Supporting Information

Convergent Total Syntheses of Fluvibactin and Vibriobactin Using Molybdenum(VI) Oxide-Catalyzed Dehydrative Cyclization as a Key Step

Akira Sakakura,[2] Shuhei Umemura[1] and Kazuaki Ishihara[*,1]*

1 Graduate School of Engineering, Nagoya University, Chikusa, Nagoya, 464-8603 Japan
2 EcoTopia Science Institute, Nagoya University

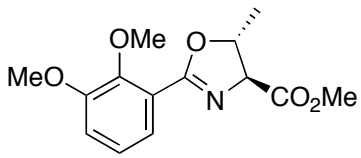
General Method.

IR spectra were recorded on a JASCO FT/IR-460 plus spectrometer. ^{1}H NMR spectra were measured on a Varian Gemini-2000 spectrometer (300 MHz) at ambient temperature. Data were recorded as follows: chemical shift in ppm from internal tetramethysilane on the δ scale, multiplicity (s = singlet; d = doublet; t = triplet; q = quartet; m = multiplet), coupling constant (Hz), and integration. ^{13}C NMR spectra were measured on a Varian Gemini-2000 spectrometer (75 MHz) or INOVA spectrometer (125 MHz) at ambient temparature. Chemical shifts were recorded in ppm from the solvent resonance employed as the internal standard ($CDCl_3$ at 77.0 ppm, CD_3OD at 49.0 ppm). All experiments were carried out under an atmosphere of dry nitrogen. For TLC analysis, Merck precoated TLC plates (silica gel 60 F_{254} 0.25 mm or NH_2 F_{254S} 0.25 mm) were used. For preparative column chromatography, Merck silica gel 60 (0.040–0.063 mm) or Fuji Silysia Chemical Ltd. Cromatorex® NH-DM1020 were used. High resolution mass spectral analysis (HRMS) was performed at Chemical Instrument Center, Nagoya University.

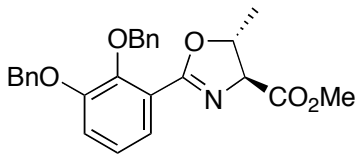
Dry toluene and tetrahydrofran (THF) was purchased from Wako as the "anhydrous" and stored under nitrogen. Dichloromethane and triethylamine were freshly distilled from calcium hydride. $(NH_4)_2MoO_4$ (Aldrich), $MoO_2(acac)_2$ (Wako Pure Chemical Industries, Ltd.), $MoO_2(TMHD)_2$ (Strem), $C_6H_5CO_2H$ (TCI), $Sb(OEt)_3$ (Aldrich), Norspermidine (Wako) and other materials were obtained from commercial supplies and used without further purification.

General Procedure of Dehydrative Cyclization of 6: The reaction was carried out in a flask fitted with a pressure-equalized addition funnel (containing a cotton plug and ca. 4 g of molecular sieves 4A, and functioning as a Soxhlet extractor) surmounted by a reflux condenser. A solution of **6d** (371 mg, 1.0 mmol), $MoO_2(TMHD)_2$ (2.5 mg, 0.0050 mmol) in toluene (100 mL) was heated at azeotropic reflux with the removal of water. After 5 h, the reaction mixture was cooled to ambient temperature, and concentrated to give a crude product. Yields were determined by ^{1}H

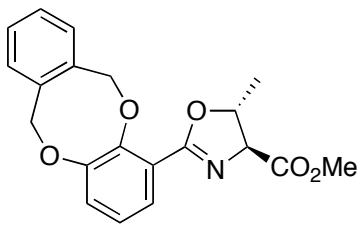
NMR analysis. The crude product was purified by column chromatography on silica gel using a mixture of hexane–EtOAc (3:1 → 2:1 → 3:2) as an eluent to give **3d**.



Methyl (4*S*,5*R*)-2-(*o*,*m*-dimethoxyphenyl)-5-methyl-4-oxazoline-carboxylate (3b): IR (neat) 1742, 1644, 1578, 1481, 1319, 1264, 1048, 1004 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.53 (d, *J* = 6.3 Hz, 3H), 3.80 (s, 3H), 3.87 (s, 6H), 4.48 (d, *J* = 7.2 Hz, 1H), 4.98 (dq, *J* = 7.2, 6.3 Hz, 1H), 7.03 (dd, *J* = 7.8, 2.1 Hz, 1H), 7.08 (dd, *J* = 7.8, 7.5 Hz, 1H), 7.37 (dd, *J* = 7.5, 2.1 Hz, 1H), 11.8 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 20.5, 52.0, 55.6, 60.9, 74.5, 78.3, 115.0, 122.0, 122.1, 123.4, 148.5, 153.0, 164.3, 171.2; HRMS (FAB) calcd for $C_{14}H_{18}NO_5$ $[M+H]^+$ 280.1185, found 280.1207.

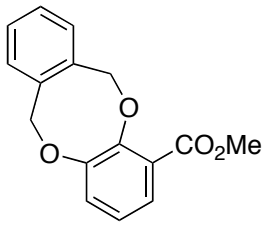


Methyl (4*S*,5*R*)-2-(*o*,*m*-dibenzyloxyphenyl)-5-methyl-4-oxazoline-carboxylate (3c): IR (neat) 1741, 1641, 1577, 1476, 1454, 1319, 1265, 1218, 1042 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.46 (d, *J* = 6.3 Hz, 3H), 3.78 (s, 3H), 4.43 (d, *J* = 7.8 Hz, 1H), 4.93 (dq, *J* = 7.8, 6.3 Hz, 1H), 5.09 (d, *J* = 4.8 Hz, 1H), 5.13 (s, 2H), 7.03-7.16 (m, 2H), 7.27-7.47 (m, 11H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 19.9, 51.5, 70.1, 74.1, 74.6, 77.8, 116.5, 122.2, 122.3, 123.3, 126.7 (2C), 127.0, 127.1, 127.3 (2C), 127.6 (2C), 127.8 (2C), 135.9, 136.9, 147.2, 151.9, 163.8, 170.6; HRMS (FAB) calcd for $C_{26}H_{26}NO_5$ $[M+H]^+$ 432.1811, found 432.1806.

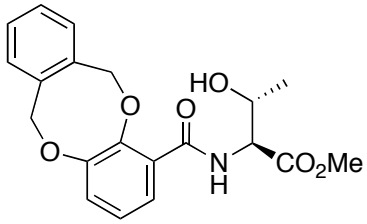


***o*-Xylylene-protected oxazolinecarboxylic acid methyl ester 3d:** IR (neat) 1741, 1638, 1579, 1466, 1376, 1280, 1259, 1207, 1008 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.55 (d, *J* = 6.3 Hz, 3H), 3.82 (s, 3H), 4.51 (d, *J* = 6.9 Hz, 1H), 4.97 (dq, *J* = 6.9, 6.3 Hz, 1H), 5.39 (d, *J* = 12.6 Hz, 1H), 5.42 (d, *J* = 13.8 Hz, 1H), 5.48 (d, *J* = 13.8 Hz, 1H), 5.49 (d, *J* = 12.6 Hz, 1H), 6.95 (dd, *J* = 7.8, 7.8 Hz, 1H), 7.10 (dd, *J* = 8.1, 1.8 Hz, 1H), 7.11-7.32 (m, 4H), 7.42 (dd, *J* = 7.8, 1.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.0, 52.5, 74.6, 75.1, 75.8, 78.4, 121.8, 123.3, 124.6,

124.9, 128.3, 128.3, 128.5, 129.3, 135.1, 135.9, 149.2, 151.2, 164.2, 171.6; HRMS (FAB) calcd for $C_{20}H_{20}NO_5$ $[M+H]^+$ 354.1341, found 354.1370.

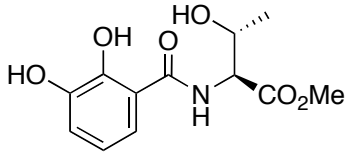


***o*-Xylylene-protected 2,3-dihydroxybenzoic acid methyl ester (7):** To a solution of 2,3-dihydroxybenzoic acid (5.0 g, 32.4 mmol) in MeOH (50 mL) was added H_2SO_4 (3.0 mL) and the mixture was heated to reflux for 5 h. The reaction mixture was cooled to ambient temparature. After MeOH was removed *in vacuo*, the crude product was diluted with EtOAc (50 mL) and washed with saturated $NaHCO_3$ (2 × 50 mL) and brine (50 mL). The combined extracts were dried over Na_2SO_4 and concentrated following was added a solution of α,α'-dibromo-*o*-xylene (8.18 g, 31 mmol), K_2CO_3 (12.4 g, 90 mmol) in DMF (100 mL). The mixture was heated at 120 °C. After 8 h, the reaction mixture was cooled to ambient temparature, poured into ice-cold water (200 mL) following was passed through cotton to remove K_2CO_3. The aqueous layer was extracted with EtOAc (200 mL, 2 × 50 mL). The organic layers ware washed with ice-cold 1 M HCl (100 mL), water (80 mL) and brine (80 mL). The crude product was purified by column chromatography on silica gel using a mixture of hexane–EtOAc (15:1 → 10:1 → 7:1) as an eluent to give **7** (6.7 g, 77%); IR (neat) 1728, 1585, 1467, 1434, 1375, 1281, 1193, 1141, 1077, 1019 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 3.91 (s, 3H), 5.42 (s, 2H), 5.48 (s, 2H), 6.95 (dd, *J* = 7.8, 7.8 Hz, 1H), 7.15 (dd, *J* = 7.8, 1.8 Hz, 1H), 7.17-7.31 (m, 4H), 7.41 (dd, *J* = 7.8, 1.8 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 51.2, 74.0, 75.1, 122.4, 124.3, 124.7, 124.8, 127.8, 127.9, 127.9, 128.4, 134.7, 135.1, 149.1, 150.7, 165.4; HRMS (FAB) calcd for $C_{16}H_{15}O_4$ $[M+H]^+$ 271.0970, found 271.0978.

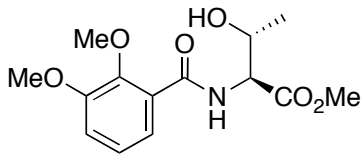


***o*-Xylylene-protected *N*-(2,3-dihydroxybenzoyl)-L-threonine methyl ester (6d):** To a solution of **7** (3.43 g, 13 mmol) in acetone (50 mL) and MeOH (50 mL) was added a 1.0 M aqueous solution of NaOH (50 mL, 50 mmol) at 0 °C, and the mixture was stirred at 0 °C for 30 min and then at 50 °C for 1 h. The reaction mixture was cooled to 0 °C and acidified (pH 2) with conc. aqueous HCl. After MeOH was removed *in vacuo*, the resulting aqueous layer was extracted with EtOAc (3 × 20 mL). The combined extracts were washed with

brine, dried over Na_2SO_4 and concentrated. To a solution of the residue in $CHCl_3$ (35 mL) was added thionyl chlroride (2 mL) and DMF (5 drops) at ambient temperature, and the mixture was heated to reflux for 1 h. The reaction mixture was concentrated, and then added CH_2Cl_2 (35 mL). The resulting solution was cooled to 0 °C. The solution was added H-L-Thr-OMe·HCl (2.15g, 13 mmol), Et_3N (3.5 mL, 25 mmol) and DMAP (155 mg, 1.3 mmol) at 0 °C. After stirring at rt for 2 h, CH_2Cl_2 was removed *in vacuo* and dissolved in EtOAc (80 mL). The resulting solution was washed with 1 M HCl (50 mL), saturated aqueous $NaHCO_3$ (50 mL) and brine (30 mL), dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography on silica gel using a mixture of hexane–EtOAc (3:2 → 1:1) as a eluent to give **6d** (4.38 g, 93%); IR (KBr) 3369, 3330, 1743, 1642, 1579, 1527, 1460, 1281, 1259, 1081, 1024 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.30 (d, *J* = 6.6 Hz, 3H), 2.19 (d, *J* = 5.1 Hz, 1H), 3.83 (s, 3H), 4.45 (qdd, *J* = 6.6, 5.1, 2.4 Hz, 1H), 4.86 (dd, *J* = 8.7, 2.4 Hz, 1H), 5.35 (d, *J* = 14.1 Hz, 1H), 5.43 (d, *J* = 14.1 Hz, 1H), 5.61 (d, *J* = 12.6 Hz, 1H), 5.67 (d, *J* = 12.6 Hz, 1H), 7.02 (dd, *J* = 8.1, 8.1 Hz, 1H), 7.12–7.25 (m, 5H), 7.82 (dd, *J* = 8.1, 2.1 Hz, 1H), 8.90 (br d, *J* = 8.7 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 20.0, 52.4, 57.7, 68.1, 75.0, 76.2, 122.9, 124.8, 126.0, 126.6, 127.8, 128.6, 129.0, 130.1, 133.7, 136.3, 149.3, 150.0, 165.4, 171.7; HRMS (FAB) calcd for $C_{20}H_{22}NO_6$ $[M+H]^+$ 372.1447, found 372.1430.

