Electronic Supplementary Material (ESI) for Organic Chemistry Frontiers.

Supporting Information

Total Synthesis of Peshawaraquinone Through Late-Stage [3+2] Cycloaddition or α-Ketol Rearrangement

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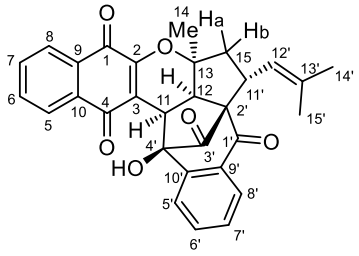
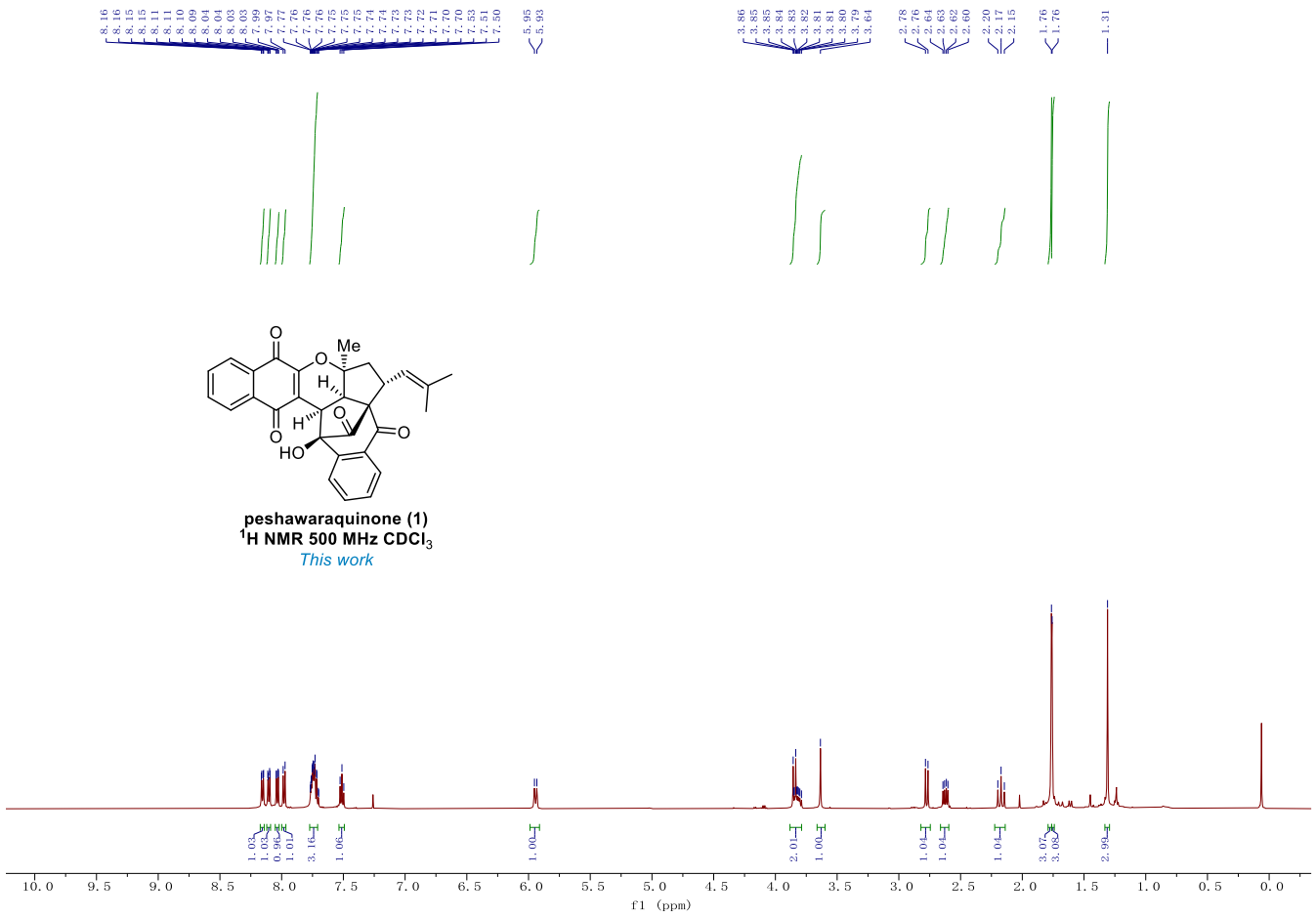
1. Comparison of natural and synthetic peshawaraquinone

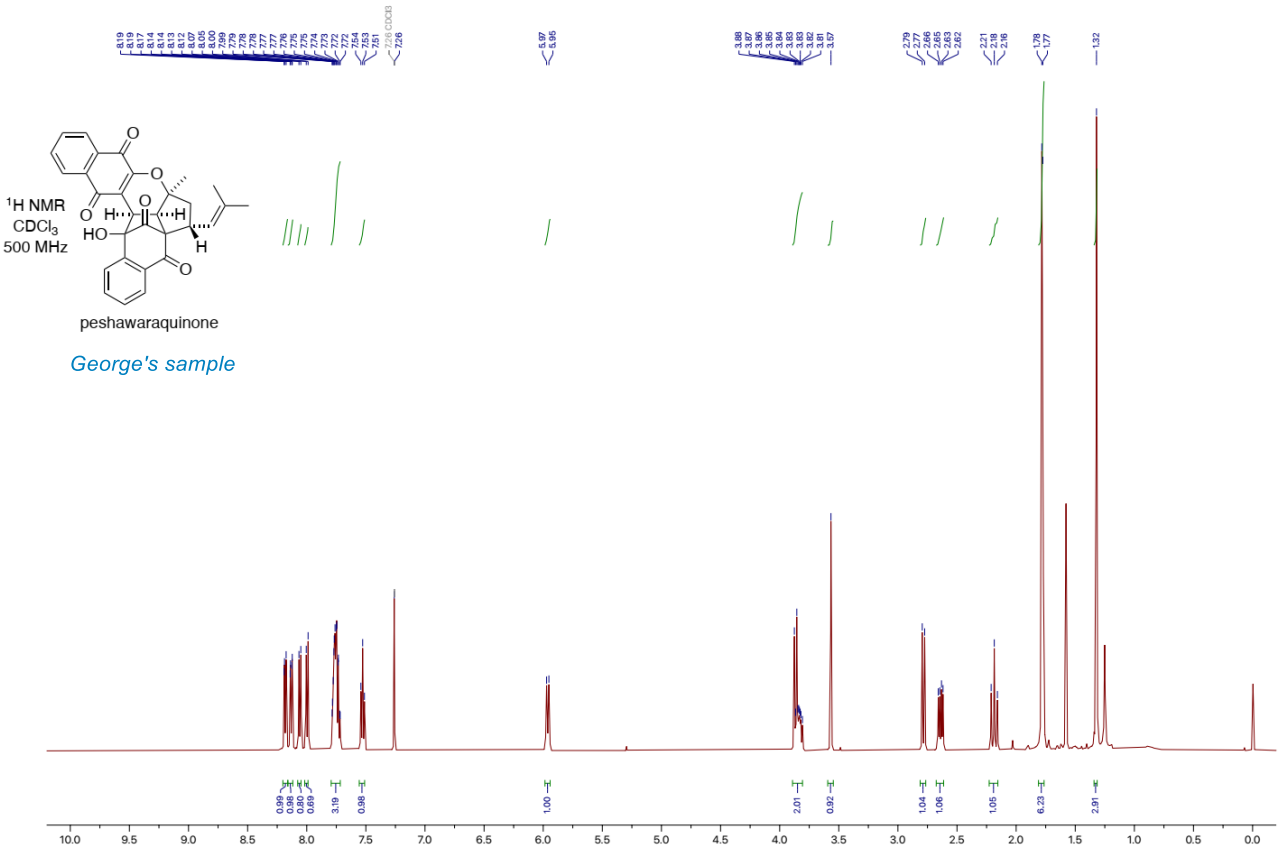


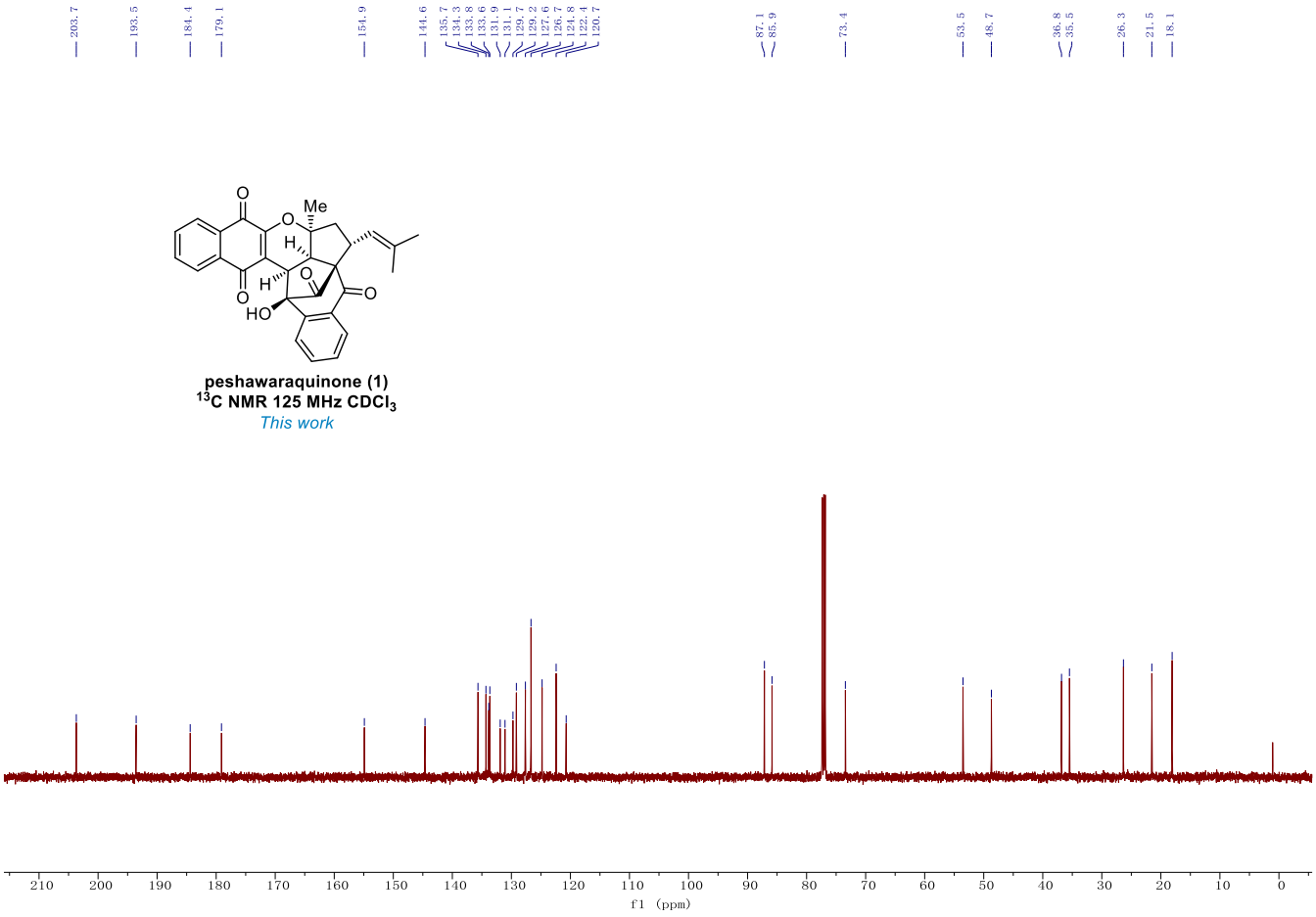
peshawaraquinone

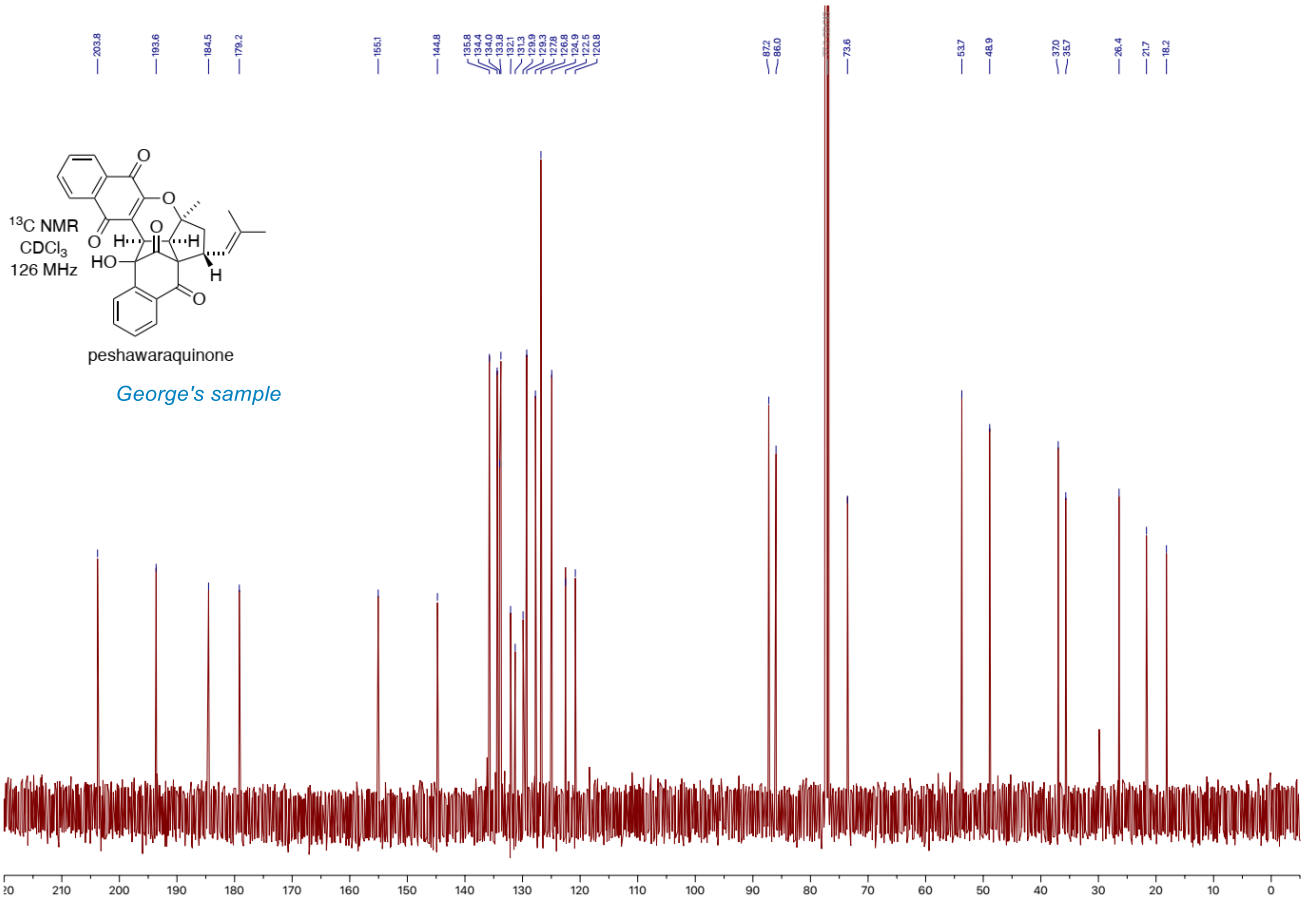
No.	Our sample, $CDCl_3$ ^1H, 500 MHz (δ)	George 's sample[1], $CDCl_3$ ^1H, 500 MHz (δ)	Natural[2], $CDCl_3$ ^1H, 400 MHz (δ)
1			
2			
3			
4			
5	8.10 (dd, *J* =7.3, 1.6 Hz, 1H)	8.13 (d, *J* =7.7 Hz, 1H)	8.12 (dd, *J* = 8.4, 1.6 Hz, 1H)
6	7.77 – 7.70 (m, 1H)	7.80 – 7.70 (m, 1H)	7.74 (m, 1H)
7	7.77 – 7.70 (m, 1H)	7.80 – 7.70 (m, 1H)	7.74 (m, 1H)
8	8.16 (dd, *J* = 7.4, 1.6 Hz, 1H)	8.16 (d, *J* = 6.8 Hz, 1H)	8.16 (dd, *J* = 8.4, 1.6 Hz, 1H)
9			
10			
11	3.85 (d, *J* = 10.3 Hz, 1H)	3.87 (d, *J* = 10.4 Hz, 1H)	3.82 (d, *J* = 10.4 Hz, 1H)
12	2.77 (d, *J* = 10.2 Hz, 1H)	2.78 (d, *J* = 10.2 Hz, 1H)	2.76 (d, *J* = 10.4 Hz, 1H)
13			
14	1.31 (s, 3H)	1.32 (s, 3H)	1.30 (s, 3H)
15	2.62 (dd, *J* = 13.6, 6.5 Hz, 1H); 2.17 (t, *J* =13.2 Hz, 1H)	2.64 (dd, *J* = 13.6, 6.4 Hz, 1H); 2.18 (t, *J* =13.2 Hz, 1H)	2.62 (dd, *J* = 13.2, 6.4 Hz, 1H); 2.17 (t, *J* = 13.2 Hz, 1H)
1’			
2’			
3’			
4’	3.64, (s, 1H)	3.57 (s, 1H)	3.54 (s, 1H)
5’	7.98 (d, *J* = 7.8 Hz, 1H)	8.00 (d, *J* = 7.8 Hz, 1H)	7.92 (dd, *J* = 8.0, 1.5 Hz, 1H)
6’	7.77 – 7.70 (m, 1H)	7.80 – 7.70 (m, 1H)	7.74 (m, 1H)
7’	7.51 (t, *J* = 7.5 Hz, 1H)	7.53 (t, *J* = 7.5 Hz, 1H)	7.51 (m, 1H)
8’	8.04 (dd, *J* = 7.9, 1.3 Hz, 1H)	8.06 (d, *J* = 7.8 Hz, 1H)	8.04 (dd, *J* = 7.6, 1.5 Hz, 1H)
9’			
10’			
11’	3.85 – 3.76 (m, 1H)	3.87 – 3.79 (m, 1H)	3.78 (m, 1H)
12’	5.94 (d, *J*= 9.7 Hz, 1H)	5.96 (d, *J*= 9.7 Hz, 1H)	5.94 (d, *J*= 9.6 Hz, 1H)
13’			
14’	1.76 (s, 3H)	1.78 (s, 3H)	1.76 (s, 3H)
15’	1.76 (s, 3H)	1.77 (s, 3H)	1.75 (s, 3H)

No.	Our sample, $CDCl_3$ ^{13}C, 125 MHz (δ)	George 's sample[1], $CDCl_3$ ^{13}C, 125 MHz (δ)	Natural[2], $CDCl_3$ ^{13}C, 100 MHz (δ)
1	184.4	184.5	184.4
2	120.7	120.8	120.7
3	154.9	155.1	154.9
4	179.1	179.2	179.3
5	126.7	126.8	126.7
6	133.6	133.8	133.6
7	134.3	134.4	134.3
8	126.7	126.8	126.7
9	131.9	132.1	131.9
10	131.1	131.1	131.1
11	35.5	35.7	35.5
12	53.5	53.7	53.6
13	87.1	87.2	87.1
14	21.6	21.7	21.5
15	48.7	48.9	48.7
1’	193.5	193.6	193.5
2’	73.4	73.6	73.4
3’	203.7	203.8	203.6
4’	85.9	86.0	85.8
5’	124.8	124.9	124.8
6’	135.7	135.8	135.5
7’	129.2	129.3	129.1
8’	127.6	127.8	127.6
9’	129.7	129.9	129.7
10’	144.6	144.8	144.6
11’	36.8	37.0	36.8
12’	133.9	122.5	122.4
13’	122.4	134.0	133.9
14’	18.1	18.2	18.1
15’	26.3	26.4	26.3


peshawaraquinone (1)
1H NMR 500 MHz CDCl3
This work
f1 (ppm)


1H NMR
CDCl3
500 MHz
peshawaraquinone
George's sample


203.7
193.5
184.4
179.1
154.9
144.6
135.7
134.3
133.8
133.6
131.9
131.1
129.7
129.2
127.6
126.7
124.8
122.4
120.7
87.1
85.9
73.4
53.5
48.7
36.8
35.5
26.3
21.5
18.1
Me
O
H
HO
peshawaraquinone (1)
13C NMR 125 MHz CDCl3
This work
f1 (ppm)


203.8
193.6
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179.2
155.1
144.8
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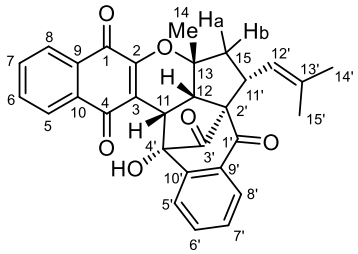
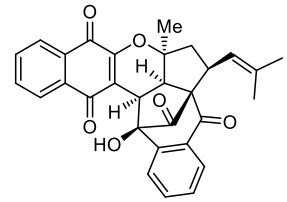
133.8
132.1
131.3
129.9
129.3
127.8
126.8
124.9
122.5
120.8
87.2
86.0
73.6
53.7
48.9
37.0
35.7
26.4
21.7
18.2
13C NMR
CDCl3
126 MHz
peshawaraquinone
George's sample

2. Comparison of synthetic 11'-*epi*-peshawaraquinone

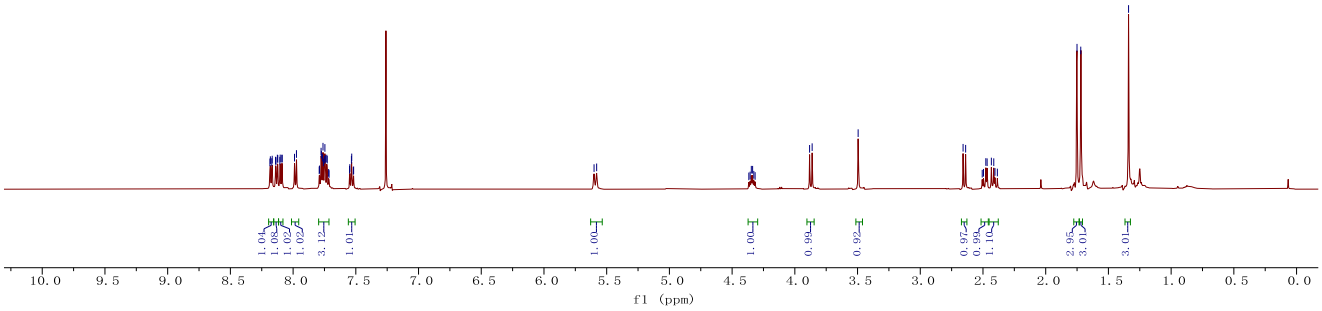


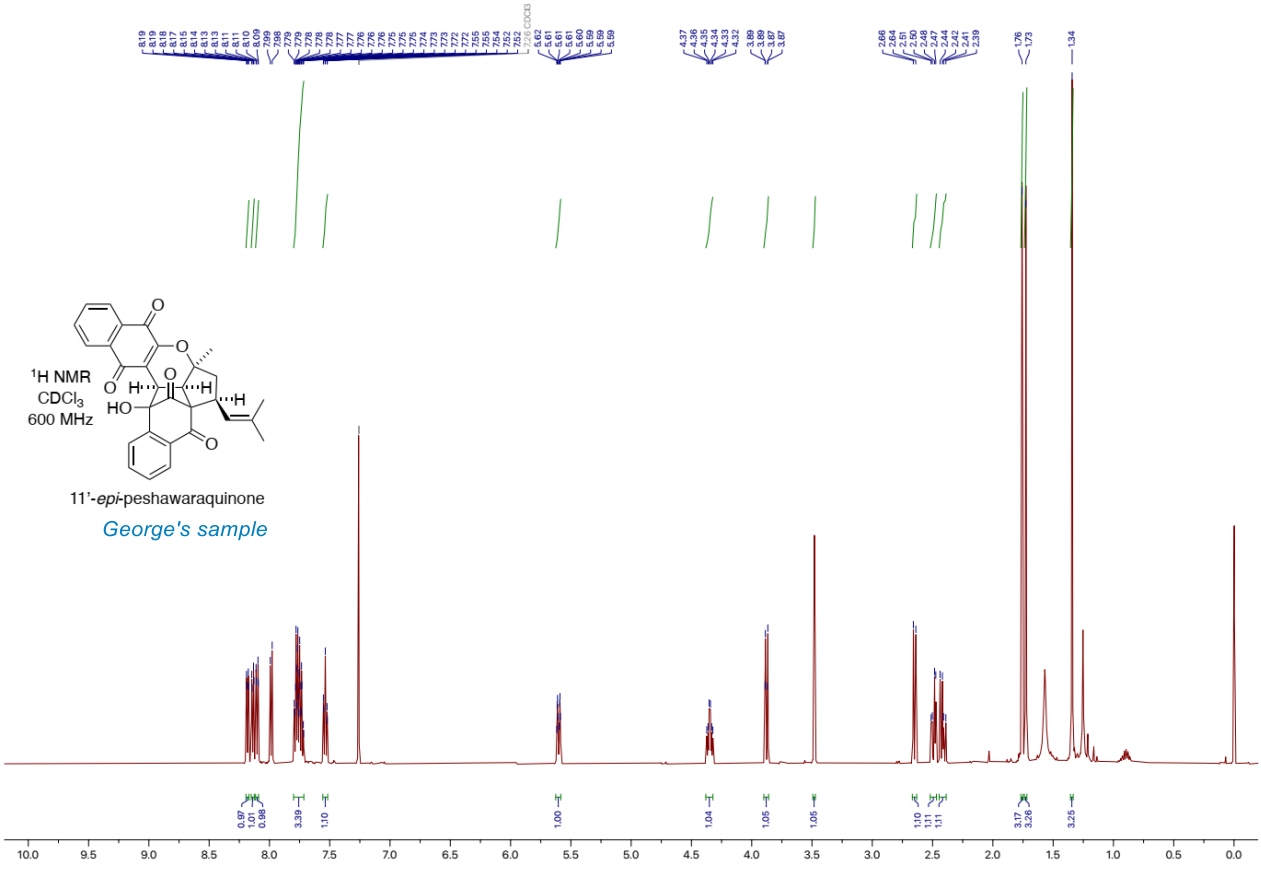
11'-*epi*-peshawaraquinone

No.	^{1}H NMR (CDCl$_3$)		^{13}C NMR (CDCl$_3$)		
	Our sample (500 Hz)	George 's sample[1] (500 Hz)	Our sample (125 Hz)	George 's sample[1] (125 Hz)	Different (Δ ppm)
1			184.0	184.2	– 0.2
2			121.2	121.3	– 0.1
3			154.4	154.5	– 0.1
4			179.0	179.2	– 0.2
5	8.13 (dd, *J* = 7.3, 1.6 Hz, 1H)	8.14 (d, *J* =7.4 Hz, 1H)	126.6	126.8	– 0.2
6	7.79 – 7.71 (m, 1H)	7.82 – 7.70 (m, 1H)	133.5	133.7	– 0.2
7	7.79 – 7.71 (m, 1H)	7.82 – 7.70 (m, 1H)	134.2	134.4	– 0.2
8	8.18 (dd, *J* = 7.3, 1.7 Hz, 1H)	8.18 (d, *J* = 7.4 Hz, 1H)	126.6	126.7	– 0.1
9			132.0	132.0	0
10			131.2	131.3	– 0.1
11	3.87 (d, *J* = 10.2 Hz, 1H)	3.88 (d, *J* = 10.1 Hz, 1H)	36.0	36.0	0
12	2.65 (d, *J* = 10.2 Hz, 1H)	2.65 (d, *J* = 10.2 Hz, 1H)	53.1	53.2	– 0.1
13			89.0	89.2	– 0.2
14	1.34 (s, 3H)	1.34 (s, 3H)	23.6	23.7	– 0.1
15	2.49 (dd, *J* = 14.4, 5.1 Hz, 1H); 2.41 (dd, *J* = 14.4, 9.5 Hz, 1H)	2.49 (dd, *J* = 14.4, 5.1 Hz, 1H); 2.41 (dd, *J* = 14.4, 9.6 Hz, 1H)	47.5	47.7	– 0.2
1’			193.0	193.2	– 0.2
2’			75.2	75.3	– 0.1
3’			202.4	202.6	– 0.2
4’	3.50 (s, 1H)	3.48, (s, 1H)	85.2	85.3	– 0.1
5’	7.98 (d, *J* = 7.8 Hz, 1H)	7.99 (d, *J* = 7.8 Hz, 1H)	124.5	124.6	– 0.1
6’	7.79 – 7.71 (m, 1H)	7.82 – 7.70 (m, 1H)	135.9	136.1	– 0.2
7’	7.53 (d, *J* = 7.5, 1.2 Hz, 1H)	7.54 (t, *J* = 7.7 Hz, 1H)	129.0	129.2	– 0.2
8’	8.10 (dd, *J* = 7.9, 1.3 Hz, 1H)	8.10 (d, *J* = 7.8 Hz, 1H)	127.9	128.0	– 0.1
9’			128.7	128.8	– 0.1
10’			146.6	146.7	– 0.1
11’	4.33 (td, *J* = 9.9, 5.1 Hz, 1H)	4.35 (td, *J* = 9.9, 5.1 Hz, 1H)	35.0	35.1	– 0.1
12’	5.59 (d, *J*= 10.3 Hz, 1H)	5.60 (d, *J*= 10.3 Hz, 1H)	123.1	123.2	– 0.1
13’			133.2	133.4	– 0.2
14’	1.75 (s, 3H)	1.76 (s, 3H)	18.0	18.1	– 0.1
15’	1.72 (s, 3H)	1.73 (s, 3H)	25.8	26.0	– 0.2

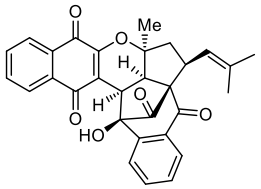


11'-*epi*-peshawaraquinone (23)
^{1}H NMR 500 MHz $CDCl_3$
This work

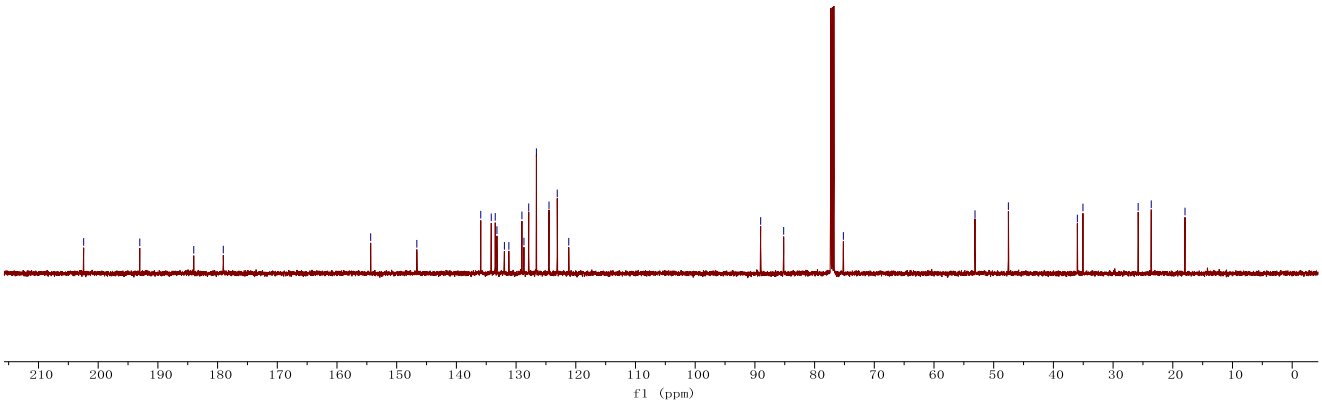


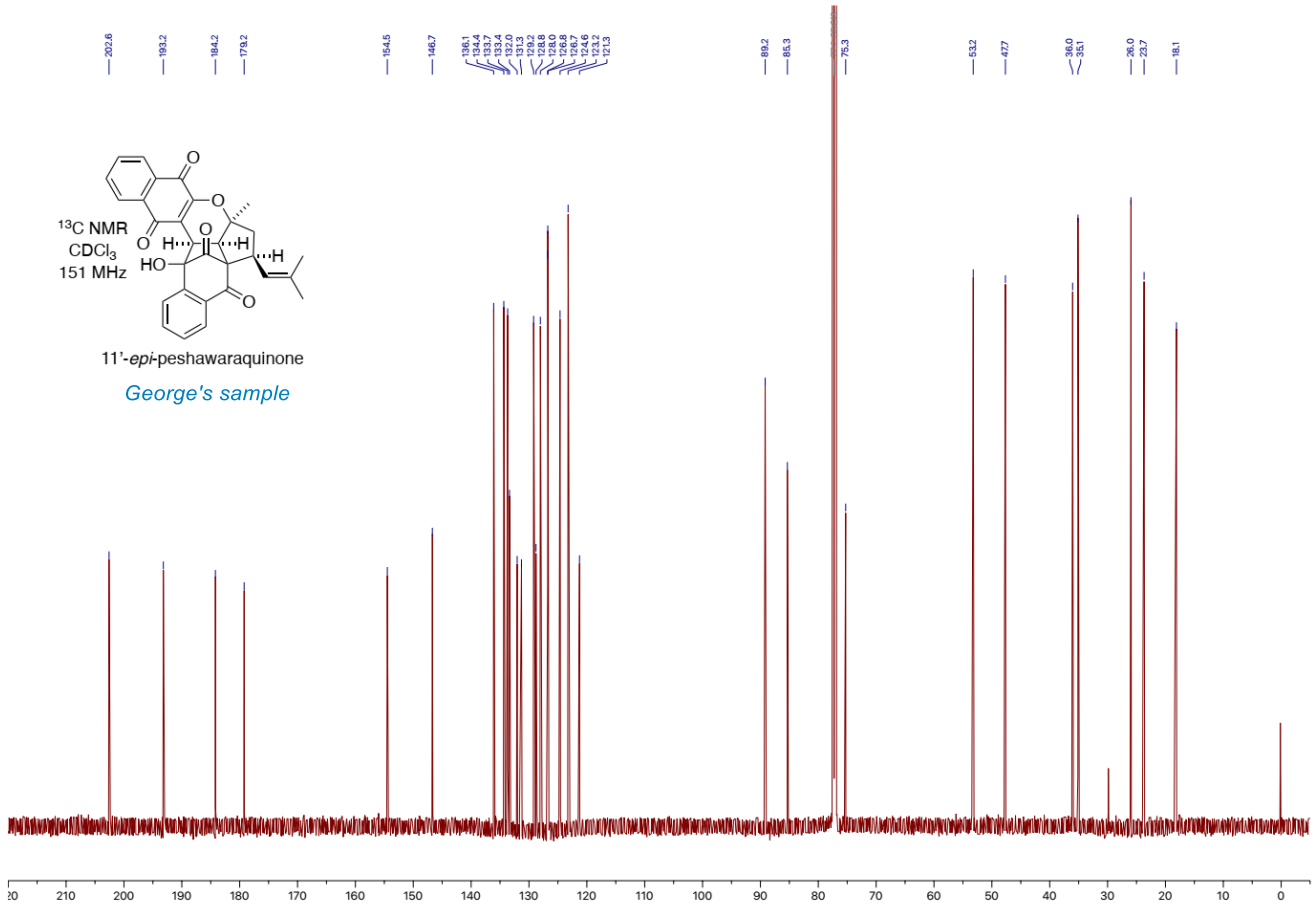


11'-*epi*-peshawaraquinone
George's sample



11'-*epi*-peshawaraquinone (23)
^{13}C NMR 125 MHz $CDCl_3$





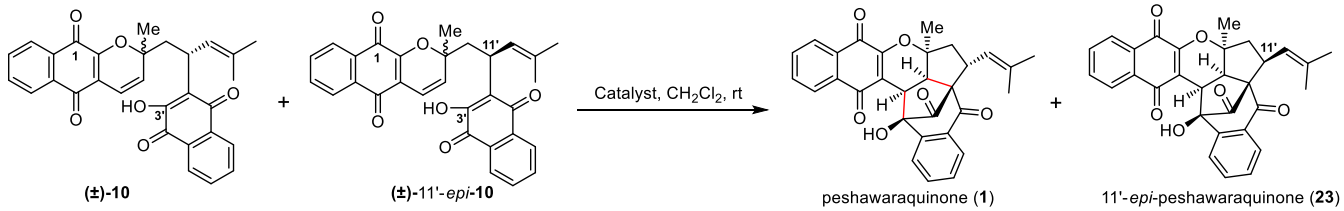
11'-*epi*-peshawaraquinone

George's sample

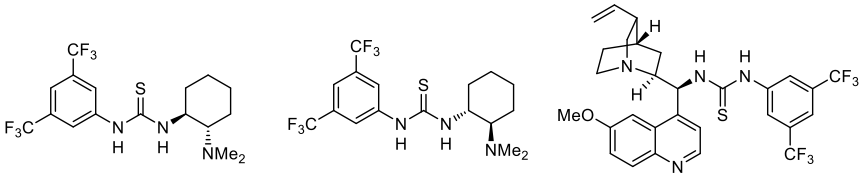
3. Evolution of synthetic strategy for Peshawaraquinone.

