Supporting Information

Rh(I)-Catalyzed Intramolecular [3 + 2] Cycloaddition of *trans*-Vinylcyclopropane-Enes

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1. General

Air and moisture sensitive reactions were carried out in oven-dried glassware sealed with rubber septa under a positive pressure of dry argon. Similarly sensitive liquids and solutions were transferred via syringe. Reactions were stirred using Teflon-coated magnetic stir bars. Elevated temperatures were maintained using Thermostat-controlled silicone oil baths. Organic solutions were concentrated using a Büchi rotary evaporator with a desktop vacuum pump. Tetrahydrofuran, diethyl ether, and toluene were distilled from sodium and benzophenone prior to use. Dichloromethane was distilled from CaH_2 prior to use. Dioxane (extra dry, water < 50 ppm) was commercially available and used as received. Synthetic reagents were purchased from Acros, Aldrich, and Alfa Aesar and used without further purification, unless otherwise indicated. Analytical TLC was performed with 0.25 mm silica gel G plates with a 254 nm fluorescent indicator. The TLC plates were visualized by ultraviolet light and treatment with phosphomolybdic acid stain followed by gentle heating. Purification of products was accomplished by flash chromatography on silica gel and the purified compounds show a single spot by analytical TLC.

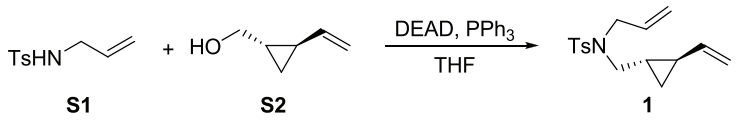
NMR spectra were measured on Varian Mercury 200 (^{1}H at 200 MHz, ^{13}C at 50 MHz) or Varian Mercury Plus 300 (^{1}H at 300 MHz, ^{13}C at 75 MHz) nuclear magnetic resonance spectrometers. Data for ^{1}H-NMR spectra are reported as follows: chemical shift (ppm, referenced to TMS; s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, dt = doublet of triplets, ddd = doublet of doublet of doublets, ddt = doublet of doublet of triplets, m = multiplet), coupling constant (Hz), and integration. Data for ^{13}C-NMR are reported in terms of chemical shift (ppm) relative to residual solvent peak ($CDCl_3$: 77.0 ppm). Optical rotations were measured on a Perkin-Elmer 341 LC spectrometer. The enatiomeric excesses (ee) of the products were determined by chiral HPLC analysis using Aglient HP 1100 instrument. Infrared spectra were recorded on an AVATAR 330 Fourier transform spectrometer (FT-IR) with an OMNI sampler and are reported in wavenumbers (cm^{-1}). Mass spectra (MS) and high-resolution mass spectra (HRMS) were recorded on a VG-ZAB-HS mass spectrometer (EI, 70 eV).

Abbreviations:
THF = tetrehydrofuran
PE = petroleum ether
EA = ethyl acetate
DEAD = diethyl azodicarboxylate
PCC = pyridinium chlorochromate

2. Experimental Procedures and Characterization Data

2.1 Synthesis of Racemic VCP-ene Substrates

***trans*-*N*-Allyl-*N*-tosyl 2-aminomethylvinylcyclopropane (1)**

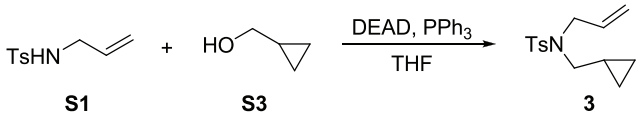


General procedure for the preparation of VCP-ene substrates by Mitsunobu reaction

To a stirred solution of tosylamide **S1** (659 mg, 3.12 mmol), alcohol **S2**[1] (300 mg, 3.06 mmol), and PPh_3 (1.598 g, 6.06 mmol) in THF (30 mL) was added DEAD (1.058 g, 6.08 mmol) at room temperature. The mixture was stirred for 16 h at room temperature. The mixture was diluted with ether, washed successively with water and brine, dried over $MgSO_4$, and concentrated. The crude product was purified by flash column chromatography on silica gel (eluted with PE / EA 20:1 to 10:1) to afford **1** as a colorless oil (600 mg, 67%).

^{1}H NMR (300 MHz, $CDCl_3$): δ 0.59-0.63 (m, 2H), 0.88-0.98 (m, 1H), 1.21-1.29 (m, 1H), 2.42 (s, 3H), 3.00 (dd, J = 7.4 and 14.2 Hz, 1H), 3.20 (dd, J = 6.5 and 14.2 Hz, 1H), 3.86 (dd, J = 6.4 and 15.9 Hz, 1H), 3.95 (dd, J = 5.9 and 15.9 Hz, 1H), 4.86 (dd, J = 1.6 and 10.1 Hz, 1H), 5.00 (dd, J = 1.6 and 17.0 Hz, 1H), 5.13-5.22 (m, 2H), 5.25-5.37 (m, 1H), 5.64 (ddt, J = 10.6, 17.1, and 6.1 Hz, 1H), 7.29 (d, J = 8.4 Hz, 2H), 7.70 (d, J = 8.4 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 12.6, 19.0, 21.5, 22.0, 49.9, 50.4, 112.6, 118.5, 127.1, 129.6, 133.3, 137.4, 140.2, 143.1. MS (EI, 70 eV): m/z 291 (M^+, 20), 224 (62), 155 (89), 136 (24), 91 (100). IR (neat): ν 2955, 1644, 1455 cm^{-1}. HRMS (EI) calcd for $C_{16}H_{21}NO_2S$: 291.1293. Found: 291.1289.

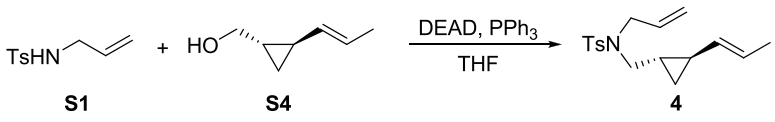
***N*-Allyl-*N*-tosyl aminomethylcyclopropane (3)**



Following the general procedure for the preparation of tosylamide derivatives by a Mitsunobu reaction, tosylamide **S1** (246 mg, 1.17 mmol) and cyclopropanemethanol **S3** (94 mg, 1.31 mmol) were converted to ene-cyclopropane **3** (178 mg, 57%).

^{1}H NMR (300 MHz, $CDCl_3$): δ 0.12-0.18 (m, 2H), 0.45-0.52 (m, 2H), 0.82-0.93 (m, 1H), 2.42 (s, 3H), 3.04 (d, J = 7.0 Hz, 2H), 3.93 (dt, J = 6.1 and 1.3 Hz, 2H), 5.12-5.22 (m, 2H), 5.66 (ddt, J = 10.0, 17.1, and 6.2 Hz, 1H), 7.28 (d, J = 8.5 Hz, 2H), 7.70 (d, J = 8.5 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 4.0, 9.6, 21.5, 50.0, 51.6, 118.3, 127.1, 129.6, 133.4, 137.5, 143.0.

***trans*-*N*-Allyl-*N*-tosyl 2-aminomethyl-(1-propenyl)cyclopropane (4)**



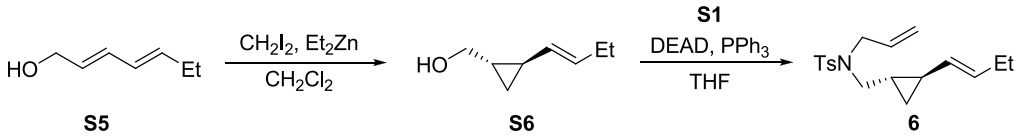
Following the general procedure for the preparation of tosylamide derivatives by a Mitsunobu reaction,

(1) Mordini, A.; Peruzzi, D.; Russo, F.; Valacchi, M.; Reginato, G.; Brandi, A. *Tetrahedron* **2005**, *61*, 3349.

tosylamide **S1** (212 mg, 1.00 mmol) and alcohol **S4**[2] (138 mg, 1.23 mmol) were converted to VCP-ene **4** (131 mg, 43%).

^{1}H NMR (300 MHz, $CDCl_3$): δ 0.52 (app. t, J = 6.8 Hz, 2H), 0.80-0.90 (m, 1H), 1.13-1.22 (m, 1H), 1.62 (dd, J = 1.3 and 6.5 Hz, 3H), 2.42 (s, 3H), 2.98 (dd, J = 7.5 and 14.5 Hz, 1H), 3.18 (dd, J = 6.4 and 14.5 Hz, 1H), 3.86 (dd, J = 6.4 and 16.0 Hz, 1H), 3.95 (dd, J = 6.0 and 16.0 Hz, 1H), 4.94 (dd, J = 8.5 and 15.3 Hz, 1H), 5.12-5.22 (m, 2H), 5.43 (dq, J = 15.1 and 6.5 Hz, 1H), 5.64 (ddt, J = 10.3, 17.1, and 6.2 Hz, 1H), 7.28 (d, J = 8.0 Hz, 2H), 7.69 (d, J = 8.0 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 12.1, 17.8, 18.5, 20.9, 21.5, 49.9, 50.5, 118.5, 123.6, 127.1, 129.6, 132.6, 133.3, 137.5, 143.0. MS (EI, 70 eV): m/z 305 (M^+, 6), 290 (8), 264 (14), 224 (70), 155 (96), 91 (100). IR (neat): ν 2923, 1598, 1450, 1342 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{23}NO_2S$: 305.1449. Found: 305.1443.

***trans*-*N*-Allyl-*N*-tosyl 2-aminomethyl-(1-butenyl)cyclopropane (6)**



S5 **S6** **6**

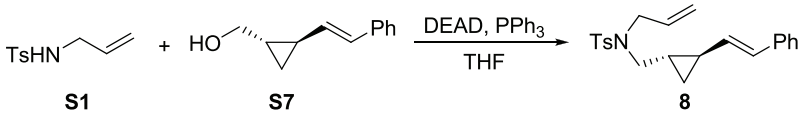
Dienyl alcohol **S5** (546 mg, 4.87 mmol) was converted to cyclopropyl alcohol **S6** (286 mg, 46%) following the cyclopropanation procedure of Charette et al.[3]

S6: ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.55-0.64 (m, 2H), 0.96 (t, J = 7.5 Hz, 3H), 1.04-1.15 (m, 1H), 1.22-1.32 (m, 1H), 1.84-1.93 (br s, 1H), 2.00 (quintet, J = 7.6 Hz, 2H), 3.47 (dd, J = 7.0 and 11.2 Hz, 1H), 3.52 (dd, J = 7.0 and 11.2 Hz, 1H), 5.02 (dd, J = 8.1 and 15.3 Hz, 1H), 5.55 (dt, J = 15.3 and 6.3 Hz, 1H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 11.3, 13.8, 19.4, 22.5, 25.4, 66.4, 130.5, 130.9.

Following the general procedure for the preparation of tosylamide derivatives by a Mitsunobu reaction, tosylamide **S1** (184 mg, 0.87 mmol) and alcohol **S6** (110 mg, 0.87 mmol) were converted to VCP-ene **6** (155 mg, 56%).

6: ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.53 (t, J = 6.8 Hz, 2H), 0.79-0.90 (m, 1H), 0.94 (t, J = 7.3 Hz, 3H), 1.11-1.23 (m, 1H), 1.97 (quintet, J = 7.3 Hz, 2H), 2.42 (s, 3H), 2.99 (dd, J = 7.4 and 14.5 Hz, 1H), 3.18 (dd, J = 6.4 and 14.5 Hz, 1H), 3.86 (dd, J = 6.3 and 15.8 Hz, 1H), 3.95 (dd, J = 6.0 and 15.8 Hz, 1H), 4.91 (dd, J = 8.4 and 15.0 Hz, 1H), 5.14 (d, J = 10.2 Hz, 1H), 5.19 (d, J = 18.6 Hz, 1H), 5.46 (dt, J = 15.3 and 6.3 Hz, 1H), 5.64 (ddt, J = 10.8, 17.1, and 6.3 Hz, 1H), 7.28 (d, J = 8.1 Hz, 2H), 7.70 (d, J = 8.1 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 12.2, 13.8, 18.5, 20.8, 21.4, 25.3, 49.8, 50.5, 118.4, 127.0, 129.5, 130.4, 130.7, 133.3, 137.4, 143.0. MS (EI, 70 eV): m/z 319 (M^+, 6), 290 (9), 278 (18), 224 (73), 164 (34), 155 (100), 91 (80). IR (neat): ν 2962, 1598, 1494, 1443, 1342 cm^{-1}. HRMS (EI) calcd for $C_{18}H_{25}NO_2S$: 319.1606. Found: 319.1601.

***trans*-*N*-Allyl-*N*-tosyl 2-aminomethyl-(2-phenylethen-1-yl)cyclopropane (8)**



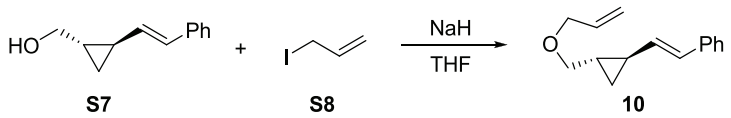
S1 **S7** **8**

(2) Lautens, M.; Delanghe, P. H. M. *J. Org. Chem.* **1993**, *58*, 5037.
(3) Charette, A. B.; Marcoux, J.-F.; Molinaro, C.; Beauchemin, A.; Brochu, C.; Isabel, E. *J. Am. Chem. Soc.* **2000**, *122*, 4508.

Following the general procedure for the preparation of tosylamide derivatives by a Mitsunobu reaction, tosylamide **S1** (217 mg, 1.03 mmol) and alcohol **S7**[4] (174 mg, 1.00 mmol) were converted to VCP-ene **8** (243 mg, 66%).

^{1}H NMR (300 MHz, $CDCl_3$): δ 0.69-0.74 (m, 2H), 1.01-1.09 (m, 1H), 1.36-1.45 (m, 1H), 2.39 (s, 3H), 3.04 (dd, J = 7.4 and 14.7 Hz, 1H), 3.26 (dd, J = 6.4 and 14.7 Hz, 1H), 3.85-4.00 (m, 2H), 5.14-5.24 (m, 2H), 5.60-5.59 (m, 2H), 6.36 (d, J = 16.0 Hz, 1H), 7.24-7.30 (m, 7H), 7.71 (d, J = 8.6 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 13.1, 19.5, 21.4, 21.8, 50.1, 50.4, 118.6, 125.6, 126.8, 127.0, 128.2, 128.5, 129.6, 132.3, 133.3, 137.3, 137.4, 143.1. MS (EI, 70 eV): m/z 367 (M^+, 8), 224 (60), 212 (22), 155 (65), 91 (100). IR (neat): ν 2955, 1597, 1493, 1448 cm^{-1}. HRMS (EI) calcd for $C_{22}H_{25}NO_2S$: 367.1606. Found: 367.1599.

***trans*-2-Allyloxymethyl-(2-phenylethen-1-yl)cyclopropane (10)**

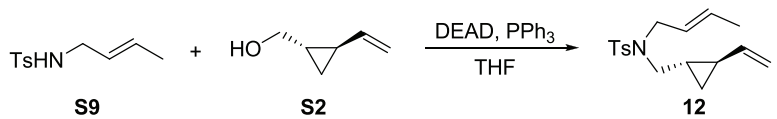


S7 **S8** **10**

To a suspension of NaH (44 mg, 1.84 mmol) in THF (10 mL) was added alcohol **S7** (144 mg, 0.83 mmol) in one portion and the mixture was stirred under reflux for 1 h. The resulting mixture was added allyl iodide **S8** (174 mg, 1.04 mmol) and refluxed for 11 h. Brine was added to quench the reaction, and the mixture was extracted by ether. The combined extract was dried over $MgSO_4$ and concentrated, and the crude product was purified by flash column chromatography on silica gel (eluted with PE/EA 30:1) to give VCP-ene **10** (168 mg, 95%).

^{1}H NMR (300 MHz, $CDCl_3$): δ 0.79 (t, J = 7.0 Hz, 2H), 1.20-1.31 (m, 1H), 1.45-1.54 (m, 1H), 3.37 (dd, J = 6.7 and 10.3 Hz, 1H), 3.42 (dd, J = 6.7 and 10.3 Hz, 1H), 4.00 (dm, J = 5.6 Hz, 2H), 5.19 (dm, J = 10.3 Hz, 1H), 5.28 (dm, J = 17.2 Hz, 1H), 5.79 (dd, J = 8.5 and 15.6 Hz, 1H), 5.93 (ddt, J = 10.3, 17.3, and 5.6 Hz, 1H), 6.45 (d, J = 15.6 Hz, 1H), 7.14-7.19 (m, 1H), 7.24-7.29 (m, 4H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 12.4, 20.6, 20.7, 71.5, 73.3, 117.0, 125.6, 126.6, 127.9, 128.5, 133.0, 134.9, 137.5. MS (EI, 70 eV): m/z 214 (M^+, 8), 156 (32), 143 (42), 130 (100), 115 (53), 91 (43). IR (neat): ν 3023, 2851, 1597, 1493, 1448 cm^{-1}. HRMS (EI) calcd for $C_{15}H_{18}O$: 214.1358. Found: 214.1356.

***trans*-*N*-(but-2-enyl)-*N*-tosyl 2-aminomethylvinylcyclopropane (12)**



S9 **S2** **12**

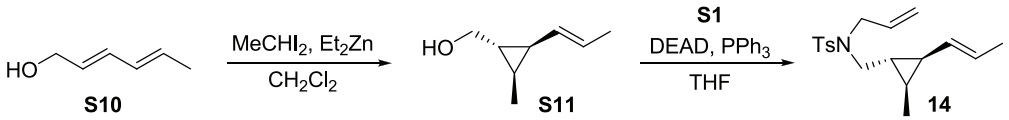
Following the general procedure for the preparation of tosylamide derivatives by a Mitsunobu reaction, tosylamide **S9** (220 mg, 0.98 mmol) and alcohol **S2** (97 mg, 0.99 mmol) were converted to VCP-ene **12** (146 mg, 49%).

^{1}H NMR (300 MHz, $CDCl_3$): δ 0.58-0.65 (m, 2H), 0.90-1.00 (m, 1H), 1.20-1.30 (m, 1H), 1.65 (dq, J = 6.4 and 1.3 Hz, 3H), 2.42 (s, 3H), 2.99 (dd, J = 7.3 and 14.5 Hz, 1H), 3.17 (dd, J = 6.5 and 14.5 Hz, 1H), 3.78 (dd, J = 6.6 and 15.3 Hz, 1H), 3.87 (dd, J = 6.3 and 15.3 Hz, 1H), 4.86 (dd, J = 1.7 and 10.0 Hz, 1H), 5.00 (dd, J = 1.7 and 17.0 Hz, 1H), 5.22-5.36 (m, 2H), 5.54-5.66 (m, 1H), 7.28 (d, J = 8.5 Hz, 2H), 7.69 (d, J = 8.5 Hz, 2H). ^{13}C

(4) Charette, A. B.; Juteau, H.; Label, H.; Deschenes, D. *Tetrahedron Lett.* **1996**, *37*, 7925.

NMR (75.5 MHz, $CDCl_3$): δ 12.6, 17.6, 19.1, 21.5, 22.0, 49.3, 50.1, 112.5, 125.9, 127.1, 129.5, 129.9, 137.5, 140.3, 142.9. MS (EI, 70 eV): *m*/*z* 305 (M^+, 8), 238 (10), 222 (6), 184 (40), 155 (60). IR (neat): *v* 2999, 1635, 1598, 1495, 1446 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{23}NO_2S$: 305.1449. Found: 305.1443.

***trans*-*N*-Allyl-*N*-tosyl 2-aminomethyl-3-methyl-(1-propenyl)cyclopropane (14)**



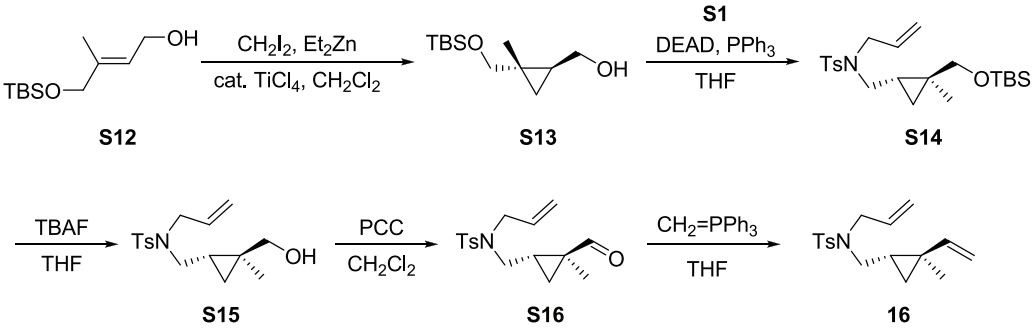
Dienyl alcohol **S10** (396 mg, 4.03 mmol) was converted to cyclopropyl alcohol **S11** (114 mg, 22%) following the cyclopropanation procedure of Charette et al.[3] The purity of **S11** was quite poor due to inseparable residual starting material **S10** and possible other diastereomers.

S11: ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.82-0.91 (m, 2H), 1.07 (d, J = 5.9 Hz, 3H), 1.28-1.36 (m, 1H), 1.52 (br, s, 1H), 1.69 (dd, J = 1.5 and 6.5 Hz, 3H), 3.50 (d, J = 6.2 Hz, 2H), 5.20 (ddq, J = 8.7, 15.0, and 1.5 Hz, 1H), 5.56 (dq, J = 15.0 and 6.5 Hz, 1H). ^{13}C NMR (75.5 Hz, $CDCl_3$): δ 13.2, 17.5, 18.1, 24.3, 29.6, 66.6, 125.6, 129.0.

Following the general procedure for the preparation of tosylamide derivatives by a Mitsunobu reaction, tosylamide **S1** (168 mg, 0.79 mmol) and alcohol **S11** (103 mg, 0.82 mmol) were converted to VCP-ene **14** (101 mg, 39%).

14: ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.56-0.63 (m, 1H), 0.72-0.80 (m, 1H), 0.98 (d, J = 6.1 Hz, 3H), 1.16-1.24 (m, 1H), 1.66 (dd, J = 1.3 and 6.3 Hz, 3H), 2.42 (s, 3H), 3.05 (dd, J = 6.5 and 14.0 Hz, 1H), 3.14 (dd, J = 6.8 and 14.0 Hz, 1H), 3.88-3.91 (m, 2H), 5.05-5.21 (m, 3H), 5.46 (dq, J = 15.0 and 6.5 Hz, 1H), 5.63 (ddt, J = 10.3, 17.4, and 6.2 Hz, 1H), 7.28 (d, J = 8.5 Hz, 2H), 7.69 (d, J = 8.5 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 12.9, 18.1, 18.4, 21.5, 25.3, 25.5, 49.8, 50.5, 118.3, 125.8, 127.1, 128.6, 129.6, 133.3, 137.5, 143.0. MS (EI, 70 eV): *m*/*z* 319 (M^+, 9), 304 (8), 264 (22), 224 (100), 155 (96), 91 (92). IR (neat): *v* 2925, 1598, 1495, 1450 cm^{-1}. HRMS (EI) calcd for $C_{18}H_{25}NO_2S$: 319.1606. Found: 319.1592.

***trans*-*N*-Allyl-*N*-tosyl 2-aminomethyl-1-methylvinylcyclopropane (16)**



Allylic alcohol **S12**[5] (2.11 g, 9.75 mmol) was converted to cyclopropyl alcohol **S13** (1.93 g, 92%) following the cyclopropanation procedure of Charette et al.[3]

S13: ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.00 (s, 6H), 0.13 (t, J = 5.0 Hz, 1H), 0.61 (dd, J = 4.7 and 8.9 Hz, 1H), 0.86 (s, 9H), 0.97-1.06 (m, 1H), 1.10 (s, 3H), 1.57-1.71 (br s, 1H), 3.30 (d, J = 10.1 Hz, 1H), 3.41 (d, J = 10.1

(5) Koppisch, A. T.; Blagg, B. S. J.; Poulter, C. D. *Org. Lett.* **2000**, *2*, 215.

Hz, 1H), 3.48 (dd, J = 8.6 and 11.3 Hz, 1H), 3.70 (dd, J = 6.7 and 11.3 Hz, 1H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ -5.3, 14.8, 15.3, 18.3, 22.1, 23.2, 25.9, 63.3, 70.5.

Following the general procedure for the preparation of tosylamide derivatives by a Mitsunobu reaction, tosylamide **S1** (2.91 g, 13.8 mmol) and alcohol **S13** (3.17 g, 13.8 mmol) were converted to ene-cyclopropane **S14** (2.82 g, 48%).

S14: ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.00 (s, 6H), 0.07 (t, J = 5.2 Hz, 1H), 0.59 (dd, J = 4.6 and 8.8 Hz, 1H), 0.77-0.86 (m, 1H), 0.86 (s, 9H), 1.05 (s, 3H), 2.41 (s, 3H), 3.17 (dd, J = 7.1 and 14.3 Hz, 1H), 3.23 (d, J = 10.0 Hz, 1H), 3.28 (dd, J = 6.7 and 14.3 Hz, 1H), 3.39 (d, J = 10.0 Hz, 1H), 3.90 (dd, J = 6.1 and 16.2 Hz, 1H), 3.99 (dd, J = 6.2 and 16.2 Hz, 1H), 5.12 (dd, J = 1.4 and 10.3 Hz, 1H), 5.18 (dd, J = 1.4 and 17.2 Hz, 1H), 5.64 (ddt, J = 10.3, 17.1, and 6.1 Hz, 1H), 7.28 (d, J = 8.4 Hz, 2H), 7.70 (d, J = 8.4 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ -5.5, 15.44, 15.46, 18.2, 18.6, 21.4, 22.0, 25.8, 46.8, 49.1, 70.0, 118.0, 127.0, 129.5, 133.3, 137.4, 142.9.

To ene-cyclopropane **S14** (2.82 g, 6.66 mmol) was added a 1.0 M solution of TBAF in THF (10 mL, 10 mmol). The resulting solution was stirred at room temperature for 15 h. Saturated aqueous NH_4Cl was added to quench the reaction, and the reaction mixture was extracted by ether. The combined organic layer was washed with water, dried over $MgSO_4$, and concentrated. The residue was filtered through a pad of silica gel (eluted with PE/EA 4:1) to afford crude alcohol **S15** (2.04 g, 99%), which was used in the next step without further purification.

To a stirred suspension of PCC (1.99 g, 9.24 mmol) in CH_2Cl_2 (50 mL) was added a solution of crude alcohol **S15** (1.91 g, 6.16 mmol) in CH_2Cl_2 (10 mL). The reaction mixture was stirred at room temperature for 17 h. The resulting solution was filtered through a pad of silica gel, and the filter cake was washed by ether. The combined filtrate was concentrated and the crude aldehyde was purified by flash column chromatography on silica gel (eluted with PE/EA 4:1) to afford aldehyde **S16** (1.32 g, 70%).

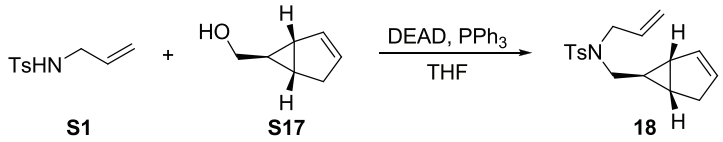
S16: ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.81 (dd, J = 5.3 and 6.7 Hz, 1H), 1.26 (s, 3H), 1.35 (dd, J = 5.2 and 9.4 Hz, 1H), 1.50-1.60 (m, 1H), 2.44 (s, 3H), 3.15 (dd, J = 7.7 and 14.8 Hz, 1H), 3.41 (dd, J = 5.8 and 14.8 Hz, 1H), 3.84 (ddt, J = 6.2, 15.8, and 1.1 Hz, 1H), 3.91 (ddt, J = 6.2, 15.8, and 1.1 Hz, 1H), 5.17 (dq, J = 10.0 and 1.4 Hz, 1H), 5.19 (dq, J = 17.1 and 1.4 Hz, 1H), 5.64 (ddt, J = 10.0, 17.1, and 6.1 Hz, 1H), 7.32 (d, J = 8.2 Hz, 2H), 7.70 (d, J = 8.2 Hz, 2H), 8.63 (s, 1H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 11.2, 19.2, 21.5, 22.6, 31.7, 46.0, 50.5, 118.9, 127.1, 129.8, 133.1, 136.8, 143.5, 201.4.

To a suspension of methyltriphenylphosphonium bromide (1.87 g, 5.15 mmol) in THF (80 mL) at 0 °C was added *n*-BuLi (2.5 M solution in hexane, 2.06 mL, 5.15 mmol), and the resulting solution was stirred for 10 min. A solution of aldehyde **S16** (1.06 g, 3.43 mmol) in THF (20 mL) was added dropwise at 0 °C, and the resulting mixture was stirred for 12 h at room temperature. Water was added to quench the reaction, and the mixture was extracted with ether. The combined extract was washed with water and brine, dried over Na_2SO_4, and concentrated. The crude product was purified by flash column chromatography on silica gel (eluted with PE/EA 20:1) to afford VCP-ene **16** (788 mg, 75%).

16: ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.42 (dd, J = 4.7 and 5.9 Hz, 1H), 0.79 (dd, J = 4.8 and 8.9 Hz, 1H), 0.91-1.00 (m, 1H), 1.16 (s, 3H), 2.42 (s, 3H), 3.16 (dd, J = 7.5 and 14.5 Hz, 1H), 3.38 (dd, J = 6.3 and 14.4 Hz, 1H), 3.84 (ddt, J = 6.1, 15.9, and 1.3 Hz, 1H), 3.91 (ddt, J = 6.3, 16.0, and 1.2 Hz, 1H), 4.87 (dd, J = 1.1 and 10.4 Hz, 1H), 4.91 (dd, J = 1.1 and 17.3 Hz, 1H), 5.13 (dq, J = 10.0 and 1.4 Hz, 1H), 5.18 (dq, J = 17.1 and 1.4 Hz, 1H), 5.32 (dd, J = 10.4 and 17.3 Hz, 1H), 5.63 (ddt, J = 10.0, 17.1, and 6.1 Hz, 1H), 7.29 (d, J = 8.5 Hz, 2H), 7.70 (d, J = 8.5 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 15.6, 20.2, 21.5, 22.4, 23.6, 46.8, 49.7, 110.0, 118.4,

127.1, 129.6, 133.2, 137.2, 143.1, 146.0. MS (EI, 70 eV): *m*/*z* 305 (M^+, 4), 224 (69), 155 (100), 91 (83). IR (neat): *v* 2923, 1598, 1495, 1444 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{23}NO_2S$: 305.1449. Found: 305.1448.