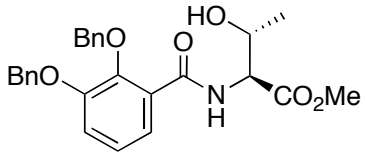


***N*-(*o,m*-Dihydroxybenzoyl)-L-threonine methyl ester (6a)**: IR (KBr) 3419, 1739, 1644, 1588, 1540, 1458, 1337, 1271, 1176 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.29 (d, *J* = 6.3 Hz, 3H), 1.80-3.20 (br, 1H), 3.80 (s, 3H), 4.50 (qd, *J* = 6.3, 2.4 Hz, 1H), 4.79 (dd, *J* = 8.7, 2.4 Hz, 1H), 5.20–6.50 (br, 1H), 6.78 (dd, *J* = 8.1, 8.1 Hz, 1H), 7.06 (dd, *J* = 8.1, 1.5 Hz, 1H), 7.08 (dd, *J* = 8.1, 1.5 Hz, 1H), 7.20 (d, *J* = 8.7 Hz, 1H), 12.3 (br, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 19.9, 52.9, 57.1, 67.9, 113.6, 116.8, 118.7, 118.8, 145.6, 148.9, 170.4, 171.3; HRMS (FAB) calcd for $C_{12}H_{16}NO_6$ $[M+H]^+$ 270.0978, found 270.0996.

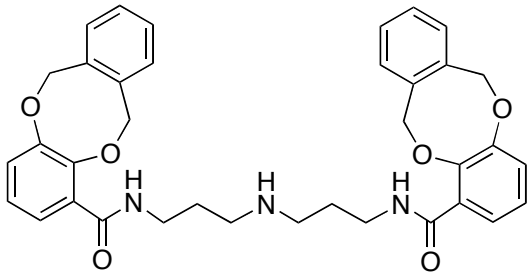


***N*-(*o,m*-Dimethoxybenzoyl)-L-threonine methyl ester (6b)**: IR (KBr) 3354, 1738, 1647, 1578, 1538, 1477, 1264, 1119, 1063 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.28 (d, *J* = 6.6 Hz, 3H), 2.44 (br, 1H), 3.79 (s, 3H), 3.91 (s, 3H), 3.99 (s, 3H), 4.44 (qd, *J* = 6.6, 2.4 Hz, 1H), 4.84 (dd, *J* = 8.4, 2.4 Hz, 1H), 7.08 (dd, *J* = 8.1, 1.8 Hz, 1H), 7.16 (dd, *J* = 8.1, 8.1 Hz, 1H), 7.71 (dd, *J* = 8.1, 1.8 Hz, 1H), 8.93 (br d, *J* = 8.4 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 19.8, 52.1,

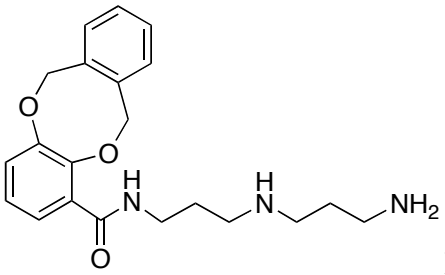
55.9, 57.7, 67.6, 115.6, 122.5, 124.1, 125.6, 147.8, 152.5, 165.5, 171.4; HRMS (FAB) calcd for $C_{14}H_{20}NO_6$ $[M+H]^+$ 298.1291, found 298.1293.



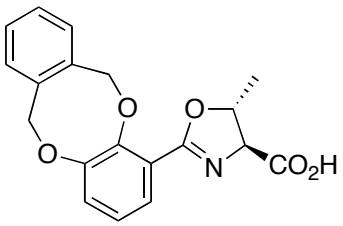
***N*-(*o,m*-Dibenzyloxybenzoyl)-L-threonine methyl ester (6c)**: IR (KBr) 3342, 1754, 1647, 1575, 1540, 1457, 1348, 1260, 1206, 1131, 1044 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.16 (d, *J* = 6.6 Hz, 3H), 1.86 (d, *J* = 5.7 Hz, 1H), 3.73 (s, 3H), 4.31 (qdd, *J* = 6.6, 5.7, 2.7 Hz, 1H), 4.76 (dd, *J* = 8.4, 2.7 Hz, 1H), 5.12 (d, *J* = 10.2 Hz, 1H), 5.15 (s, 2H), 5.23 (d, *J* = 10.2 Hz, 1H), 7.16-7.48 (m, 12H), 7.75 (dd, *J* = 6.0, 3.6 Hz, 1H), 8.78 (d, *J* = 8.4 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 19.7, 51.8, 57.8, 67.2, 70.7, 75.6, 116.8, 122.6, 122.7, 124.0, 126.3, 127.5 (2C), 127.8 (3C), 128.2 (2C), 128.6 (2C), 135.8, 135.9, 146.5, 151.4, 165.5, 170.9; HRMS (FAB) calcd for $C_{26}H_{26}NO_5$ $[M+H]^+$ 450.1917, found 450.1917.



Diamide 8: A mixture of **7** (620 mg, 2.3 mmol), **5** (150 mg, 160 μL, 1.1 mmol) was charged with $Sb(OEt)_3$ (293 mg, 190 μL, 1.1 mmol) at ambient temparature in N_2 atmosphere. The mixture was heated at 80 °C for 24 h. After cooling to ambient temparature, the mixture was quenched with MeOH (3 mL) and then filtered through pad of celite using $CHCl_3$–MeOH–*i*-$PrNH_2$, evaporated. The residue was purified by column chromatography on Cromatorex® NH-DM1020 using a mixture of $CHCl_3$–MeOH (1:0 → 300:1 → 100:1) as an eluent to give **8** (523 mg, 86%) along with **9** (54 mg, 13%): IR (neat) 3395, 1653, 1540, 1521, 1457, 1280 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.79 (tt, *J* = 6.6, 6.6 Hz, 4H), 2.73 (t, *J* = 6.6 Hz, 4H), 3.53 (td, *J* = 6.6, 6.0 Hz, 4H), 5.35 (s, 4H), 5.48 (s, 4H), 6.99 (dd, *J* = 7.8, 7.8 Hz, 2H), 7.12–7.32 (m, 10H) 7.75 (dd, *J* = 7.8, 1.5 Hz, 1H) 8.05 (br t, *J* = 6.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 29.4, 37.4, 47.1, 74.9, 75.6, 122.6, 124.7, 125.6, 125.9, 127.7, 128.2, 128.6, 129.0, 133.6, 135.8, 148.5, 150.0, 164.7; HRMS (FAB) calcd for $C_{36}H_{38}N_3O_6$ $[M+H]^+$ 608.2761, found 608.2742.

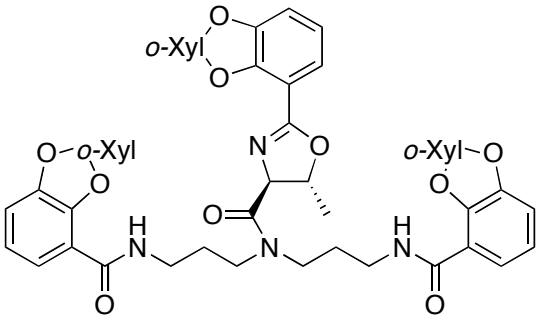


Monoamide 9: A mixture of **7** (280 mg, 1.0 mmol), **5** (270 mg, 280 μL, 2.0 mmol) was charged with $Sb(OEt)_3$ (260 mg, 170 μL, 2.0 mmol) at ambient temparature in N_2 atmosphere. The mixture was heated at 80 °C for 3 h. After cooling to ambient temparature, the mixture was quenched with MeOH (3 mL) and then filtered through pad of celite using $CHCl_3$–MeOH–*i*-$PrNH_2$, evaporated. The residue was purified by column chromatography on Cromatorex® NH-DM1020 using a mixture of hexane–$CHCl_3$–*i*-$PrNH_2$ (12:8:1 → 10:10:1 → 4:16:1) as an eluent to give **9** (330 mg, 88%) along with **8** (35 mg, 6%): IR (neat) 3386, 1648, 1578, 1530, 1464, 1442, 1375, 1280, 1260, 1074, 1011 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.60 (tt, *J* = 6.9, 6.9 Hz, 2H), 1.80 (tt, *J* = 6.9, 6.9 Hz, 2H), 2.66 (t, *J* = 6.9 Hz, 2H), 2.72 (t, *J* = 6.9 Hz, 2H), 3.54 (td, *J* = 6.9, 6.0 Hz, 2H), 5.36 (s, 2H), 5.50 (s, 2H), 7.00 (dd, *J* = 7.8, 7.8 Hz, 1H), 7.12–7.35 (m, 5H) 7.76 (dd, *J* = 7.5, 2.1 Hz, 1H) 8.07 (br t, *J* = 6.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 29.8, 33.7, 37.9, 40.4, 47.6, 47.8, 75.4, 76.0, 123.0, 125.0, 126.0, 126.1, 128.0, 128.4, 129.0, 129.3, 134.0, 136.1, 148.9, 150.4, 165.0; HRMS (FAB) calcd for $C_{21}H_{28}N_3O_3$ $[M+H]^+$ 370.2131, found 370.2131.

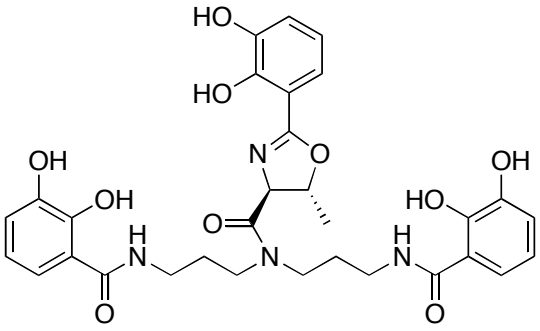


***o*-Xylylene-protected oxazolinecarboxylic acid 10:** To a solution of **3d** (300 mg, 0.85 mmol) in acetone (3.5 mL), MeOH (1.7 mL) and H_2O (1.7 mL) was added CsOH•H_2O (77 μL, 1.7 mmol) at 0 °C, and the mixture was stirred for 1 h. After MeOH was removed *in vacuo*, the resulting aqueous layer was acidified with conc. aqueous HCl, then white solid precipitated. The solid was collected by filtration, washed with 1 M aqueous HCl, and dried *in vacuo*, to give **10** (277 mg, 96%): IR (KBr) 3369 (br), 1742, 1627, 1487, 1420, 1381, 1287, 1260, 1034, 934 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.69 (d, *J* = 6.5 Hz, 3H), 5.04 (d, *J* = 6.5 Hz, 1H), 5.41 (s, 2H), 5.78 (qd, *J* = 6.5, 6.5 Hz, 1H), 6.23 (d, *J* = 11.0 Hz, 1H), 6.27 (d, *J* = 11.0 Hz, 1H), 7.04 (d, *J* = 7.5 Hz, 1H), 7.05 (dd, *J* = 8.0, 8.0 Hz, 1H), 7.28 (dd, *J* = 7.5, 7.5 Hz, 1H), 7.32 (dd, *J* = 7.5, 7.5 Hz, 1H), 7.55 (dd, *J* = 8.0, 2.0 Hz, 1H), 7.64 (dd, *J* = 8.0, 2.0 Hz, 1H), 7.82 (d *J* = 7.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 20.2, 65.8, 73.9, 77.9, 83.9, 110.5, 122.4, 126.6, 128.0, 129.2,

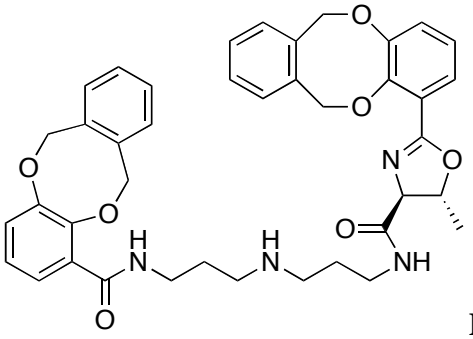
129.6, 132.3, 133.4, 133.6, 136.0, 148.5, 153.8, 166.9, 167.3; HRMS (FAB) calcd for $C_{19}H_{18}NO_5$ $[M+H]^+$ 340.1185, found 340.1194.



