

**The stereochemical outcome of allyl magnesium and indium additions to 5-substituted norbornen-7-ones and its application to *cis* fused carbocycle formation *via* ring rearrangement metathesis**

Patricia E. Standen,<sup>a</sup> Dharati Dodia,<sup>a</sup> Mark R. J. Elsegood,<sup>a</sup> Simon J. Teat<sup>b</sup> and Marc C. Kimber<sup>\*a</sup>

<sup>a</sup>The Department of Chemistry, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK.

<sup>b</sup>ALS, Berkeley Laboratory, 1 Cyclotron Road, CA 94720, USA

\*Corresponding author. Tel.: +44 (0)150-922-2570, Fax: +44 (0)150-922-3925, E-mail: M.C.Kimber@lboro.ac.uk

<b>Synthetic procedures for 18, 19, 20.</b>	<b>S1-S2</b>
<b>Copies of <sup>1</sup>H and <sup>13</sup>C NMR spectra</b>	<b>S3-S19</b>
<b>Crystallographic tables for 25</b>	<b>S20-S23</b>

**7,7-Dimethoxy-2-endo-carboethoxy-1,4,5,6-tetrachlorobicyclohept-5-ene 18.**<sup>1</sup> 5,5-dimethoxy-1,2,3,4-tetrachlorocyclopentadiene **10** (4.54 g, 3.00 mL, 0.017 mol) was added to dry 3-necked round bottomed flask fitted with a condenser. Methyl acrylate (2.94 g, 3.00 mL, 0.034 mol) was added and the reaction heated to 75°C for 48 hours under nitrogen. The crude product was then distilled at 200°C at 2 mbar to give the titled compound as a clear oil (4.94 g, 85%);  $\nu_{\max}$  3155, 2953, 2254, 1737  $\text{cm}^{-1}$ ; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  3.70 (s, 3H) 3.60 (s, 3H) 3.54 (s, 3H) 3.42 (dd,  $J = 4.2, 9.2$  Hz, 1H) 2.49 (dd,  $J = 9.2, 11.8$  Hz, 1H), 2.25 (dd,  $J = 4.2, 11.8$  Hz, 1H); <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  170.3, 130.6, 128.0, 111.9, 76.9, 74.1, 52.8, 52.5, 21.8, 50.4, 38.9; IR (CH<sub>2</sub>Cl<sub>2</sub>) MS-ESI found 372.9345 C<sub>11</sub>H<sub>12</sub>Cl<sub>4</sub>O<sub>4</sub>, [M+Na]<sup>+</sup> requires 372.9352.

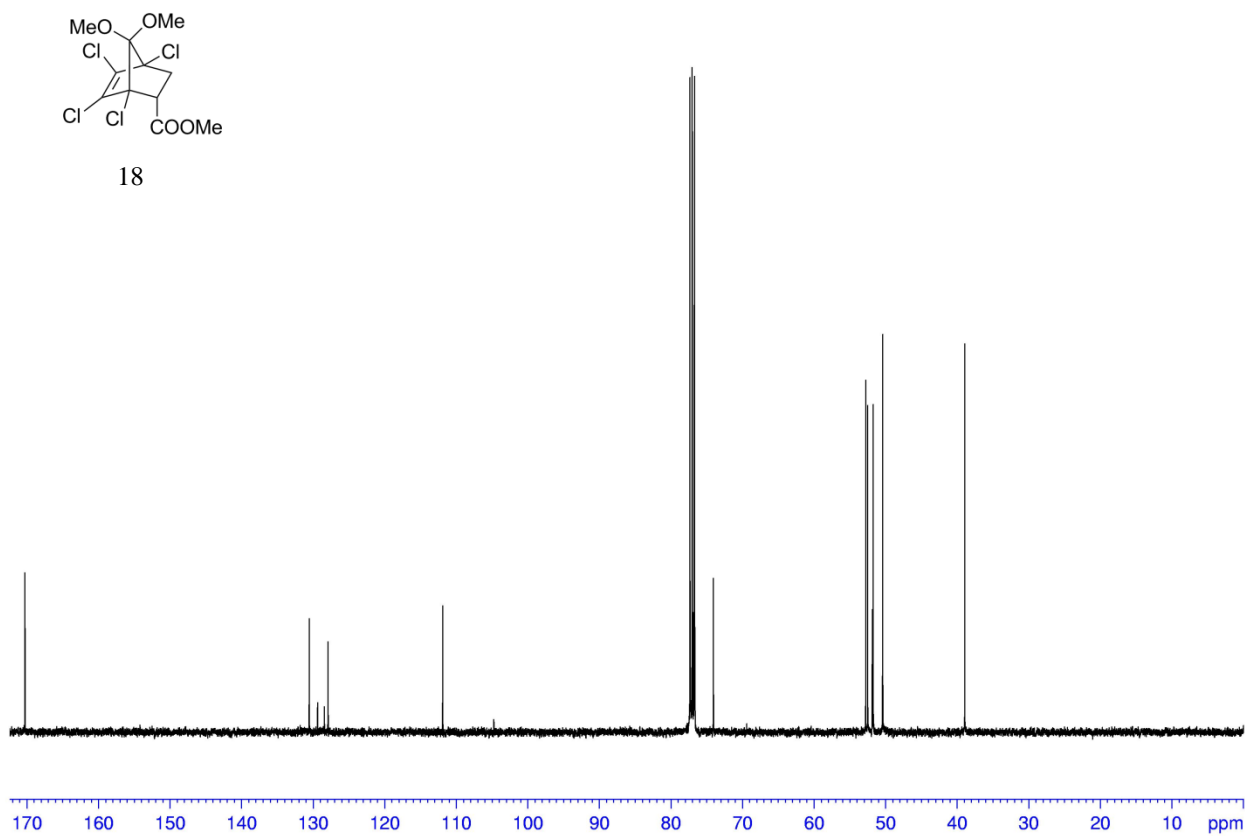
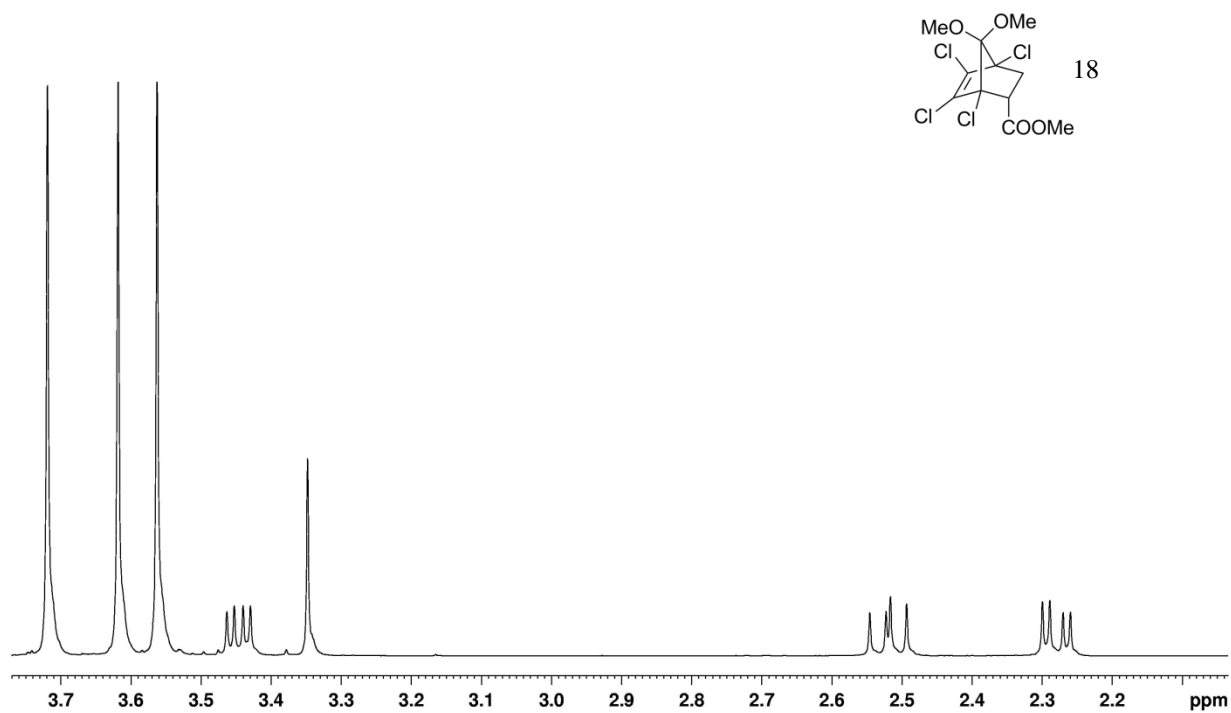
**7,7-Dimethoxy-1,4,5,6-tetrachlorobicyclohept-5-ene-2-endo-carboxylic acid 19.**<sup>1</sup> KOH (1.23 g, 23 mmol) was dissolved in EtOH/H<sub>2</sub>O (50 mL, 1:1) and added to a dry round bottomed flask. 7,7-Dimethoxy-2-endo-carboethoxy-1,4,5,6-tetrachlorobicyclohept-5-ene (1.50 g, 44 mmol) was then added, once dissolved the reaction was heated to reflux for 45 min under nitrogen. The volume was then partially reduced under vacuum. A saturated oxalic acid solution was then added and the aqueous layer extracted with ethyl acetate and the organic layers then dried over magnesium sulphate. The excess volatiles were removed under reduced pressure furnishing the title compound as a colourless solid (1.37 g, 95%); m.p. 161-163 °C; IR (CH<sub>2</sub>Cl<sub>2</sub>)  $\nu_{\max}$  3500, 2900, 1713, 1423  $\text{cm}^{-1}$ ; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  3.62 (s, 3H) 3.57 (s, 3H), 3.48 (dd,  $J = 4.4, 9.6$  Hz, 1H) 2.54 (dd,  $J = 9.6, 11.0$  Hz, 1H), 2.25 (dd,  $J = 4.4, 11.6$  Hz, 1H); <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  175.6, 130.7, 127.9, 112.0, 77.2, 74.0, 52.9, 51.9, 50.4, 38.9; MS-ESI found 358.9193 C<sub>10</sub>H<sub>14</sub>Cl<sub>4</sub>O<sub>4</sub>, [M+Na]<sup>+</sup> requires 358.9196.

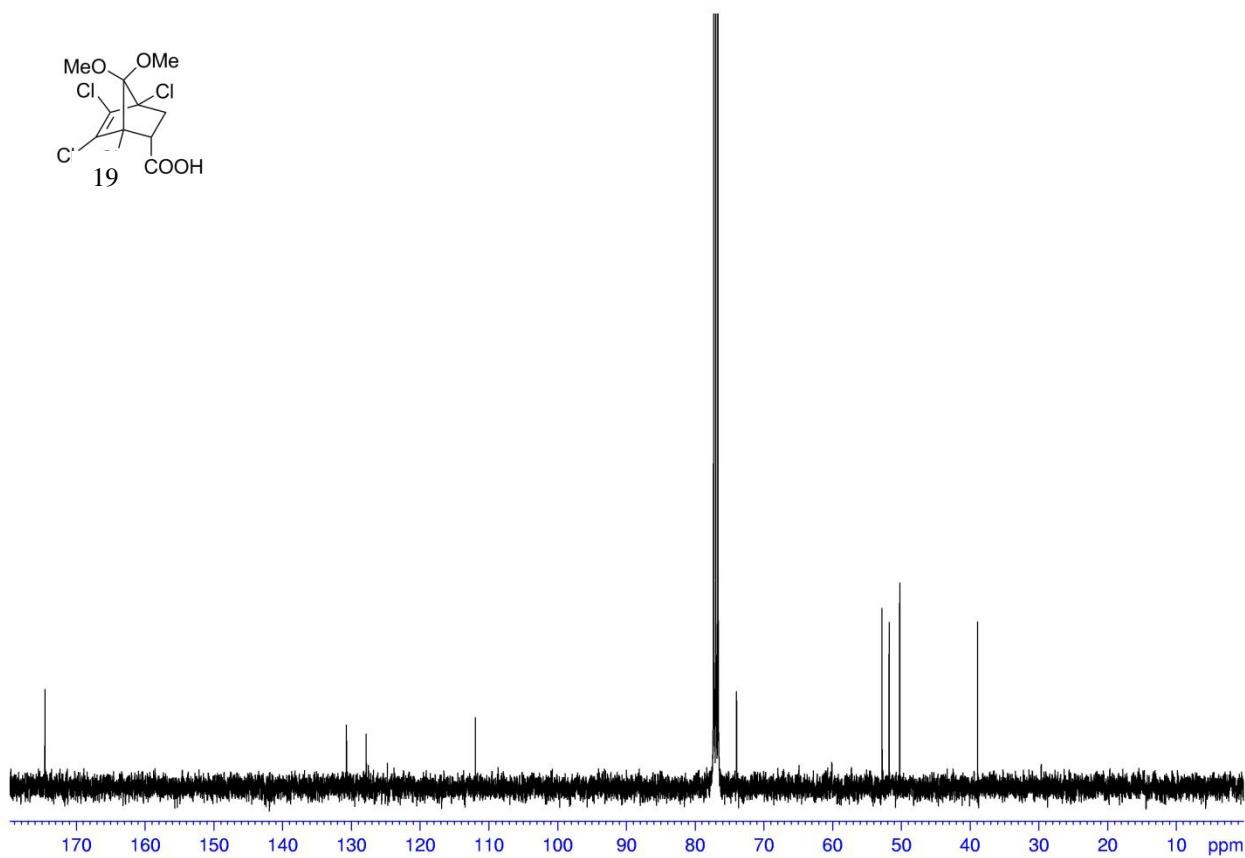
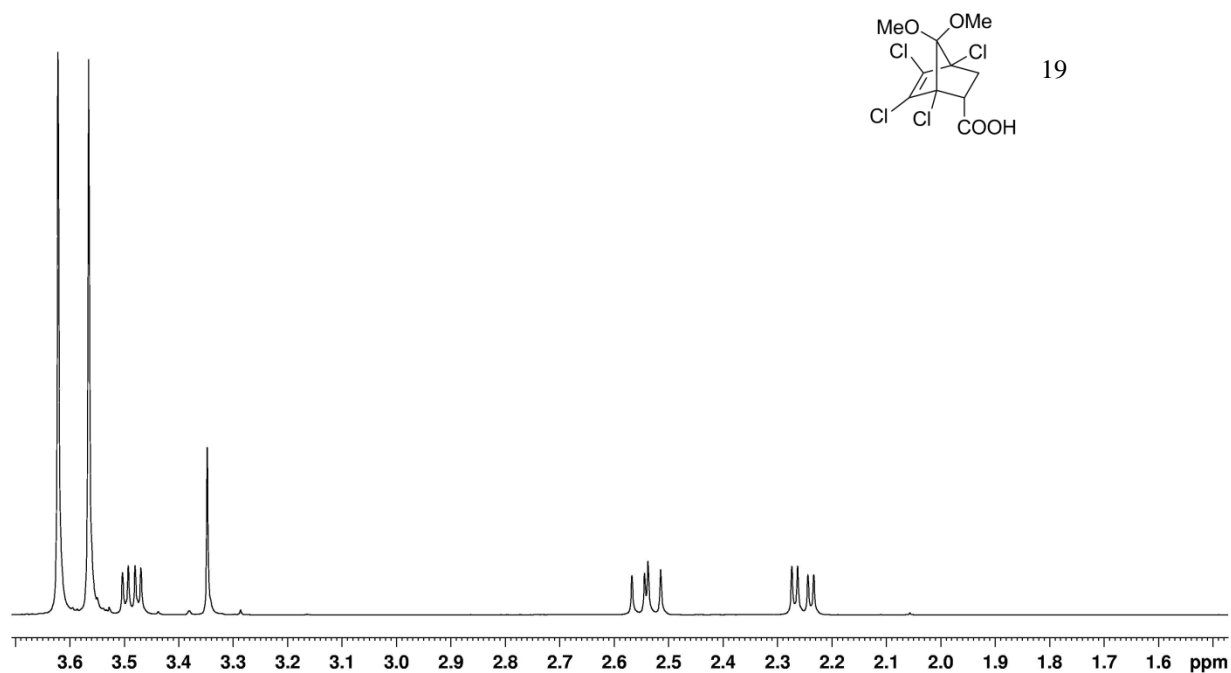
**7,7-Dimethoxyhept-5-ene-2-endo-carboxylic acid 20.** A 3-necked round bottomed flask was fitted with a dropping funnel, nitrogen inlet and cold trap. Sodium (4.00 g, 170 mmol) was chopped into 1mm by 1mm cubes and added to the flask and dissolved in aqueous liquid ammonia (75-100 mL). 7,7-Dimethoxy-1,4,5,6-tetrachlorobicyclohept-5-ene-2-endo-carboxylic acid (3.00 g, 8.70 mmol) was then dissolved in EtOH/Et<sub>2</sub>O (50 mL 1:1) and added drop wise for 30 min. The reaction was then quenched using NH<sub>4</sub>Cl and then left to warm to room temperature while the ammonia evaporated off. The resulting liquid was then added to ice water and acidified using 2M HCL. Aqueous work up was then afforded and organic layers dried over magnesium sulphate. Excess volatiles were removed under reduced pressure. This furnished the title compound as colourless solid (1.48 g, 82%); m.p. 75-78 °C; IR (CH<sub>2</sub>Cl<sub>2</sub>)  $\nu_{\max}$  3050, 2955, 2253, 1705 cm<sup>-1</sup>; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  6.25 (dd, *J* = 3.4, 6.2 Hz, 1H), 6.05 (dd, *J* = 2.3, 6.0 Hz, 1H), 3.22 (s, 3H), 3.12 (s, 3H), 2.88 (t, *J* = 3.7 Hz, 1H), 2.14 – 2.08 (m, 1H), 1.41 (dd, *J* = 3.6, 12.0 Hz, 1H); <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  179.8, 135.7, 130.6, 118.7, 52.1, 49.8, 47.5, 44.8, 41.2, 27.3; MS-ESI found 221.0782, C<sub>10</sub>H<sub>14</sub>O<sub>4</sub> [M+Na]<sup>+</sup> requires 221.0784.