***trans*-*N*-Allyl-*N*-tosyl 6-aminomethylbicyclo[3.1.0]hex-2-ene (18)**

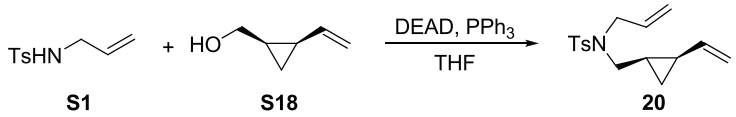


S1 **S17** **18**

Following the general procedure for the preparation of tosylamide derivatives by a Mitsunobu reaction, tosylamide **S1** (845 mg, 4.00 mmol) and alcohol **S17**[6] (446 mg, 4.05 mmol) were converted to bicyclic VCP-ene **18** (593 mg, 48%).

^{1}H NMR (300 MHz, $CDCl_3$): δ 0.33-0.39 (m, 1H), 1.42-1.47 (m, 1H), 1.70-1.76 (m, 1H), 2.26 (dd, *J* = 2.3 and 17.9 Hz, 1H), 2.42 (s, 3H), 2.53 (dd, *J* = 7.3 and 17.9 Hz, 1H), 3.02 (dd, *J* = 7.2 and 14.3 Hz, 1H), 3.09 (dd, *J* = 7.0 and 14.3 Hz, 1H), 3.89 (d, *J* = 6.2 Hz, 2H), 5.15 (dq, *J* = 10.1 and 1.4 Hz, 1H), 5.19 (dq, *J* = 17.0 and 1.4 Hz, 1H), 5.36-5.40 (m, 1H), 5.66 (ddt, *J* = 10.1, 17.0, and 6.2 Hz, 1H), 5.80-5.84 (m, 1H), 7.29 (d, *J* = 8.5 Hz, 2H), 7.69 (d, *J* = 8.5 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 21.4, 21.7, 27.9, 30.4, 35.6, 49.5, 50.2, 118.3, 127.0, 128.9, 129.5, 133.0, 133.3, 137.3, 143.0. MS (EI, 70 eV): *m*/*z* 303 (M^+, 6), 224 (79), 155 (58), 91 (100). IR (neat): *v* 2906, 1597, 1494, 1439 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{21}NO_2S$: 303.1293. Found: 303.1292.

***cis*-*N*-Allyl-*N*-tosyl 2-aminomethylvinylcyclopropane (20)**



S1 **S18** **20**

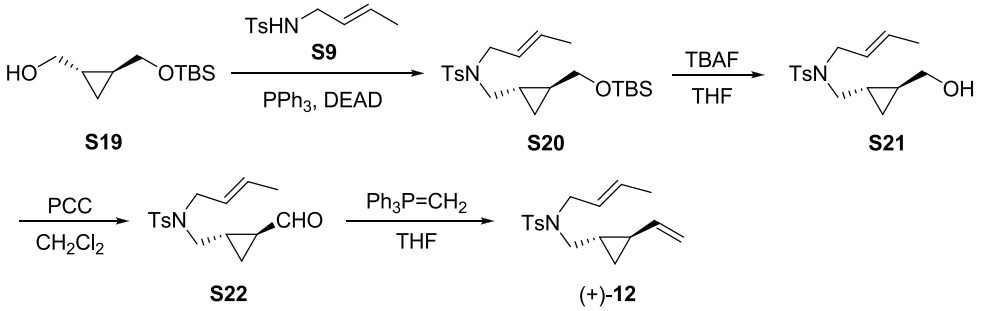
Following the general procedure for the preparation of tosylamide derivatives by a Mitsunobu reaction, tosylamide **S1** (226 mg, 1.07 mmol) and alcohol **S18**[7] (103 mg, 1.05 mmol) were converted to *cis*-VCP-ene **20** (180 mg, 58%).

^{1}H NMR (300 MHz, $CDCl_3$): δ 0.39 (q, *J* = 5.7 Hz, 1H), 0.88-0.95 (m, 1H), 1.11-1.22 (m, 1H), 1.57 (ddd, *J* = 6.2, 8.5, and 17.1 Hz, 1H), 2.42 (s, 3H), 3.13 (d, *J* = 7.5 and 14.6 Hz, 1H), 3.21 (dd, *J* = 6.2 and 14.6 Hz, 1H), 3.82-3.98 (m, 2H), 5.00 (dm, *J* = 10.0 Hz, 1H), 5.10 (dm, *J* = 8.1 Hz, 1H), 5.14-5.22 (m, 2H), 5.50 (ddd, *J* = 8.4, 10.0, and 17.0 Hz, 1H), 5.64 (ddt, *J* = 10.3, 16.9, and 6.1 Hz, 1H), 7.29 (d, *J* = 8.1 Hz, 2H), 7.70 (d, *J* = 8.1 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 11.6, 17.2, 19.9, 21.5, 46.7, 49.8, 115.4, 118.2, 127.1, 129.6, 133.4, 136.6, 137.4, 143.0. MS (EI, 70 eV): *m*/*z* 291 (M^+, 9), 224 (30), 155 (50), 136 (16), 91 (100). IR (neat): *v* 2924, 1634, 1598, 1495 cm^{-1}. HRMS (EI) calcd for $C_{16}H_{21}NO_2S$: 291.1293. Found: 291.1304.

(6) Barraclough, P.; Young, D. W.; Ferrige, A. G.; Lindon, J. C. *J. Chem. Soc., Perkin Trans. 2* **1982**, 651.
(7) Gajewski, J. J.; Hawkins, C. M.; Jimenez, J. L. *J. Org. Chem.* **1990**, *55*, 674.

2.2 Synthesis of Optically Active VCP-ene Substrates

(+)-(1*R*,2*S*)-*N*-(but-2-enyl)-*N*-tosyl 2-aminomethylvinylcyclopropane (12)

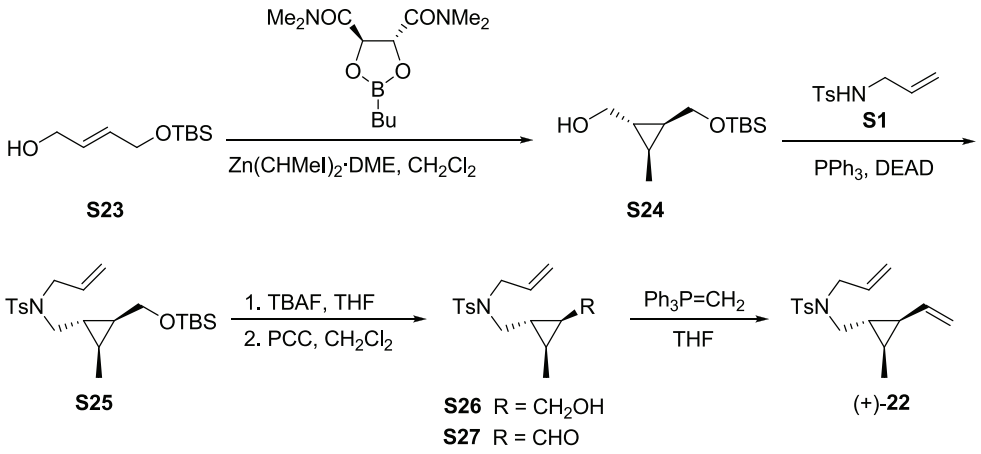


Optically active alcohol **S19**[8] (497.9 mg, 2.21 mmol) was converted to crude ene-cyclopropane **S20** following the general procedure for the preparation of tosylamide derivatives by a Mitsunobu reaction. Crude **S20** was deprotected and oxidized to obtain crude aldehyde **S22** following the procedure for converting **S14** to **S16**. Crude aldehyde **S22** was converted to VCP-ene (+)-**12** (130.7 mg, 19% for 4 steps) following the procedure for converting **S16** to **16**.

The enantiomeric purity of (+)-**12** was determined by HPLC analysis of alcolol **S21** using chiral stationary phase columns. See section 3 for details.

(+)-**12**: 93% ee. $[\alpha]_D$ = + 11.1° (*c* 0.8, $CHCl_3$).

(+)-(1*S*,2*S*,3*R*)-*N*-Allyl-*N*-tosyl 2-aminomethyl-3-methyl-1-vinylcyclopropane (22)



Allylic alcohol **S23**[9] (607.9 mg, 3.00 mmol) was converted to cyclopropyl alcohol (+)-**S24**[10] (688.2 mg, 99%) following the asymmetric cyclopropanation procedure of Charette et al.[3]

Optically active alcohol **S24** (649.2 mg, 2.82 mmol) was converted to crude ene-cyclopropane **S25** following the general procedure for the preparation of tosylamide derivatives by a Mitsunobu reaction. Crude **S25** was deprotected and oxidized to obtain crude aldehyde **S27** following the procedure for converting **S14** to **S16**. Crude aldehyde **S27** was converted to VCP-ene (+)-**22** (372.6 mg, 41% for 4 steps) following the procedure for

(8) Wipf, P.; Reeves, J. T.; Balachandran, R.; Day, B. W. *J. Med. Chem.* **2002**, *45*, 1901.
(9) Koppisch, A. T.; Blagg, B. S. J.; Poulter, C. D. *Org. Lett.* **2000**, *2*, 215.
(10) Kirkland, T. A.; Colucci, J.; Geraci, L. S.; Marx, M. A.; Schneider, M.; Kaelin, D. E.; Martin, S. F. *J. Am. Chem. Soc.* **2001**, *123,* 12432.

converting **S16** to **16**.

The enantiomeric purity of (+)-**22** was determined by HPLC analysis of alcolol **S27** using chiral stationary phase columns. See section 3 for details.

(+)-**22**: 95% ee. $[\alpha]_D$ = + 16.3° (*c* 0.96, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.66-0.74 (m, 1H), 0.81-0.92 (m, 1H), 1.00 (d, *J* = 6.1 Hz, 3H), 1.28 (dt, *J* = 4.7 and 9.0 Hz, 1H), 2.42 (s, 3H), 3.08 (dd, *J* = 6.9 and 14.3 Hz, 1H), 3.16 (dd, *J* = 6.9 and 14.3 Hz, 1H), 3.89 (dm, *J* = 6.3 Hz, 2H), 4.96-5.22 (m, 4H), 5.46 (ddd, *J* = 9.0, 10.4, and 17.1 Hz, 1H), 5.63 (ddt, *J* = 10.3, 17.1, and 6.1 Hz, 1H), 7.29 (d, *J* = 8.6 Hz, 2H), 7.69 (d, *J* = 8.6 Hz, 2H). ^{13}C NMR (50 MHz, $CDCl_3$): 12.8, 19.0, 21.4, 25.7, 26.7, 49.8, 50.3, 114.8, 118.4, 127.0, 129.6, 133.3, 136.3, 137.3, 143.0. MS (EI, 70 eV): *m*/*z* 305 (M^+, 5), 224 (70), 155 (100), 91 (74). IR (neat): *v* 2955, 2922, 2850, 1599, 1494, 1455 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{23}NO_2S$: 305.1449. Found: 305.1449.

2.3 General Procedures for Rh(I)-Catalyzed [3+2] Cycloadditions

General Procedures

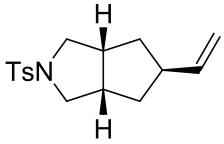
Two general procedures, employing either $[Rh(CO)_2Cl]_2$ or the combination of $[Rh(CO)_2Cl]_2$ and AgOTf as the catalyst, were used.

Condition A ($[Rh(CO)_2Cl]_2$ as the catalyst): To a solution of $[Rh(CO)_2Cl]_2$ (3.9 mg, 0.01 mmol, 5 mol %) in toluene (4 mL) was added a solution of VCP-ene substrate (0.2 mmol) in toluene (4 mL) at room temperature under argon. The resulting solution was immersed into an oil bath and was stirred under the indicated temperature. When TLC indicated the disappearance of the starting material, the reaction mixture was cooled to room temperature and filtered through a thin pad of silica gel. The filter cake was washed with ether, and the combined filtrate was concentrated. The crude product was purified by flash column chromatography on silica gel to afford the corresponding [3+2] cycloadduct.

Condition B ($[Rh(CO)_2Cl]_2$ + AgOTf as the catalyst): A mixture of $[Rh(CO)_2Cl]_2$ (3.9 mg, 0.01 mmol, 5 mol %) and AgOTf (5.1 mg, 0.02 mmol, 10 mol %) was added toluene (4 mL) and stirred at room temperature under argon for 5 min. A solution of VCP-ene substrate (0.2 mmol) in toluene (4 mL) was added at room temperature, and the resulting solution was immersed into an oil bath and was stirred under the indicated temperature. When TLC indicated the disappearance of the starting material, the reaction mixture was cooled to room temperature and filtered through a thin pad of silica gel. The filter cake was washed with ether, and the combined filtrate was concentrated. The crude product was purified by flash column chromatography on silica gel to afford the corresponding [3+2] cycloadduct.

Spectroscopic Data for Cycloadducts

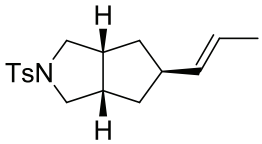
***N*-Tosyl 3-aza-7-vinylbicyclo[3.3.0]octane (2)**



This cycloadduct was obtained from VCP-ene **1** by using **Condition A** (110 °C, 5.5 h).

^{1}H NMR (300 MHz, $CDCl_3$): δ 1.50-1.65 (m, 4H), 2.44 (s, 3H), 2.55-2.69 (m, 3H), 2.87 (dd, J = 3.9 and 9.7 Hz, 2H), 3.16 (dd, J = 7.8 and 9.7 Hz, 2H), 4.90 (dm, J = 10.3 Hz, 1H), 4.97 (dm, J = 17.3 Hz, 1H), 5.67 (ddd, J = 7.0, 10.3, and 17.3 Hz, 1H), 7.34 (d, J = 8.3 Hz, 2H), 7.68 (d, J = 8.3 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 21.5, 39.0, 41.8, 42.4, 55.1, 113.4, 128.0, 129.5, 131.7, 141.1, 143.5. MS (EI, 70 eV): m/z 291 (M^+, 20), 155 (9), 136 (100), 91 (50). IR (neat): ν 2926, 1640, 1597, 1344 cm^{-1}. HRMS (EI) calcd for $C_{16}H_{21}NO_2S$: 291.1293. Found: 291.1282.

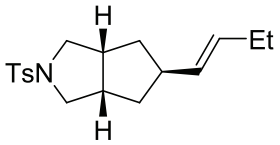
***N*-Tosyl 3-aza-7-(1-propenyl)bicyclo[3.3.0]octane (5)**



This cycloadduct was obtained from VCP-ene **4** by using **Condition A** (110 °C, 8 h).

^{1}H NMR (300 MHz, $CDCl_3$): δ 1.42-1.58 (m, 4H), 1.61 (d, J = 6.3 Hz, 3H), 2.44 (s, 3H), 2.47-2.57 (m, 1H), 2.61-2.67 (m, 2H), 2.83 (dd, J = 4.2 and 9.6 Hz, 2H), 3.18 (dd, J = 8.1 and 9.6 Hz, 2H), 5.26 (dd, J = 6.9 and 15.3 Hz, 1H), 5.40 (dq, J = 15.3 and 6.3 Hz, 1H), 7.34 (d, J = 8.4 Hz, 2H), 7.68 (d, J = 8.4 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 17.9, 21.5, 39.4, 41.4, 41.9, 55.2, 124.1, 128.0, 129.5, 131.8, 133.7, 143.5. MS (EI, 70 eV): *m*/*z* 305 (M^+, 18), 150 (100), 91 (42). IR (neat): ν 2954, 1459, 1344 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{23}NO_2S$: 305.1449. Found: 305.1456.

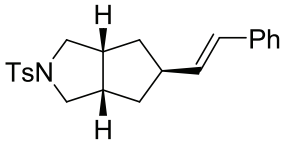
***N*-Tosyl 3-aza-7-(but-1-enyl)bicyclo[3.3.0]octane (7)**



This cycloadduct was obtained from VCP-ene **6** by using **Condition A** (110 °C, 14 h).

^{1}H NMR (300 MHz, $CDCl_3$): δ 0.93 (t, J = 7.4 Hz, 3H), 1.42-1.61 (m, 4H), 1.96 (quintet, J = 7.0 Hz, 2H), 2.44 (s, 3H), 2.47-2.56 (m, 1H), 2.59-2.70 (m, 2H), 2.82 (dd, J = 3.9 and 9.8 Hz, 2H), 3.19 (dd, J = 8.1 and 9.8 Hz, 2H), 5.23 (ddt, J = 7.0, 15.1, and 1.2 Hz, 1H), 5.42 (ddt, J = 0.9, 15.1, and 6.3 Hz, 1H), 7.33 (d, J = 8.3 Hz, 2H), 7.68 (d, J = 8.3.Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 17.8, 21.5, 25.4, 39.4, 41.2, 41.8, 55.2, 128.0, 129.4, 131.3, 131.4, 131.7, 143.4. MS (EI, 70 eV): *m*/*z* 319 (M^+, 15), 224 (12), 198 (8), 164 (100), 155 (23), 91 (32). IR (neat): ν 2948, 1598, 1456, 1337 cm^{-1}. HRMS (EI) calcd for $C_{18}H_{25}NO_2S$: 319.1606. Found: 319.1610.

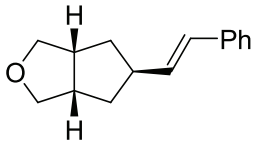
***N*-Tosyl 3-aza-7-(2-phenylethen-1-yl)bicyclo[3.3.0]octane (9)**



This cycloadduct was obtained from VCP-ene **8** by using **Condition B** (30 °C, 13 h).

^{1}H NMR (300 MHz, $CDCl_3$): δ 1.58-1.73 (m, 4H), 2.46 (s, 3H), 2.68-2.80 (m, 3H), 2.92 (dd, J = 3.7 and 10.1 Hz, 2H), 3.18 (dd, J = 8.1 and 10.1 Hz, 2H), 6.05 (dd, J = 7.2 and 15.8 Hz, 1H), 6.37 (d, J = 15.8 Hz, 1H), 7.17-7.31 (m, 5H), 7.36 (d, J = 8.0 Hz, 2H), 7.71 (d, J = 8.0 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 21.6, 39.6, 42.0, 55.2, 125.9, 127.0, 128.1, 128.5, 129.0, 129.5, 131.7, 132.9, 137.4, 143.5. MS (EI, 70 eV): *m*/*z* 367 (M^+, 3), 219 (36), 212 (16), 155 (21), 91 (100). IR (neat): ν 2922, 1597, 1493, 1344 cm^{-1}. HRMS (EI) calcd for $C_{22}H_{25}NO_2S$: 367.1606. Found: 367.1607.

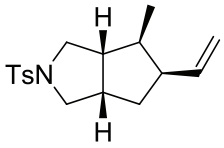
3-Oza-7-(2-phenylethen-1-yl)bicyclo[3.3.0]octane (11)



This cycloadduct was obtained from VCP-ene **10** by using **Condition B** (30 °C, 38 h).

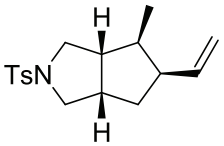
^{1}H NMR (300 MHz, $CDCl_3$): δ 1.58-1.74 (m, 4H), 2.73-2.85 (m, 3H), 3.48 (dd, J = 4.0 and 8.8 Hz, 2H), 3.88 (m, 2H), 6.11 (dd, J = 8.0 and 15.9 Hz, 1H), 6.40 (d, J = 15.9 Hz, 1H), 7.16-7.35 (m, 5H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 39.3, 42.2, 43.6, 75.7, 125.9, 126.9, 128.4, 128.8, 133.5, 137.5. MS (EI, 70 eV): m/z 214 (M^+, 66), 183 (68), 129 (100), 104 (61), 91 (62). IR (neat): ν 3024, 2928, 2854, 1599, 1492, 1448 cm^{-1}. HRMS (EI) calcd for $C_{15}H_{18}O$: 214.1358. Found: 214.1357.

***N*-Tosyl 3-aza-6-methyl-7-vinylbicyclo[3.3.0]octane (13)**

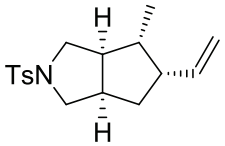


This cycloadduct was obtained from VCP-ene **12** by using **Condition A** (110 °C, 16 h).

^{1}H NMR (300 MHz, $CDCl_3$): δ 0.85 (d, J = 7.0 Hz, 3H), 1.53-1.62 (m, 1H), 1.85-1.94 (m, 2H), 2.12-2.20 (m, 1H), 2.44 (s, 3H), 2.59-2.71 (m, 2H), 2.89 (dd, J = 2.8 and 8.1 Hz, 1H), 2.92 (dd, J = 2.5 and 8.1 Hz, 1H), 3.04 (dd, J = 3.1 and 9.5 Hz, 1H), 3.08 (dd, J = 3.1 and 9.5 Hz, 1H), 4.94-5.00 (m, 2H), 5.60-5.72 (m, 1H), 7.34 (d, J = 7.6 Hz, 2H), 7.68 (d, J = 7.6 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 15.5, 21.5, 37.2, 40.7, 43.9, 47.9, 49.5, 53.5, 55.0, 114.9, 128.0, 129.5, 131.6, 138.4, 143.5. MS (EI, 70 eV): m/z 305 (M^+, 30), 224 (8), 150 (100), 91 (50). IR (neat): ν 2953, 1598, 1476, 1453 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{23}NO_2S$: 305.1449. Found: 305.1447.



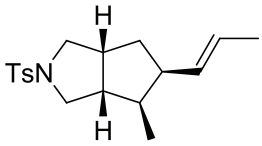
(+)-13



(–)-13

(+)-**13** (obtained from (+)-**12**): 91% ee, $[\alpha]_D$ = + 8.7° (c 0.73, $CHCl_3$).
(–)-**13** (obtained from (+)-**22**): 95% ee, $[\alpha]_D$ = – 8.0° (c 1.21, $CHCl_3$).

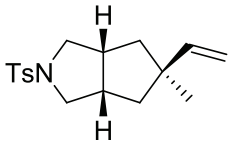
***N*-Tosyl 3-aza-6-methyl-7-(1-propenyl)bicyclo[3.3.0]octane (15)**



This cycloadduct was obtained from VCP-ene **14** by using **Condition A** (90 °C, 26 h).

^{1}H NMR (300 MHz, $CDCl_3$): δ 0.82 (d, J = 6.9 Hz, 3H), 1.49-1.57 (m, 1H), 1.63 (d, J = 5.9 Hz, 3H), 1.78-1.87 (m, 2H), 2.09-2.18 (m, 1H), 2.44 (s, 3H), 2.52-2.68 (m, 2H), 2.89-2.95 (m, 2H), 2.99-3.07 (m, 2H), 5.24 (dd, J = 8.3 and 15.2 Hz, 1H), 5.39 (dq, J = 15.2 and 6.2 Hz, 1H), 7.33 (d, J = 7.9 Hz, 2H), 7.68 (d, J = 7.9 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 15.5, 18.0, 21.5, 37.7, 40.7, 44.1, 46.8, 49.5, 53.5, 55.0, 125.5, 128.0, 129.4, 130.9, 131.7, 143.4. MS (EI, 70 eV): m/z 319 (M^+, 15), 164 (100), 91 (32). IR (neat): ν 2951, 1598, 1452 cm^{-1}. HRMS (EI) calcd for $C_{18}H_{25}NO_2S$: 319.1606. Found: 319.1601.

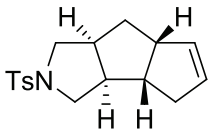
_N_-Tosyl 3-aza-7-methyl-7-vinylbicyclo[3.3.0]octane (17)



This cycloadduct was obtained from VCP-ene **16** by using **Condition B** (30 °C, 41 h).

^{1}H NMR (300 MHz, $CDCl_3$): δ 1.10 (s, 3H), 1.33 (dd, J = 8.4 and 12.6 Hz, 2H), 1.97 (dm, J = 12.6 Hz, 2H), 2.44 (s, 3H), 2.51-2.58 (m, 2H), 2.67 (dd, J = 7.4 and 9.4 Hz, 2H), 3.16 (d, J = 9.4 Hz, 2H), 4.87-4.93 (m, 2H), 5.71 (dd, J = 10.6 and 17.6 Hz, 1H), 7.33 (d, J = 7.8 Hz, 2H), 7.67 (d, J = 7.8 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 21.5, 26.2, 41.7, 45.1, 47.7, 54.0, 110.6, 128.0, 129.4, 131.5, 143.5, 145.7. MS (EI, 70 eV): m/z 305 (M^+, 8), 264 (8), 235 (5), 222 (6), 150 (100), 91 (20). IR (neat): ν 2954, 2854, 1598, 1496, 1477 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{23}NO_2S$: 305.1449. Found: 305.1447.

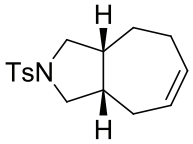
_N_-Tosyl 4-azatricyclo[6.3.0.0^{2,6}]undec-9-ene (19)



This cycloadduct was obtained from VCP-ene **18** by using **Condition A** (80 °C, 24 h).

^{1}H NMR (300 MHz, $CDCl_3$): δ 1.37-1.47 (m, 1H), 1.62-1.70 (m, 1H), 2.02-2.23 (m, 2H), 2.43 (s, 3H), 2.34-2.63 (m, 4H), 3.00 (dd, J = 6.4 and 9.7 Hz, 1H), 3.12 (dd, J = 3.4 and 9.7 Hz, 1H), 3.26 (dd, J = 6.9 and 9.8 Hz, 1H), 3.40 (dd, J = 8.1 and 9.8 Hz, 1H), 5.41-5.45 (m, 1H), 5.53-5.57 (m, 1H), 7.32 (d, J = 8.3 Hz, 2H), 7.70 (d, J = 8.3 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 21.5, 35.5, 40.3, 42.7, 45.4, 51.7, 52.5, 52.6, 53.2, 127.5, 127.6, 129.1, 129.5, 134.1, 143.2. MS (EI, 70 eV): m/z 303 (M^+, 50), 155 (12), 148 (100), 91 (54). IR (neat): ν 2906, 1597, 1494, 1439 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{21}NO_2S$: 303.1293. Found: 303.1295.

_N_-Tosyl 9-azabicyclo[5.3.0]dec-3-ene (21)



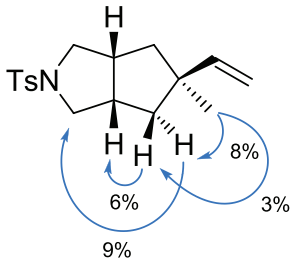
This cycloadduct was obtained from VCP-ene **18** by using **Condition A** (90 °C, 19 h).

^{1}H NMR (300 MHz, $CDCl_3$): δ 1.51-1.80 (m, 3H), 2.04-2.21 (m, 3H), 2.30-2.39 (m, 1H), 2.44 (s, 3H), 2.47-2.56 (m, 1H), 2.80 (t, J = 9.4 Hz, 1H), 2.87 (dd, J = 4.0 and 10.1 Hz, 1H), 3.40-3.51 (m, 2H), 5.47-5.60 (m, 2H), 7.33 (d, J = 8.2 Hz, 2H), 7.70 (d, J = 8.2 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 21.5, 27.0, 27.6, 28.6, 41.1, 41.8, 53.1, 54.6, 127.5, 127.6, 129.5, 131.3, 133.0, 143.3. MS (EI, 70 eV): m/z 291 (M^+, 40), 222 (33), 155 (26), 136 (100), 91 (83). IR (neat): ν 2922, 1597, 1477, 1343 cm^{-1}. HRMS (EI) calcd for $C_{16}H_{21}NO_2S$: 291.1293. Found: 291.1305.

2.4 Stereochemical Determination

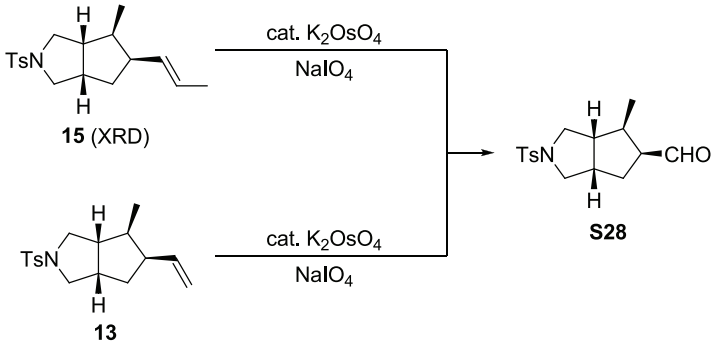
The *cis* ring-fusion of [3+2] cycloadducts **2**, **5**, **7**, **9**, **11**, and **17** was determined by symmetry as shown in their ^{1}H and ^{13}C NMR spectra (planar symmetry, four ^{13}C peaks for the bicyclic skeleton; *trans* ring-fusion will break the planar symmetry and show seven ^{13}C peaks for the bicyclic skeleton).

The stereochemistry of the vinyl substituted carbon of cycloadduct **17** was determined by nOe experiment:

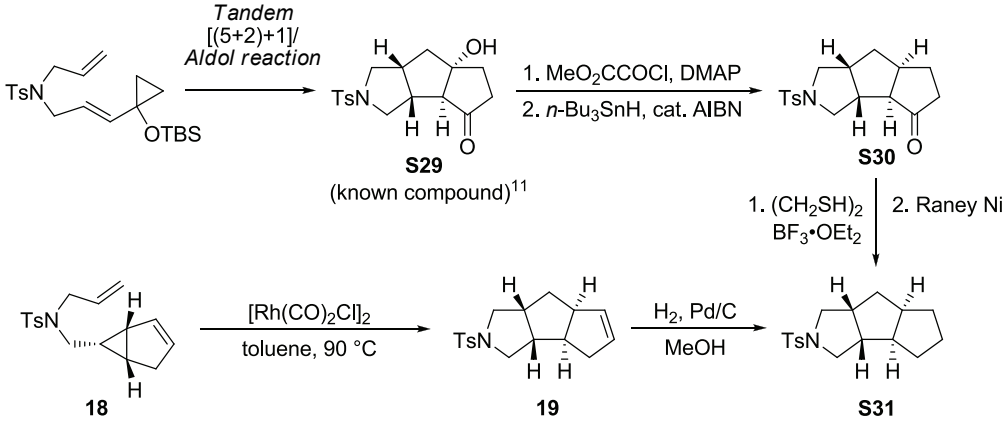


The stereochemistry of cycloadducts **2**, **5**, **7**, **9**, and **11** was also deduced based on this assignment.