Triamide 11: To a solution of **8** (61 mg, 0.10 mmol), **10** (37 mg, 0.11 mmol), HOAt (20 mg, 0.15 mmol) and Et_3N (21 μL, 0.15 mmol) in THF (2.5 mL) and DMF (0.1 mL) was added WSCI•HCl (29 mg, 0.15 mmol) at 0 °C. After the mixture was stirred at ambient temperature for 12 h, solvent was removed *in vacuo* and dissolved in EtOAc (20 mL). The resulting solution was washed with 1 M HCl (2 × 15 mL), saturated aqueous $NaHCO_3$ (2 × 15 mL) and brine (15 mL), and combined organic phase was combined and dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography on Cromatorex® NH-DM1020 using a mixture of hexane–EtOAc–MeOH (10:20:1) as an eluent to give **11** (91 mg, 98%): $[\alpha]^{21}_D$ +112.8 (c 1.0, $CHCl_3$); IR (neat) 3388, 1647, 1523, 1460, 1377, 1281, 1072, 1010 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.40 (d, *J* = 6.5 Hz, 3H), 1.87 (tdd, *J* = 6.0, 6.0, 6.0 Hz, 2H), 2.00–2.10 (m, 1H), 2.12–2.23 (m, 1H), 3.34 (m, 1H), 3.43–3.51 (m, 2H), 3.54 (m, 1H), 3.64 (m, 1H), 3.66–3.75 (m, 2H), 3.91 (ddd, *J* = 14.5, 9.0, 5.5 Hz, 1H), 4.63 (d, *J* = 6.5 Hz, 1H), 5.23–5.38 (m, 8H), 5.40–5.46 (m, 1H), 5.43 (s, 2H), 5.67 (d, *J* = 12.5 Hz, 1H), 5.73 (d, *J* = 12.5 Hz, 1H), 6.87 (t, *J* = 8.0 Hz, 1H), 6.94 (t, *J* = 8.0 Hz, 1H), 6.97 (t, *J* = 8.0 Hz, 1H), 7.00 (br d, *J* = 7.5 Hz, 1H), 7.05 (dd, *J* = 8.0, 1.5 Hz, 1H), 7.07–7.16 (m, 6H), 7.18 (dd, *J* = 8.0, 2.0 Hz, 1H), 7.19 (dd, *J* = 7.5, 1.0 Hz, 1H), 7.21–7.28 (m, 4H), 7.28 (dd, *J* = 8.0, 2.0 Hz, 1H), 7.33 (br d, *J* = 7.5 Hz, 1H), 7.64 (d, *J* = 6.0 Hz, 1H), 7.84 (d, *J* = 6.0 Hz, 1H), 8.21 (t, *J* = 5.5 Hz, 1H), 8.71 (t, *J* = 5.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 20.3, 27.5, 29.0, 36.3, 37.1, 42.5, 44.9, 73.7, 74.5, 74.8, 75.6, 75.8, 76.4, 77.7, 121.9, 122.4, 123.1, 123.2, 124.5, 124.8, 125.0, 125.4, 125.4, 125.6, 126.3, 126.5, 126.5, 127.4, 128.1, 128.3, 128.4, 128.5, 128.5, 128.8, 128.9, 129.0, 129.2, 130.2, 134.1, 134.2, 135.1, 135.6, 136.0, 136.4, 148.9, 149.2, 149.5, 150.0, 150.5, 151.1, 163.1, 165.0, 165.5, 170.0; HRMS (FAB) calcd for $C_{55}H_{52}N_4O_{10}Na$ $[M+Na]^+$ 951.3581, found 951.3594.

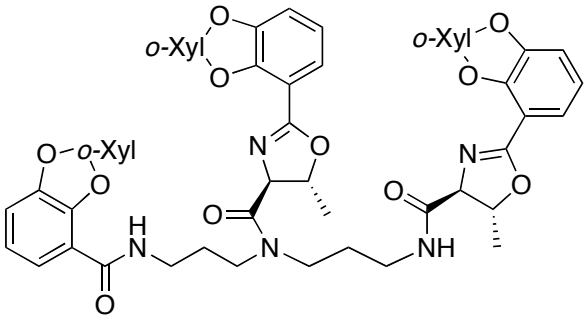


Fluvibactin (1): A mixture of triamide **11** (30 mg, 0.032 mmol) and 10% Pd/C (3.0 mg) in EtOH (4 mL) was stirred under a hydrogen atmosphere at 60 °C for 2 h. The mixture was filtered through a pad on Celite, and the residue was washed with EtOH. The filtrate and washings were combined and concentrated. The residue was purified by column chromatography on Sephadex® G-25 using EtOH as an eluent to give **1** (20 mg, 99%): $[\alpha]^{22}_{D}$ +59.9 (c 0.92, CH_3OH); IR (neat) 3363, 1636, 1592, 1541, 1458, 1324, 1264, 1170, 741 cm^{-1}; ^1H NMR (500 MHz, CD_3OD) δ 1.39 (d, *J* = 6.0 Hz, 3H), 1.80–1.93 (m, 2H), 1.98–2.14 (m, 2H), 3.28–3.71 (m, 6H), 3.78–3.88 (m, 2H), 4.80 (d, *J* = 6.0 Hz, 1H), 5.24 (qd, *J* = 6.0, 6.0 Hz, 1H), 6.62 (dd, *J* = 8.0, 7.0 Hz, 1H), 6.68 (dd, *J* = 8.0, 8.0 Hz, 1H), 6.72 (dd, *J* = 8.0, 8.0 Hz, 1H), 6.86 (d, *J* = 8.0 Hz, 1H), 6.89 (d, *J* = 8.0 Hz, 1H), 6.93 (d, *J* = 8.0 Hz, 1H), 7.12 (d, *J* = 8.0 Hz, 1H), 7.14–7.23 (m, 1H), 7.18 (d, *J* = 8.0 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 20.2, 28.4, 30.3, 37.9, 45.0, 46.7, 72.9, 79.7, 111.8, 116.7, 118.6, 118.6, 119.6, 119.9, 120.2, 146.7, 147.4, 149.4, 150.4, 167.8, 171.4, 171.5, 171.8; HRMS (FAB) calcd for $C_{31}H_{35}N_4O_{10}$ $[M+H]^+$ 623.2353, found 623.2352.



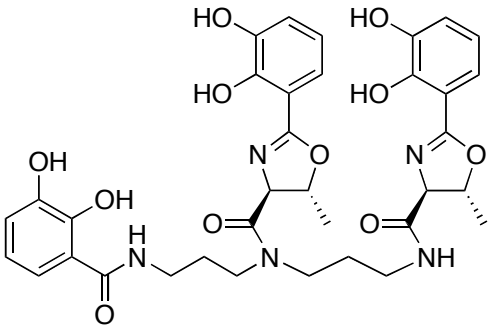
Diamide 12: A mixture of **9** (183 mg, 0.5 mmol), **3d** (178 mg, 0.5 mmol) was charged with $Sb(OEt)_3$ (128 mg, 85 μL, 0.5 mmol) at ambient temparature in N_2 atmosphere. The mixture was heated at 80 °C for 5 h. After cooling to ambient temparature, the mixture was quenched with MeOH (1 mL) and then filtered through pad of celite using $CHCl_3$, evaporated. The residue was purified by column chromatography on Chromatorex® NH-DM1020 using a mixture of hexane–$CHCl_3$ (1:2→ 1: 3 → 1:5) as an eluent to give **12** (311 mg, 90%): IR (KBr) 3387, 2931, 1648, 1578, 1526, 1465, 1376, 1280, 1075, 1009 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.57 (d, *J* = 6.3 Hz, 3H), 1.66 (tt, *J* = 6.6, 6.6 Hz, 2H), 1.72 (tt, *J* = 6.6, 6.6 Hz, 2H), 2.65 (t, *J* = 6.6 Hz, 4H), 3.22-3,42 (m, 2H), 3.48 (td, *J* = 6.6, 6.6 Hz, 2H), 4.32 (d, *J* = 7.2 Hz, 1H), 4.87

(dq, *J* = 7.2, 6.3 Hz, 1H), 5.35 (s, 2H), 5.39 (s, 1H), 5.40 (s, 1H), 5.44 (s, 2H), 5.47 (s, 2H), 6.95 (dd, *J* = 8.1, 8.1 Hz, 1H), 6.99 (dd, *J* = 8.1, 8.1 Hz, 1H), 7.05–7.36 (m, 10H), 7.38 (dd, *J* = 7.8, 1.8 Hz, 1H), 7.75 (dd, *J* = 8.1, 1.5 Hz, 1H), 8.01 (br t, *J* = 6.6 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.6, 29.2, 29.4, 37.2, 37.5, 47.1, 47.3, 74.8 75.1, 75.2, 75.5, 75.6, 79.2, 121.4, 122.7, 122.9, 124.5, 124.6, 124.7, 125.6, 126.1, 127.8, 127.8, 128.2, 128.2, 128.3, 128.6, 128.7, 129.0, 129.0, 133.8, 135.1, 135.2, 135.8, 148.5, 149.2, 150.1, 150.9, 163.5, 164.8, 171.2; HRMS (FAB) calcd for $C_{40}H_{43}N_4O_7$ $[M+H]^+$ 691.3132, found 691.3154.

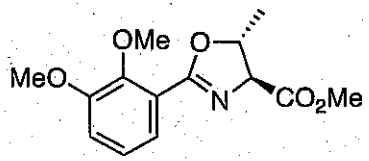


Triamide 13: To a solution of **12** (69 mg, 0.10 mmol), **10** (51 mg, 0.15 mmol), HOAt (20 mg, 0.15 mmol) and Et_3N (21 μL, 0.15 mmol) in THF (1.8 mL) and DMF (0.20 mL) was added WSCI•HCl (29 mg, 0.15 mmol) at 0 °C. After the mixture was stirred at ambient temperature for 12 h, solvent was removed *in vacuo* and dissolved in EtOAc (20 mL). The resulting solution was washed with 1 M HCl (2 × 15 mL), saturated aqueous $NaHCO_3$ (2 × 15 mL) and brine (15 mL), and dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography on Cromatorex® NH-DM1020 using a mixture of hexane–EtOAc–MeOH (10:20:1) as an eluent to give **13** (83 mg, 82%): $[\alpha]^{22}_D$ +102.5 (c 1.0, $CHCl_3$); IR (KBr) 3398, 1645, 1524, 1465, 1377, 1281, 1259, 1076, 1009 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.33 (d, *J* = 6.5 Hz, 1.2H), 1.42 (d, *J* = 6.5 Hz, 1.8H), 1.50 (d, *J* = 6.5 Hz, 1.8H), 1.58 (d, *J* = 6.5 Hz, 1.2H), 1.75–1.87 (m, 2.4H), 1.87–2.18 (m, 1.6H), 3.15 (m, 0.4H), 3.30 (m, 0.6H), 3.34–3.46 (m, 3H), 3.48–3.75 (m, 3H), 3.78–3.87 (m, 1H), 4.25 (d, *J* = 7.0 Hz, 0.6H), 4.37 (d, *J* = 7.5 Hz, 0.4H), 4.57 (d, *J* = 7.0 Hz, 0.4H), 4.59 (d, *J* = 6.0 Hz, 0.6H), 4.85 (dq, *J* = 7.0, 6.0 Hz, 0.4H), 4.86 (dq, *J* = 7.0, 6.5 Hz, 0.6H), 5.22–5.48 (m, 11.4H), 5.50 (d, *J* = 13.5 Hz, 0.4H), 5.67 (d, *J* = 12.0 Hz, 0.6H), 5.73 (d, *J* = 12.0 Hz, 0.4H), 6.82 (dd, *J* = 8.0, 8.0 Hz, 0.4H), 6.89 (dd, *J* = 8.0, 8.0 Hz, 0.6H), 6.90 (dd, *J* = 8.0, 8.0 Hz, 0.6H), 6.92 (dd, *J* = 8.0, 8.0 Hz, 0.4H), 6.93 (dd, *J* = 8.0, 8.0 Hz, 0.4H), 6.97 (dd, *J* = 8.0, 8.0 Hz, 0.6H), 7.01 (dd, *J* = 8.0, 1.5 Hz, 0.4H), 7.03 (br dd, *J* = 7.5, 7.5 Hz, 1H), 7.06 (dd, *J* = 8.0, 2.0 Hz, 0.6H), 7.07–7.30 (m, 16H), 7.32 (br d, *J* = 7.0 Hz, 0.8H), 7.33 (dd, *J* = 7.5, 1.5 Hz, 0.6H), 7.35 (dd, *J* = 7.5, 2.0 Hz, 0.6H), 7.42 (br t, *J* = 6.0 Hz, 0.4H), 7.53 (dd, *J* = 8.0, 2.0 Hz, 0.4H), 7.59 (dd, *J* = 8.0, 2.0 Hz, 0.4H), 7.84 (dd, *J* = 8.0, 1.5 Hz, 0.6H), 8.19 (br d, *J* = 5.5 Hz, 0.4H), 8.69 (br d, *J* = 6.0 Hz, 0.6H), (a 3:2 mixture of rotamer); ^{13}C NMR (125 MHz,

$CDCl_3$) δ 17.7, 20.3, 20.4, 20.7, 21.7, 22.0, 24.3, 27.5, 28.9, 36.0, 36.2, 36.5, 37.0, 42.5, 42.7, 44.7, 45.1, 58.8, 72.7, 73.9, 74.0, 74.5, 74.7, 74.8, 75.0, 75.1, 75.2, 75.5, 75.6, 75.7, 75.8, 75.9, 76.0, 76.5, 77.6, 77.8, 79.3, 79.5, 128.0, 128.2, 128.3, 128.4, 128.5, 128.6, 128.7, 128.8, 128.9, 129.0, 129.1, 134.2, 134.6, 135.2, 135.4, 135.5, 135.5, 135.7, 135.8, 136.0, 136.4, 147.4, 148.8, 149.2, 149.3, 149.5, 149.6, 149.7, 150.1, 150.5, 150.8, 151.1, 151.2, 151.2, 151.3, 157.3, 163.0, 163.2, 163.9, 164.0, 164.4, 165.0, 169.6, 170.3, 171.8; HRMS (FAB) calcd for $C_{40}H_{43}N_4O_7Na$ $[M+Na]^+$ 1034.3952, found 1034.3933.

