

# Synthesis of Novel Crown Ether-Squaramides and Their Application as Phase-Transfer Catalysts

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# 1. NMR spectra

NMR spectra of intermediate **C-HSQ**

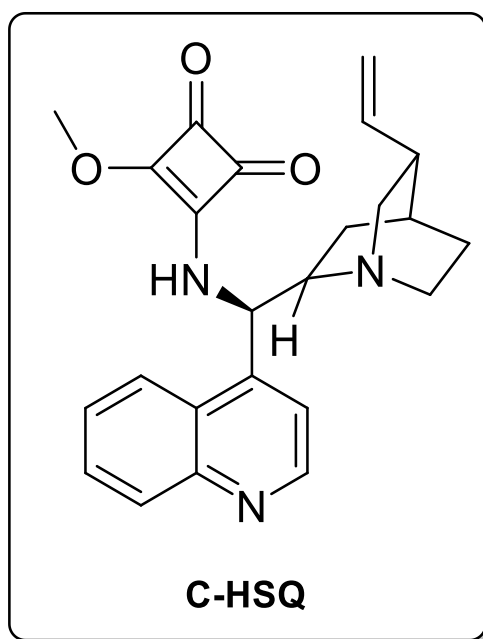


Figure S1. Molecule structure of intermediate **C-HSQ**

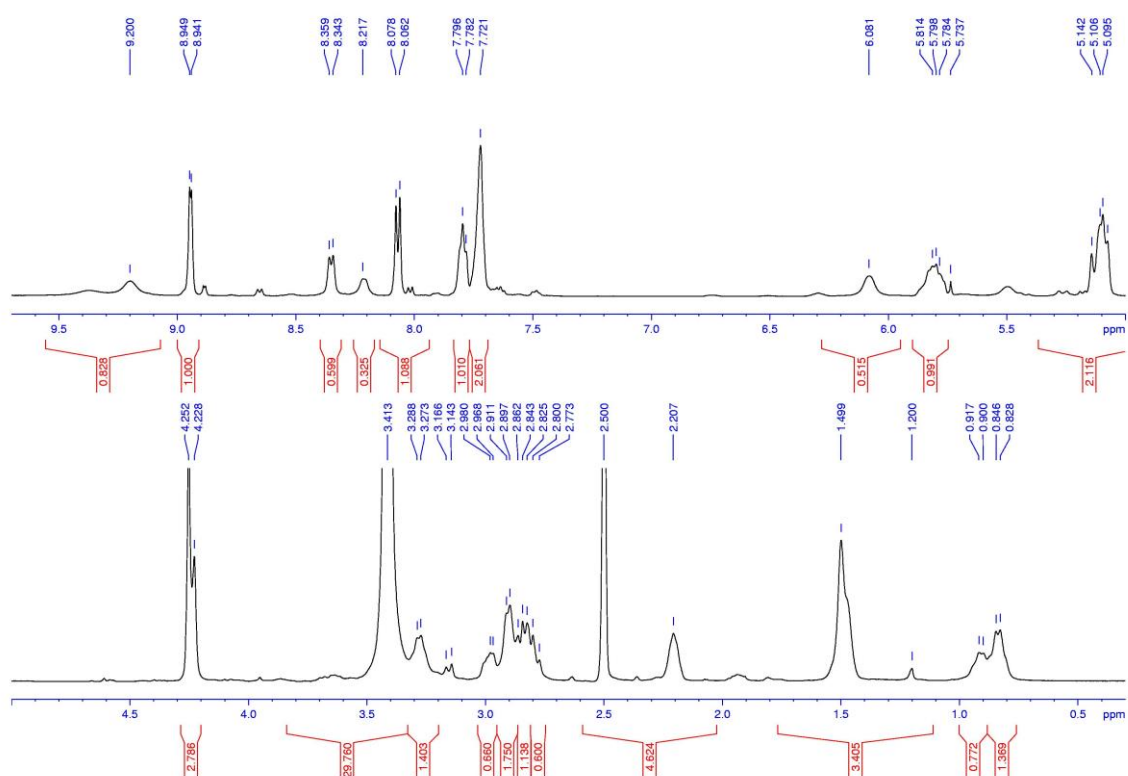
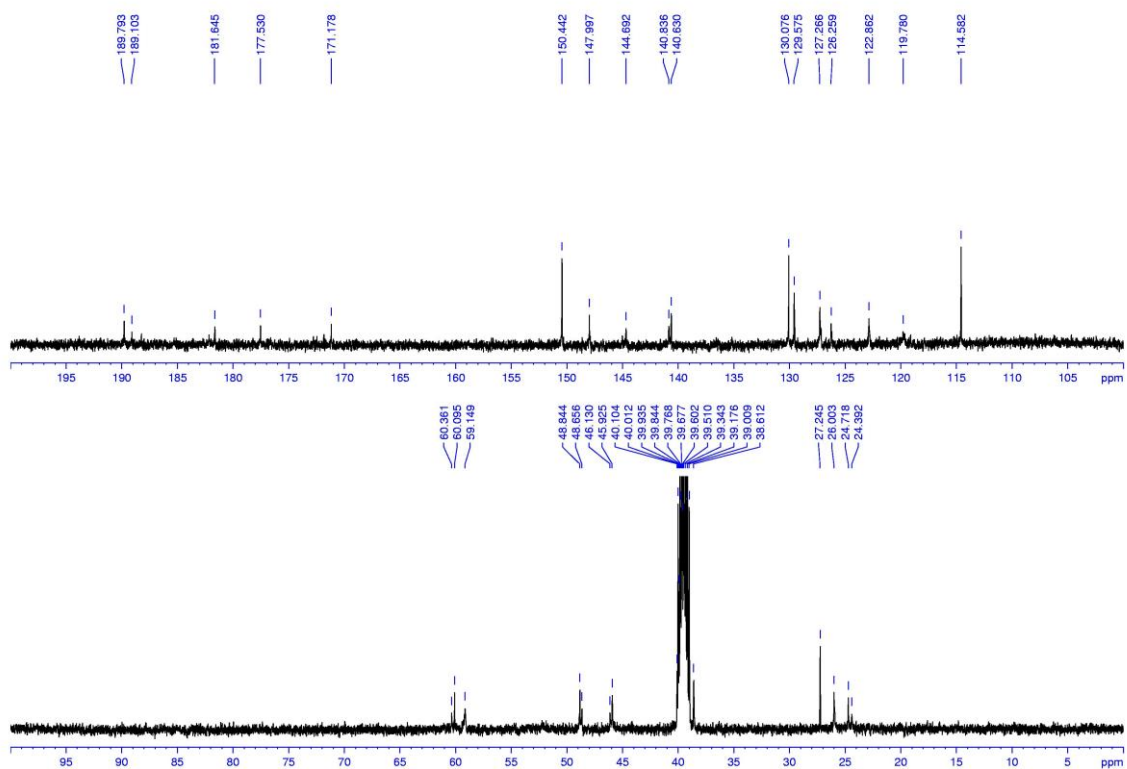
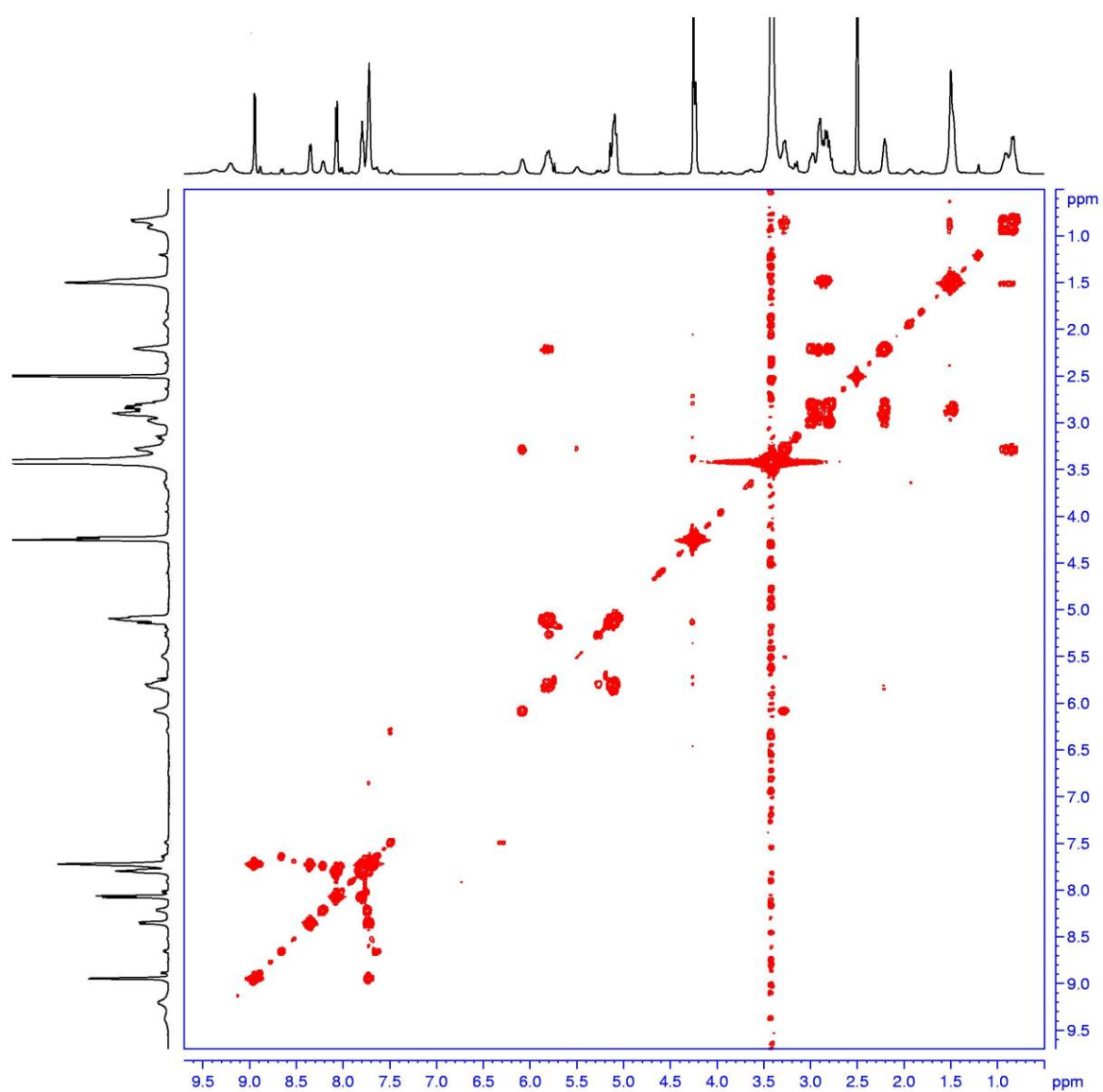


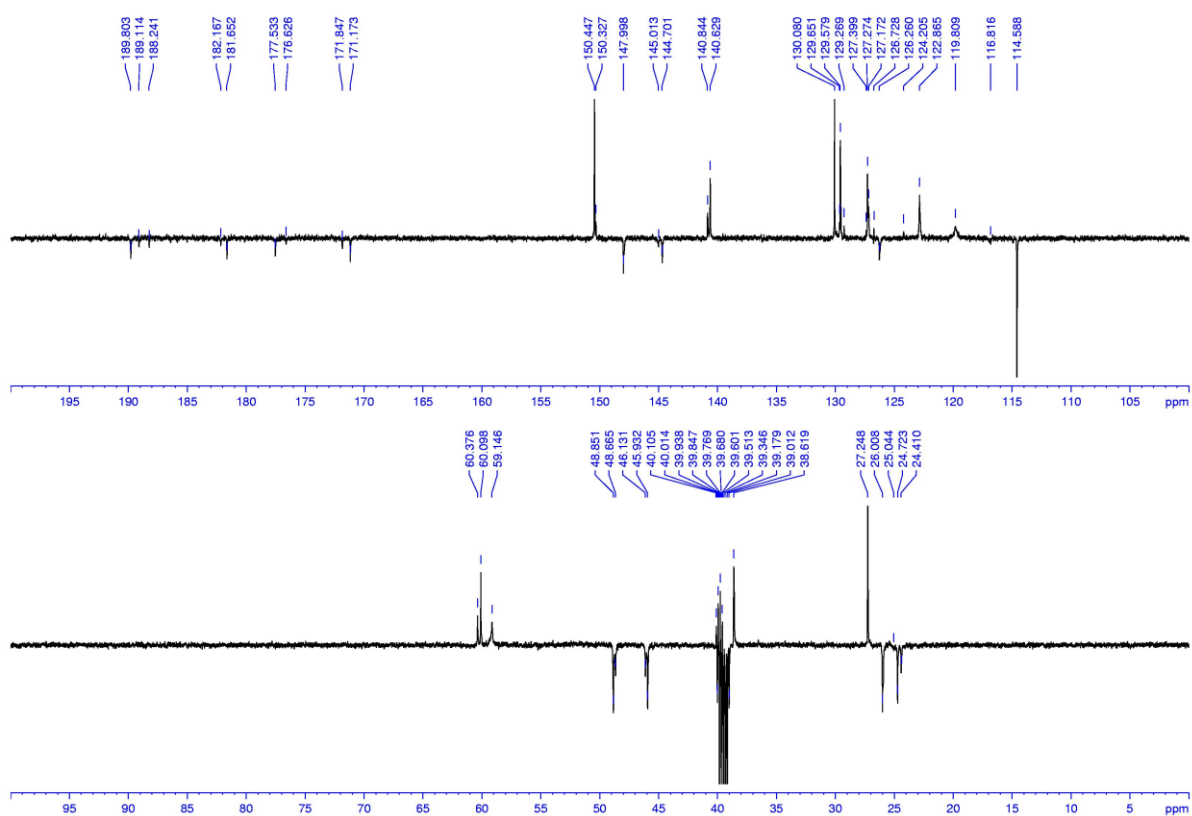
Figure S2. <sup>1</sup>H NMR spectrum of intermediate **C-HSQ** (500.13 MHz, DMSO-d<sub>6</sub>)



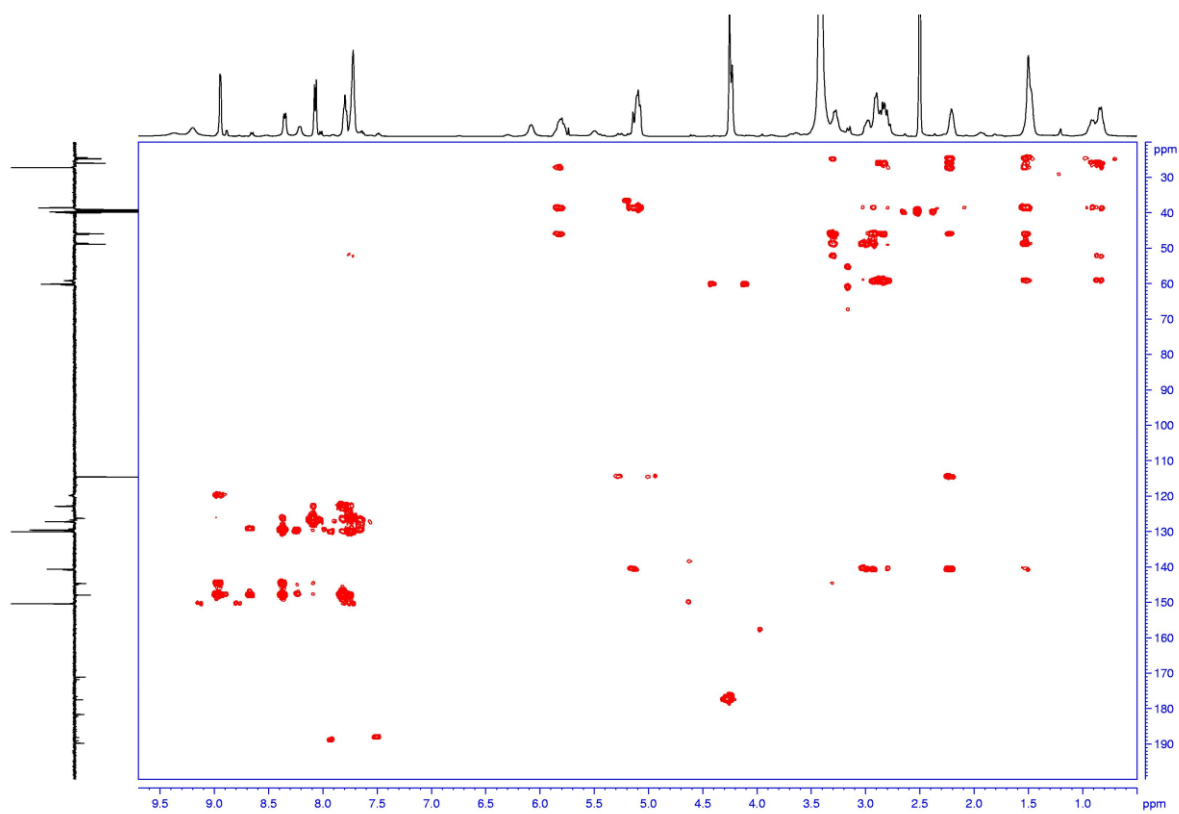
**Figure S3.**  $^{13}\text{C}$  NMR spectrum of intermediate C-HSQ (125.76 MHz, DMSO- $\text{d}_6$ )



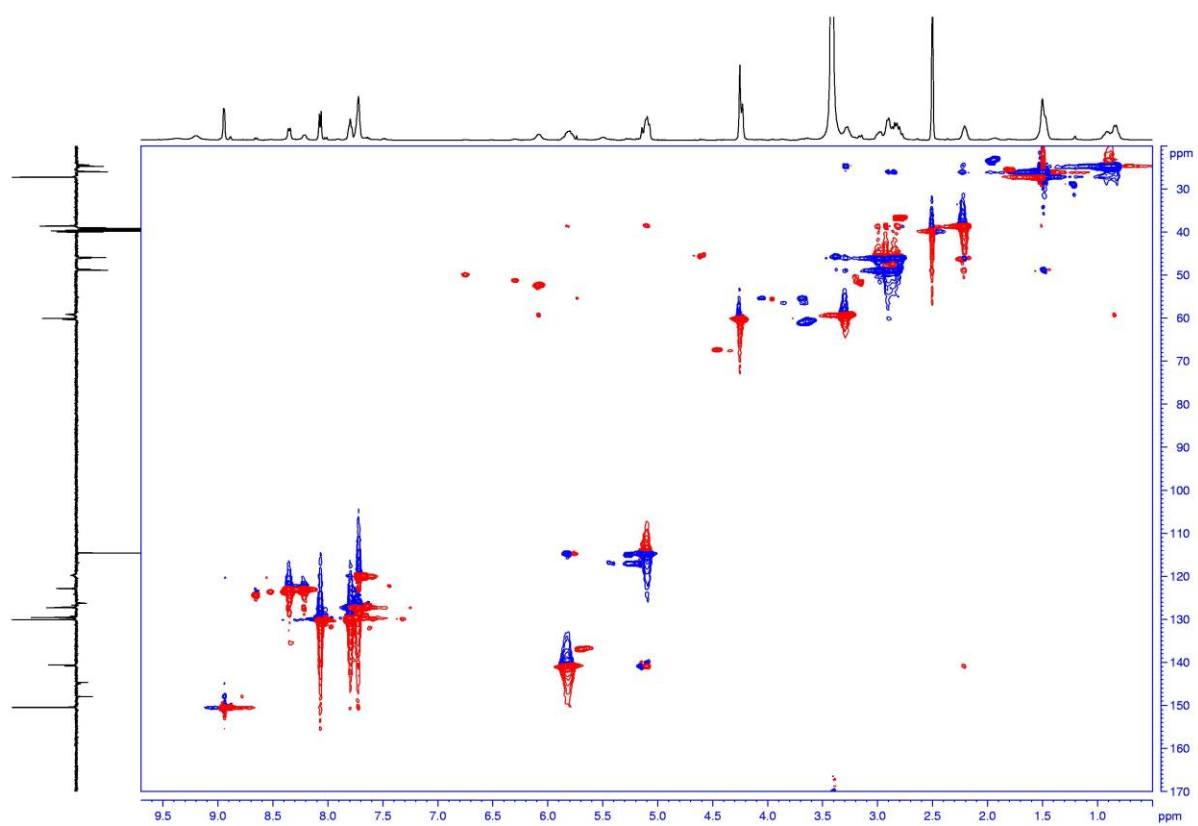
**Figure S4.**  $^1\text{H}$ -gs-COSY NMR spectrum of intermediate **C-HSQ** ( $\text{DMSO-d}_6$ )



