Supporting Information

A Rapid, Asymmetric Synthesis of the Decahydrofluorene Core of the Hirsutellones

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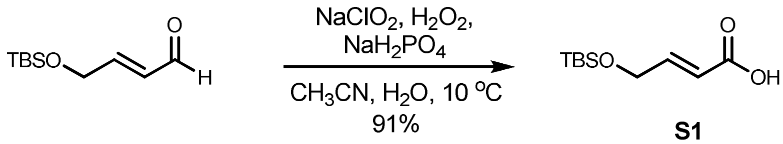
Experimental Section

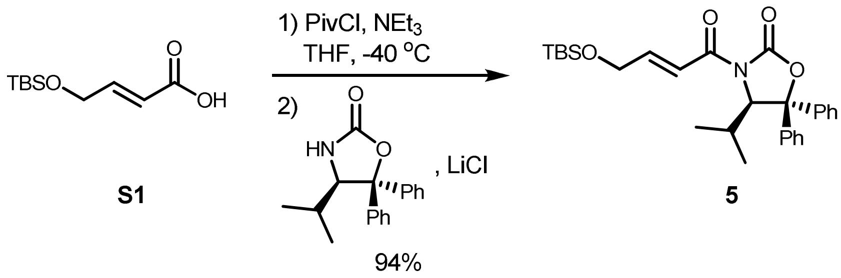
General Methods. All reactions were carried out under an atmosphere of argon with magnetic stirring unless otherwise indicated. Crabtree's catalyst was prepared according to a known literature procedure.[1] Di-μ-chlorobis(η^4-1,5-cyclooctadiene) diiridium(I) was purchased from Strem. In all other cases, commercial reagents of high purity were purchased from either Aldrich or Acros and used without further purification. Tetrahydrofuran (THF), dichloromethane (CH_2Cl_2), toluene, benzene, acetonitrile (CH_3CN), dimethyl sulfoxide (DMSO), triethylamine (NEt_3), and pyridine were dried by passing through activated alumina columns. Reactions were monitored by thin layer chromatography (TLC) carried out on 0.25 mm Merck silica gel plates (60 F_{254}) using UV light as a visualizing agent and aqueous potassium permanganate or ethanolic *p*-anisaldehyde solution and heat as developing agents. E. Merck silica gel 60 (230-400 mesh) was used for flash column chromatography.

Instrumentation. Optical rotations were recorded on a Perkin-Elmer model 241 polarimeter using a 1 mL, 1 dm cell. Melting points were determined using a Fisher-Jones melting point apparatus and are uncorrected. FT-IR spectra were obtained on a Perkin-Elmer Paragon 500. Nuclear magnetic resonance (NMR) spectra were obtained on a 500 MHz Bruker AVANCE spectrometer and calibrated to the residual solvent peak. Coupling constant values were extracted assuming first-order coupling. The multiplicities are abbreviated as follows: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, and br = broad signal. High resolution mass spectra were obtained on a Kratos MS 50 using electrospray ionization (ESI). High-performance liquid chromatography (HPLC) was performed on an Agilent 1200 series instrument equipped with a diode array UV detector.



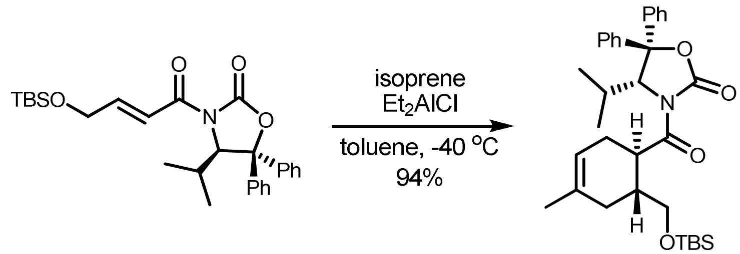
(*E*)-4-(tert-butyldimethylsilyloxy)but-2-enoic acid (S1). To a solution of aldehyde (*E*)-4-(*tert*-butyldimethylsilyloxy)but-2-enal[2] (11.55 g, 57.6 mmol, 1.00 eq.) in 60 mL of CH_3CN was added a solution of sodium dihydrogen phosphate monohydrate (2.15 g, 15.6 mmol, 0.27 eq.) in 30 mL of water. The reaction mixture was cooled to 10 ^oC in an ice/water bath, and a 35% aqueous hydrogen peroxide solution (5.16 mL, 59.1 mmol, 1.04 eq.) was added. The flask was then equipped with an additional funnel containing a solution of sodium chlorite (80% tech grade, 9.12 g, 80.7 mmol, 1.40 eq.) in 90 mL of water, which was added dropwise to the reaction mixture over 30 minutes. After addition was complete, the reaction mixture was stirred at 10 ^oC for an additional 2.5 hours at which time TLC (10:1 hexanes / EtOAc, $KMnO_4$) showed complete consumption of the starting aldehyde (R_f = 0.29). The reaction was quenched by the addition of solid sodium sulfite (500 mg) and diluted with water and EtOAc. The layers were separated, and the organic phase was washed with water and brine before drying over anhydrous Na_2SO_4. Removal of the solvent under reduced pressure and thorough drying under high vacuum gave **S1** as an amorphous off-white solid (11.30 g, 91%) which was used in the next step without further purification. An analytical sample was obtained by recrystallization of the crude product from hexanes (m.p. = 75 – 76 ^oC).

IR (neat) ν 1693, 1657 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ 0.07 (6H, s), 0.91 (9H, s), 4.36 (2H, t, J = 3.00 Hz), 6.11 (1H, d, J = 15.43 Hz), 7.11 (1H, dt, J = 2.90 Hz, 15.44 Hz), 9.39 (1H, br s); ^{13}C NMR (125 MHz, $CDCl_3$): δ -5.4, 18.4, 25.9, 62.2, 119.0, 150.3, 172.0; HRMS (ESI+) calculated for $C_{10}H_{21}O_3Si$ ($[M+H]^+$): 217.1260, found: 217.1253.



(R,E)-3-(4-(*tert*-butyldimethylsilyloxy)but-2-enoyl)-4-isopropyl-5,5-diphenyloxazolidin-2-one (5). To an oven-dried 1L flask was added a solution of acid **S1** (11.30 g, 52.2 mmol, 1.20 eq.) in 250 mL of THF. This solution was cooled to -40 °C in a dry ice / CH_3CN bath, and neat NEt_3 (18.93 mL, 136 mmol, 3.12 eq.) was added followed by the dropwise addition of trimethylacetyl chloride (6.75 mL, 54.8 mmol, 1.26 eq.). The resulting white slurry was stirred at -40 °C for 1.5 hours before the addition of solid flame-dried lithium chloride (2.55 g, 60.2 mmol, 1.38 eq.) and solid (R)-4-isopropyl-5,5-diphenyloxazolidin-2-one (12.25 g, 43.5 mmol,1.00 eq.) in single portions. The cooling bath was removed, and the heterogeneous tan reaction mixture was left to stir at room temperature overnight. After this time TLC (10:1 hexanes / EtOAc, $KMnO_4$) showed formation of the product at R_f = 0.28, and the reaction was quenched with saturated NH_4Cl solution and diluted with water and ether. The organic phase was isolated and washed with brine before drying over anhydrous $MgSO_4$. The solvent was removed under reduced pressure, and the residue was purified by column chromatography (9:1 hexanes / EtOAc) to give **5** as a viscous colorless oil (19.59 g, 94%).

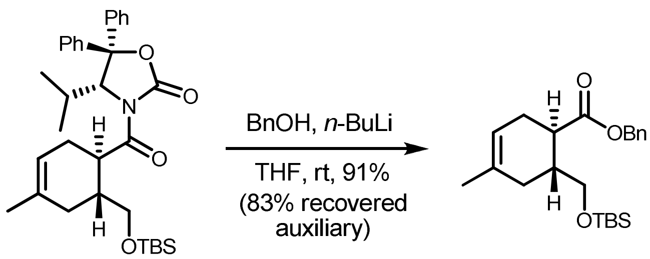
$[\alpha]^{20}_D$ = +102.7 (c 0.79, CH_2Cl_2); IR (neat) ν 2958, 2930, 2857, 1785, 1688, 1644 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ 0.07 (3H, s), 0.08 (3H, s), 0.77 (3H, d, J = 6.74 Hz), 0.89 (3H, d, J = 6.98 Hz), 0.92 (9H, s), 1.99 (1H, dtd, J = 3.32 Hz, 6.84 Hz, 13.70 Hz), 4.36 (2H, m), 5.47 (1H, d, J = 3.27), 7.14 (1H, dt, J = 3.42 Hz, 15.20 Hz), 7.27 (2H, m), 7.33 (4H, m), 7.39 (2H, m), 7.48 (3H, m); ^{13}C NMR (125 MHz, $CDCl_3$): δ -5.5, 16.4, 18.3, 21.8, 25.8, 30.2, 62.7, 64.3, 89.1, 118.4, 125.7, 126.0, 127.9, 128.4, 128.6, 128.9, 138.3, 142.3, 149.8, 152.8, 164.9; HRMS (ESI+) calculated for $C_{28}H_{38}NO_4Si$ ($[M+H]^+$): 480.2570, found 480.2567.



5 6

(*R*)-3-((1*R*,6*R*)-6-((*tert*-butyldimethylsilyloxy)methyl)-4-methylcyclohex-3-enecarbonyl) -4-isopropyl-5,5-diphenyloxazolidin-2-one (6). To an oven-dried 1L flask was added a solution of **5** (19.59 g, 40.8 mmol, 1.00 eq.) in 350 mL of toluene. The resulting solution was cooled to -40 °C in a dry ice / CH_3CN bath, and neat isoprene (40.85 mL, 409 mmol, 10.0 eq.) was added, followed by the dropwise addition of a 1.0M solution of diethylaluminum chloride in hexanes (61.26 mL, 61.3 mmol, 1.50 eq.). The bright yellow reaction mixture was stirred at -40 °C for 30 minutes, at which time TLC (10:1 hexanes / EtOAc, $KMnO_4$) showed complete consumption of the starting material and formation of the product at R_f = 0.45. The reaction was quenched at -40 °C with pH 7 phosphate buffer, diluted with EtOAc, and allowed to warm slowly to room temperature. The aluminum salts were removed by vacuum filtration through Celite, and the solids were washed with EtOAc. The layers of the filtrate were separated, and the aqueous phase was extracted with two portions of EtOAc. The combined organics were dried over anhydrous Na_2SO_4 before removal of the solvent under reduced pressure. The residue was purified by column chromatography (10:1 hexanes / EtOAc) to afford **6** as a viscous colorless oil (21.10 g, 94%).

$[\alpha]^{20}_D$ = +53.3 (*c* 1.88, CH_2Cl_2); IR (neat) ν 2959, 2928, 2856, 1787, 1701 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): δ -0.12 (3H, s), -0.02 (3H, s), 0.84 (3H, d, *J* = 6.87 Hz), 0.85 (9H, s), 0.95 (3H, d, *J* = 6.97 Hz), 1.73 (3H, s), 1.89 (1H, m), 2.03 (1H, m), 2.08 (1H, m), 2.16 (1H, m), 2.23 (1H, m), 2.55 (1H, m), 3.20 (1H, dd, *J* = 7.50 Hz, 9.61 Hz), 3.37 (1H, dd, *J* = 3.49 Hz, 9.67 Hz), 3.71 (1H, td, *J* = 5.65 Hz, 9.90 Hz), 5.43 (1H, s), 5.54 (1H, d, *J* = 3.20 Hz), 7.35 (3H, m), 7.41 (3H, m), 7.48 (2H, d, *J* = 7.50 Hz), 7.59 (2H ,d, *J* = 7.60 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ -5.5, 16.2, 18.1, 21.9, 23.6, 25.8, 29.7, 30.0, 32.1, 37.1, 39.1, 64.0, 64.6, 89.0, 118.1, 125.6, 125.9, 127.9, 128.4, 128.7, 128.9, 133.5, 138.3, 142.4, 152.4, 176.0; HRMS (ESI+) calculated for $C_{33}H_{46}NO_4Si$ ($[M+H]^+$): 548.3196, found 548.3194.

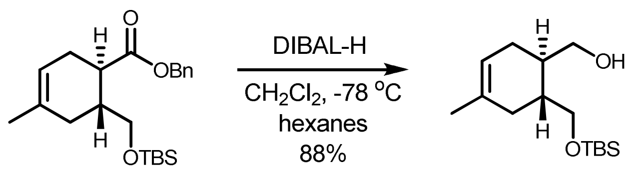


6 **7**

(1*R*,6*R*)-benzyl 6-((*tert*-butyldimethylsilyloxy)methyl)-4-methylcyclohex-3-enecarboxyl -ate (7). To a flame-dried flask equipped with a magnetic stirring bar was added a solution of benzyl alcohol (750 µL, 7.21 mmol, 1.50 eq.) in 25 mL of THF. This solution was cooled to 0 °C in an ice bath, and a 2.5M solution of *n*-butyllithium in hexanes (2.88 mL, 7.21 mmol, 1.50 eq.) was added dropwise. After ten minutes at 0 °C, a solution of **6** (2.63 g, 4.80 mmol, 1.00 eq.) in 10 mL of THF was added dropwise, and the reaction mixture was heated to 35 °C overnight at which point TLC (10:1 hexanes / EtOAc, $KMnO_4$) showed complete conversion to the product at R_f = 0.50. The reaction was quenched with saturated NH_4Cl solution, and the THF was removed under reduced pressure. Ether and water were added, and the resulting white suspension was stirred vigorously at room temperature for 15 minutes. The accumulated solids were isolated by vacuum filtration, sequentially washed with water, ether, and pentane, and dried under high vacuum to afford the recovered auxiliary as a fluffy white solid (1.12 g, 83%). The filtrate was diluted with ether, the layers were separated, and the organic phase was washed with brine before drying over anhydrous $MgSO_4$. Removal of the solvent under reduced pressure gave an oil that was purified by column chromatography (24:1 hexanes / EtOAc) to give **7** as a colorless oil (1.63 g, 91%).

$[\alpha]^{20}_D$ = -45.2 (*c* 1.80, CH_2Cl_2); IR (neat) ν 2956, 2928, 2856, 1734 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ -0.02 (3H, s), -0.01 (3H, s), 0.86 (9H, s), 1.65 (3H, s), 1.89 (1H, m), 2.01 (1H, dd, *J* = 5.04 Hz, 17.74 Hz), 2.12 (1H, m), 2.26 (2H, m), 2.65 (1H, td, *J* = 6.03 Hz, 9.30 Hz), 3.52 (2H, m), 5.10 (1H, d, *J* = 12.43 Hz), 5.13 (1H, d, *J* = 12.46 Hz), 5.33 (1H, s), 7.35 (5H, m);

^{13}C NMR (125 MHz, $CDCl_3$): δ -5.52, -5.49, 18.3, 23.5, 25.9, 28.2, 32.0, 37.8, 41.2, 65.0, 66.0, 118.4, 128.1, 128.5, 133.3, 136.2, 175.9; HRMS (ESI+) calculated for $C_{22}H_{35}O_3Si$ ($[M+H]^+$): 375.2355, found 375.2352.



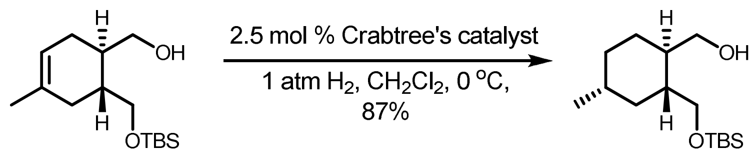
7

8

((1*R*,6*R*)-6-((*tert*-butyldimethylsilyloxy)methyl)-4-methylcyclohex-3-enyl)methanol (8). To an oven-dried 100 mL flask was added a solution of **7** (1.60 g, 4.27 mmol, 1.00 eq.) in 15 mL of CH_2Cl_2. This was cooled to -78 ^oC in a dry ice / isopropanol bath, and a 1.0M solution of diisobutylaluminum hydride in hexanes (12.80 mL, 12.8 mmol, 3.00 eq.) was added slowly over 10 minutes. After two hours at -78 ^oC, TLC (10:1 hexanes / EtOAc, $KMnO_4$) showed complete consumption of the starting material and clean formation of the product at R_f = 0.17. The reaction was diluted with CH_2Cl_2 and quenched at -78 ^oC by the dropwise addition of pH 7 phosphate buffer. After warming to room temperature, the accumulated aluminum salts were removed by filtration through Celite and washed with CH_2Cl_2. The layers of the filtrate were separated, and the organic phase was washed with brine before drying over anhydrous $MgSO_4$. Removal of the solvent under reduced pressure gave an oil that was purified by column chromatography (9:1 hexanes / EtOAc) to afford **8** as a colorless oil (1.01 g, 88%). Enantiomeric excess was determined by HPLC using a Chiralpak AS-H column (Daicel Chemical Industries, Ltd.) with UV detection at 220 nm. Isocratic elution of a racemic sample with 0.5% isopropanol in hexanes yielded two peaks with retention times of 10.485 min and 11.074 min. Coinjection of **8** with the racemic sample resulted in increased absorption for the latter peak. Injection of pure **8** gave a single peak, corresponding to an enantiomeric excess of greater than 99%.

$[\alpha]^{20}_D$ = -35.1 (*c* 0.94, CH_2Cl_2); IR (neat) 3370, 1088 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ 0.09 (6H, s), 0.91 (9H, s), 1.54 (1H, m), 1.65 (3H, s), 1.66-1.98 (5H, m), 3.50 (1H, dd, *J* = 5.93 Hz, 11.46 Hz), 3.58 (1H, m), 3.60 (1H, m), 3.64 (1H, dd, *J* = 3.07 Hz, 10.55 Hz), 3.67

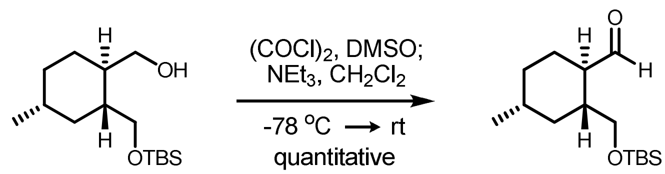
(1H, dd, J = 3.58 Hz, 11.47 Hz), 5.36 (1H, m); ^{13}C NMR (125 MHz, $CDCl_3$): δ -5.5, -5.4, 18.2, 23.3, 25.8, 29.1, 33.5, 39.8, 40.7, 65.9, 67.2, 120.6, 132.7; HRMS (ESI+) calculated for $C_{15}H_{31}O_2Si$ ($[M+H]^+$): 271.2093, found 271.2086.



8 **9**

((1*R*,2*R*,4*R*)-2-((*tert*-butyldimethylsilyloxy)methyl)-4-methylcyclohexyl)methanol (9). To an oven-dried 250 mL flask was added a solution of **8** (494 mg, 1.83 mmol, 1.00 eq.) in 60 mL of CH_2Cl_2. The solution was cooled to 0 °C in an ice bath and sparged with a stream of argon for 30 minutes. Solid Crabtree's catalyst (36.9 mg, 45.8 µmol, 0.025 eq.) was added in a single portion, giving an orange solution. The flask was then evacuated and backfilled with hydrogen gas (1 atm, balloon). After two hours, TLC (4:1 hexanes / EtOAc, anisaldehyde) showed complete conversion of the starting material to the hydrogenated product at R_f = 0.49. The solvent was removed under reduced pressure to give a yellow oil, which was purified by column chromatography (9:1 hexanes / EtOAc) to afford **9** as a colorless oil (431 mg, 87%).

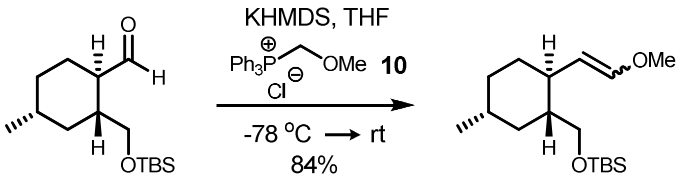
$[\alpha]^{20}_{D}$ = +4.71 (c 0.68, CH_2Cl_2); IR (neat) ν 3418 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): δ 0.06 (6H, s), 0.65 (1H, dd, J = 12.30 Hz, 12.32 Hz), 0.87 (3H, d, J = 6.51 Hz), 0.89 (9H, s), 0.91 (1H, m), 1.11 (1H, ddd, J = 3.52 Hz, 12.67 Hz, 25.31 Hz), 1.19 (1H, m), 1.35 (2H, m), 1.51 (1H, dd, J = 1.93 Hz, 12.78 Hz), 1.60 (1H, ddd, J = 3.05 Hz, 6.25 Hz, 12.72 Hz), 1.69 (1H, m), 3.45 (1H, dt, J = 5.65 Hz, 11.39 Hz), 3.56 (3H, m), 3.81 (1H, dd, J = 5.32 Hz, 8.36 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ -5.6, -5.4, 18.2, 22.6, 25.8, 30.1, 32.5, 34.8, 38.6, 44.0, 45.4, 67.3, 68.7; HRMS (EI) calculated for $C_{15}H_{33}O_2Si$: 273.2250, found: 273.2244.



9 **S2**

(1*R*,2*R*,4*R*)-2-((*tert*-butyldimethylsilyloxy)methyl)-4-methylcyclohexanecarbaldehyde (S2). To a flame-dried flask was added a solution of oxalyl chloride (1.69 mL, 19.7 mmol, 2.00 eq.) in 46 mL of CH_2Cl_2. The flask was cooled to -78 ^oC in a dry ice / isopropanol bath, and a solution of DMSO (1.75 mL, 24.6 mmol, 2.50 eq.) in 46 mL of CH_2Cl_2 was added slowly via cannula. After 15 minutes, a solution of **9** (2.68, 9.83 mmol, 1.00 eq.) in 25 mL of CH_2Cl_2 was added dropwise, and the resulting solution was stirred at -78 ^oC for one hour. After this time, neat NEt_3 (8.21 mL, 59.0 mmol, 6.00 eq.) was added dropwise, and the flask was allowed to warm slowly to room temperature at which point TLC (10:1 hexanes / EtOAc, anisaldehyde) showed complete conversion to the product at R_f = 0.43. The flask was again cooled to -78 ^oC, and the reaction was quenched sequentially with methanol and saturated $NaHCO_3$ solution. After warming to room temperature, the organic phase was sequentially washed with water and brine, dried over anhydrous Na_2SO_4, evaporated, and dried under high vacuum to give **S2** as a yellow oil that was used directly in the next step without further purification (2.66 g, quantitative).

$[\alpha]^{20}_D$ = -13.2 (*c* 0.63, CH_2Cl_2); IR (neat) ν 1727 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ 0.01 (6H, d, *J* = 3.29 Hz), 0.68 (1H, dd, *J* = 12.11 Hz, 24.64 Hz), 0.87 (9H, s), 0.91 (3H, d, *J* = 6.55 Hz), 0.93 (1H, m), 1.34 (1H, ddd, *J* = 3.75 Hz, 13.02 Hz, 25.46 Hz), 1.42 (1H, m), 1.70 (2H, m), 1.79 (1H, m), 1.91 (1H, m), 1.97 (1H, m), 3.37 (1H, dd, *J* = 7.45 Hz, 9.86 Hz), 3.55 (1H, dd, *J* = 4.66 Hz, 9.93 Hz), 9.53 (1H, d, *J* = 4.27 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ -5.63, -5.58, 18.3, 22.5, 25.9, 26.3, 31.5, 33.5, 36.3, 40.8, 53.9, 67.2, 204.8; HRMS (ESI+) calculated for $C_{15}H_{31}O_2Si$ ($[M+H]^+$): 271.2093, found 271.2088.