3.1 Asymmetric investigation.

We tried racemic intermediate **10** as substrate for [3+2] cycloaddition:



Entry	Catalyst	peshawaraquinone er	11'-epi-peshawaquinone er	dr (1:23)	Yield
1	Catalyst 1	82:18	93:7	1:1.4	58%
2	Catalyst 2	17:83	35:65	1:1.5	67%
3	Catalyst 3	83:17	71:29	1:1.5	53%
4	1+2 (1:1)	48.9:51.1	50.5:49.5	1:1.5	45%

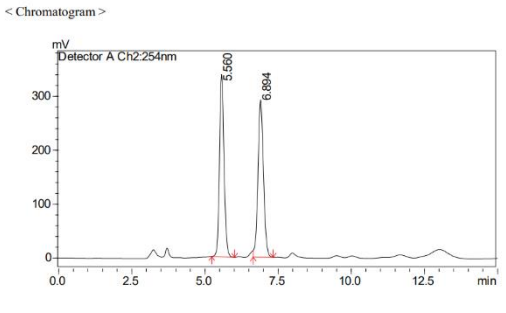


Catalyst 1 (**22**) Catalyst 2 Catalyst 3

From catalyst 1 (22), Peshawaraquinone (82:18 er)

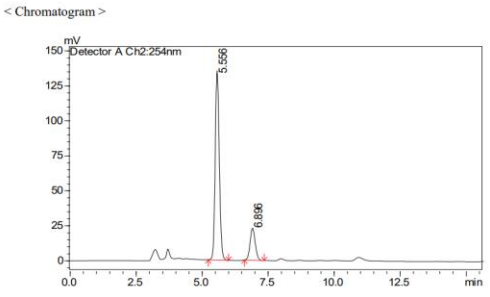
HPLC (CHIRALCEL, *n*-Hex/Ethanol/Diethylamine = 75/25/0.1 (v/v/v), flow rate = 1 mL/min, UV 254 nm), t_R = 5.556 min (major), t_R = 6.896 min (minor).

Racemic mixture of peshawaraquinone **peshawaraquinone (82:18 er)**



<Column Performance Report>

Peak No.	Time	Area	Area %	Plate number	Tailing	Resolution
1	5.560	3631922	48.8882	5205.697	1.195	--
2	6.894	3797109	51.1118	5687.305	1.058	3.958



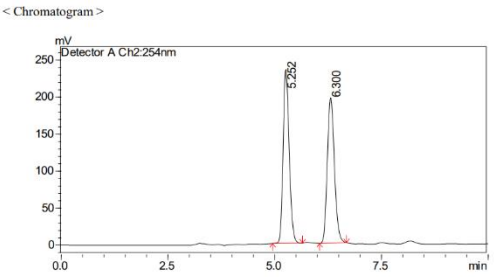
<Column Performance Report>

Peak No.	Time	Area	Area %	Plate number	Tailing	Resolution
1	5.556	1429385	82.1911	5297.704	1.192	--
2	6.896	309715	17.8089	5201.308	1.132	3.896

From catalyst 1 (22), 11'-*epi*-peshawaraquinone (93:7 er)

HPLC (CHIRALCEL, *n*-Hex/Ethanol/Diethylamine = 75/25/0.1 (v/v/v), flow rate = 1 mL/min, UV 254 nm), t_R = 5.256 min (major), t_R = 6.298 min (minor).

Racemic mixture of **11'-*epi*-peshawaraquinone** **11'-*epi*-peshawaraquinone (93:7 er)**



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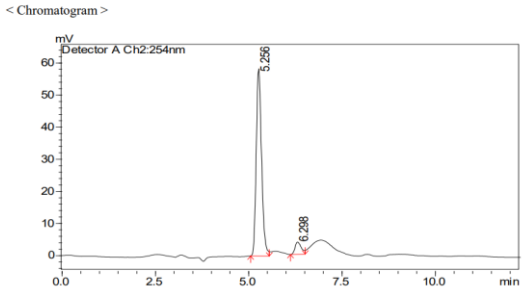
Peak No.	Time	Area	Area %	Plate number	Tailing	Resolution
1	5.252	2320397	50.5452	5283.892	1.257	--
2	6.300	2270340	49.4548	5874.208	1.230	3.391



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Peak No.	Time	Area	Area %	Plate number	Tailing	Resolution
1	5.256	585111	92.7509	5235.599	1.313	--
2	6.298	45730	7.2491	5418.434	--	3.292

From intermediate **20**, chiral prep-HPLC was performed and two enantiopure products were isolated, their absolute configuration was confirmed by comparing the experimental and calculated electronic circular dichroism (ECD) spectra. (Figure S1)

HPLC (CHIRALPAK IG, *n*-Hex/IPA = 90/10 (v/v), flow rate = 1 mL/min, UV 254 nm), t_R = 3.602 min (**(+)-20**), t_R = 4.360 min (**(–)-20**).

***R*-20: $[\alpha]_D^{20}$ = –22.50 (c = 0.1, $CHCl_3$); *S*-20: $[\alpha]_D^{20}$ = +19.40 (c = 0.1, $CHCl_3$).**

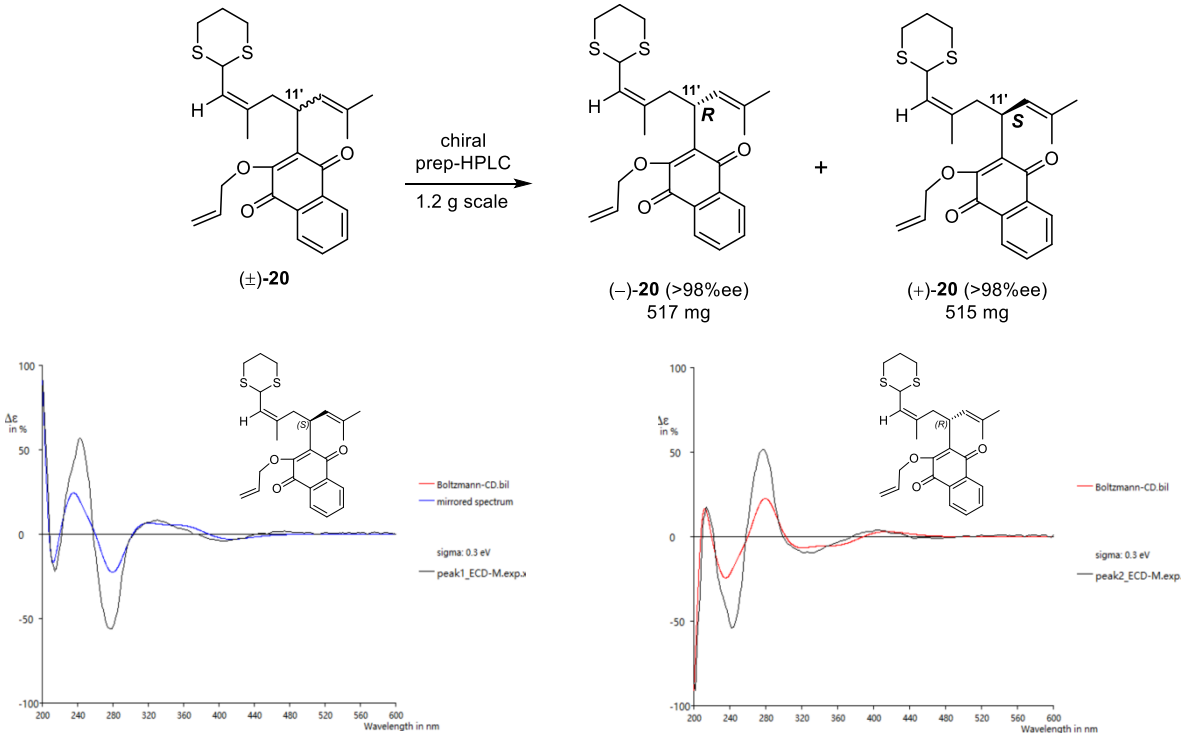
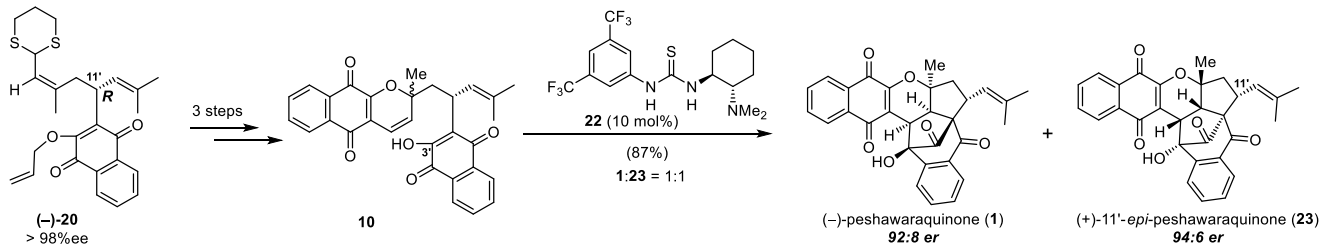


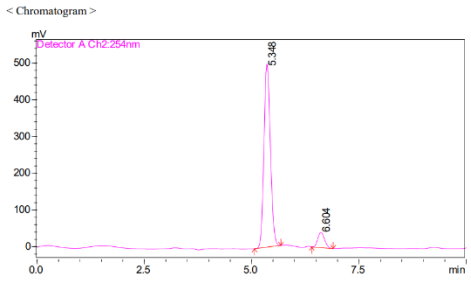
Figure S1. Experimental and calculated ECD spectra of S-20 and R-20.

From **(–)-20**, through the synthetic route, (–)-peshawaraquinone and (+)-11'-*epi*-peshawaraquinone were synthesized.



(–)-Peshawaraquinone (92:8 er)

$[a]_D^{20}$ = – 133.72 (c = 0.2, $CHCl_3$)



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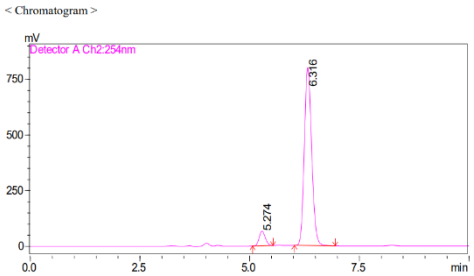
Peak No.	Time	Area	Area %	Plate number	Tailing	Resolution
1	5.348	5191387	92.0545	4936.920	1.191	--
2	6.604	448084	7.9455	6942.675	1.223	4.044

(+)-11'-epi-peshawaraquinone (94:6 er)

$[a]_D^{20}$ = + 144.06 (c = 0.2, $CHCl_3$)



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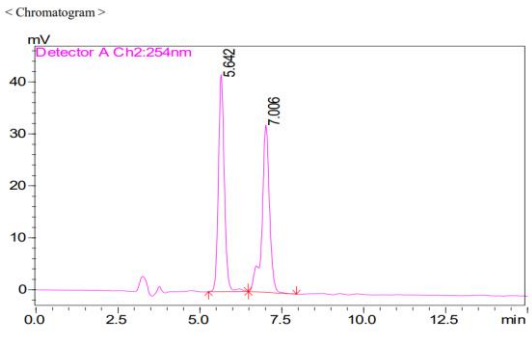
Peak No.	Time	Area	Area %	Plate number	Tailing	Resolution
1	5.274	642303	6.4308	5380.986	1.206	--
2	6.316	9345624	93.5692	5773.684	1.200	3.361

Natural product peshawaraquinone was re-isolated by Abdur Rauf and sent to us, chiral HPLC measurement confirmed that natural sample was a racemic mixture.



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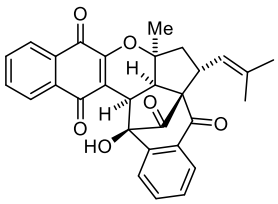
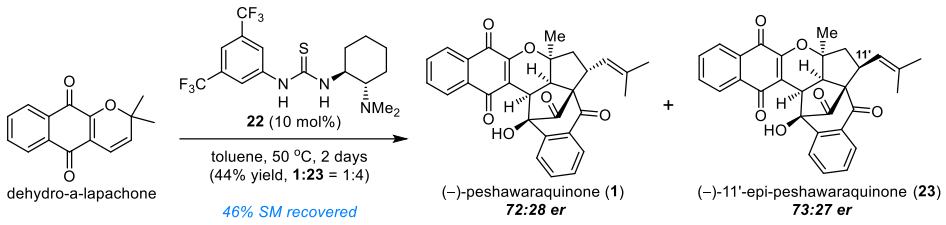
Peak No.	Time	Area	Area %	Plate number	Tailing	Resolution
1	5.642	522209	50.4152	4194.142	1.153	--
2	7.006	513608	49.5848	4977.921	0.854	3.659



peshawaraquinone (**1**)
authentic sample
50.4:49.6 er

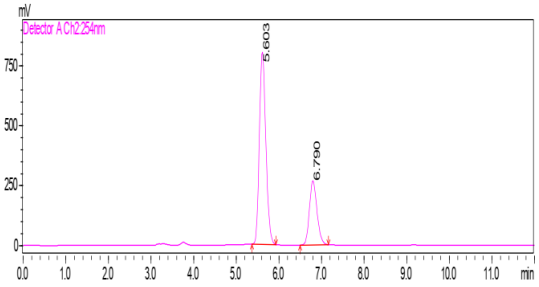
We also tried Takemoto's catalyst on George's sequence and found both **1** and **23** could be prepared.



To a stirred solution of dehydro-α-lapachone (50 mg, 0.21 mmol) in dry toluene (1 mL) at 50 °C was added (S, S)-Takemoto's catalyst (8.6 mg, 0.021 mmol) for 48 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 10:1 to 2:1) afforded a mixture of **(–)-peshawaraquinone (1)** and **(+)-11'-epi-peshawaraquinone (23)** (22 mg, 0.046 mmol, 44%) in a ratio of 1:4, which was further separated through preparative TLC.

HPLC measurment:

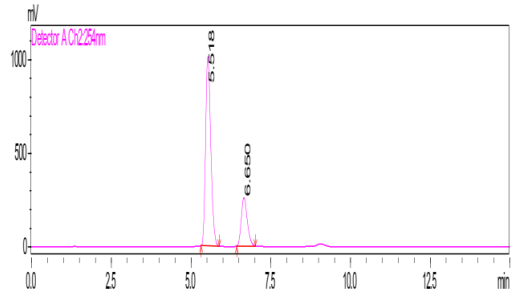
For peshawaraquinone (72:28 er)



<Column Performance Report>

Peak No.	Time	Area	Area %	Plate number	Tailing	Resolution
1	5.603	8540301	71.9486	5273.759	1.251	--
2	6.790	3329704	28.0514	5908.597	1.230	3.586

For 11'-*epi*-peshawaraquinone (77:23 er)

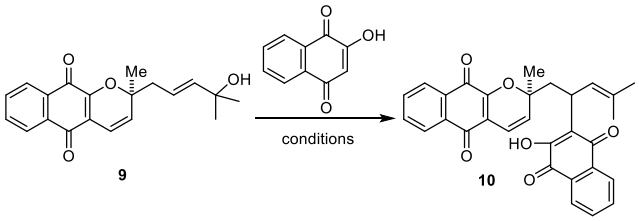


<Column Performance Report>

Peak No.	Time	Area	Area %	Plate number	Tailing	Resolution
1	5.518	11482784	77.2786	4536.495	1.321	--
2	6.650	3376162	22.7214	5216.506	1.293	3.251

3.2 Attempted synthesis peshawaraquinone through allylic substitution.

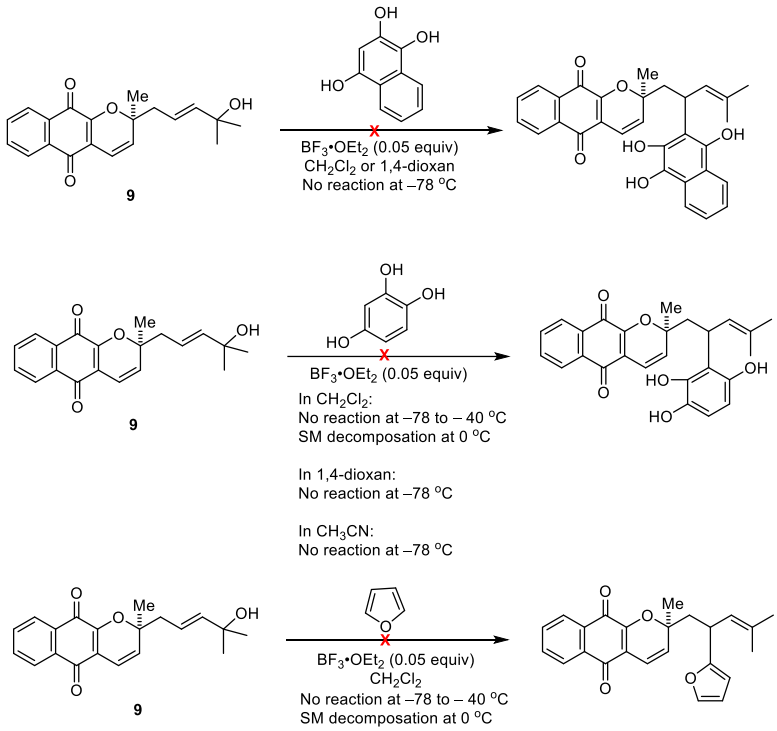
Several Lewis acids were screened for coupling **9** with lawsone:



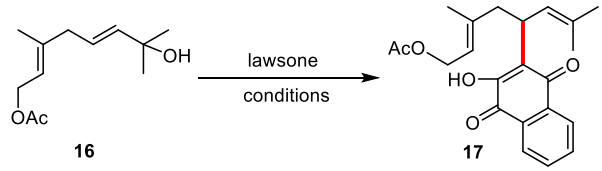
Entry	Conditions[a]	Result
1	BF_3•OEt_2	No reaction
2	$Yb(OTf)_3$	unidentified product formed
3	$Sc(OTf)_3$	unidentified product formed
4	$SnCl_4$	No reaction
5	TFA[b]	No reaction
6	$Pd(TFA)_2$	No reaction
7	HFIP[c], 70 °C	No reaction
8	HFIP[c], 100 °C	No reaction

[a]Reaction conditions: **9** (1 equiv), lawsone (2.5 equiv), acid (0.05 equiv) in dry CH_2Cl_2 at 0 °C. [b]Reaction set up at r.t. [c]used as reaction solvent.

Coupling reaction between **9** and three other aromatic compounds (furan, 1,2,4-benzenetriol and 1,2,4-naphthalenetriol) were also investigated.



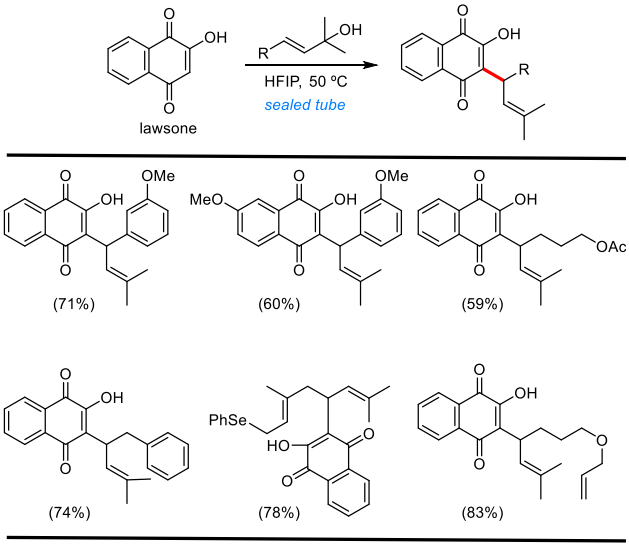
Several Lewis acids were screened for coupling **16** with lawsone:



Entry	Conditions[a]	Result
1	BF_3•OEt_2	No reaction
2	$Yb(OTf)_3$	No reaction
3	$Sc(OTf)_3$	No reaction
4	$SnCl_4$	No reaction
5	TFA[b]	No reaction
6	TFE,[c] 70 °C	No reaction
7	HFIP,[c] 50 °C	95% **17**

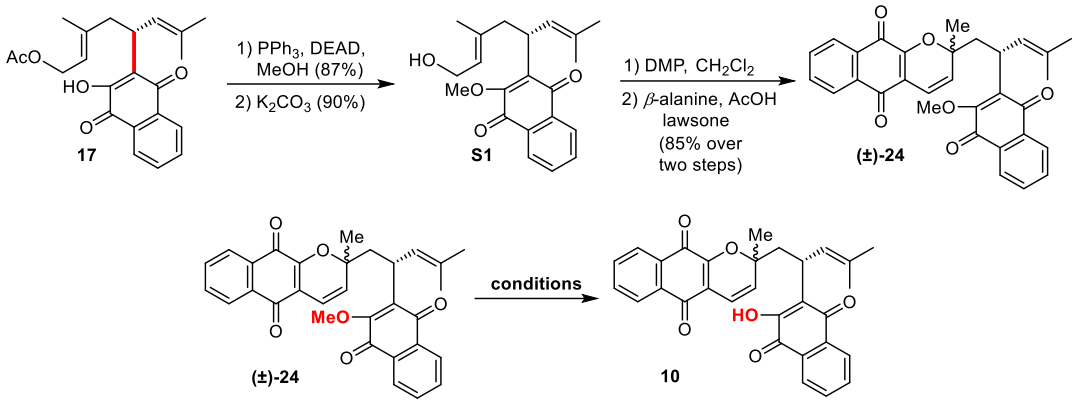
[a]Reaction conditions: **16** (1 equiv), lawsone (2.5 equiv), acid (0.05 equiv) in dry CH_2Cl_2 at 0 °C. [b]Reaction set up at r.t. [c]used as reaction solvent.

This HFIP-promoted allylation was further tested on different substrates.[a,b]



[a]Reaction conditions: alcohol (1 equiv), naphthoquinone (2.5 equiv) in HFIP (1 mmol/mL for alcohol), 50 °C. [b]Yields of isolated products are given.

3.3 Dead-end when methoxy group was used as protecting group.



entry	conditions	result
1	LiI (10 eq), DMSO, 50 °C	SM decomposition
2	LiI (2 eq), 2,6-lutidine, toluene, rt	No reaction
3	KOH (22 eq or 5 eq), MeOH, rt	SM decomposition
4	$AlCl_3$ (2 eq), DCE, - 78 °C	No reaction
5	$AlCl_3$ (15 eq), DCM, rt	SM decomposition
6	$AlCl_3$ (5 eq), DCM, 0 °C	SM decomposition
7	MgI_2 (7.5 eq), quinoline, THF, rt	SM decomposition
8	MgI_2 (7.5 eq), quinoline 2-Methyl-2-butene, THF, rt	SM decomposition
9	SiO_2, DCM, rt	No reaction
10	HFIP, rt	No reaction
11	K_2CO_3 (1.2 eq), MeOH, rt	SM decomposition
12	K_2CO_3 (5 eq), MeOH/H_2O=1:1, rt	No reaction

entry	conditions	result
13	TMSOK (0.5 eq), THF, rt	SM decomposition
14	TMSI (1.3 eq), $CHCl_3$, rt	SM decomposition
15	TMSI (0.4 eq), 2.6-lutidine $CHCl_3$, 0 °C	No reaction
16	HCl (0.5 eq), THF, 0 °C	No reaction
17	LiOH (2 eq), dioxane/H_2O=2:1, rt	SM decomposition
18	LiCl (5 eq), DMSO, rt	SM decomposition
19	$MeTeAlMe_2$ (5 eq), toluene, rt	No reaction
20	$(PhSe)_2$ (4 eq), $NaBH_4$, EtOH, 0 °C-75 °C	No reaction
21	NBS (1 eq), THF, 0 °C	No reaction
22	$BF_3{\cdot}Et_2O$, DCM, rt 	No reaction
23	BBr_3 (1eq, 2eq, 5eq), DCM, –78 °C	SM decomposition

4. Experimental Procedures and Characterization Data

4.1 General Experimental Details

Unless otherwise stated, all reactions were performed with magnetic stirring under a positive pressure of nitrogen or argon gas. Oven-dried glassware (70 °C oven temperature) was further dried with a heat-gun at 650 °C under vacuum, followed by back-filling with inert gas, three times and fitted with rubber septa prior to use. Solids were added under inert gas counter flow or were dissolved and transferred in the appropriate solvent. Solutions and liquids reagents were transferred to reaction vessels by oven-dried stainless-steel cannulas or nitrogen flushed syringes. Low temperature reactions were carried out in a Dewar vessel filled with acetone/dry ice (−78 °C) or distilled water/ice (0 °C). High temperature reactions were conducted using a heated silicon oil bath in reaction vessels equipped with a reflux condenser.

4.2 Materials

Dry tetrahydrofuran (THF), *t*-BuOMe, dichloromethane (CH_2Cl_2), ethanol (EtOH), toluene (PhMe) and methanol (MeOH) were purchased from Tansoole company as extra dry regents under inert gas atmosphere and stored over molecular sieves. Ethyl acetate (EtOAc), pentane, *t*-BuOMe, CH_2Cl_2 and MeOH used specifically for extraction and flash column chromatography were purchased at technical grade from commercial sources and distilled under reduced pressure. All other solvents and regents were used as received from commercial sources (Sigma Aldrich, Energy chemical, 3A, Innochem, and Adamas).

Reactions were monitored by thin-layer chromatography (TLC) using silica gel F254 precoated glass plates (*Merck*) and visualized by exposure to ultraviolet light (λ = 254 nm) or by staining with aqueous potassium permanganate ($KMnO_4$) solution (1.05 g $KMnO_4$, 7.2 g K_2CO_3, 1.5 mL 1N NaOH, 150 mL distilled H_2O), phosphomolybdic acid hydrate (PMA) solution (10.0 g $12MoO_3•H_3PO_4$, 100 mL distilled EtOH) followed by heating with a heat gun (150–600 ºC). Flash column chromatography was performed using silica gel (60 Å, 40–63 µm, Merck) and a forced flow of eluent.

4.3 Instrumentation

Proton (^1H) and carbon (^{13}C) nuclear magnetic resonance spectra were recorded on a Brucker Avance III HD 500 MHz and 400 MHz spectrometer equipped with a CryoProbeTM. Proton chemical shifts are expressed in parts per million (ppm, δ scale) and referenced to residual undeuterated solvent signals ($CDCl_3$: 7.26 ppm; C_6D_6: 7.16 ppm). Carbon chemical shifts are expressed in parts per million (ppm, δ scale) and referenced to the central carbon resonance of the solvent ($CDCl_3$: 77.16 ppm; C_6D_6: 128.06 ppm). The reported data is represented as follows: chemical shift in parts per million (ppm, δ scale) (multiplicity, coupling constants J in Hz, integration intensity, proton assignment). Abbreviations used for analysis of multiplets are as follows: s (singlet), br (broad singlet), d (doublet), t (triplet), q (quartet),

quin (quintet), h (hextet), and m (multiplet). Variable temperature NMR spectroscopy was performed at the *Northwest A&F University* NMR facility.

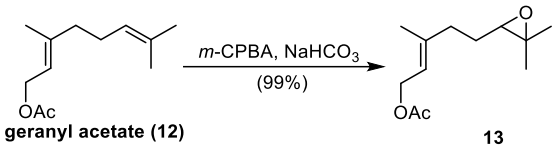
Mass spectroscopy (MS) experiments were performed in high resolution with an AB SCIEX Triple TOF 5600+ spectrometer (AB SCIEX, Boston, MA, USA) at the *Northwest A&F University* mass spectrometry facility.

IR spectra were recorded on a PerkinElmer Spectrum BXII FTIR spectrometer equipped with an attenuated total reflection (ATR) measuring unit. IR data is recorded in frequency of absorption (wavenumber in cm^{-1}) with bands described as weak (w), medium (m), strong (s), broad (br) and combinations thereof.

4.4 Experimental Procedures

Attempted synthesis peshawaraquinone through allylation.

Compound 13



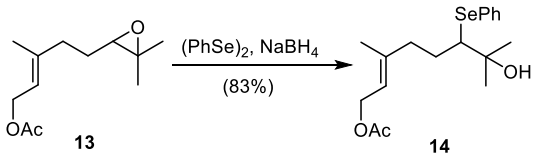
geranyl acetate (12) 13

To a stirred solution of geranyl acetate (3.0 g, 15.3 mmol) in dry CH_2Cl_2 (180 mL) at 0 °C was added $NaHCO_3$ (1.28 g, 15.3 mmol), then a solution of *m*-CPBA (70%-75%, 3.66 g, 15.3 mmol) in dry CH_2Cl_2 (60 mL) was added dropwise over 30 mins. After stirring at r.t for 8 h, the reaction mixture was directly washed with sat. $NaHCO_3$ (3 × 80 mL) and sat. NaCl (80 mL), dried over anhydrous Na_2SO_4. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 10:1) afforded compound **13**[3] (3.21 g, 15.22 mmol, 99 %) as a colorless oil.

R_f = 0.48 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

^{1}H NMR (500 MHz, $CDCl_3$): δ = 5.22 (t, *J* = 7.8 Hz, 1 H), 5.17 (s, 1H), 4.41 (d, *J* = 7.2 Hz, 2H), 2.52 (t, *J* = 6.3 Hz, 1H), 2.09–1.96 (m, 2H), 1.87 (s, 3H), 1.56 (s, 3H), 1.51–1.47 (m, 2H), 1.13 (s, 3H), 1.09 (s, 3H).

Compound 14



13 14

To a stirred solution of diphenyl diselenide (3.68 g, 11.8 mmol) in anhydrous ethanol (20 mL) at 0 °C was added $NaBH_4$ (870 mg, 23.5 mmol) in portions. After the bubbling ceased and the yellow color of reaction mixture disappeared, a solution of epoxide **13** (1.0 g, 4.7 mmol) in anhydrous ethanol (20 mL) was added in one portion. The reaction mixture was refluxed for 10 mins (pre-heated oil bath) and then directly cooled down to r.t. Then the reaction mixture was directly concentrated to remove most of the solvent under reduced pressure and re-dissolved in EtOAc (30 mL). The reaction mixture was quenched

with sat. $NaHCO_3$ (30 mL), extracted with EtOAc (3 × 30 mL), and the combined organic layers were dried over anhydrous Na_2SO_4. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 15:1) afforded compound **14** (1.44 g, 3.90 mmol, 83%) as a pale-yellow oil.

R_f =0.44 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

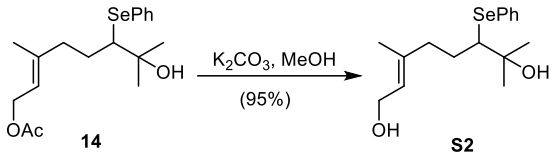
^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.45–7.43 (m, 2H), 7.08–7.06 (m, 3H), 5.06 (t, *J* = 7.2 Hz, 1H), 4.40–4.32 (m, 2H), 2.92–2.90 (m, 1H), 2.36–2.31 (m, 1H), 2.08–2.02 (m, 1H), 1.96–1.90 (m, 1H), 1.85 (s, 3H), 1.51 (s, 3H), 1.49–1.44 (m, 1H), 1.19 (s, 3H), 1.13 (s, 3H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 170.7, 140.9, 133.4 (2C), 131.4, 129.0 (2C), 127.0, 119.5, 72.9, 62.8, 61.1, 38.4, 30.2, 27.6, 26.6, 20.9, 16.2;

HRMS (ESI) calcd. for $C_{18}H_{26}O_3SeNa$ $[M+Na]^+$ 393.0939; found: 393.0938;

IR (neat) ν_{max} 2967, 1730, 1451, 1374, 1240, 1024, 958, 741 cm^{-1}.