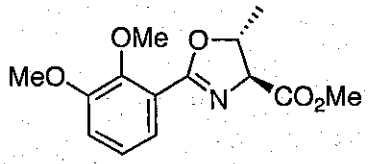


Vibriobactin (2): A mixture of **13** (40 mg, 0.039 mmol) and 10% Pd/C (3.7 mg) in EtOH (4 mL) was stirred under a hydrogen atmosphere at 60 °C for 2 h. The mixture was filtered through a pad on Celite, and the residue was washed with EtOH. The filtrate and washings were combined and concentrated. The residue was purified by column chromatography on Sephadex® G-25 using EtOH as an eluent to give **2** (27 mg, 99%): $[\alpha]^{22}_D$ +32.6 (c 1.0, $CHCl_3$–DMSO 10:1); UV (EtOH) λ_{max} 318 (ε 5970), 256 (ε 18500) nm; IR (neat) 3344, 1637, 1541, 1473, 1458, 1379, 1340, 1261, 1147, 1026, 741 cm^{-1}; ^1H NMR (500 MHz, DMSO-d_6) δ 1.34 (d, *J* = 6.5 Hz, 1.5H), 1.41 (d, *J* = 6.5 Hz, 1.5H), 1.42 (d, *J* = 6.5 Hz, 1.5H), 1.43 (d, *J* = 6.5 Hz, 1.5H), 1.61–1.71 (m, 1H), 1.71–1.79 (m, 1H), 1.81–2.02 (m, 2H), 3.00–3.56 (m, 6H), 3.61–3.74 (m, 2H), 4.41 (d, *J* = 7.5 Hz, 0.5H), 4.44 (d, *J* = 7.5 Hz, 0.5H), 4.84 (d, *J* = 6.5 Hz, 0.5H), 4.88 (d, *J* = 6.5 Hz, 0.5H), 4.80–4.90 (m, 1H), 5.17 (qd, *J* = 6.5, 6.5 Hz, 0.5H), 5.21 (qd, *J* = 6.5, 6.5 Hz, 0.5H), 6.63–4.90 (m, 3H), 6.89 (d, *J* = 8.0 Hz, 1H), 6.96 (d, *J* = 7.0 Hz, 2H), 7.05 (d, *J* = 8.5 Hz, 1H), 7.07 (d, *J* = 8.0 Hz, 1H), 7.24 (d, *J* = 8.0 Hz, 0.5H), 7.29 (d, *J* = 8.0 Hz, 0.5H), 8.24 (t, *J* = 6.5 Hz, 1H), 8.39 (t, *J* = 6.5 Hz, 1H), 8.75 (t, *J* = 6.5 Hz, 1H), 8.86 (t, *J* = 6.5 Hz, 1H), 9.01–9.08 (m, 3H), 11.6–11.9 (m, 1H), 12.6–12.8 (m, 0.5H), (a 1:1 mixture of rotamer); ^{13}C NMR (125 MHz, DMSO-d_6) δ 19.7, 19.8, 20.6, 27.1, 27.2, 28.5, 28.8, 36.3, 36.4, 36.7, 43.1, 43.3, 44.9, 70.5, 73.7, 78.3, 78.4, 78.8, 110.2, 110.3, 114.9, 117.0, 117.2, 117.9, 118.6, 118.8, 119.4, 119.5, 145.7, 146.2, 148.2, 148.3, 149.6, 149.7, 165.4, 165.5, 165.7, 165.7, 168.3, 168.4, 169.4, 169.7, 170.0; HRMS (FAB) calcd for $C_{35}H_{40}N_5O_{11}$ $[M+H]^+$ 706.2724, found 706.2720.



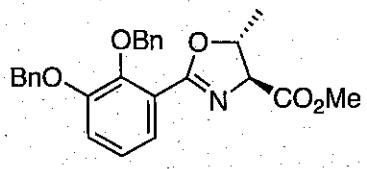
3b

^{1}H NMR ($CDCl_3$)



3b

^{13}C NMR ($CDCl_3$)



3c

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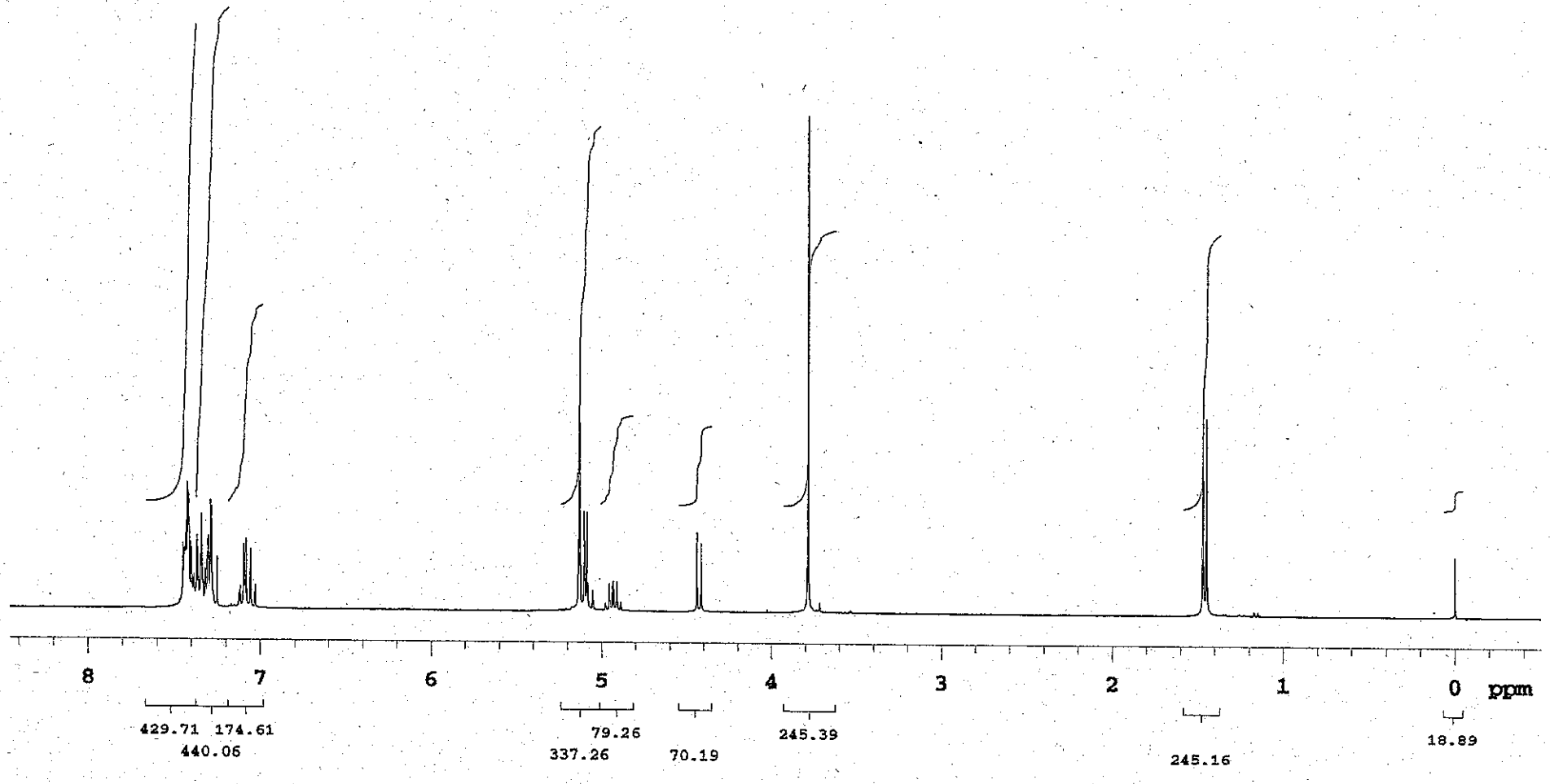

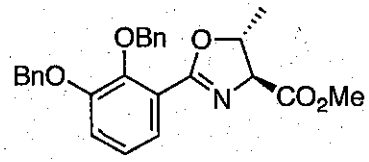

3c

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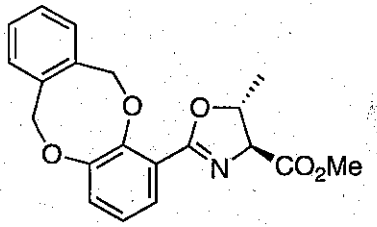
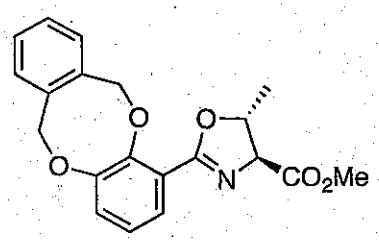


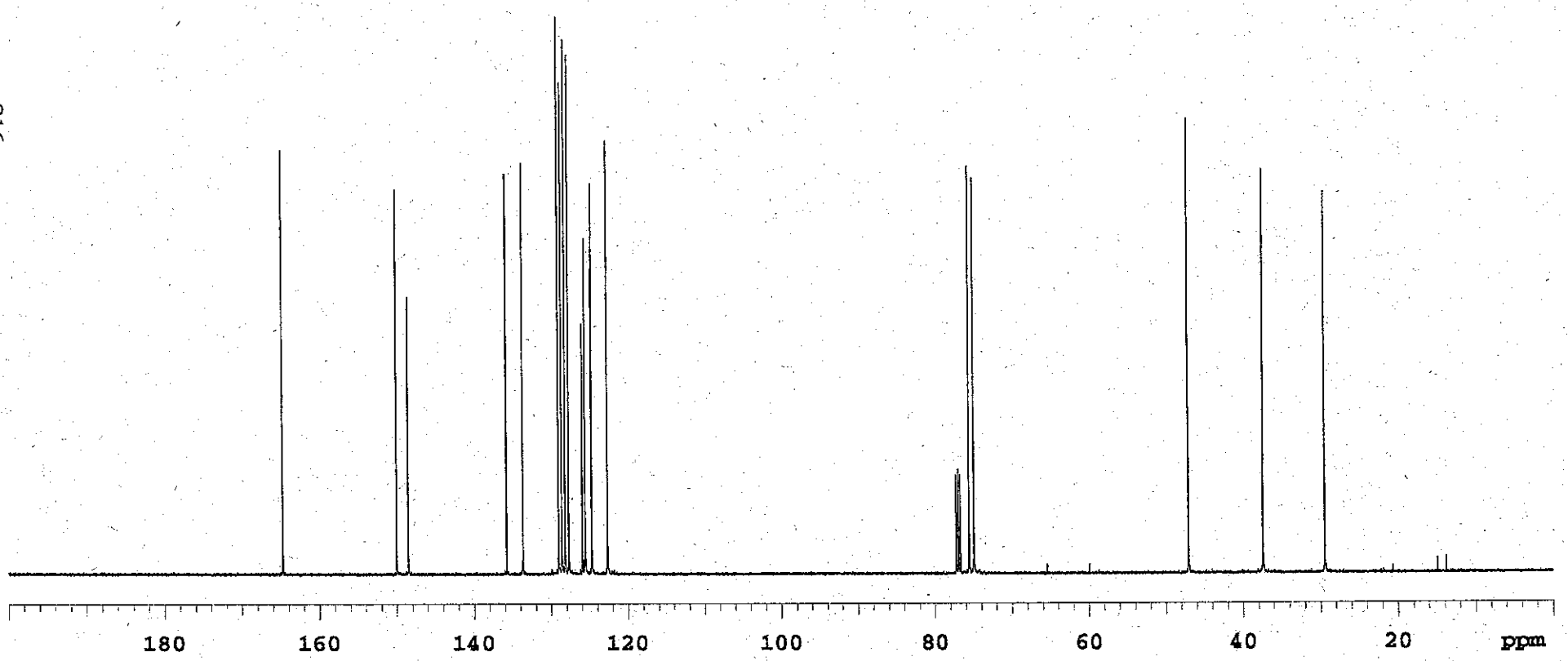
3d

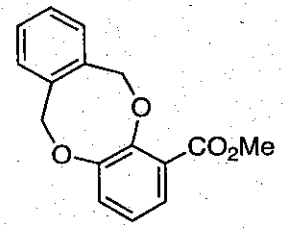
^{1}H NMR ($CDCl_3$)