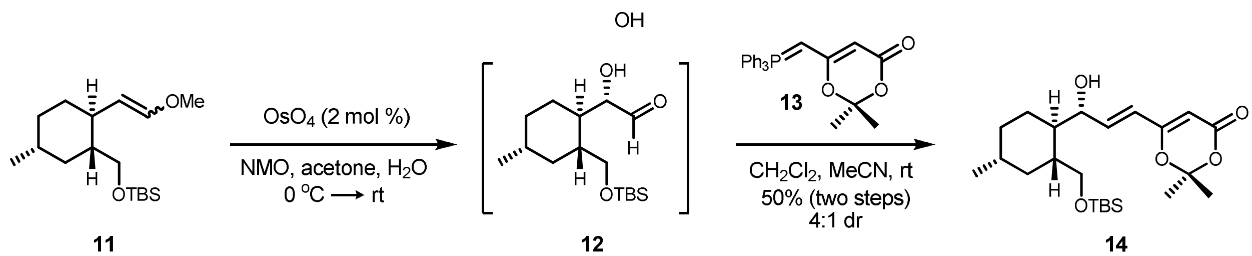


S2 11

tert-butyl(((1R,2R,5R)-2-(2-methoxyvinyl)-5-methylcyclohexyl)methoxy)dimethylsilane (11). To a 500 mL flame-dried flask was added (methoxymethyl)triphenylphosphonium chloride (6.48 g, 18.9 mmol, 1.92 eq.) and 50 mL of THF to give a white slurry. The flask was cooled to -78 °C in a dry ice / isopropanol bath, and a 0.5 M solution of potassium bis(trimethylsilyl)amide (KHMDS) in toluene (36.60 mL, 18.3 mmol, 1.86 eq.) was added dropwise. The reaction mixture immediately turned dark orange and then dark red upon warming to 0 °C in an ice bath. After 30 minutes, the reaction mixture was cooled to -78 °C, and a solution of **S2** (2.66 g, 9.83 mmol, 1.00 eq.) in 40 mL of THF was added slowly via cannula. The cooling bath was allowed to expire, and the reaction mixture was left to stir at room temperature overnight. After this time, TLC (10:1 hexanes / EtOAc, anisaldehyde) showed formation of the desired product at R_f = 0.77, and the reaction was quenched with saturated NH_4Cl solution and diluted with EtOAc. The organic phase was then washed twice with water, once with 3% aqueous hydrogen peroxide,[3] and once with brine before drying over anhydrous $MgSO_4$. The solvent was removed under reduced pressure, and the residue was purified by column chromatography (25:1 hexanes / EtOAc) to give **11** as a 6:1 mixture of the *trans* and *cis* enol ether isomers (2.47 g, 84%).

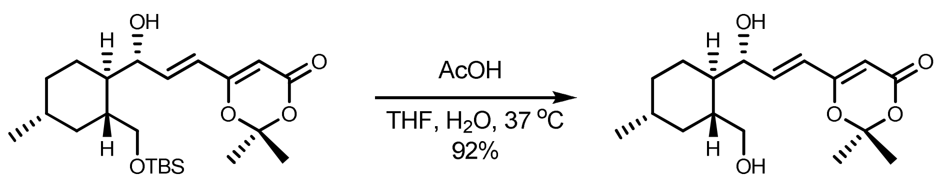
IR (neat) ν 1652, 1255 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) *trans*: δ 0.02 (6H, s), 0.78 (1H, dd, *J* = 12.07 Hz, 24.75 Hz), 0.84 - 0.90 (13H, m), 1.19 (2H, m), 1.36 (1H, m), 1.63 (3H, m), 1.82 (1H, dd, *J* = 1.68 Hz, 13.03 Hz), 3.36 (1H, dd, *J* = 6.93 Hz, 9.75 Hz), 3.49 (3H, s), 3.60 (1H, dd, *J* = 2.87 Hz, 9.71 Hz), 4.51 (1H, dd, *J* = 9.24 Hz, 12.56 Hz), 6.24 (1H, d, *J* = 12.62 Hz); *cis*: δ 0.02 (6H, s), 0.66 (1H, dd, *J* = 12.19 Hz, 24.69 Hz), 0.84 - 0.90 (10H, m), 0.94 (3H, d, *J* = 6.27 Hz), 1.19 (2H, m), 1.36 (1H, m), 1.63 (3H, m), 1.82 (1H, dd, *J* = 1.68 Hz, 13.03 Hz), 3.25 (1H, m), 3.54 (3H, s), 3.68 (1H, dd, *J* = 3.37 Hz, 9.86 Hz), 4.14 (1H, dd, *J* = 6.31 Hz, 9.56 Hz), 5.84 (1H, d, *J* = 6.30 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) *trans*: δ -5.37, -5.35, 18.4, 22.85, 26.00, 32.3, 35.0, 35.2, 38.3, 38.47, 44.92, 55.9, 66.2, 107.6, 146.7; *cis*:

-5.31, -5.28, 18.4, 22.90, 26.04, 32.1, 34.6, 34.9, 38.3, 38.54, 44.95, 59.4, 66.9, 111.7, 145.7; HRMS (ESI+) calculated for $C_{17}H_{35}O_2Si$ ($[M+H]^+$): 299.2406, found 299.2399.



6-((*R*,*E*)-3-((1*R*,2*R*,4*R*)-2-((*tert*-butyldimethylsilyloxy)methyl)-4-methylcyclohexyl)-3-hydroxyprop-1-enyl)-2,2-dimethyl-4H-1,3-dioxin-4-one (14). A solution of **11** (1.16 g, 3.89 mmol, 1.00 eq.) in 20 mL of acetone and 2.50 mL of water was cooled to 0 °C in an ice bath. Solid *N*-methylmorpholine oxide (684 mg, 5.84 mmol, 1.50 eq.) was added in a single portion followed by a 0.08M solution of osmium tetroxide in *t*-butanol (973 µL, 77.8 µmol, 0.02 eq.). The reaction mixture turned from colorless to dull yellow and then to darker brown upon warming to room temperature. After 45 minutes, TLC (10:1 hexanes / EtOAc, anisaldehyde) showed essentially complete consumption of the starting material and formation of the α-hydroxyaldehyde **12** at R_f = 0.25. The reaction mixture was partitioned between water and ether, and the aqueous phase was extracted with two additional portions of ether. The combined organics were washed with brine and dried over anhydrous Na_2SO_4. The drying agent was removed by filtration, 24 mL of dry CH_3CN was added, and the solution was concentrated to a volume of ~24 mL under reduced pressure. A solution of phosphorane **13** (2.35 g, 5.84 mmol, 1.50 eq.) in 12 mL of dry CH_2Cl_2 was added in a single portion; the reaction mixture turned dark brown and was left to stir at room temperature overnight. After this time, TLC (4:1 hexanes / EtOAc, $KMnO_4$) showed the two product diastereomers near R_f = 0.21. The dark black reaction mixture was concentrated under reduced pressure, and the resulting oil was purified by column chromatography (9:1 hexanes / EtOAc). This yielded 586 mg (36%) of the major product diastereomer **14** (upper spot near R_f = 0.21), and 228 mg (14%) of a mixture of **14** with the minor product diastereomer, for an overall yield of 50% with 4:1 diastereoselectivity, as determined by NMR.

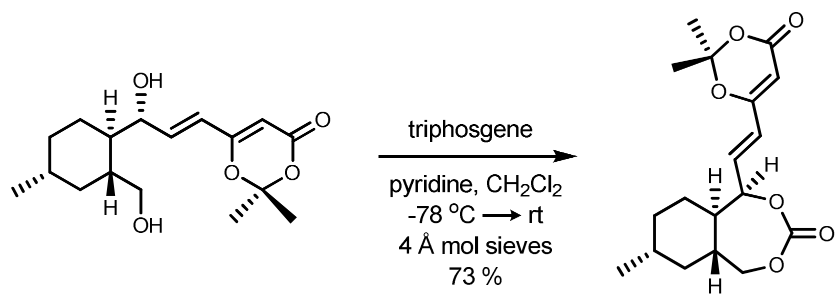
$[\alpha]^{20}_D$ = +5.8 (*c* 0.89, CH_2Cl_2); IR (neat) ν 3456, 1728, 1652 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): δ 0.10 (6H, d, *J* = 5.77 Hz), 0.74 (1H, dd, *J* = 12.70 Hz, 13.01 Hz), 0.85 (1H, m), 0.88 (3H, d, *J* = 6.51 Hz), 0.91 (9H, s), 1.18 (1H, ddd, J = 3.54 Hz, 12.91 Hz, 25.61 Hz), 1.40 (2H, m), 1.55 (2H, m), 1.68 (1H, m), 1.71 (6H, s), 3.54 (1H, dd, J = 7.35 Hz, 10.36 Hz), 3.61 (1H, dd, *J* = 2.31 Hz, 10.41 Hz), 3.84 (1H, d, *J* = 6.29 Hz), 4.49 (1H, m), 5.31 (1H, s), 6.18 (1H, dd, *J* = 1.75 Hz, 15.52 Hz), 6.58 (1H, dd, *J* = 4.67 Hz, 15.53 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ -5.54, -5.45, 18.3, 22.5, 25.0, 25.1, 25.9, 27.4, 32.5, 34.7, 39.1, 41.3, 48.2, 68.7, 73.0, 94.2, 106.3, 121.8, 142.2, 162.1, 163.2; HRMS (ESI+) calculated for $C_{23}H_{41}O_5Si$ ($[M+H]^+$): 425.2723, found 425.2720.



14 **S3**

6-((*R*,*E*)-3-hydroxy-3-((1*R*,2*R*,4*R*)-2-(hydroxymethyl)-4-methylcyclohexyl)prop-1-enyl)-2,2-dimethyl-4*H*-1,3-dioxin-4-one (S3). To a solution of **14** (18.0 mg, 42.4 µmol, 1.00 eq.) in 1.14 mL of 1:1 THF / water was added glacial acetic acid (1.70 mL, 29.7 mmol, 700 eq.). The reaction mixture was heated to 37 °C in an oil bath overnight, at which point TLC (3:1 EtOAc / hexanes, $KMnO_4$) showed complete consumption of the starting material and formation of the product at R_f = 0.35. The solvent was removed under reduced pressure, and the residue was purified by column chromatography (1:1 hexanes / EtOAc → 100% EtOAc) to give **S3** as a colorless oil (12.0 mg, 92%).

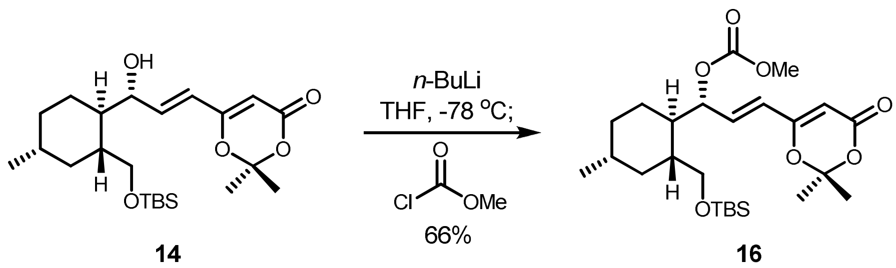
IR (neat) ν 3407, 1706, 1653, 1588 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): δ 0.80 (1H, dd, *J* = 11.99 Hz, 24.27 Hz), 0.89 (3H, d, *J* = 6.51 Hz), 0.90 (1H, m), 1.22 (2H, m), 1.40 (1H, m), 1.46 (1H, m), 1.51 (1H, m), 1.60 (2H, m), 1.71 (3H, s), 1.72 (3H, s), 3.56 (1H, dd, *J* = 6.37 Hz, 10.78 Hz), 3.71 (1H, dd, *J* = 2.80 Hz, 10.75 Hz), 4.55 (1H, m), 5.31 (1H, s), 6.19 (1H, dd, *J* = 1.74 Hz, 15.55 Hz), 6.60 (1H, dd, *J* = 4.43 Hz, 15.54 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ 21.4, 23.9, 24.2, 26.5, 31.3, 33.6, 37.9, 39.8, 46.0, 66.5, 72.4, 93.3, 105.4, 120.9, 140.9, 161.2, 162.0; HRMS (ESI+) calculated for $C_{17}H_{27}O_5$ ($[M+H]^+$): 311.1858, found 311.1850.



S3 **15**

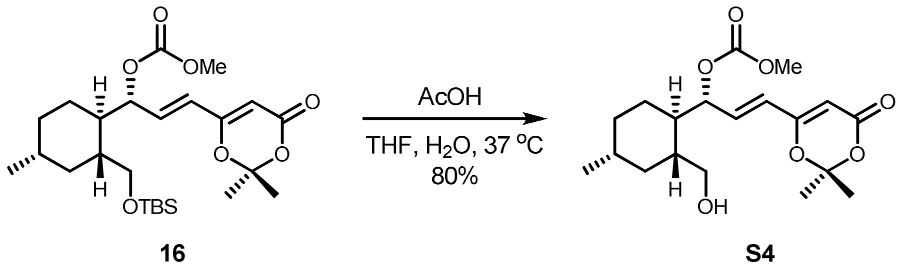
(1*R*,5a*R*,7*R*,9a*R*)-1-((*E*)-2-(2,2-dimethyl-4-oxo-4*H*-1,3-dioxin-6-yl)vinyl)-7-methylocta-hydrobenzo[*e*][1,3]dioxepin-3-one (15). To an oven-dried 20 mL vial containing 30 mg of 4Å molecular sieves was added a solution of **S3** (6.5 mg, 21 µmol, 1.00 eq.) in 1.00 mL of CH_2Cl_2. This solution was cooled to -78 °C in a dry ice / acetone bath, and neat pyridine (30 µL, 37 µmol, 1.76 eq.) was added followed by the dropwise addition of 400 µL of a 0.03M solution of triphosgene in CH_2Cl_2. After 30 minutes at -78 °C, the reaction mixture was allowed to warm to room temperature, and additional 400 µL portions of the phosgene solution were added every hour until the starting material had been consumed. After a total of five such additions of triphosgene (19.2 mg, 65 µmol, 3.10 eq.), TLC (3:1 EtOAc / hexanes, $KMnO_4$) showed clean formation of the product at R_f = 0.75. The reaction was quenched with pH 7 phosphate buffer and filtered through Celite to remove the molecular sieves. The pad was then rinsed with an additional 50 mL of CH_2Cl_2 and 20 mL of pH 7 phosphate buffer. The organic layer of the filtrate was isolated, washed with brine, and dried over anhydrous Na_2SO_4. The solvent was removed under reduced pressure, and the residue was purified by column chromatography (10:1 hexanes / EtOAc → 1:1 hexanes / EtOAc) to give cyclic carbonate **15** as a colorless oil (5.2 mg, 73%).

IR (neat) ν ; 2360, 2342, 1757, 1728, 1653 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ 0.71 (1H, q, *J* = 11.99 Hz), 0.94 (3H, d, *J* = 6.54 Hz), 1.02 (2H, m), 1.50 (1H, m), 1.63 (2H, m), 1.71 (3H, s), 1.73 (3H, s), 1.81 (3H, m), 3.92 (1H, dd, *J* = 9.62 Hz, 11.88 Hz), 4.10 (1H, dd, *J* = 2.98 Hz, 11.90 Hz), 4.80 (1H, dd, *J* = 3.86 Hz, 7.50 Hz), 5.40 (1H, s), 6.23 (1H, dd, *J* = 0.90 Hz, 15.47 Hz), 6.53 (1H, dd, *J* = 7.78 Hz, 15.48 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ 22.2, 24.6, 25.6, 28.0, 31.9, 34.1, 36.5, 37.9, 46.1, 74.7, 83.4, 97.0, 107.0, 128.6, 131.1, 153.3, 161.1, 161.3; HRMS (ESI+) calculated for $C_{18}H_{24}NaO_6$ ($[M+Na]^+$): 359.1471, found 359.1468.



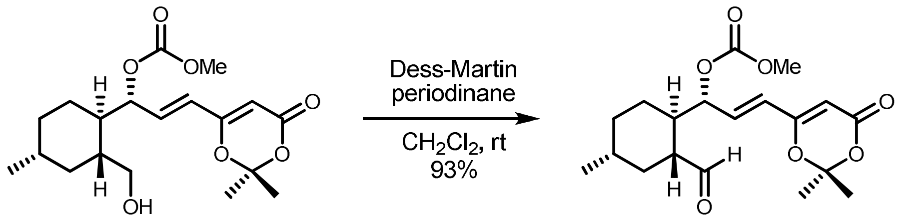
(*R*,*E*)-1-((1*R*,2*R*,4*R*)-2-((*tert*-butyldimethylsilyloxy)methyl)-4-methylcyclohexyl)-3-(2,2-dimethyl-4-oxo-4*H*-1,3-dioxin-6-yl)allyl methyl carbonate (16). A solution of **14** (152 mg, 0.36 mmol, 1.00 eq.) was dissolved in 11 mL of THF, transferred to an oven-dried flask, and cooled to -78 °C in a dry ice / isopropanol bath. A 2.5M solution of *n*-butyllithium in hexanes (143 µL, 0.36 mmol, 1.00 eq.) was added dropwise, and the solution turned yellow/orange. After five minutes, neat methyl chloroformate (42 µL, 0.54 mmol, 1.50 eq.) was added dropwise, and the reaction mixture was allowed to warm to room temperature. After this time, TLC (4:1 hexanes / EtOAc, $KMnO_4$) showed consumption of the starting material and formation of the product at R_f = 0.31. The reaction was quenched with pH 7 phosphate buffer and diluted with EtOAc. The layers were separated, and the organic phase was washed with brine before drying over anhydrous Na_2SO_4. The solvent was removed under reduced pressure, and the residue was purified by column chromatography (9:1 hexanes / EtOAc) to give **16** as a pale yellow oil (115 mg, 66%).

$[\alpha]^{20}_D$ = -23.7 (*c* 2.44, CH_2Cl_2); IR (neat) ν 1749, 1659, 1269 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ 0.04 (3H, s), 0.05 (3H, s), 0.85-0.90 (13H, m), 0.97 (1H, m), 1.21-1.68 (7H, m), 1.71 (3H, s), 1.72 (3H, s), 3.53 (1H, dd, *J* = 2.28 Hz, 10.31 Hz), 3.68 (1H, dd, *J* = 4.88 Hz, 10.13 Hz), 3.78 (3H, s), 5.32 (1H, s), 5.54 (1H, m), 5.99 (1H, d, *J* = 15.66 Hz), 6.45 (1H, dd, *J* = 4.93 Hz, 15.67 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ -5.49, -5.45, 18.4, 22.6, 25.0, 25.2, 25.5, 25.9, 32.1, 34.6, 38.9, 40.1, 42.0, 55.0, 65.0, 77.0, 95.2, 106.6, 122.6, 138.1, 155.3, 161.7, 162.2; HRMS (ESI+) calculated for $C_{25}H_{43}O_7Si$ ($[M+H]^+$): 483.2778, found 483.2777.



(R,E)-3-(2,2-dimethyl-4-oxo-4H-1,3-dioxin-6-yl)-1-((1R,2R,4R)-2-(hydroxymethyl)-4-methylcyclohexyl)allyl methyl carbonate (S4). To an oven-dried vial equipped with a stir bar was added a solution of carbonate **16** (115 mg, 0.24 mmol, 1.00 eq.) in 6.4 mL of 1:1 THF / water. Neat glacial acetic acid (9.6 mL, 168 mmol, 700 eq.) was added, and the reaction mixture was heated to 37 °C overnight. After this time, TLC (1:1 hexanes / EtOAc, $KMnO_4$) showed complete consumption of the starting material and formation of the product at R_f = 0.26. The reaction mixture was cooled to room temperature, diluted with EtOAc, and quenched with saturated $NaHCO_3$ solution. The organic layer was then isolated, washed with water and brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (2:1 hexanes / EtOAc) to give the alcohol **S4** as a colorless oil (70 mg, 80%).

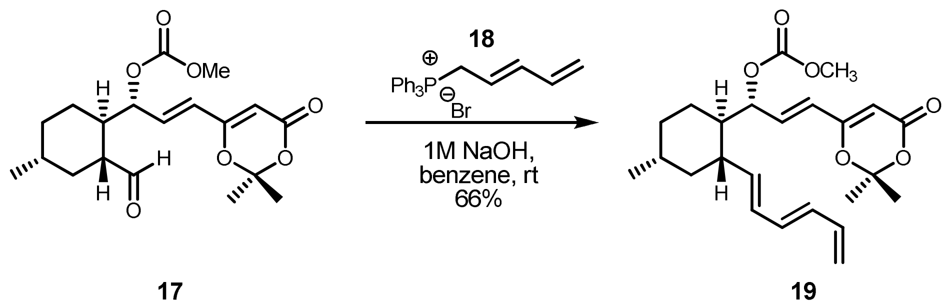
$[\alpha]^{20}_{D}$ = -28.9 (c 1.71, CH_2Cl_2); IR (neat) ν 1748, 1724, 1658, 1268 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): δ 0.89 (1H, m), 0.90 (3H, d, J = 6.52 Hz), 0.95 (1H, dd, J = 11.04 Hz, 23.38 Hz), 1.26 (2H, m), 1.39 (1H, m), 1.48 (2H, m), 1.59-1.67 (2H, m), 1.70 (3H, s), 1.72 (3H, s), 3.63 (1H, dd, J = 3.29 Hz, 11.04 Hz), 3.73 (1H, dd, J = 4.57 Hz, 11.03 Hz), 3.81 (3H, s), 5.33 (1H, s), 5.58 (1H, m), 6.05 (1H, dd, J = 1.17 Hz, 15.66 Hz), 6.48 (1H, dd, J = 4.98 Hz, 15.65 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ 22.5, 25.0, 25.2, 26.1, 32.1, 34.5, 38.7, 40.0, 42.4, 55.2, 65.4, 77.7, 95.4, 105.6, 123.0, 137.2, 155.3, 161.7, 162.0; HRMS (ESI+) calculated for $C_{19}H_{29}O_7$ ($[M+H]^+$): 369.1913, found 369.1911.



S4 **17**

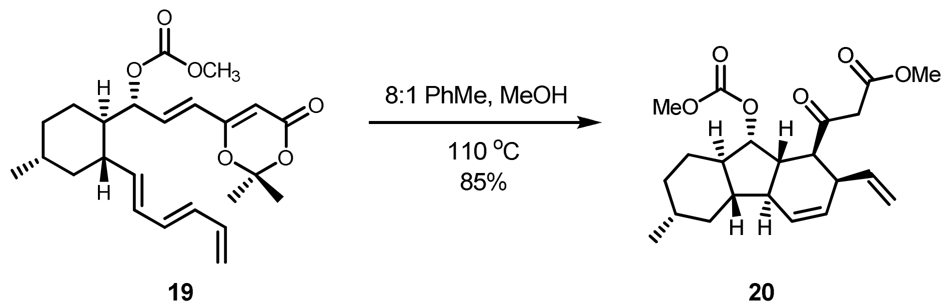
(*R*,*E*)-3-(2,2-dimethyl-4-oxo-4*H*-1,3-dioxin-6-yl)-1-((1*R*,2*R*,4*R*)-2-(hydroxymethyl)-4-methylcyclohexyl)allyl methyl carbonate (17). To an oven-dried vial was added a solution of **S4** (70 mg, 0.19 µmol, 1.00 eq.) in 5 mL of CH_2Cl_2. Solid Dess-Martin periodinane (120 mg, 0.29 mmol, 1.53 eq.) was added in a single portion, and the reaction mixture became cloudy. After 15 minutes, TLC (1:1 hexanes / EtOAc, $KMnO_4$) showed clean conversion of the alcohol to the aldehyde at R_f = 0.49. The reaction was quenched with saturated $NaHCO_3$ and diluted with CH_2Cl_2. The organic phase was washed with saturated $NaHCO_3$ and brine before drying over anhydrous Na_2SO_4. The solvent was removed under reduced pressure, and the residue was purified by column chromatography (3:1 hexanes / EtOAc) to give **17** as a colorless oil (65 mg, 93%).