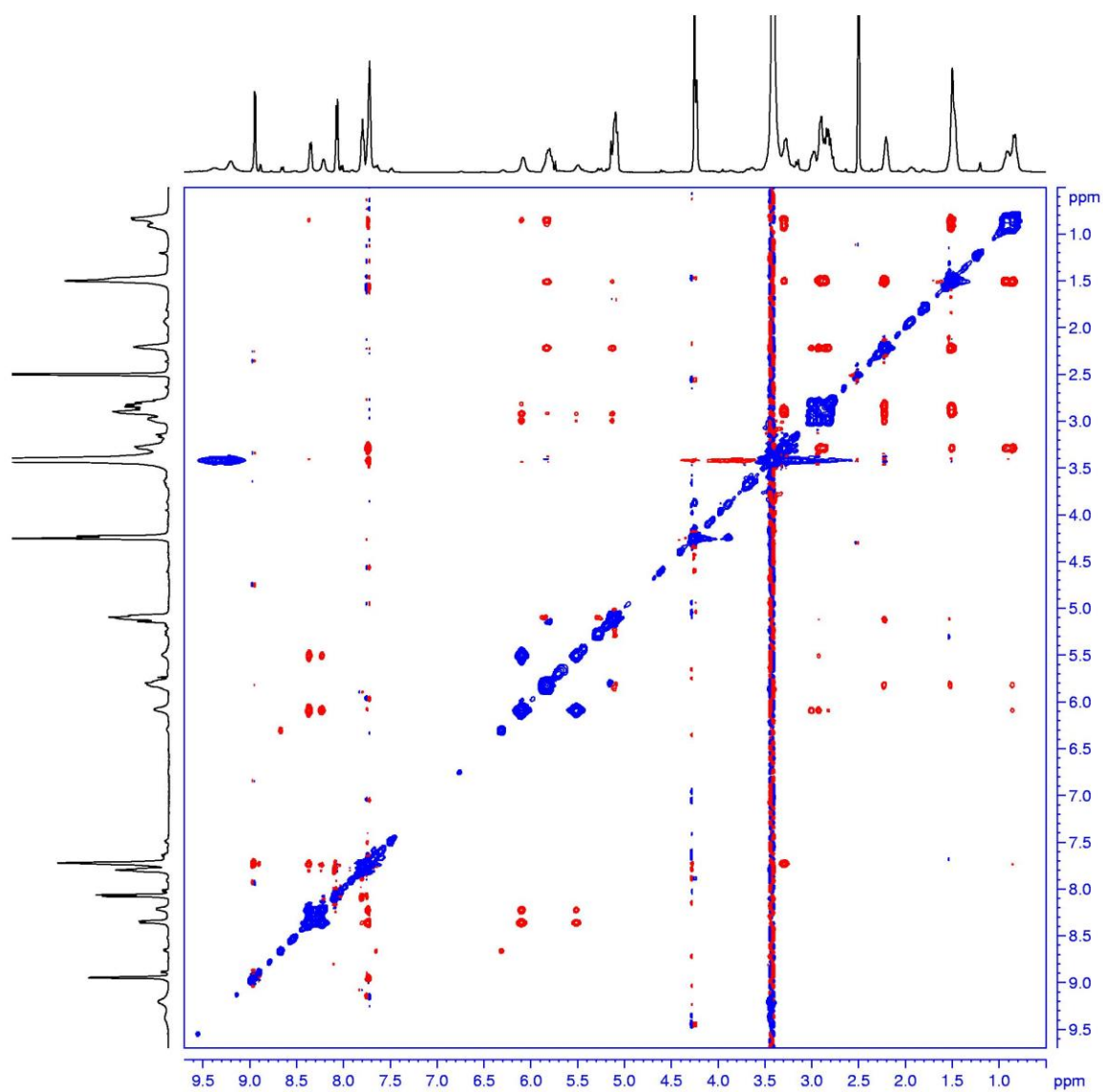
**Figure S5.**  $^{13}\text{C}$  DEPTQ NMR spectrum of intermediate **C-HSQ** ( $\text{DMSO-d}_6$ )



**Figure S6.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HMBC NMR spectrum of intermediate **C-HSQ** ( $\text{DMSO-d}_6$ )

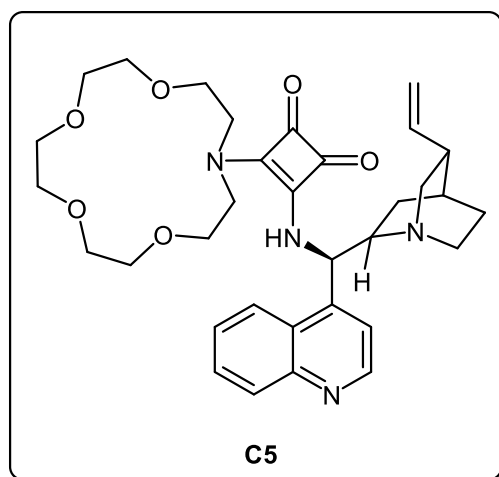


**Figure S7.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HSQC NMR spectrum of intermediate **C-HSQ** ( $\text{DMSO-d}_6$ )

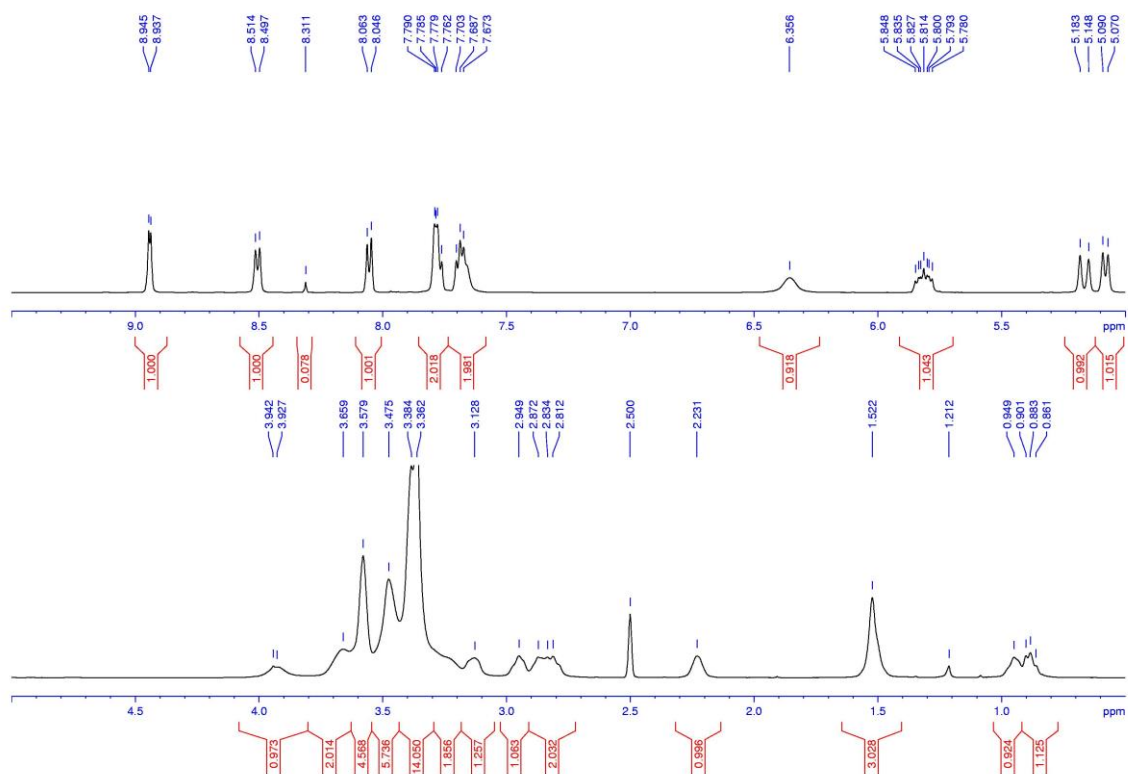


**Figure S8.**  $^1\text{H}$ ,  $^1\text{H}$ -gs-ROESY NMR spectrum of intermediate **C-HSQ** ( $\text{DMSO-d}_6$ )

## NMR spectra of catalyst **C5**

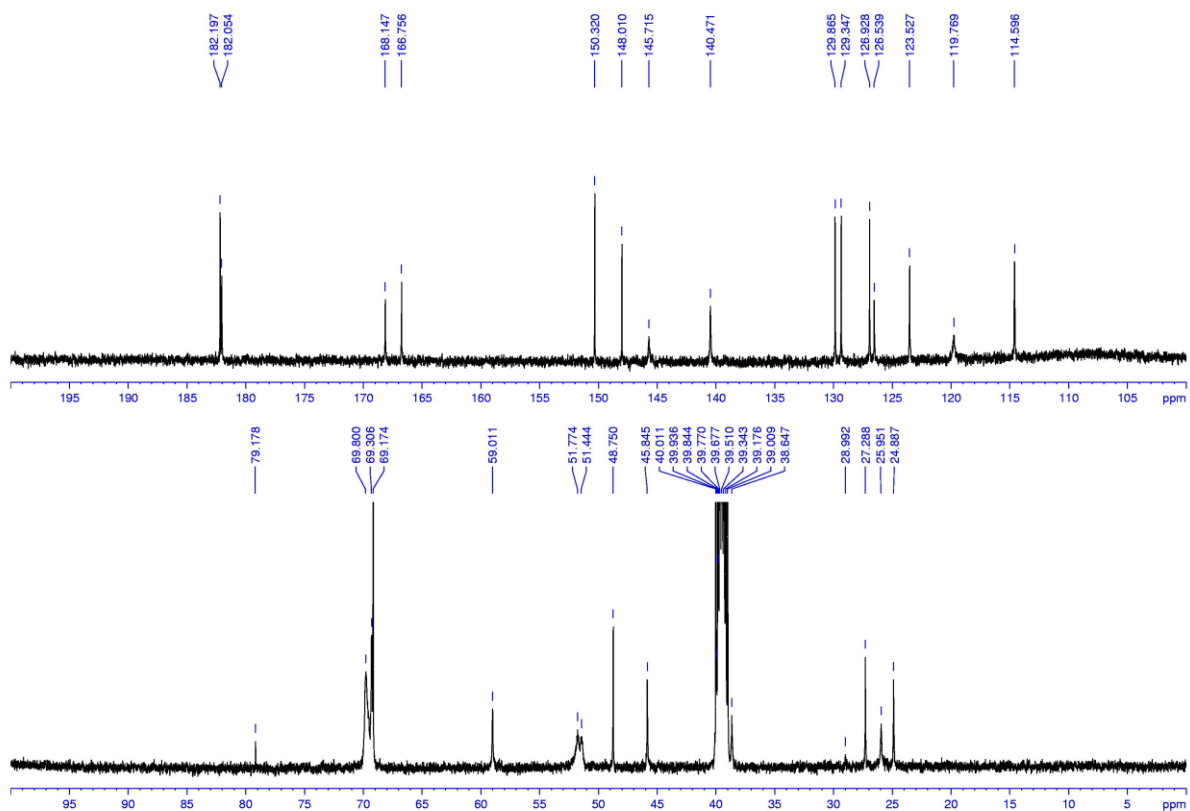


**Figure S9.** Molecule structure of catalyst **C5**

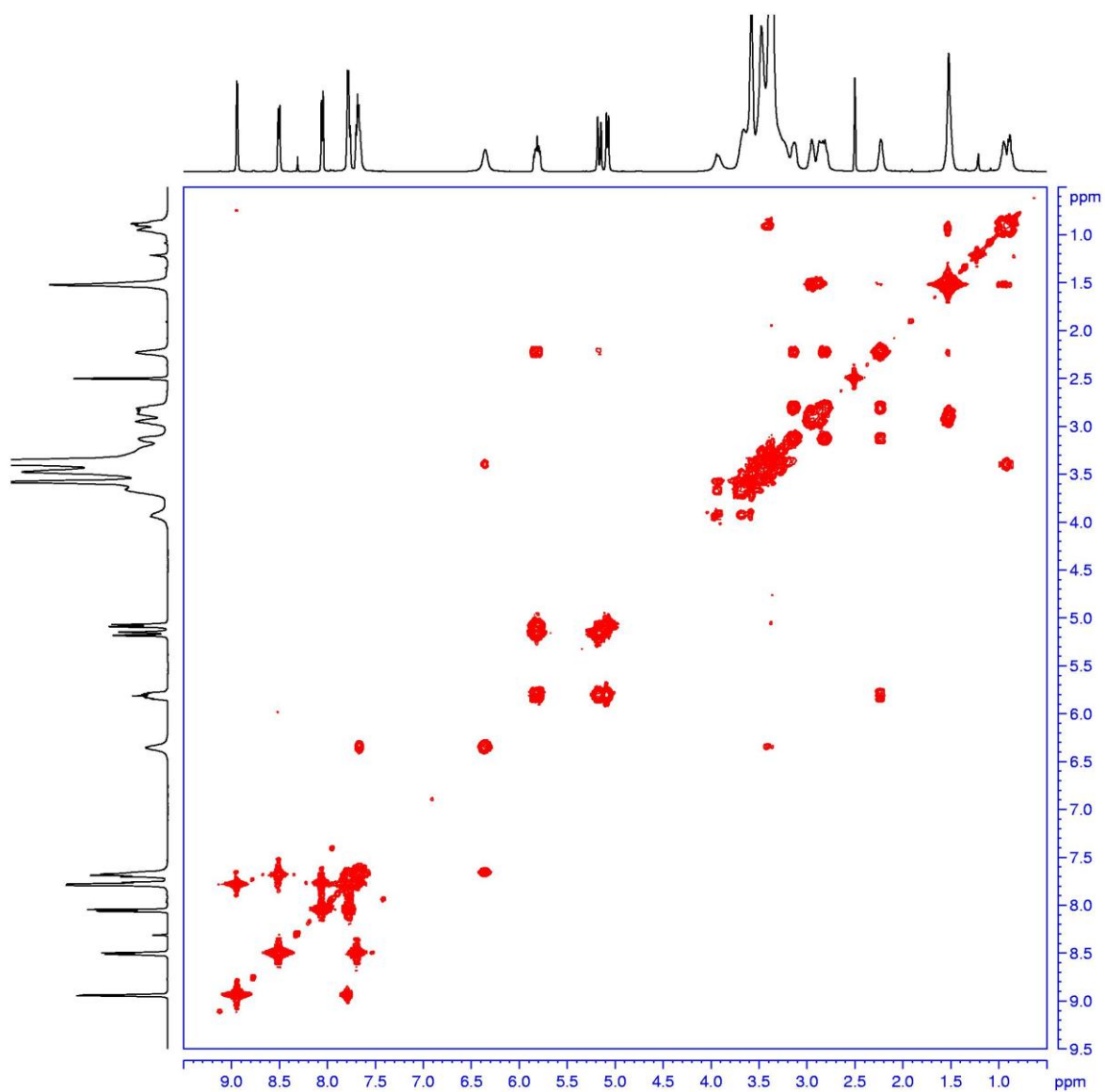


**Figure S10.**  $^1\text{H}$  NMR spectrum of catalyst **C5** (500.13 MHz,  $\text{DMSO-d}_6$ )

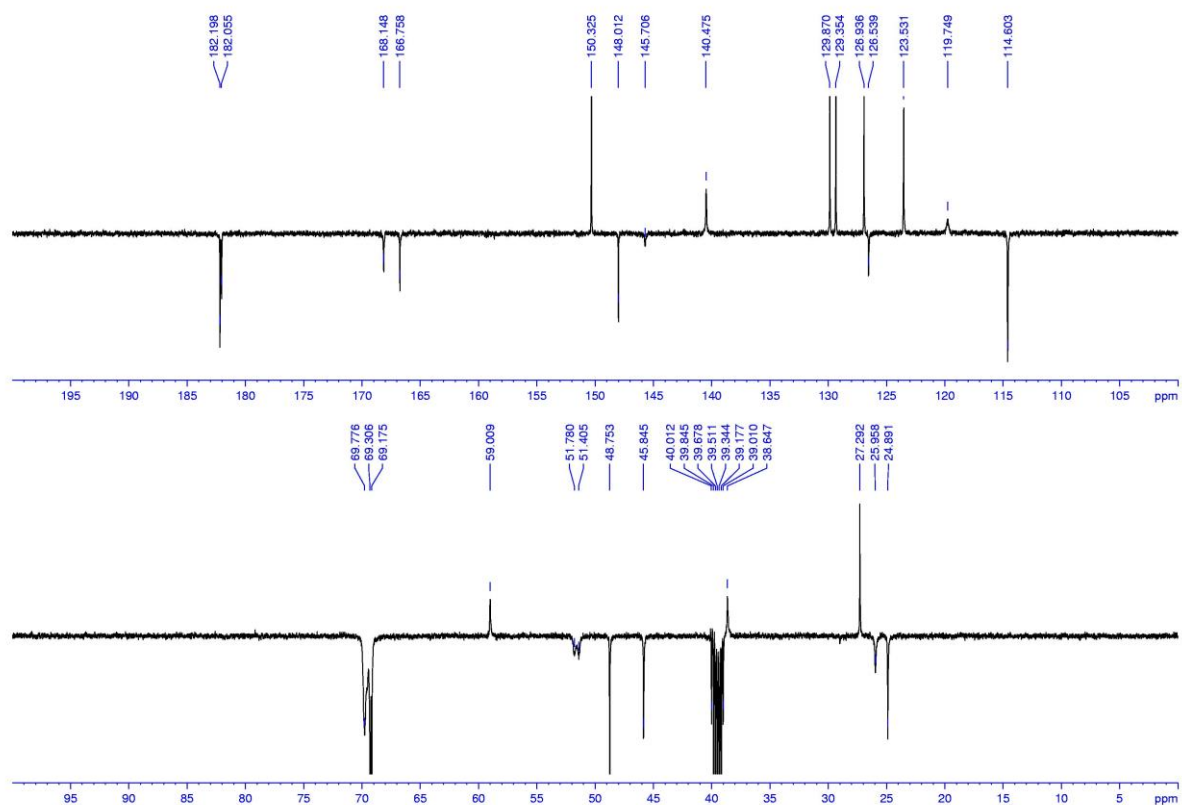




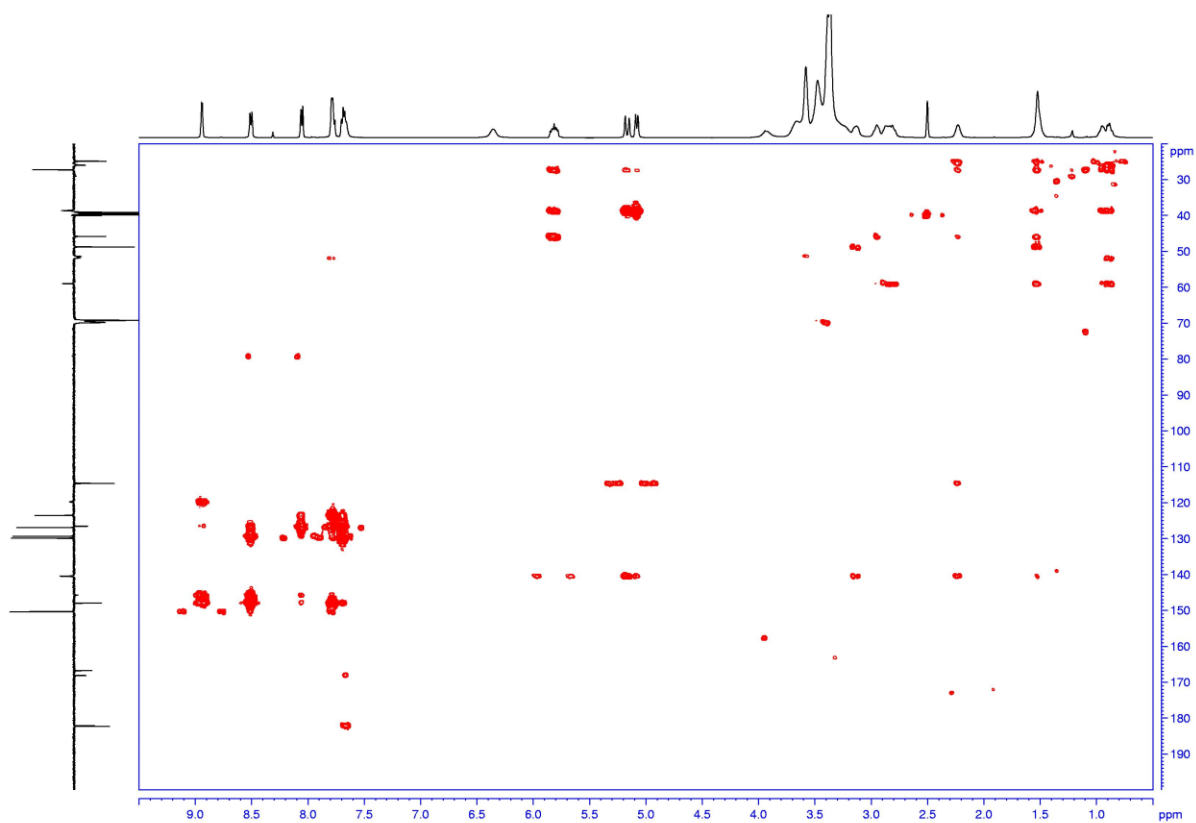
**Figure S11.**  $^{13}\text{C}$  NMR spectrum of catalyst **C5** (125.76 MHz,  $\text{DMSO-d}_6$ )



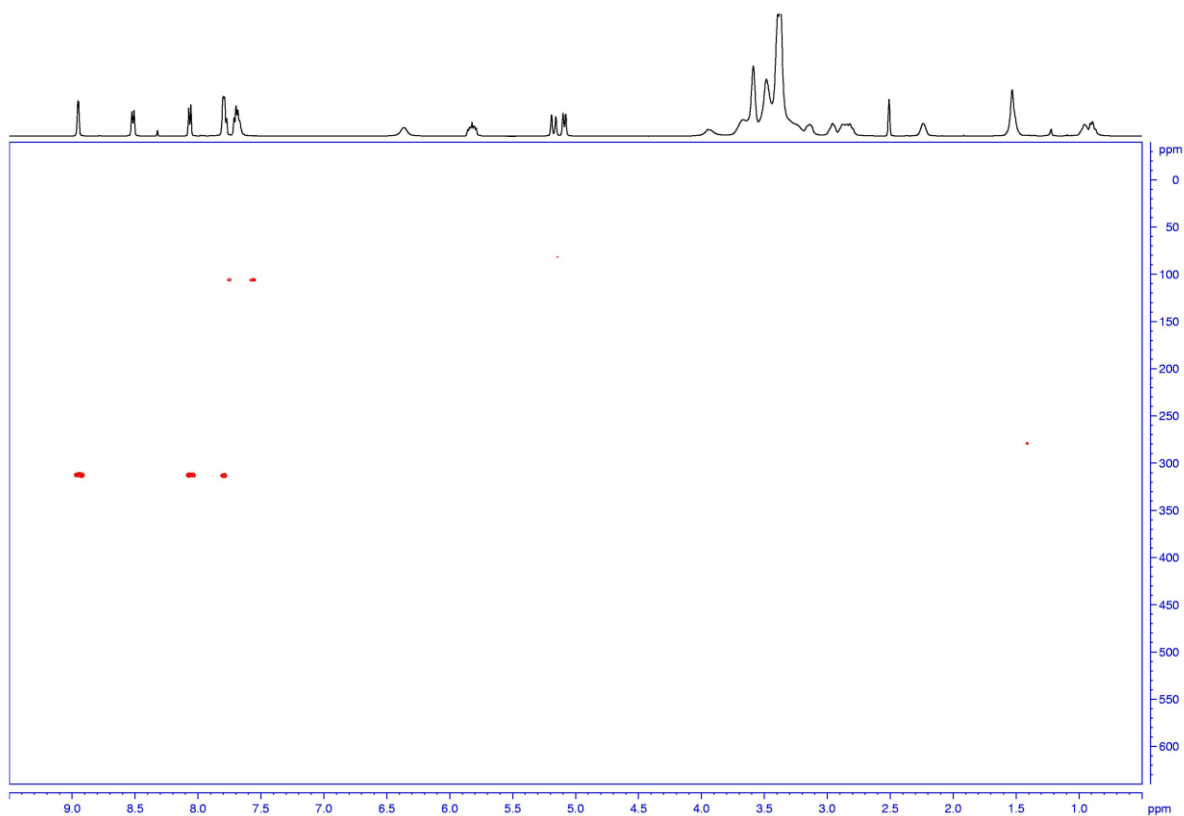
**Figure S12.**  $^1\text{H}$ -gs-COSY NMR spectrum of catalyst **C5** ( $\text{DMSO-d}_6$ )