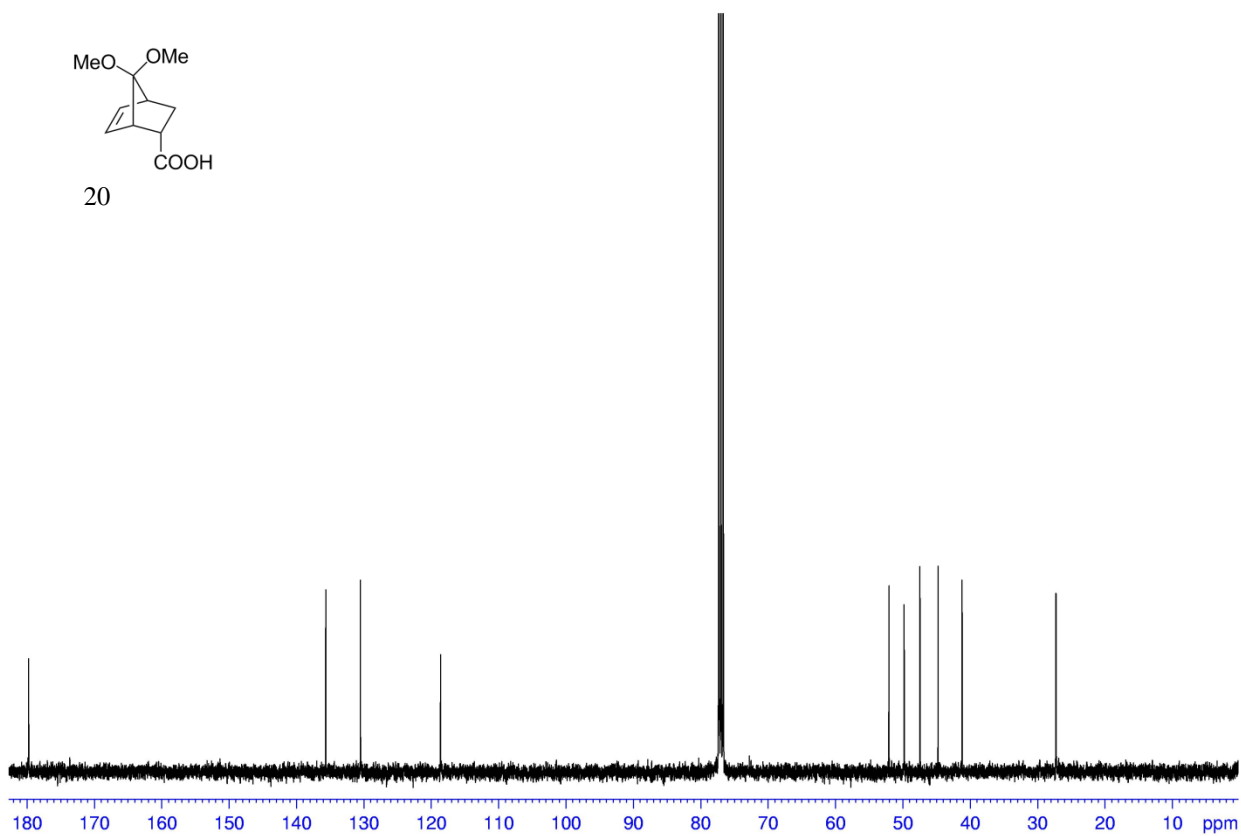
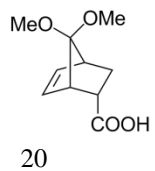
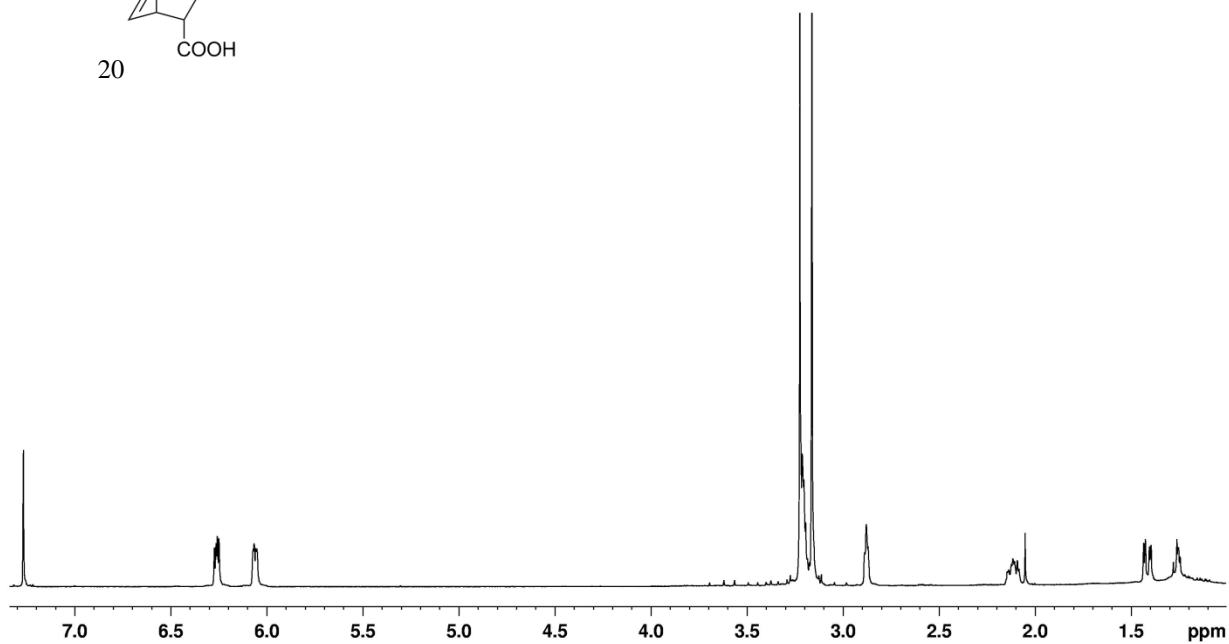
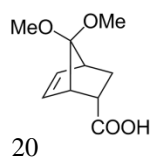
## References

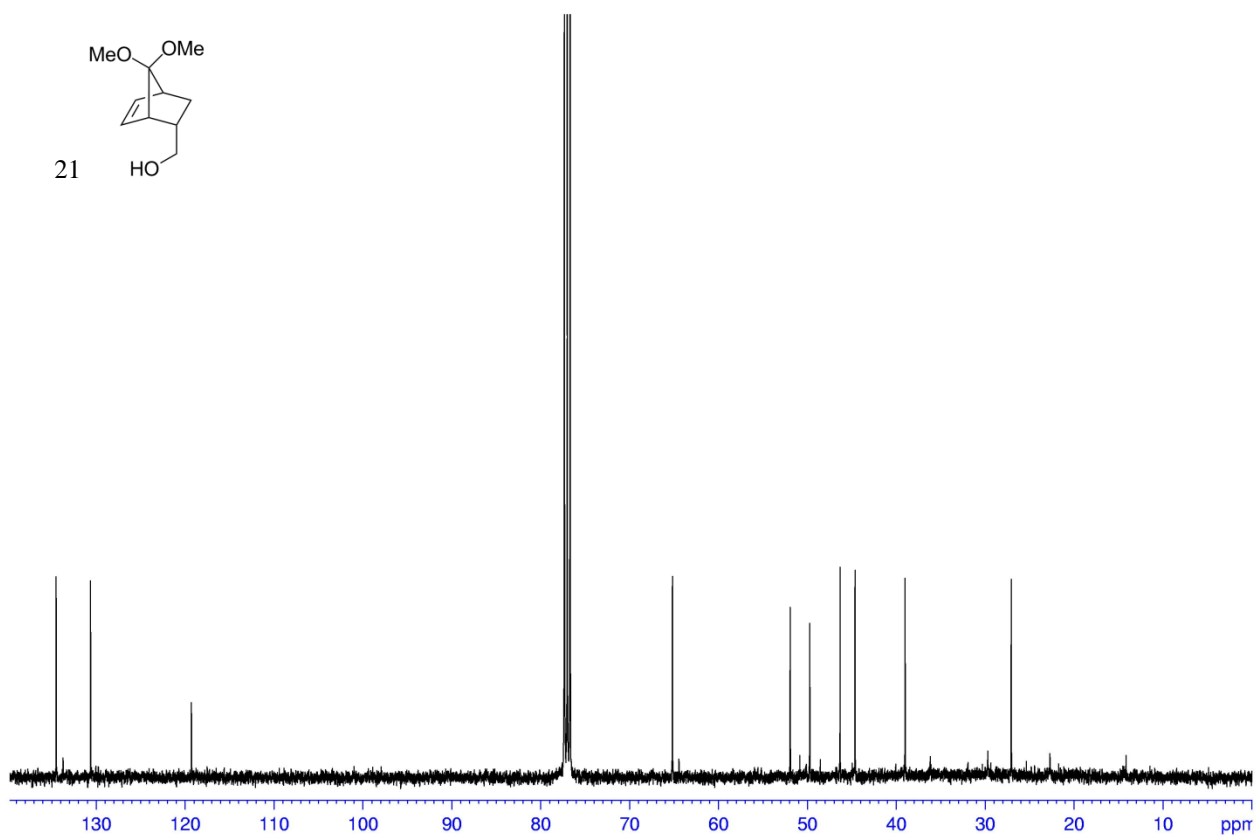
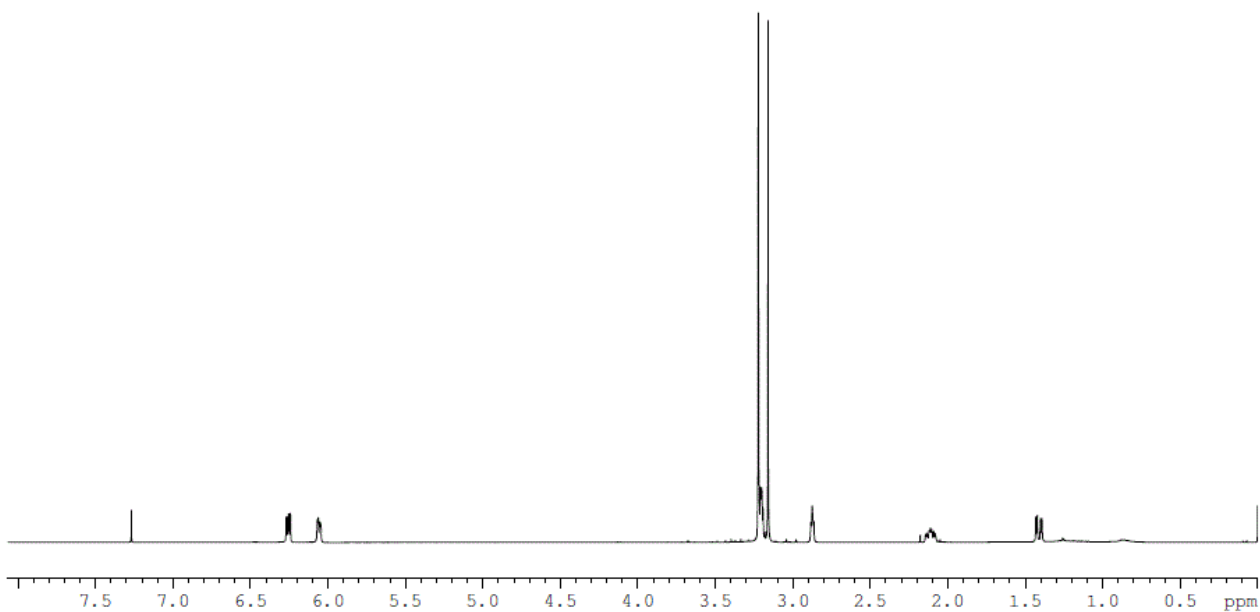
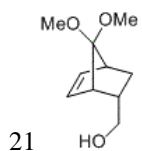
- (1) Thompson, H. W.; Wong, J. K.; Lalancette, R. A.; Boyko, J. A.; Robertiello, A. M. *J. Org. Chem.*, 1985, **50**, 2115.