3d

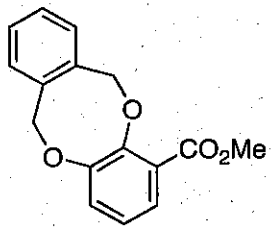
^{13}C NMR ($CDCl_3$)





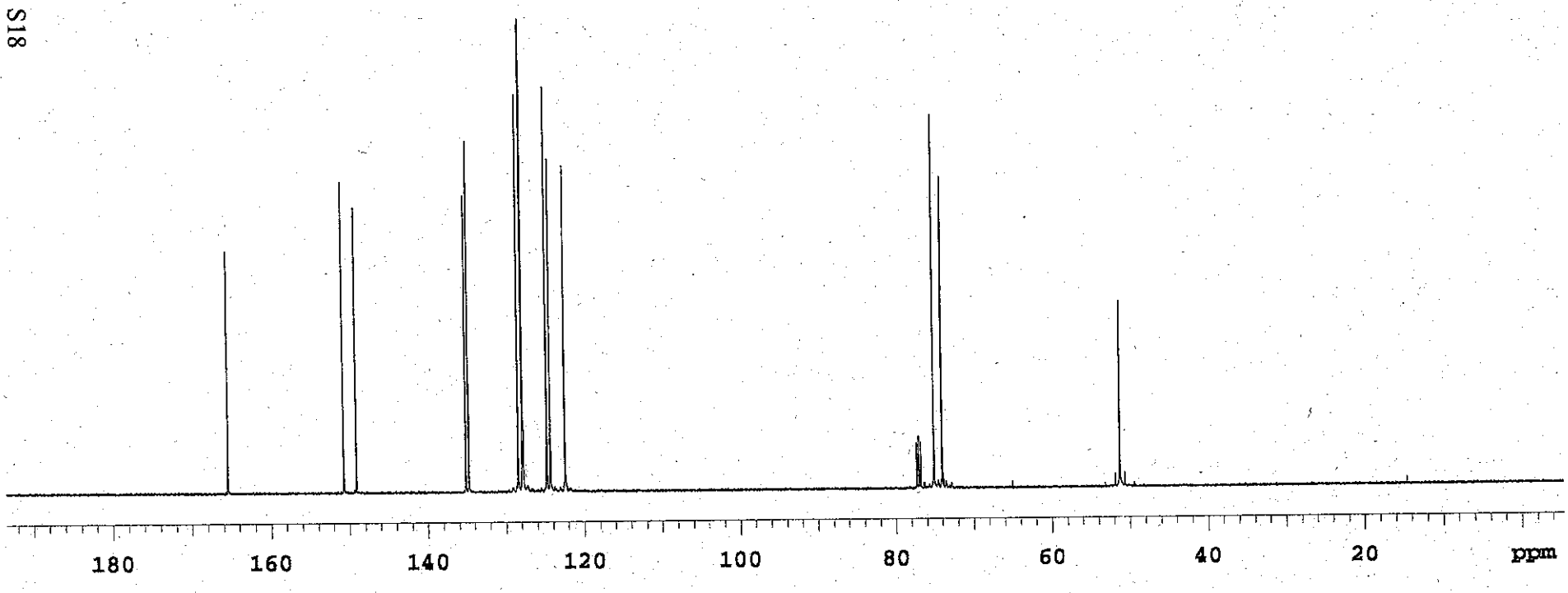
7

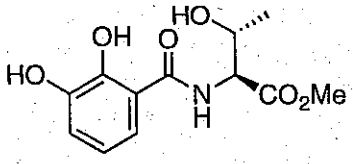
^{1}H NMR ($CDCl_3$)



7

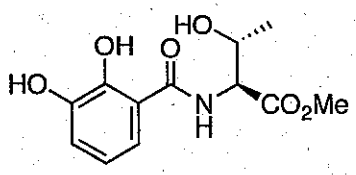
^{13}C NMR ($CDCl_3$)





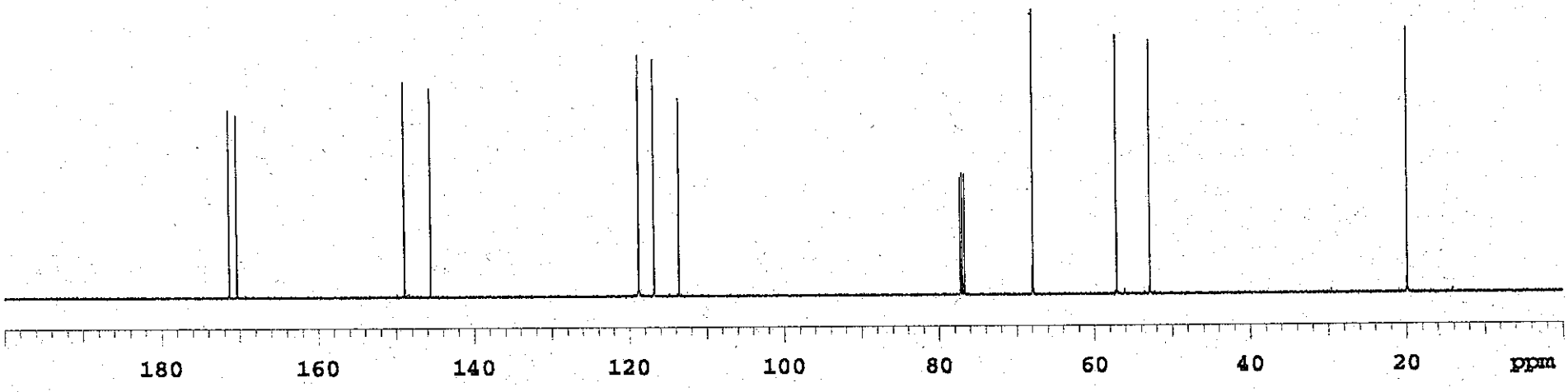
6a

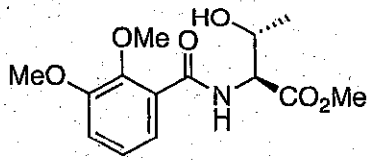
^{1}H NMR ($CDCl_3$)



6a

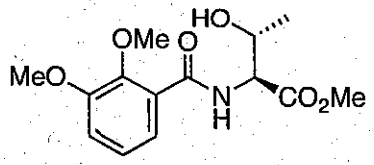
^{13}C NMR ($CDCl_3$)





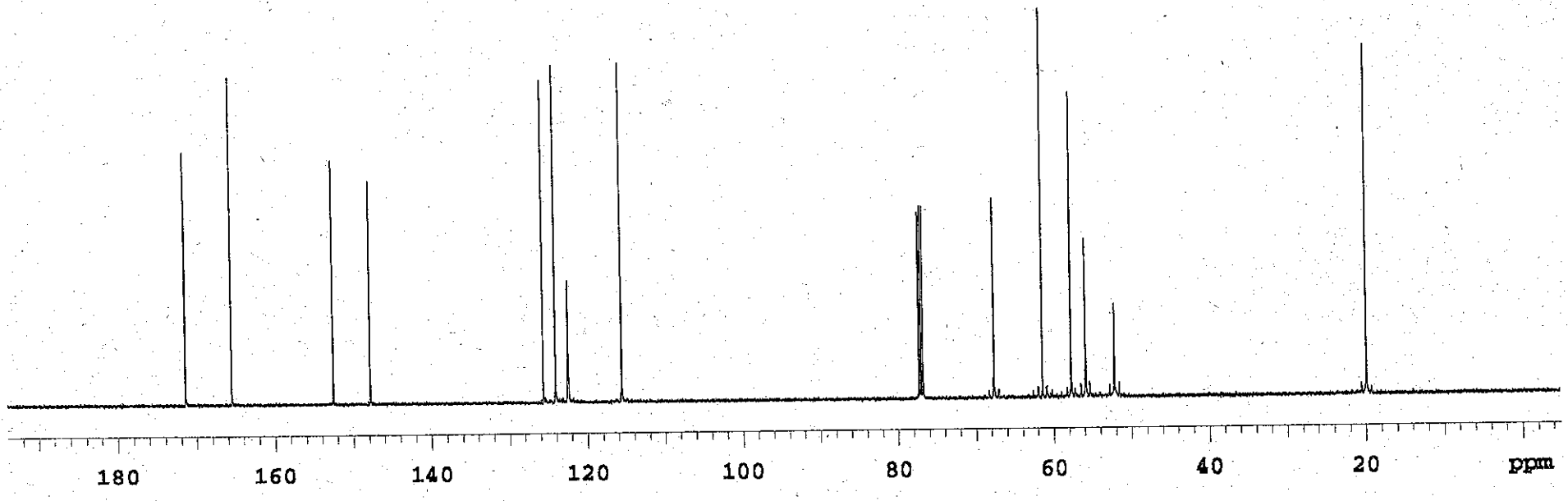
6b

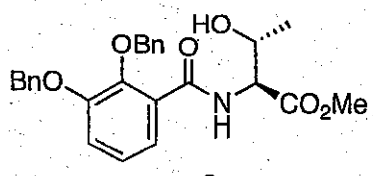
^{1}H NMR ($CDCl_3$)



6b

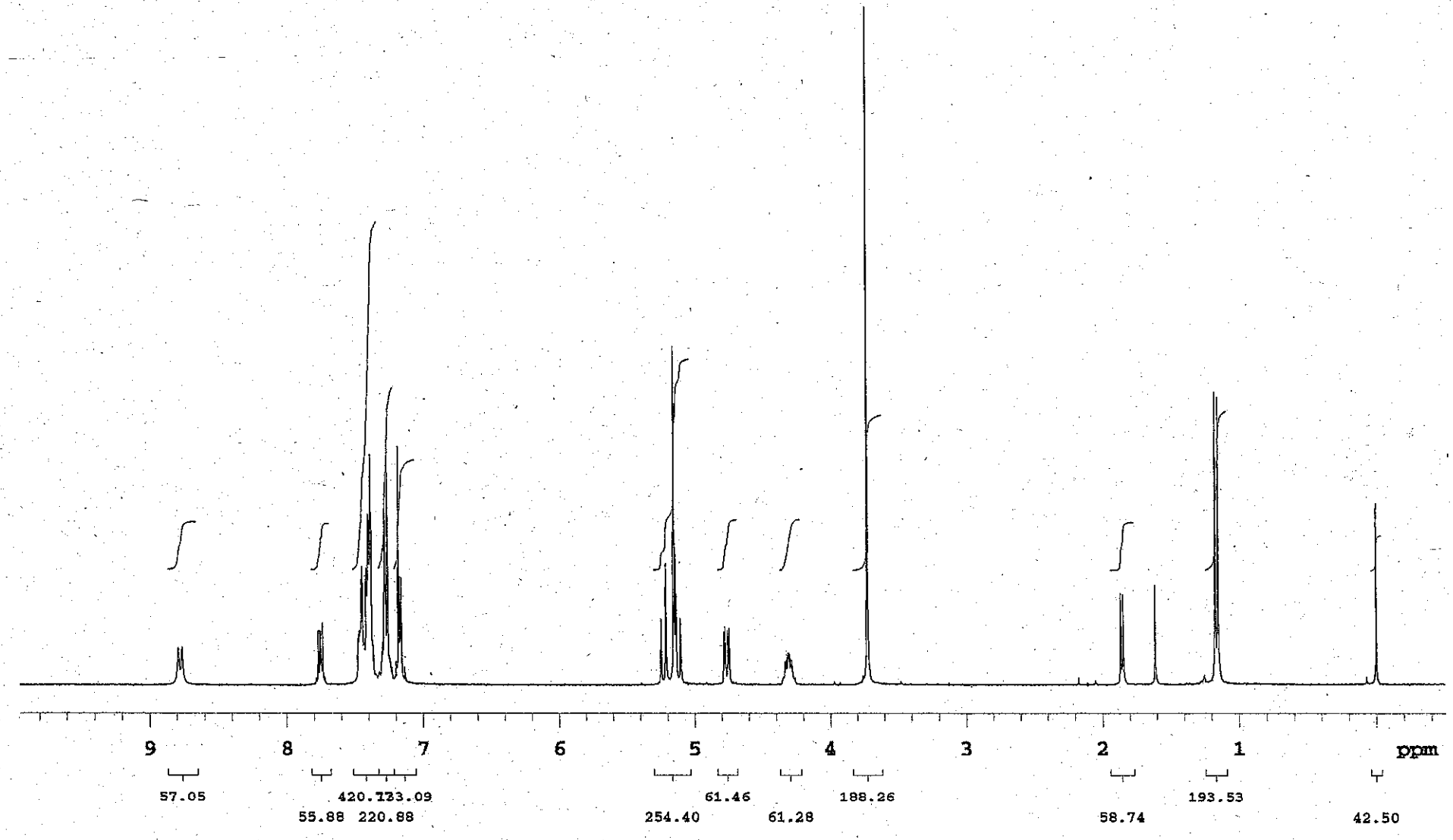
^{13}C NMR ($CDCl_3$)