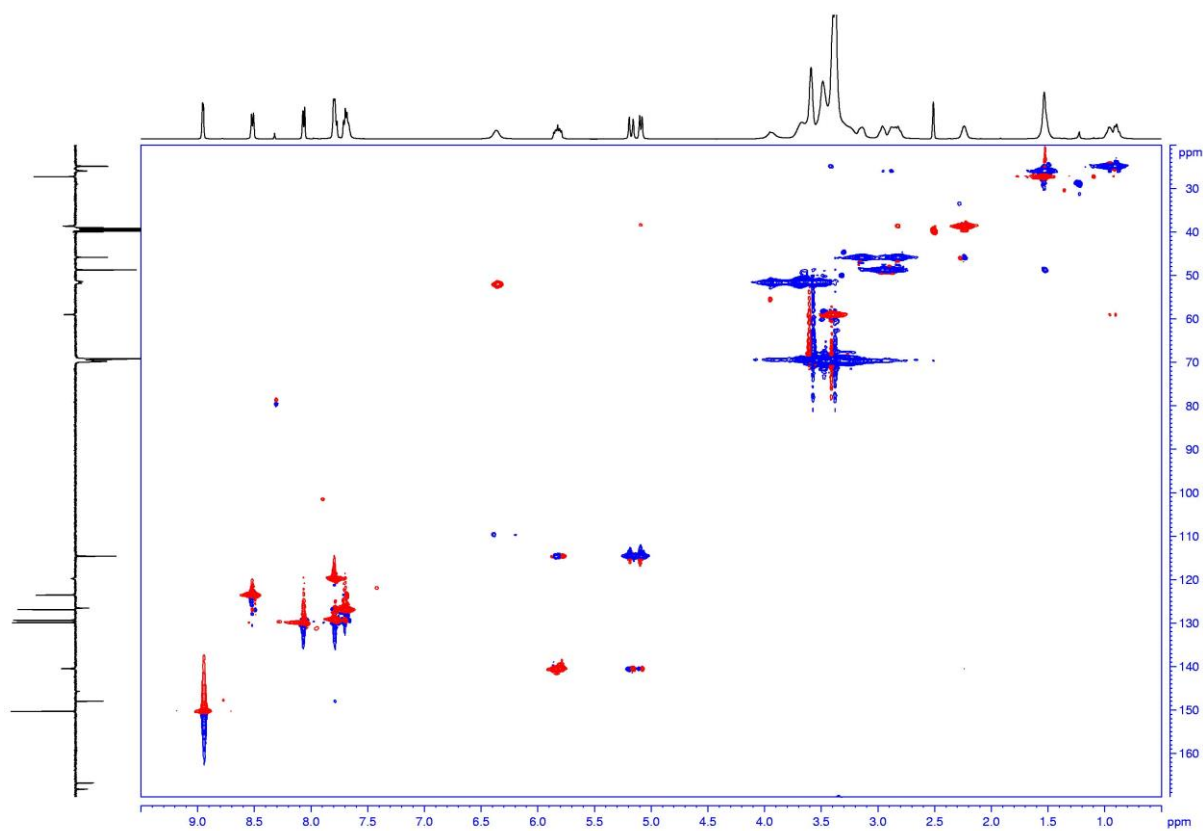
**Figure S13.**  $^{13}\text{C}$  DEPTQ NMR spectrum of catalyst **C5** ( $\text{DMSO-d}_6$ )



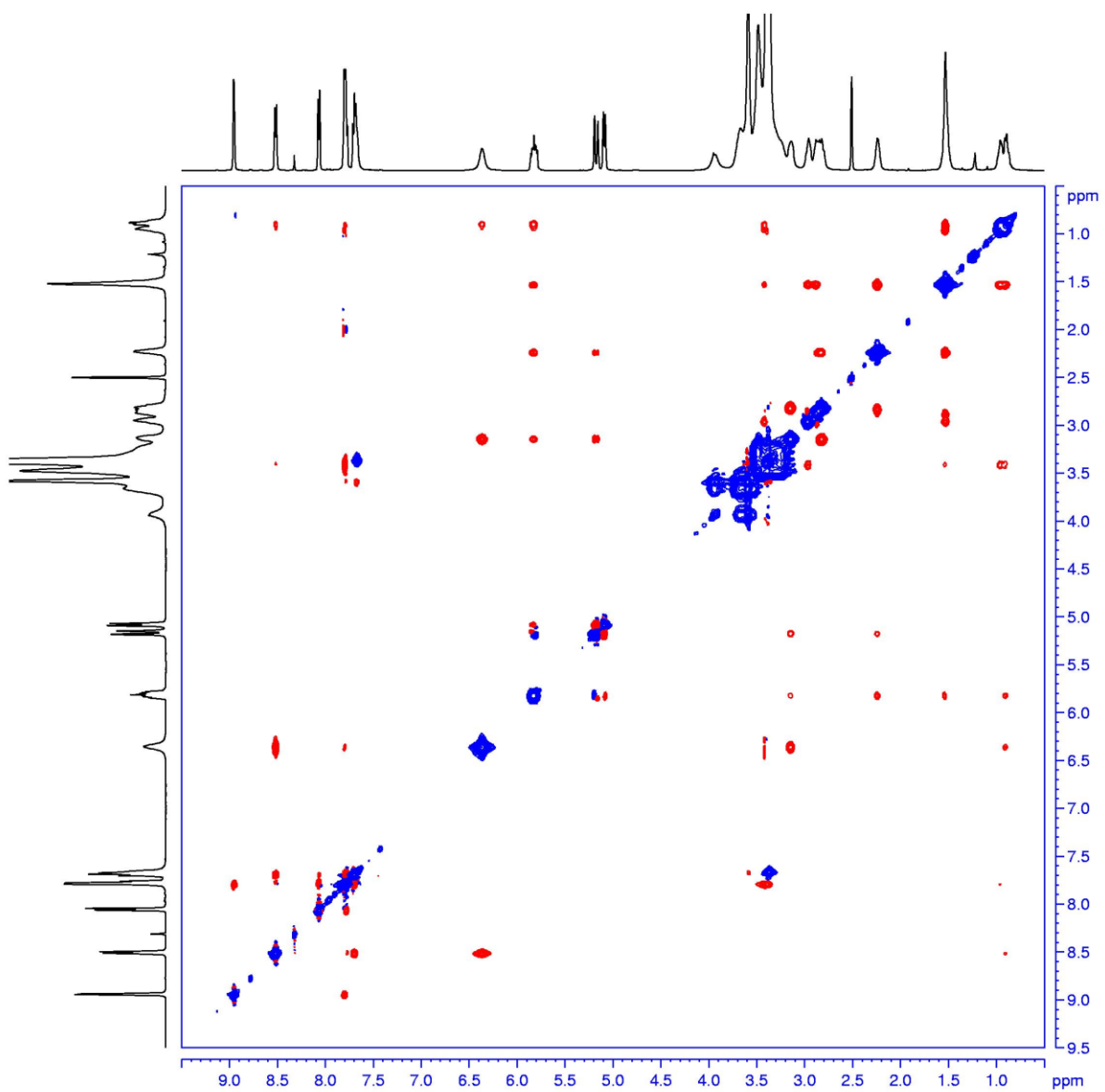
**Figure S14.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HMBC NMR spectrum of catalyst **C5** ( $\text{DMSO-d}_6$ )



**Figure S15.**  $^1\text{H}$ ,  $^{15}\text{N}$ -gs-HMBC NMR spectrum of catalyst **C5** (DMSO- $\text{d}_6$ )

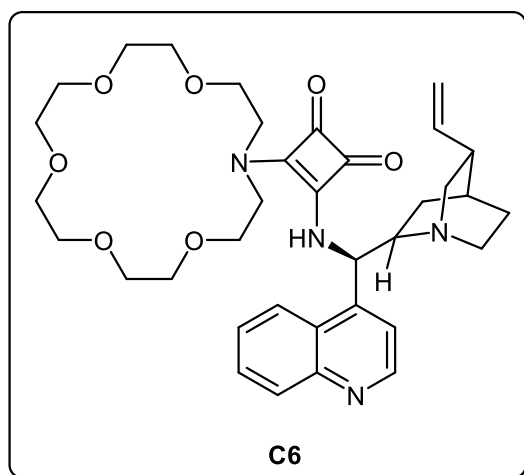


**Figure S16.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HSQC NMR spectrum of intermediate **C5** (DMSO- $\text{d}_6$ )

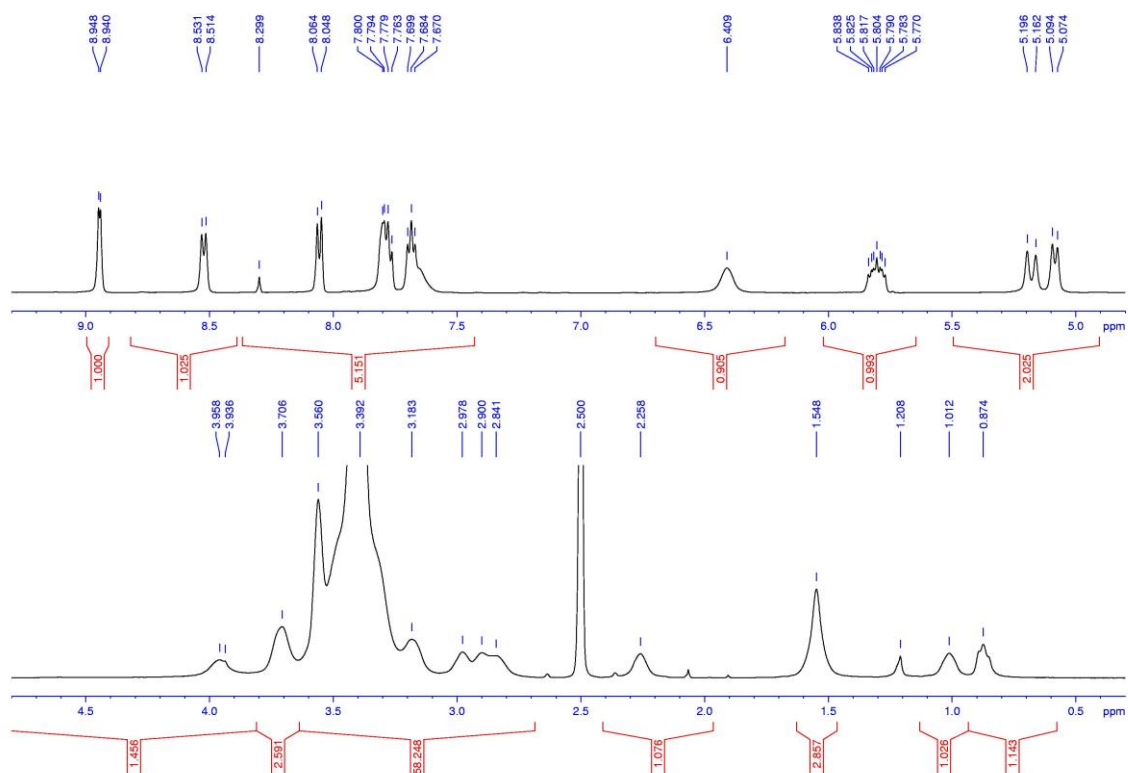


**Figure S17.**  $^1\text{H}$ ,  $^1\text{H}$ -gs-ROESY NMR spectrum of intermediate **C5** ( $\text{DMSO-d}_6$ )

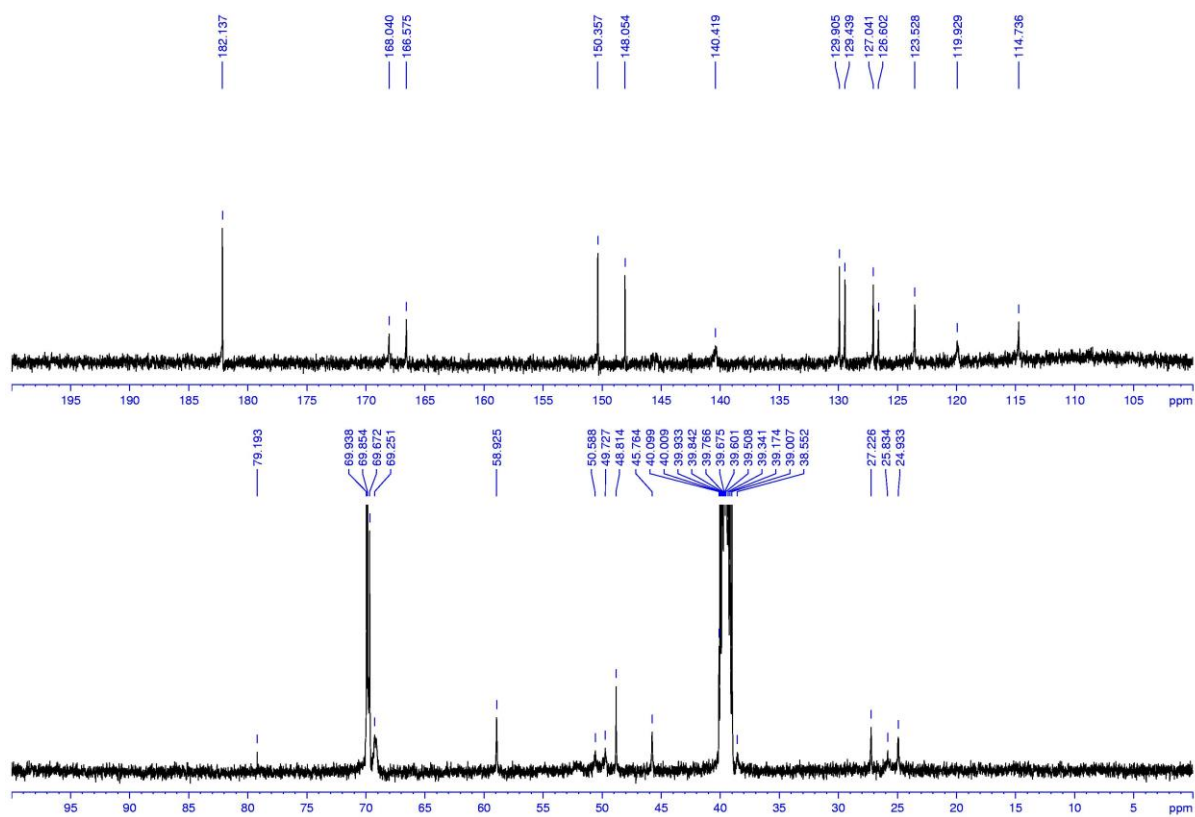
## NMR spectra of catalyst **C6**



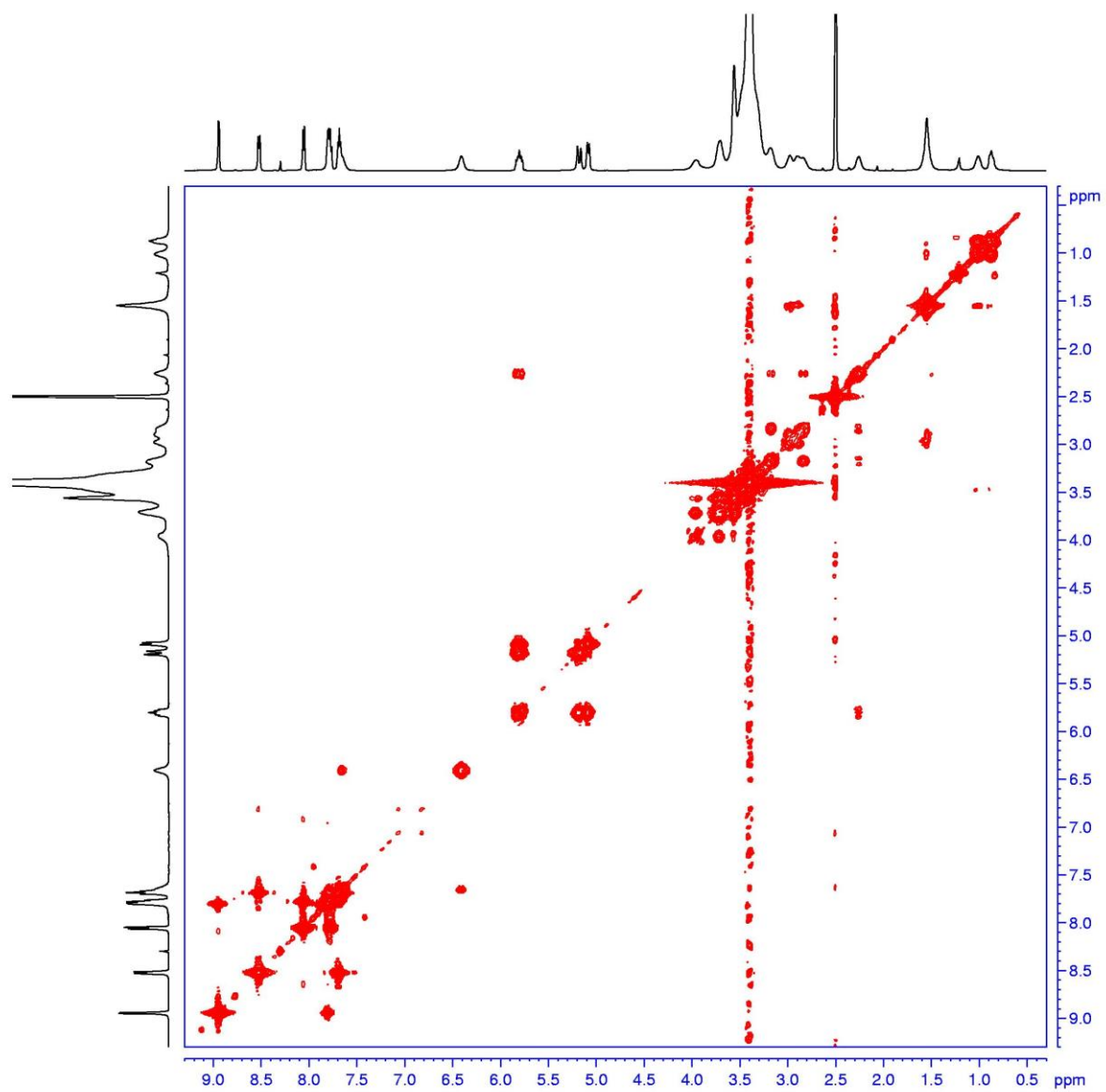
**Figure S18.** Molecule structure of catalyst **C6**



**Figure S19.**  $^1\text{H}$  NMR spectrum of catalyst **C6** (500.13 MHz,  $\text{DMSO-d}_6$ )



**Figure S20.**  $^{13}\text{C}$  NMR spectrum of catalyst **C6** (125.76 MHz,  $\text{DMSO-d}_6$ )



**Figure S21.**  $^1\text{H}$ -gs-COSY NMR spectrum of catalyst **C6** ( $\text{DMSO-d}_6$ )



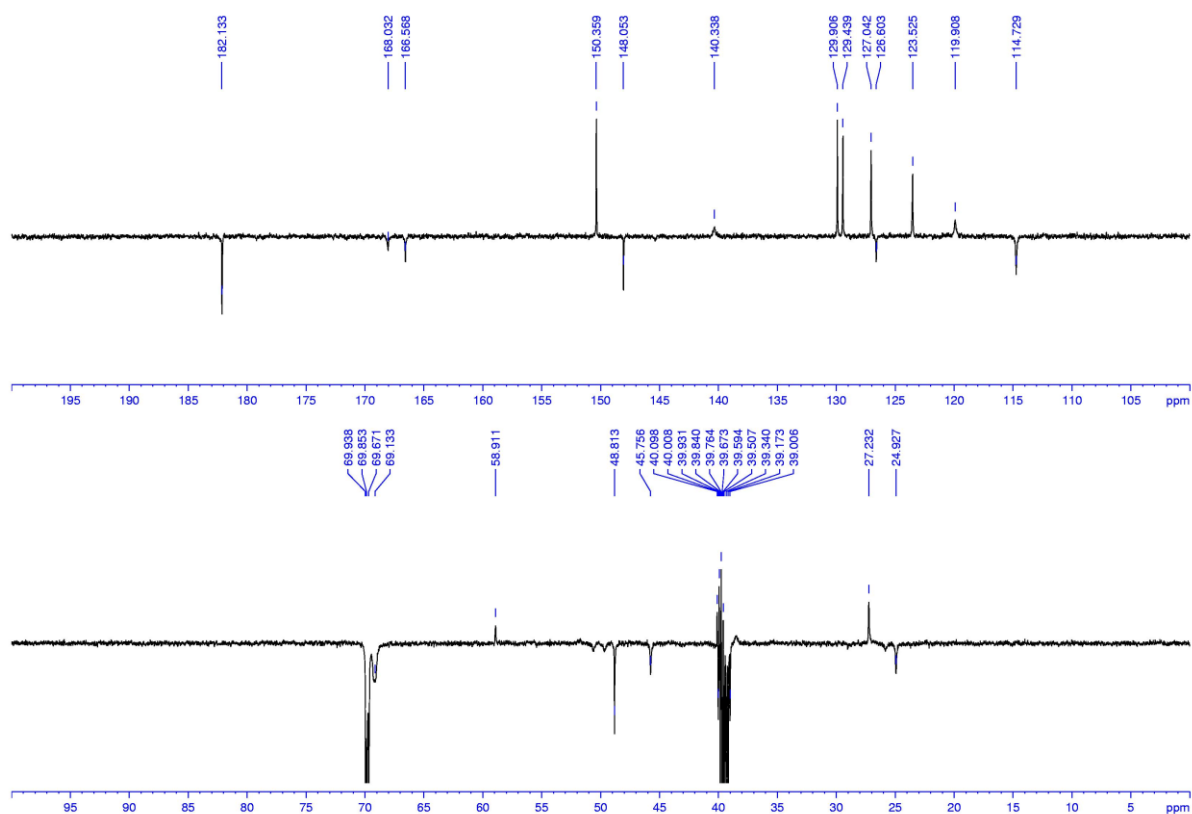


Figure S22.  $^{13}\text{C}$  DEPTQ NMR spectrum of catalyst C6 (DMSO- $\text{d}_6$ )

