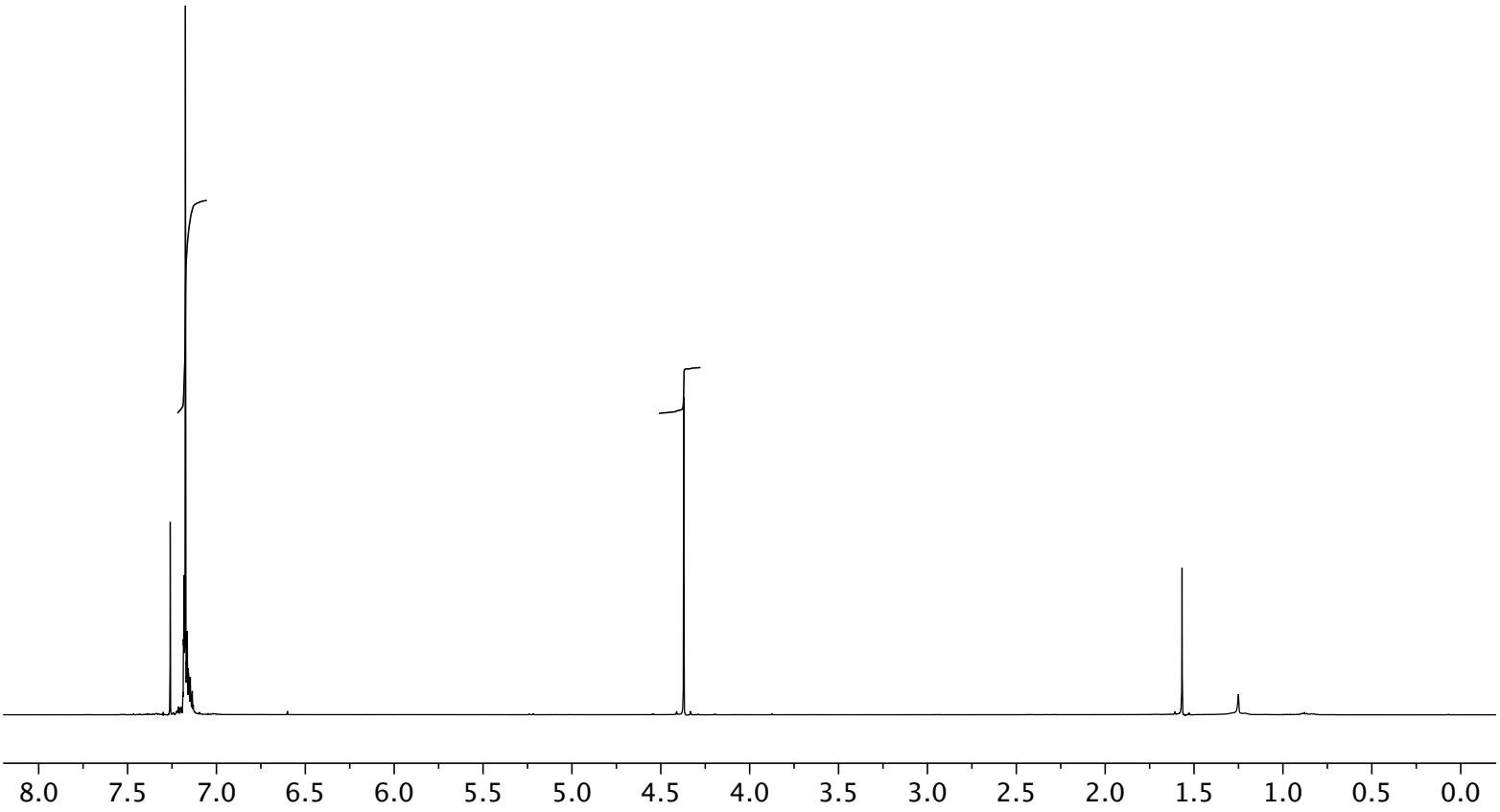


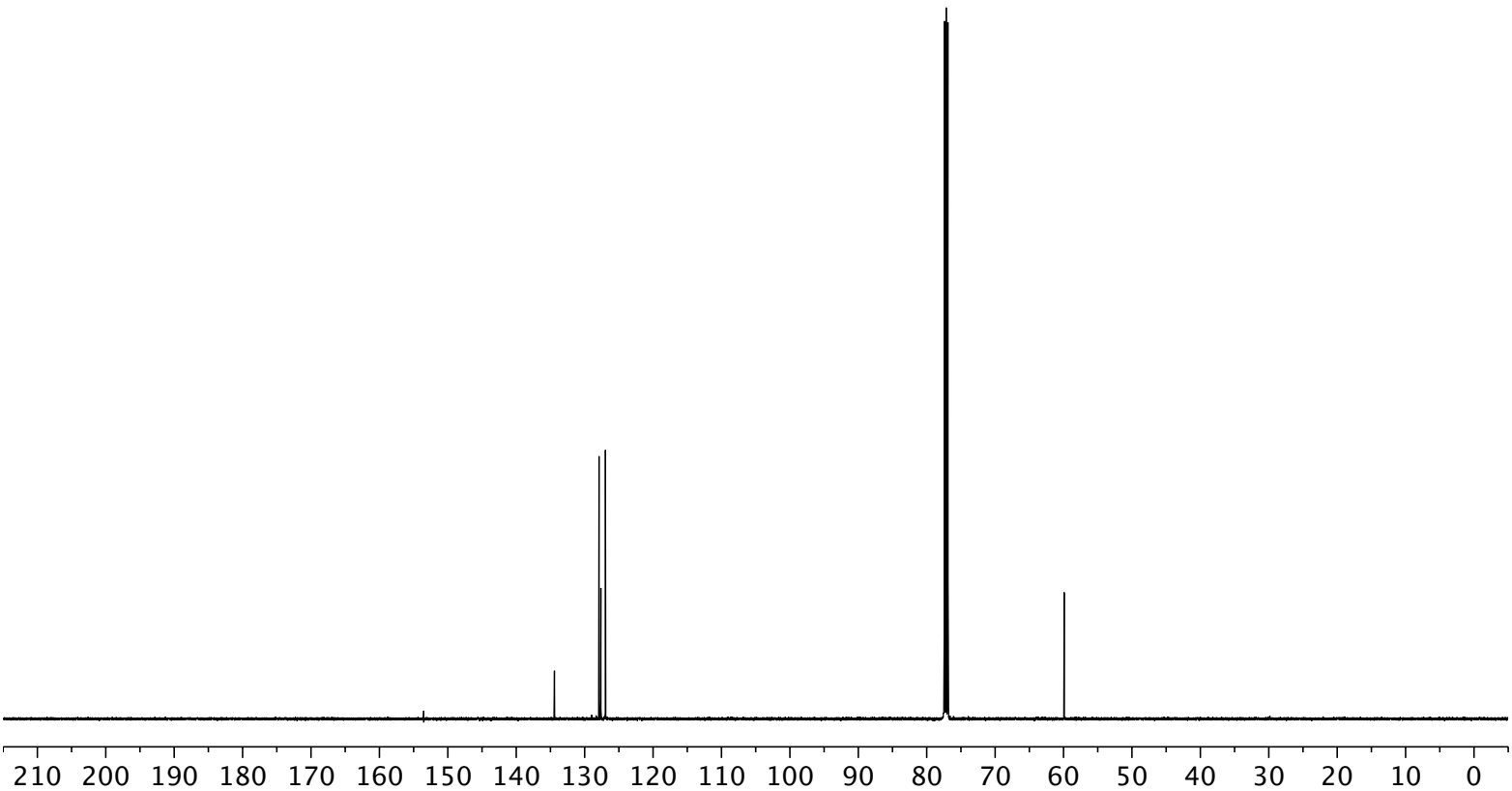
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **15b** in $CDCl_3$



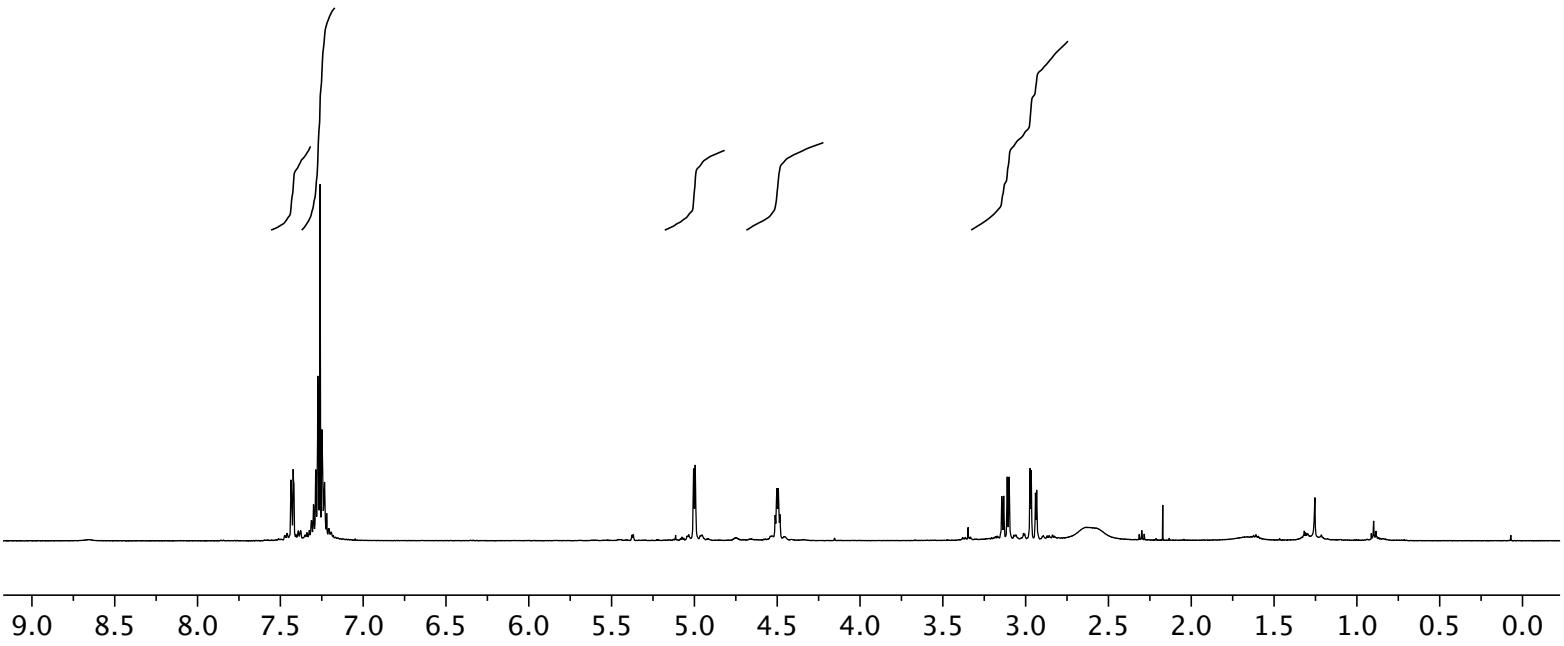


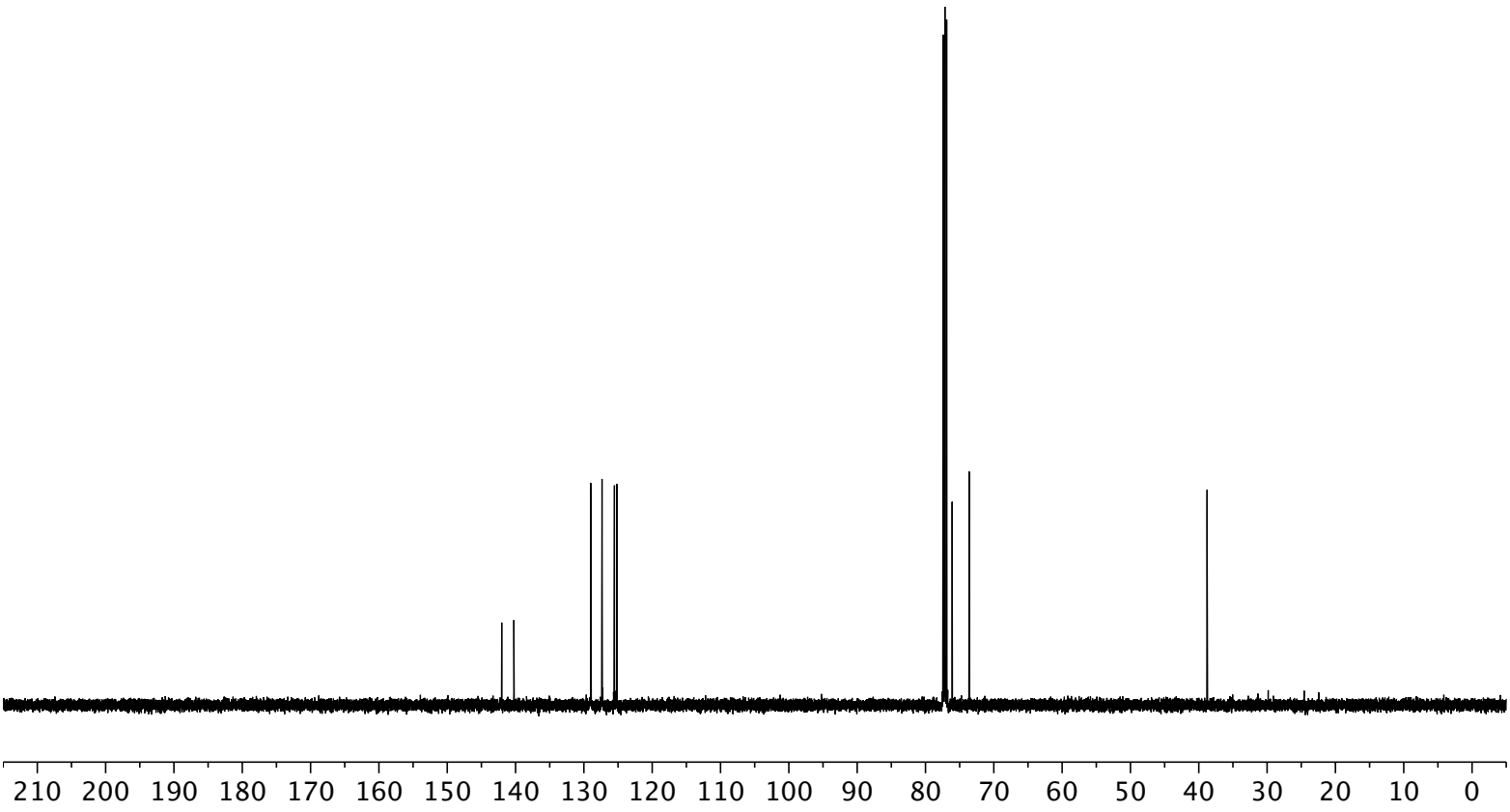
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **16b** in $CDCl_3$