Compound S2



To a stirred solution of compound **14** (1.25 g, 3.4 mmol) in MeOH (15 mL) at r.t was added K_2CO_3 (937 mg, 6.8 mmol). After 5 h, the reaction mixture was directly concentrated to remove most of the solvent under reduced pressure and re-dissolved in EtOAc (15 mL). The reaction mixture was quenched with 1N HCl (7 mL), extracted with EtOAc (3 × 10 mL), and the combined organic layers were dried over anhydrous Na_2SO_4. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 2:1) afforded compound **S2** (1.06 g, 3.24 mmol, 95%) as a pale-yellow oil.

R_f = 0.29 (petroleum ether/ethyl acetate = 2:1, stains with PMA);

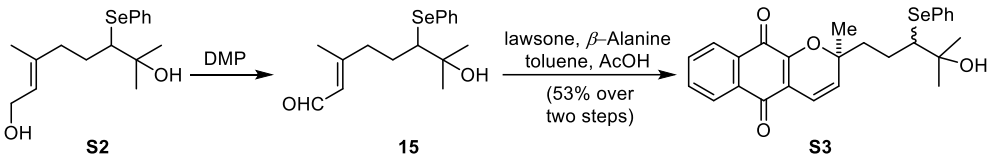
^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.54–7.53 (m, 2H), 7.19–7.17 (m, 3H), 5.14 (t, *J* = 7.0 Hz, 1H), 4.00–3.94 (m, 2H), 3.00 (dd, *J* = 11.7, 2.1 Hz, 1H), 2.67 (br, 1H), 2.42–2.37 (m, 1H), 2.14–2.08 (m, 1H), 1.97–1.90 (m, 1H), 1.62–1.58 (m, 1H), 1.55 (s, 3H), 1.28 (s, 3H), 1.18 (s, 3H) ;

^{13}C NMR (125 MHz, $CDCl_3$): δ = 138.3, 133.5 (2C), 131.4, 129.2 (2C), 127.2, 124.7, 72.8, 64.5, 59.2, 38.5, 30.9, 27.0, 26.8, 16.1;

HRMS (ESI) calcd. for $C_{16}H_{24}O_2SeNa$ $[M+Na]^+$ 351.0833; found: 351.0833;

IR (neat) ν_{max} 2966, 1452, 1374, 1001, 739 cm^{-1}.

Compound S3



To a stirred solution of allylic alcohol **S2** (300 mg, 0.92 mmol) in CH_2Cl_2 (6 mL) at r.t was added Dess-Martin periodinane (466 mg, 1.1 mmol), after stirred for 20 mins, the reaction mixture was quenched with sat. Na_2SO_3 (5 mL), then extracted with CH_2Cl_2 (3 × 5 mL). The combined organic layers were washed with sat. NaCl (10 mL) and dried over anhydrous Na_2SO_4. Concentrated afford compound **15** which was directly used for the next step.

A solution of unsaturated aldehyde **15** (298 mg, 0.92 mmol), lawsone (240 mg, 1.38mmol), *β*-alanine (12 mg, 0.14 mmol) and AcOH (0.03 mL) in toluene (15 mL) was heated at 120 °C for 8 h. Then solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 15:1) afforded compound **S3** (233 mg, 0.48 mmol, 53% over two steps) as an orange oil.

Compound **S3** is a 1:1 diastereisomer mixture.

Data for compound S3:

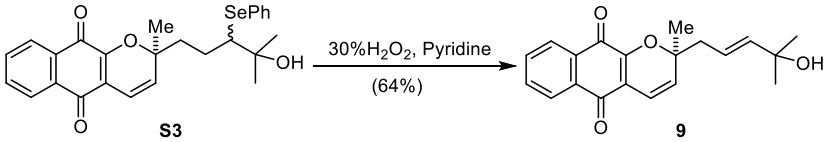
R_f = 0.50 (petroleum ether/ethyl acetate = 2:1, stains with PMA);

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.07–8.04 (m, 2H), 7.71–7.65 (m, 2H), 7.55–7.53 (m, 2H), 7.23–7.16 (m, 3H), 6.66 (dd, *J* = 22.4, 10.0 Hz, 1H), 5.61 (dd, *J* = 10.1, 5.7 Hz, 1H), 3.07 (td, *J* = 13.4, 2.4 Hz,, 1H), 2.37–2.22 (m, 1H), 2.15–2.04 (m, 1H), 2.00–1.79 (m, 1H), 1.75–1.56 (m, 1H), 1.48 (d, *J* = 10.4 Hz, 3H), 1.32 (d, *J* = 5.9 Hz, 3H), 1.24 (d, *J* = 9.2 Hz, 3H);

HRMS (ESI) calcd. for $C_{26}H_{26}O_4SeNa$ $[M+Na]^+$ 505.0888; found: 505.0890;

IR (neat) ν_{max} 2971, 1723, 1659, 1364, 1162, 970 cm^{-1}.

Compound 9



To a stirred solution of compound **S3** (553 mg, 1.15 mmol) in CH_2Cl_2 (5 mL) at 0 °C was added pyridine (0.32 mL, 4.03 mmol) followed by H_2O_2 (0.94 mL, 9.19 mmol, 30% wt in H_2O). After stirred at 0 °C for 1 h, the reaction mixture was quenched with water (5 mL), extracted with EtOAc (3 × 5 mL), and the combined organic layers were dried over anhydrous Na_2SO_4. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded compound **9** (237 mg, 0.73 mmol, 64%) as an orange oil.

R_f = 0.24 (petroleum ether/ethyl acetate = 2:1, stains with PMA);

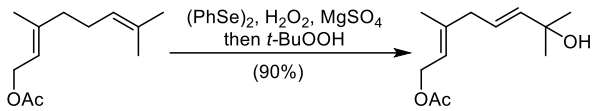
^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.07 (d, *J* = 7.3 Hz, 2H), 7.72–7.65 (m, 2H), 6.68 (d, *J* = 10.0 Hz, 1H), 5.73–5.63 (m, 3H), 2.56 (dd, *J* = 14.1, 6.8 Hz, 1H), 2.43 (dd, *J* = 14.1, 6.3 Hz, 1H), 1.55 (br, 1H), 1.54 (s, 3H), 1.22 (s, 3H), 1.21 (s, 3H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 181.8, 179.6, 152.7, 143.3, 134.0, 133.3, 131.50, 131.47, 129.5, 126.3, 126.2, 119.7, 117.9, 116.3, 82.4, 70.6, 44.3, 29.74, 29.68, 27.1;

HRMS (ESI) calcd. for $C_{20}H_{20}O_4Na$ $[M+Na]^+$ 347.1253; found: 347.1255;

IR (neat) ν_{max} 2971, 2924, 1660, 1595, 1354, 1268, 1207, 1152, 968, 722 cm^{-1}.

Compound 16



geranyl acetate(12) **16**

To a stirred solution of $(PhSe)_2$ (1.6 g, 5.09 mmol) in CH_2Cl_2 (15 mL) at 0 °C was added H_2O_2 (0.5 mL, 5.09 mmol, 30% wt in H_2O). After stirring vigorously for 0.5 h, powered anhydrous $MgSO_4$ (3.1 g, 25.47 mmol) was added to the reaction mixture and stirred at 0 °C for 0.5 h. Geranyl acetate (500 mg, 2.55 mmol) was added to the mixture, after stirred at r.t for 5 h, the reaction mixture was cooled down to 0 °C and chilled *t*-BuOOH (70% wt solution in H_2O, 3.3 mL, 25.47 mmol) was added. The reaction mixture was warmed up to r.t and stirred for 12 h, quenched with sat. Na_2SO_3 (20 mL) and extracted with EtOAc (3 × 30 mL). The combined organic layers were washed with sat. NaCl (100 mL) and dried over anhydrous Na_2SO_4. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 30:1 to 2:1) afforded compound **16** (487 mg, 2.29 mmol, 90%) as a colorless oil.

R_f = 0.53 (petroleum ether/ethyl acetate = 2:1, stains with PMA);

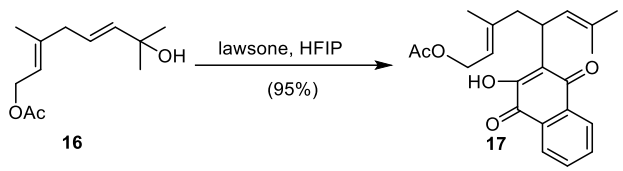
^{1}H NMR (500 MHz, C_6D_6): δ = 5.57–5.49 (m, 2H), 5.44–5.42 (m, 1H), 4.59 (d, *J* = 7.1 Hz, 2H), 2.55 (d, *J* = 5.2 Hz, 2H), 1.69 (s, 3H), 1.50 (s, 3H), 1.18 (s, 6H);

^{13}C NMR (125 MHz, C_6D_6): δ = 169.9, 140.8, 140.3, 123.3, 119.6, 69.8, 60.9, 42.1, 29.7 (2C), 20.2, 16.0;

HRMS (ESI) calcd. for $C_{12}H_{20}O_3Na$ $[M+Na]^+$ 235.1304; found: 235.1305;

IR (neat) ν_{max} 2929, 2872, 1458, 1215, 1140, 1122, 1083, 1042 cm^{-1}.

Compound 17



16 **17**

To a stirred solution of compound **16** (262 mg, 1.23 mmol) in HFIP (1.0 mL) in a sealed tube was added lawsone (537 mg, 3.08 mmol), then the flask was sealed and the reaction mixture was stirred at

50 °C for 15 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 30:1 to 5:1) afforded compound **17** (421 mg,1.14 mmol, 95%) as an orange oil.

R_f = 0.50 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

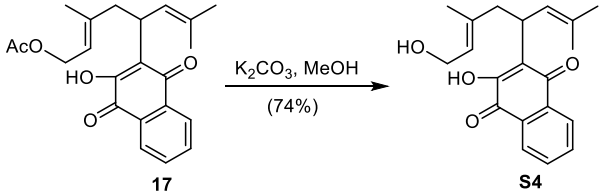
^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.08 (d, *J* = 8.0 Hz, 1H), 8.03 (d, *J* = 7.2 Hz, 1H), 7.72 (t, *J* = 7.5 Hz, 1H), 7.64 (t, *J* = 7.5 Hz, 1H), 7.49 (br, 1H), 5.54 (d, *J* = 9.2 Hz, 1H), 5.25 (t, *J* = 7.1 Hz, 1H), 4.42 (d, *J* = 7.1 Hz, 2H), 4.31–4.26 (m, 1H), 2.63 (dd, *J* = 13.2, 9.2 Hz, 1H), 2.38 (dd, *J* = 13.2, 6.8 Hz, 1H), 1.80 (s, 3H), 1.71 (s, 3H), 1.66 (s, 6H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 184.2, 181.7, 170.9, 152.6, 140.7, 134.9, 133.1, 132.9, 132.8, 129.3, 126.9, 125.9, 125.6, 125.0, 120.2, 61.1, 43.0, 33.3, 25.7, 20.7, 18.1, 16.3;

HRMS (ESI) calcd. for $C_{22}H_{24}O_5Na$ $[M+Na]^+$: 391.1515; found: 391.1515;

IR (neat) ν_{max} 2976, 2926, 1737, 1668, 1648, 1614, 1595, 1368, 1338, 1267, 1234, 1022, 726 cm^{-1}.

Compound S4



To a stirred solution of compound **17** (494 mg, 1.34 mmol) in MeOH (7 mL) at r.t was added K_2CO_3 (278 mg, 2.01 mmol). After 5 h, the reaction mixture was quenched with 1N HCl (5 mL), extracted with CH_2Cl_2 (3 × 5 mL), and the combined organic layers were dried over anhydrous Na_2SO_4. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 10:1 to 2:1) afforded compound **S4** (325 mg, 0.99 mmol, 74%) as an orange oil.

R_f = 0.38 (petroleum ether/ethyl acetate = 2:1, stains with PMA);

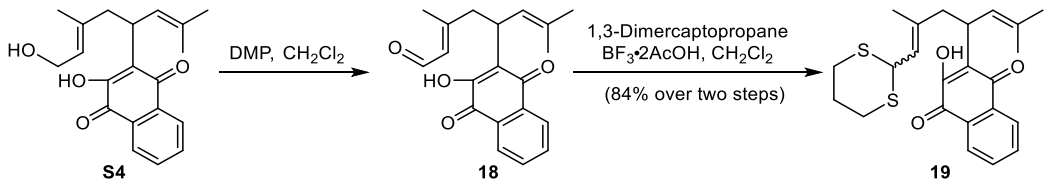
^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.05 (dd, *J* = 7.7, 1.3 Hz, 1H), 7.99 (dd, *J* = 7.6, 1.3 Hz, 1H), 7.76 (s, 1H), 7.70 (td, *J* = 7.6, 1.4 Hz, 1H), 7.62 (td, *J* = 7.5, 1.3 Hz, 1H), 5.54 (d, *J* = 9.3 Hz, 1H), 5.35 (td, *J* = 7.1, 4.2 Hz, 1H), 4.27 (td, *J* = 9.0, 6.9 Hz, 1H), 4.04 (dd, *J* = 12.4, 7.0 Hz, 1H), 3.98 (dd, *J* = 12.3, 6.8 Hz, 1H), 2.59 (dd, *J* = 13.4, 8.7 Hz, 1H), 2.39 (dd, *J* = 13.4, 6.9 Hz, 1H), 1.67 (s, 3H), 1.65 (s, 6H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 184.4, 181.8, 152.8, 138.0, 134.8, 132.9, 132.85, 132.79, 129.3, 126.9, 125.99, 125.95, 125.21, 125.17, 59.3, 43.0, 33.3, 25.8, 18.1, 16.2;

HRMS (ESI) calcd. for $C_{20}H_{22}O_4Na$ $[M+Na]^+$: 349.1410; found: 349.1409;

IR (neat) ν_{max} 2969, 2918, 1668, 1645, 1594, 1367, 1269, 1218, 996, 726 cm^{-1}.

Compound 19

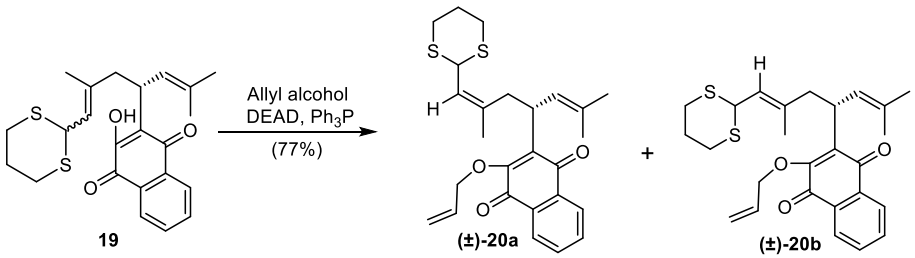


To a stirred solution of allylic alcohol **S4** (315 mg, 0.96 mmol) in CH_2Cl_2 (5 mL) at r.t was added Dess-Martin periodinane (400 mg, 0.96 mmol), after stirred for 10 mins, the reaction was quenched with sat. Na_2SO_3 (5 mL) and extracted with CH_2Cl_2 (3 × 5 mL). The combined organic layers were washed with sat. NaCl (10 mL) and dried over anhydrous Na_2SO_4. Concentrated afford crude compound **18** which was directly used for the next step.

To a stirred solution of compound **18** (0.96 mmol) in dry CH_2Cl_2 (5 mL) at r.t was added 1,3-dimercaptopropane (0.14 mL, 1.45 mmol) and BF_3•2AcOH (23.8 μL, 0.19 mmol) for 2.5 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded compound **19** (338 mg, 0.81 mmol, 84% over two steps) as a yellow oil.

*****We found that, after protecting the aldehyde group, compound **19** could be isolated as a mixture of geometric isomers in a ratio of 1:1.

Compound 20a and compound 20b



To a stirred solution of compound **19** (273.0 mg, 0.66 mmol) in dry THF (4 mL) at r.t was added PPh_3 (432.8 mg, 1.65 mmol), allyl alcohol (0.22 mL, 3.29 mmol), then DEAD (0.2 mL, 1.27 mmol) was added dropwise. After the reaction mixture was stirred at r.t for 12 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 30:1 to 5:1) afforded compound **20** (230 mg, 0.50 mmol, 77%) as a yellow oil.

***20a** and **20b** was obtained in a ratio of 1:1 and further isolated by prep TLC, then (+)-**20a** and (–)-**20a** were separated through chiral HPLC separation. Details were described in page S3.

*For racemic synthesis, the mixture of **20a** and **20b** was used directly for next steps.

$\mathbf{R_f}$ = 0.68 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

Data for compound 20a:

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.05–8.03 (m, 1H), 7.97–7.95 (m, 1H), 7.69–7.58 (m, 2H), 6.16–6.03 (m, 1H), 5.61 (dt, *J* = 8.8, 1.4 Hz, 1H), 5.43 (dd, *J* = 17.2, 1.4 Hz, 1H), 5.29 (dd, *J* = 10.5, 1.4 Hz, 1H) , 5.06–4.99 (m, 2H), 4.73–4.68 (m, 2H), 4.32 (td, *J* = 9.6, 5.3 Hz, 1H), 3.02 (dd, *J* = 13.1, 10.2 Hz, 1H), 2.88–2.81 (m, 1H), 2.72–2.61 (m, 1H), 2.42 (d, *J* = 12.8 Hz, 1H), 2.31 (d, *J* = 14.0 Hz, 1H), 2.22 (d, *J* = 13.1, 5.3 Hz, 1H), 1.97–1.90 (m, 1H), 1.79 (d, *J* = 1.4 Hz, 3H), 1.68 (d, *J* = 1.4 Hz, 3H), 1.66–1.62 (m, 1H), 1.61 (d, *J* = 1.4 Hz, 3H);

^{13}C NMR (100 MHz, $CDCl_3$): δ = 185.3, 181.7, 157.2, 139.2, 137.1, 133.5, 133.4, 133.0, 132.9, 132.3, 131.7, 126.3, 126.1, 125.8, 123.1, 118.4, 74.3, 44.7, 37.2, 33.4, 30.7, 30.5, 25.8, 24.8, 23.7, 18.2;

HRMS (ESI) calcd. for $C_{26}H_{30}O_3S_2Na$ $[M+Na]^+$: 477.1528; found: 477.1531;

IR (neat) ν_{max} 2915, 1660, 1594, 1297, 1258, 1195, 993, 722 cm^{-1}.

Data for compound 20b:

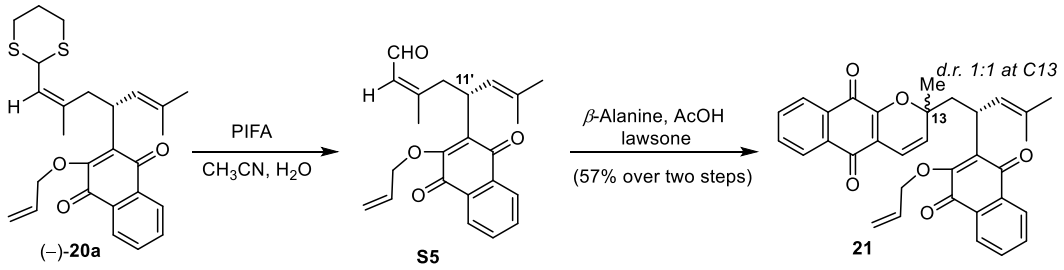
^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.03(d, *J* = 7.1 Hz, 1H), 7.98 (d, *J* = 6.7 Hz, 1H), 7.69–7.62 (m, 2H), 6.14–6.04 (m, 1H), 5.50 (d, *J* = 9.1 Hz, 1H), 5.41 (d, *J* = 17.2 Hz, 1H), 5.29 (d, *J* = 10.4 Hz, 1H), 5.07 (d, *J* = 10.1 Hz, 1H), 4.93 (dd, *J* = 12.4, 5.8 Hz, 1H), 4.83 (dd, *J* = 12.4, 5.9 Hz, 1H), 4.72 (d, *J* = 10.0 Hz, 1H), 4.32 (q, *J* = 8.3 Hz, 1H), 2.96–2.69 (m, 3H), 2.62 (dt, *J* = 14.1,3.8 Hz, 1H), 2.52 (dd, *J* = 13.0, 8.4 Hz, 1H), 2.38 (dd, *J* = 13.0, 7.3 Hz, 1H), 2.03–1.96 (m, 1H), 1.75 (s, 3H), 1.71 (d, *J* = 2.6 Hz, 1H),1.67 (s, 3H), 1.63 (s, 3H);

^{13}C NMR (100 MHz, $CDCl_3$): δ = 185.1, 182.0, 156.8, 139.0, 137.1, 133.7, 133.4, 133.1, 133.0, 132.1, 131.4, 126.4, 125.9, 125.5, 123.2, 118.5, 74.2, 44.0, 43.4, 33.7, 30.3(2C), 25.7, 24.9, 18.2, 16.7;

HRMS (ESI) calcd. for $C_{26}H_{30}O_3S_2Na$ $[M+Na]^+$: 477.1528; found: 477.1531;

IR (neat) ν_{max} 2918, 1663, 1595, 1438, 1379, 1268, 1185, 999, 724 cm^{-1}.

Compound 21



To a stirred solution of (–)-**20a** (133 mg, 0.29 mmol) in MeCN/H_2O (1 mL) at 0 °C was added PIFA (126 mg, 0.29 mmol) for 5 h. The reaction mixture was quenched with H_2O (5 mL), extracted with EtOAc (3 × 5 mL), and the combined organic layers were dried over anhydrous Na_2SO_4. Concentrated to afford crude product **S5** which was directly used for the next step.

A solution of above **S5** (0.29 mmol), lawsone (101 mg, 0.58 mmol), *β*-alanine (3.9 mg, 0.044 mmol) and AcOH (10 μL) in toluene (5 mL) was heated at 75 °C for 12 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded compound **21** (86 mg, 0.16 mmol, 57%) as an orange oil.

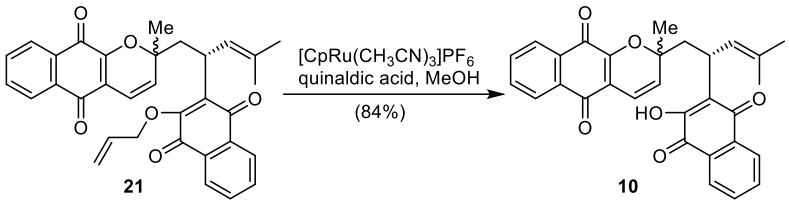
$\mathbf{R_f}$ = 0.53 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.05–7.89 (m, 3H), 7.79–7.77 (m, 1H), 7.73–7.52 (m, 4H), 6.64 (d, *J* = 10.2 Hz, 0.5H), 6.55 (d, *J* = 10.1 Hz, 0.5H), 6.09–5.96 (m, 1H), 5.69 (d, *J* = 10.2 Hz, 0.5H), 5.55 (d, *J* = 10.0 Hz, 0.5H), 5.54–5.49 (m, 1H), 5.37 (d, *J* = 17.1 Hz, 0.5H), 5.31 (dd, *J* = 17.1, 1.5 Hz, 0.5H), 5.23–5.19 (m, 1H), 4.94–4.91 (m, 1H), 4.87 (dd, *J* = 12.2, 5.8 Hz, 0.5H), 4.79 (dd, *J* = 12.2, 6.0 Hz, 0.5H), 4.53–4.43 (m, 1H), 2.68 (dd, *J* = 15.0, 8.4 Hz, 0.5H), 2.35–2.26 (m, 1.5H), 1.62 (d, *J* = 5.0 Hz, 3H), 1.54 (d, *J* = 22.8 Hz, 3H), 1.48 (d, *J* = 3.8 Hz, 3H);

HRMS (ESI) calcd. for $C_{33}H_{28}O_6Na$ $[M+Na]^+$: 543.1778; found: 543.1778;

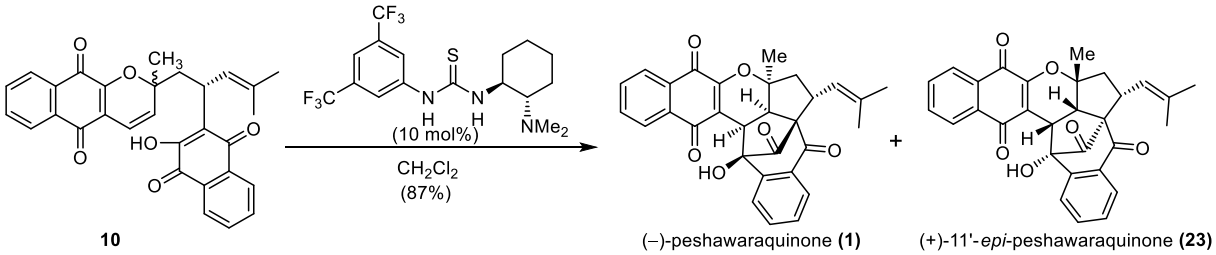
IR (neat) ν_{max} 2971, 2924, 1673, 1650, 1595, 1572, 1334, 1303, 1260, 1197, 965, 721 cm^{-1}.

Compound 10



To a stirred solution of **21** (120 mg, 0.23 mmol) in MeOH (2 mL) at r.t was added $[CpRu(CH_3CN)_3]PF_6$ (10 mg, 0.023 mmol) and quinaldic acid (4 mg, 0.023 mmol) for 5 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded compound **10** (93 mg, 0.19 mmol, 84%) as an orange oil. Compound **10** is not stable and was directly used for the next step.

Peshawaraquinone (1) and 11'-*epi*-peshawaraquinone (23)



To a stirred solution of compound **10** (30 mg, 0.062 mmol) in CH_2Cl_2 (1 mL) at r.t was added (*S*, *S*)-Takemoto's catalyst (2.6 mg, 0.0062 mmol) for 12 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded a mixture of **(–)-peshawaraquinone (1)** and **(+)-11'-*epi*-peshawaraquinone (23)** (26 mg, 0.054 mmol, 87%) in a ratio of 1:1, which was further separated through preparative TLC.

We found peshawaraquinone decomposed slowly in $CDCl_3$.

Data for peshawaraquinone (1):

R_f = 0.35 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

$[\alpha]_D^{20}$ = –132.72 (c = 0.2, $CHCl_3$);

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.16 (dd, *J* = 7.4, 1.6 Hz, 1H), 8.10 (dd, *J* = 7.3, 1.6 Hz, 1H), 8.04 (dd, *J* = 7.8, 1.3 Hz, 1H), 7.98 (d, *J* = 7.8 Hz, 1H), 7.77–7.70 (m, 3H), 7.51 (t, *J* = 7.5 Hz, 1H), 5.94 (d, *J* = 9.7 Hz, 1H), 3.85 (d, *J* = 10.3 Hz, 1H), 3.85–3.76 (m, 1H), 3.64 (br, 1H), 2.77 (d, *J* = 10.2 Hz, 1H), 2.62 (dd, *J* = 13.6, 6.5 Hz, 1H), 2.17 (t, *J* = 13.2 Hz, 1H), 1.764 (s, 3H), 1.758 (s, 3H), 1.31 (s, 3H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 203.7, 193.5, 184.4, 179.1, 154.9, 144.6, 135.7, 134.3, 133.8, 133.6, 131.9, 131.1, 129.7, 129.2, 127.6, 126.7 (2C), 124.8, 122.4, 120.7, 87.1, 85.9, 73.4, 53.5, 48.7, 36.8, 35.5, 26.3, 21.5, 18.1;

HRMS (ESI) calcd. for $C_{30}H_{24}O_6Na$ $[M+Na]^+$: 503.1465; found: 503.1468;

IR (neat) ν_{max} 2926, 1768, 1680, 1608, 1353, 1265, 1190, 965, 724 cm^{-1}.

Data for 11'-*epi*-peshawaraquinone (23):

R_f = 0.35 (petroleum ether/ethyl acetate =5:1, stains with PMA);

$[\alpha]_D^{20}$ = +144.06 (c = 0.2, $CHCl_3$);

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.18 (dd, *J* = 7.3, 1.7 Hz, 1H), 8.13 (dd, *J* = 7.3, 1.6 Hz, 1H), 8.10 (dd, *J* = 7.9, 1.3 Hz, 1H), 7.98 (d, *J* = 7.8 Hz, 1H), 7.79–7.71 (m, 3H), 7.53 (td, *J* = 7.5, 1.2 Hz, 1H), 5.59 (d, *J* = 10.3 Hz, 1H), 4.34 (td, *J* = 9.9, 5.1 Hz, 1H), 3.87 (d, *J* = 10.2 Hz, 1H), 3.50 (br, 1H), 2.65 (d, *J* = 10.2 Hz, 1H), 2.49 (dd, *J* = 14.4, 5.1 Hz, 1H), 2.41 (dd, *J* = 14.4, 9.5 Hz, 1H), 1.75 (s, 3H), 1.72 (s, 3H), 1.34(s, 3H);

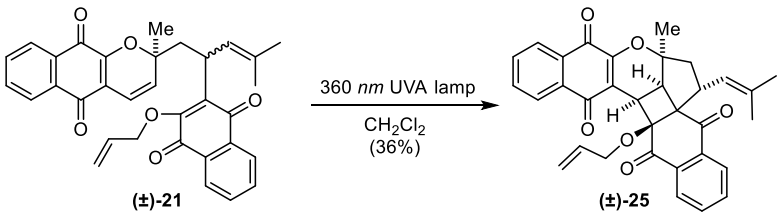
^{13}C NMR (125 MHz, $CDCl_3$): δ = 202.4, 193.0, 184.0, 179.0, 154.4, 146.6, 135.9, 134.2, 133.5, 133.2, 132.0, 131.2, 129.0, 128.7, 127.9, 126.6 (2C), 124.5, 123.1, 121.2, 89.0, 85.2, 75.2, 53.1, 47.5, 36.0, 35.0, 25.8, 23.6, 18.0;

HRMS (ESI) calcd. for $C_{30}H_{24}O_6Na$ $[M+Na]^+$:503.1465; found: 503.1468;

IR (neat) ν_{max} 2925, 1763, 1678, 1373,1264, 1211, 973, 725 cm^{-1}.

α-ketol rearrangement approach to peshawaraquinone

Compound (±)-25



A solution of **(±)-21** (139 mg, 0.27 mmol) in CH_2Cl_2 (1.3 mL) was illuminated with a 360 *nm* UVA lamp for 12 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded compound **(±)-25** (50 mg, 0.096 mmol, 36%) as a yellow solid.

R_f = 0.12 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

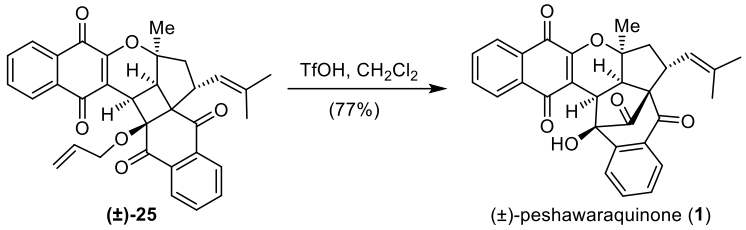
^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.15 (ddd, *J* = 11.0, 7.2, 1.8 Hz, 2H), 8.17–8.12 (m, 1H), 8.08–8.06 (m, 1H), 7.82–7.68 (m, 4H), 5.54–5.45 (m, 1H), 5.19 (d, *J* = 9.5 Hz, 1H), 4.91 (dd, *J* = 17.2, 1.8 Hz, 1H), 4.80 (dd, *J* = 10.6, 1.8 Hz, 1H), 4.14 (d, *J* = 10.0 Hz, 1H), 4.00–3.93 (m, 1H), 3.81–3.93 (m, 1H), 3.67–3.61 (m, 1H), 2.94 (d, *J* = 10.0 Hz, 1H), 2.50 (dd, *J* = 13.2, 5.9 Hz, 1H), 2.26 (t, *J* = 13.2 Hz, 1H), 1.54 (s, 3H), 1.49 (s, 3H), 1.37 (s, 3H);

^{13}C NMR (100 MHz, $CDCl_3$): δ = 197.3, 193.1, 182.0, 178.6, 155.7, 135.8, 134.8, 134.7, 133.5, 133.3, 133.0, 132.4, 132.1, 130.9, 130.2, 126.4, 125.7, 125.6, 125.4, 120.7, 117.6, 114.6, 86.2, 79.9, 65.3, 64.0, 48.7, 46.9, 38.8, 29.9, 24.8, 23.6, 17.3;

HRMS (ESI) calcd. for $C_{33}H_{28}O_6Na$ $[M+Na]^+$: 543.1778; found: 543.1780;

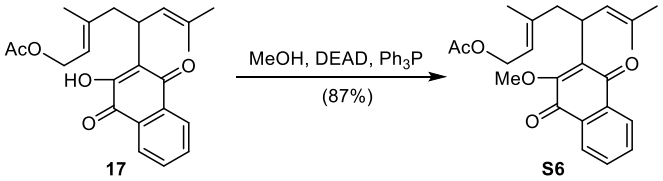
IR (neat) ν_{max} 2926, 1676, 1604, 1374, 1331, 1264, 1097, 996, 798, 725 cm^{-1}.

Peshawaraquinone (1)



To a stirred solution of compound **(±)-25** (35 mg, 0.067 mmol) in dry CH_2Cl_2 (1 mL) at r.t was added TfOH (3.0 μL, 0.034 mmol) for 27 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded **(±)-peshawaraquinone (1)** (25 mg, 0.052 mmol, 77%) as a yellow solid. *The data matched with the natural product synthesized through [3+2] cycloaddition.

Compound S6



To a stirred solution of compound **17** (312 mg, 0.85 mmol) in dry THF (5 mL) at r.t was added PPh_3 (278 mg, 1.06 mmol), MeOH (0.2 mL, 4.23 mmol), then DEAD (0.2 mL, 1.27 mmol) was added dropwise. The reaction mixture was stirred at r.t for 12 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 30:1 to 5:1) afforded compound **S6** (280 mg, 0.73 mmol, 87%) as an orange oil.