$[\alpha]^{20}_D$ = -6.4 (*c* 1.82, CH_2Cl_2); IR (neat) ν 1749, 1724, 1659, 1265 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): δ 0.87 (1H, dd, *J* = 12.47 Hz, 24.81 Hz), 0.89 (1H, m), 0.94 (3H, d, *J* = 6.52 Hz), 1.27 (1H, m), 1.45 (1H, m), 1.71 (3H, s), 1.72 (3H, s), 1.76 (2H, m), 1.88 (1H, dd, *J* = 1.69 Hz, 12.93 Hz), 2.02 (1H, t, *J* = 11.62 Hz), 2.40 (1H, t, *J* = 11.73 Hz), 3.79 (3H, s), 5.34 (1H, s), 5.42 (1H, m), 6.07 (1H, dd, *J* = 1.47 Hz, 15.64 Hz), 6.45 (1H, dd, J = 5.34 Hz, 15.64 Hz), 9.58 (1H, d, *J* = 2.48 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ 22.2, 24.9, 24.95, 25.2, 31.6, 33.7, 34.6, 40.5, 51.0, 55.2, 77.8, 95.8, 106.7, 123.9, 136.0, 155.0, 161.6, 161.8, 202.8; HRMS (ESI+) calculated for $C_{19}H_{27}O_7$ ($[M+H]^+$): 367.1757, found 367.1748.



(R,E)-3-(2,2-dimethyl-4-oxo-4H-1,3-dioxin-6-yl)-1-((1R,2S,4R)-2-((1E,3E)-hexa-1,3,5-trienyl)-4-methylcyclohexyl)allyl methyl carbonate (19). To a solution of **17** (65 mg, 0.18 mmol, 1.00 eq.) in 6.25 mL of benzene was added solid phosphonium salt **18** (146 mg, 0.36 mmol, 2.00 eq.). Approximately 2.0 mL of 1 M aqueous NaOH solution was added, and the biphasic reaction mixture was stirred vigorously at room temperature. The organic layer turned dark red and gradually faded to a dull brown over 15 minutes. Two additional 63 mg (0.15 mmol, 0.83 eq.) portions of **18** were added after 15 minute intervals, and the reaction mixture was stirred for an additional 15 minutes at room temperature. After this time, TLC (3:1 hexanes / EtOAc, $KMnO_4$) showed almost complete conversion to the product at R_f = 0.43. The organic phase was isolated and washed with pH 7 phosphate buffer and brine before drying over anhydrous Na_2SO_4. The solvent was removed under reduced pressure, and the residue was purified by column chromatography (4:1 hexanes / EtOAc) to afford **19** as a bright yellow oil (48.8 mg, 66%).

$[\alpha]^{20}_D$ = +10.4 (*c* 2.37, CH_2Cl_2); IR (neat) ν 2925, 1752, 1727, 1658, 1596, 1264 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): δ 0.80 – 0.90 (2H, m), 0.89 (3H, d, *J* = 6.48 Hz), 1.20 – 1.50 (3H, m), 1.65 – 1.75 (3H, m), 1.69 (3H, s), 1.71 (3H, s), 2.11 (1H, m), 3.81 (3H, s), 5.07 (1H, d, *J* = 10.07 Hz), 5.19 (1H, d, *J* = 17.11 Hz), 5.31 (1H, s), 5.36 (1H, m), 5.52 (1H, dd, *J* = 9.25 Hz, 15.08 Hz), 5.96 (1H, dd, *J* = 1.45 Hz, 15.62 Hz), 6.02 (1H, m), 6.13 (1H, dd, *J* = 10.28 Hz, 15.04 Hz), 6.18 (1H, dd, *J* = 10.28 Hz, 15.04 Hz), 6.34 (1H, ddd, *J* = 10.06 Hz, 10.06 Hz, 16.88 Hz), 6.44 (1H, dd, *J* = 4.93 Hz, 15.65 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ 22.4, 24.9, 25.0, 25.3, 31.8, 34.4, 42.1, 43.1, 45.0, 55.1, 77.6, 95.2, 106.6, 117.0, 122.6, 131.2, 132.1, 133.1, 137.0, 137.9, 138.1, 154.9, 161.8, 162.1; HRMS (ESI+) calculated for $C_{21}H_{27}O_5$([M+H-acetone]$^+$): 359.1858, found 359.1864.

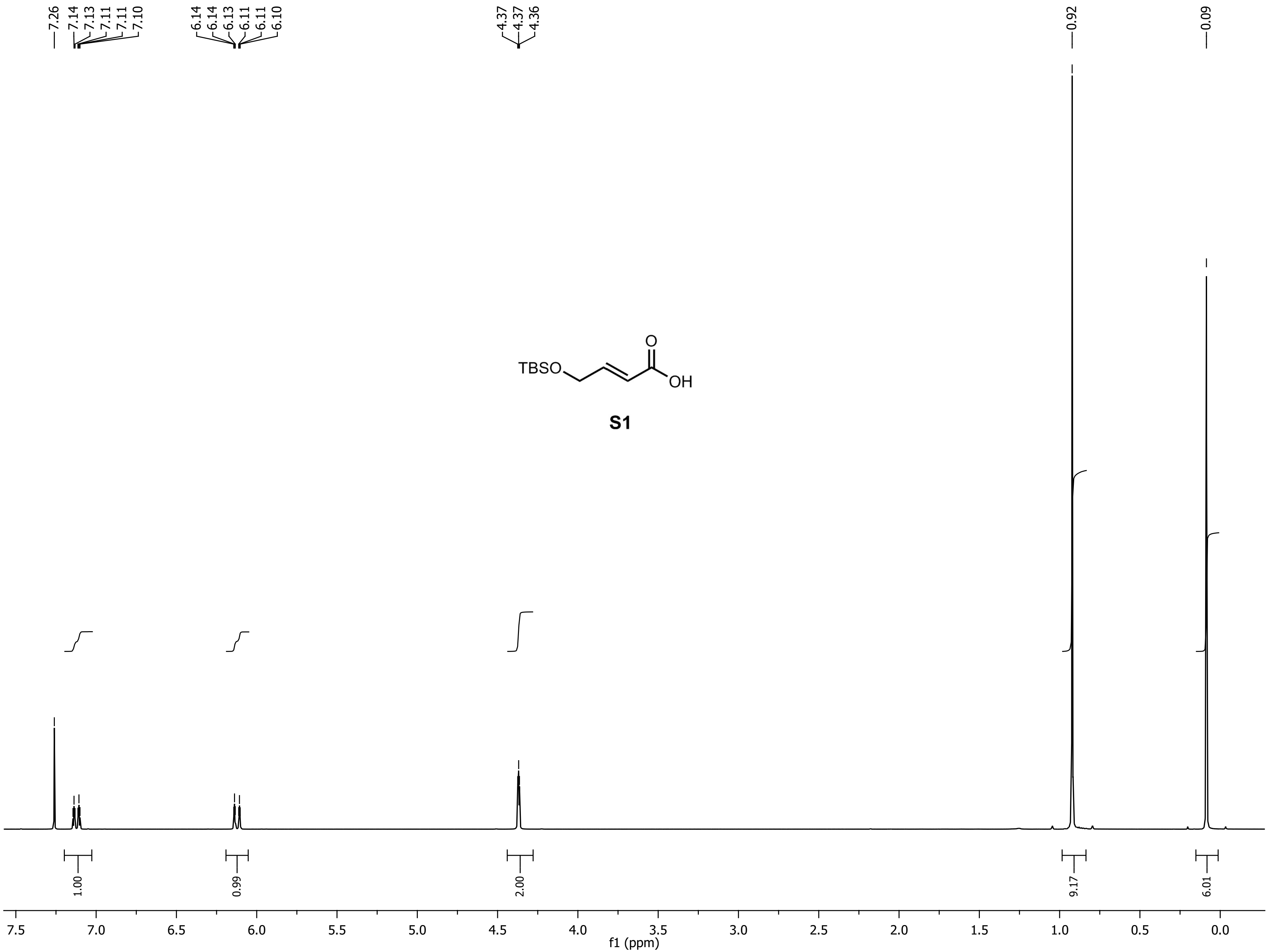


methyl 3-((1*S*,2*S*,4a*S*,4b*S*,6*R*,8a*R*,9*S*,9a*S*)-9-(methoxycarbonyloxy)-6-methyl-2-vinyl-2,4a,4b,5,6,7,8,8a,9,9a-decahydro-1H-fluoren-1-yl)-3-oxopropanoate (20). To an oven-dried 20 mL vial containing 4Å molecular sieves (approximately 1 gram) was added 8.0 mL of toluene and 1.5 mL of anhydrous methanol (37.0 mmol, 426 eq.). This solution was degassed with a stream of argon for 30 minutes. After this time, the solvent mixture was transferred to a dry 20 mL vial containing neat **19** (36.2 mg, 86.9 μmol, 1.00 eq.). The resulting light yellow solution was tightly capped and heated to 110 °C in an oil bath for 1.5 hours. After this time, the vial was removed from the heating bath and allowed to cool slowly to room temperature. TLC (3:1 hexanes / EtOAc) showed the desired product at R_f = 0.45. The solvent was removed under reduced pressure, and the residue was purified by column chromatography (4:1 hexanes / EtOAc) to give **20** as a colorless oil (28.9 mg, 85%).

$[\alpha]^{20}_D$ = +70.1 (*c* 0.83, CH_2Cl_2); IR (neat) ν 2923, 2854, 2360, 2342, 1750, 1716, 1442, 1267 cm^{-1}; ^1H NMR (500 MHz, C_6D_6): δ 0.51 (1H, dd, *J* = 11.67 Hz, 23.31 Hz), 0.69 (1H, ddd, *J* = 2.39 Hz, 11.49 Hz, 22.55 Hz), 0.77 (1H, m), 0.81 (3H, d, *J* = 6.50 Hz), 1.06 (1H, m), 1.15 (1H, ddd, *J* = 3.53 Hz, 12.63 Hz, 25.35 Hz), 1.24 (1H, m), 1.61 (1H, dd, *J* = 2.05 Hz, 12.65 Hz), 1.68 (1H, d, *J* = 11.47 Hz), 1.77 (1H, ddd, *J* = 1.64 Hz, 11.43 Hz, 11.56 Hz), 1.94 (1H, ddd, *J* = 7.40 Hz, 11.41 Hz, 11.42 Hz), 2.38 (1H, d, *J* = 10.31 Hz), 2.99 (1H, m), 3.14 (1H, dd, *J* = 6.51 Hz, 11.29 Hz), 3.22 (1H, d, *J* = 15.20 Hz), 3.29 (1H, d, *J* = 14.98 Hz), 3.37 (3H, s), 3.39 (3H, s), 4.91 (1H, d, *J* = 16.93 Hz), 4.95 (1H, dd, *J* = 1.09 Hz, 9.93 Hz), 5.26 (1H, dd, *J* = 4.76 Hz, 7.08 Hz), 5.33 (1H, ddd, *J* = 3.31 Hz, 6.75 Hz, 9.50 Hz), 5.66 Hz (1H, ddd, *J* = 8.87 Hz, 9.90 Hz, 17.02 Hz), 5.77 (1H, d, *J* = 9.63 Hz); ^{13}C NMR (125 MHz, C_6D_6): δ 22.6, 29.7, 32.7, 36.1, 38.1, 43.4, 44.6, 45.4, 48.8, 49.2, 51.8, 51.8, 54.2, 57.2, 79.8, 116.8, 128.5, 129.3, 137.2, 155.9, 167.1, 201.9; HRMS (ESI+) calculated for $C_{22}H_{30}NaO_6$ ($[M+Na]^+$): 413.1940, found 413.1938.

References:

1. Crabtree, R. H., Morehouse, S. M. and Quirk, J.M. *Inorganic Syntheses*. **1986**, *24*, 173-176.
2. Marshall, J. and Garofalo, A., *J. Org. Chem.* **1996**, *61*, 8732-8738.
3. We found that commercial (methoxymethyl)triphenylphosphonium chloride contained excess triphenylphosphine as an impurity that was copolar with **11**. Washing the organic layer with 3% aqueous hydrogen peroxide converted the triphenylphosphine to triphenylphosphine oxide (as monitored by TLC), which was easily removed by column chromatography.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7.14
7.13
7.11
7.11
7.10
6.14
6.14
6.13
6.11
6.11
6.10
4.37
4.37
4.36
0.92
0.09
TBSO
O
OH
S1
1.00
0.99
2.00
9.17
6.01
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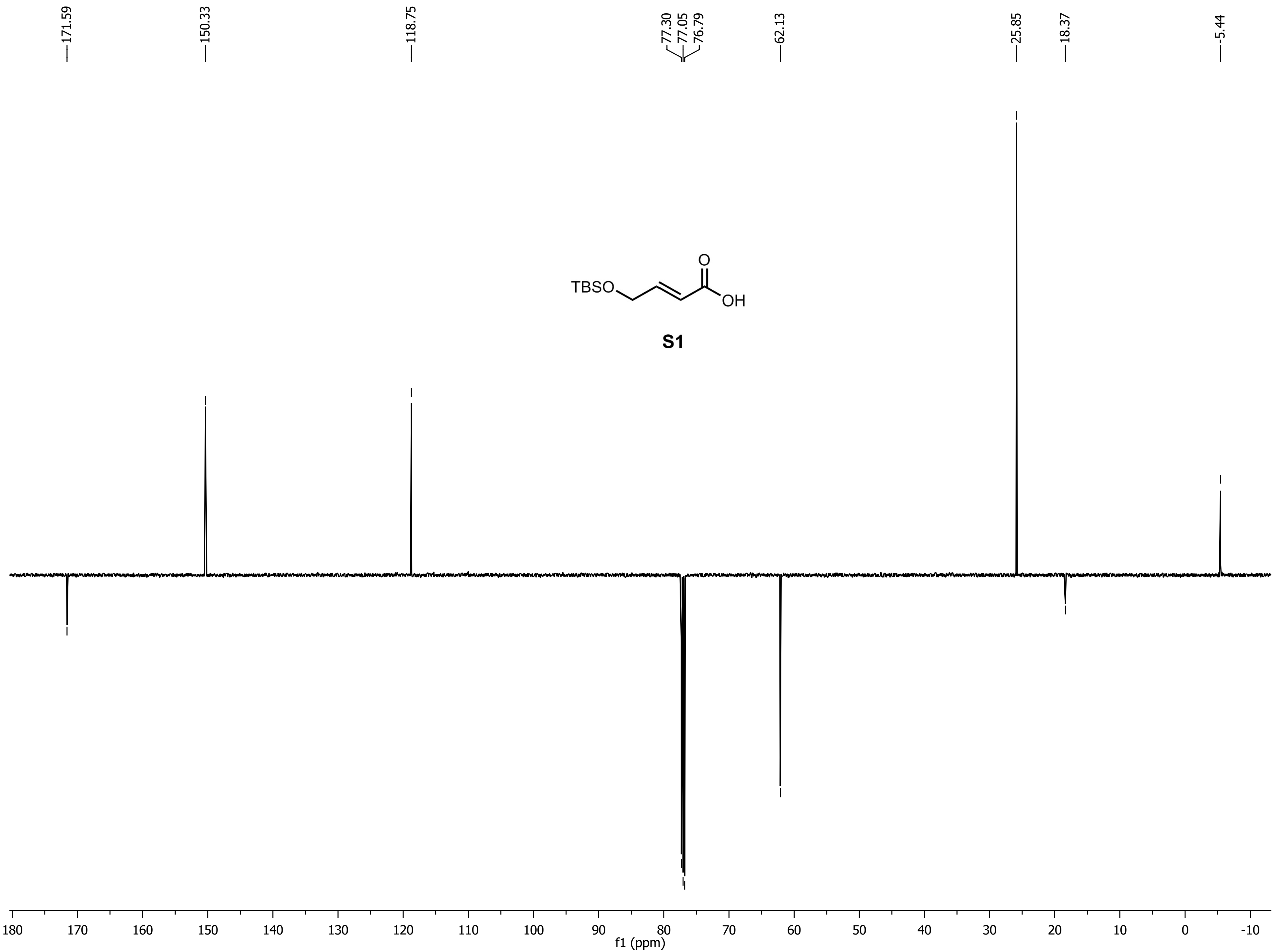
f1 (ppm)



171.59
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-5.44
TBSO
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120
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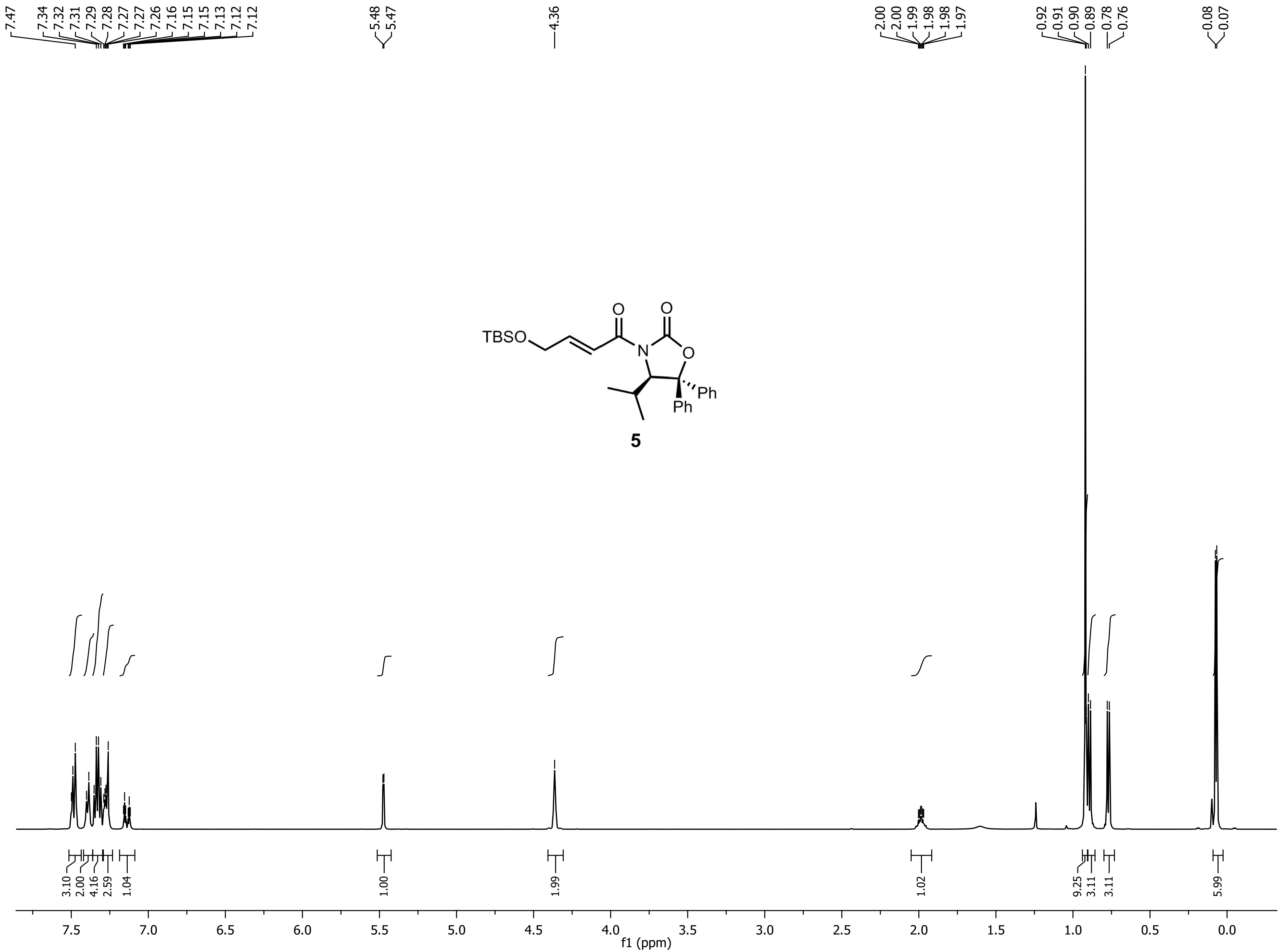
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)



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7.27
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7.16
7.15
7.15
7.13
7.12
7.12
5.48
5.47
4.36
2.00
2.00
1.99
1.98
1.98
1.97
0.92
0.91
0.90
0.89
0.78
0.76
0.08
0.07
TBSO
O
O
N
O
Ph
Ph
5
3.10
2.00
4.16
2.59
1.04
1.00
1.99
1.02
9.25
3.11
3.11
5.99
7.5
7.0
6.5
6.0
5.5
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3.0
2.5
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1.0
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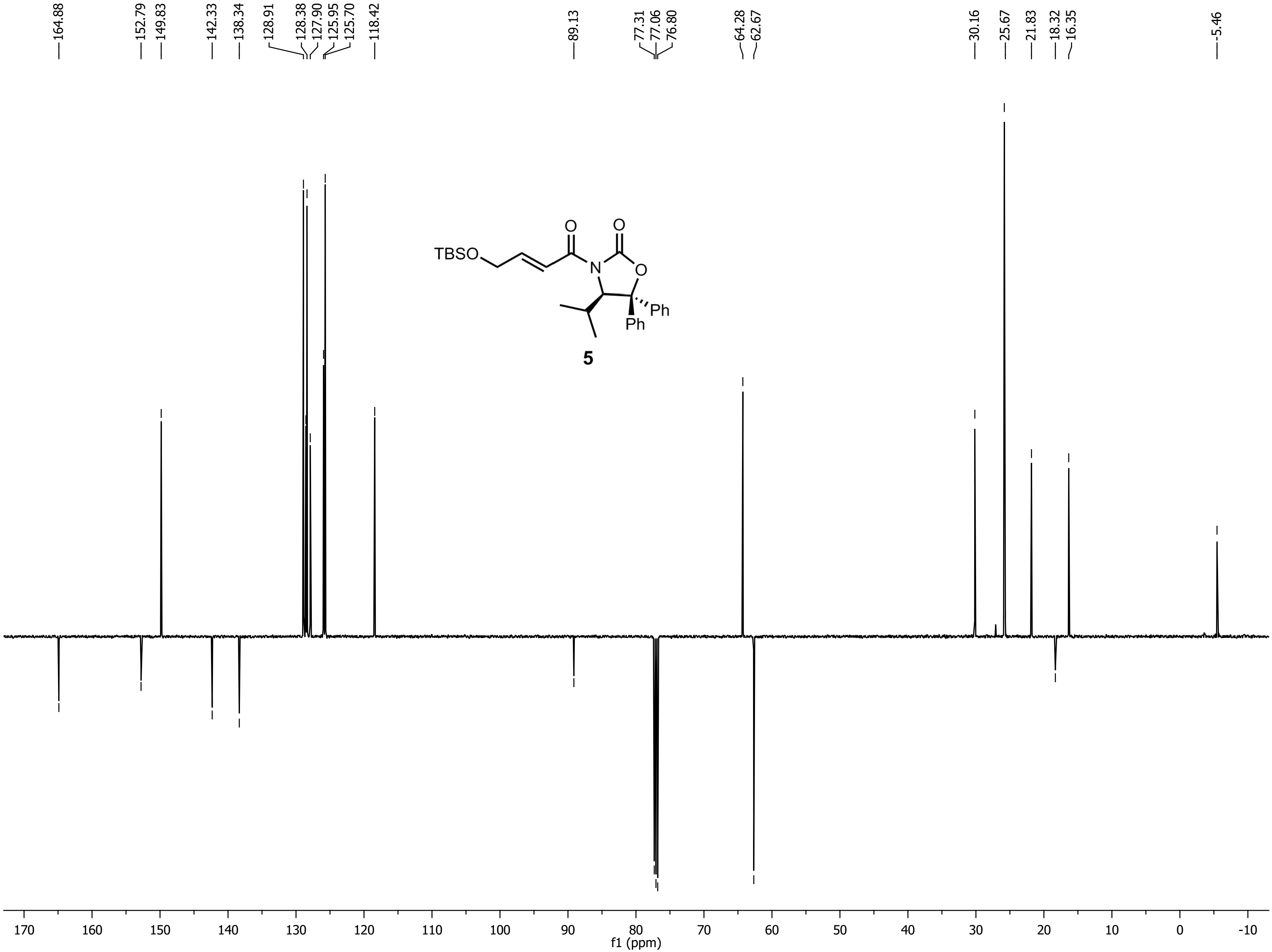
f1 (ppm)