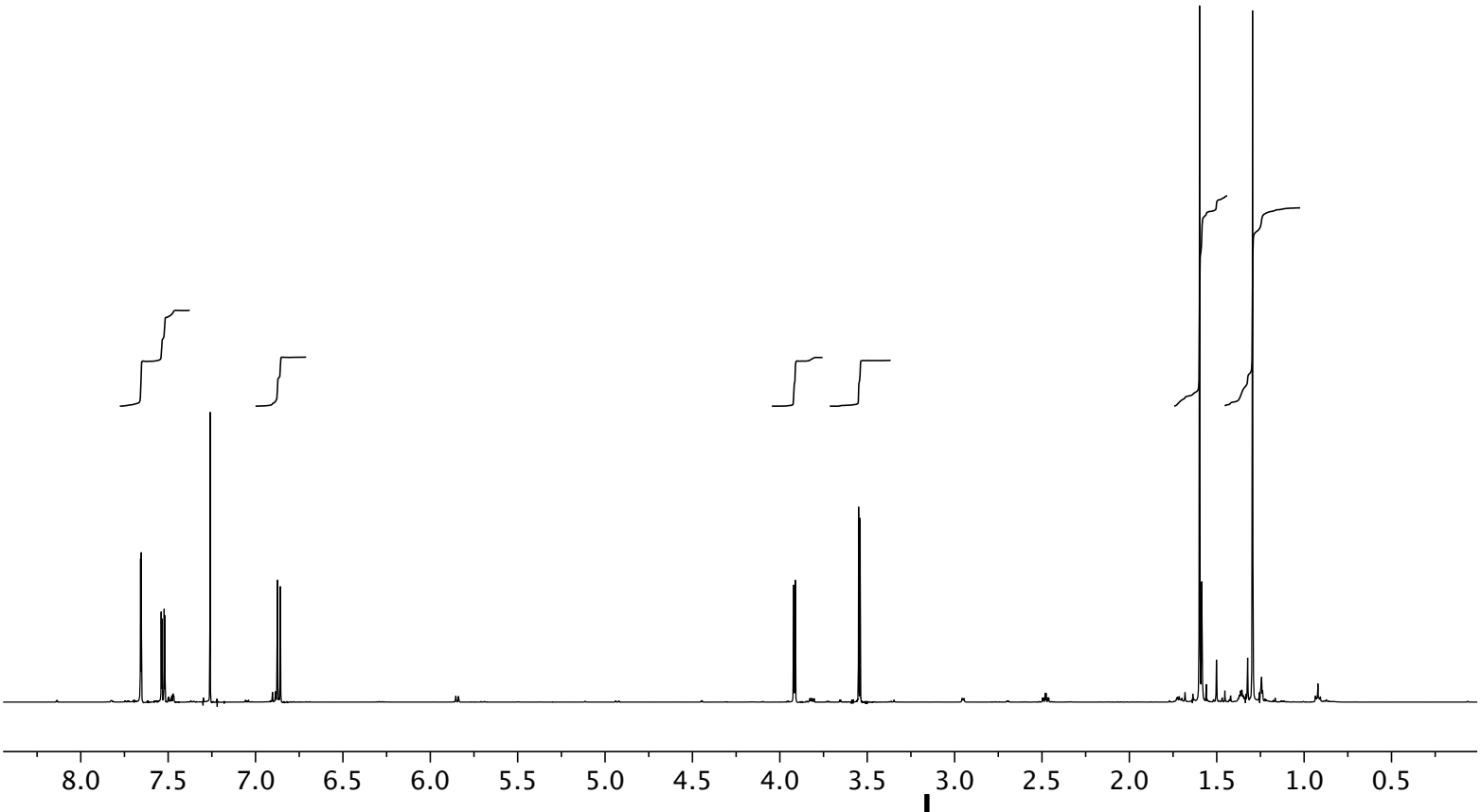


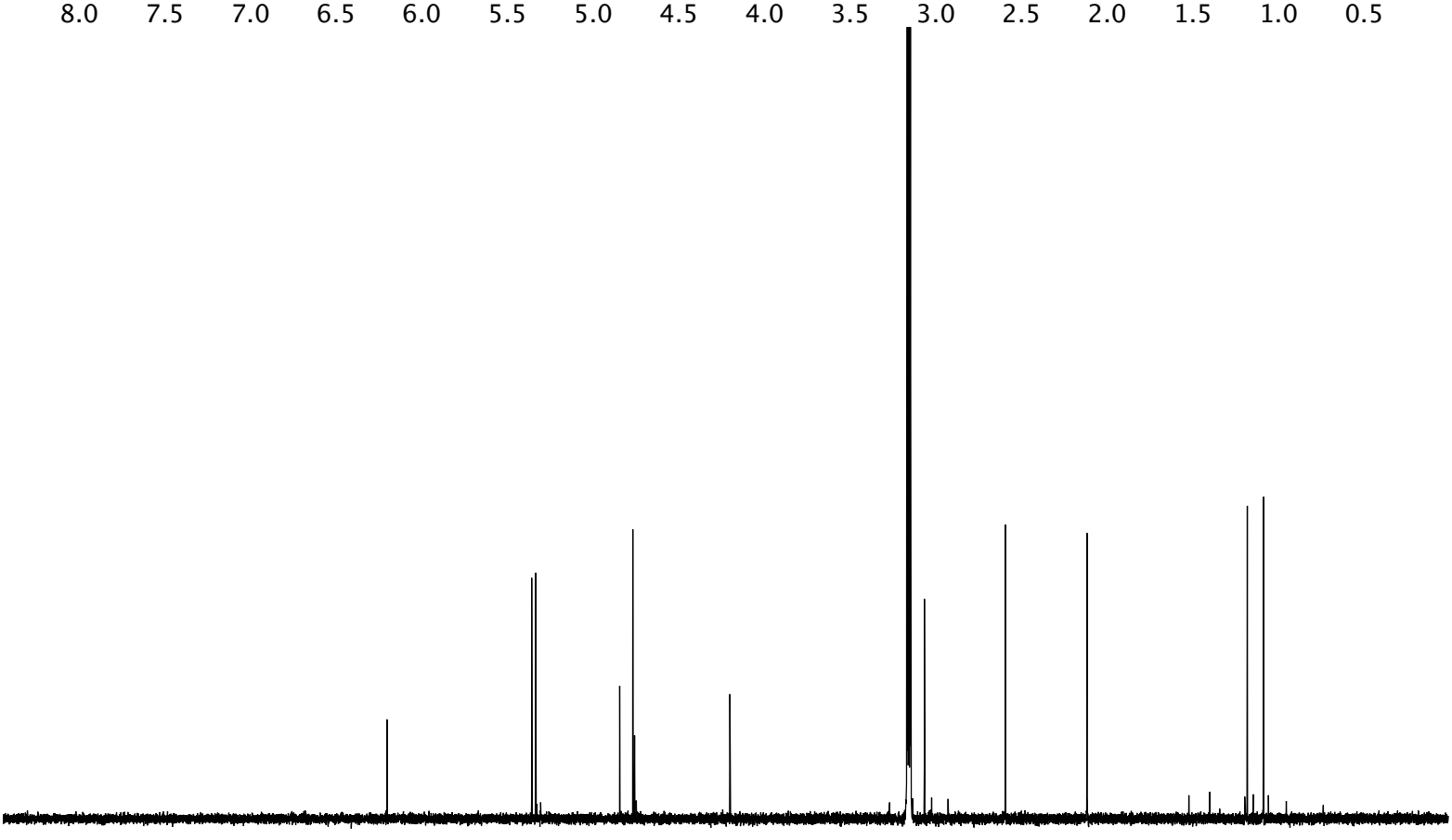
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of diol **17b** in $CDCl_3$



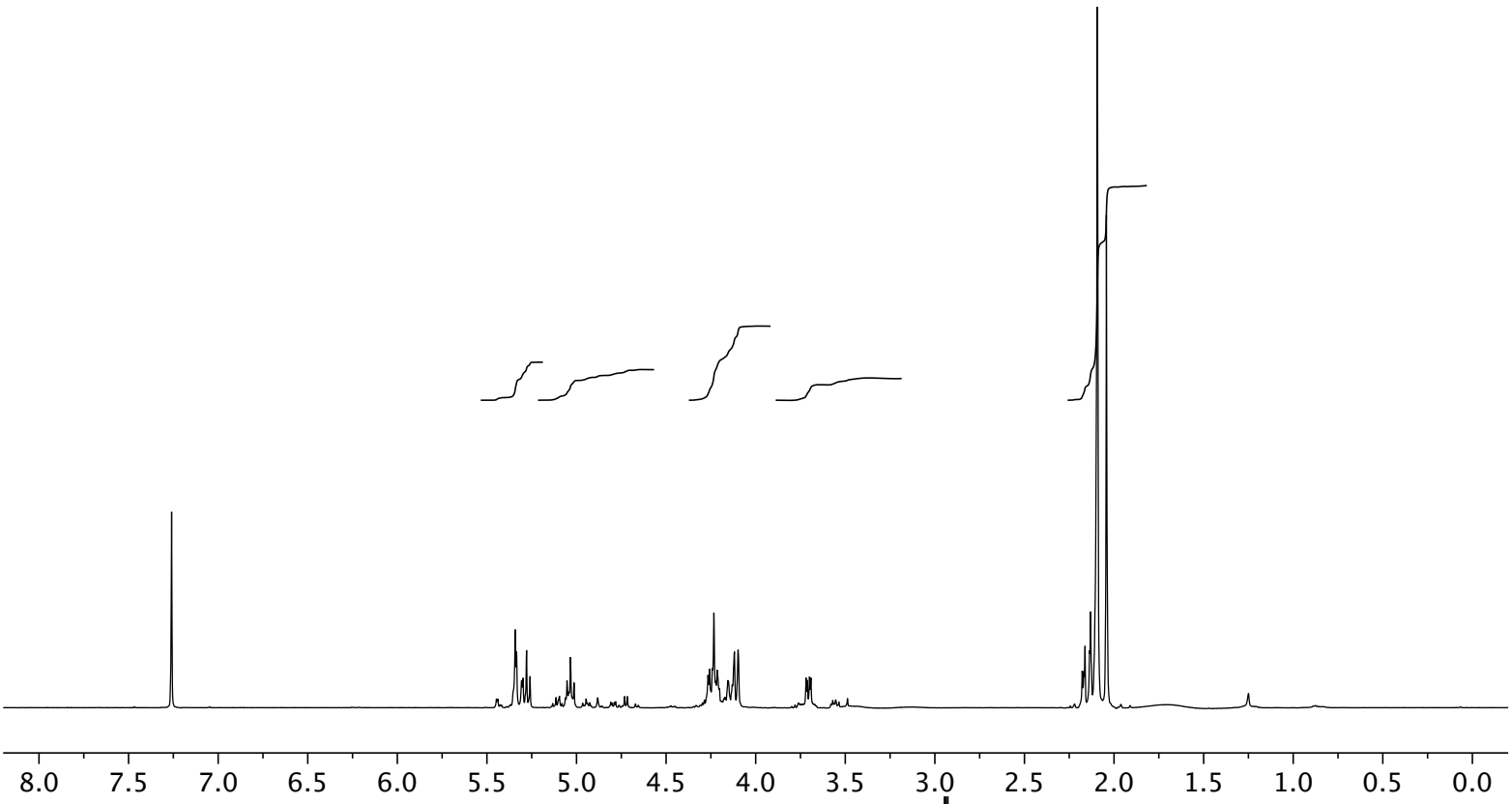


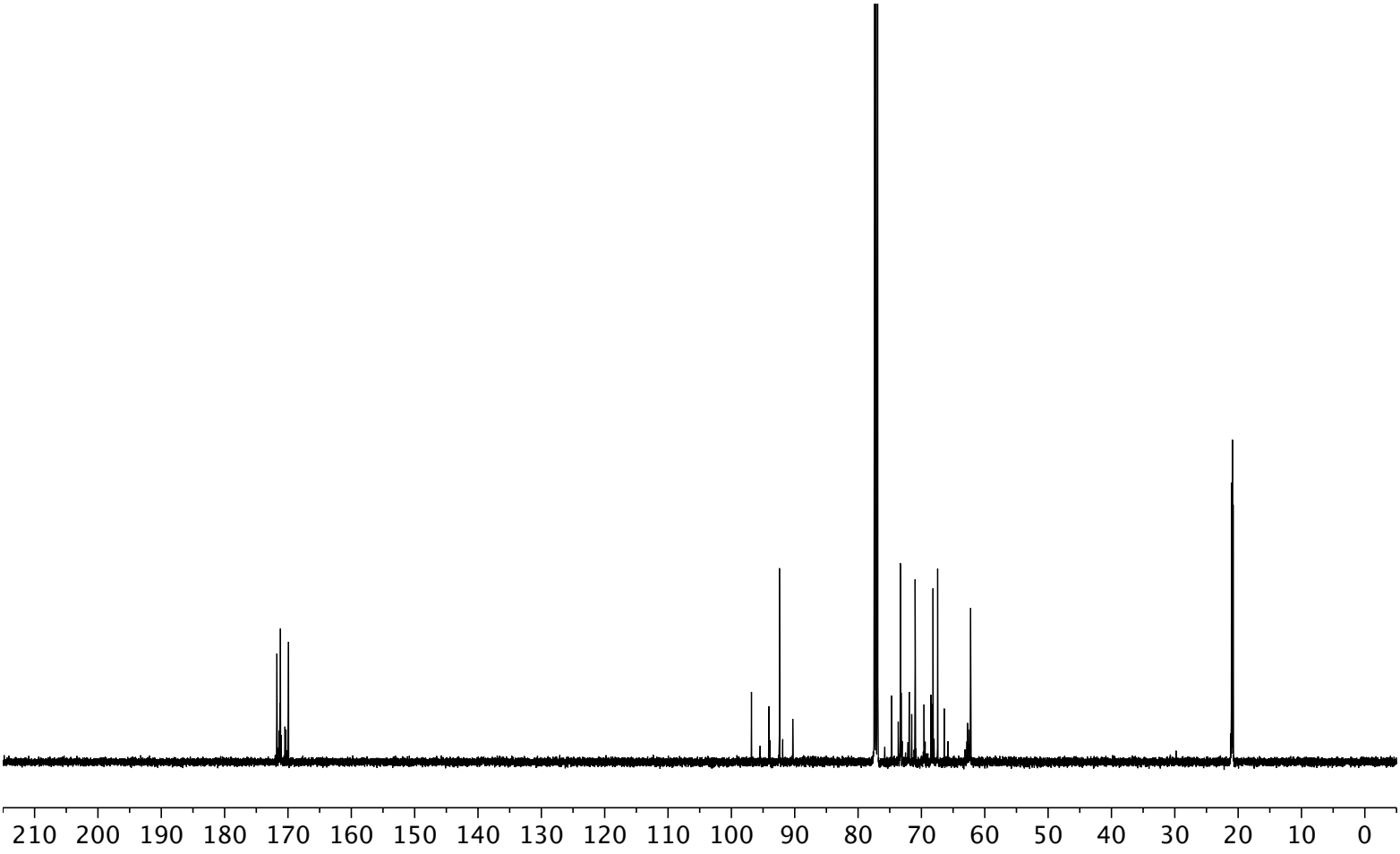
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **18b** in $CDCl_3$