The stereochemistry of cycloadduct **15** was determinded by X-ray single crystal structure. The stereochemistry of cycloadduct **13** was determined by correlation. Both cycloadducts **15** and **13** gave the same aldehyde (**S28**) upon oxidation, indicating that these two compounds have the same stereochemistry.

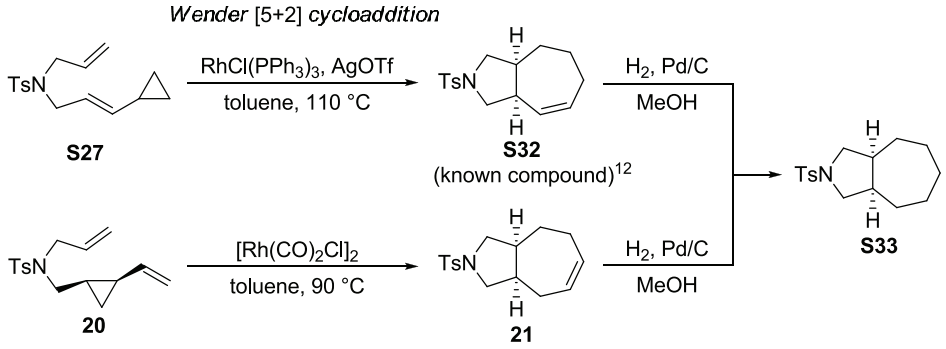


The stereochemistry of cycloadduct **19** was determined by correlation. The known compound **S29**[11] was deoxygenated to remove both hydroxy group and the carbonyl group, affording aza-triquinane **S31**. Catalytic hydrogenation of [3+2] cycloadduct **19** also gave compound **S31**, confirming the stereochemistry of compound **19**.



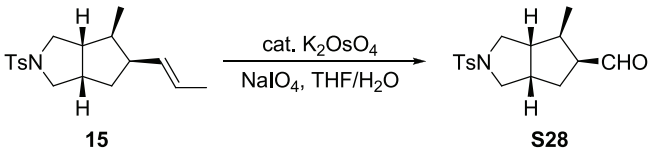
(11) Jiao, L.; Yuan, C.; Yu, Z.-X. *J. Am. Chem. Soc.* **2008**, *130*, 4421.

The stereochemistry of cycloadduct **21** was determined by correlation. Both cycloadduct **21** and Wender [5+2] cycloadduct **S32**[12] gave the same hydrogenation product **S33**, indicating the *cis* ring-fusion of cycloadduct **21**.



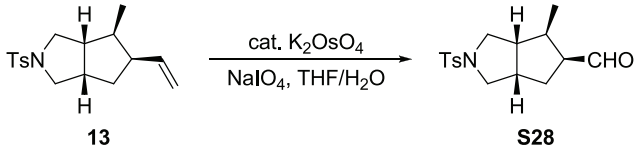
Experimental Details for Stereochemistry Determination

***N*-Tosyl 3-aza-6-methyl-7-formylbicyclo[3.3.0]octane (S28)**



To a stirred mixture of bicyclic compound **15** (7.2 mg, 0.022 mmol) and $K_2OsO_4{\cdot}2H_2O$ (1.7 mg, 4.6 μmol) in THF/H_2O (4:1, 1 mL) was added powdered $NaIO_4$ (18.6 mg, 0.087 mmol) that was divided into three potions, every 10 min a potion. The reaction was further stirred for 4 h under room temperature. Water (1.5 mL) and ether (3 mL) was added to quench the reaction, and the mixture was extracted with ether three times. The combined organic extract was combined, dried over Na_2SO_4, and concentrated. The crude oil was purified by flash column chromatography on silica gel (eluted with PE/EA 10:1 to 5:1) to afford aldehyde **S28** (3.3 mg, 48%).

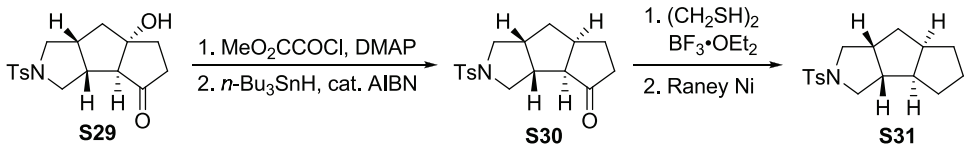
^{1}H NMR (300 MHz, $CDCl_3$): δ 1.06 (d, J = 6.9 Hz, 3H), 1.55 (m, 1H), 2.17-2.35 (m, 3H), 2.44 (s, 3H), 2.68-2.78 (m, 1H), 2.84 (dd, J = 4.4 and 9.9 Hz, 1H), 2.86 (dd, J = 4.5 and 9.3 Hz, 1H), 2.98 (m, 1H), 3.10 (dd, J = 2.7 and 9.6 Hz, 1H), 3.15 (dd, J = 2.4 and 9.9 Hz, 1H), 7.34 (d, J = 8.4 Hz, 2H), 7.67 (d, J = 8.4 Hz, 2H), 9.78 (d, J = 2.0 Hz, 1H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 15.5, 21.5, 31.9, 40.9, 42.9, 49.9, 53.1, 54.8, 56.2, 128.0, 129.6, 131.5, 143.7, 204.2. MS (EI, 70 eV): *m/z* 307 (M^+, 6), 278 (100), 152 (60), 124 (65), 91 (80). IR (neat): ν 2957, 1719, 1597, 1456 cm^{-1}. HRMS (EI) calcd for $C_{16}H_{21}NO_3S$: 307.1242. Found: 307.1245.



Following the procedure for the $NaIO_4$ oxidation of compound **15**, bicyclic cycloadduct **13** (26.7 mg, 0.087 mmol) was also converted to aldehyde **S28** (10.4 mg, 39%).

(12) Compound **S32** was synthesized following the procedure described in Wender, P. A.; Husfeld, C. O.; Langkopf, E.; Love, J. A. *J. Am. Chem. Soc.* **1998**, *120*, 1940. The spectroscopic data was identical to that reported in Wender, P. A.; Haustedt, L. O.; Lim, J.; Love, J. A.; Williams, T. J.; Yoon, J.-Y. *J. Am. Chem. Soc.* **2006**, *128*, 6302.

***cis-anti-cis-N*-Tosyl 4-azatricyclo[6.3.0.0^{2,6}]undecane (S31)**

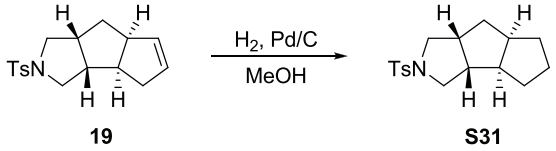


To a stirred solution of compound **S29**[11] (7.0 mg, 0.021 mmol) and DMAP (7.3 mg, 0.060 mmol) in dry CH_2Cl_2 (1 mL) was added methyl chlorooxalate (7.0 mg, 0.057 mmol) under room temperature. The resulting solution was stirred for 3 h under room temperature. Saturated $NaHCO_3$ solution was added and the organic phase was separated. The organic phase was washed with dilute aqueous HCl and brine, dried over Na_2SO_4, and concentrated. The residue was filtered through a pad of silica gel (eluted with PE/EA 3:1 to 1:1) to afford the crude methoxy oxalate. It was then dissolved in toluene (0.8 mL) and heated to 105 °C in an oil bath. A solution of n-Bu_3SnH (10.5 mg, 0.036 mmol) and AIBN (0.5 mg, 0.003 mmol) in toluene (0.5 mL) was added. The reaction mixture was stirred under 105 °C for 2 h and then concentrated. The residue was purified by flash column chromatography to afford tricyclic ketone **S30** (2.4 mg, 36% for 2 steps).

S30: ^{1}H NMR (300 MHz, $CDCl_3$): 1.42-1.52 (m, 1H), 1.66-1.83 (m, 2H), 2.02-2.16 (m, 1H), 2.23-2.30 (m, 2H), 2.36 (dm, J = 8.1 Hz, 1H), 2.44 (s, 3H), 2.59-2.66 (m, 1H), 2.74-2.79 (m, 1H), 2.95-3.11 (m, 4H), 3.18 (dd, J = 3.4 and 10.1 Hz, 1H), 7.33 (d, J = 8.0 Hz, 2H), 7.67 (d, J = 8.0 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): 21.5, 24.2, 35.8, 37.6, 41.1, 43.4, 45.8, 53.9, 55.0, 59.9, 127.9, 129.6, 131.2, 143.7, 220.8.

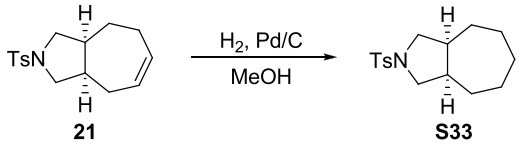
A solution of tricyclic ketone **S30** (2.4 mg, 0.0075 mmol), ethanedithiol (7 μL, 0.0084 mmol), and $BF_3{\cdot}OEt_2$ (1.5 μL, 0.012 mmol) in dry CH_2Cl_2 was stirred under room temperature for 16 h. Ether was added and the solution was washed successively with 10% aqueous NaOH and water. The organic phase was dried over Na_2SO_4 and concentrated. Flash column chromatography provided thioketal derivative of ketone **S30** (2.2 mg, 74%). It was dissolved in ethanol (2 mL) and freshly prepared W-2 Raney-Ni (ca. 1 g, suspension in ethanol) was added. The mixture was refluxed for 40 min and filtered through a pad of silica gel. Concentration of the filtrate afforded crude aza-triquinane **S31** (1.1 mg, 62%).

S31: ^{1}H NMR (300 MHz, $CDCl_3$): 1.16-1.29 (m, 2H), 1.39-1.58 (m, 4H), 1.62-1.76 (m, 2H), 2.09-2.22 (m, 2H), 2.44 (s, 3H), 2.47-2.61 (m, 2H), 2.98-3.06 (m, 2H), 3.28 (dd, J = 7.7 and 22.7 Hz, 1H), 3.32 (dd, J = 7.7 and 22.7 Hz, 1H), 7.32 (d, J = 8.3 Hz, 2H), 7.70 (d, J = 8.3 Hz, 2H). ^{13}C NMR (75.5 Hz, $CDCl_3$): 21.5, 26.1, 33.5, 33.6, 37.6, 43.7, 43.8, 49.1, 51.0, 52.9, 53.7, 127.5, 129.5, 133.4, 143.2. MS (EI, 70 eV): m/z 305 (M^+, 16), 240 (4), 198 (2), 150 (100), 91 (91). IR (neat): ν 2941, 2862, 1598, 1450 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{23}NO_2S$: 305.1449. Found: 305.1452.



To a solution of **19** (13.6 mg, 0.0448 mmol) in MeOH (2 mL) was added Pd/C (5% palladium on charcoal, 2.7 mg). The mixture was degassed in vacuum and hydrogen was run through for 2 min. The mixture was stirred at room temperature under an atmosphere of hydrogen for 12 h. The mixture was filtered through a thin pad of silica gel and the filter cake was washed with ether. The combined filtrate was concentrated and purified by flash column chromatography to give the hydrogenated product **S31** (11.2 mg, 82%).

***cis*-*N*-Tosyl 9-azabicyclo[5.3.0]decane (S33)**



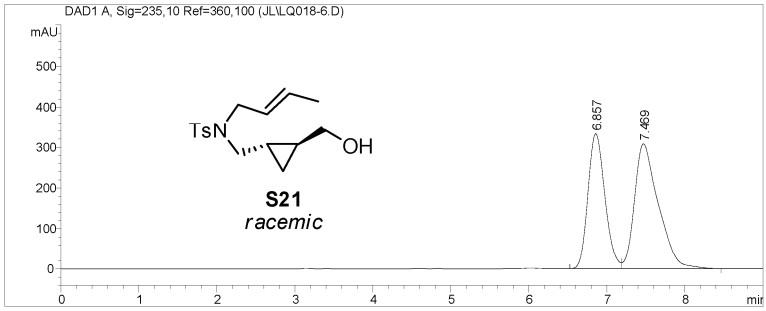
To a solution of **21** (24.9 mg, 0.085 mmol) in MeOH (3 mL) was added Pd/C (5% palladium on charcoal, 3.0 mg). The mixture was degassed in vacuum and hydrogen was run through for 2 min. The mixture was stirred at room temperature under an atmosphere of hydrogen for 12 h. The mixture was filtered through a thin pad of silica gel and the filter cake was washed with ether. The combined filtrate was concentrated to give the hydrogenated crude product **S33** (23.2 mg, 93%).

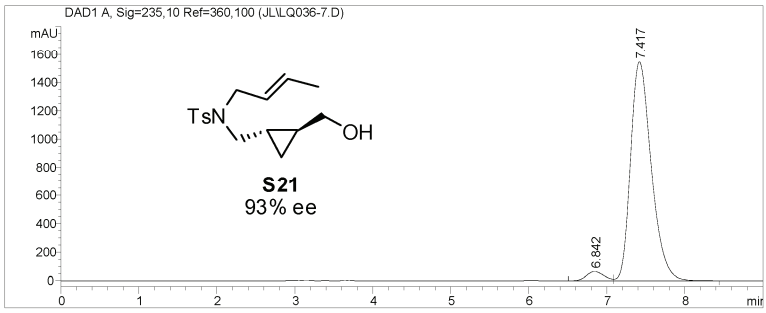
^{1}H NMR (300 MHz, $CDCl_3$): δ 1.13-1.25 (m, 5H), 1.52-1.60 (m, 2H), 1.73-1.80 (m, 3H), 2.26-2.35 (m, 2H), 2.44 (s, 3H), 2.55 (dd, J = 7.4 and 9.9 Hz, 2H), 3.51 (dd, J = 8.1 and 9.9 Hz, 2H), 7.33 (d, J = 8.1 Hz, 2H), 7.69 (d, J = 8.1 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 21.5, 28.4, 30.1, 31.2, 42.1, 55.0, 127.9, 129.5, 132.4, 143.3. MS (EI, 70 eV): m/z 293 (M^+, 12), 184 (16), 155 (20), 138 (100), 91 (31). IR (neat): ν 2922, 2851, 1597, 1455 cm^{-1}. HRMS (EI) calcd for $C_{16}H_{23}NO_2S$: 293.1449. Found: 293.1448.

3. HPLC Diagrams for Enantiomeric Purity Determination

1. HPLC diagrams for determining the enantiomeric purity of VCP-ene (+)-**12**

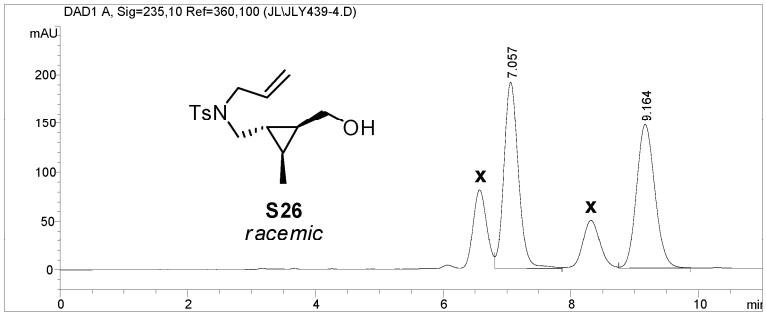
Enantiomeric excess of (+)-**12** was determined by measuring the e.e. of a synthetic intermediate, alcohol **S21**. HPLC conditions: Daicel Chiralcel OD-H column, column temperature 30 °C, eluted with hexanes/*i*-PrOH 85:15, flow rate 1.00 mL/min, DAD detector, detecting at 235 nm.

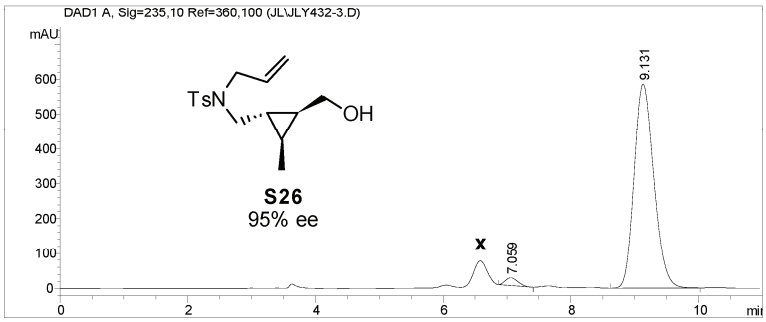




2. HPLC diagrams for determining the enantiomeric purity of VCP-ene (+)-**22**

Enantiomeric excess of (+)-**22** was determined by measuring the e.e. of a synthetic intermediate, alcohol **S26**. HPLC conditions: Daicel Chiralcel OD-H column, column temperature 30 °C, eluted with hexanes/*i*-PrOH 85:15, flow rate 1.00 mL/min, DAD detector, detecting at 235 nm.

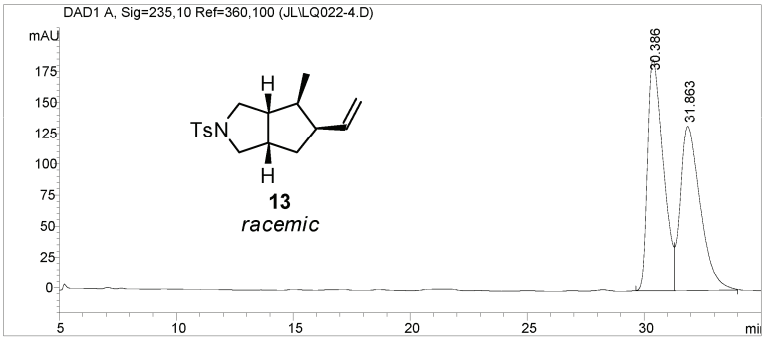


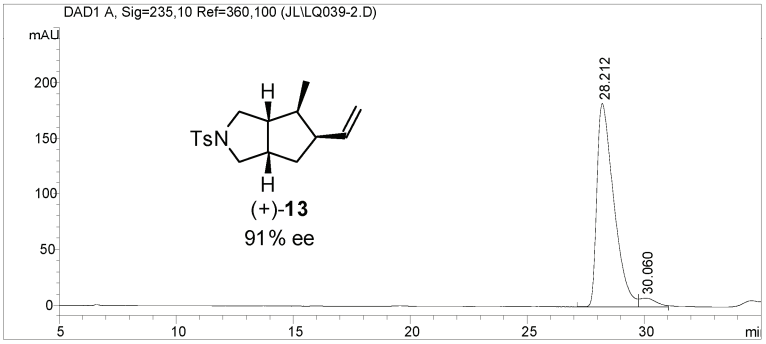


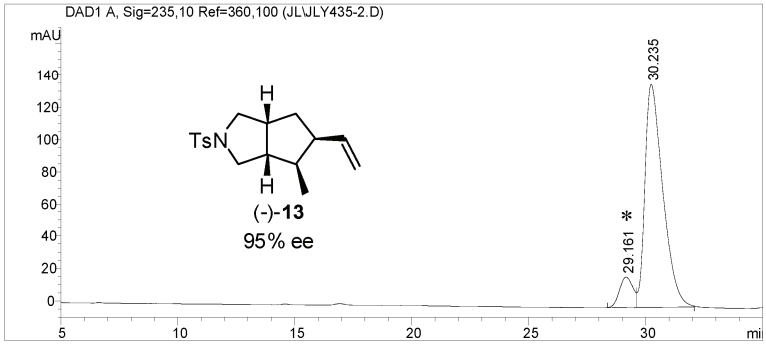
x - impurities

3. HPLC diagrams for determining the enantiomeric purity of VCP-ene (+)-**13** and (-)-**13**

HPLC conditions: Daicel Chiralcel OJ-H column, column temperature 30 °C, eluted with hexanes/*i*-PrOH 99:1, flow rate 1.00 mL/min, DAD detector, detecting at 235 nm.







* An impurity peak has the same retention time (29.2 min) to the minor enantiomer. The e.e. of (-)-**13** is calculated based on the peak area after taking out the area of impurity peak (the impurity peak is distinguishable from the main peak when eluted with hexanes/^{i}PrOH 95:5, however, the two enantiomers could not be separated under this condition).

4. Crystal Structure of Bicyclic [3+2] Cycloadduct 15

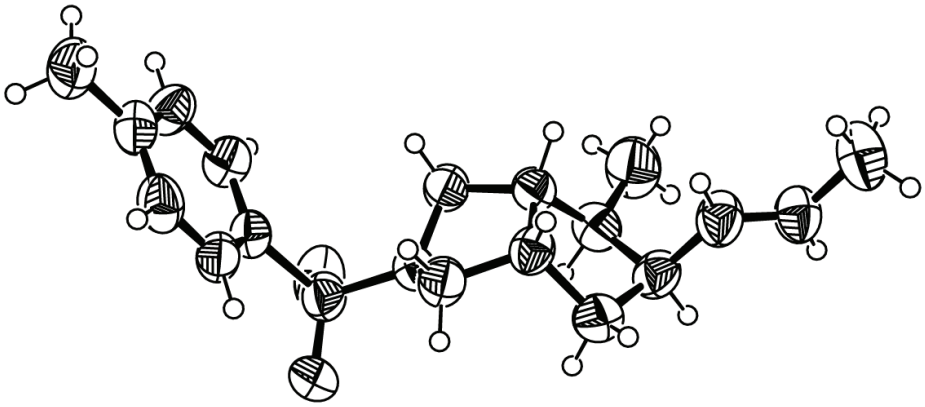
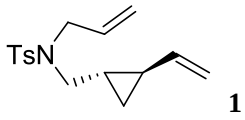


Figure S1. ORTEP Figure for Compound **15**

Table 1. Crystal Data and Structure Refinement

Identification code	8304
Empirical formula	$C_{18}H_{25}NO_2$ S
Formula weight	319.45
Temperature	293(2) K
Wavelength	0.71073 Å
Crystal system	Monoclinic
Space group	P2(1)/n
Unit cell dimensions	a = 10.304(2) Å α = 90°
	b = 13.205(3) Å β = 110.89(3)°
	c = 13.799(3) Å γ = 90°
Volume	1754.3(6) $Å^3$
Z	4
Density (calculated)	1.210 Mg/m^3
Absorption coefficient	0.191 mm^{-1}
F(000)	688
Crystal size	0.60 × 0.40 × 0.40 mm^3
Theta range for data collection	2.14 to 27.48°.
Index ranges	$-13 \le h \le 13$, $-17 \le k \le 17$, $-17 \le l \le 16$
Reflections collected	12934
Independent reflections	3998 [R(int) = 0.05651297]
Completeness to theta = 27.48	99.4 %
Absorption correction	Empirical
Max. and min. transmission	0.9274 and 0.8938
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	3998 / 0 / 218
Goodness-of-fit on F^2	0.974
Final R indices [I > 2sigma(I)]	R1 = 0.0577, wR^2 = 0.1258
R indices (all data)	R1 = 0.1189, wR^2 = 0.1400
Largest diff. peak and hole	0.269 and -0.302 e. $Å^{-3}$

5. ^{1}H and ^{13}C-NMR Spectra for New Compounds



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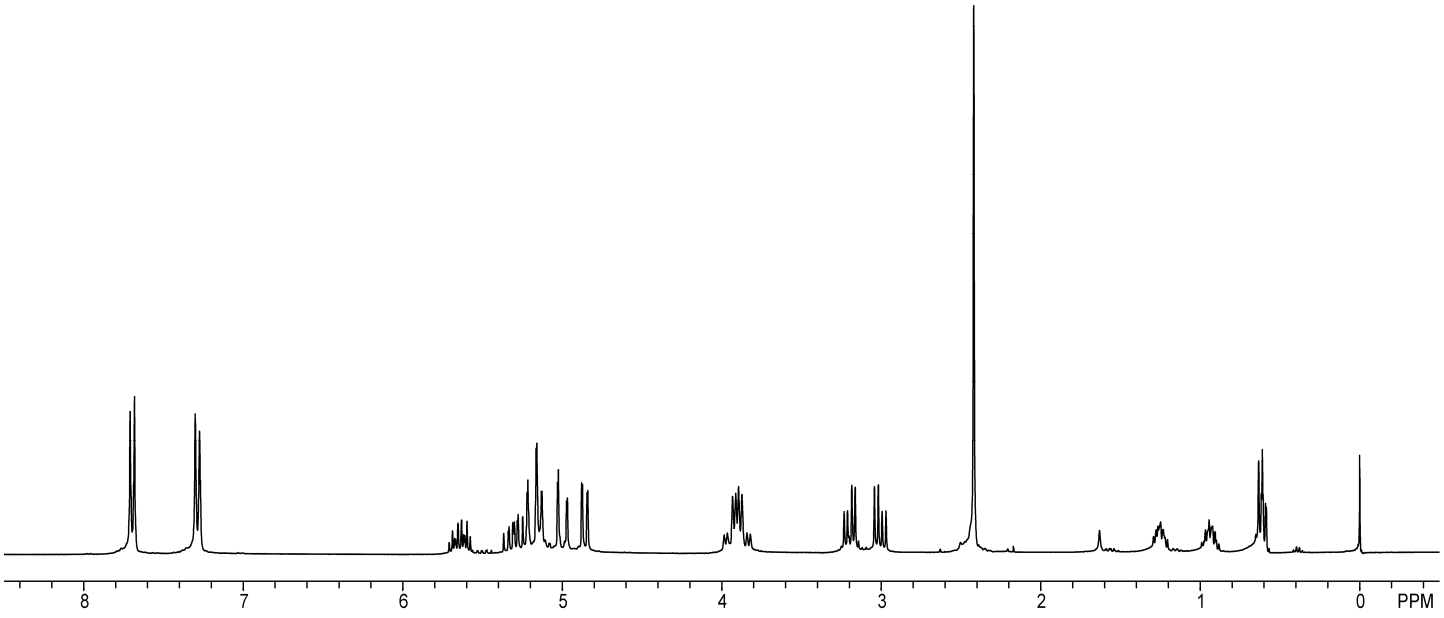

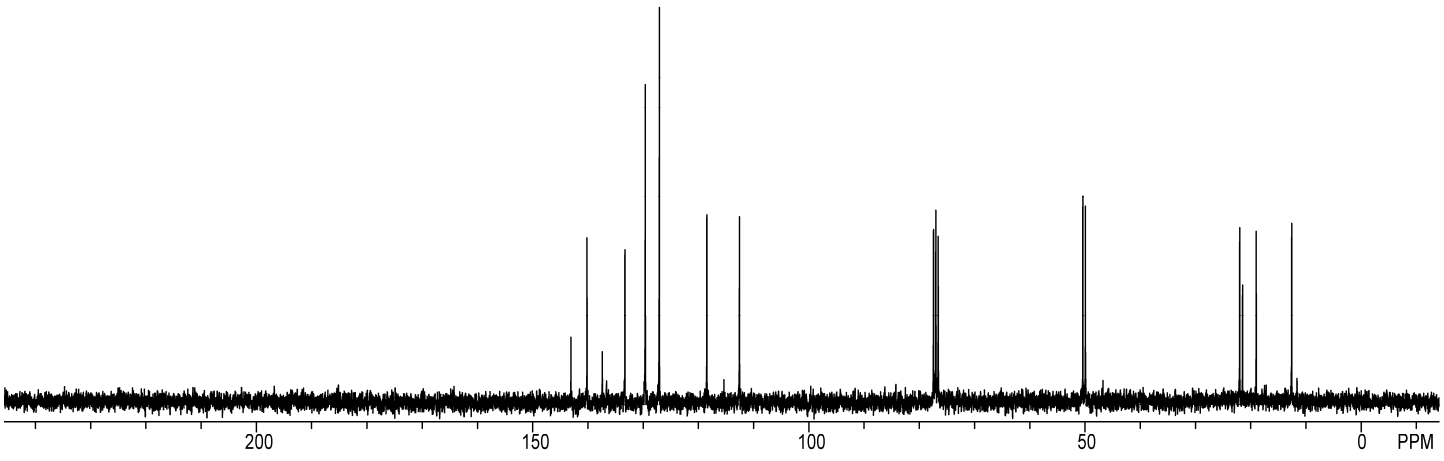

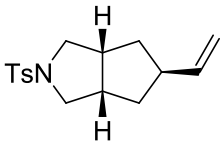

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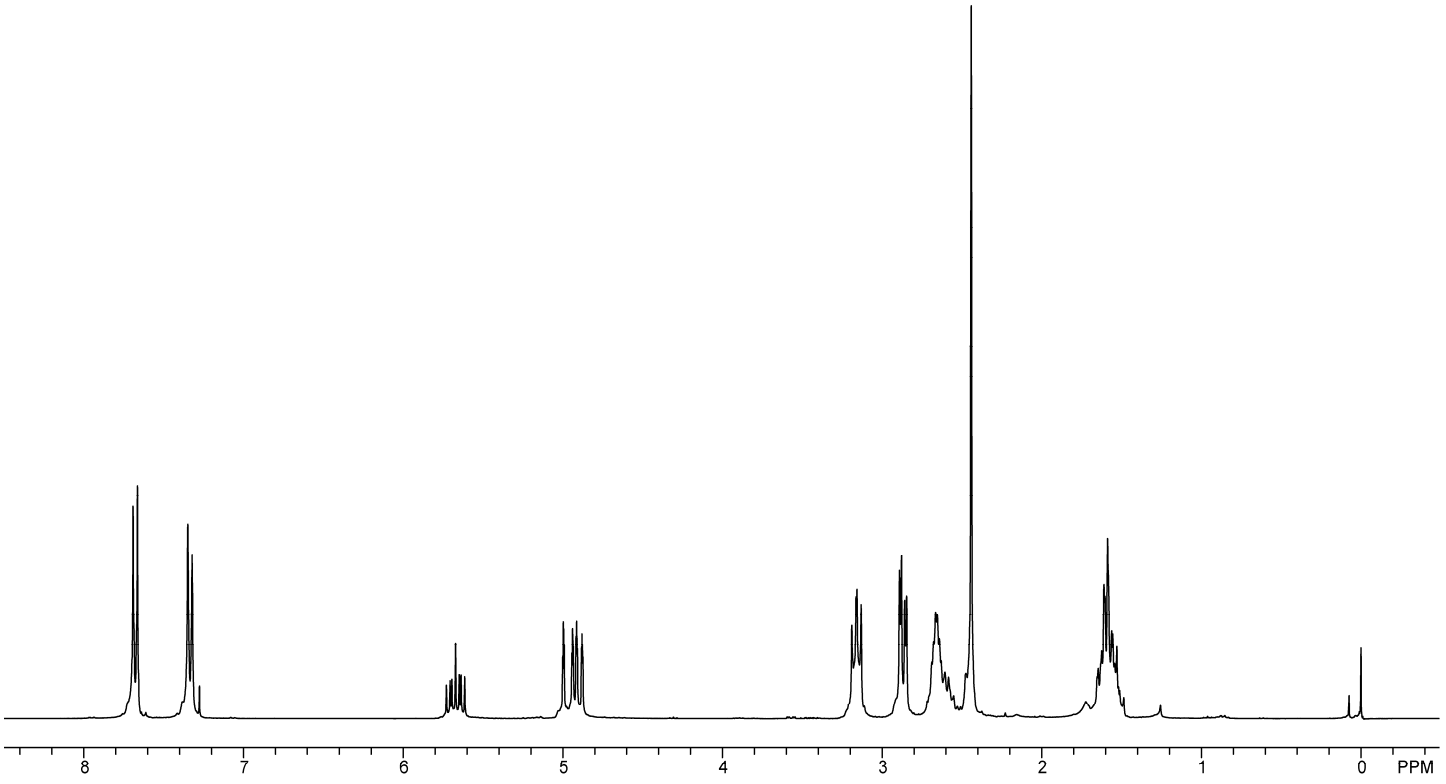