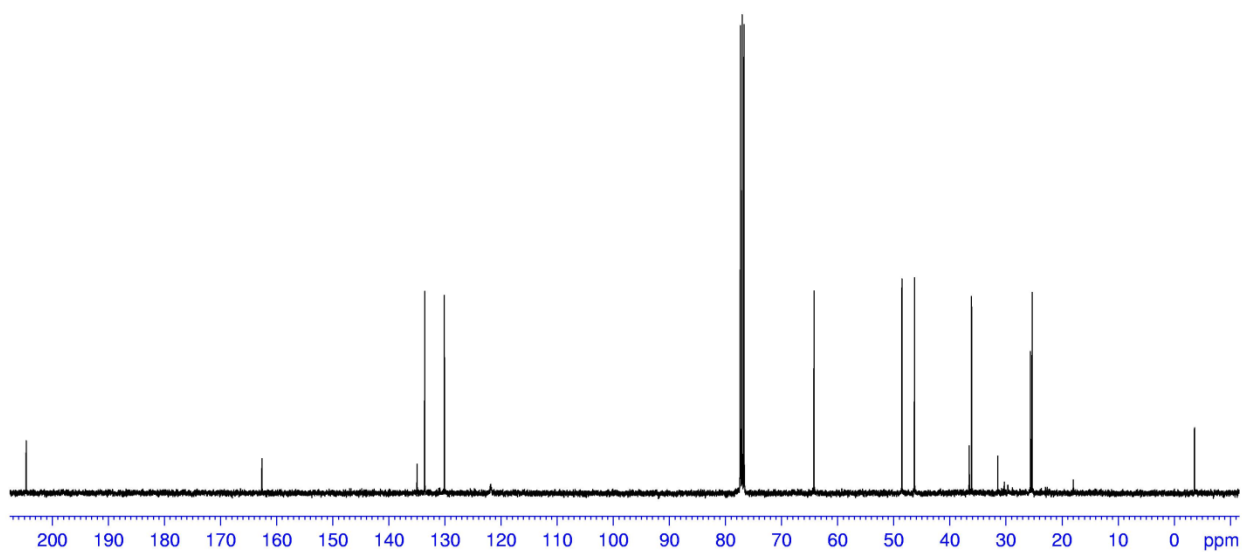
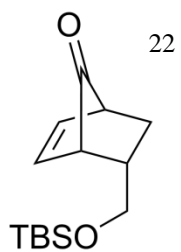
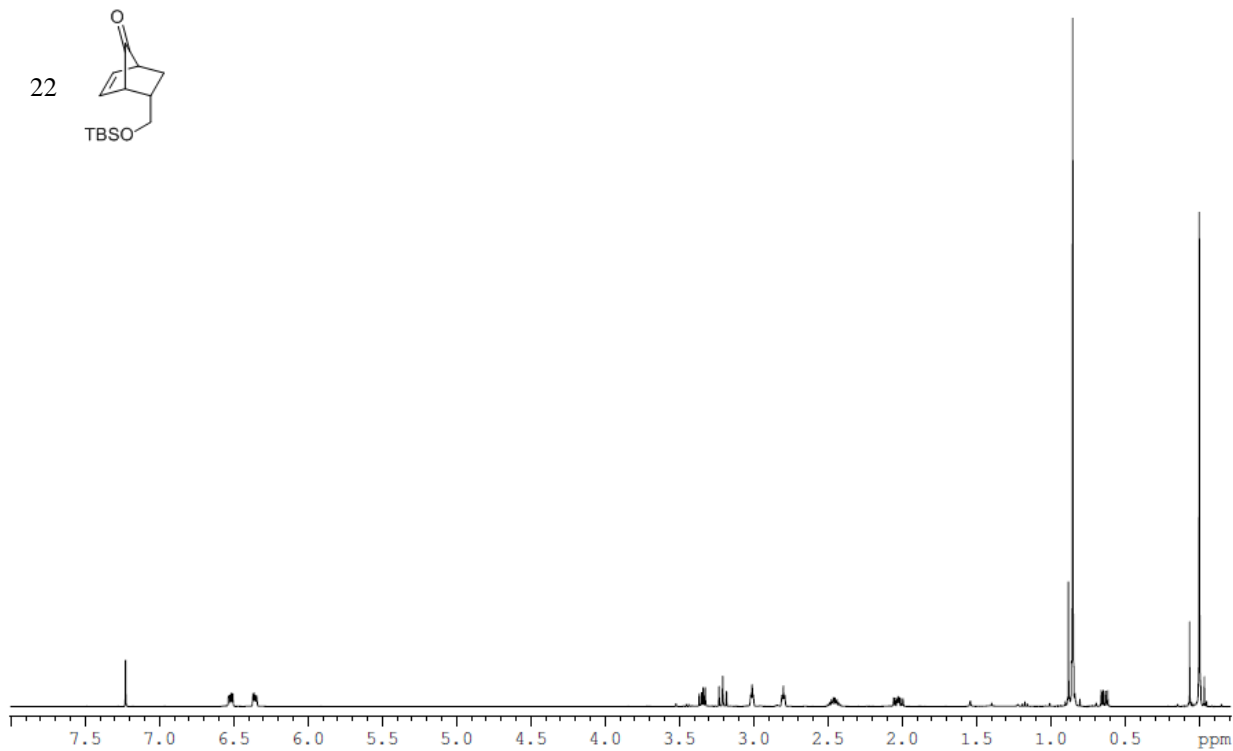
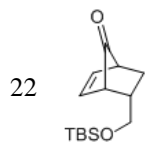
S3

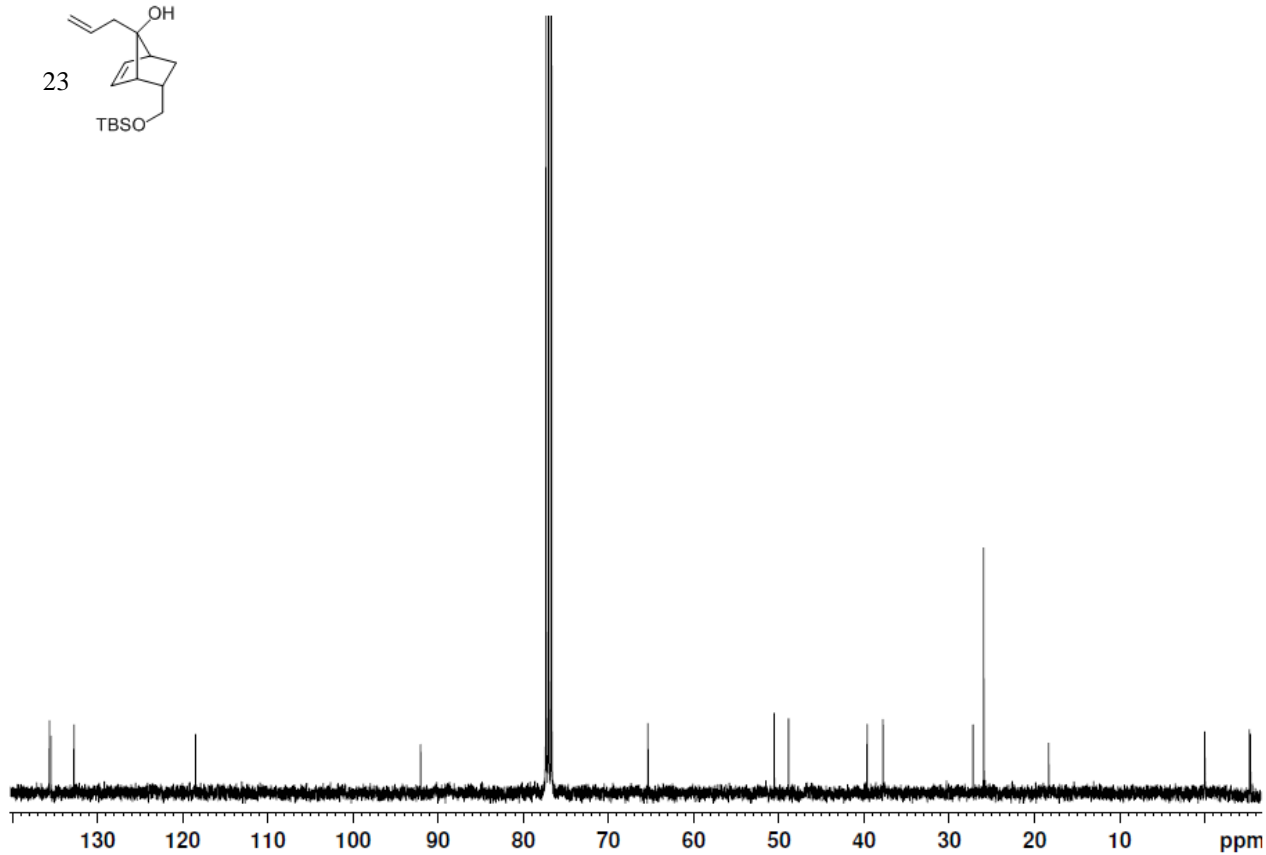
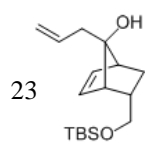
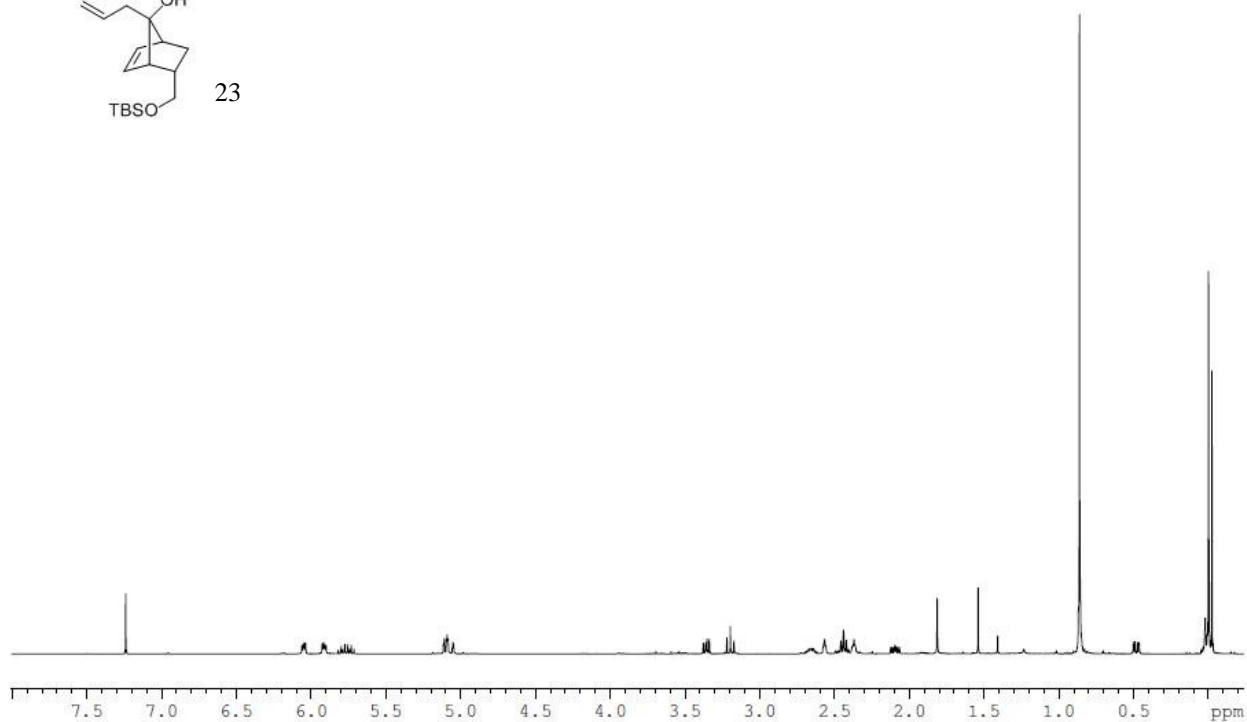
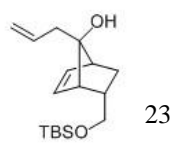