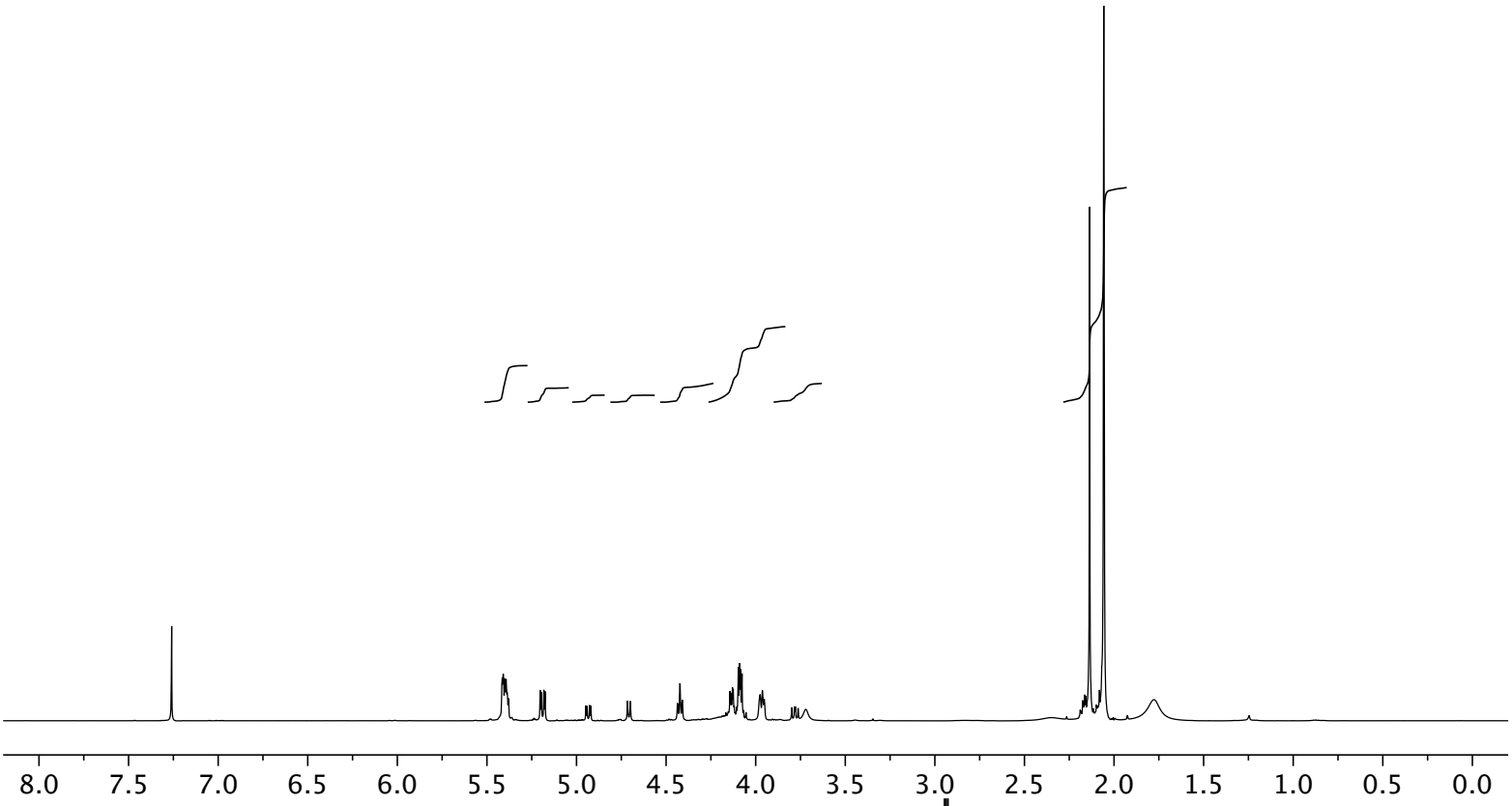


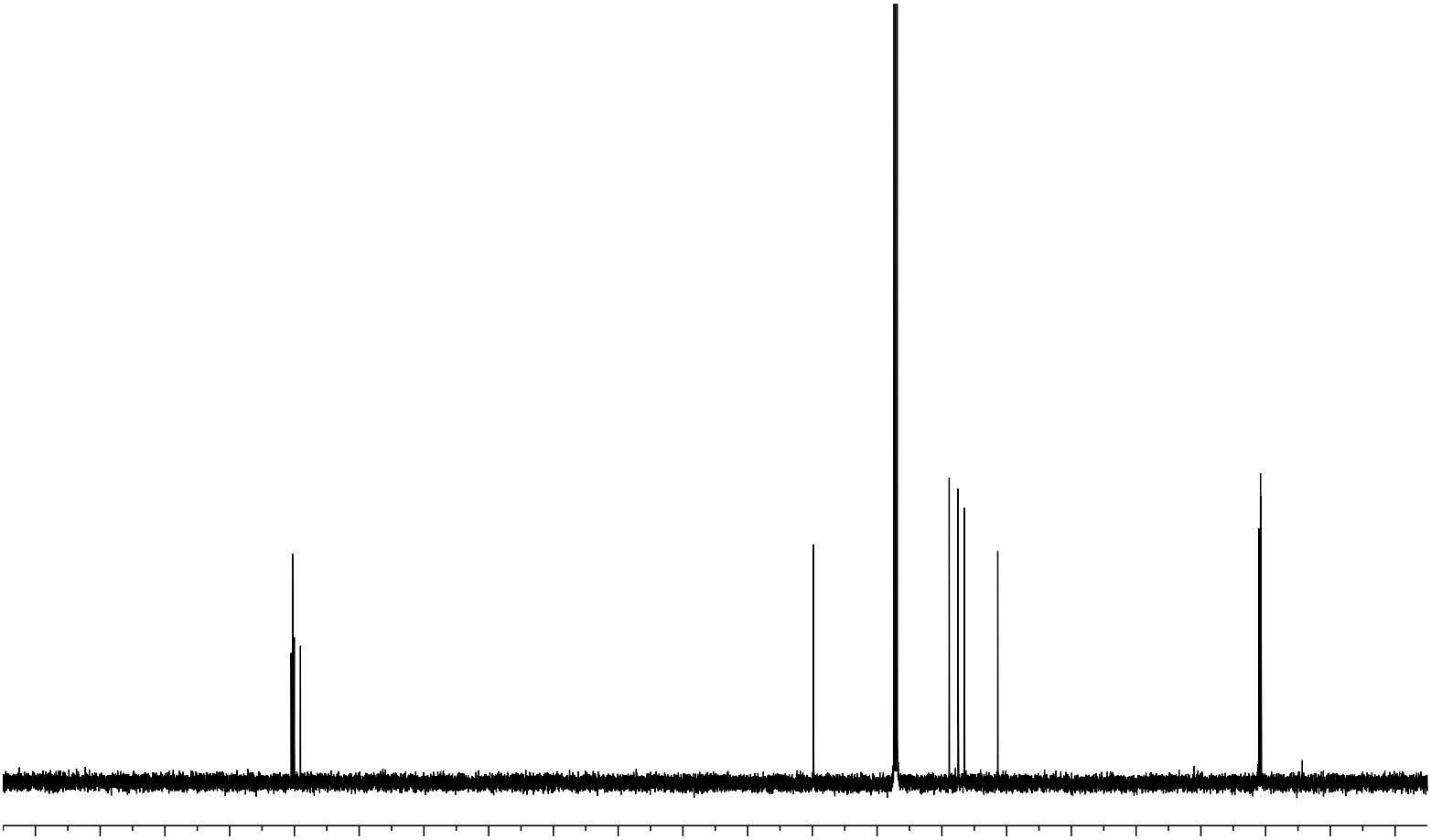
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of **19b** in $CDCl_3$



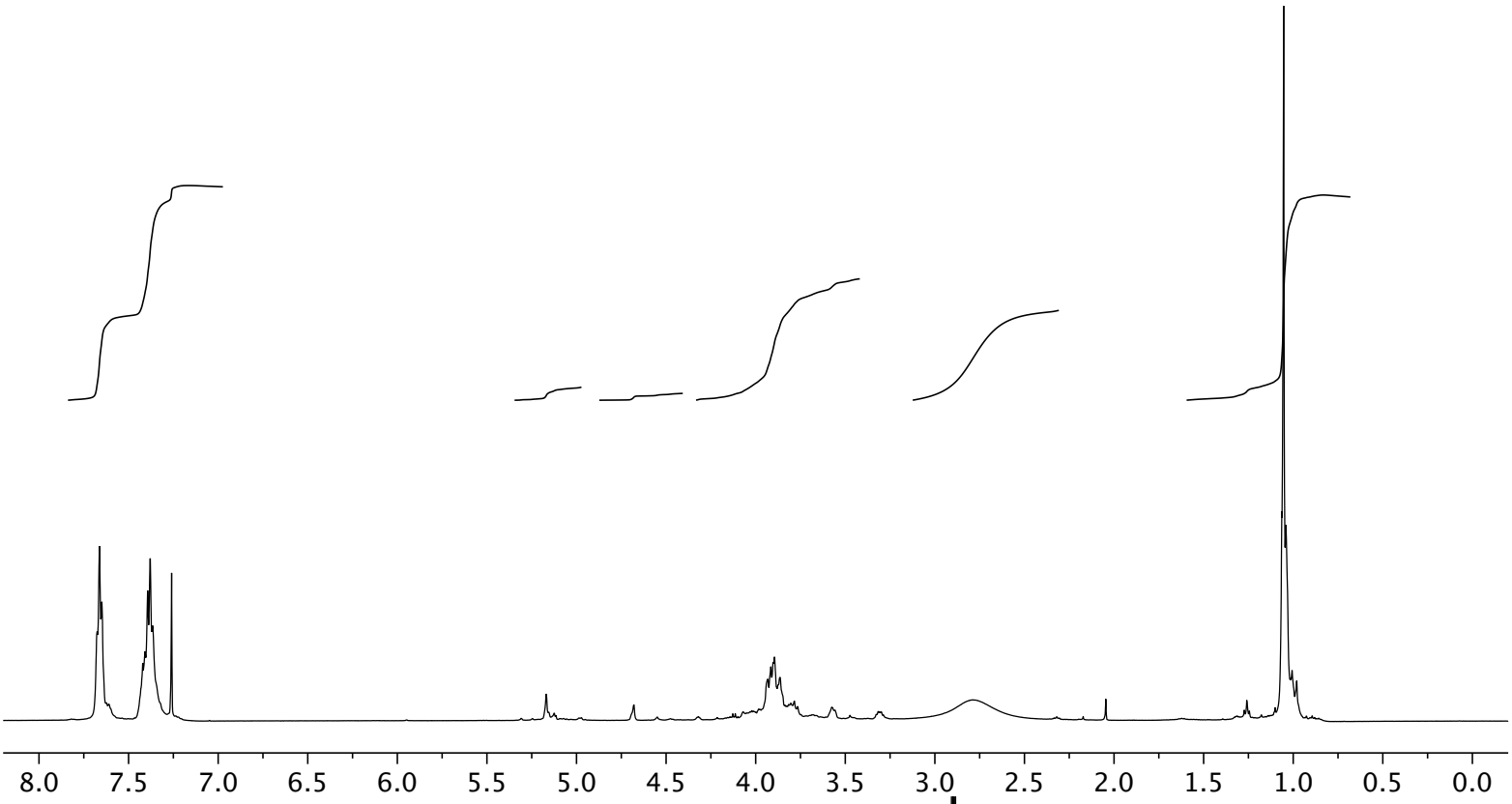


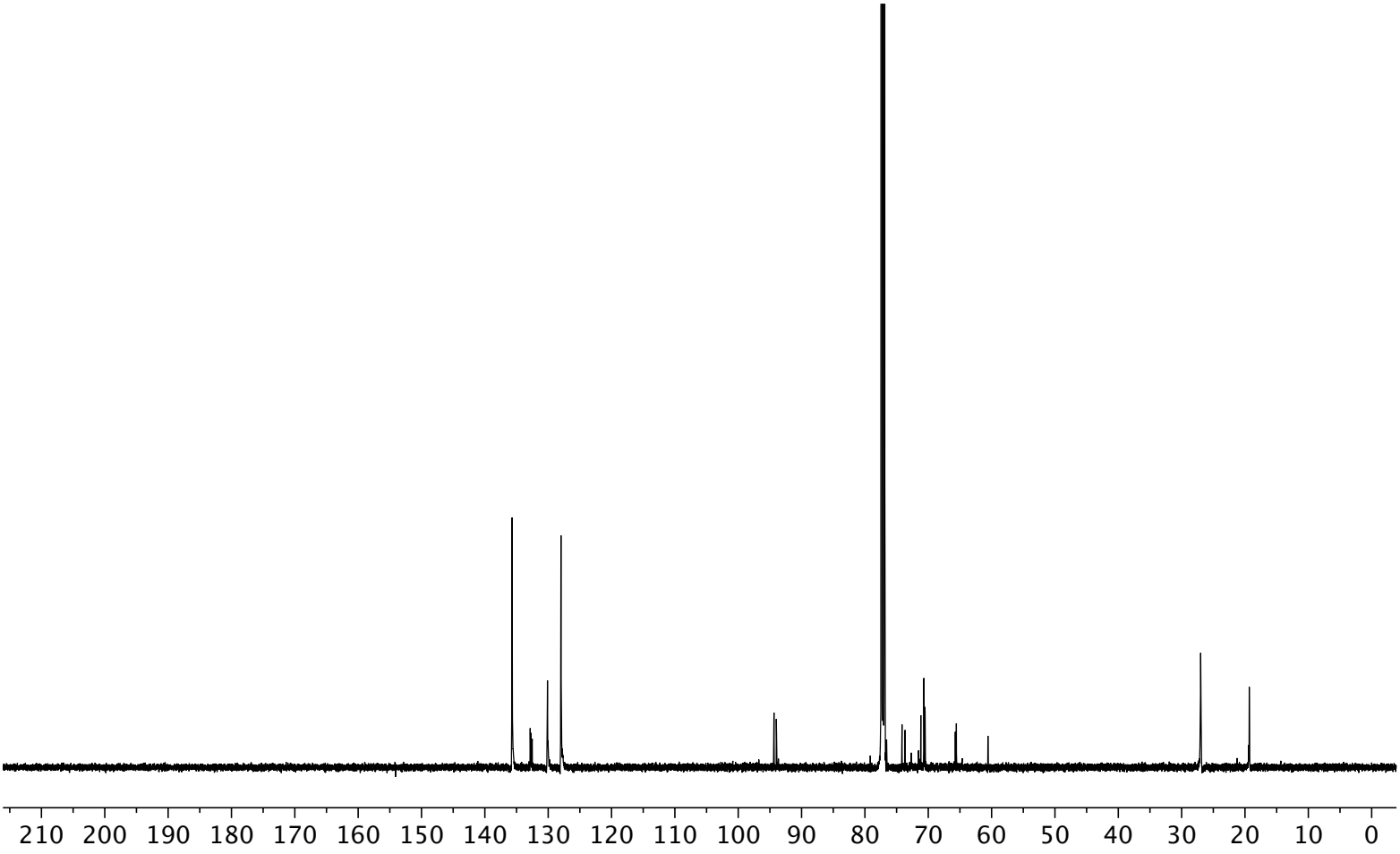
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of **20b** in $CDCl_3$