R_f = 0.50 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

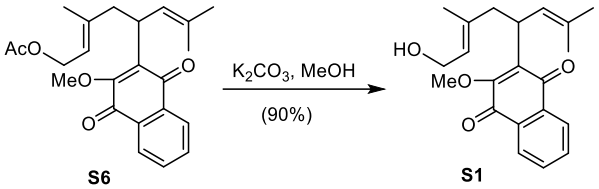
^{1}H NMR (500 MHz, $CDCl_3$): δ = 5.48 (dd, *J* = 7.7, 1.4 Hz, 1H), 7.99 (dd, *J* = 7.2, 1.8 Hz, 1H),, 7.69–7.63 (m, 2H), 5.48 (d, *J* = 9.4 Hz, 1H), 5.23 (t, *J* = 7.2 Hz, 1H), 4.42 (d, *J* = 7.2 Hz, 2H), 4.30 (q, *J* = 8.8 Hz, 1H), 4.08 (s, 3H), 2.55 (dd, *J* = 13.1, 8.8 Hz, 1H), 2.36 (dd, *J* = 13.2, 6.9 Hz, 1H), 1.80 (s, 3H), 1.70 (s, 3H), 1.66 (s, 3H), 1.62 (s, 3H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 185.0, 181.8, 170.8, 157.6, 140.6, 137.0, 133.7, 133.1, 132.9, 132.0, 131.5, 126.3, 125.9, 125.8, 120.4, 61.14, 61.07, 43.6, 33.5, 25.7, 20.7, 18.1, 16.3;

HRMS (ESI) for $C_{23}H_{26}O_5Na$ $[M+Na]^+$ calcd. 405.1672, found: 405.1671;

IR (neat) ν_{max} 2932, 1734, 1665, 1597, 1448, 1371, 1240, 1028, 723 cm^{-1}.

Compound S1



To a stirred solution of compound **S6** (280 mg, 0.73 mmol) in MeOH (3 mL) at r.t was added K_2CO_3 (304 mg, 2.20 mmol). After stirred for 5 h, the reaction mixture was quenched with 1N HCl (5 mL), extracted with EtOAc (3 × 5 mL), and the combined organic layers were dried over anhydrous Na_2SO_4. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1 to 2:1) afforded compound **S1** (225 mg, 0.66 mmol, 90%) as an orange oil.

R_f = 0.47 (petroleum ether/ethyl acetate = 2:1, stains with PMA);

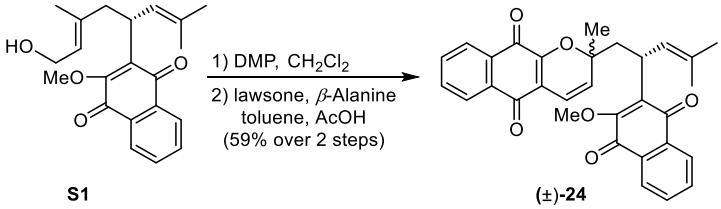
^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.01 (dd, *J* = 6.9, 1.9 Hz, 1H), 7.98 (dd, *J* = 7.1, 1.8 Hz, 1H), 7.68–7.62 (m, 2H), 5.48 (d, *J* = 8.2 Hz, 1H), 5.33 (t, *J* = 6.9 Hz, 1H), 4.28 (q, *J* = 8.2 Hz, 1H), 4.07 (s, 3H), 4.05–3.96 (m, 2H), 2.49 (dd, *J* = 13.3, 8.3 Hz, 1H), 2.37 (dd, *J* = 13.3, 7.2 Hz, 1H), 1.67 (s, 3H), 1.66 (s, 3H), 1.61 (s, 3H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 185.2, 181.8, 157.6, 137.8, 137.5, 133.8, 133.2, 132.8, 132.0, 131.4, 126.3, 126.0, 125.9, 125.5, 61.2, 59.2, 43.8, 33.6, 25.8, 18.1, 16.2;

HRMS (ESI) for $C_{21}H_{24}O_4Na$ $[M+Na]^+$ calcd. 363.1566, found: 363.1566;

IR (neat) ν_{max} 2927, 1728, 1662, 1594, 1447, 1257, 1009, 724 cm^{-1}.

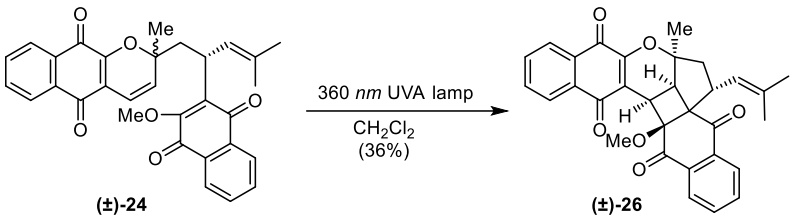
Compound (±)-24



To a stirred solution of allylic alcohol **S1** (295 mg, 0.87 mmol) in CH_2Cl_2 (5 mL) at r.t was added Dess-Martin periodinane (441 mg, 1.04 mmol), after stirred for 10 mins, the reaction was quenched with sat. Na_2SO_3 (5 mL), extracted with CH_2Cl_2 (3 × 5 mL). The combined organic layers were washed with sat. NaCl (5 mL) and dried over anhydrous Na_2SO_4. Concentrated afford crude aldehyde which was directly used for the next step.

A solution of crude aldehyde (0.87 mmol), lawsone (377 mg, 2.17 mmol), *β*-alanine (12 mg, 0.13 mmol) and AcOH (40 μL) in toluene (25 mL) was heated at 75 °C for 12 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded **(±)-24** (255 mg, 0.51 mmol, 59% over 2 steps) as an orange oil. ⋆This intermediate was directly used for next step.

Compound (±)-26



A solution of **(±)-24** (100 mg, 0.20 mmol) in CH_2Cl_2 (1 mL) at r.t was illuminated with a 360 *nm* UVA lamp for 12 h. Then solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded compound **(±)-26** (36 mg, 0.072 mmol, 36%) as a yellow oil.

R_f = 0.62 (petroleum ether/ethyl acetate = 2:1, stains with PMA);

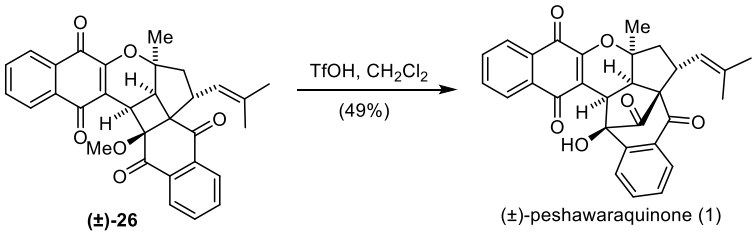
^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.24–8.22 (m, 1H), 8.16–8.10 (m, 3H), 7.83–7.81 (m, 2H), 7.73–7.67 (m, 2H), 5.47 (dt, *J* = 9.4, 1.4 Hz, 1H), 4.05 (d, *J* = 10.2 Hz, 1H), 3.86–3.79 (m, 1H), 3.03 (s, 3H), 2.86 (d, *J* = 10.2 Hz, 1H), 2.45 (dd, *J* = 13.2, 6.0 Hz, 1H), 2.35 (t, *J* = 13.2 Hz, 1H), 1.60 (s, 3H), 1.55 (s, 3H), 1.49 (s, 3H);

^{13}C NMR (100 MHz, $CDCl_3$): δ = 197.3, 194.22, 182.9, 179.7, 156.1, 135.7, 135.33, 135.1, 134.8, 134.6, 134.0, 133.1, 132.0, 131.3, 127.8, 127.3, 126.8, 126.4, 121.6, 117.5, 86.6, 81.4, 84.9, 53.6, 50.1, 48.0, 40.1, 31.2, 25.9, 25.1, 18.4;

HRMS (ESI) calcd. for $C_{31}H_{26}O_6Na$ $[M+Na]^+$ 517.1622, found: 517.1625;

IR (neat) ν_{max} 2926, 2859, 1673, 1381, 1330, 1265, 1161, 975, 723 cm^{-1}.

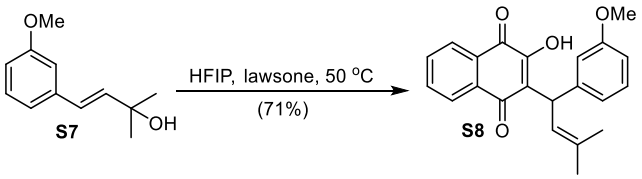
Peshawaraquinone (1)



To a stirred solution of compound **(±)-26** (32 mg, 0.064 mmol) in dry CH_2Cl_2 (1 mL) at r.t was added TfOH (2.85 uL, 0.032 mmol) for 27 h. Then solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded **(±)-peshawaraquinone** (**1**) (25 mg, 0.052 mmol, 49%) as a yellow solid. *The data matched with the natural product synthesized through [3+2] cycloaddition.

HFIP promoted allylation. (Table 1)

Compound S8



To a stirred solution of compound **S7**[4,5] (200 mg, 1.04 mmol) in HFIP (0.9 mL) in a sealed tube was added lawsone (453 mg, 2.60 mmol), then the flask was sealed and the reaction mixture stirred at 50 °C for 15 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 30:1 to 5:1) afforded compound **S8** (257 mg, 0.74 mmol, 71%) as an orange oil.

R_f = 0.48 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

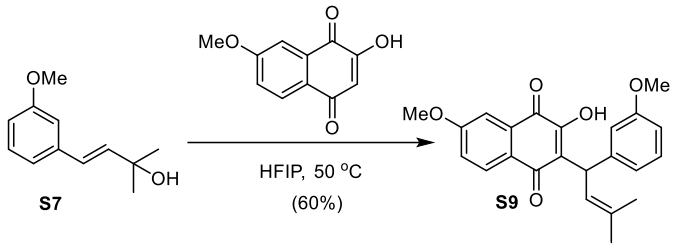
^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.10 (d, *J* = 7.5 Hz, 1H), 8.04 (d, *J* = 7.7 Hz, 1H), 7.72 (td, *J* = 7.5, 1.5 Hz, 1H), 7.64 (dd, *J* = 13.1, 8.4 Hz, 1H), 7.62 (br, 1H), 7.20 (t, *J* = 8.1 Hz, 1H), 6.98 (d, *J* = 2.6 Hz, 2H), 6.74 (dd, *J* = 8.0, 2.6 Hz, 1H), 6.00 (d, *J* = 9.7 Hz, 1H), 5.46 (d, *J* = 9.5 Hz, 1H), 3.78 (s, 3H), 1.83 (s, 3H), 1.77 (s, 3H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 183.9, 181.9, 159.6, 152.9, 144.2, 135.0, 134.7, 132.91, 132.89, 129.3, 129.2, 127.1, 126.0, 125.8, 123.0, 120.1, 114.0, 111.0, 55.2, 39.0, 26.0, 18.2;

HRMS (ESI) calcd. for $C_{22}H_{20}O_4Na$ $[M+Na]^+$: 371.1253; found: 371.1253;

IR (neat) ν_{max} 3421, 3359, 1655, 1363, 1275, 1106, 1043 cm^{-1}.

Compound S9



To a stirred solution of compound **S7**[4,5] (200 mg, 1.04 mmol) in HFIP (0.9 mL) in a sealed tube was added naphthoquinone (531 mg, 2.60 mmol), then the flask was sealed and the reaction mixture stirred at 50 °C for 15 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 10:1) afforded compound **S9** (236 mg, 0.62 mmol, 60%) as an orange oil.

R_f = 0.27 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

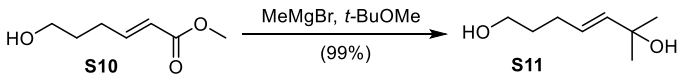
^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.02 (d, *J* = 8.6 Hz, 1H), 7.51 (br, 1H), 7.48 (d, *J* = 2.7 Hz, 1H), 7.23–7.13 (m, 2H), 6.99–6.92 (m, 2H), 6.72 (d, *J* = 6.9 Hz, 1H), 5.97 (d, *J* = 9.0 Hz, 1H), 5.44 (d, *J* = 9.4 Hz, 1H), 3.90 (s, 3H), 3.78 (s, 3H), 1.82 (s, 3H), 1.76 (s, 3H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 183.6, 182.1, 163.4, 159.5, 152.7, 144.3, 134.7, 131.1, 129.3, 129.1, 126.2, 125.5, 123.1, 120.9, 120.1, 114.0, 110.9, 109.8, 55.9, 55.1, 38.9, 25.9, 18.1;

HRMS (ESI) calcd. for $C_{23}H_{22}O_5Na$ $[M+Na]^+$: 401.1359; found: 401.1358;

IR (neat) ν_{max} 3400, 2964, 2930, 1736, 1646, 1368, 1262, 1091 cm^{-1}.

Compound S11



To a stirred solution of compound **S10**[6] (630 mg, 4.37 mmol) in anhydrous *t*-BuOMe (20 mL) at r.t was added MeMgBr (7.3 mL, 21.85 mmol, 3.0 M solution in hexane) dropwise. The reaction mixture was stirred at r.t for 5 h, then quenched with sat. NH_4Cl (20 mL) and extracted with EtOAc (3 × 20 mL). The combined organic layers were washed with sat. NaCl (40 mL) and dried over anhydrous Na_2SO_4. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 1:2) afforded compound **S11** (625 mg, 4.33 mmol, 99%) as a colorless oil.

R_f = 0.40 (petroleum ether/ethyl acetate = 1:4, stains with PMA);

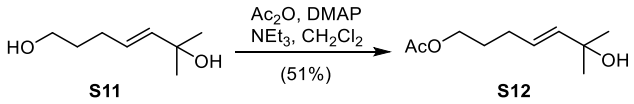
^{1}H NMR (500 MHz, $CDCl_3$): δ = 5.63 (t, *J* = 2.7 Hz, 2H), 3.63 (t, *J* = 6.5 Hz, 2H), 2.12–2.08 (m, 2H), 1.75 (br, 2H), 1.75–1.61 (m, 2H), 1.29 (s, 6H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 138.6, 126.4, 70.6, 62.3, 32.2, 29.8 (2C), 28.5;

HRMS (ESI) calcd. for $C_8H_{16}O_2Na$ $[M+Na]^+$: 167.1042; found: 167.1044;

IR (neat) ν_{max} 2936, 1446, 1370, 1223, 1151, 1056, 973, 910 cm^{-1}.

Compound S12



To a stirred solution of compound **S11** (100 mg, 0.69 mmol) in CH_2Cl_2 (3 mL) at r.t was added DMAP (8.5 mg, 0.069 mmol), Et_3N (96 μL, 0.69 mmol) and acetic anhydride (98 μL, 1.04 mmol) for 1 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 2:1) afforded compound **S12** (66 mg, 0.35 mmol, 51%) as a colorless oil.

R_f = 0.47 (petroleum ether/ethyl acetate = 2:1, stains with PMA);

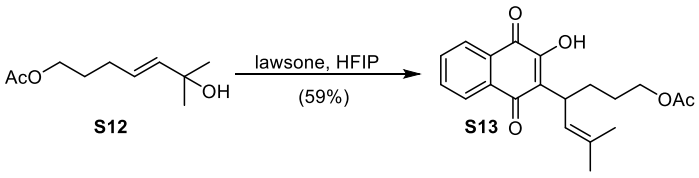
^{1}H NMR (500 MHz, $CDCl_3$): δ = 5.65–5.56 (m, 2H), 4.05 (t, *J* = 6.7 Hz, 2H), 2.10–2.05 (m, 2H), 2.04 (s, 3H), 1.73–1.67 (m, 2H), 1.52 (br, 1H), 1.29 (s, 6H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 171.1, 139.0, 125.7, 70.6, 63.8, 29.8 (2C), 28.5, 28.2, 21.0;

HRMS (ESI) calcd. for $C_{10}H_{18}O_3Na$ $[M+Na]^+$: 209.1148; found: 209.1150;

IR (neat) ν_{max} 2968, 1733, 1452, 1372, 1245, 1149, 1042, 972, 909 cm^{-1}.

Compound S13



To a stirred solution of compound **S12** (34 mg, 0.18 mmol) in HFIP (0.3 mL) in a sealed tube was added lawsone (78 mg, 0.45 mmol), then the flask was sealed and the reaction mixture was stirred at 50 °C for 15 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 10:1) afforded compound S**13** (37 mg, 0.11 mmol, 59%) as an orange oil.

R_f = 0.42 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

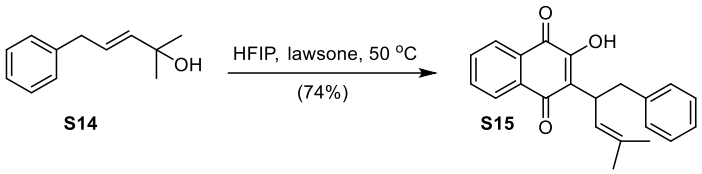
^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.10 (d, *J* = 7.7 Hz, 1H), 8.05 (d, *J* = 7.6 Hz, 1H), 7.74 (t, *J* = 7.5 Hz, 1H), 7.66 (t, *J* = 7.5 Hz, 1H), 7.43 (br, 1H), 5.54 (d, *J* = 9.3 Hz, 1H), 4.08–4.01 (m, 3H), 2.02 (s, 3H), 1.87–1.80 (m, 2H), 1.69 (s, 3H), 1.67 (s, 3H), 1.63–1.62 (m, 1H), 1.59–1.51 (m, 1H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 184.3, 181.8, 171.2, 152.6, 134.9, 133.5, 133.0, 132.8, 129.3, 126.9, 126.1, 126.0, 125.1, 64.5, 34.5, 29.5, 27.1, 25.8, 21.0, 18.1;

HRMS (ESI) calcd. for $C_{20}H_{22}O_5Na$ $[M+Na]^+$: 365.1359; found: 365.1352;

IR (neat) ν_{max} 2920, 2864, 1671, 1365, 1273, 720 cm^{-1}.

Compound S15



To a stirred solution of compound **S14**[7,8] (66 mg, 0.37 mmol) in HFIP (0.4 mL) in a sealed tube was added lawsone (160 mg, 0.92 mmol), then the flask was sealed and the reaction mixture stirred at 50 °C for 15 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 10:1) afforded compound **S15** (93 mg, 0.28 mmol, 74%) as an orange oil.

R_f = 0.62 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

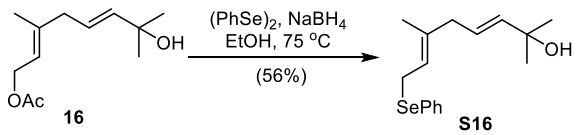
^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.08 (d, *J* = 7.7 Hz, 1H), 8.00 (d, *J* = 7.6 Hz, 1H), 7.71 (t, *J* = 7.4 Hz, 1H), 7.62 (t, *J* = 7.5 Hz, 1H), 7.22–7.18 (m, 4H), 7.13–7.10 (m, 1H), 5.68 (d, *J* = 9.1 Hz, 1H), 4.42 (q, *J* = 8.4 Hz, 1H), 3.19 (dd, *J* = 13.5, 8.2 Hz, 1H), 3.11 (dd, *J* = 13.5, 7.7 Hz, 1H), 1.69 (s, 3H), 1.60 (s, 3H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 184.3, 181.8, 152.7, 140.5, 134.9, 133.6, 132.9, 132.8, 129.2, 129.0 (2C), 128.1 (2C), 126.9, 126.0, 125.9, 125.8, 124.7, 39.4, 36.8, 25.8, 18.1;

HRMS (ESI) calcd. for $C_{22}H_{20}O_3Na$ $[M+Na]^+$: 355.1304; found: 355.1304;

IR (neat) ν_{max} 2921, 2852, 1662, 1592, 1369, 1265, 1214, 727 cm^{-1}.

Compound S16



To a stirred solution of diphenyl diselenide (2.6 g, 8.25 mmol) in anhydrous ethanol (30 mL) at 0 °C was added $NaBH_4$ (624 mg, 37.83 mmol) in portions. After the bubbling ceased and the yellow color of reaction mixture disappeared, a solution of allyl alcohol **16** (500 mg, 2.36 mmol) in anhydrous ethanol (20 mL) was added in one portion. The reaction mixture was heated to reflux for 12 h. After the reaction mixture was cooled down to r.t, concentrated to remove most of the solvent and re-dissolved in EtOAc (30 mL). The reaction mixture was quenched with sat. $NaHCO_3$ (30 mL), extracted with EtOAc (3 × 30 mL), and the combined organic layers were dried over anhydrous Na_2SO_4. Solvent removal under reduced

pressure and flash chromatography (petroleum ether/ethyl acetate = 15:1) afforded compound **S16** (410 mg, 1.33 mmol, 56%) as a colorless oil.

R_f = 0.47 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

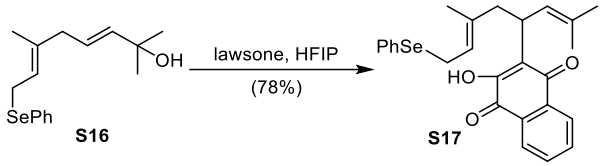
^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.51–7.49 (m, 2H), 7.24–7.22 (m, 3H), 5.58 (d, *J* = 15.4 Hz, 1H), 5.38 (td, *J* = 15.5, 6.8 Hz, 1H), 5.38 (dt, *J* = 8.2, 1.3 Hz, 1H), 3.53 (d, *J* = 8.2 Hz, 2H), 2.64 (d, *J* = 6.7 Hz, 2H), 1.76 (br, 1H), 1.42(s, 3H), 1.28 (s, 6H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 139.9, 137.9, 134.0 (2C), 130.2, 128.8 (2C), 127.2, 124.5, 121.1, 70.7, 42.2, 29.9 (2C), 25.9, 15.8;

HRMS (ESI) calcd. for $C_{16}H_{22}OSeNa$ $[M+Na]^+$: 333.0728; found: 333.0726;

IR (neat) ν_{max} 2967, 2923, 1658, 1433, 1372, 1143, 1086, 1026, 974, 801, 737 cm^{-1}.

Compound S17



To a stirred solution of compound **S16** (205 mg, 0.66 mmol) in HFIP (0.7 mL) in a sealed tube was added lawsone (287 mg, 1.65 mmol), then the flask was sealed and the reaction mixture was stirred at 50 °C for 15 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 10:1) afforded compound **S17** (240 mg, 0.51 mmol, 78%) as an orange oil.

R_f = 0.52 (petroleum ether/ethyl acetate = 10:1, stains with PMA);

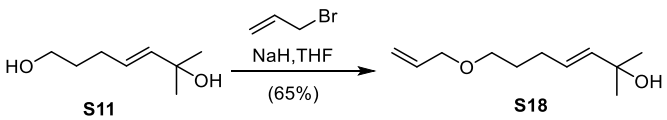
^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.08 (d, *J* = 7.7 Hz, 1H), 8.03(d, *J* = 7.4 Hz, 1H), 7.72 (td, *J* = 7.6, 1.3 Hz, 1H), 7.64 (td, *J* = 7.5, 1.3 Hz, 1H), 7.32–7.30 (m, 2H), 7.15–7.14 (m, 3H), 5.55 (d, *J* = 9.2 Hz, 1H), 5.35 (t, *J* = 8.1 Hz, 1H), 4.27 (td, *J* = 9.2, 6.6 Hz, 1H), 3.48–3.40 (m, 2H), 2.63 (dd, *J* = 13.2, 9.3 Hz,1H), 2.35 (dd, *J* = 13.2, 6.6 Hz, 1H), 1.68 (s, 6H), 1.60 (s, 3H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 184.3, 181.7, 152.6, 137.8, 134.8, 133.1, 133.0, 132.8, 132.6 (2C), 131.0, 129.3, 128.8 (2C), 126.9, 126.7, 126.0, 125.7, 125.2, 121.8, 43.0, 33.4, 25.8, 25.7, 18.2, 15.8;

HRMS (ESI) calcd. for $C_{26}H_{26}O_3SeNa$ $[M+Na]^+$: 489.0939; found: 489.0940;

IR (neat) ν_{max} 2924, 1765, 1682, 1594, 1378, 1335, 1264, 1209, 975, 725 cm^{-1}.

Compound S18



To a stirred solution of sodium hydride (33.3 mg, 1.38 mmol) in anhydrous, degassed THF (2 mL) at 0 °C was added allyl alcohol **S11** (100 μL, 0.69 mmol) dropwise. After hydrogen gas evolution finished, allyl bromide (167.8 mg, 1.38 mmol) was added dropwise. The reaction mixture was warm up to r.t and stirred for 12 h. Then the reaction mixture was quenched with water (4 mL), extracted with EtOAc (3 ×

5 mL), and the combined organic layers were dried over anhydrous Na_2SO_4. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded compound **S18** (83 mg, 0.45 mmol, 65%) as a colorless oil.

R_f = 0.38 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

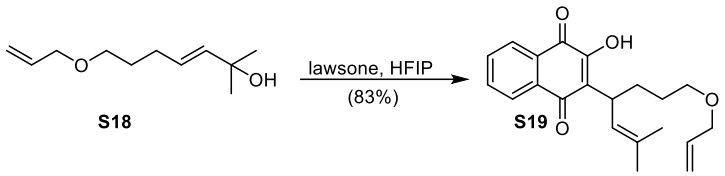
^{1}H NMR (500 MHz, $CDCl_3$): δ = 5.59–5.87 (m, 1H), 5.62 (s, 2H), 5.26 (d, *J* = 17.2 Hz, 1H), 5.16 (d, *J* = 10.3 Hz, 1H), 3.95 (d, *J* = 5.0 Hz, 2H), 3.42 (t, *J* = 6.5 Hz, 2H), 2.12–2.08 (m, 2H), 1.69–1.63 (m, 2H), 1.44 (br, 1H), 1.29 (s, 6H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 138.4, 135.1, 126.5, 116.7, 71.8, 70.6, 69.6, 29.9 (2C), 29.3, 28.7;

HRMS (ESI) calcd. for $C_{11}H_{20}O_2Na$ $[M+Na]^+$: 207.1355; found: 207.1357.

IR (neat) ν_{max} 2957, 2860, 1365, 1104, 978, 922 cm^{-1}.

Compound S19



To a stirred solution of compound **S18** (68 mg, 0.37 mmol) in HFIP (0.4 mL) in a sealed tube was added lawsone (160 mg, 0.92 mmol), then the flask was sealed and the reaction mixture was stirred at 50 °C for 15 h. Solvent removal under reduced pressure and flash chromatography (petroleum ether/ethyl acetate = 5:1) afforded compound **S19** (104 mg, 0.31 mmol, 83%) as an orange oil.

R_f = 0.52 (petroleum ether/ethyl acetate = 5:1, stains with PMA);

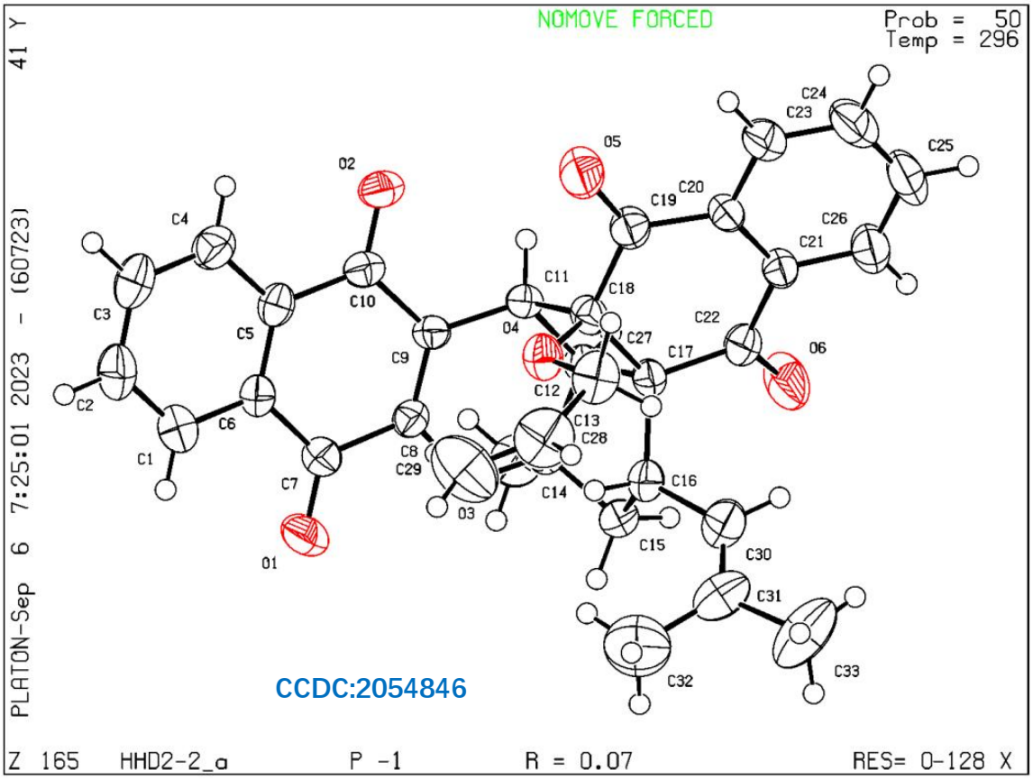
^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.09 (d, *J* = 7.6 Hz, 1H), 8.04 (d, *J* = 7.5 Hz, 1H), 7.73 (t, *J* = 7.5 Hz, 1H), 7.65 (t, *J* = 7.4 Hz, 1H), 7.42 (br, 1H), 5.93–5.85 (m, 1H) 5.55 (d, *J* = 9.4 Hz, 1H), 5.24 (dd, *J* = 17.2, 1.9 Hz, 1H), 5.13 (dd, *J* = 10.4, 1.8 Hz, 1H), 4.03 (q, *J* = 8.2 Hz, 1H), 3.94 (d, *J* = 5.7 Hz, 2H), 3.43–3.41 (m, 2H), 1.84 (q, *J* = 7.8 Hz, 2H), 1.68 (s, 3H), 1.67 (s, 3H), 1.62 (q, *J* = 7.3 Hz, 1H), 1.56–1.49 (m, 1H);

^{13}C NMR (125 MHz, $CDCl_3$): δ = 184.3, 181.8, 152.5, 135.1, 134.9, 133.1, 133.0, 132.8, 129.3, 126.9, 126.4, 125.9, 125.4, 116.7, 71.8, 70.3, 34.7, 29.7, 28.2, 25.8, 18.1;

HRMS (ESI) calcd. for $C_{21}H_{24}O_4Na$ $[M+Na]^+$: 363.1566; found: 363.1564;

IR (neat) ν_{max} 2922, 1592, 1369, 1262, 1214 cm^{-1}.

5. Crystal data for compound 25.



Bond precision: C-C = 0.0048 A Wavelength=0.71073

Cell: a=10.3950(8) b=11.4001(8) c=12.5959(10)
alpha=96.504(2) beta=103.662(2) gamma=110.075(2)

Temperature: 296 K

	Calculated	Reported
Volume	1331.07(18)	1331.06(18)
Space group	P -1	P -1
Hall group	-P 1	-P 1
Moiety formula	C33 H28 O6	?
Sum formula	C33 H28 O6	C33 H28 O6
Mr	520.55	520.55
Dx, g cm-3	1.299	1.299
Z	2	2
Mu (mm-1)	0.089	0.089
F000	548.0	548.0
F000'	548.28	
h, k, lmax	13, 14, 15	13, 14, 15
Nref	5526	5517
Tmin, Tmax	0.970, 0.974	0.745, 0.745
Tmin'	0.970	

Correction method= # Reported T Limits: Tmin=0.745 Tmax=0.745 AbsCorr = MULTI-SCAN

Data completeness= 0.998 Theta(max)= 26.513

R(reflections)= 0.0747(2537) wR2(reflections)= 0.1443(5517)

S = 1.015 Npar= 355

6. References

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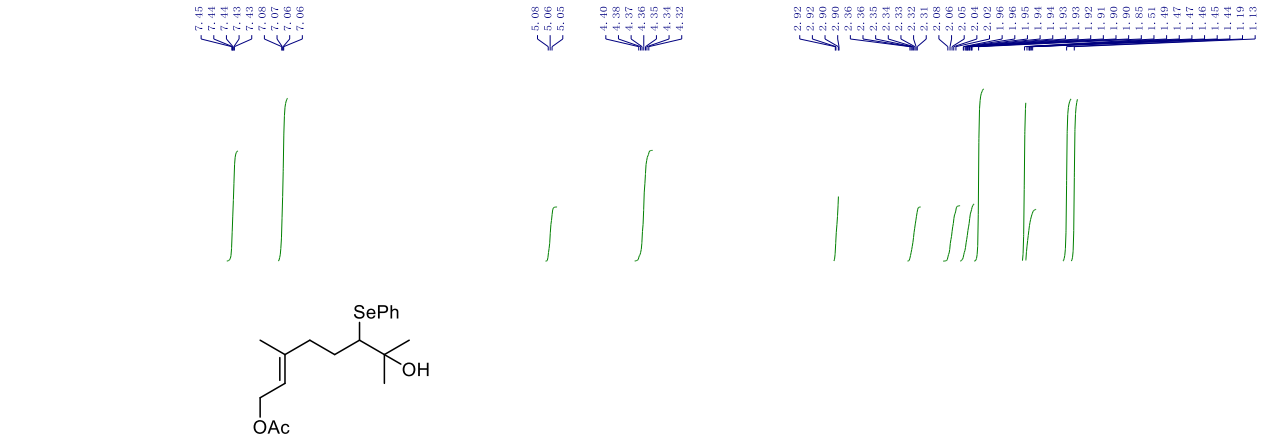
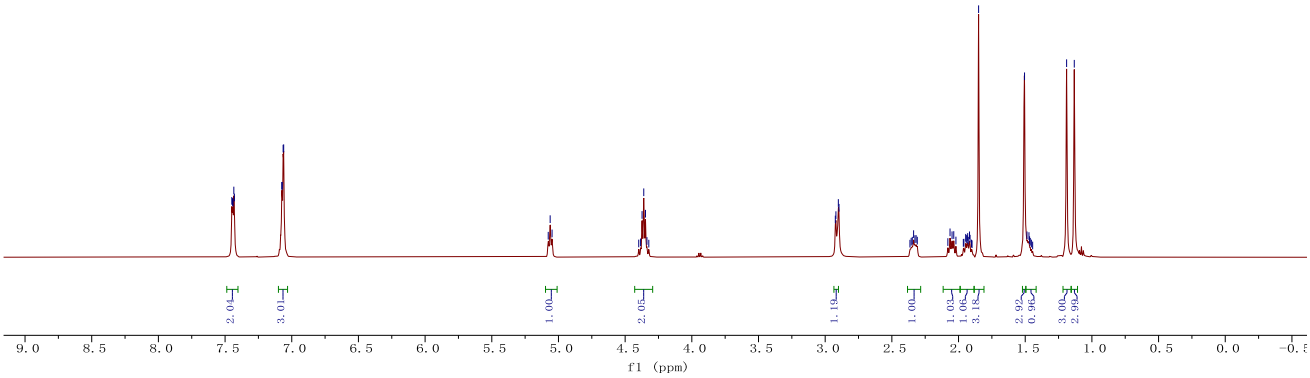
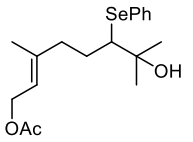
8. H. J. Reich, S. K. Shah, F. Chow, Selenium stabilized carbanions. α-Lithio selenoxides as reagents for the synthesis of olefins, allyl alcohols, and dienes, *J. Am. Chem. Soc.,* 1979, **101**, 6648–6656.

