Electronic Supplementary Material (ESI) for RSC Advances.

Supporting Information

Synthesis of benzonaphthofuroquinones and benzoylnaphthindolizinediones by reactions of flavonoids with dichlone under basylous, oxygenous and aqueous conditions: their cytotoxic and apoptopic activities

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[c] Guangxi University of Chinese Medicine, Nanning, Guangxi 530001, China

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1 Figures of apoptosis analysis and western blotting analysis

1.1 Apoptosis analysis

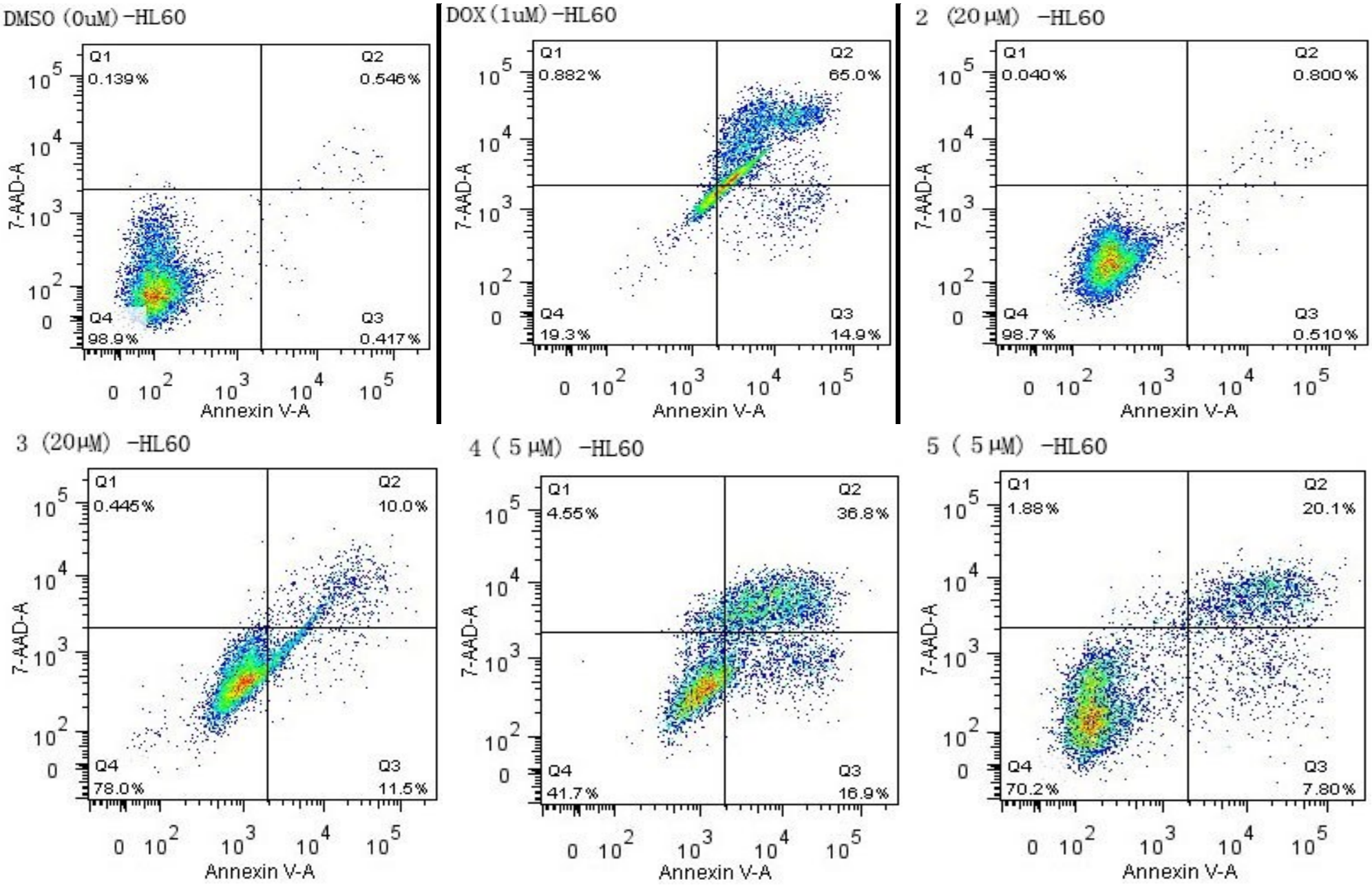


Figure S1. Derivatives induce apoptosis in Human Leukemia

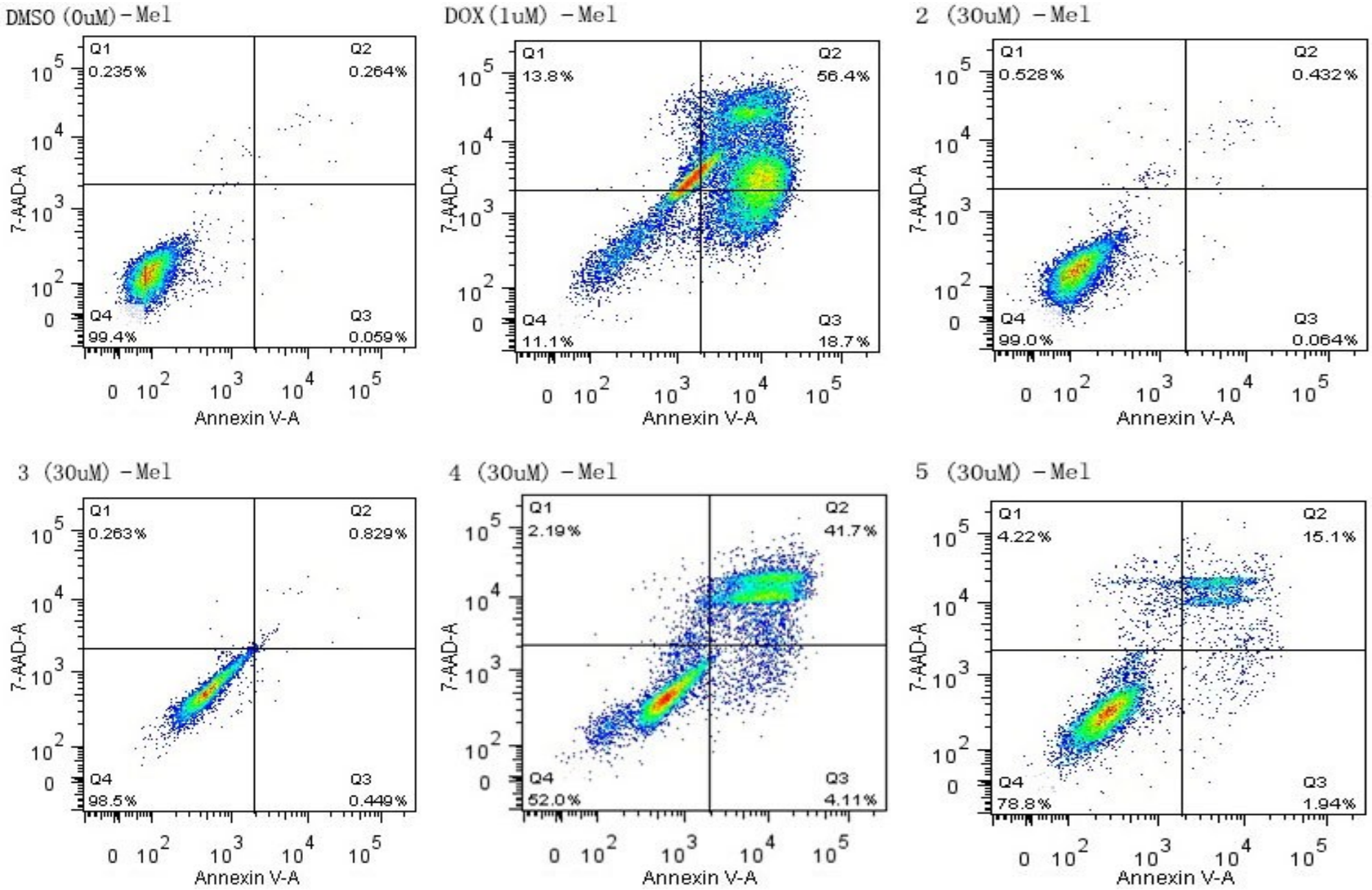


Figure S2. Derivatives induce apoptosis in Melanoma

1.2 Western blotting analysis

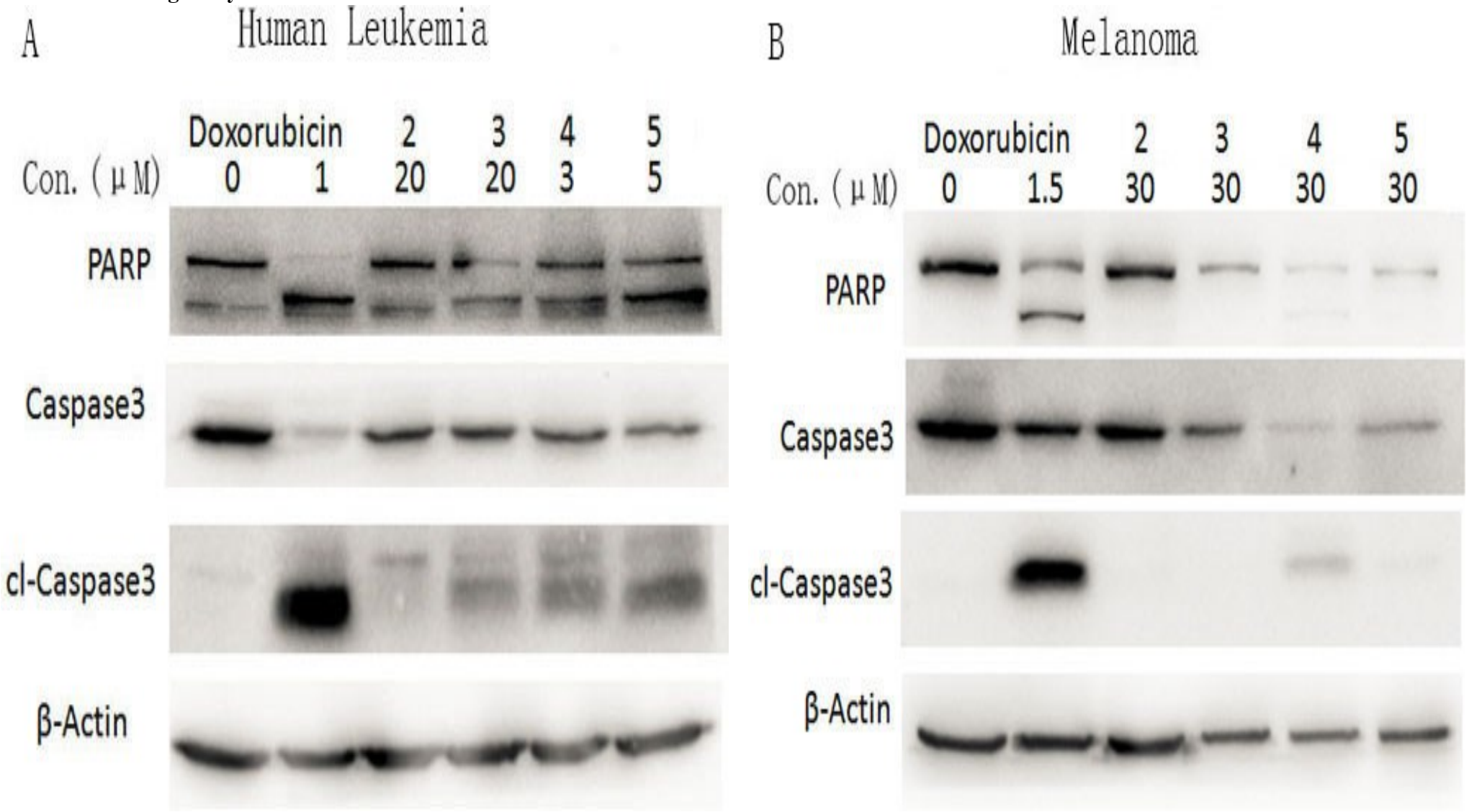
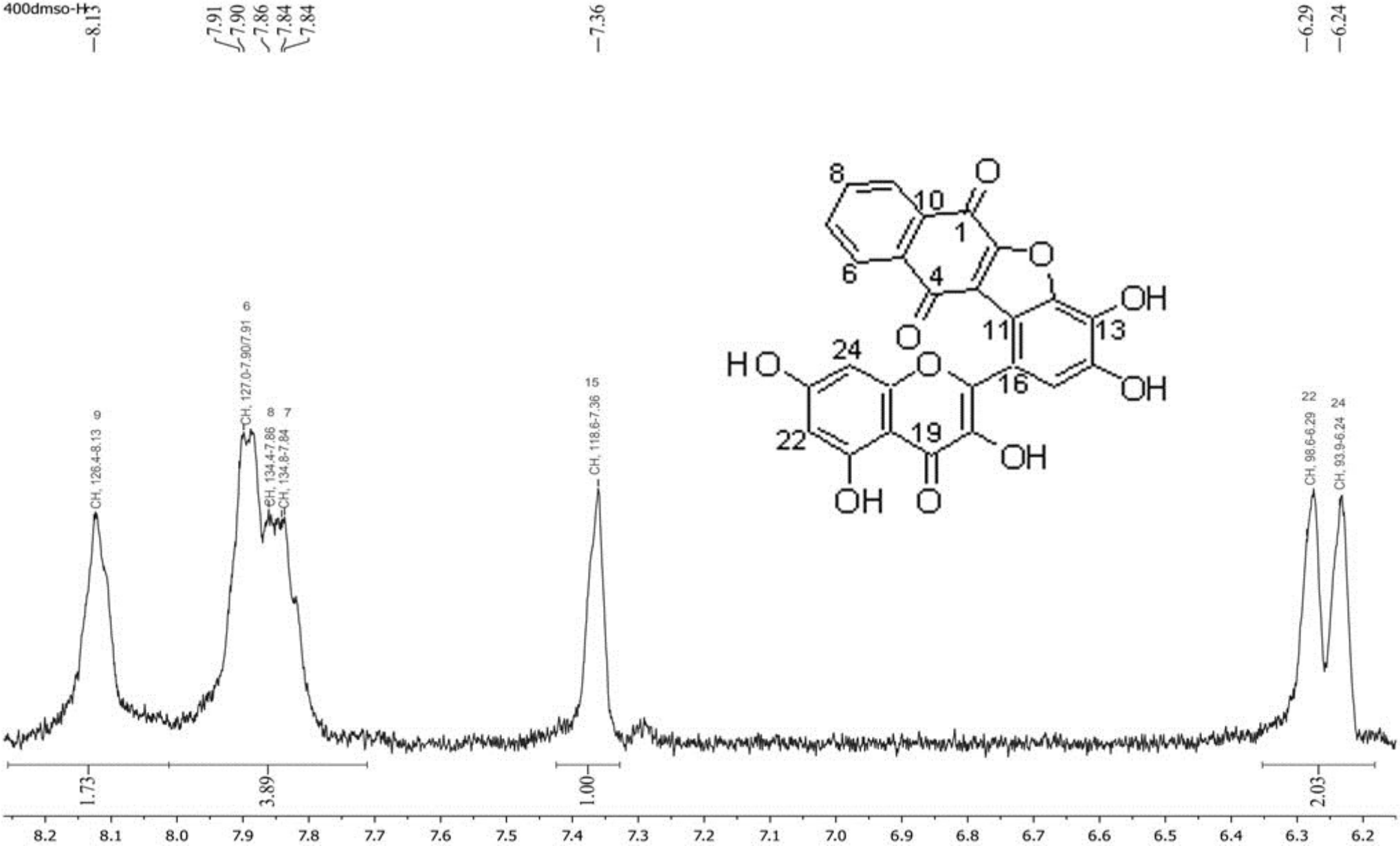


Figure S3. Derivatives regulate the apoptopic markers

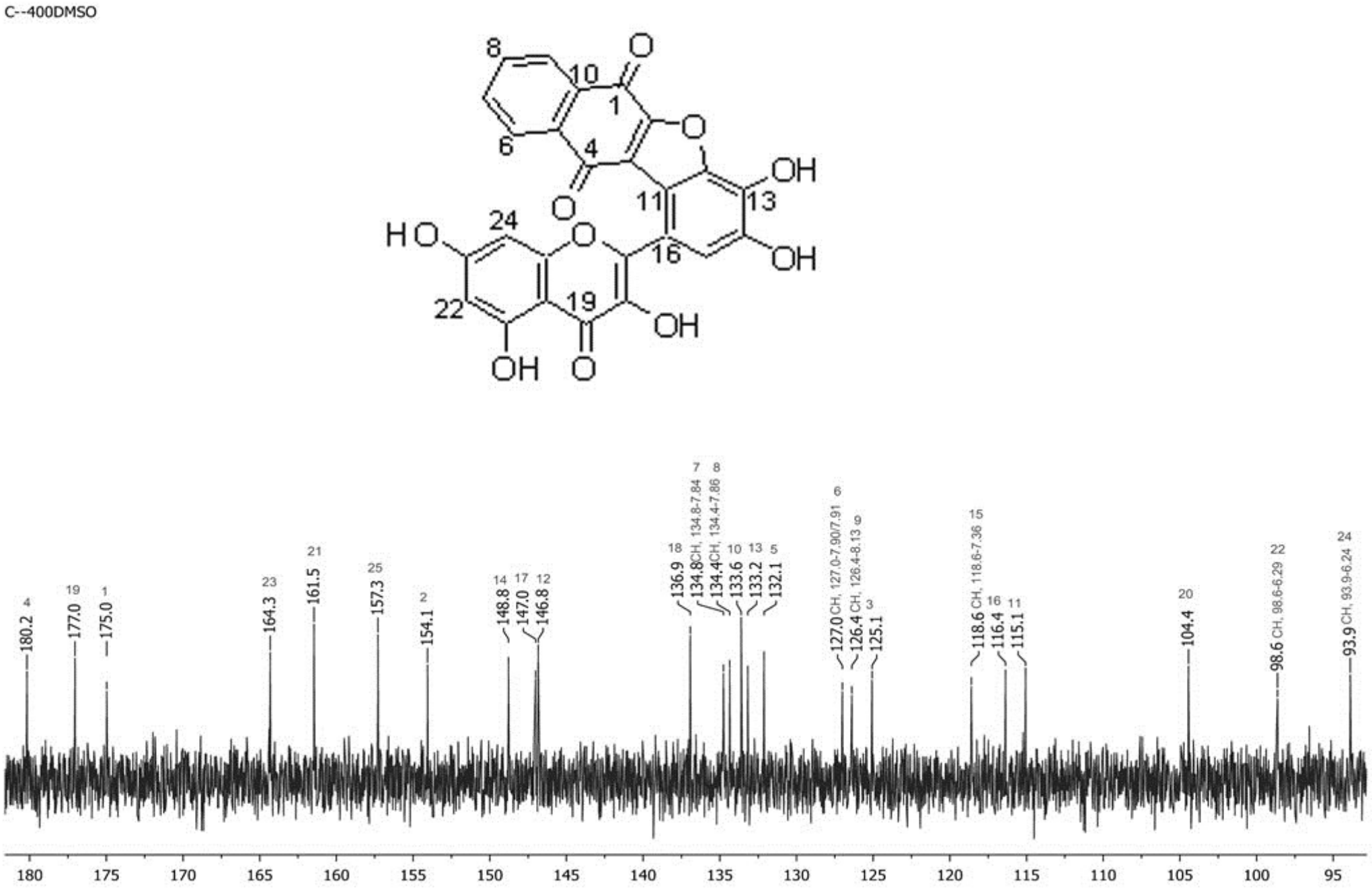
2. NMR spectra of derivatives

2.1. NMR spectra of derivative **1**

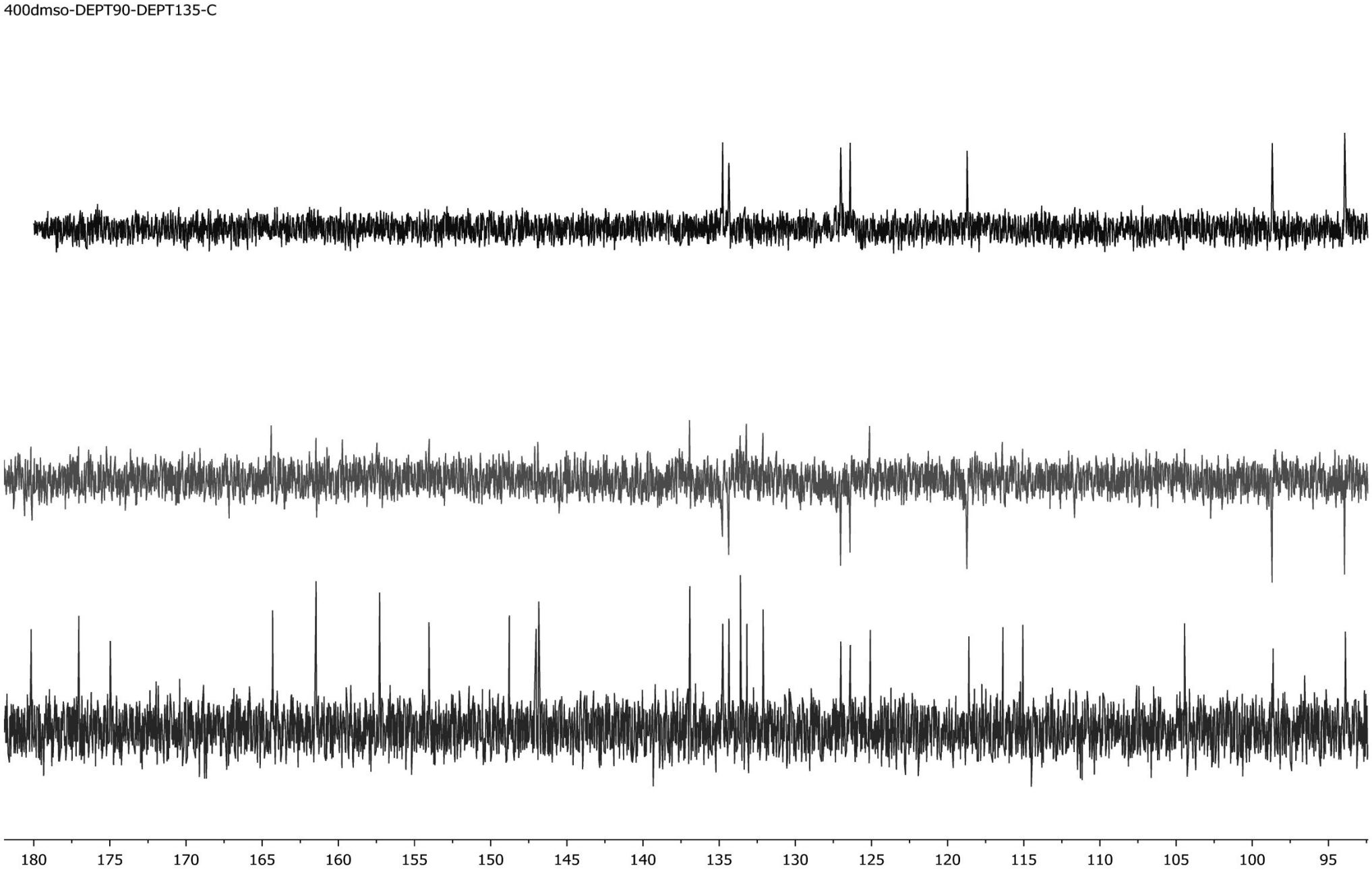
^{1}H-NMR of derivative **1**



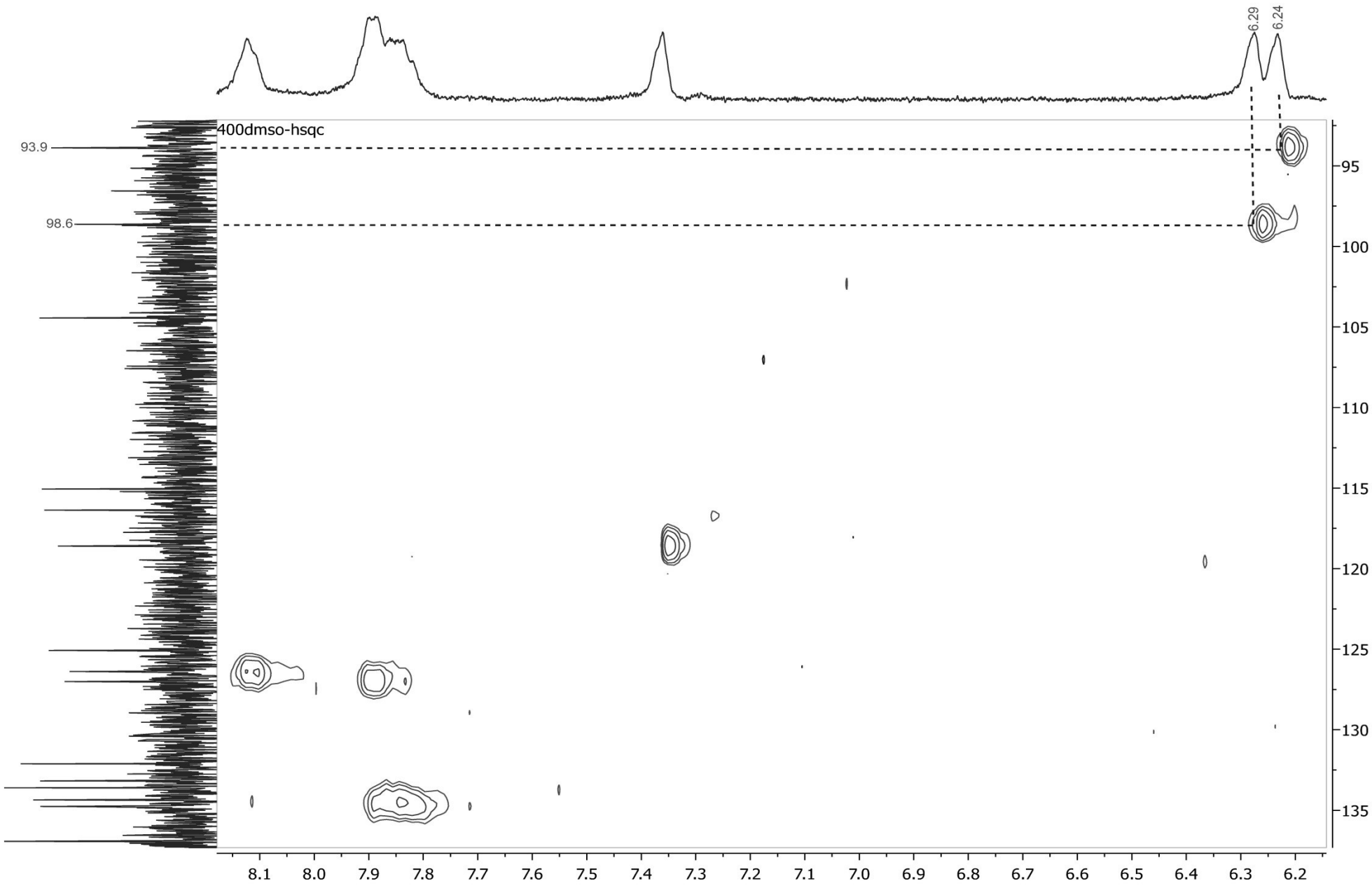
^{13}C-NMR of derivative **1**

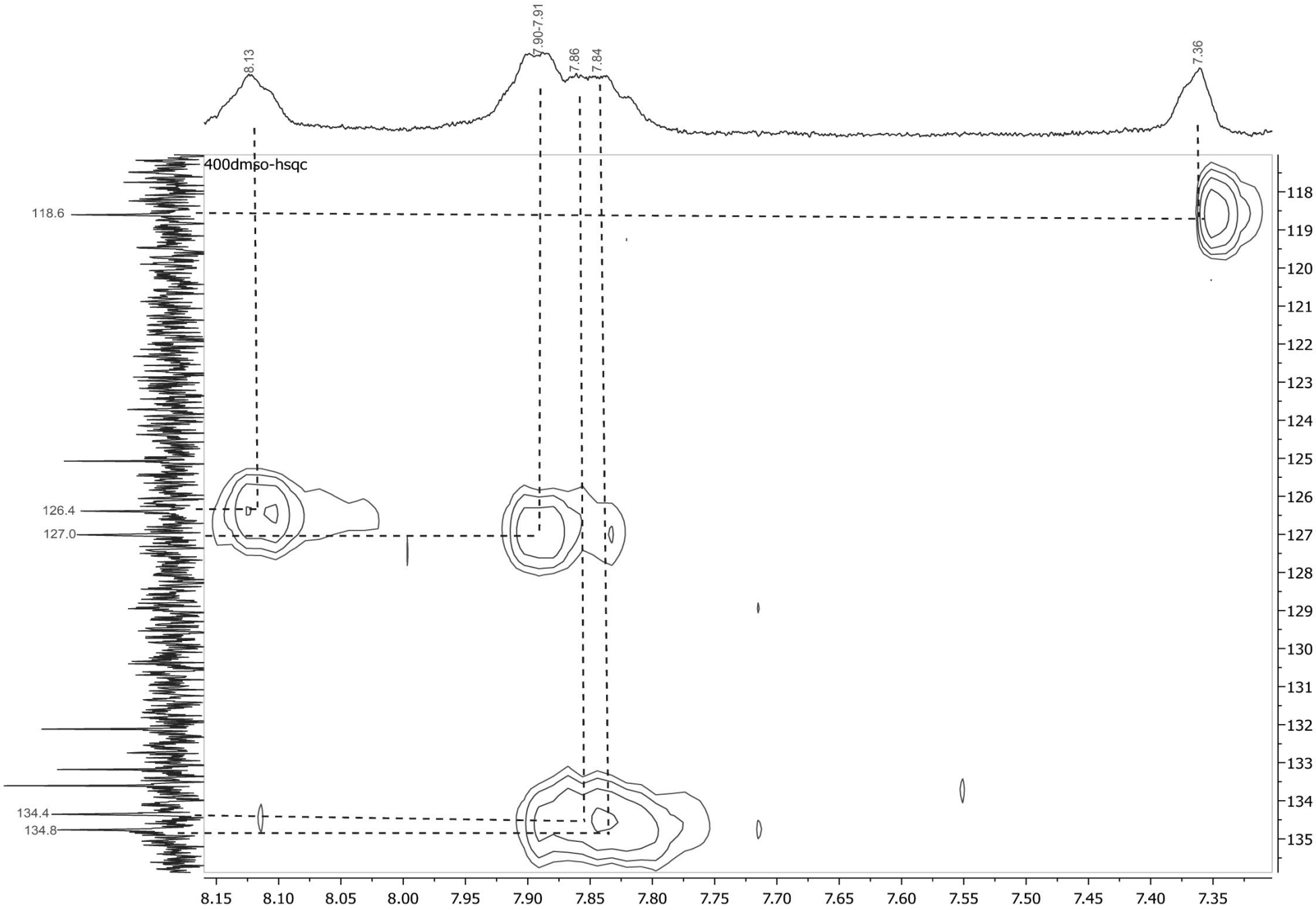


DEPT of derivative **1**

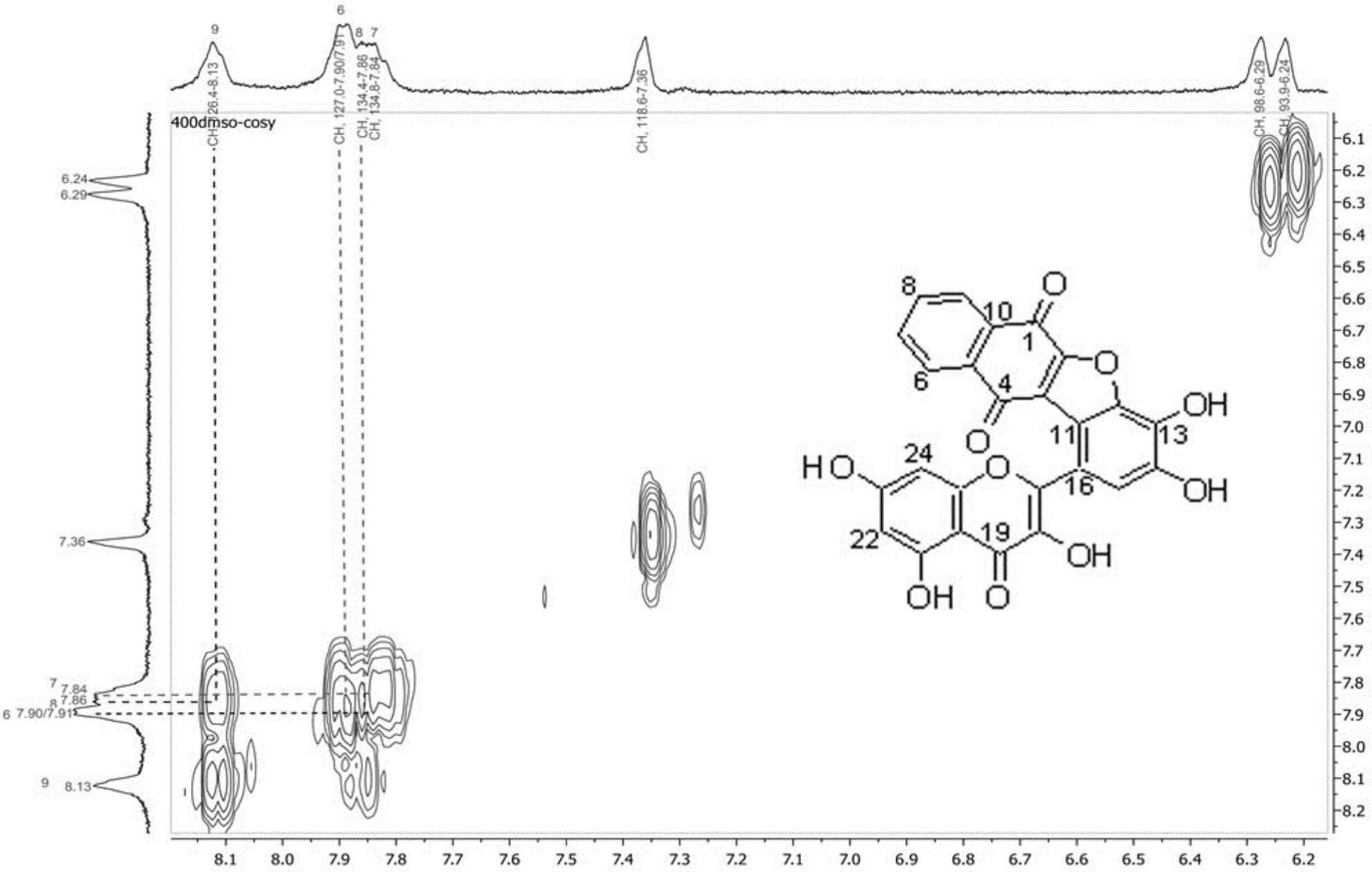


HSQC of derivative **1**

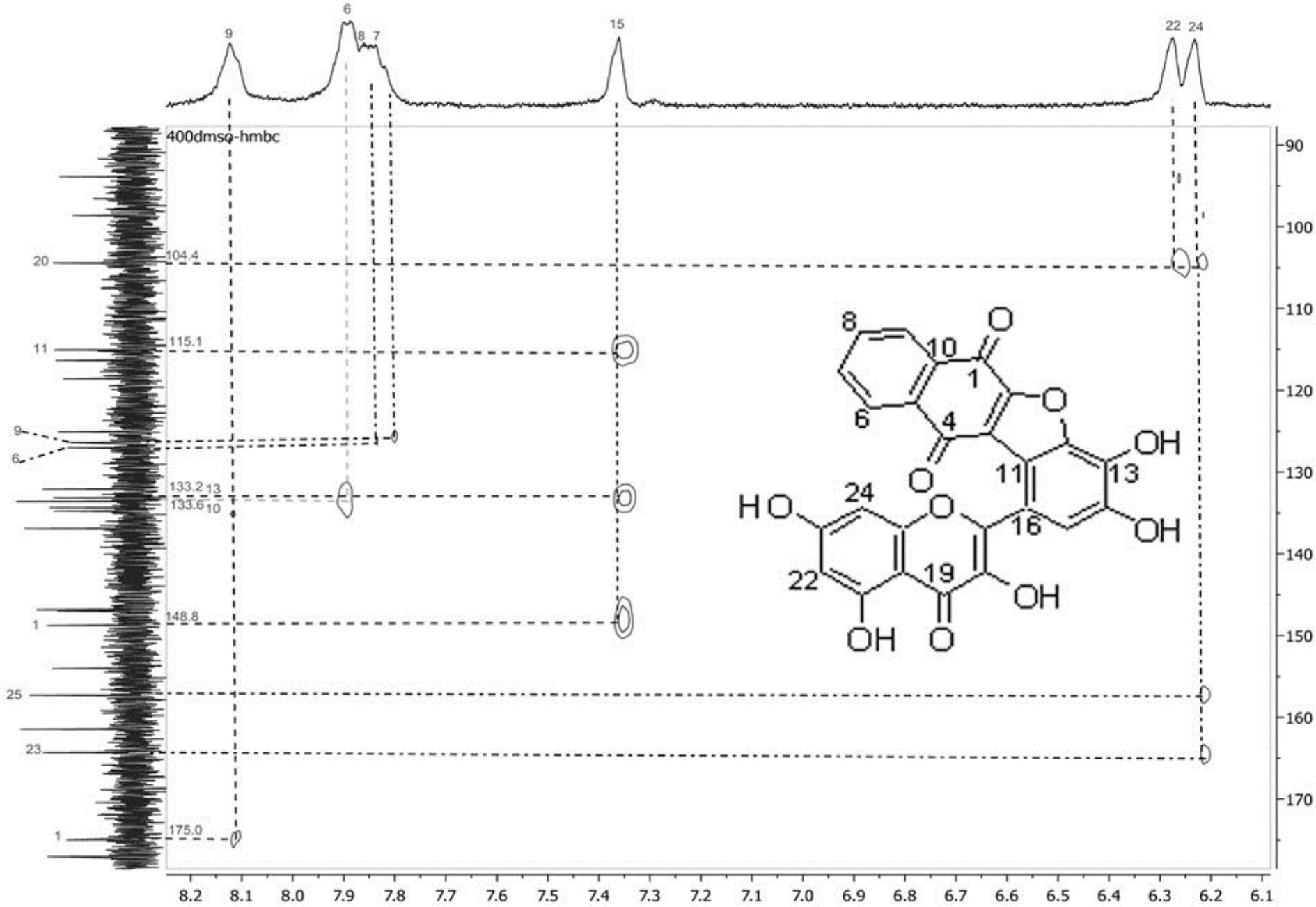



8.13
7.90-7.91
7.86
7.84
7.36
400dmso-hsqc
118.6
126.4
127.0
134.4
134.8
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
8.15
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
7.55
7.50
7.45
7.40
7.35