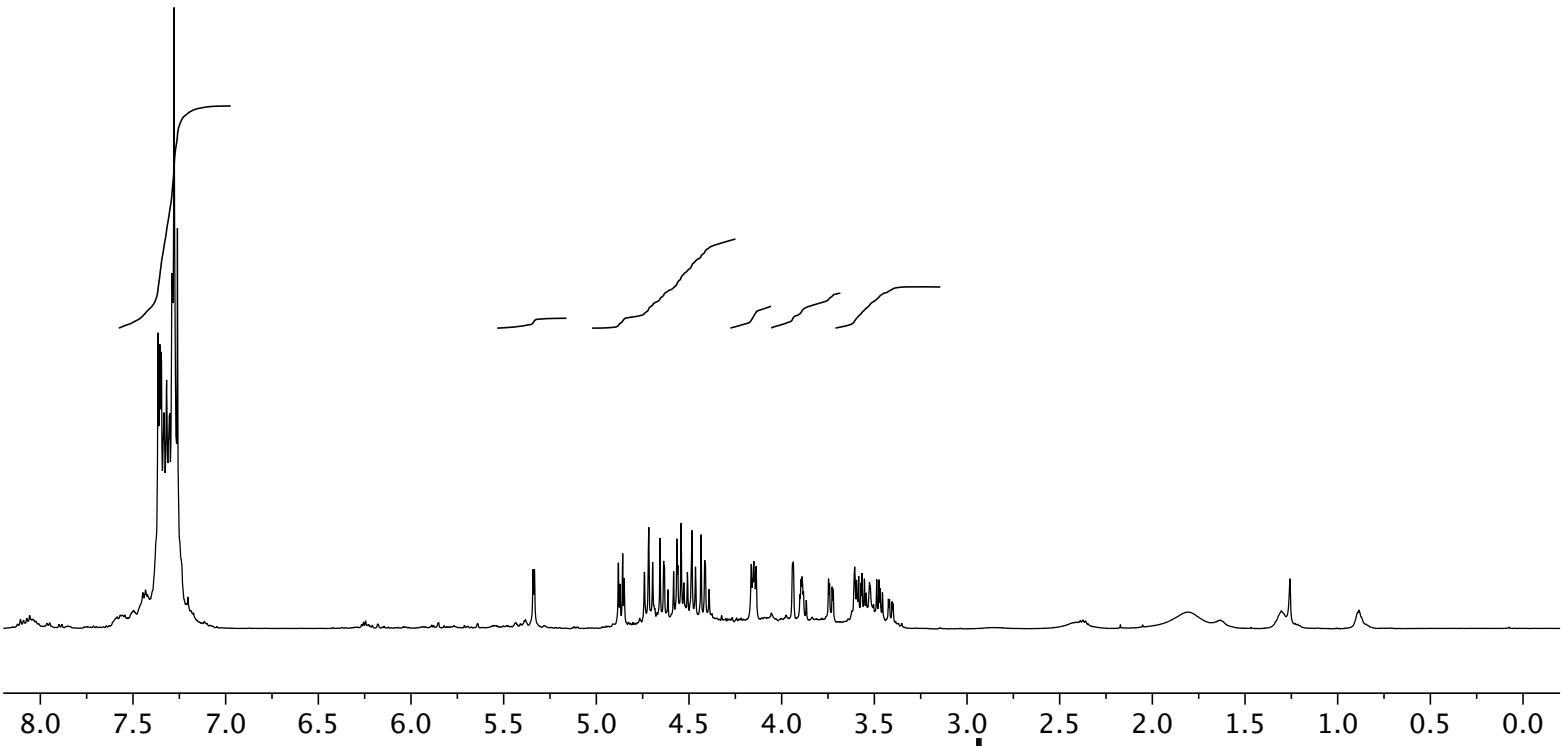


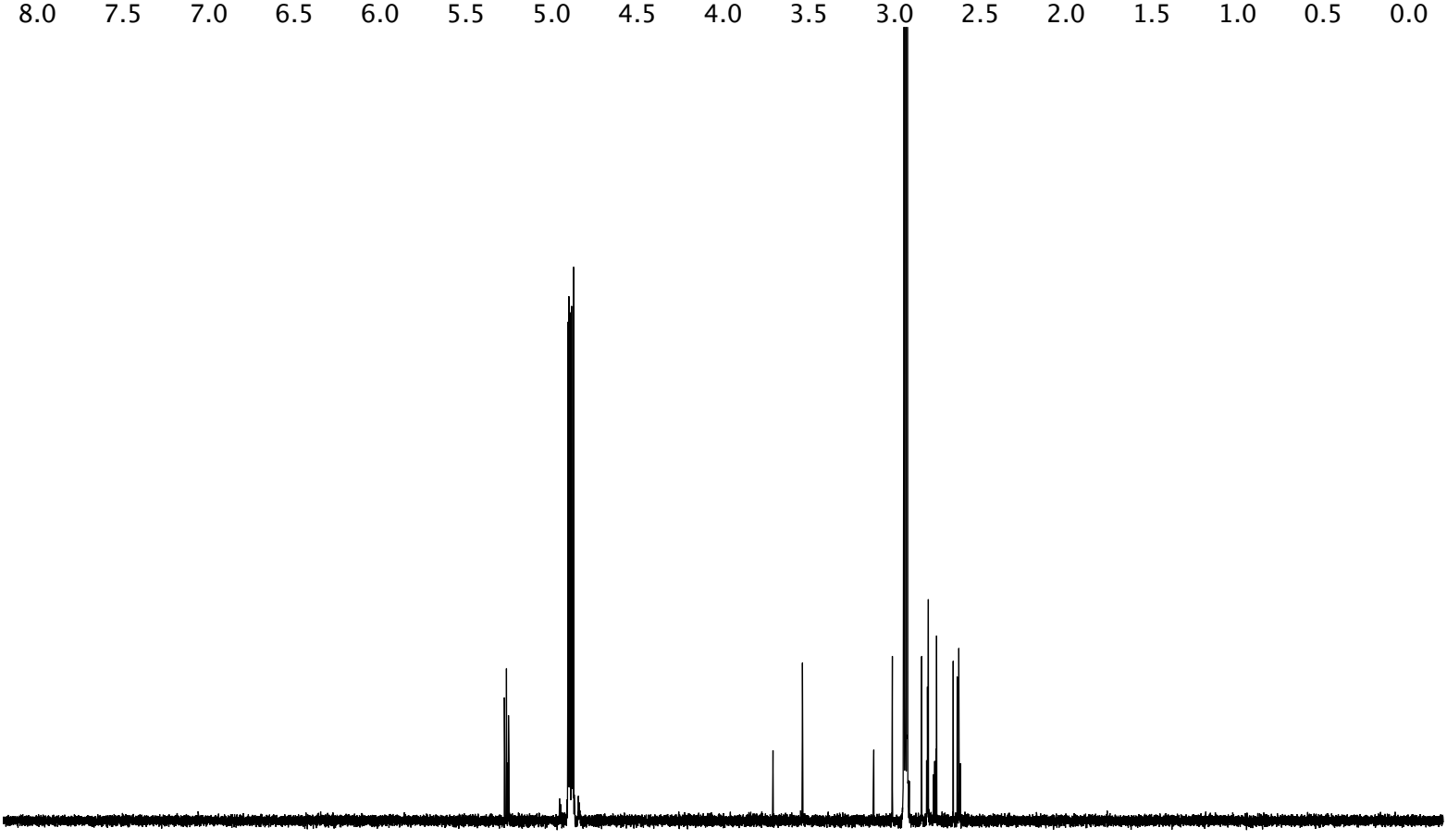
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of **21b** in $CDCl_3$



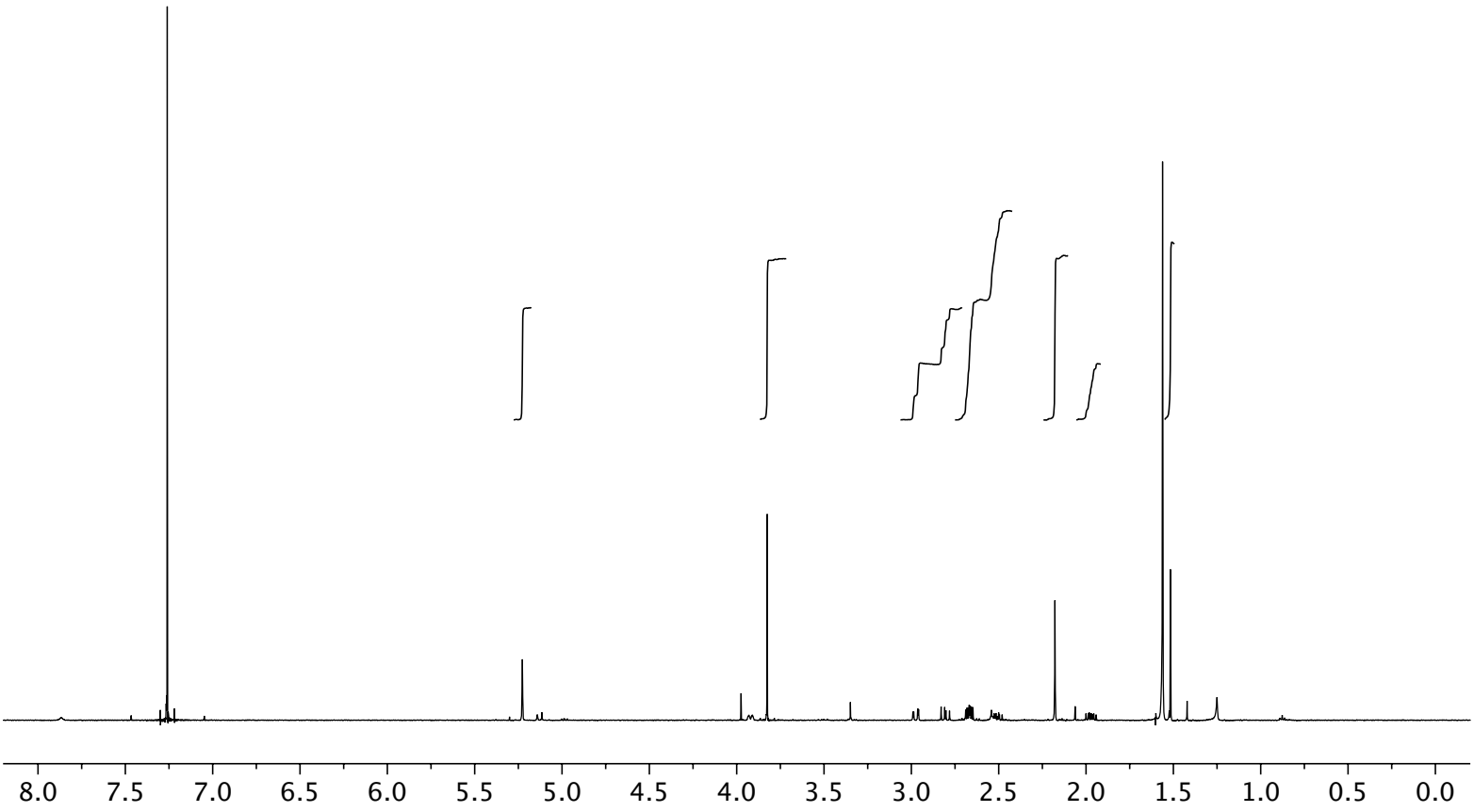


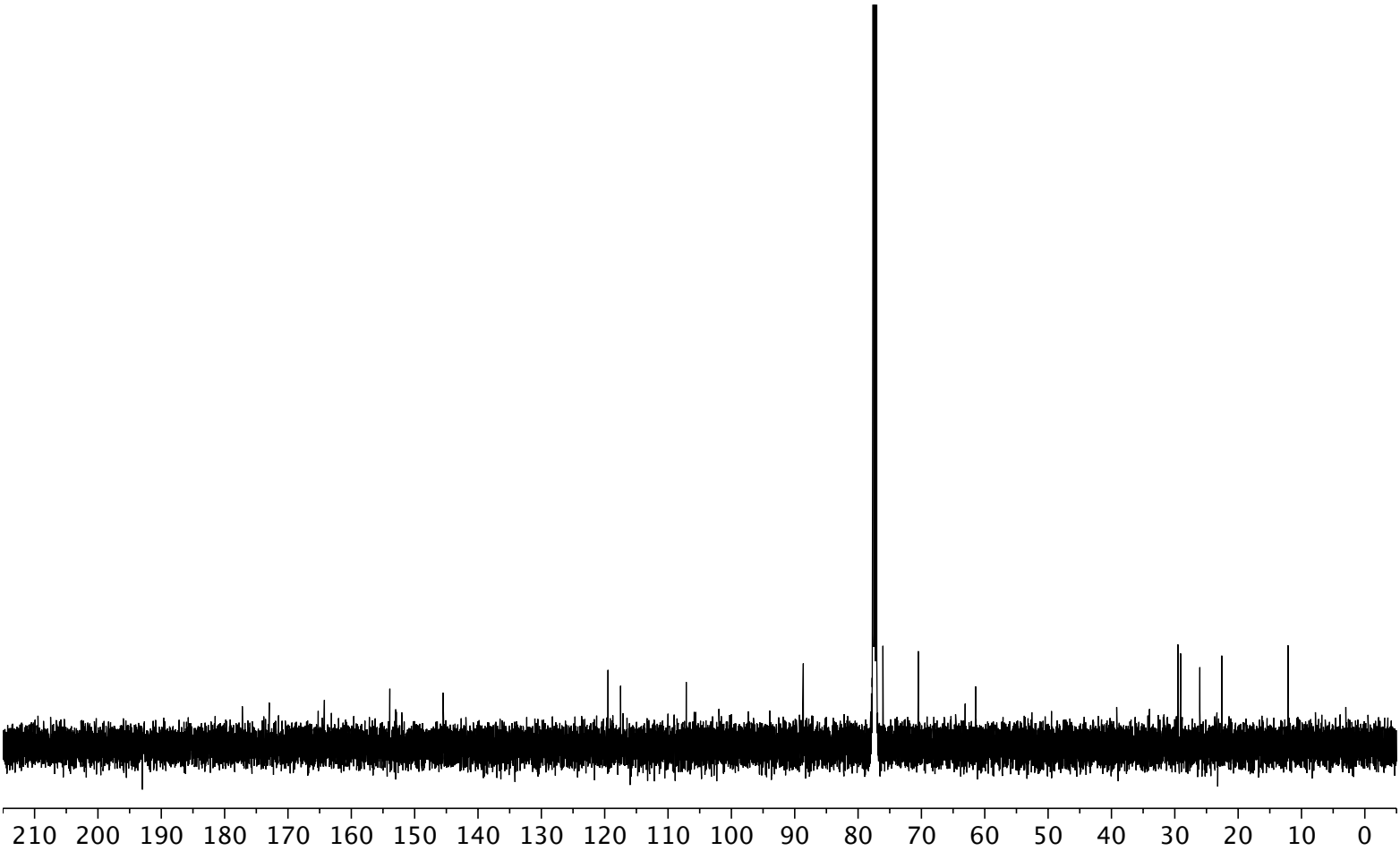
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of **22b** in $CDCl_3$