7. ^{1}H and ^{13}C NMR Spectra

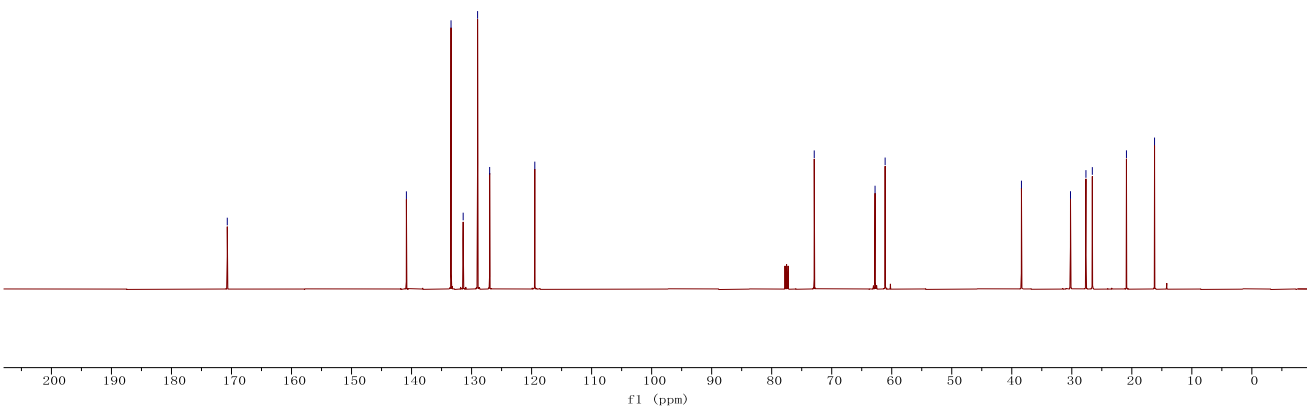


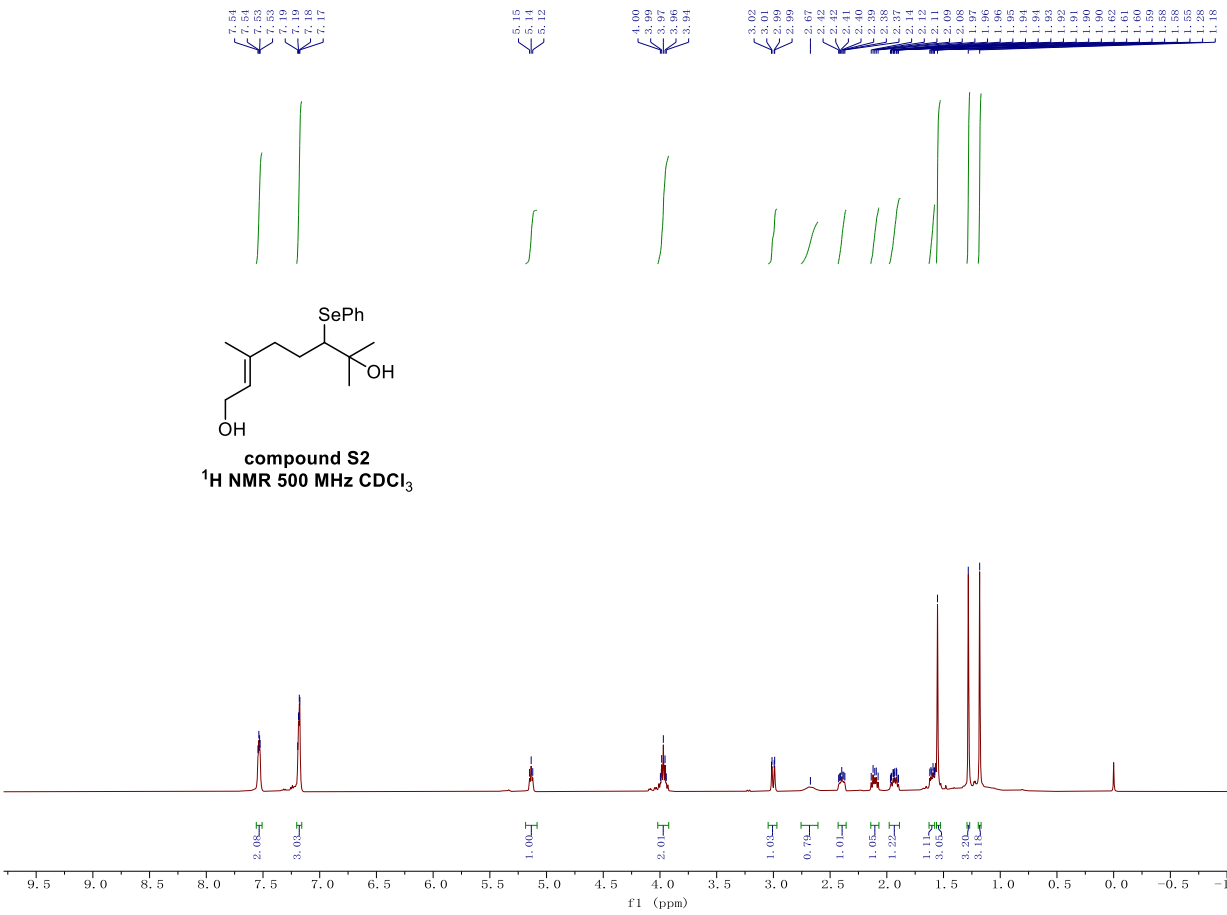
compound 14
^{1}H NMR 500 MHz $CDCl_3$



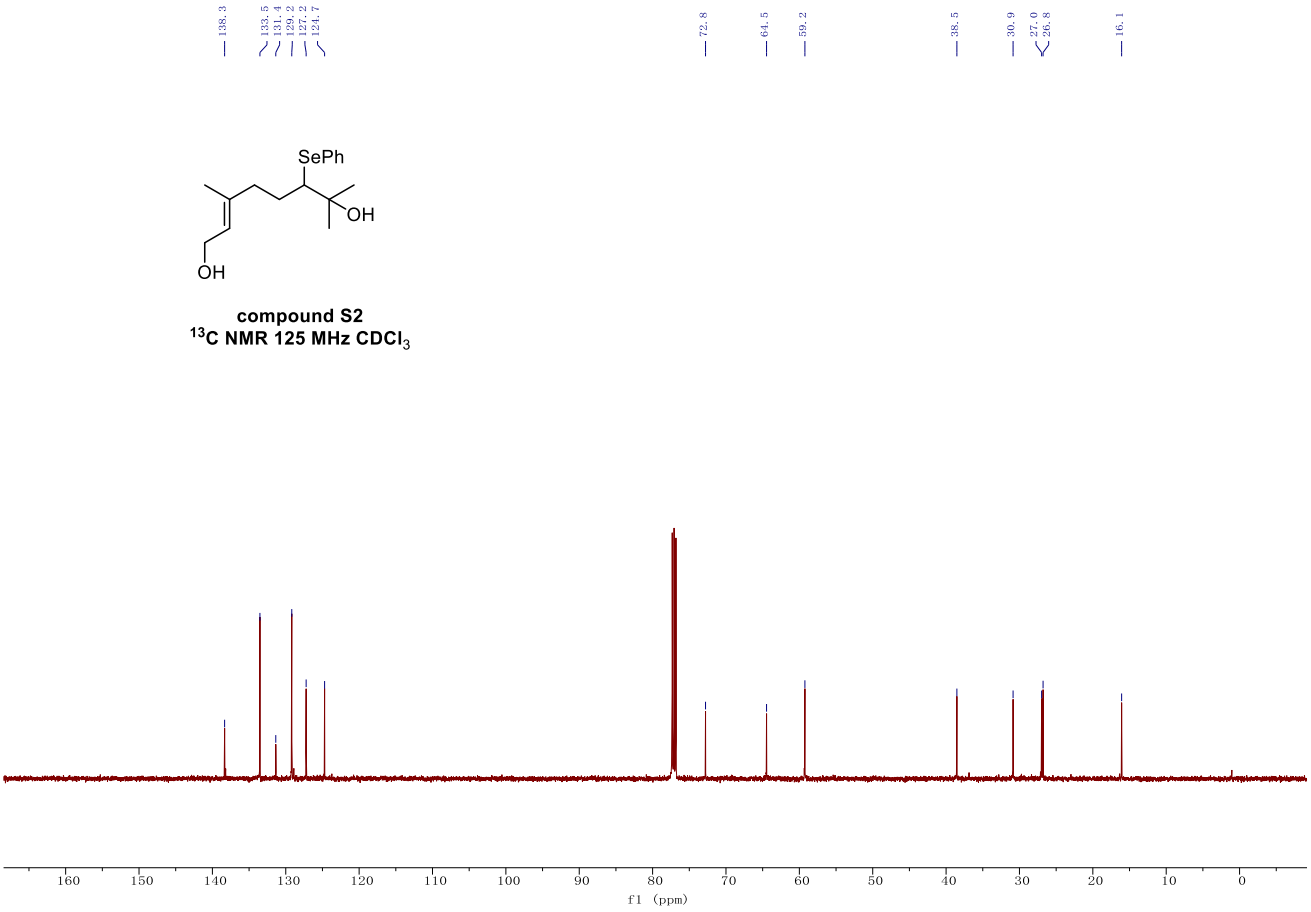


compound 14
^{13}C NMR 125 MHz $CDCl_3$

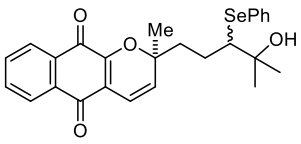




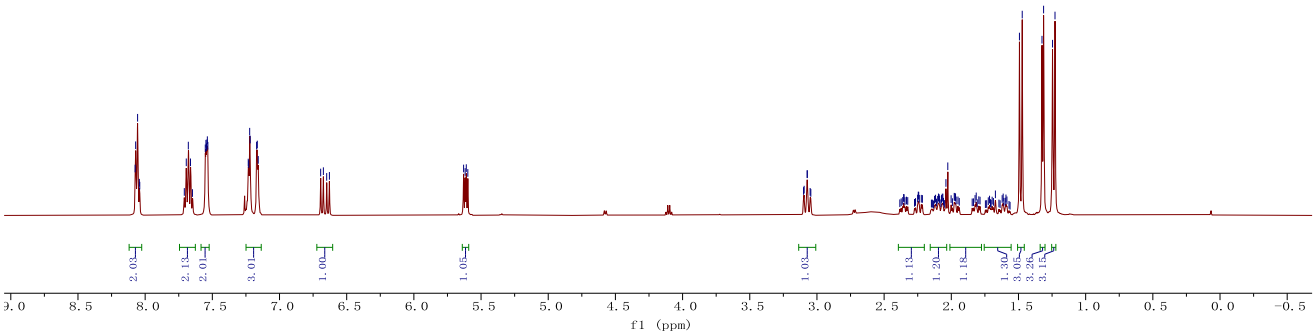
compound S2
^{1}H NMR 500 MHz $CDCl_3$

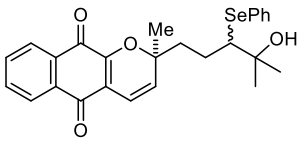


compound S2
^{13}C NMR 125 MHz $CDCl_3$

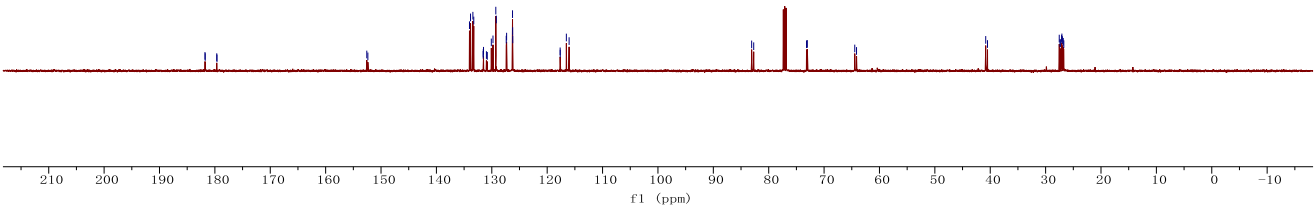


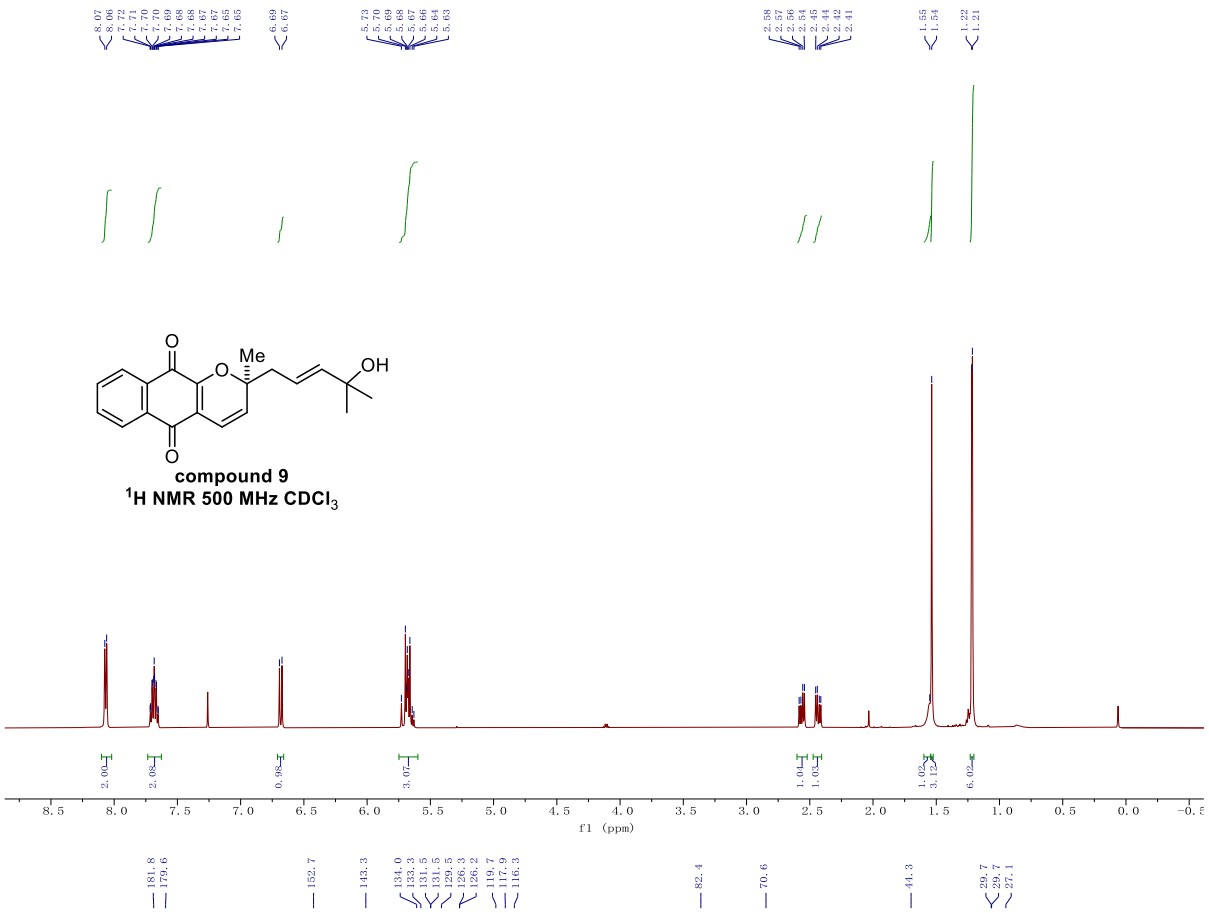
compound S3
^{1}H NMR 500 MHz CDCl$_3$



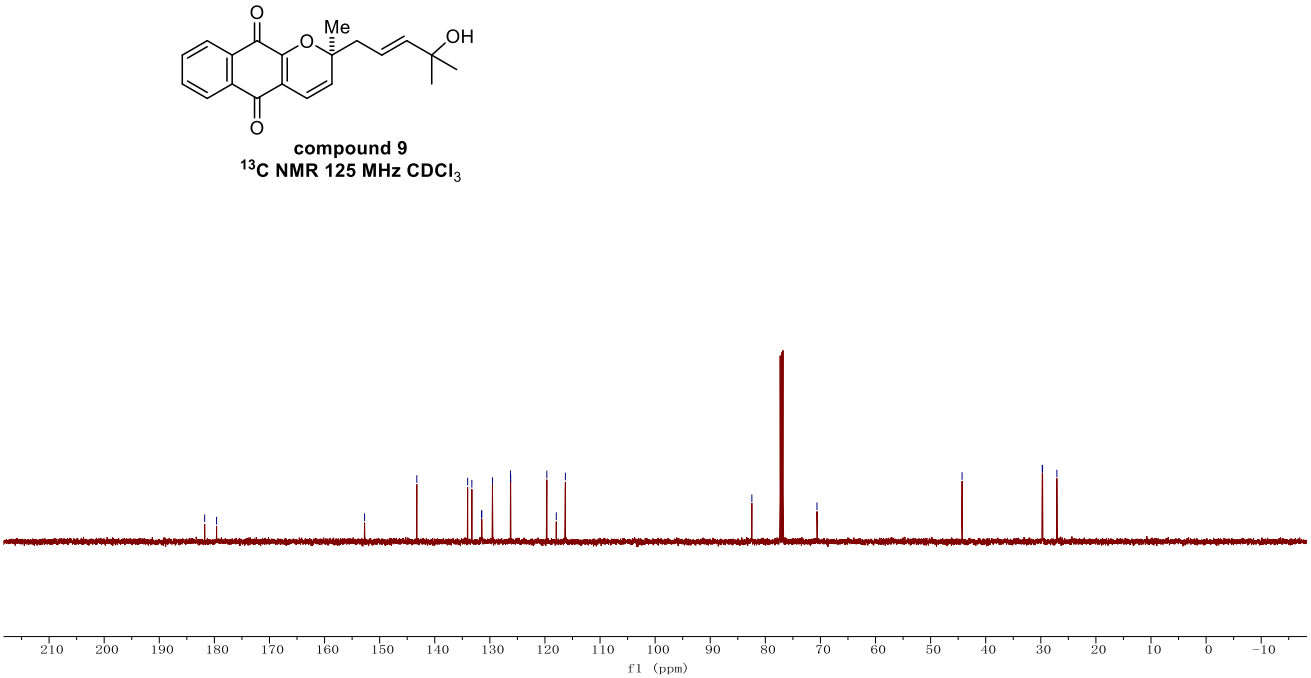


compound S3
^{13}C NMR 125 MHz CDCl$_3$

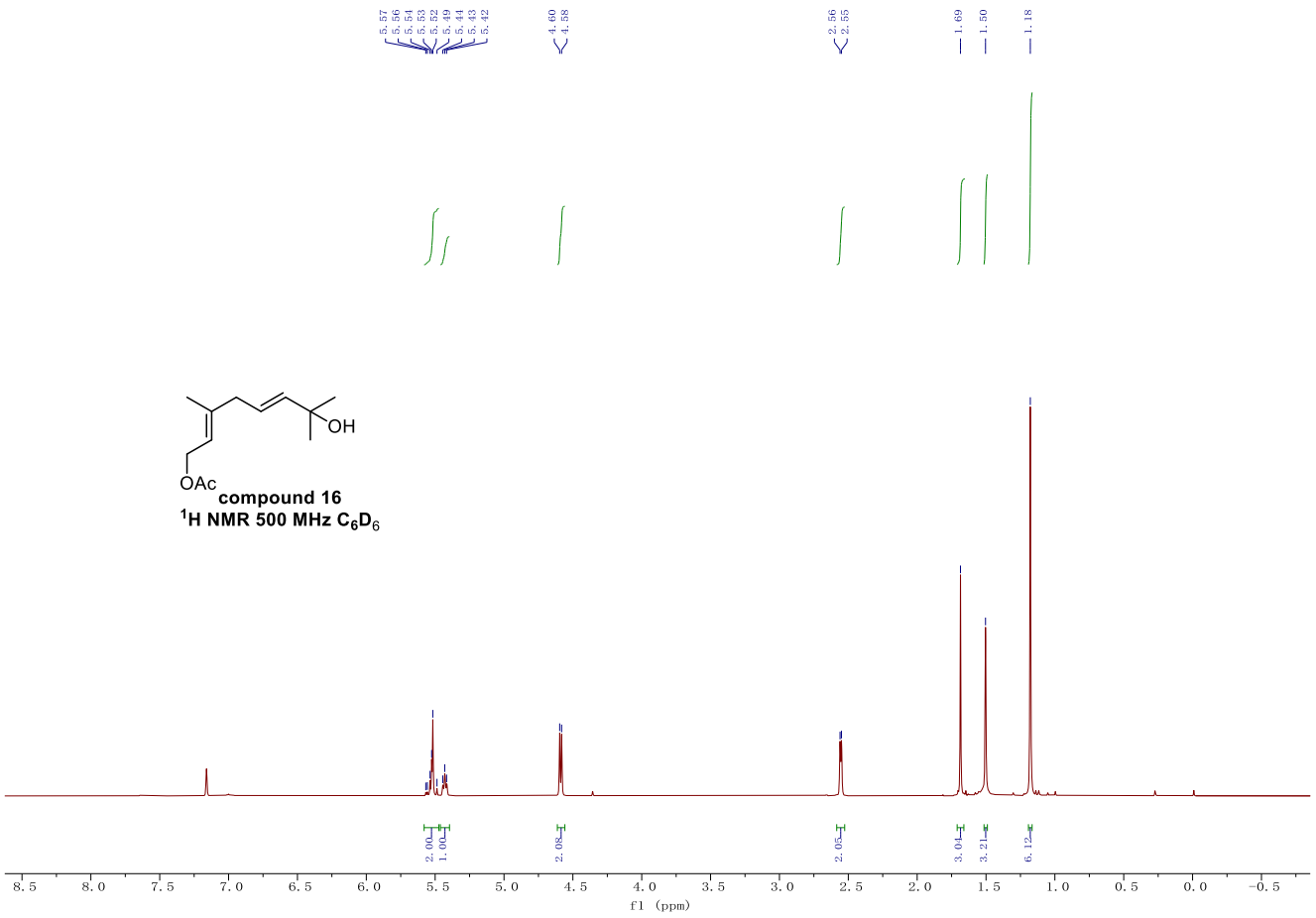


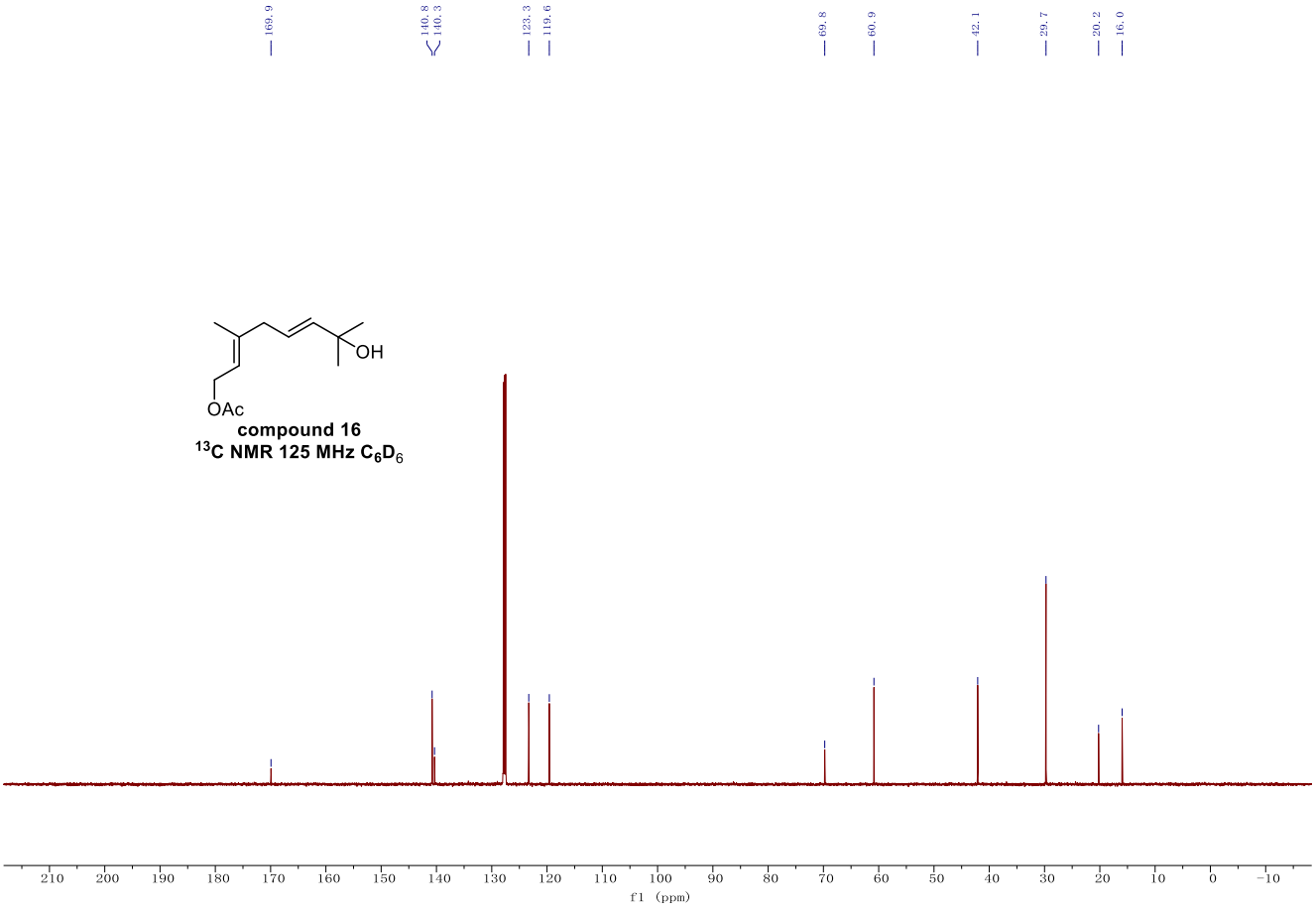


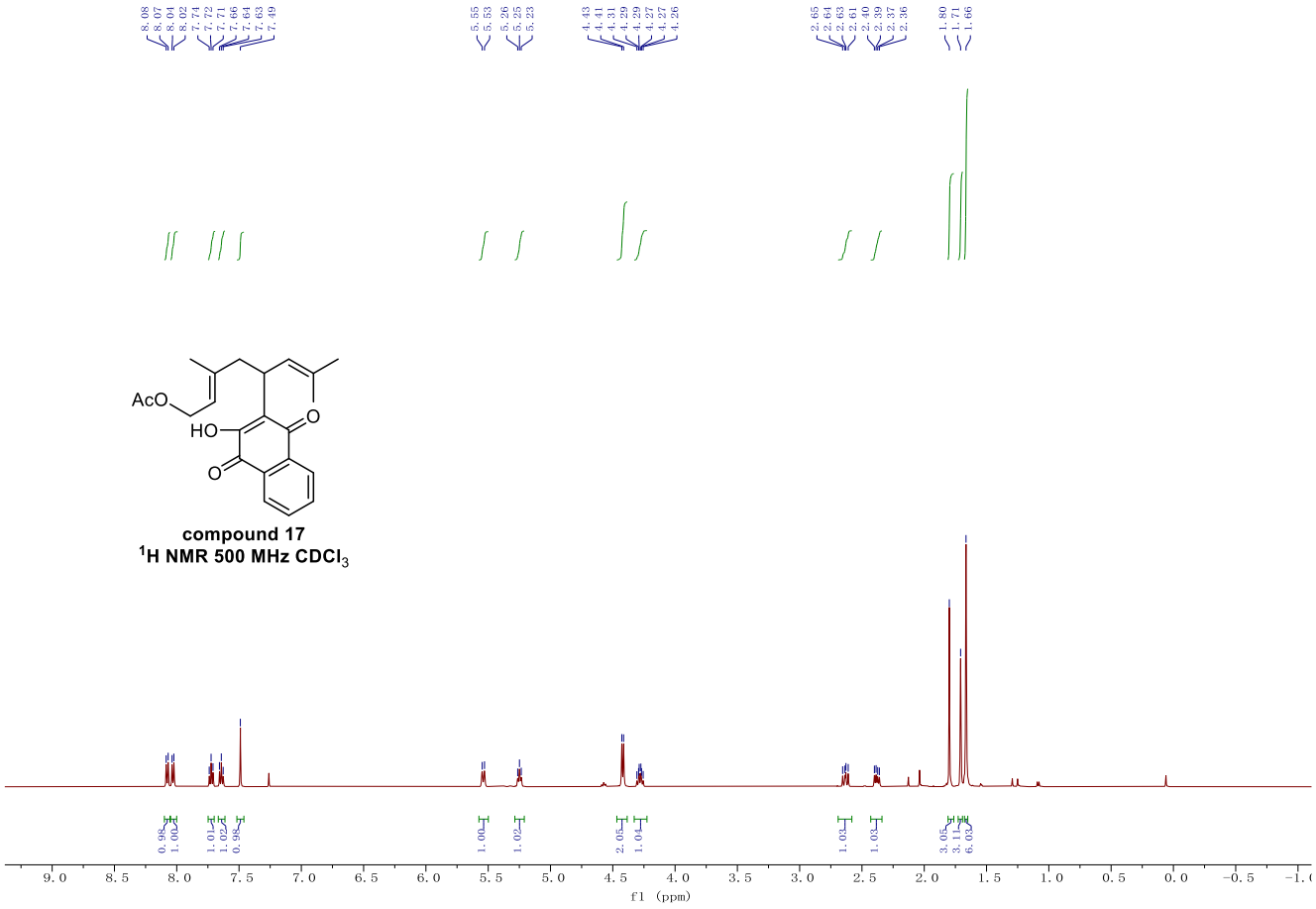
compound 9
^{1}H NMR 500 MHz CDCl$_3$



compound 9
^{13}C NMR 125 MHz CDCl$_3$

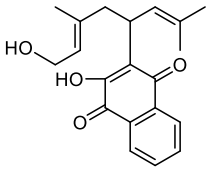

5.57
5.56
5.54
5.53
5.52
5.49
5.44
5.43
5.42
4.60
4.58
2.56
2.55
1.69
1.50
1.18
OH
OAc
compound 16
1H NMR 500 MHz C6D6
2.00
1.00
2.08
2.05
3.04
3.21
6.12
f1 (ppm)


169.9
140.8
140.3
123.3
119.6
69.8
60.9
42.1
29.7
20.2
16.0
OH
OAc
compound 16
13C NMR 125 MHz C6D6
f1 (ppm)

