Electronic Supplementary Material (ESI) for Chemical Communications

# ***SUPPLEMENTARY INFORMATION FOR***

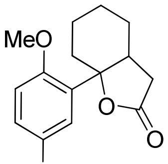
# Model Studies towards the Challenging Angularly-Oxygenated Core of Several Angucyclinones from an Oxidative Dearomatization Strategy

Silvia Vila-Gisbert, Antonio Urbano,* M. Carmen Carreño*

## Experimental Procedures

**General**: Melting points were obtained in open capillary tubes and are uncorrected. $^{1}$H- and $^{13}$C-NMR spectra were recorded in $CDCl_3$ at 300 and 75 MHz, respectively. All reactions were monitored by thin layer chromatography that was performed on precoated sheets of silica gel 60, and flash column chromatography was done with silica gel 60 (230-400 mesh) of Merck. Eluting solvents are indicated in the text. Water was distilled prior to use. The apparatus for inert atmosphere experiments was dried by flaming in a stream of dry argon. Anhydrous solvents were pre-dried over molecular sieves (3 or 4 Å) previously activated under microwaves (500 W, 2 min) and kept under an argon atmosphere. For routine workup, hydrolysis was carried out with water, extractions with $CH_2Cl_2$, $Et_2O$ or EtOAc, solvent drying with $MgSO_4$, filtration and evaporation under reduced pressure.

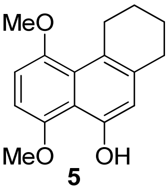
### (±) 7a-(2,5-Dimethoxyphenyl)hexahydrobenzofuran-2(3*H*)-one (8)



**8**

To a suspension of dried magnesium turnings (93.1 mg, 3.88 mmol, 2.2 equiv) in dry THF (0.6 mL) under nitrogen, a few crystals of iodine were added. A solution of commercially available 1-bromo-2,5-dimethoxybenzene (764.8 mg, 3.52 mmol, 2 equiv) in dry THF (2.8 mL) was added dropwise and the reaction was refluxed for 2 h. Then, a solution of commercially available ethyl-2-cyclohexanoneacetate (324.6 mg, 1.76 mmol, 1 equiv) in THF (2.5 mL) was added dropwise. The reaction mixture was stirred for 2 h, poured into a mixture of ice/10% HCl/ethyl ether and the organic layer washed twice with water. After workup and flash chromatography (EtOAc/hexane, 1:9), lactone **8** was obtained as a white solid (320 mg, 1.16 mmol, 66% yield). **Rf:** 0.49 (EtOAc/hexane 1:5); **mp**: 127.1-127.7 °C; **$^{1}$H NMR δ:** 7.02 (d, *J* = 2.9 Hz, 1H), 6.83 (d, *J* = 8.8 Hz, 1H), 6.78 (dd, *J* = 8.8, 2.9 Hz, 1H), 3.82 (s, 3H), 3.75 (s, 3H), 3.08 (dt, *J* = 11.4, 6.6 Hz, 1H), 2.38 (dd, *J* = 16.8, 6.6 Hz, 1H), 2.32 – 2.19 (m, 1H), 2.05 – 1.84 (m, 2H), 1.77 – 1.62 (m, 2H), 1.55 – 1.36 (m, 2H), 1.28 – 1.10 (m, 1H); **$^{13}$C NMR δ:** 178.38, 154.07, 149.58, 133.36, 113.68, 112.86, 112.57, 88.03, 56.07, 55.89, 37.96, 37.55, 32.72, 29.97, 23.25, 21.68; **HRMS (ESI+)** calcd for $C_{16}H_{21}O_4$ $[M+H]^+$ 277.1434, found 277.1443.

### 5,8-Dimethoxy-1,2,3,4-tetrahydrophenanthren-9-ol (5)

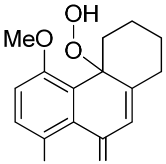


**5**

Polyphosporic acid (3.5 g) was heated at 90 °C for 20 min. Then, lactone **8** (863.0 mg, 3.11 mmol) was added and the mixture was stirred at the same temperature for 2 h. The reaction mixture was poured into ice, extracted with EtOAc (4 x 80 ml) and washed with brine. After workup and flash chromatography (EtOAc/hexane 1:9), phenol **5** was obtained as a yellow solid (635.4 mg, 2.46 mmol, 79% yield). **R$_f$**: 0.53 (EtOAc/hexane 1:5); **mp**:

114.5 – 116.9 °C; **$^1$H NMR δ:** 9.58 (s, 1H), 6.81 – 6.50 (m, 3H), 3.99 (s, 3H), 3.83 (s, 3H), 3.33 (s, 2H), 2.86 (s, 2H), 1.95 – 1.61 (m, 4H); **$^{13}$C NMR δ:** 153.37, 151.56, 150.54, 136.85, 128.35, 124.57, 115.81, 113.30, 105.93, 103.62, 56.62, 56.01, 31.43, 29.61, 24.46, 22.37; **HRMS (EI+)** calcd for $C_{16}H_{18}O_3$ $[M]^+$ 258.1256, found 258.1252.

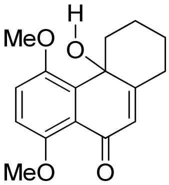
### (±)-4a-Hydroperoxy-5,8-dimethoxy-2,3,4,4a-tetrahydrophenanthren-9(1*H*)-one (10)



**10**

To a vigorously stirred mixture of phenol **5** (213.1 mg, 0.86 mmol, 1 equiv), water (13.8 mL) and $CH_3CN$ (9 mL), a mixture of Oxone® (4.06 g, 6.61 mmol, 8 equiv) and $NaHCO_3$ (1.72 g, 20.48 mmol, 24.8 equiv), previously ground into powder, was slowly added portion wise but without stop. A septum with an empty balloon was immediately placed to avoid overpressure into the flask and loss of generated singlet oxygen. After vigorously stirring for 2 h, the reaction was quenched with water and extracted with EtOAc (x 5). After workup and flash chromatography (EtOAc/hexane 1:1), *p*-peroxyquinol **10** was obtained as a yellow solid (109.3 mg, 0.38 mmol, 44% yield). **$R_f$:** 0.25 (EtOAc/hexane 2:1); **mp**: 172.0 – 173.1°C; **$^1$H NMR δ**: 8.58 (s, 1H), 7.09 (d, *J* = 9.1 Hz, 1H), 6.91 (d, *J* = 9.1 Hz, 1H), 6.19 (s, 1H), 3.82 (s, 3H), 3.79 (s, 3H), 3.22 – 3.08 (m, 1H), 2.82 (td, *J* = 12.7, 4.5, 1H), 2.40 – 2.27 (ddt, *J* = 12.7, 4.3, 2.2 Hz, 1H), 2.10 – 1.96 (m, 1H), 1.96 – 1.81 (m, 1H), 1.63 – 1.49 (m, 1H), 1.49 – 1.33 (m, 2H); **$^{13}$C NMR δ:** 184.65, 160.86, 154.56, 151.61, 133.97, 126.75, 122.29, 118.13, 113.23, 82.08, 56.83, 56.57, 36.79, 32.20, 28.62, 21.17; **HRMS (ESI+)** calcd for $C_{16}H_{19}O_5$ $[M+H]^+$ 291.1227, found 291.1226

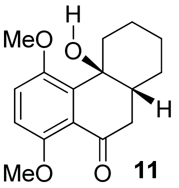
### (±)-4a-Hydroxy-5,8-dimethoxy-2,3,4,4a-tetrahydrophenanthren-9(1*H*)-one (4)



**4**

To a vigorously stirred mixture of phenol **5** (255.5 mg, 0.99 mmol, 1 equiv), water (16.5 mL) and $CH_3CN$ (16.5 mL), a mixture of Oxone® (4.87 g, 7.92 mmol, 8 equiv) and $NaHCO_3$ (2.06 g, 24.56 mmol, 24.8 equiv), previously ground into powder, was very slowly added portion wise but without stop. A septum with an empty balloon was immediately placed to avoid overpressure into the flask and loss of generated singlet oxygen. After vigorously stirring for 2 h, water followed by solid $Na_2S_2O_3$ (3.13 g, 19.81 mmol, 20 equiv) were slowly added. The reaction mixture was stirred for 2 h, quenched with water and extracted with EtOAc (x 5). After workup and flash chromatography (EtOAc/hexane 1:1), *p*-quinol **4** was obtained as a yellow solid (141.8 mg, 0.52 mmol, 52% yield). **$R_f$:** 0.30 (EtOAc/hexane 2:1); **mp**: 139.0 – 140.0°C; **$^1$H NMR δ:** 7.11 (d, *J* = 9.1 Hz, 1H), 6.94 (d, *J* = 9.2 Hz, 1H), 6.12 (s, 1H), 4.49 (s, 1H), 3.94 (s, 3H), 3.88 (s, 3H), 2.81 (td, *J* = 12.5, 4.6 Hz, 1H), 2.77 – 2.66 (m, 1H), 2.36 – 2.23 (m, 1H), 2.13 – 1.97 (m, 2H), 1.66 – 1.54 (m, 1H), 1.47 – 1.31 (m, 2H); **$^{13}$C NMR δ:** 184.30, 161.71, 154.74, 150.12, 137.64, 124.21, 120.38, 115.95, 112.23, 71.39, 56.74, 56.00, 40.85, 31.87, 29.05, 21.10; **HRMS (ESI+)** calcd for $C_{16}H_{19}O_4$ $[M+H]^+$ 275.1277, found 275.1273

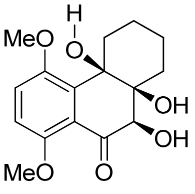
### (4a*S**,10a*R**)-4a-Hydroxy-5,8-dimethoxy-2,3,4,4a,10,10a-hexahydrophenanthren-9(1*H*)-one (11)



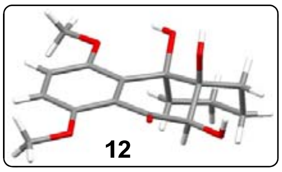
**11**

To a solution of *p*-quinol **4** (27.7 mg, 0.10 mmol, 1 equiv) in EtOH (1.6 mL), 10% Pd-C (145.1 mg, 0.14 mmol, 1.35 equiv) and a 25% aq. $NaNO_2$ solution (583 µL, 2.12 mmol, 20.9 equiv) were added and the mixture was hydrogenated at atmospheric pressure using and hydrogen balloon. After 4 h, the mixture was filtered through a short column of celite and the residue was washed with EtOAc. After evaporation of the solvent, hydroxy ketone **11** was obtained as yellow oil (21.6 mg, 0.08 mmol, 78% yield). **$R_f$:** 0.25 (EtOAc/hexane 1:1); **$^1$H NMR δ:** 7.08 (d, *J* = 9.1 Hz, 1H), 6.87 (d, *J* = 9.2 Hz, 1H), 4.70 (s, 1H), 3.90 (s, 3H), 3.85 (s, 3H), 3.00 – 2.83 (m, 1H), 2.49 – 2.38 (m, 2H), 2.24 – 2.13 (m, 2H), 1.91 – 1.71 (m, 2H), 1.60 – 1.50 (m, 2H), 1.47 – 1.36 (m, 2H); **$^{13}$C NMR δ:** 198.36, 154.66, 150.77, 140.15, 122.30, 117.55, 112.03, 73.56, 56.92, 56.46, 43.55, 40.04, 32.46, 26.82, 21.34, 20.07; **HRMS (ESI+)** calcd for $C_{16}H_{21}O_4$ $[M+H]^+$ 277.1434 found 277.1428.

### (4a*R**,10*R**,10a*S**)-4a,10,10a-Trihydroxy-5,8-dimethoxy-2,3,4,4a,10,10a-hexahydrophenanthren-9(1*H*)-one (12).



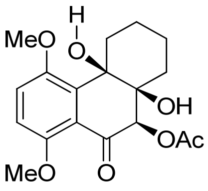
**12**



**12**

A mixture of NaIO$_4$ (19.9 mg, 0.09 mmol, 1.5 equiv) and CeCl$_3$·7H$_2$O (2.3 mg, 0.006 mmol, 0.1 equiv) in H$_2$O (59 µL) was gently heated to 40 °C until a bright yellow suspension was formed. After cooling to 0 °C, ethyl acetate (186 µL) and acetonitrile (186 µL) were added, and the suspension stirred for 2 min. A 0.1 M aqueous solution of RuCl$_3$ (3 µL, 0.0003 mmol, 0.5 mol%) was added, and the mixture was stirred for 2 min. The *p*-quinol **4** (17 mg, 0.06 mmol, 1 equiv) was added in one portion and the resulting slurry was stirred for 90 minutes. Then, solid Na$_2$SO$_4$ was added followed by ethyl acetate (1 mL). The solid was filtered off, the filter cake washed several times with ethyl acetate and the filtrate washed with saturated aq Na$_2$SO$_3$ solution (3 mL). After workup, triol **12** was obtained as a yellow solid that does not need further purification (19.0 mg, 0.06 mmol, 99% yield). **R$_f$:** 0.15 (EtOAc/hexane 2:1); **mp**: 186.8-188.6 °C; **$^1$H NMR δ:** 7.16 (d, *J* = 9.1 Hz, 1H), 6.91 (d, *J* = 9.2 Hz, 1H), 4.82 (s, 1H), 4.62 (d, *J* = 3.3 Hz, 1H), 4.03 (d, *J* = 4.1 Hz, 1H), 3.93 (s, 3H), 3.87 (s, 3H), 2.84 (s, 1H), 2.54 – 2.40 (m, 1H), 2.33 – 2.20 (m, 1H), 1.89 – 1.68 (m, 4H), 1.67 – 1.46 (m, 2H); **$^{13}$C NMR δ:** 195.77, 152.89, 149.73, 134.37, 118.26, 117.18, 110.83, 78.01, 74.19, 73.04, 55.54, 55.22, 34.56, 29.72, 22.01, 19.70; **HRMS (ESI+)** calcd for $C_{16}H_{20}O_6Na$ $[M+Na]^+$ 331.1152 found 331.1161

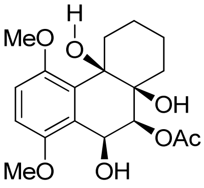
### (4b*R**,8a*S**,9*R**)-4b,8a-Dihydroxy-1,4-dimethoxy-10-oxo-4b,5,6,7,8,8a,9,10-octahydrophenanthren-9-yl acetate (13)



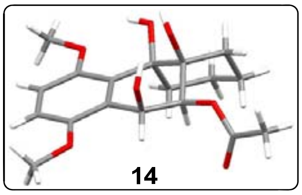
**13**

To a mixture of triol **12** (55.6 mg, 0.18 mmol, 1 equiv), $Et_3N$ (39.5 µl, 0.28 mmol, 1.56 equiv) and DMAP (2.2 mg, 0.02 mmol, 0.1 equiv) in dry $CH_2Cl_2$ (653 µL) at 0 °C, acetic anhydride (19.8 µL, 0.21 mmol, 1.16 equiv) was added. The mixture was stirred at 0 °C for 4 h and overnight at room temperature. The reaction was quenched by addition of saturated aq. $NH_4Cl$ solution and extracted with EtOAc. After workup, acetate **13** was obtained as a colorless solid that does not need further purification (52.2 mg, 0.15 mmol, 83% yield). **$R_f$:** 0.14 (EtOAc/hexane 2:1); **mp**: 155-175 °C (dec.); **$^1$H NMR δ:** 7.14 (d, *J* = 9.2 Hz, 1H), 6.90 (d, *J* = 9.2 Hz, 1H), 5.80 (s, 1H), 4.98 (s, 1H), 3.93 (s, 3H), 3.83 (s, 3H), 3.08 (s, 1H), 2.52 – 2.43 (m, 1H), 2.30 (s, 3H), 2.10 – 1.99 (m, 1H), 1.95 – 1.48 (m, 7H); **$^{13}$C NMR δ:** 188.24, 169.56, 153.37, 149.44, 133.55, 118.86, 116.73, 111.17, 74.64 (2C), 74.39, 55.53, 55.18, 34.50, 29.73, 21.76, 19.73, 19.46; **HRMS (ESI+)** calcd for $C_{18}H_{22}O_7Na$ $[M+Na]^+$ 373.1257 found 373.1274.

### (4b*R**,8a*S**,9*S**,10*S**)-4b,8a,10-Trihydroxy-1,4-dimethoxy-4b,5,6,7,8,8a,9,10-octahydrophenanthren-9-yl acetate (14)



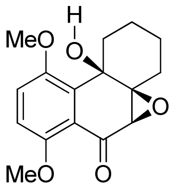
14



14

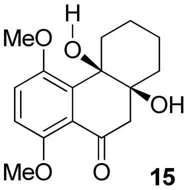
To a solution of ketone **13** (17 mg, 0.048 mmol, 1 equiv) in $CH_2Cl_2$ (0.5 mL), $NaBH_4$ (1.8 mg, 0.048 mmol, 1 equiv) was added, under argon. After stirring for 2 h, the mixture was quenched with water and extracted with EtOAc several times. After workup and flash chromatography (EtOAc/hexane 1:1), triol **14** was obtained as a yellow solid (10.2 mg, 0.03 mmol, 60% yield). **$R_f$:** 0.20 (EtOAc/hex 2:1); **mp**: 172.8 – 174.5 °C; **$^1$H NMR δ:** 6.88 (d, *J* = 9.0 Hz, 1H), 6.81 (d, *J* = 9.0 Hz, 1H), 5.37 (d, *J* = 4.7 Hz, 1H), 5.17 (d, *J* = 4.7 Hz, 1H), 5.05 (s, 1H), 4.42 (s, 1H), 3.89 (s, 3H), 3.84 (s, 3H), 2.39 – 2.29 (m, 1H), 2.26 (s, 3H), 2.17 – 2.08 (m, 1H), 1.77 – 1.65 (m, 2H), 1.65 – 1.56 (m, 1H), 1.53 – 1.43 (m, 2H), 1.34 – 1.27 (m, 1H); **$^{13}$C NMR δ:** 170.68, 152.67, 150.93, 128.26, 125.95, 111.71, 110.04, 76.36, 76.31, 68.87, 63.67, 56.18, 55.86, 36.35, 30.53, 22.49, 21.07, 20.54; **HRMS (ESI+)** calcd for $C_{18}H_{24}O_7Na$ $[M+Na]^+$ 375.1414 found 375.1411

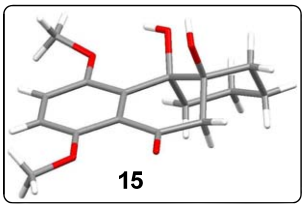
### (4a*S**,5a*R**,10b*R**)-10b-Hydroxy-7,10-dimethoxy-3,4,5a,10b-tetrahydro-1H-phenanthro[8a,9-b]oxiren-6(2*H*)-one (3)


**3**

To a stirred solution of *p*-quinol **4** (33.7 mg, 0.12 mmol, 1 equiv) and 33% aq. hydrogen peroxide (123 µL, 1.23 mmol, 10 equiv) in methanol (1.1 mL), a 6M NaOH aq. solution (20 µL, 0.12 mmol, 1 equiv) was added dropwise. The reaction mixture was stirred for 3 h, quenched with a saturated solution of $NH_4Cl$ and extracted with EtOAc (x 4). After workup, epoxy ketone **3** was obtained as a yellow solid (35 mg, 0.12 mmol, 98% yield). **$R_f$:** 0.55 (EtOAc/hexane 2:1); **mp**: 153.4 – 155.0 °C; **$^1$H NMR δ:** 7.08 (d, *J* = 9.1 Hz, 1H), 6.88 (d, *J* = 9.2 Hz, 1H), 5.08 (s, 1H), 3.90 (s, 3H), 3.82 (s, 3H), 3.49 (s, 1H), 2.65 (td, *J* = 13.3, 3.9 Hz, 1H), 2.38 – 2.26 (m, 1H), 2.02 – 1.83 (m, 2H), 1.66 – 1.47 (m, 2H), 1.37 (td, *J* = 13.7, 3.9 Hz, 1H), 1.29 – 1.18 (m, 1H); **$^{13}$C NMR δ:** 194.82, 153.88, 150.48, 134.29, 120.04, 117.55, 112.26, 74.02, 66.18, 62.29, 56.87, 56.64, 39.83, 29.85, 25.49, 20.78; **HRMS (ESI+)** calcd for $C_{16}H_{19}O_5$ $[M+H]^+$ 291.1227, found 291.1225.