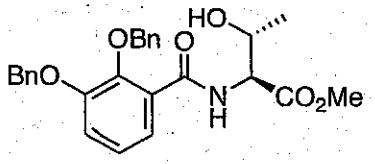




6c

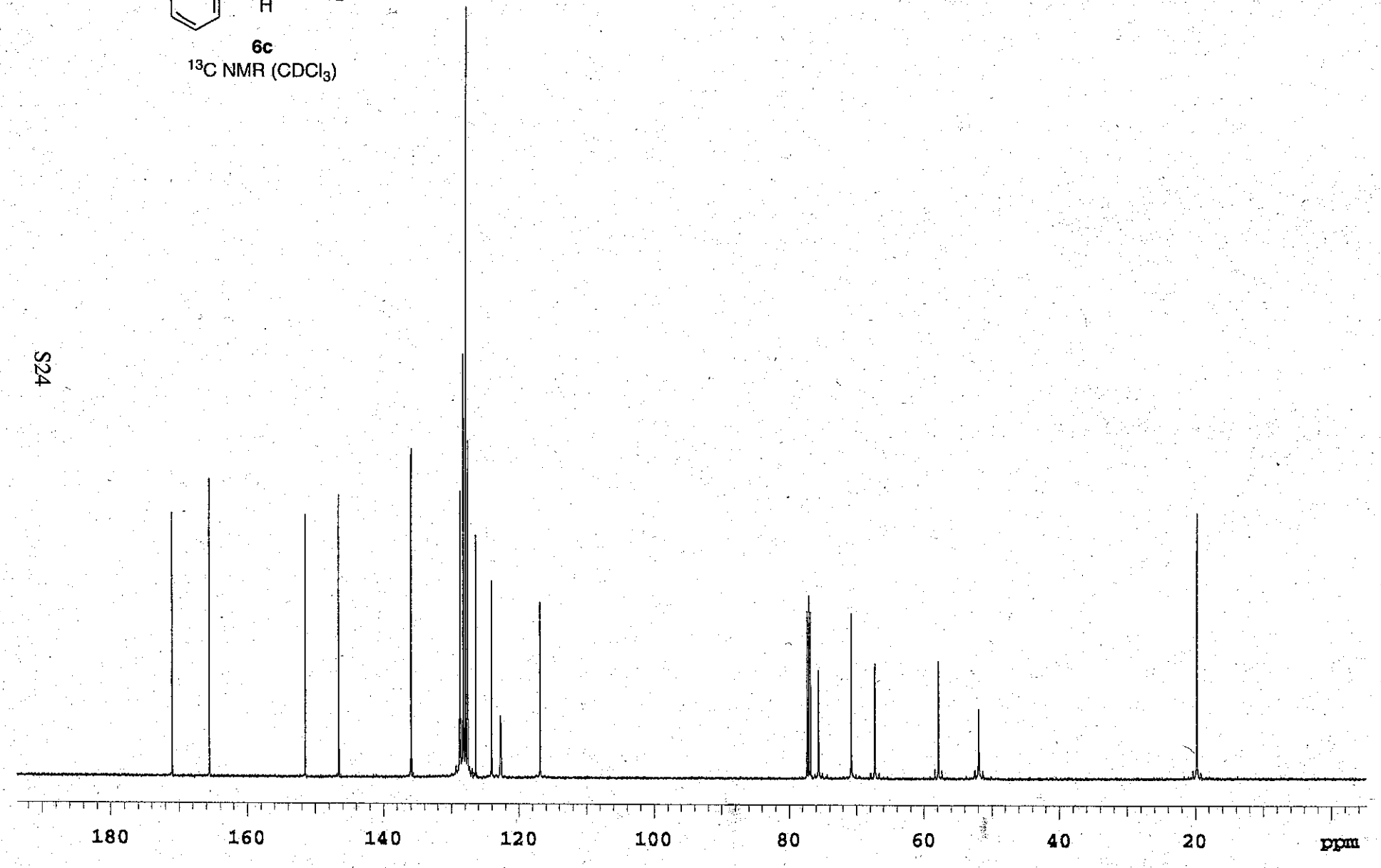
^{1}H NMR ($CDCl_3$)

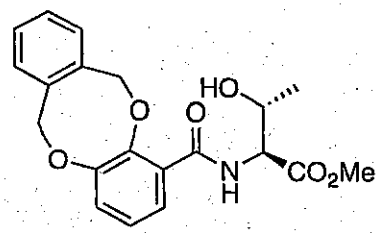




6c

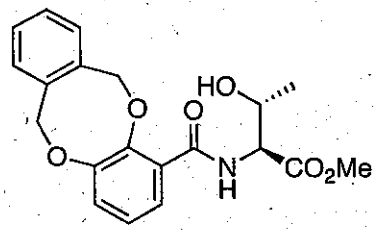
^{13}C NMR ($CDCl_3$)





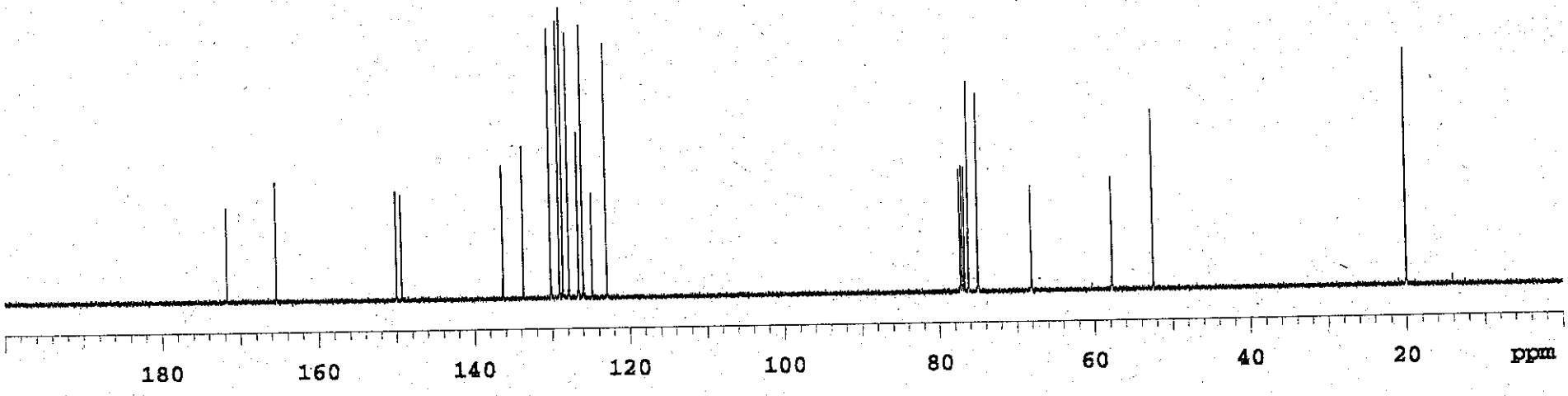
6d

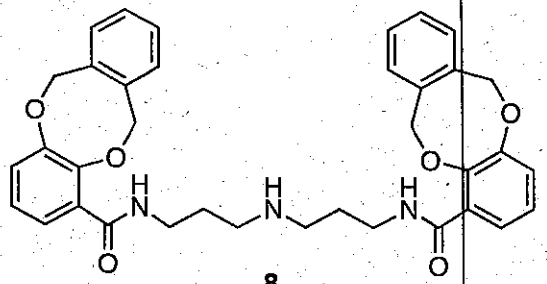
^{1}H NMR ($CDCl_3$)



6d

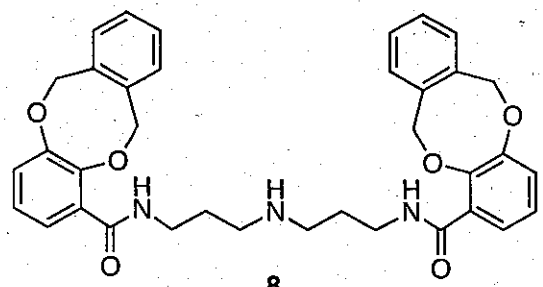
^{13}C NMR ($CDCl_3$)





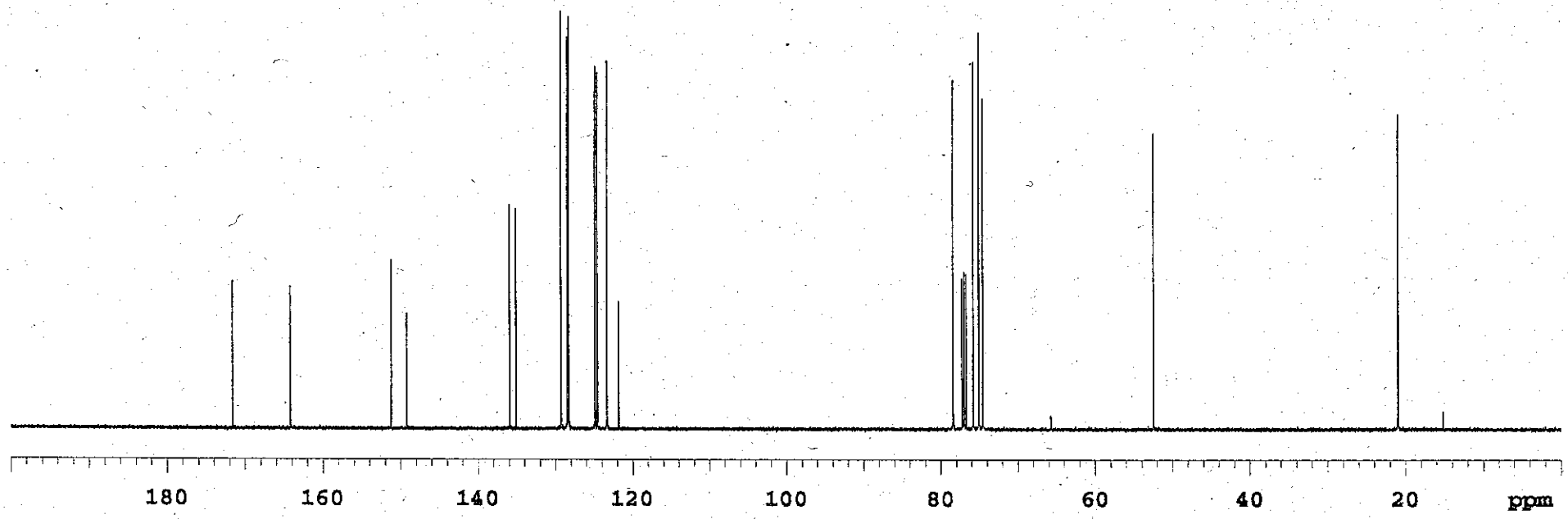
8

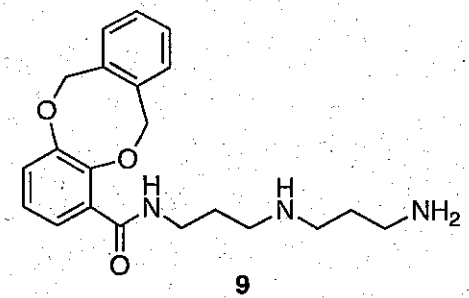
^{1}H NMR ($CDCl_3$)