1H-1H COSY of derivative **1**

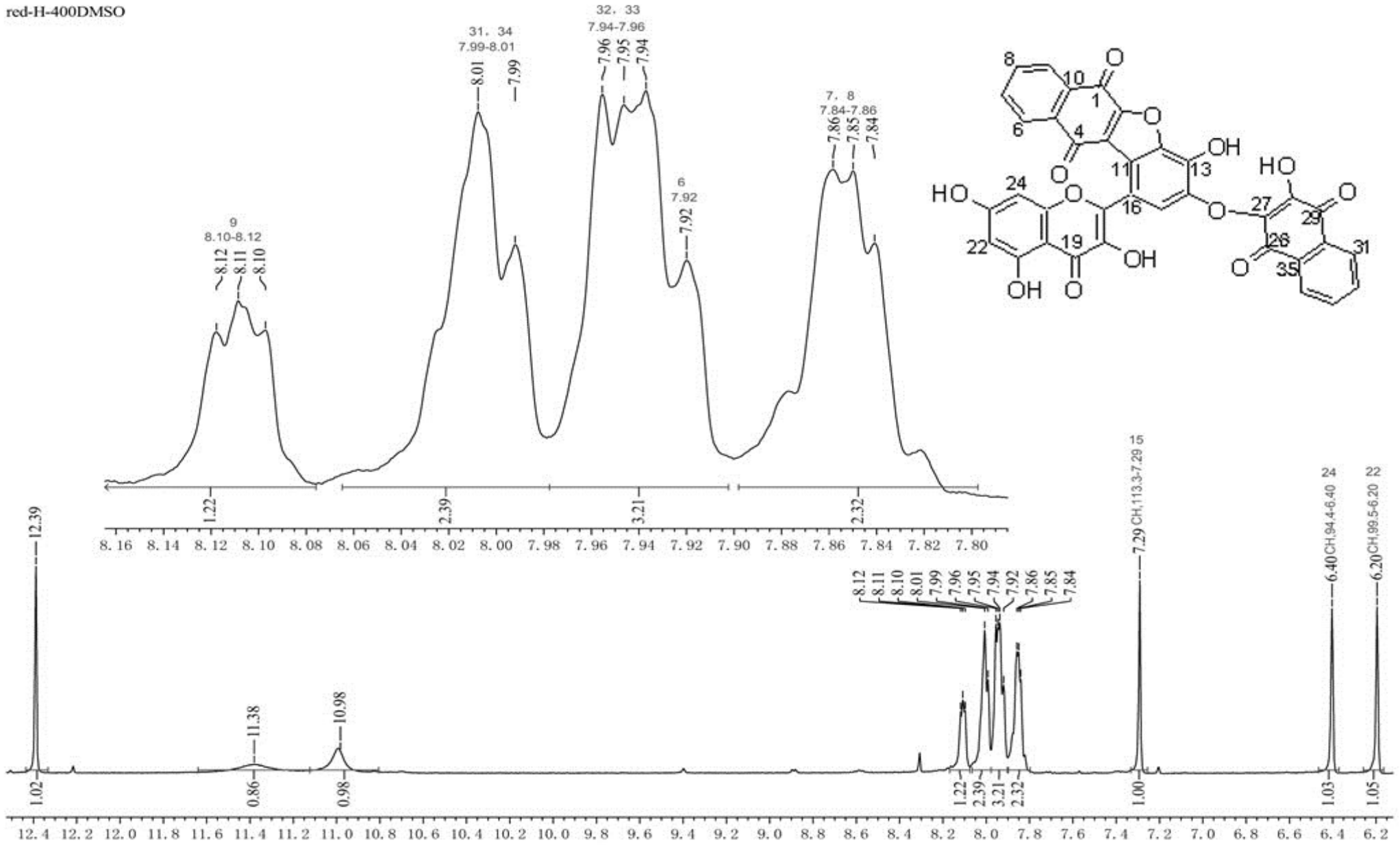


HMBC of derivative **1**

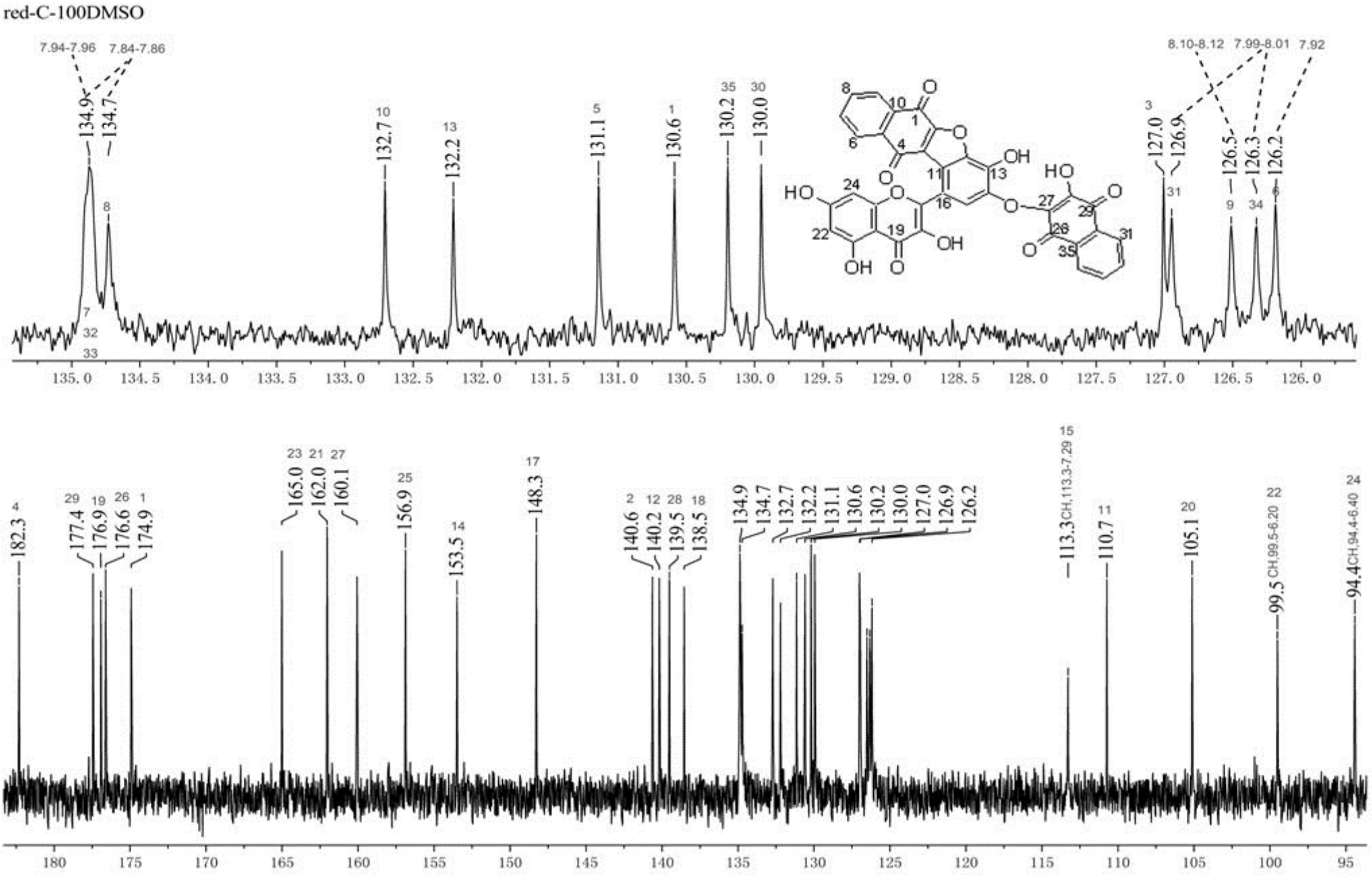


2.2. NMR spectra of derivative **2**

^{1}H-NMR of derivative **2**

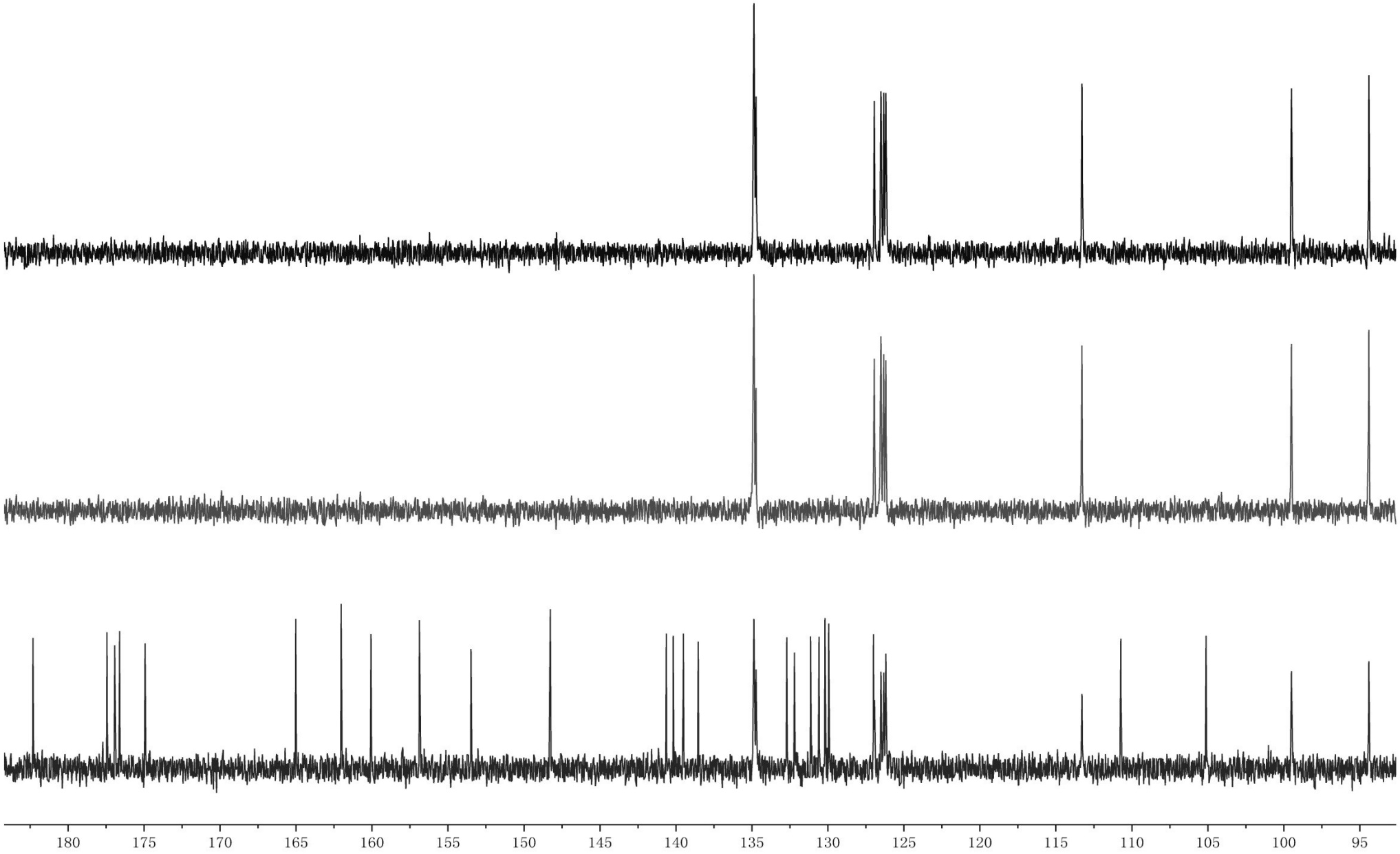


^{13}C-NMR of derivative **2**

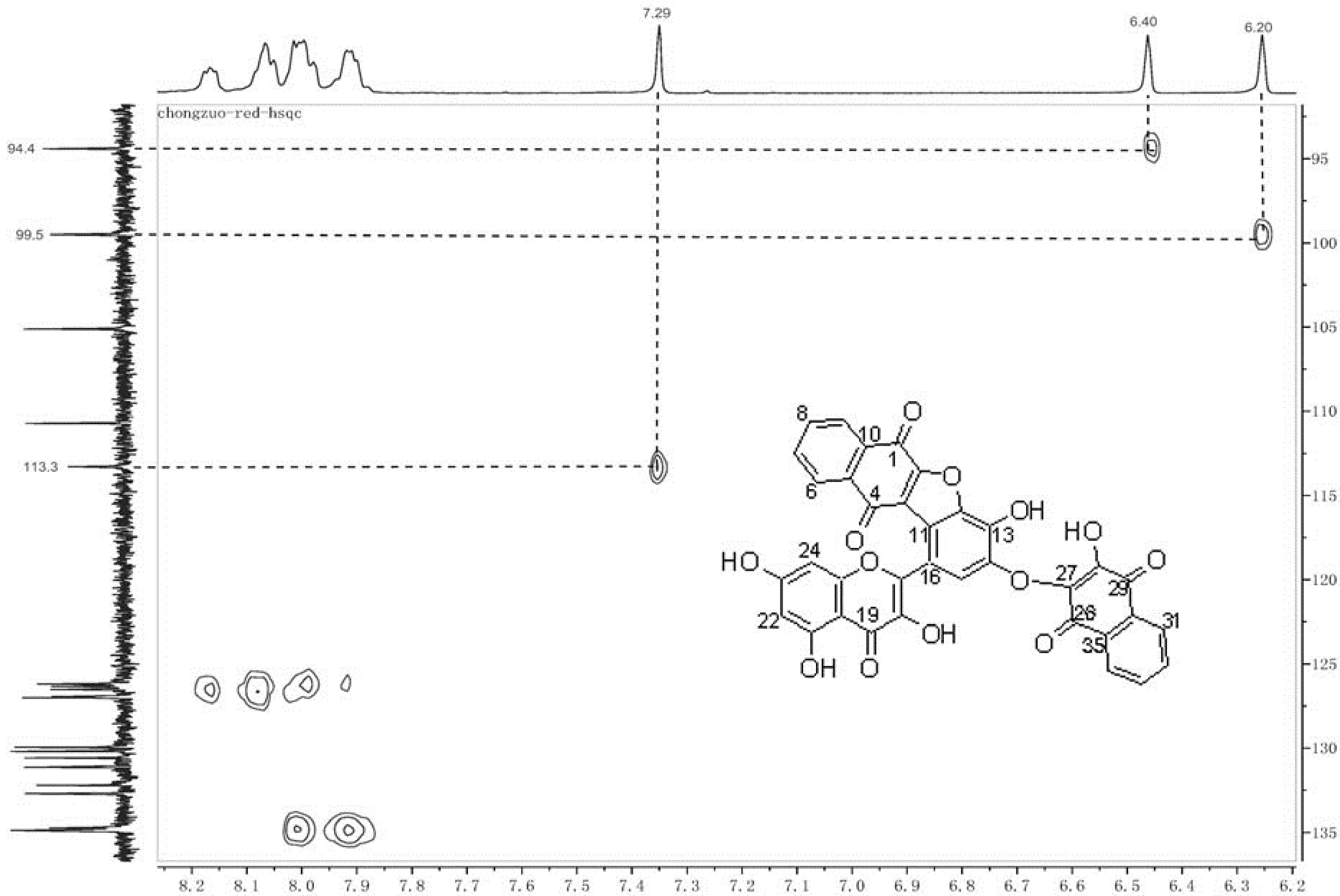


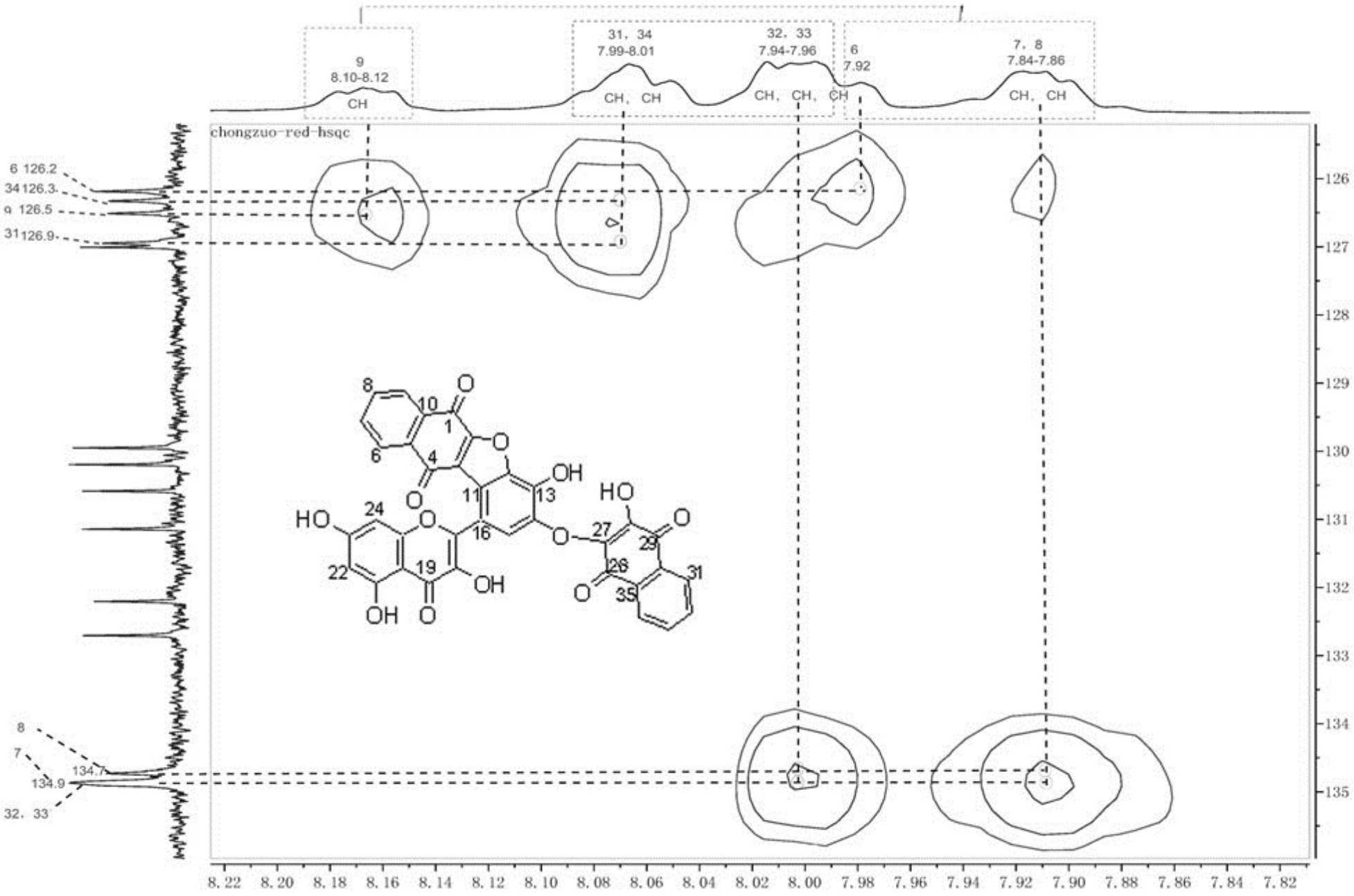
DEPT of derivative **2**

red-100DMSO-DEPT45,135,C

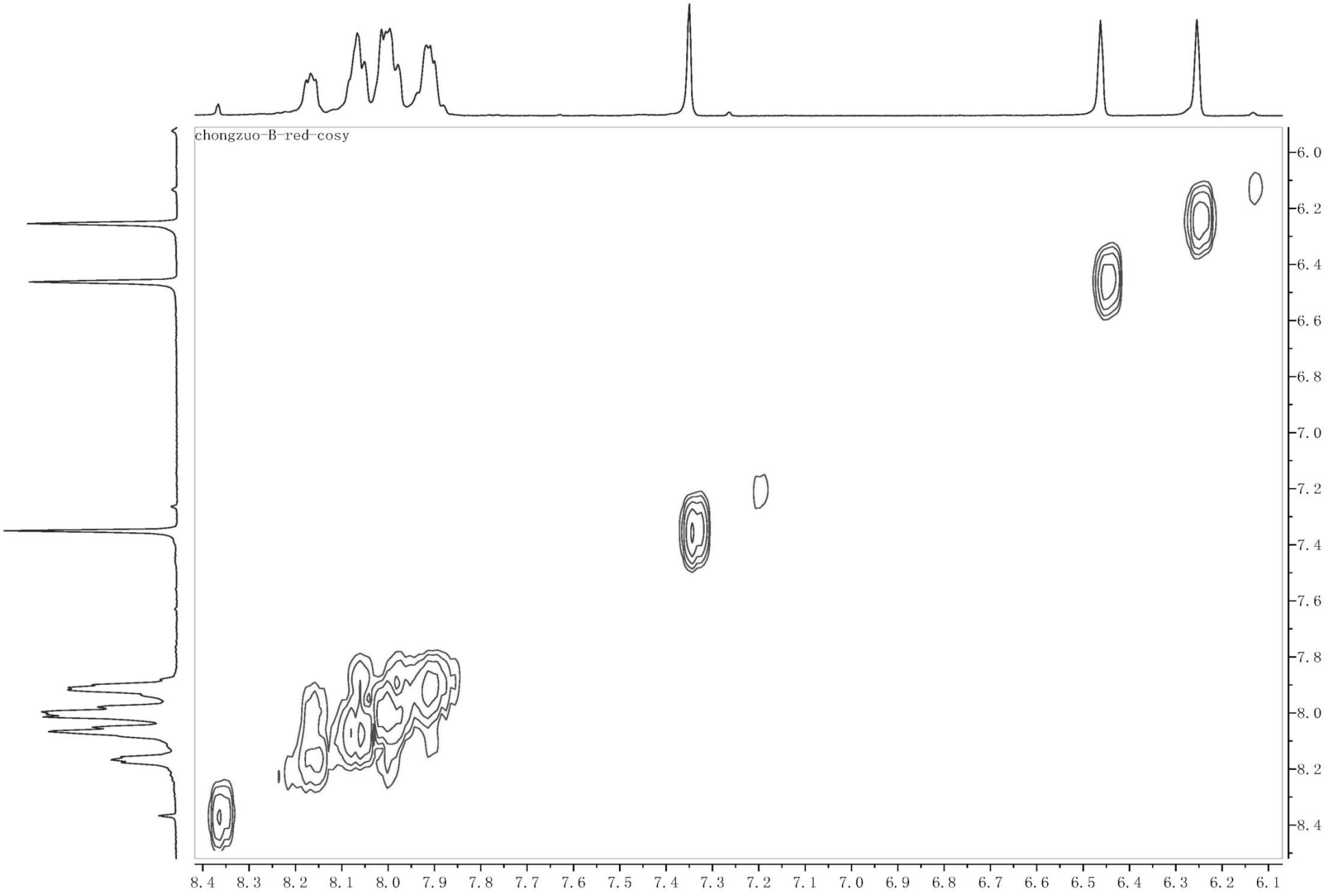


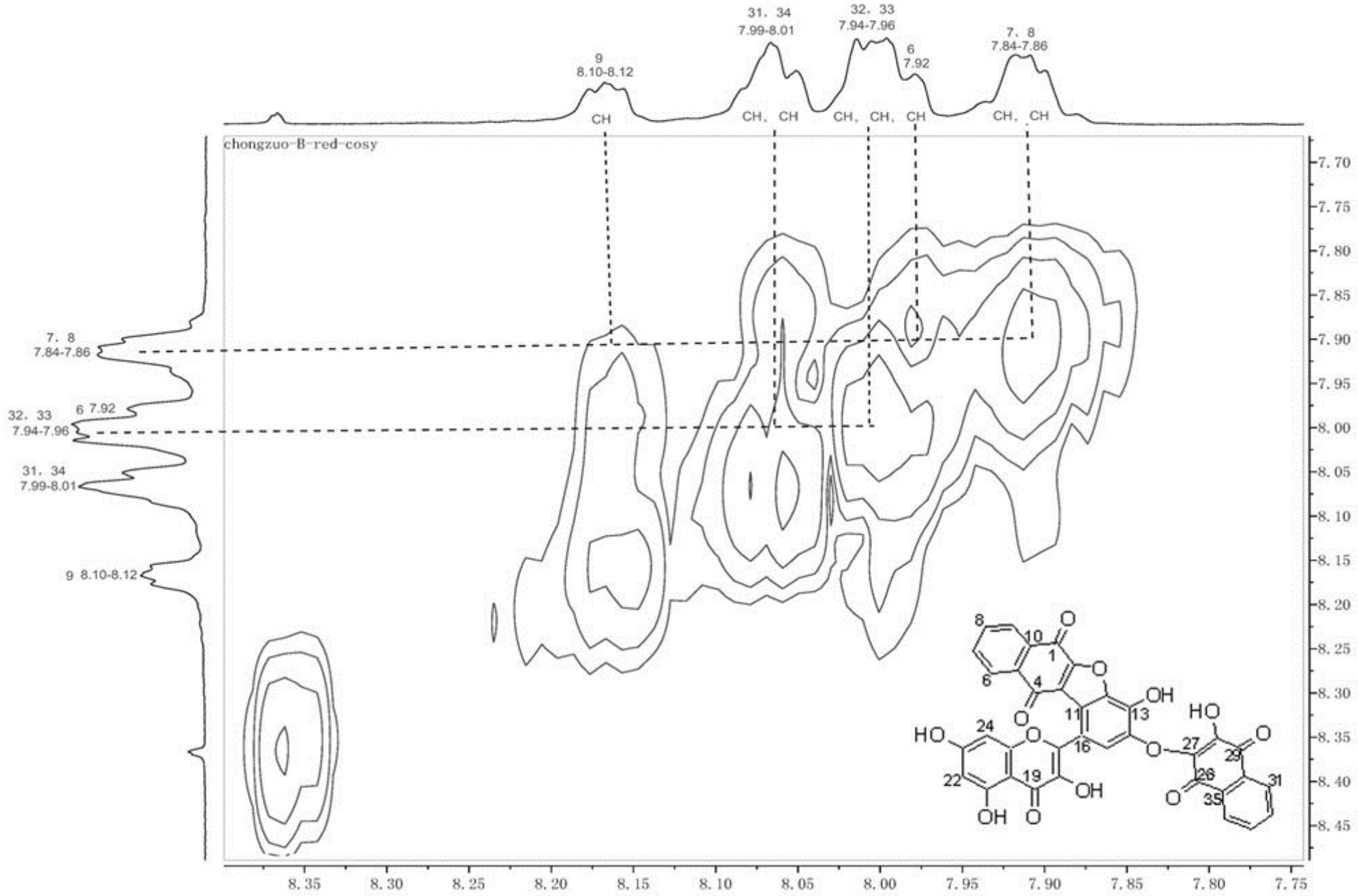
HSQC of derivative **2**



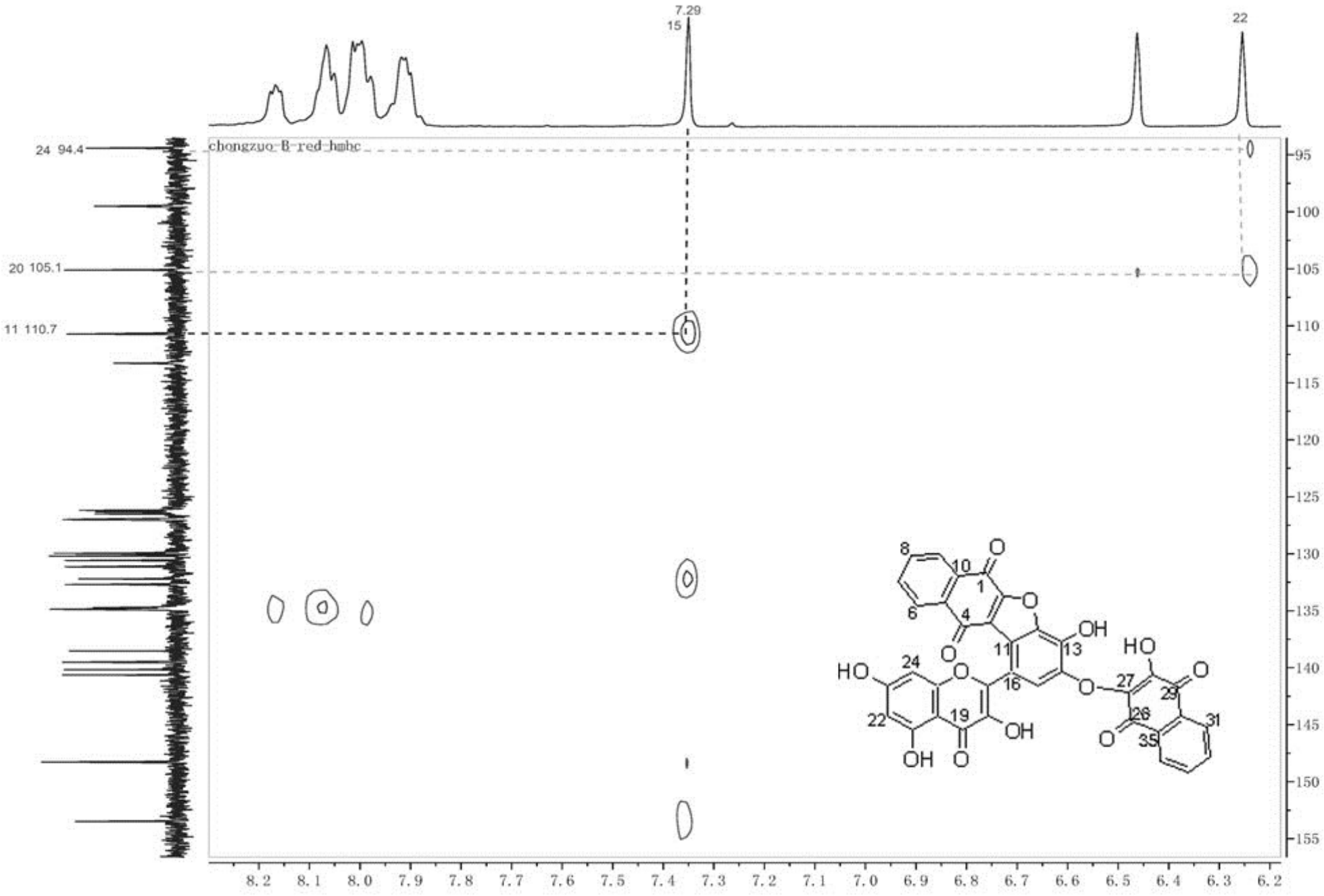

9
8.10-8.12
CH
31, 34
7.99-8.01
CH, CH
32, 33
7.94-7.96
CH, CH, CH
6
7.92
7, 8
7.84-7.86
CH, CH
chongzuo-red-hsqc
6 126.2
34 126.3
9 126.5
31 126.9
8
7
134.7
134.9
32, 33
126
127
128
129
130
131
132
133
134
135
8.22 8.20 8.18 8.16 8.14 8.12 8.10 8.08 8.06 8.04 8.02 8.00 7.98 7.96 7.94 7.92 7.90 7.88 7.86 7.84 7.82
HO
OH
O

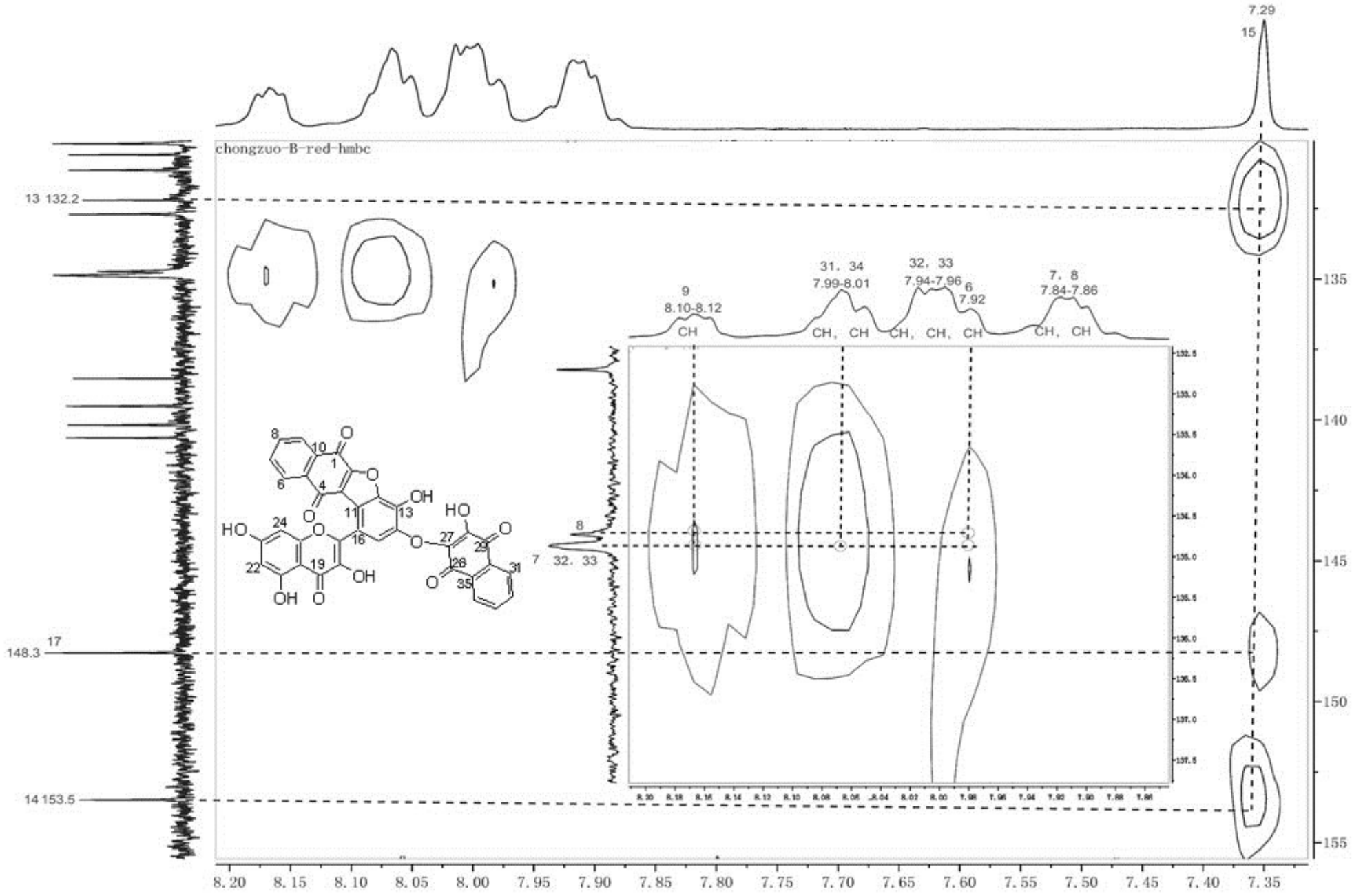
^{1}H-^{1}H COSY of derivative **2**




31, 34
7.99-8.01
32, 33
7.94-7.96
7, 8
7.84-7.86
9
8.10-8.12
6
7.92
CH
CH, CH
CH, CH, CH
CH, CH
chongzuo-B-red-cosy
7, 8
7.84-7.86
6 7.92
32, 33
7.94-7.96
31, 34
7.99-8.01
9 8.10-8.12
7.70
7.75
7.80
7.85
7.90
7.95
8.00
8.05
8.10
8.15
8.20
8.25
8.30
8.35
8.40
8.45
8.35
8.30
8.25
8.20
8.15
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
HO
OH
O

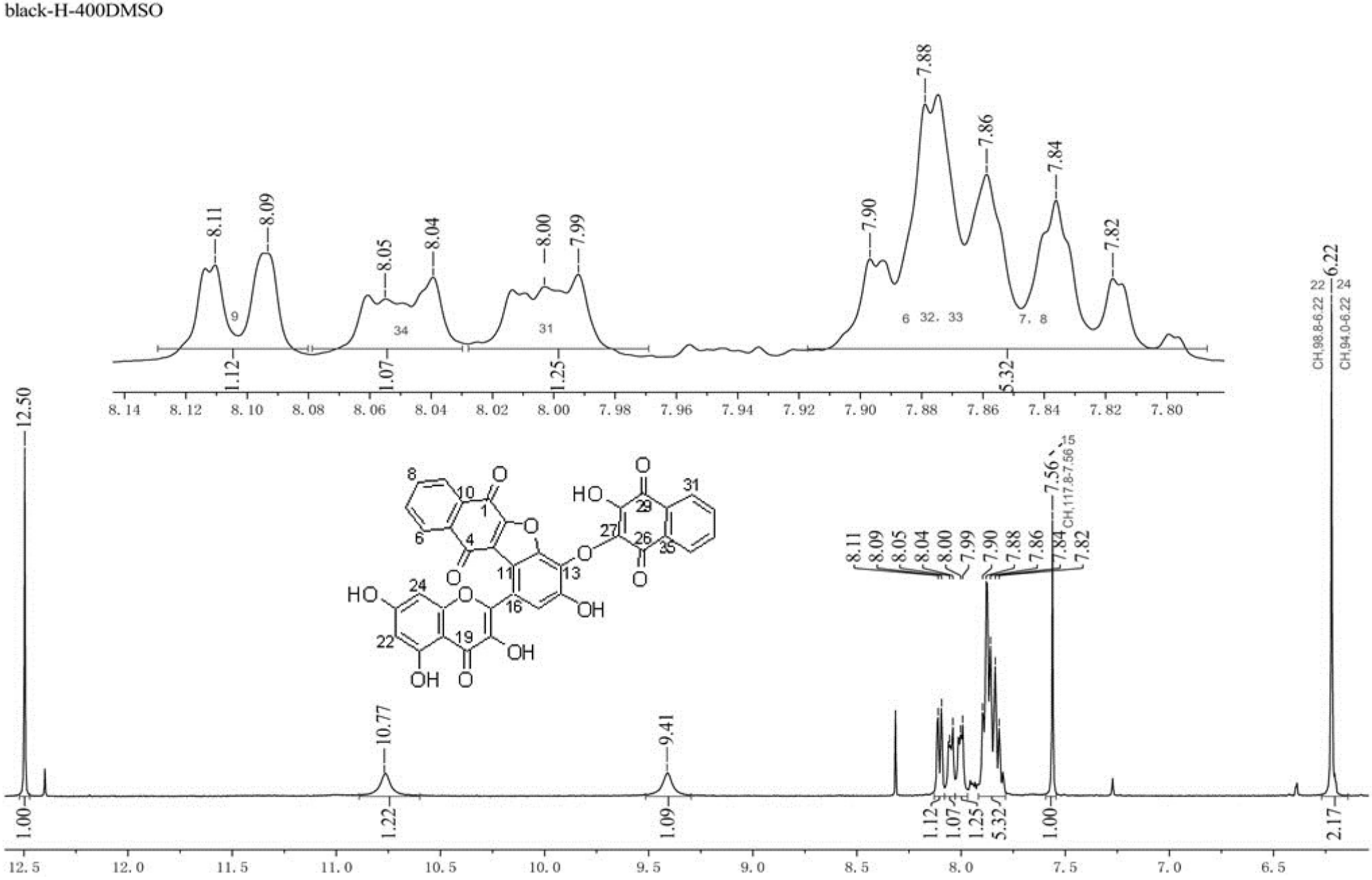
HMBC of derivative **2**



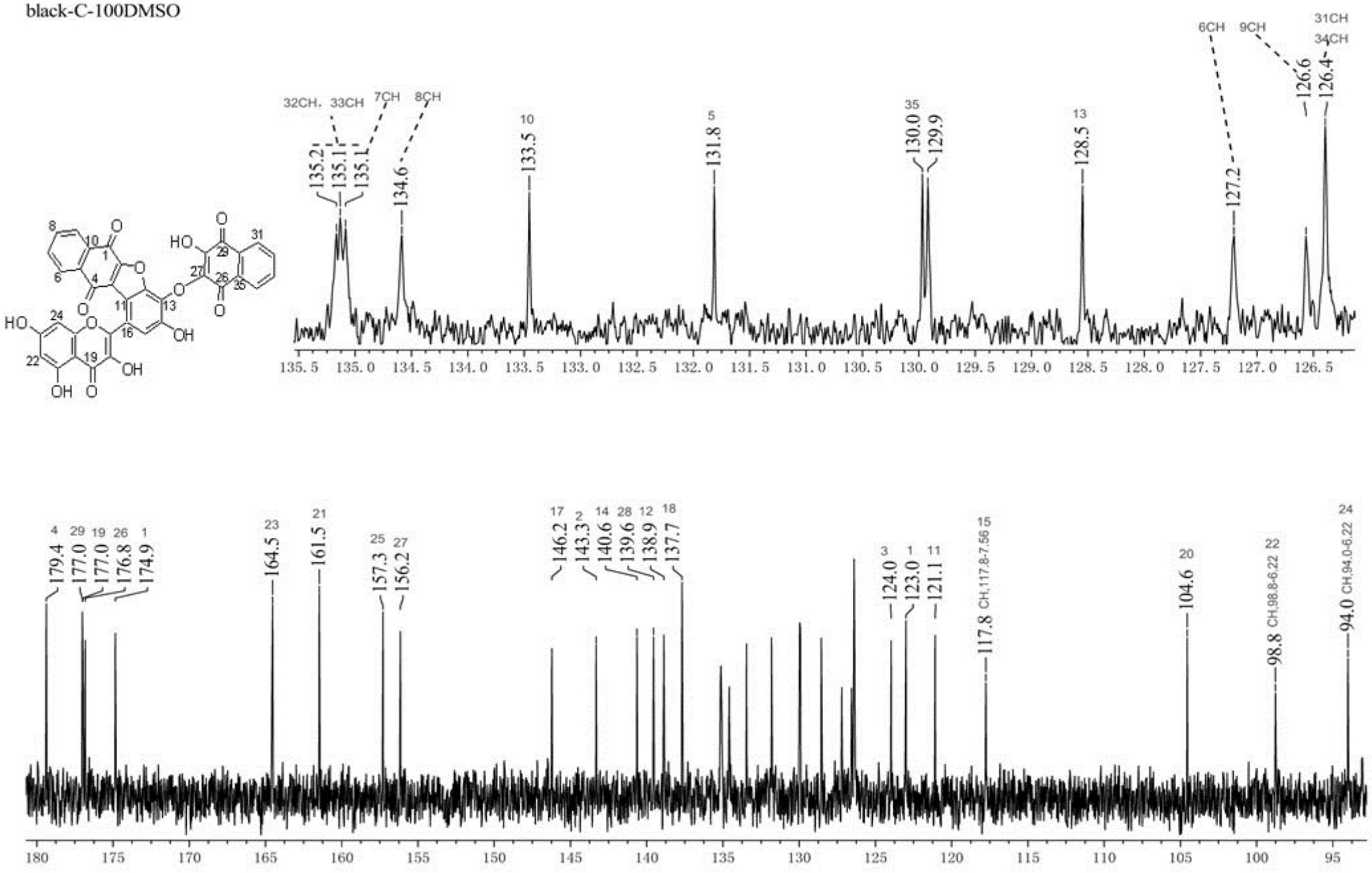

chongzuo-B-red-hmbc
7.29
15
13 132.2
17
148.3
14 153.5
9
8.10-8.12
CH
31, 34
7.99-8.01
CH, CH
32, 33
7.94-7.96
6
7.92
CH, CH, CH
7, 8
7.84-7.86
CH, CH
8
7 32, 33
OH
HO
O
135
140
145
150
155
8.20
8.15
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
7.55
7.50
7.45
7.40
7.35