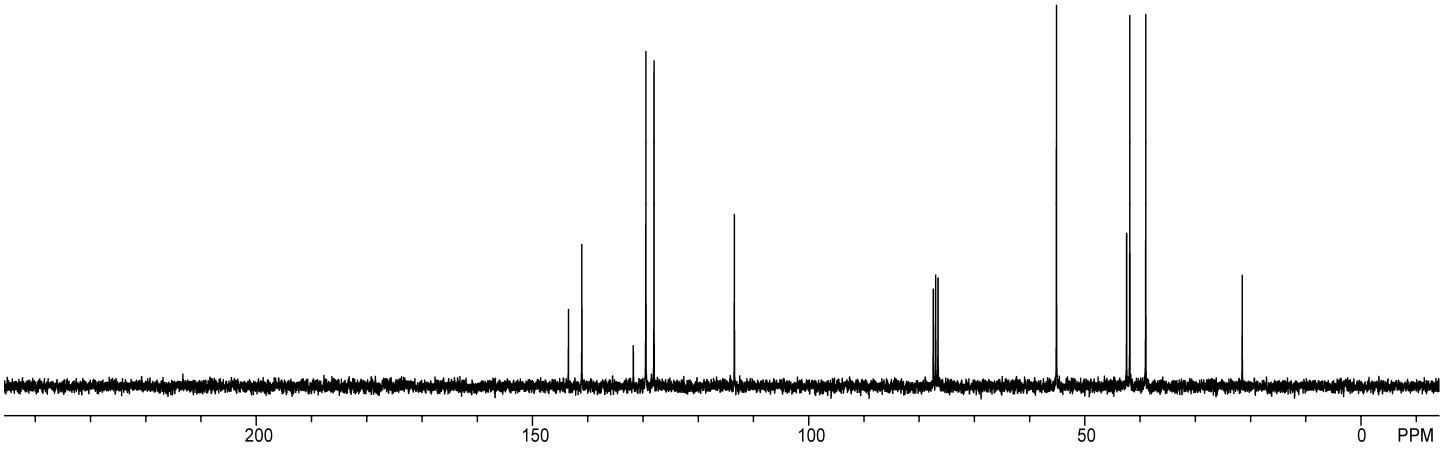

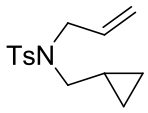

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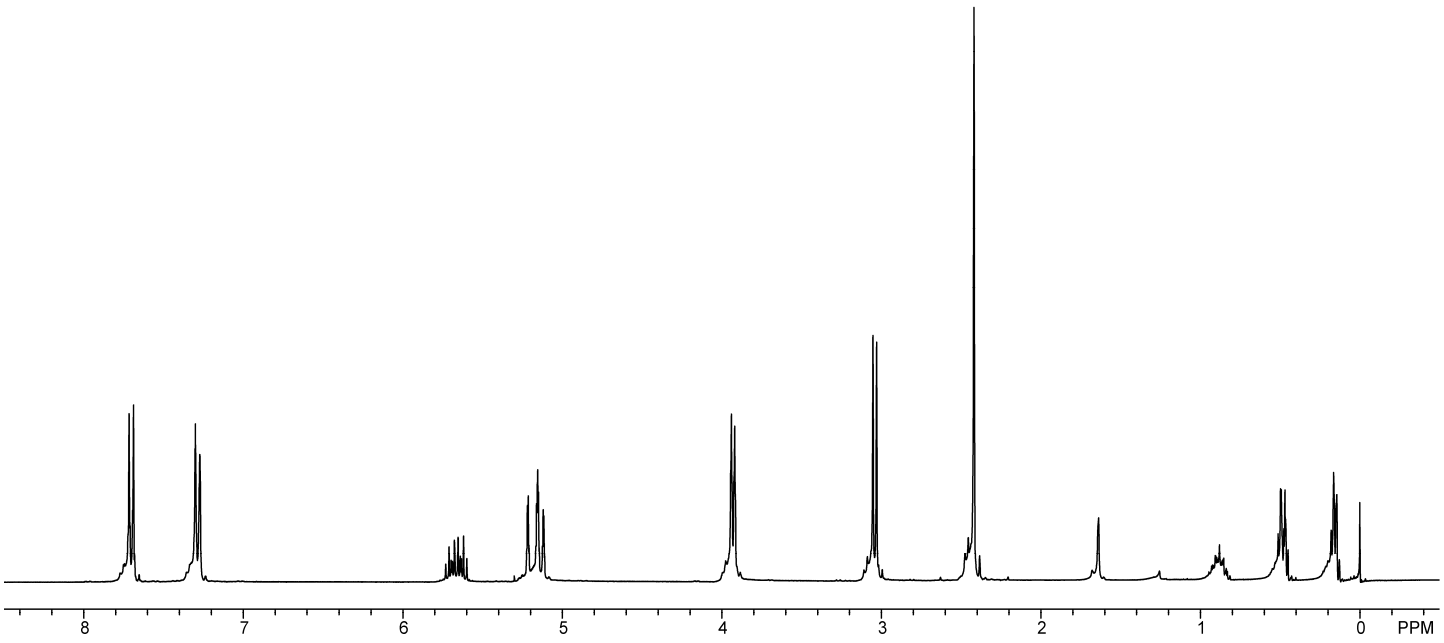

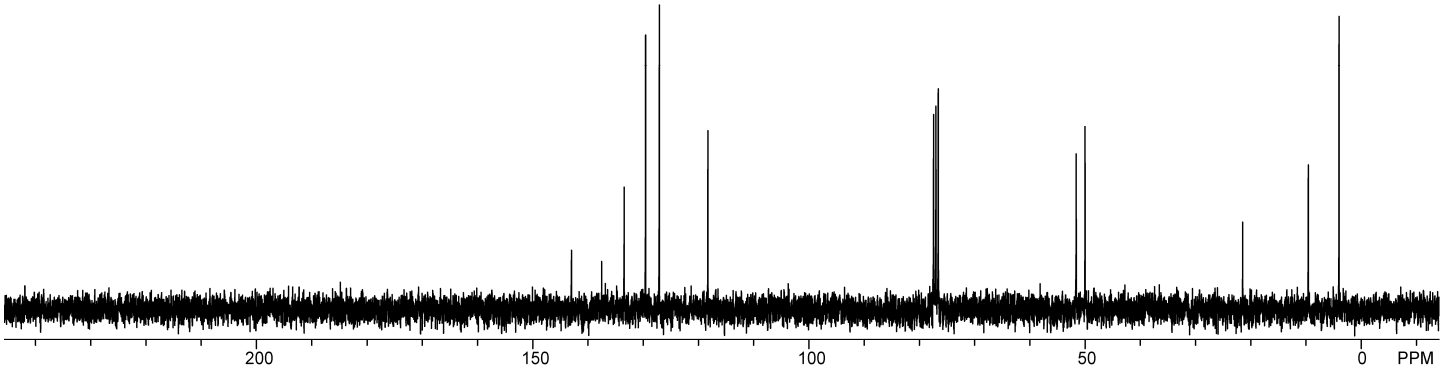

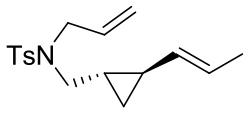

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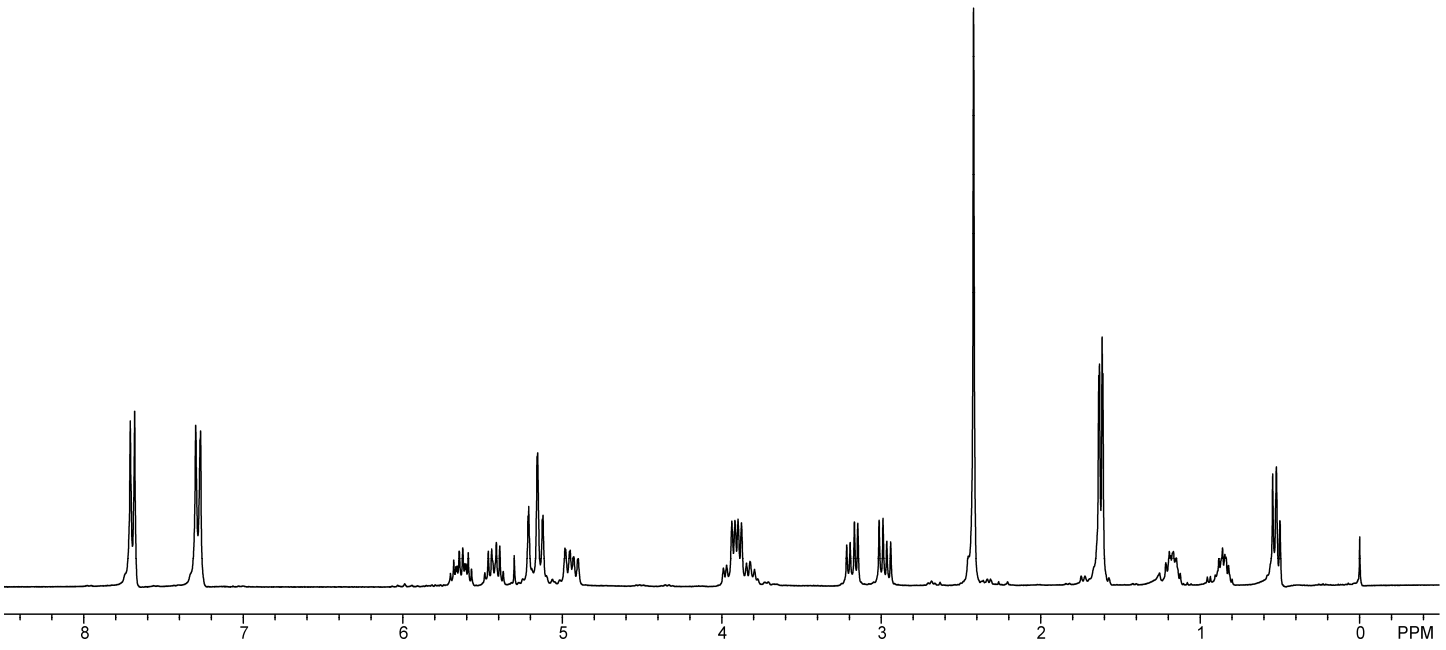

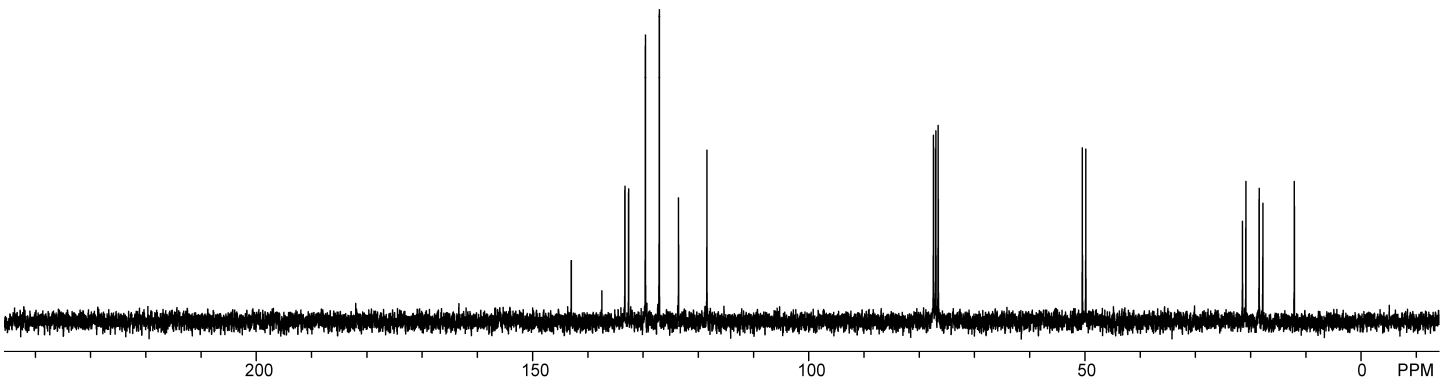

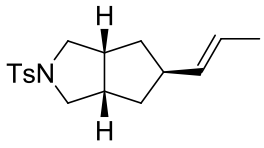

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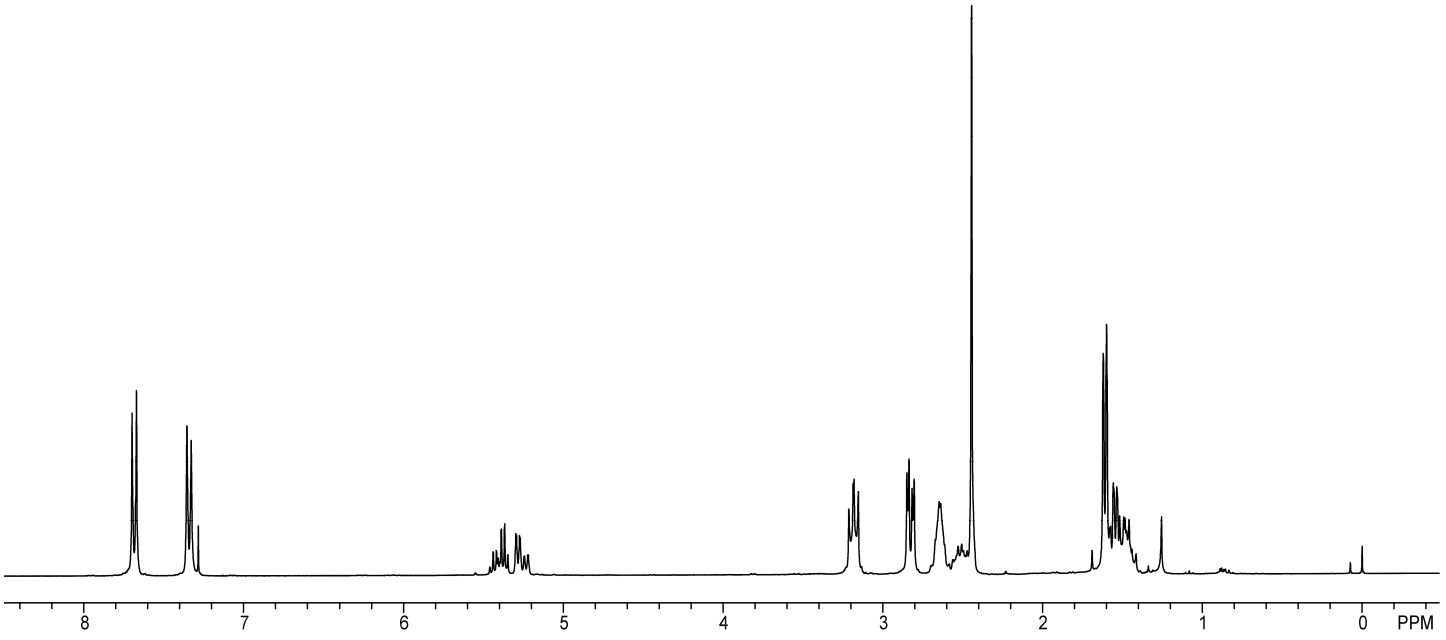

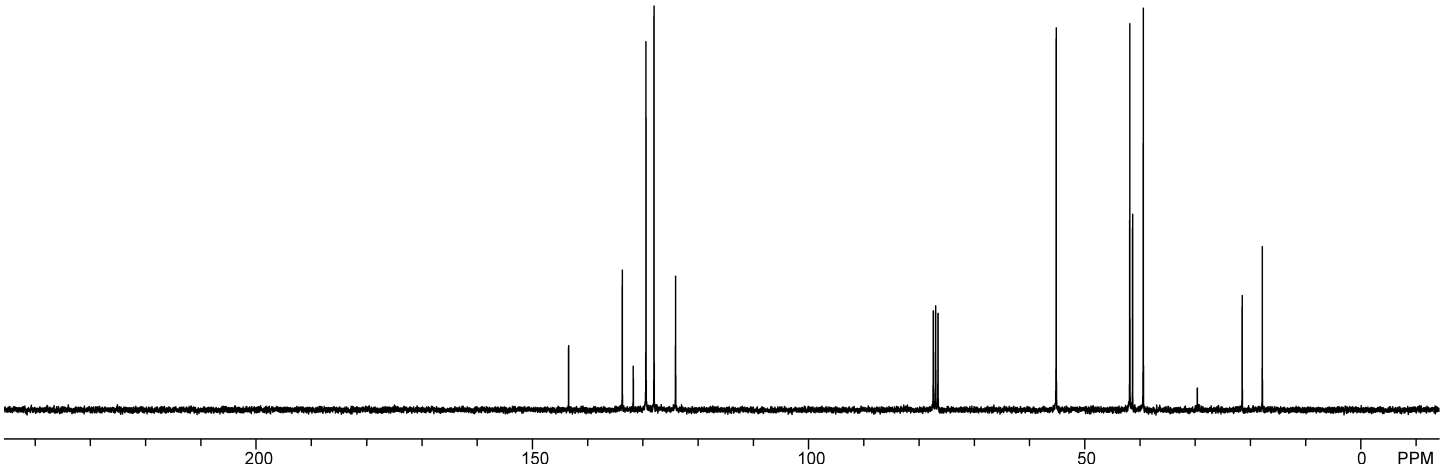

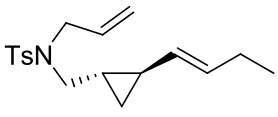

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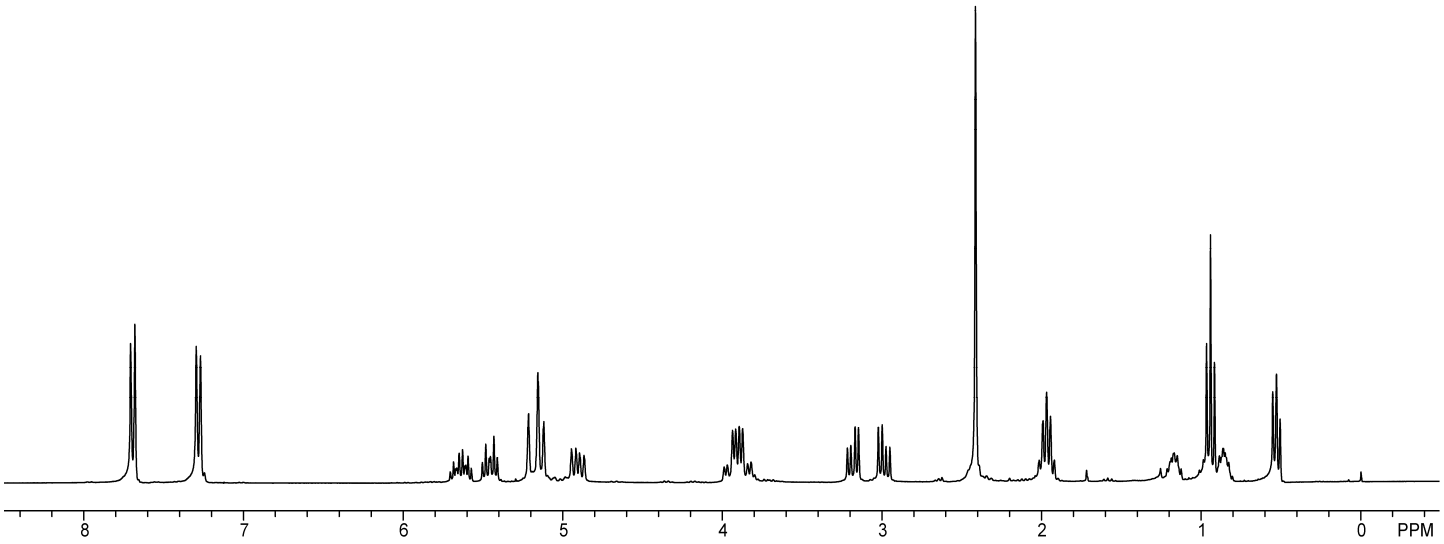

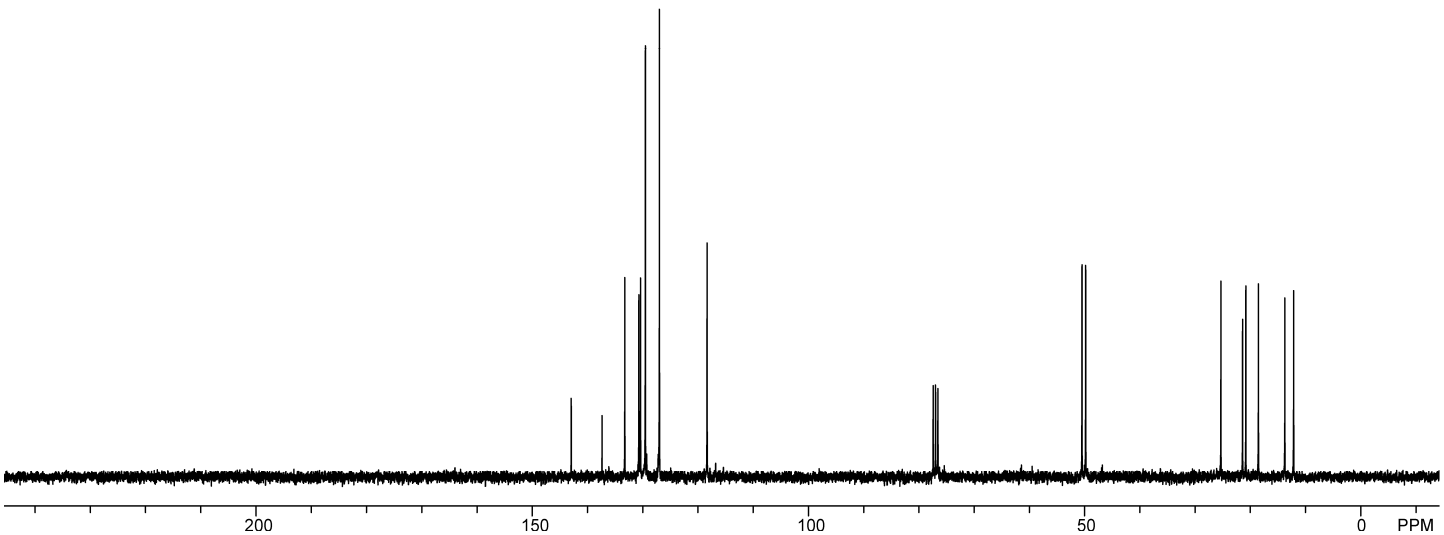

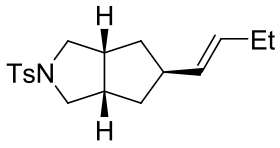

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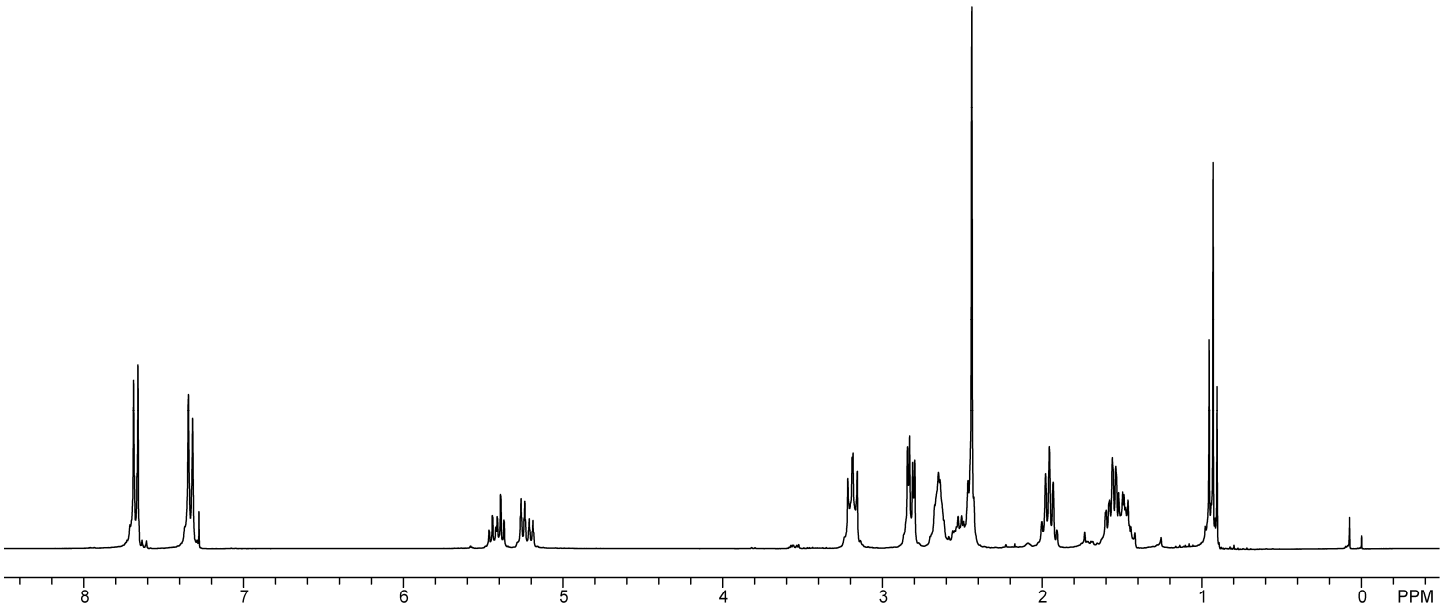

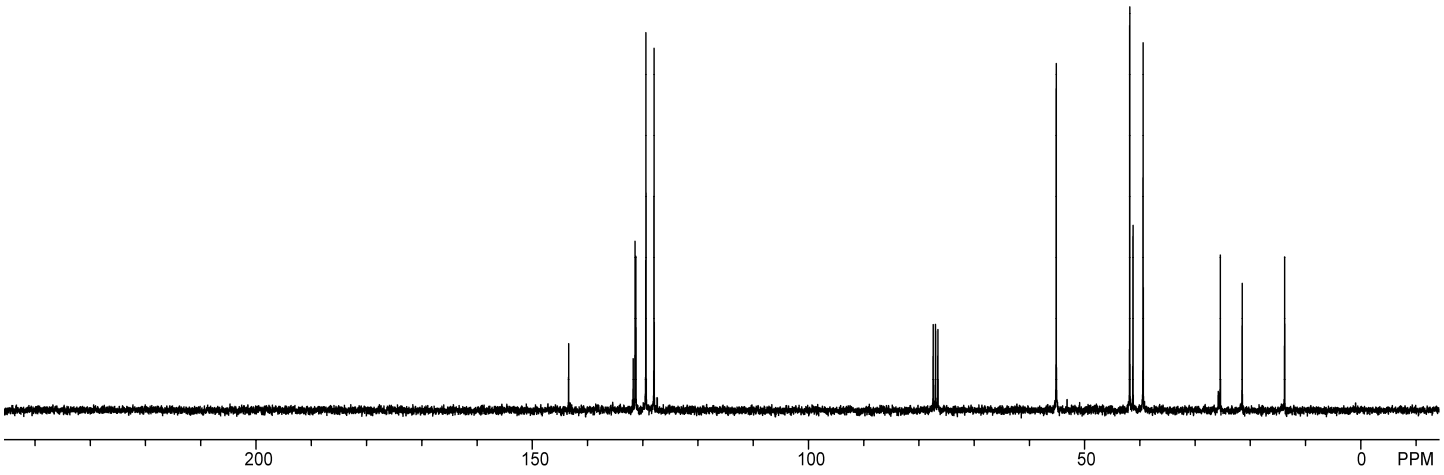

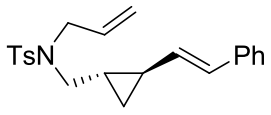

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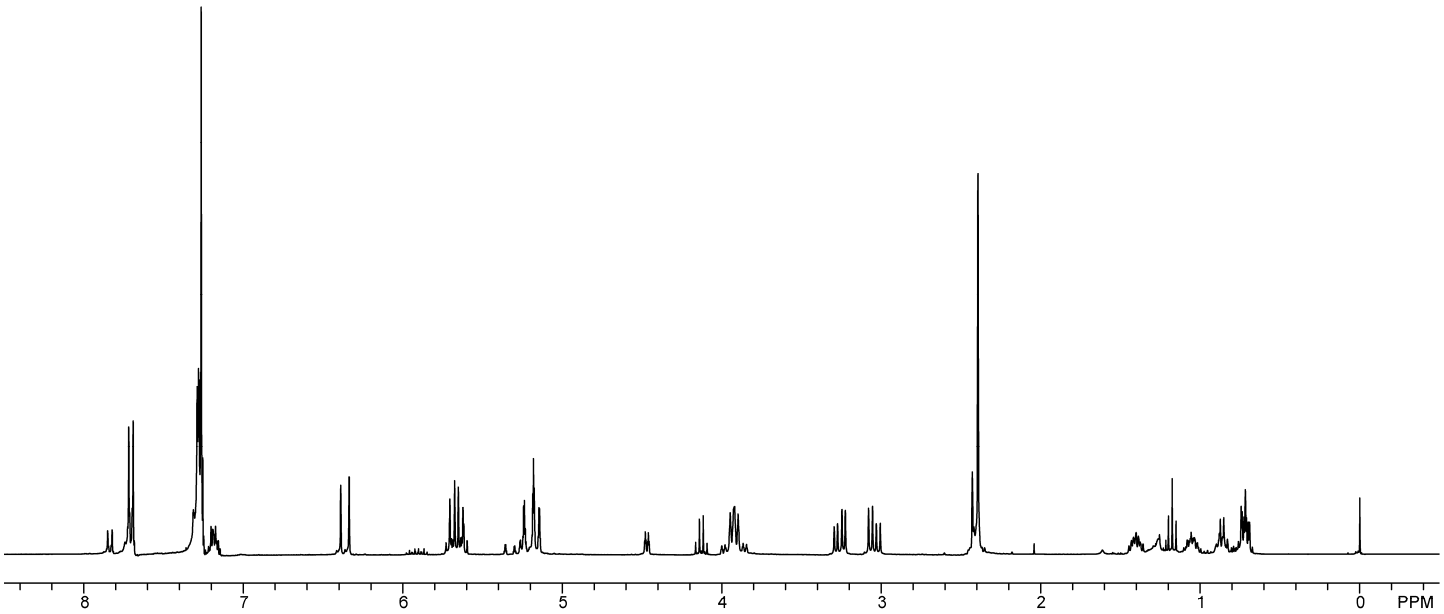