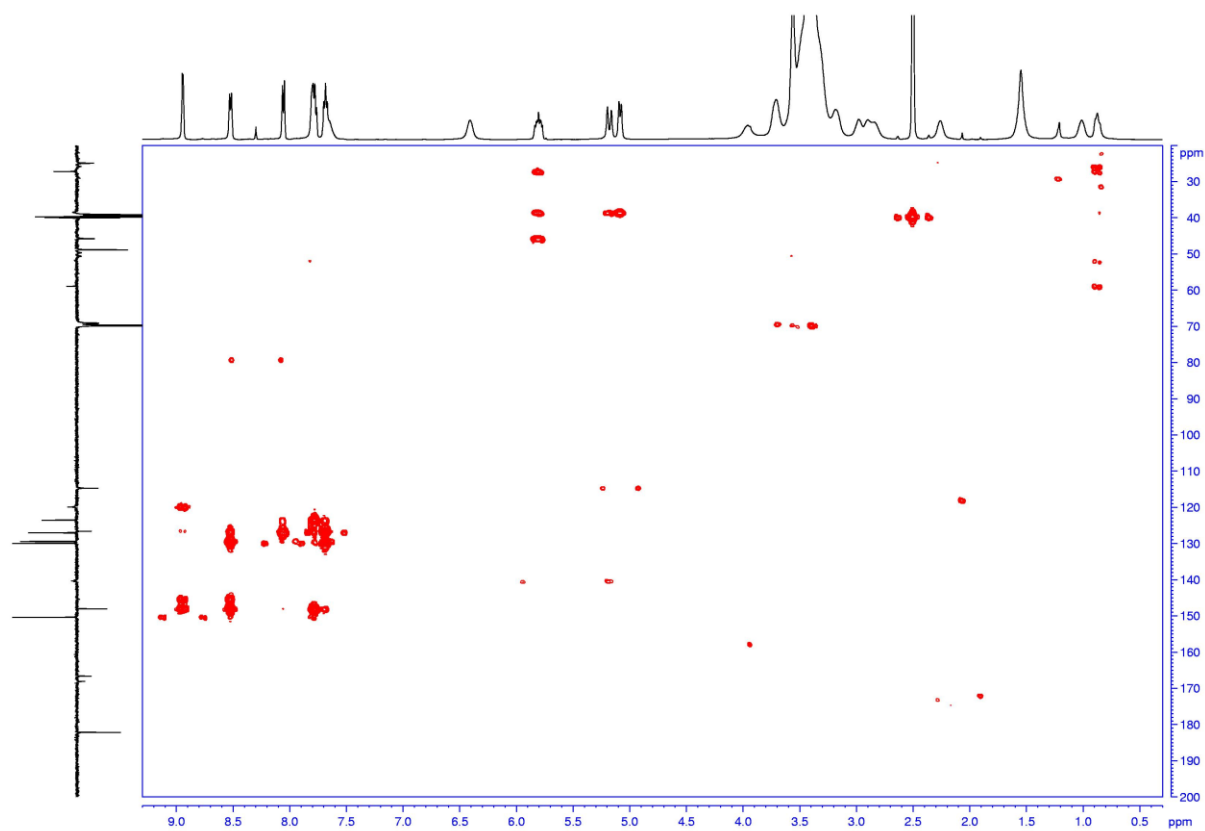
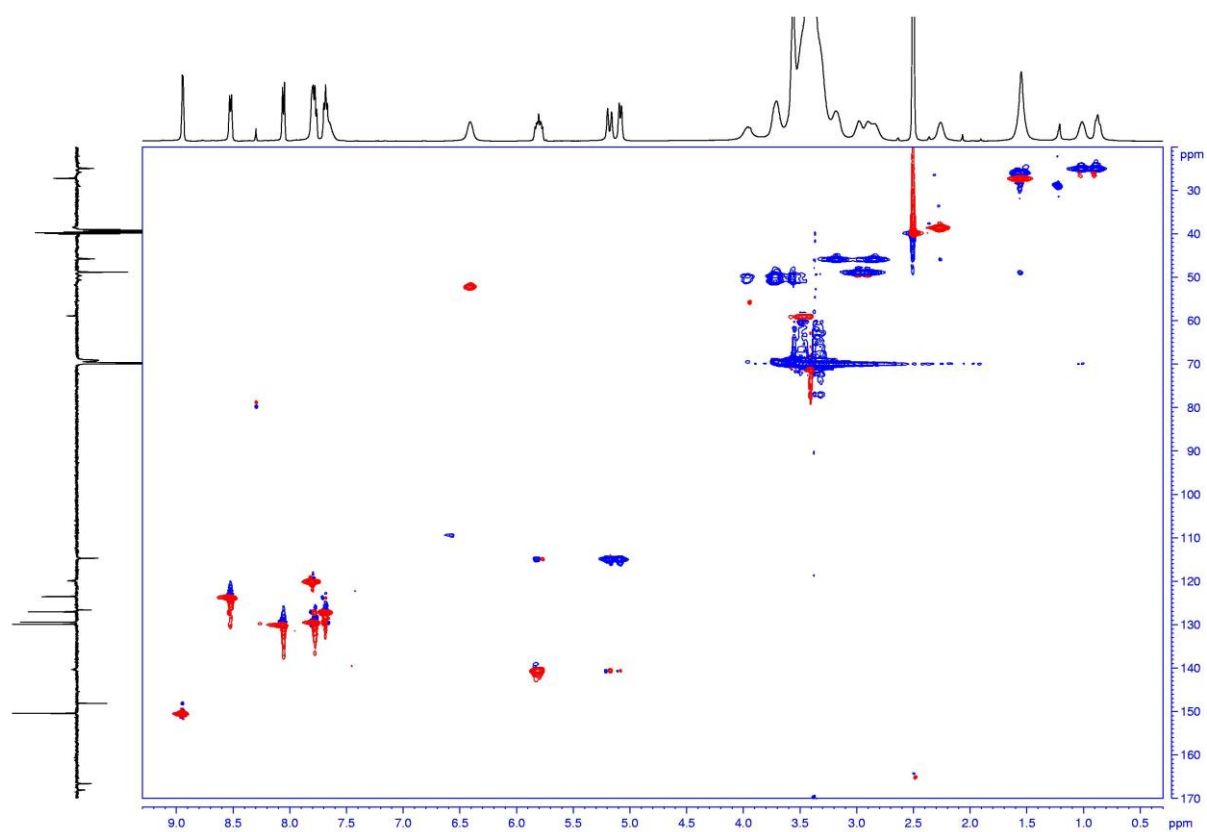
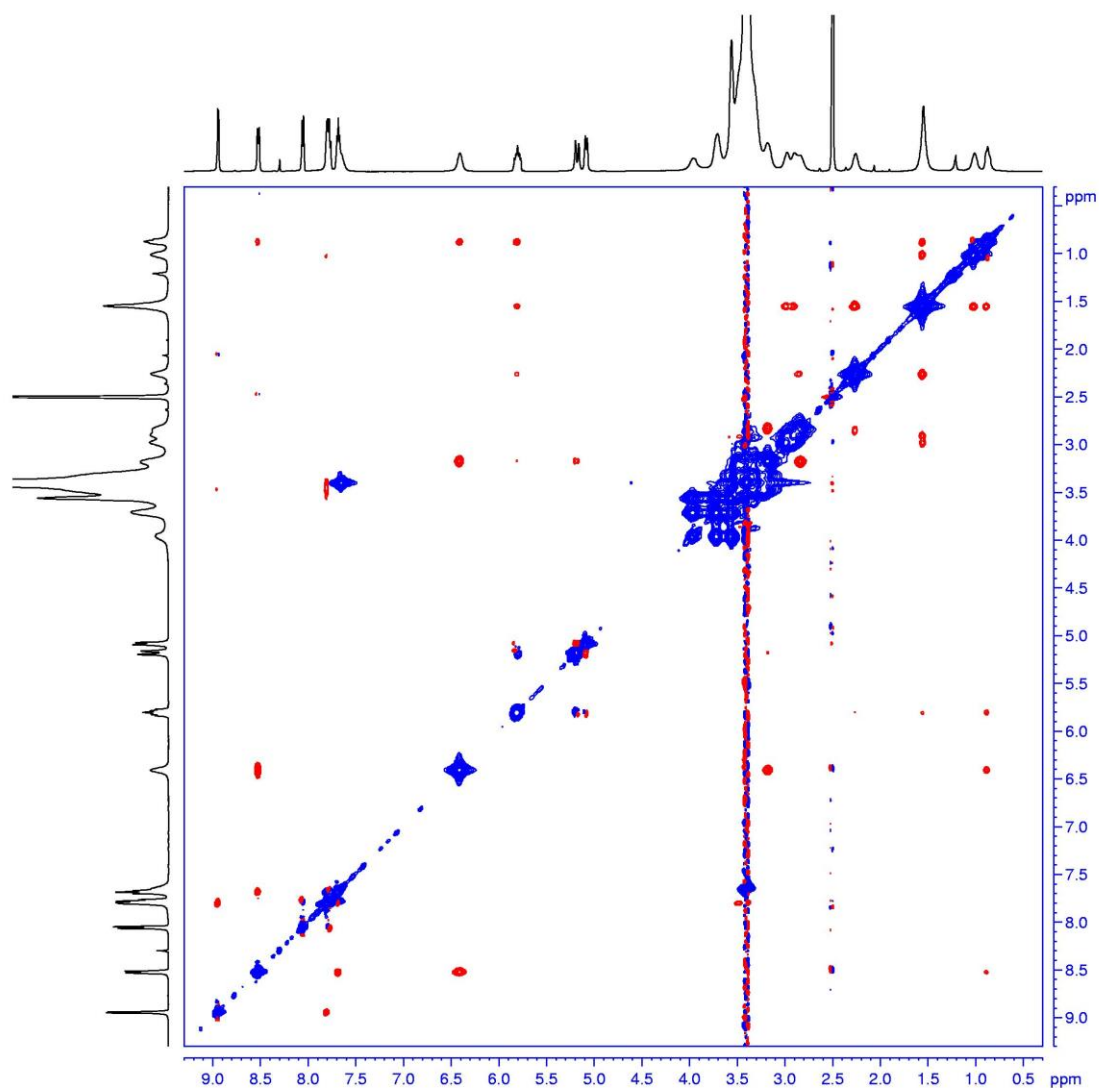


Figure S23.  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HMBC NMR spectrum of catalyst C6 (DMSO- $\text{d}_6$ )

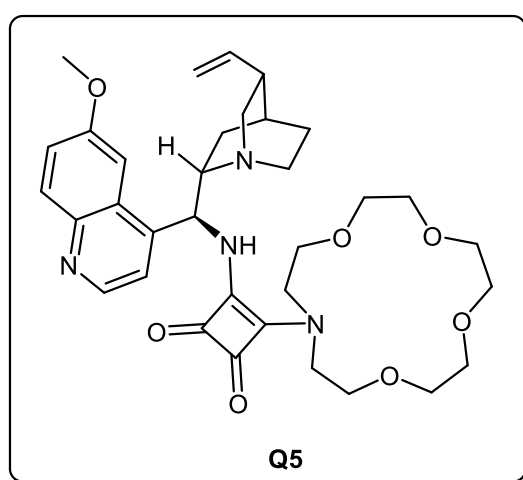


**Figure S24.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HSQC NMR spectrum of intermediate **C6** ( $\text{DMSO-d}_6$ )

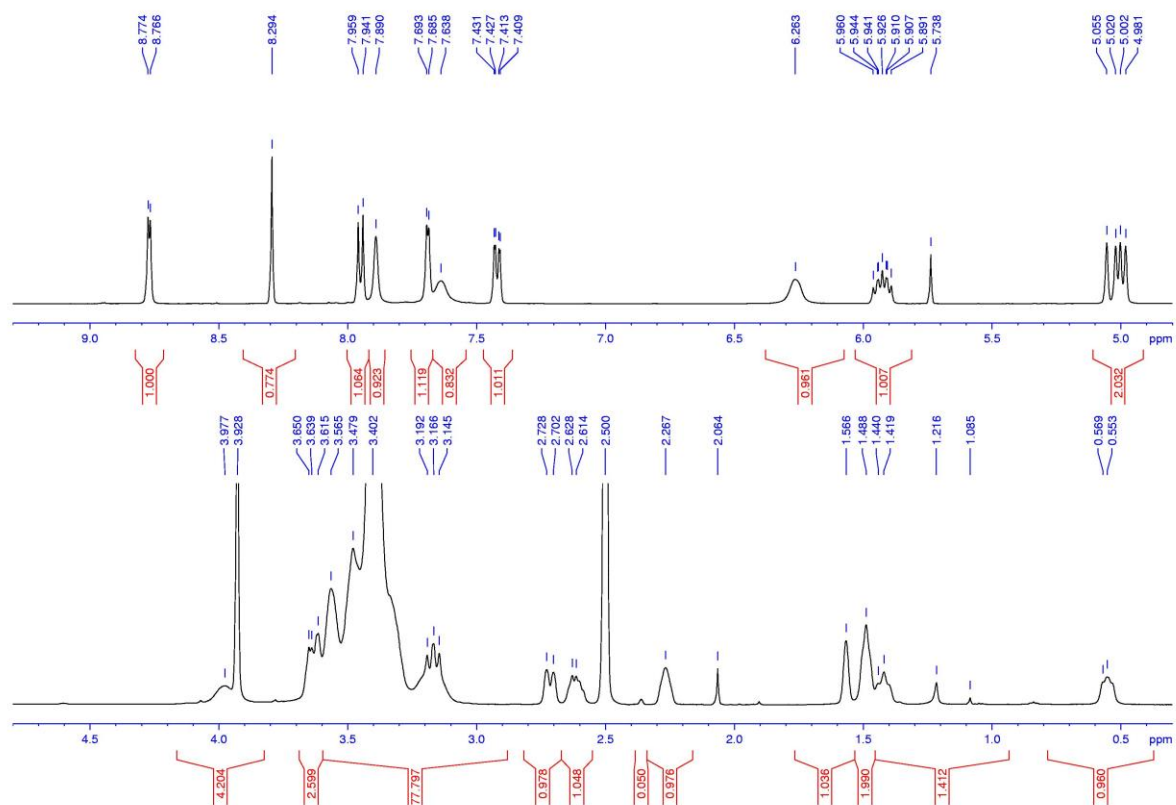


**Figure S25.**  $^1\text{H}$ ,  $^1\text{H}$ -gs-ROESY NMR spectrum of intermediate **C6** ( $\text{DMSO-d}_6$ )

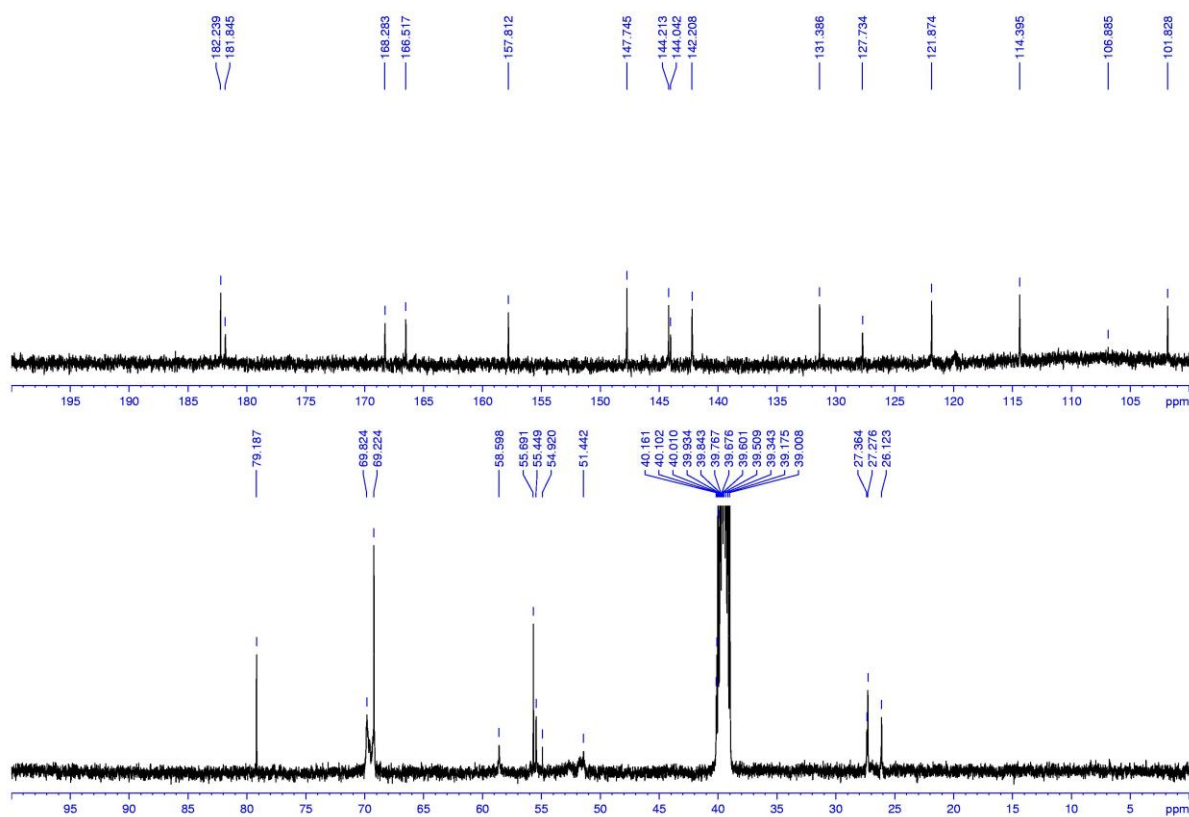
NMR spectra of catalyst **Q5**



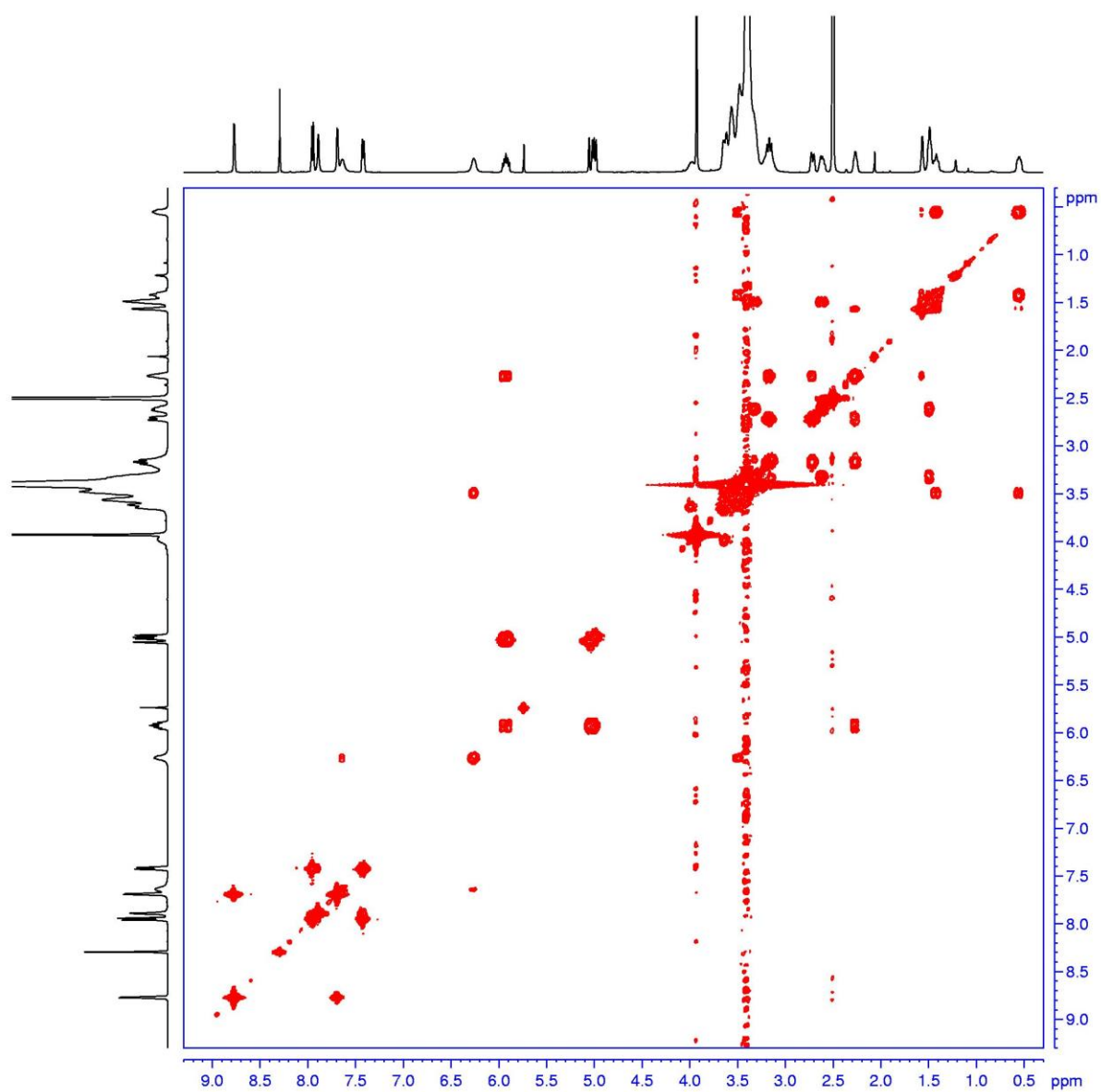
**Figure S26.** Molecule structure of catalyst **Q5**