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128.38
127.90
125.95
125.70
118.42
89.13
77.31
77.06
76.80
64.28
62.67
30.16
25.67
21.83
18.32
16.35
-5.46
TBSO
O
O
N
O
Ph
Ph
5
170
160
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140
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120
110
100
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80
70
60
50
40
30
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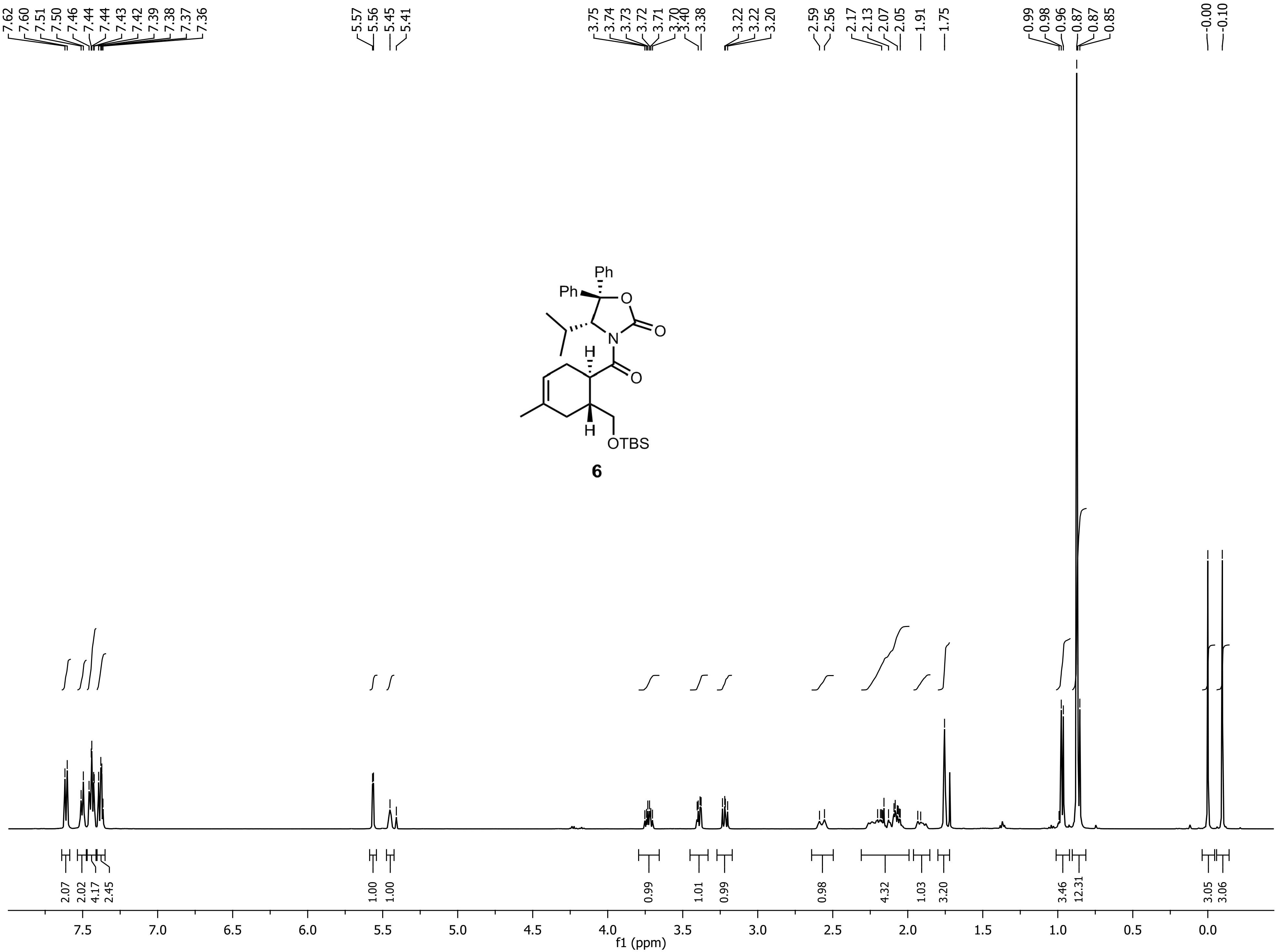
10
0
-10
f1 (ppm)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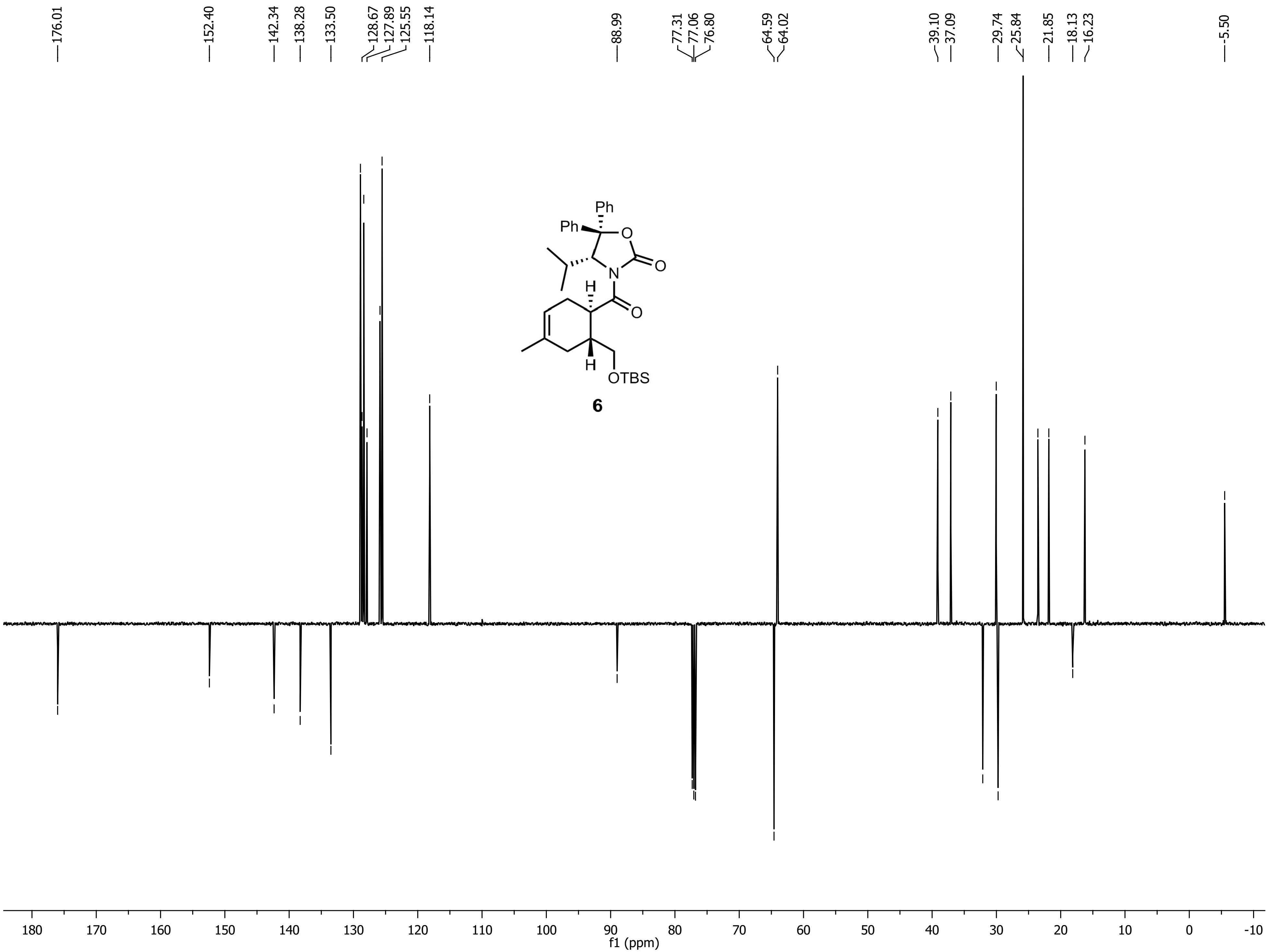
5.57 5.56 5.45 5.41
3.75 3.74 3.73 3.72 3.71 3.70 3.40 3.38
3.22 3.22 3.20
2.59 2.56
2.17 2.13 2.07 2.05
1.91
1.75
0.99 0.98 0.96 0.87 0.87 0.85
-0.00 -0.10
Ph
Ph
O
O
N
H
O
H
OTBS
6
2.07 2.02 4.17 2.45
1.00 1.00
0.99 1.01 0.99
0.98 4.32 1.03 3.20
3.46 12.31
3.05 3.06
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)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88.99
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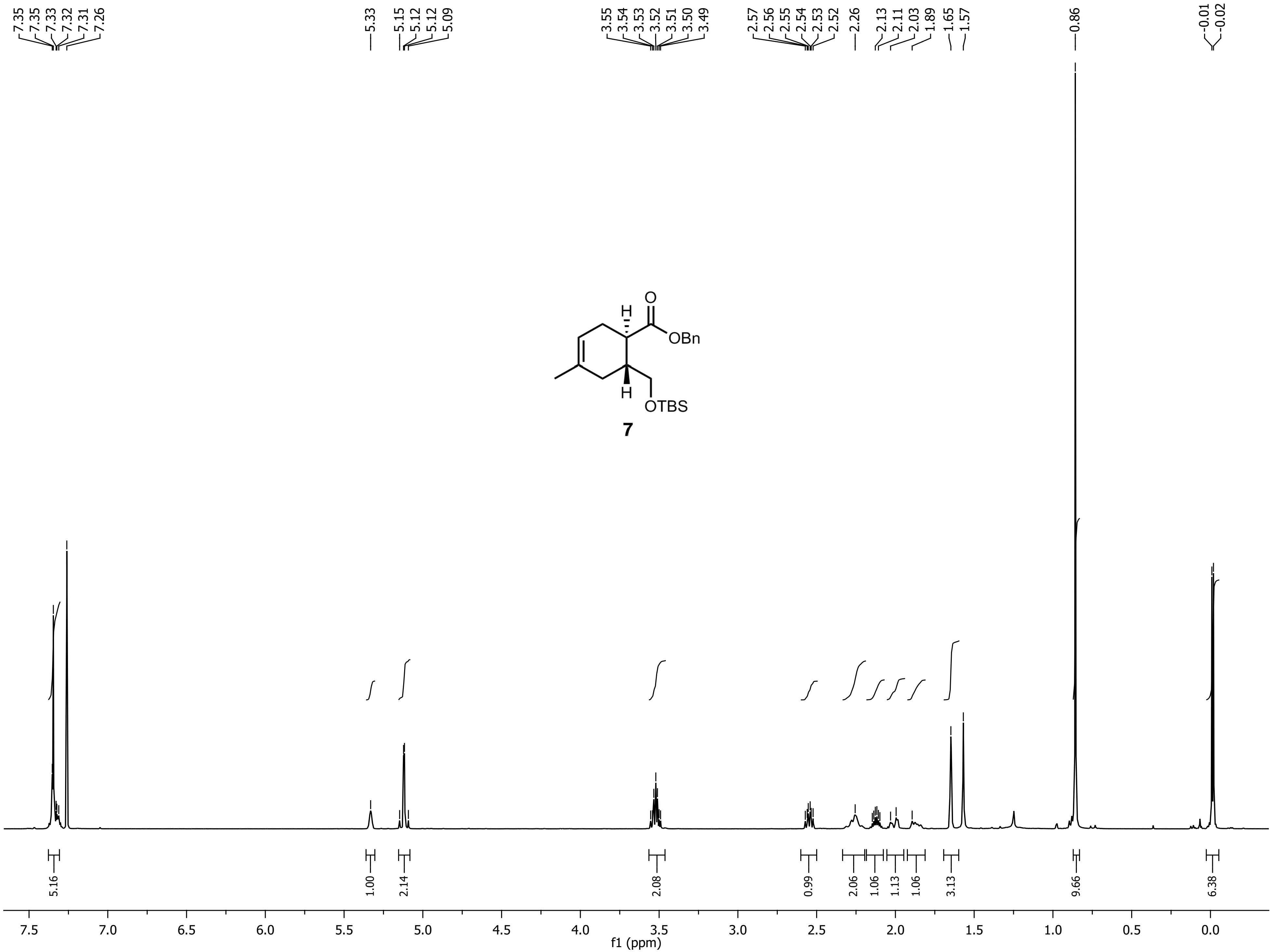
77.06
76.80
64.59
64.02
39.10
37.09
29.74
25.84
21.85
18.13
16.23
-5.50
Ph
Ph
O
O
N
H
O
H
OTBS
6
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)



7.35
7.35
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5.15
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5.12
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3.54
3.53
3.52
3.51
3.50
3.49
2.57
2.56
2.55
2.54
2.53
2.52
2.26
2.13
2.11
2.03
1.89
1.65
1.57
0.86
-0.01
-0.02
H
O
OBn
H
OTBS
7
5.16
1.00
2.14
2.08
0.99
2.06
1.06
1.13
1.06
3.13
9.66
6.38
7.5
7.0
6.5
6.0
5.5
5.0
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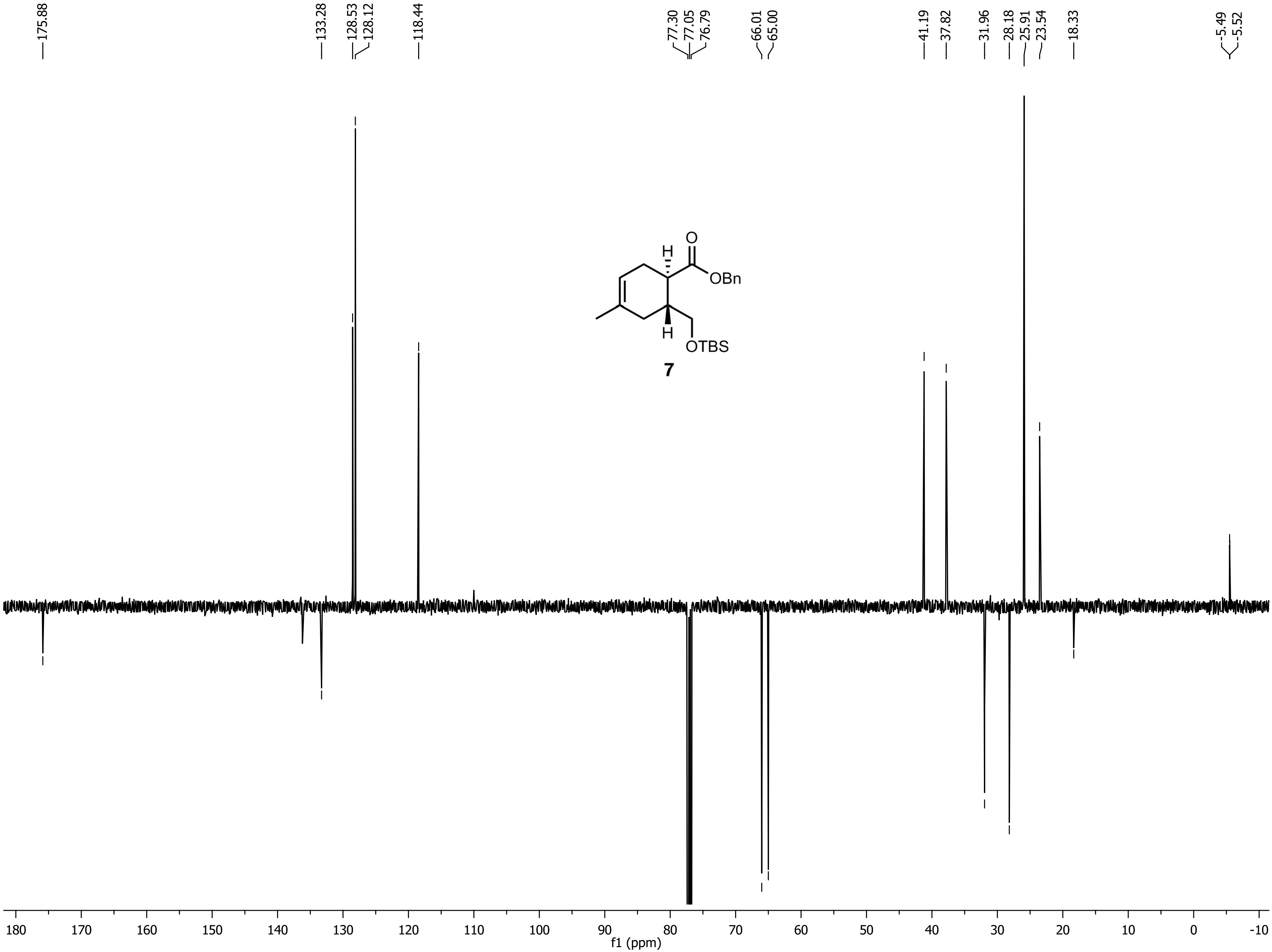
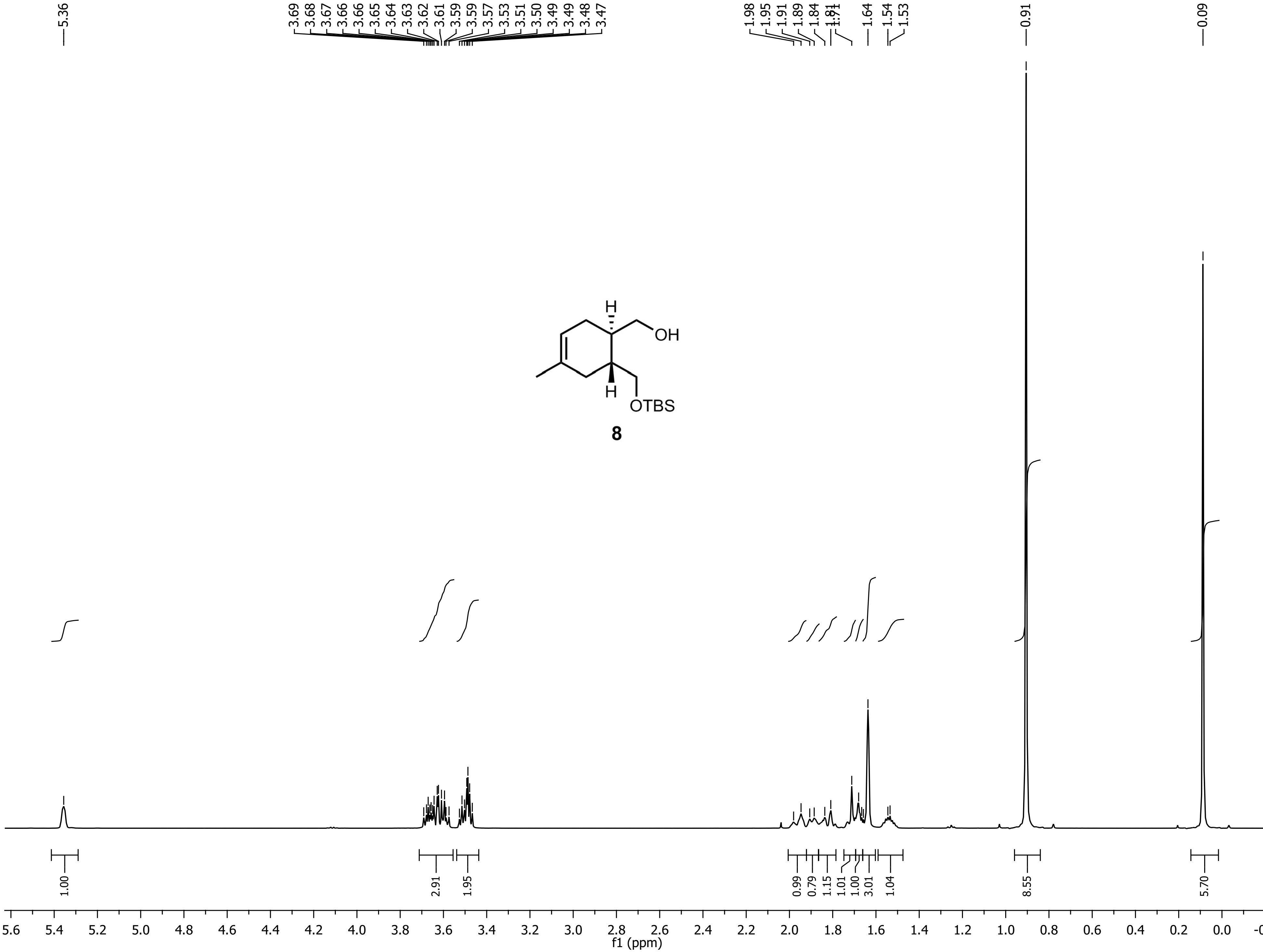
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)