2.3. NMR spectra of derivative **3**

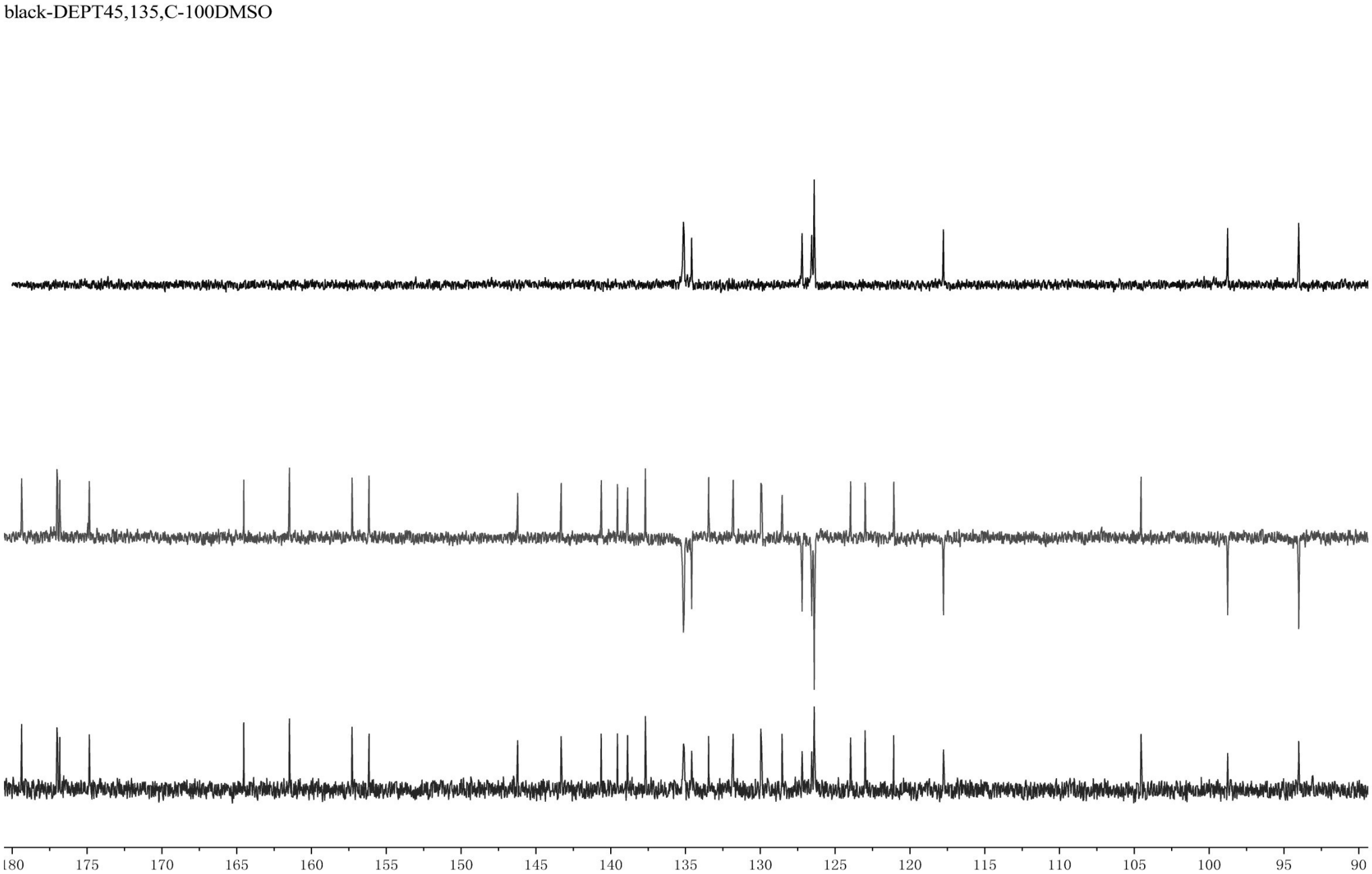
^{1}H-NMR of derivative **3**



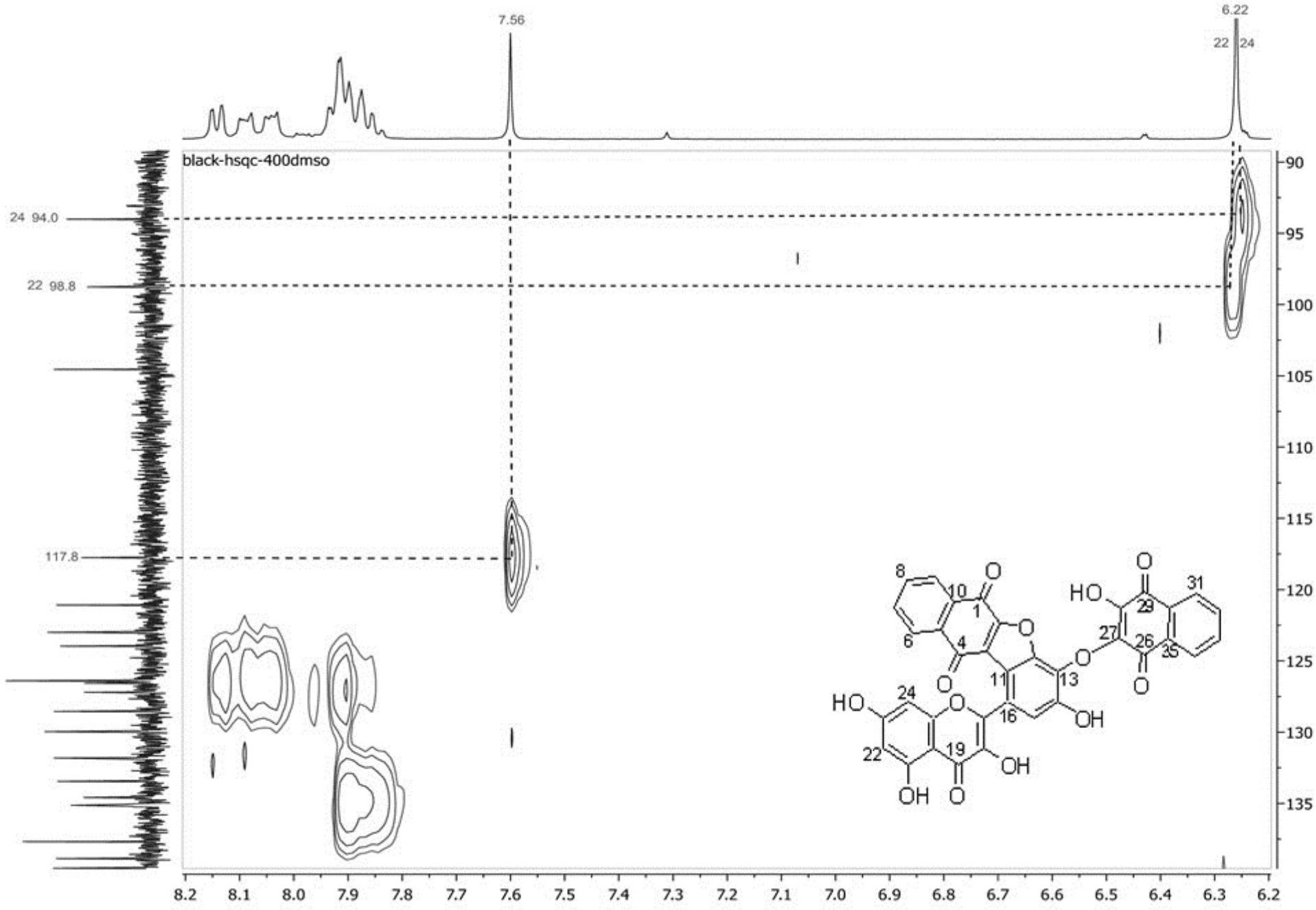
^{13}C-NMR of derivative **3**

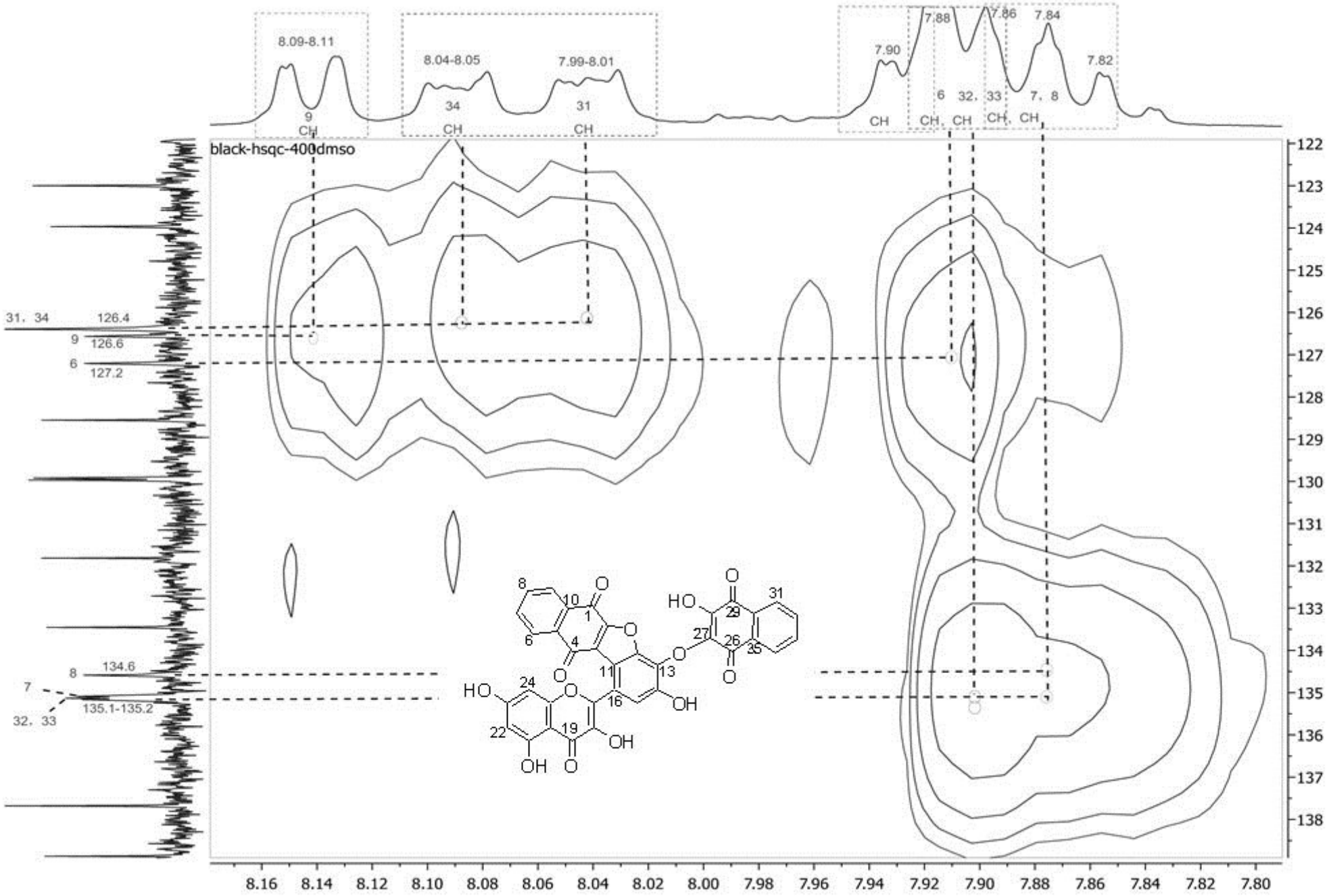


DEPT of derivative **3**



HSQC of derivative **3**




black-hsqc-400dmso
8.09-8.11
8.04-8.05
7.99-8.01
7.90
7.88
7.86
7.84
7.82
9 CH
34 CH
31 CH
6 CH
32, 33 CH, CH
7, 8 CH, CH
31, 34
126.4
9
126.6
6
127.2
8
134.6
7
135.1-135.2
32, 33
HO
OH
O
8.16 8.14 8.12 8.10 8.08 8.06 8.04 8.02 8.00 7.98 7.96 7.94 7.92 7.90 7.88 7.86 7.84 7.82 7.80
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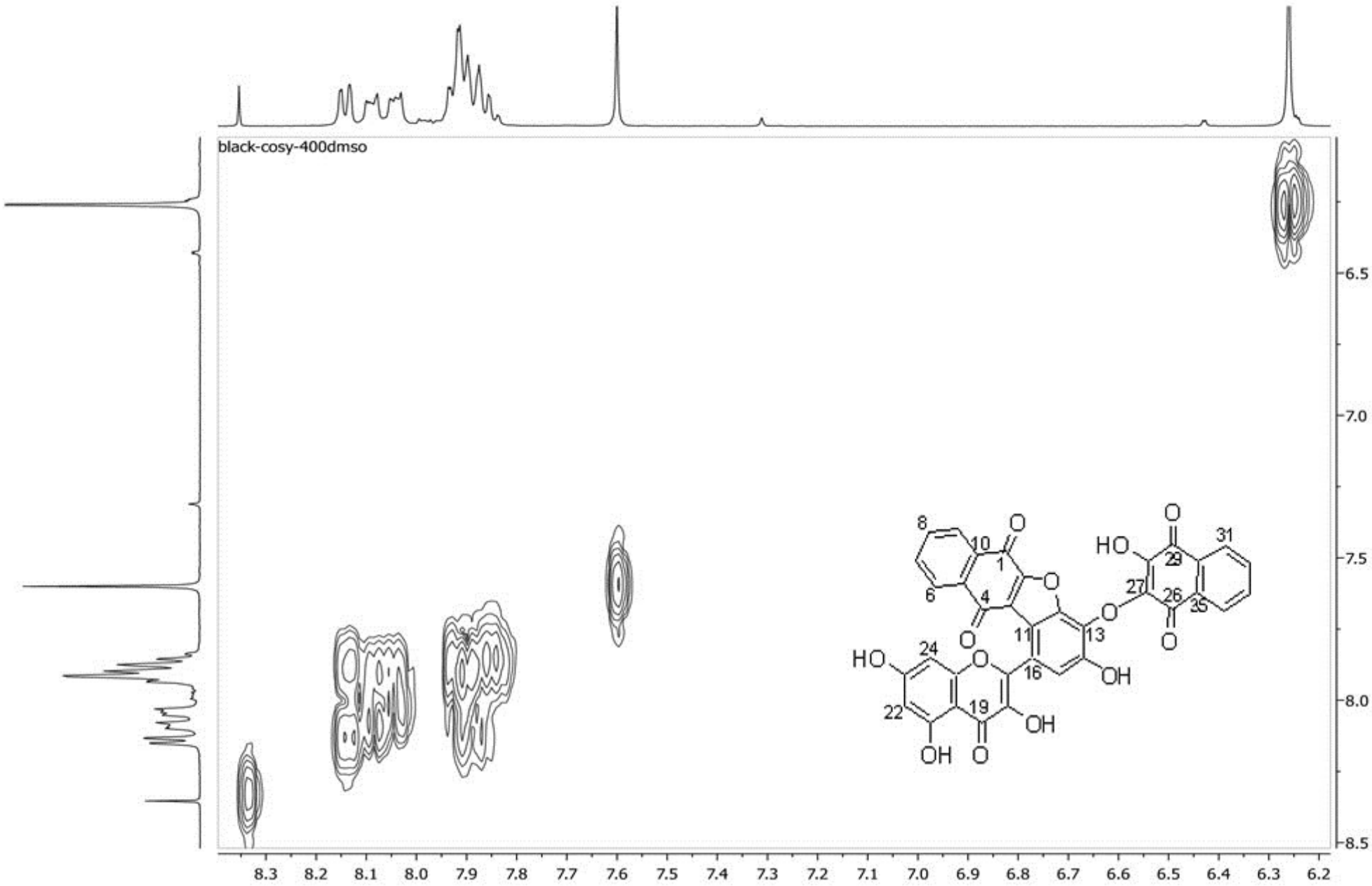
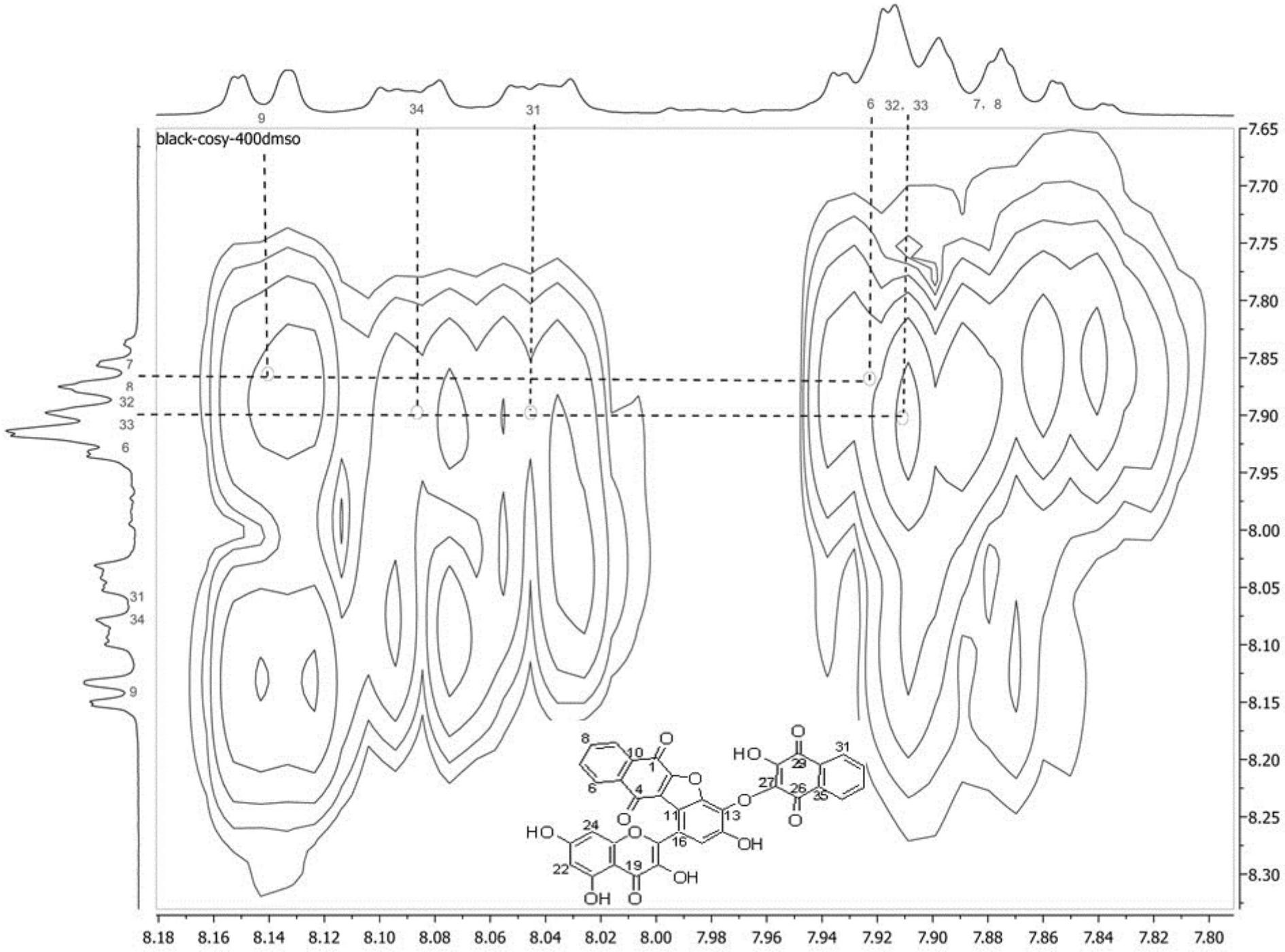
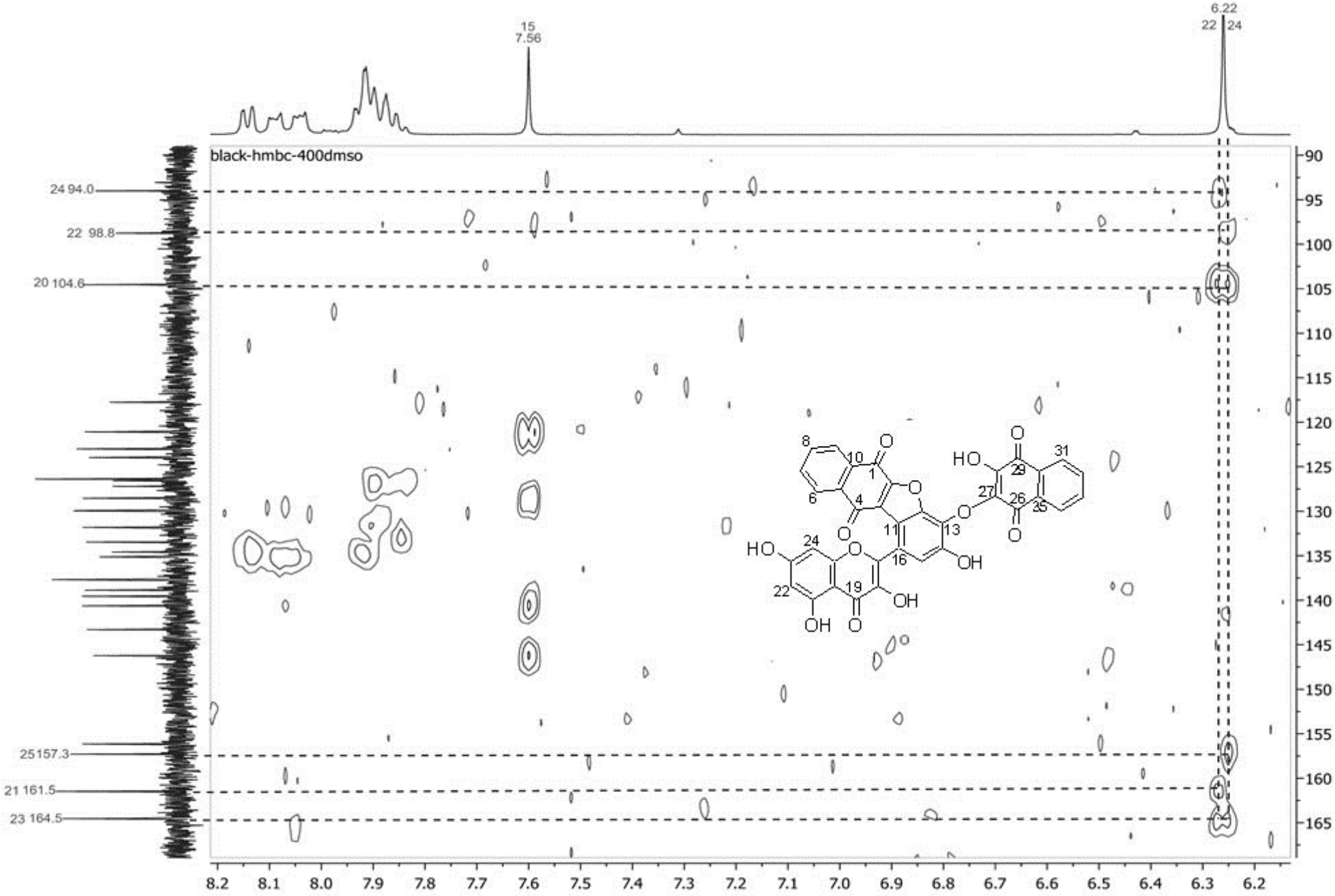
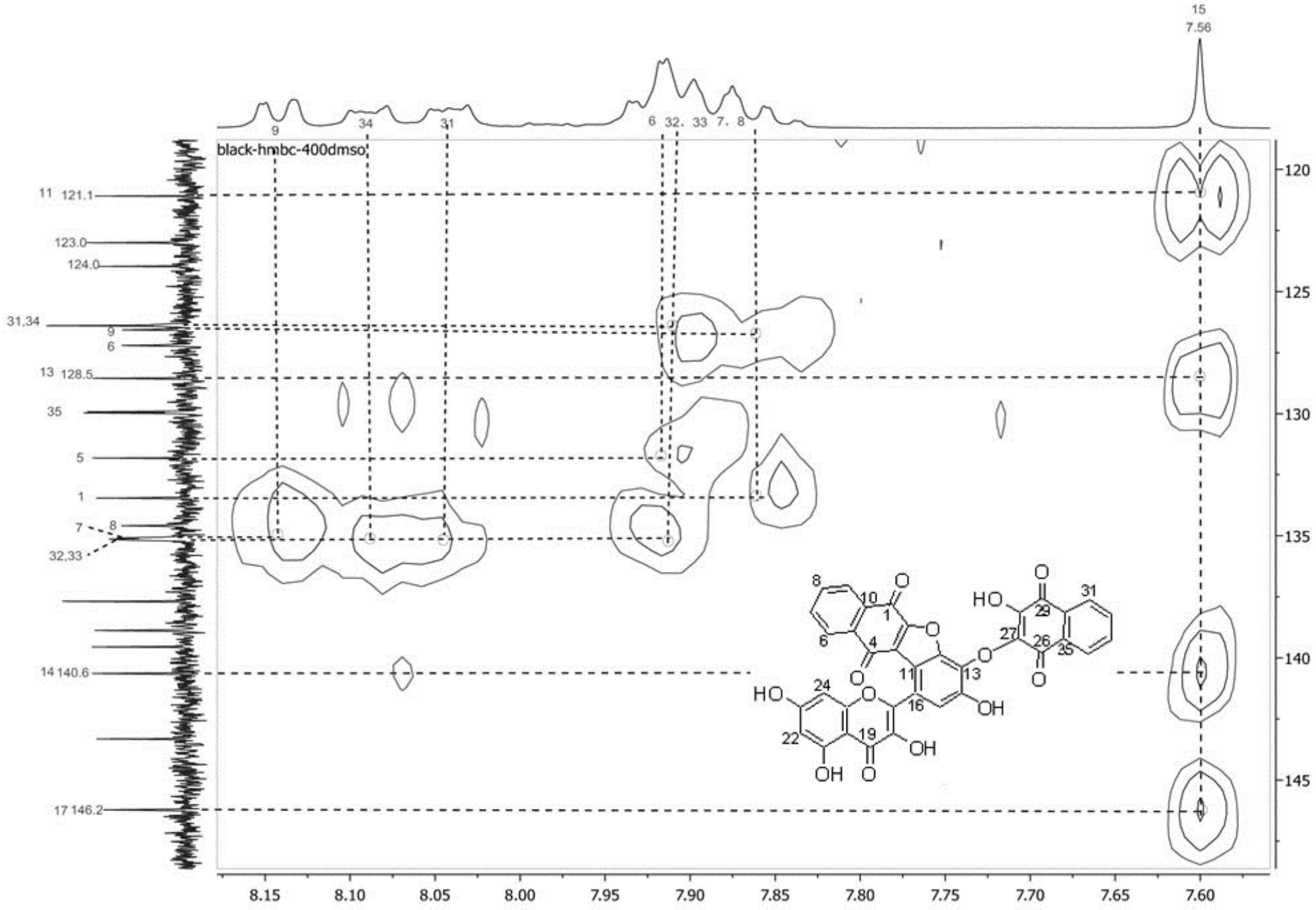
^{1}H-^{1}H COSY of derivative **3**




black-cosy-400dmso
9
34
31
6
32, 33
7, 8
8.18
8.16
8.14
8.12
8.10
8.08
8.06
8.04
8.02
8.00
7.98
7.96
7.94
7.92
7.90
7.88
7.86
7.84
7.82
7.80
7.65
7.70
7.75
7.80
7.85
7.90
7.95
8.00
8.05
8.10
8.15
8.20
8.25
8.30
HO
OH
O

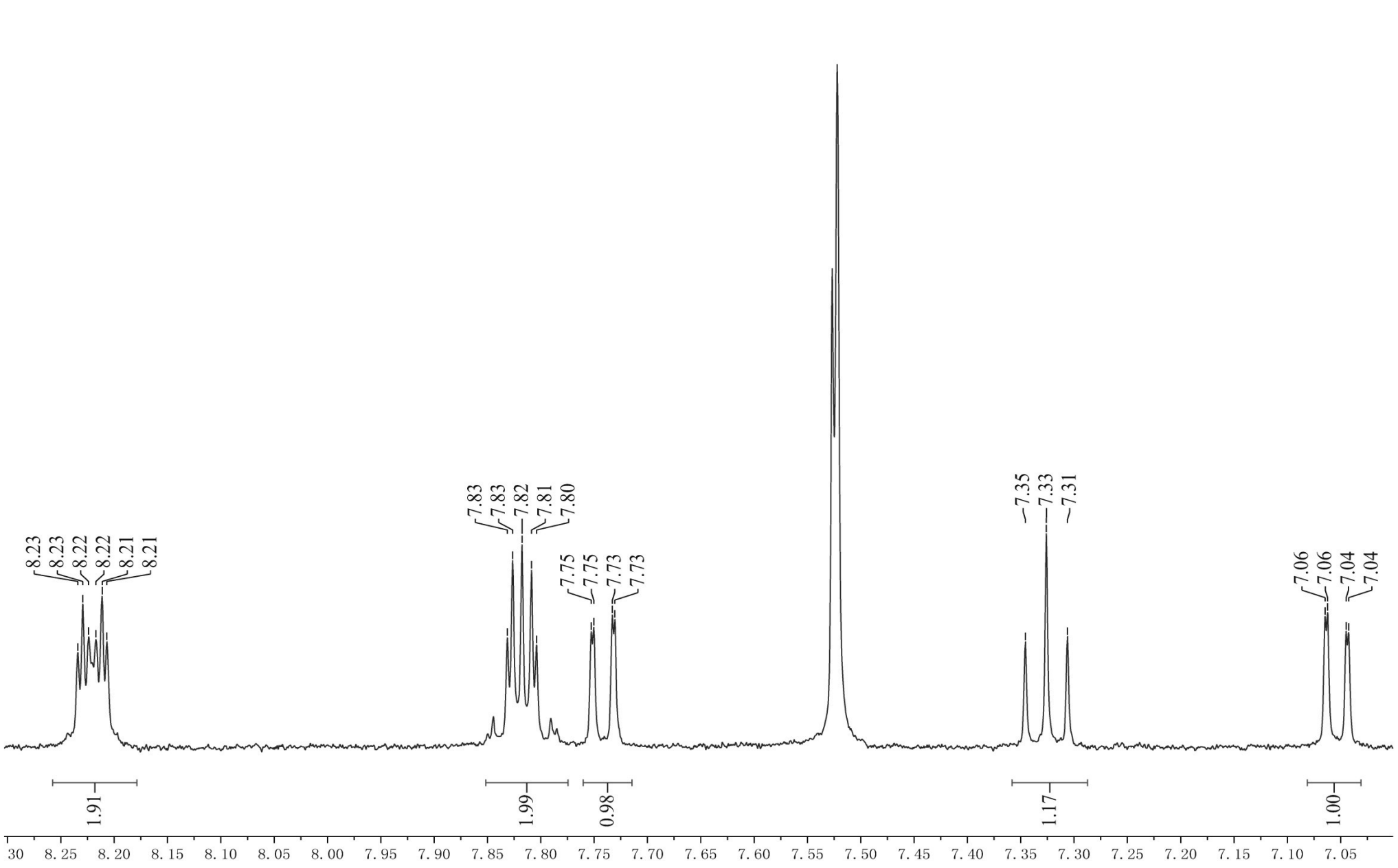
HMBC of derivative **3**



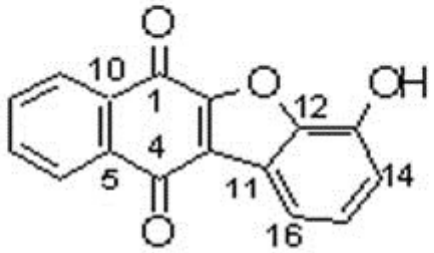

15
7.56
9
34
31
6
32. 33
7. 8
black-hmbc-400dmso
11 121.1
123.0
124.0
31,34
9
6
13 128.5
35
5
1
7
8
32,33
14 140.6
17 146.2
120
125
130
135
140
145
8.15
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
HO
OH
O

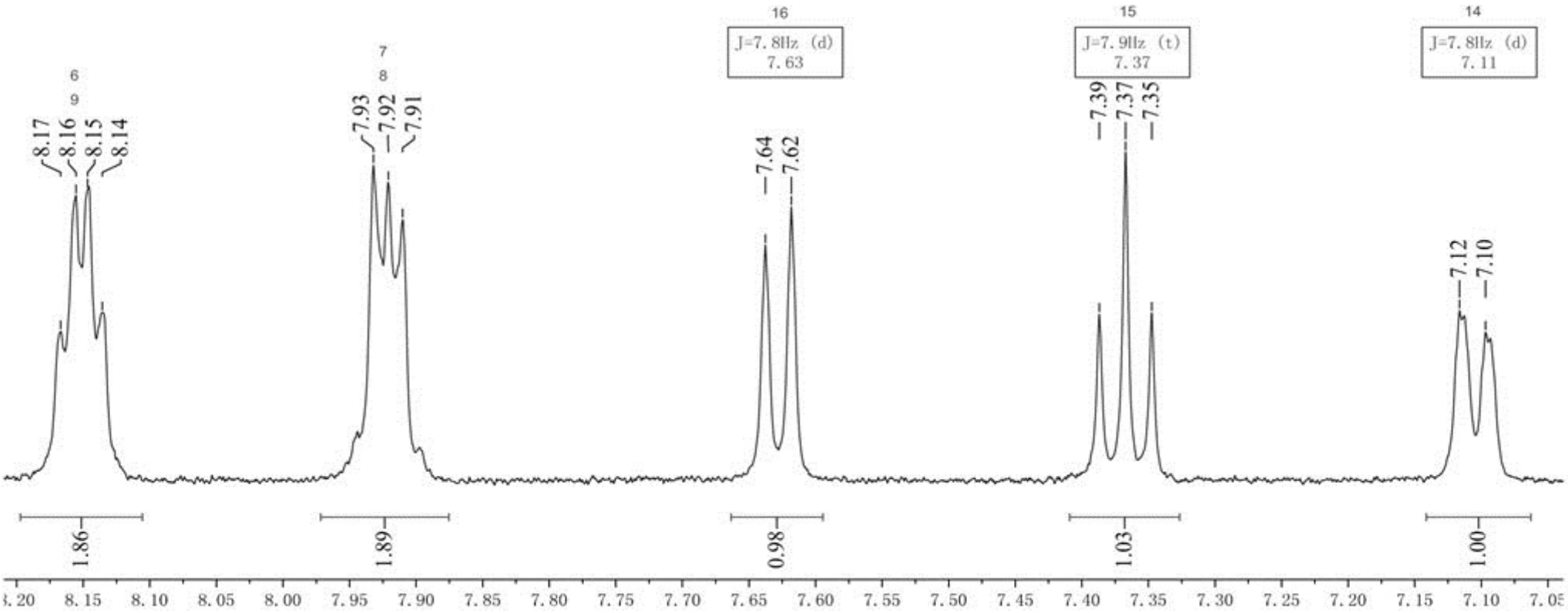
2.4. NMR spectra of derivative **4**

^{1}H-NMR of derivative **4**

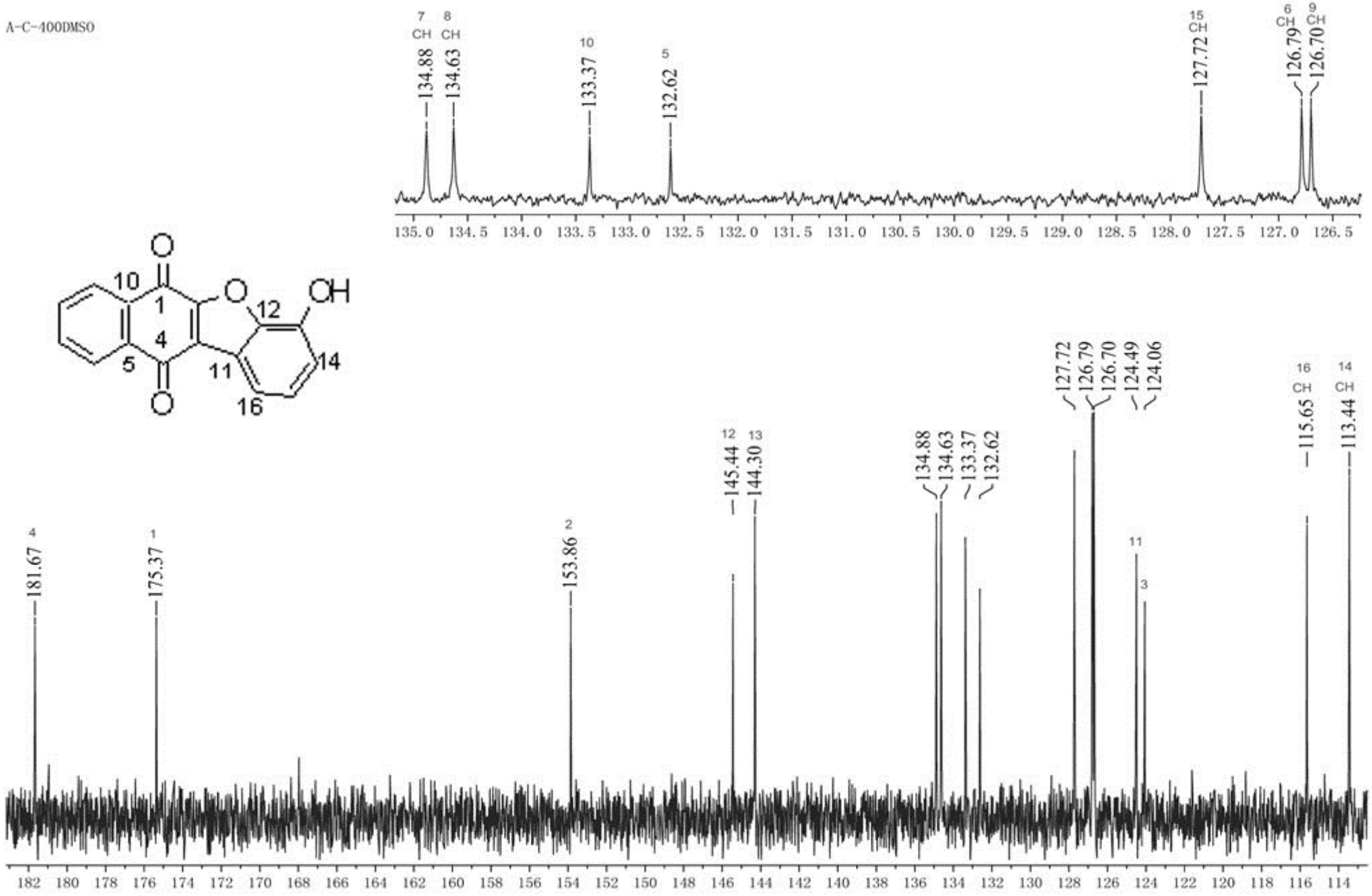


A-H-400DMSO

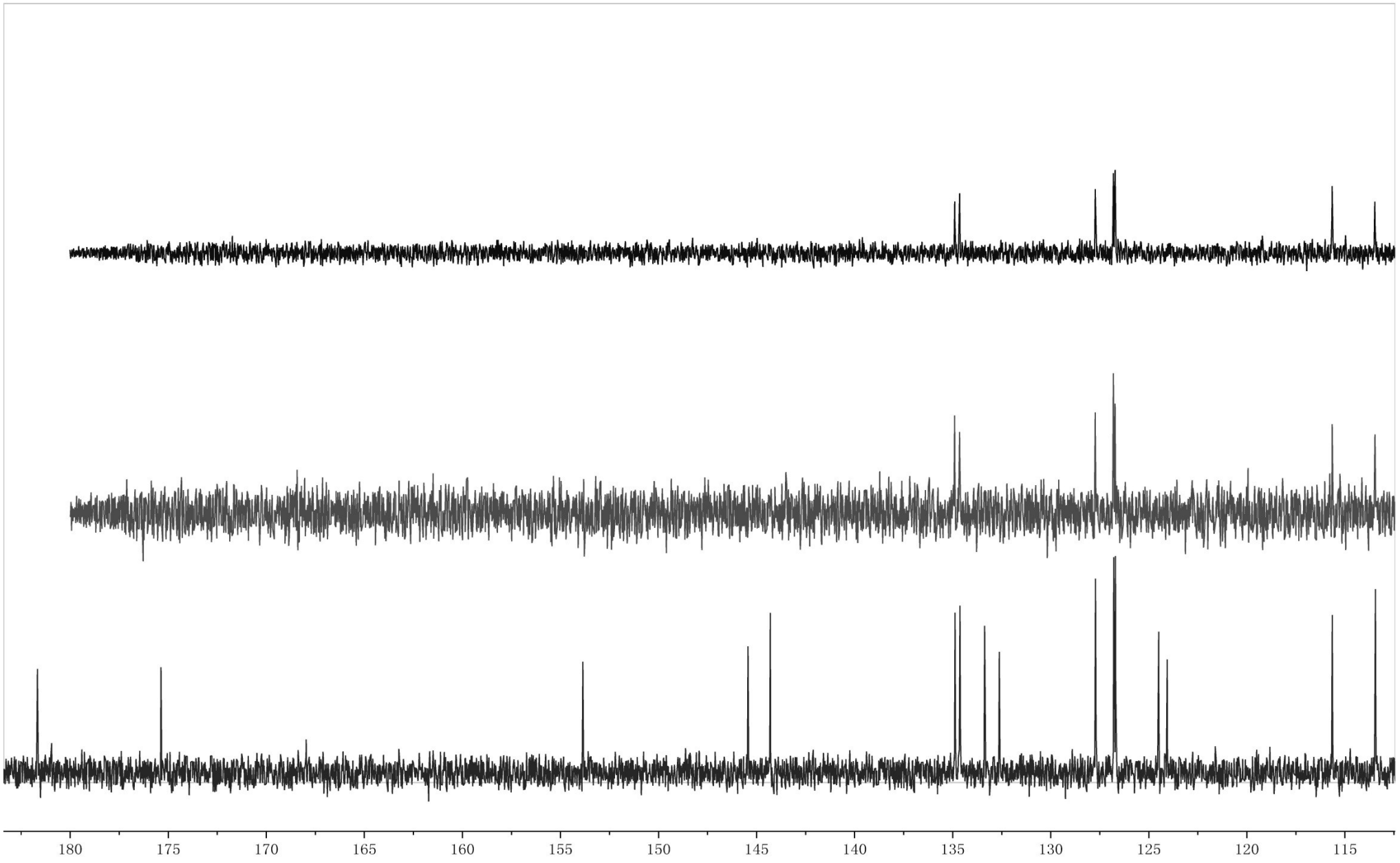

O
10
1
O
12
OH
4
5
11
14
O
16


16
J=7.8Hz (d)
7.63
15
J=7.9Hz (t)
7.37
14
J=7.8Hz (d)
7.11
6
9
8.17
8.16
8.15
8.14
7
8
7.93
7.92
7.91
7.64
7.62
7.39
7.37
7.35
7.12
7.10
1.86
1.89
0.98
1.03
1.00
8.20
8.15
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
7.55
7.50
7.45
7.40
7.35
7.30
7.25
7.20
7.15
7.10