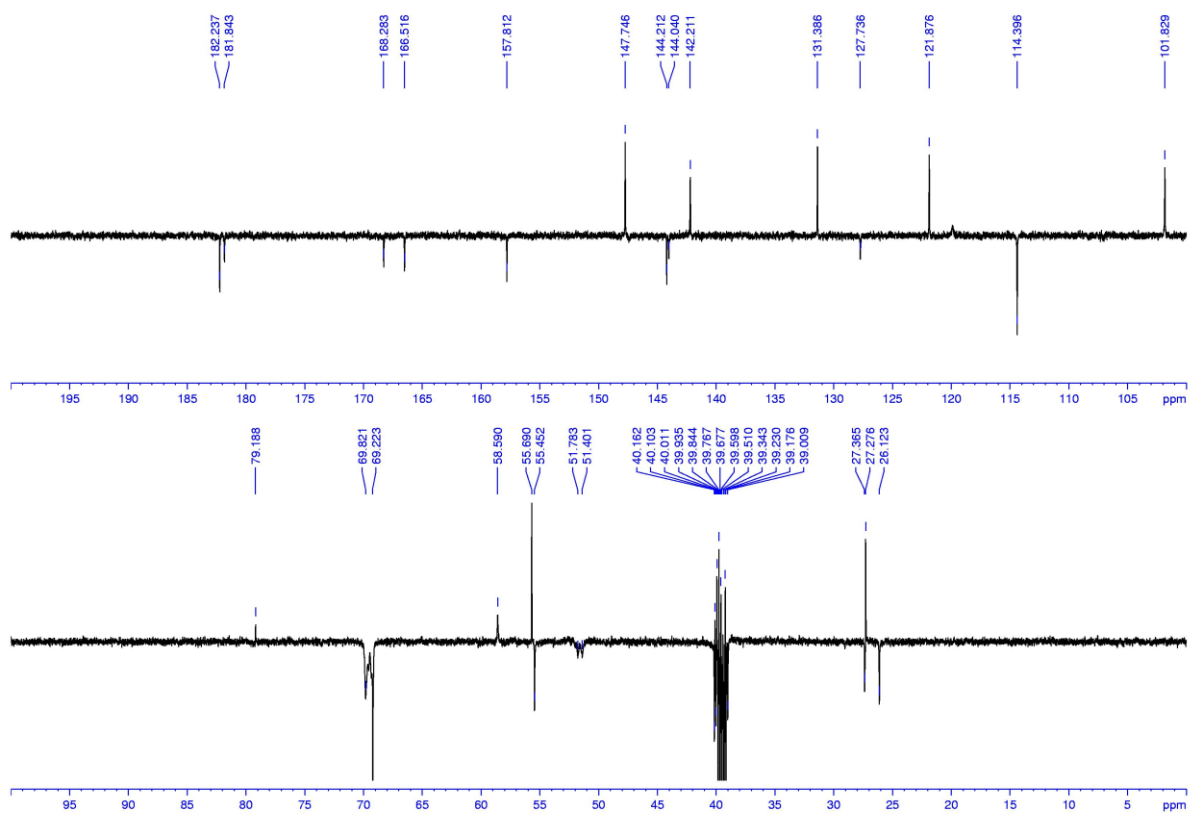
**Figure S27.** <sup>1</sup>H NMR spectrum of catalyst **Q5** (500.13 MHz, DMSO-d<sub>6</sub>)



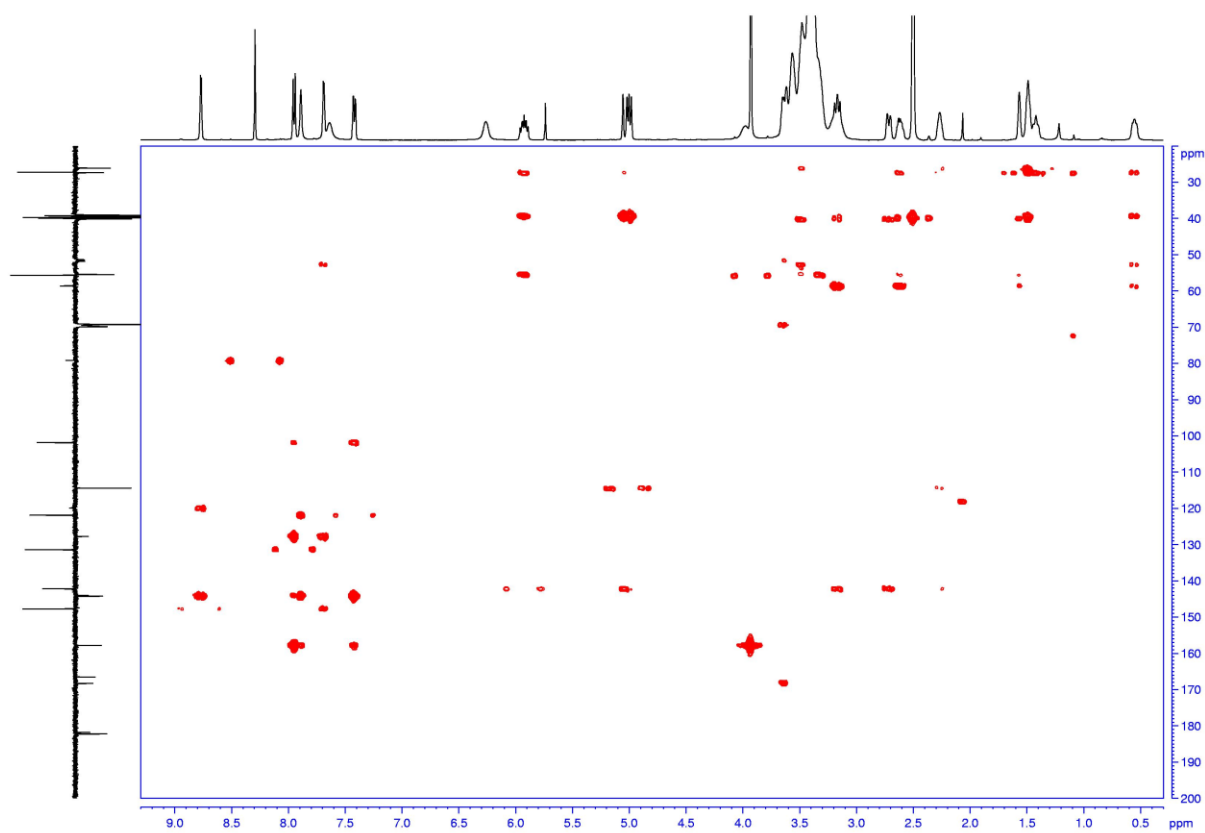
**Figure S28.** <sup>13</sup>C NMR spectrum of catalyst **Q5** (125.76 MHz, DMSO-d<sub>6</sub>)



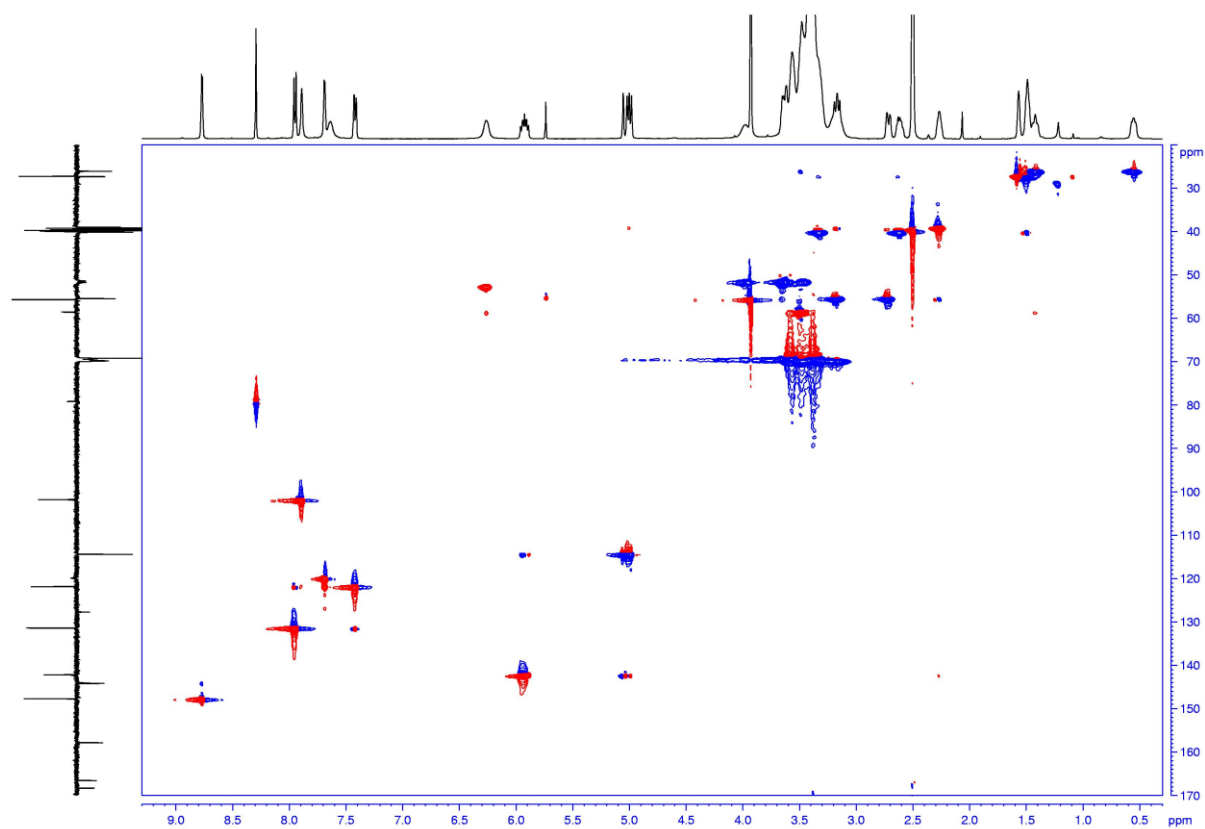
**Figure S29.** <sup>1</sup>H-gs-COSY NMR spectrum of catalyst **Q5** (DMSO-d<sub>6</sub>)



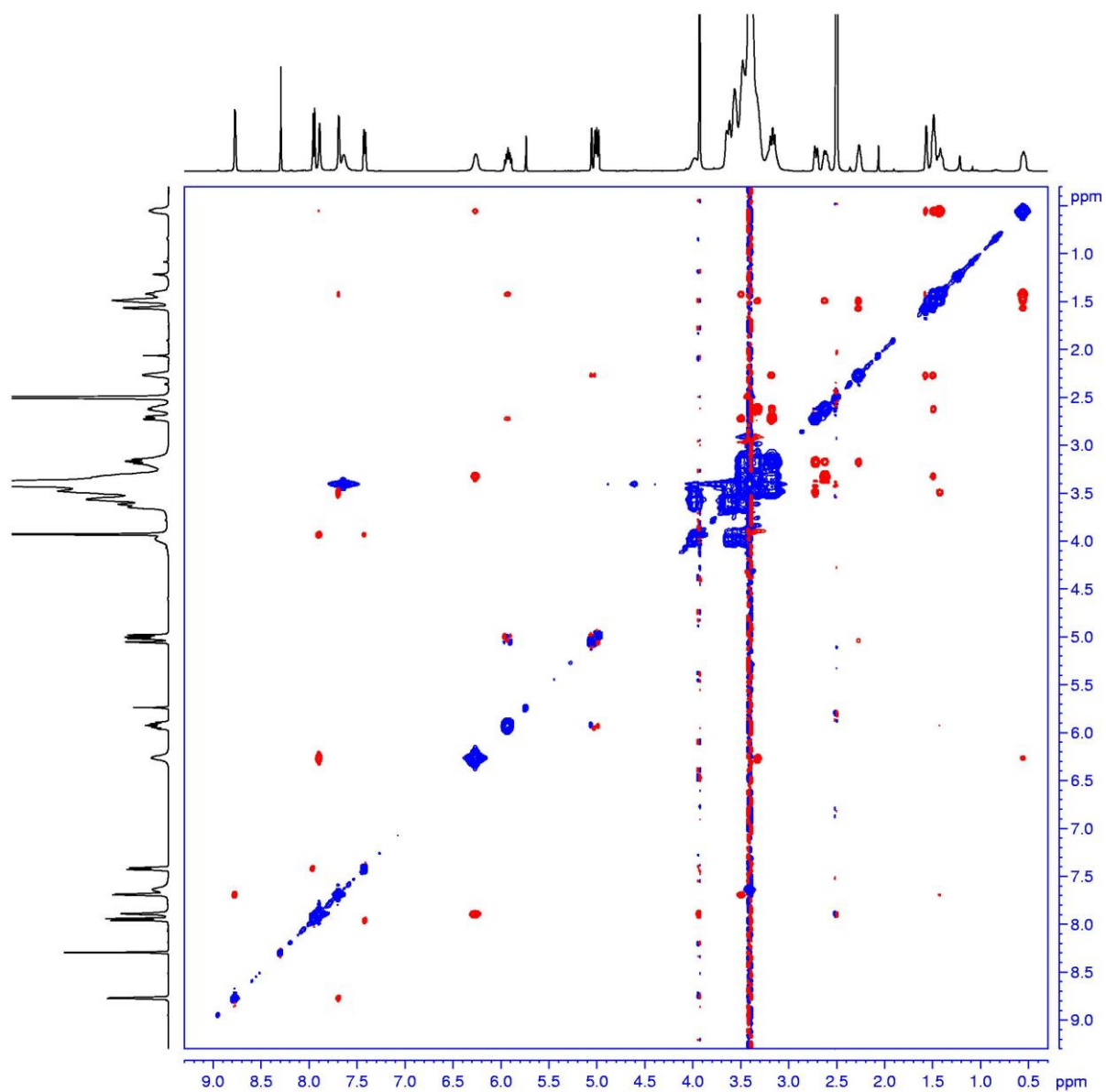
**Figure S30.**  $^{13}\text{C}$  DEPTQ NMR spectrum of catalyst **Q5** ( $\text{DMSO-d}_6$ )



**Figure S31.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HMBC NMR spectrum of catalyst **Q5** ( $\text{DMSO-d}_6$ )



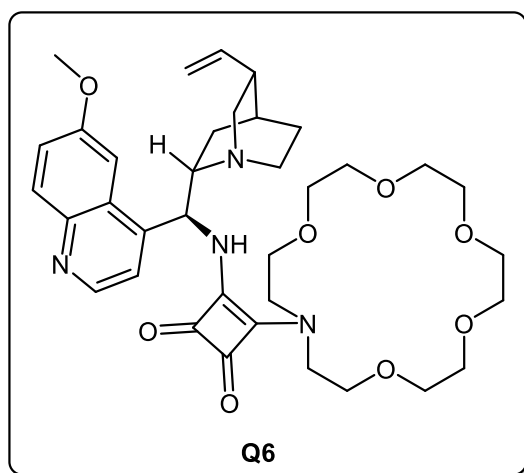
**Figure S32.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HSQC NMR spectrum of intermediate **Q5** ( $\text{DMSO-d}_6$ )



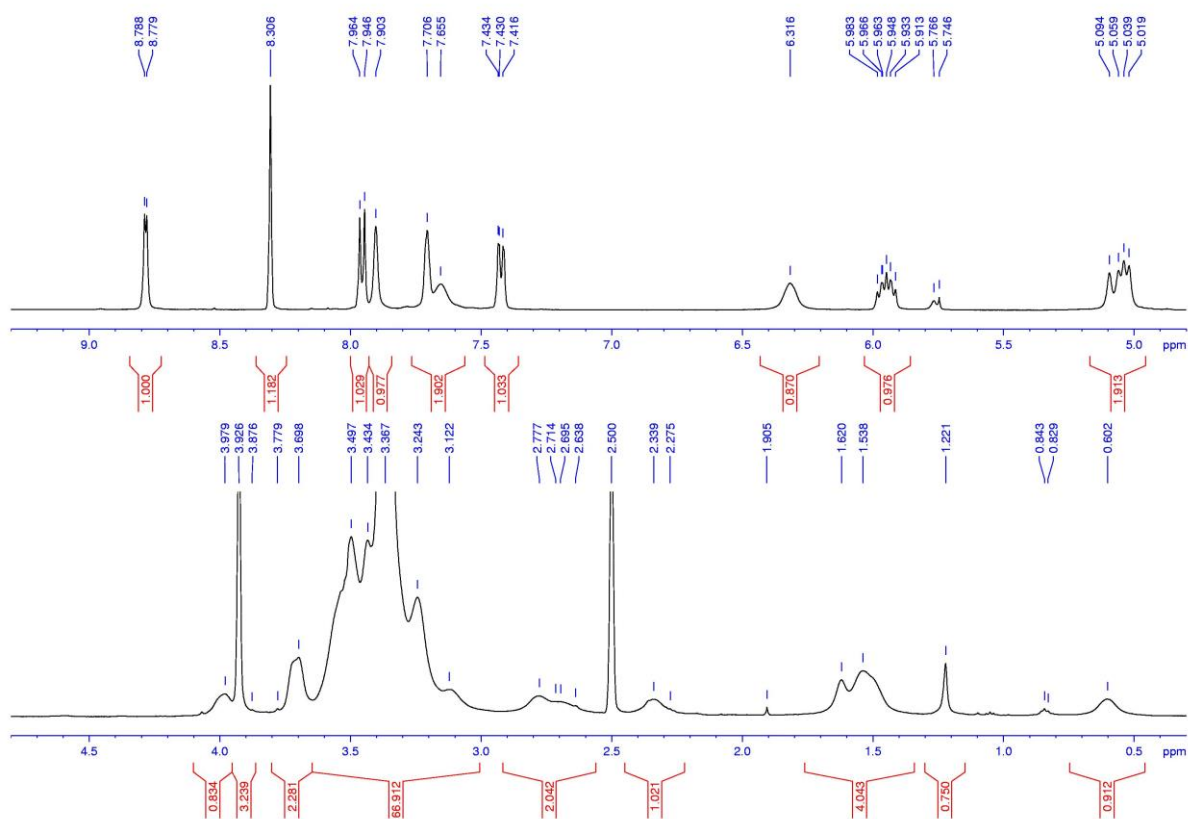
**Figure S33.**  $^1\text{H}$ ,  $^1\text{H}$ -gs-ROESY NMR spectrum of intermediate **Q5** ( $\text{DMSO-d}_6$ )



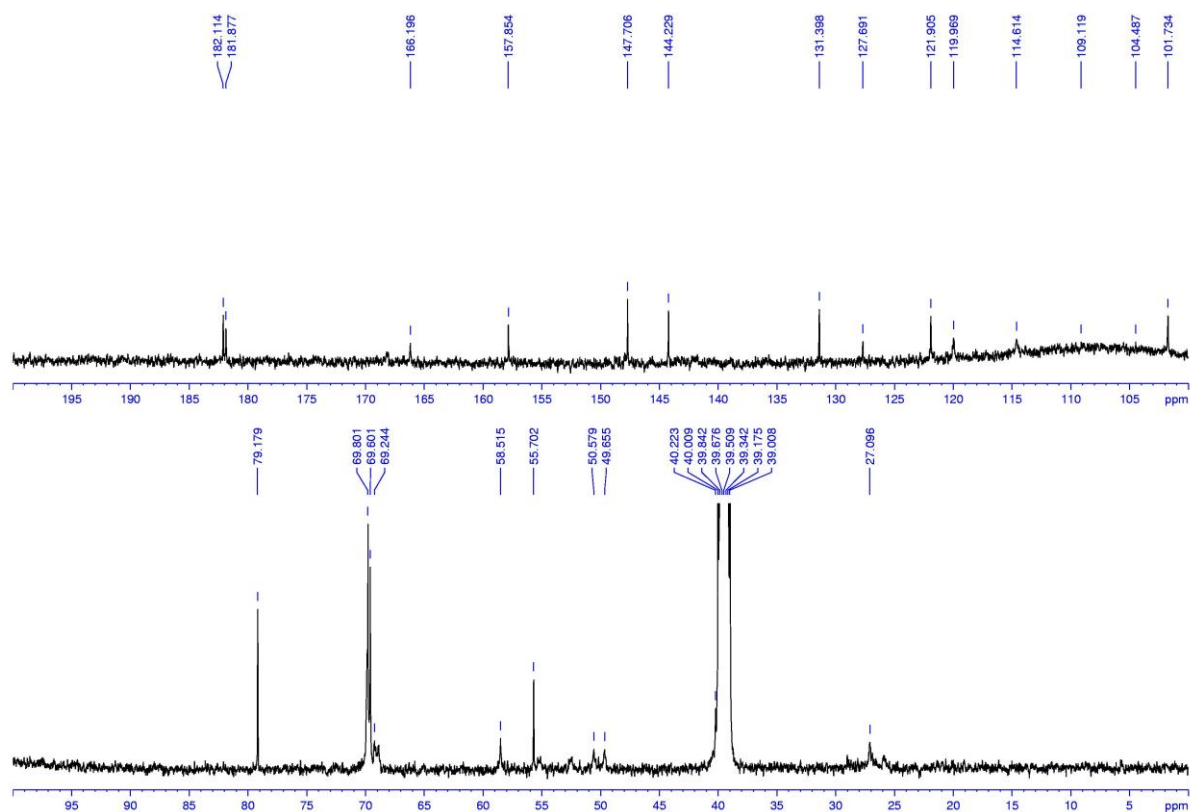
## NMR spectra of catalyst **Q6**



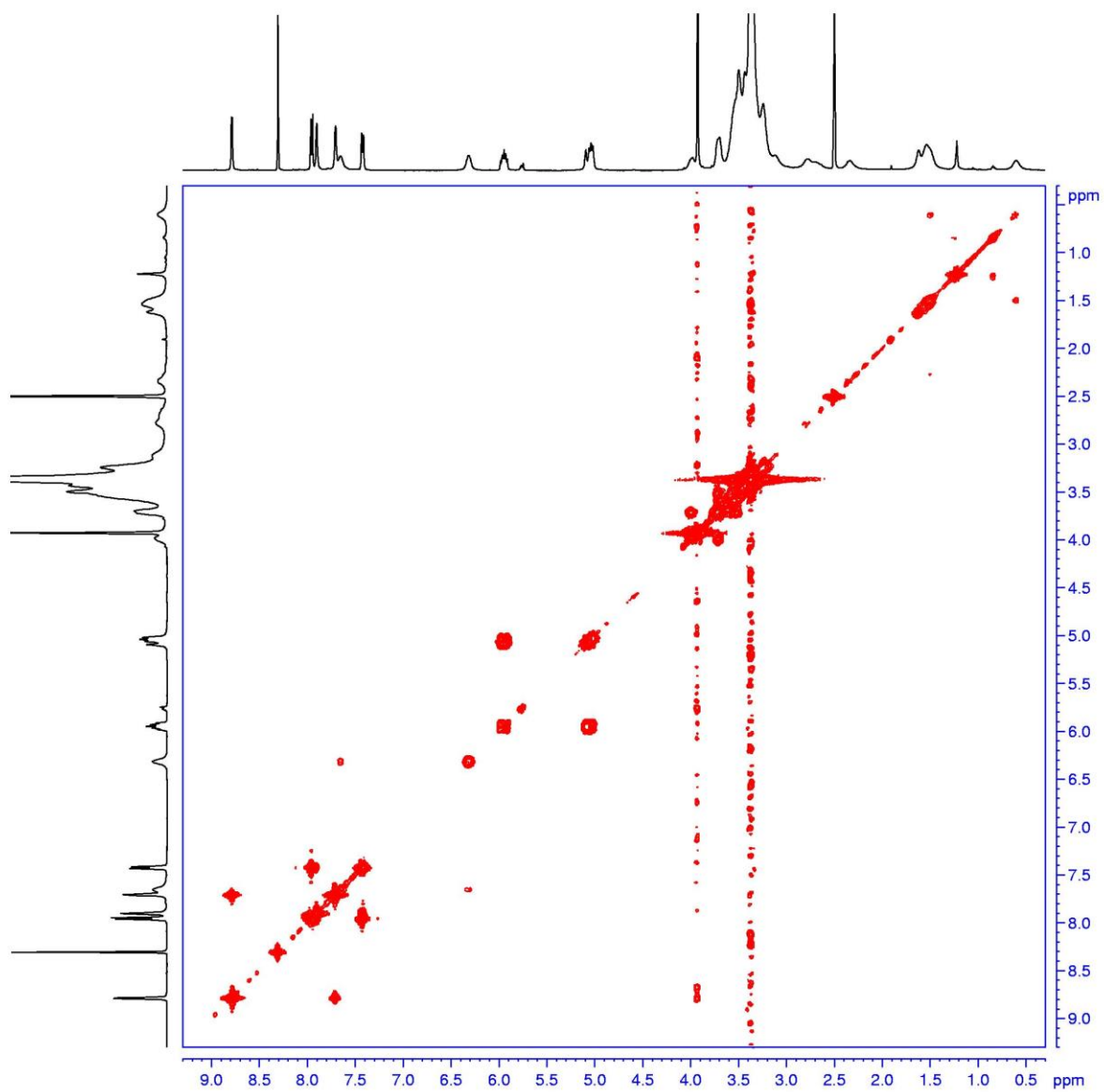
**Figure S34.** Molecule structure of catalyst **Q6**