### (4a*R**,10a*S**)-4a,10a-Dihydroxy-5,8-dimethoxy-2,3,4,4a,10,10a-hexahydrophenanthren-9(1*H*)-one (15)


**15**


**15**

To a solution of epoxy ketone **3** (119.3 mg, 0.41 mmol, 1 equiv) in a mixture of THF (6 mL), EtOH (3 ml), $H_2O$ (3 mL) and an aqueous saturated solution of $NaHCO_3$ (0.6 mL) at 0 °C, aluminum amalgam (freshly prepared from aluminum foil)[1] was added. The reaction mixture was vigorously stirred at 0 °C for 45 min and filtered over celite. The resulting solution was washed with brine and the aqueous phase extracted with EtOAc. After workup and flash chromatography (EtOAc/hexane 1:1), diol **15** was obtained as a yellow solid (68.8 mg, 0.24 mmol, 58%

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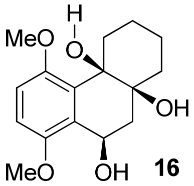
(1) The preparation of aluminum amalgam was done submerging aluminum pellets consecutively in solutions of 10% HCl, 5% $HgCl_2$, EtOH and $Et_2O$.

yield). **R$_f$:** 0.38 (EtOAc/hexane 2:1); **mp**: 160.1 – 161.9°C; **$^1$H NMR δ:** 7.12 (d, *J* = 9.0 Hz, 1H), 6.89 (d, *J* = 9.1 Hz, 1H), 5.13 (s, 1H), 3.92 (s, 3H), 3.85 (s, 3H), 3.18 – 3.01 (m, 2H), 2.59 (d, *J* = 16.2 Hz, 1H), 2.34 (d, *J* = 13.5 Hz, 1H), 2.07 – 1.91 (m, 1H), 1.83 – 1.48 (m, 6H); **$^{13}$C NMR δ:** 195.64, 154.29, 150.75, 135.94, 121.71, 117.48, 112.14, 75.53, 74.31, 56.62, 56.26, 47.14, 36.15, 35.65, 23.47, 20.28; **HRMS (ESI+)** calcd for $C_{16}H_{21}O_5$ $[M+H]^+$ 293.1383 found 293.1386.

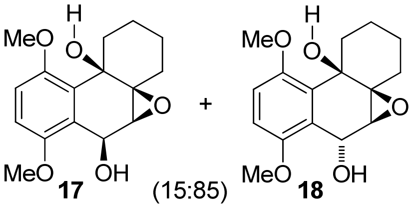
**(4a*R*,9*R*,10a*S*)-5,8-Dimethoxy-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-4a,9,10a-triol (16)**



16

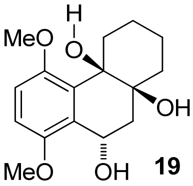
To a solution of ketone **15** (18.3 mg, 0.063 mmol, 1 equiv) in MeOH (2.1 mL) at 0 °C under argon, $CeCl_3{\cdot}7H_2O$ (39.7 mg, 0.11 mmol, 1.7 equiv) was added. After stirring for 30 min, the mixture was cooled to −78 °C and $NaBH_4$ (4 mg, 0.11 mmol, 1.7 equiv) was added. The mixture was stirred for 90 min at −78 °C and 3 h at room temperature, quenched with water and extracted with EtOAc. After workup, triol **16** was obtained as yellow oil (17.5 mg, 0.06 mmol, 95% yield). **R$_f$:** 0.23 (EtOAc/hexane 1:2 (3x)); **$^1$H NMR δ:** 6.81 (m, 2H), 5.06 – 4.92 (m, 2H), 4.61 (d, *J* = 10.0 Hz, 1H), 3.88 (s, 3H), 3.86 (s, 3H), 3.66 (s, 1H), 2.40 (dd, *J* = 14.9, 4.8 Hz, 1H), 2.31 – 2.22 (m, 1H), 2.09 (dd, *J* = 15.0, 1.8 Hz, 1H), 1.96 (td, *J* = 14.1, 13.6, 4.4 Hz, 1H), 1.75 – 1.61 (m, 3H), 1.49 – 1.28 (m, 3H); **$^{13}$C NMR δ:** 152.47, 151.35, 127.94, 111.09, 109.74, 75.68, 73.37, 62.25, 56.18, 55.78, 37.23, 36.01, 35.90, 23.29, 20.66; **HRMS (ESI+)** calcd for $C_{16}H_{22}O_5Na$ $[M+Na]^+$ 317.1359, found 317.1344.

**(4a*S**,5a*S**,6*R**,10b*R**) and (4a*S**,5a*S**,6*S**,10b*R**)-7,10-Dimethoxy-2,3,4,5a,6,10b-hexahydro-1*H*-phenanthro[8a,9-b]oxirene-6,10b-diol (17 and 18)**



To a solution of epoxy ketone **3** (23.5 mg, 0.08 mmol, 1 equiv) in EtOH (0.6 mL), $NaBH_4$ (3.1 mg, 0.081 mmol, 1 equiv) was added under argon. After 1 h, another equivalent of $NaBH_4$ was added and the mixture was stirred for 90 min, quenched with water and extracted with EtOAc. After workup, a non-separable 15:85 mixture of epoxy diols **17** and **18** was obtained as yellow oil (21.8 mg, 0.075 mmol, 92% yield). **$R_f$:** 0.24 (EtOAc/hexane 1:2 (2x)); Diastereoisomer **17**: **$^1$H NMR δ**: 6.84 (d, *J* = 8.7 Hz, 1H), 6.78 (d, *J* = 8.9 Hz, 1H), 5.17 (d, *J* = 2.8 Hz, 1H), 4.89 (s, 1H), 3.86 (s, 3H), 3.82 (s, 3H), 3.48 (d, *J* = 2.8 Hz, 1H), 2.53-2.66 (m, 2H), 2.38 – 2.23 (m, 1H), 1.90 (m, 2H), 1.65 – 1.48 (m, 3H); **$^{13}$C NMR δ:** 152.43, 151.59, 129.44, 123.34, 111.32, 109.84, 73.60, 65.25, 63.24, 61.31, 55.99, 55.88, 39.68, 30.39, 25.46, 20.78. Diastereoisomer **18**: **$^1$H NMR δ:** 6.86 (d, *J* = 9.0 Hz, 1H), 6.76 (d, *J* = 9.0 Hz, 1H), 5.45 (d, *J* = 2.4 Hz, 1H), 4.85 (s, 1H), 3.86 (s, 3H), 3.82 (s, 3H), 3.35 (d, J = 2.4 Hz, 1H), 2.53-2.66 (m, 2H), 2.38 – 2.23 (m, 1H), 1.90 (m, 2H), 1.65 – 1.48 (m, 3H); **$^{13}$C NMR δ:** 152.13, 151.28, 128.69, 123.77, 111.97, 109.45, 73.37, 63.12, 62.64, 60.15, 55.95, 55.88, 39.90, 30.13, 25.37, 20.99. Diastereoisomers **17** and **18**: **HRMS (ESI+)** calcd for $C_{16}H_{21}O_5$ $[M+H]^+$ 293.1383 found 293.1386.

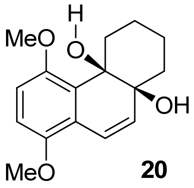
### (4a*R**,9*S**,10a*S**)-5,8-Dimethoxy-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-4a,9,10a-triol (19)



**19**

To a stirred suspension of $LiAlH_4$ (14.4 mg, 0.38 mmol, 6 equiv) in THF (760 µL), a solution of the 15:85 mixture of diastereoisomers **17** and **18** (18.5 mg, 0.063 mmol, 1 equiv) in THF (500 µL) was added dropwise. After 2 h, the reaction was quenched by a very slow addition of MeOH. After stirring for 15 min, the mixture was filtered through celite and concentrated under reduced pressure to afford the corresponding 15:85 mixture of diastereoisomer triols **16** and **19**, that were separated by flash chromatography on silica gel (AcOEt/ hexane 1:1) to afford pure diastereoisomer **19** as a yellow oil (12.8 mg, 0.044 mmol, 69% yield). **$R_f$:** 0.31 (EtOAc/hexane 1:2 (3x)); **$^1$H NMR δ:** 6.86 – 6.74 (m, 2H), 5.28 (dd, *J* = 9.3, 7.9 Hz, 1H), 4.85 (s, 1H), 4.31 (s, 1H), 3.87 (s, 3H), 3.86 (s, 3H), 2.94 (s, 1H), 2.34 – 2.27 (m, 1H), 2.24 (d, *J* = 2.6 Hz, 1H), 2.21 (d, *J* = 4.0 Hz, 1H), 2.01 – 1.91 (m, 1H), 1.80 – 1.60 (m, 4H), 1.54 – 1.37 (m, 2H); **$^{13}$C NMR δ:** 152.09, 151.65, 130.56, 128.70, 110.61, 109.32, 75.03, 72.96, 64.93, 55.82, 55.77, 37.15, 36.55, 36.07, 23.27, 20.89; **HRMS (ESI+)** calcd for $C_{16}H_{22}O_5Na$ $[M+Na]^+$ 317.1359, found 317.1344.

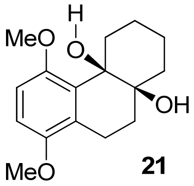
### (4a*R**,10a*S**)-5,8-Dimethoxy-1,2,3,4,4a,10a-hexahydrophenanthrene-4a,10a-diol (20)



**20**

To a stirred solution of epoxy ketone **3** (22.4 mg, 0.077 mmol, 1 equiv) in MeOH (770 µL), hydrazine monohydrate (7.5 µL, 0.155 mmol, 2 equiv) was added at 0 °C. After 15 min, acetic acid (8.8 µL, 0.15 mmol, 2 equiv) was added and the reaction mixture stirred for 2 h at room temperature, quenched with saturated aq. solution of $NaHCO_3$ and extracted with EtOAc. After workup and flash chromatography (florisil, EtOAc/hexane 1:5), allylic diol **20** was obtained as a colorless oil (12.1 mg, 0.044 mmol, 57% yield). **$R_f$:** 0.45 (EtOAc/hexane 1:4); **$^1$H NMR** (acetone $d_6$) **δ:** 6.97 (d, *J* = 9.2 Hz, 1H), 6.90 – 6.80 (m, 2H), 5.84 (d, *J* = 10.0 Hz, 1H), 5.44 (s, 1H), 3.92 (s, 3H), 3.79 (s, 3H), 3.28 (s, 1H), 1.94 – 1.73 (m, 2H), 1.71 – 1.44 (m, 4H), 1.36 – 1.27 (m, 2H); **$^{13}$C NMR** (acetone $d_6$) **δ:** 152.66, 150.90, 133.27, 130.22, 123.83, 122.76, 113.34, 110.91, 78.09, 70.83, 56.91, 56.28, 37.19, 37.11, 23.83, 20.02; **HRMS (FAB+)** calcd for $C_{16}H_{20}O_4$ $[M]^+$ 276.1362 found 276.1357.

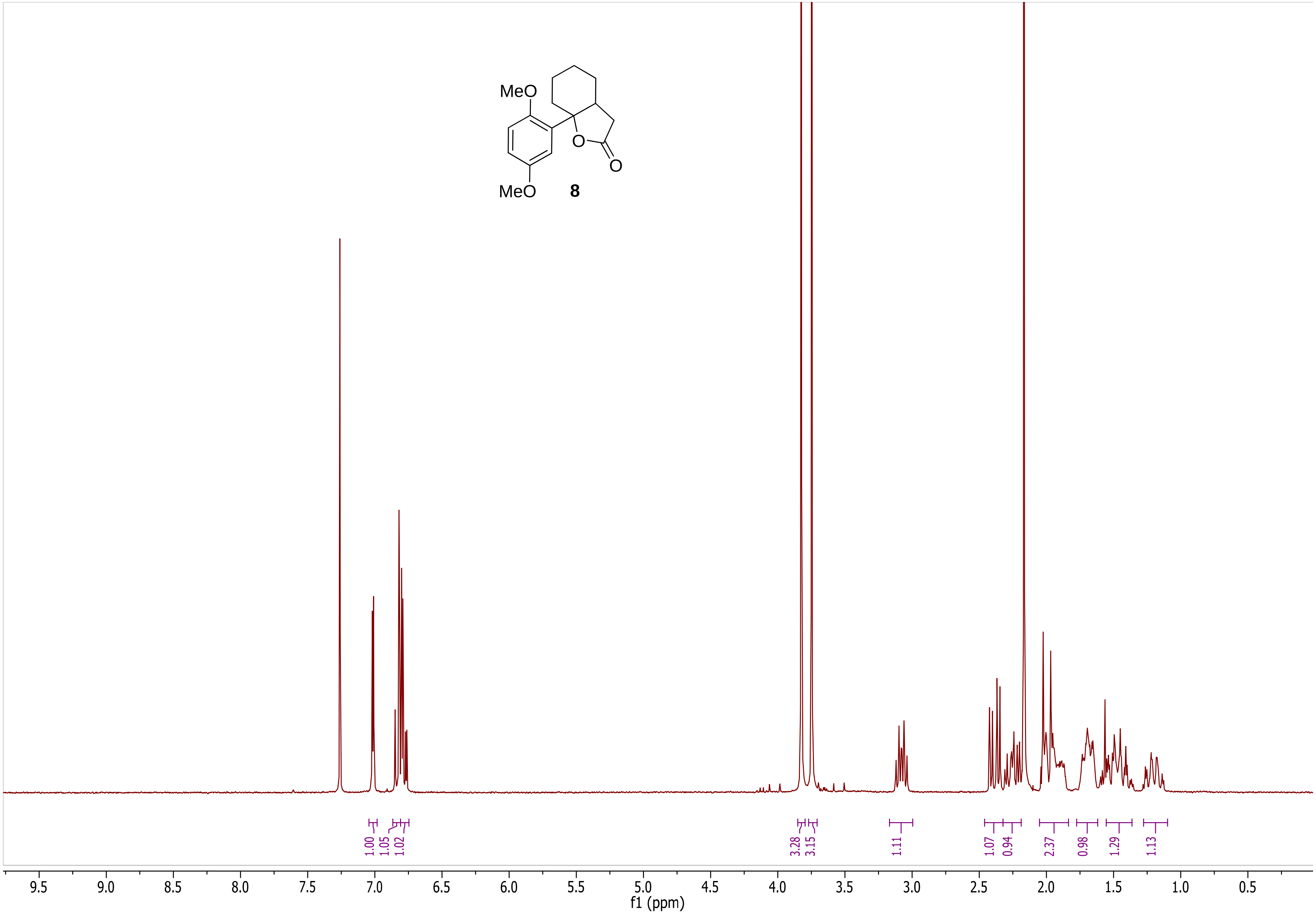
### (4a*R**,10a*S**)-5,8-Dimethoxy-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-4a,10a-diol (21)



**21**

To a stirred solution of epoxy ketone **3** (19.7 mg, 0.068 mmol, 1 equiv) in MeOH (680 µL), hydrazine monohydrate (6.6 µL, 0.14 mmol, 2 equiv) was added at 0 °C. After 15 min, acetic acid (7.8 µL, 0.0.14 mmol, 2 equiv) was added and the reaction mixture stirred for 2 h at room temperature, quenched with saturated aq. solution of $NaHCO_3$ and extracted with EtOAc. After workup, crude alkene **20** was obtained, dissolved in MeOH