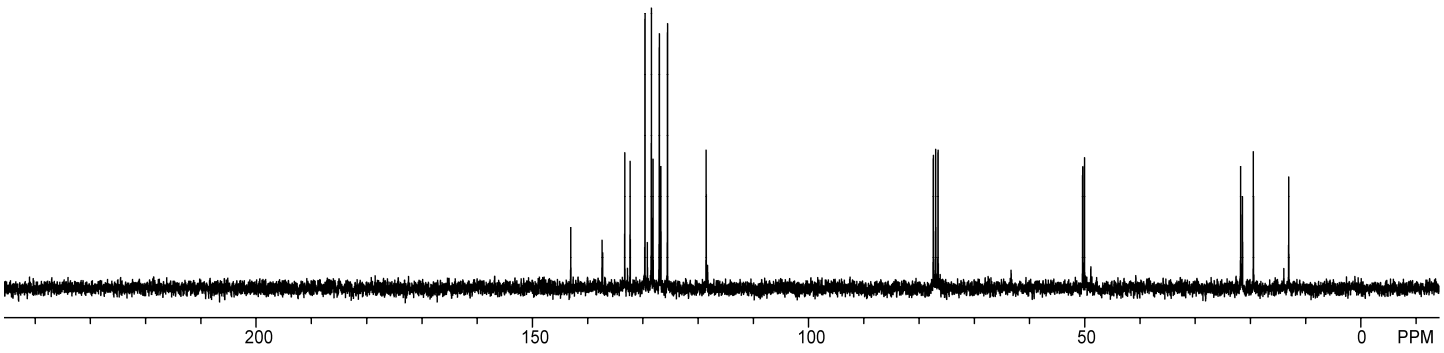

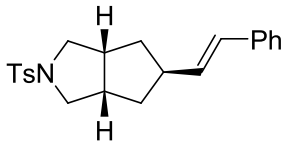

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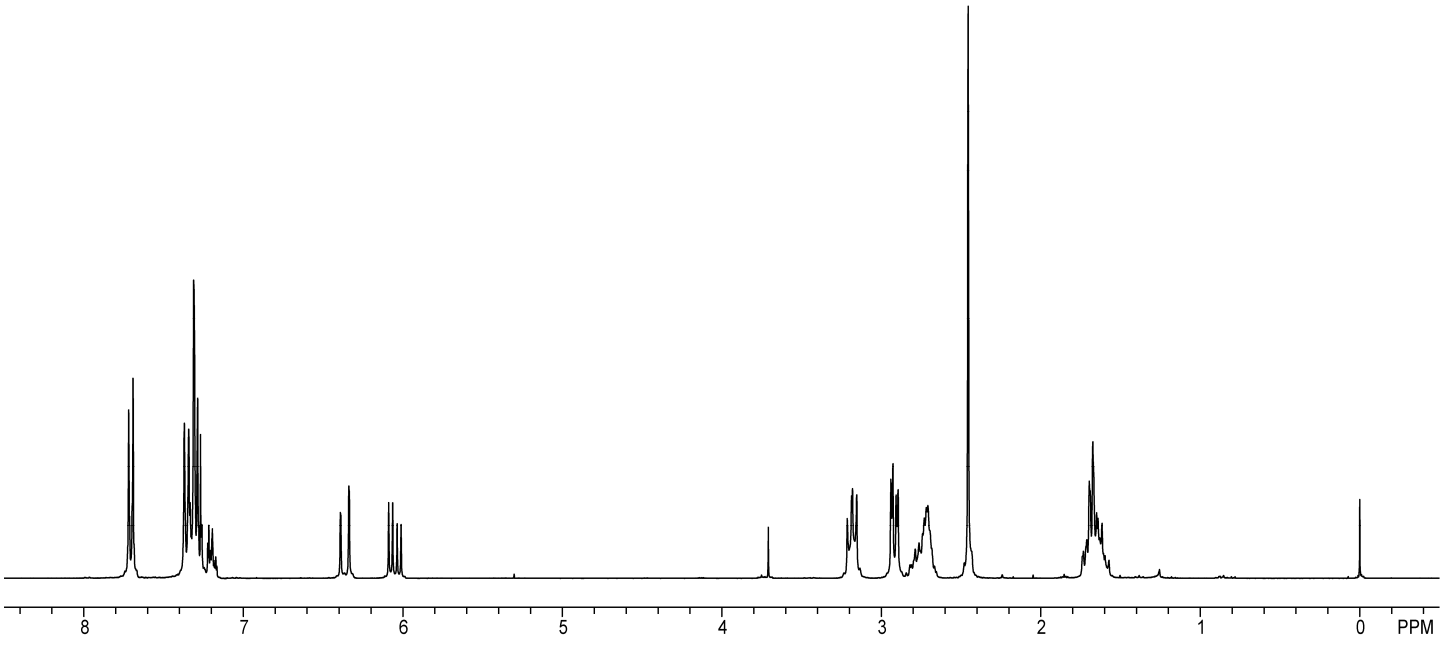

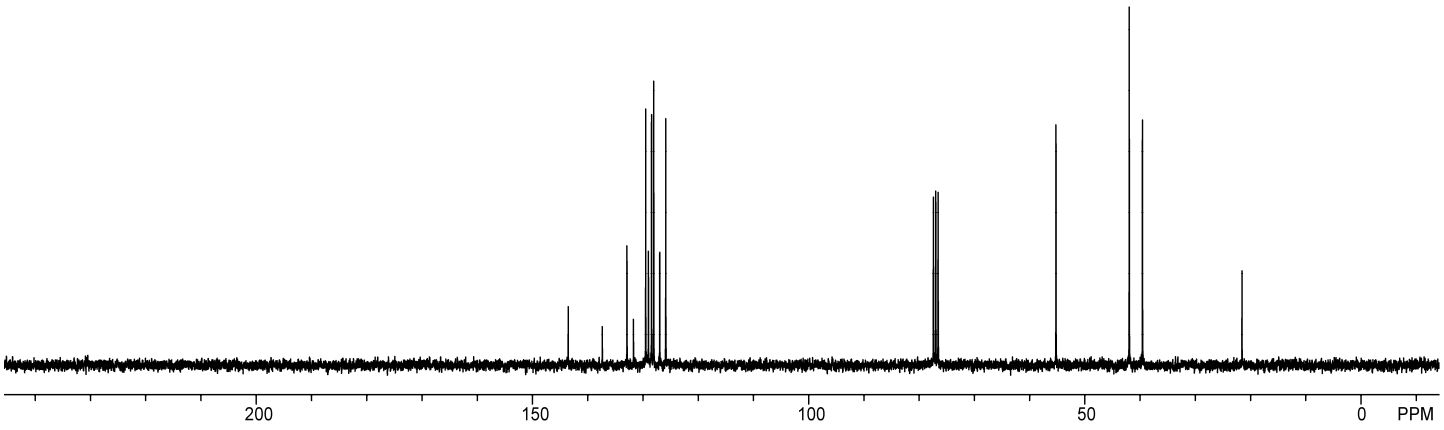

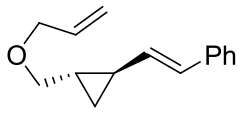

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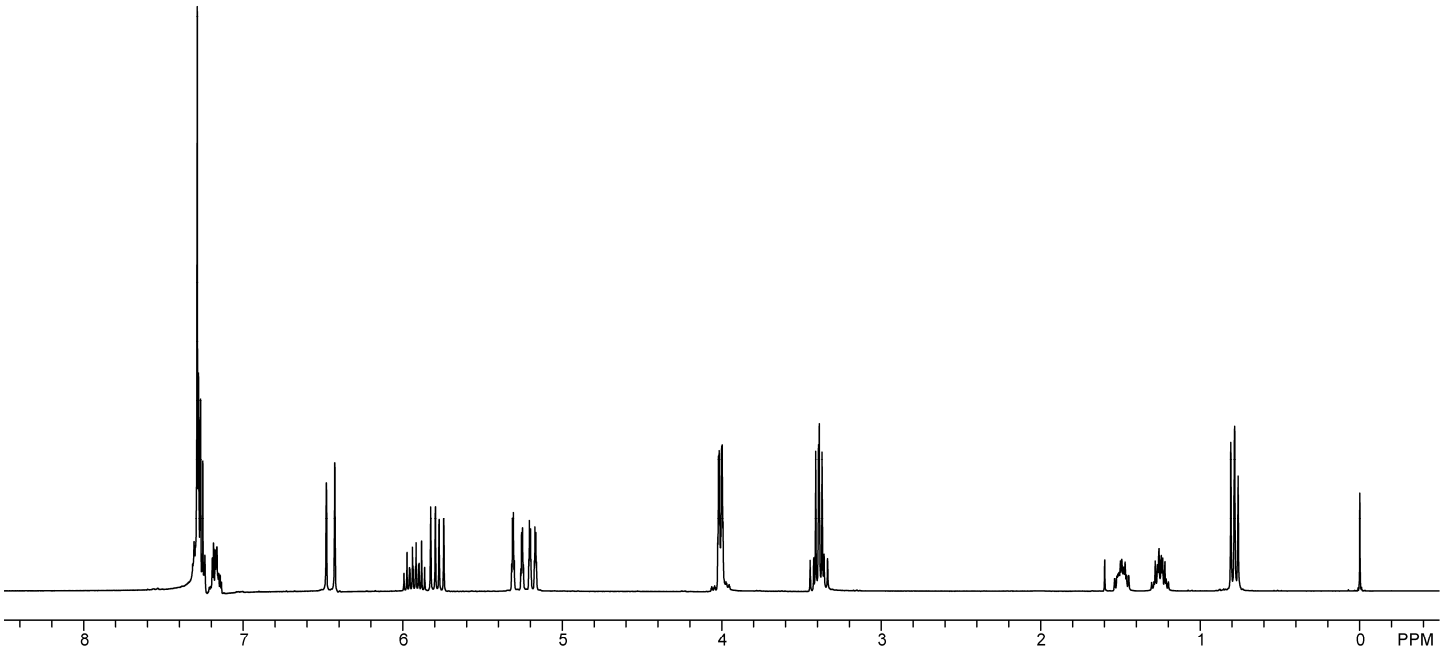

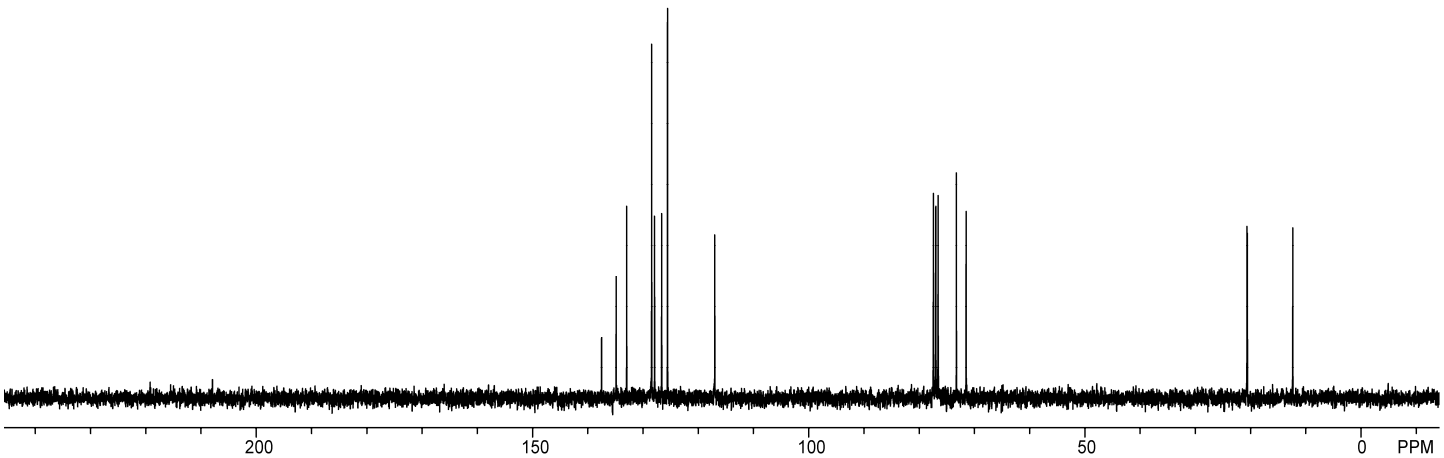

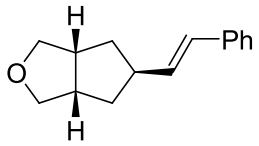

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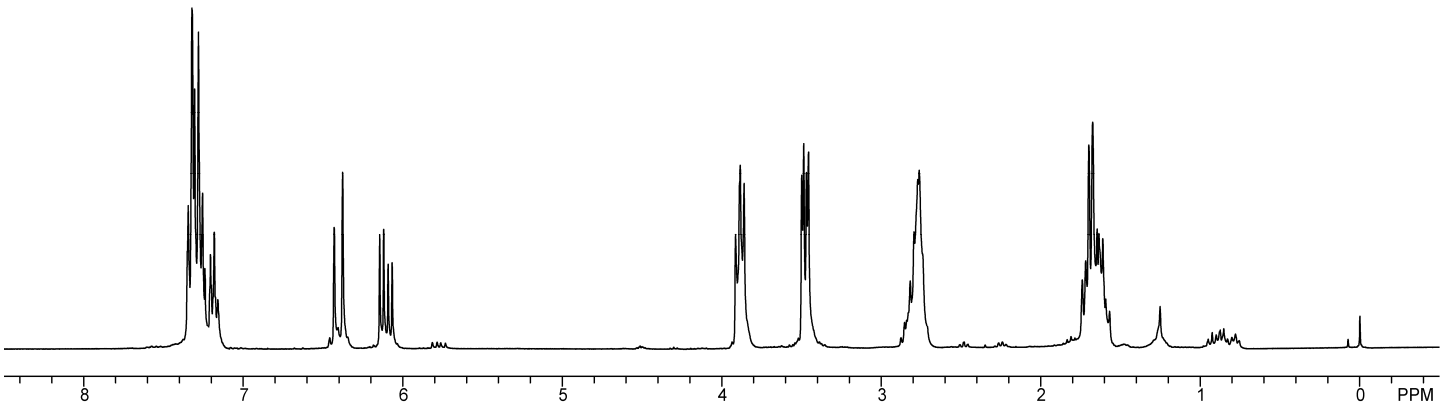

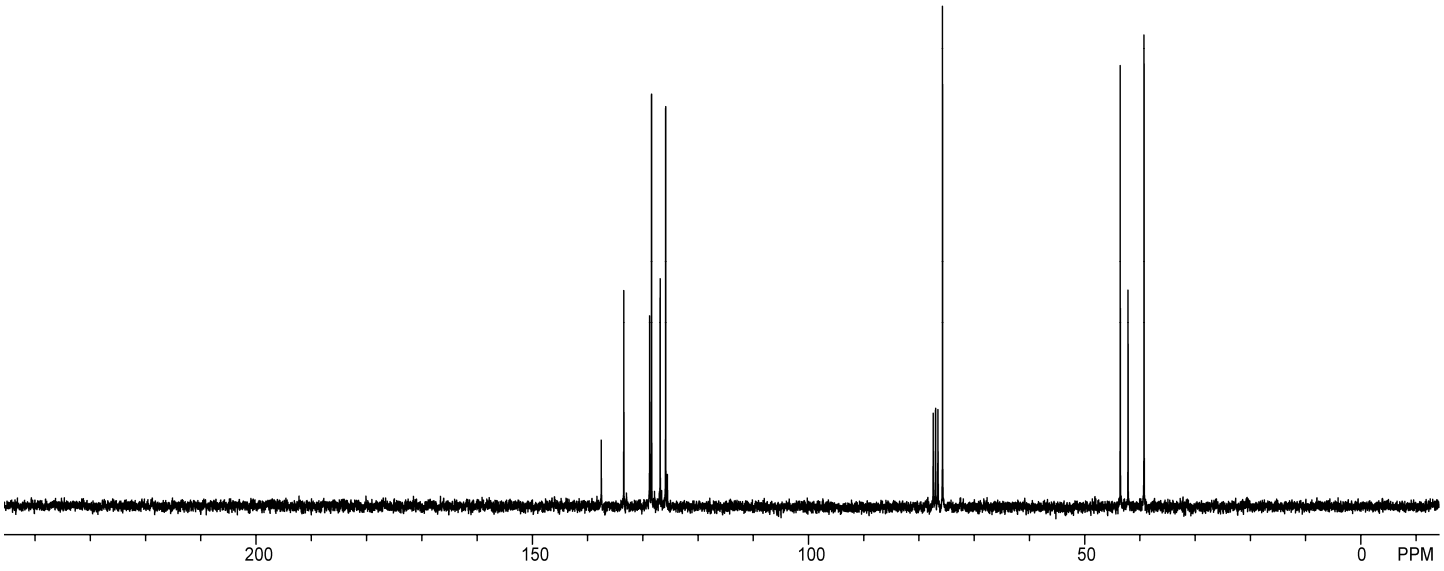

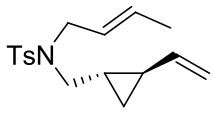

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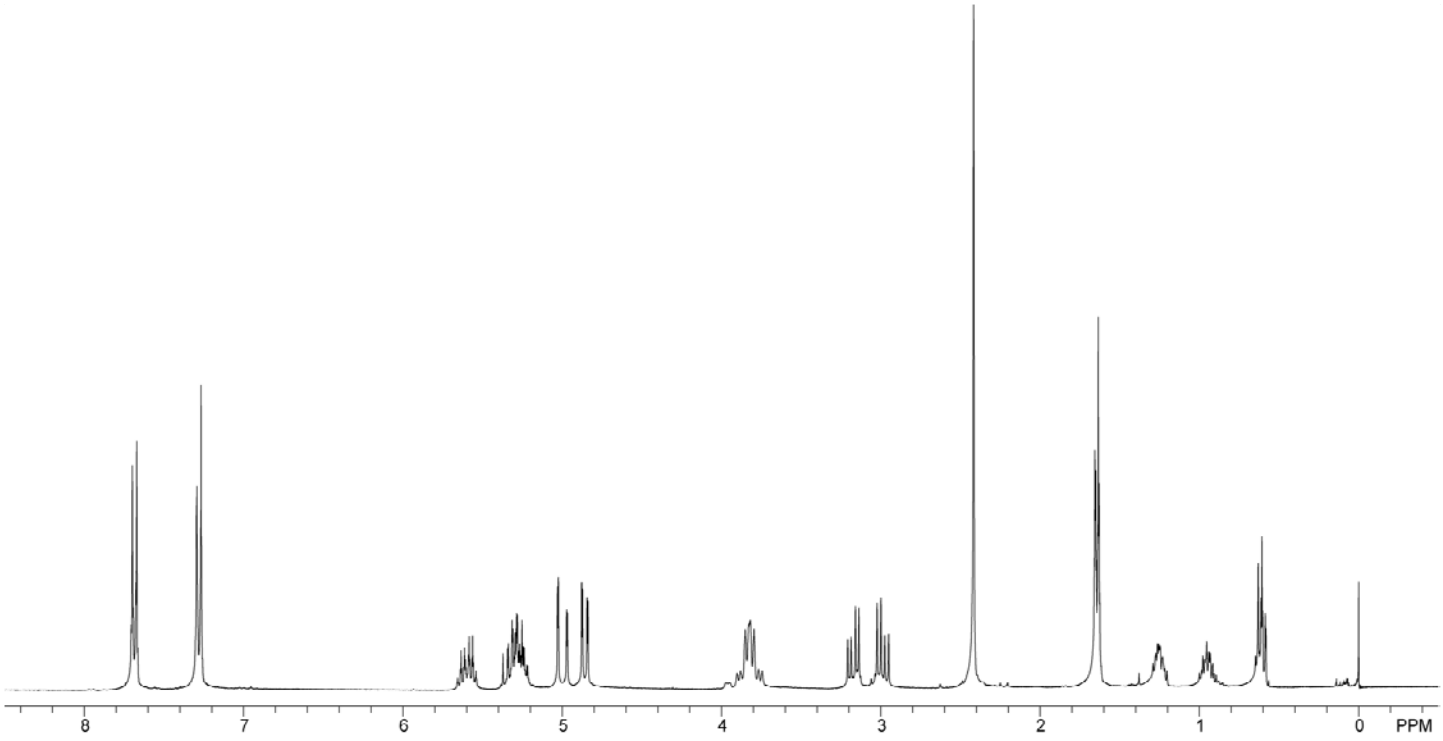

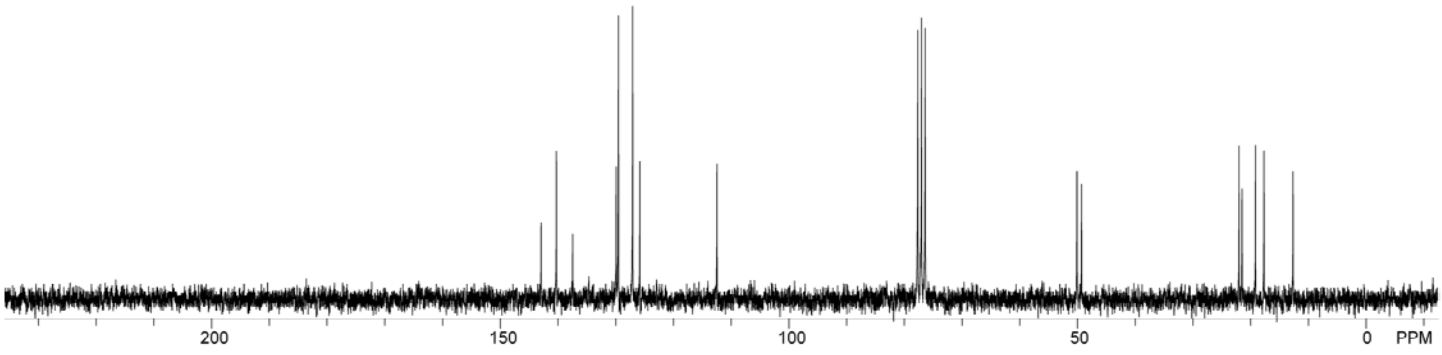

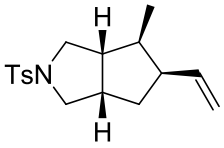

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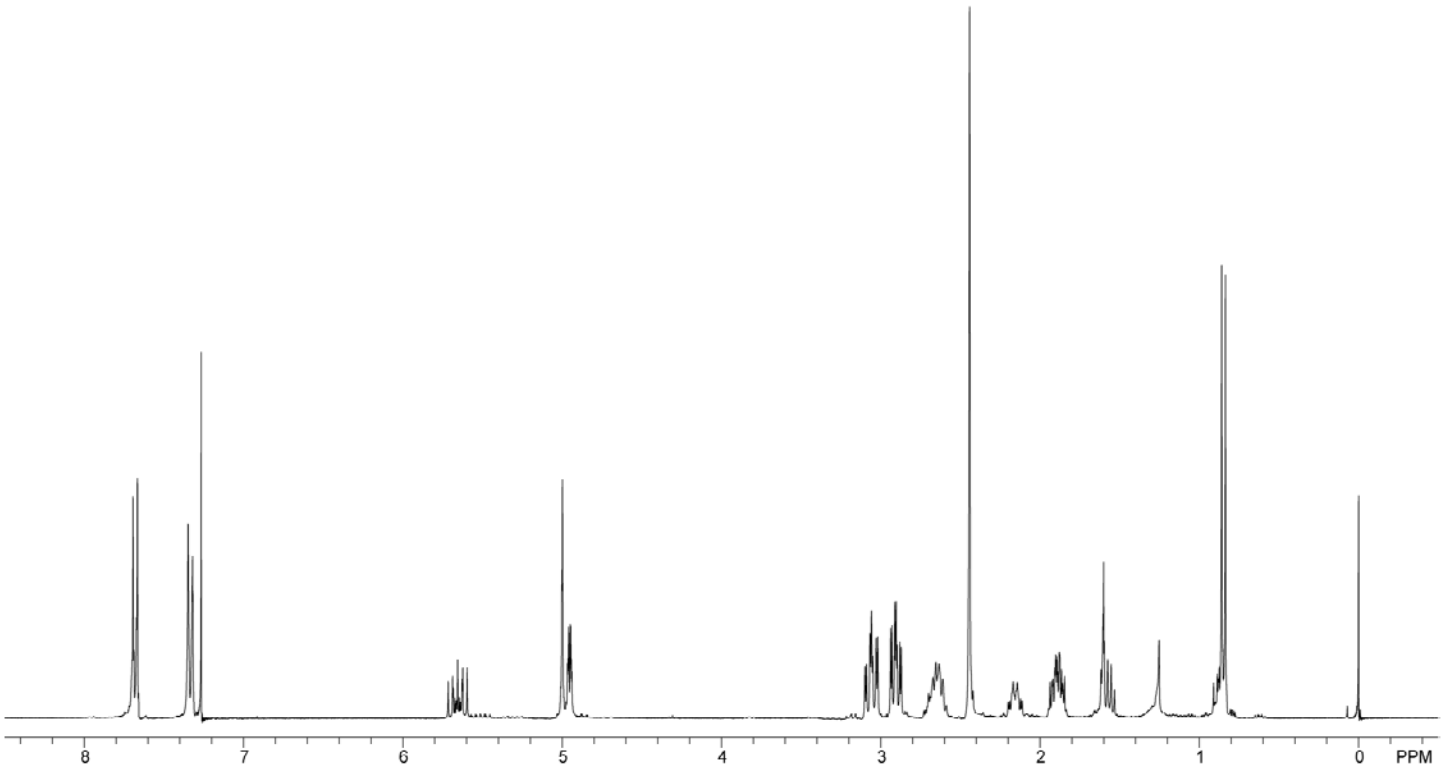

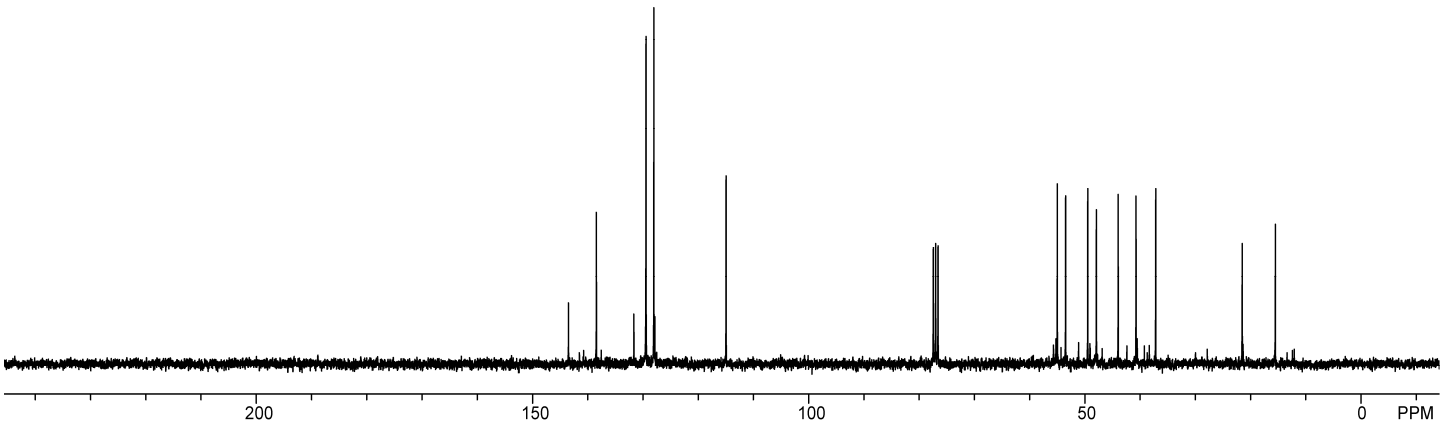

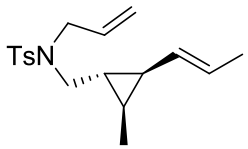

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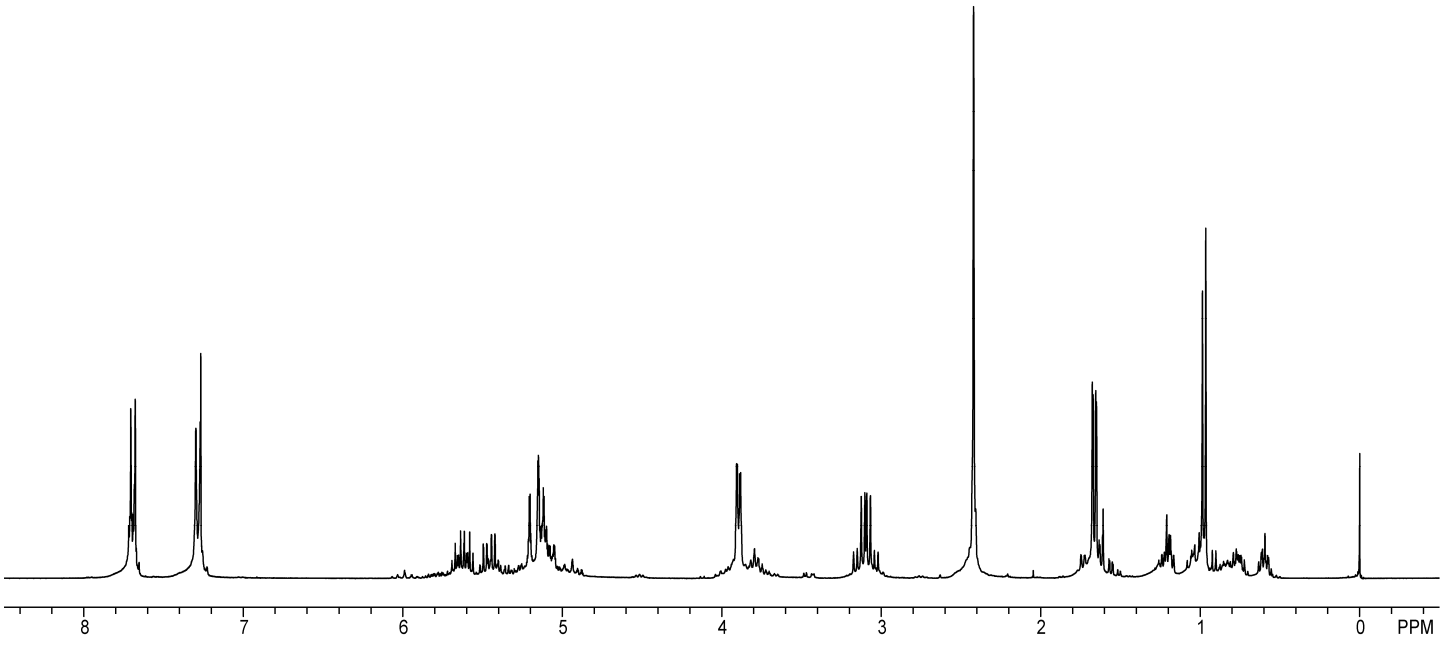