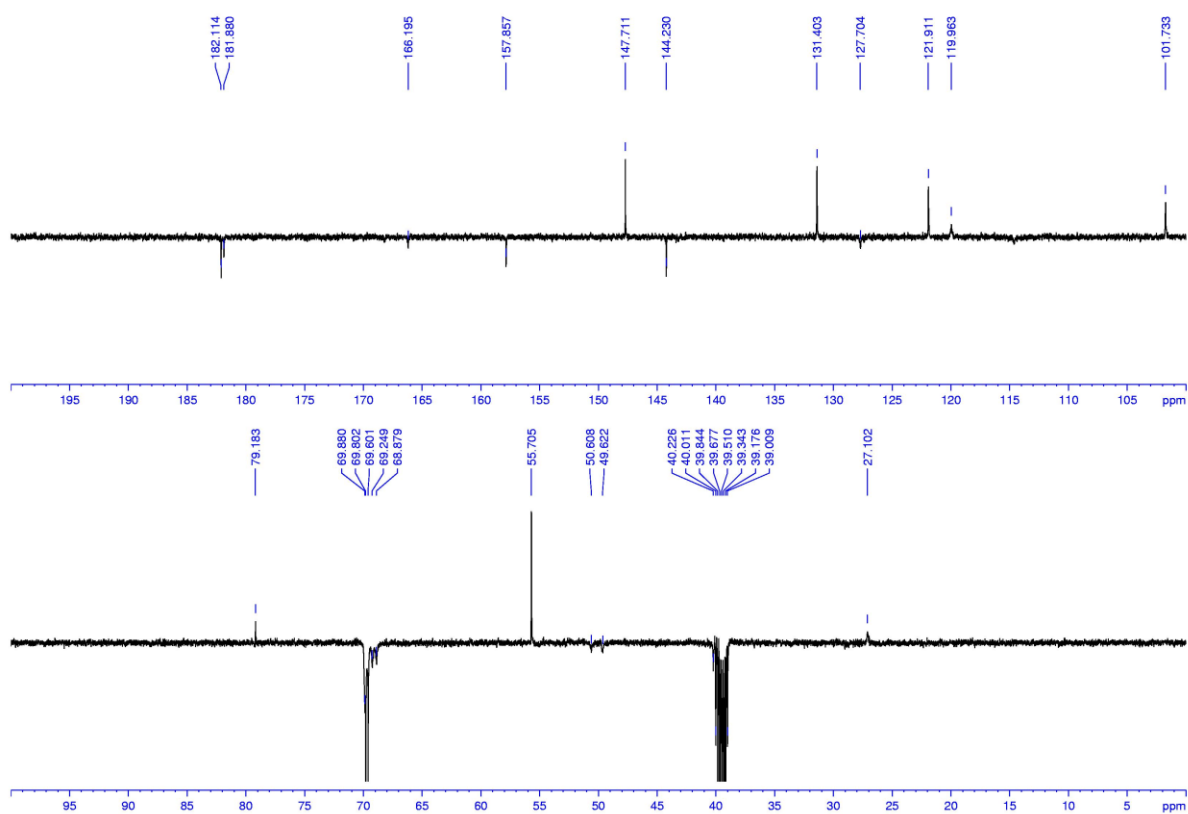
**Figure S35.**  $^1\text{H}$  NMR spectrum of catalyst **Q6** (500.13 MHz,  $\text{DMSO-d}_6$ )



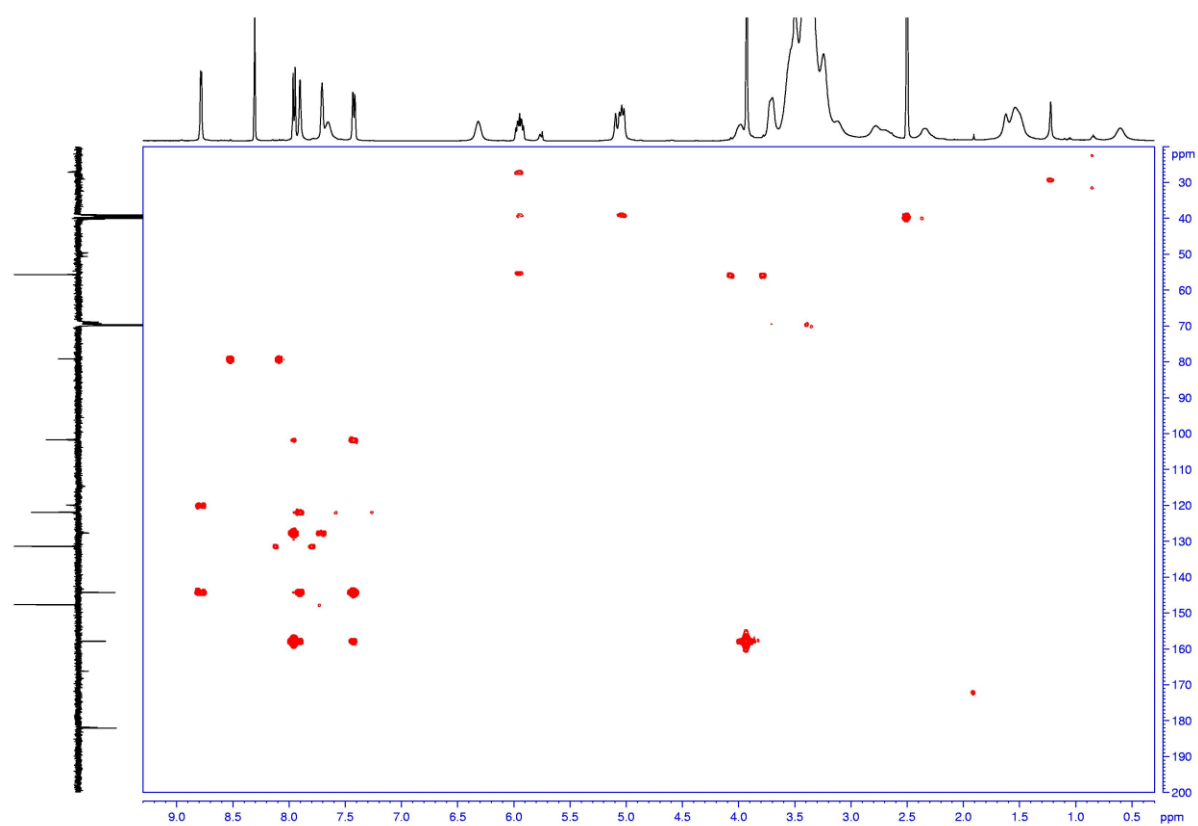
**Figure S36.**  $^{13}\text{C}$  NMR spectrum of catalyst **Q6** (125.76 MHz,  $\text{DMSO-d}_6$ )



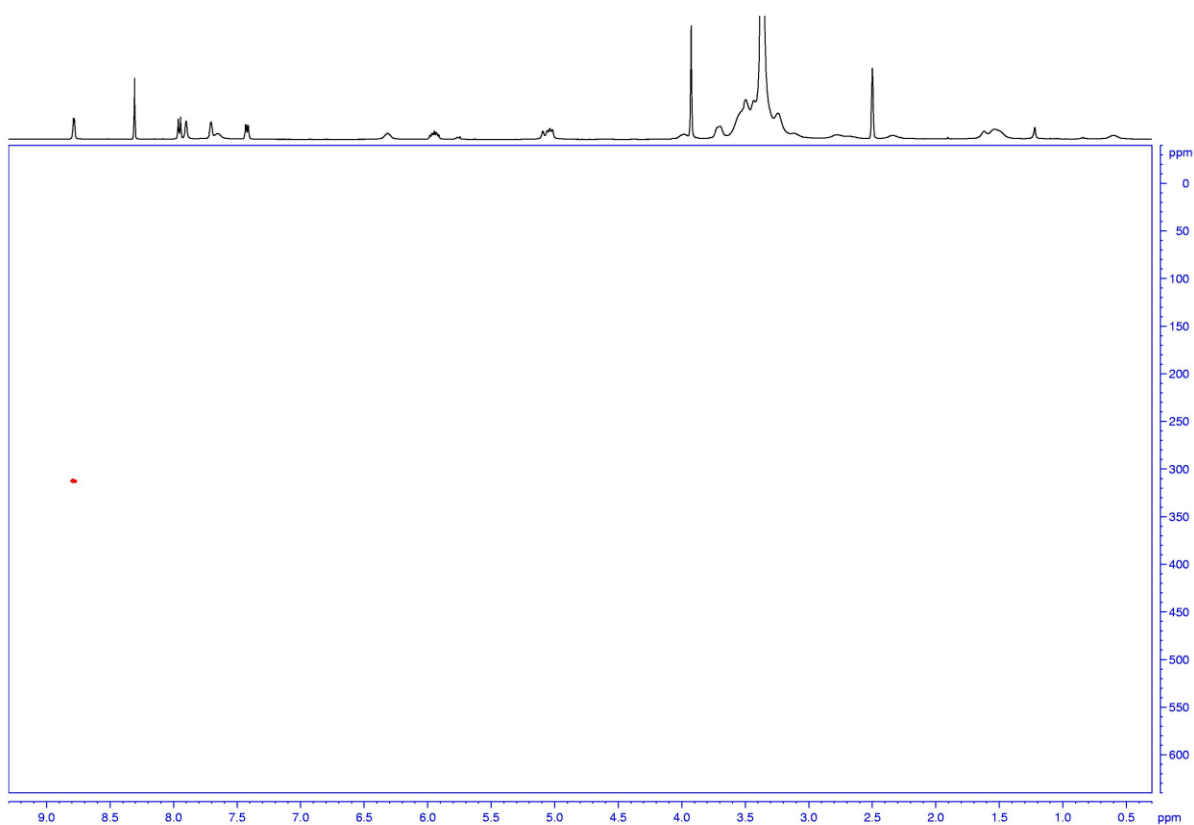
**Figure S37.**  $^1\text{H}$ -gs-COSY NMR spectrum of catalyst **Q6** ( $\text{DMSO-d}_6$ )



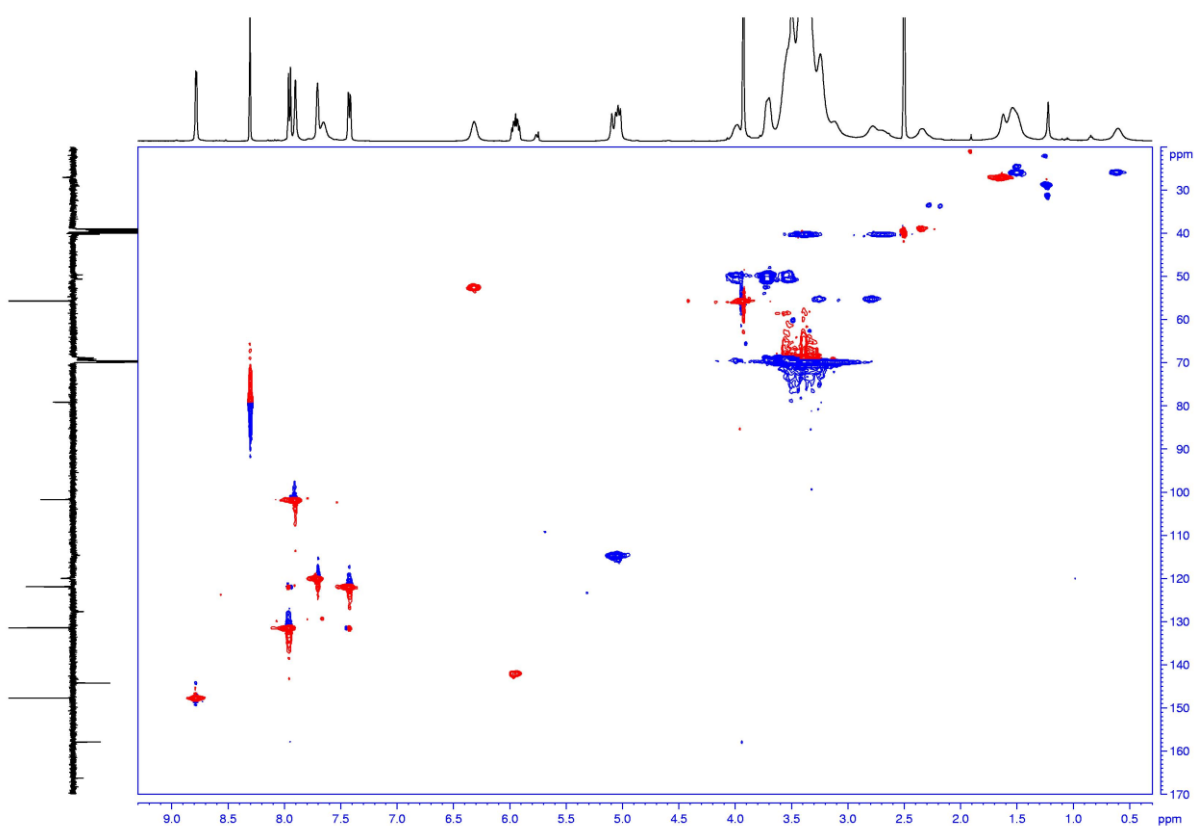
**Figure S38.**  $^{13}\text{C}$  DEPTQ NMR spectrum of catalyst **Q6** (DMSO- $\text{d}_6$ )



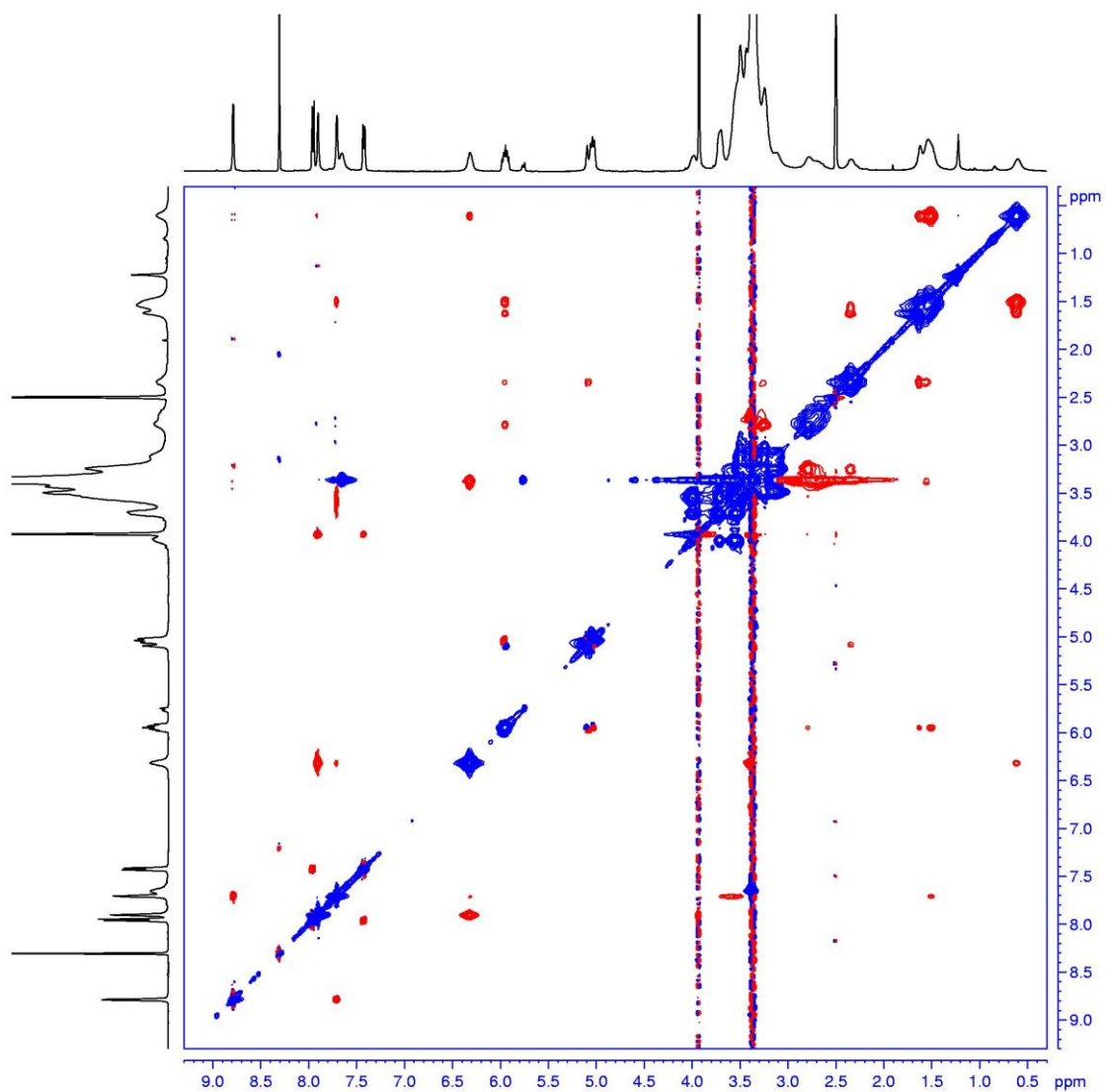
**Figure S39.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HMBC NMR spectrum of catalyst **Q6** (DMSO- $\text{d}_6$ )



**Figure S40.**  $^1\text{H}$ ,  $^{15}\text{N}$ -gs-HMBC NMR spectrum of catalyst **Q6** ( $\text{DMSO-d}_6$ )

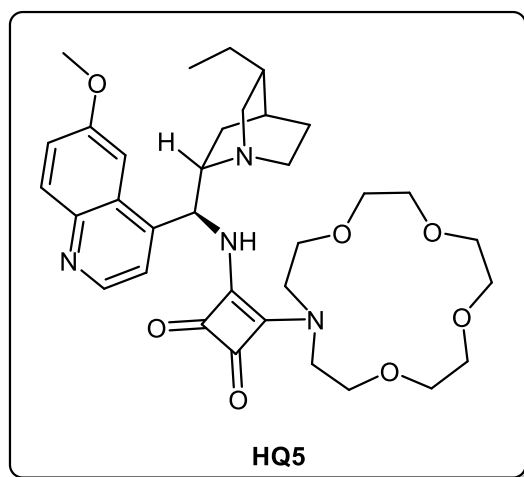


**Figure S41.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HSQC NMR spectrum of intermediate **Q6** ( $\text{DMSO-d}_6$ )