(0.5 mL) and 10% Pd-C (4.3 mg, 0.004 mmol, 0.06 equiv) was added. Then, $H_2$ was bubbled into the solution with a balloon and stirred under $H_2$ atmosphere. After 24 h, more 10% Pd-C (8.6 mg, 0.008 mmol, 0.12 equiv) was added and the mixture stirred for 1 h, filtered over celite and rinsed several times with EtOAc. After evaporation of the solvent and flash chromatography (EtOAc/hexane 1:5), diol **21** was obtained as a yellow oil (9.9 mg, 0.036 mmol, 53% yield for two steps). **$R_f$:** 0.64 (EtOAc/hexane 1:1); **$^1$H NMR δ:** 6.72 (d, *J* = 9.0 Hz, 1H), 6.67 (d, *J* = 8.9 Hz, 1H), 4.89 (s, 1H), 3.86 (s, 3H), 3.77 (s, 3H), 3.08 (s, 1H), 2.87 – 2.76 (m, 2H), 2.37 – 2.11 (m, 2H), 2.11 – 1.95 (m, 1H), 1.85 – 1.52 (m, 5H), 1.52 – 1.34 (m, 2H); **$^{13}$C NMR δ:** 151.73, 151.52, 130.82, 126.95, 108.47, 108.07, 75.18, 70.92, 55.60, 37.38, 36.71, 28.18, 23.41, 21.12, 20.03; **HRMS (ESI+)** calcd for $C_{16}H_{22}O_4Na$ $[M+Na]^+$ 301.1410 found 301.1425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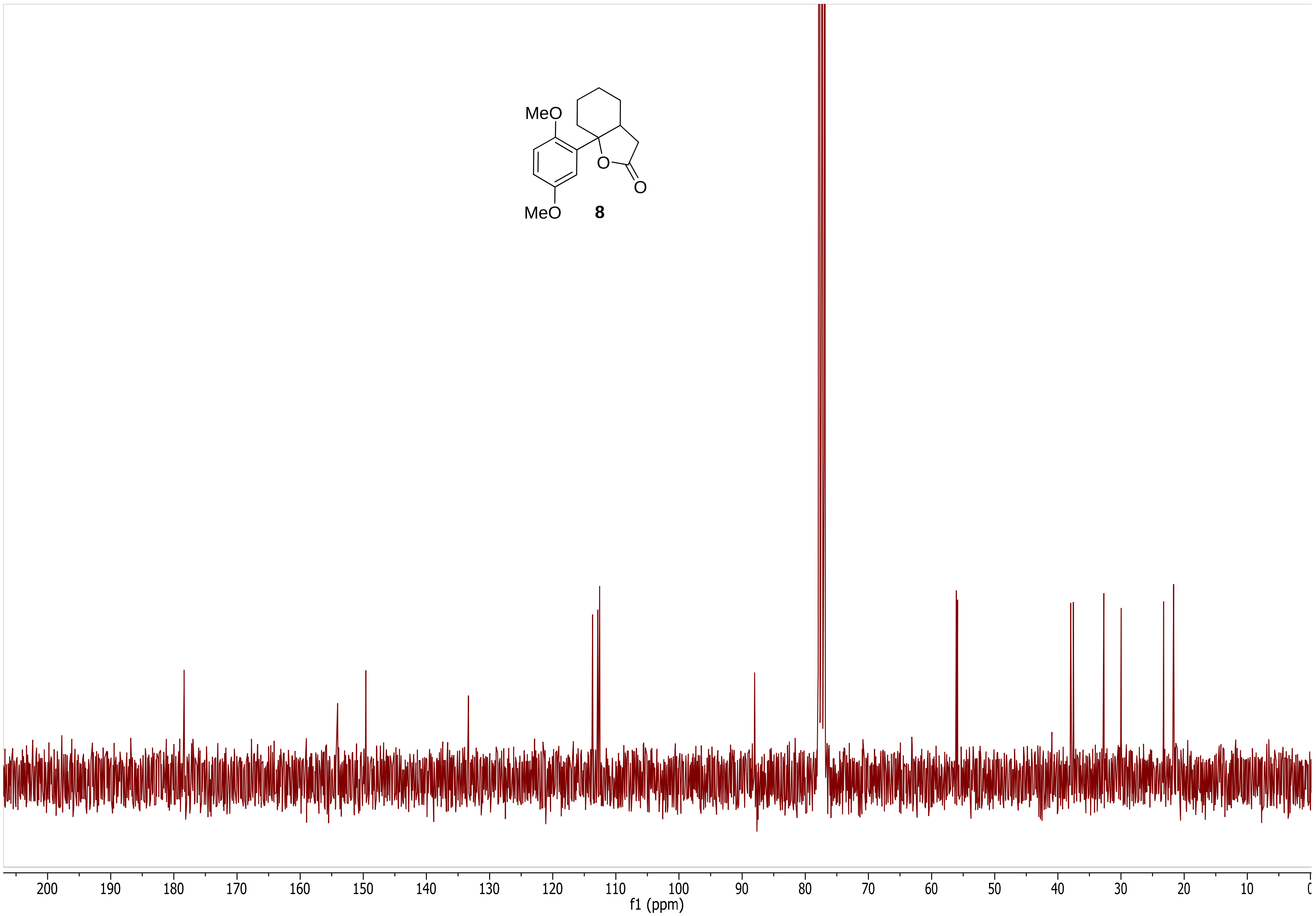
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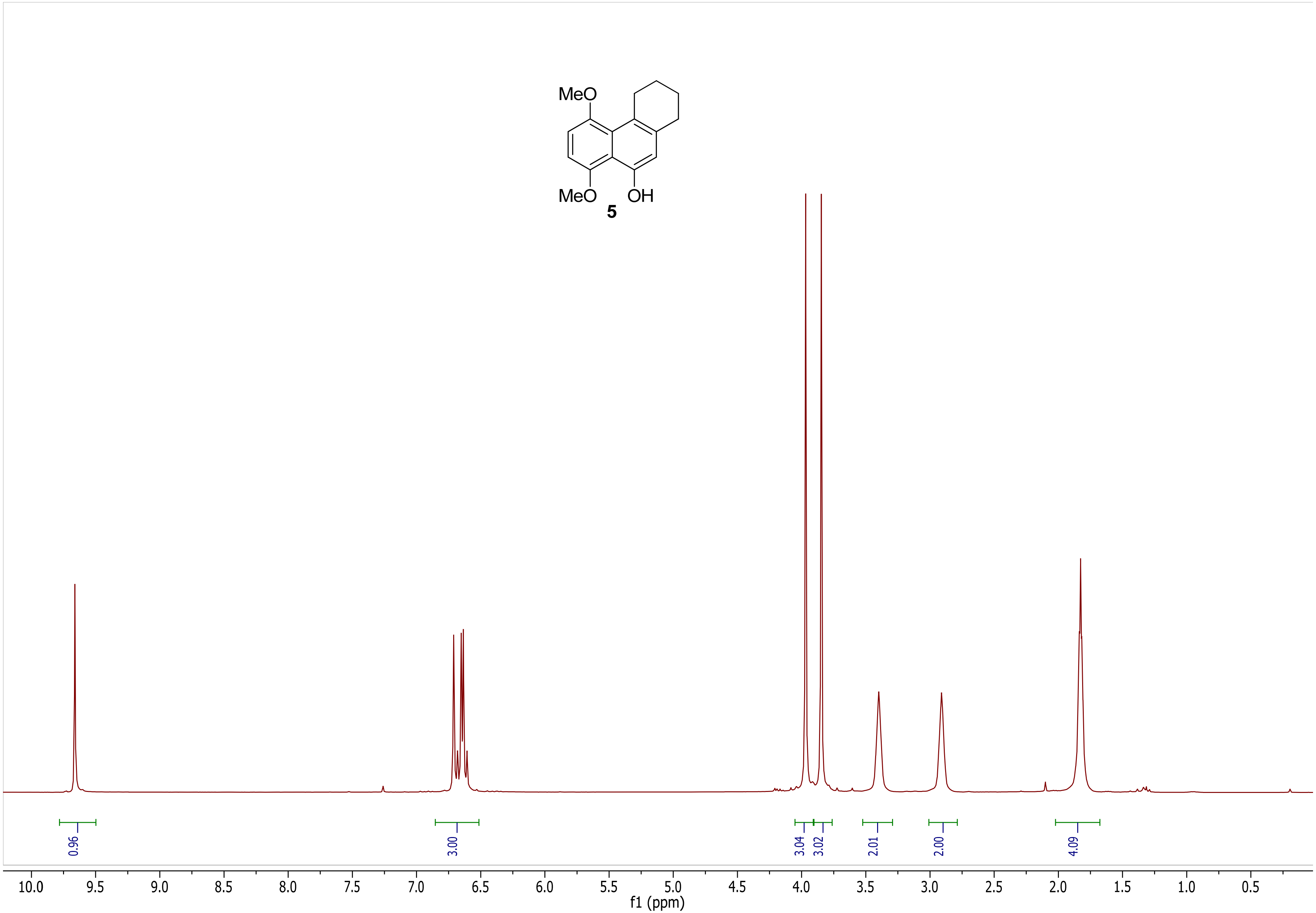
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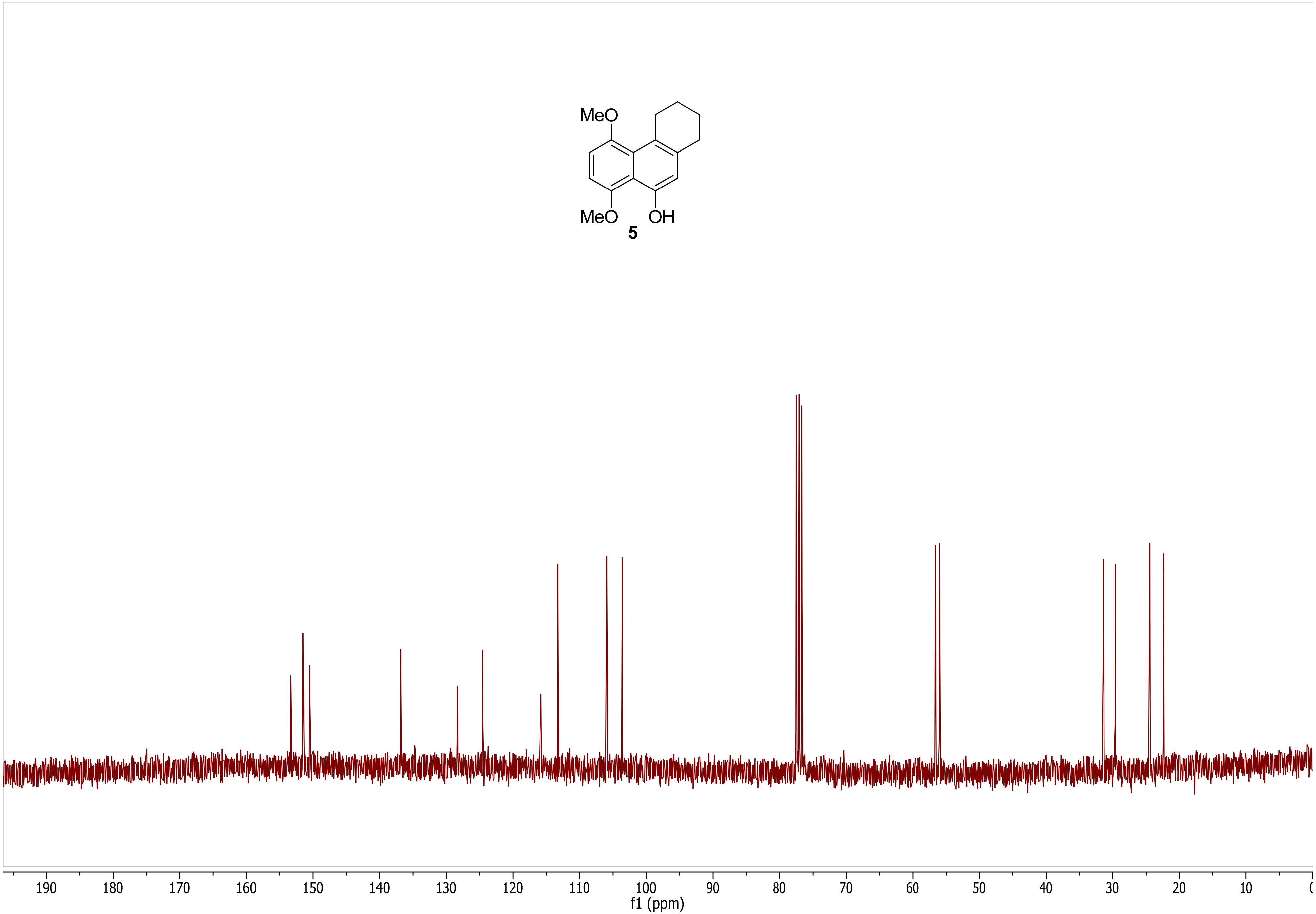