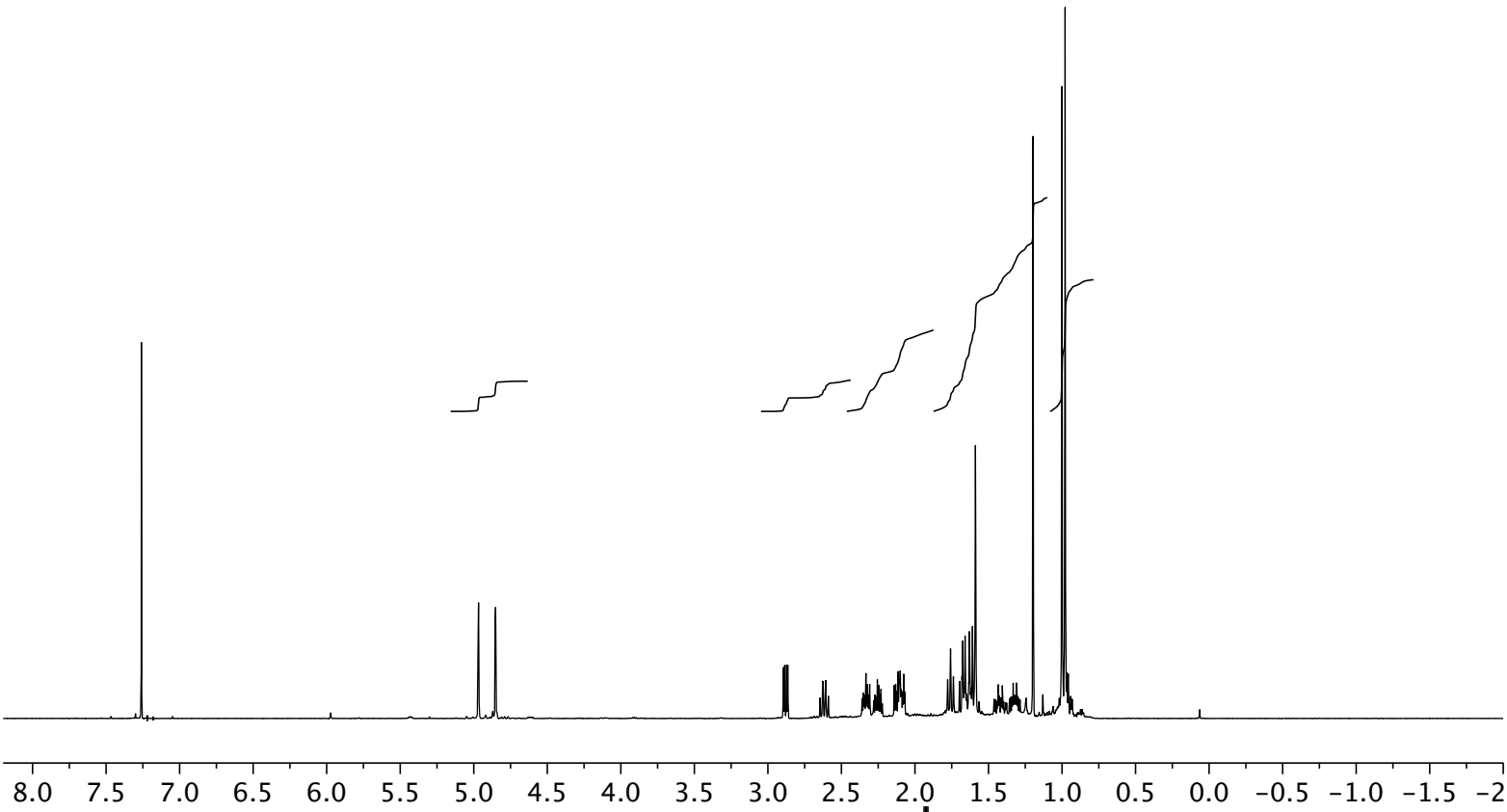


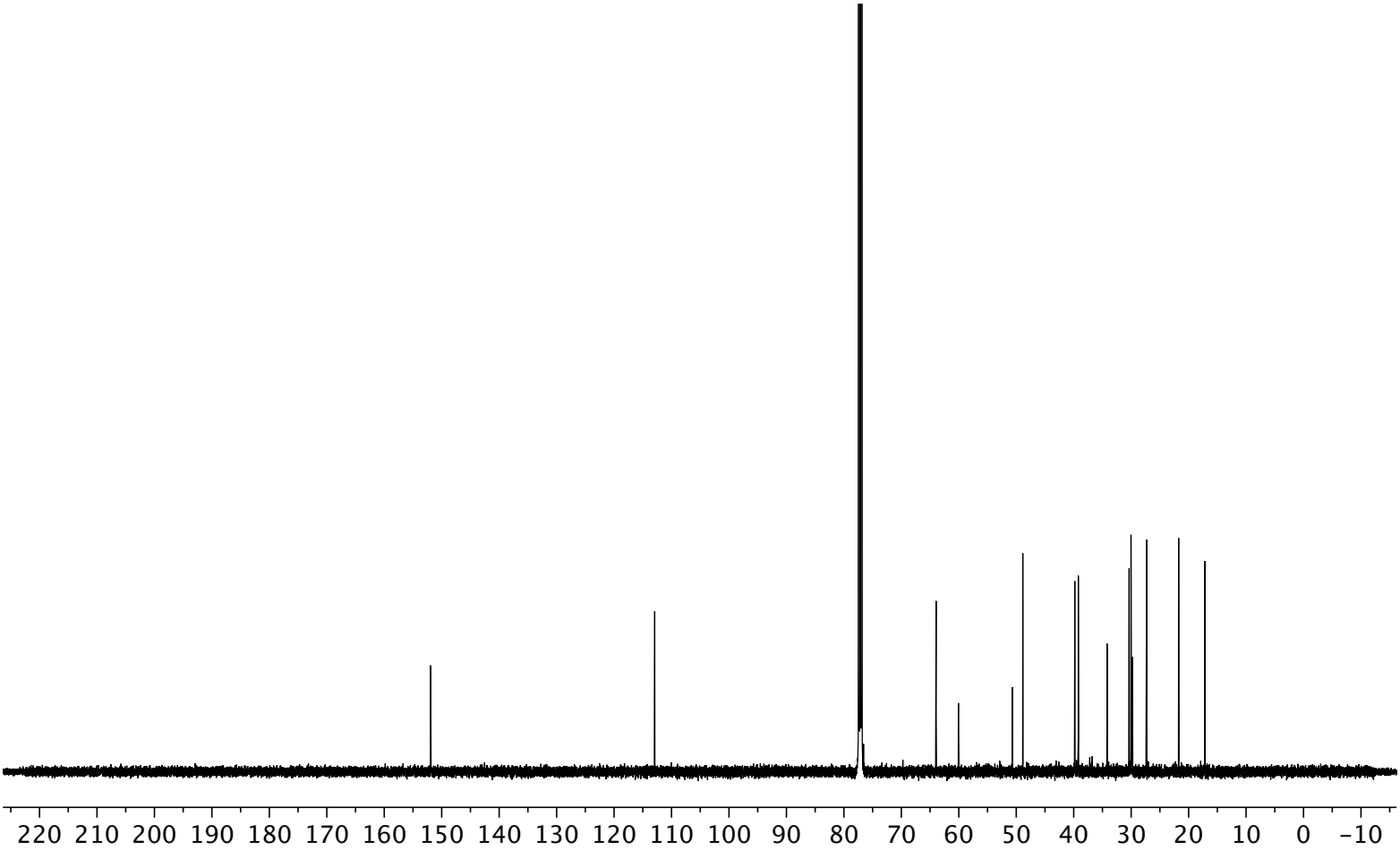
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **23b** in $CDCl_3$



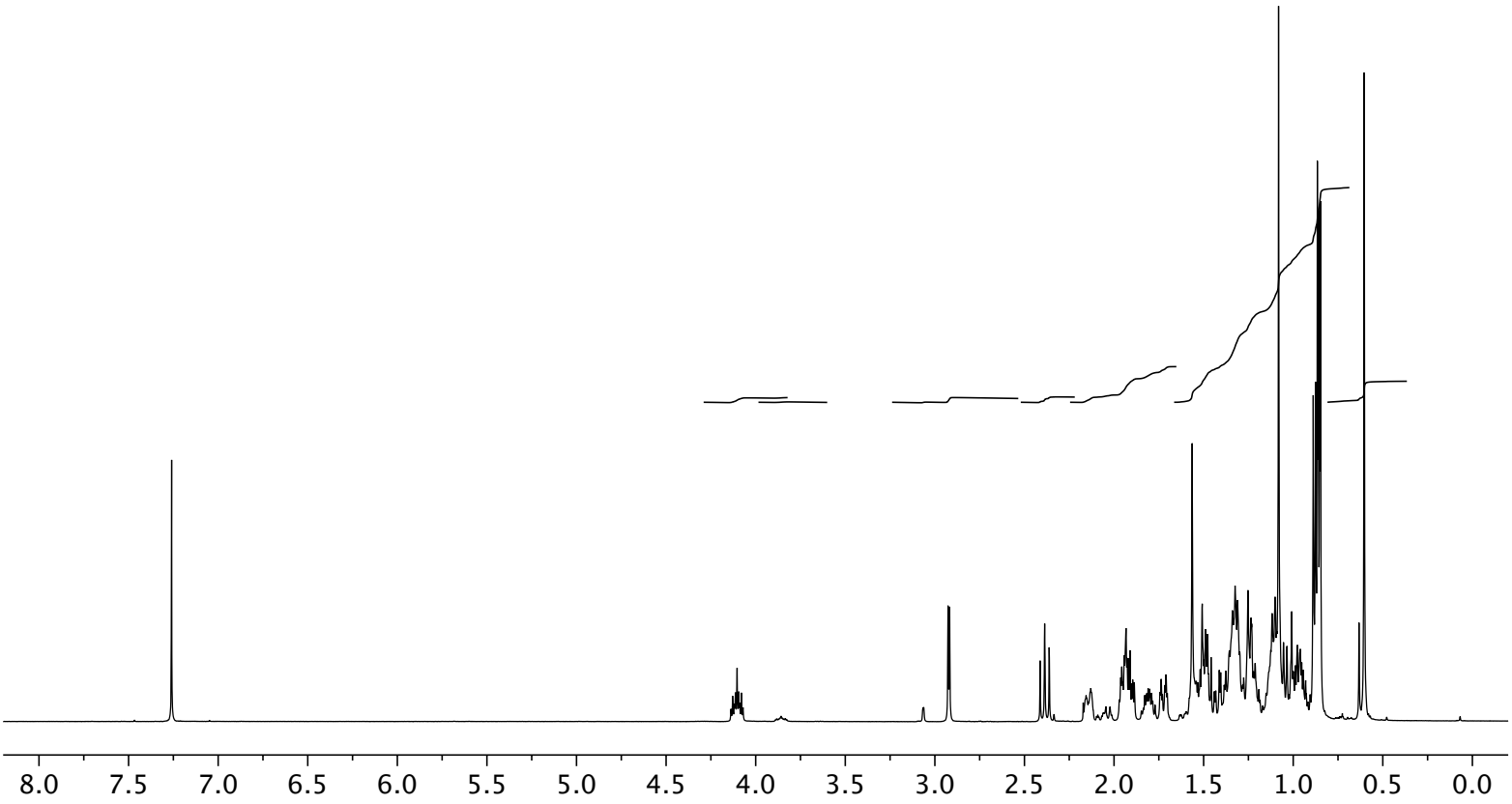


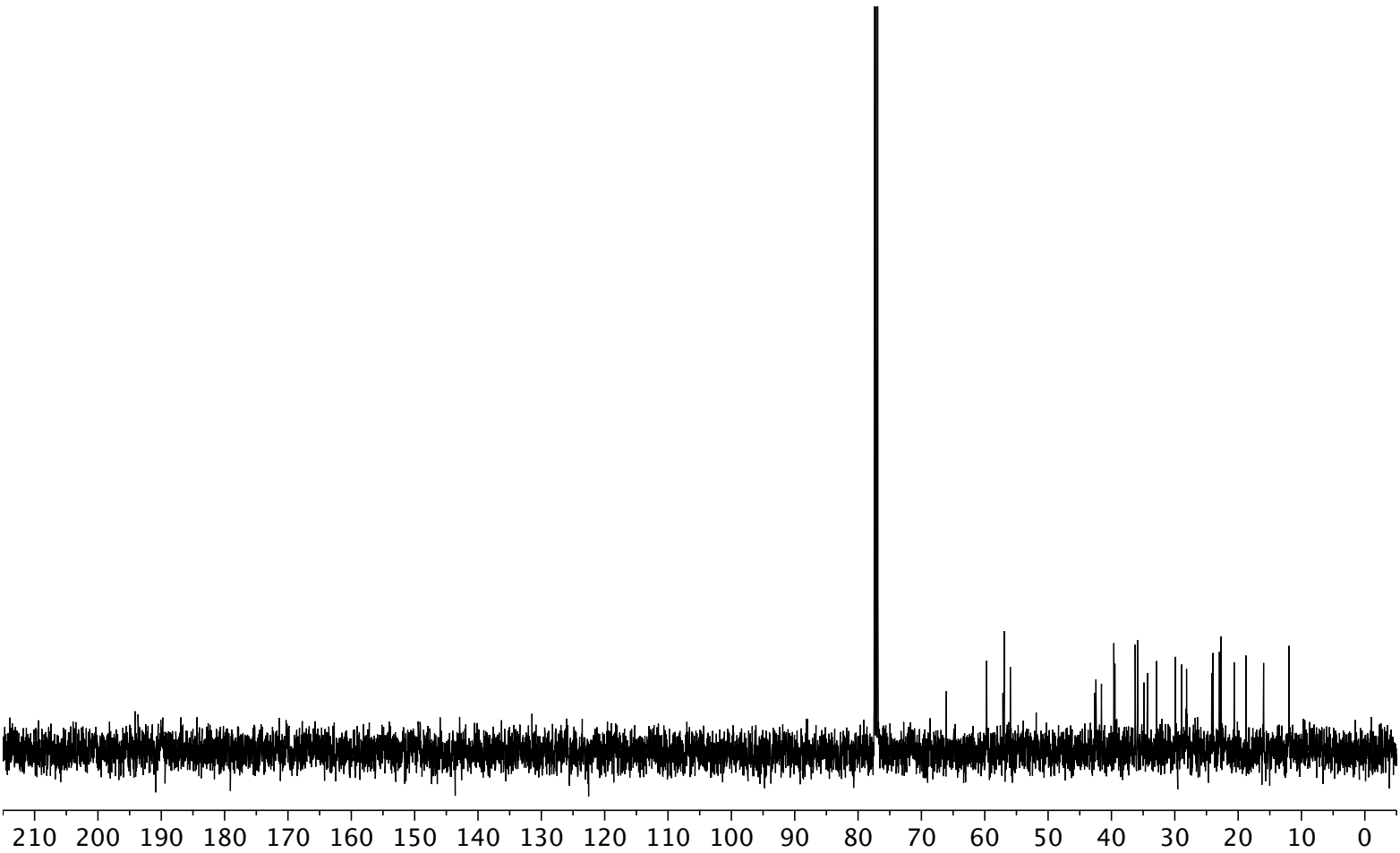
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **24b** in $CDCl_3$