^{13}C-NMR of derivative **4**

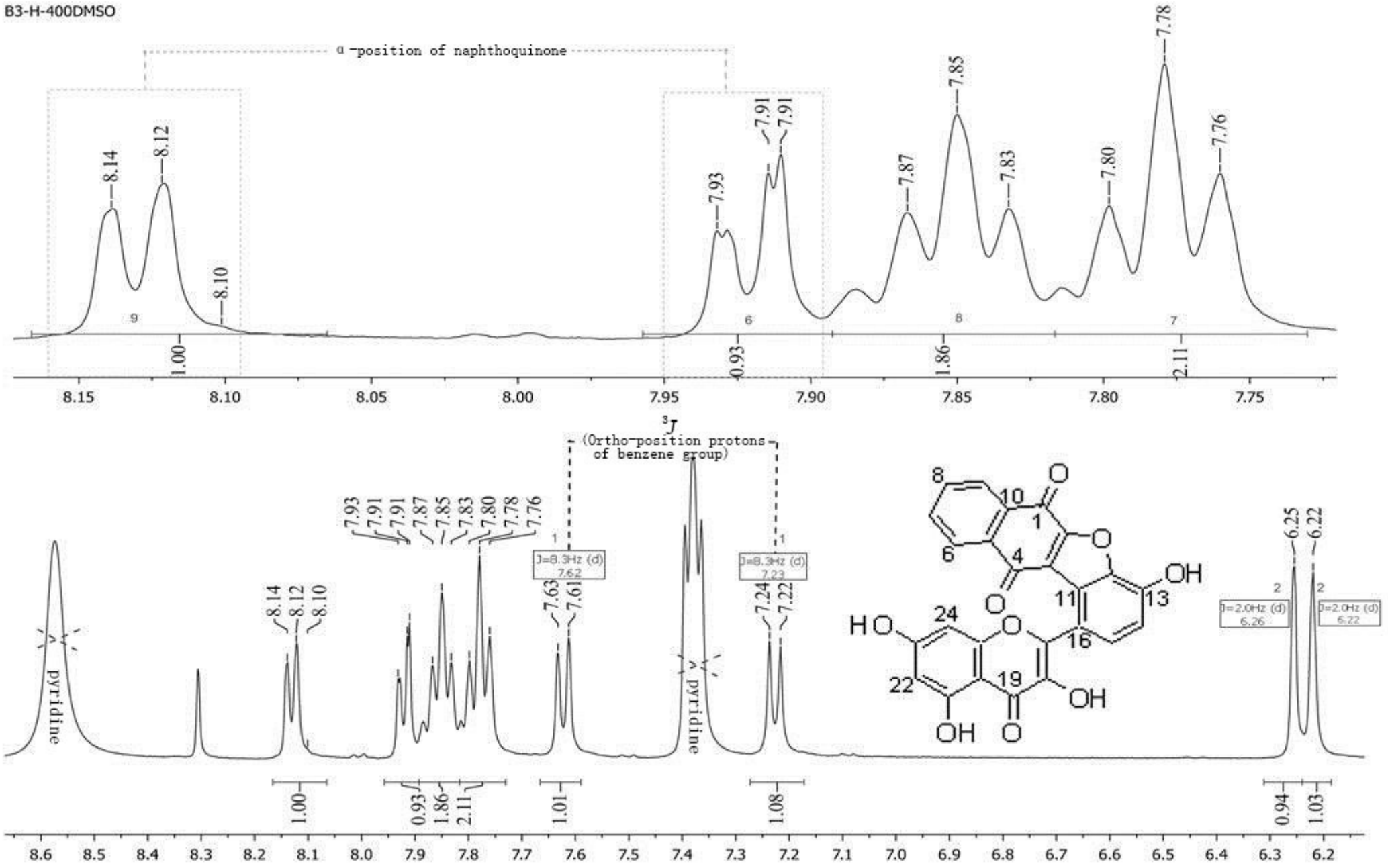


DEPT of derivative **4**

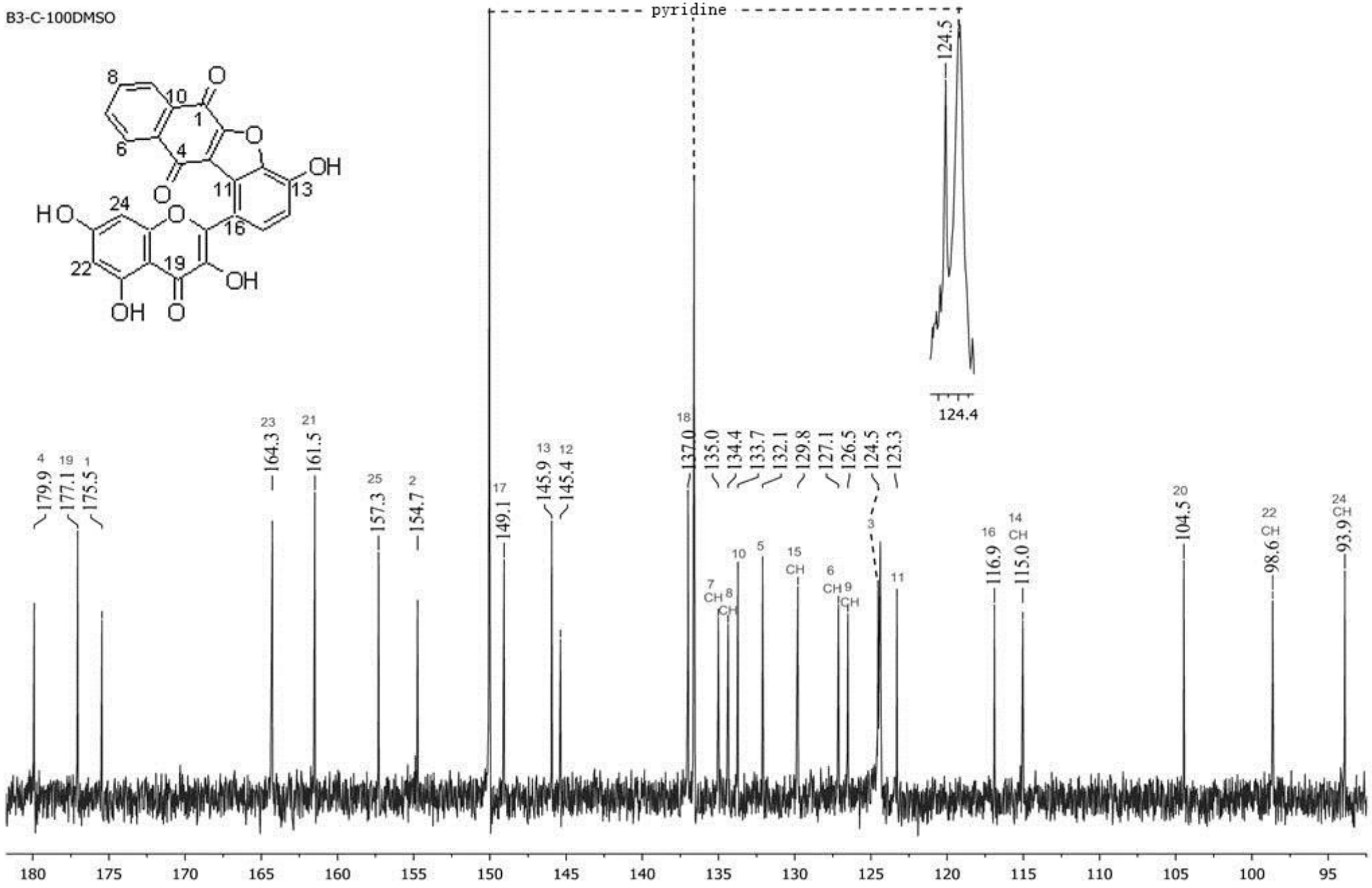


2.5. NMR spectra of derivative **5**

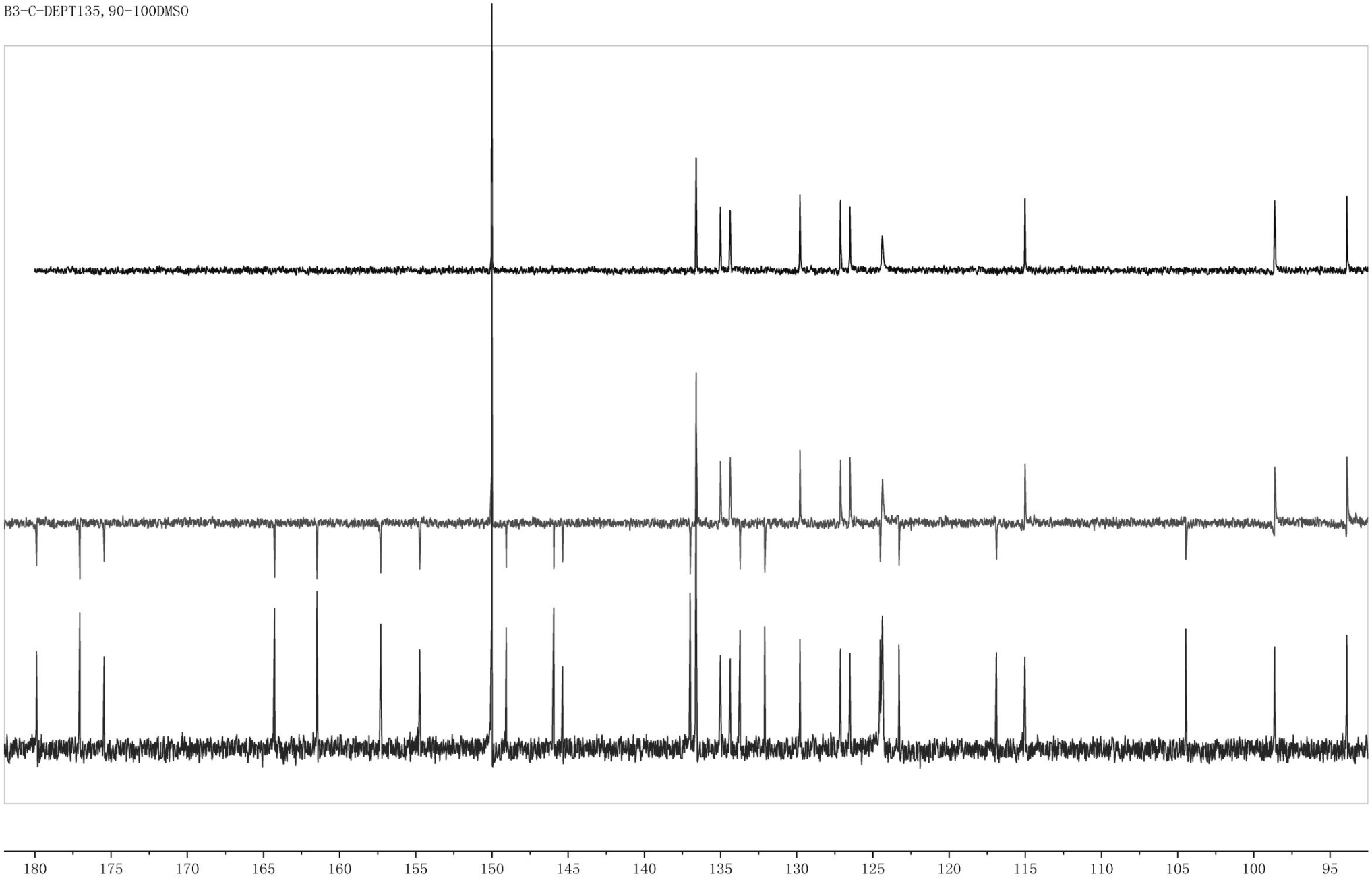
^{1}H-NMR of derivative **5**



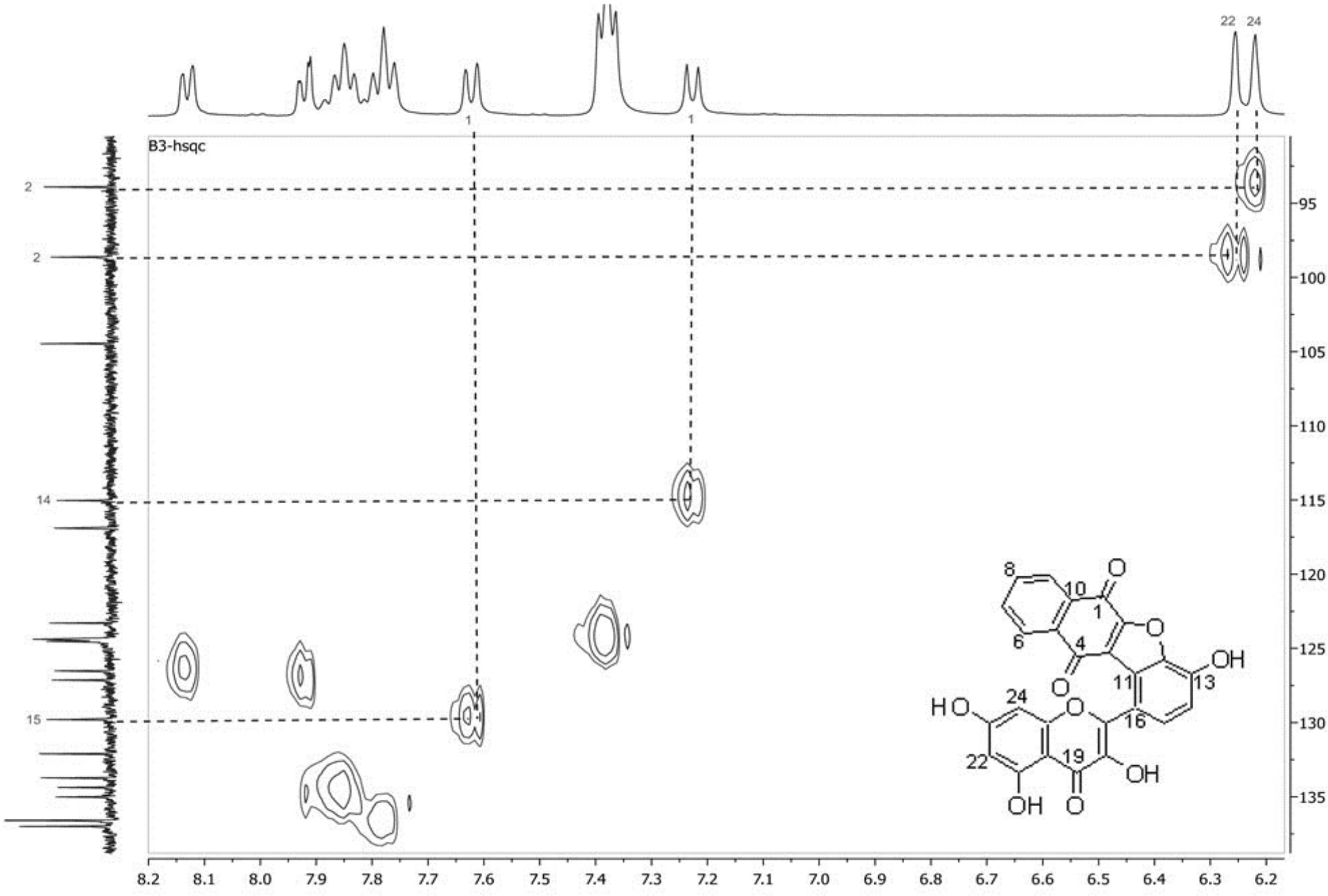
^{13}C-NMR of derivative **5**

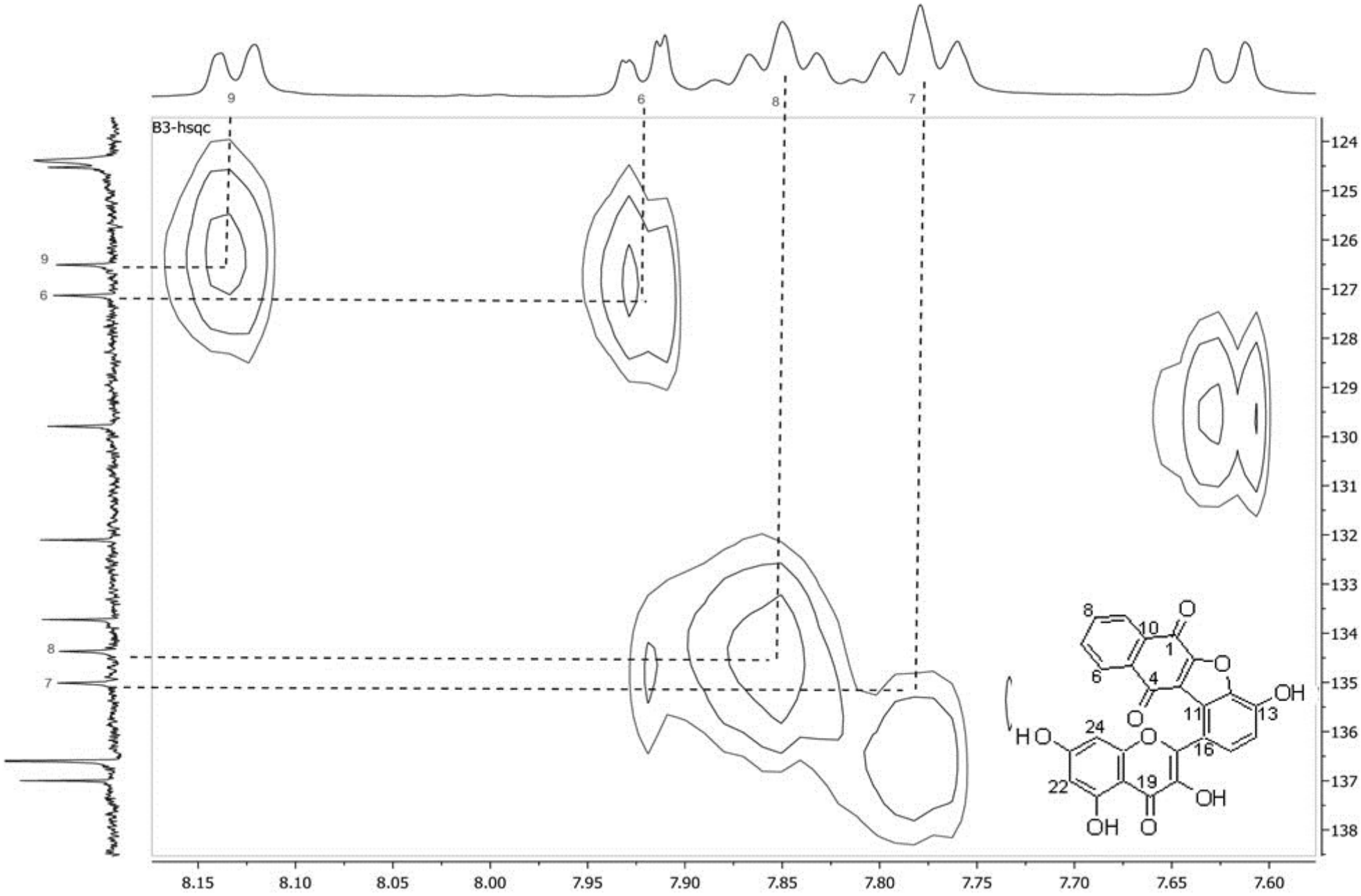


DEPT of derivative **5**

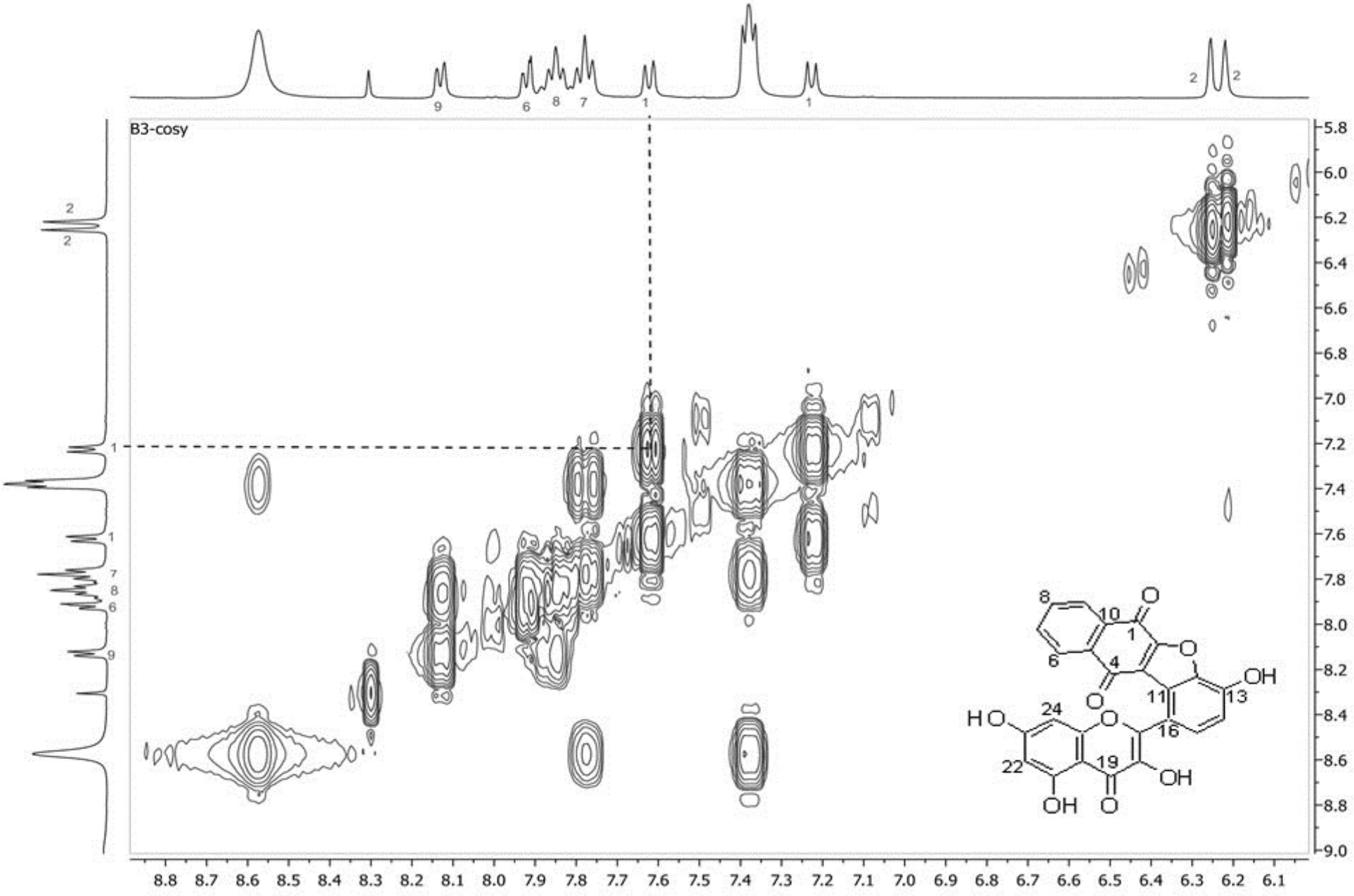


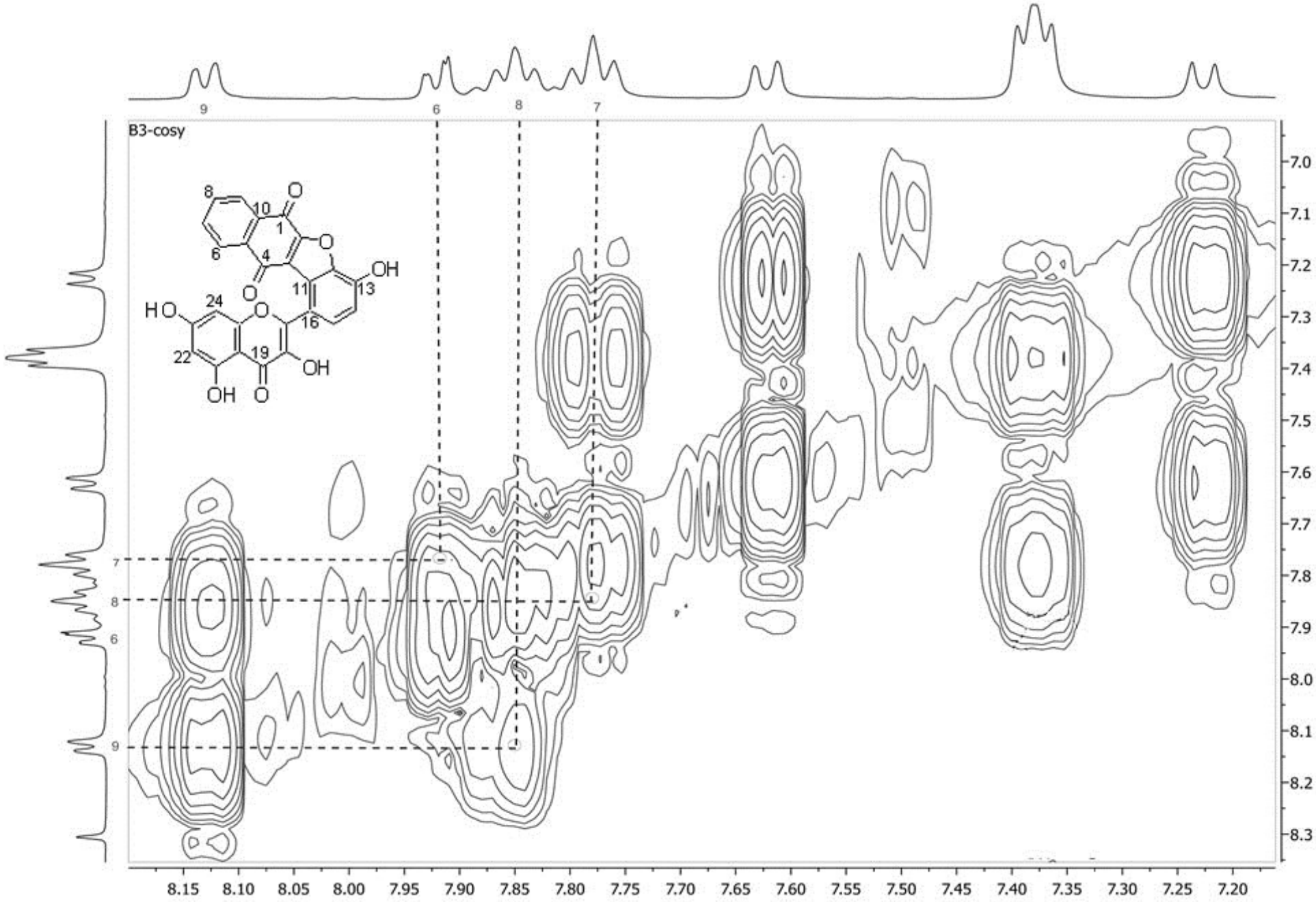
HSQC of derivative **5**



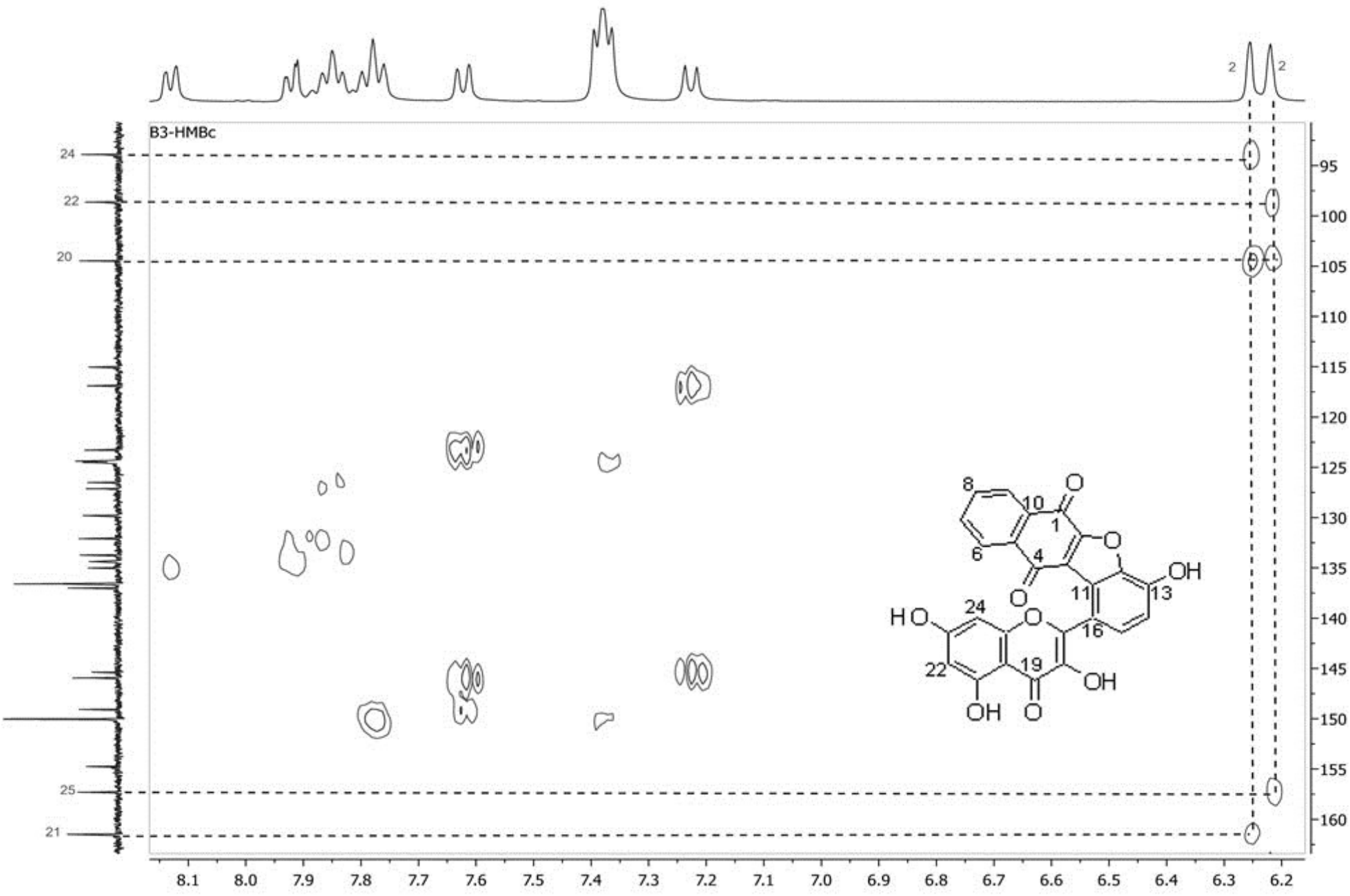

B3-hsqc
9
6
8
7
8.15
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
O
OH
HO
OH
OH
O

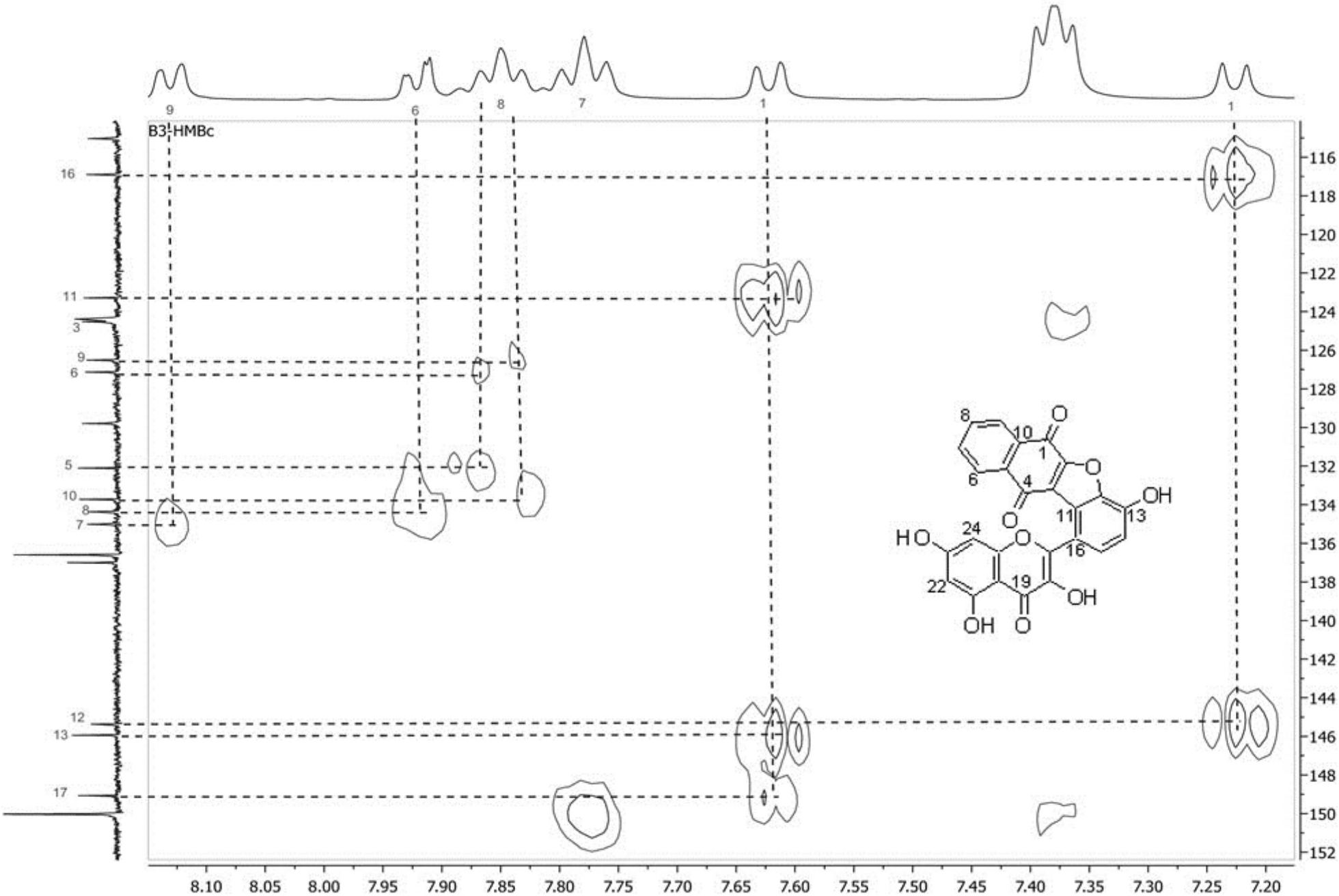
^{1}H-^{1}H COSY of derivative **5**




B3-cosy
9
6
8
7
HO
OH
OH
OH
O
8.15
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
7.55
7.50
7.45
7.40
7.35
7.30
7.25
7.20
7.0
7.1
7.2
7.3
7.4
7.5
7.6
7.7
7.8
7.9
8.0
8.1
8.2
8.3

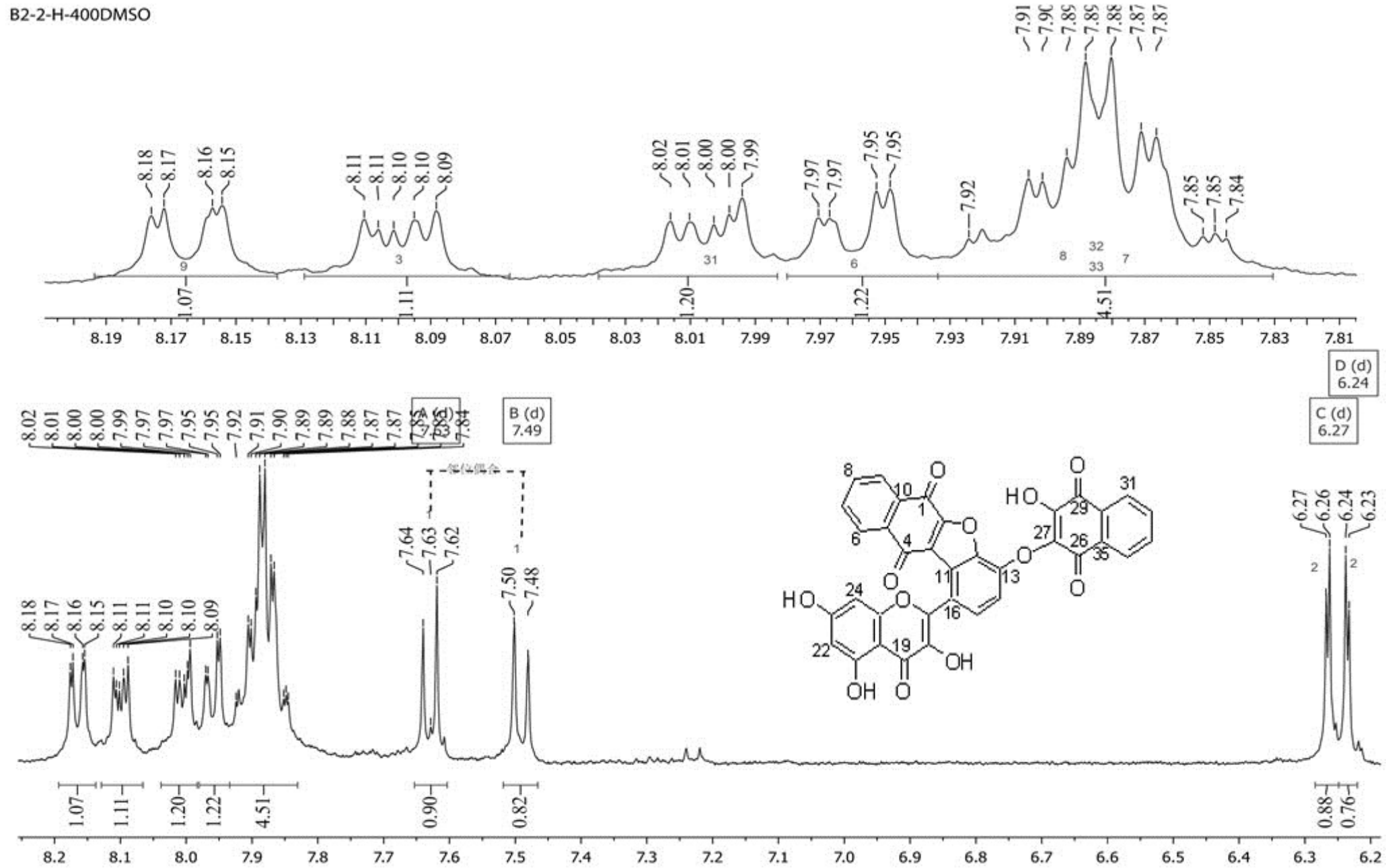
HMBC of derivative **5**



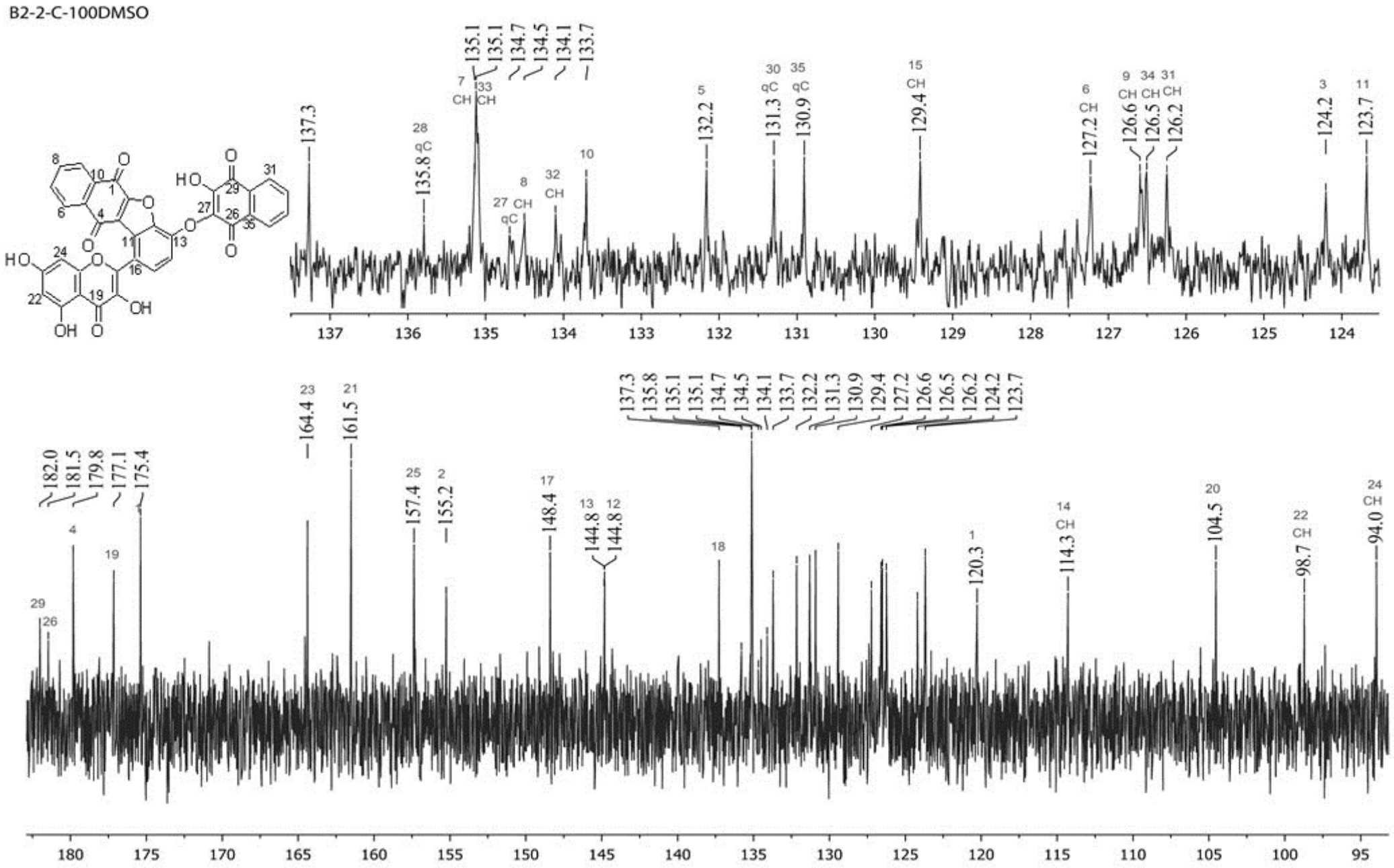

B3-HMBc
9
6
8
7
1
1
16
11
3
9
6
5
10
8
7
12
13
17
116
118
120
122
124
126
128
130
132
134
136
138
140
142
144
146
148
150
152
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
7.55
7.50
7.45
7.40
7.35
7.30
7.25
7.20
O
8
10
1
6
4
O
O
11
OH
13
HO
24
O
16
22
19
OH
OH
O