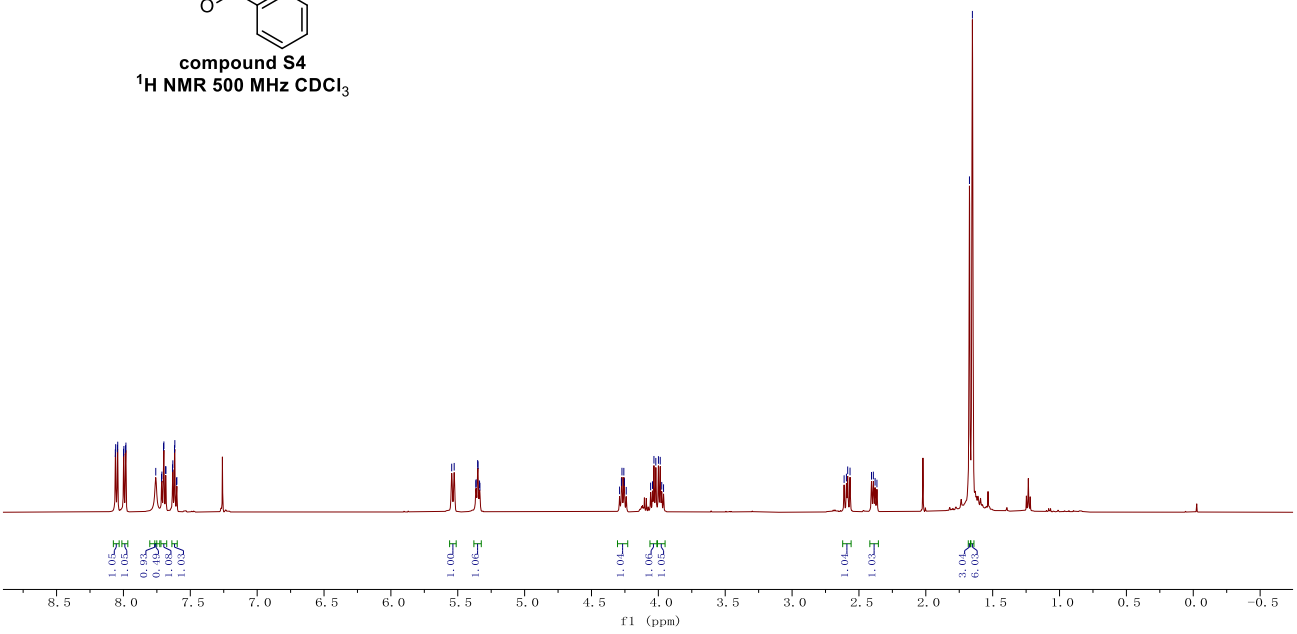


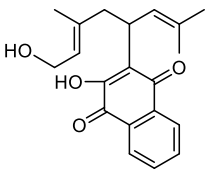
compound 17
^{1}H NMR 500 MHz $CDCl_3$

compound 17
^{13}C NMR 125 MHz $CDCl_3$

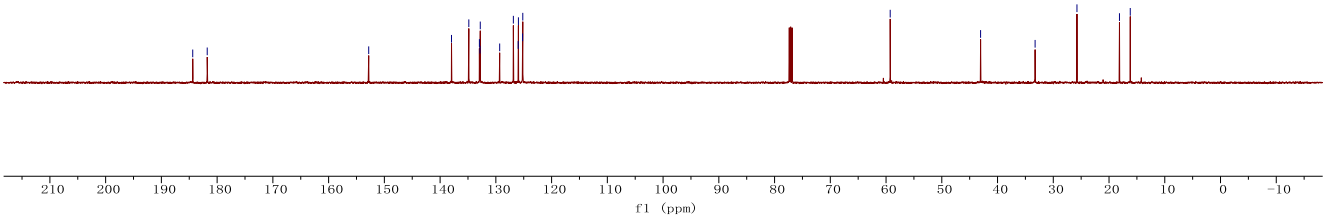


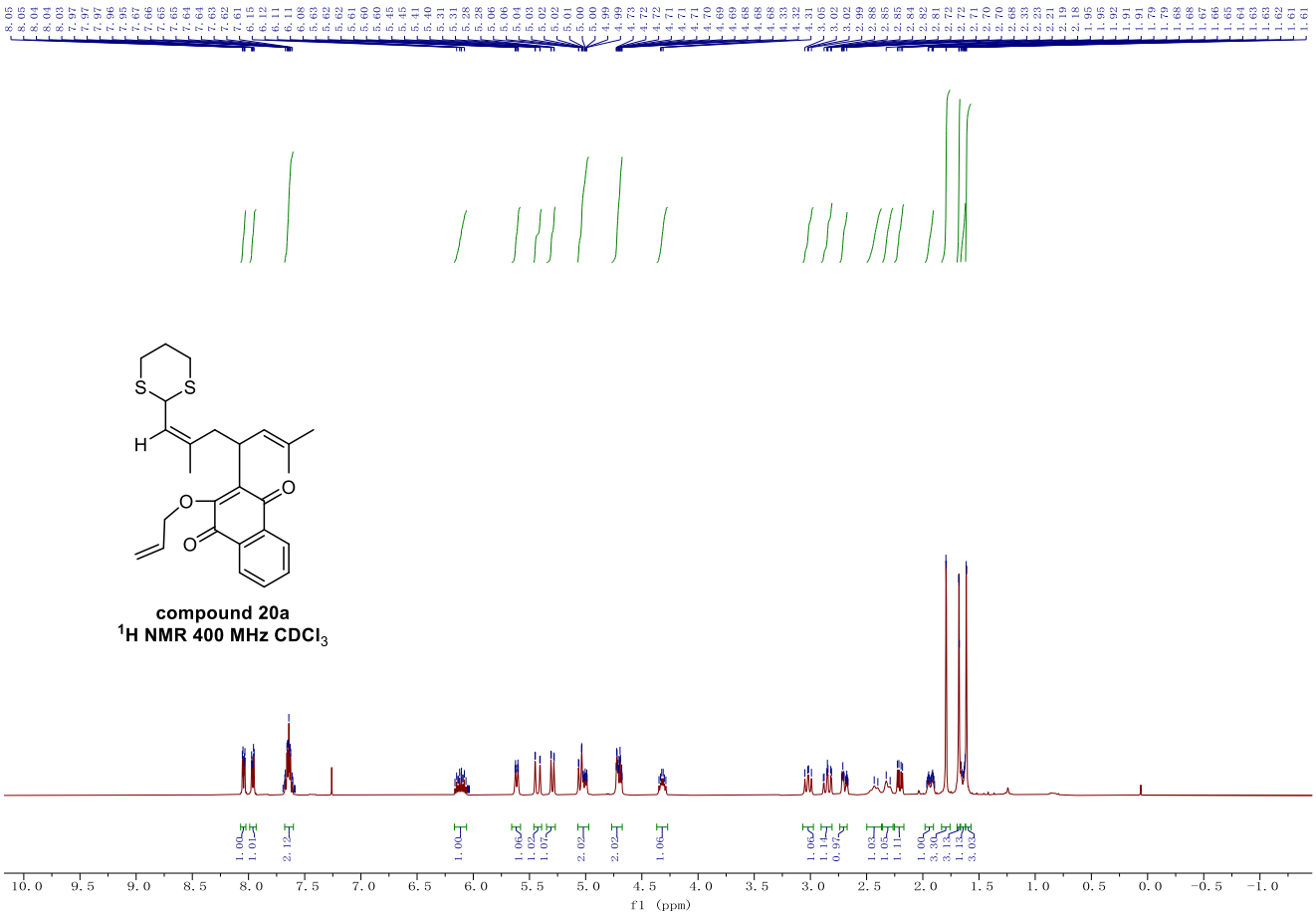
compound S4
^{1}H NMR 500 MHz CDCl$_3$



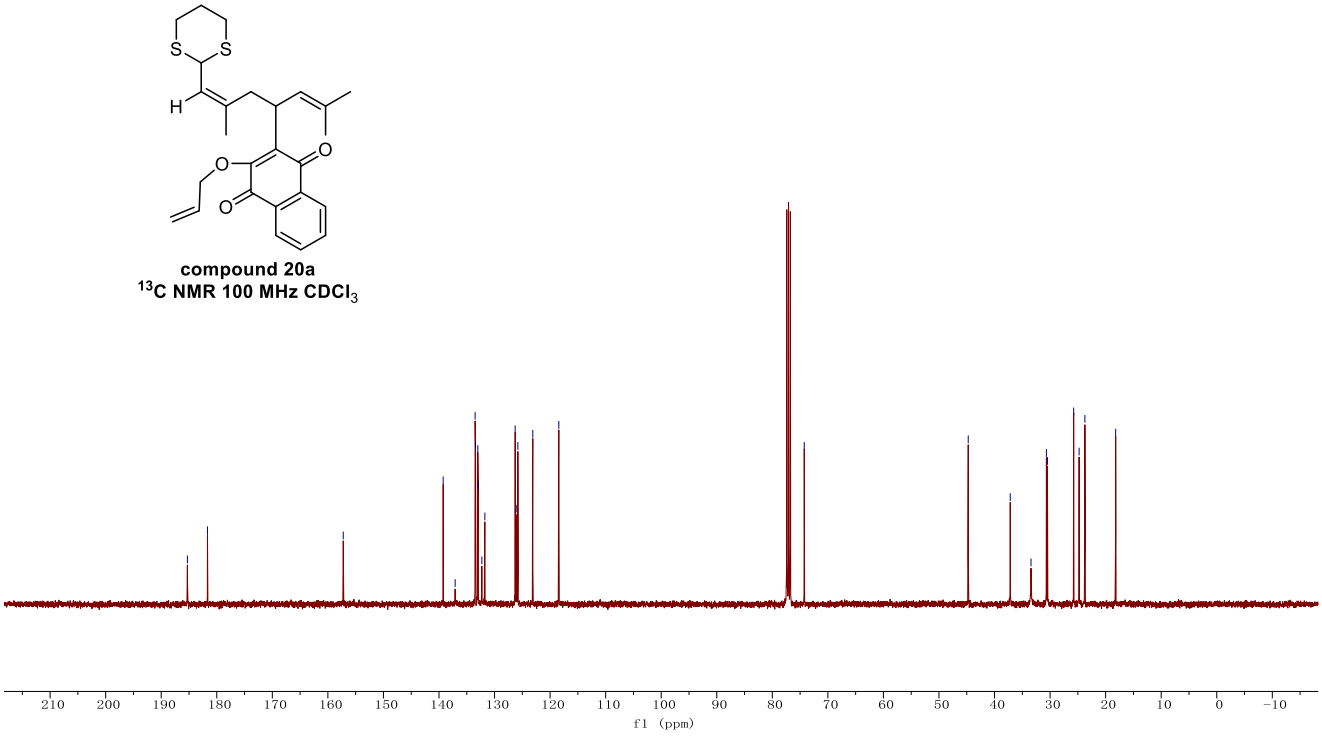


compound S4
^{13}C NMR 125 MHz CDCl$_3$

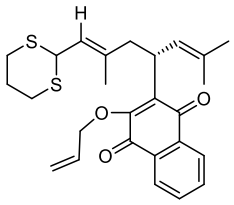




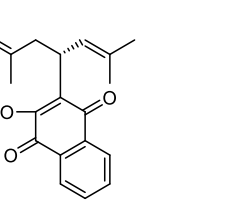
compound 20a
^{1}H NMR 400 MHz CDCl$_3$



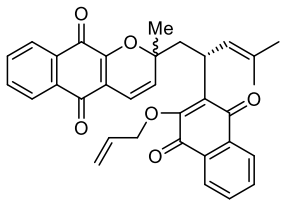
compound 20a
^{13}C NMR 100 MHz CDCl$_3$



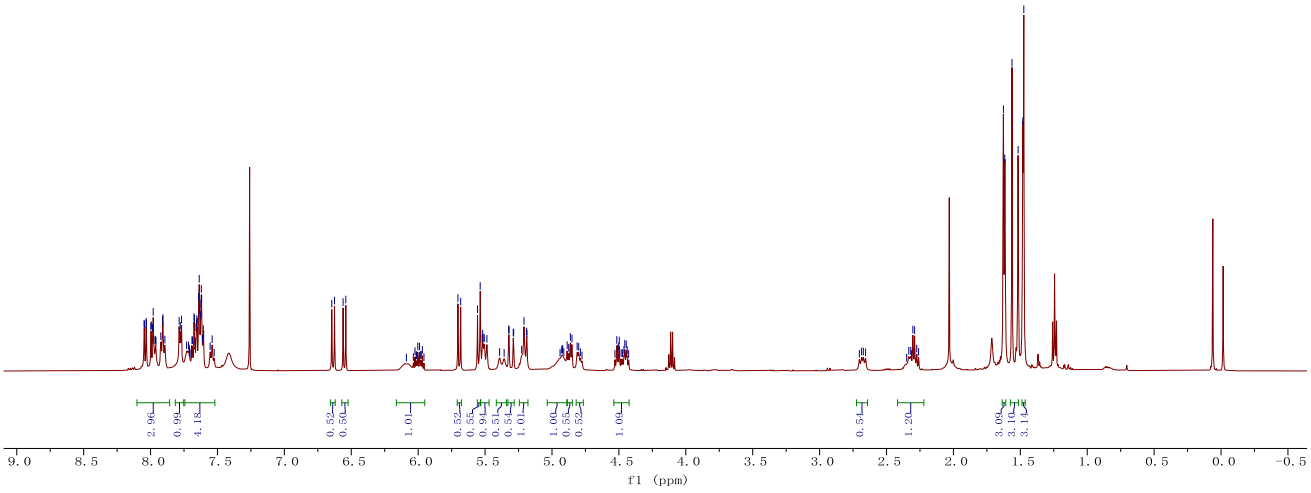
compound 20b
^{1}H NMR 400 MHz $CDCl_3$

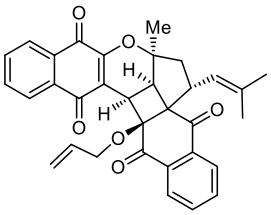


compound 20b
^{13}C NMR 100 MHz $CDCl_3$

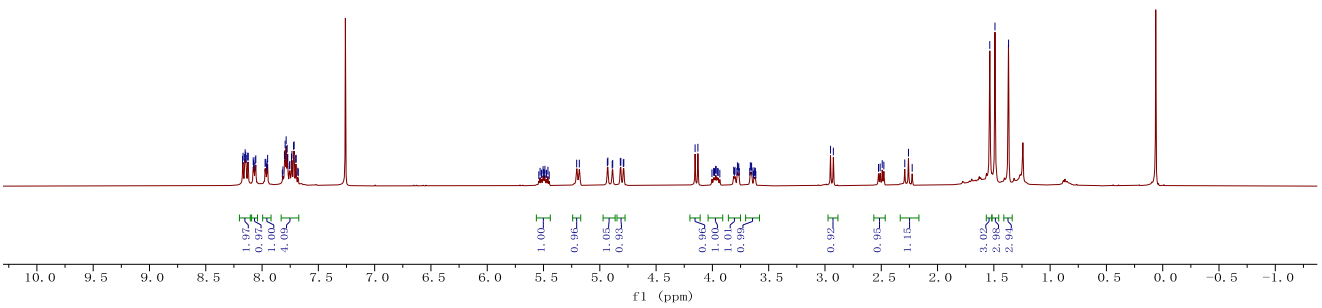


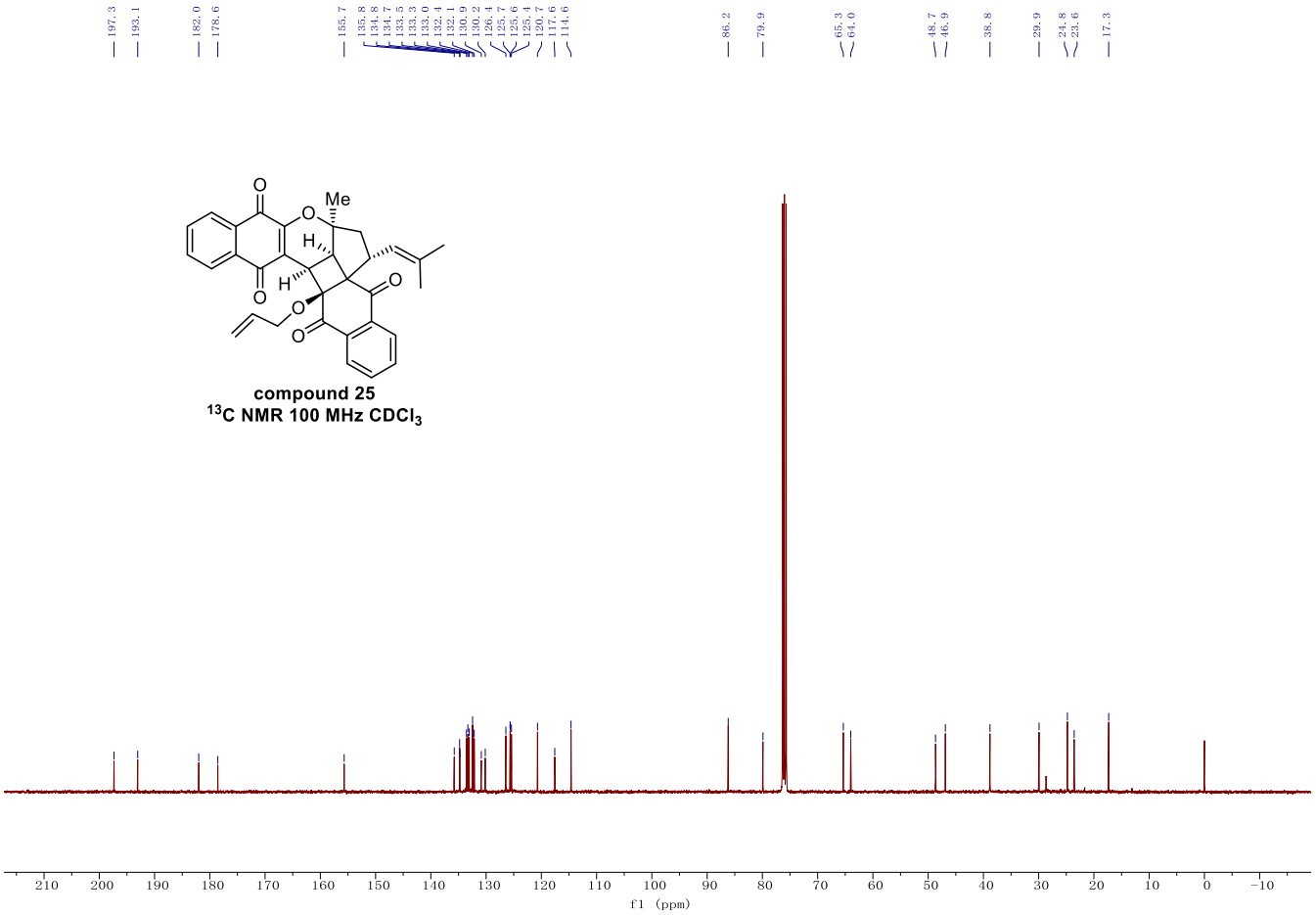
compound 21
^{1}H NMR 500 MHz $CDCl_3$





compound 25
^{1}H NMR 400 MHz $CDCl_3$




197.3
193.1
182.0
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155.7
135.8
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134.7
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133.3
133.0
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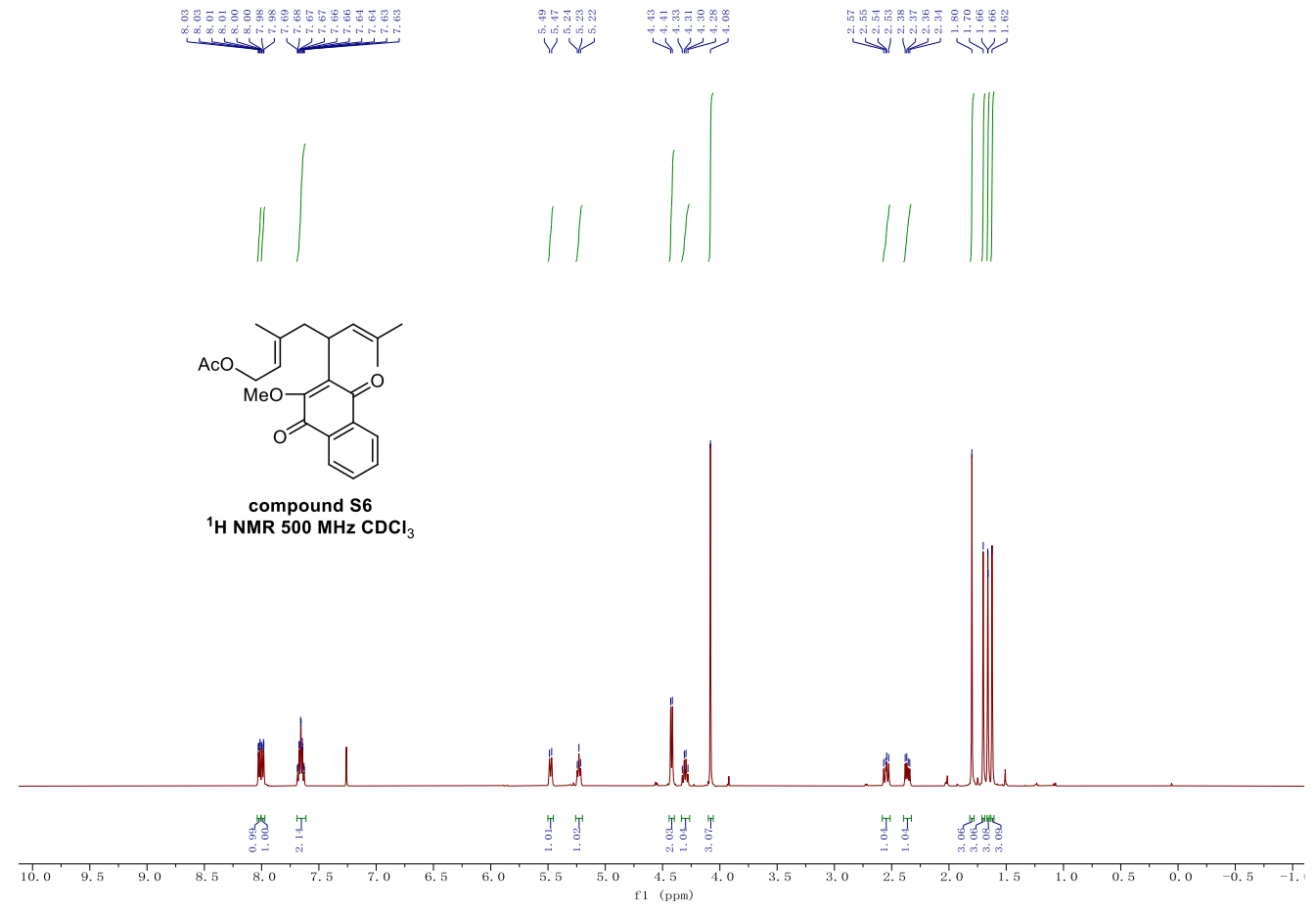
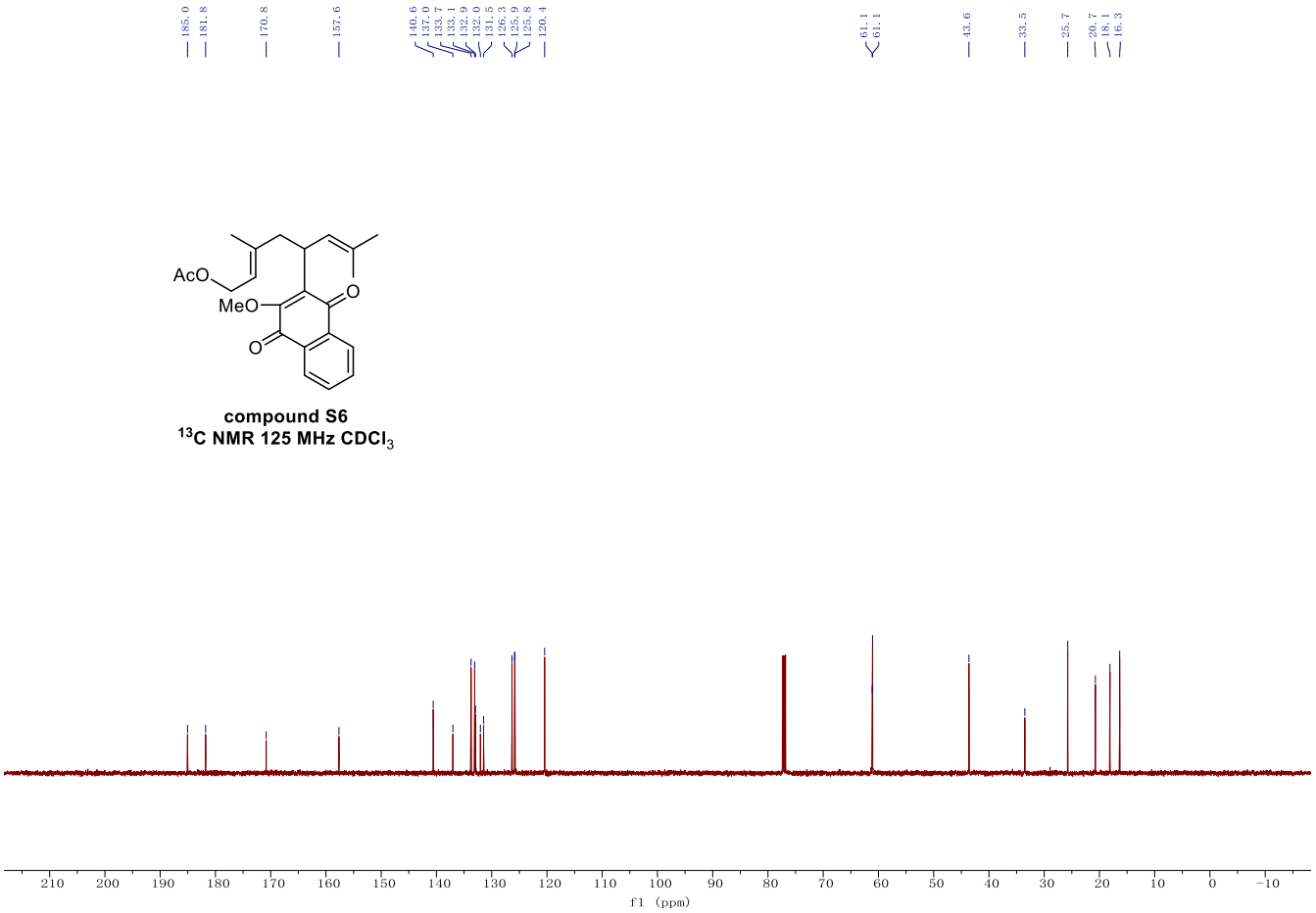
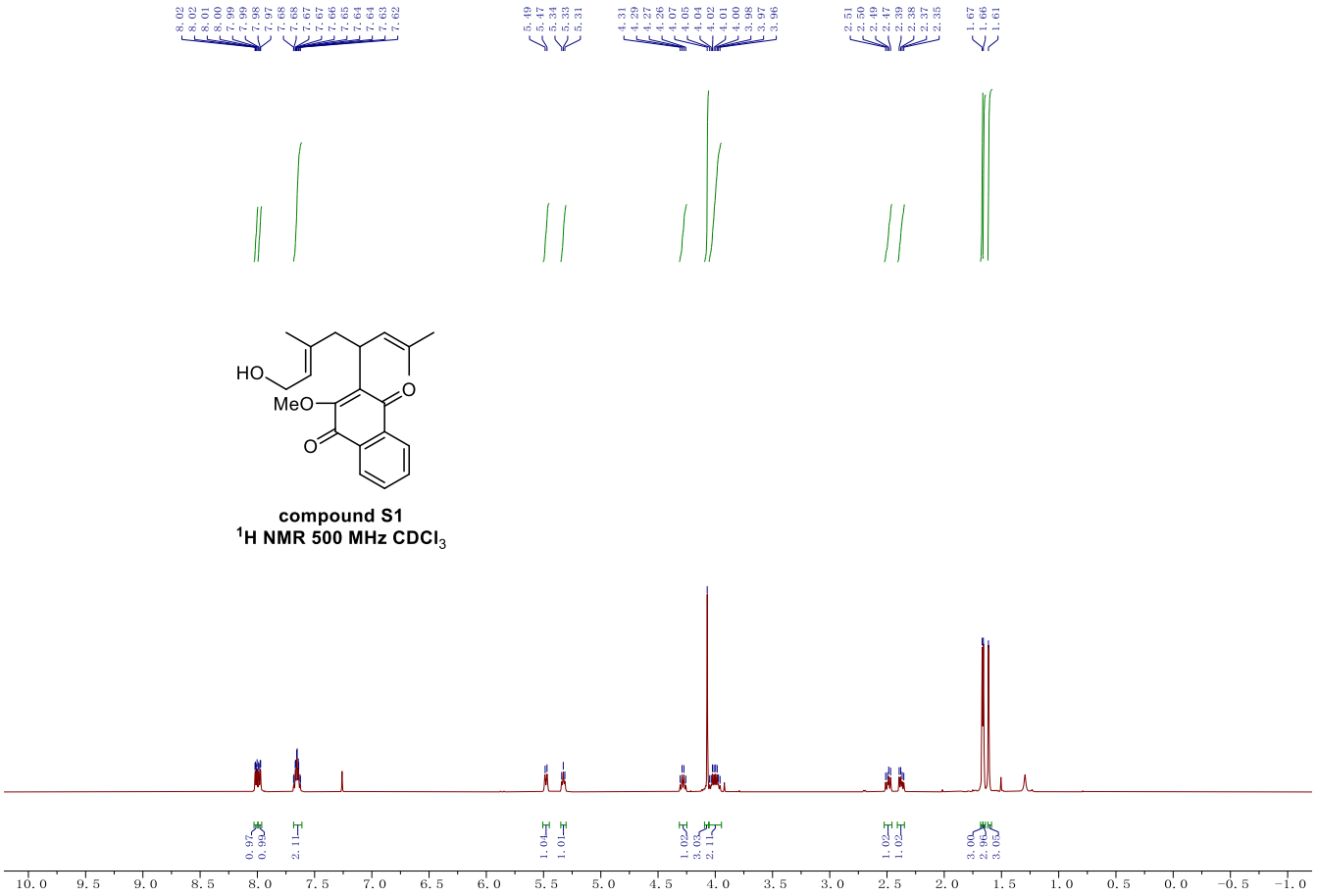
132.1
130.9
130.2
126.4
125.7
125.6
125.4
120.7
117.6
114.6
86.2
79.9
65.3
64.0
48.7
46.9
38.8
29.9
24.8
23.6
17.3
Me
O
H
H
O
O
O
O
O
O
compound 25
13C NMR 100 MHz CDCl3
f1 (ppm)

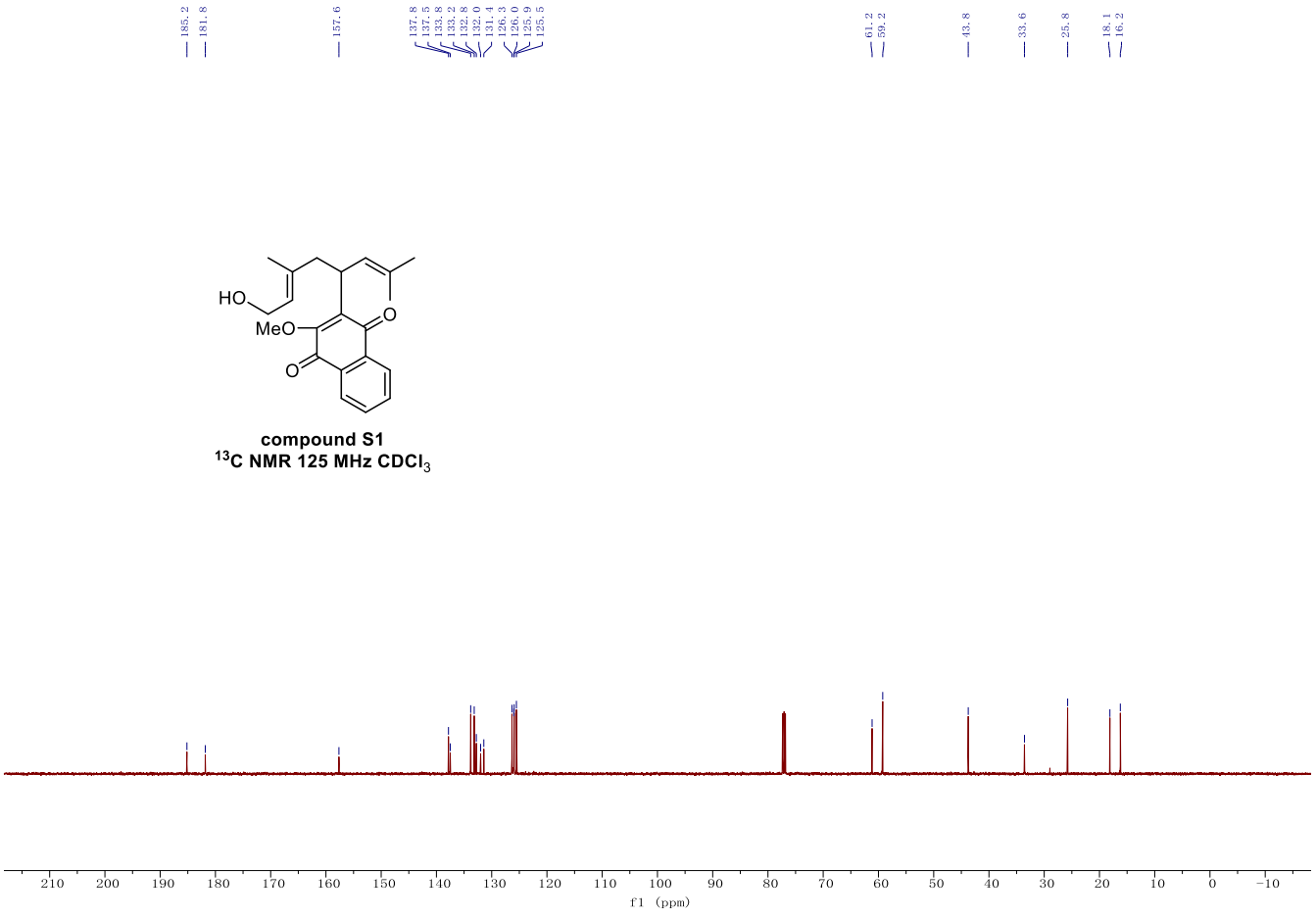

8.03
8.03
8.01
8.01
8.00
8.00
7.98
7.98
7.69
7.68
7.67
7.67
7.66
7.66
7.64
7.64
7.63
7.63
5.49
5.47
5.24
5.23
5.22
4.43
4.41
4.33
4.31
4.30
4.28
4.08
2.57
2.55
2.54
2.53
2.38
2.37
2.36
2.34
1.80
1.70
1.66
1.66
1.62
AcO
MeO
O
O
compound S6
1H NMR 500 MHz CDCl3
0.99
1.00
2.14
1.01
1.02
2.03
1.04
3.07
1.04
1.04
3.06
3.06
3.08
3.09
f1 (ppm)