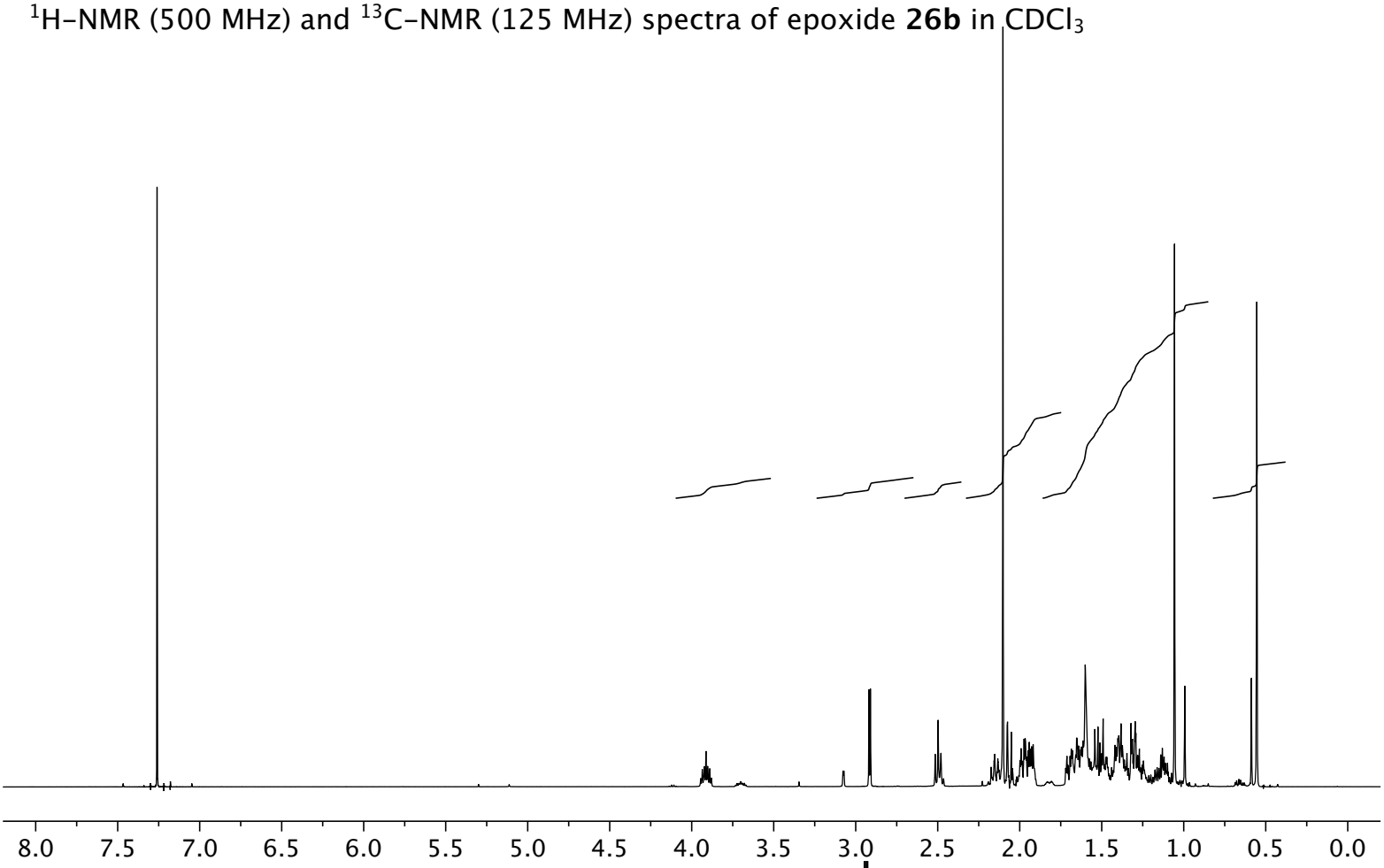


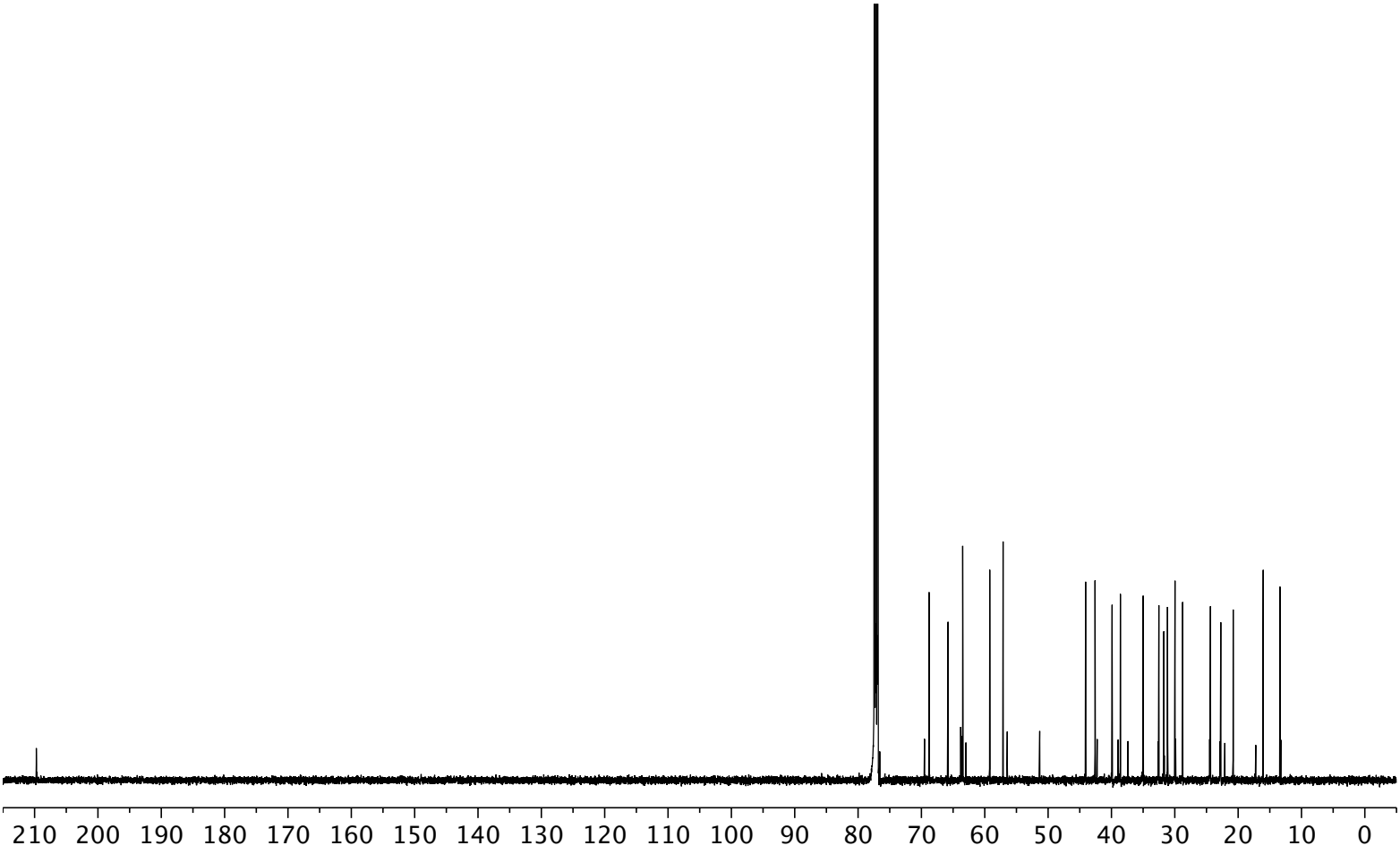
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **25b** in $CDCl_3$



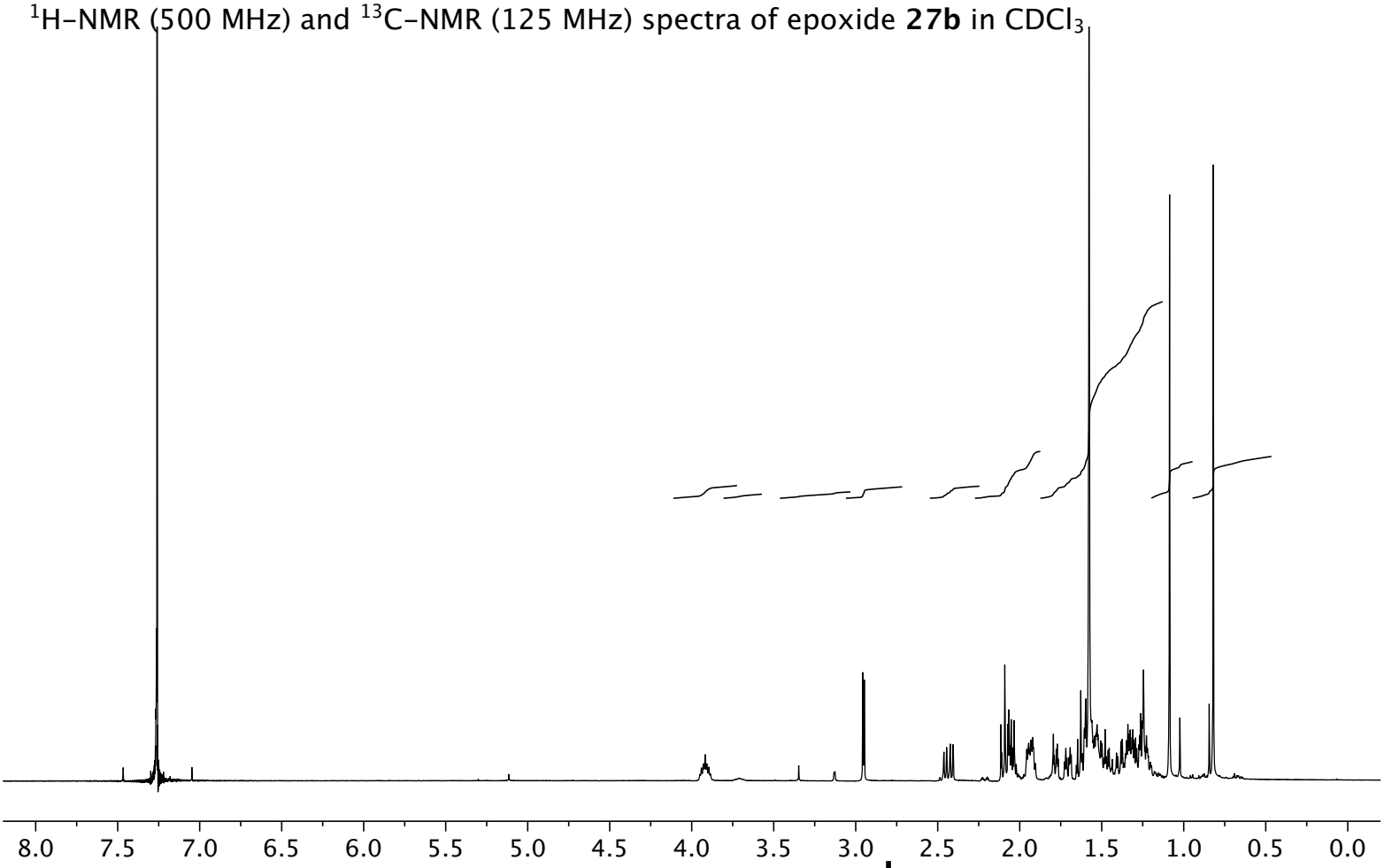


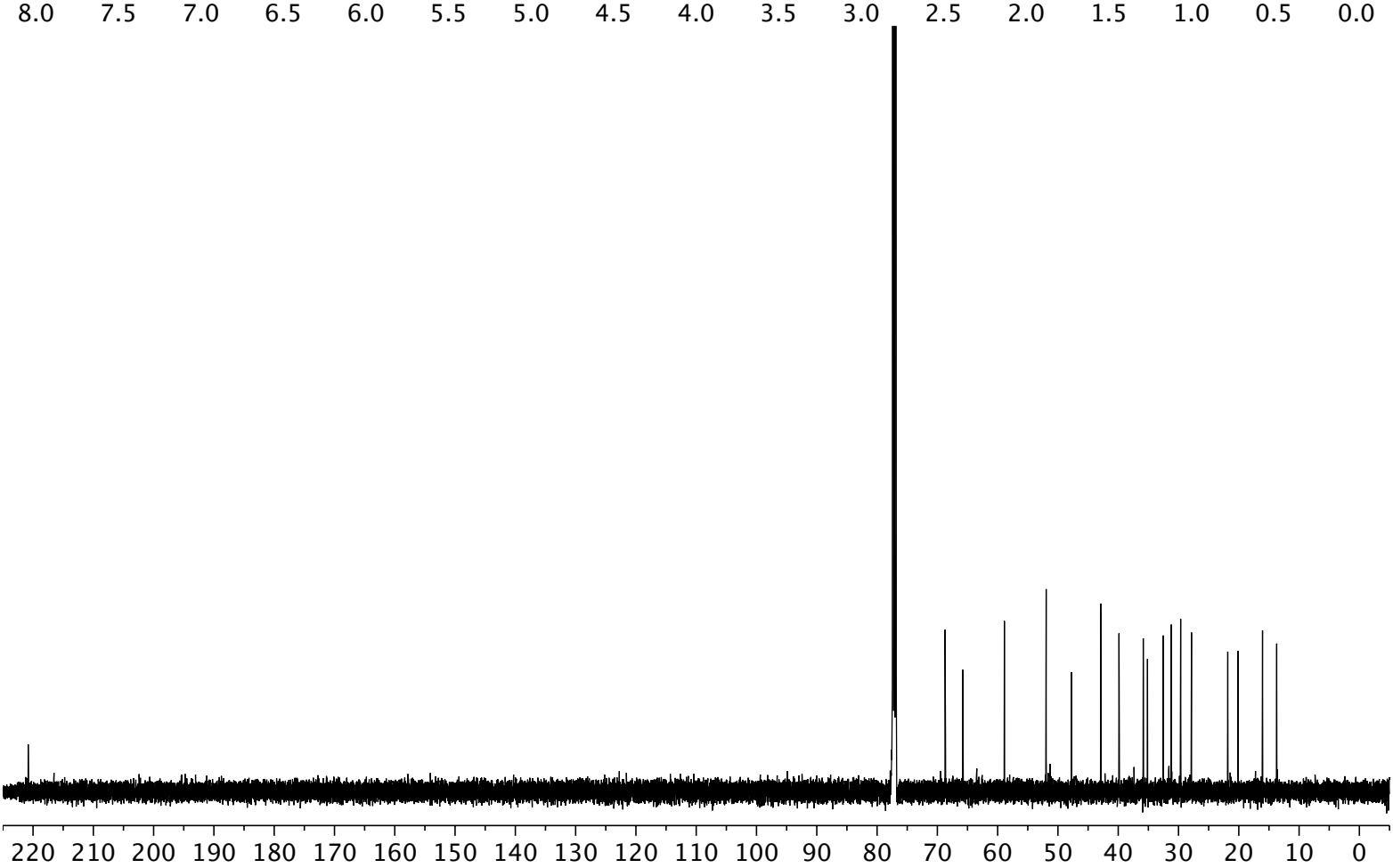
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **26b** in $CDCl_3$