175.88
133.28
128.53
128.12
118.44
77.30
77.05
76.79
66.01
65.00
41.19
37.82
31.96
28.18
25.91
23.54
18.33
-5.49
-5.52
O
H
OBn
H
OTBS
7
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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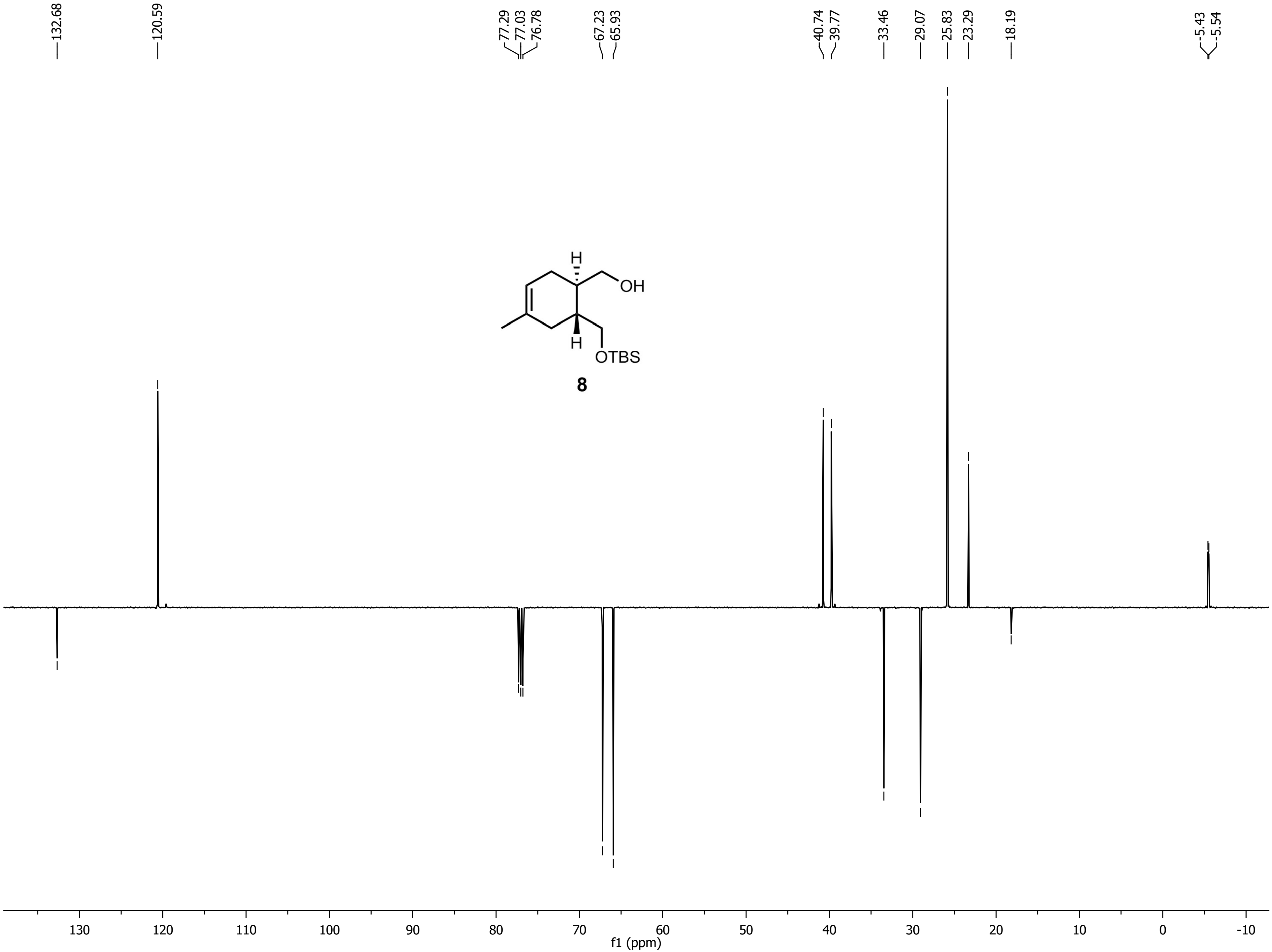
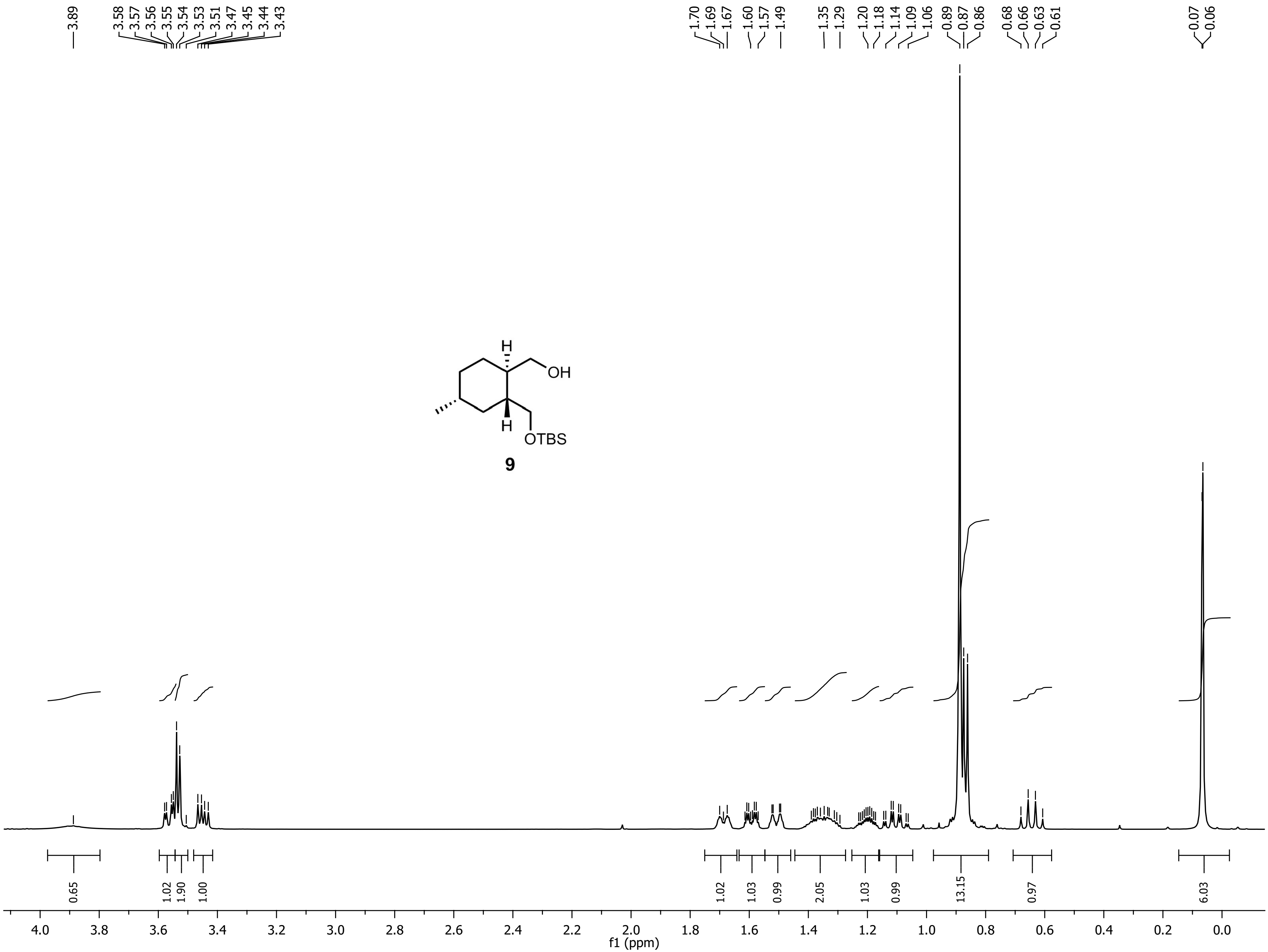
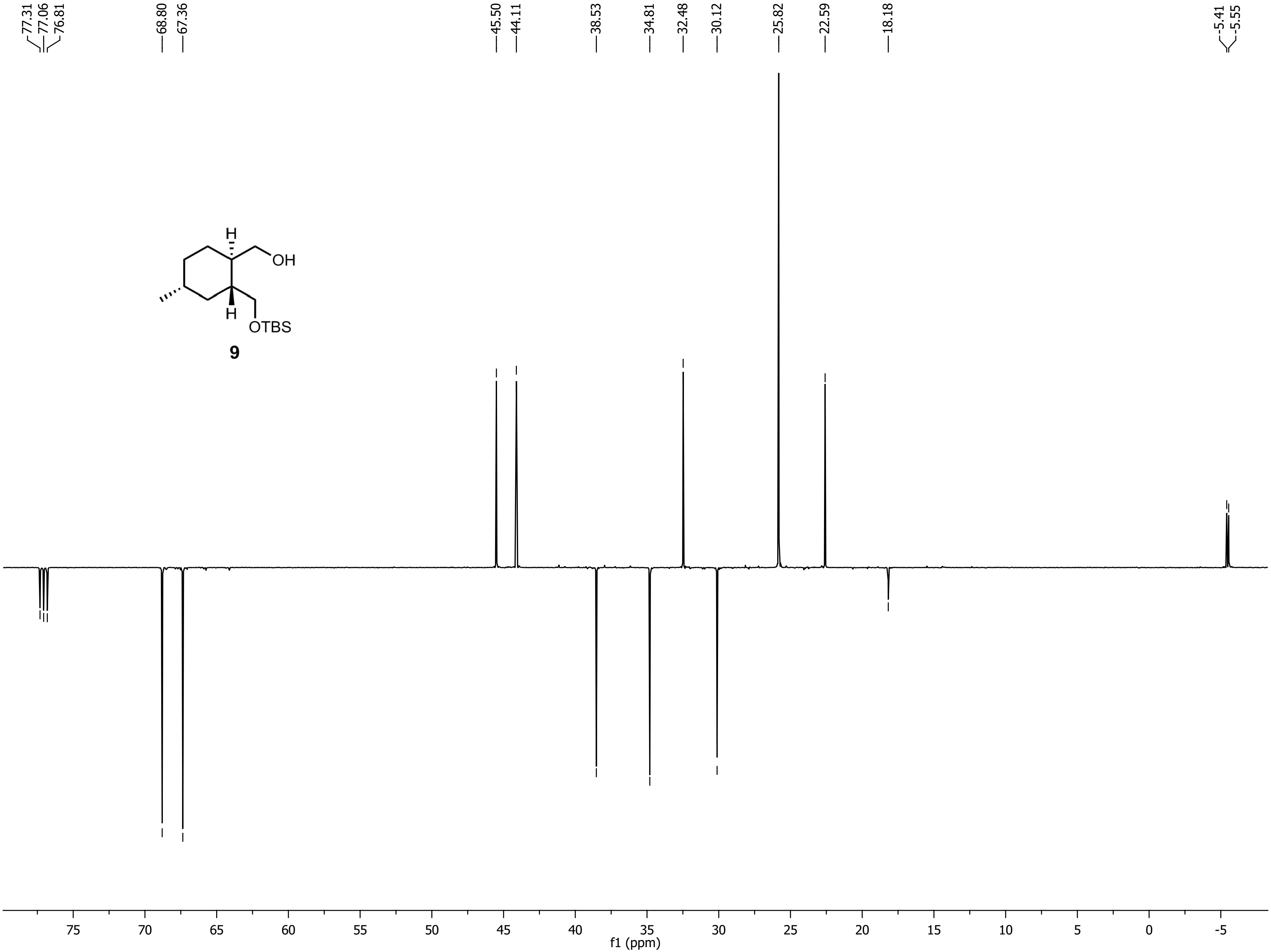
3.69 3.68 3.67 3.66 3.66 3.65 3.64 3.63 3.62 3.61 3.59 3.59 3.57 3.53 3.51 3.50 3.49 3.49 3.48 3.47
1.98 1.95 1.91 1.89 1.84 1.81 1.71 1.64 1.54 1.53
0.91
0.09
OH
OTBS
8
1.00
2.91
1.95
0.99
0.79
1.15
1.01
1.00
3.01
1.04
8.55
5.70
5.6 5.4 5.2 5.0 4.8 4.6 4.4 4.2 4.0 3.8 3.6 3.4 3.2 3.0 2.8 2.6 2.4 2.2 2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0.0 -0.2
f1 (ppm)



132.68
120.59
77.29
77.03
76.78
67.23
65.93
40.74
39.77
33.46
29.07
25.83
23.29
18.19
-5.43
-5.54
H
OH
H
OTBS
8
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)



3.89
3.58 3.57 3.56 3.55 3.54 3.53 3.51 3.47 3.45 3.44 3.43
1.70 1.69 1.67 1.60 1.57 1.49 1.35 1.29 1.20 1.18 1.14 1.09 1.06 0.89 0.87 0.86 0.68 0.66 0.63 0.61 0.07 0.06
H
OH
H
OTBS
9
0.65
1.02
1.90
1.00
1.02
1.03
0.99
2.05
1.03
0.99
13.15
0.97
6.03
4.0 3.8 3.6 3.4 3.2 3.0 2.8 2.6 2.4 2.2 2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0.0
f1 (ppm)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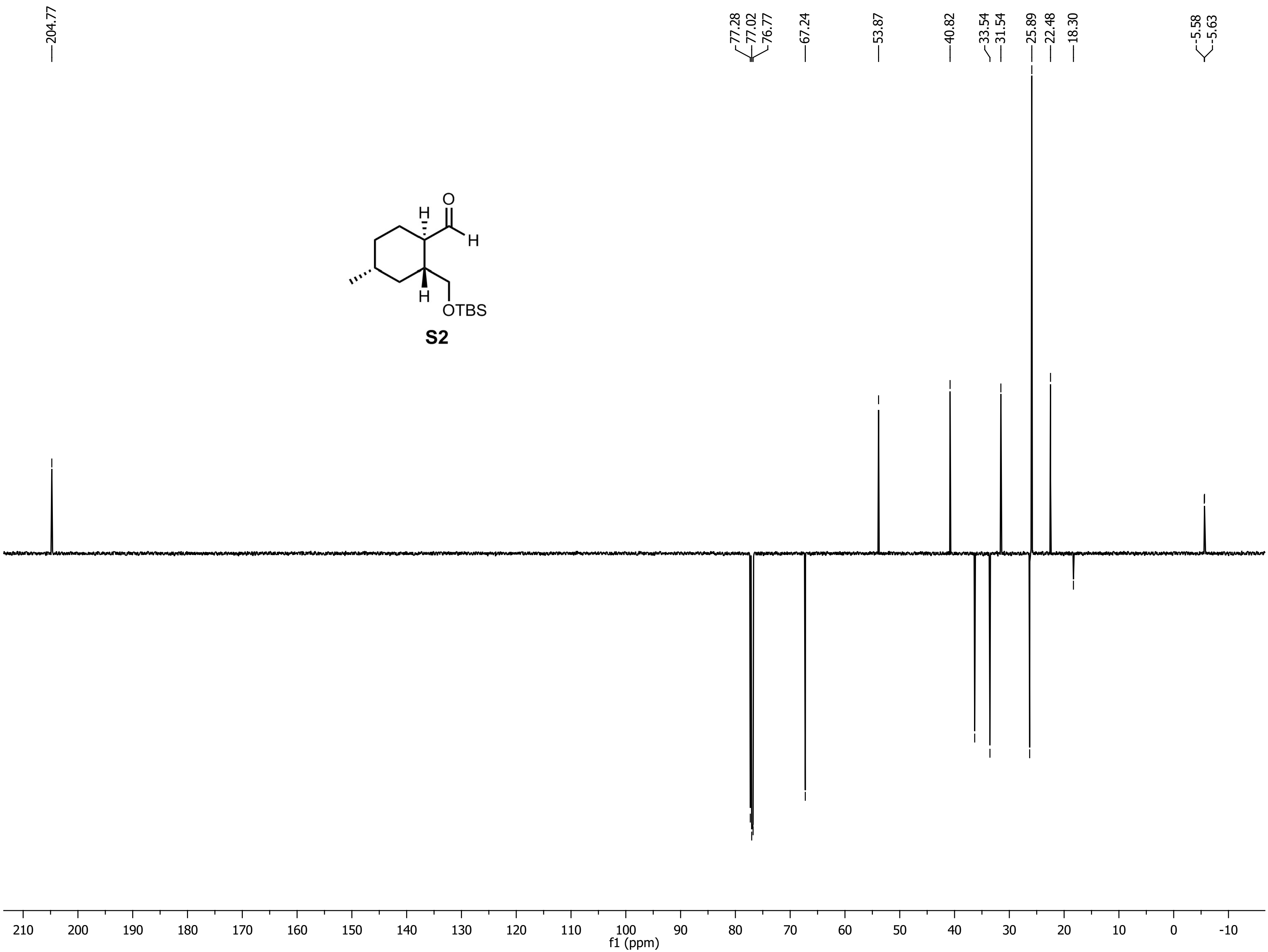
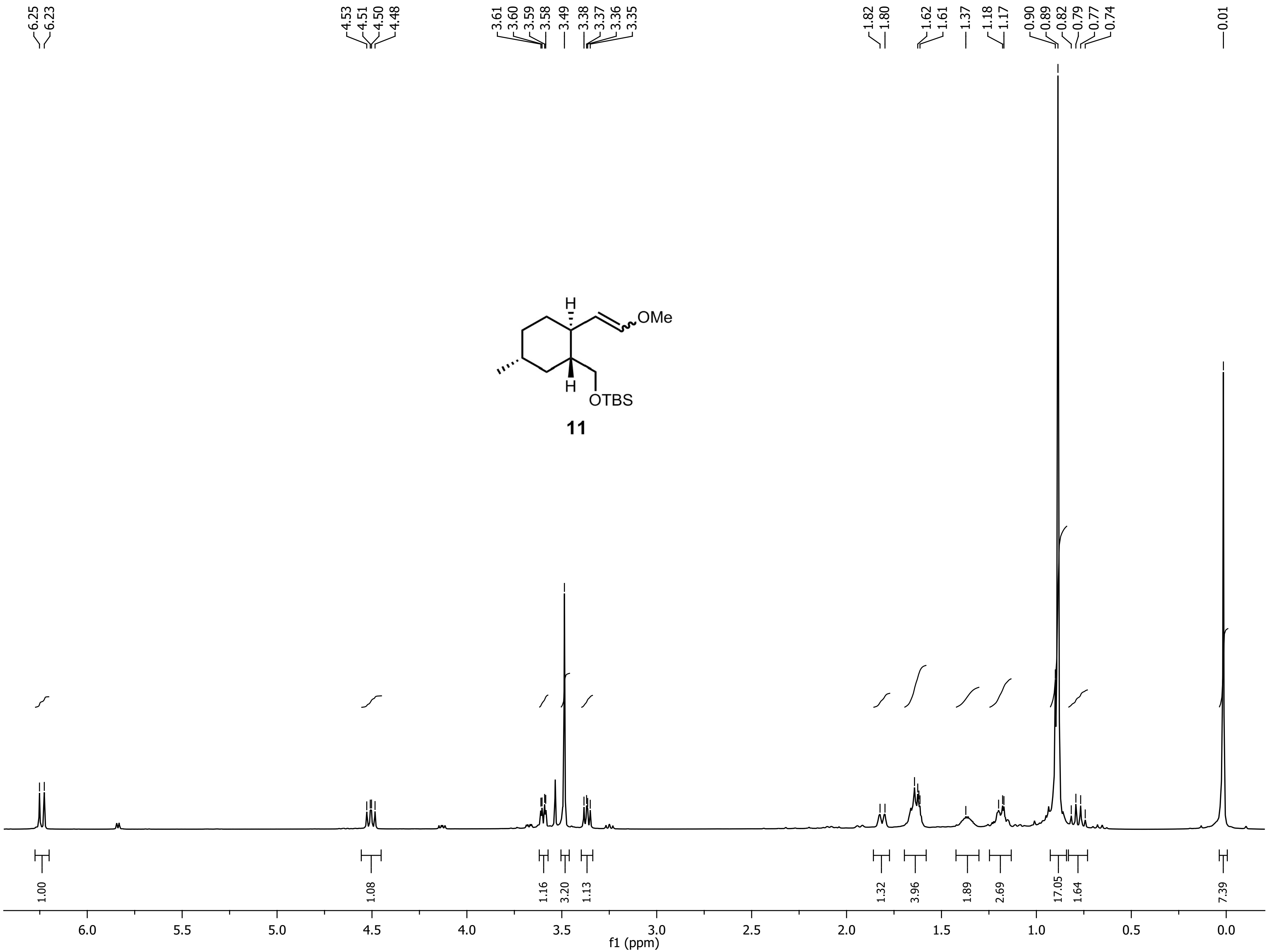
77.06
76.81
68.80
67.36
45.50
44.11
38.53
34.81
32.48
30.12
25.82
22.59
18.18
-5.41
-5.55
H
OH
H
OTBS
9
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
f1 (ppm)

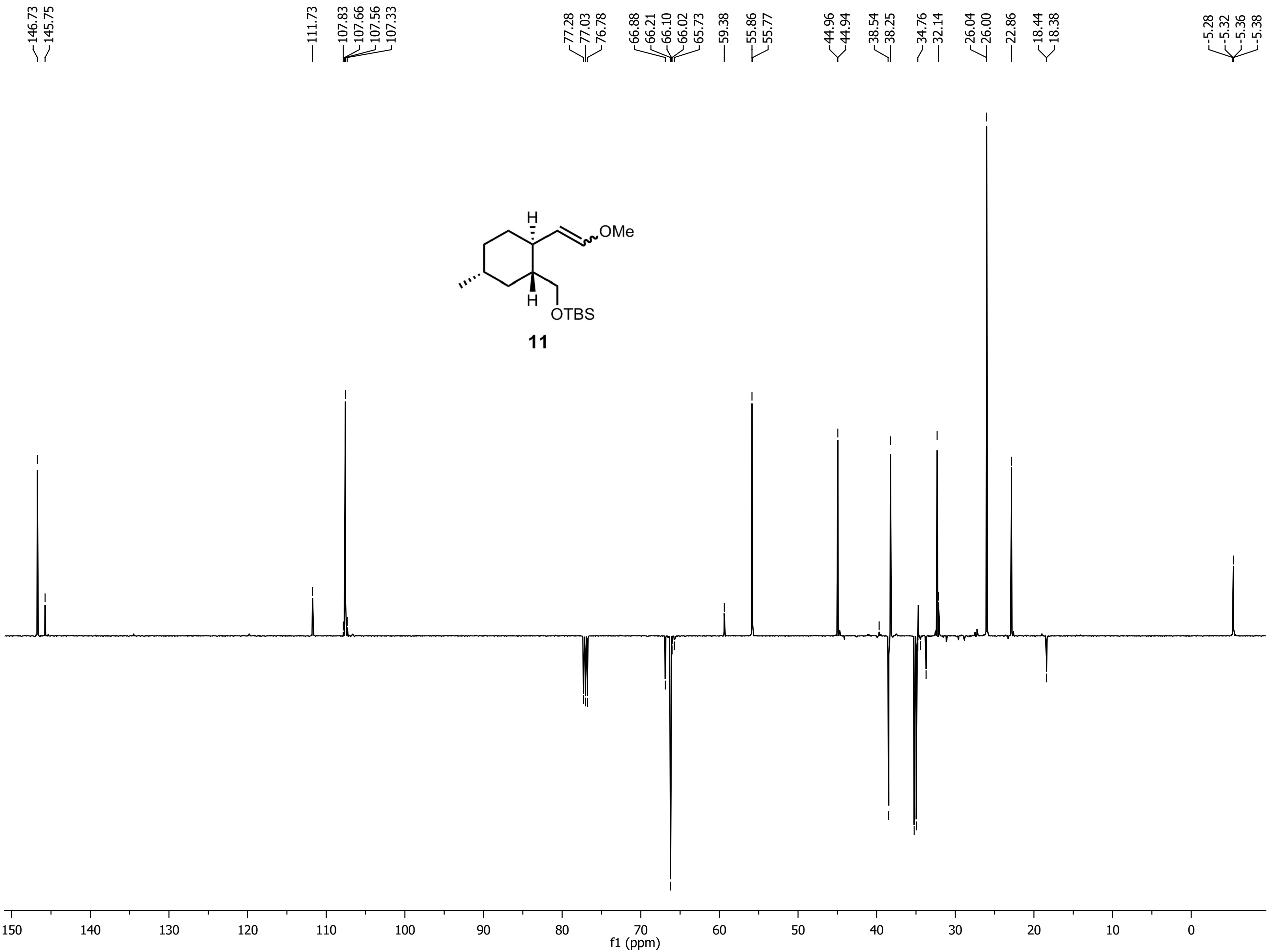

9.54
9.53
7.26
3.56
3.55
3.54
3.53
3.39
3.38
3.36
1.98
1.91
1.80
1.77
1.72
1.71
1.70
1.67
1.57
1.36
1.34
1.31
0.91
0.87
0.69
0.67
0.65
0.02
0.01
O
H
H
H
OTBS
S2
1.00
1.10
1.09
2.06
1.07
1.90
1.10
1.11
3.07
7.46
1.09
5.27
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)