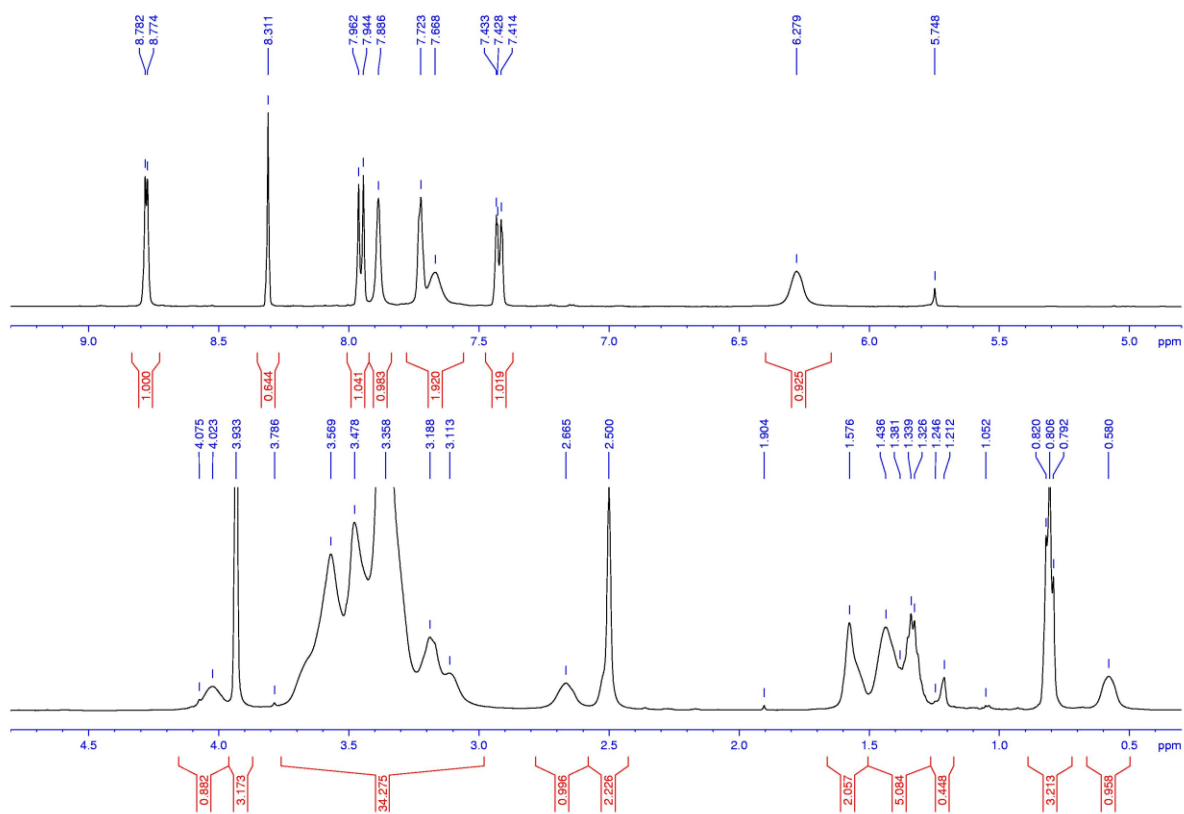


**Figure S42.**  $^1\text{H}$ ,  $^1\text{H}$ -gs-ROESY NMR spectrum of intermediate **Q6** ( $\text{DMSO-d}_6$ )

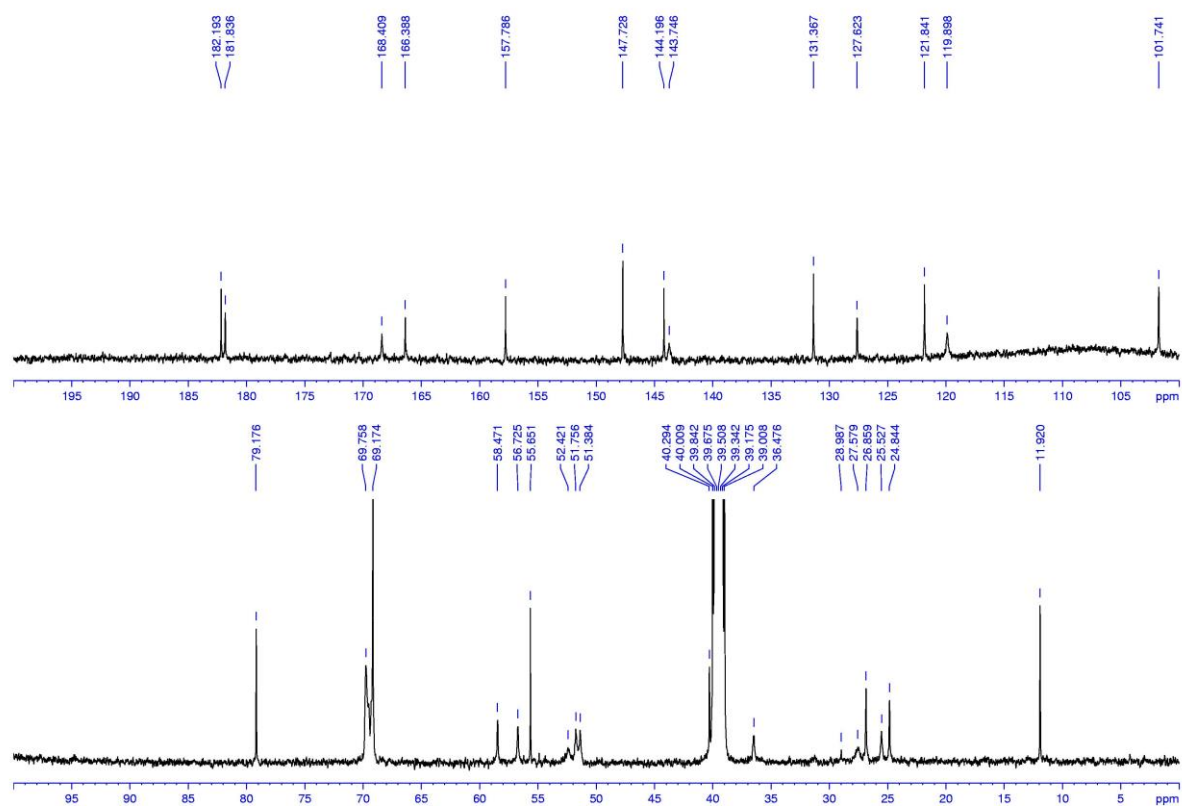
NMR spectra of catalyst **HQ5**



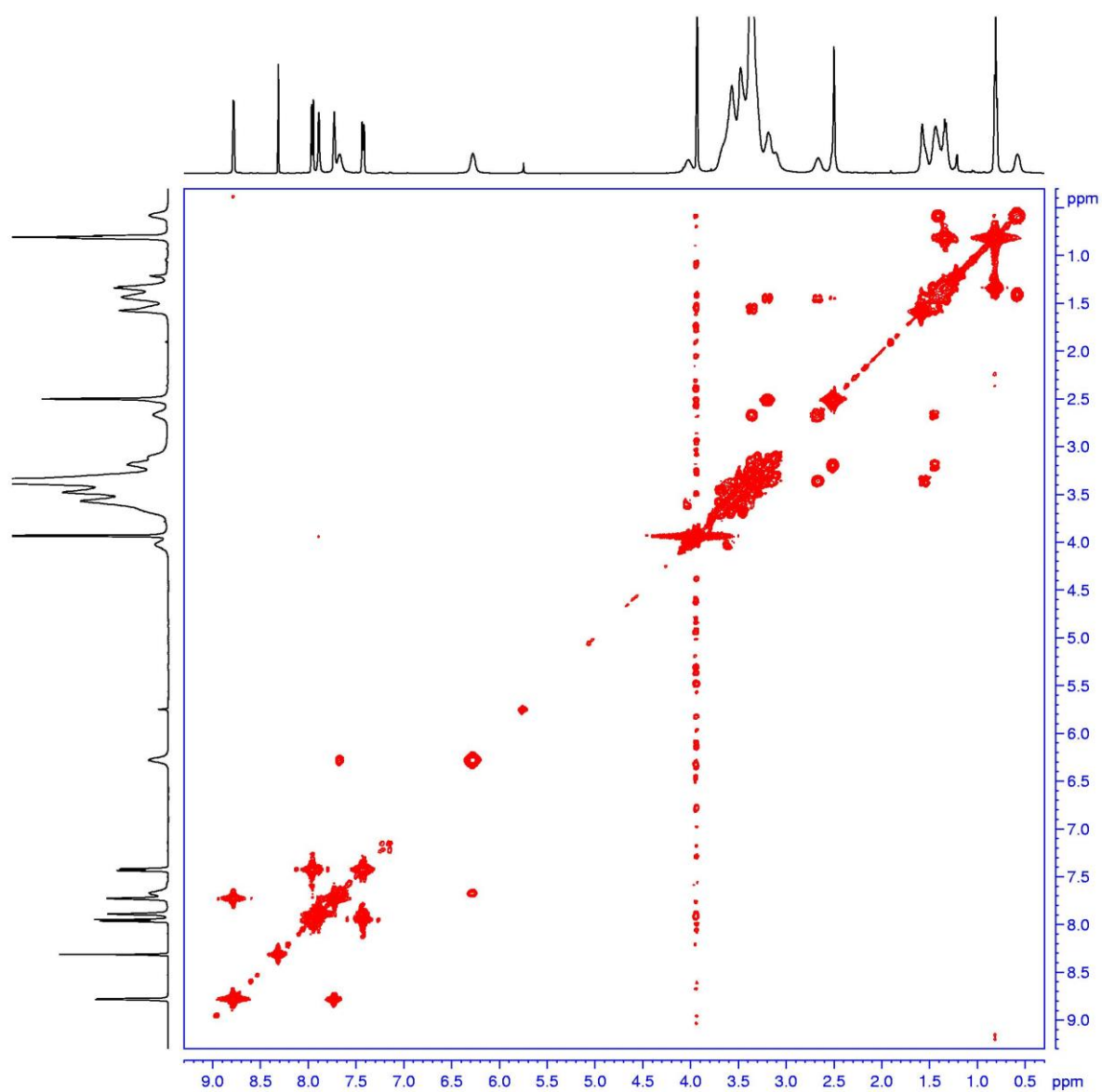
**Figure S43.** Molecule structure of catalyst **HQ5**



**Figure S44.** <sup>1</sup>H NMR spectrum of catalyst **HQ5** (500.13 MHz, DMSO-d<sub>6</sub>)

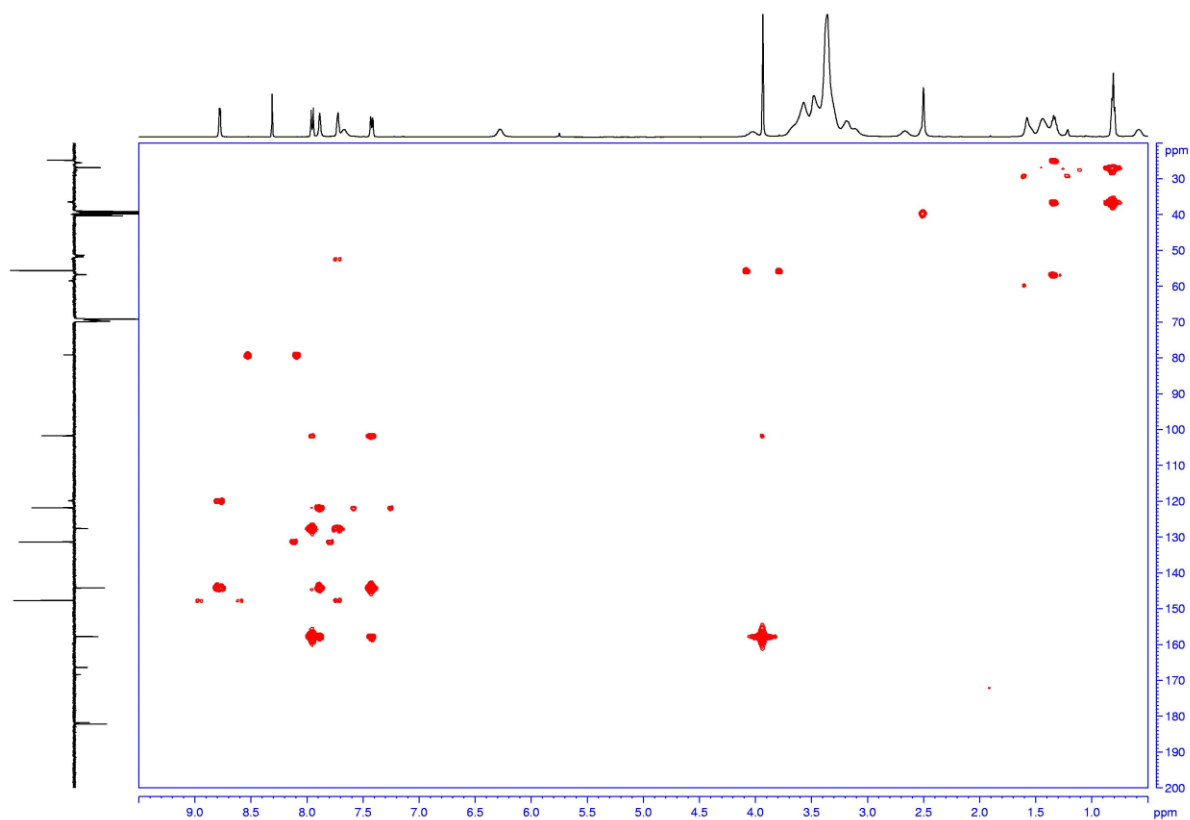
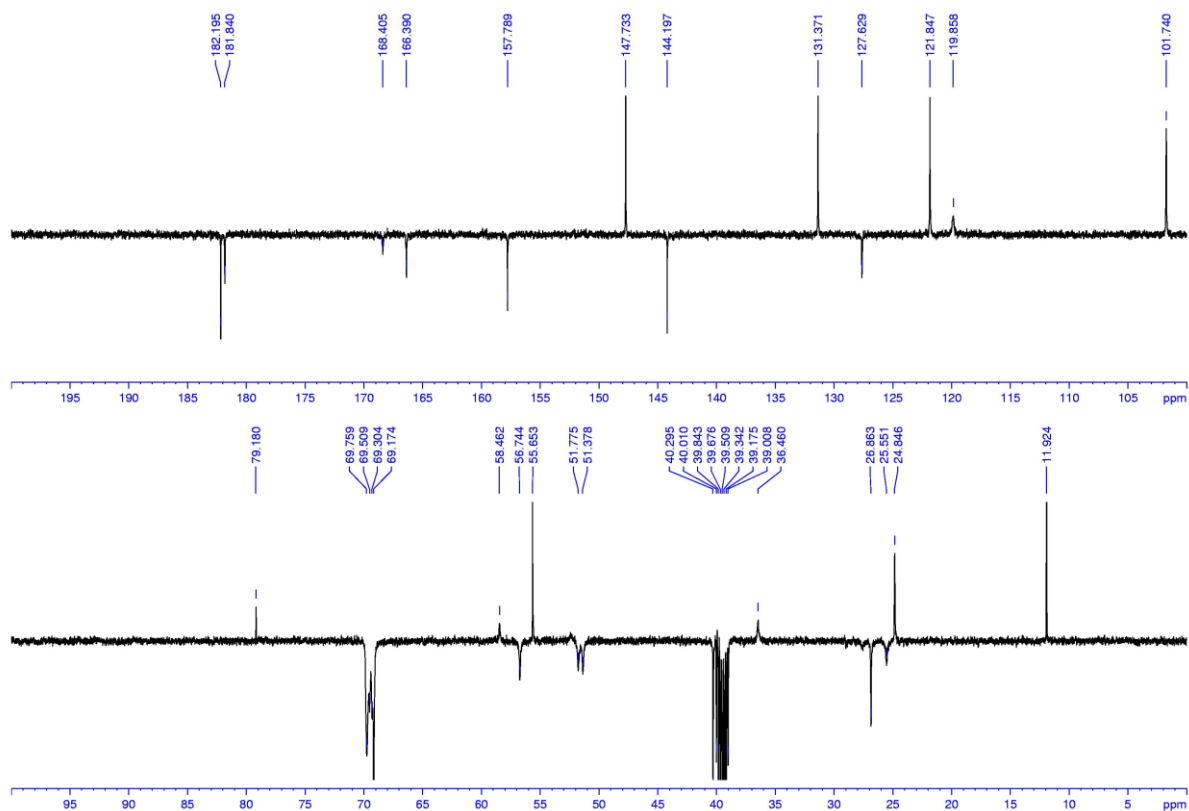


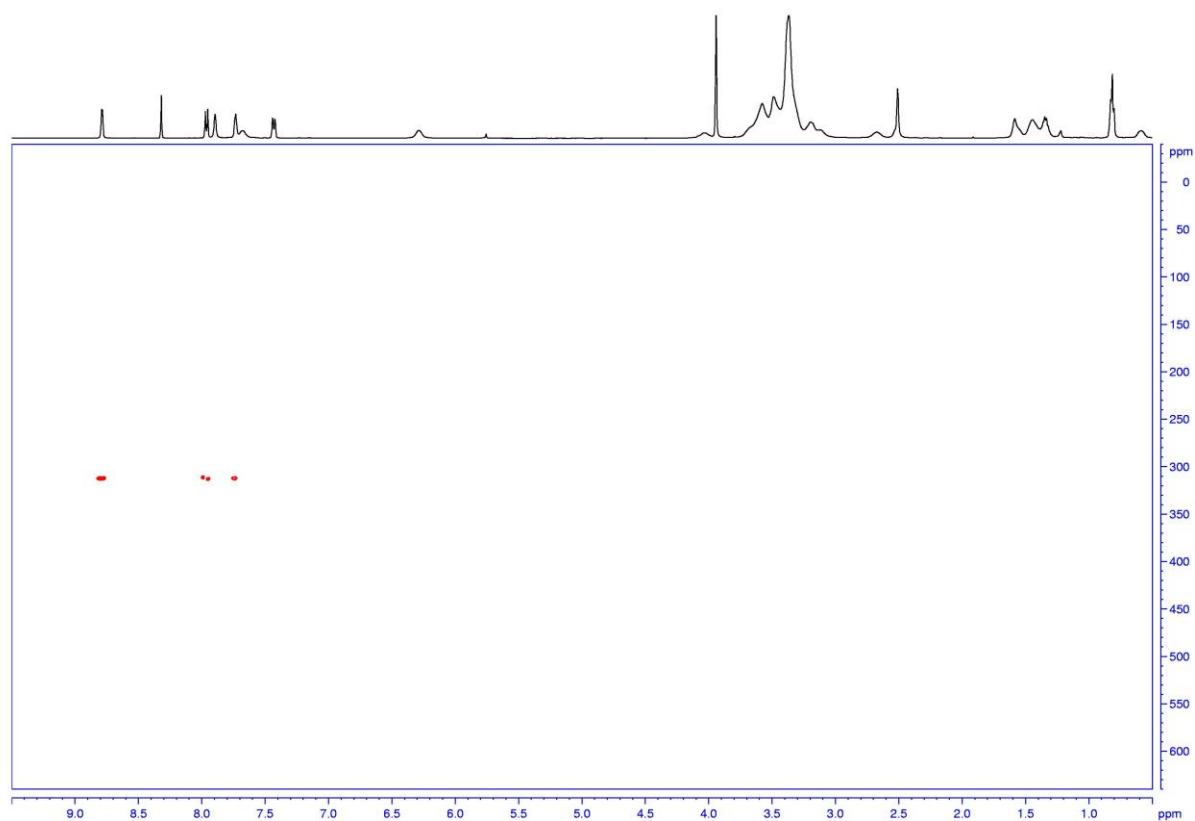
**Figure S45.** <sup>13</sup>C NMR spectrum of catalyst **HQ5** (125.76 MHz, DMSO-d<sub>6</sub>)



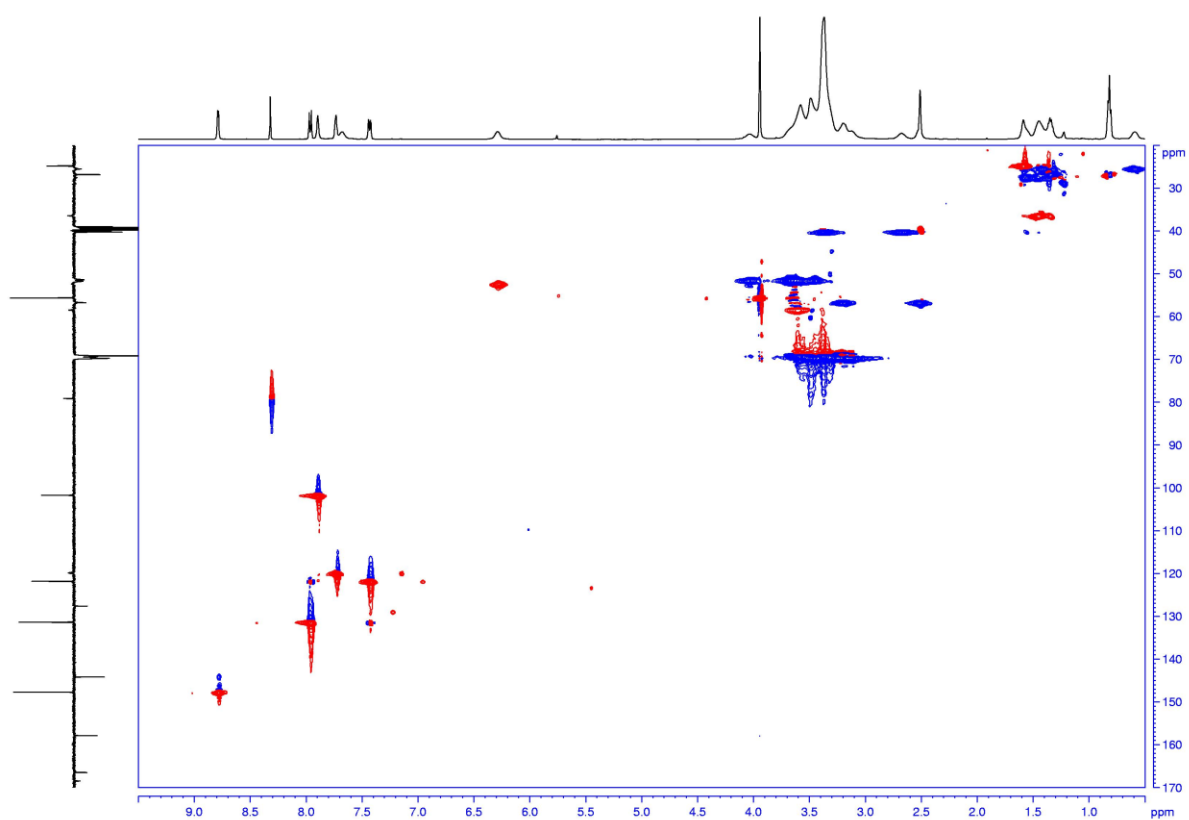
**Figure S46.**  $^1\text{H}$ -gs-COSY NMR spectrum of catalyst **HQ5** ( $\text{DMSO-d}_6$ )