2.6. NMR spectra of derivative **6**

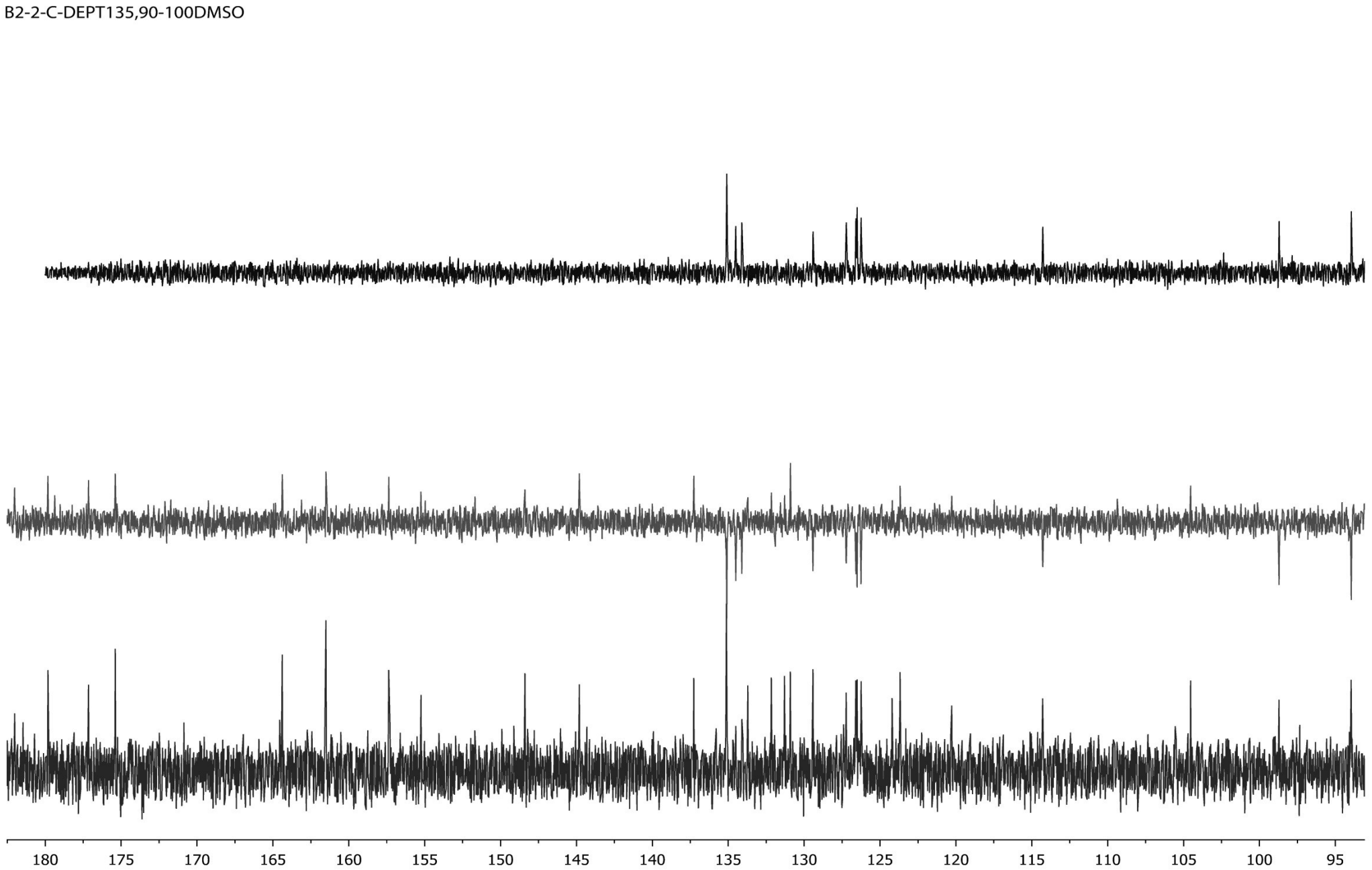
^{1}H-NMR of derivative **6**



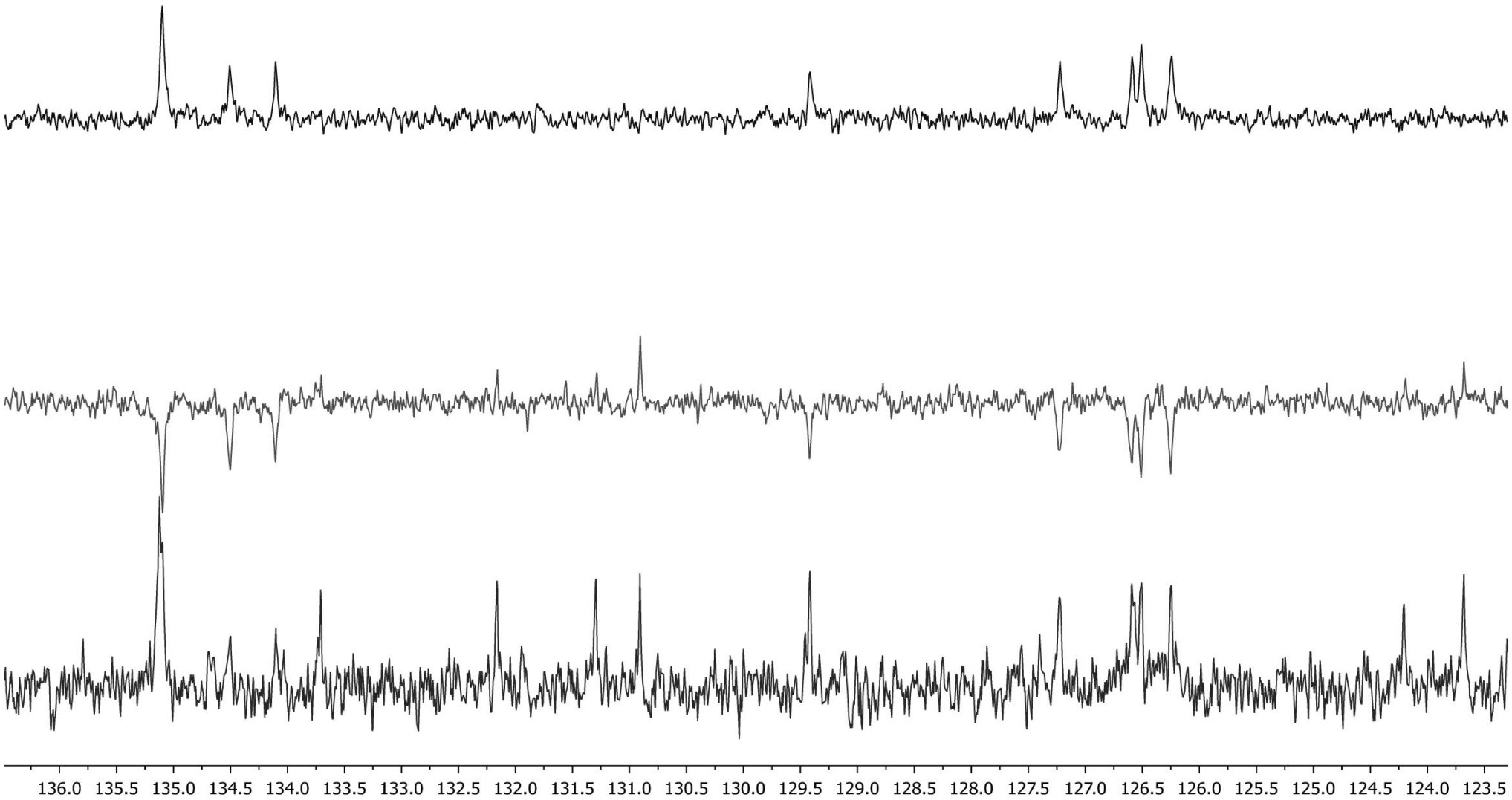
^{13}C-NMR of derivative **6**



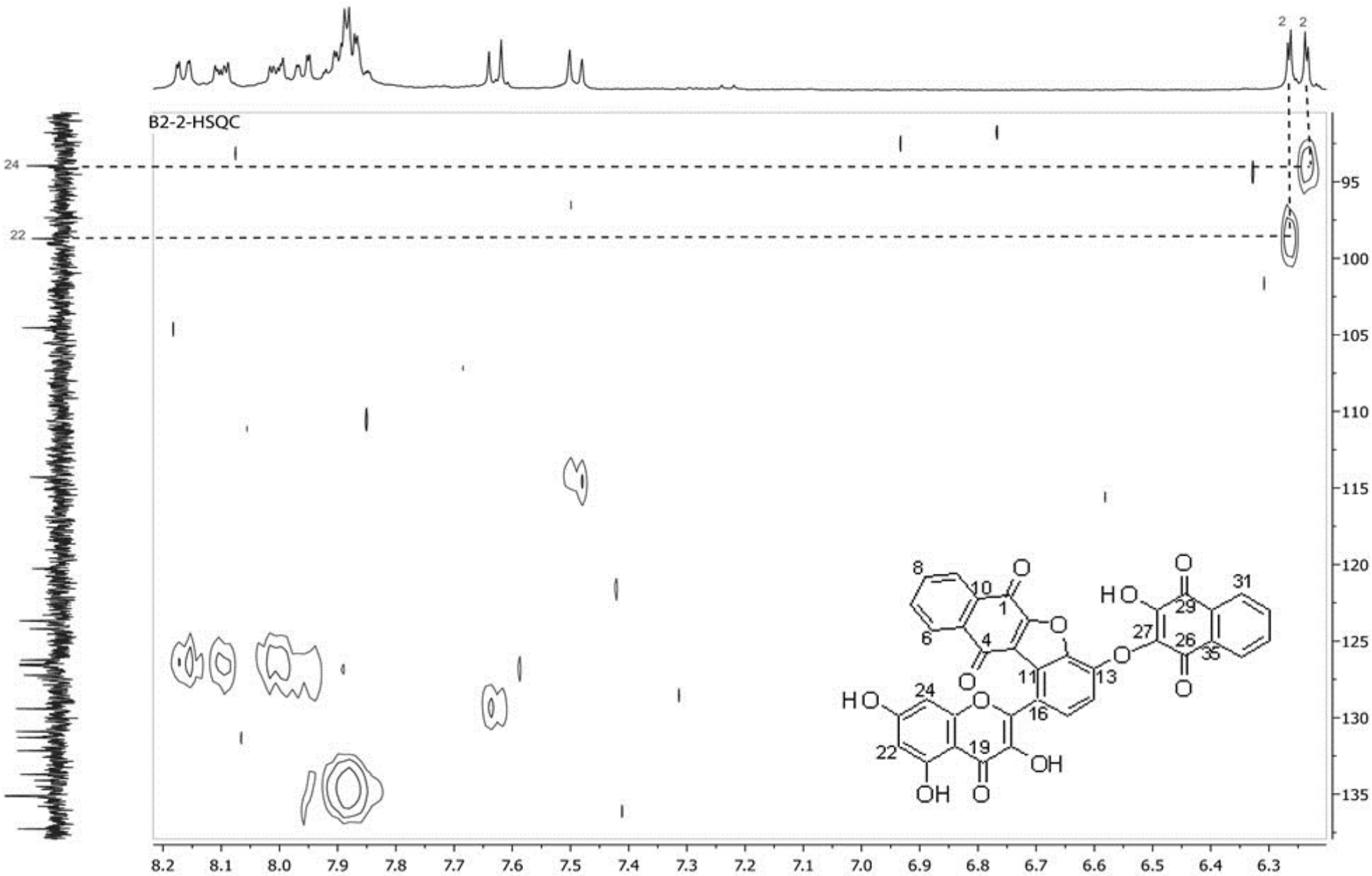
DEPT of derivative **6**

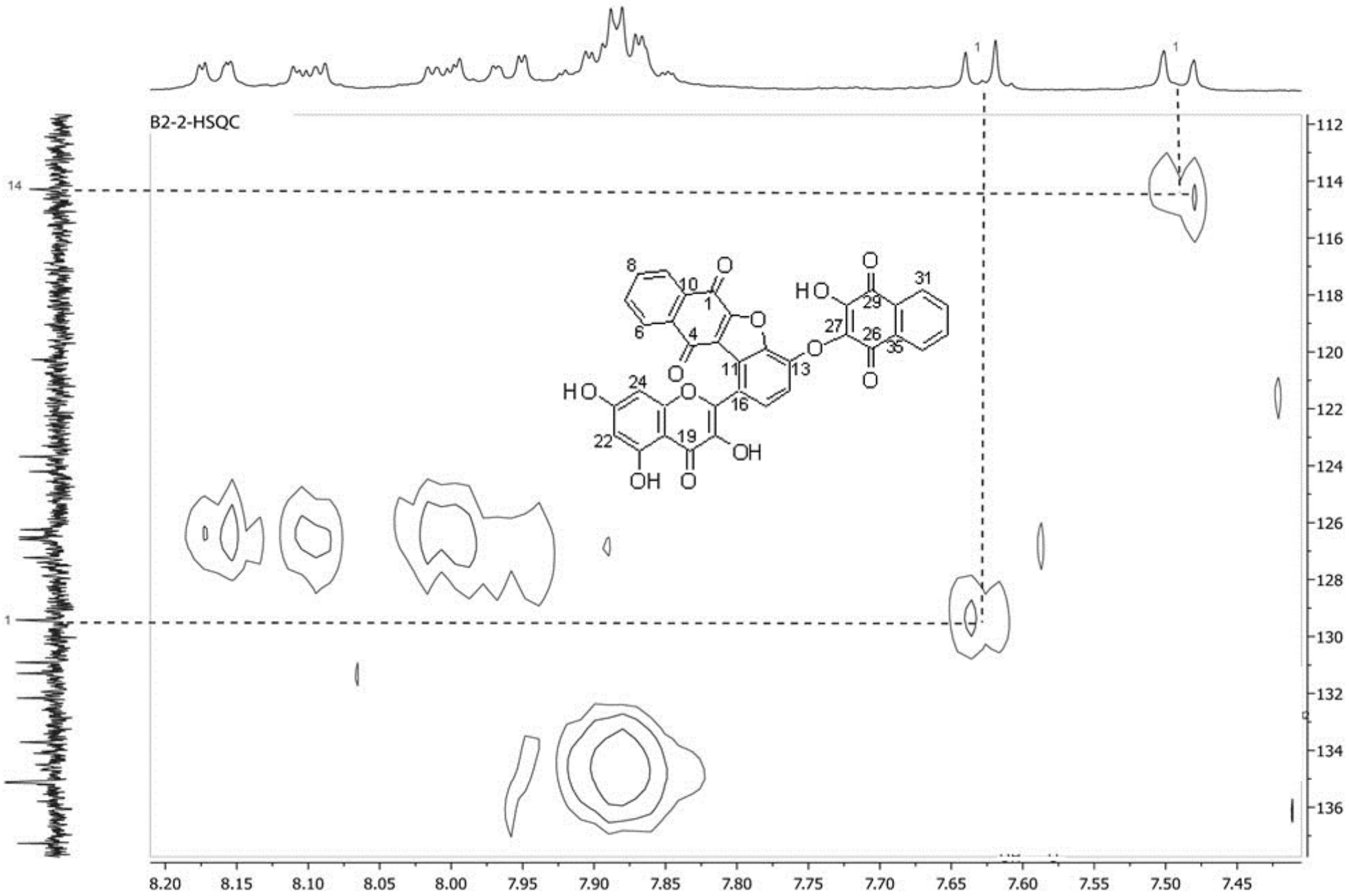


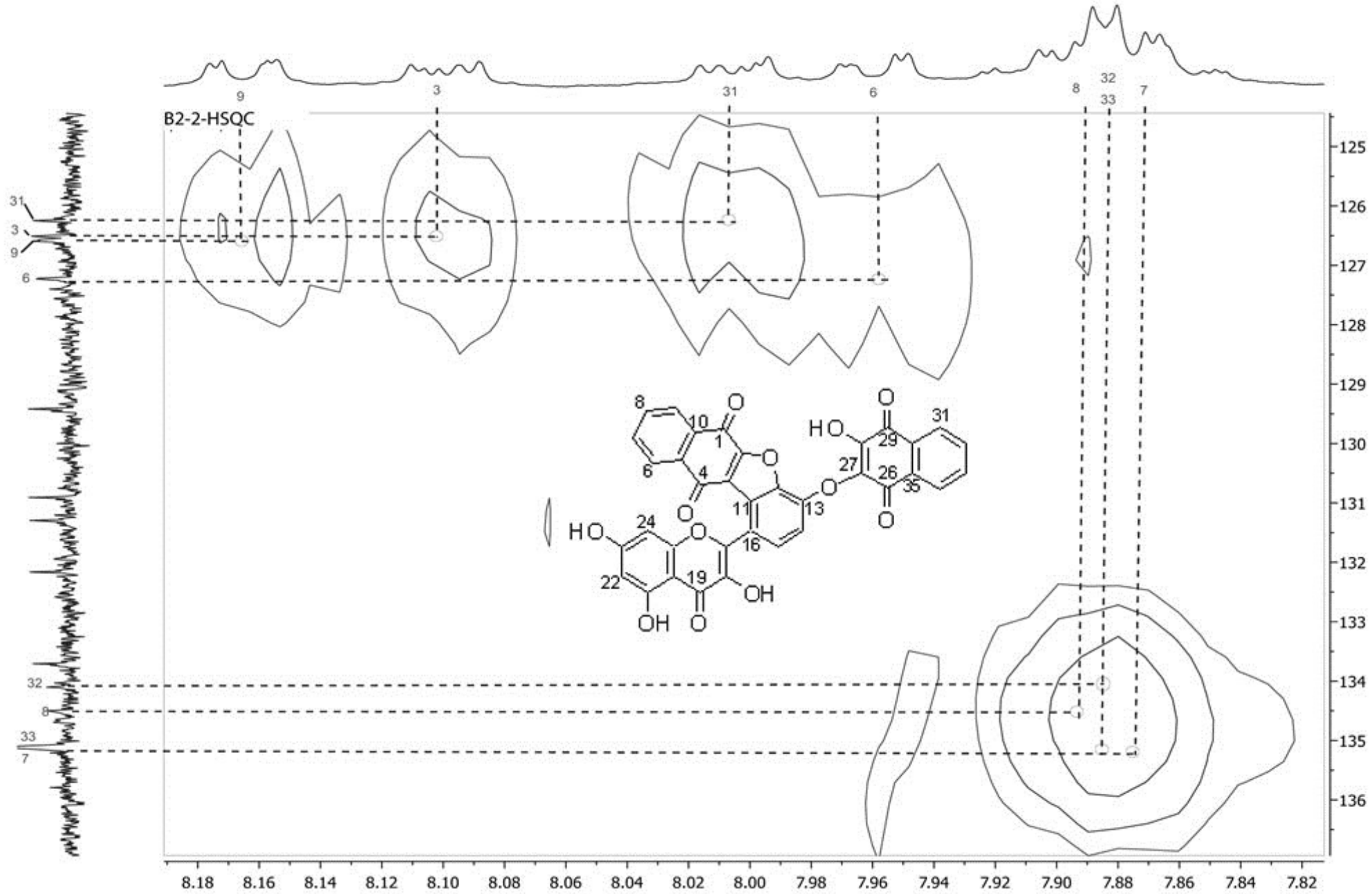
B2-2-C-DEPT135,90-100DMSO



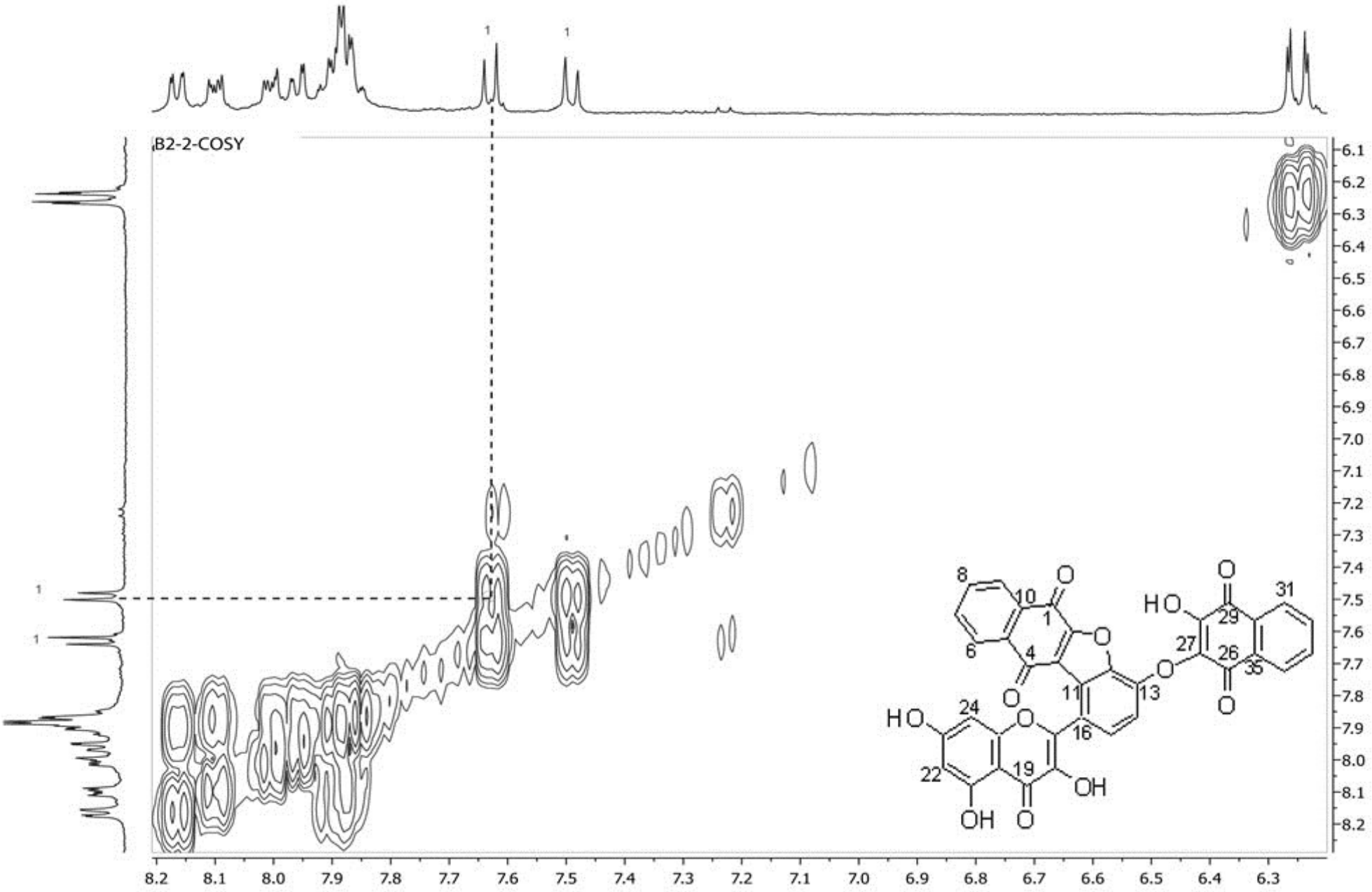
HSQC of derivative **6**

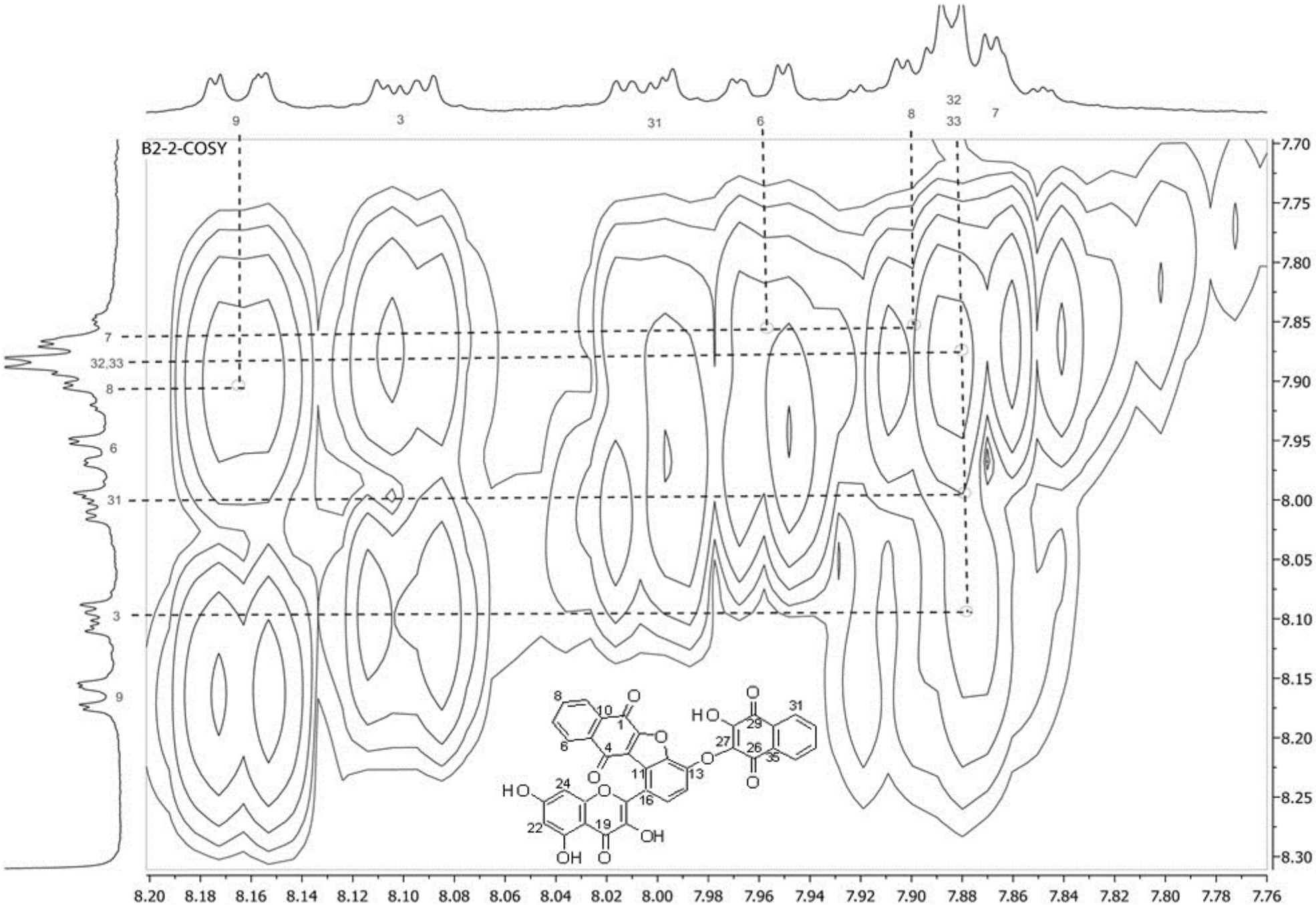



B2-2-HSQC
14
1
8.20
8.15
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
7.55
7.50
7.45
112
114
116
118
120
122
124
126
128
130
132
134
136
HO
OH
OH
O


B2-2-HSQC
9
3
31
6
8
32
33
7
31
3
9
6
32
8
33
7
125
126
127
128
129
130
131
132
133
134
135
136
8.18
8.16
8.14
8.12
8.10
8.08
8.06
8.04
8.02
8.00
7.98
7.96
7.94
7.92
7.90
7.88
7.86
7.84
7.82
HO
OH
OH
O

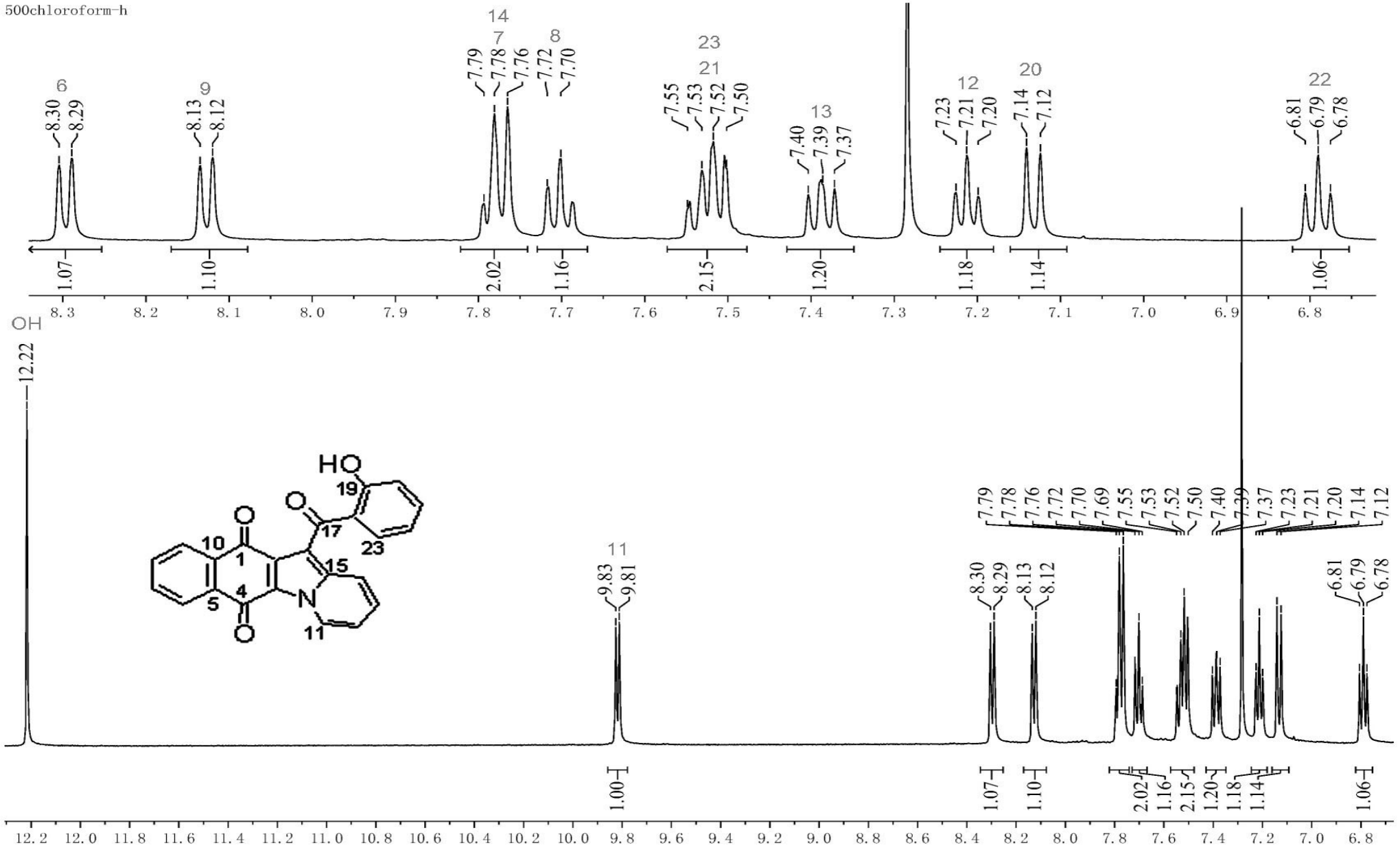
^{1}H-^{1}H COSY of derivative **6**



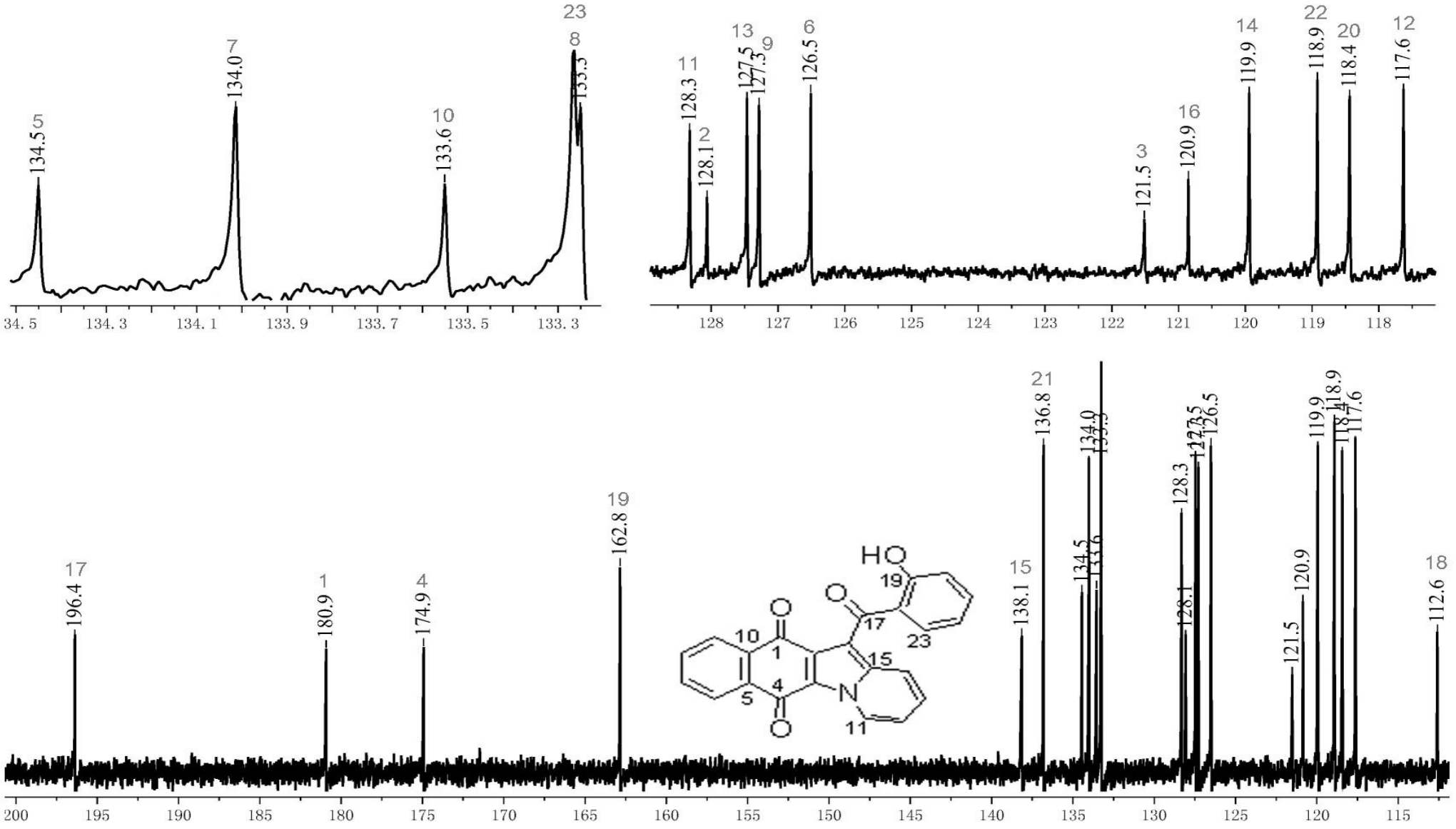

B2-2-COSY
9
3
31
6
8
32
33
7
7
32,33
8
6
31
3
9
7.70
7.75
7.80
7.85
7.90
7.95
8.00
8.05
8.10
8.15
8.20
8.25
8.30
8.20 8.18 8.16 8.14 8.12 8.10 8.08 8.06 8.04 8.02 8.00 7.98 7.96 7.94 7.92 7.90 7.88 7.86 7.84 7.82 7.80 7.78 7.76
HO
OH
OH
O