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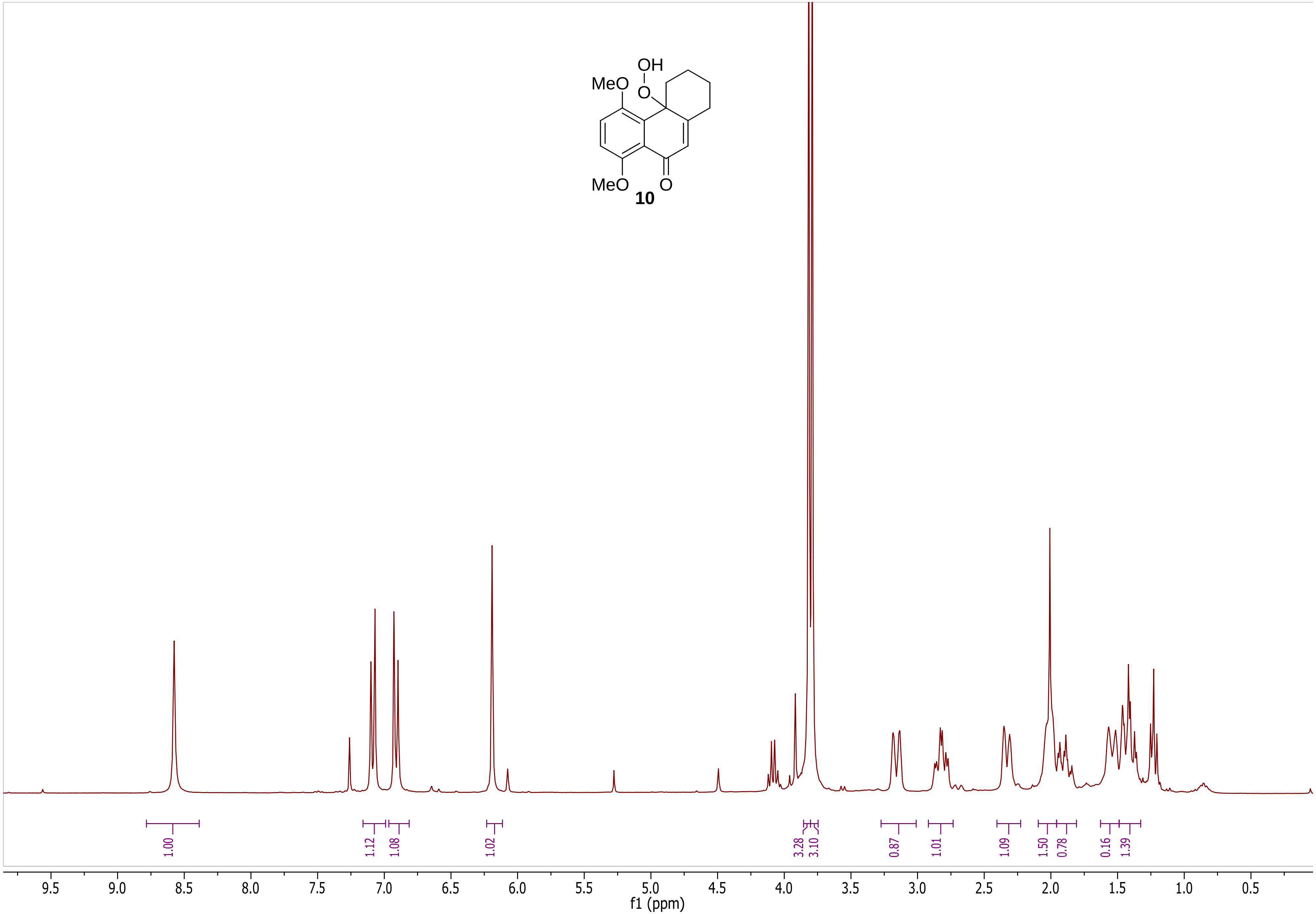
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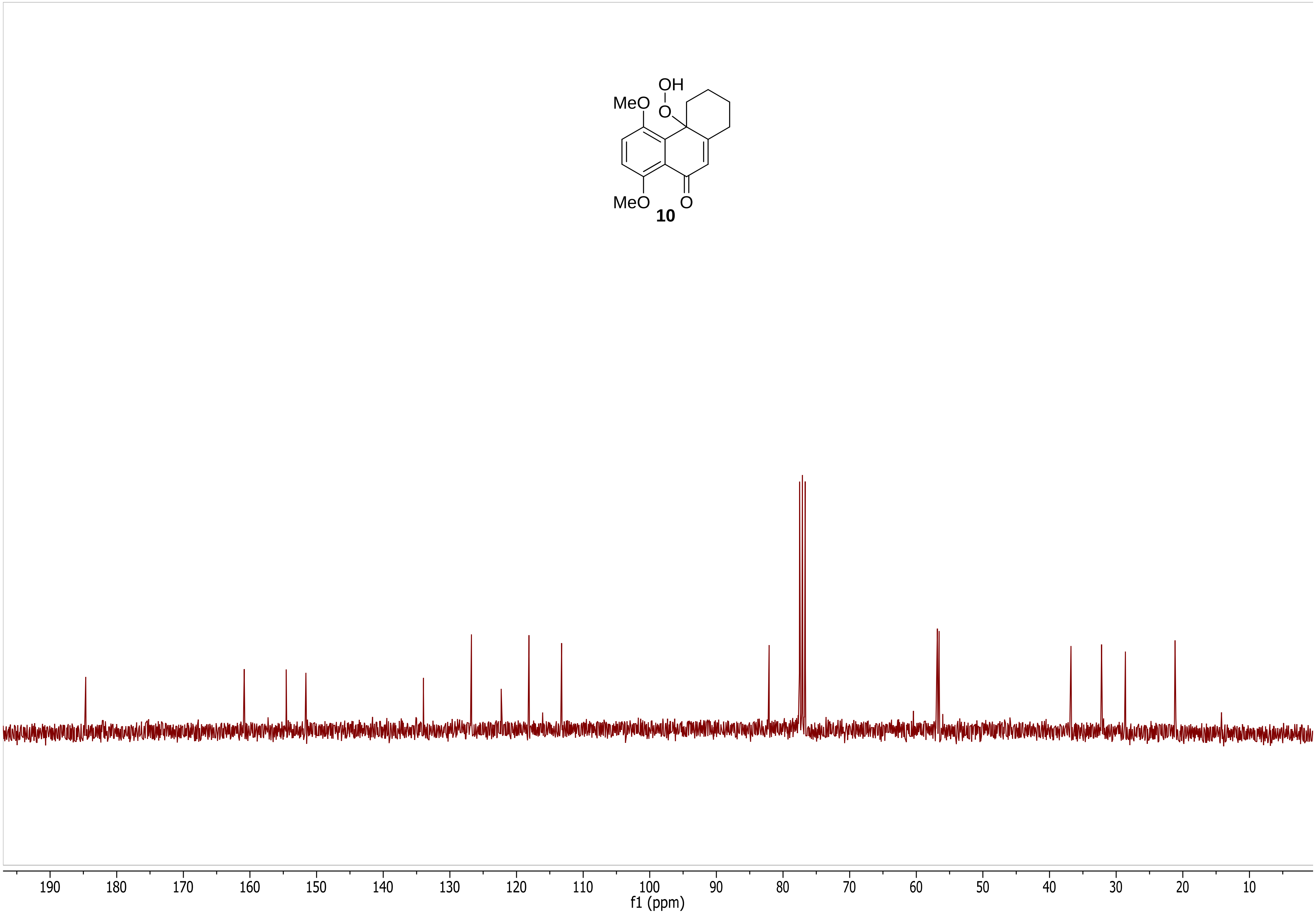
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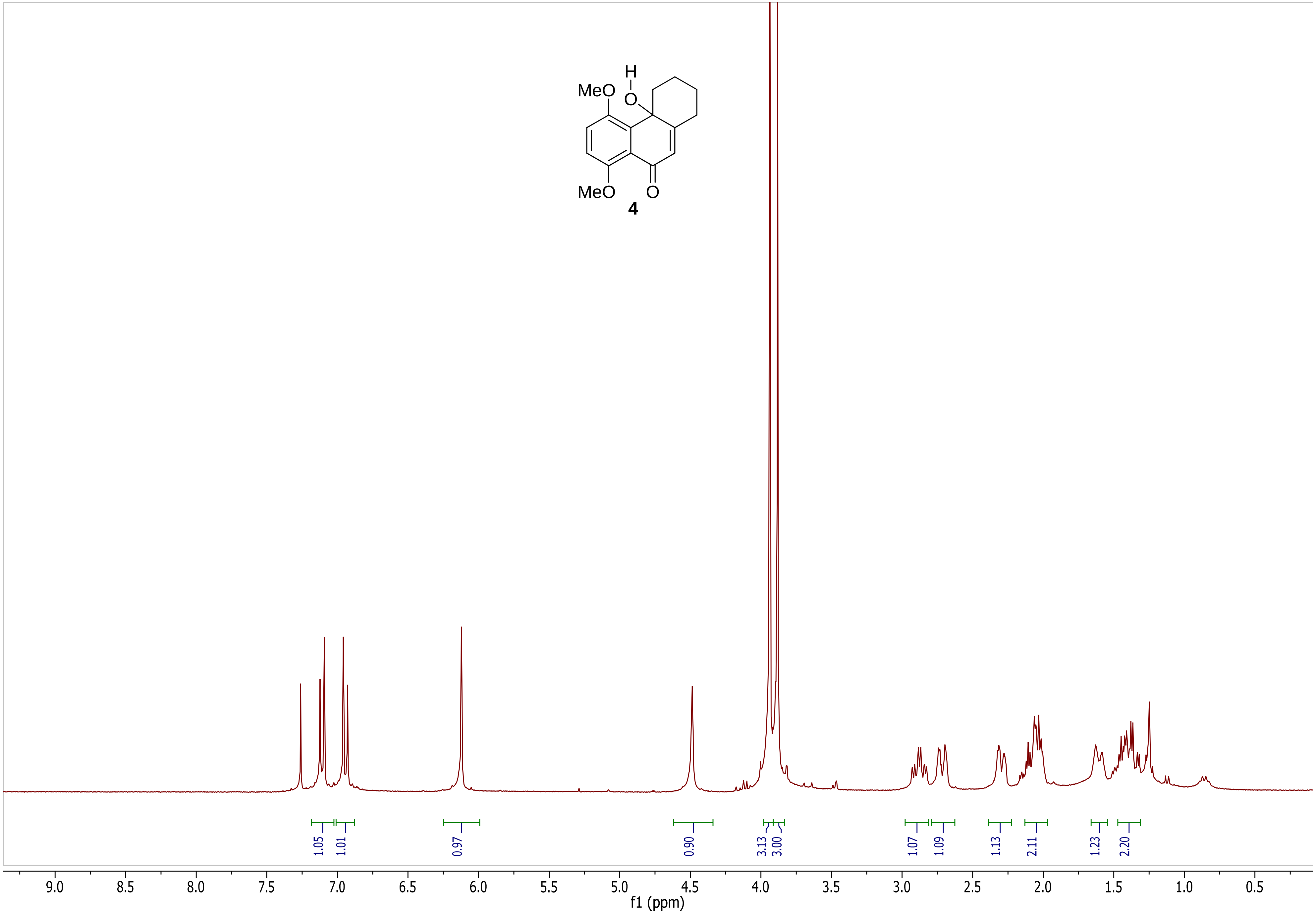
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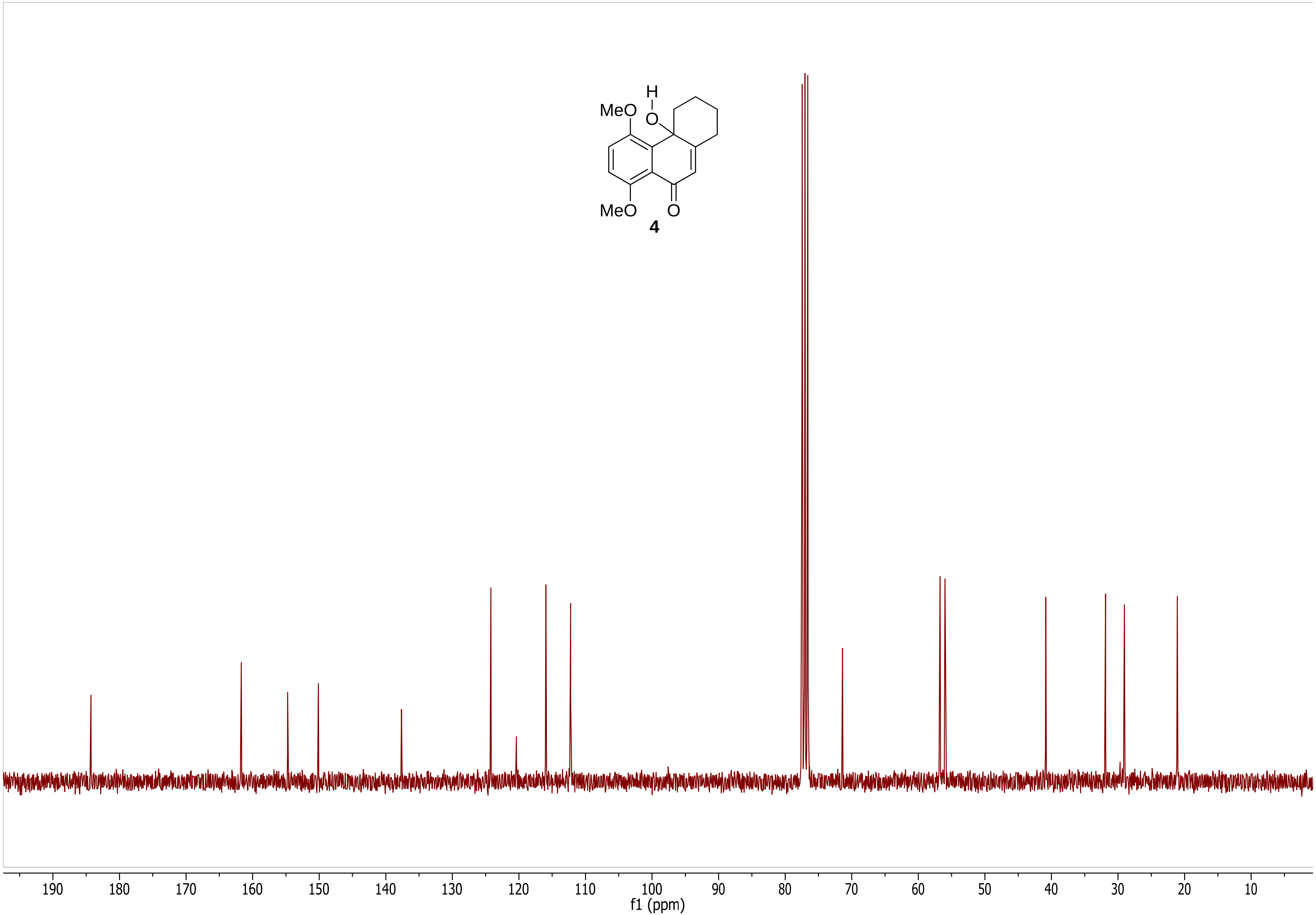
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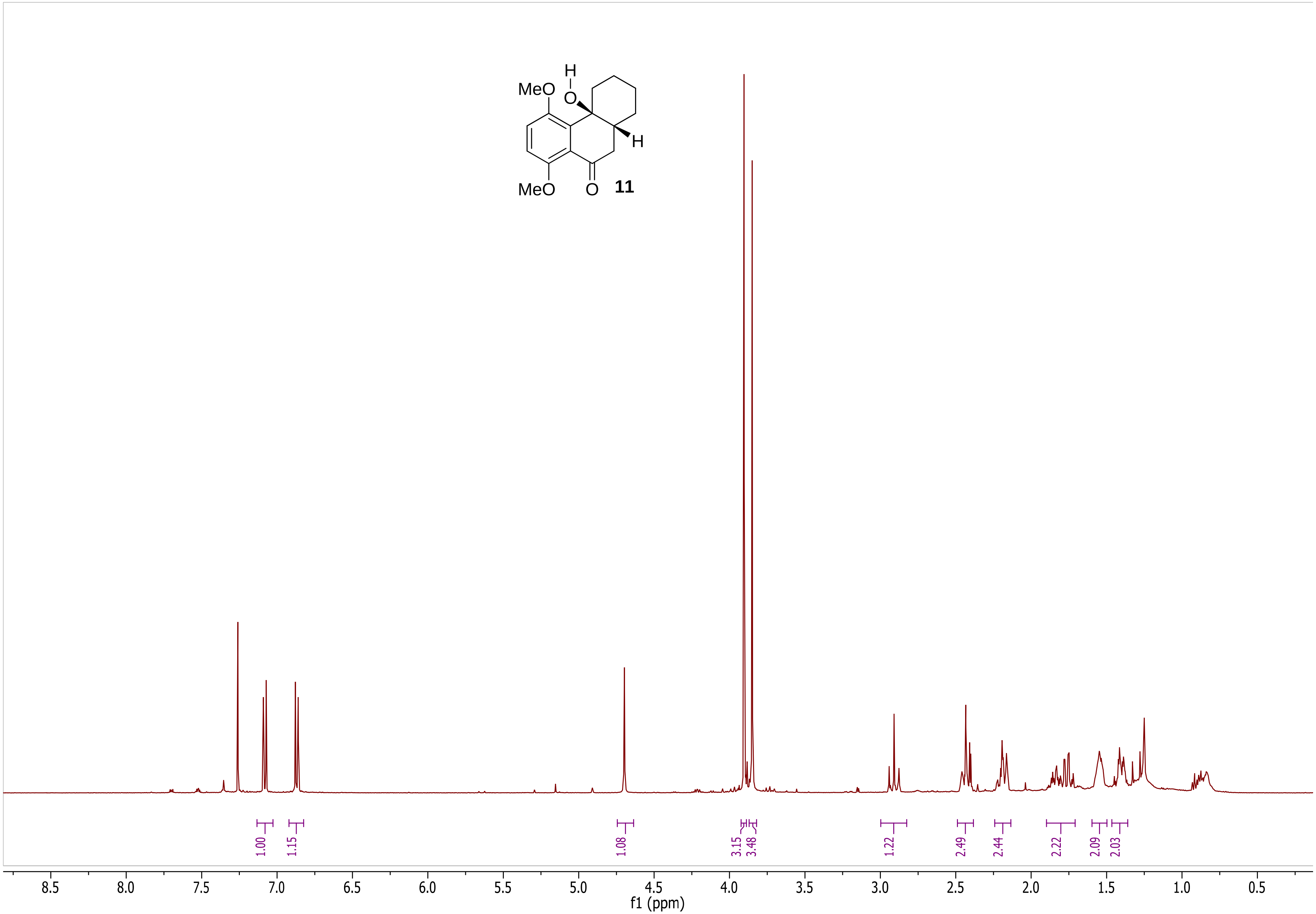
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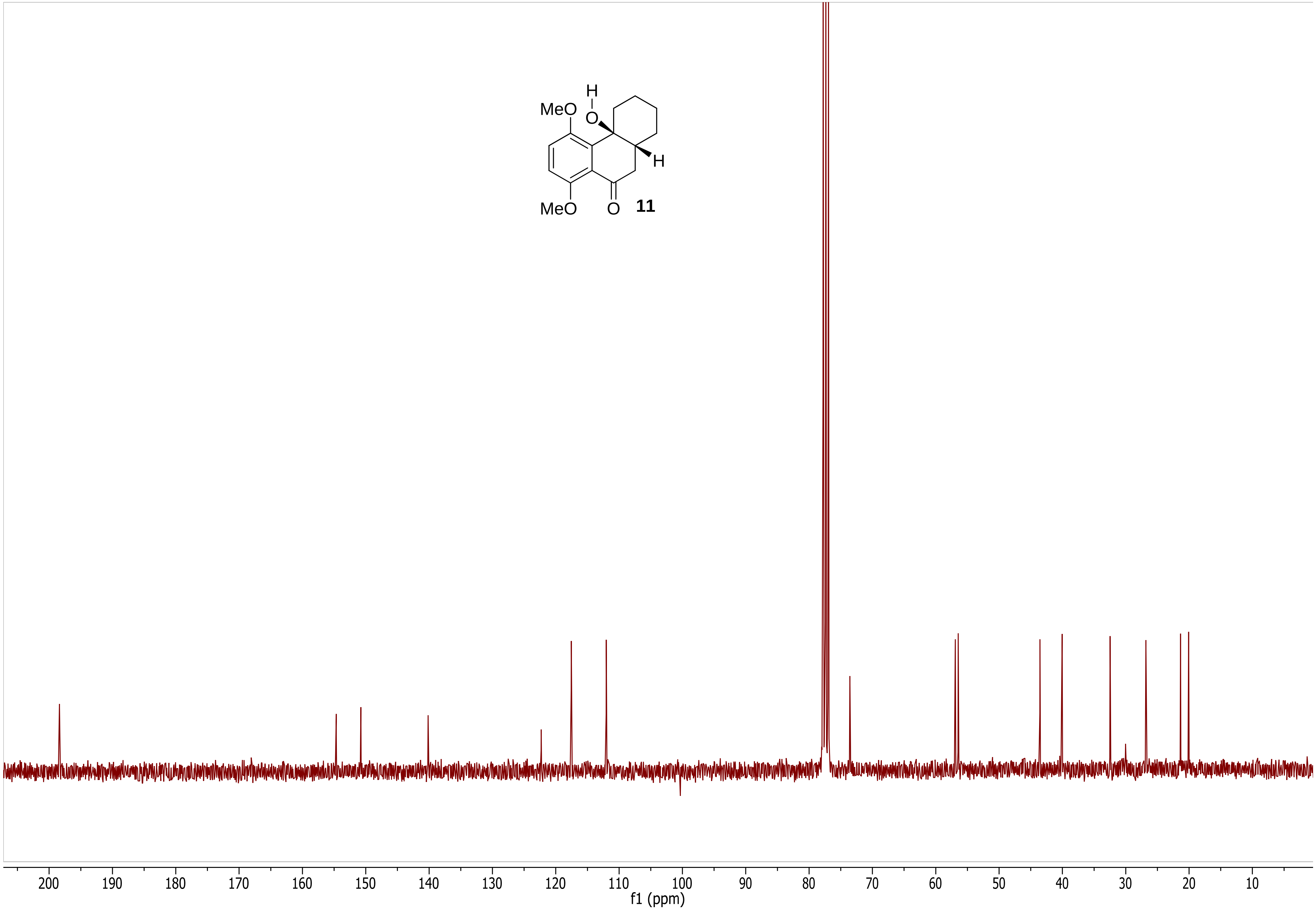
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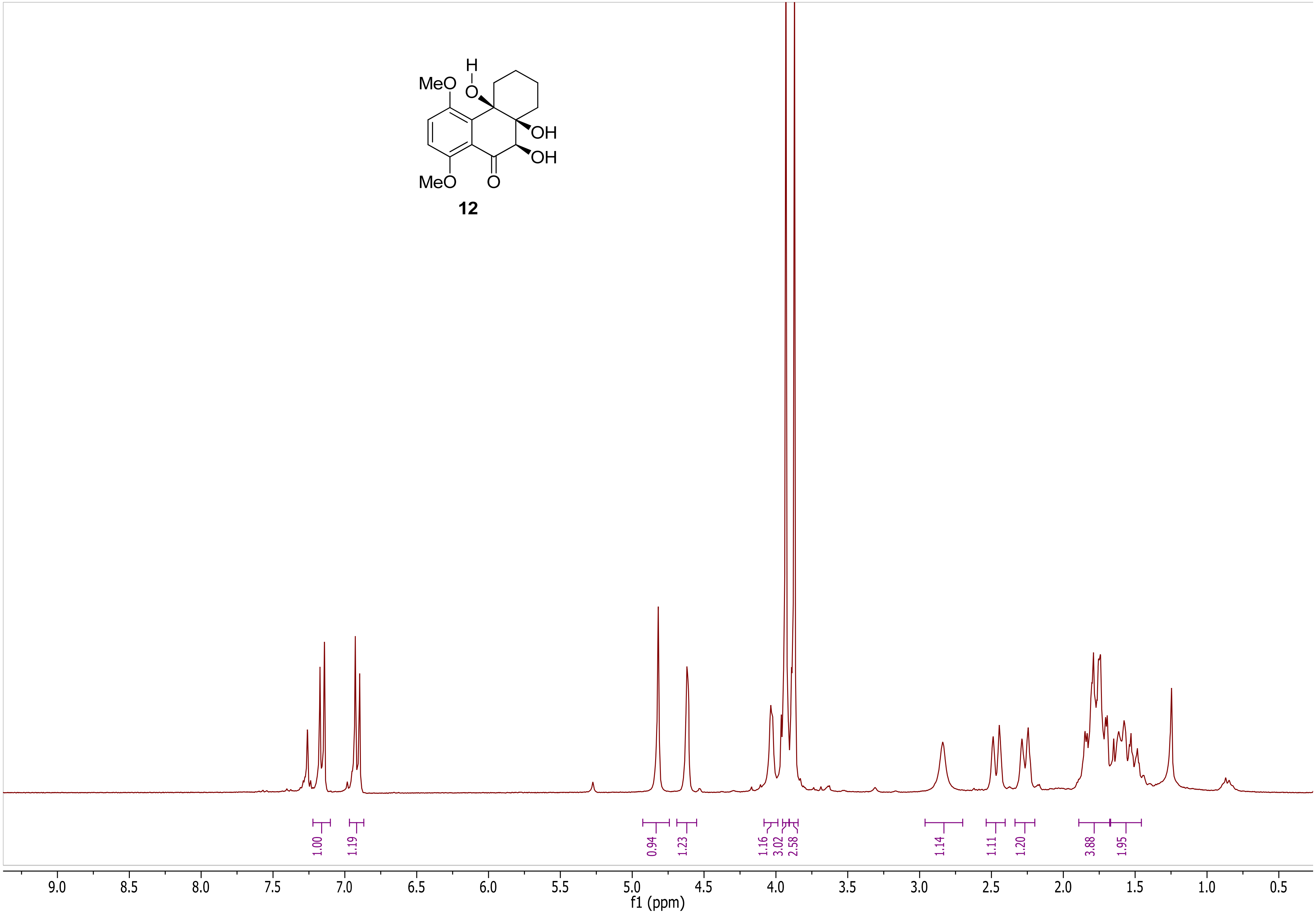
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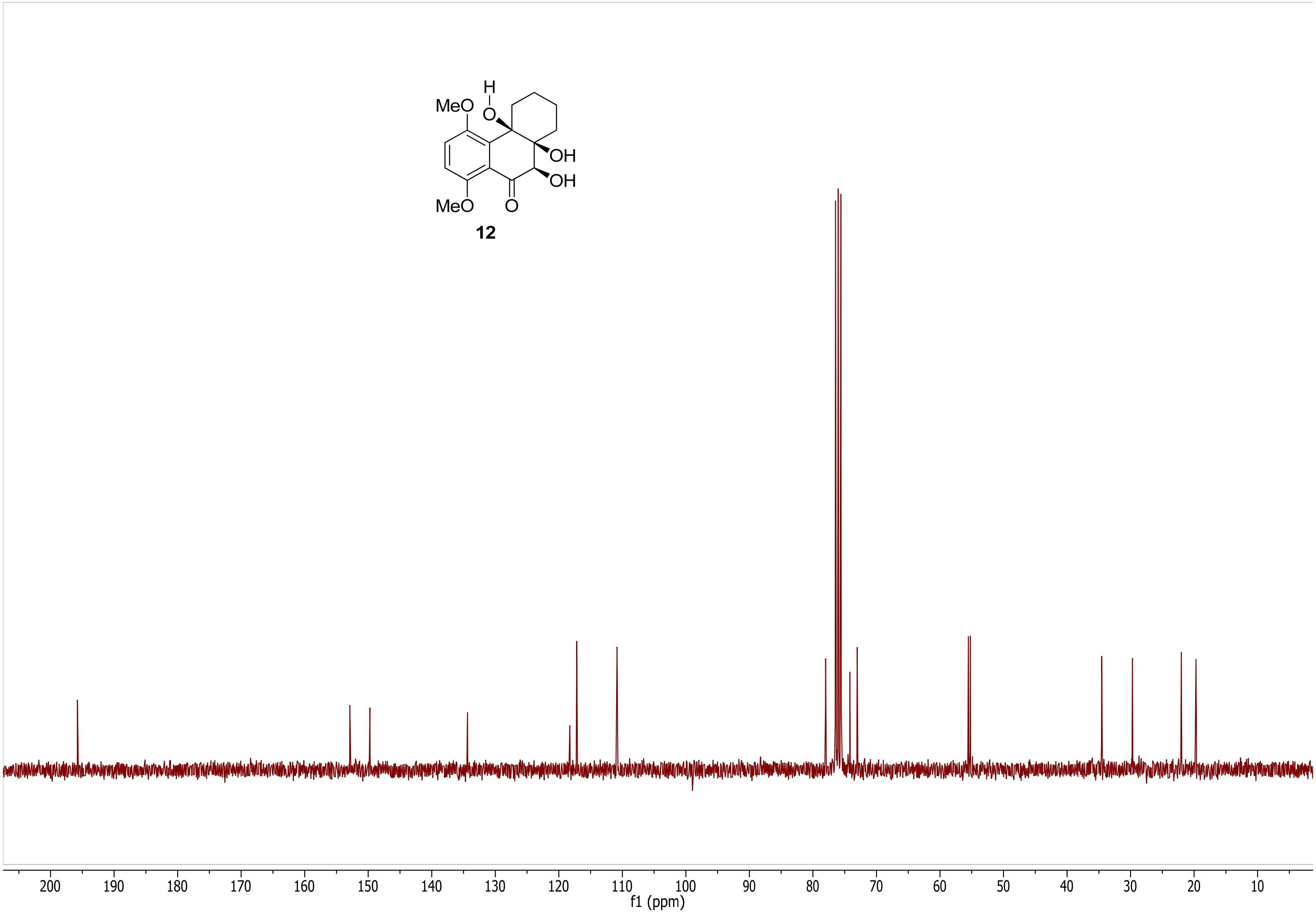
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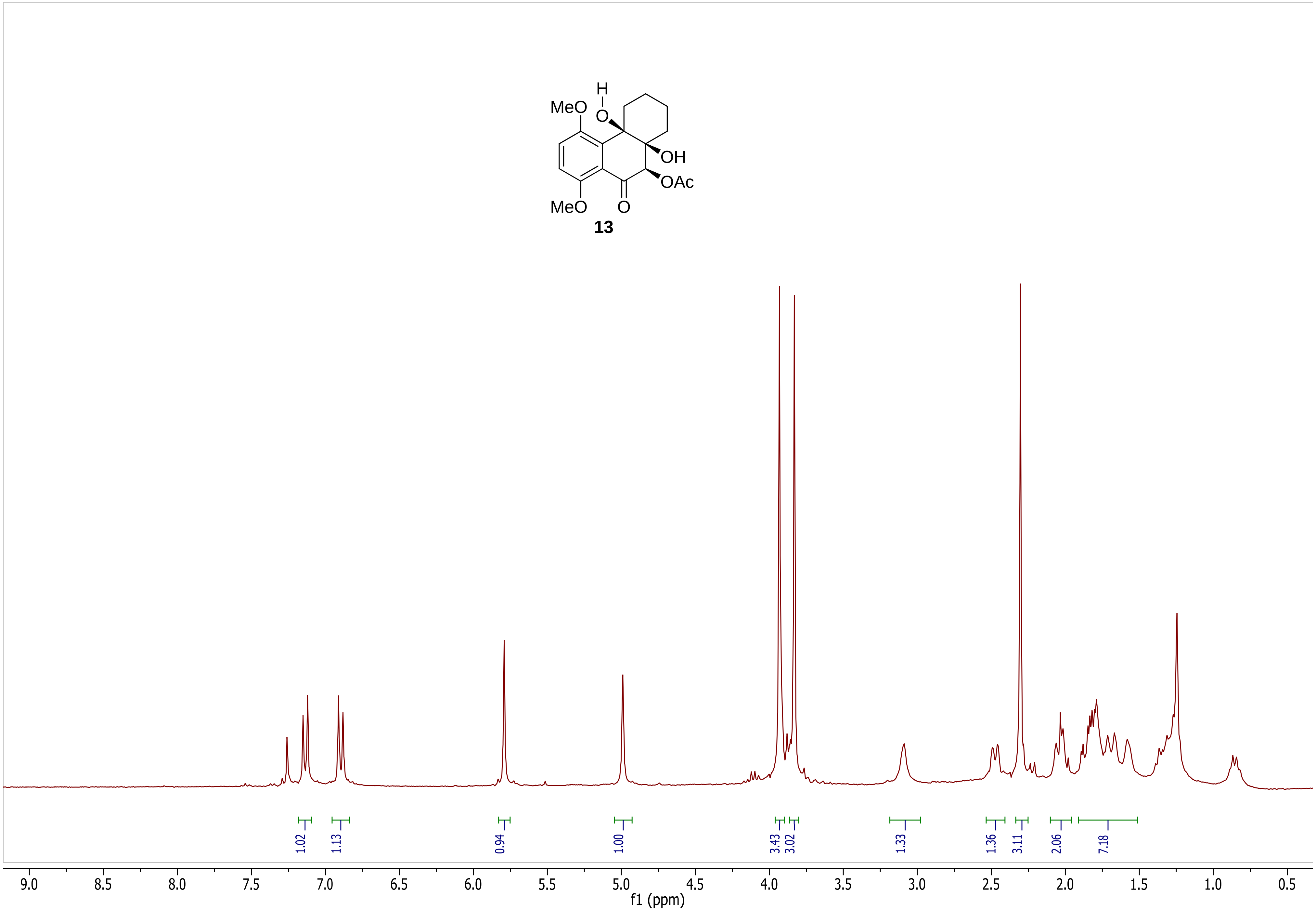
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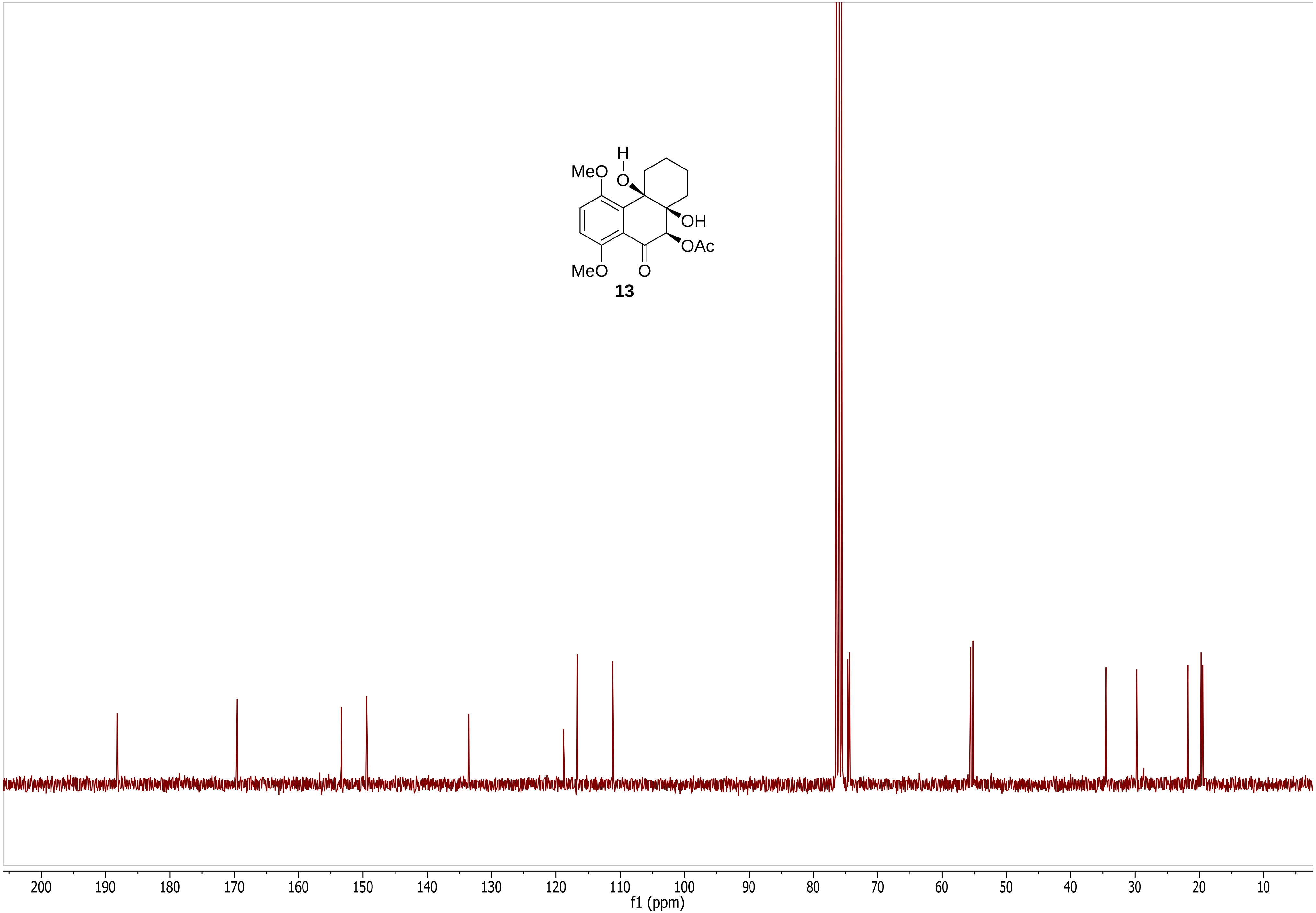
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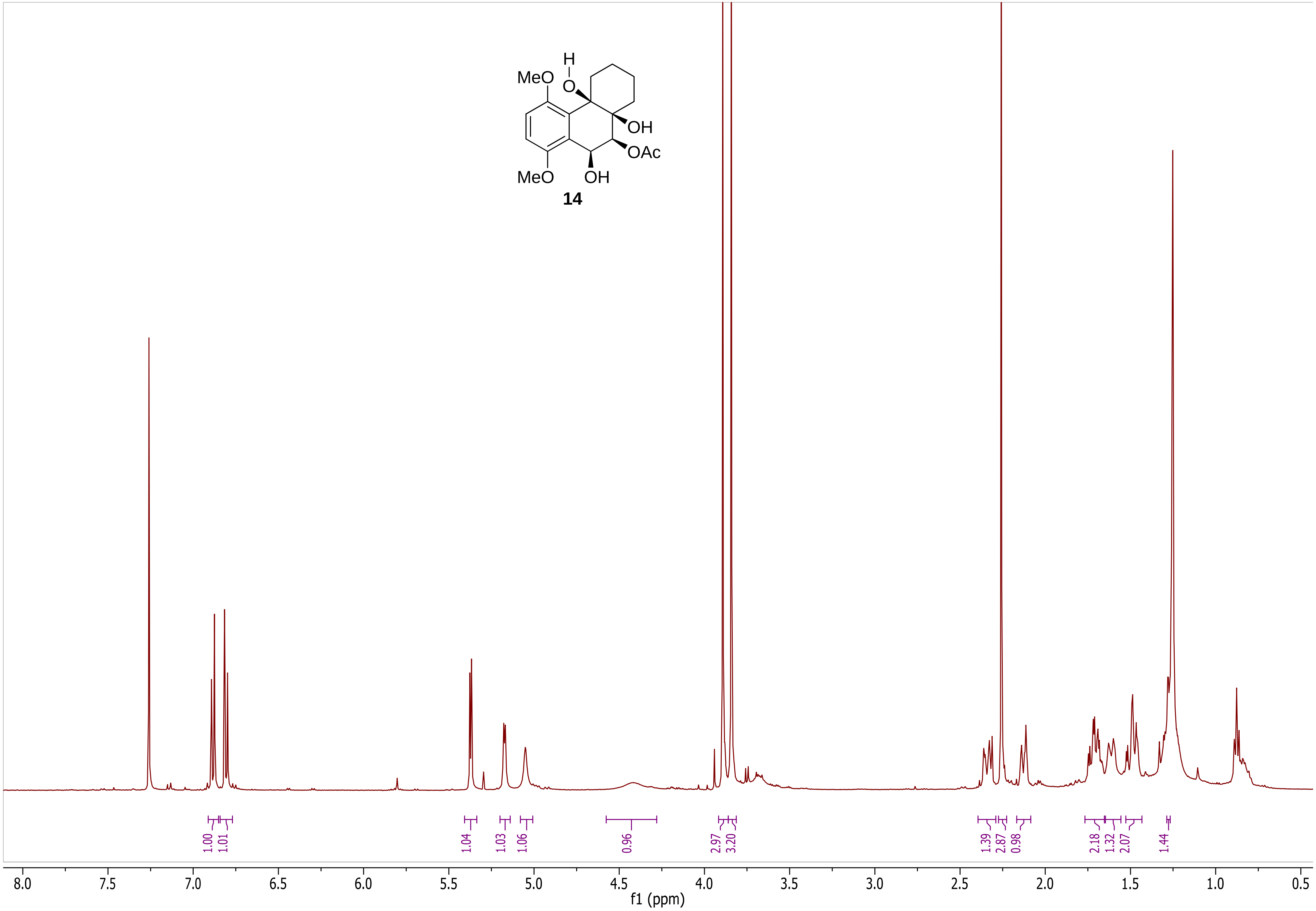
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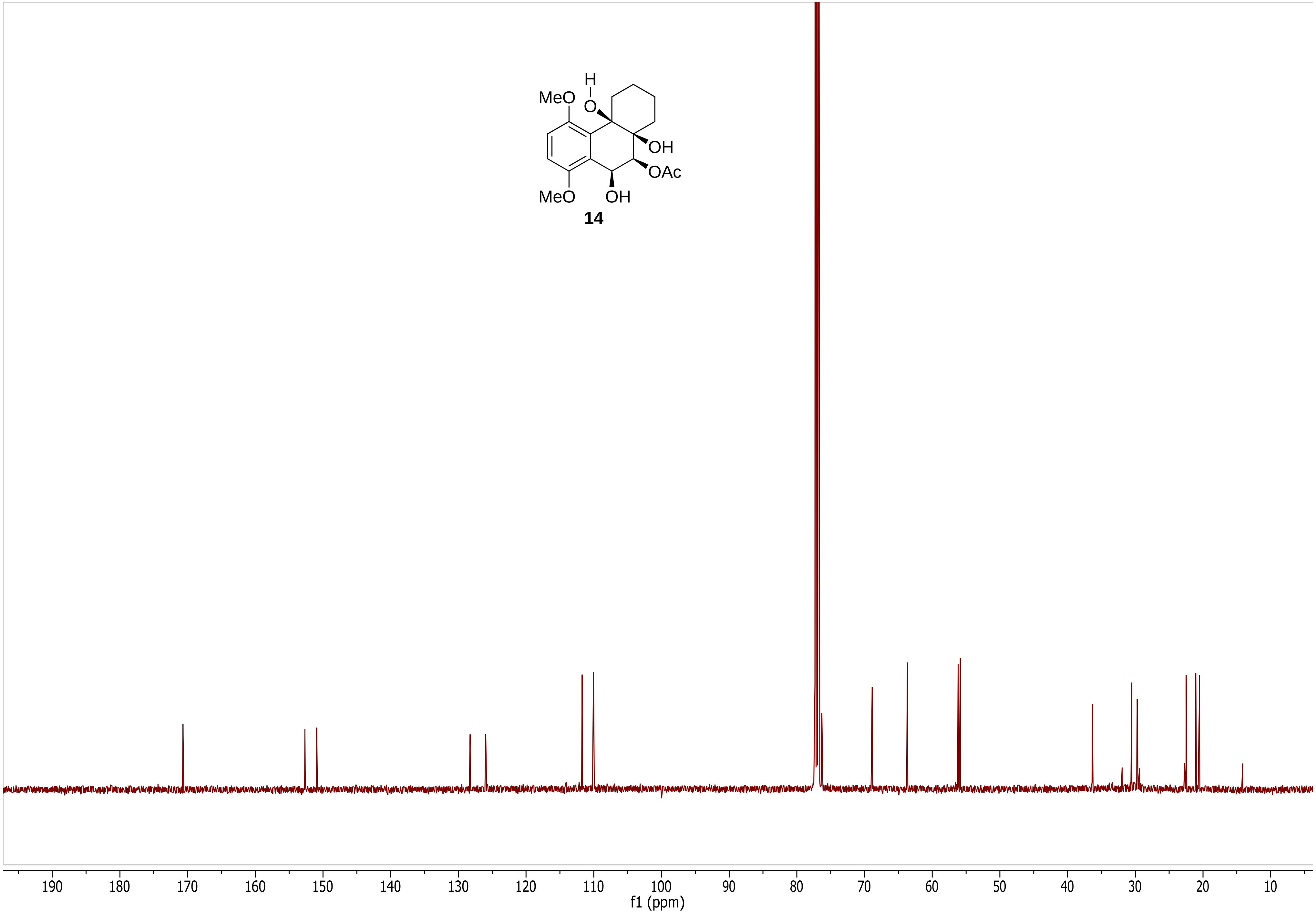
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**14**