204.77
77.28
77.02
76.77
67.24
53.87
40.82
33.54
31.54
25.89
22.48
18.30
-5.58
-5.63
O
H
H
H
OTBS
S2
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



6.25
6.23
4.53
4.51
4.50
4.48
3.61
3.60
3.59
3.58
3.49
3.38
3.37
3.36
3.35
1.82
1.80
1.62
1.61
1.37
1.18
1.17
0.90
0.89
0.82
0.79
0.77
0.74
0.01
OMe
H
H
OTBS
11
1.00
1.08
1.16
3.20
1.13
1.32
3.96
1.89
2.69
17.05
1.64
7.39
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)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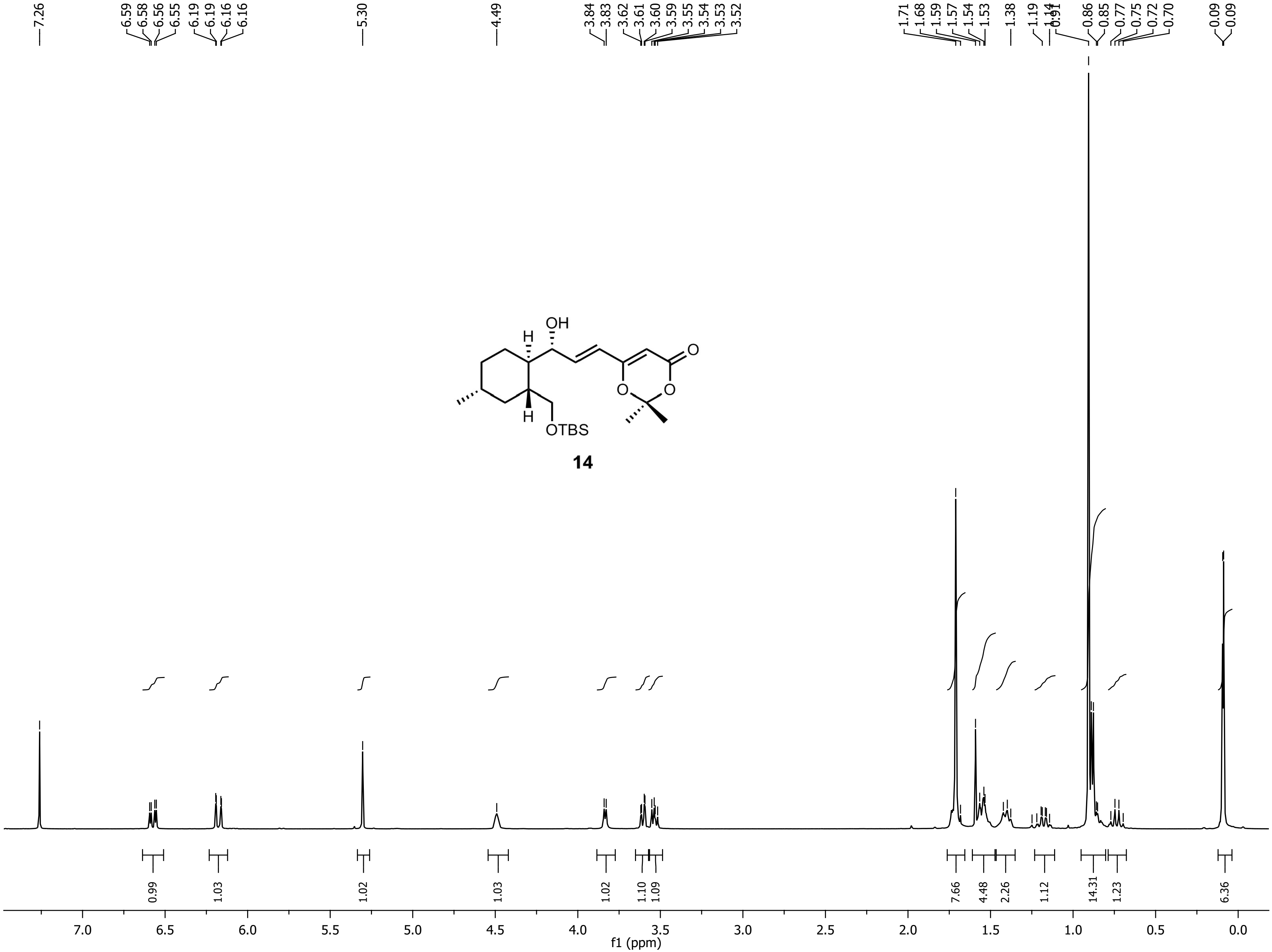
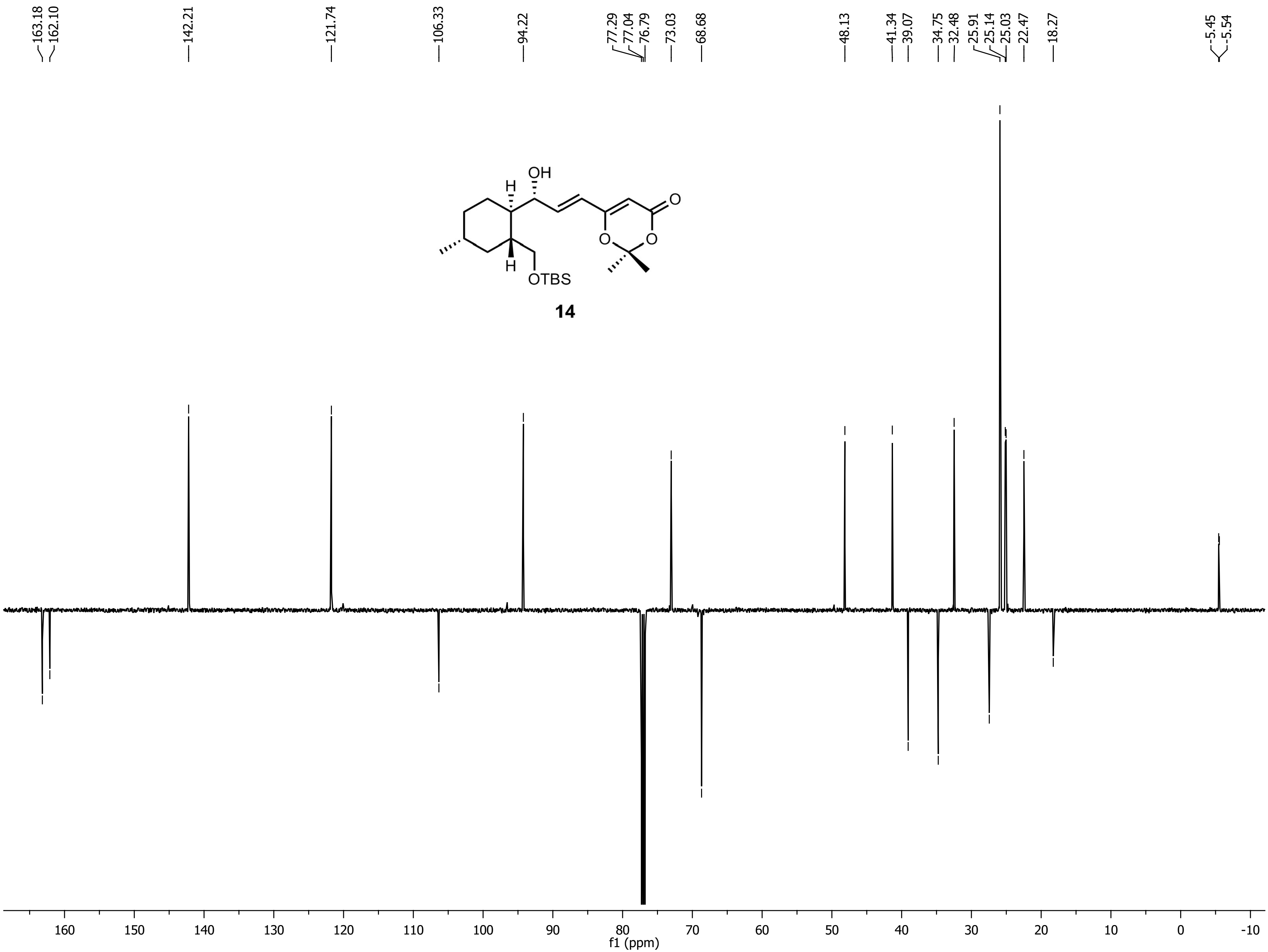
111.73
107.83
107.66
107.56
107.33
77.28
77.03
76.78
66.88
66.21
66.10
66.02
65.73
59.38
55.86
55.77
44.96
44.94
38.54
38.25
34.76
32.14
26.04
26.00
22.86
18.44
18.38
-5.28
-5.32
-5.36
-5.38
H
OMe
H
OTBS
11
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


7.26
6.59 6.58 6.56 6.55 6.19 6.19 6.16 6.16
5.30
4.49
3.84 3.83 3.62 3.61 3.60 3.59 3.55 3.54 3.53 3.52
1.71 1.68 1.59 1.57 1.54 1.53 1.38 1.19 1.14 0.91 0.86 0.85 0.77 0.75 0.72 0.70 0.09 0.09
OH
H
H
O
O
O
OTBS
14
0.99 1.03 1.02 1.03 1.02 1.10 1.09 7.66 4.48 2.26 1.12 14.31 1.23 6.36
7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)



163.18
162.10
142.21
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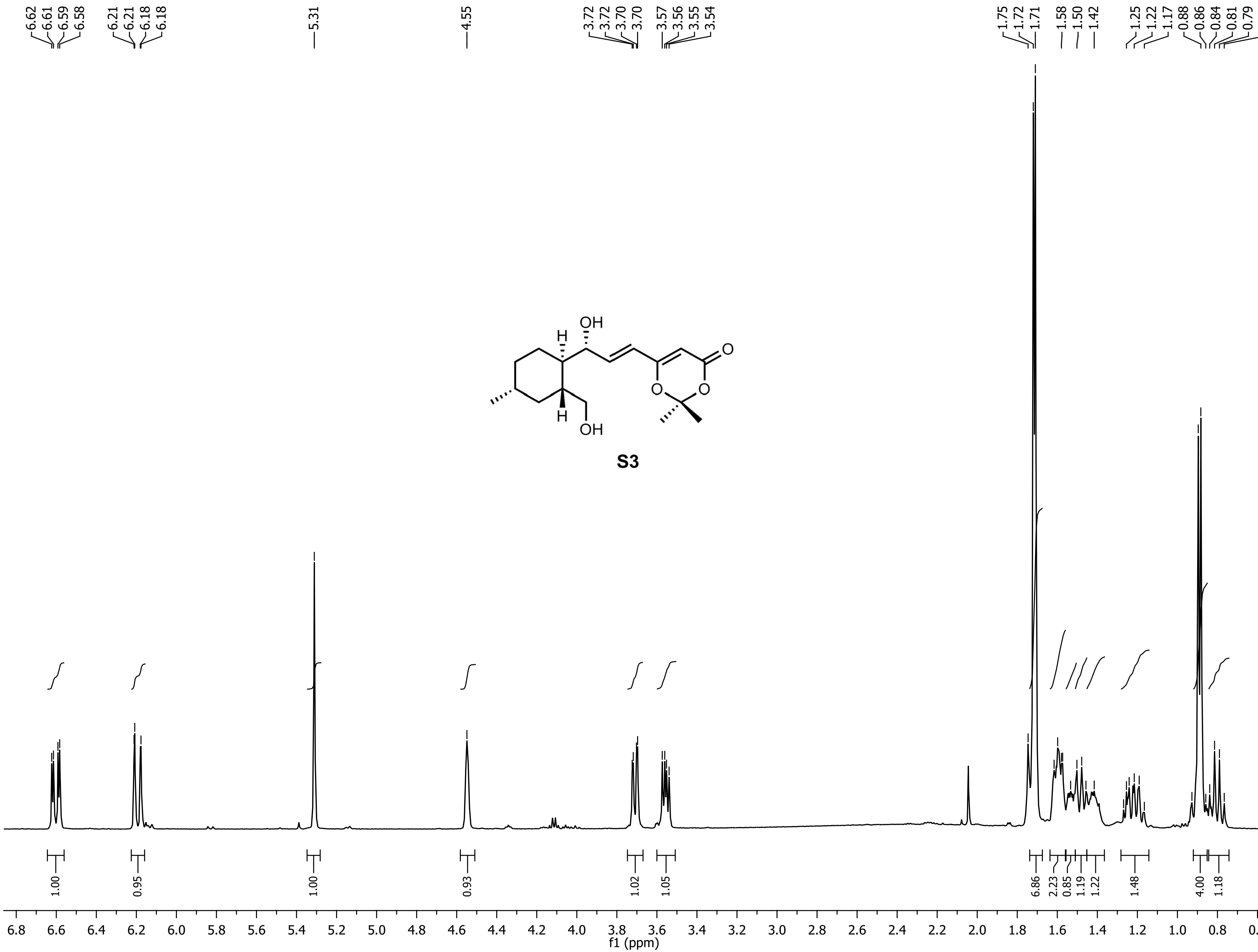
106.33
94.22
77.29
77.04
76.79
73.03
68.68
48.13
41.34
39.07
34.75
32.48
25.91
25.14
25.03
22.47
18.27
-5.45
-5.54
OH
H
H
O
O
O
OTBS
14
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)



6.62
6.61
6.59
6.58
6.21
6.21
6.18
6.18
5.31
4.55
3.72
3.72
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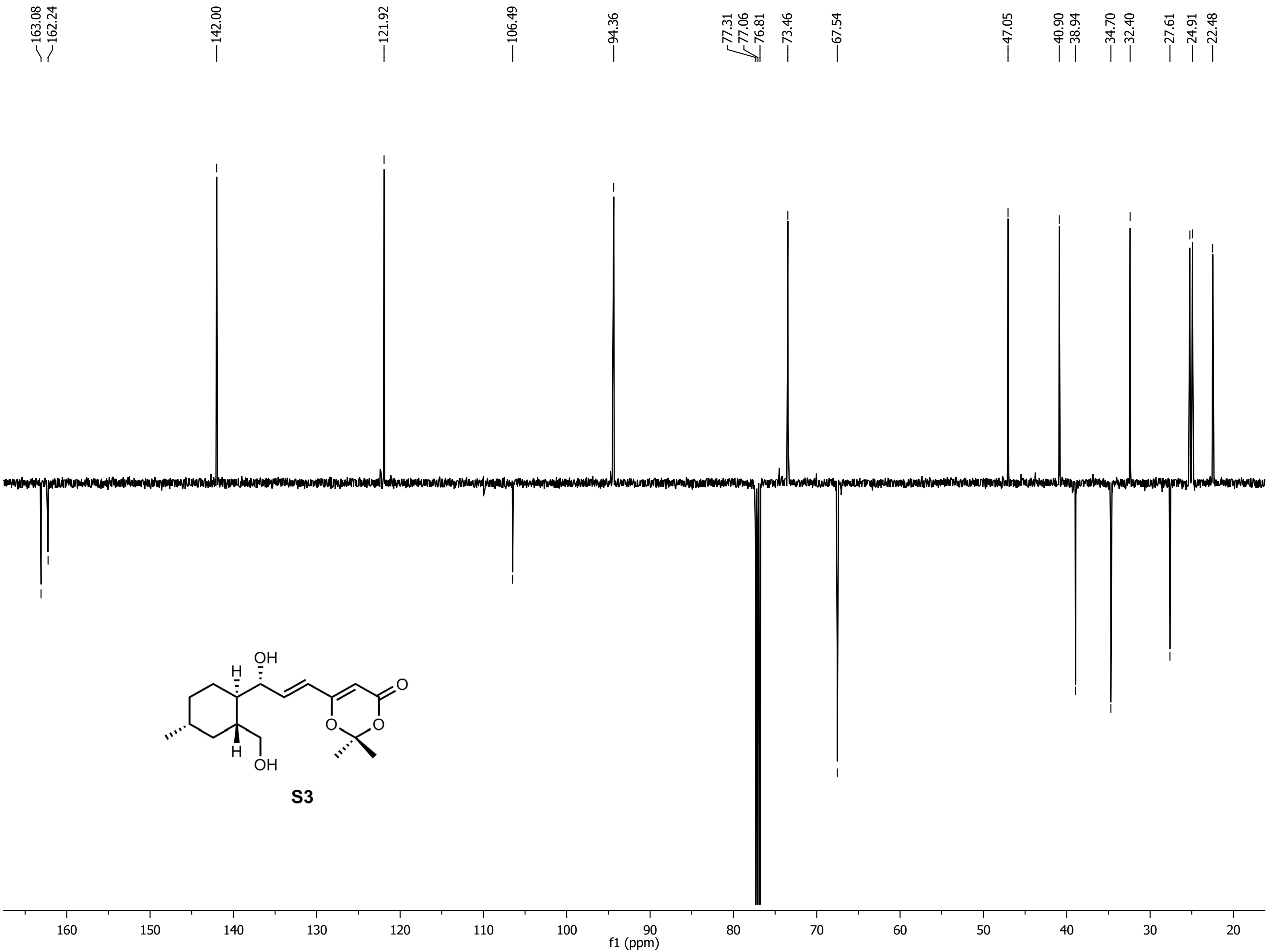
3.70
3.57
3.56
3.55
3.54
1.75
1.72
1.71
1.58
1.50
1.42
1.25
1.22
1.17
0.88
0.86
0.84
0.81
0.79
0.77
OH
H
O
O
O
H
OH
S3
1.00
0.95
1.00
0.93
1.02
1.05
6.86
2.23
0.85
1.19
1.22
1.48
4.00
1.18
6.8 6.6 6.4 6.2 6.0 5.8 5.6 5.4 5.2 5.0 4.8 4.6 4.4 4.2 4.0 3.8 3.6 3.4 3.2 3.0 2.8 2.6 2.4 2.2 2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6
f1 (ppm)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94.36
77.31
77.06
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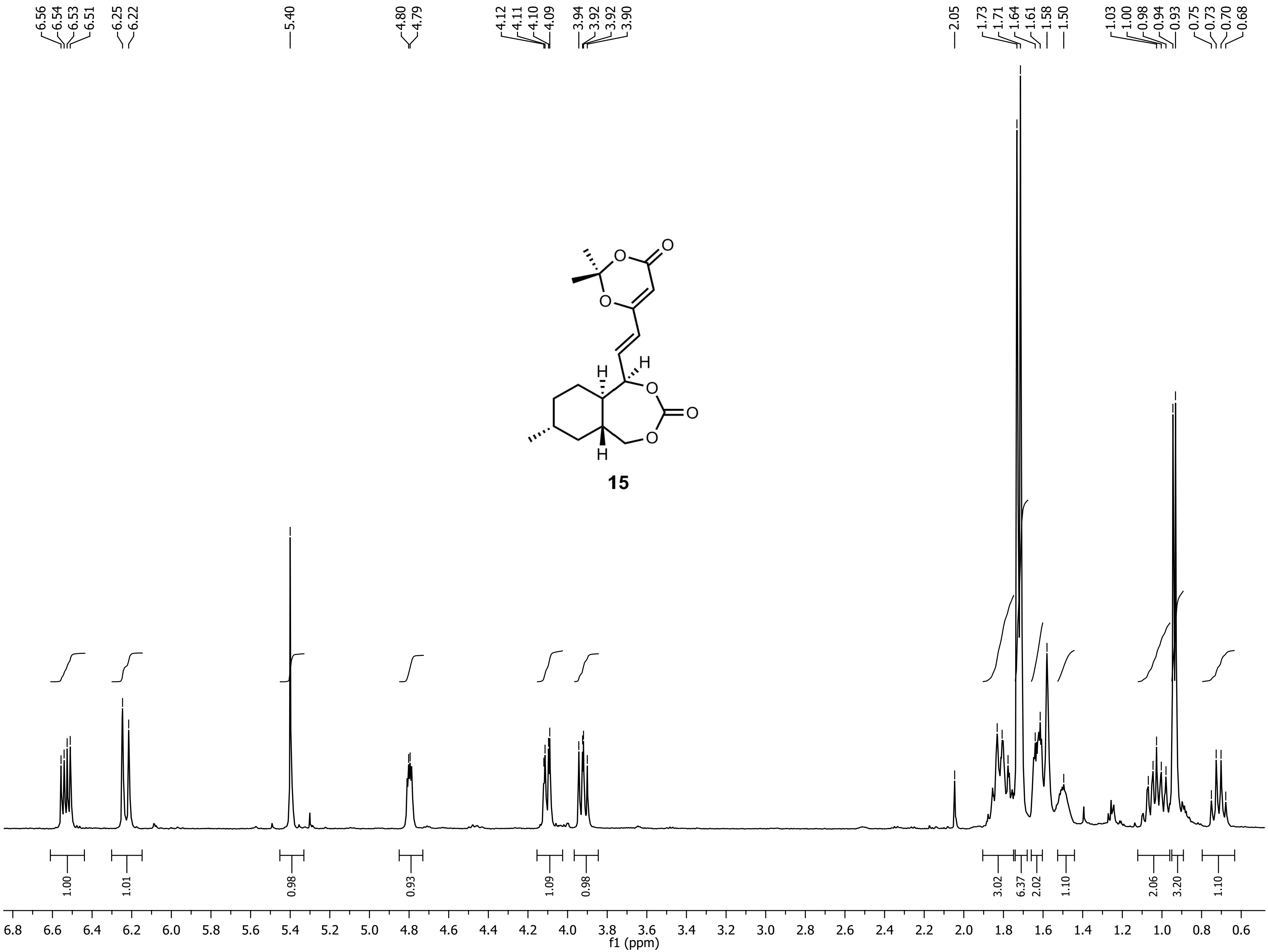
73.46
67.54
47.05
40.90
38.94
34.70
32.40
27.61
24.91
22.48
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
f1 (ppm)
OH
H
O
O
O
H
OH