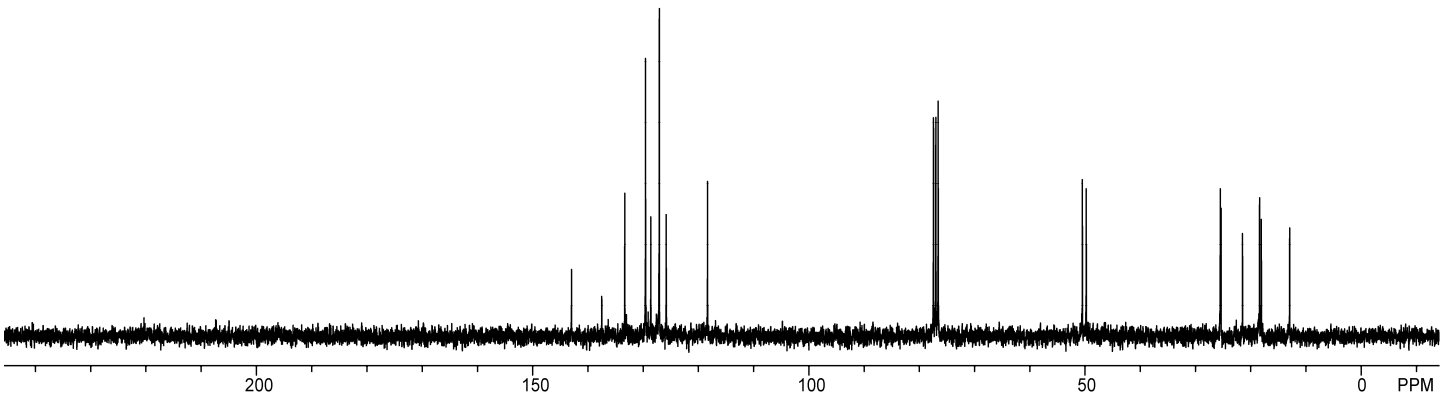

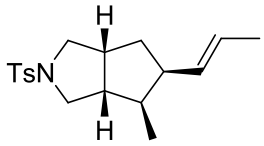

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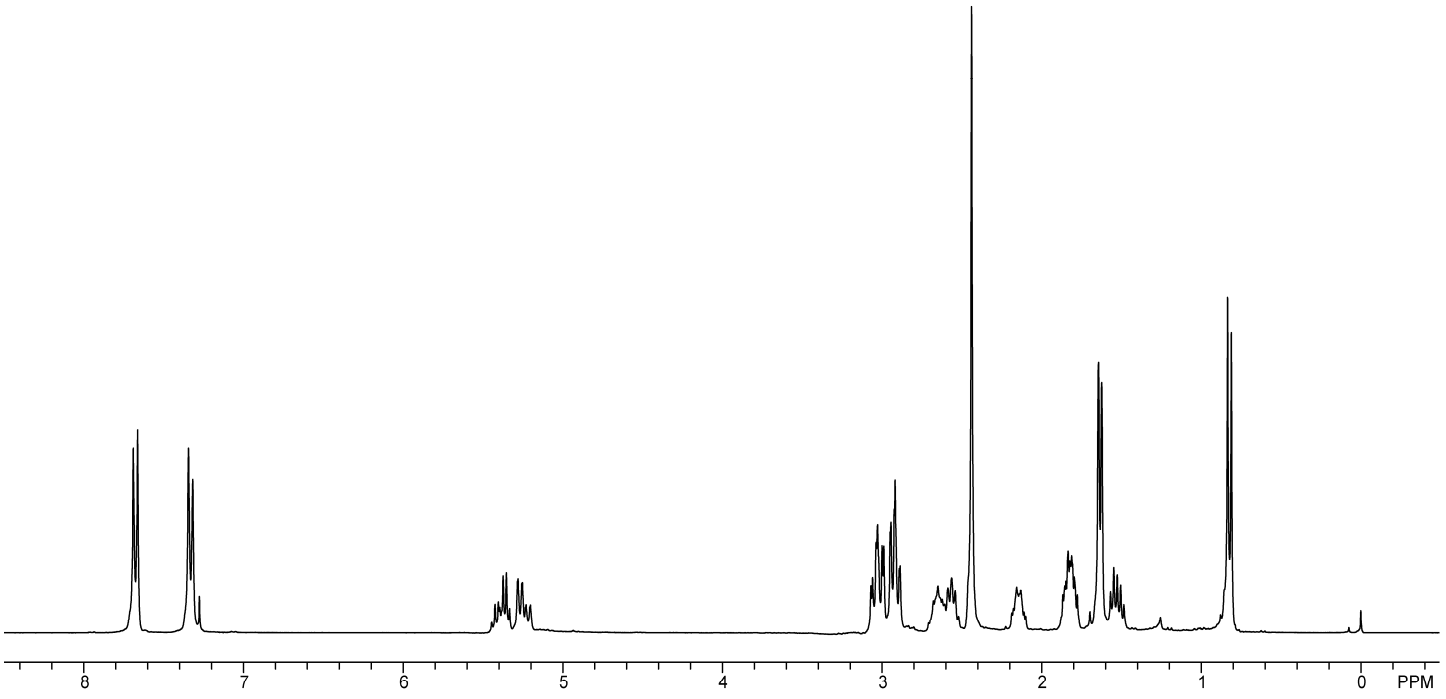

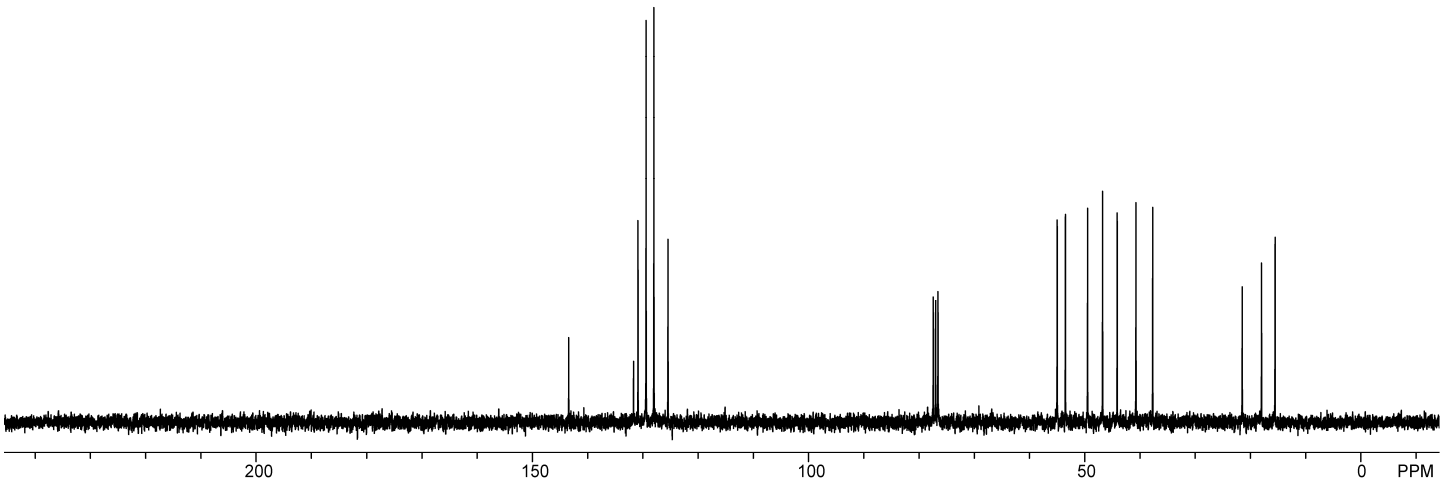

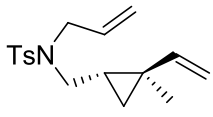

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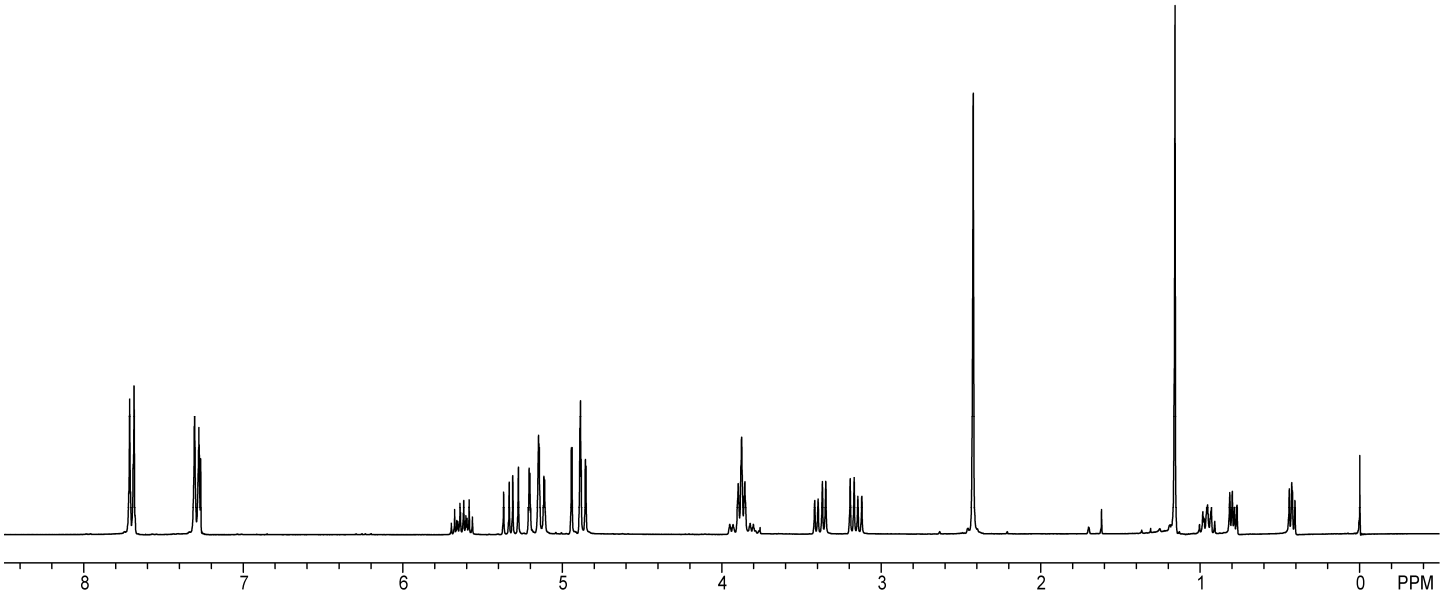

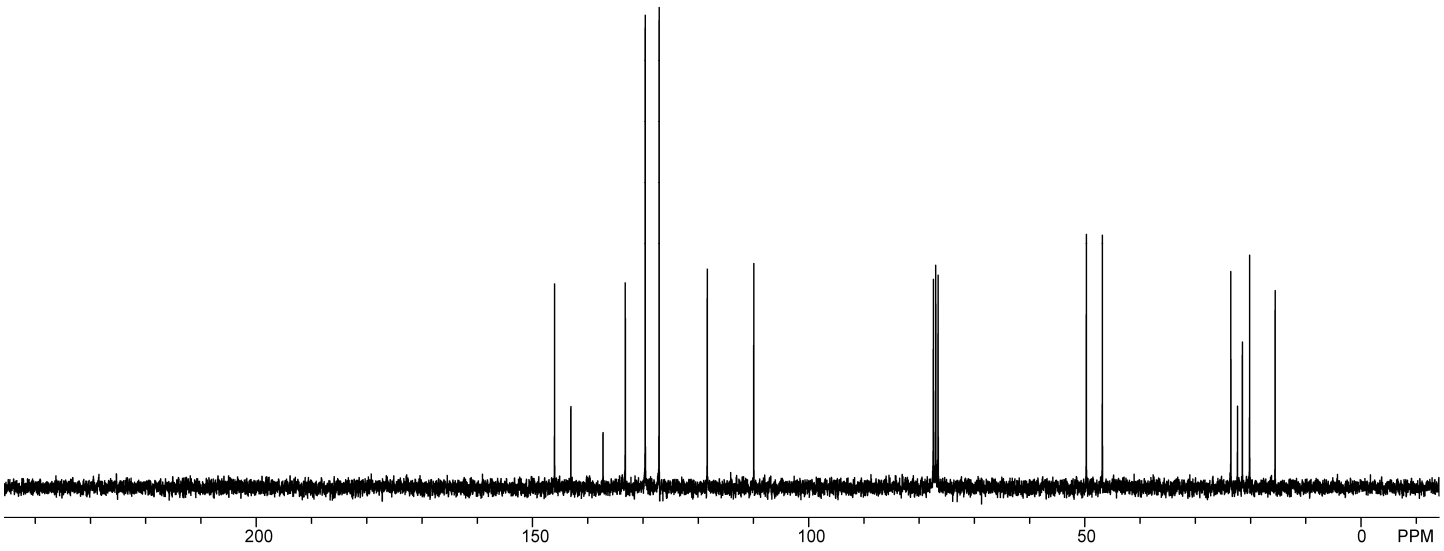

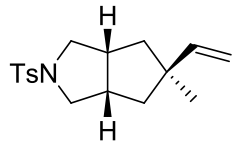

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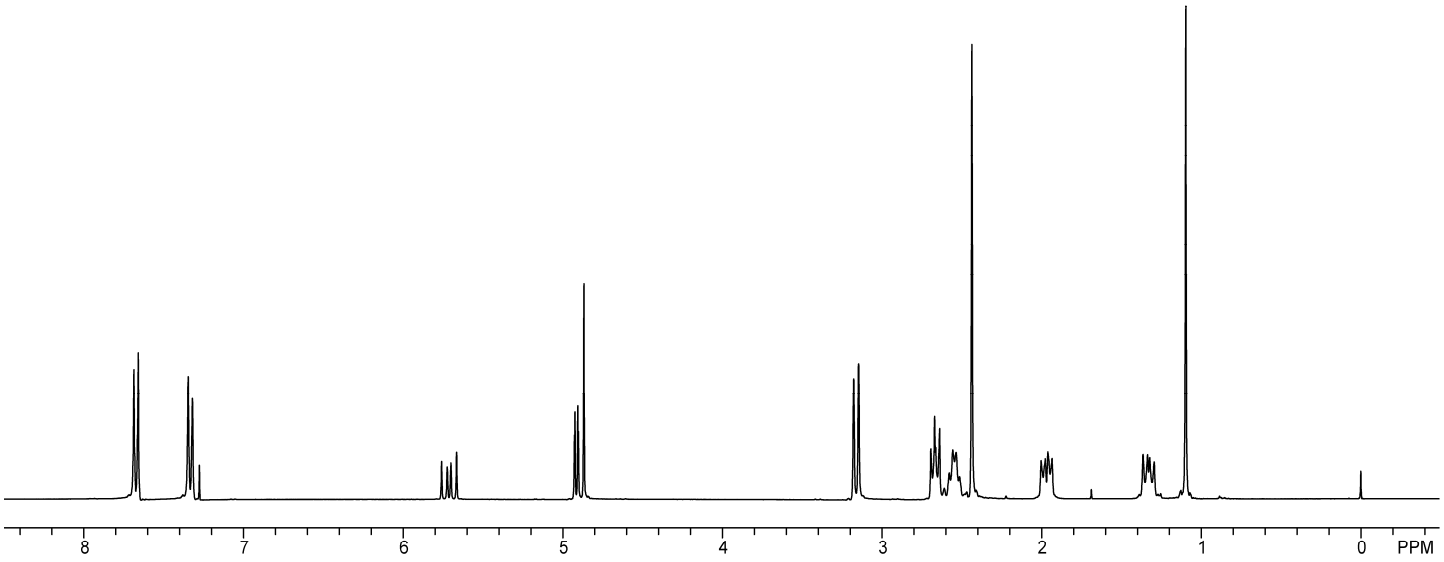

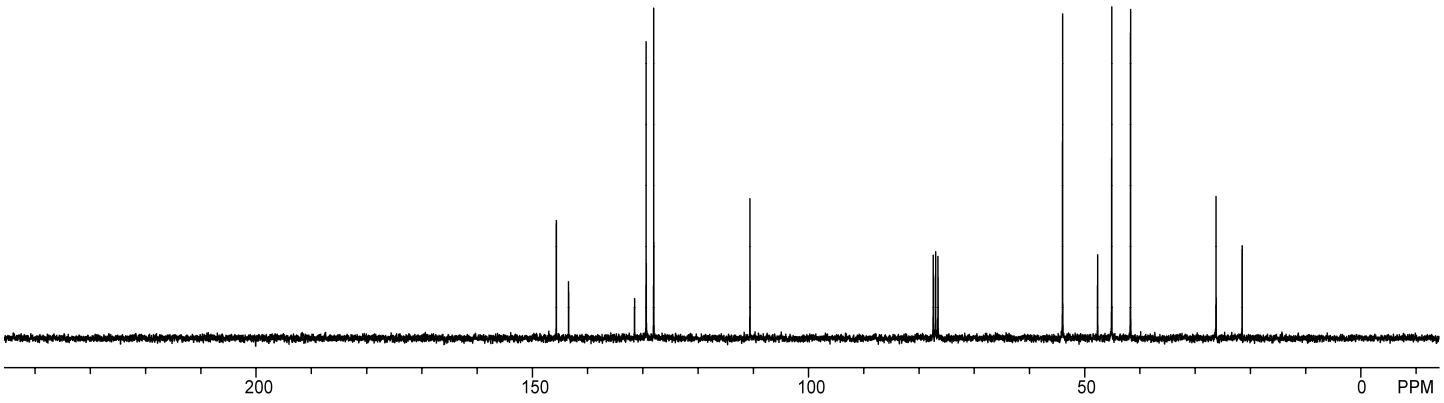

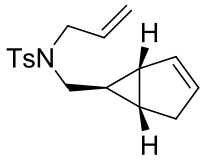

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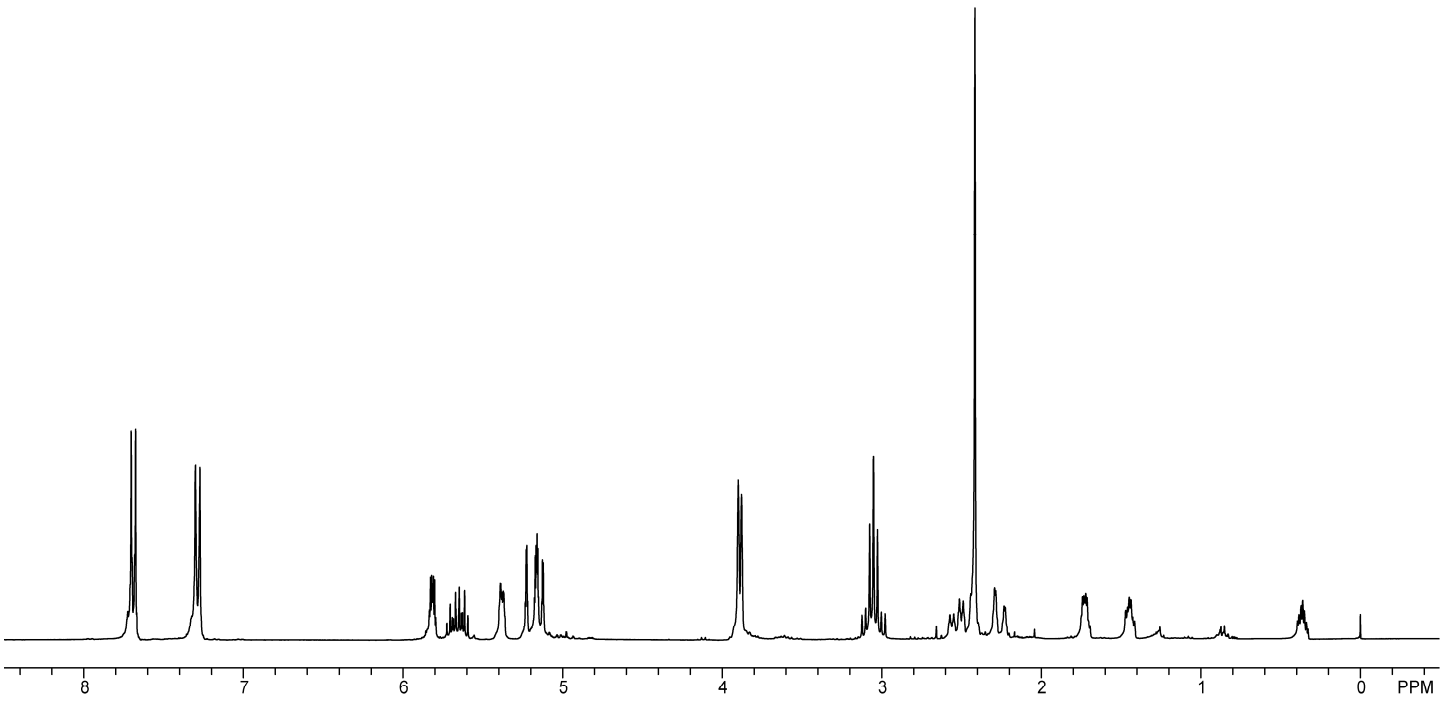

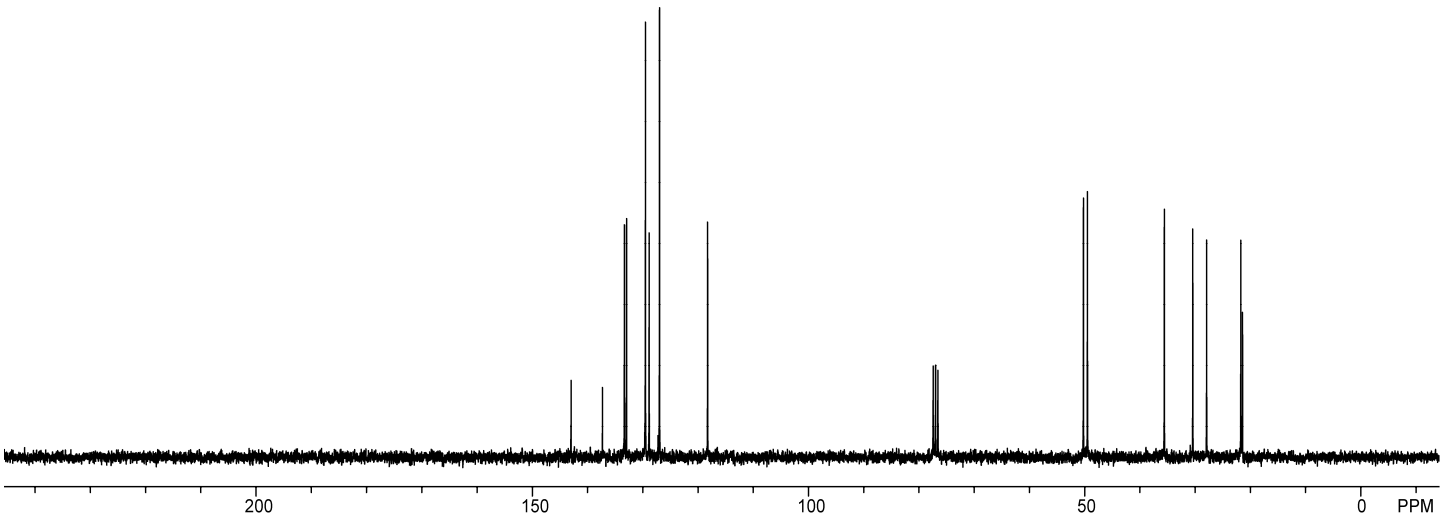

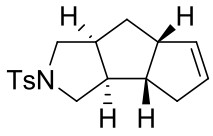

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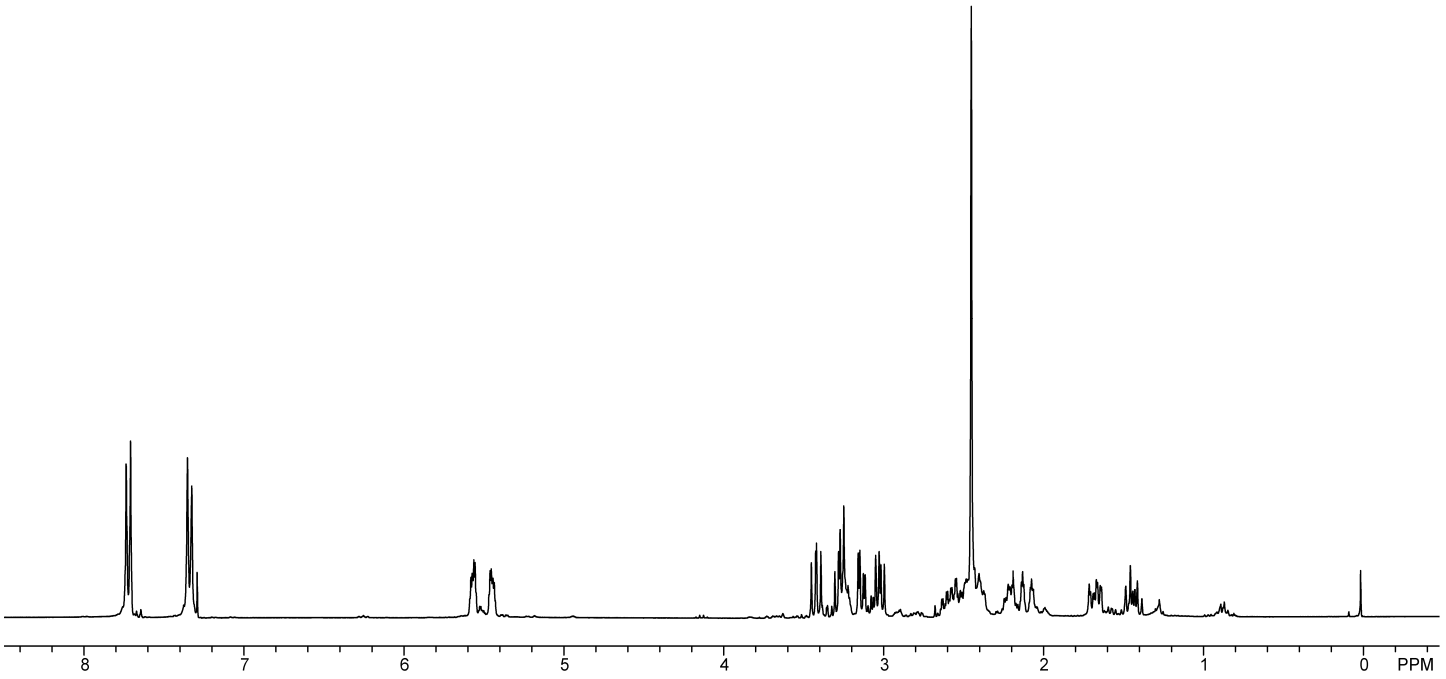

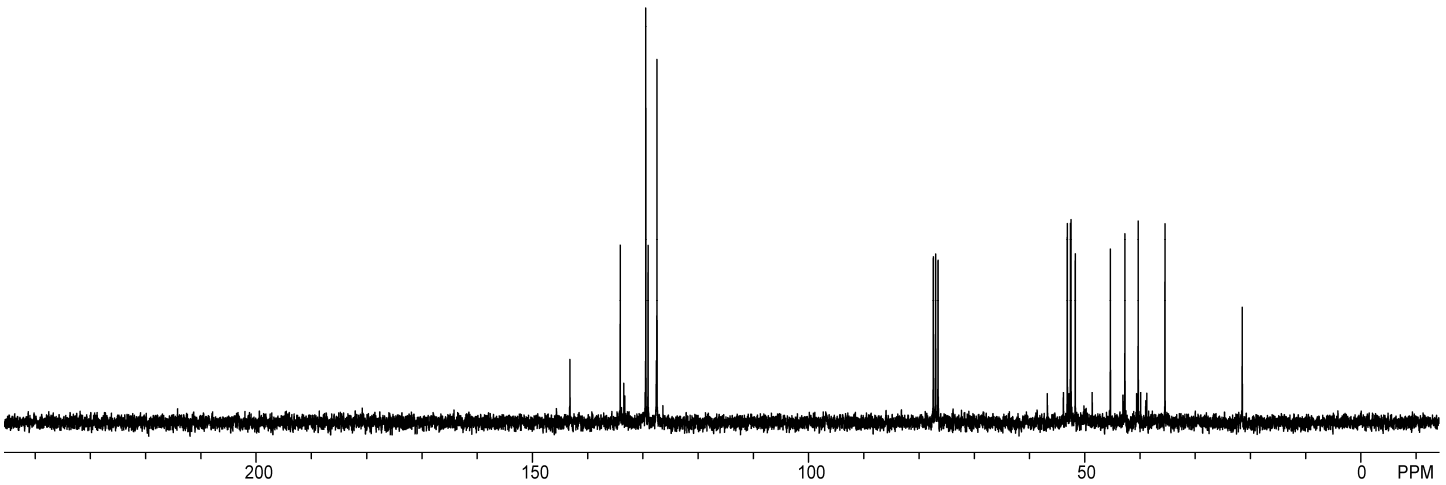

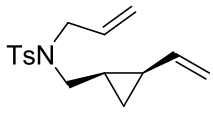

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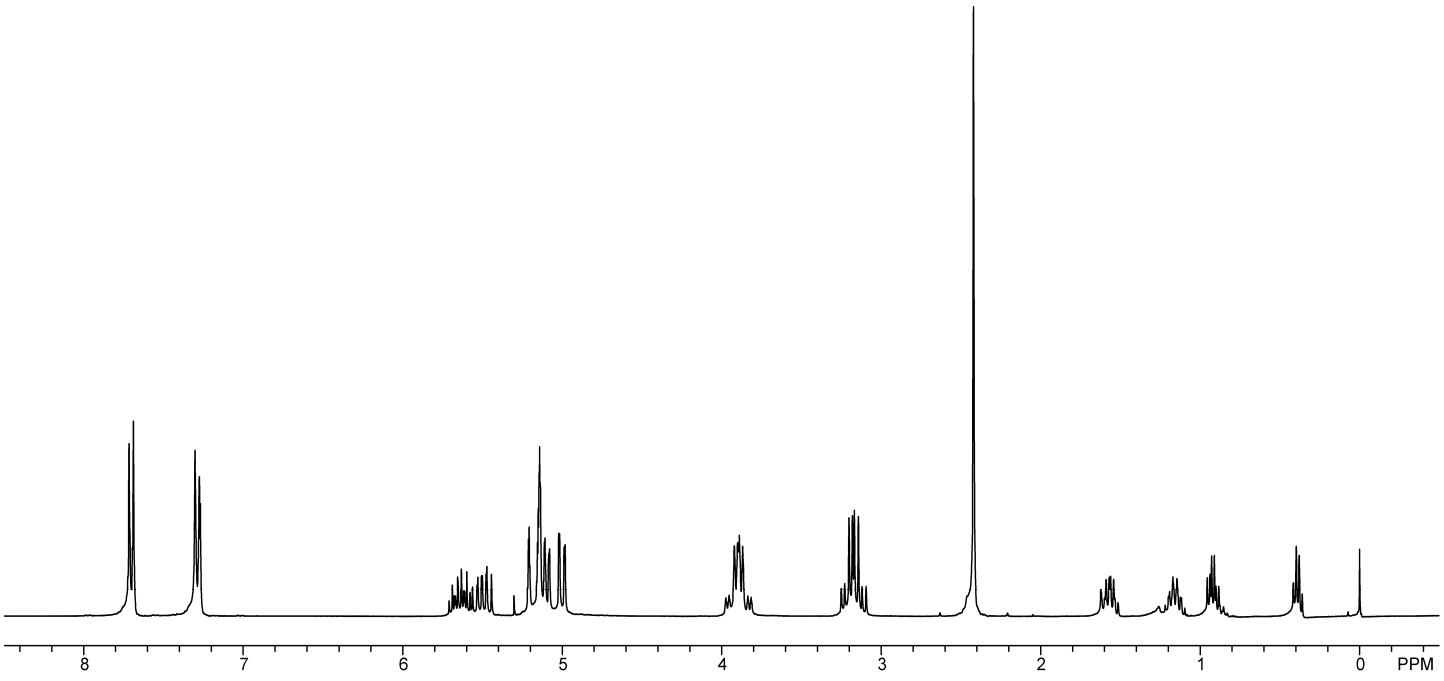