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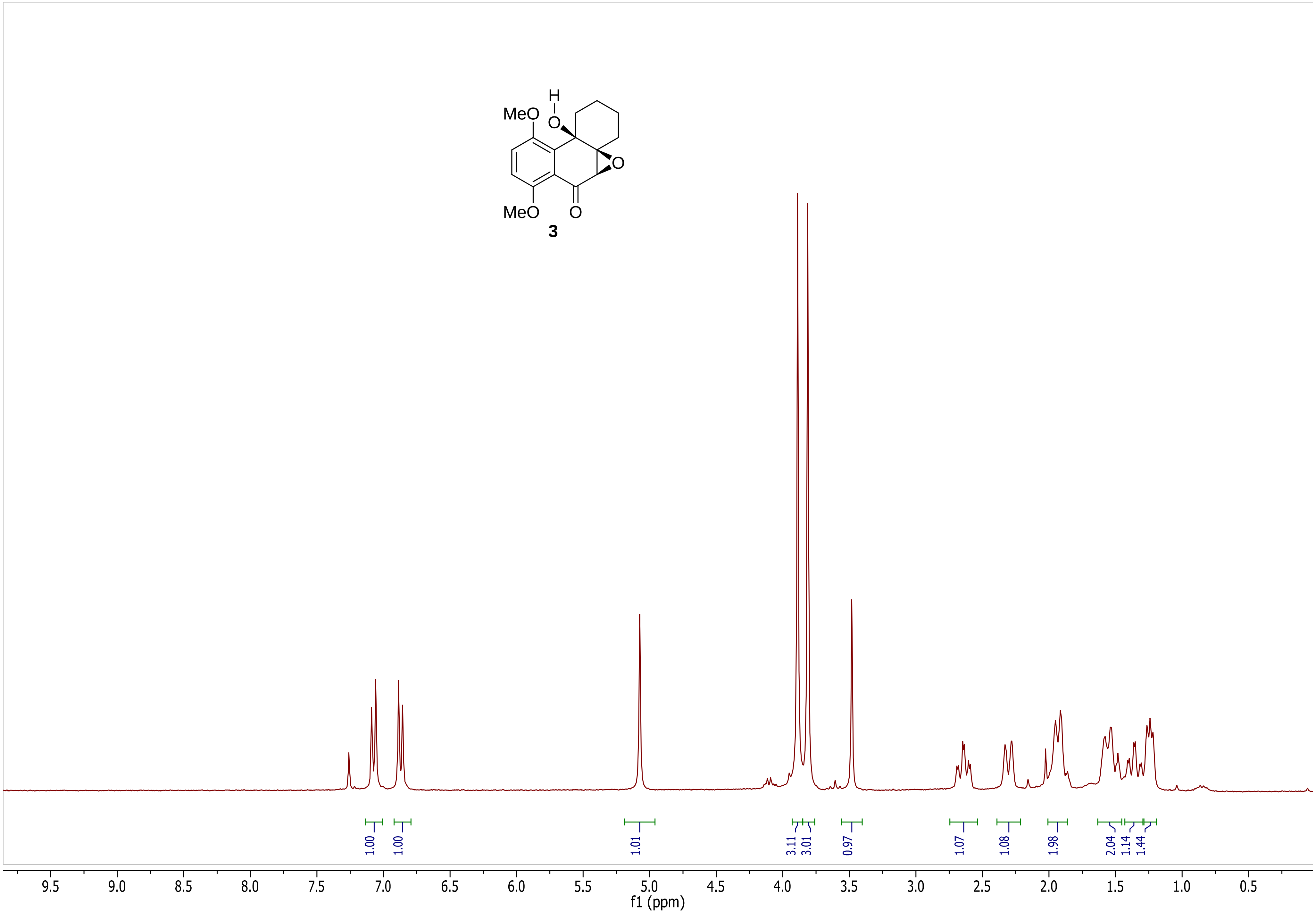
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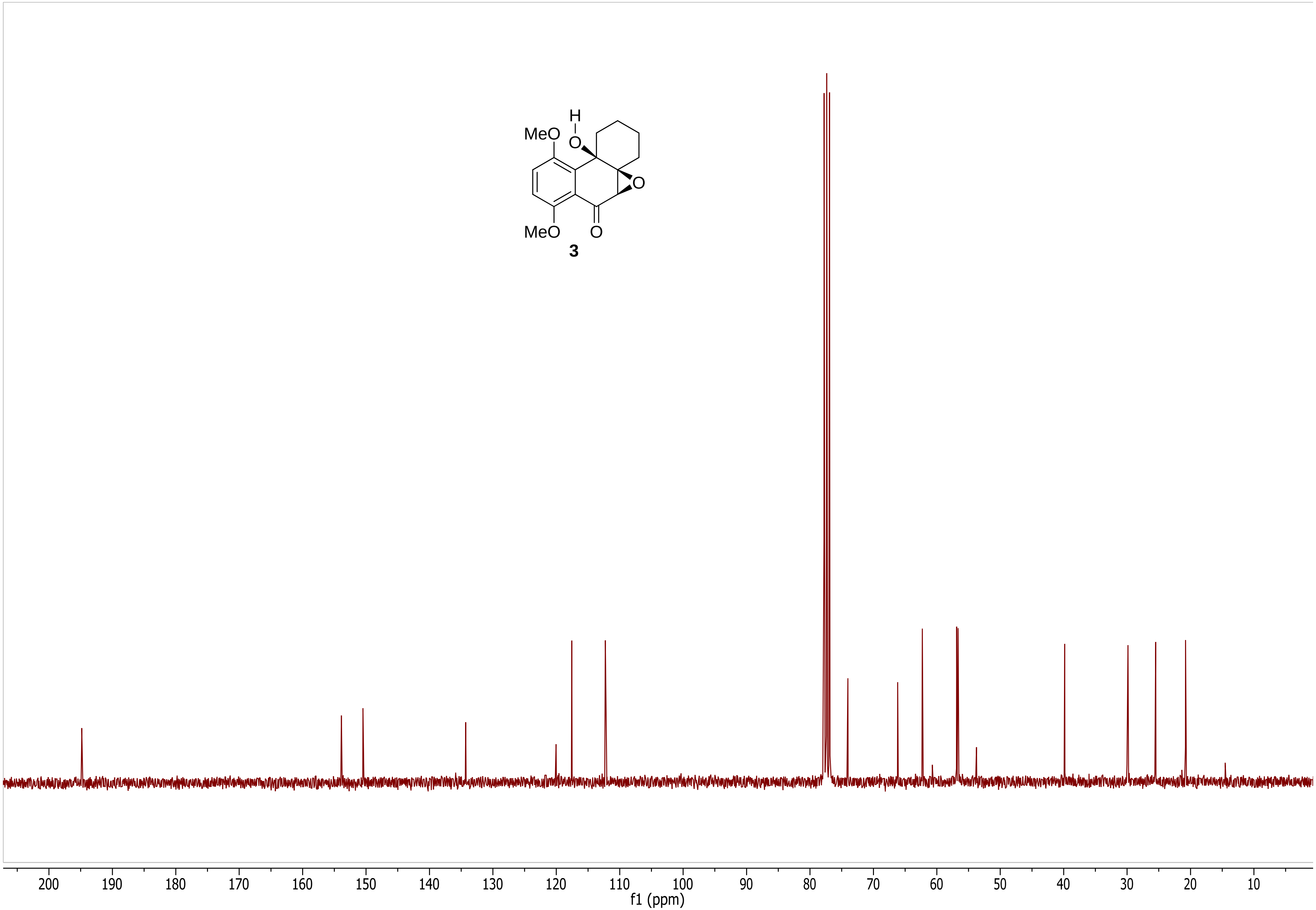
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**3**