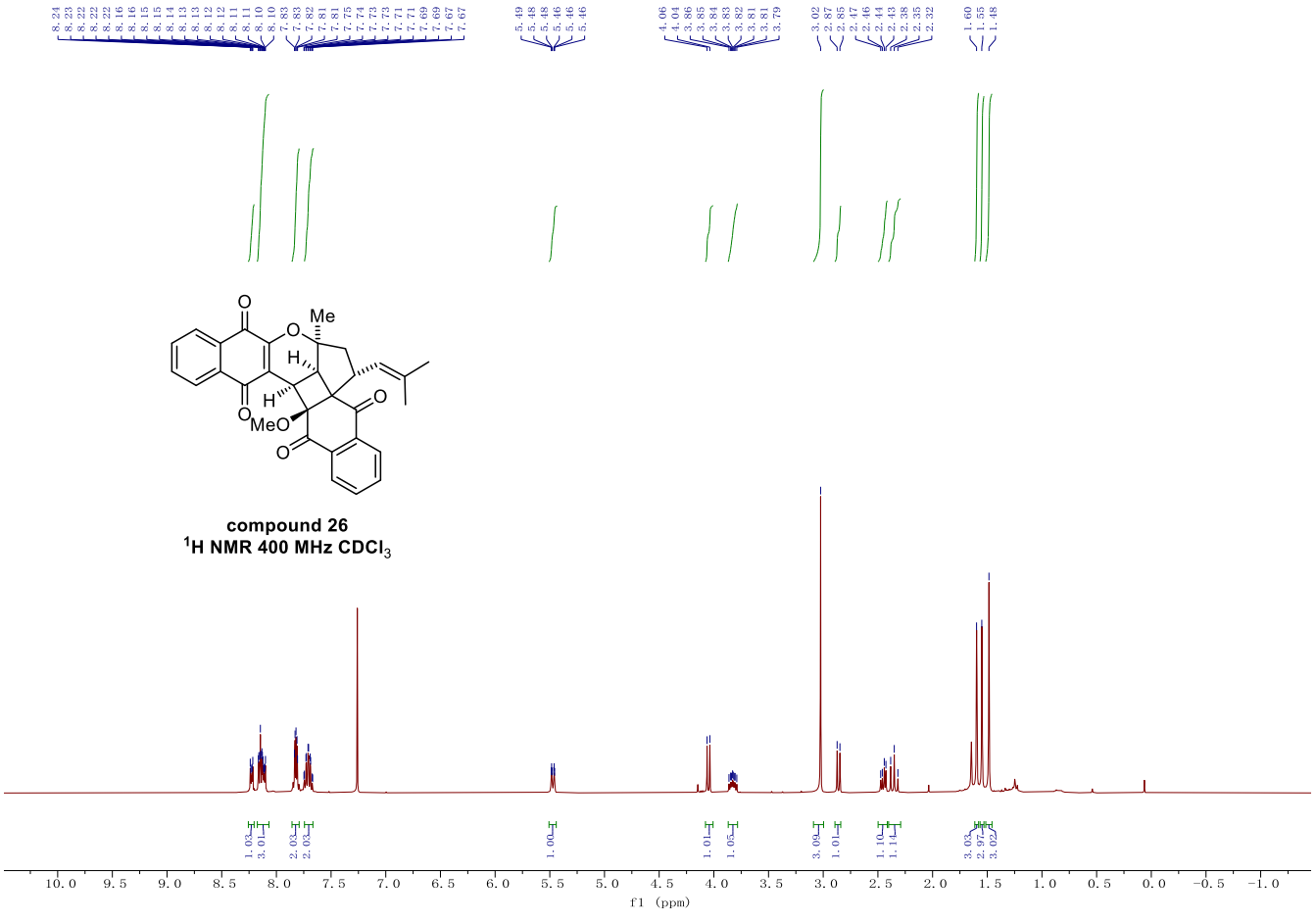
compound S6
^{13}C NMR 125 MHz $CDCl_3$



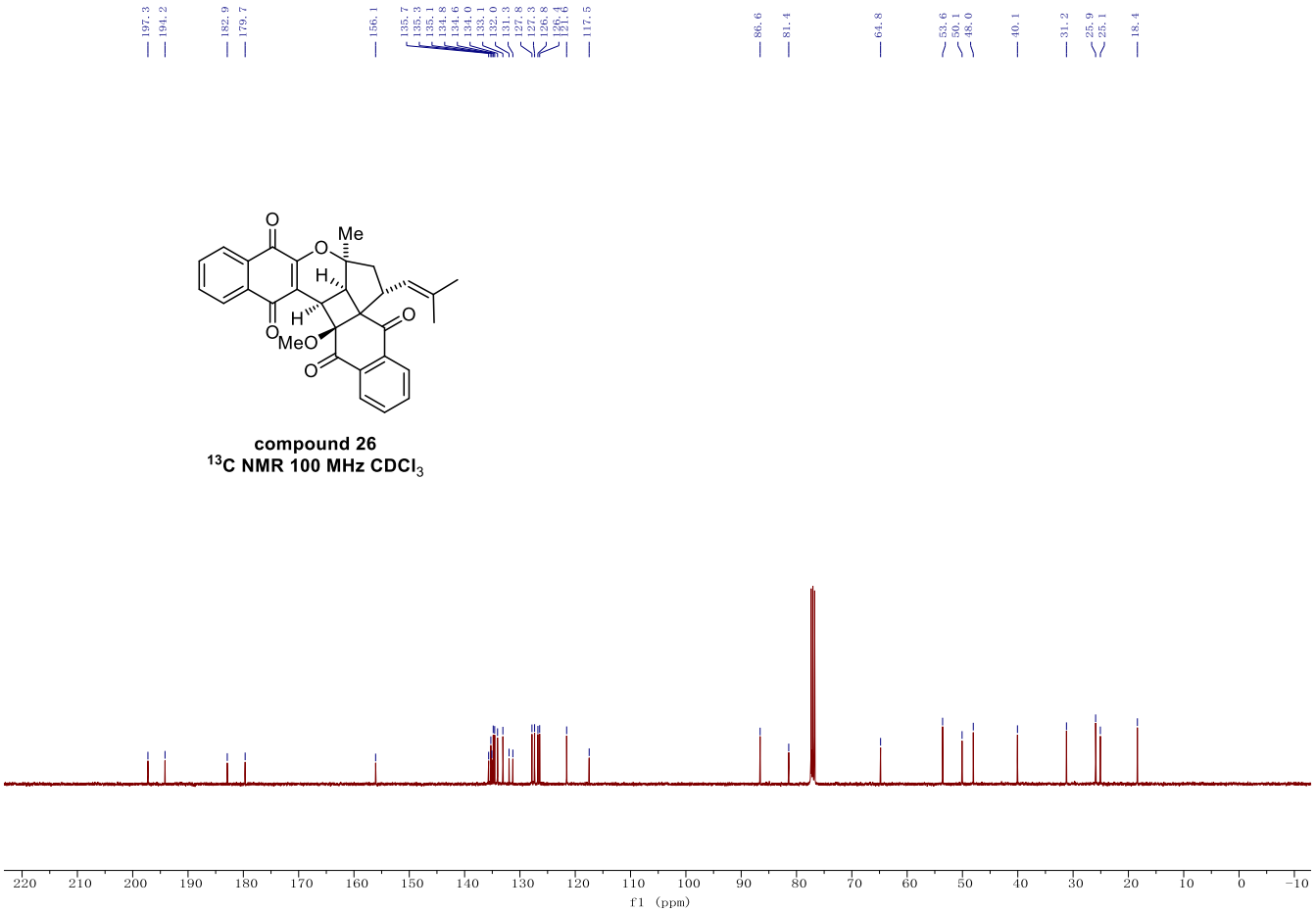
compound S1
^{1}H NMR 500 MHz $CDCl_3$



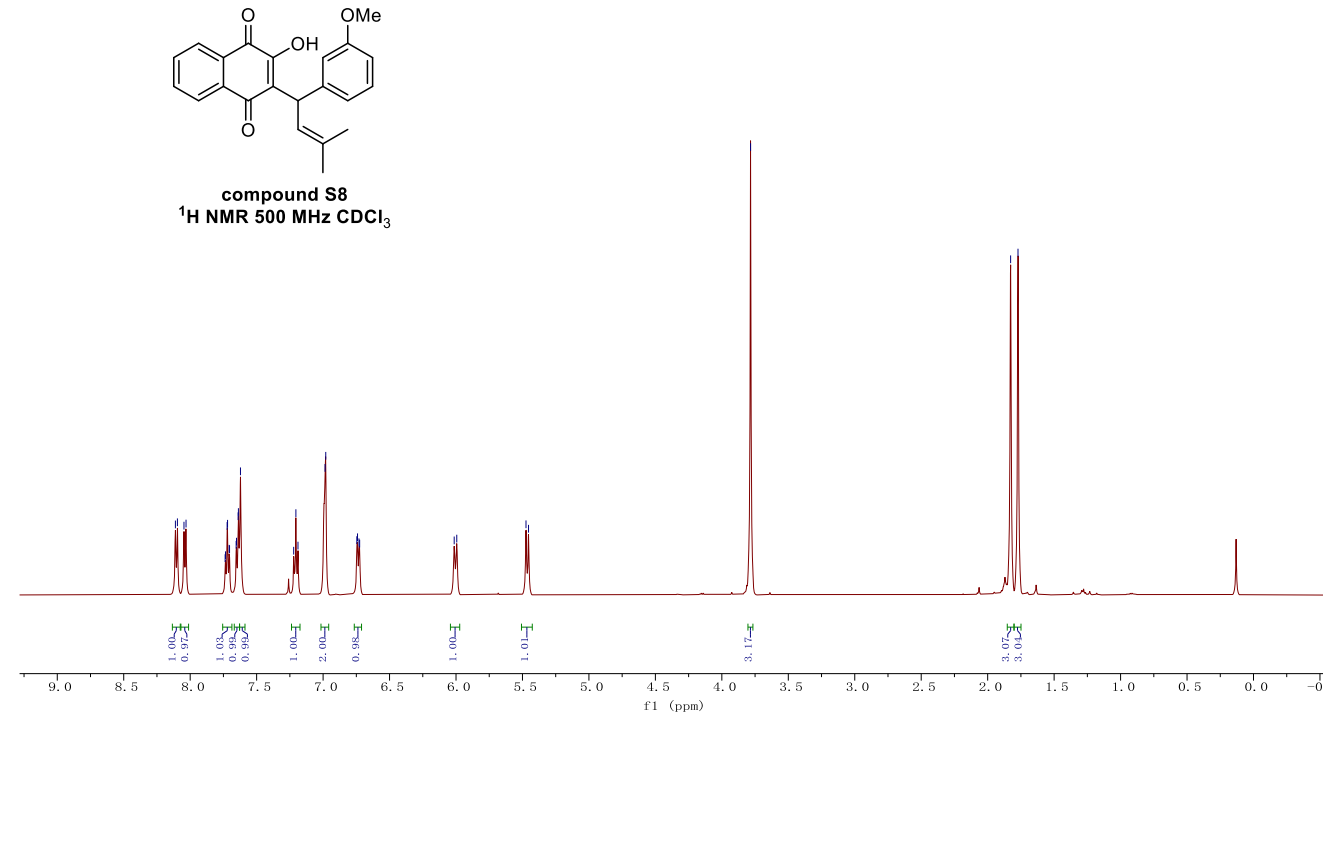
compound S1
^{13}C NMR 125 MHz $CDCl_3$



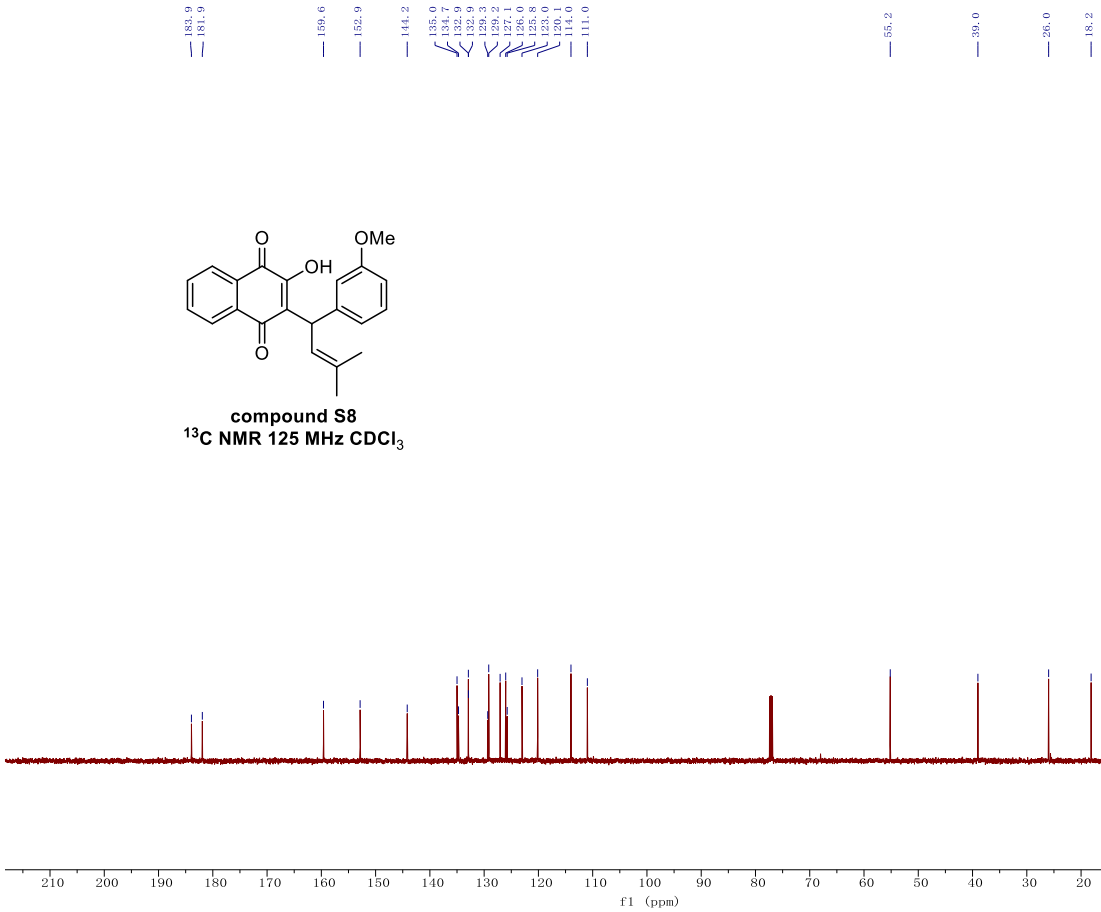
compound 26
^{1}H NMR 400 MHz $CDCl_3$



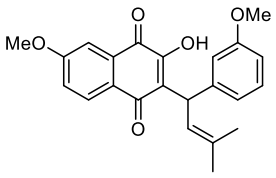
compound 26
^{13}C NMR 100 MHz $CDCl_3$



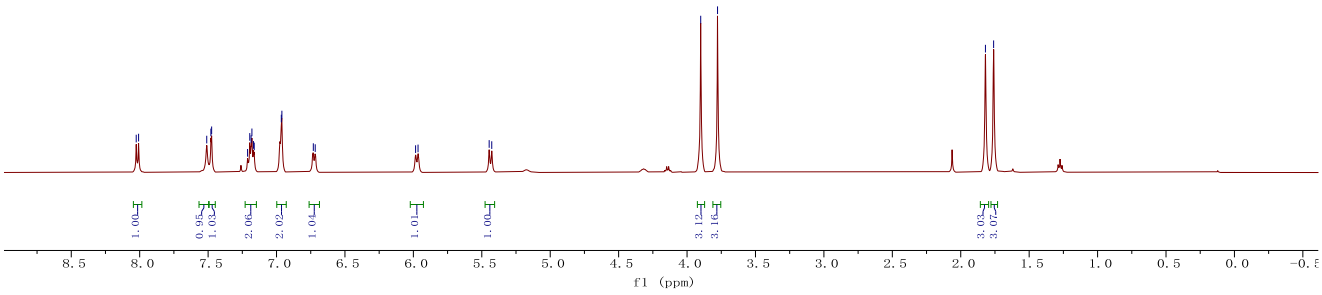
compound S8
^{1}H NMR 500 MHz $CDCl_3$

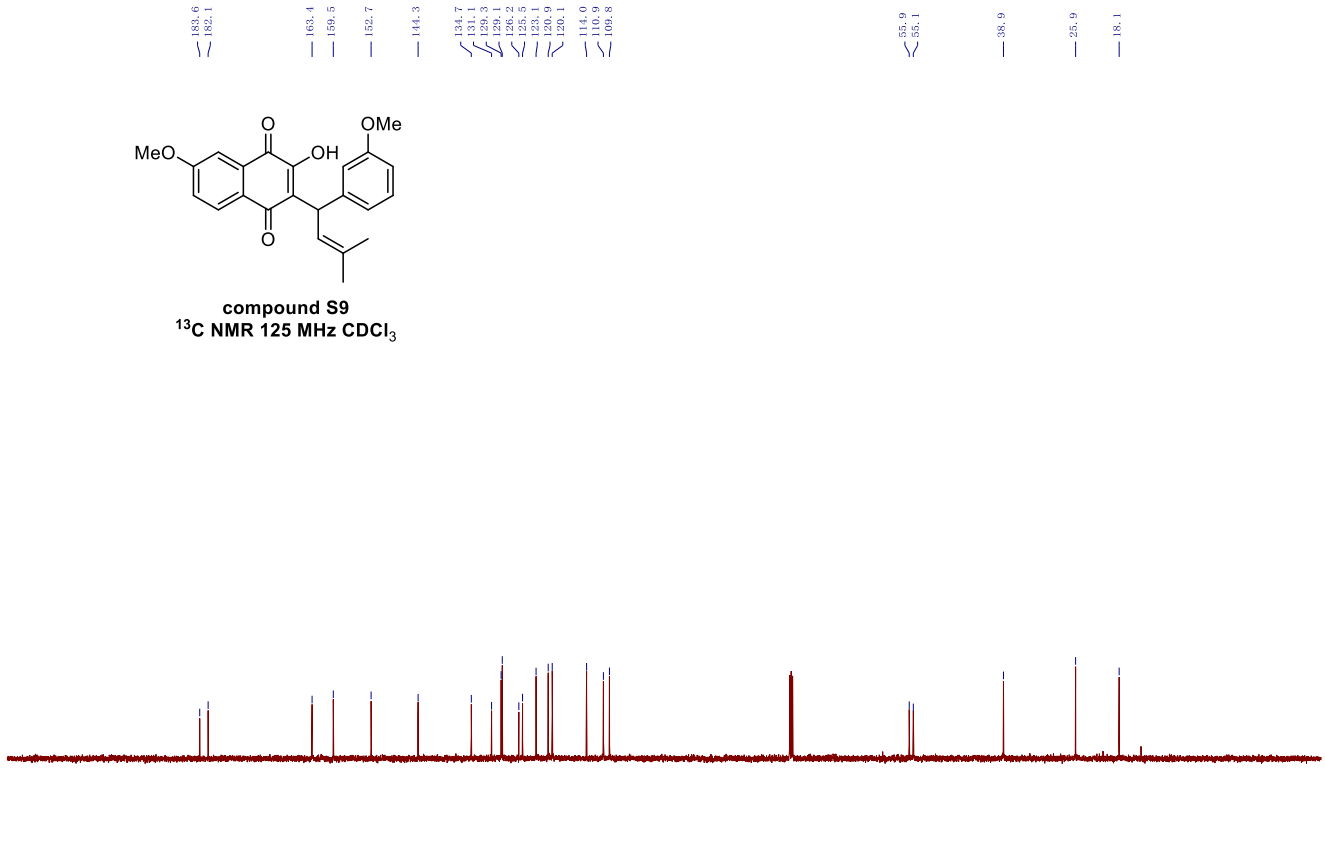


compound S8
^{13}C NMR 125 MHz $CDCl_3$

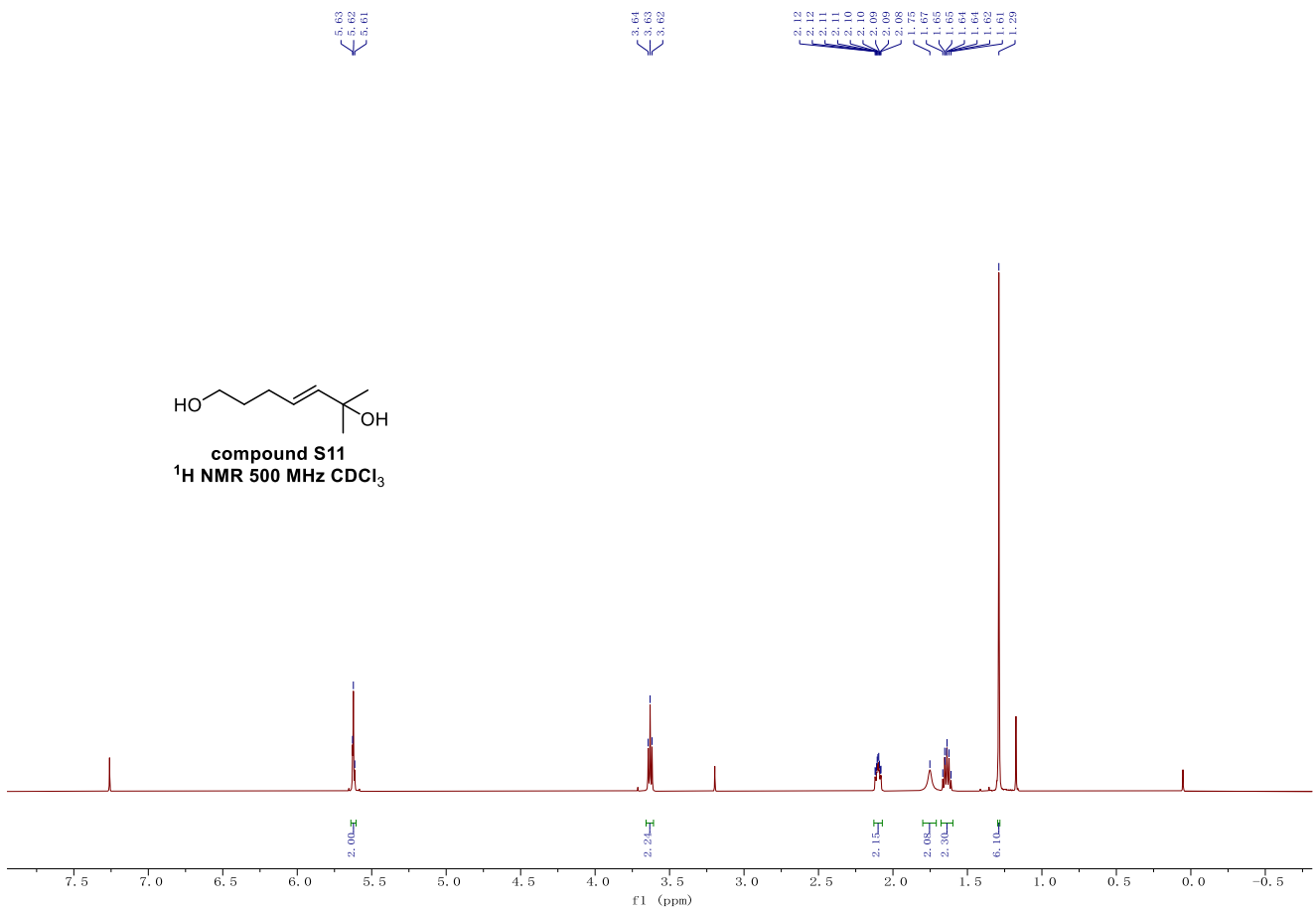


compound S9
^{1}H NMR 500 MHz $CDCl_3$

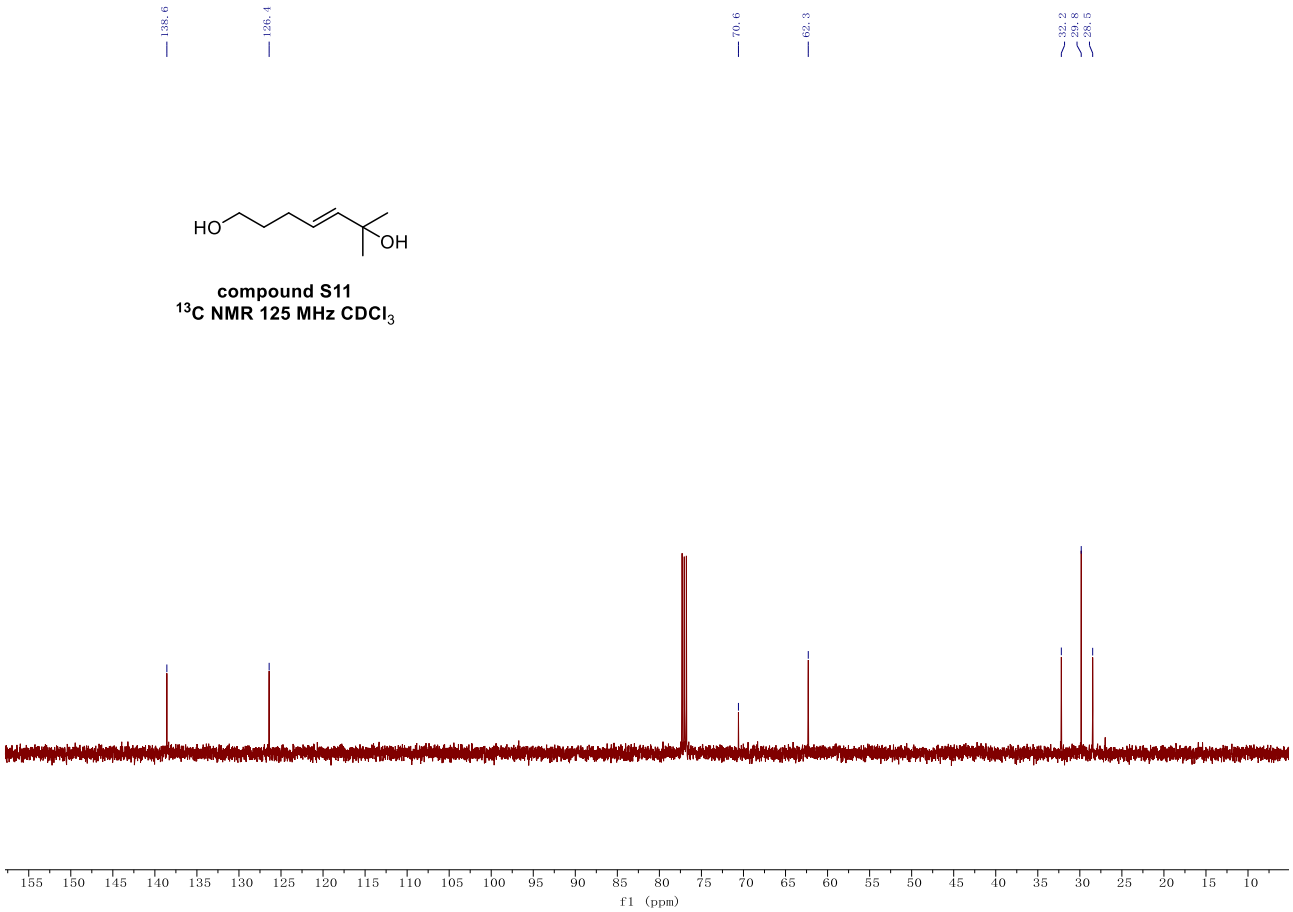




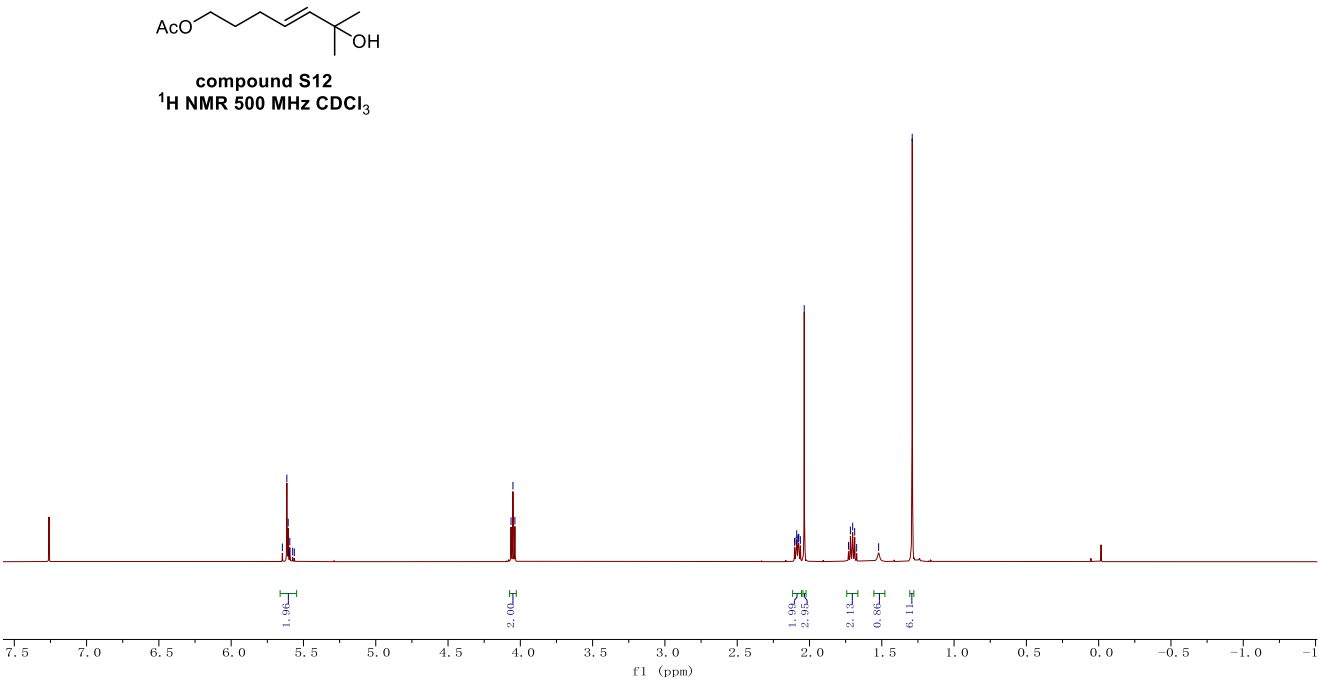
compound S9
^{13}C NMR 125 MHz $CDCl_3$



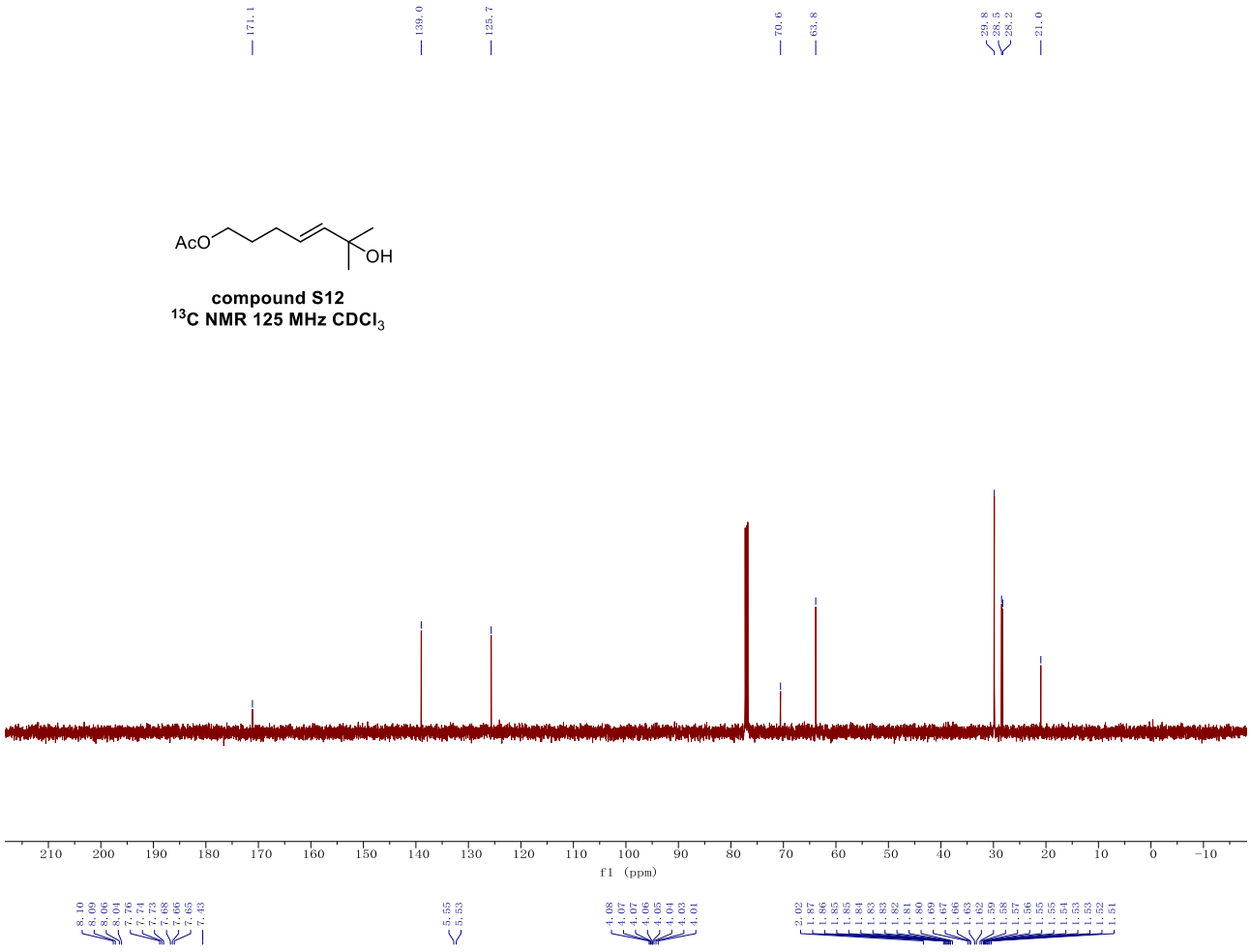
compound S11
^{1}H NMR 500 MHz $CDCl_3$



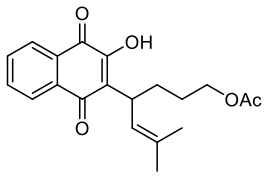
compound S11
^{13}C NMR 125 MHz $CDCl_3$