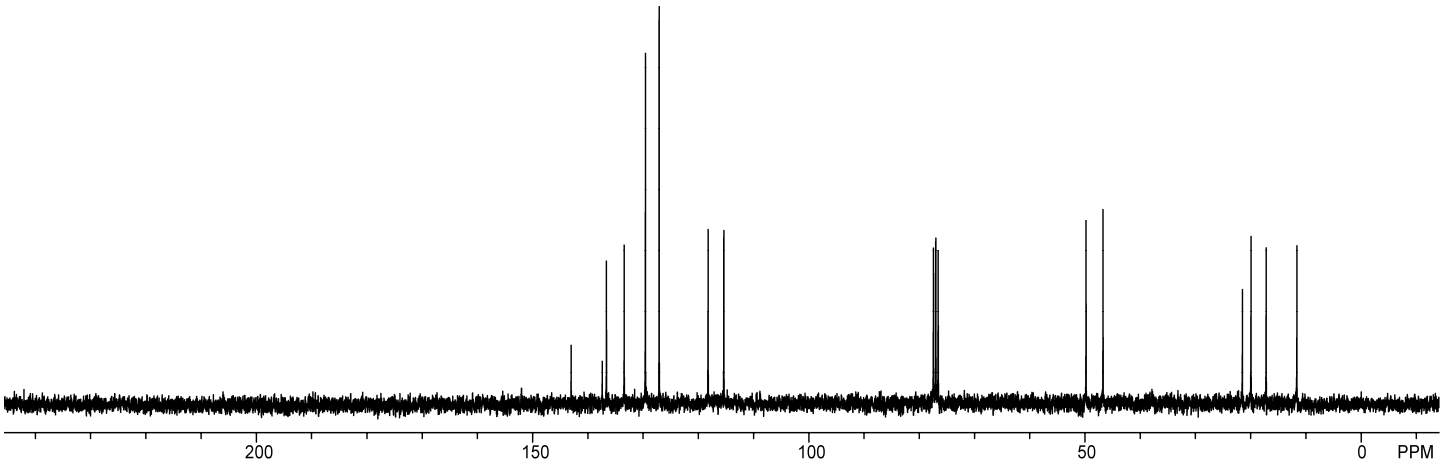

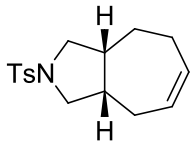

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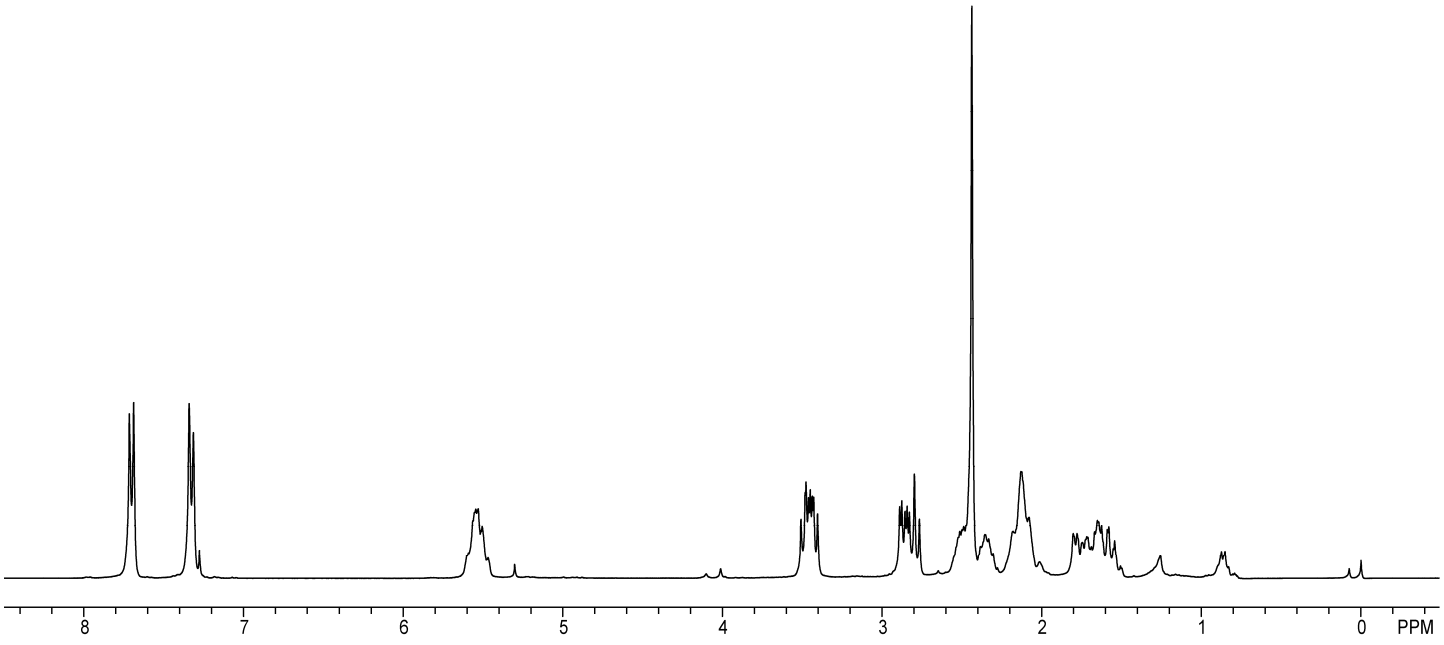

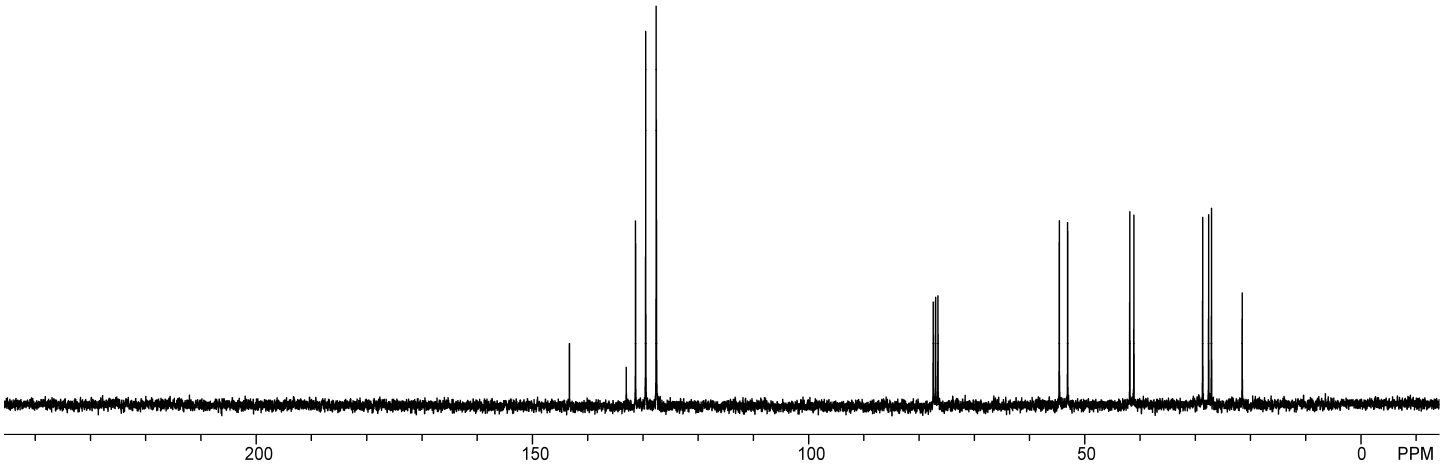

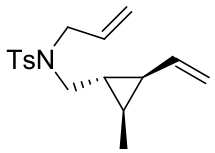

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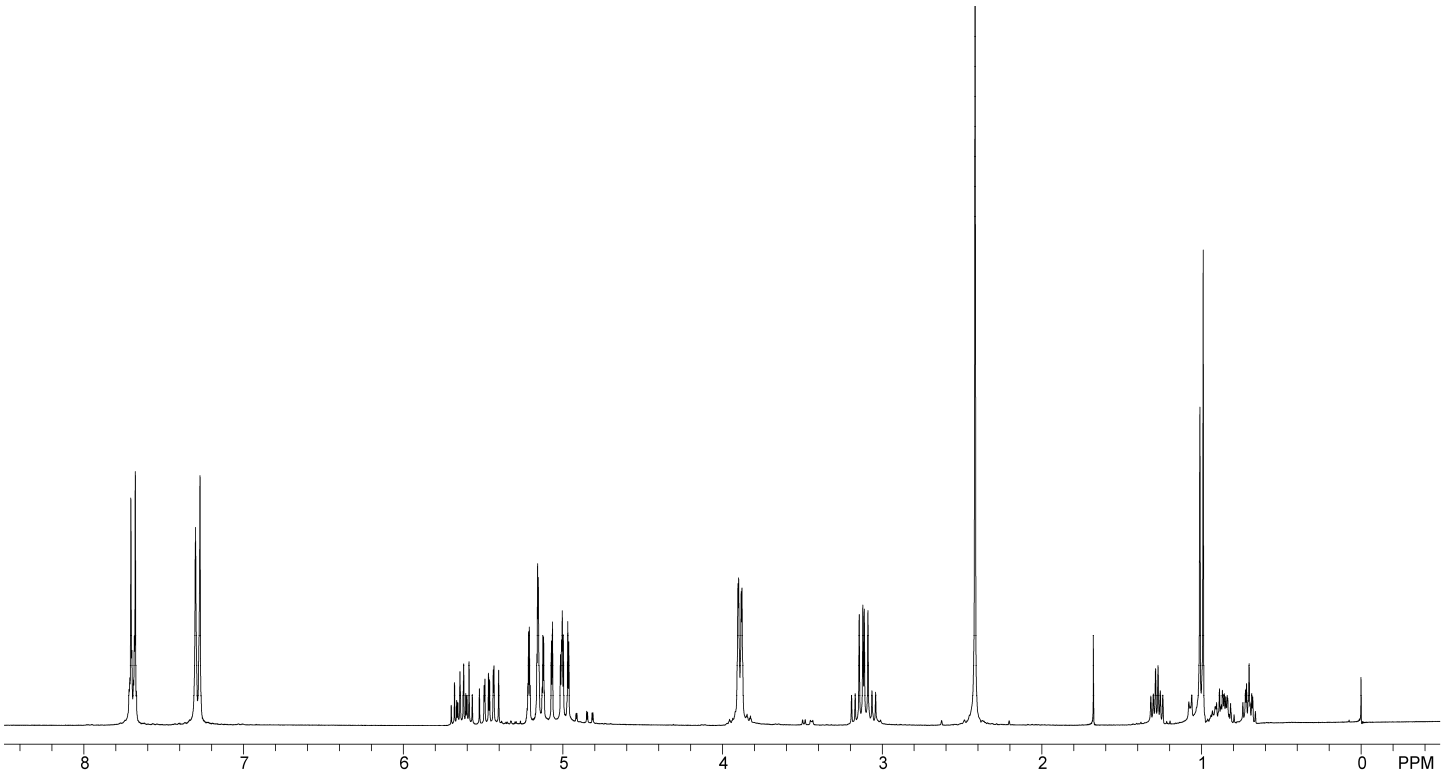

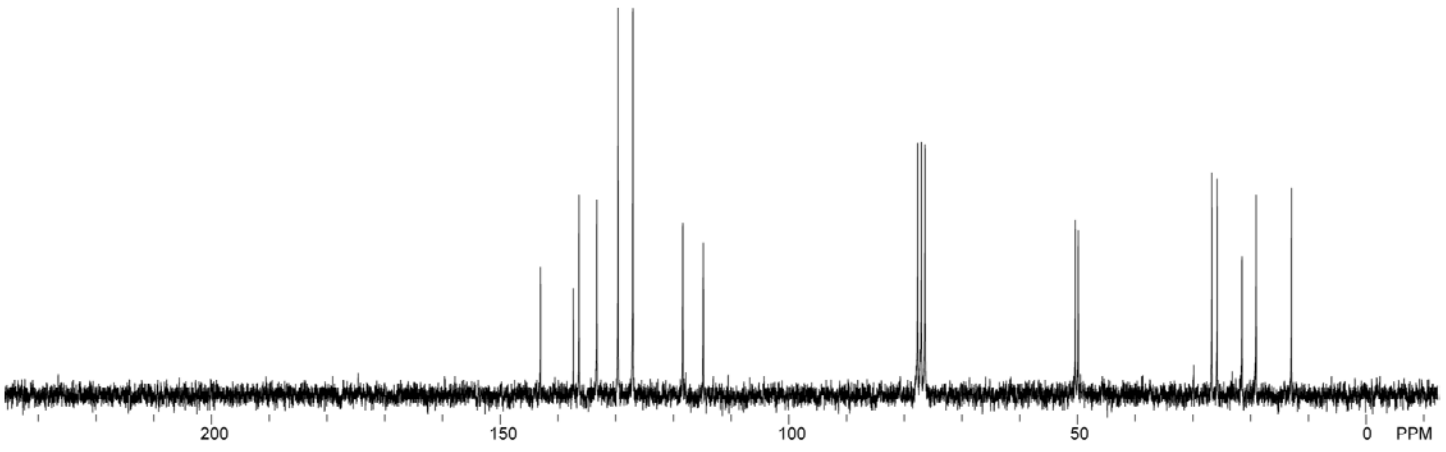

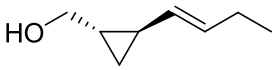

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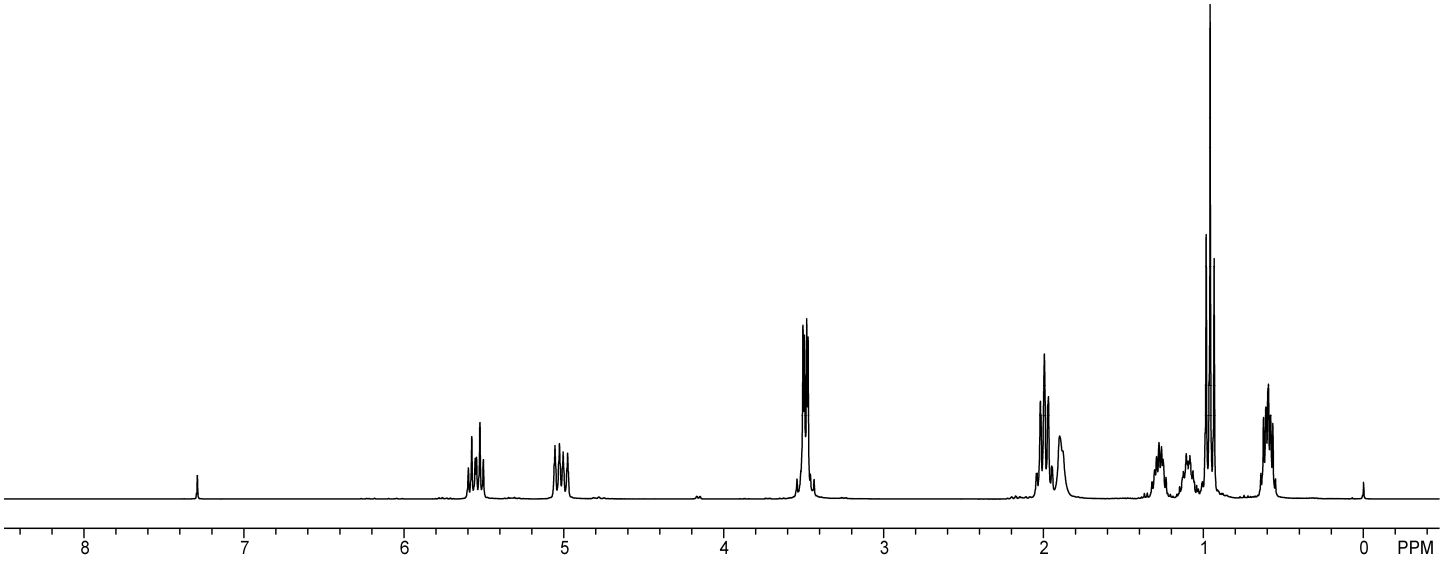

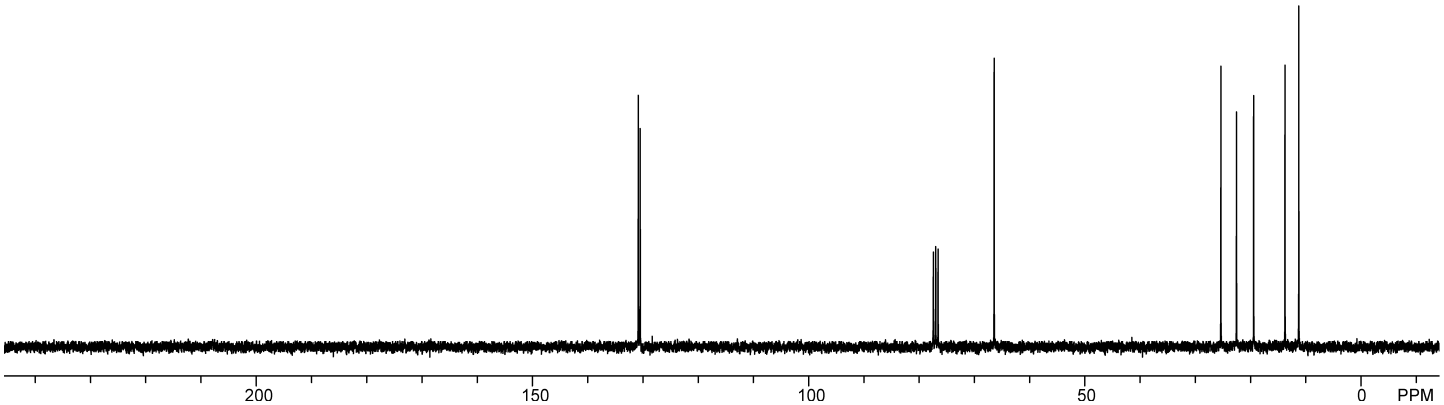

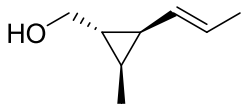

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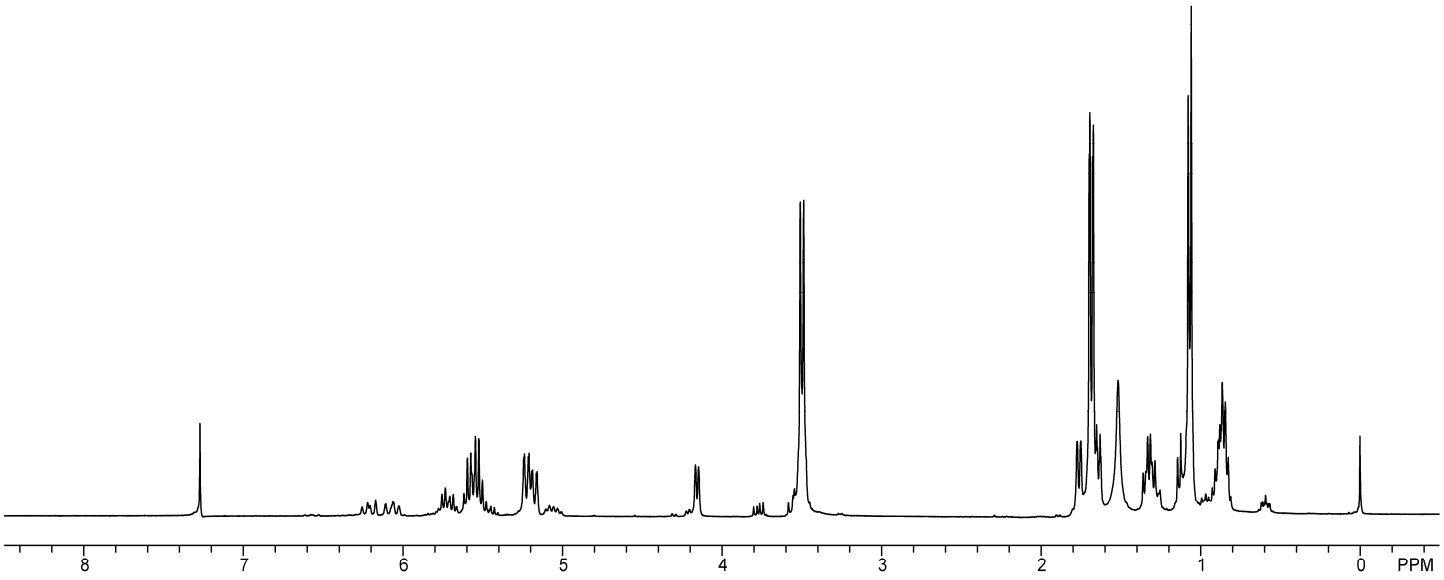

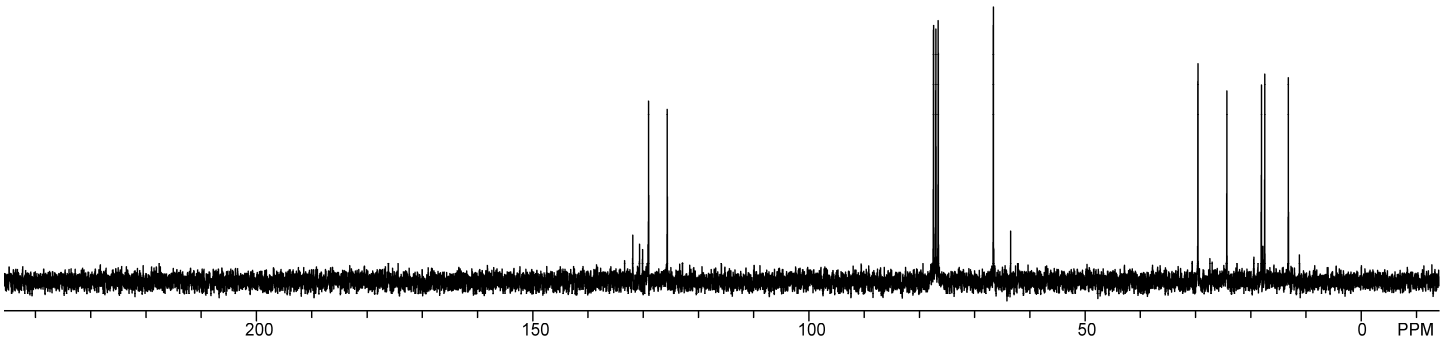

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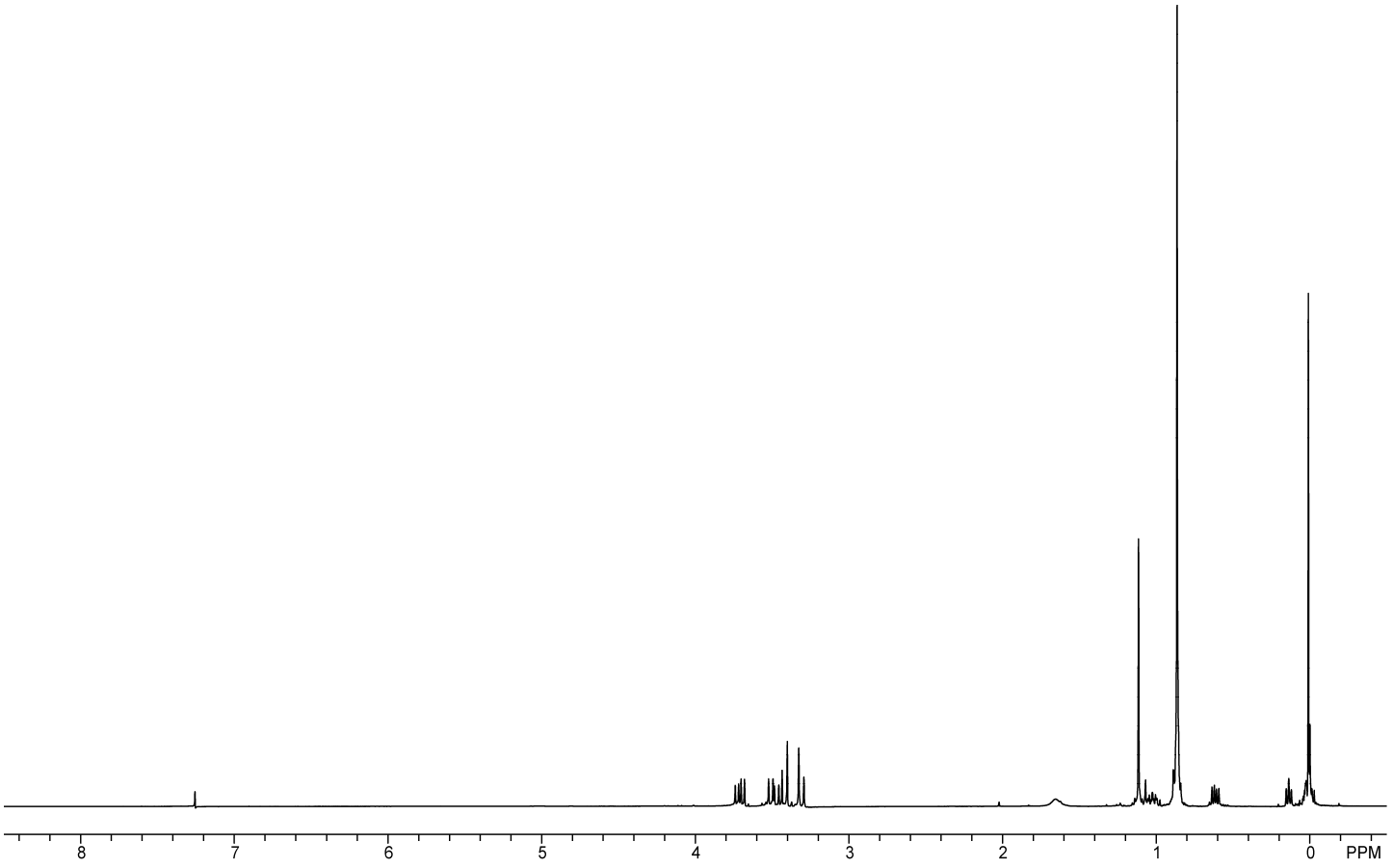