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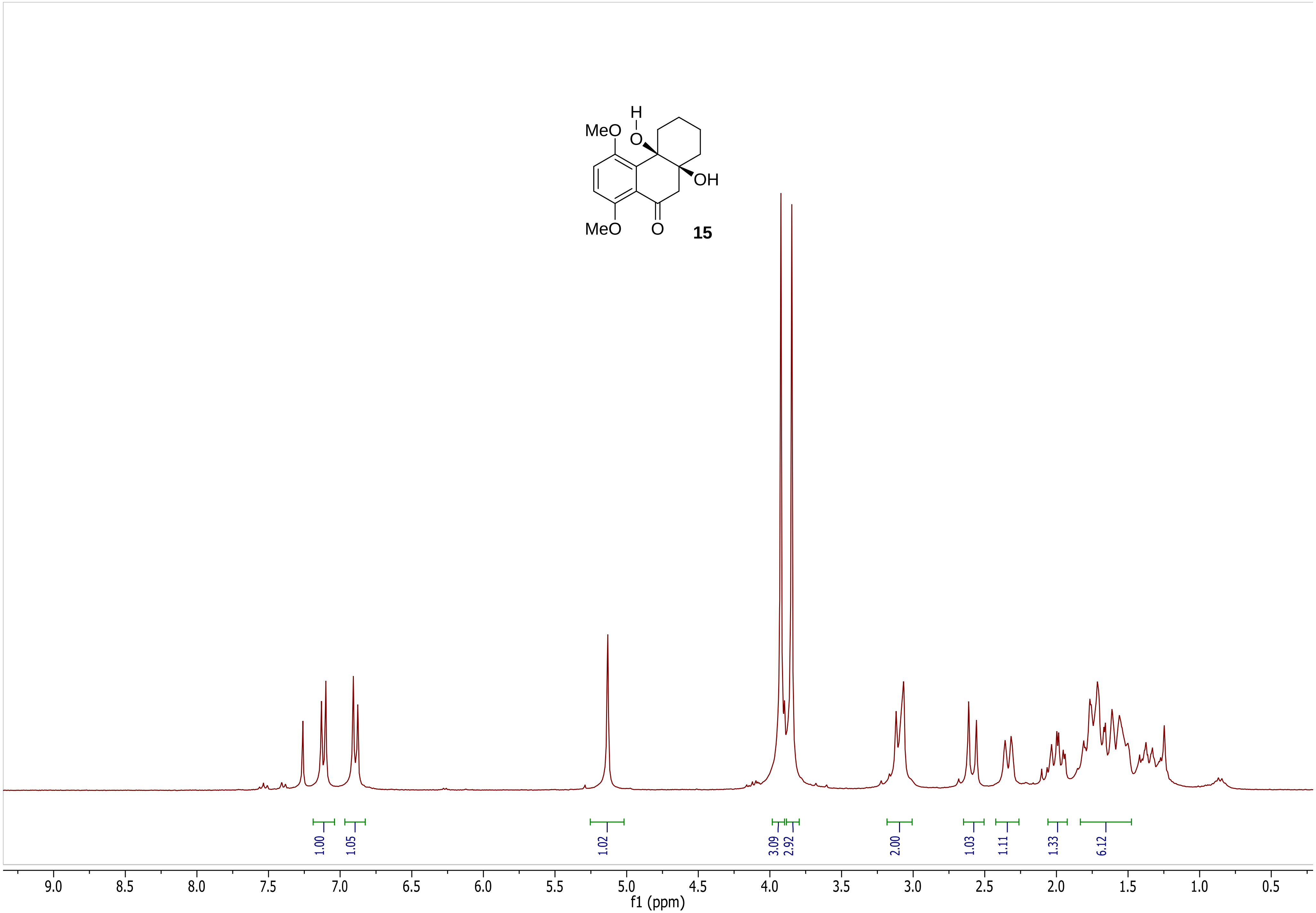
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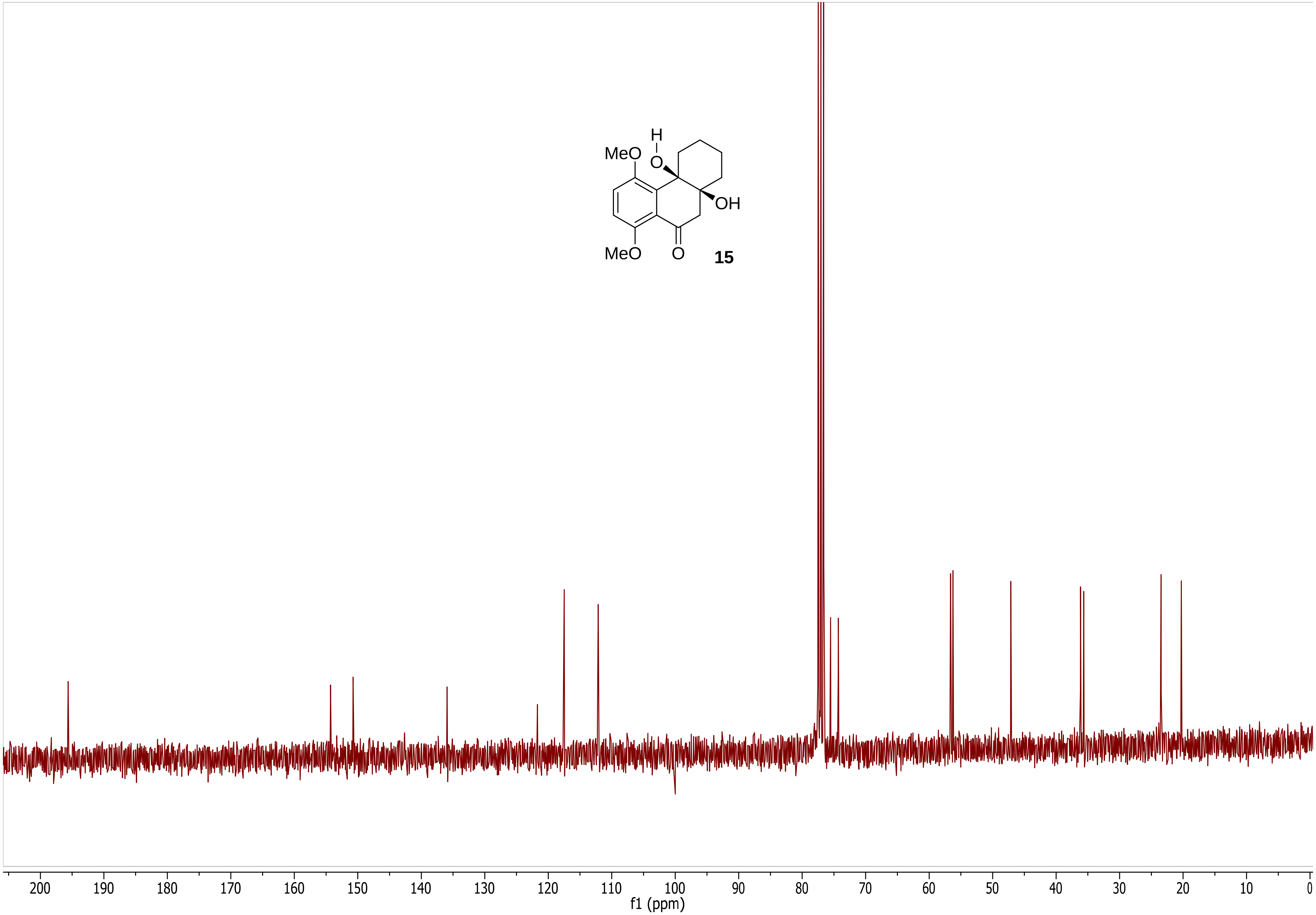
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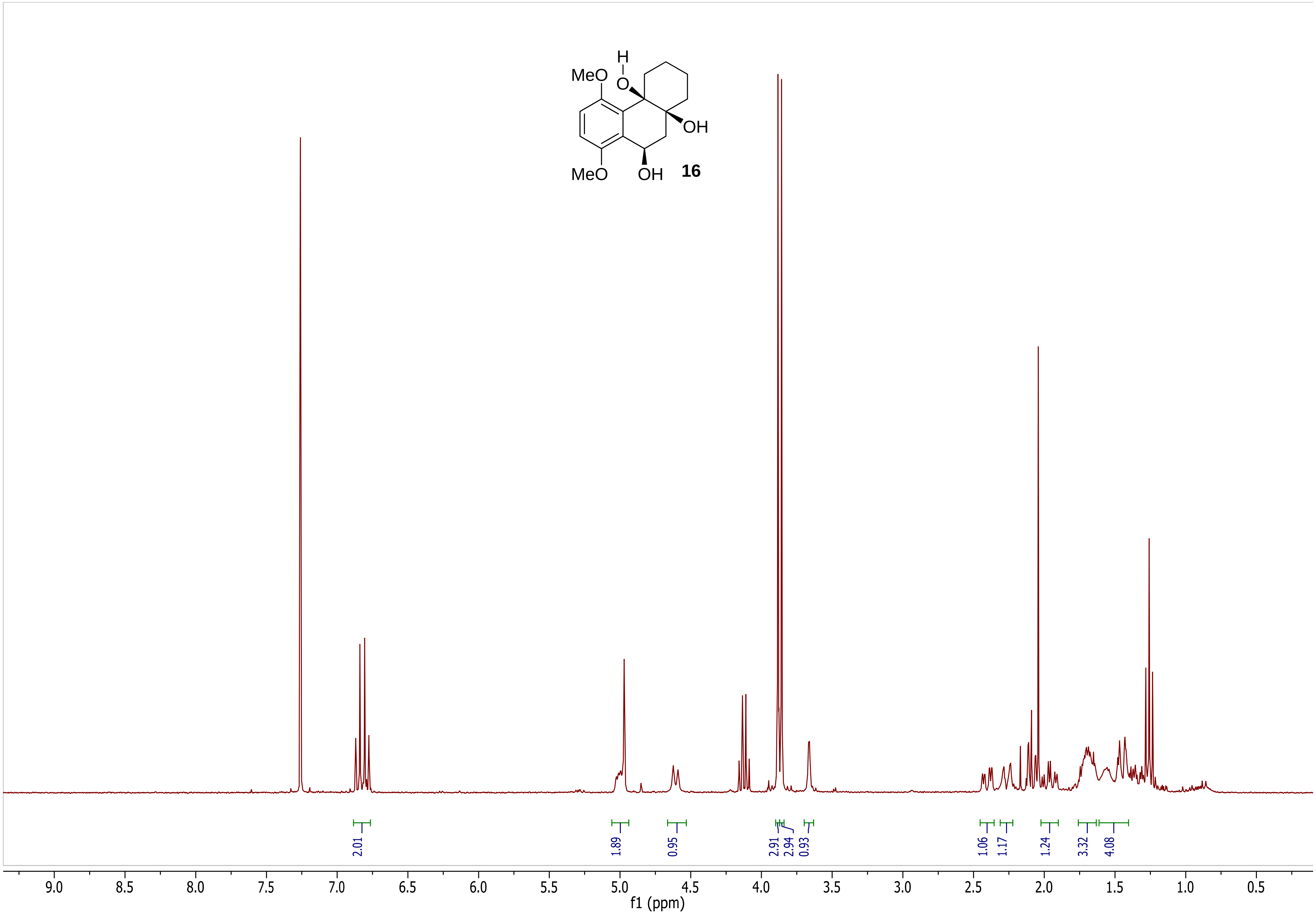
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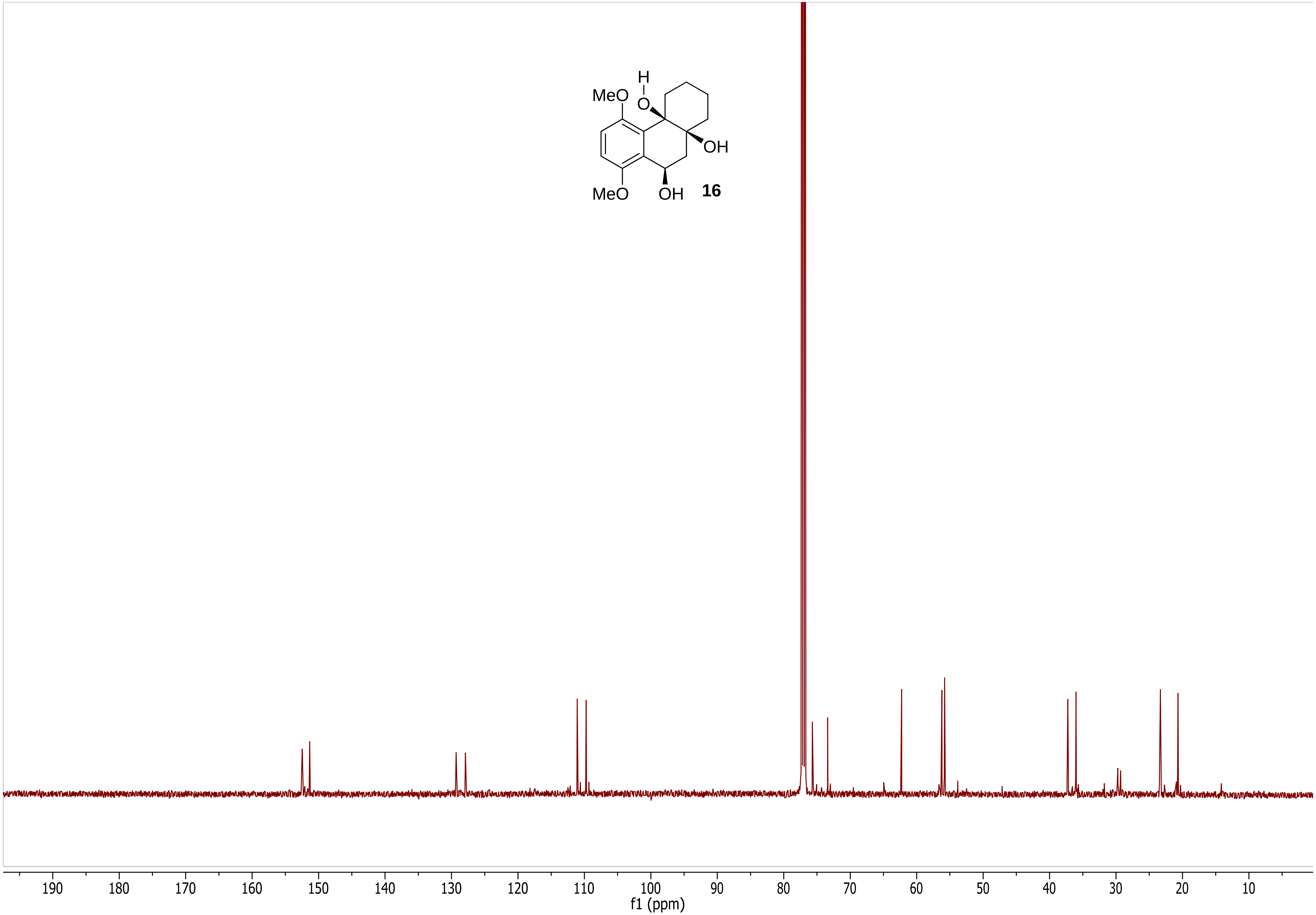