S3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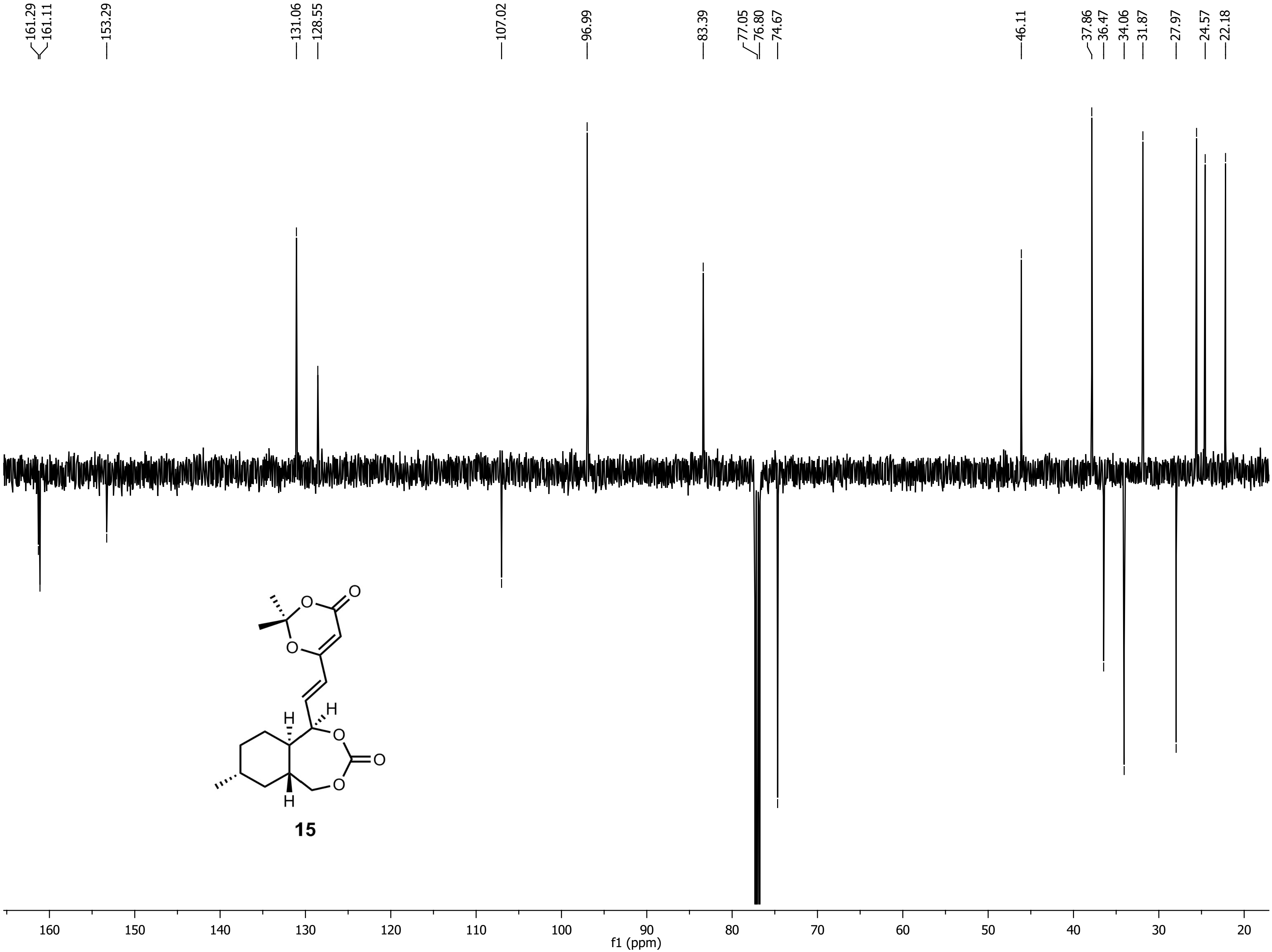
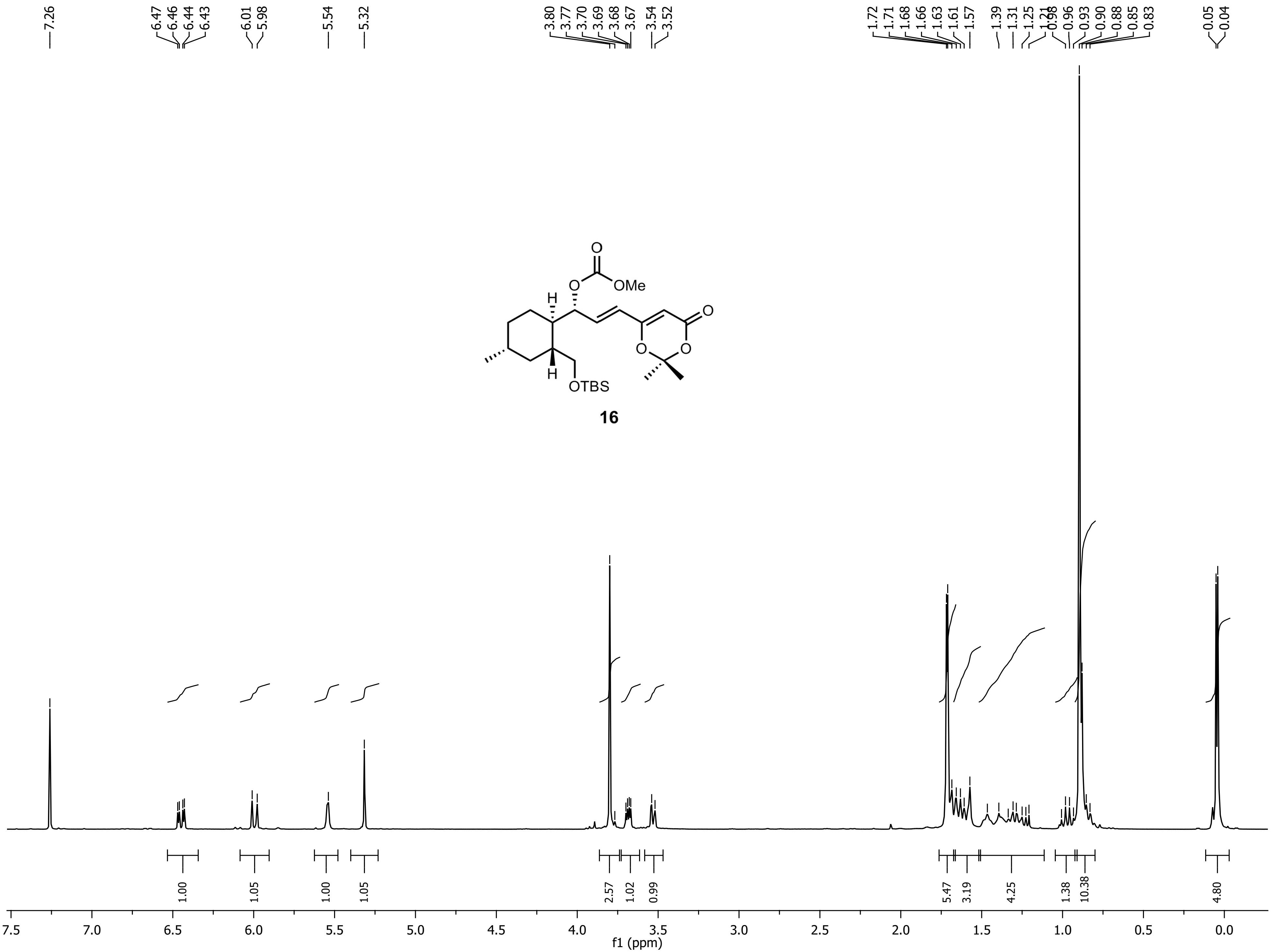
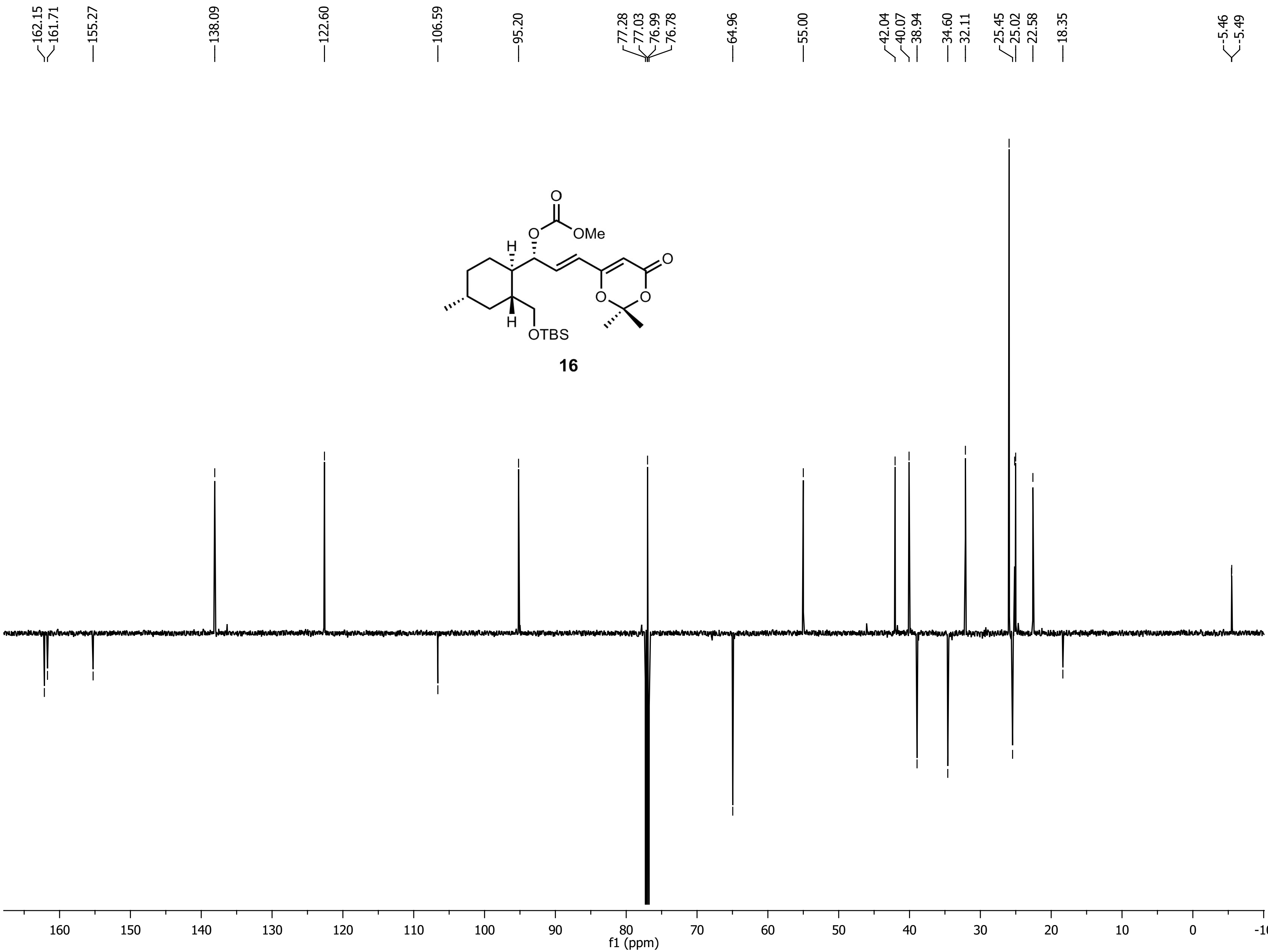
6.51
6.25
6.22
5.40
4.80
4.79
4.12
4.11
4.10
4.09
3.94
3.92
3.92
3.90
2.05
1.73
1.71
1.64
1.61
1.58
1.50
1.03
1.00
0.98
0.94
0.93
0.75
0.73
0.70
0.68
O
O
O
O
O
O
O
H
H
H
15
1.00
1.01
0.98
0.93
1.09
0.98
3.02
6.37
2.02
1.10
2.06
3.20
1.10
6.8 6.6 6.4 6.2 6.0 5.8 5.6 5.4 5.2 5.0 4.8 4.6 4.4 4.2 4.0 3.8 3.6 3.4 3.2 3.0 2.8 2.6 2.4 2.2 2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6
f1 (ppm)



161.29
161.11
153.29
131.06
128.55
107.02
96.99
83.39
77.05
76.80
74.67
46.11
37.86
36.47
34.06
31.87
27.97
24.57
22.18
160 150 140 130 120 110 100 90 80 70 60 50 40 30 20
f1 (ppm)
15



7.26
6.47
6.46
6.44
6.43
6.01
5.98
5.54
5.32
3.80
3.77
3.70
3.69
3.68
3.67
3.54
3.52
1.72
1.71
1.68
1.66
1.63
1.61
1.57
1.39
1.31
1.25
1.21
0.98
0.96
0.93
0.90
0.88
0.85
0.83
0.05
0.04
O
OMe
H
O
O
O
O
H
OTBS
16
1.00
1.05
1.00
1.05
2.57
1.02
0.99
5.47
3.19
4.25
1.38
10.38
4.80
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)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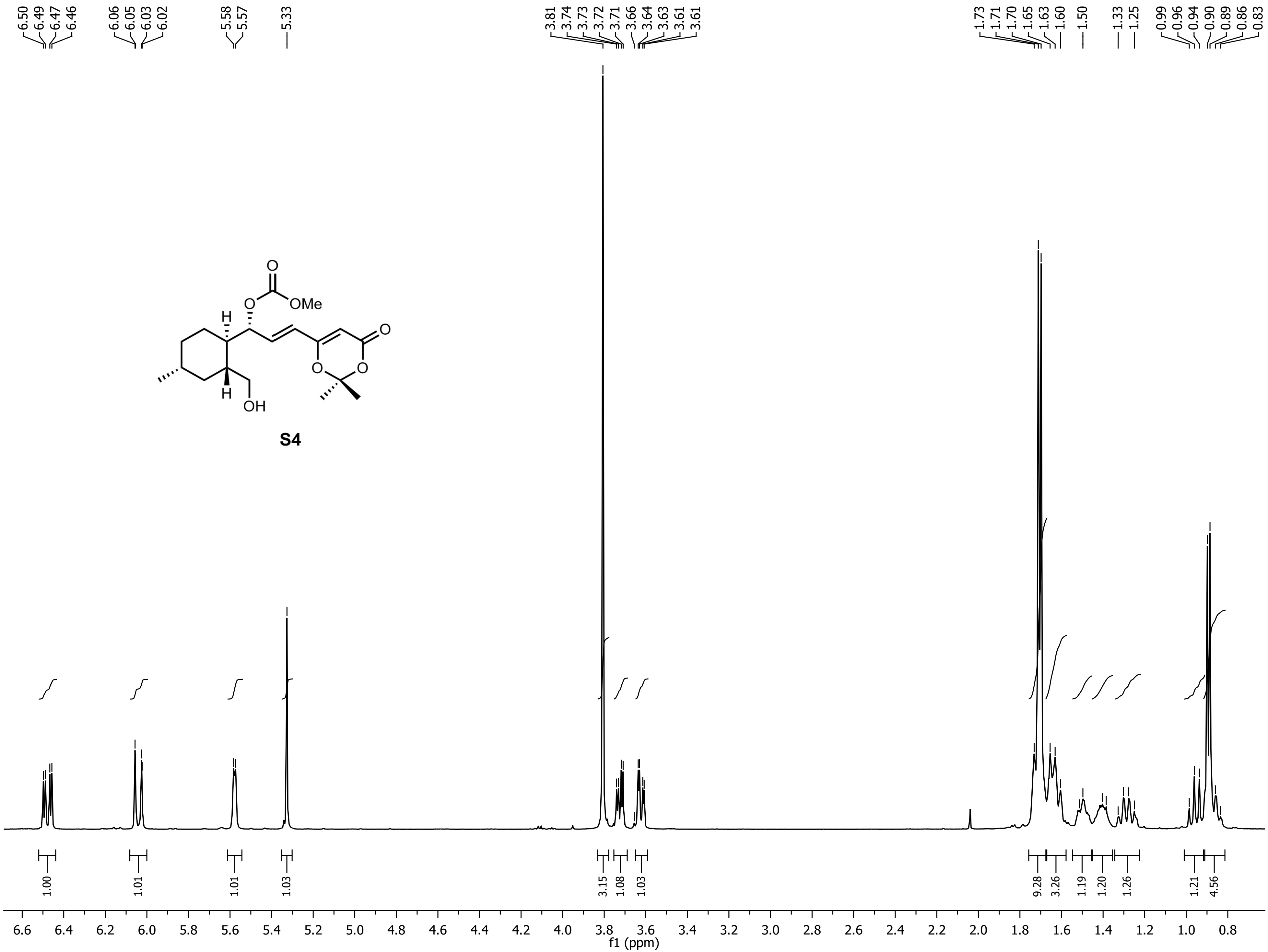
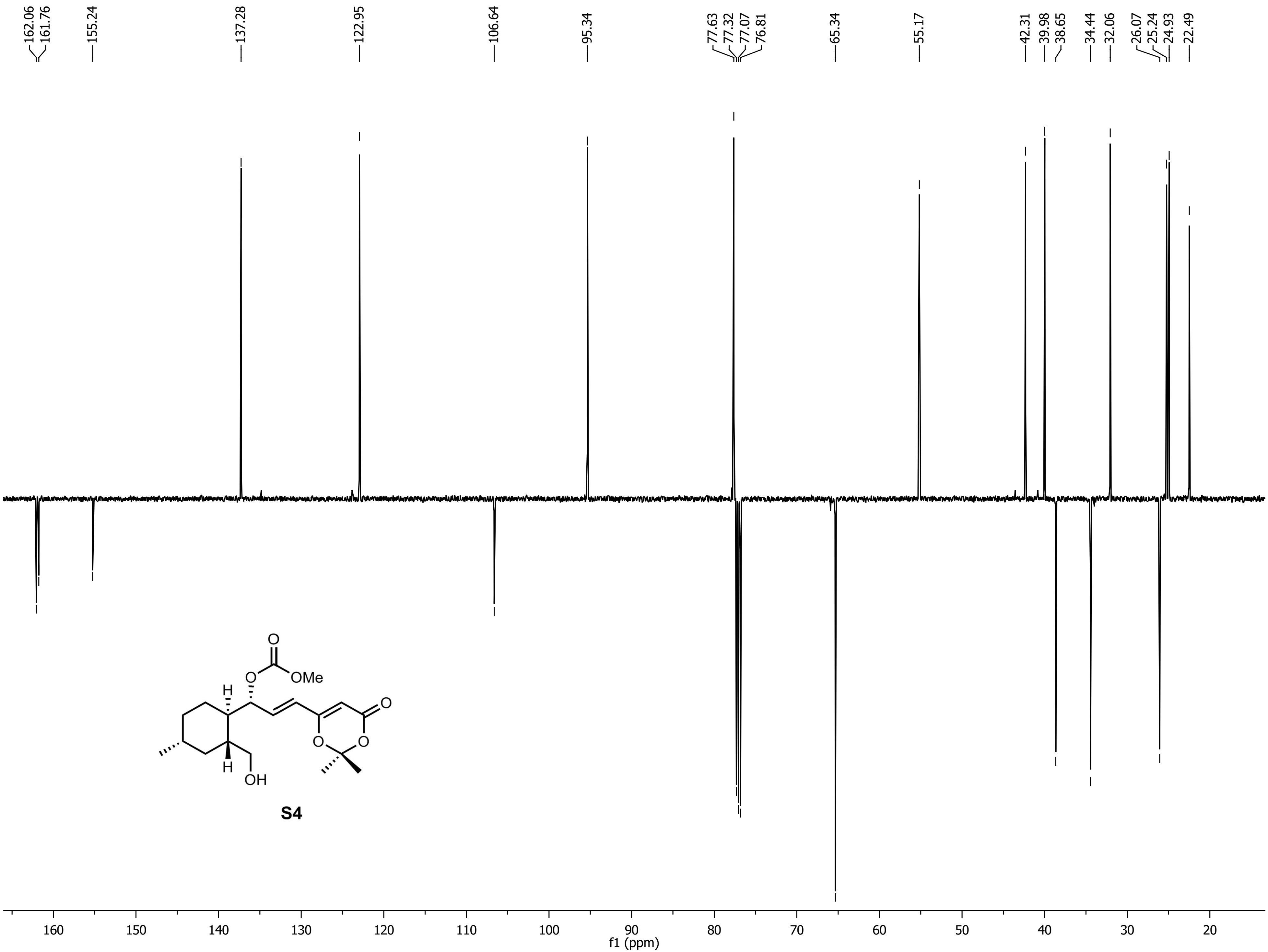
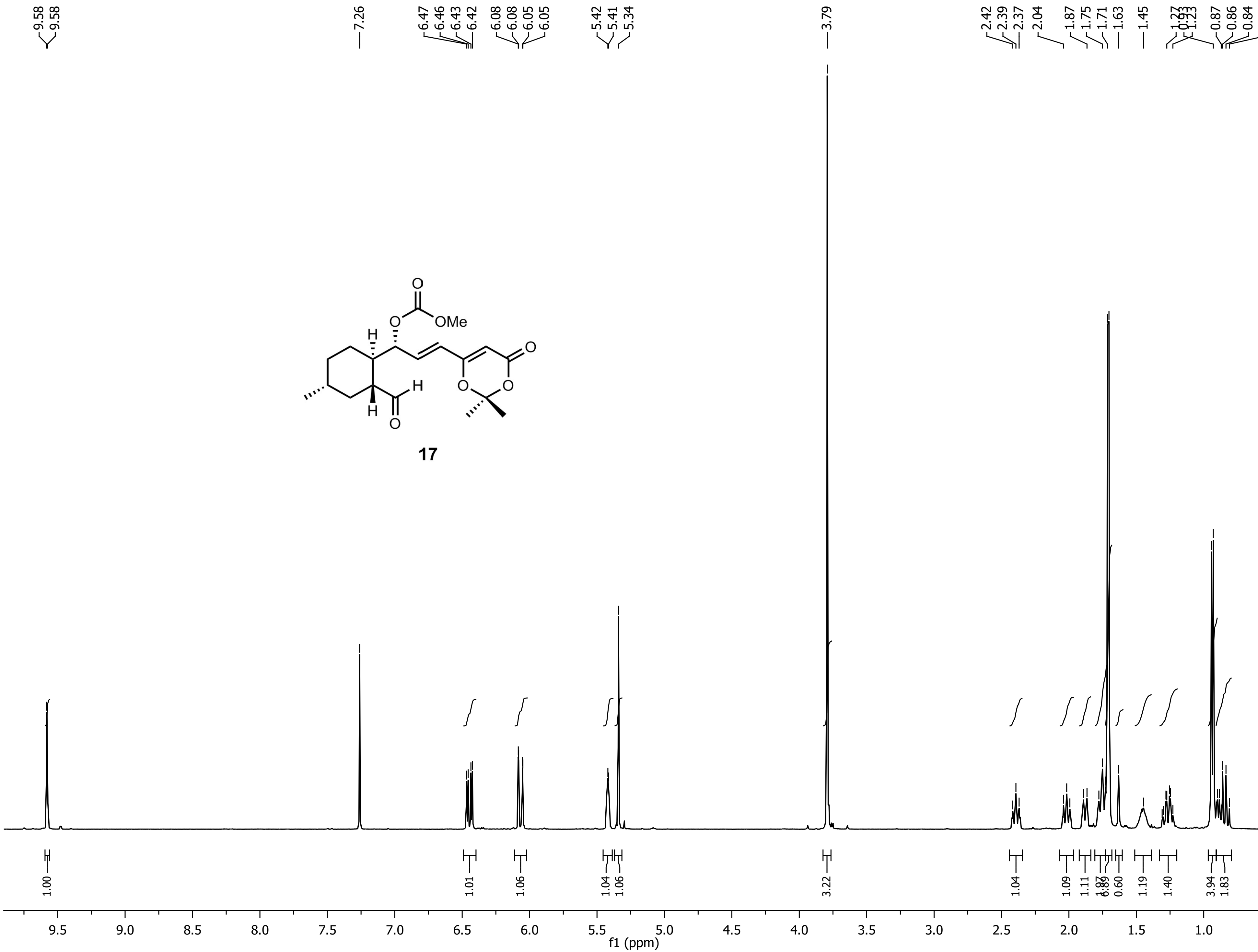
106.59
95.20
77.28
77.03
76.99
76.78
64.96
55.00
42.04
40.07
38.94
34.60
32.11
25.45
25.02
22.58
18.35
-5.46
-5.49
O
OMe
H
O
OTBS
16
f1 (ppm)