2.7. NMR spectra of derivative **7**

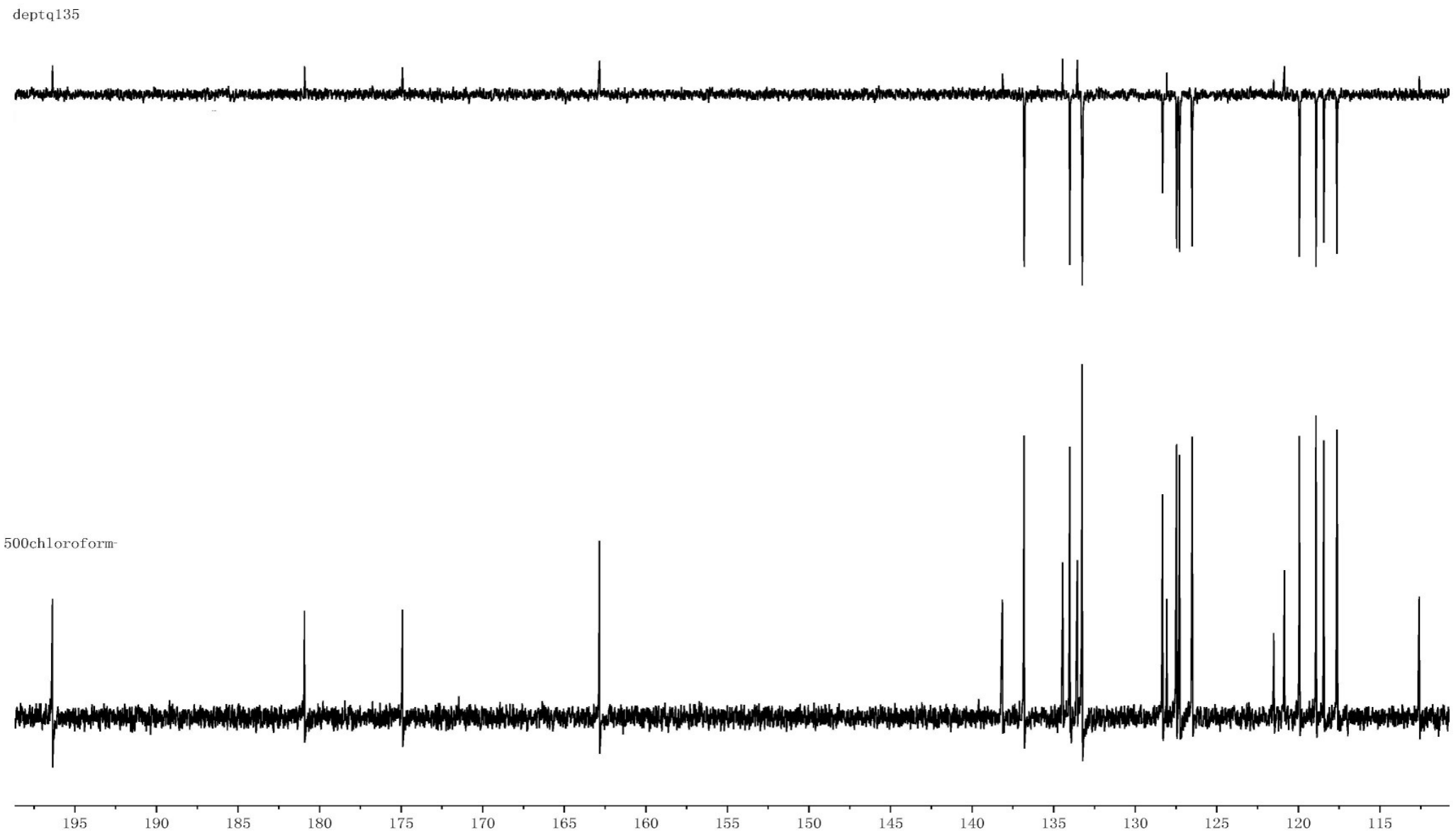
^{1}H-NMR of derivative **7**



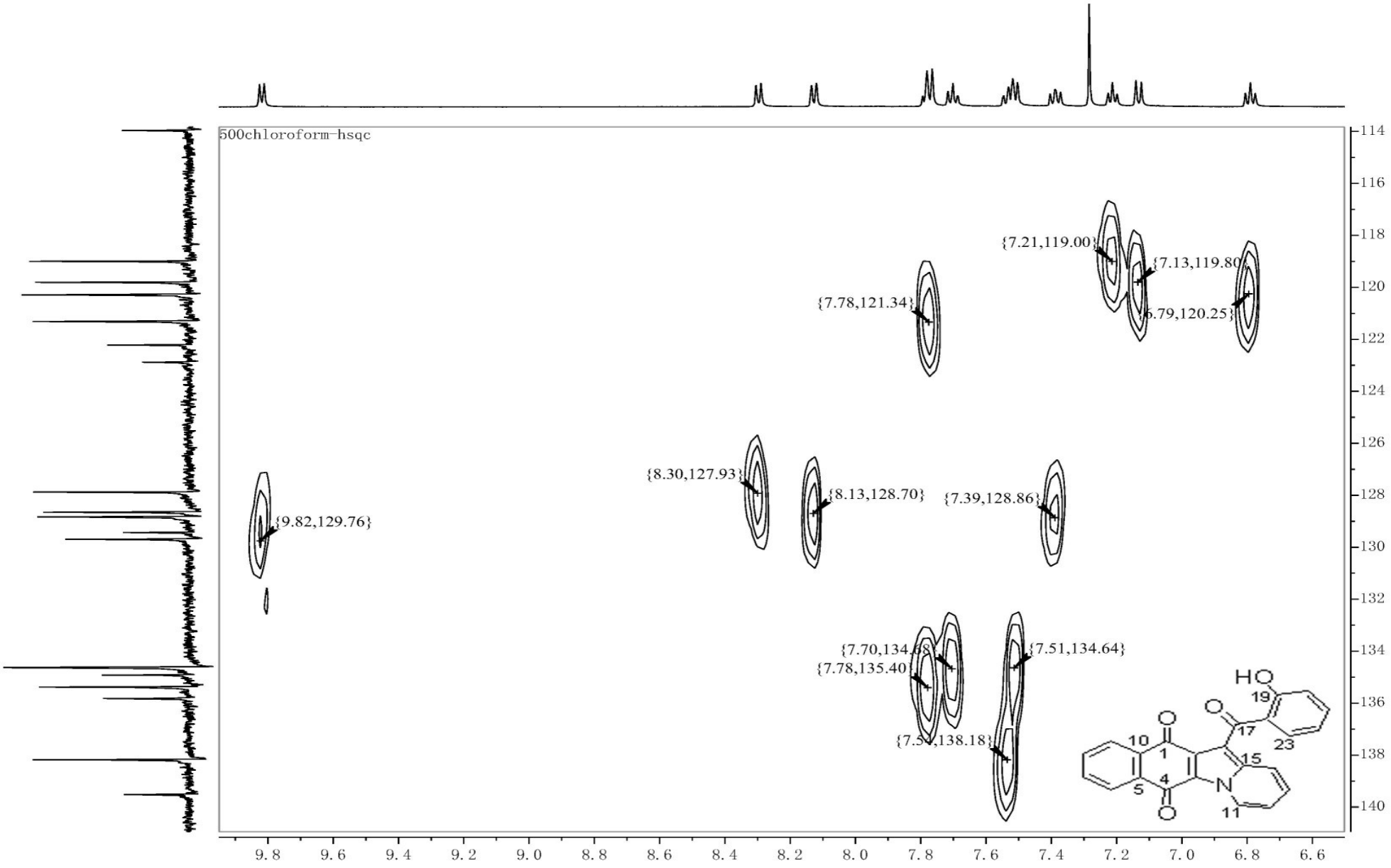
^{13}C-NMR of derivative **7**



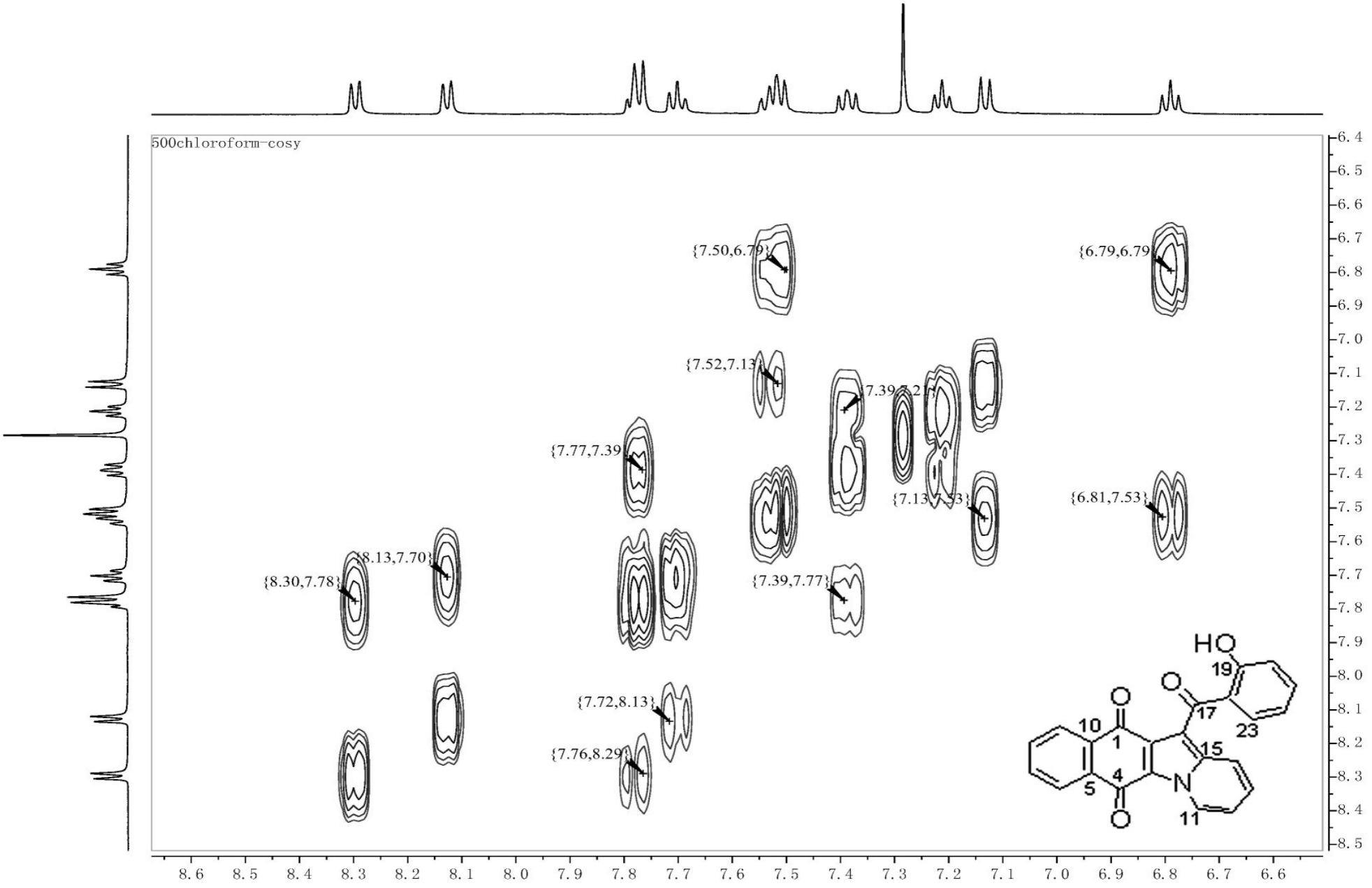
DEPT of derivative **7**



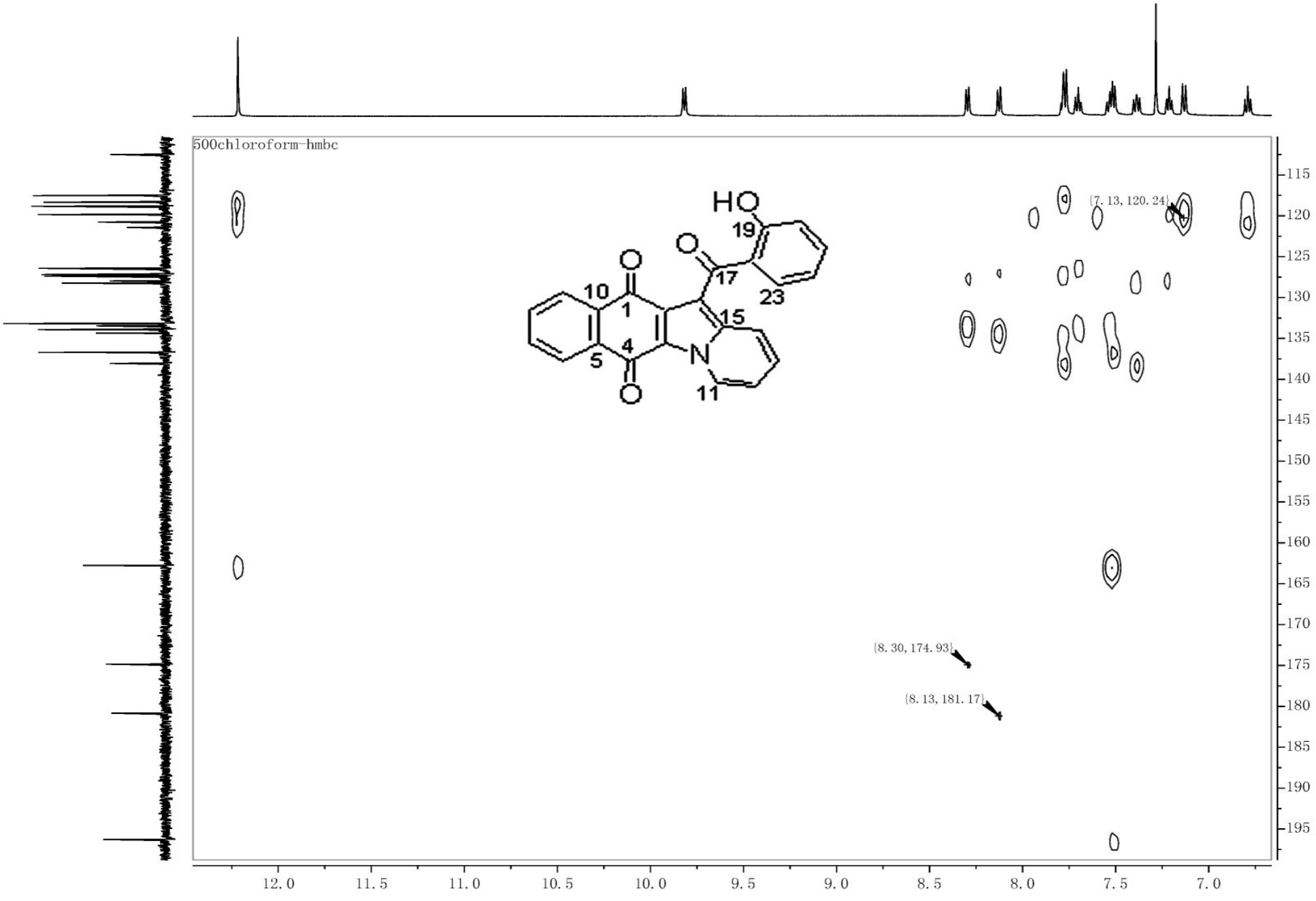
HSQC of derivative **7**

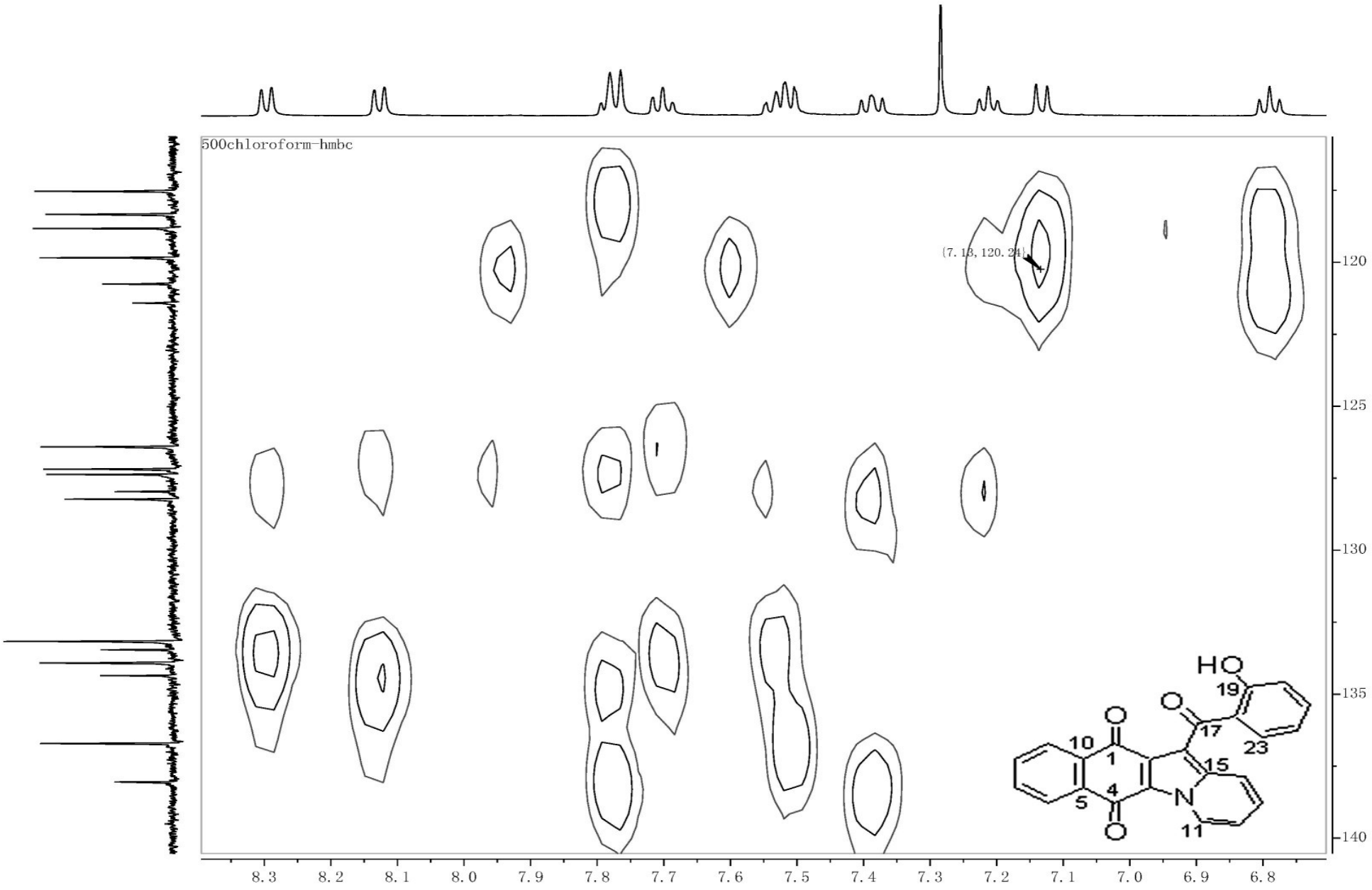


^{1}H-^{1}H COSY of derivative **7**



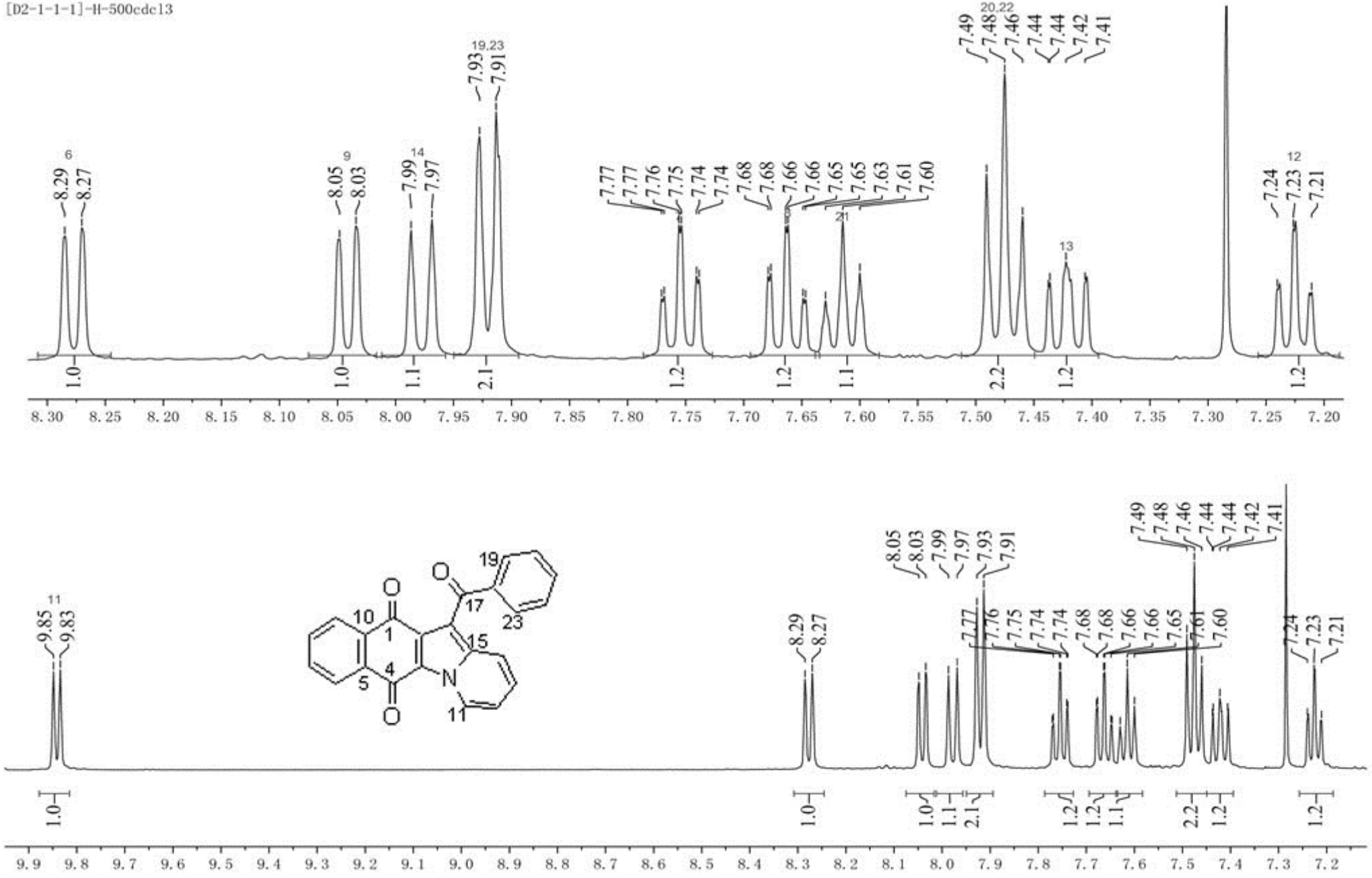
HMBC of derivative **7**



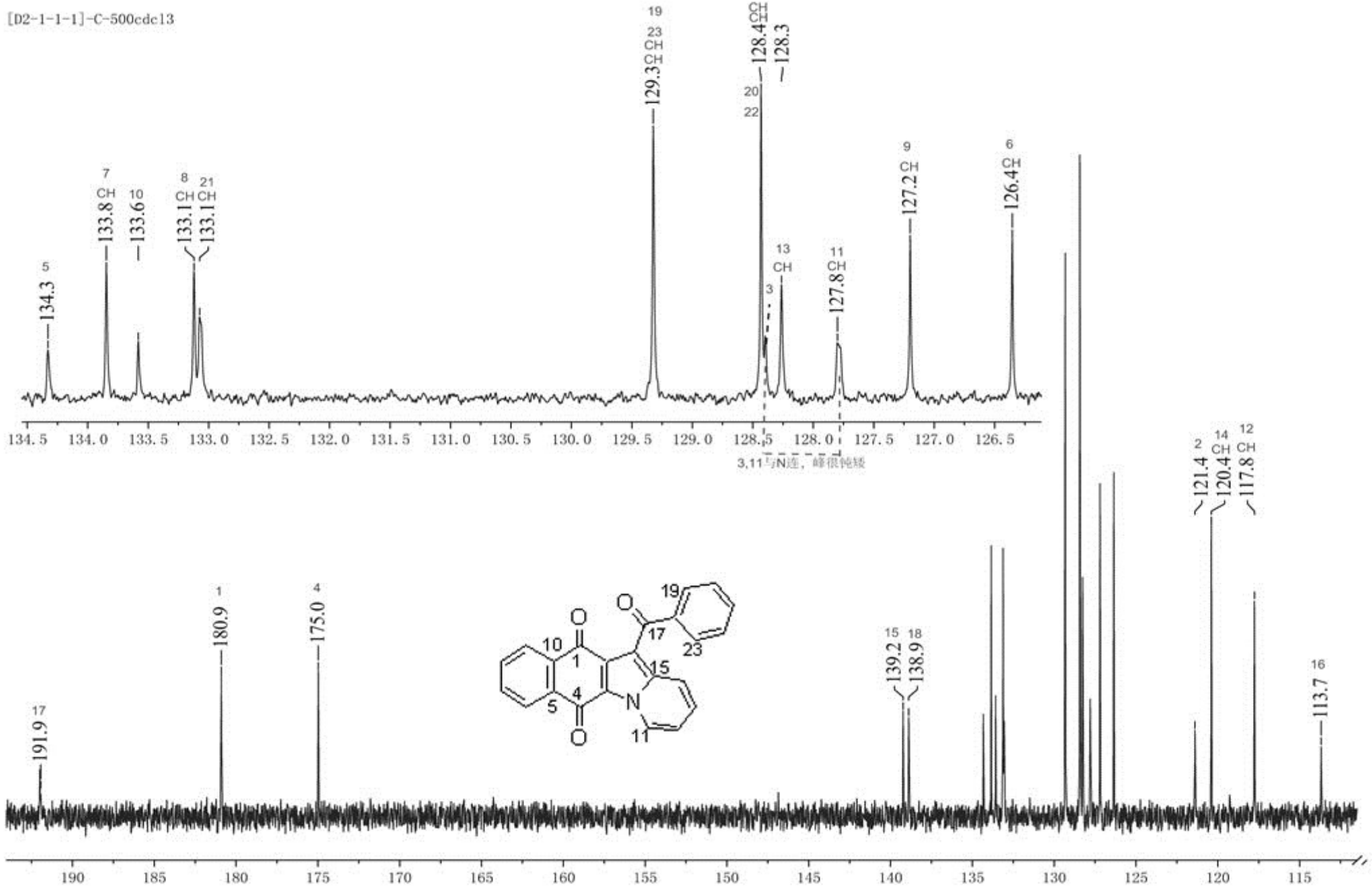

500chloroform-hmbc
(7.13, 120.24)
120
125
130
135
140
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
6.9
6.8
HO
19
O
17
23
10
1
15
5
4
N
11
O
O

2.8. NMR spectra of derivative **8**

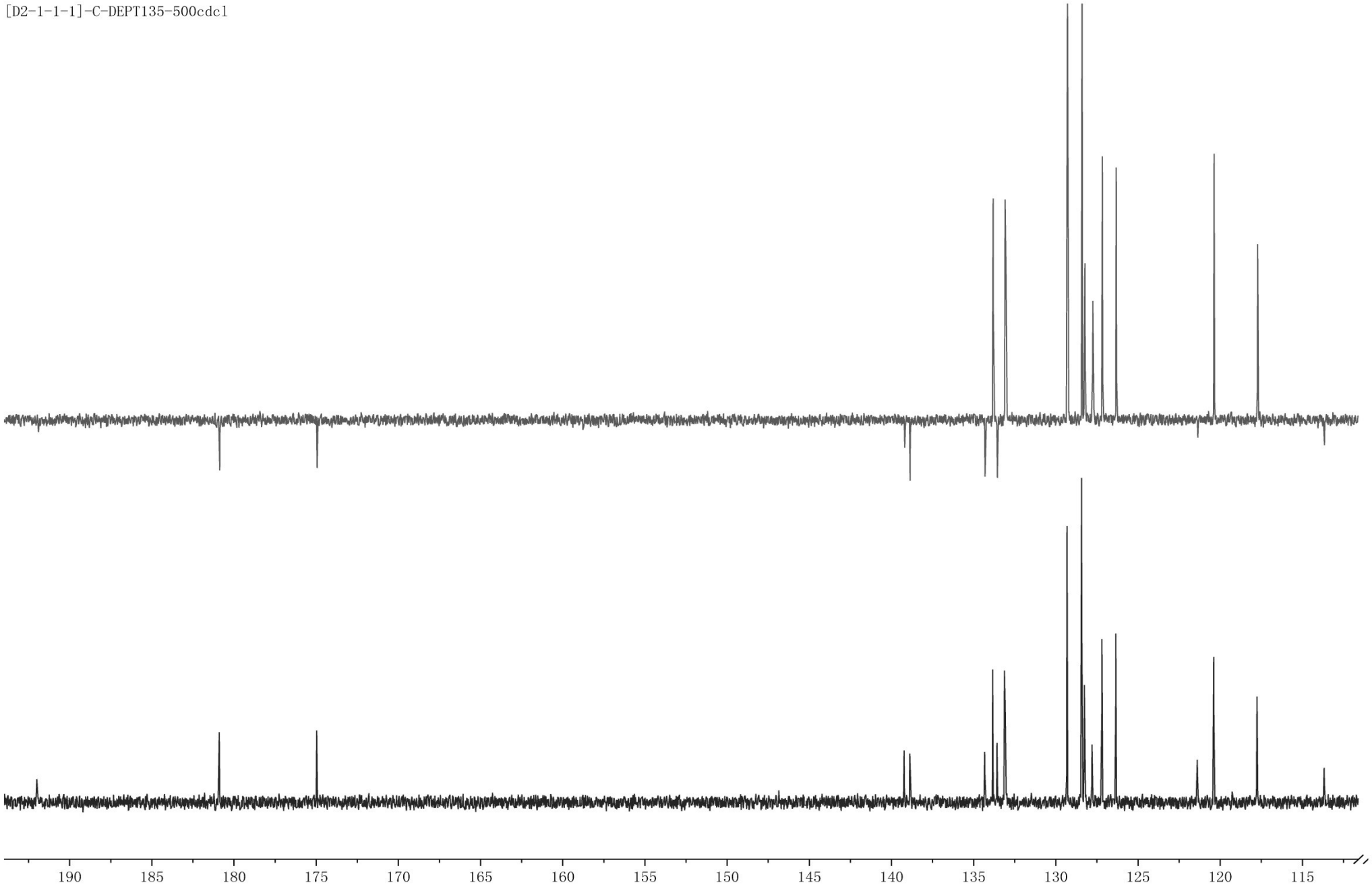
^{1}H-NMR of derivative **8**



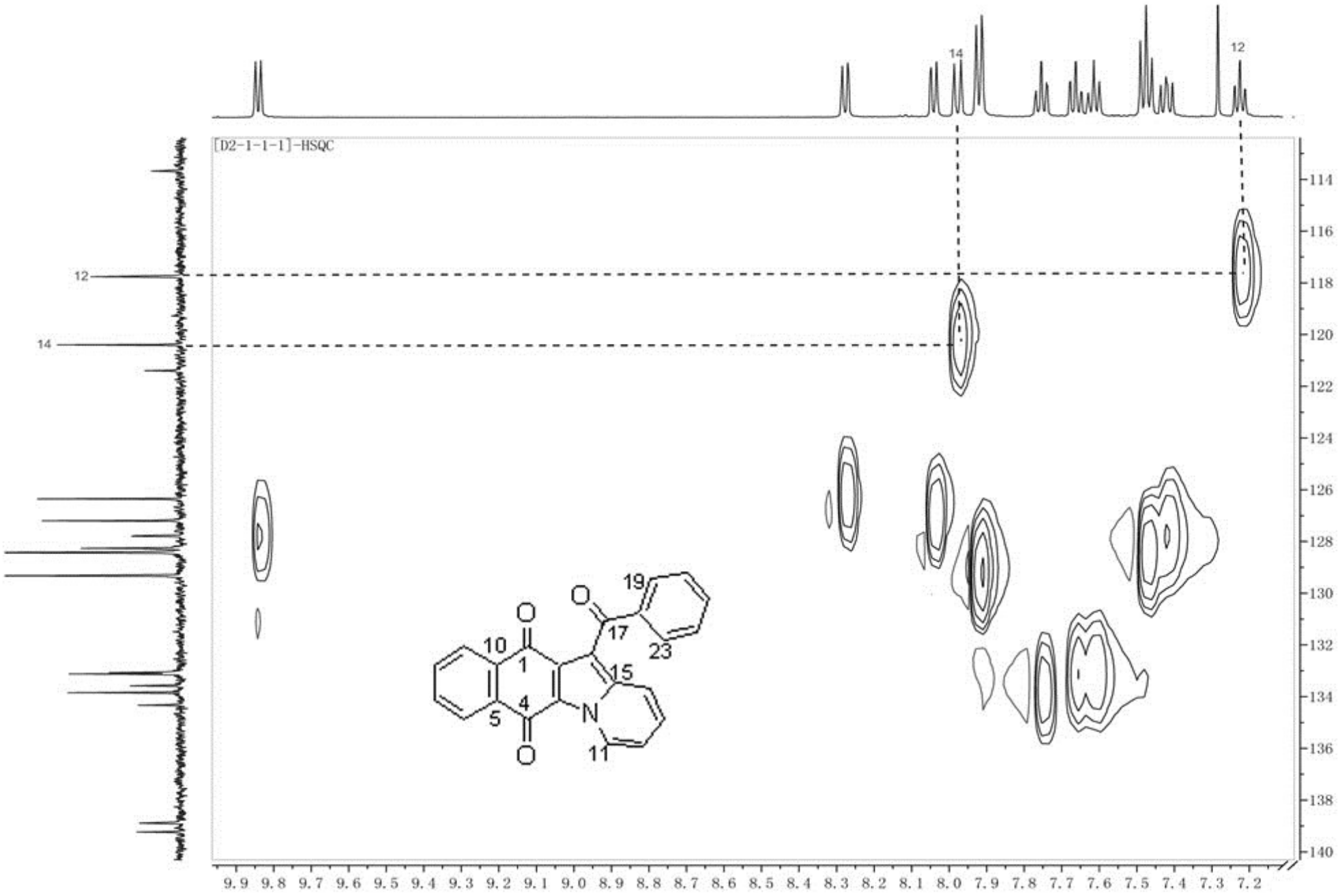
^{13}C-NMR of derivative **8**

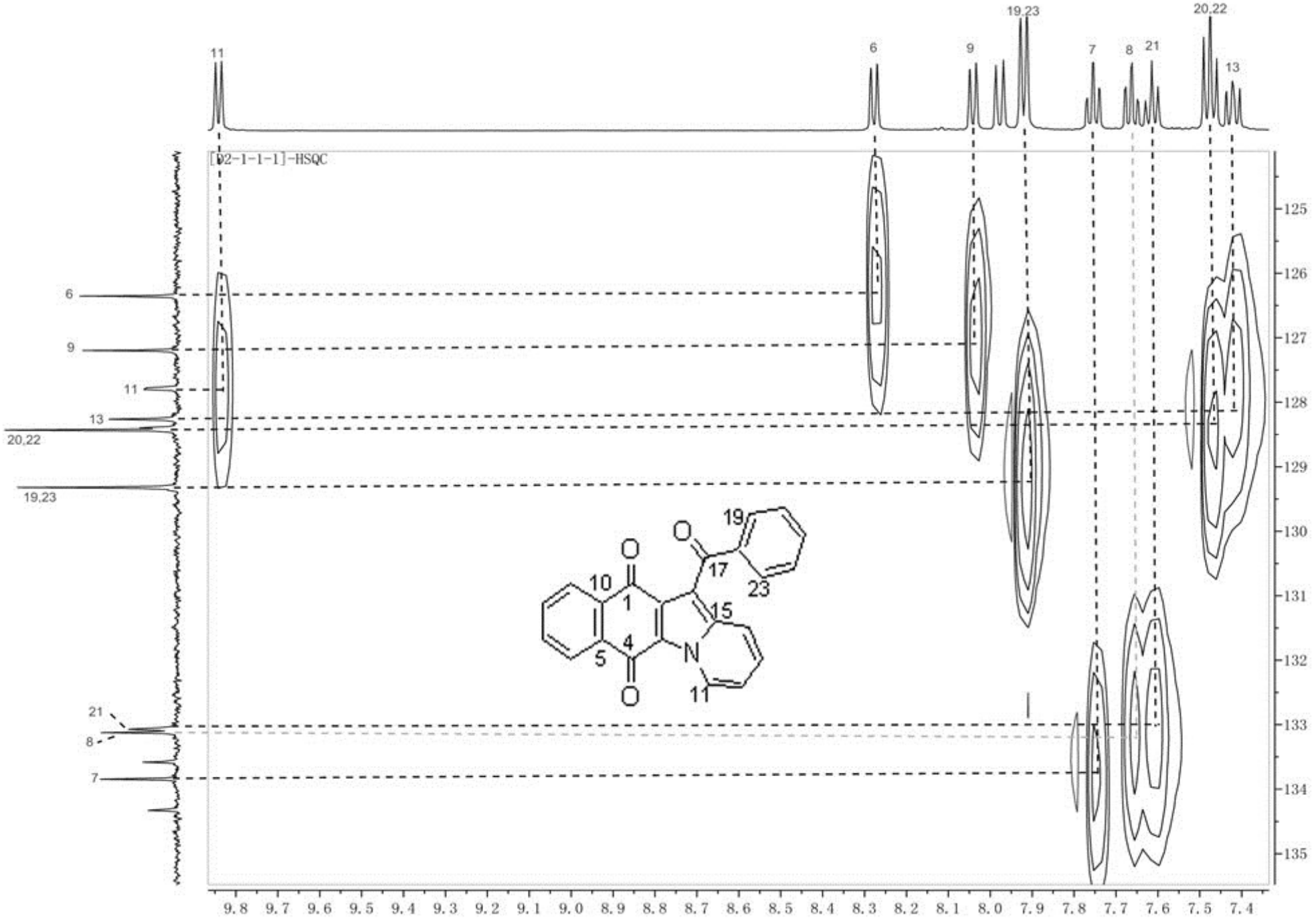


DEPT of derivative **8**

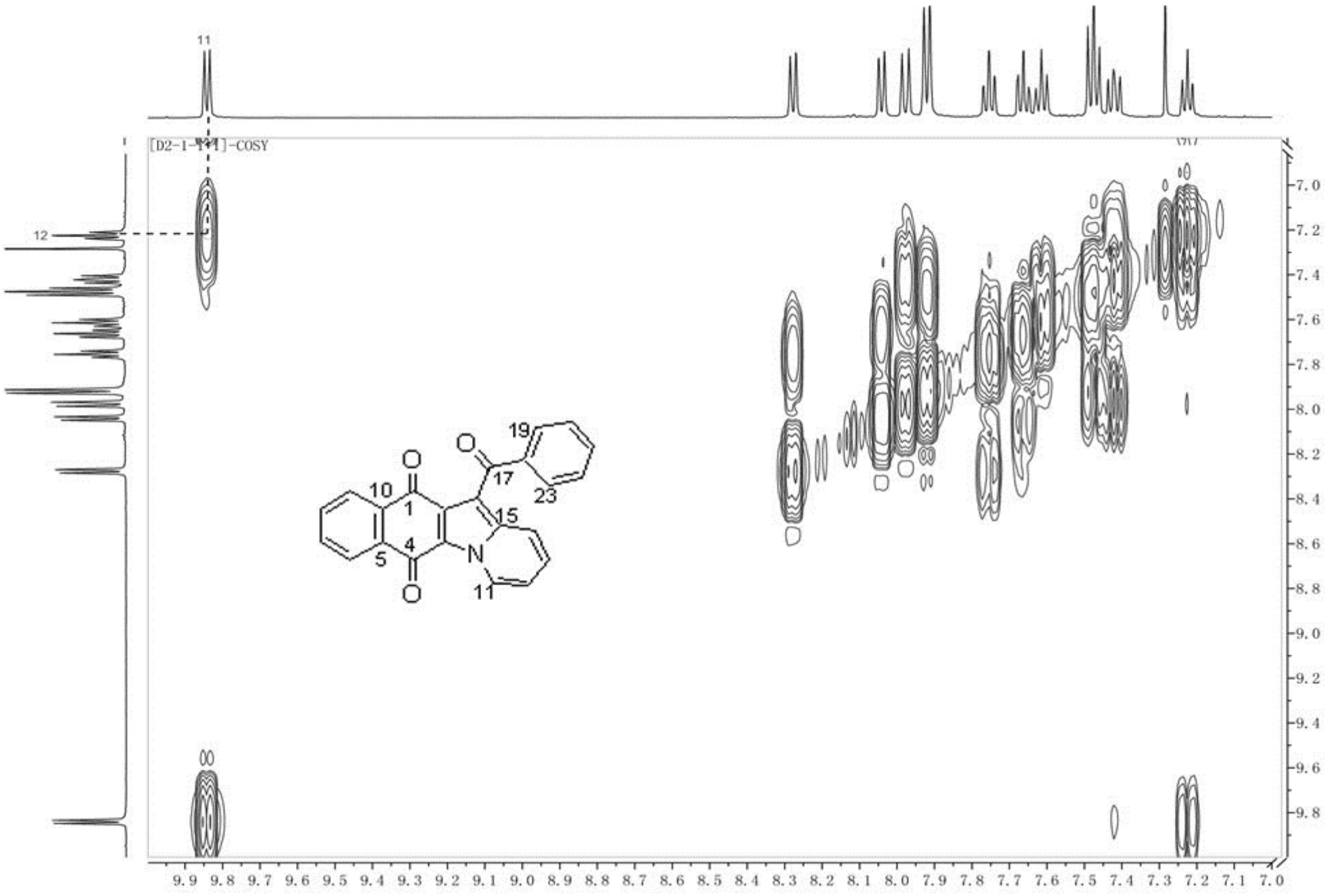


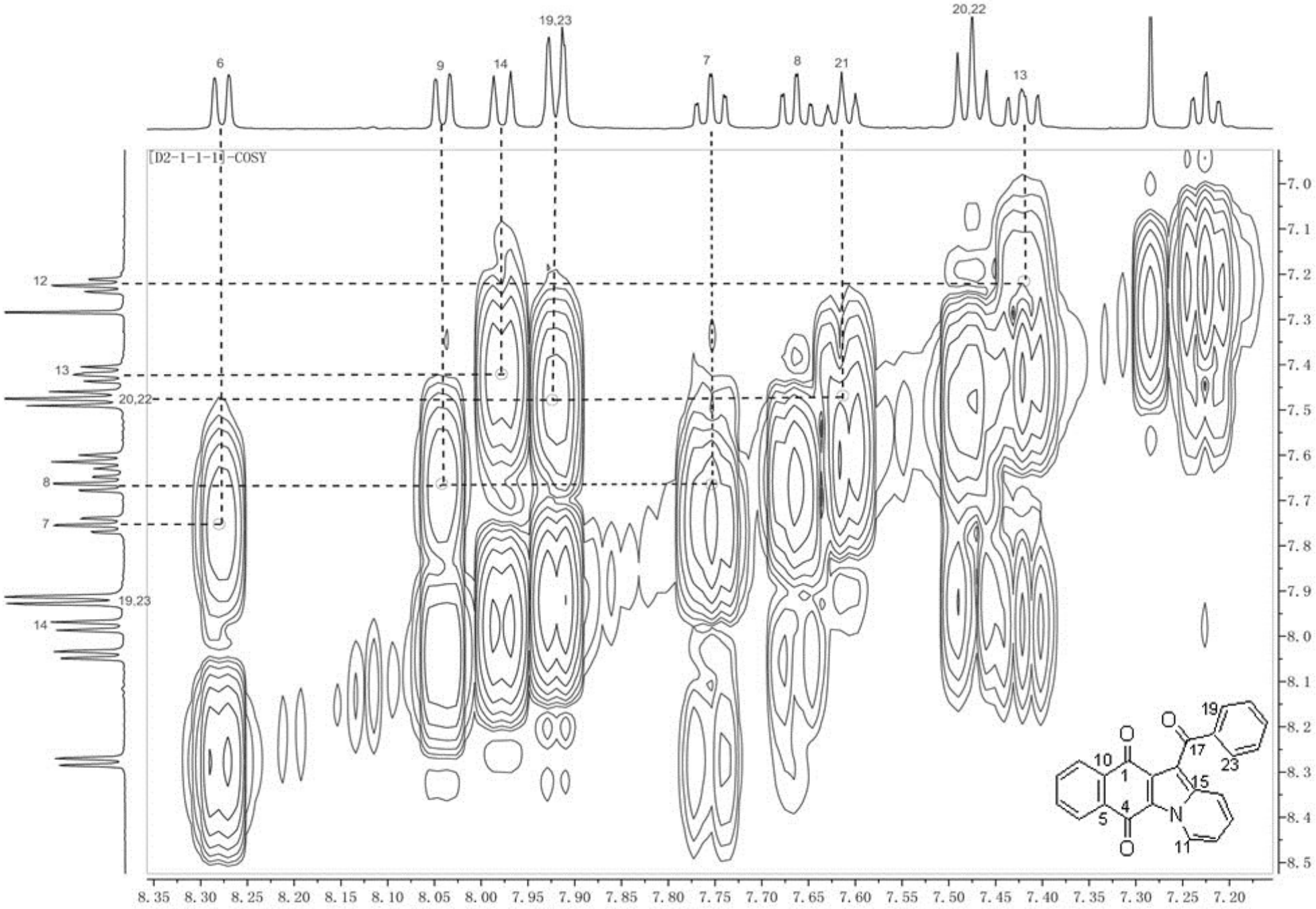
HSQC of derivative **8**



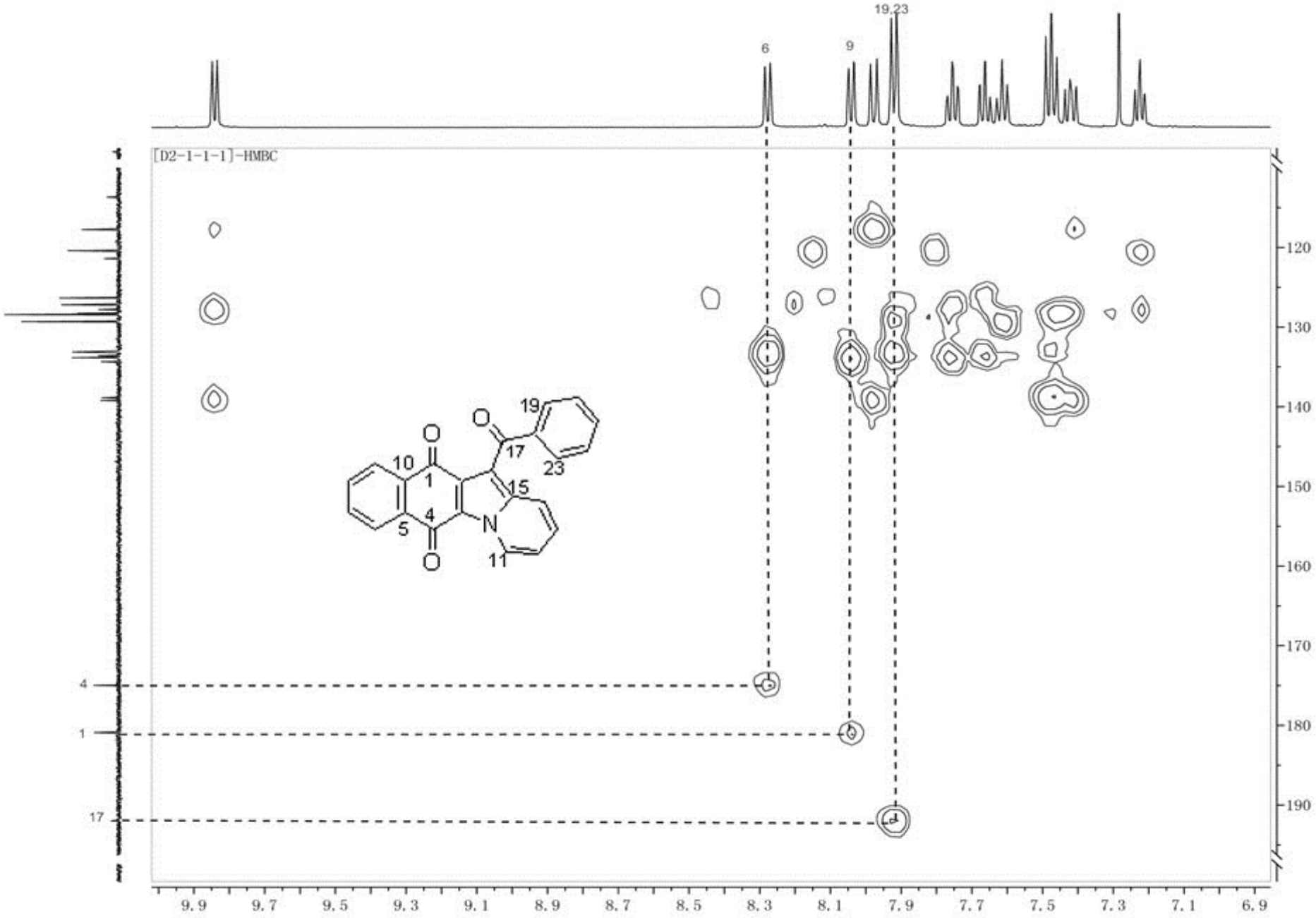

[02-1-1-1]-HSQC
11
6
9
19,23
7
8
21
20,22
13
6
9
11
13
20,22
19,23
21
8
7
O
O
O
19
17
23
10
1
15
4
5
N
11
125
126
127
128
129
130
131
132
133
134
135
9.8 9.7 9.6 9.5 9.4 9.3 9.2 9.1 9.0 8.9 8.8 8.7 8.6 8.5 8.4 8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4