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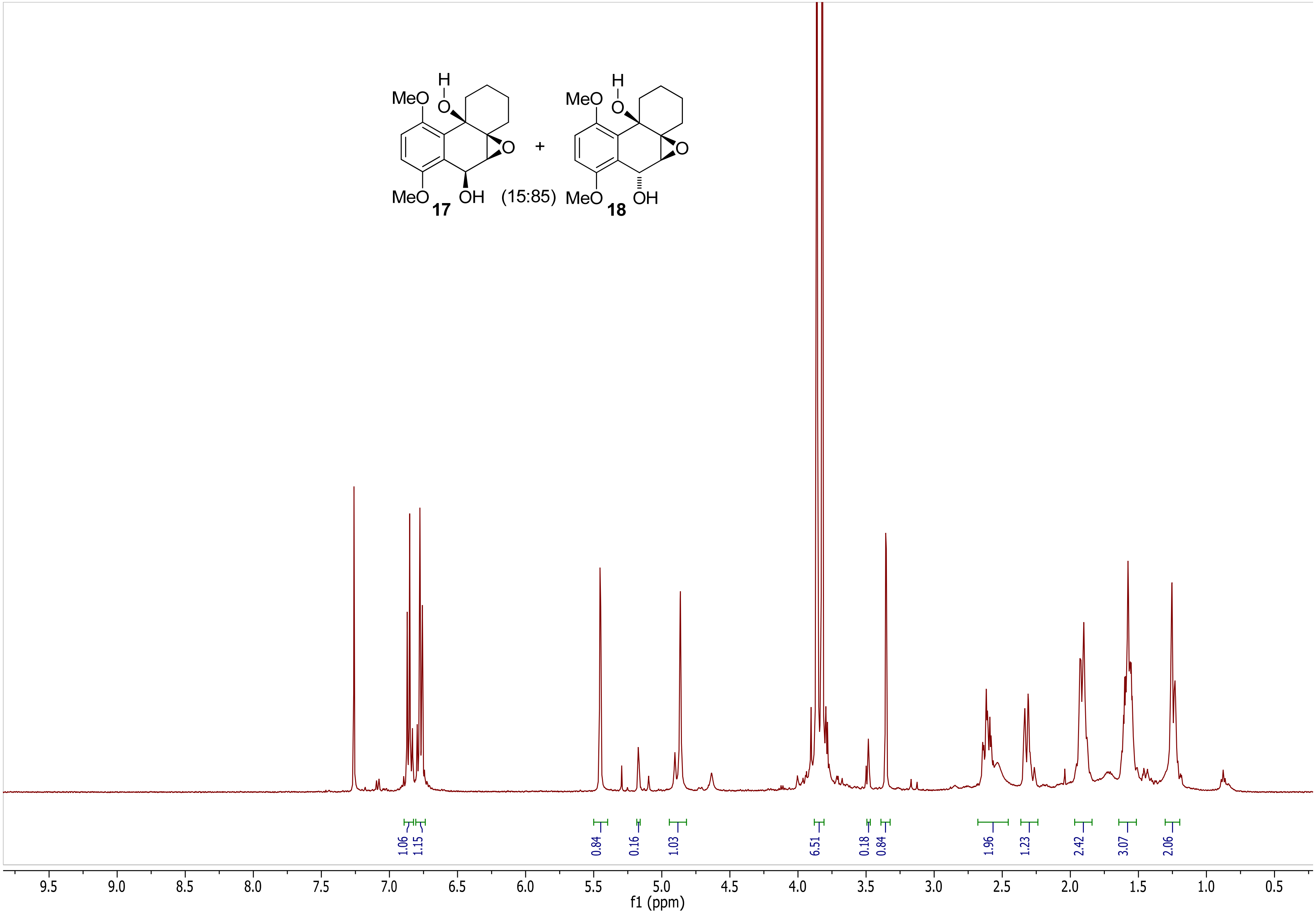
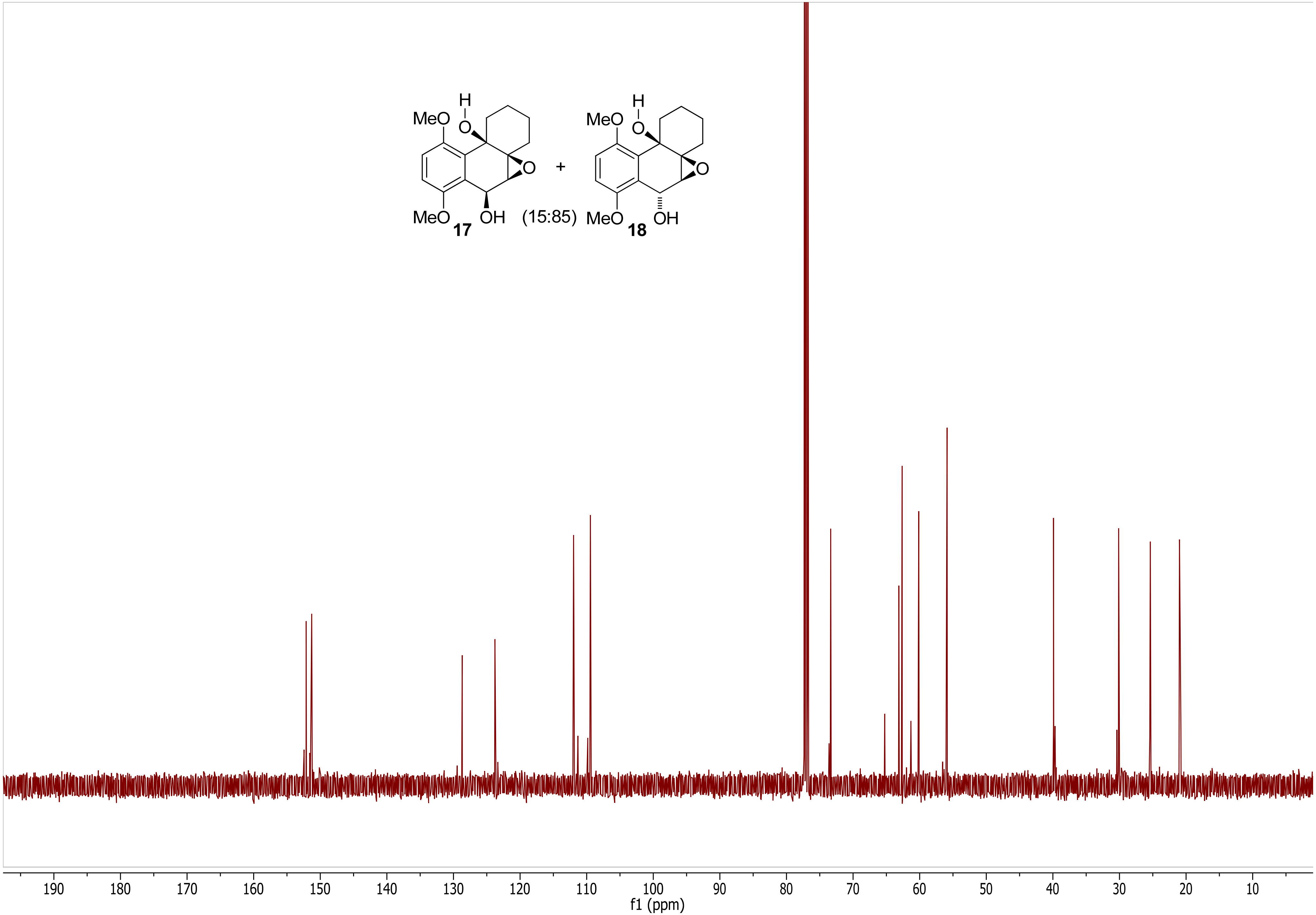
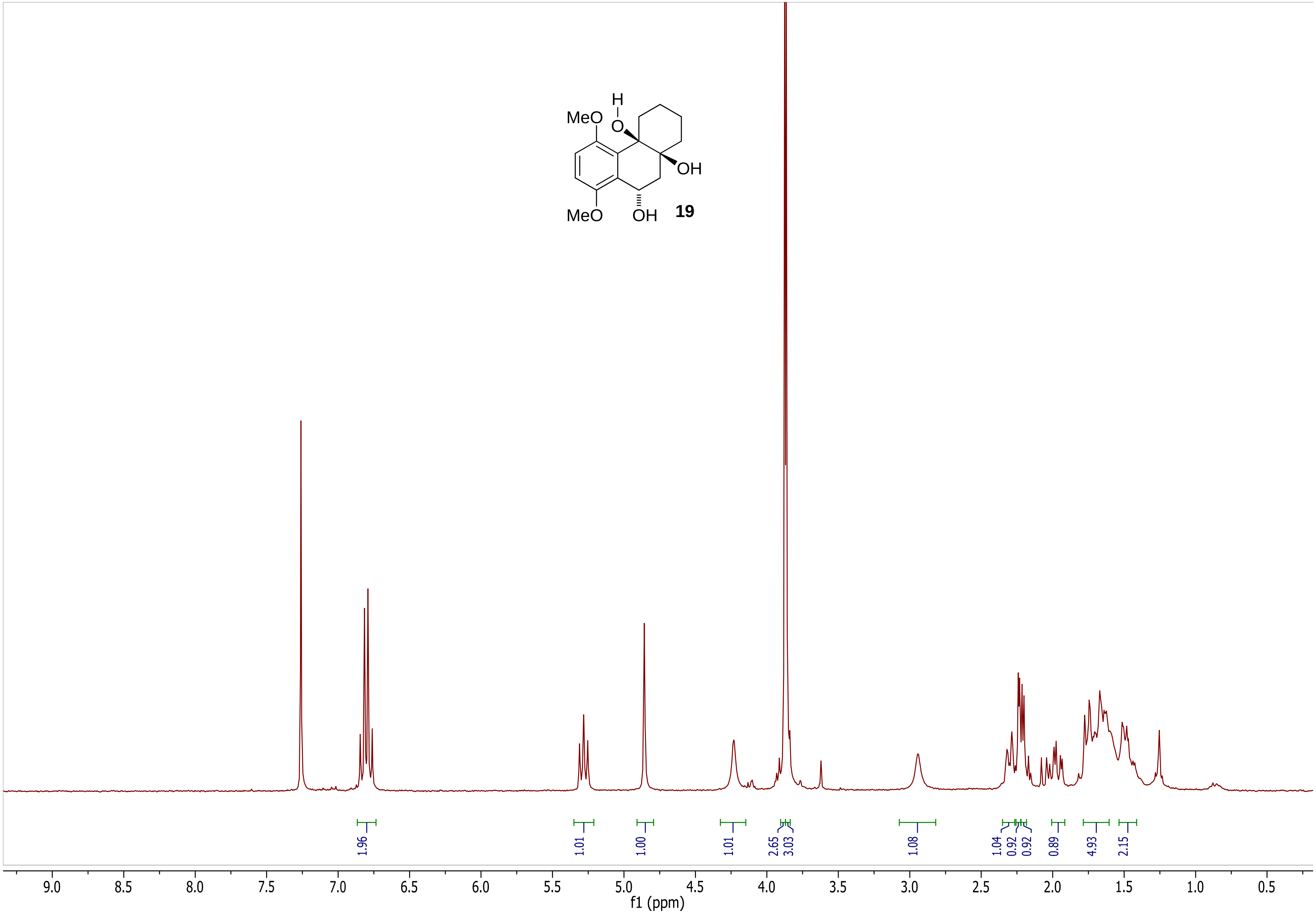
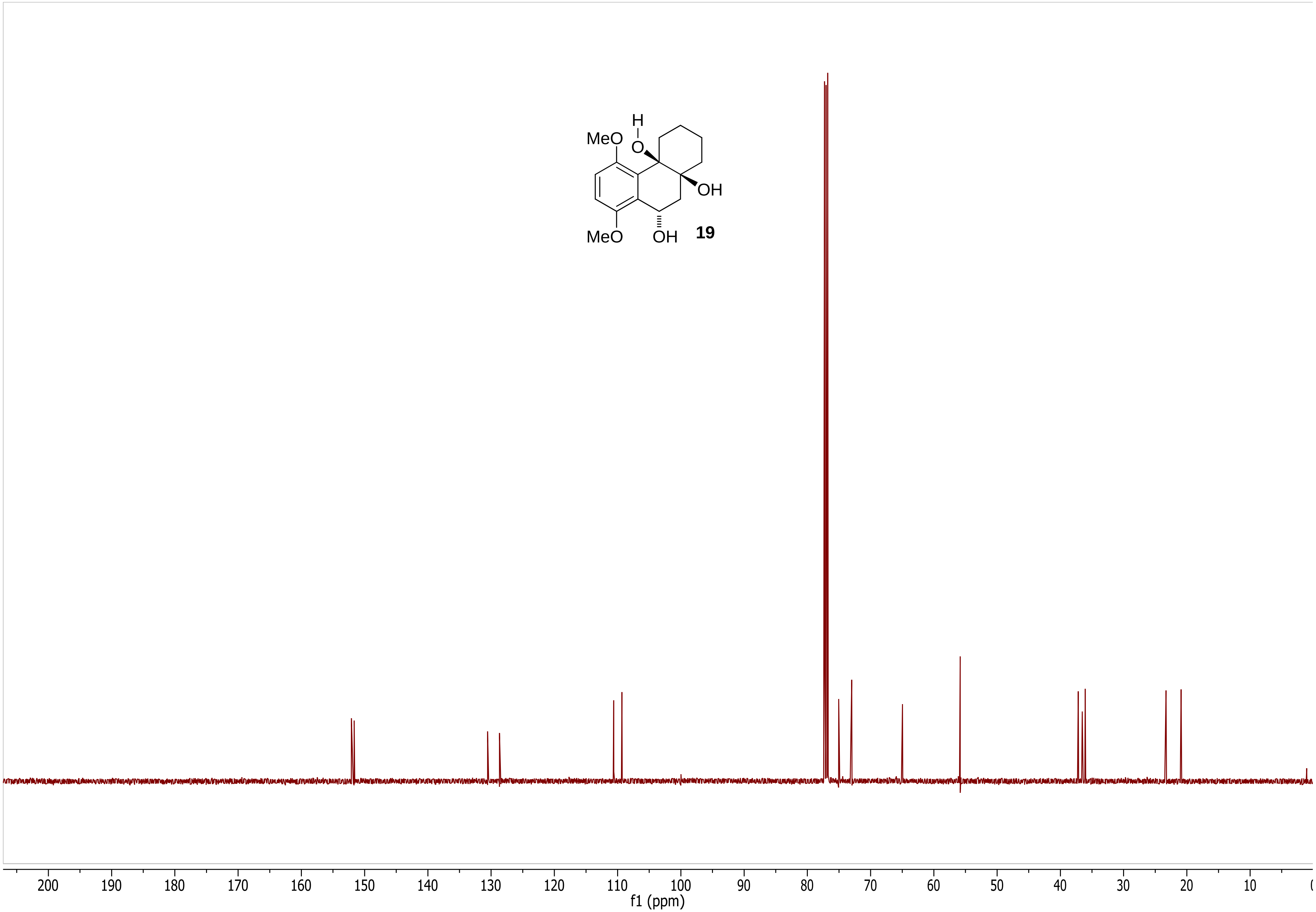
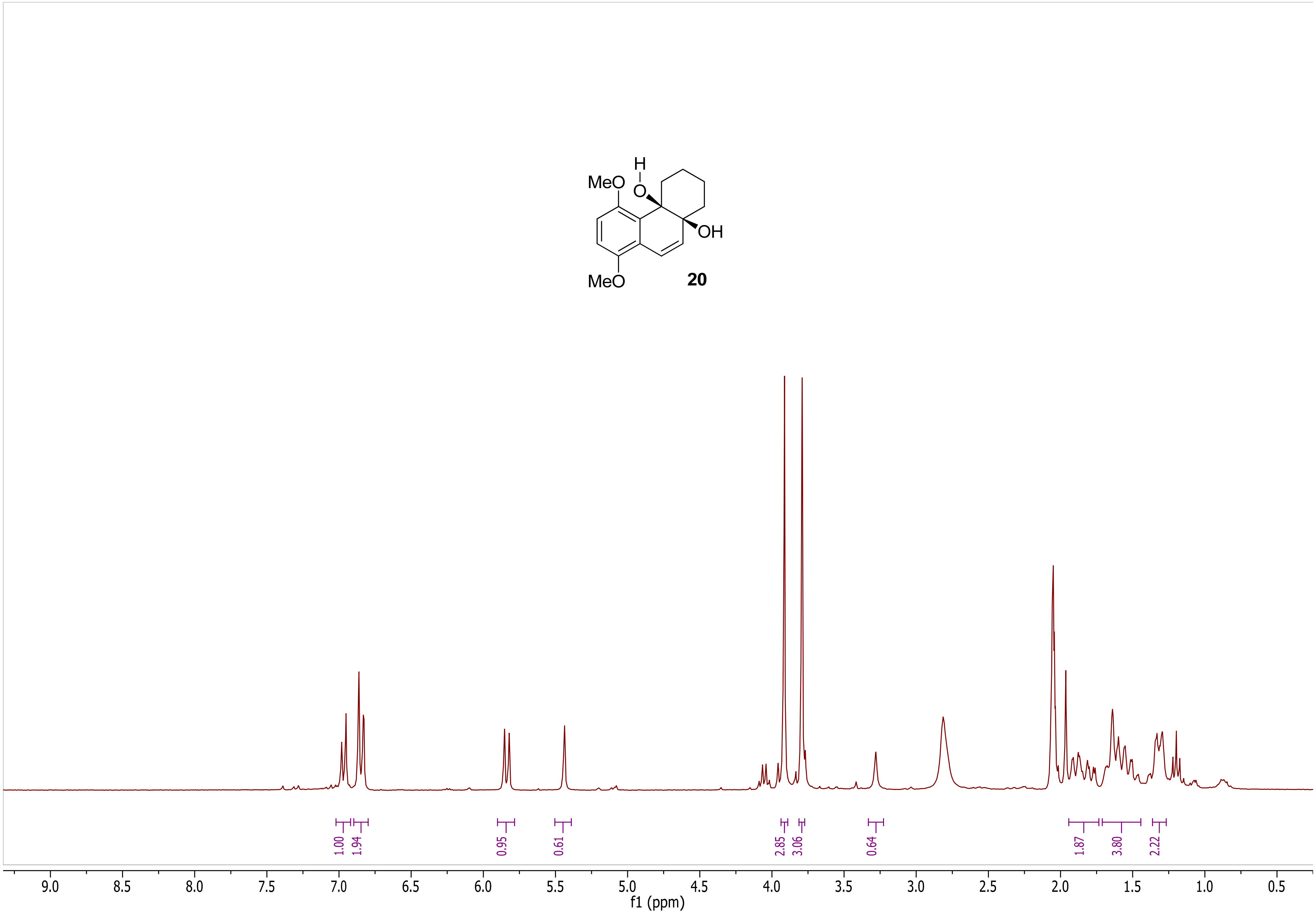
10
f1 (ppm)