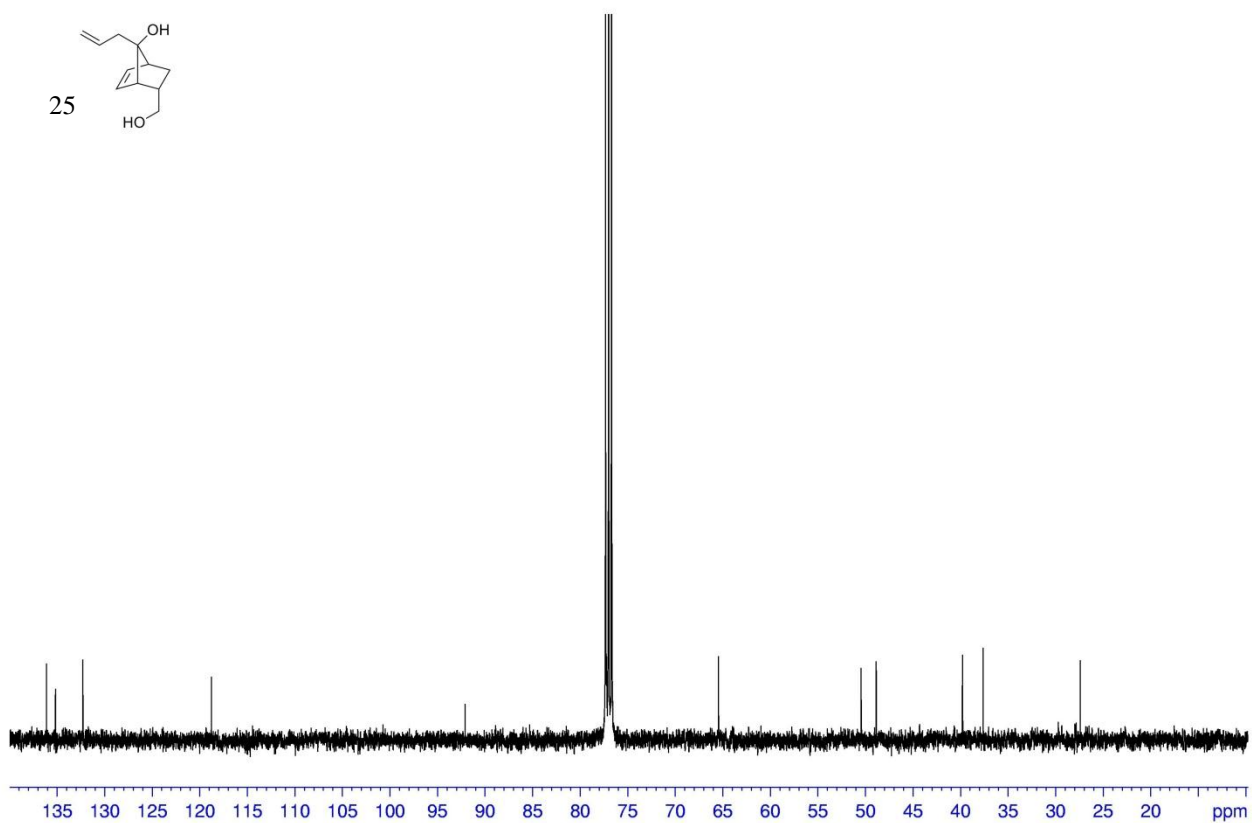
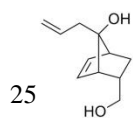
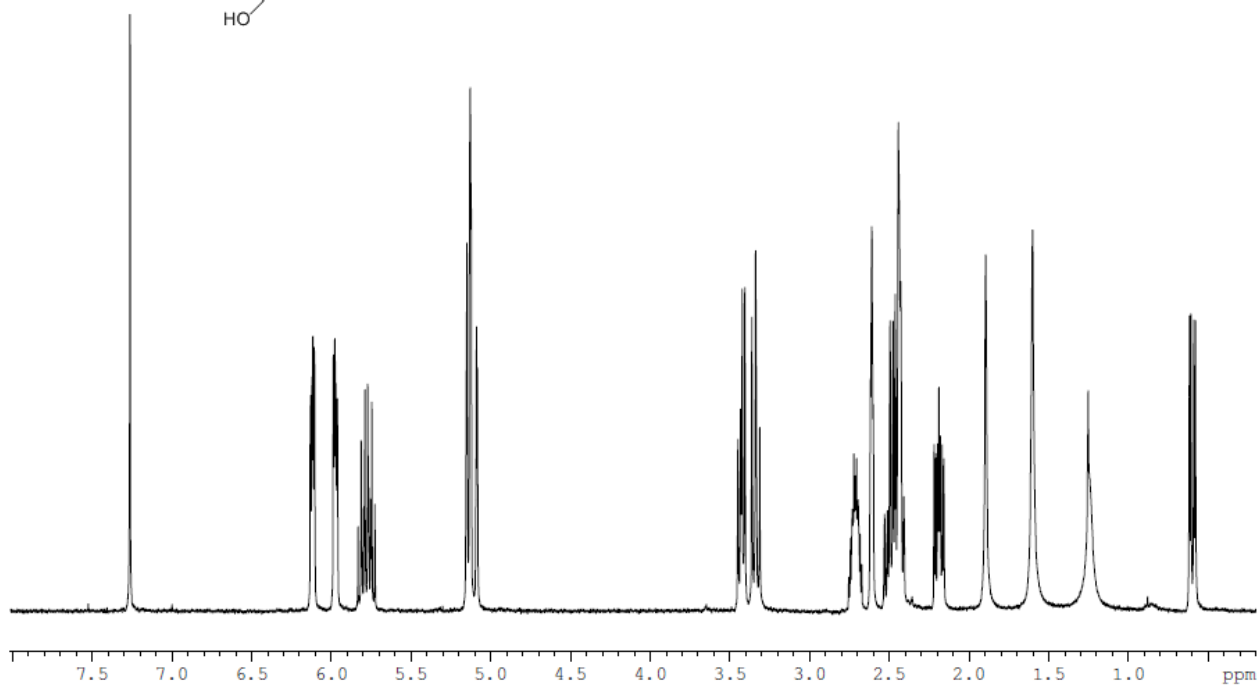
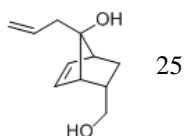






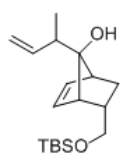


S9



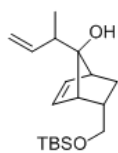
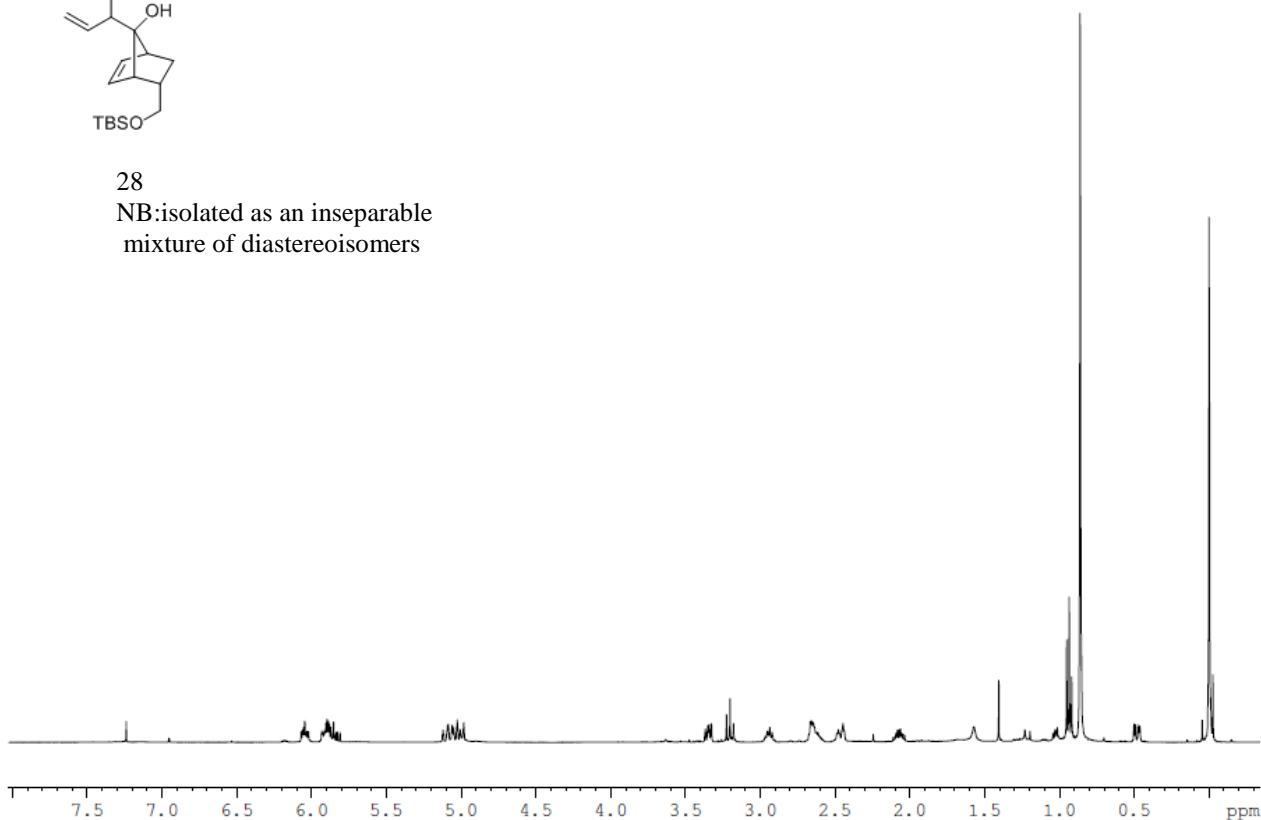


S11



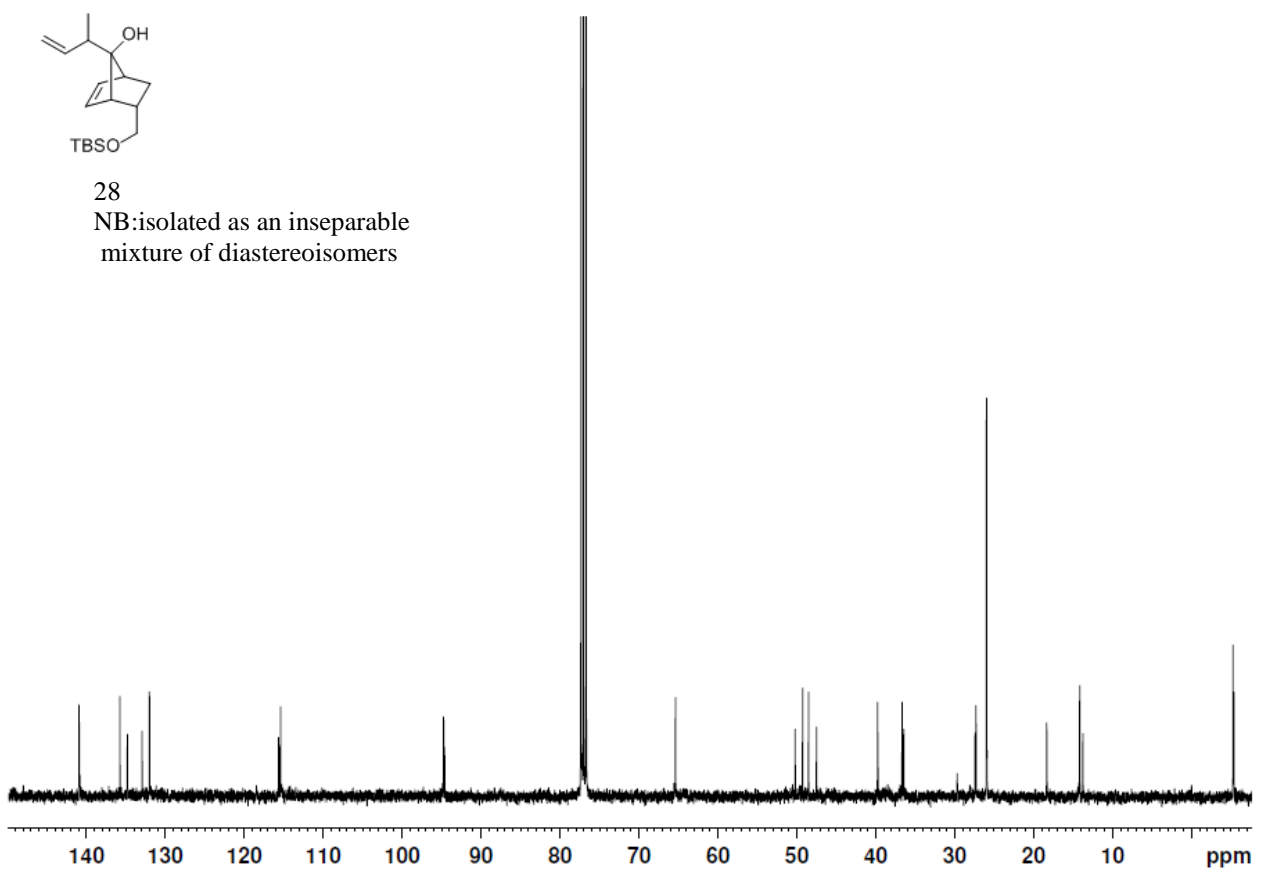
28

NB:isolated as an inseparable  
mixture of diastereoisomers

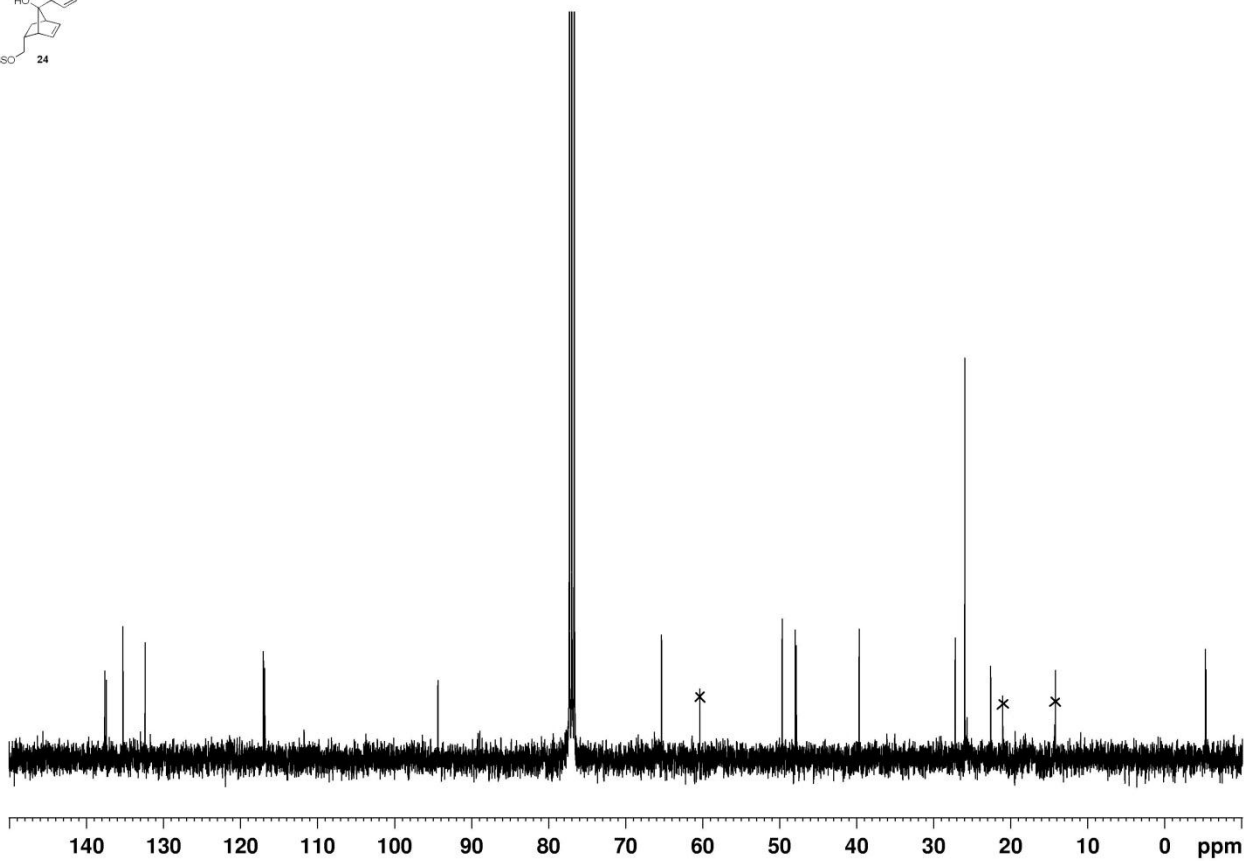
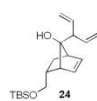
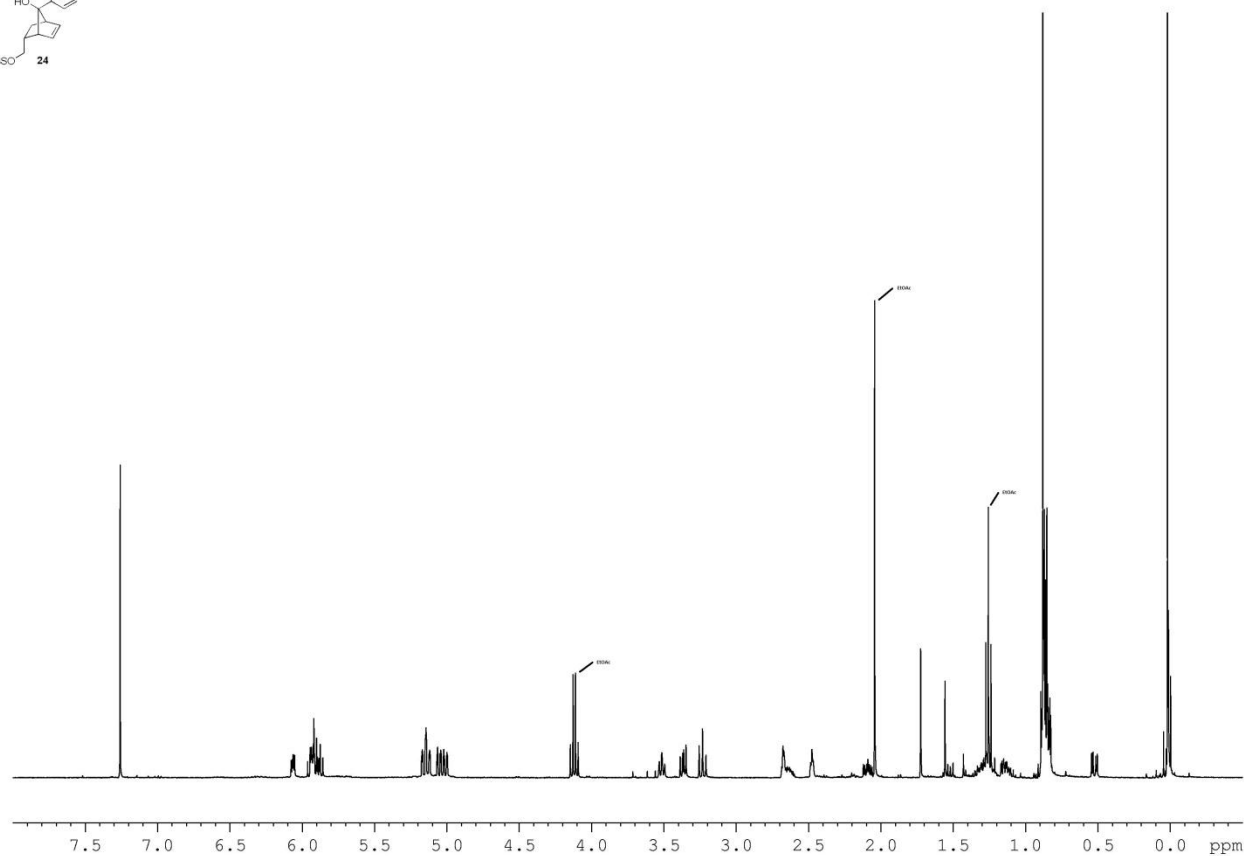