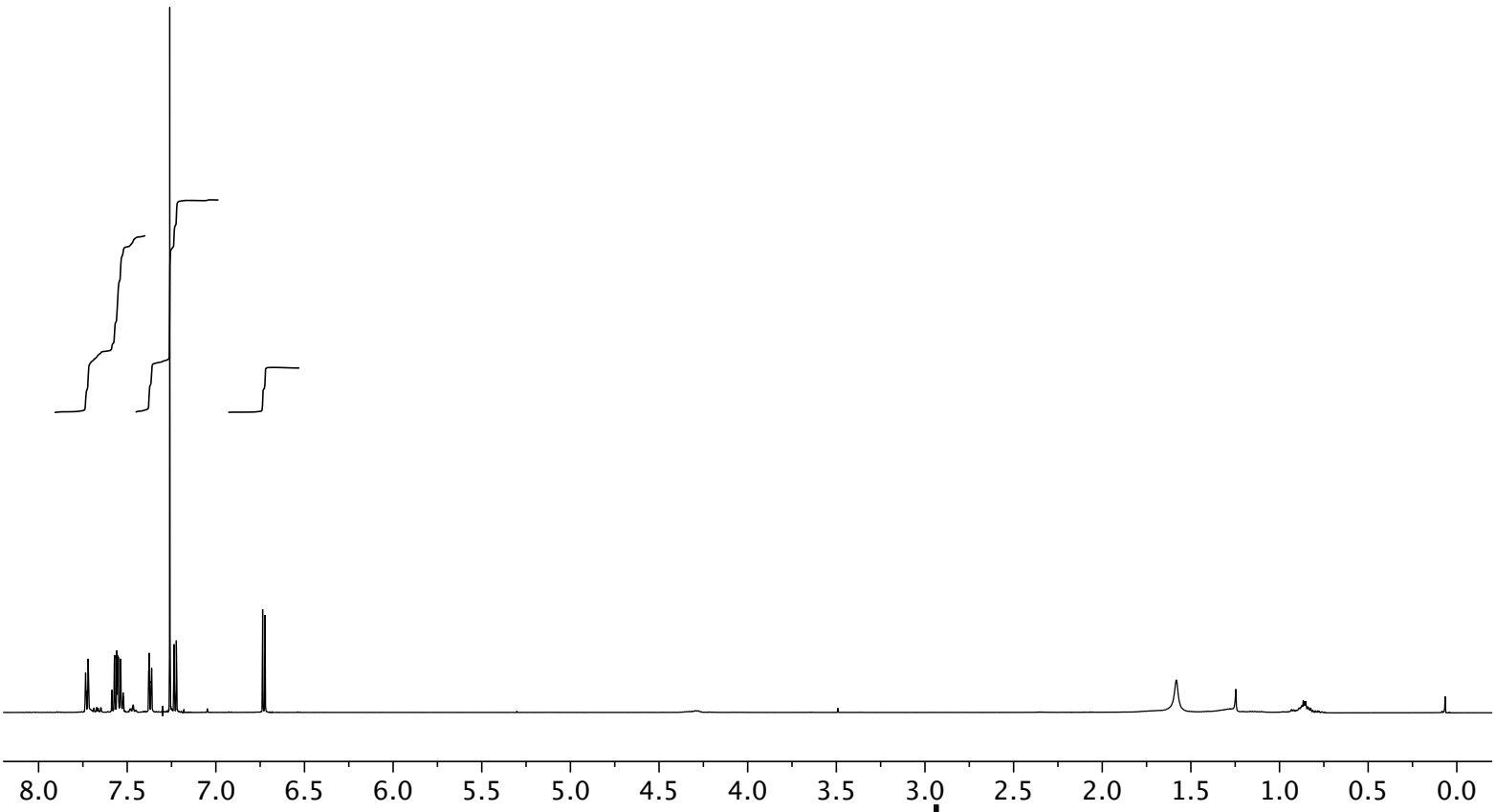


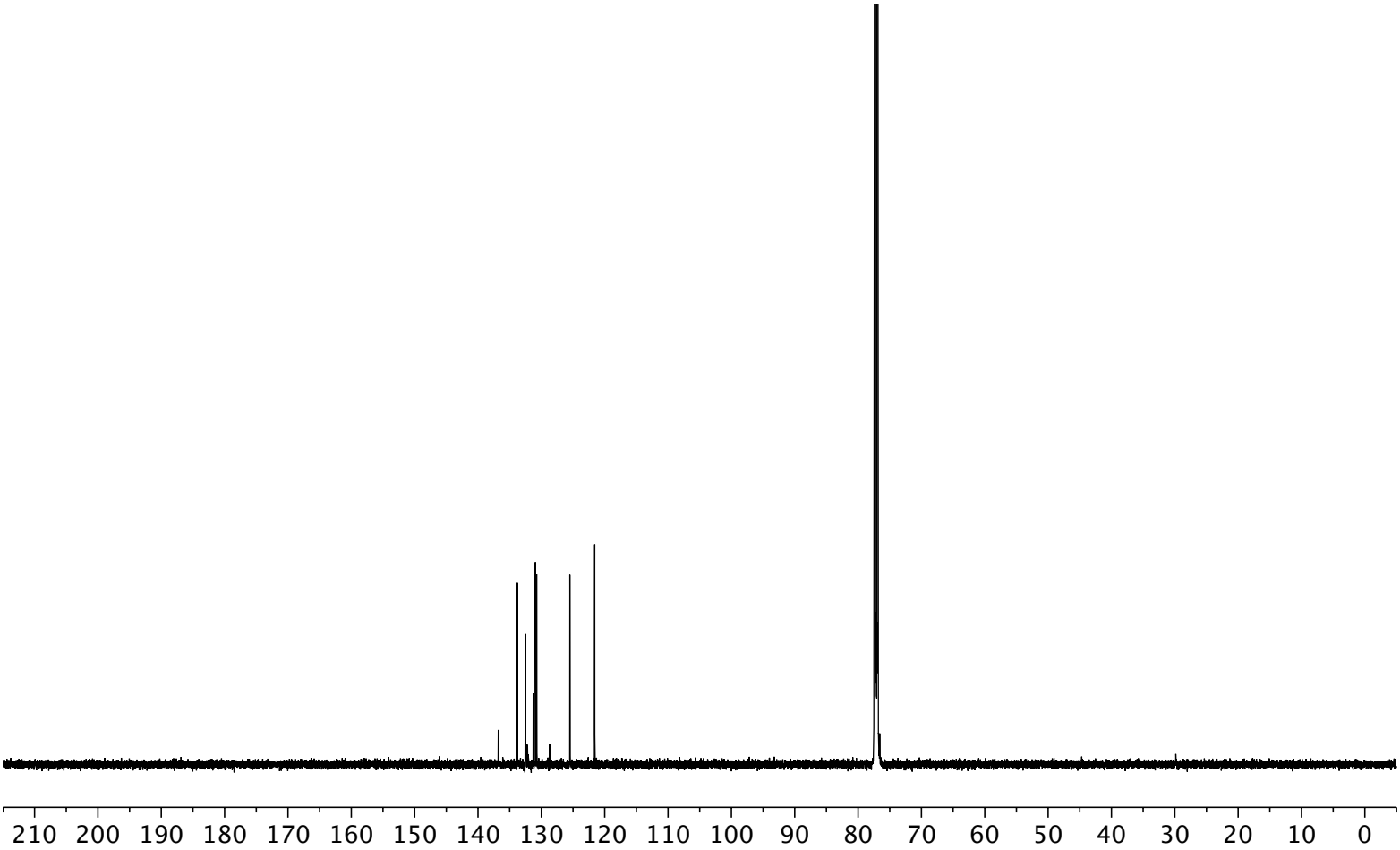
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of epoxide **27b** in $CDCl_3$



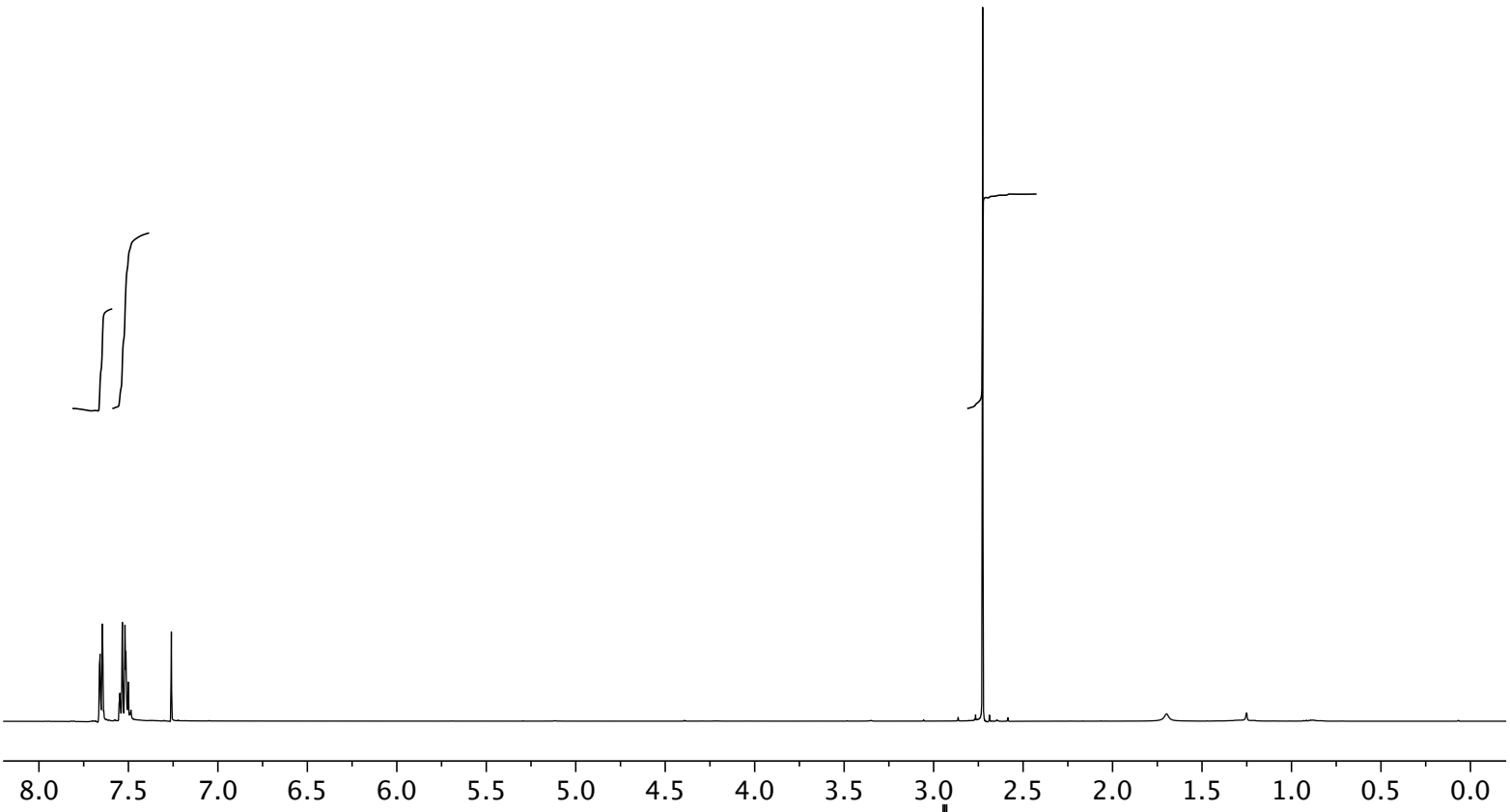


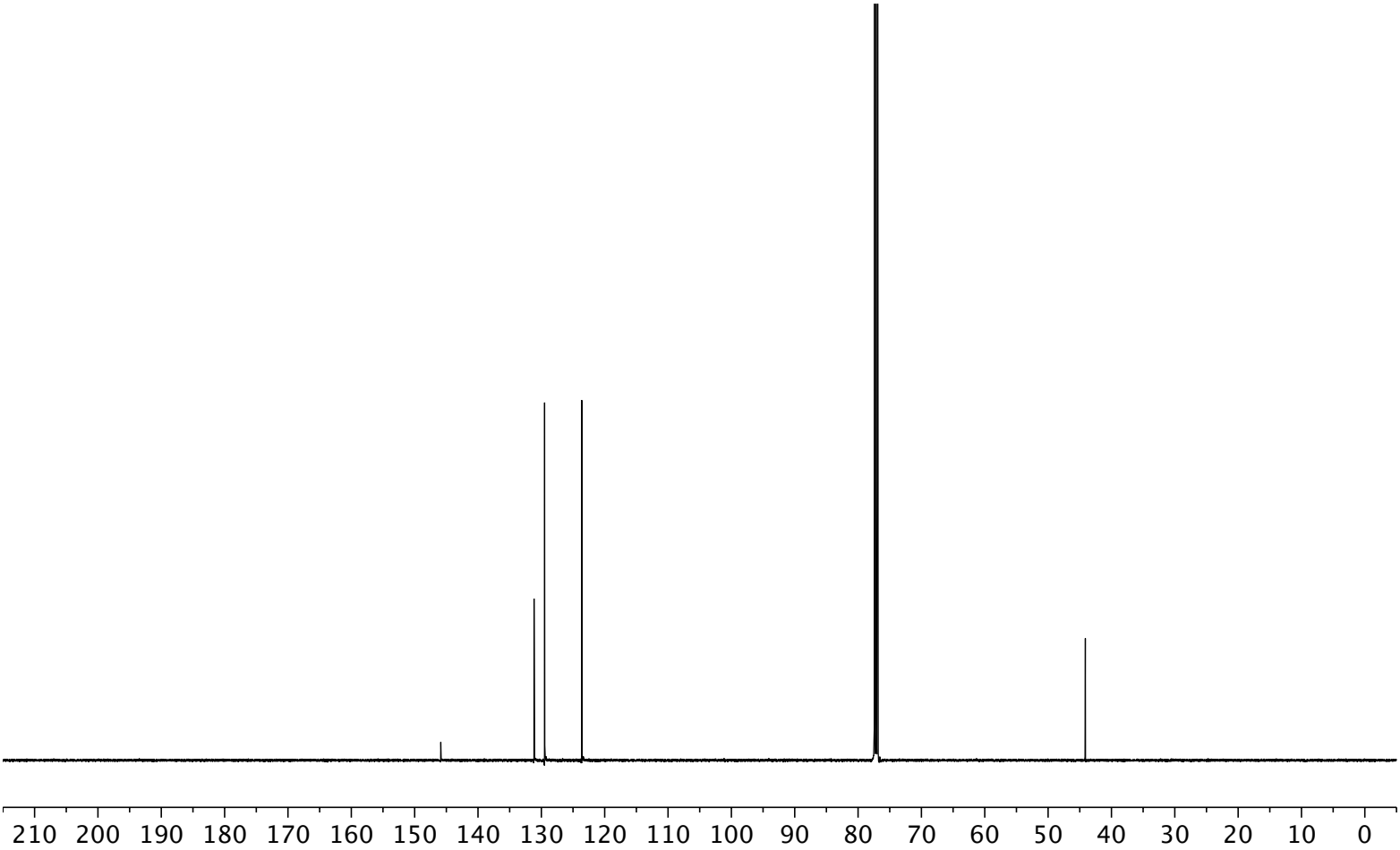
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of sulfone **28b** in $CDCl_3$