8

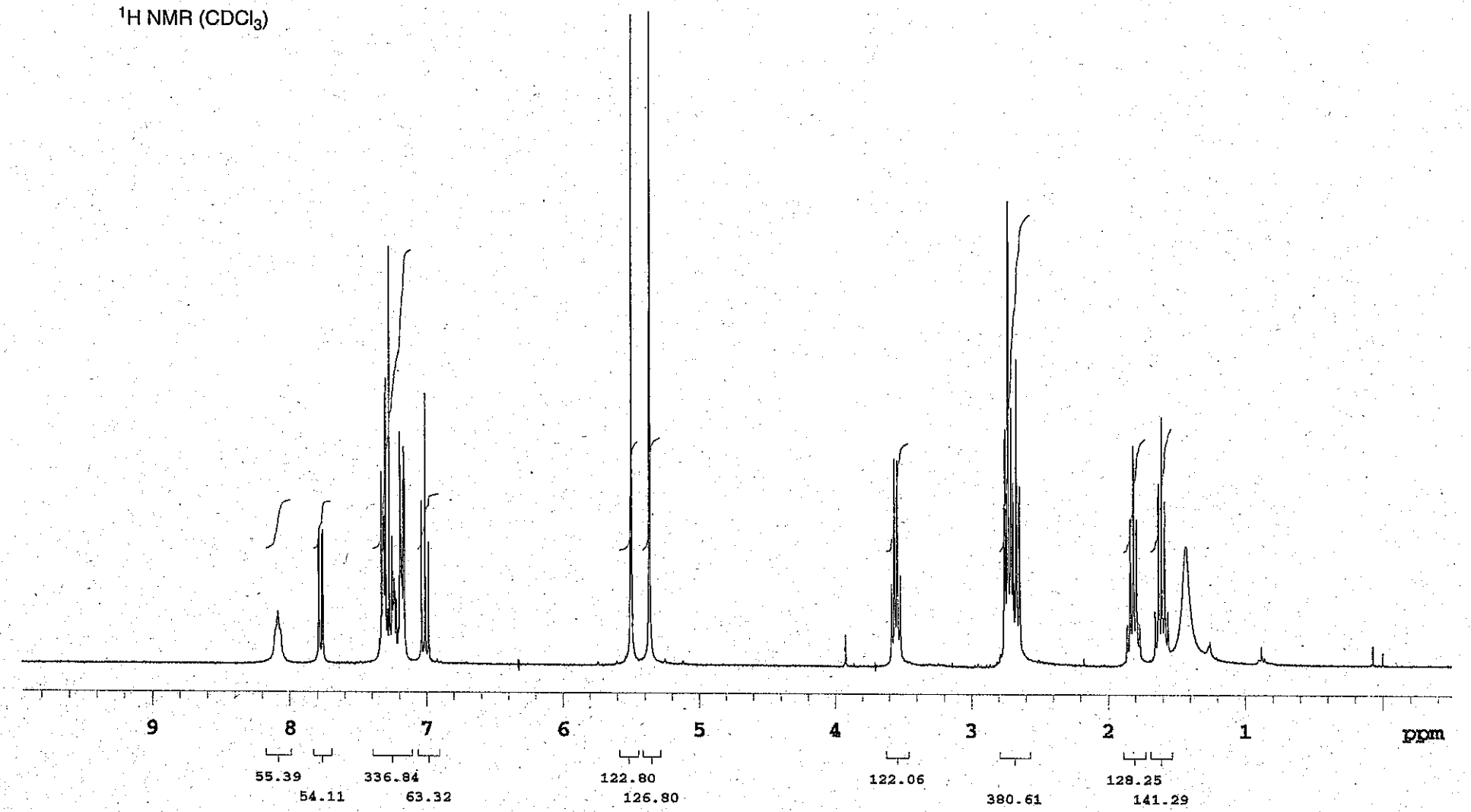
^{13}C NMR ($CDCl_3$)

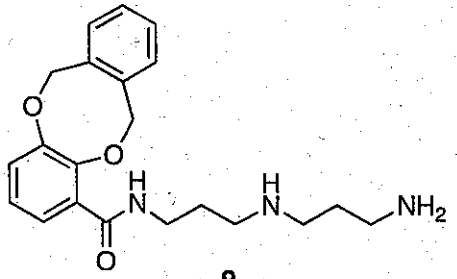




9

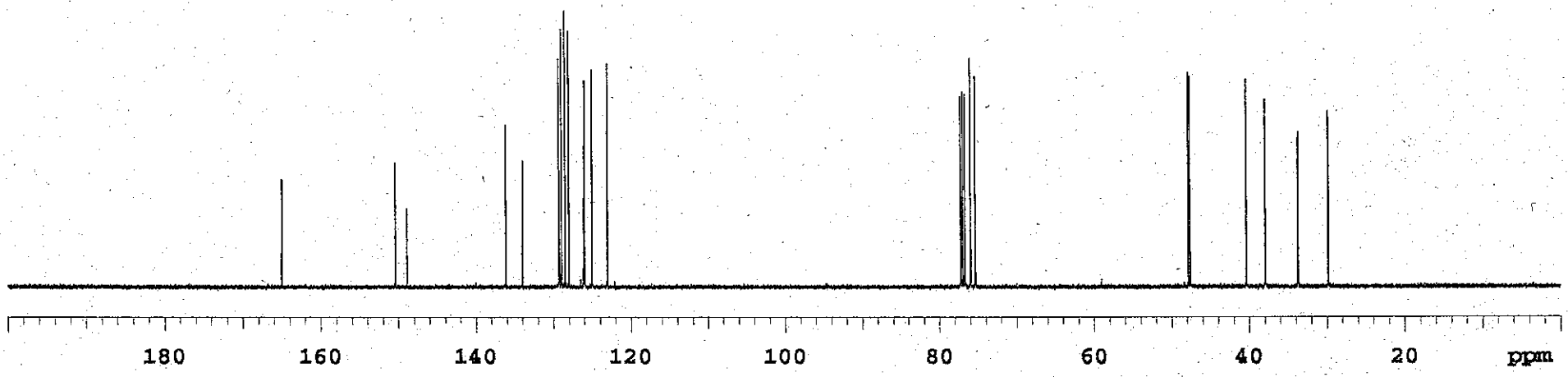
^{1}H NMR ($CDCl_3$)

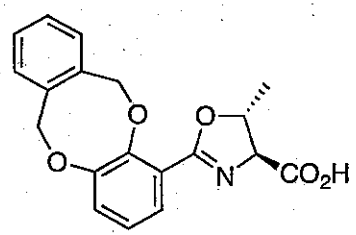




9

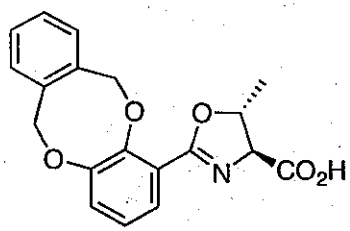
^{13}C NMR ($CDCl_3$)





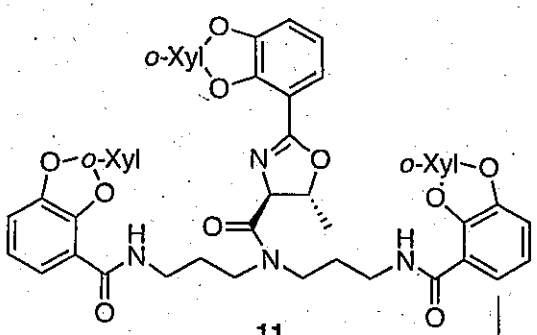
10

^{1}H NMR ($CDCl_3$)



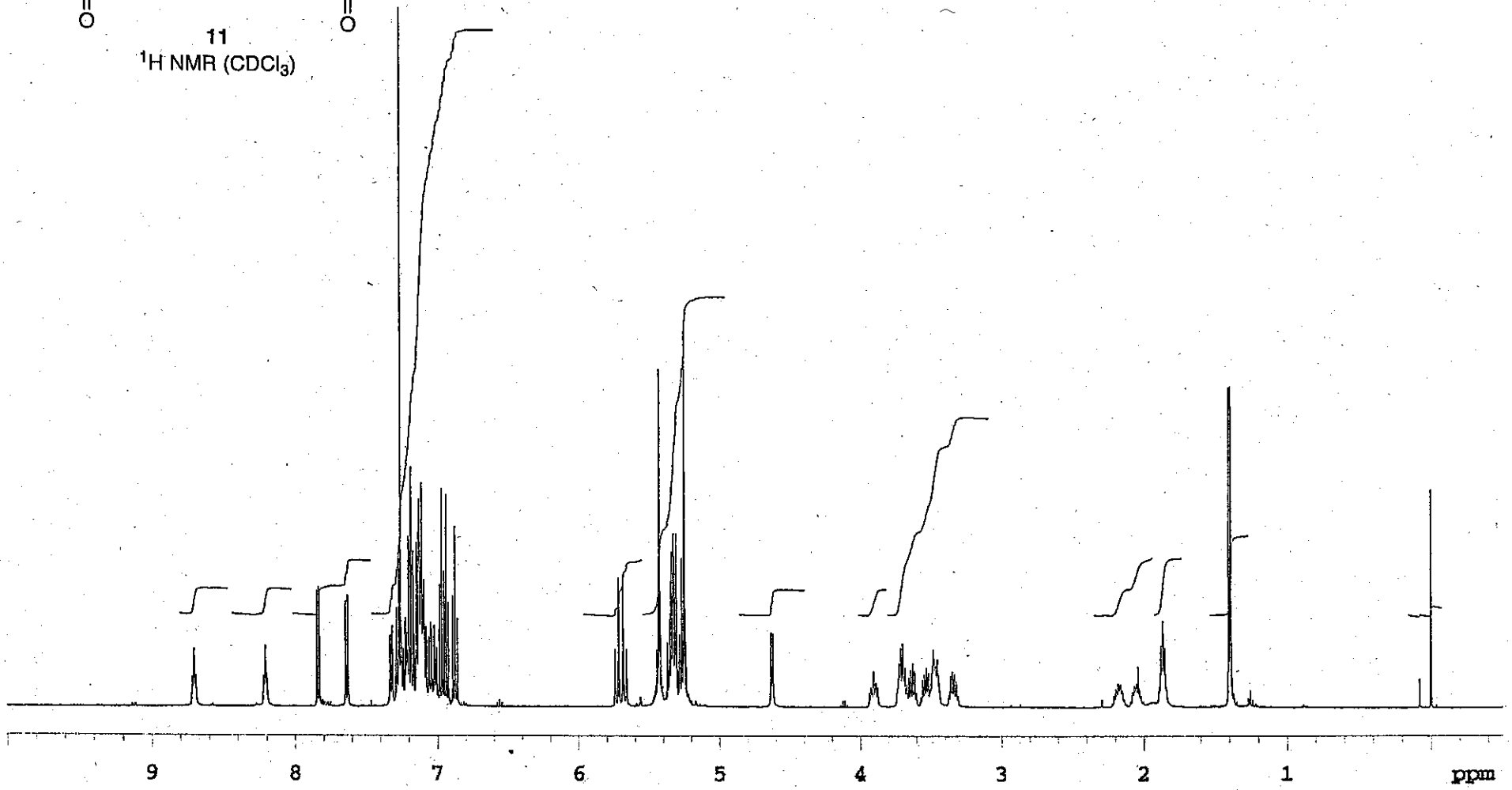
10

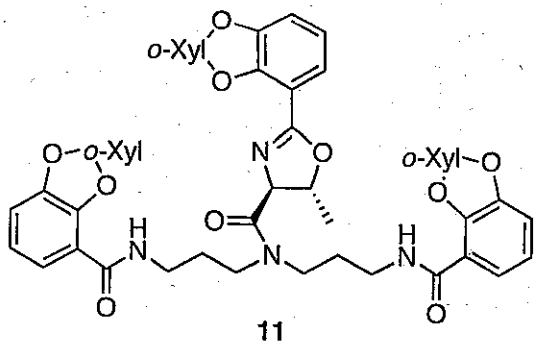
^{13}C NMR ($CDCl_3$)