28

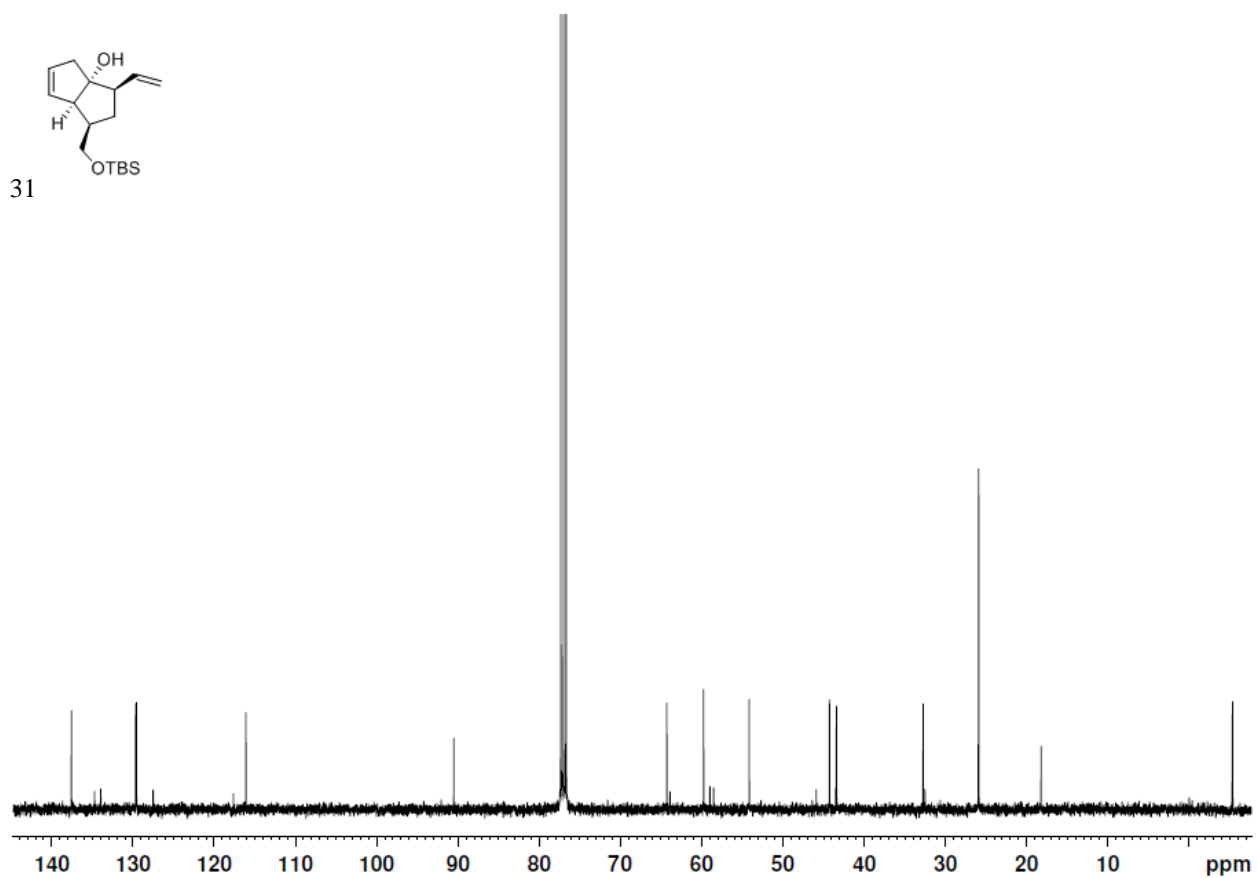
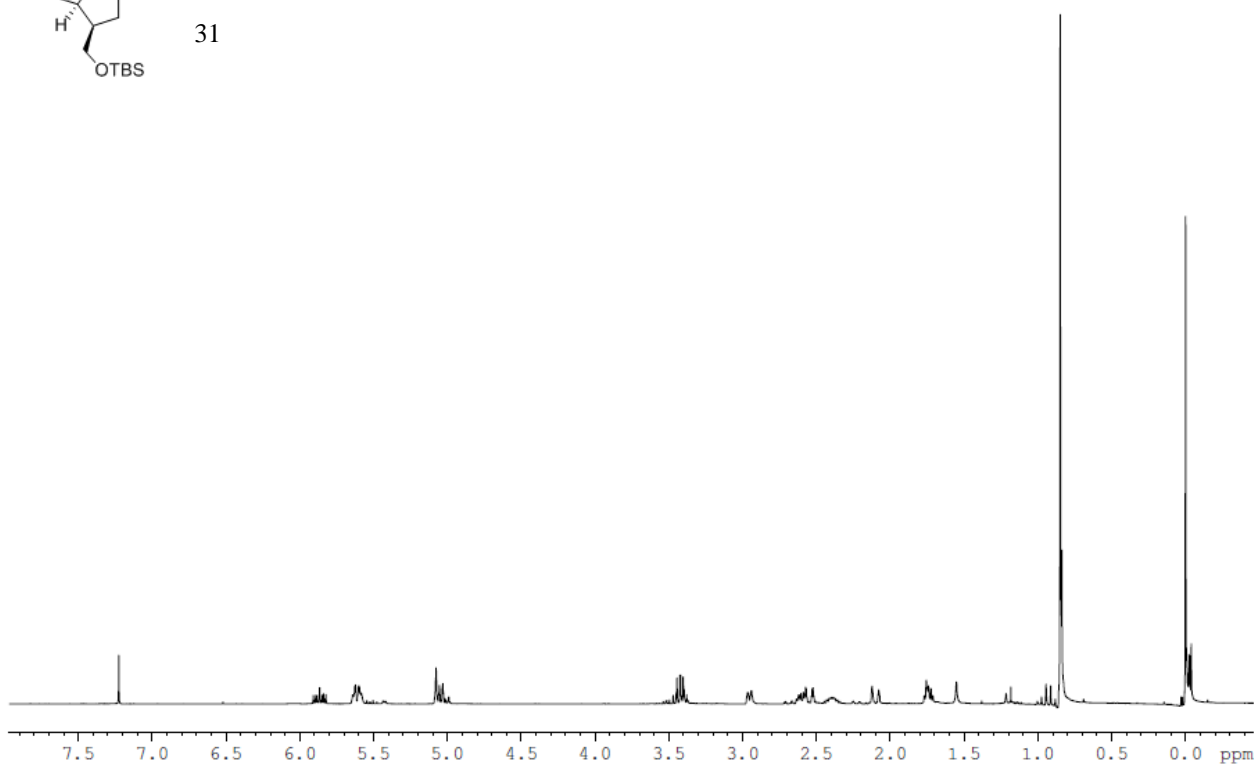
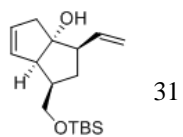
NB:isolated as an inseparable  
mixture of diastereoisomers



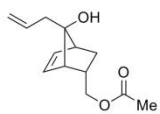
S12



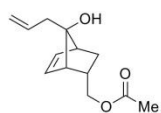
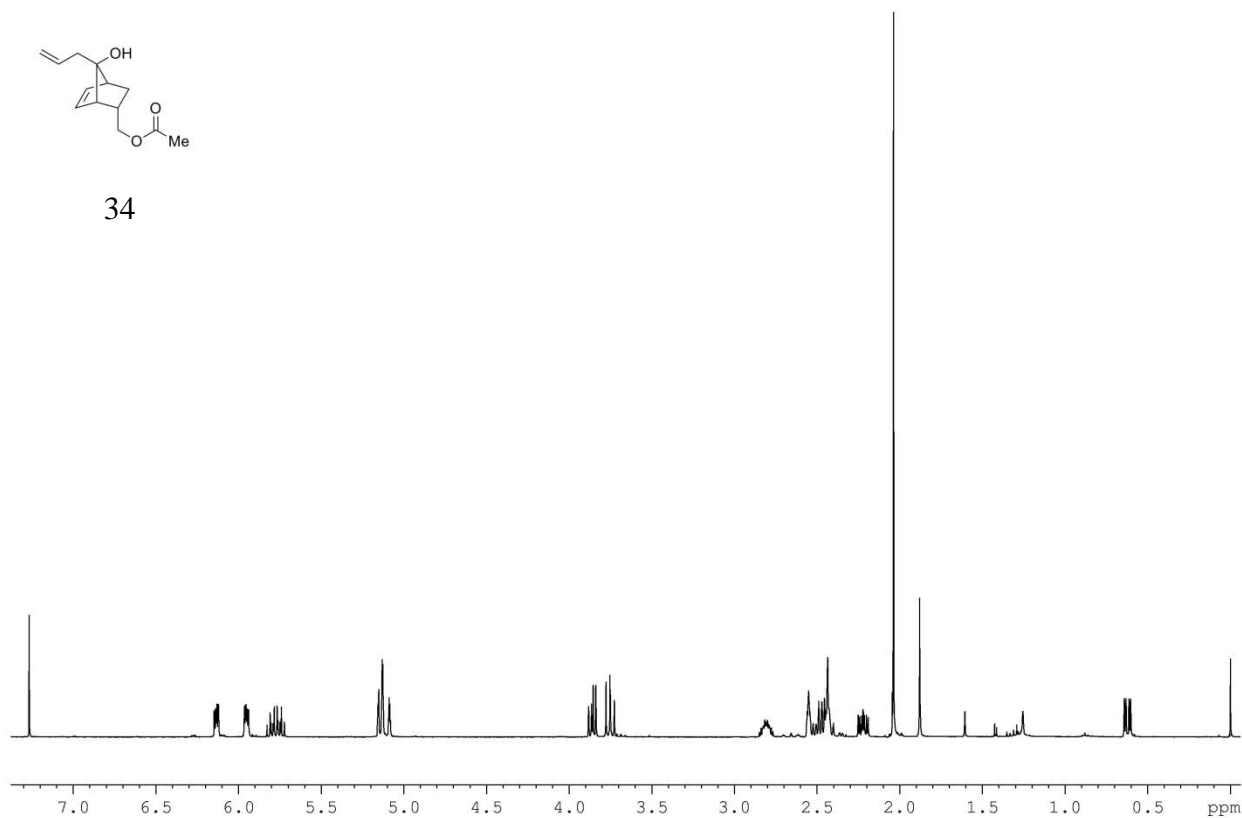
S13