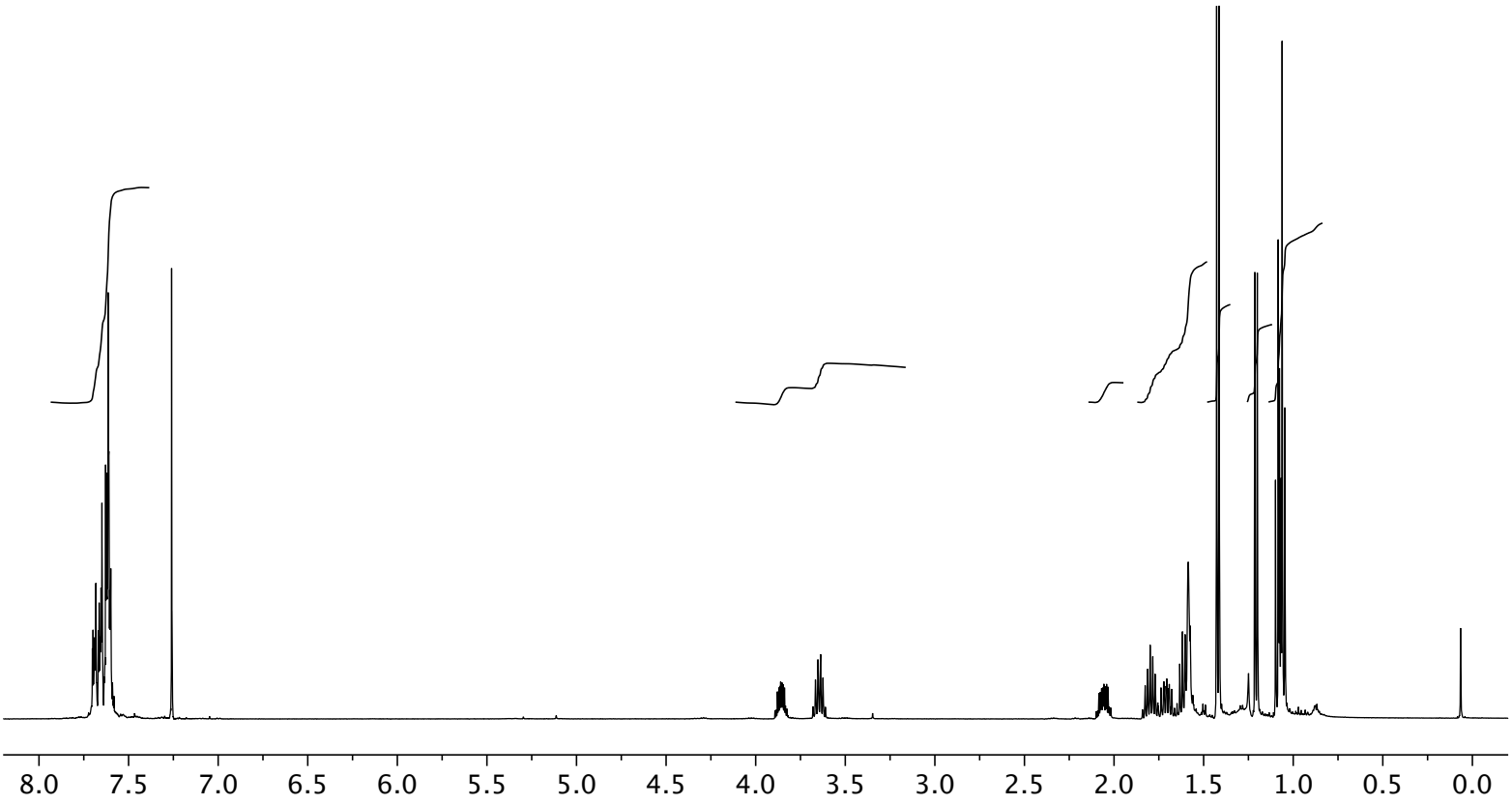


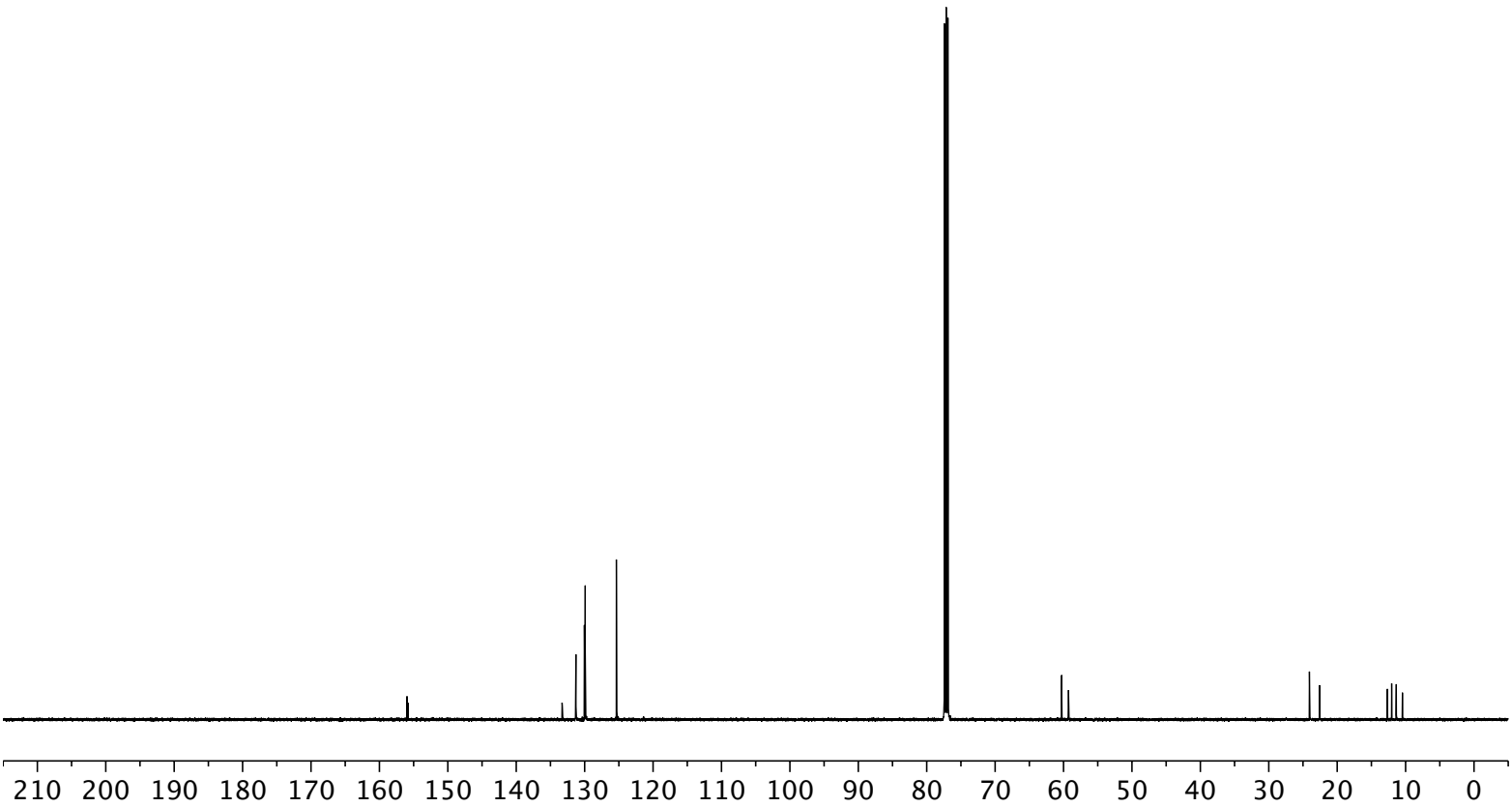
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of sulfoxide **29b** in $CDCl_3$



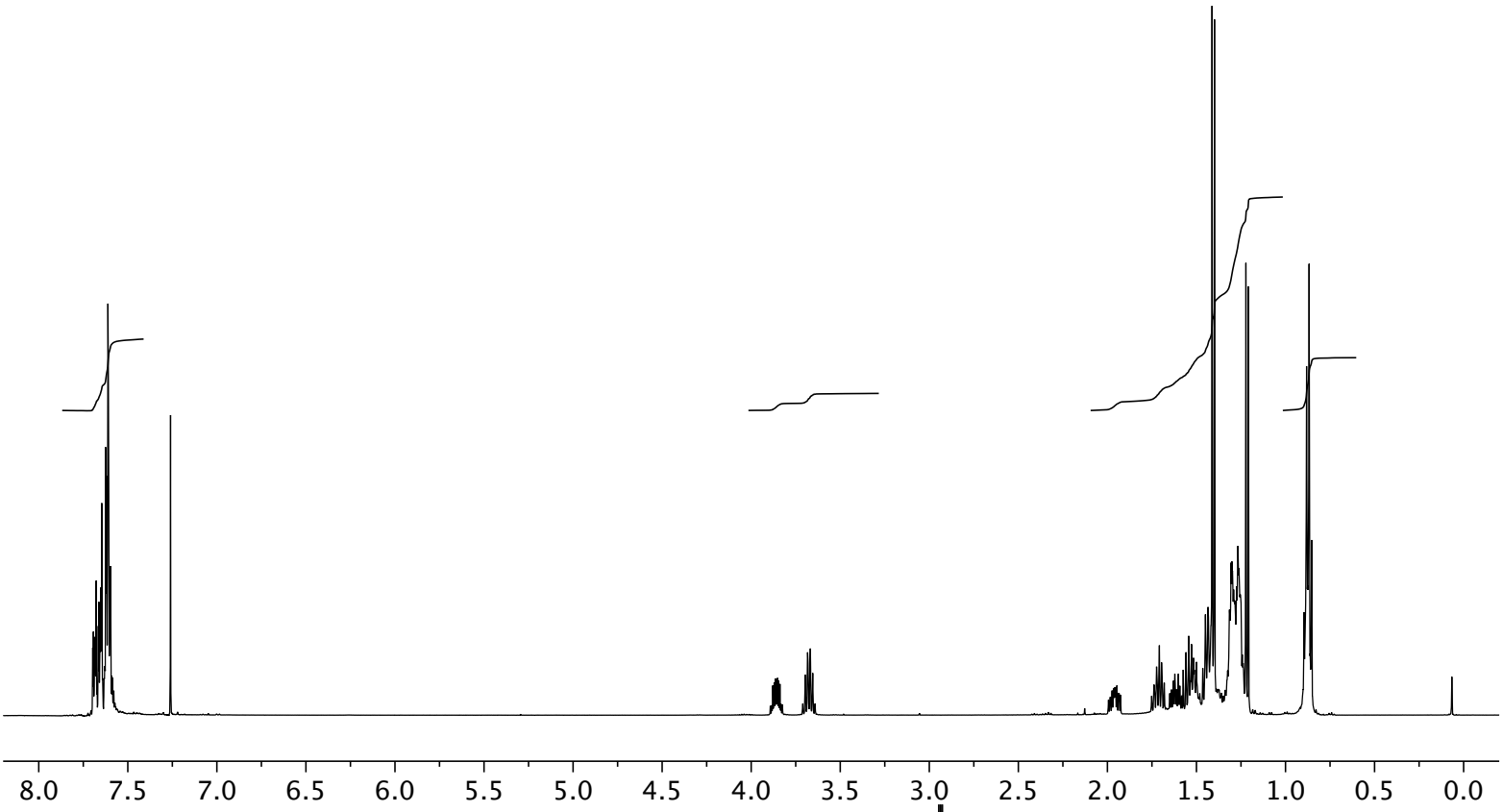


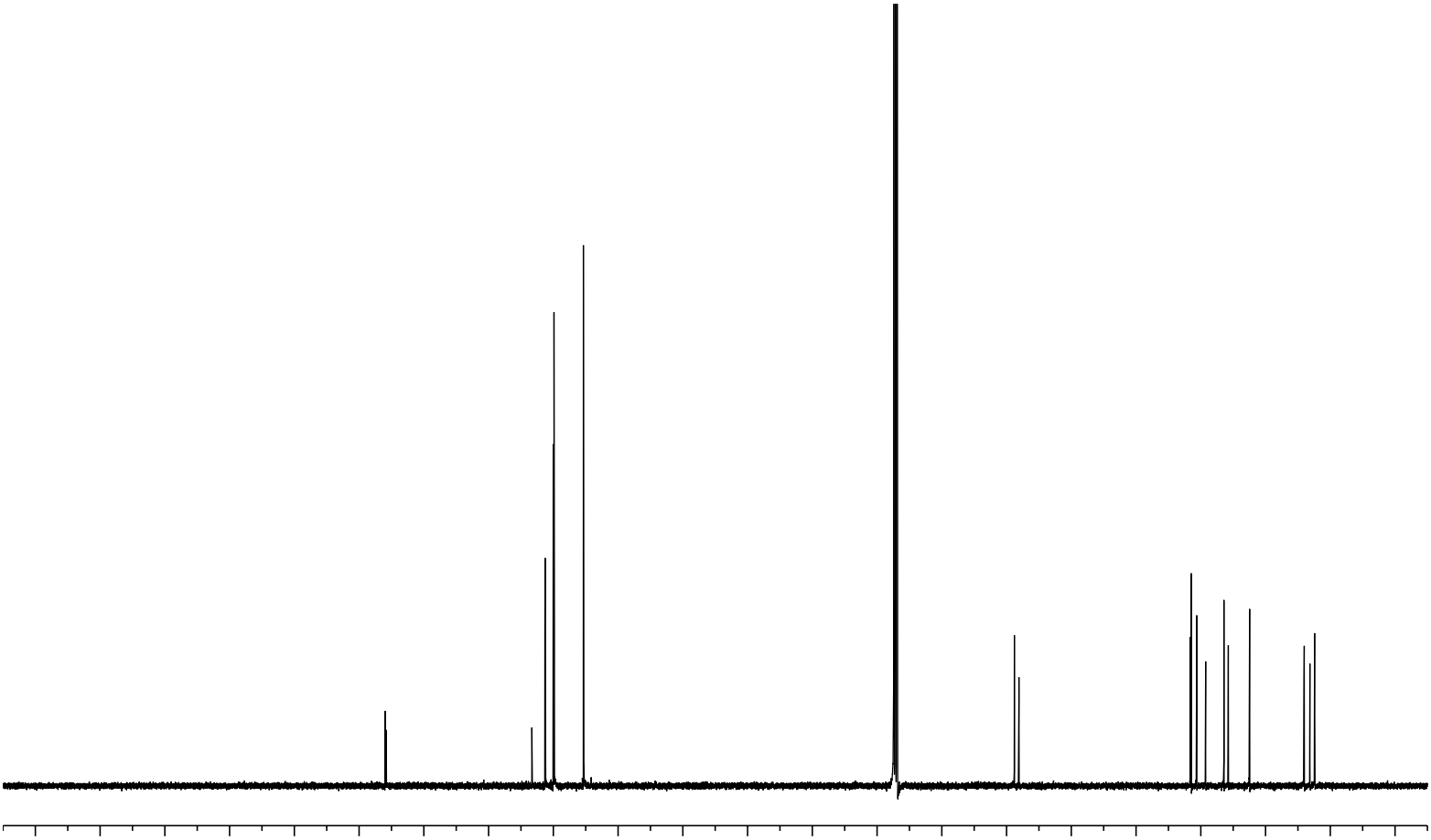
^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of sulfoxide **30b** in $CDCl_3$





^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of sulfoxide **31b** in $CDCl_3$





^{1}H-NMR (500 MHz) and ^{13}C-NMR (125 MHz) spectra of sulfoxide **32b** in $CDCl_3$