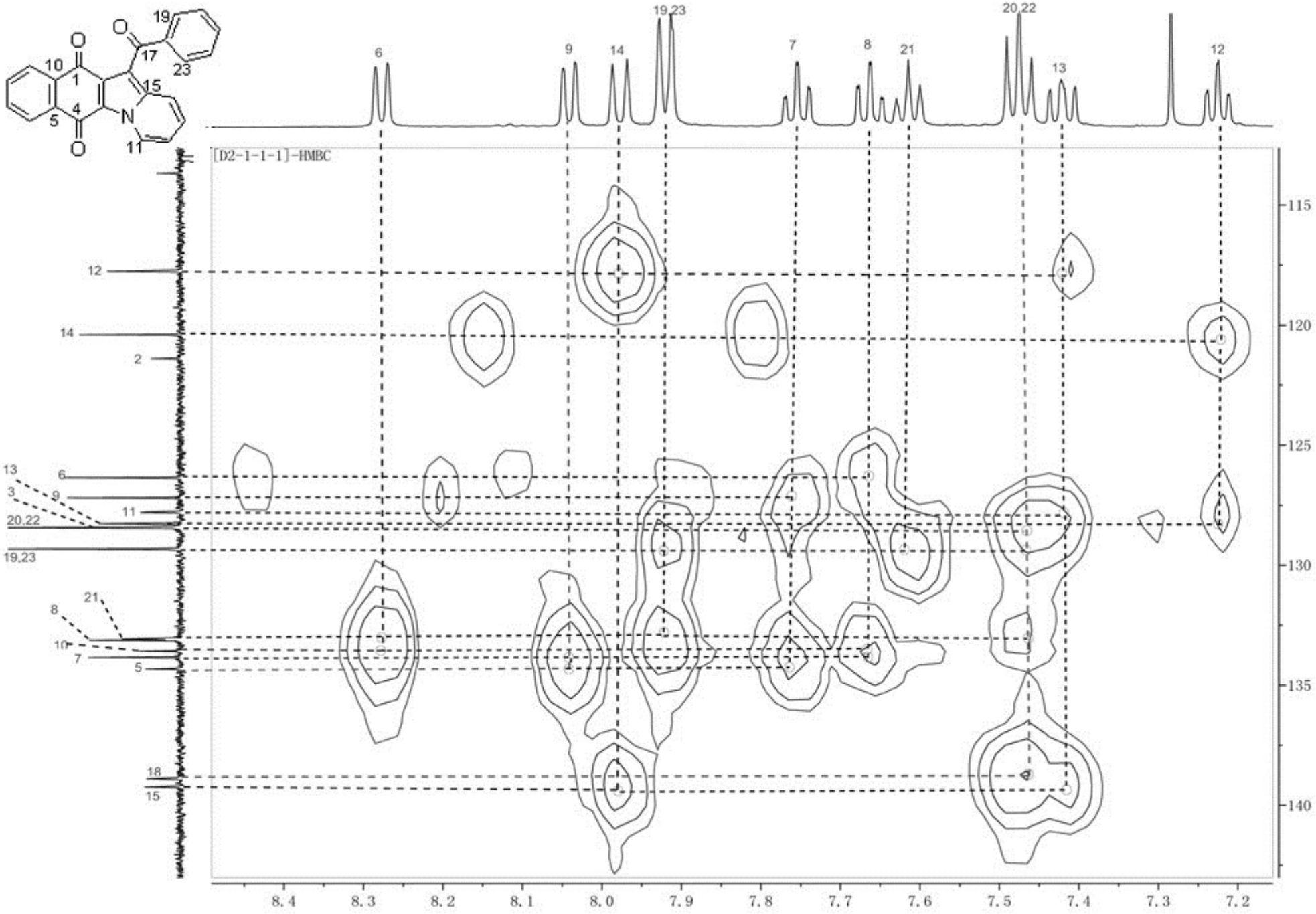
^{1}H-^{1}H COSY of derivative **8**

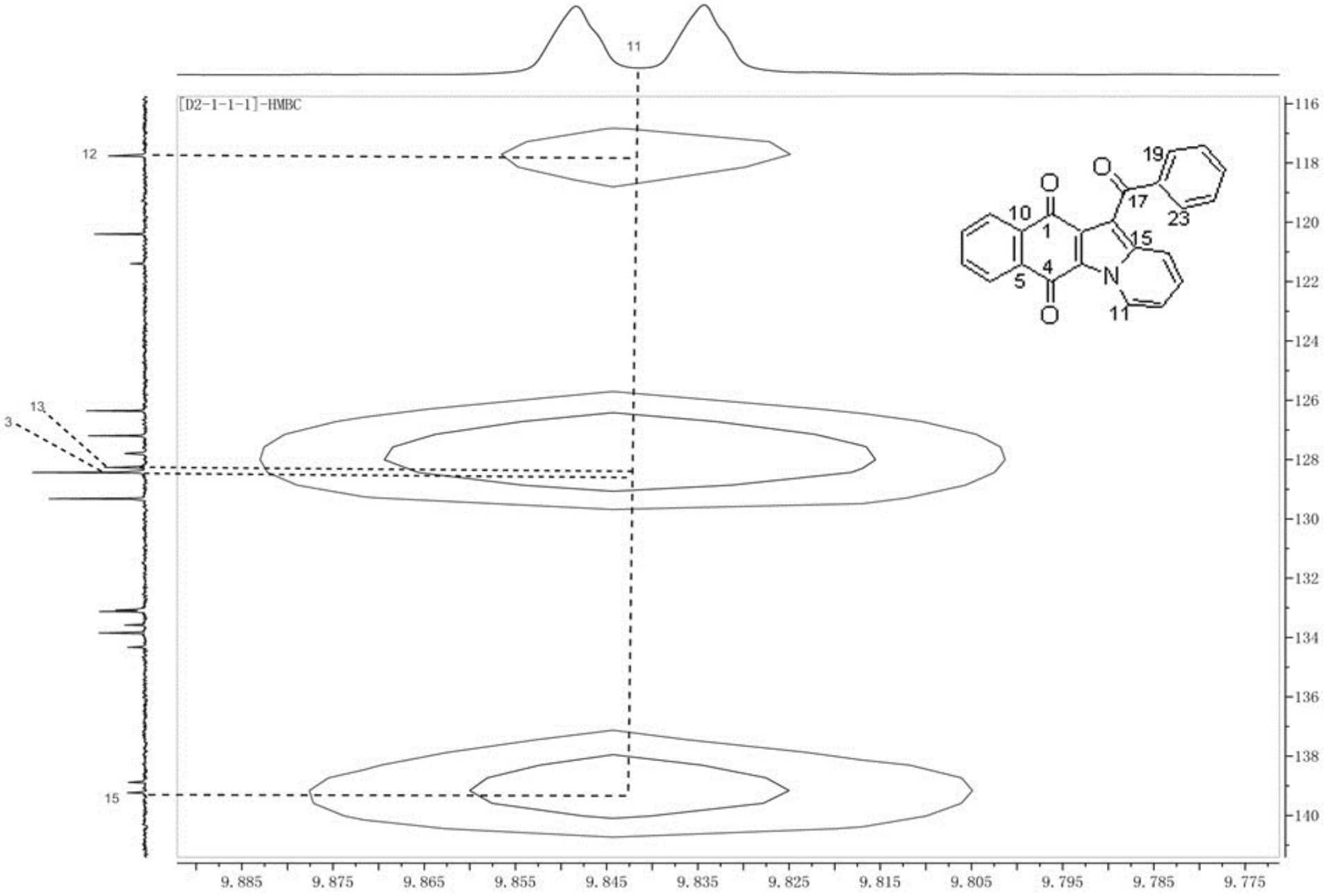



[D2-1-1-1]-COSY
6
9
14
19,23
7
8
21
20,22
13
12
13
20,22
8
7
19,23
14
8.35 8.30 8.25 8.20 8.15 8.10 8.05 8.00 7.95 7.90 7.85 7.80 7.75 7.70 7.65 7.60 7.55 7.50 7.45 7.40 7.35 7.30 7.25 7.20
7.0 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.9 8.0 8.1 8.2 8.3 8.4 8.5
O
19
17
23
10
1
15
5
4
N
11
O

HMBC of derivative **8**

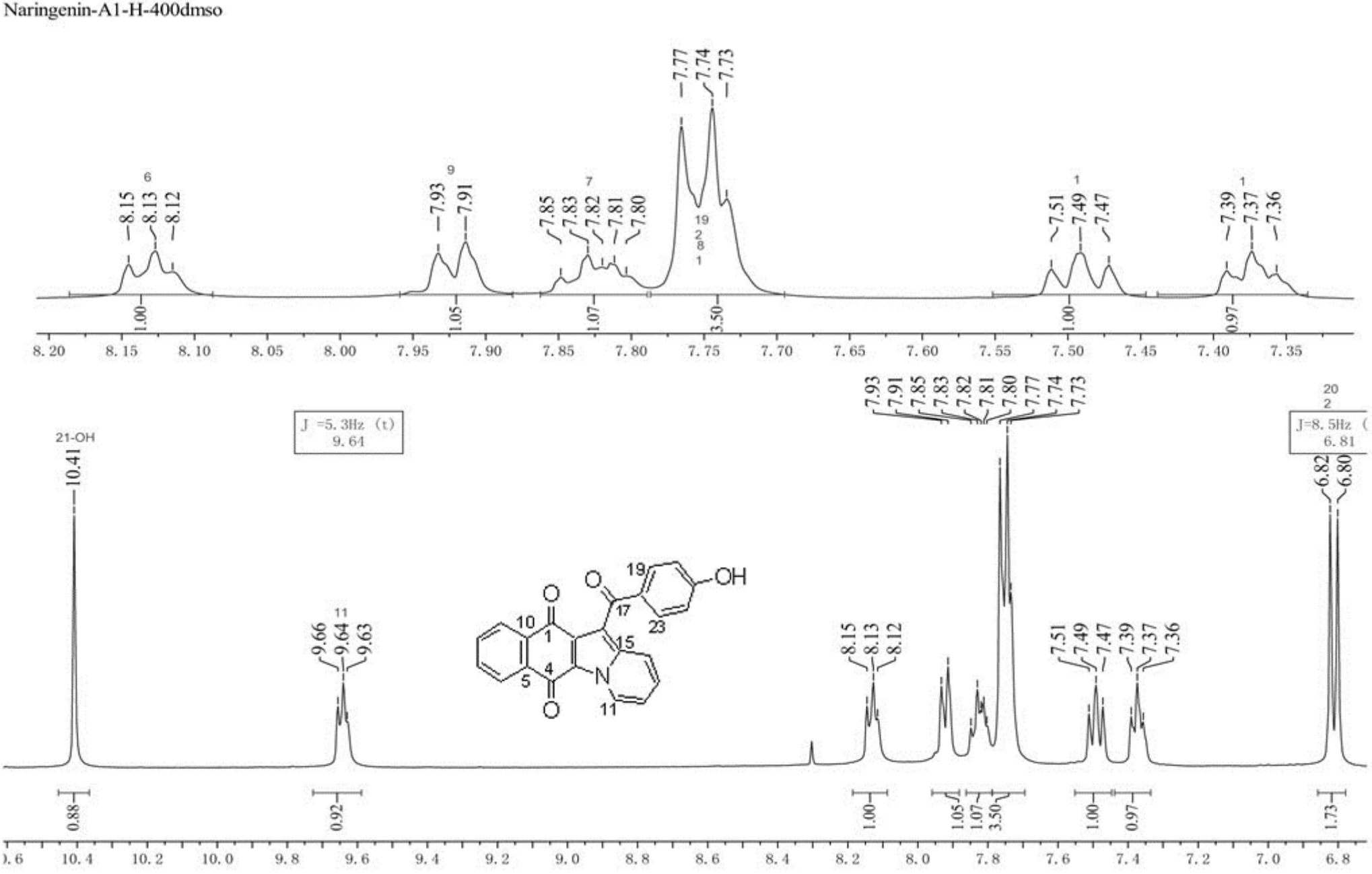



[D2-1-1-1]-HMBC
6
9
14
19,23
7
8
21
20,22
13
12
12
14
2
13
6
3
9
11
20.22
19,23
21
8
10
7
5
18
15
115
120
125
130
135
140
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2

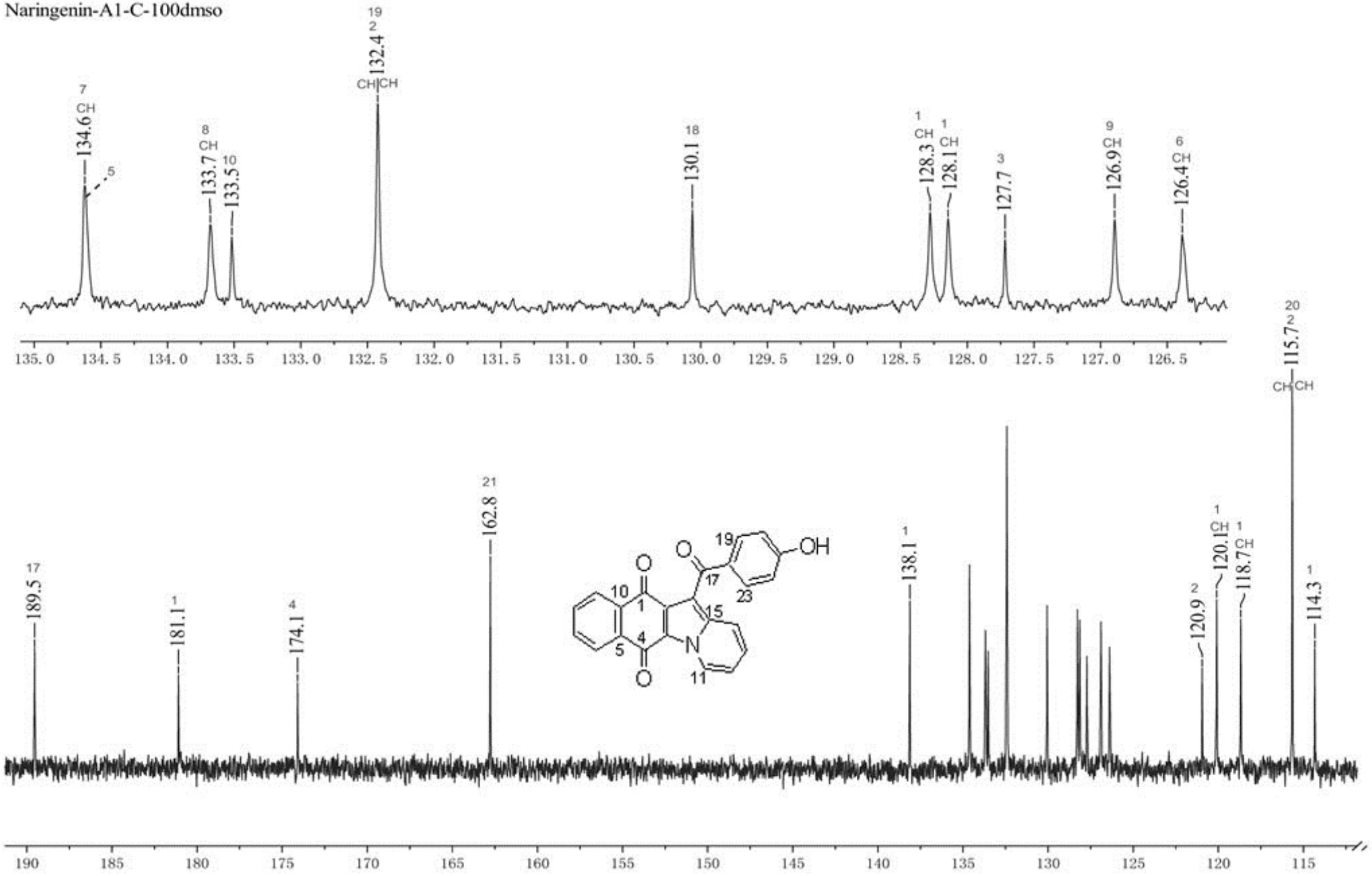

[D2-1-1-1]-HMBC
11
12
13
3
15
116
118
120
122
124
126
128
130
132
134
136
138
140
9.885
9.875
9.865
9.855
9.845
9.835
9.825
9.815
9.805
9.795
9.785
9.775
O
19
O
17
23
10
1
15
4
5
N
O
11

2.9. NMR spectra of derivative **9**

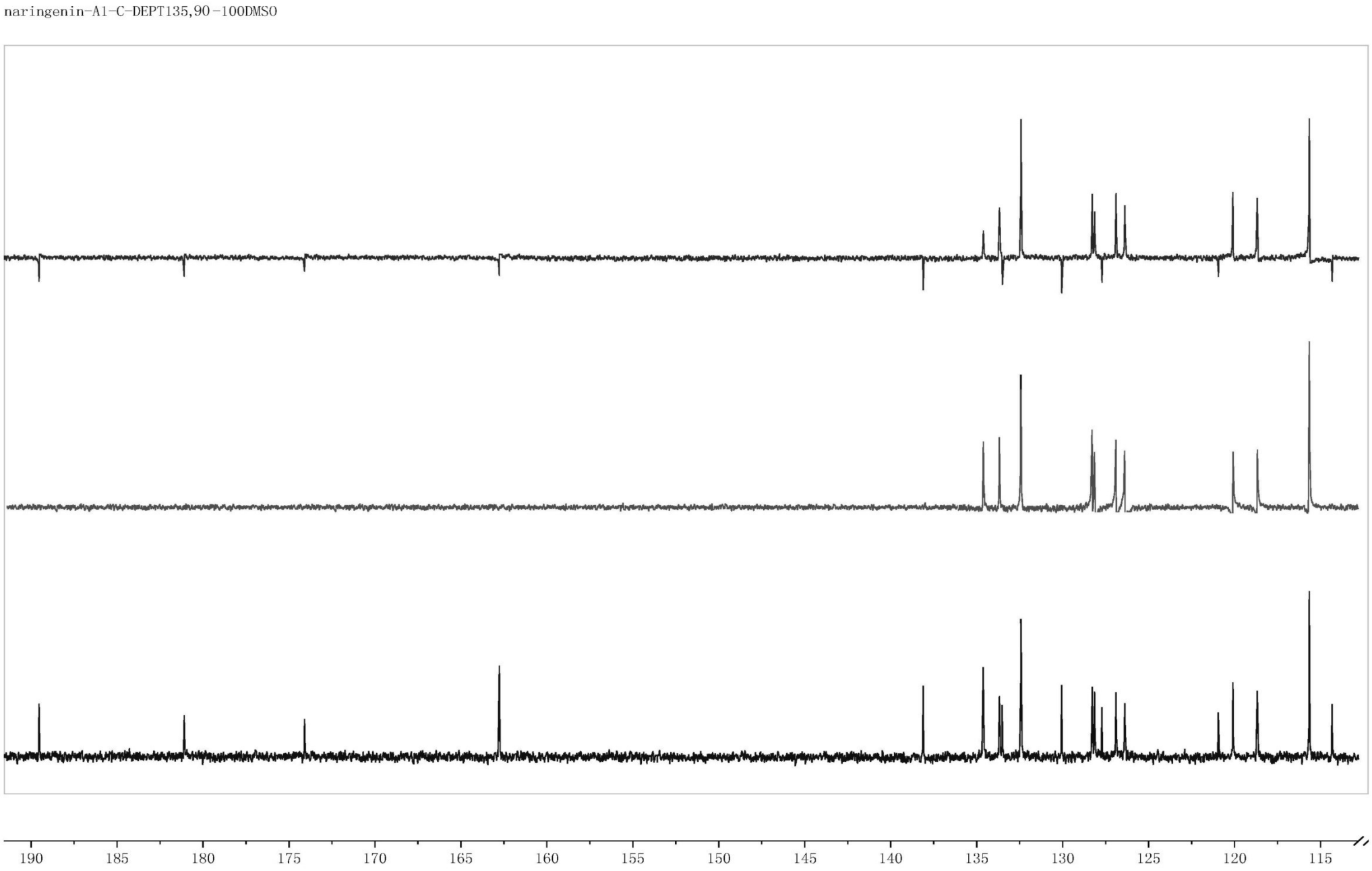
^{1}H-NMR of derivative **9**



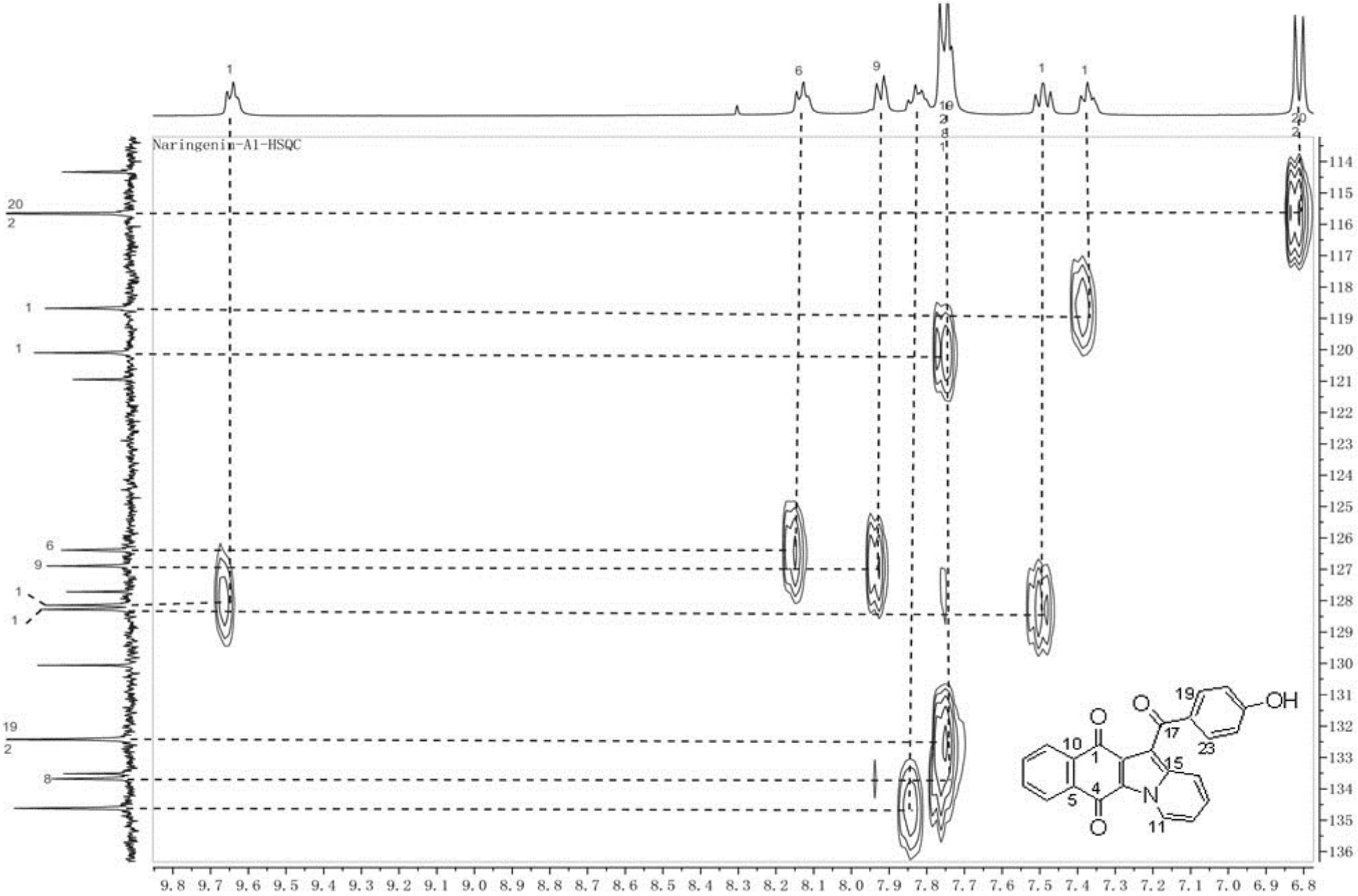
^{13}C-NMR of derivative **9**



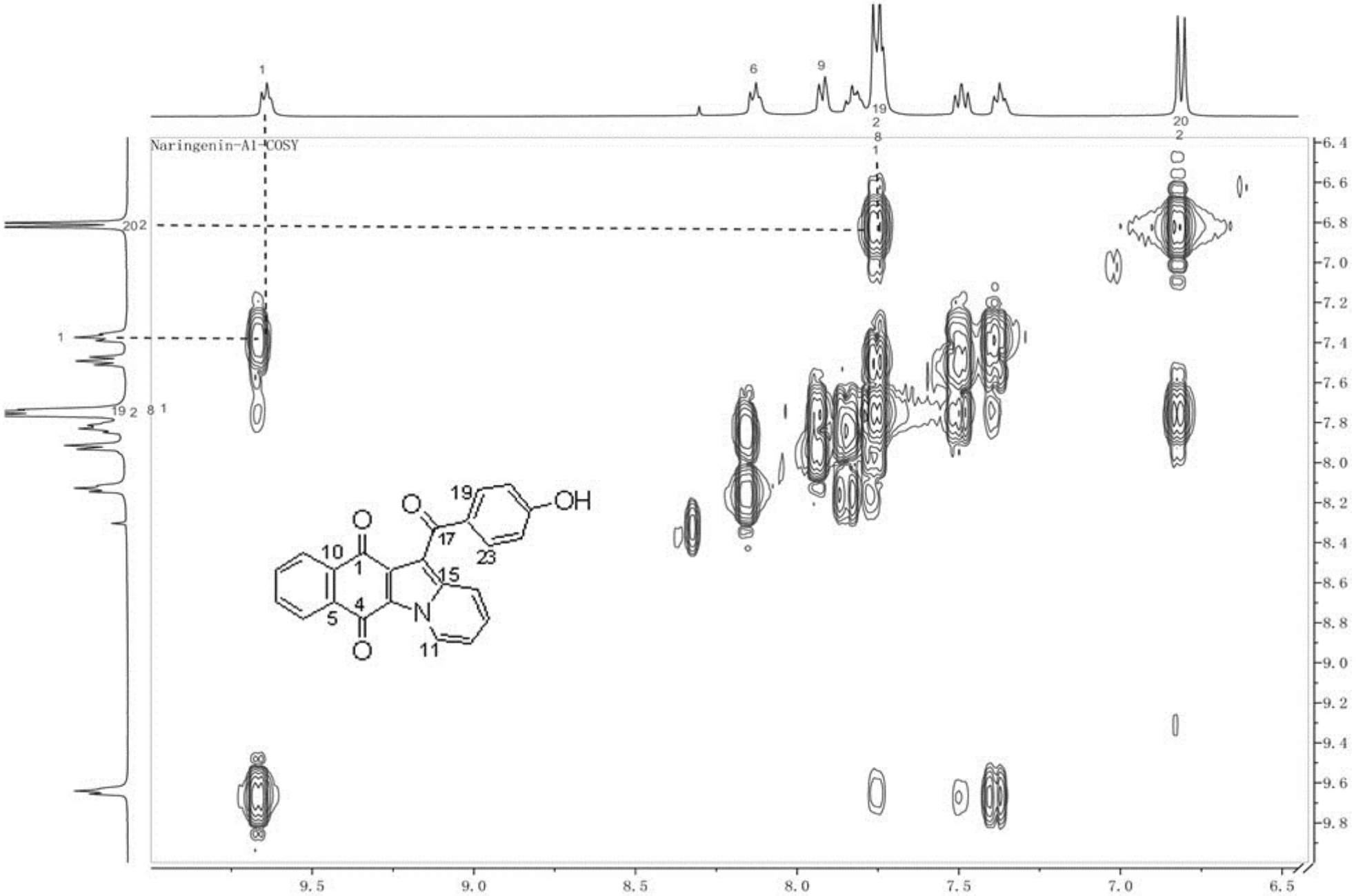
DEPT of derivative **9**

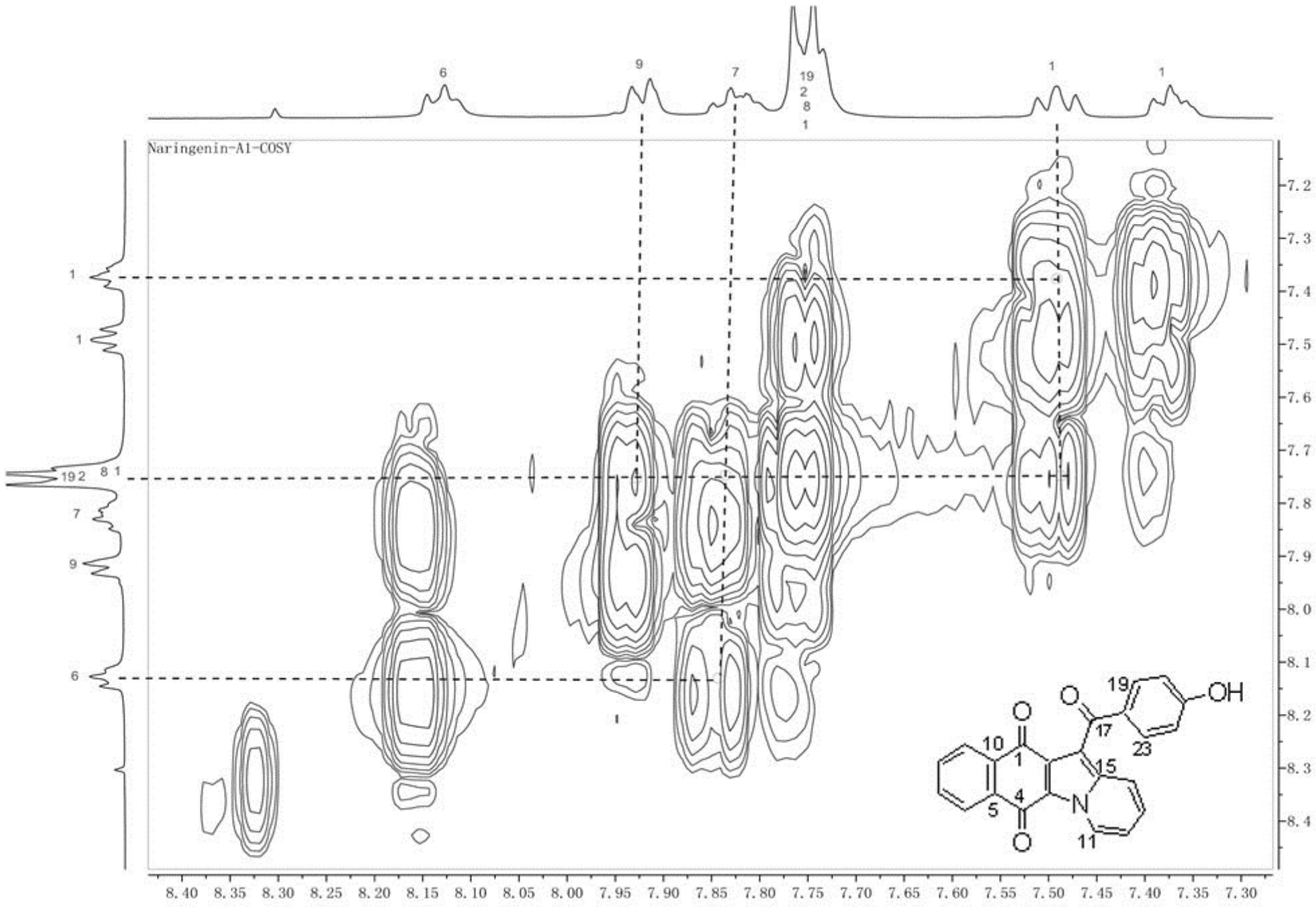


HSQC of derivative **9**

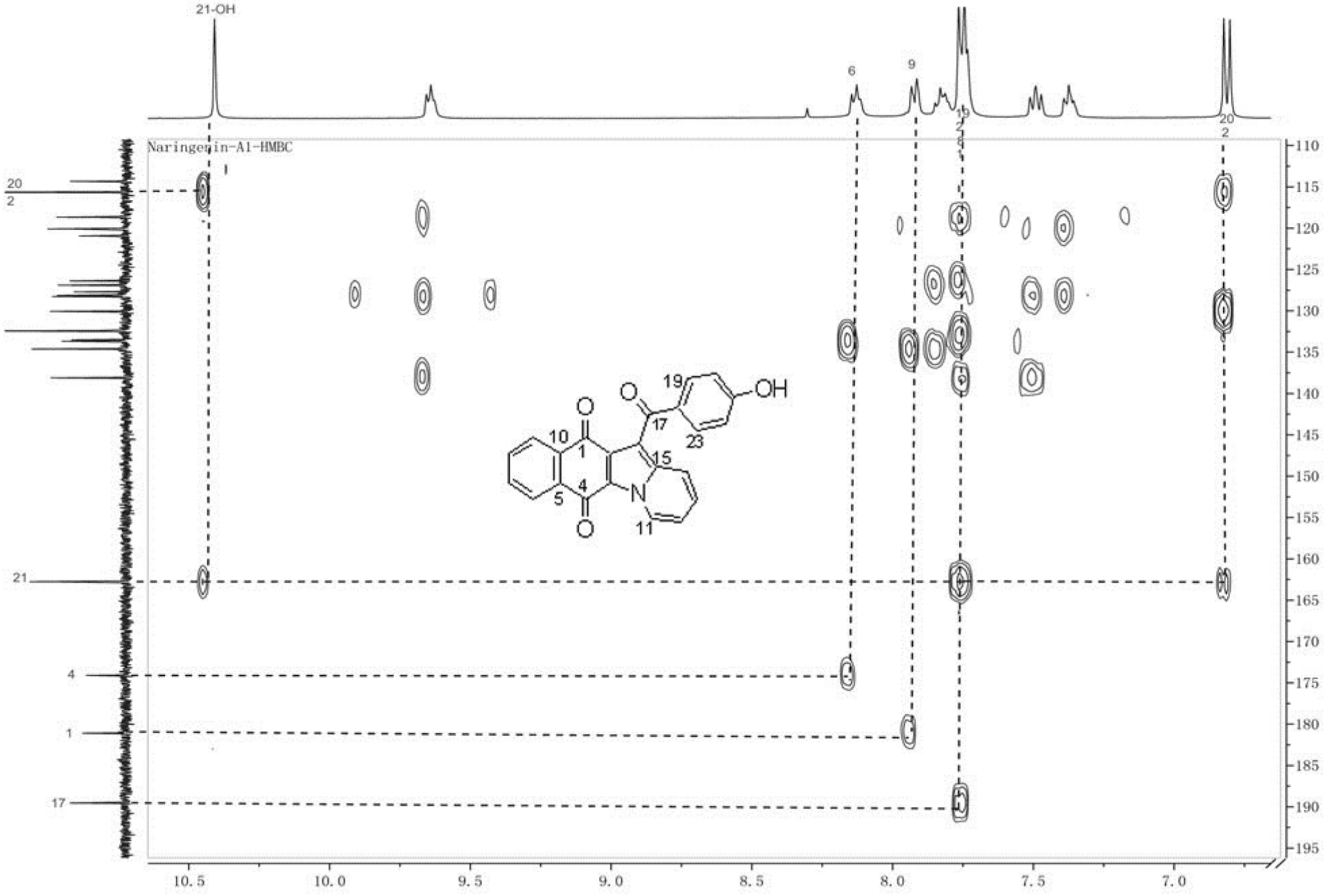


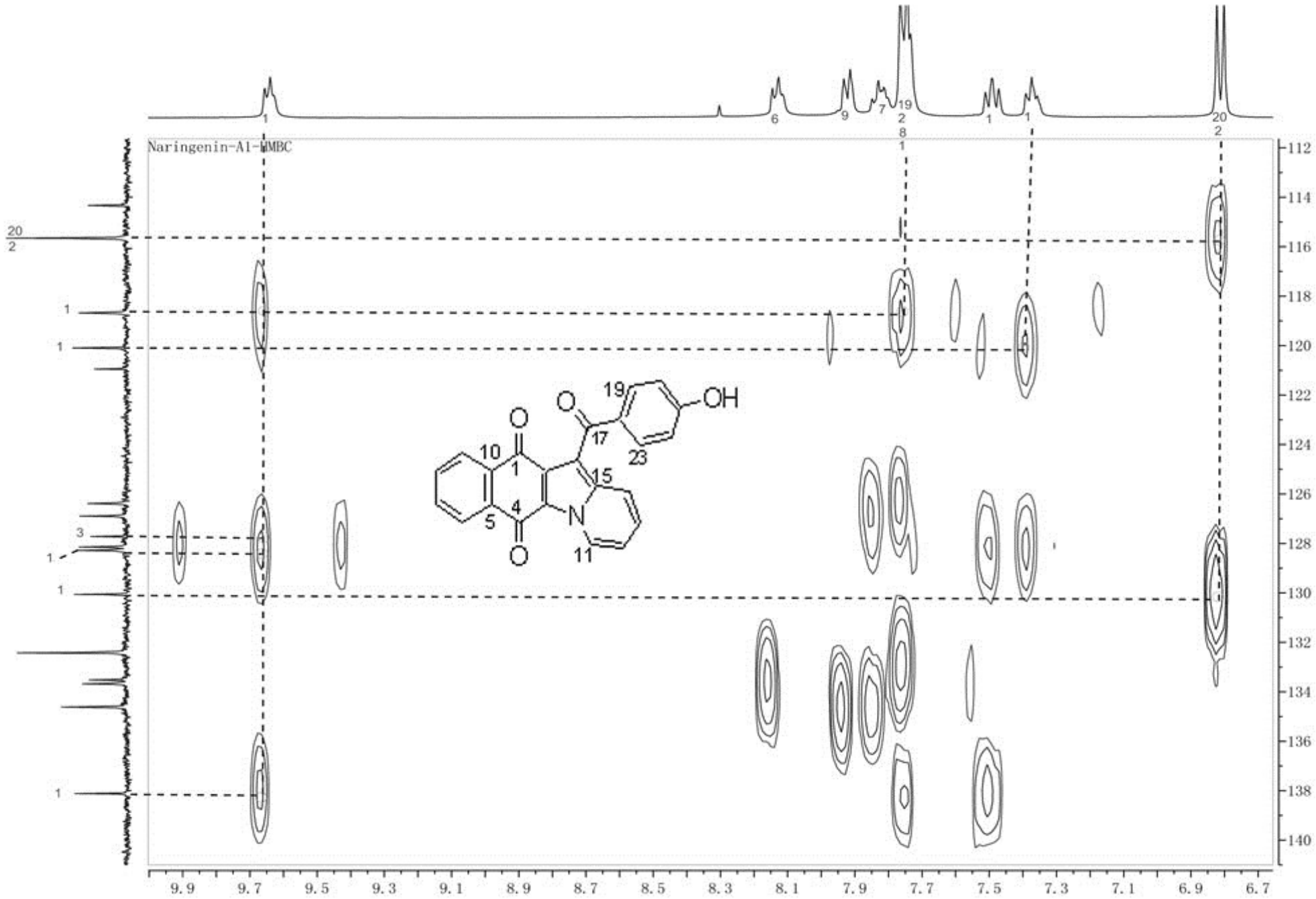
^{1}H-^{1}H COSY of derivative **9**

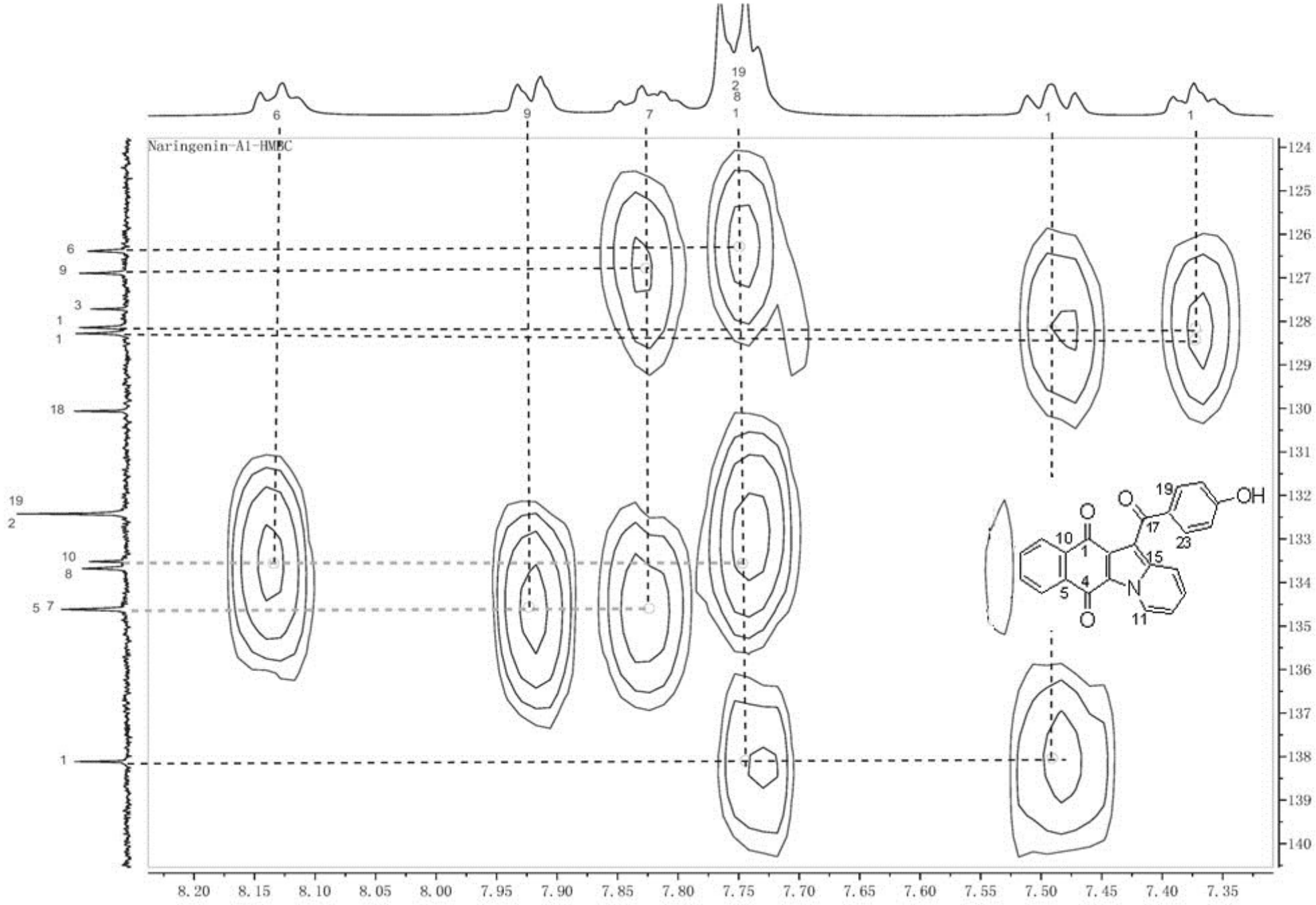



Naringenin-A1-COSY
6
9
7
19
2
8
1
1
1
1
1
1
9
6
8.40 8.35 8.30 8.25 8.20 8.15 8.10 8.05 8.00 7.95 7.90 7.85 7.80 7.75 7.70 7.65 7.60 7.55 7.50 7.45 7.40 7.35 7.30
7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.9 8.0 8.1 8.2 8.3 8.4
OH
O
19
17
23
10
1
15
5
4
N
11
O
O