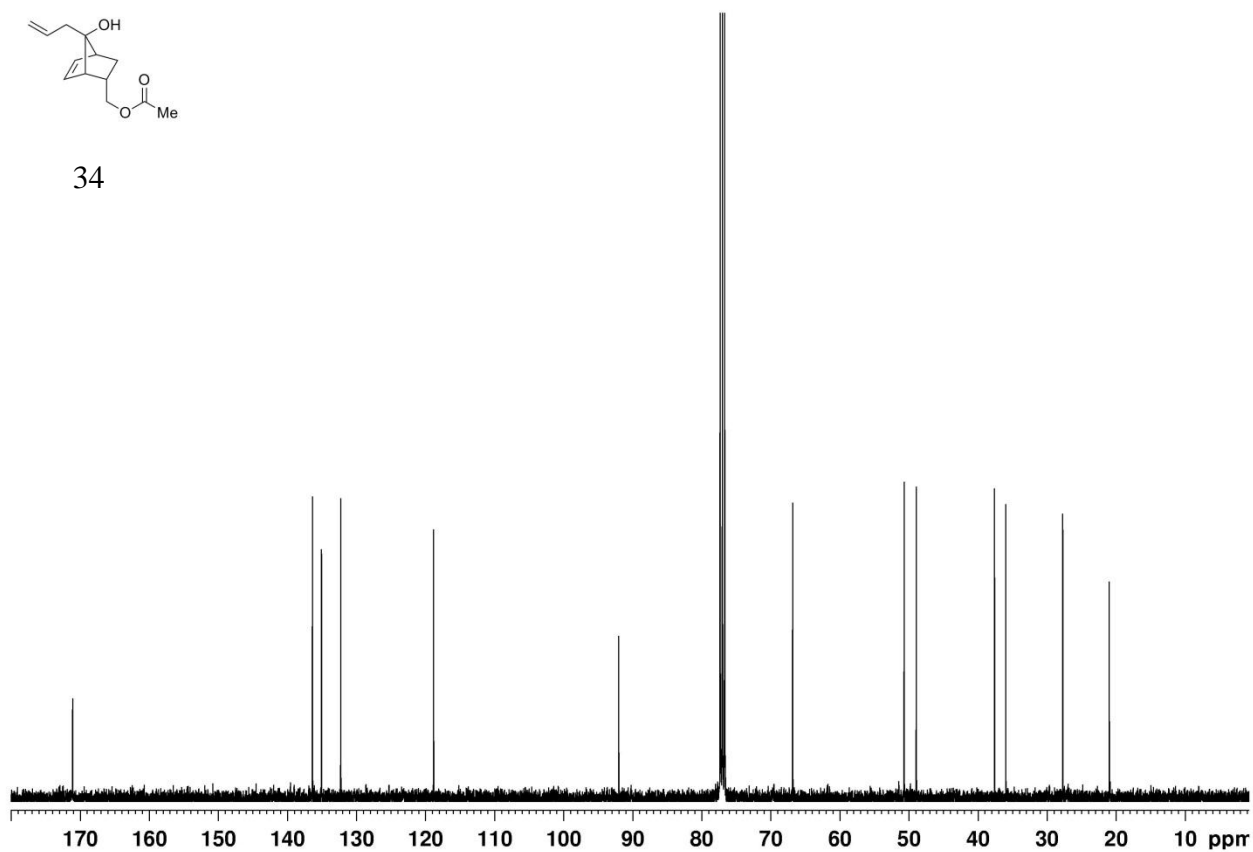
S14



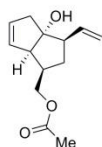
34



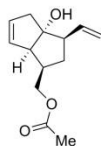
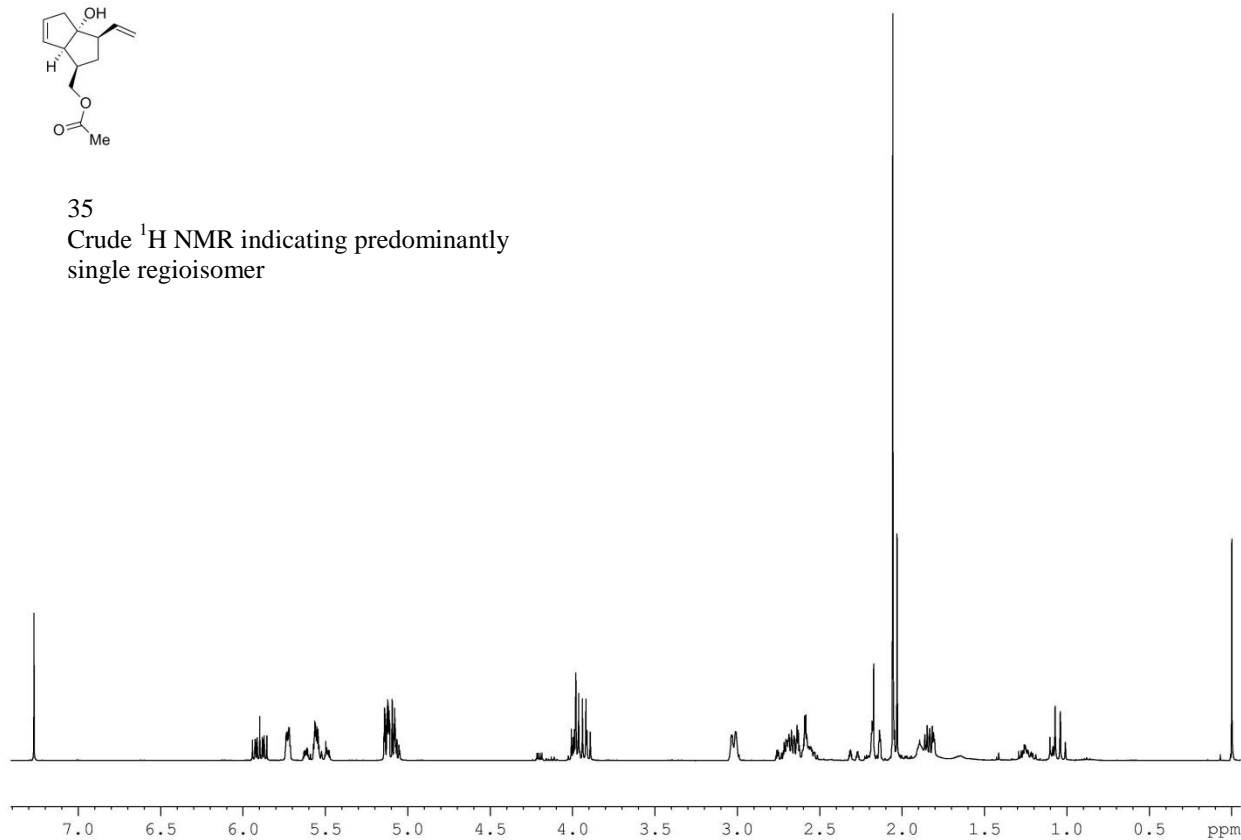
34



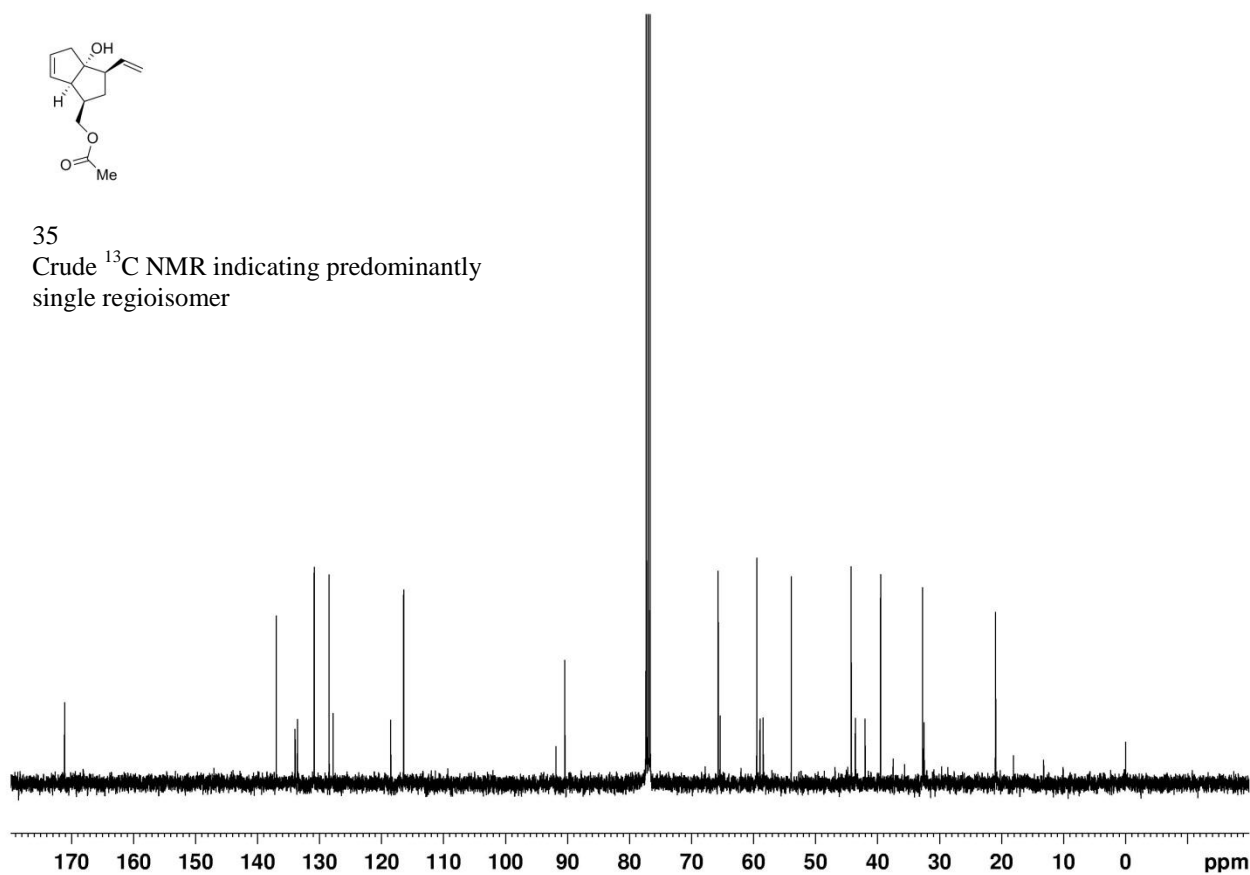
S15



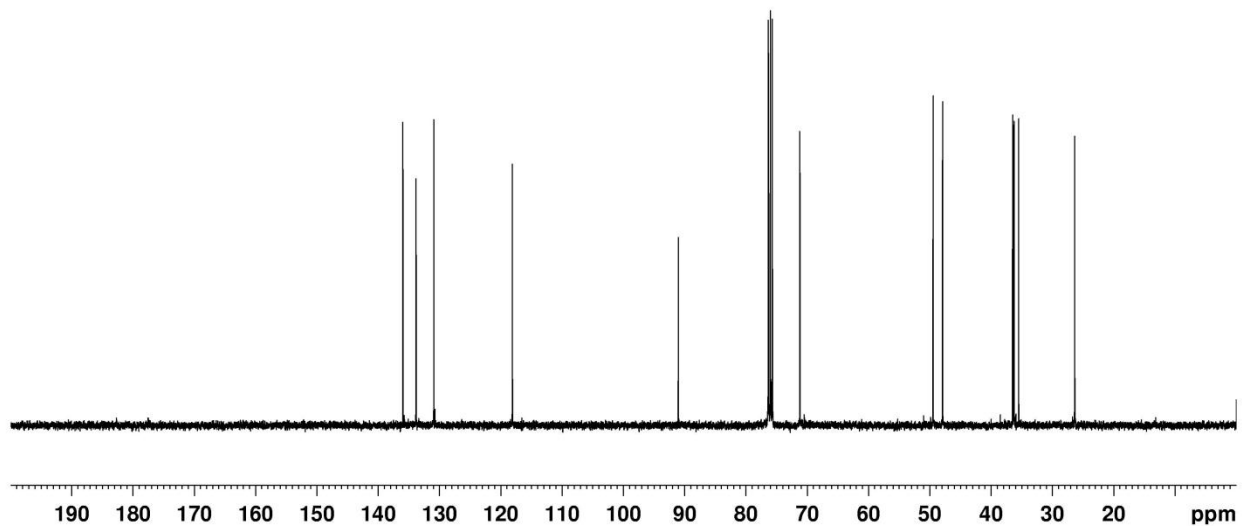
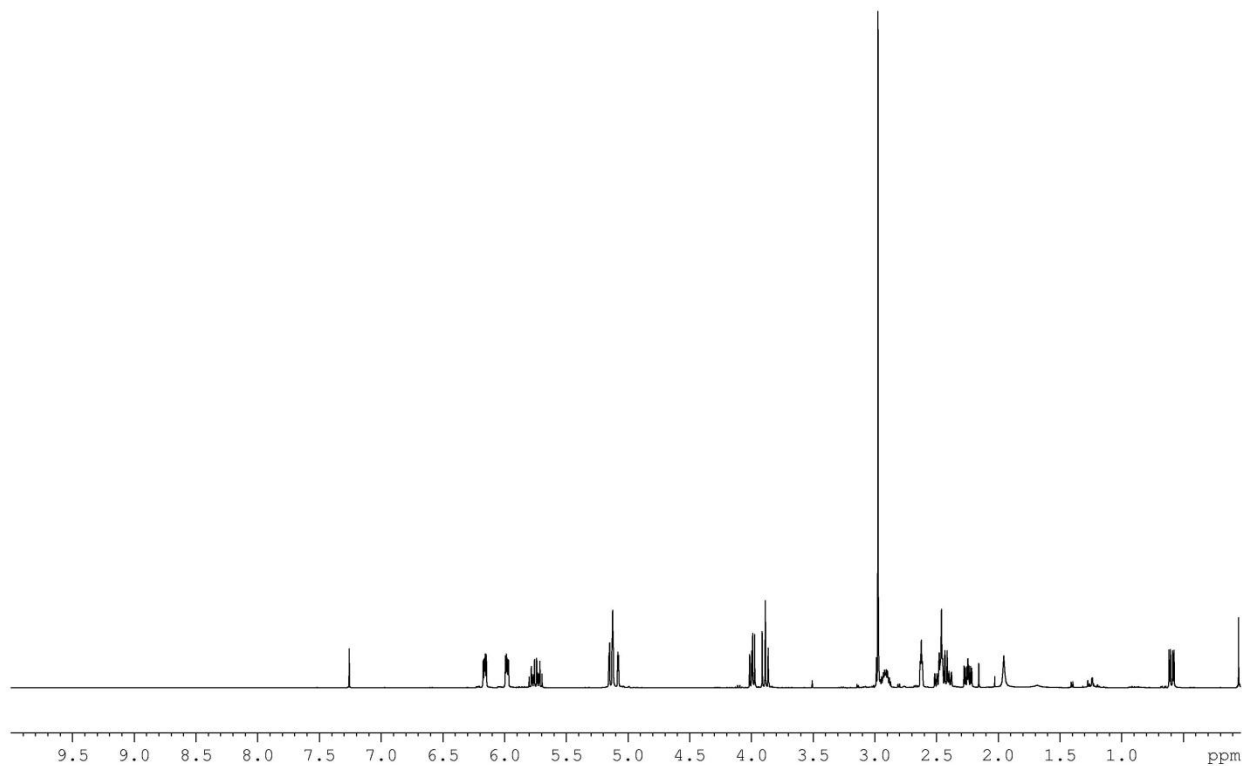
35  
Crude <sup>1</sup>H NMR indicating predominantly  
single regioisomer



35  
Crude <sup>13</sup>C NMR indicating predominantly  
single regioisomer

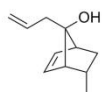


S16

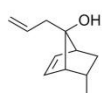
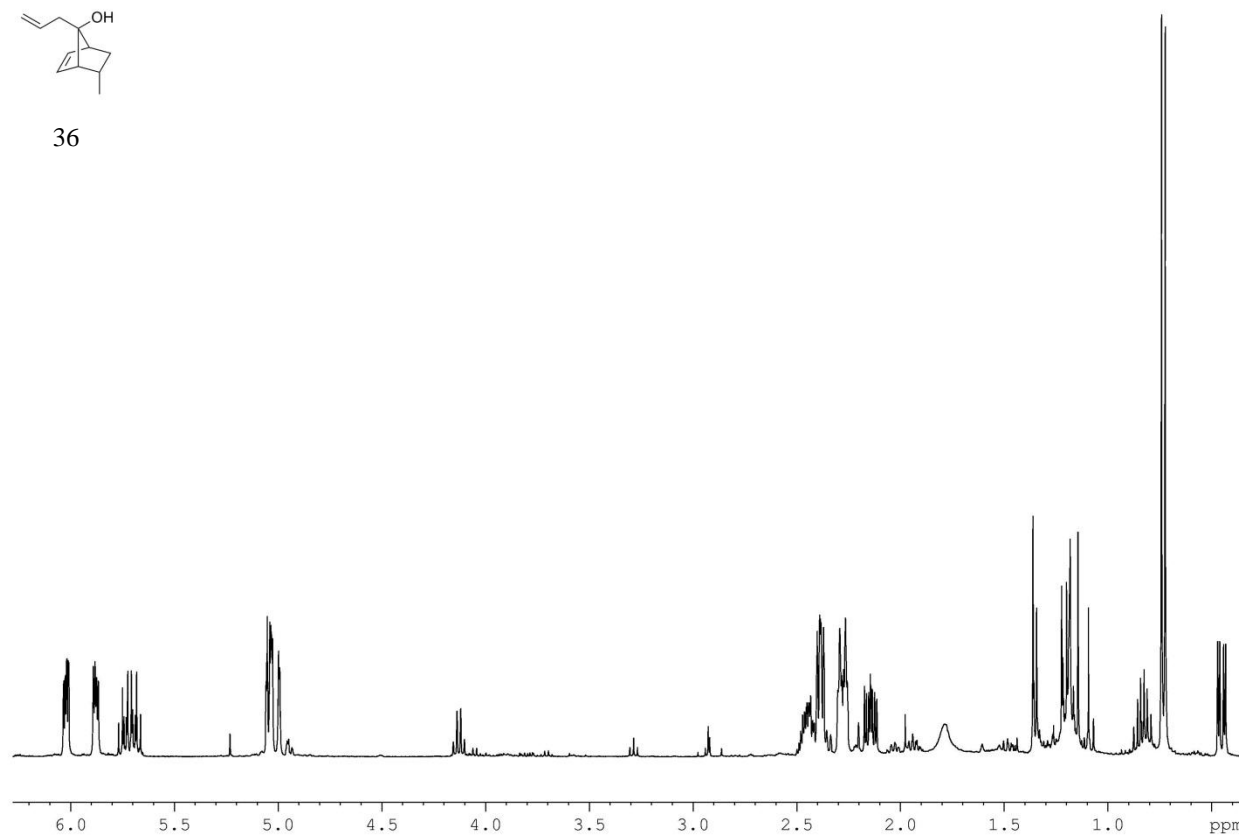