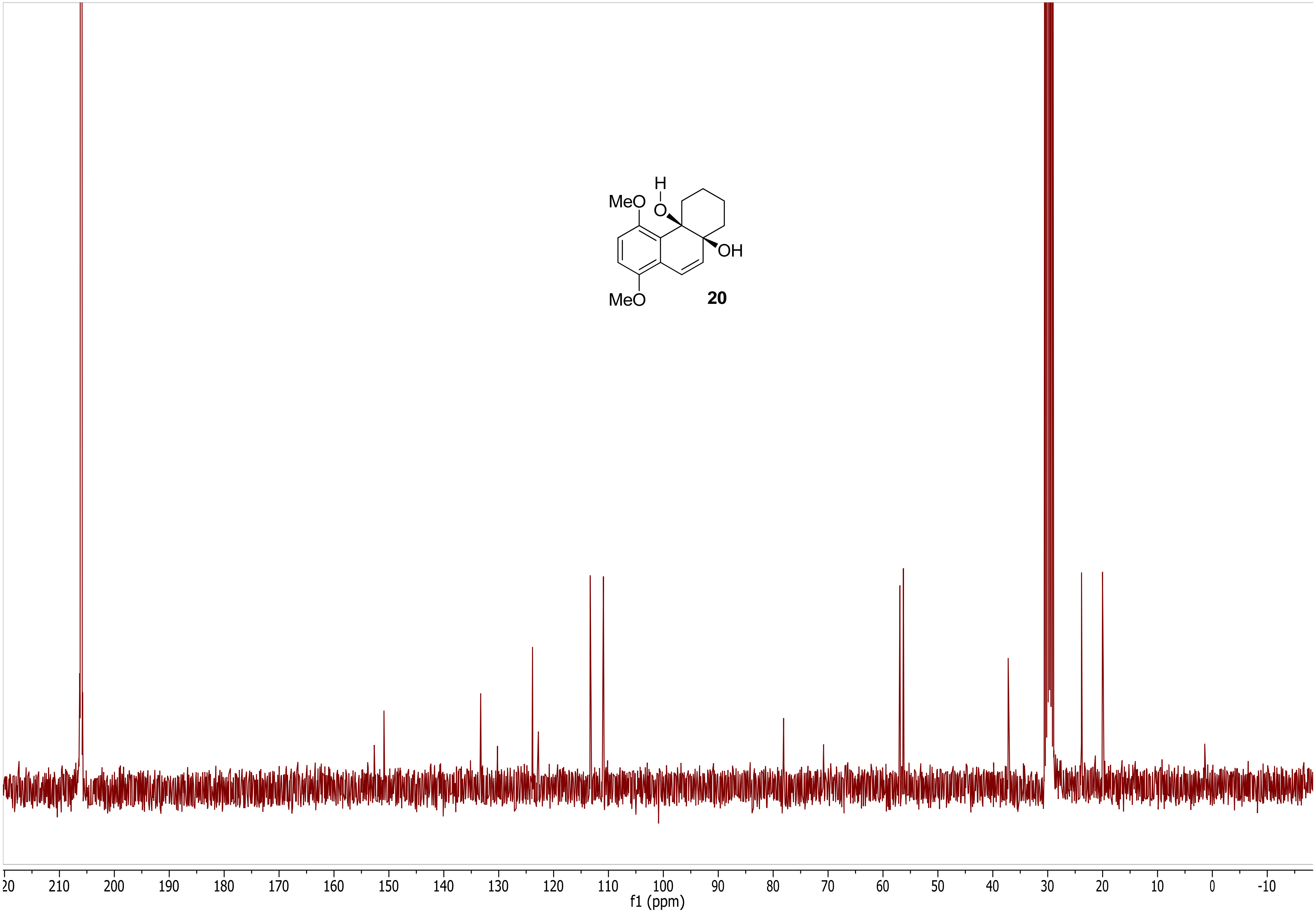

MeO
H
O
O
+
MeO
OH
17
(15:85)
MeO
H
O
O
MeO
OH
18
1.06
1.15
0.84
0.16
1.03
6.51
0.18
0.84
1.96
1.23
2.42
3.07
2.06
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

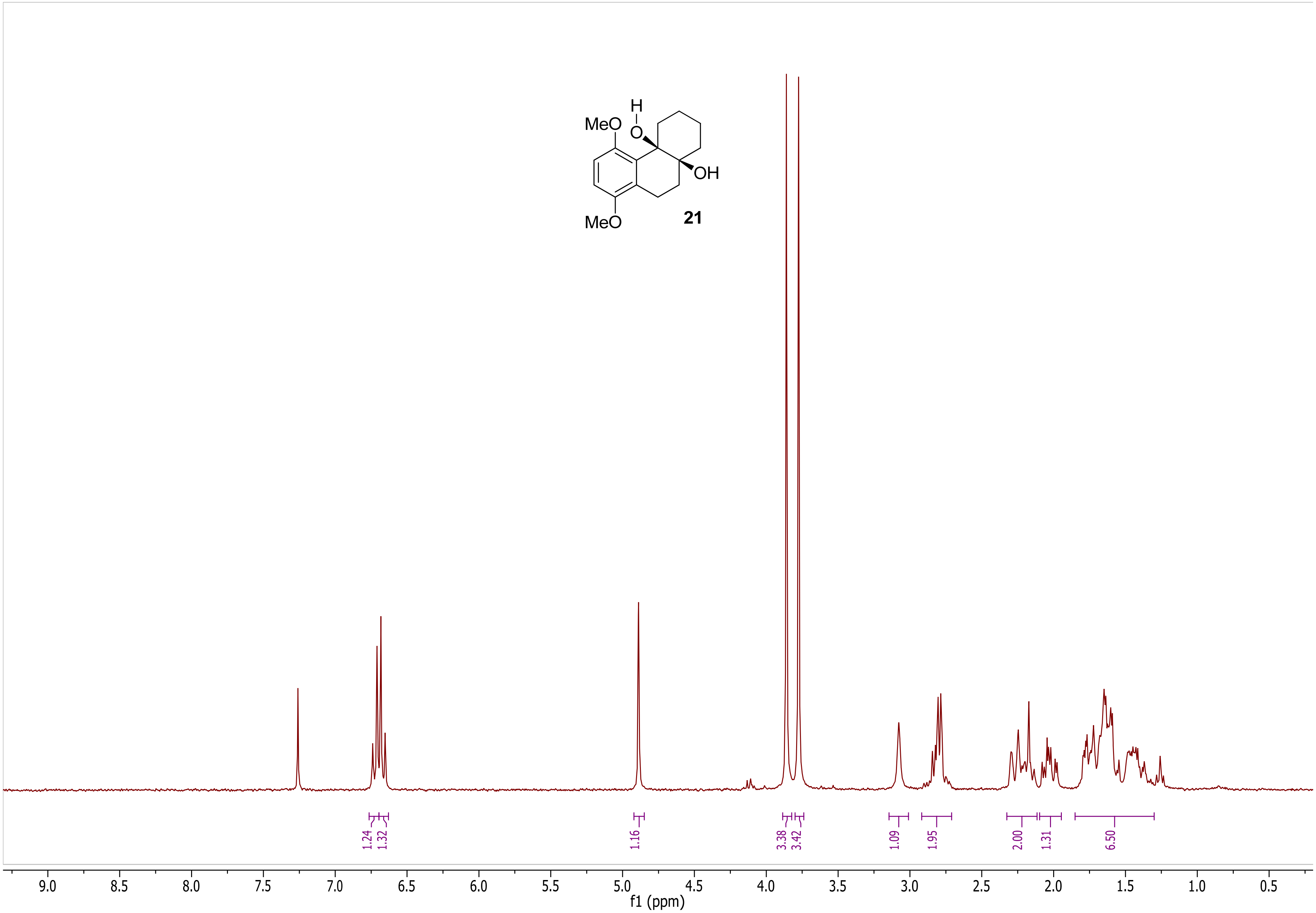

H
MeO
O
O
MeO
17
OH
(15:85)
+
H
MeO
O
O
MeO
18
OH
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

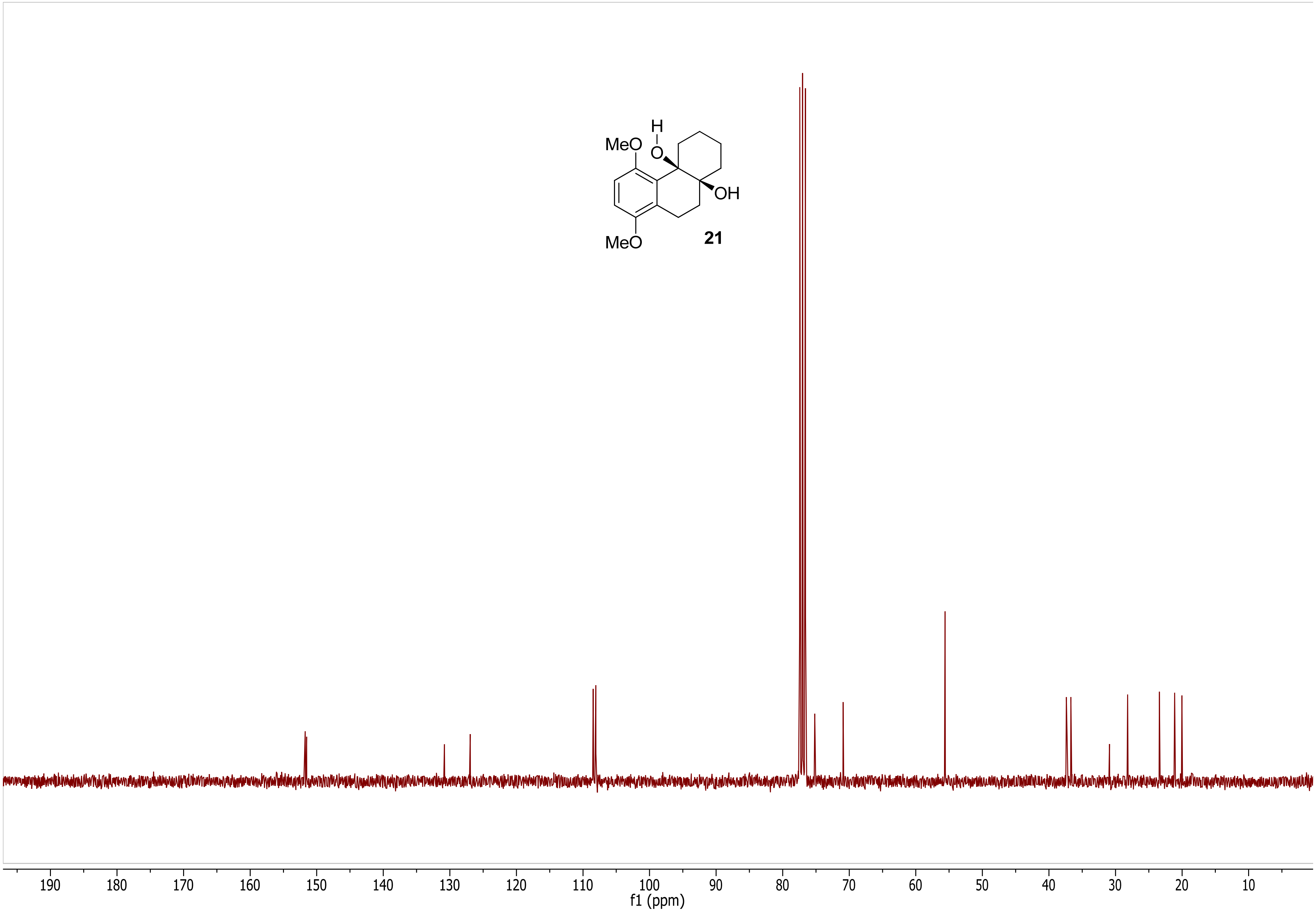

MeO
H
O
OH
MeO
OH
19
1.96
1.01
1.00
1.01
2.65
3.03
1.08
1.04
0.92
0.92
0.89
4.93
2.15
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


MeO
H
O
OH
MeO
OH
19
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)


H
MeO
O
OH
MeO
20
1.00
1.94
0.95
0.61
2.85
3.06
0.64
1.87
3.80
2.22
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
f1 (ppm)


MeO
H
O
OH
MeO
20
20
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)


MeO
H
O
OH
MeO
21
1.24
1.32
1.16
3.38
3.42
1.09
1.95
2.00
1.31
6.50
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
f1 (ppm)



**21**

MeO
H
O
OH
MeO
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)