6.50 6.49 6.47 6.46
6.06 6.05 6.03 6.02
5.58 5.57
5.33
3.81 3.74 3.73 3.72 3.71 3.66 3.64 3.63 3.61 3.61
1.73 1.71 1.70 1.65 1.63 1.60
1.50
1.33 1.25
0.99 0.96 0.94 0.90 0.89 0.86 0.83
O
OMe
H
O
H
OH
O
O
O
S4
1.00
1.01
1.01
1.03
3.15
1.08
1.03
9.28
3.26
1.19
1.20
1.26
1.21
4.56
6.6 6.4 6.2 6.0 5.8 5.6 5.4 5.2 5.0 4.8 4.6 4.4 4.2 4.0 3.8 3.6 3.4 3.2 3.0 2.8 2.6 2.4 2.2 2.0 1.8 1.6 1.4 1.2 1.0 0.8
f1 (ppm)

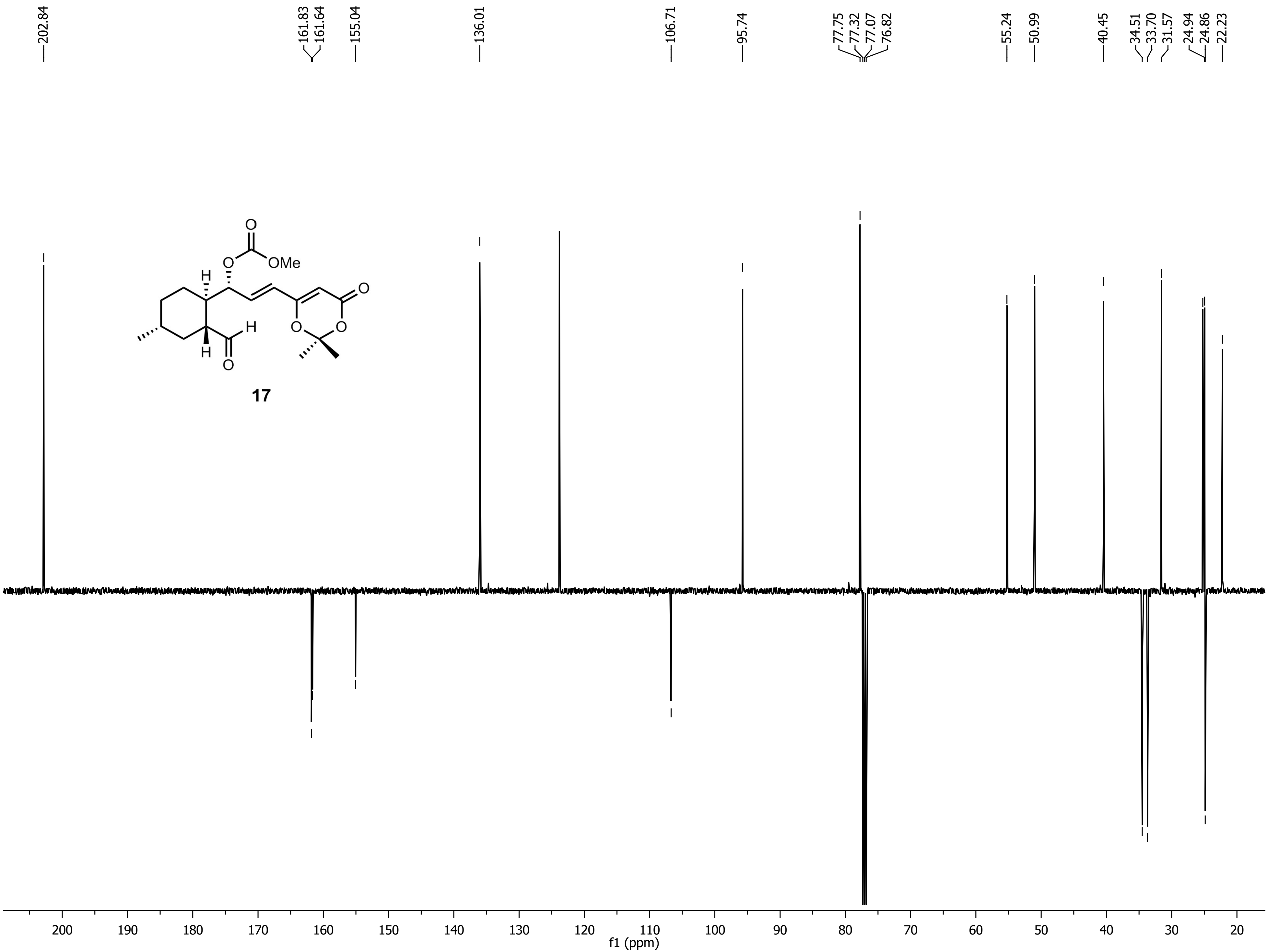


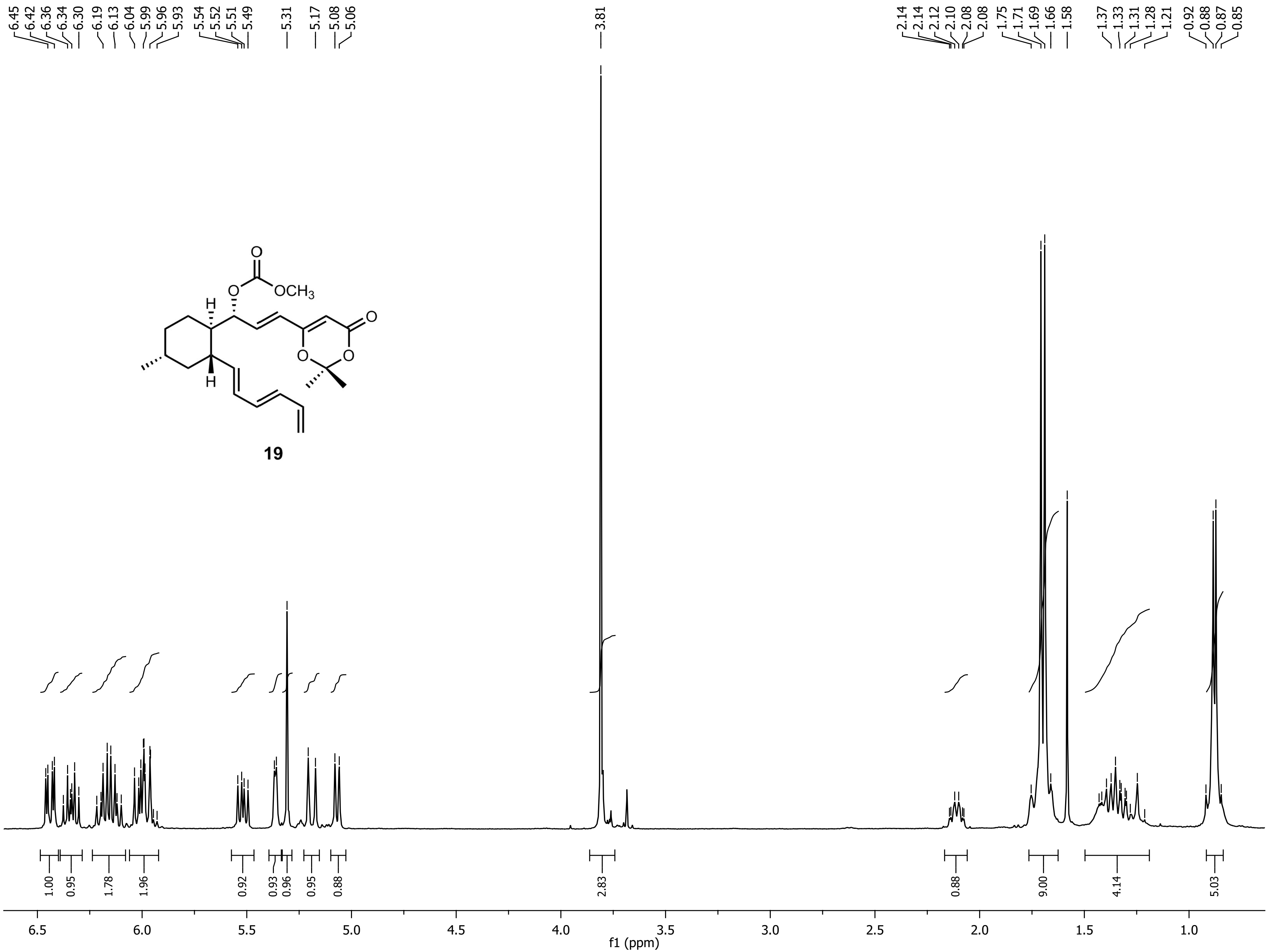
162.06
161.76
155.24
137.28
122.95
106.64
95.34
77.63
77.32
77.07
76.81
65.34
55.17
42.31
39.98
38.65
34.44
32.06
26.07
25.24
24.93
22.49
O
O
OMe
H
H
OH
O
O
O
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
f1 (ppm)

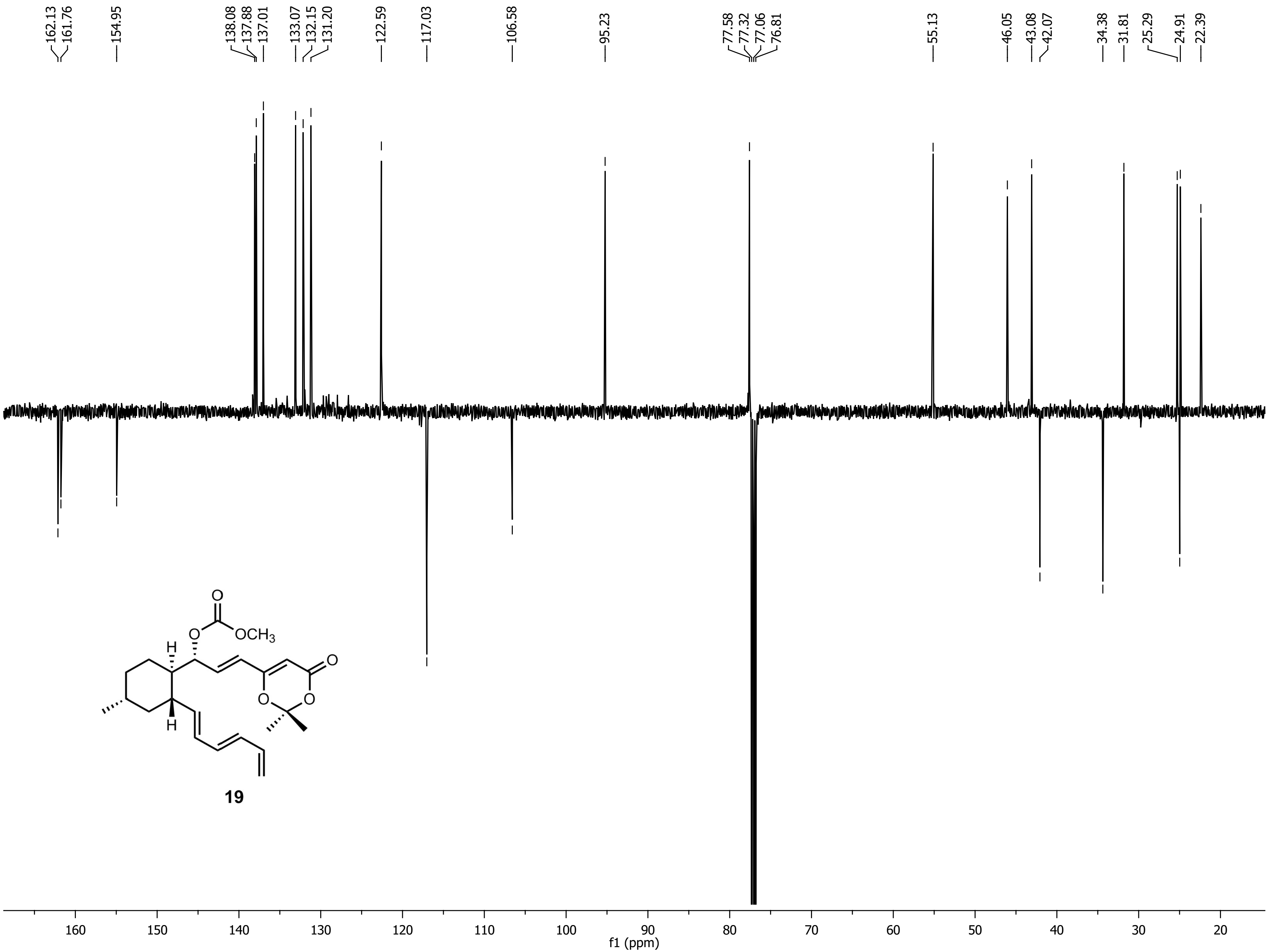
S4

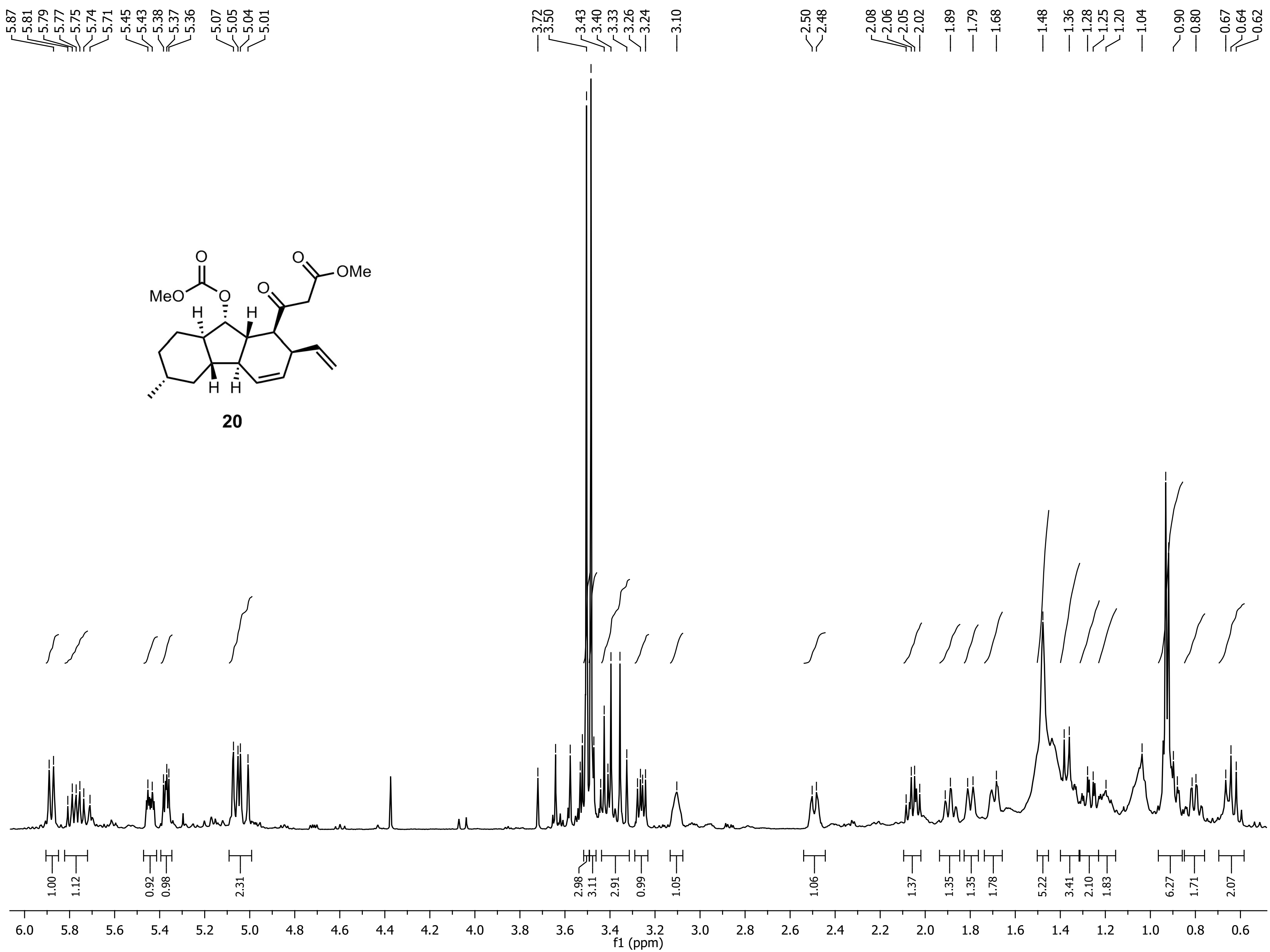


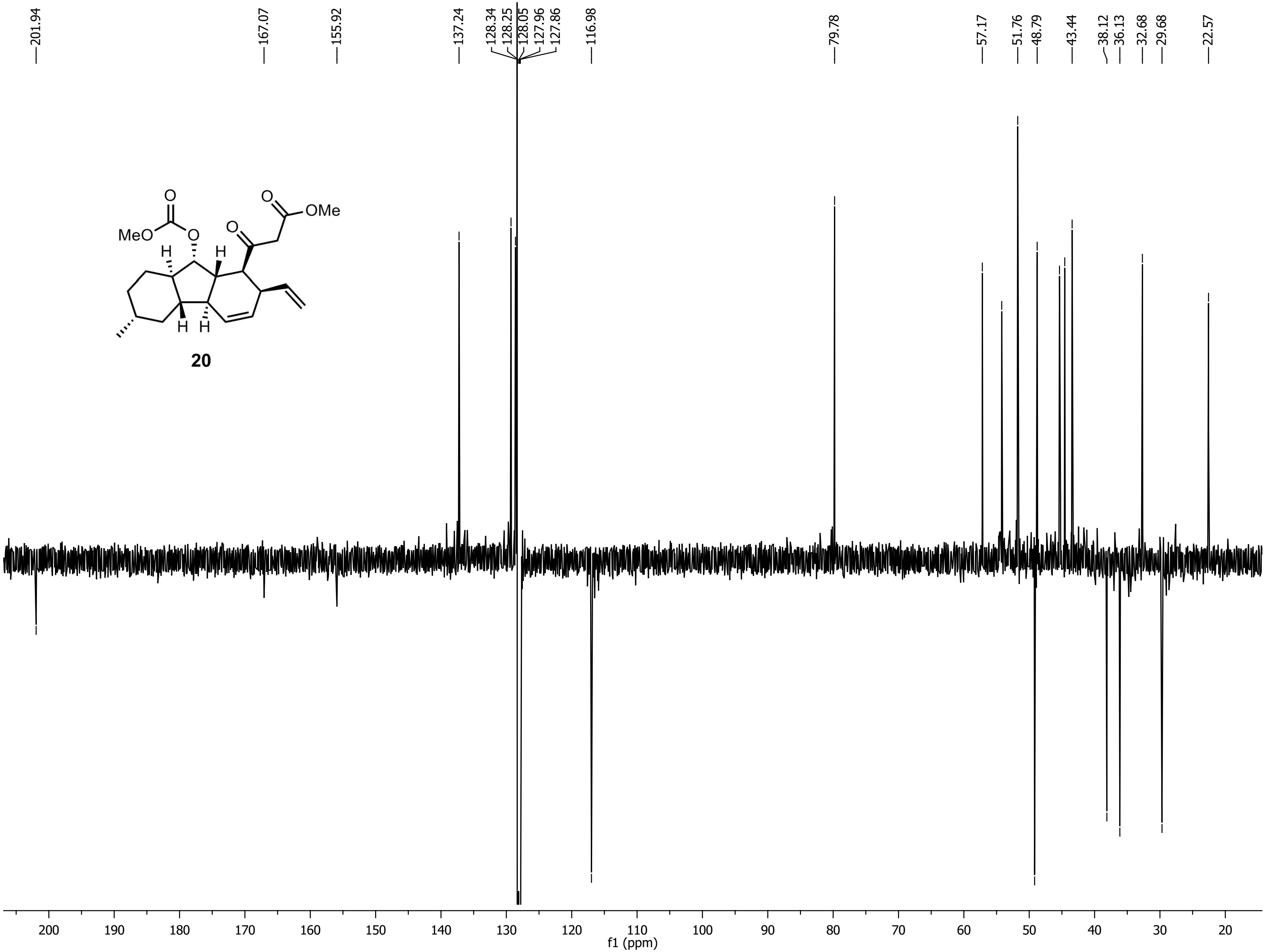
9.58
9.58
7.26
6.47
6.46
6.43
6.42
6.08
6.08
6.05
6.05
5.42
5.41
5.34
3.79
2.42
2.39
2.37
2.04
1.87
1.75
1.71
1.63
1.45
1.27
0.93
1.23
0.87
0.86
0.84
0.81
O
OMe
H
O
O
H
O
O
H
O
17
1.00
1.01
1.06
1.04
1.06
3.22
1.04
1.09
1.11
1.87
6.89
0.60
1.19
1.40
3.94
1.83
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)


202.84
161.83
161.64
155.04
136.01
106.71
95.74
77.75
77.32
77.07
76.82
55.24
50.99
40.45
34.51
33.70
31.57
24.94
24.86
22.23
OMe
17
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
f1 (ppm)


6.45 6.42 6.36 6.34 6.30 6.19 6.13 6.04 5.99 5.96 5.93 5.54 5.52 5.51 5.49 5.31 5.17 5.08 5.06
3.81
2.14 2.14 2.12 2.10 2.08 2.08 1.75 1.71 1.69 1.66 1.58 1.37 1.33 1.31 1.28 1.21 0.92 0.88 0.87 0.85
1.00 0.95 1.78 1.96 0.92 0.93 0.96 0.95 0.88 2.83 0.88 9.00 4.14 5.03
6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0
f1 (ppm)
OCH3
19


162.13
161.76
154.95
138.08
137.88
137.01
133.07
132.15
131.20
122.59
117.03
106.58
95.23
77.58
77.32
77.06
76.81
55.13
46.05
43.08
42.07
34.38
31.81
25.29
24.91
22.39
O
OCH3
H
O
O
O
O
H
19
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
f1 (ppm)


5.87 5.81 5.79 5.77 5.75 5.74 5.71 5.45 5.43 5.38 5.37 5.36 5.07 5.05 5.04 5.01
3.72 3.50 3.43 3.40 3.33 3.26 3.24 3.10
2.50 2.48 2.08 2.06 2.05 2.02 1.89 1.79 1.68 1.48 1.36 1.28 1.25 1.20 1.04 0.90 0.80 0.67 0.64 0.62
1.00 1.12 0.92 0.98 2.31 2.98 3.11 2.91 0.99 1.05 1.06 1.37 1.35 1.35 1.78 5.22 3.41 2.10 1.83 6.27 1.71 2.07
6.0 5.8 5.6 5.4 5.2 5.0 4.8 4.6 4.4 4.2 4.0 3.8 3.6 3.4 3.2 3.0 2.8 2.6 2.4 2.2 2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6
f1 (ppm)
O
MeO
O
O
OMe
H
H
H
H
20


201.94
167.07
155.92
137.24
128.34
128.25
128.05
127.96
127.86
116.98
79.78
57.17
51.76
48.79
43.44
38.12
36.13
32.68
29.68
22.57
MeO
O
OMe
H
20
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
f1 (ppm)