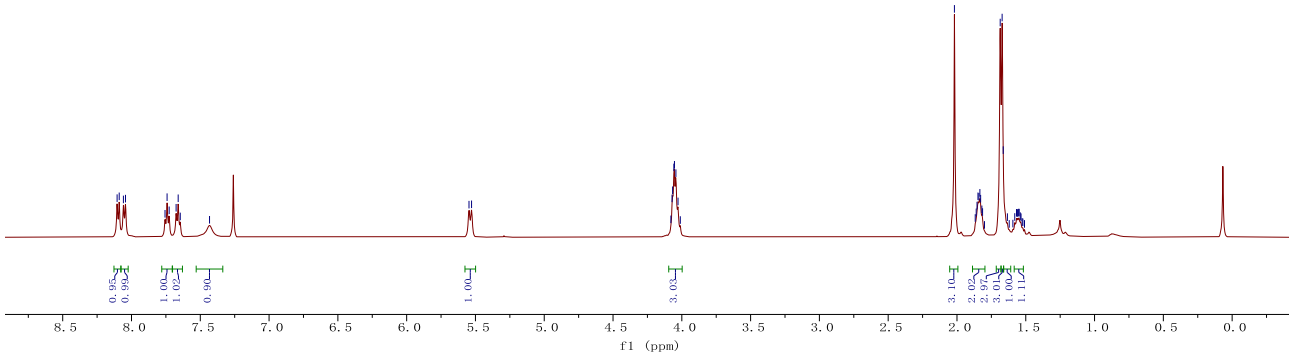
compound S12
^{1}H NMR 500 MHz $CDCl_3$

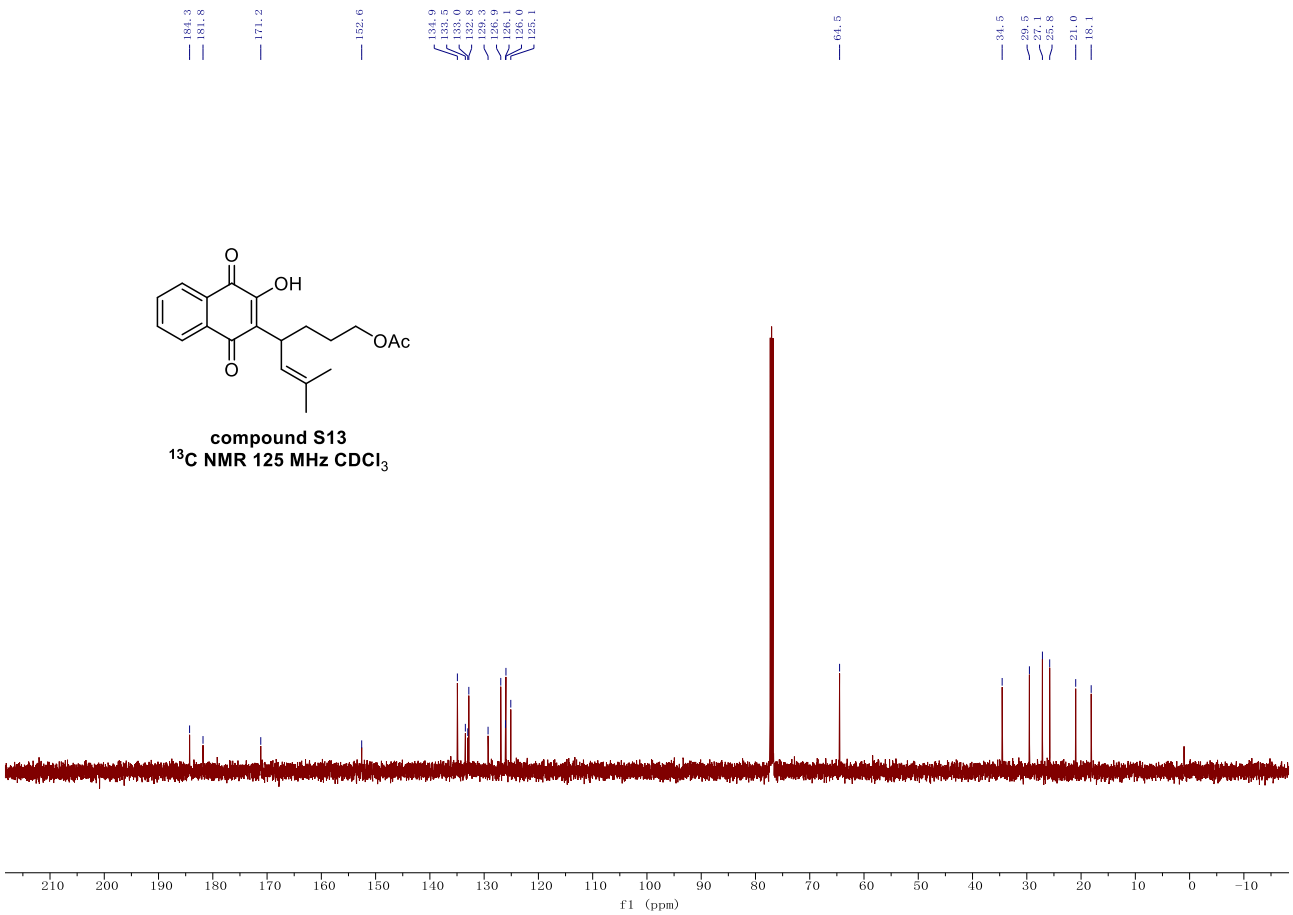


compound S12
^{13}C NMR 125 MHz $CDCl_3$

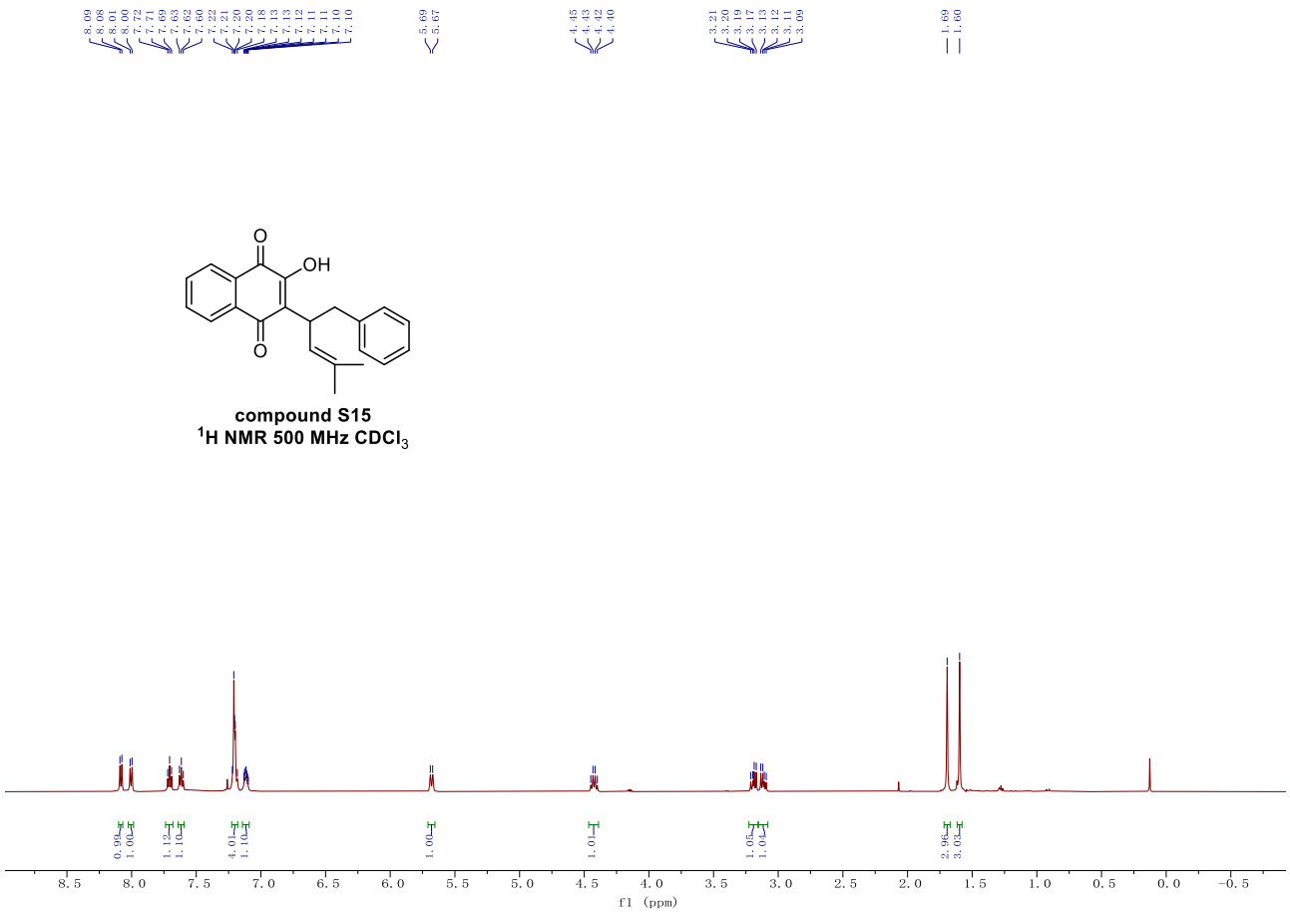


compound S13
^{1}H NMR 500 MHz $CDCl_3$

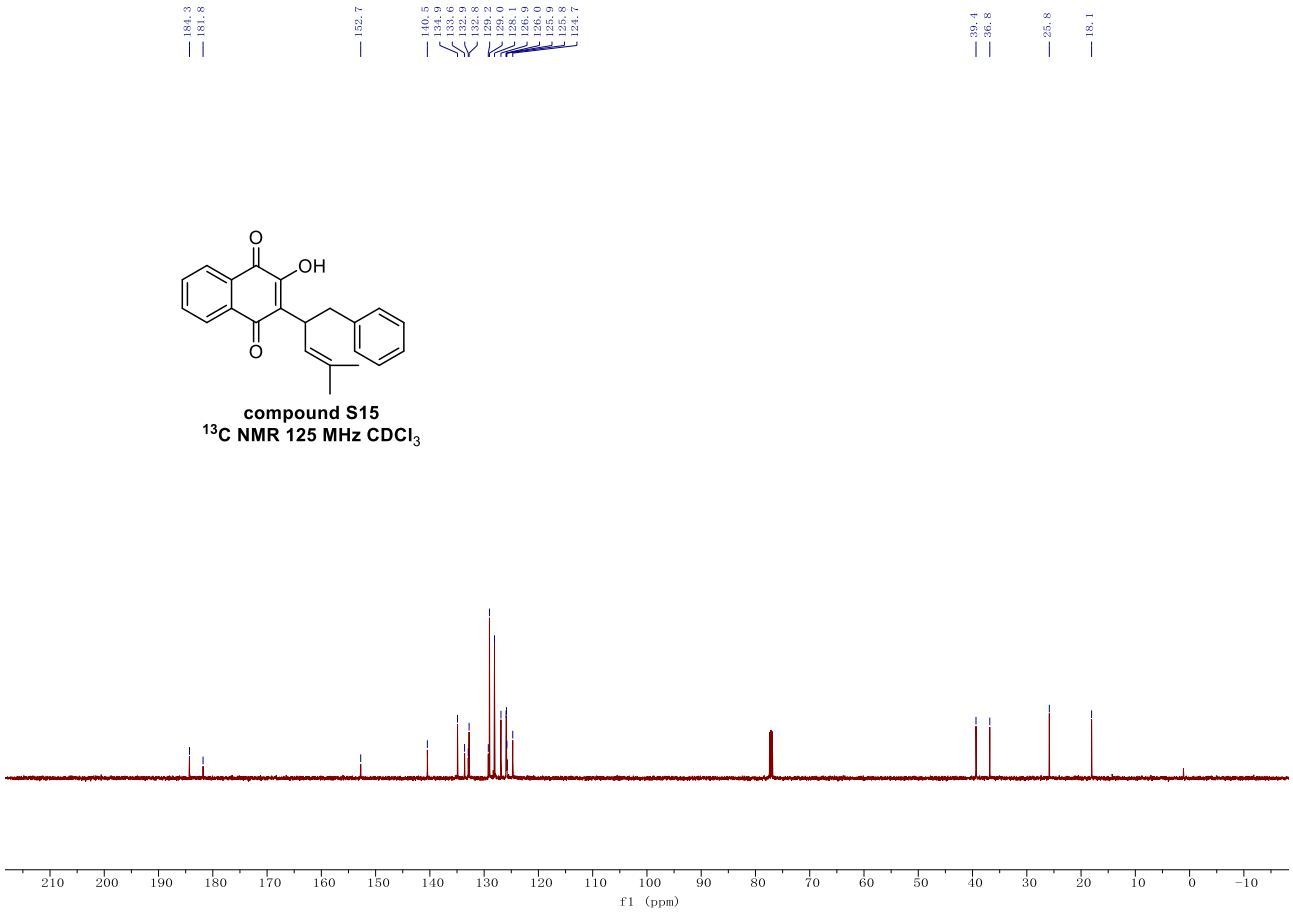




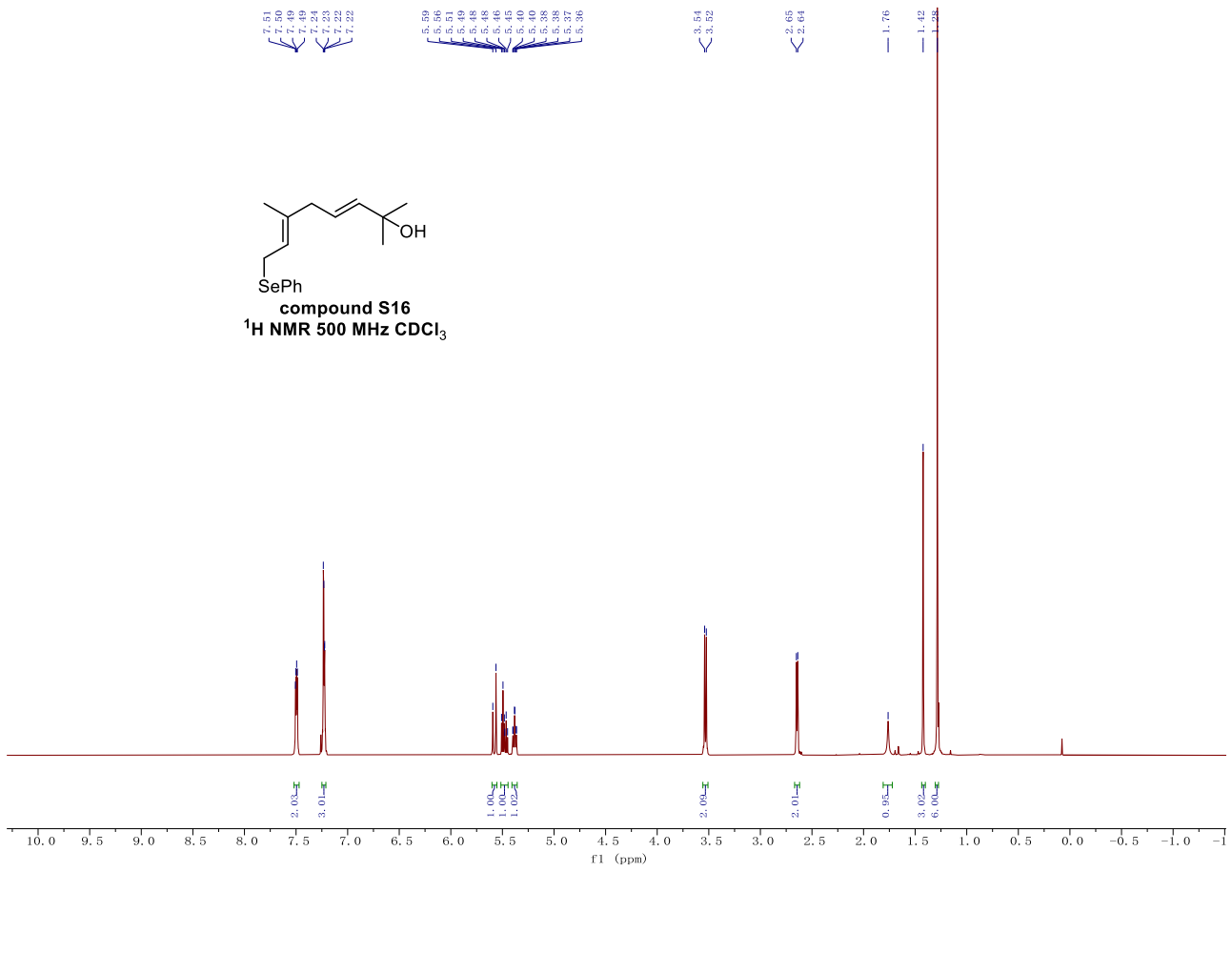
compound S13
^{13}C NMR 125 MHz $CDCl_3$



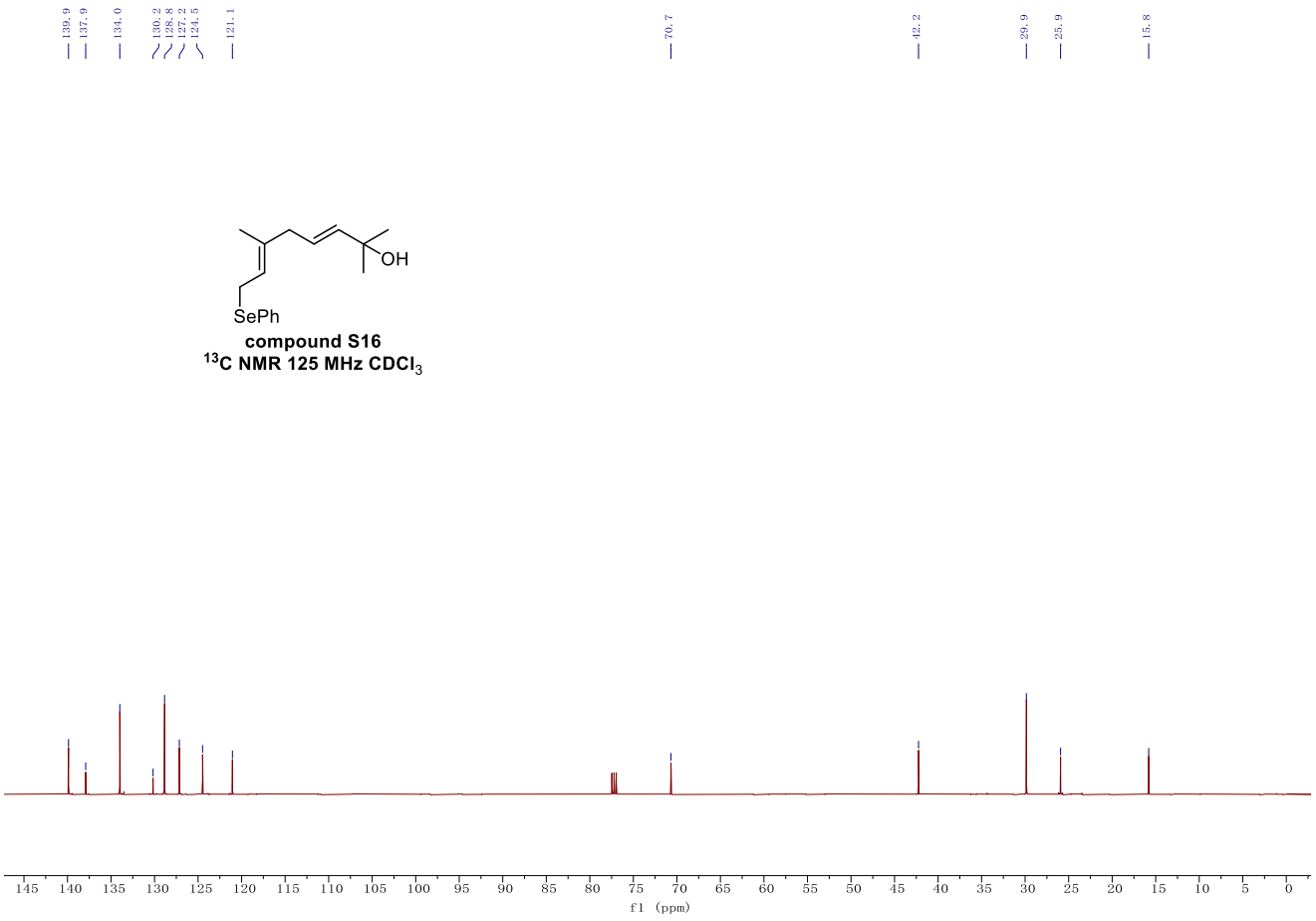
compound S15
^{1}H NMR 500 MHz $CDCl_3$



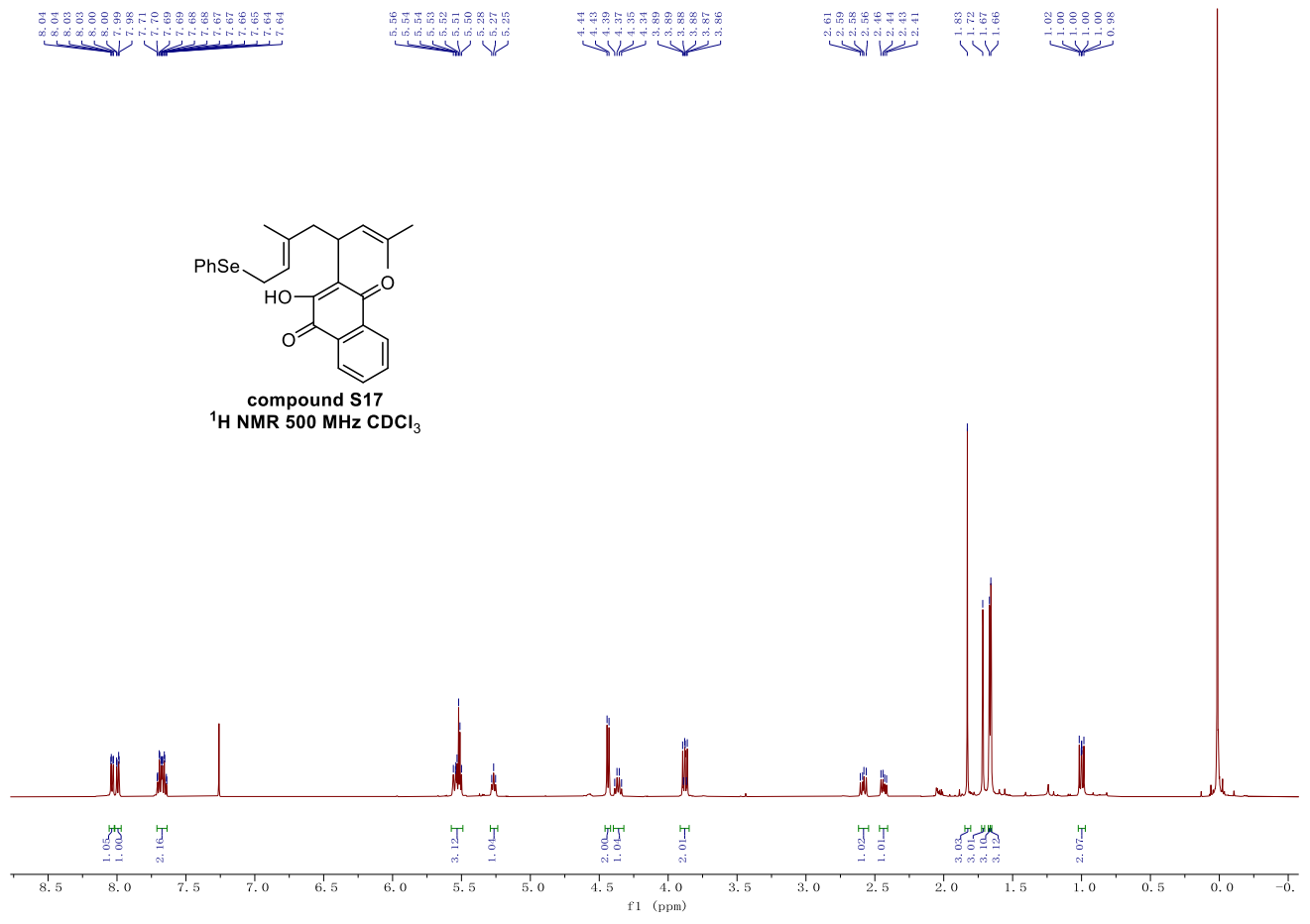
compound S15
^{13}C NMR 125 MHz $CDCl_3$



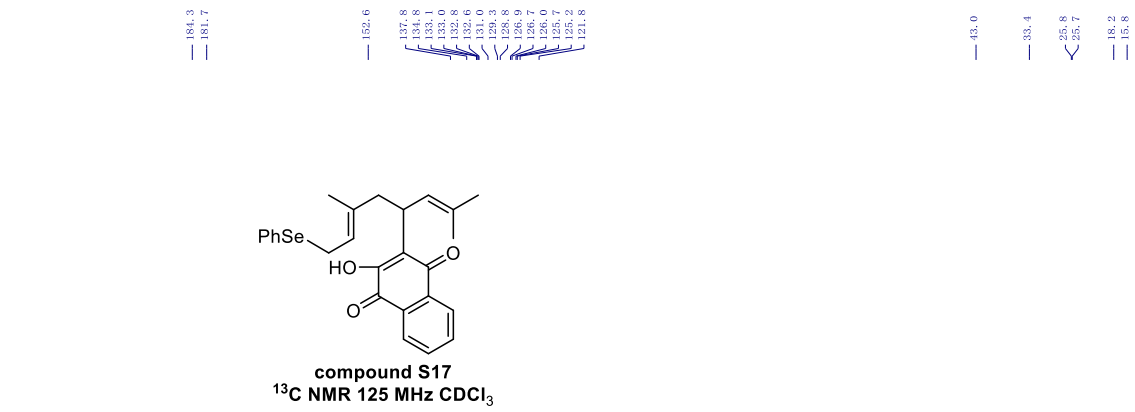
compound S16
^{1}H NMR 500 MHz $CDCl_3$



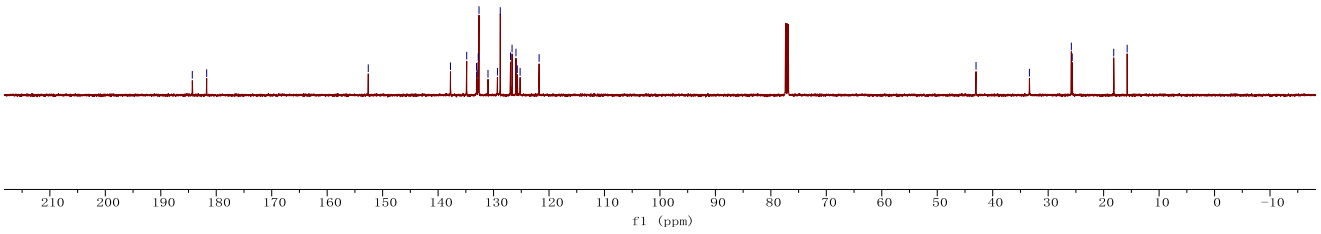
compound S16
^{13}C NMR 125 MHz $CDCl_3$

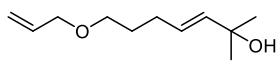


compound S17
^{1}H NMR 500 MHz $CDCl_3$

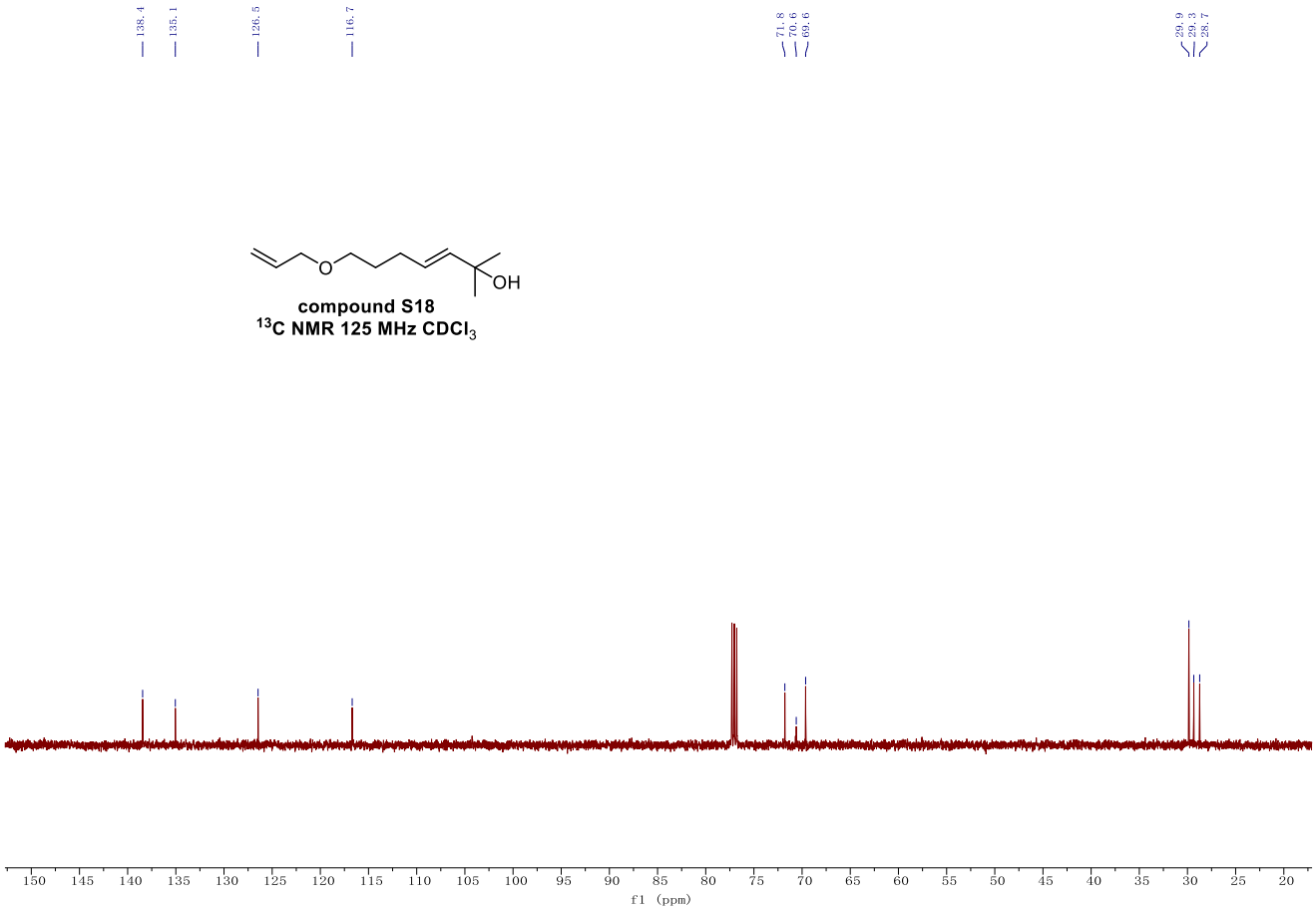


compound S17
^{13}C NMR 125 MHz $CDCl_3$

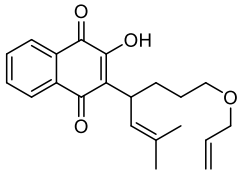




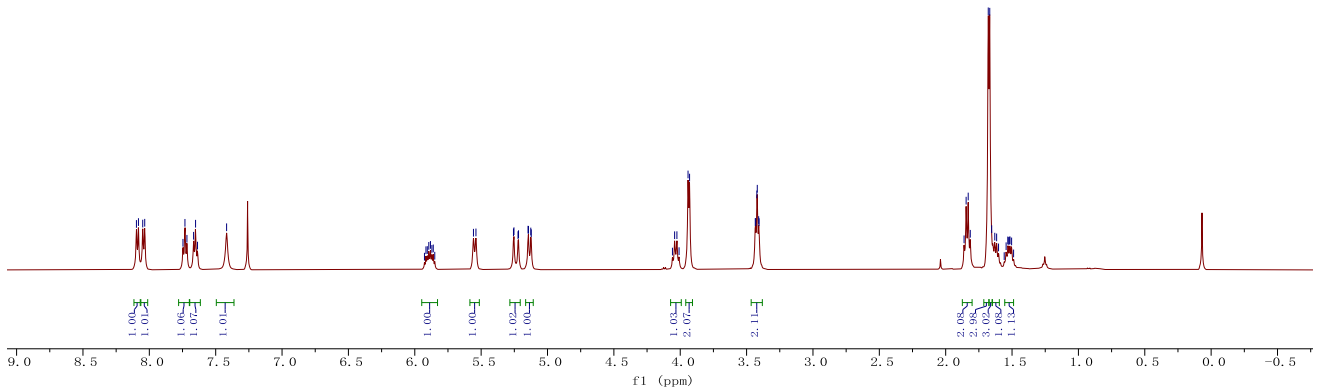
compound S18
^{1}H NMR 500 MHz $CDCl_3$

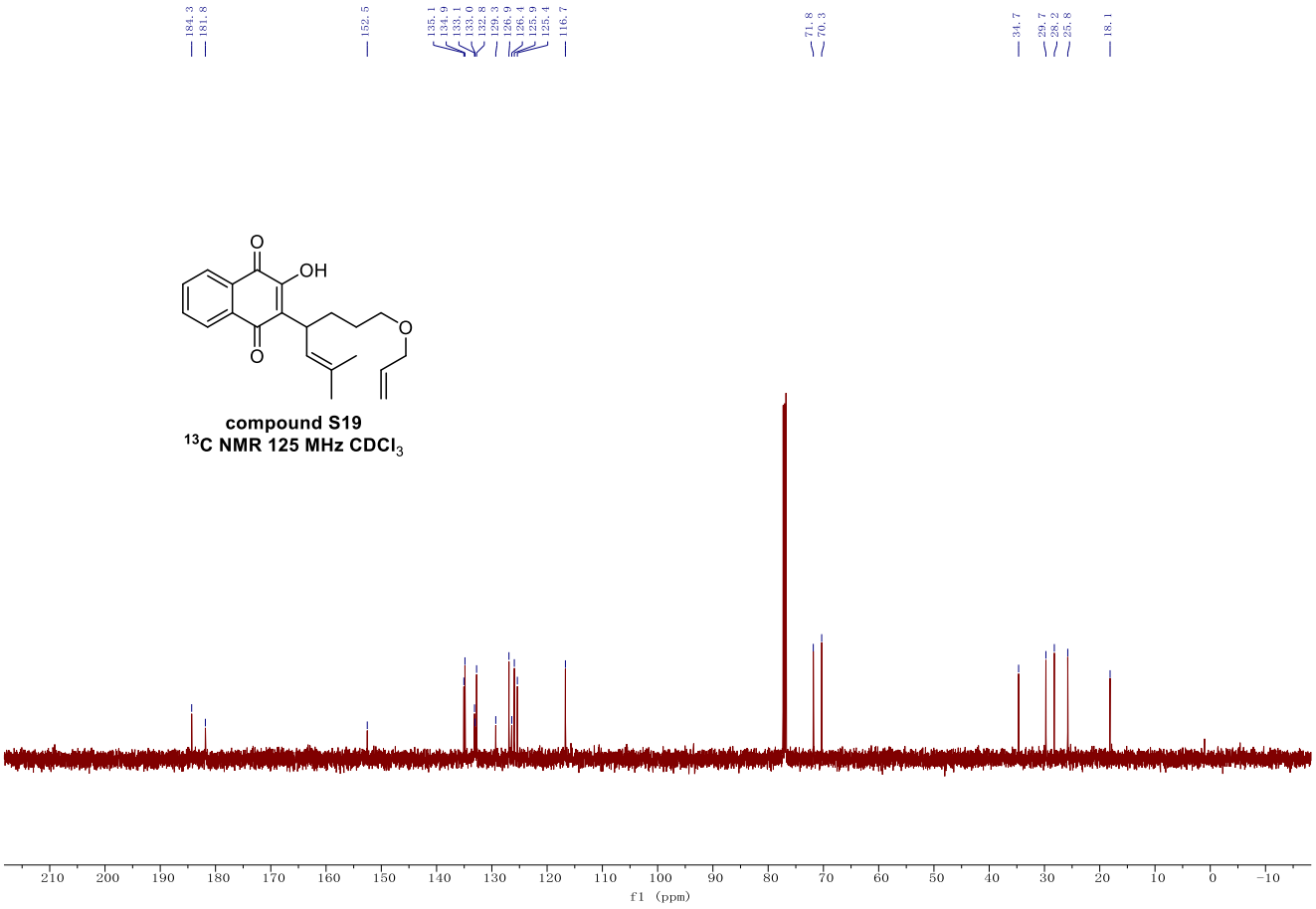


compound S18
^{13}C NMR 125 MHz $CDCl_3$



compound S19
^{1}H NMR 500 MHz $CDCl_3$




184.3
181.8
152.5
135.1
134.9
133.1
133.0
132.8
129.3
126.9
126.4
125.9
125.4
116.7
71.8
70.3
34.7
29.7
28.2
25.8
18.1
O
OH
O
O
compound S19
13C NMR 125 MHz CDCl3
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
f1 (ppm)