11

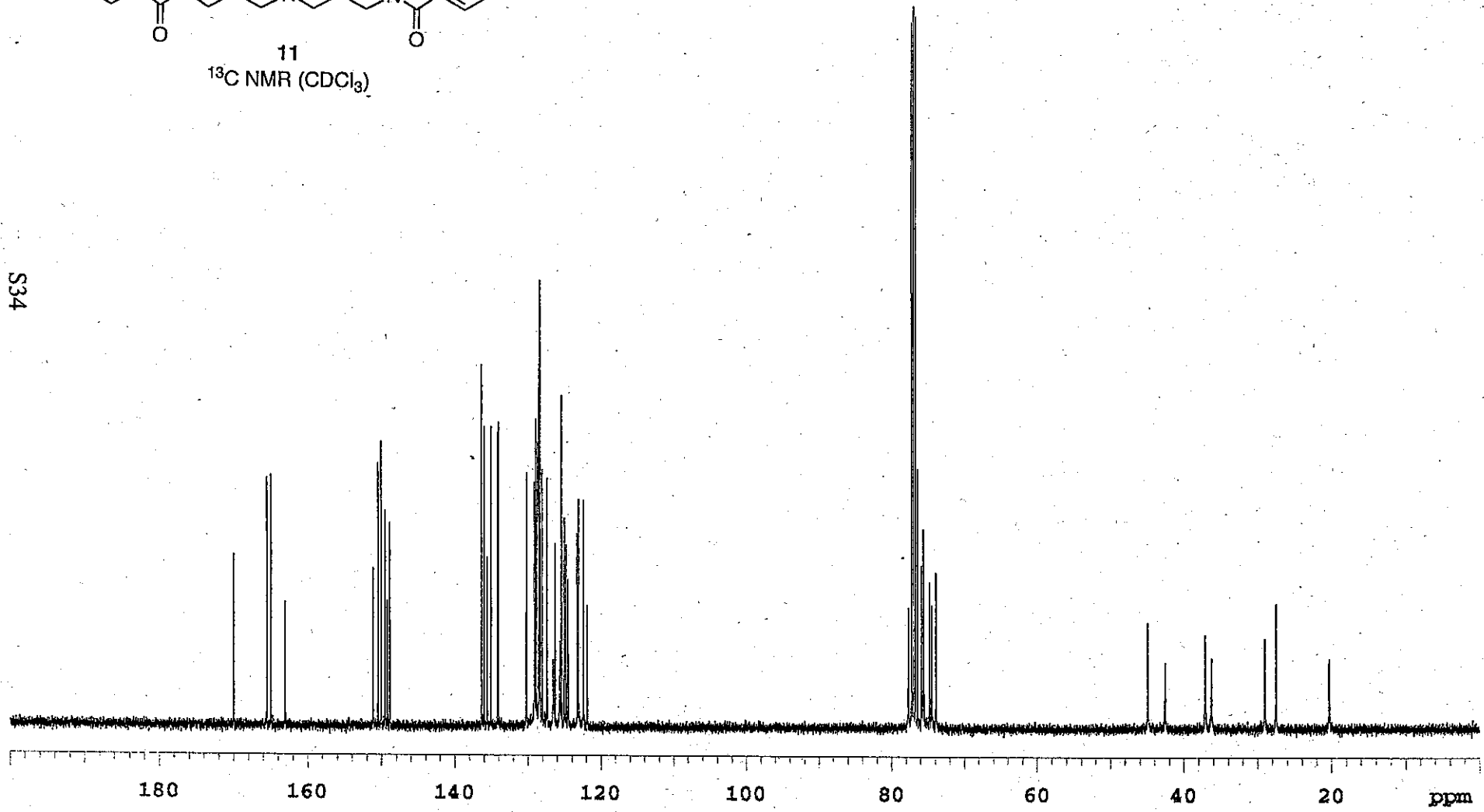
^{1}H NMR ($CDCl_3$)

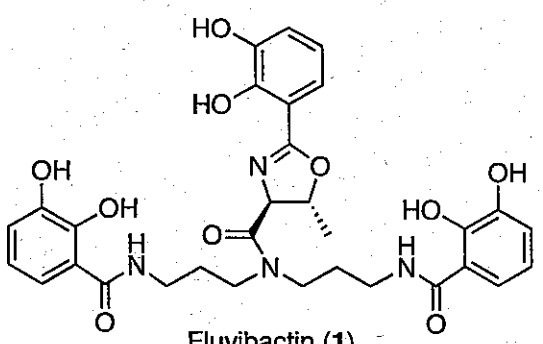




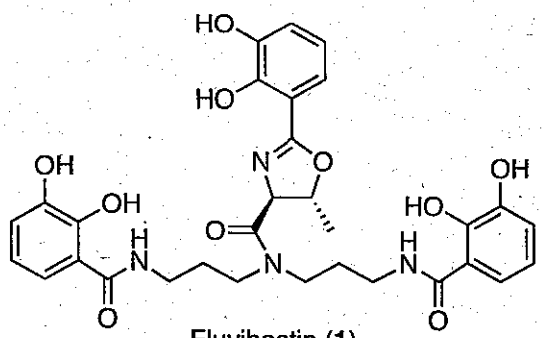
11

^{13}C NMR ($CDCl_3$)

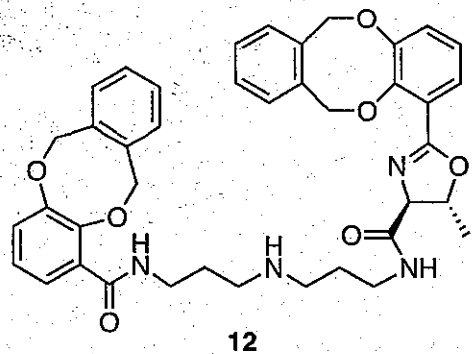




Fluvibactin (**1**)
^{1}H NMR (CD_3OD)

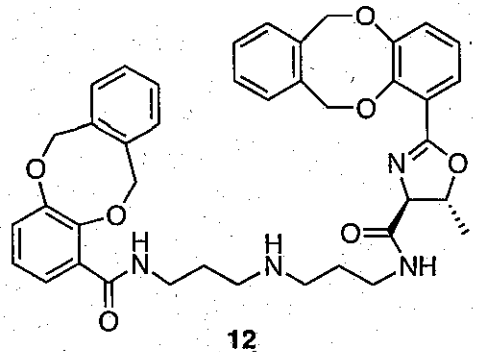


Fluvibactin (**1**)
^{13}C NMR (CD_3OD)



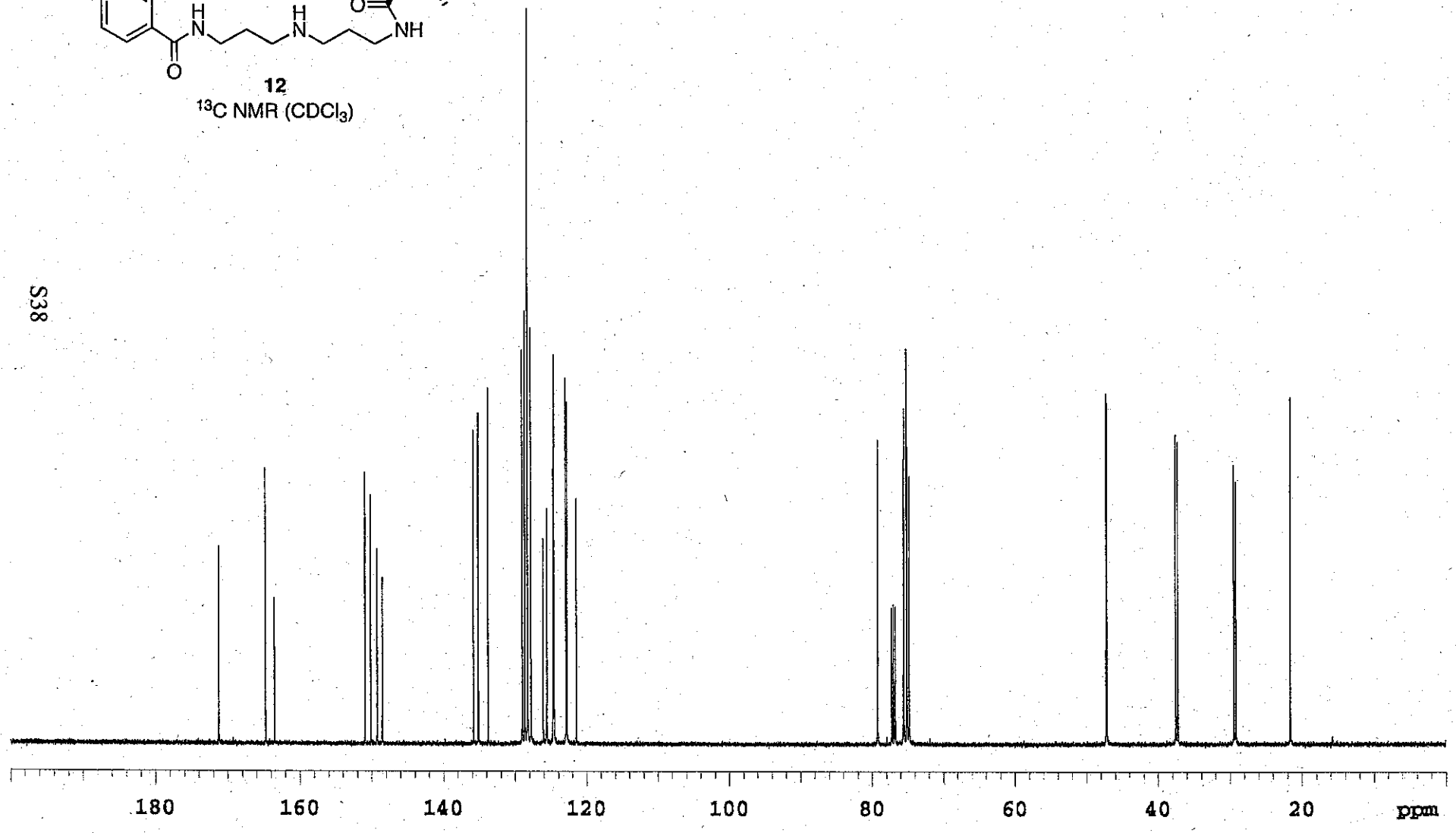
12

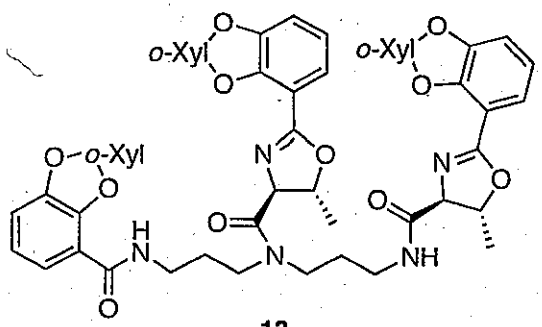
^{1}H NMR ($CDCl_3$)



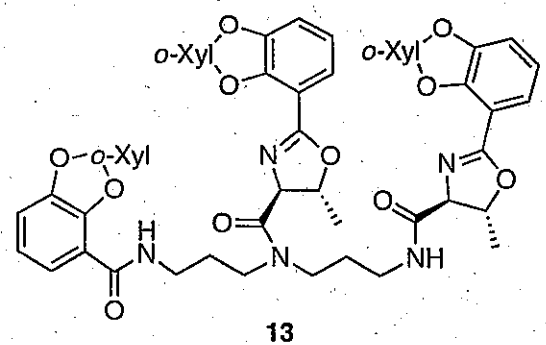
12

^{13}C NMR ($CDCl_3$)



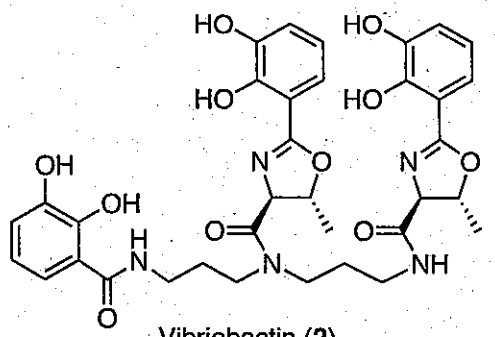


13
^{1}H NMR ($CDCl_3$)

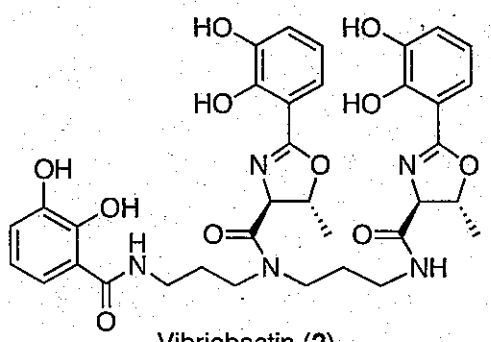


13

^{13}C NMR ($CDCl_3$)



Vibriobactin (**2**)
^{1}H NMR (DMSO-d_6)



Vibriobactin (**2**)
^{13}C NMR (DMSO-d_6)