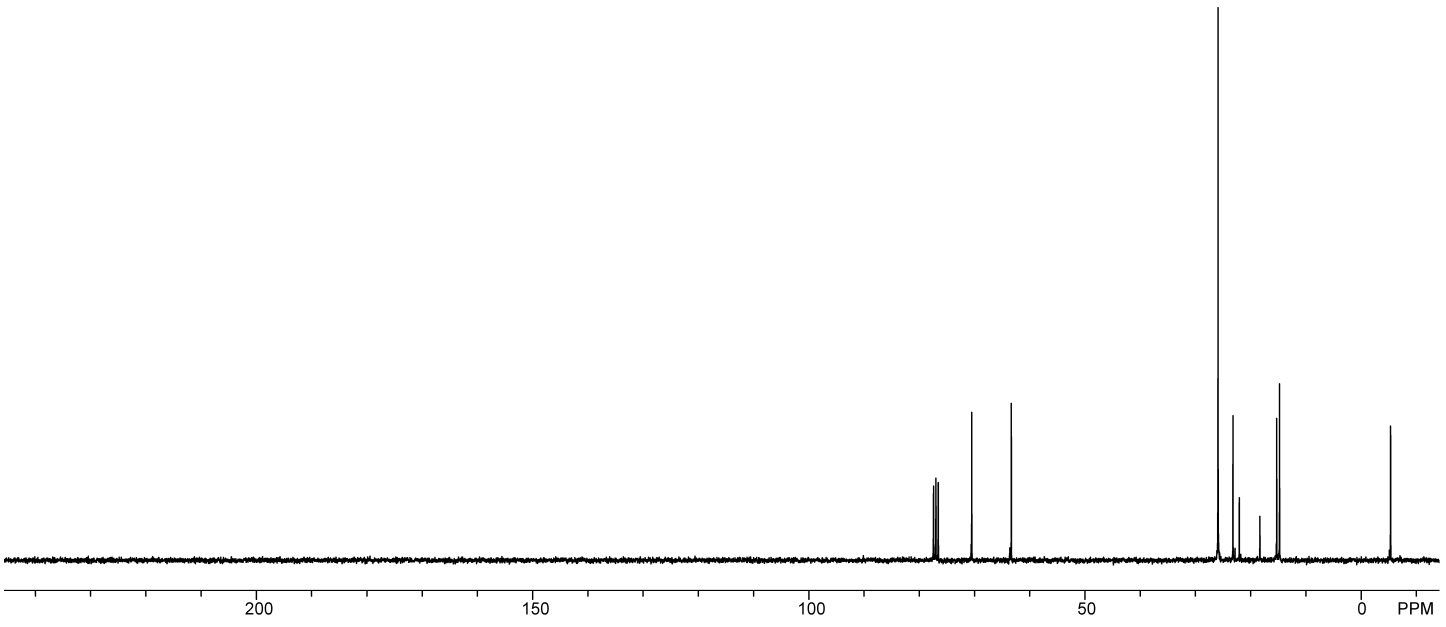

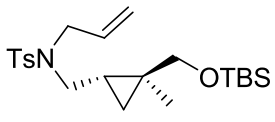

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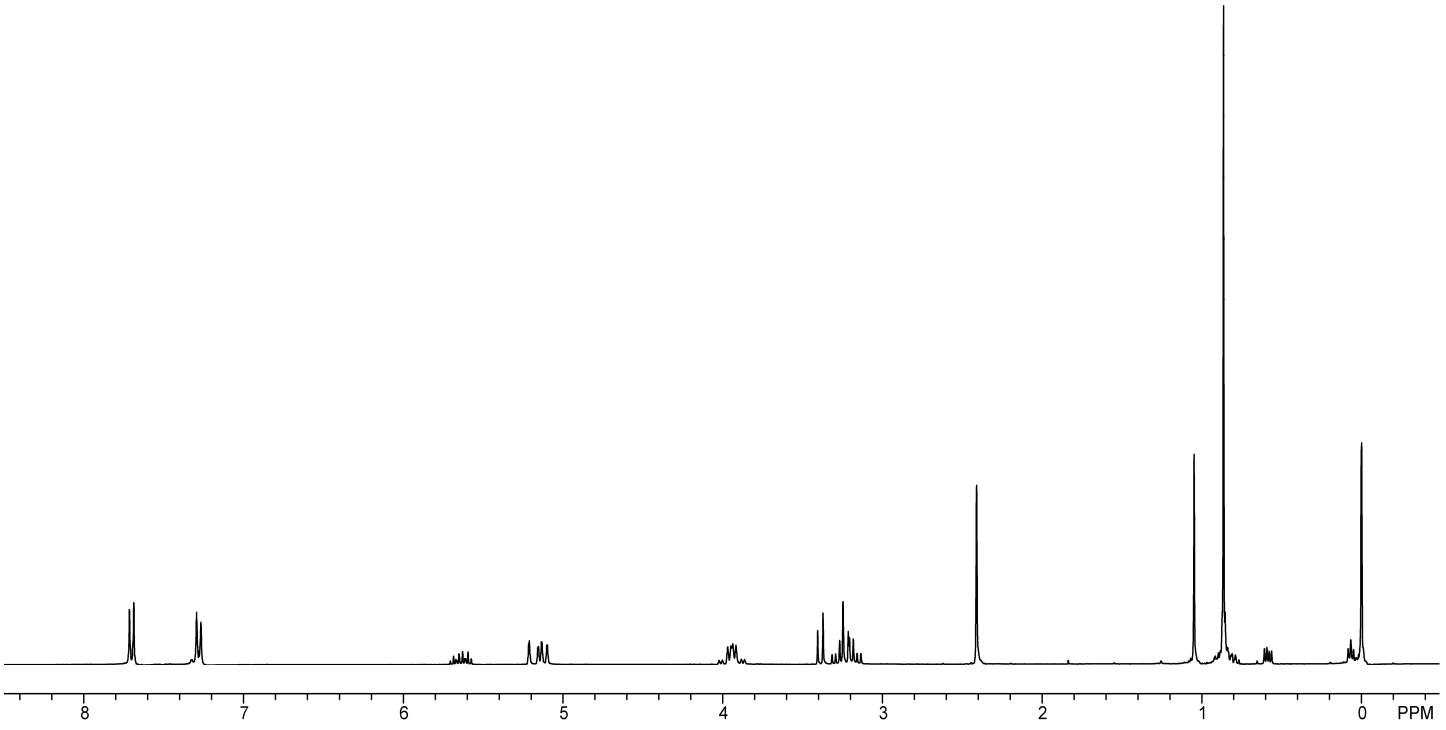

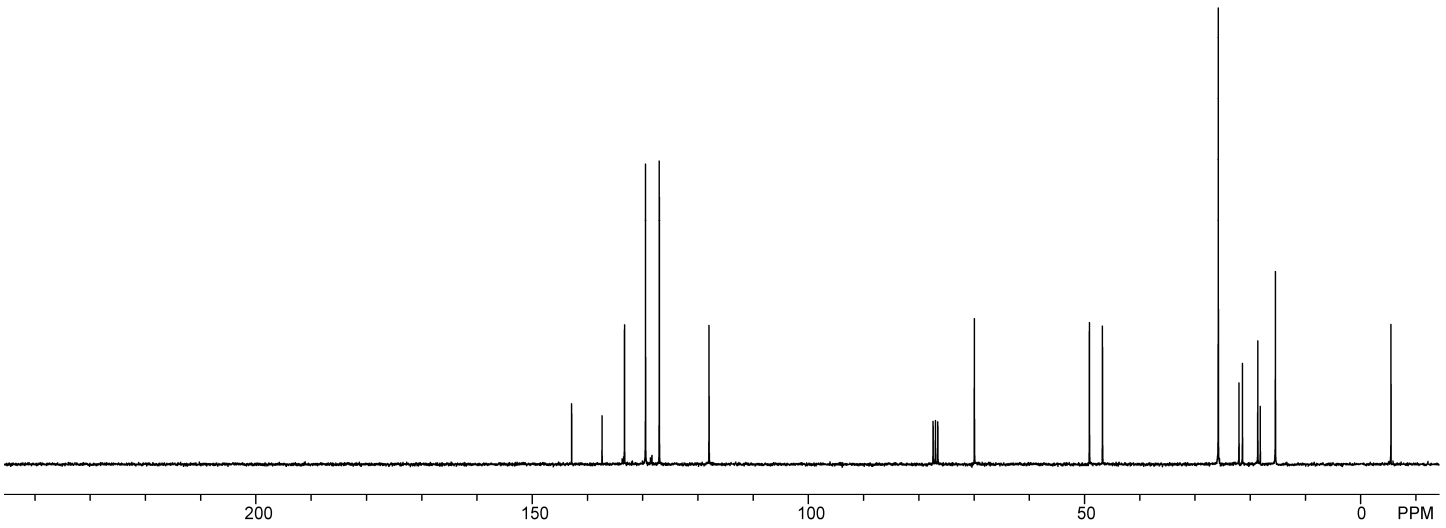

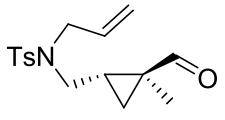

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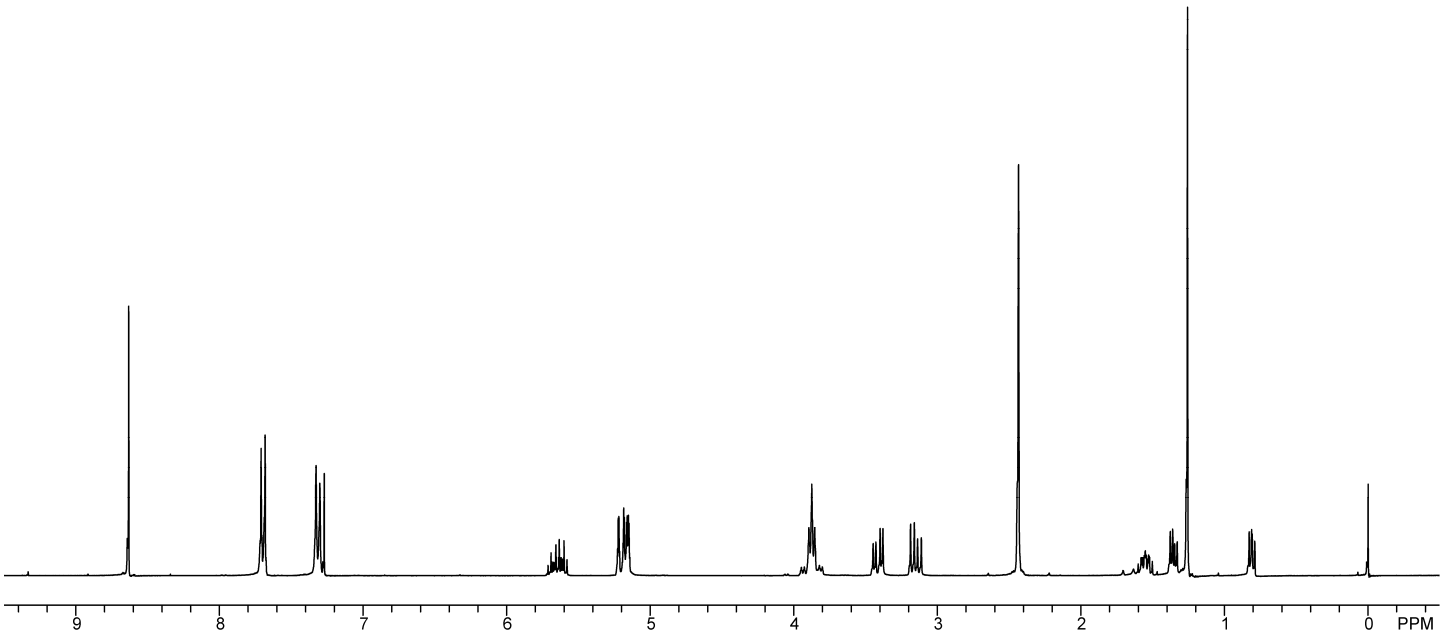

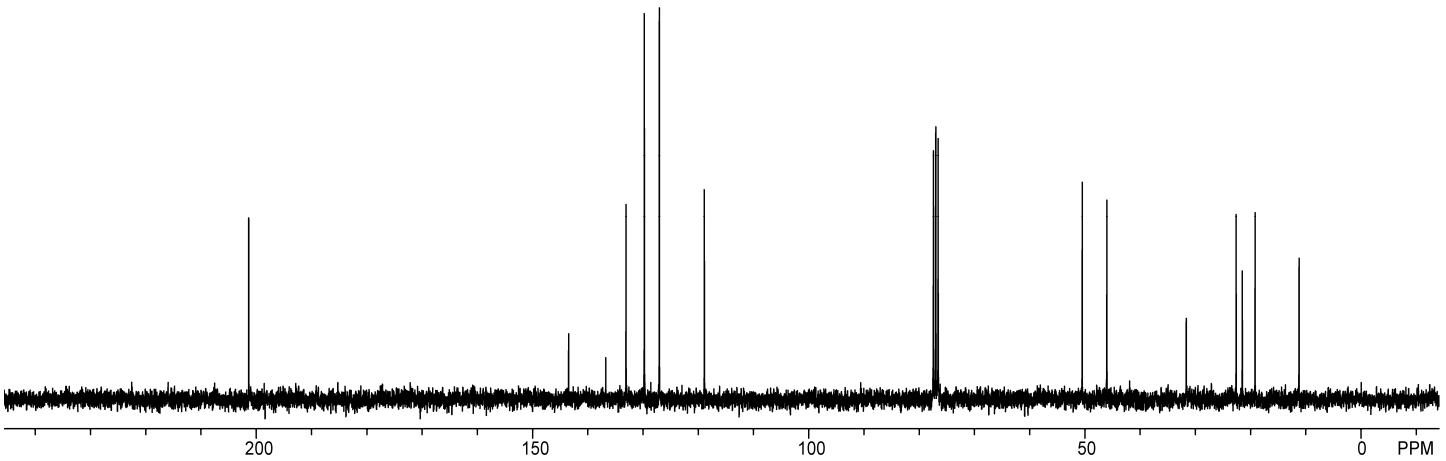

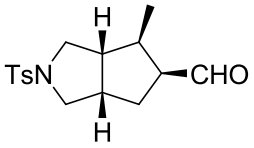

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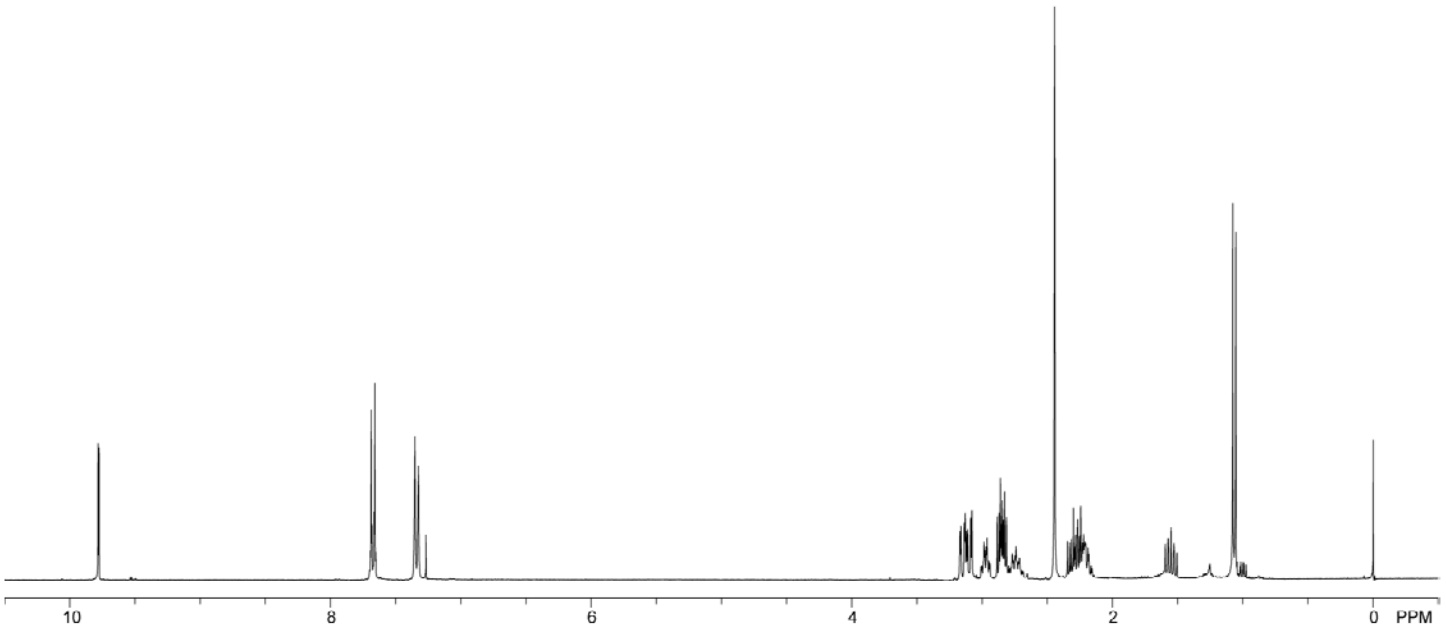

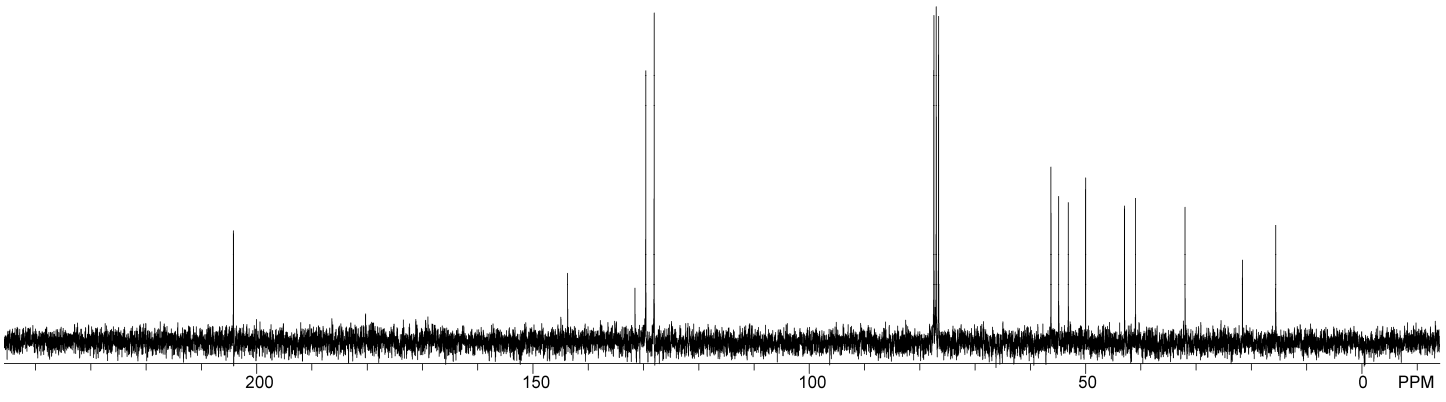

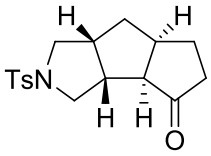

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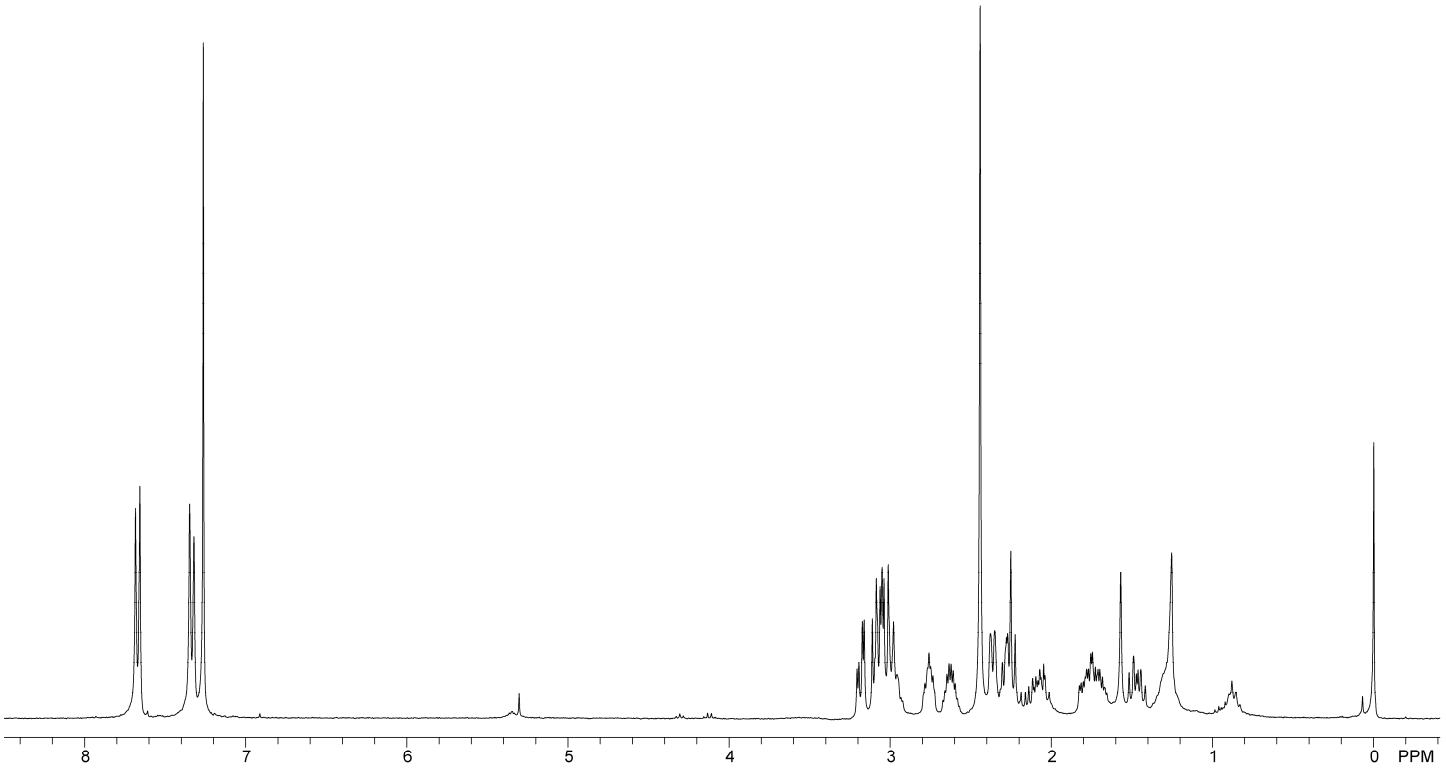

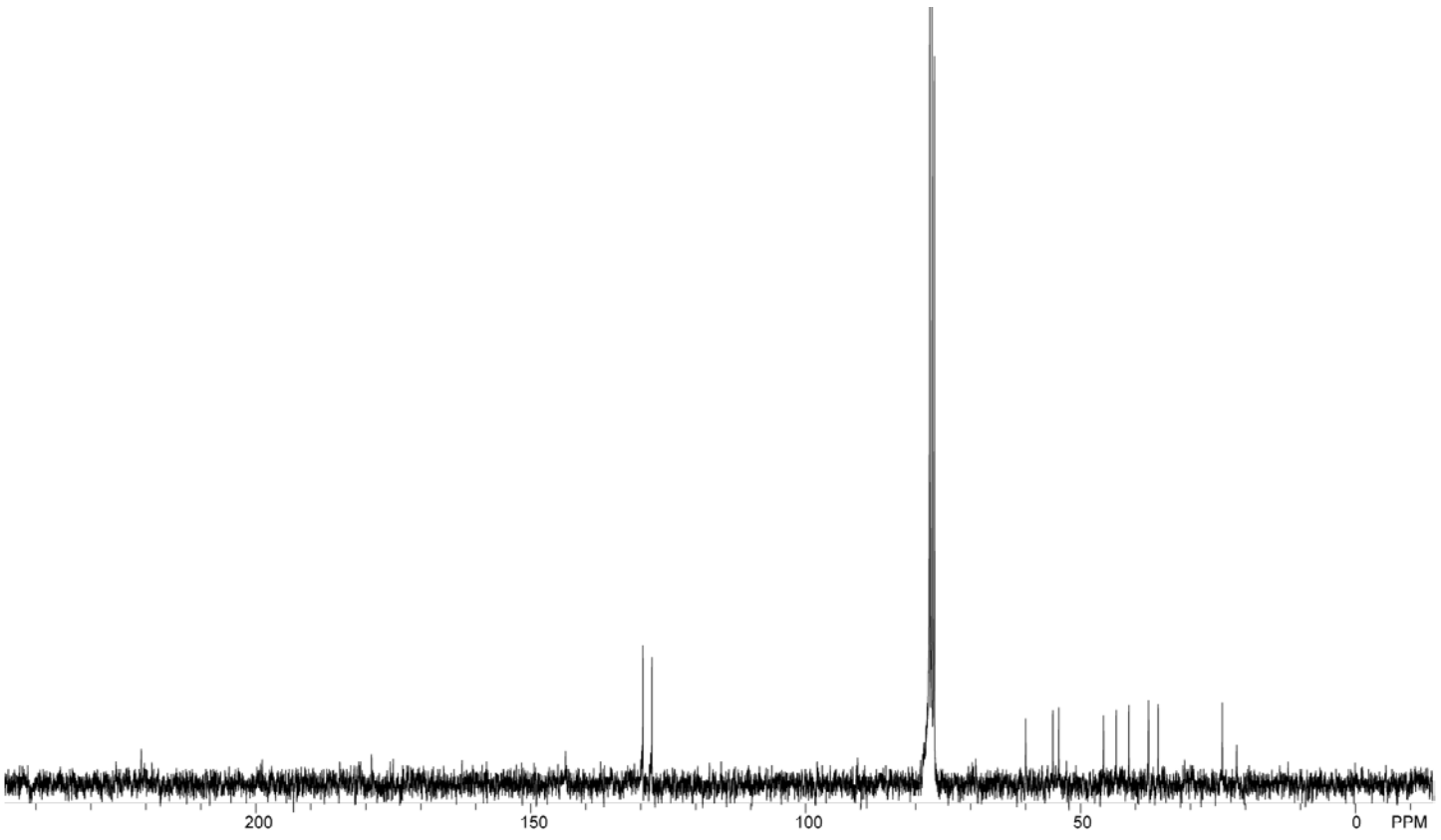

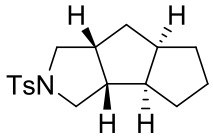

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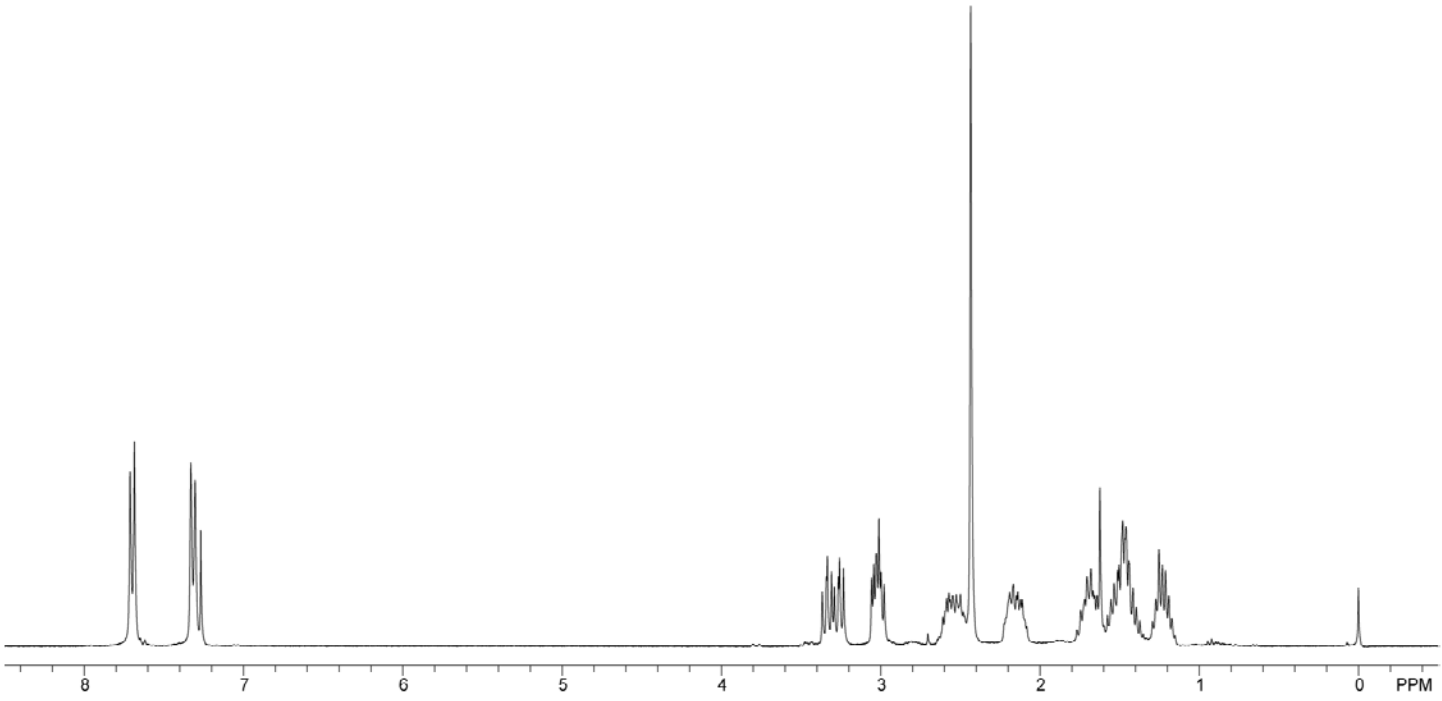

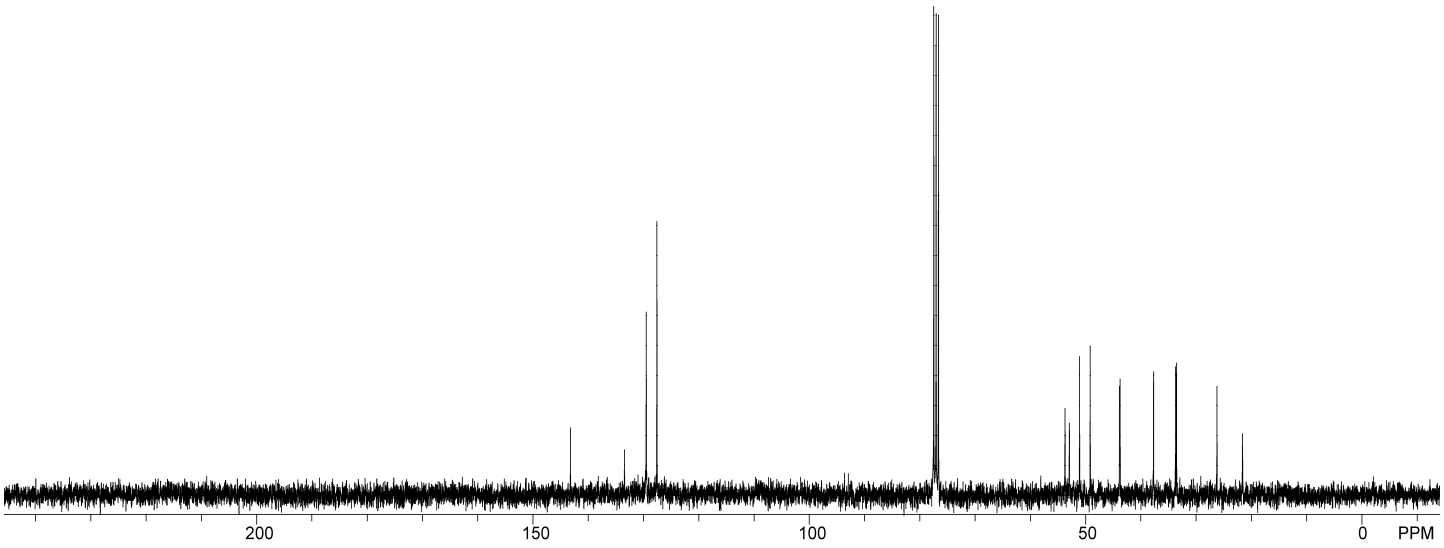

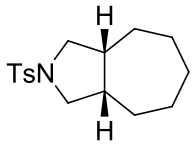

S33