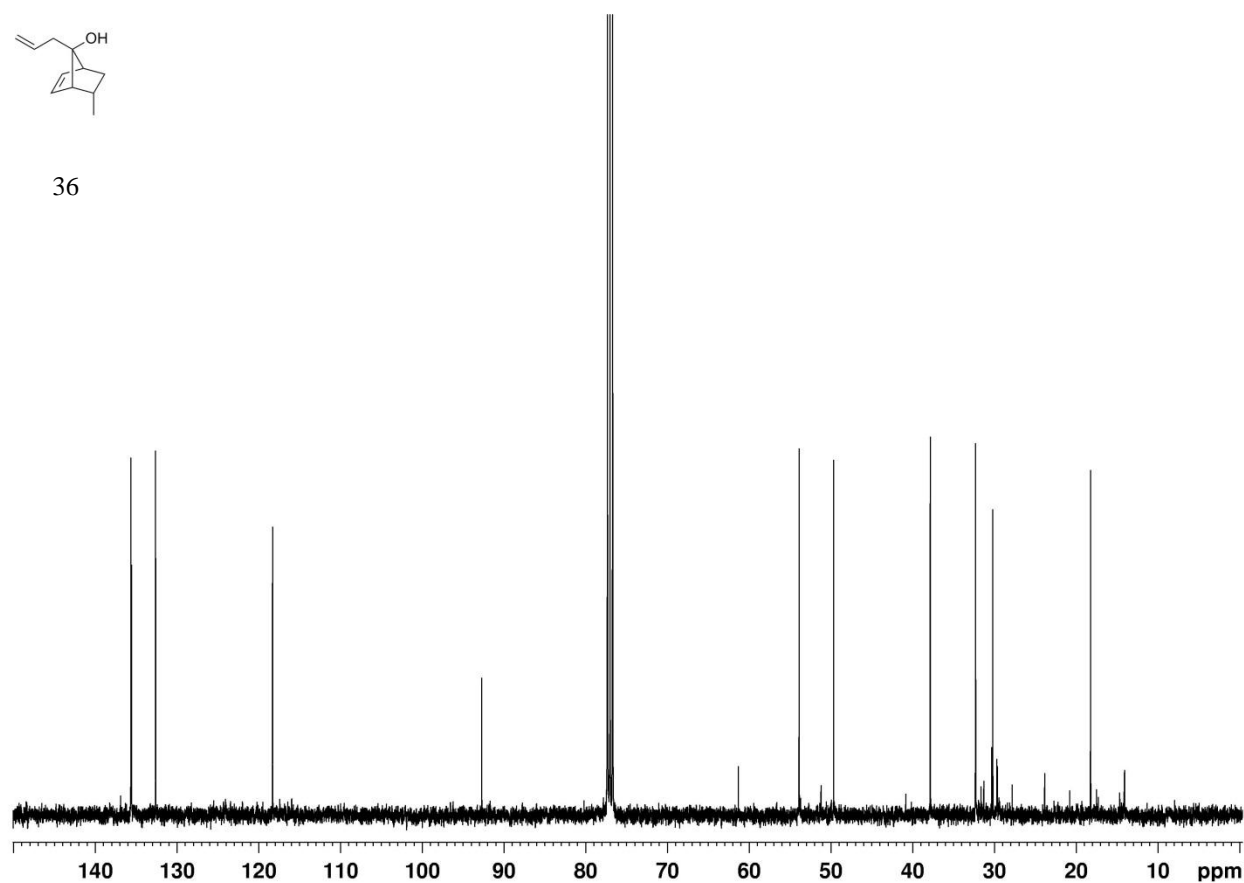
S17

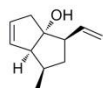


36

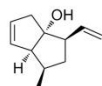
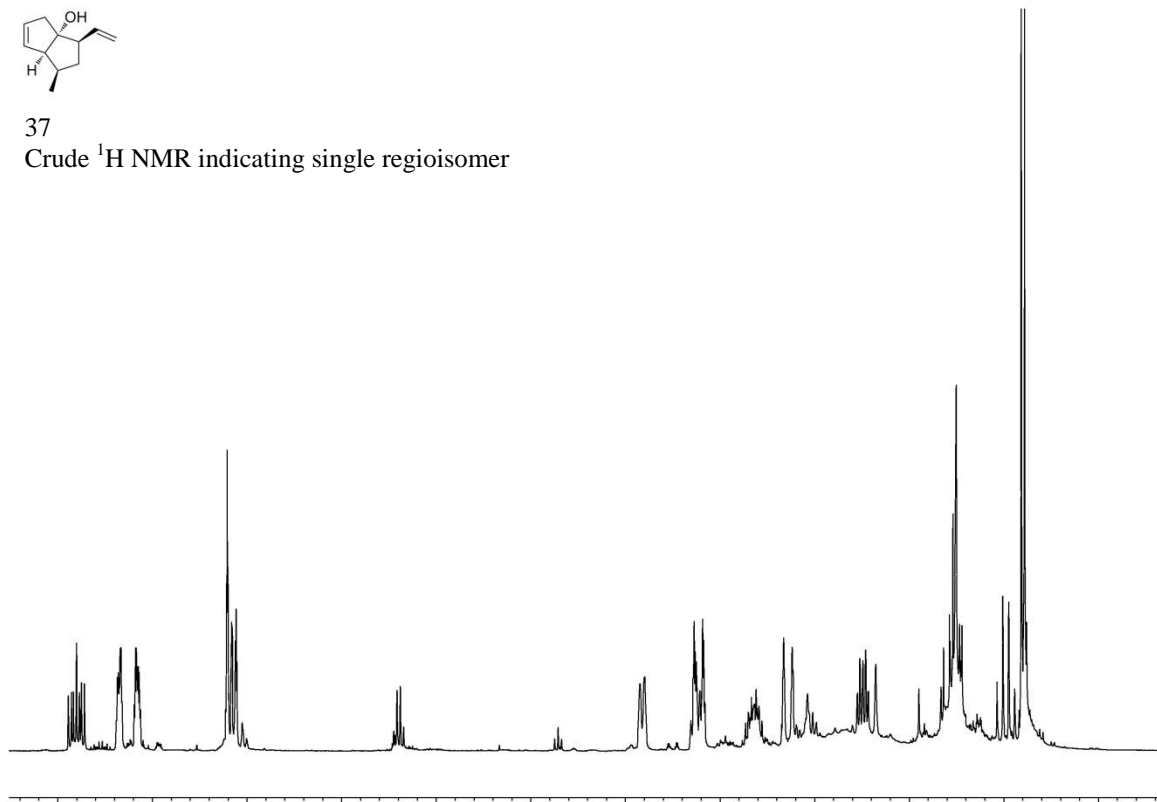


36

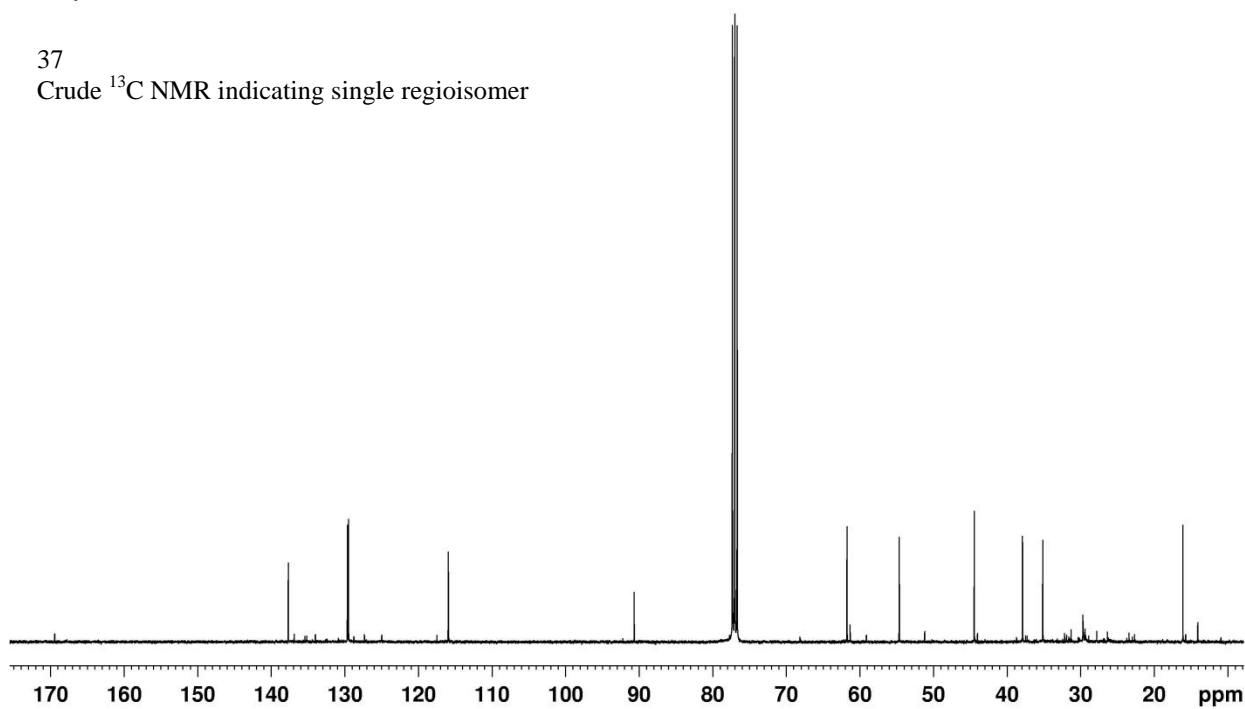




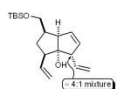
37  
Crude <sup>1</sup>H NMR indicating single regioisomer



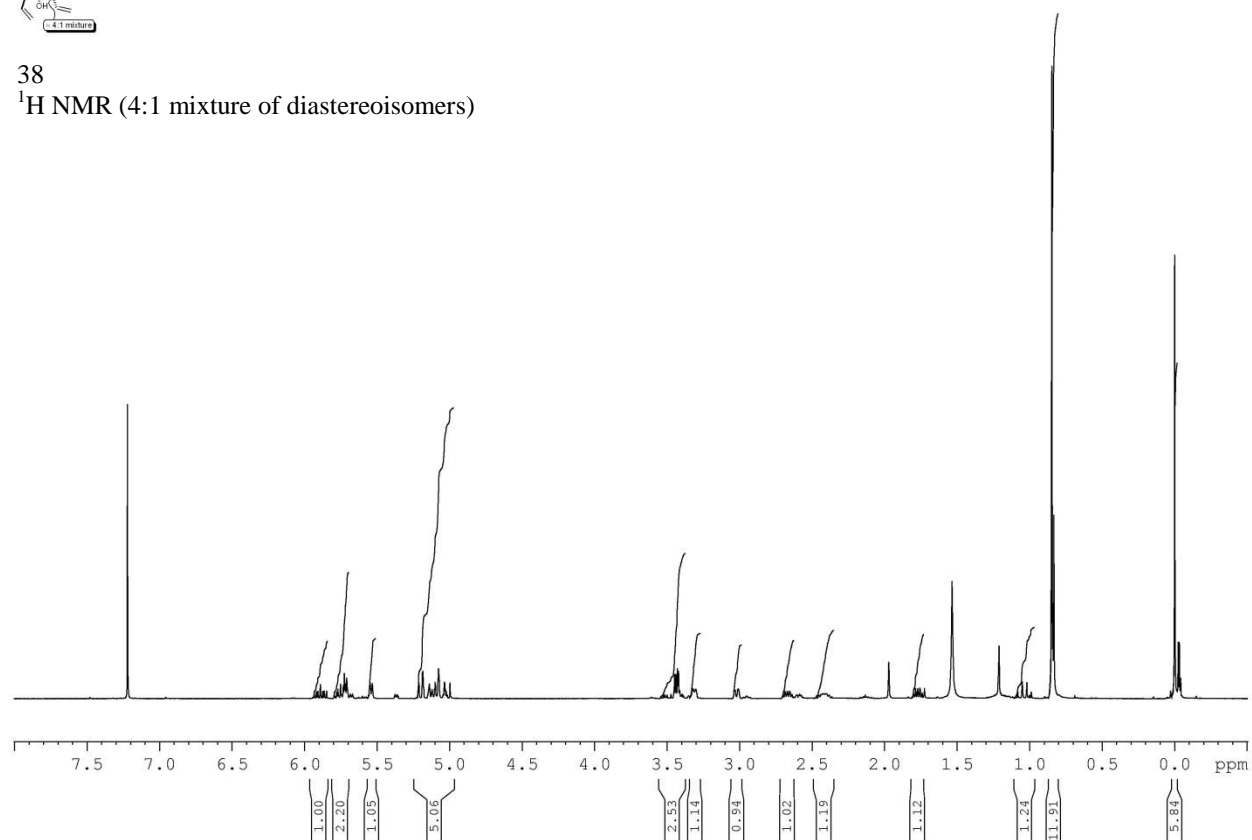
37  
Crude <sup>13</sup>C NMR indicating single regioisomer