HMBC of derivative **9**

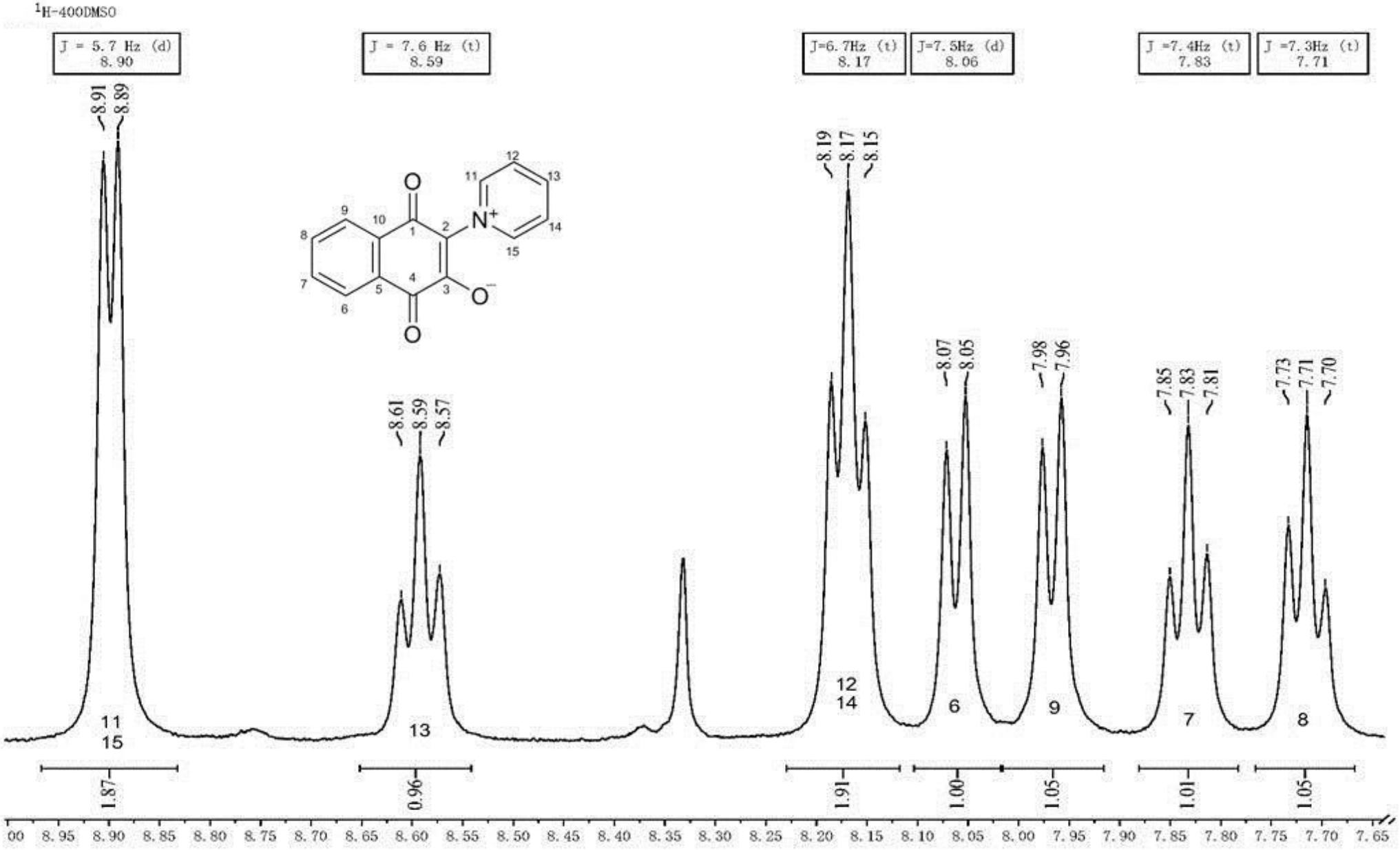



Naringenin-A1-HMBC
OH
O
O
O
19
17
23
10
1
15
4
5
N
11
9.9
9.7
9.5
9.3
9.1
8.9
8.7
8.5
8.3
8.1
7.9
7.7
7.5
7.3
7.1
6.9
6.7
112
114
116
118
120
122
124
126
128
130
132
134
136
138
140

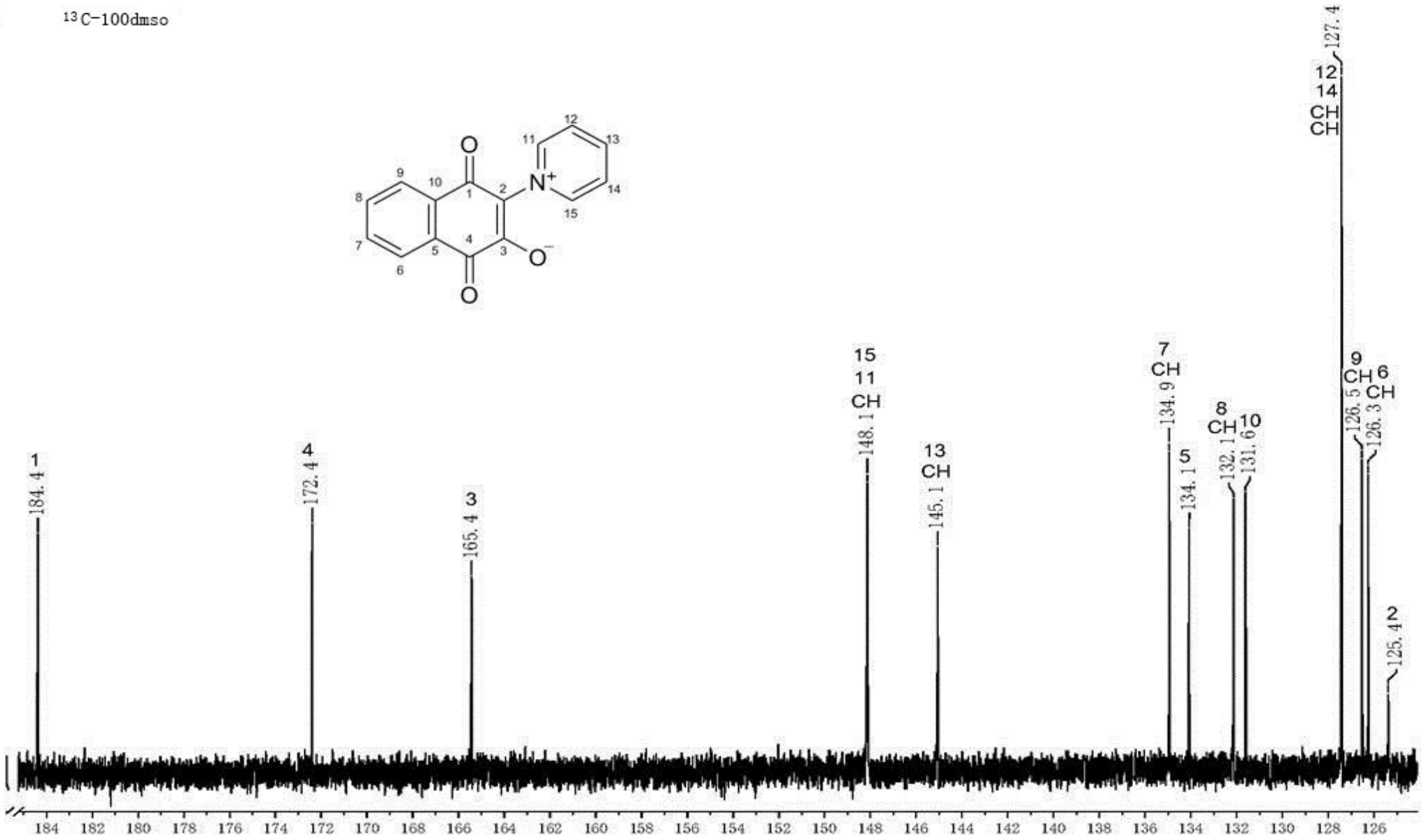

Naringenin-A1-HMBC
6
9
7
19
2
8
1
1
1
6
9
3
1
1
18
19
2
10
8
5 7
1
OH
O
O
O
17
19
23
10
1
15
4
5
N
11
8.20
8.15
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
7.55
7.50
7.45
7.40
7.35
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140

2.10. NMR spectra of derivative **10**

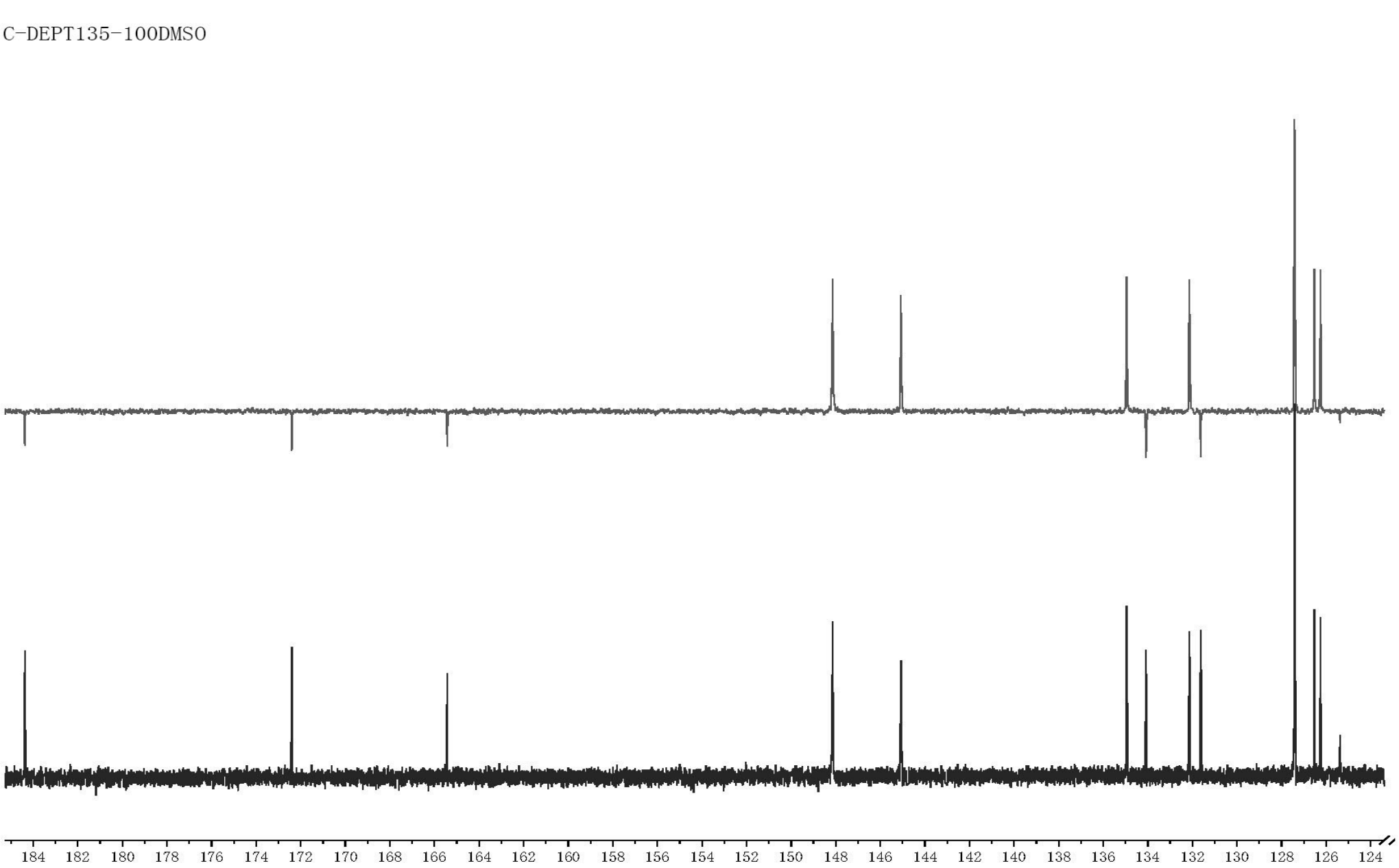
^{1}H-NMR of derivative **10**



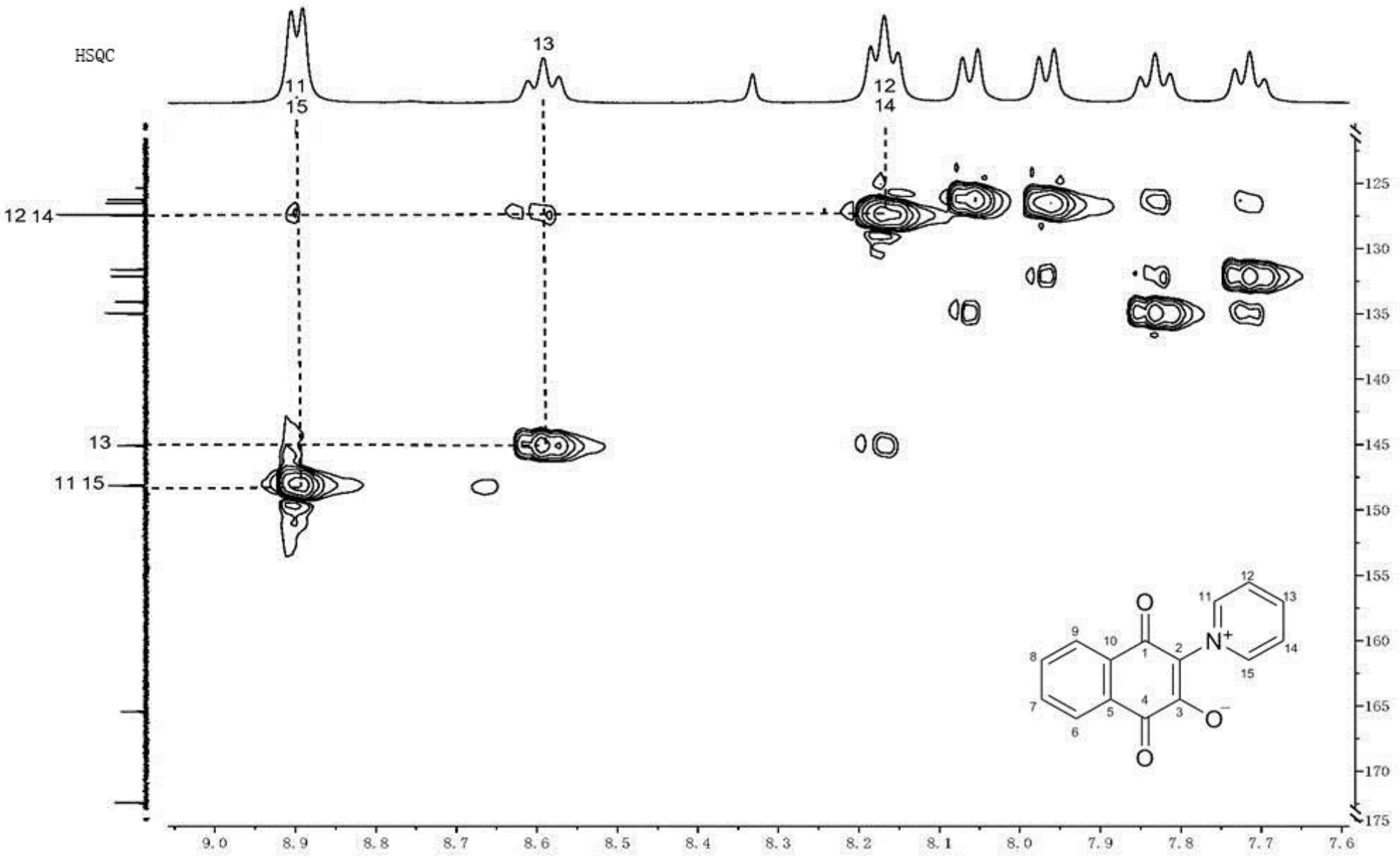
^{13}C-NMR of derivative **10**

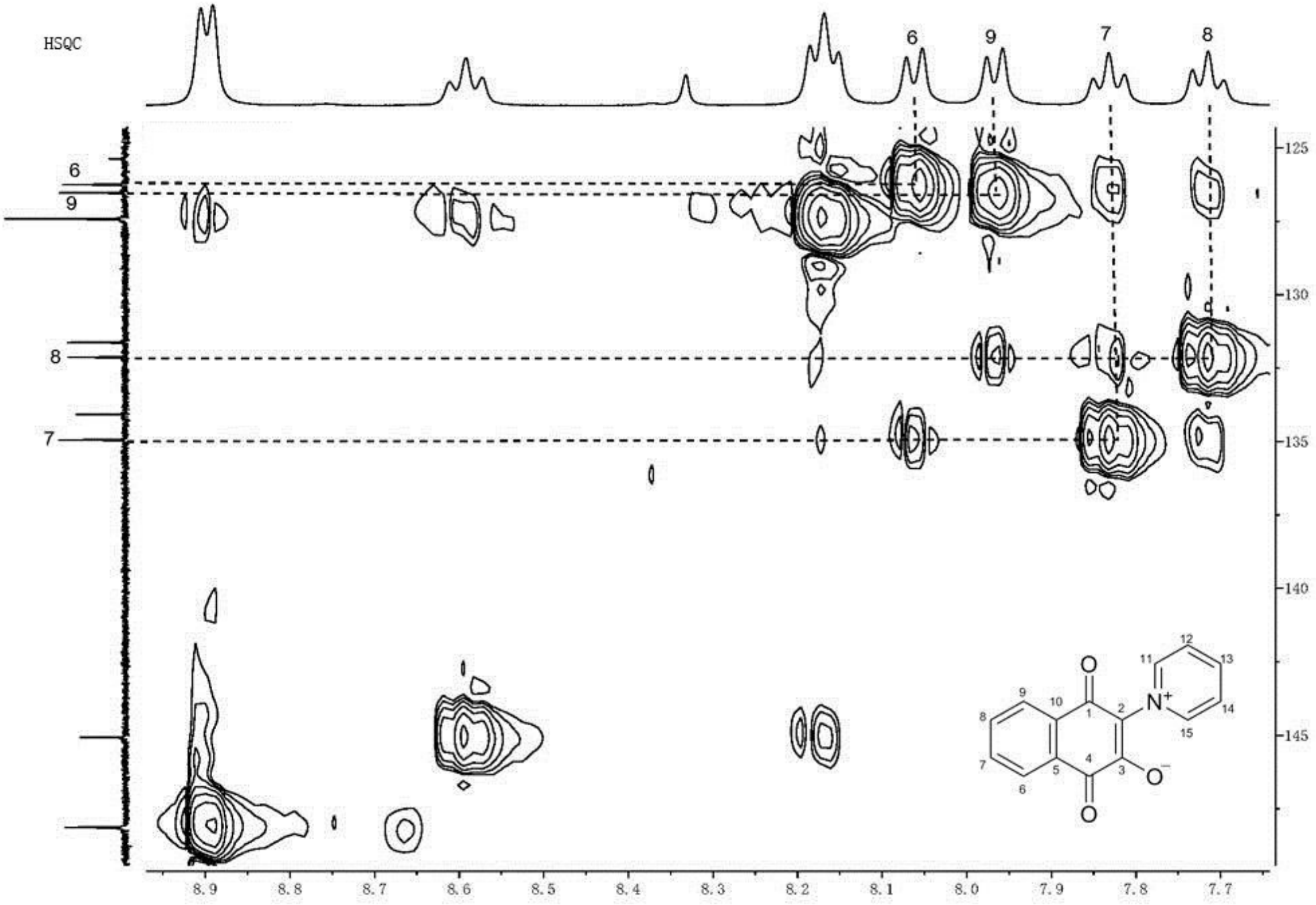


DEPT of derivative **10**

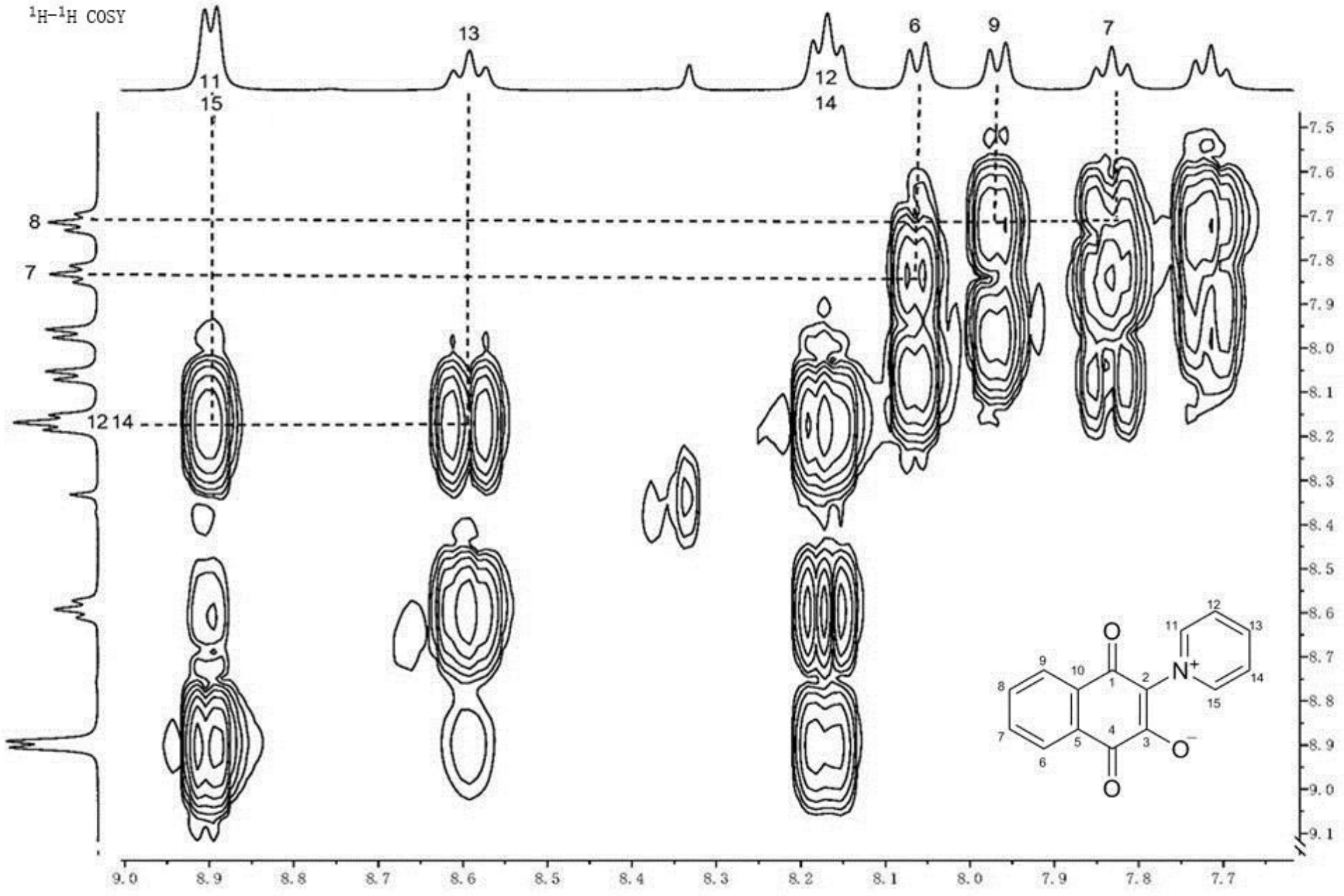


HSQC of derivative **10**

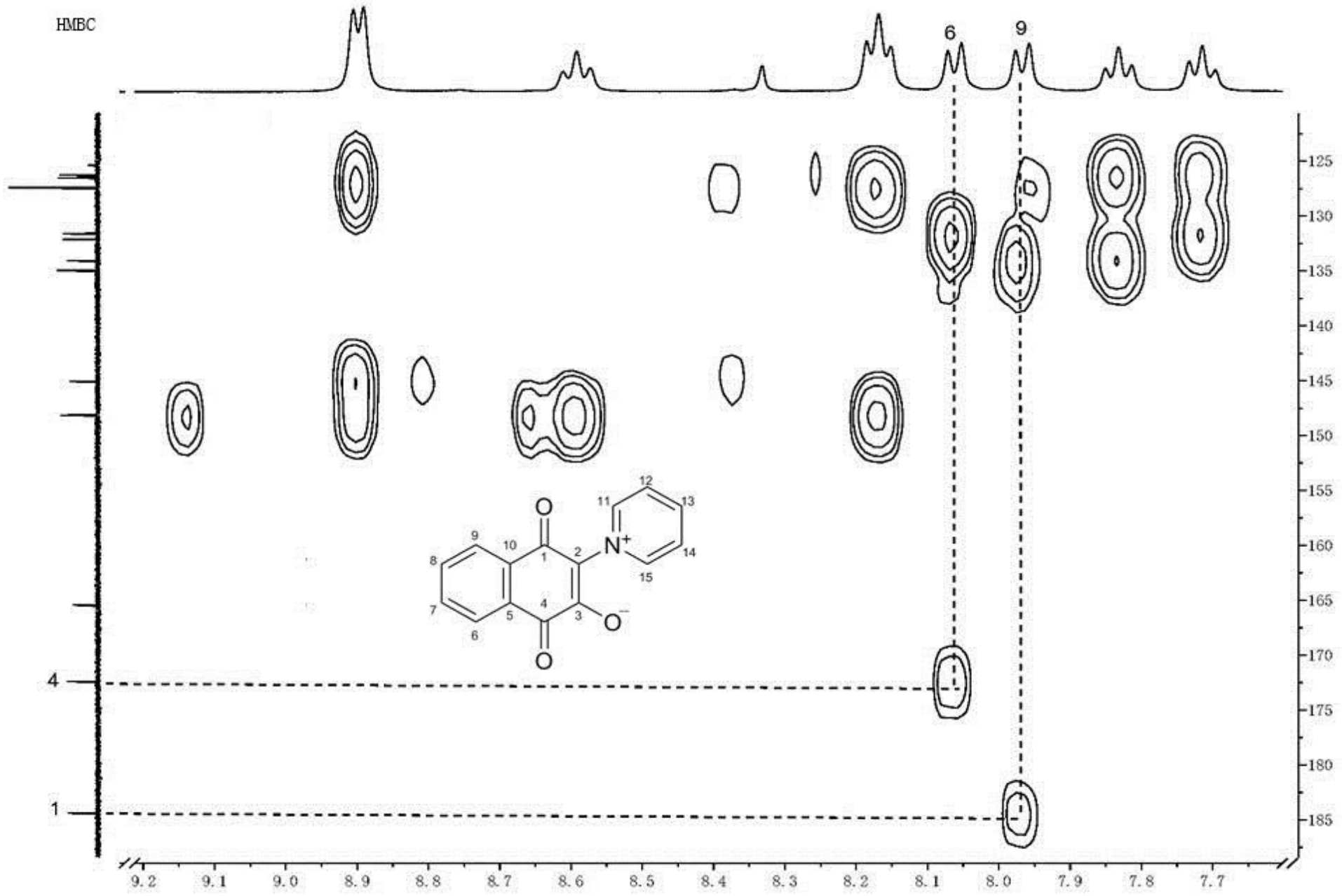


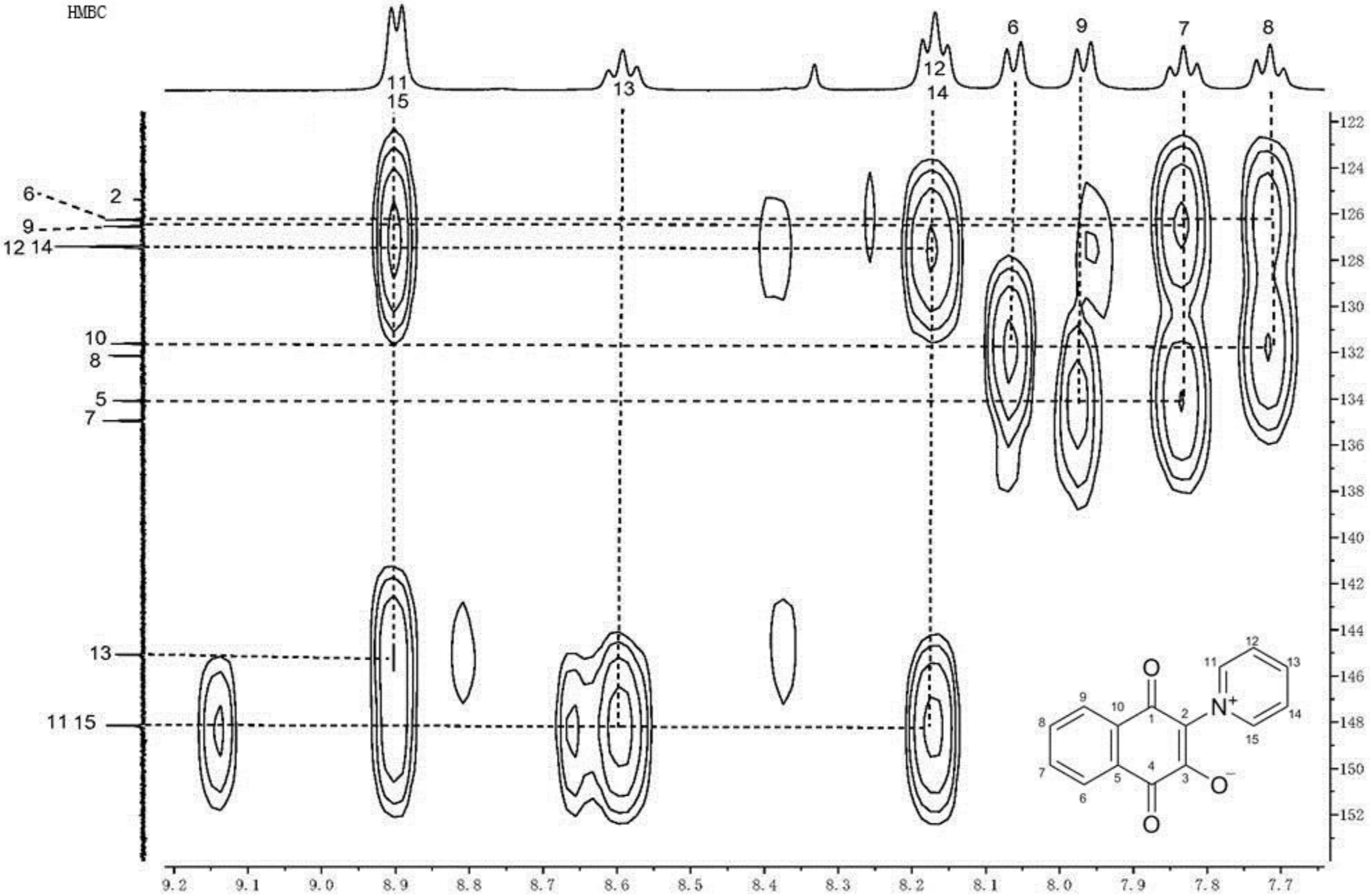

HSQC
6
9
7
8
125
130
135
140
145
8.9
8.8
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7

^{1}H-^{1}H COSY of derivative **10**



HMBC of derivative **10**

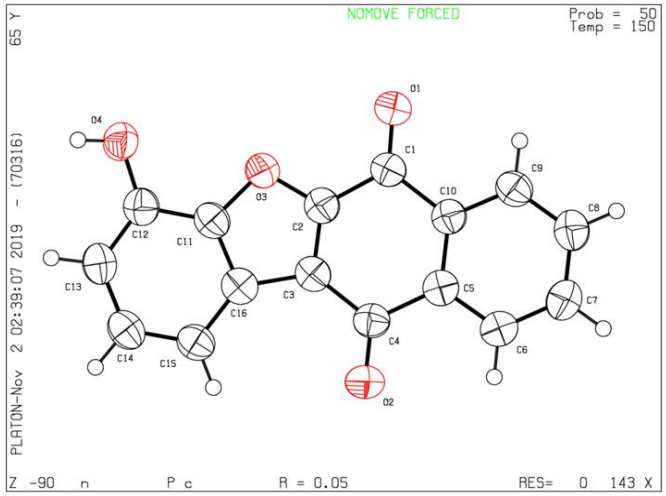


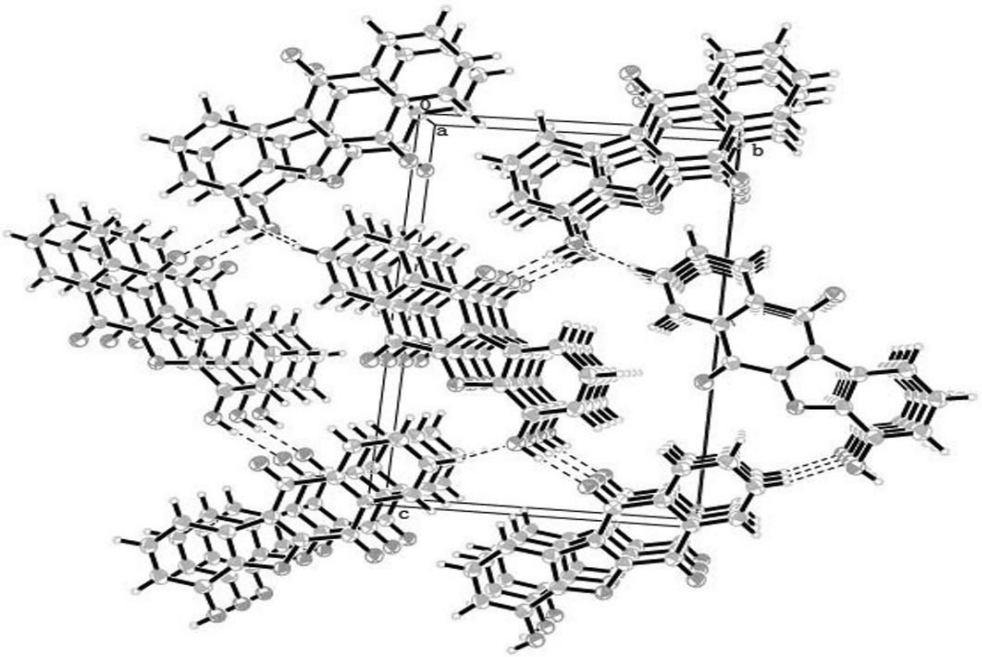

HMBC
11
15
13
12
14
6
9
7
8
6
2
9
12 14
10
8
5
7
13
11 15
122
124
126
128
130
132
134
136
138
140
142
144
146
148
150
152
9.2
9.1
9.0
8.9
8.8
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7

3 Crystal structures of benzonaphthofuroquinone and benzoylnaphthindolizinedione

3.1 Crystal structure of **4** (Our previous work, which was reported in the literature: P. Luo, A.-G. Chittiboyina, W.-G. Pan and W.-X. Wei, *Z. Krist.-New Cryst. St.*, 2020, 235, 565-567.)

Benzonaphthofuroquinone





checkCIF/PLATON report

Bond precision: C-C = 0.0042 A Wavelength=1.54178

Cell: a=3.7133(1) b=9.7214(4) c=15.5765(6)
alpha=90 beta=96.121(2) gamma=90

Temperature: 150 K

	Calculated	Reported
Volume	559.08(3)	559.08(3)
Space group	P c	P c
Hall group	P -2yc	P -2yc
Moiety formula	C16 H8 O4	C16 H8 O4
Sum formula	C16 H8 O4	C16 H8 O4
Mr	264.22	264.22
Dx,g cm-3	1.570	1.570
Z	2	2
Mu (mm-1)	0.951	0.951
F000	272.0	272.0
F000'	272.94	
h,k,lmax	4,12,19	4,12,19
Nref	2302[1157]	1904
Tmin,Tmax	0.843,0.909	
Tmin'	0.684	

Correction method= Not given

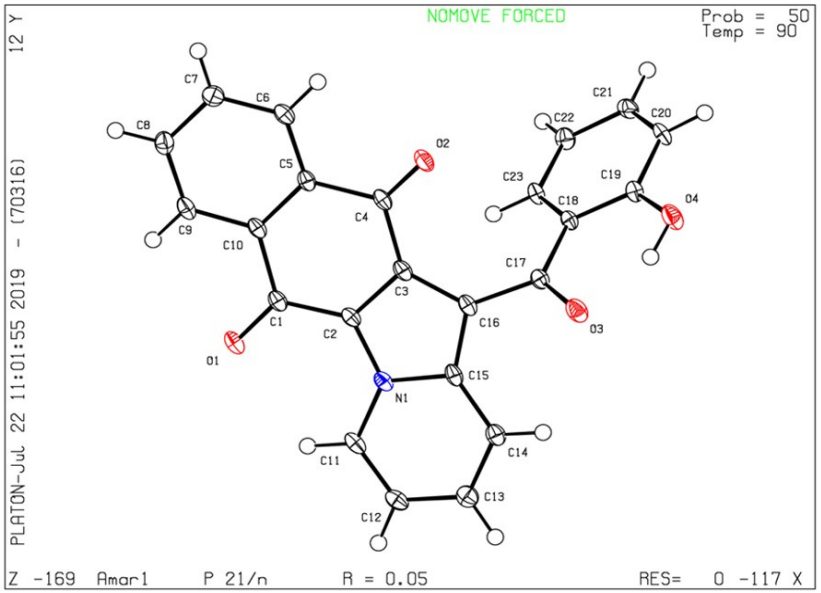
Data completeness= 1.65/0.83 Theta(max)= 74.702

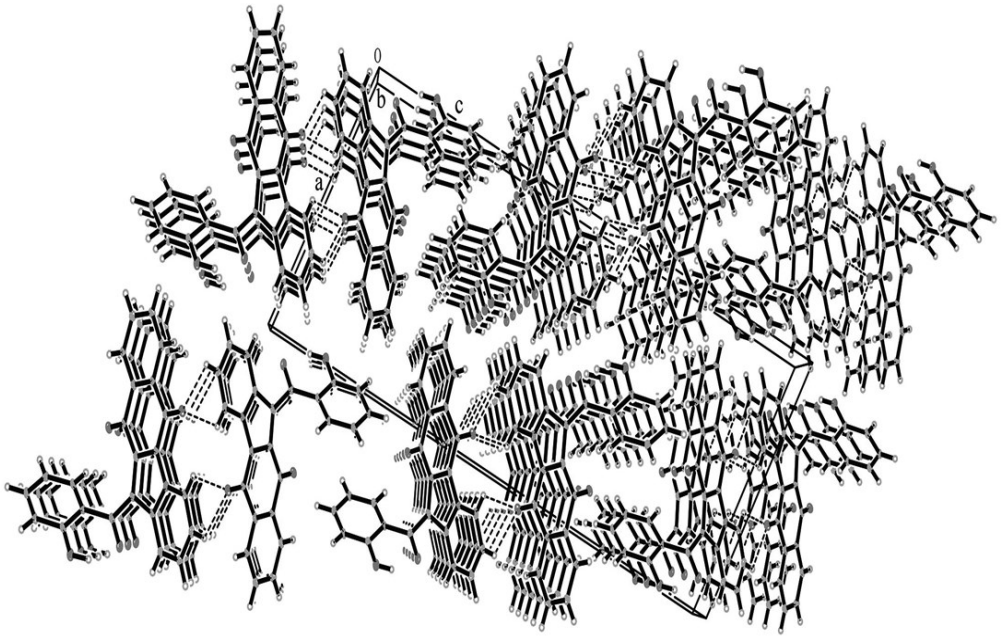
R(reflections)= 0.0506(1848) wR2(reflections)= 0.1274(1904)

S = 1.097 Npar= 182

3.2 Crystal structure of **7** (Our previous work, which was reported in the literature: P. Luo, A.-G. Chittiboyina, M. Wang, I.-A. Khan, W.-G. Pan and W.-X. Wei, *Z. Krist.-New Cryst. St.*, 2020, 235, 105-107.)

Benzoylnaphthindolizinedione





checkCIF/PLATON report

Bond precision: C-C = 0.0020 A Wavelength=0.71073

Cell: a=11.6537(6) b=5.1315(2) c=26.8047(13)
alpha=90 beta=96.266(3) gamma=90

Temperature: 90 K

	Calculated	Reported
Volume	1593.37(13)	1593.37(13)
Space group	P 21/n	P 21/n
Hall group	-P 2yn	-P 2yn
Moiety formula	C23 H13 N O4	C23 H13 N O4
Sum formula	C23 H13 N O4	C23 H13 N O4
Mr	367.34	367.34
Dx,g cm-3	1.531	1.531
Z	4	4
Mu (mm-1)	0.106	0.106
F000	760.0	760.0
F000′	760.39	
h,k,lmax	16,7,38	16,7,37
Nref	4865	4810
Tmin,Tmax	0.979,0.997	0.829,0.997
Tmin′	0.968	

Correction method= # Reported T Limits: Tmin=0.829 Tmax=0.997
AbsCorr = MULTI-SCAN

Data completeness= 0.989 Theta(max)= 30.513

R(reflections)= 0.0531(3317) wR2(reflections)= 0.1432(4810)

S = 1.023 Npar= 256