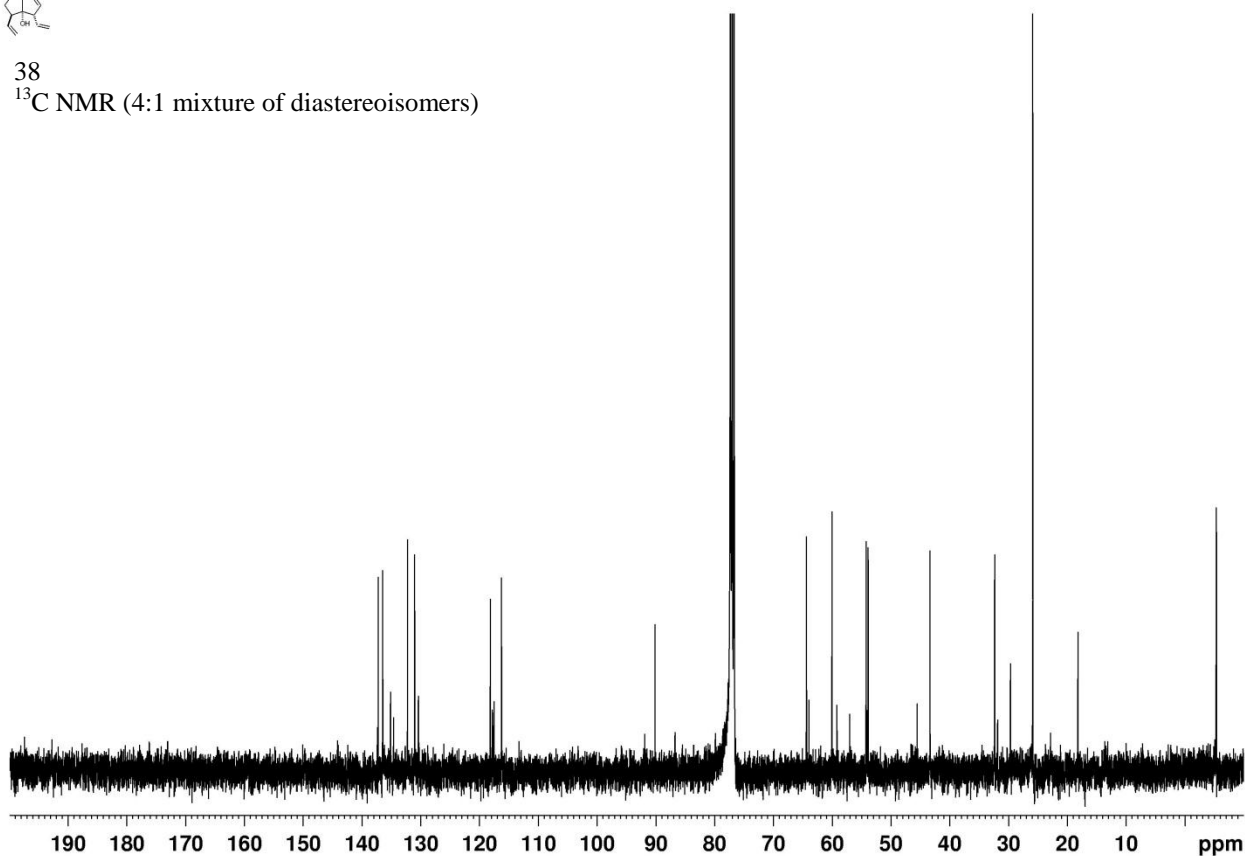
S19



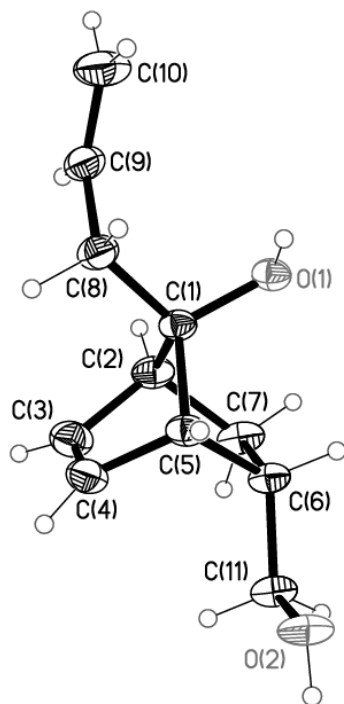
38  
 $^1\text{H}$  NMR (4:1 mixture of diastereoisomers)



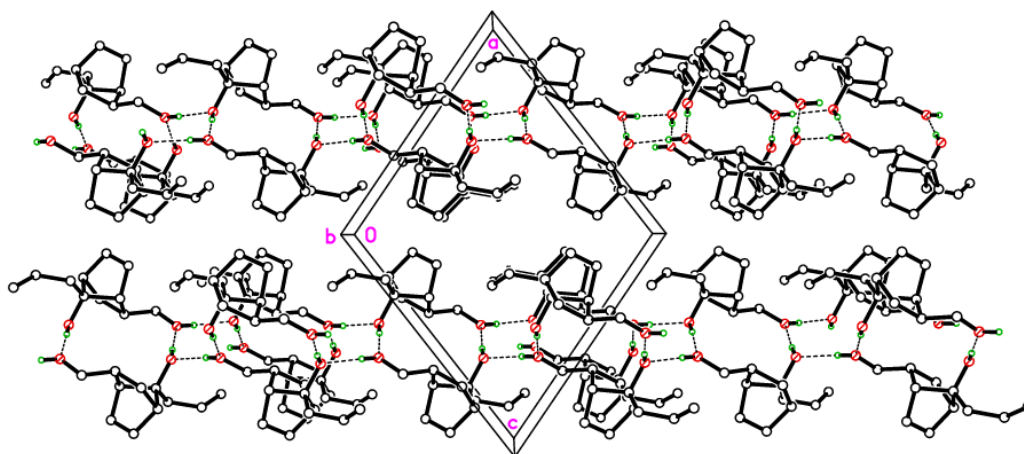
38  
 $^{13}\text{C}$  NMR (4:1 mixture of diastereoisomers)



S20



Displacement ellipsoid plot of **25** at the 50% probability level.



Packing plot of **25** showing the 2D layers formed by hydrogen bonds between OH groups.

**Table 1.** Crystal data and structure refinement for **25**.

Identification code	<b>25</b>	
Chemical formula	C <sub>11</sub> H <sub>16</sub> O <sub>2</sub>	
Formula weight	180.24	
Temperature	150(2) K	
Radiation, wavelength	synchrotron, 0.7749 Å	
Crystal system, space group	monoclinic, P2 <sub>1</sub> /n	
Unit cell parameters	a = 11.3188(14) Å	α = 90°
	b = 7.8255(10) Å	β = 107.7750(18)°
	c = 11.8409(15) Å	γ = 90°
Cell volume	998.7(2) Å <sup>3</sup>	
Z	4	
Calculated density	1.199 g/cm <sup>3</sup>	
Absorption coefficient μ	0.081 mm <sup>-1</sup>	
F(000)	392	
Crystal colour and size	colourless, 0.20 × 0.20 × 0.08 mm <sup>3</sup>	
Reflections for cell refinement	6497 (θ range 3.46 to 33.60°)	
Data collection method	Bruker APEX 2 CCD diffractometer ω rotation with narrow frames	
θ range for data collection	3.46 to 33.62°	
Index ranges	h -16 to 16, k -11 to 11, l -16 to 16	
Completeness to θ = 33.62°	99.2 %	
Intensity decay	0%	
Reflections collected	14038	
Independent reflections	3034 (R <sub>int</sub> = 0.0311)	
Reflections with F <sup>2</sup> > 2σ	2659	
Absorption correction	semi-empirical from equivalents	
Min. and max. transmission	0.984 and 0.994	
Structure solution	direct methods	
Refinement method	Full-matrix least-squares on F <sup>2</sup>	
Weighting parameters a, b	0.0621, 0.1811	
Data / restraints / parameters	3034 / 0 / 120	
Final R indices [F <sup>2</sup> > 2σ]	R1 = 0.0391, wR2 = 0.1093	
R indices (all data)	R1 = 0.0441, wR2 = 0.1141	
Goodness-of-fit on F <sup>2</sup>	1.045	
Largest and mean shift/su	0.000 and 0.000	
Largest diff. peak and hole	0.328 and -0.185 e Å <sup>-3</sup>	

Acknowledgement: The Advanced Light Source is supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

**Table 2.** Atomic coordinates and equivalent isotropic displacement parameters ( $\text{\AA}^2$ ) for **25**.  $U_{\text{eq}}$  is defined as one third of the trace of the orthogonalized  $U^{\text{ij}}$  tensor.

	x	y	z	$U_{\text{eq}}$
O(1)	0.37404(5)	0.04096(7)	0.79369(5)	0.02265(14)
C(1)	0.49572(7)	0.03635(10)	0.78060(7)	0.02147(16)
C(2)	0.51887(8)	0.20243(11)	0.71900(7)	0.02679(18)
C(3)	0.65772(9)	0.19017(14)	0.74291(9)	0.0338(2)
C(4)	0.70616(8)	0.11714(12)	0.84910(8)	0.03000(19)
C(5)	0.60027(7)	0.07841(10)	0.89816(7)	0.02227(16)
C(6)	0.55306(8)	0.25416(10)	0.93041(7)	0.02337(17)
C(7)	0.50013(9)	0.34099(11)	0.80680(8)	0.02870(19)
C(8)	0.51324(8)	-0.13361(11)	0.72280(8)	0.02805(19)
C(9)	0.42127(9)	-0.15931(12)	0.60253(8)	0.02950(19)
C(10)	0.33824(12)	-0.28210(16)	0.57436(10)	0.0449(3)
C(11)	0.65197(8)	0.36001(11)	1.01765(8)	0.02695(18)
O(2)	0.69274(7)	0.27124(9)	1.12852(6)	0.03243(17)

**Table 3.** Bond lengths [ $\text{\AA}$ ] and angles [ $^\circ$ ] for **25**.

O(1)–C(1)	1.4326(10)	C(1)–C(8)	1.5361(11)
C(1)–C(2)	1.5513(11)	C(1)–C(5)	1.5623(11)
C(2)–C(3)	1.5124(13)	C(2)–C(7)	1.5609(13)
C(3)–C(4)	1.3369(14)	C(4)–C(5)	1.5137(12)
C(5)–C(6)	1.5644(11)	C(6)–C(11)	1.5168(11)
C(6)–C(7)	1.5581(12)	C(8)–C(9)	1.4990(13)
C(9)–C(10)	1.3139(14)	C(11)–O(2)	1.4314(10)
O(1)–C(1)–C(8)	109.22(6)	O(1)–C(1)–C(2)	109.62(6)
C(8)–C(1)–C(2)	116.91(7)	O(1)–C(1)–C(5)	112.96(6)
C(8)–C(1)–C(5)	114.44(6)	C(2)–C(1)–C(5)	92.96(6)
C(3)–C(2)–C(1)	100.01(7)	C(3)–C(2)–C(7)	105.32(7)
C(1)–C(2)–C(7)	101.07(7)	C(4)–C(3)–C(2)	107.91(8)
C(3)–C(4)–C(5)	107.52(8)	C(4)–C(5)–C(1)	99.98(7)
C(4)–C(5)–C(6)	106.69(7)	C(1)–C(5)–C(6)	100.39(6)
C(11)–C(6)–C(7)	113.19(7)	C(11)–C(6)–C(5)	114.22(7)
C(7)–C(6)–C(5)	102.49(6)	C(6)–C(7)–C(2)	103.37(6)
C(9)–C(8)–C(1)	113.13(7)	C(10)–C(9)–C(8)	125.08(9)
O(2)–C(11)–C(6)	108.90(7)		

**Table 4.** Hydrogen coordinates and isotropic displacement parameters ( $\text{\AA}^2$ ) for **25**.

	x	y	z	U
H(1)	0.3576	-0.0546	0.8175	0.034
H(2A)	0.4682	0.2167	0.6341	0.032
H(3)	0.7026	0.2277	0.6915	0.041
H(4)	0.7915	0.0938	0.8869	0.036
H(5)	0.6169	-0.0114	0.9612	0.027
H(6)	0.4835	0.2333	0.9643	0.028
H(7A)	0.5464	0.4467	0.8020	0.034
H(7B)	0.4112	0.3692	0.7902	0.034
H(8A)	0.5981	-0.1374	0.7156	0.034
H(8B)	0.5055	-0.2289	0.7751	0.034
H(9)	0.4232	-0.0807	0.5420	0.035
H(10A)	0.3334	-0.3632	0.6324	0.054
H(10B)	0.2831	-0.2897	0.4959	0.054
H(11A)	0.7229	0.3785	0.9866	0.032
H(11B)	0.6177	0.4729	1.0288	0.032
H(2)	0.7446	0.3316	1.1785	0.049

**Table 5.** Torsion angles [ $^\circ$ ] for **25**.

O(1)–C(1)–C(2)–C(3)	166.31(7)	C(8)–C(1)–C(2)–C(3)	-68.74(8)
C(5)–C(1)–C(2)–C(3)	50.65(7)	O(1)–C(1)–C(2)–C(7)	58.38(8)
C(8)–C(1)–C(2)–C(7)	-176.68(7)	C(5)–C(1)–C(2)–C(7)	-57.28(7)
C(1)–C(2)–C(3)–C(4)	-34.29(10)	C(7)–C(2)–C(3)–C(4)	70.22(10)
C(2)–C(3)–C(4)–C(5)	0.22(11)	C(3)–C(4)–C(5)–C(1)	33.65(9)
C(3)–C(4)–C(5)–C(6)	-70.48(9)	O(1)–C(1)–C(5)–C(4)	-163.36(7)
C(8)–C(1)–C(5)–C(4)	70.83(8)	C(2)–C(1)–C(5)–C(4)	-50.59(7)
O(1)–C(1)–C(5)–C(6)	-54.17(8)	C(8)–C(1)–C(5)–C(6)	-179.98(7)
C(2)–C(1)–C(5)–C(6)	58.60(7)	C(4)–C(5)–C(6)–C(11)	-57.29(9)
C(1)–C(5)–C(6)–C(11)	-161.12(7)	C(4)–C(5)–C(6)–C(7)	65.52(8)
C(1)–C(5)–C(6)–C(7)	-38.30(8)	C(11)–C(6)–C(7)–C(2)	125.54(8)
C(5)–C(6)–C(7)–C(2)	2.03(8)	C(3)–C(2)–C(7)–C(6)	-68.48(8)
C(1)–C(2)–C(7)–C(6)	35.25(8)	O(1)–C(1)–C(8)–C(9)	59.95(9)
C(2)–C(1)–C(8)–C(9)	-65.20(10)	C(5)–C(1)–C(8)–C(9)	-172.31(7)
C(1)–C(8)–C(9)–C(10)	-116.93(12)	C(7)–C(6)–C(11)–O(2)	178.91(7)
C(5)–C(6)–C(11)–O(2)	-64.30(10)		

**Table 6.** Hydrogen bonds for **25** [ $\text{\AA}$  and  $^\circ$ ].

D–H...A	d(D–H)	d(H...A)	d(D...A)	$\angle(\text{DHA})$
O(1)–H(1)...O(2')	0.84	1.96	2.7953(9)	176.0
O(2)–H(2)...O(1'')	0.84	1.94	2.7831(9)	175.7

Symmetry operations for equivalent atoms

'  $-x+1, -y, -z+2$  "  $x+1/2, -y+1/2, z+1/2$