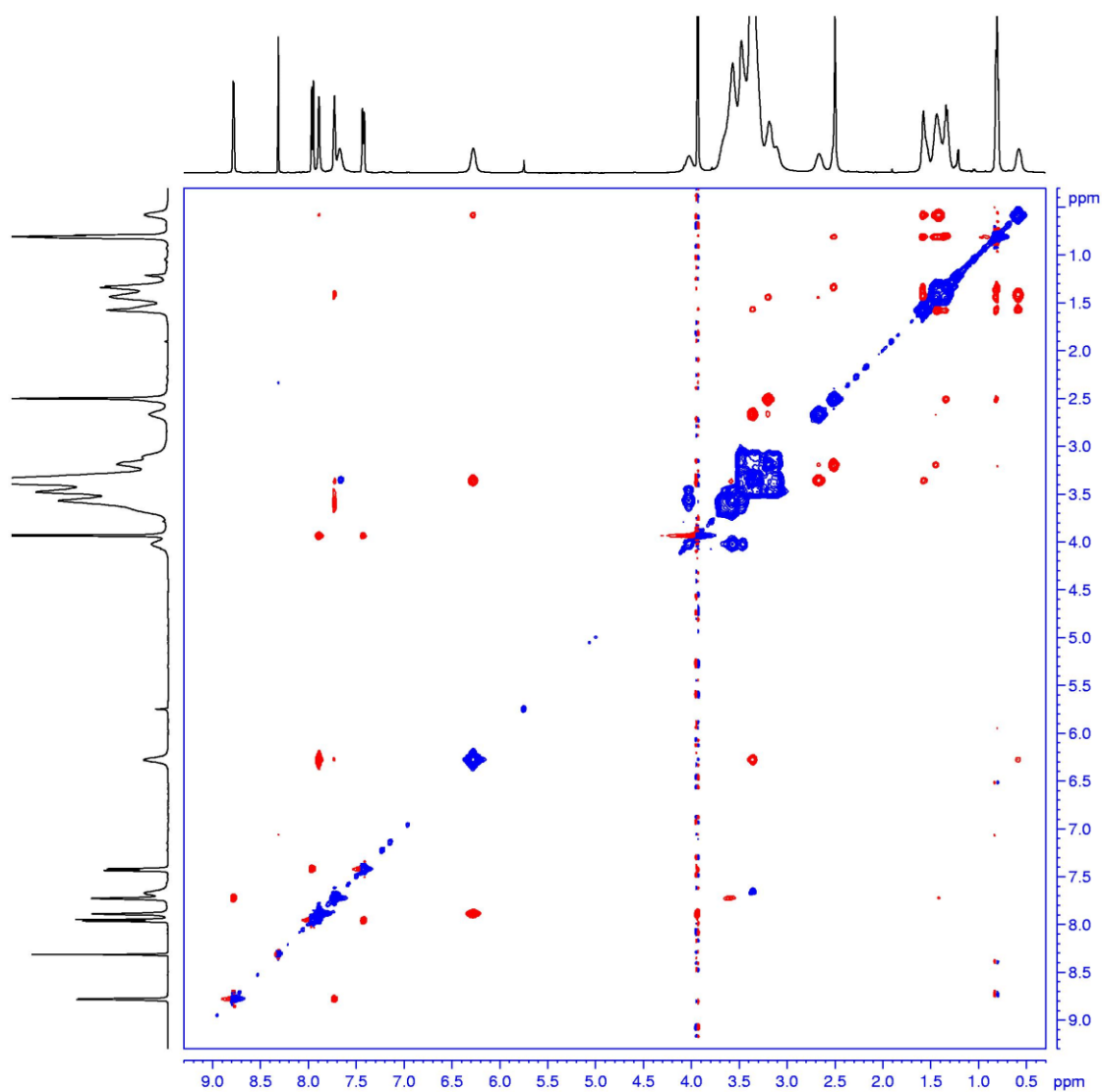




**Figure S49.**  $^1\text{H}$ ,  $^{15}\text{N}$ -gs-HMBC NMR spectrum of catalyst **HQ5** ( $\text{DMSO-d}_6$ )

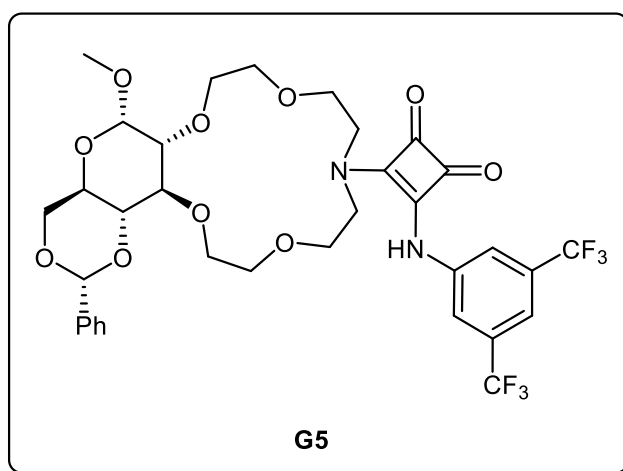


**Figure S50.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HSQC NMR spectrum of intermediate **HQ5** ( $\text{DMSO-d}_6$ )

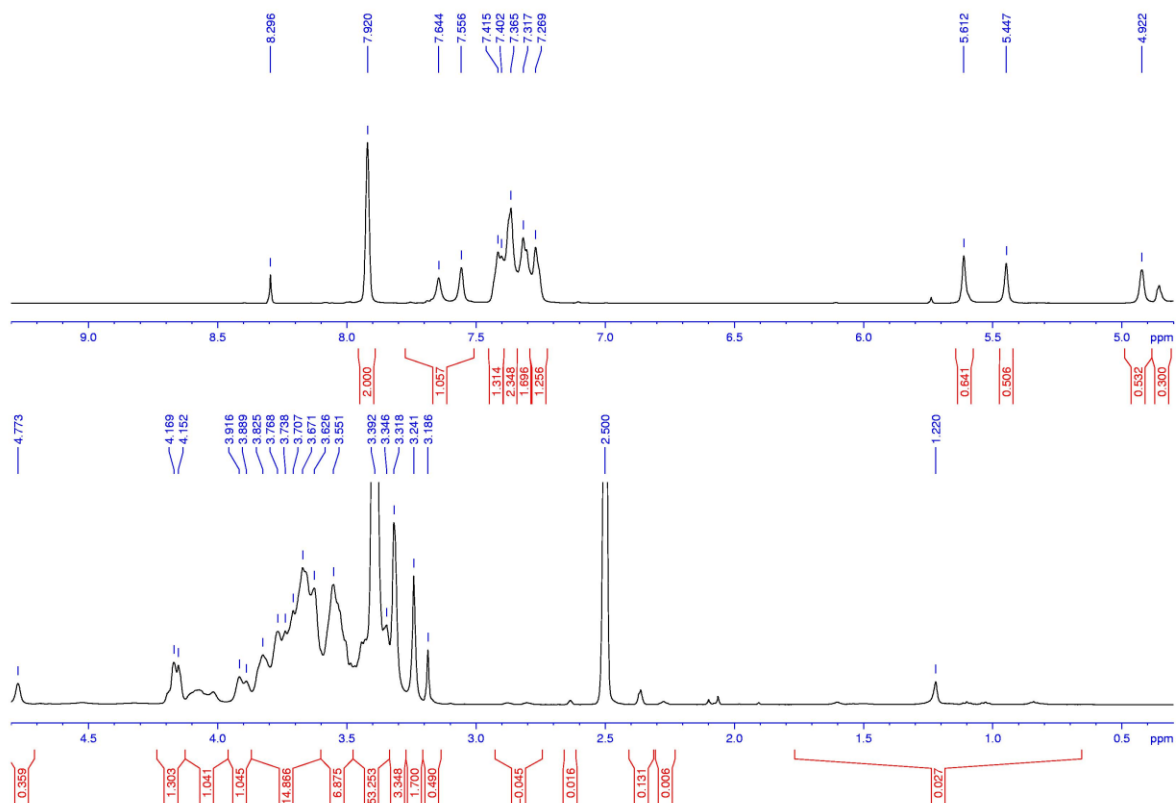


**Figure S51.**  $^1\text{H}$ ,  $^1\text{H}$ -gs-ROESY NMR spectrum of intermediate **HQ5** ( $\text{DMSO-d}_6$ )

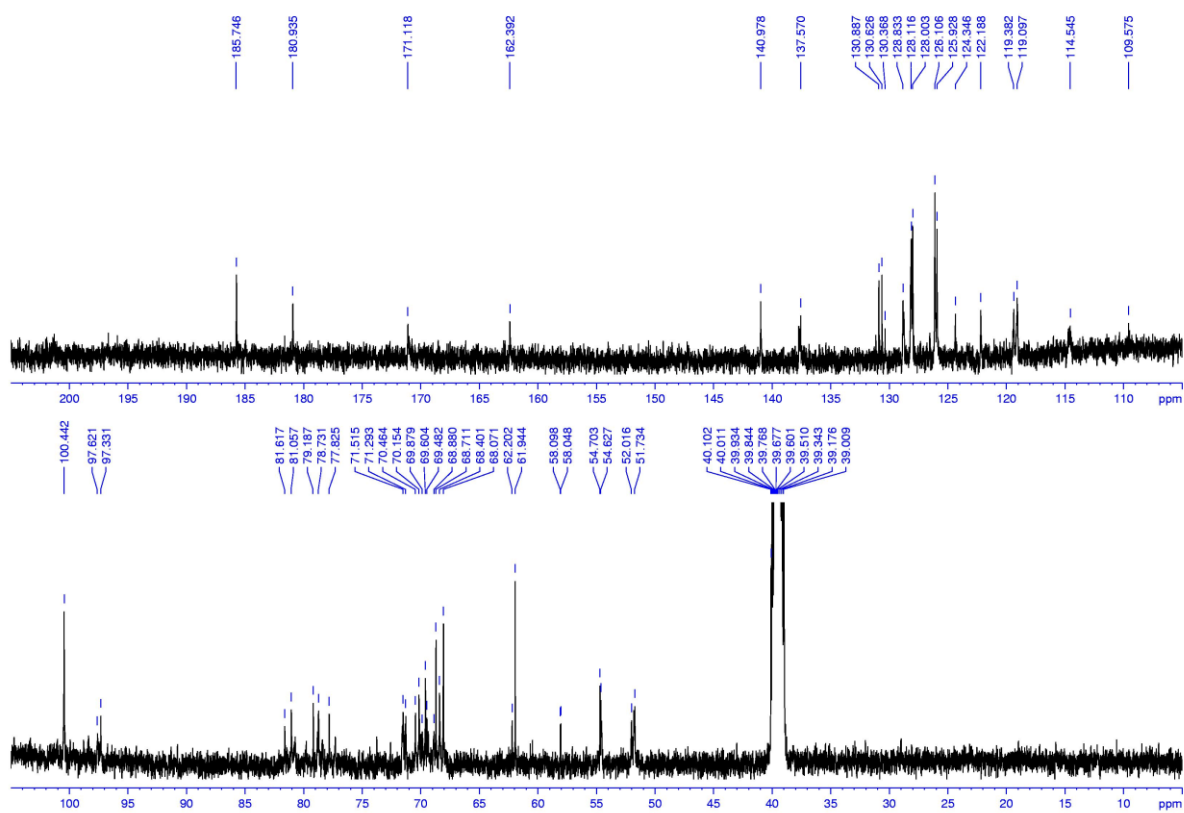
NMR spectra of catalyst **G5**



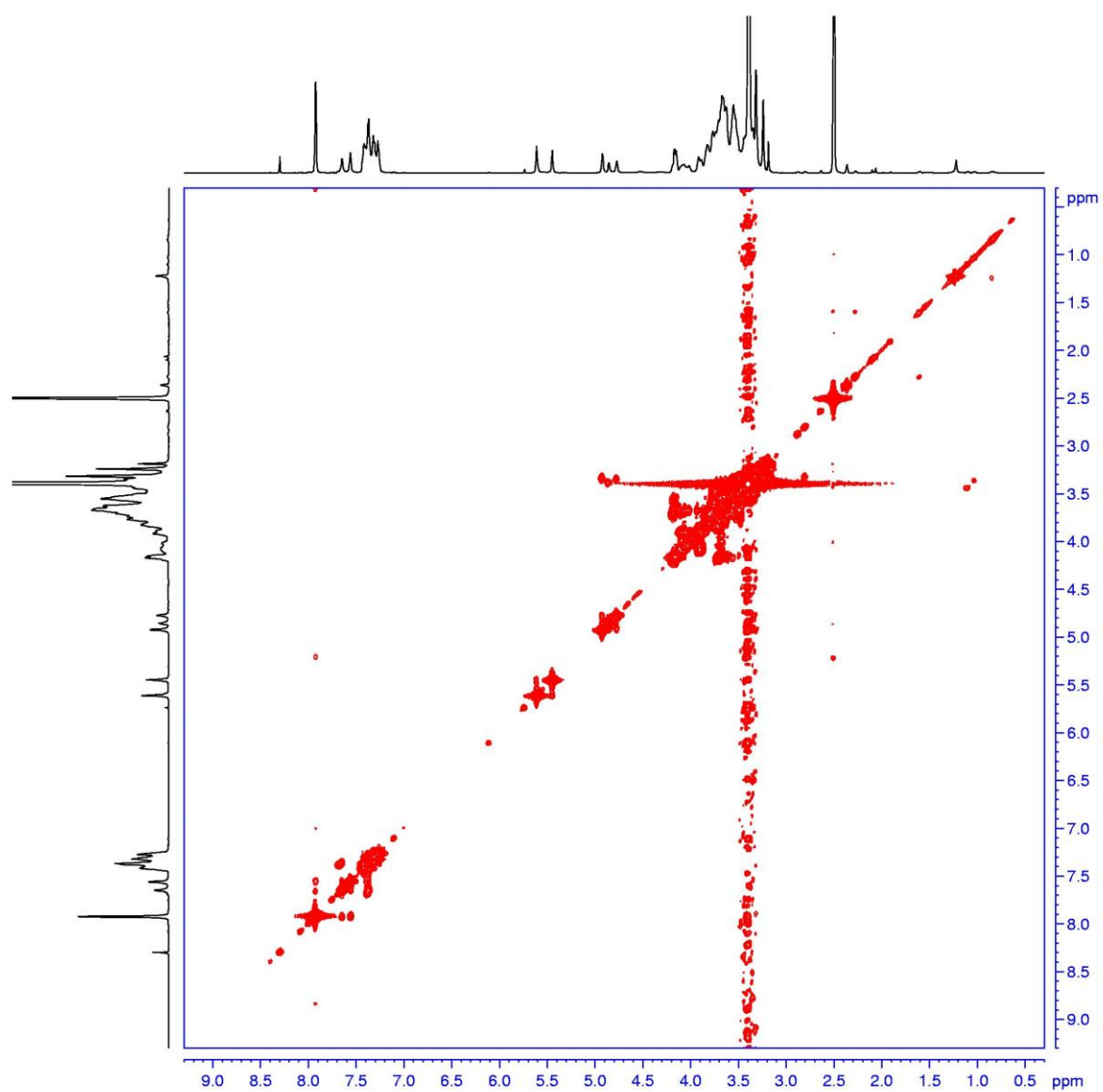
**Figure S52.** Molecule structure of catalyst **G5**



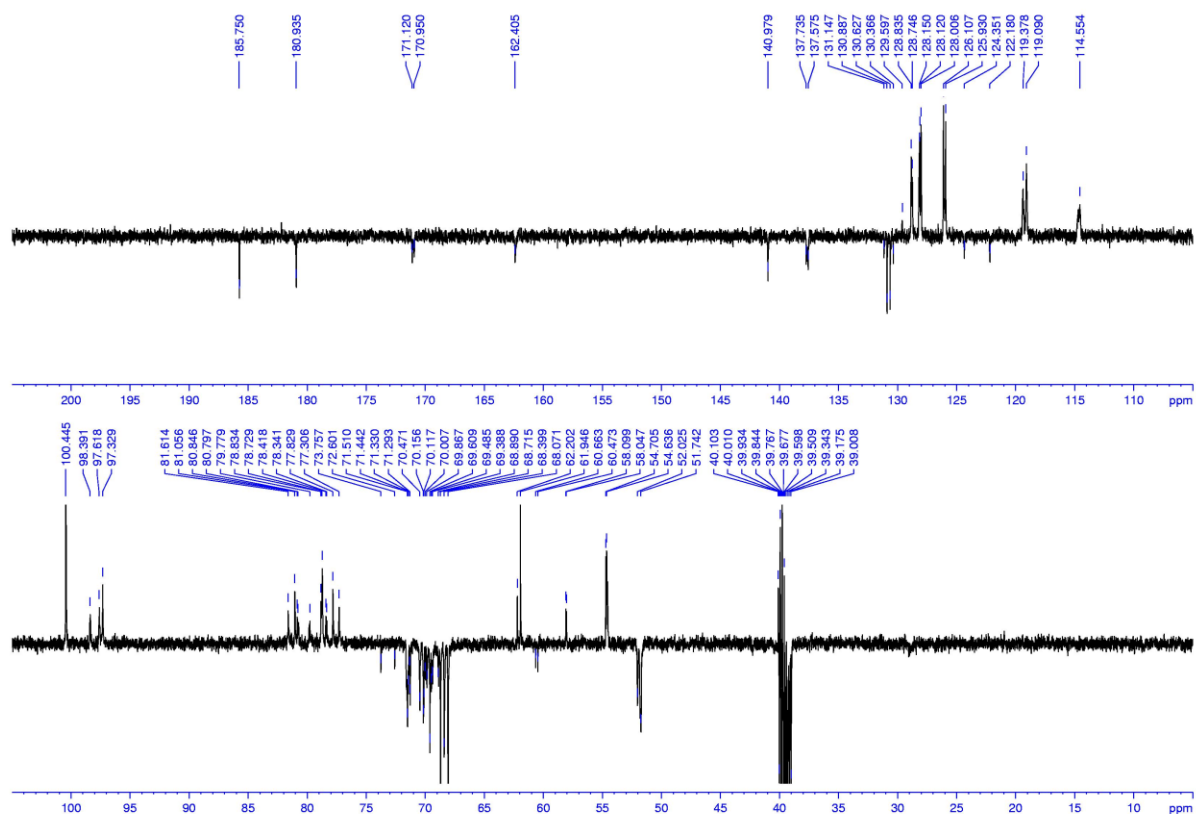
**Figure S53.**  $^1\text{H}$  NMR spectrum of catalyst **G5** (500.13 MHz,  $\text{DMSO-d}_6$ )



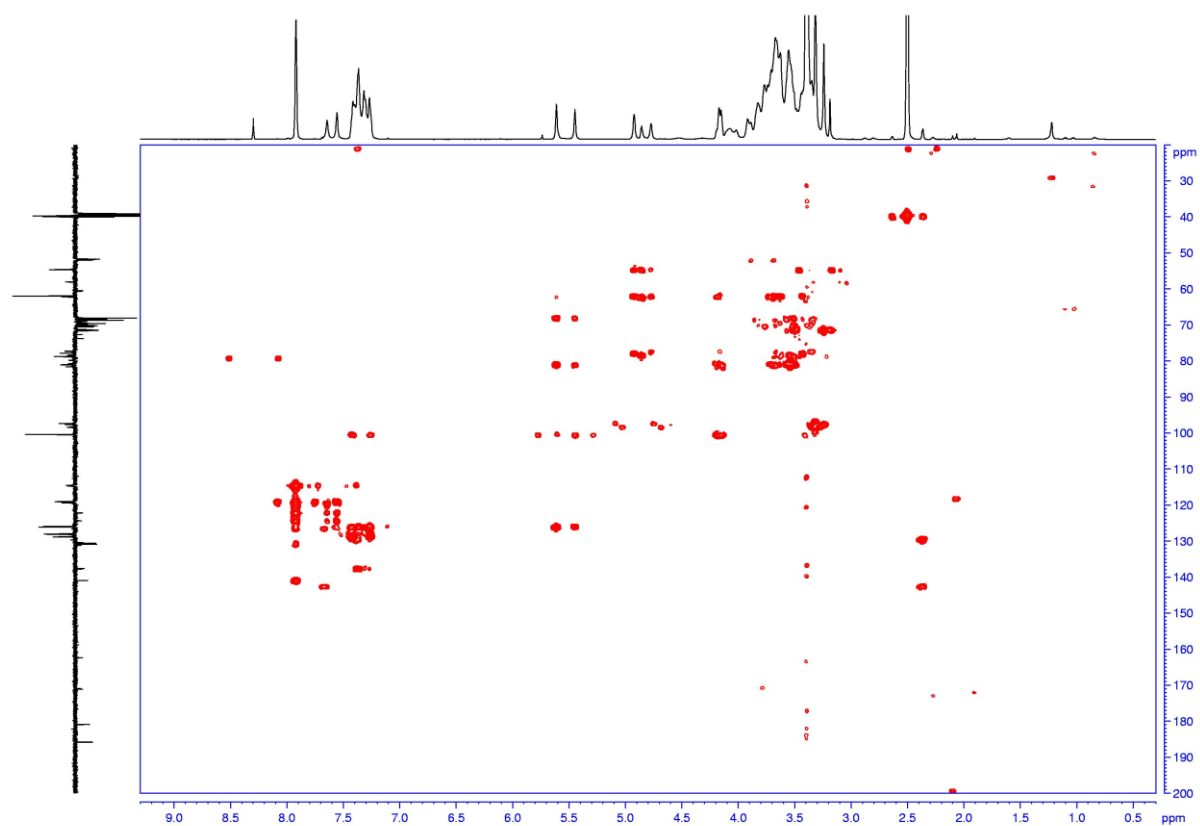
**Figure S54.**  $^{13}\text{C}$  NMR spectrum of catalyst **G5** (125.76 MHz,  $\text{DMSO-d}_6$ )



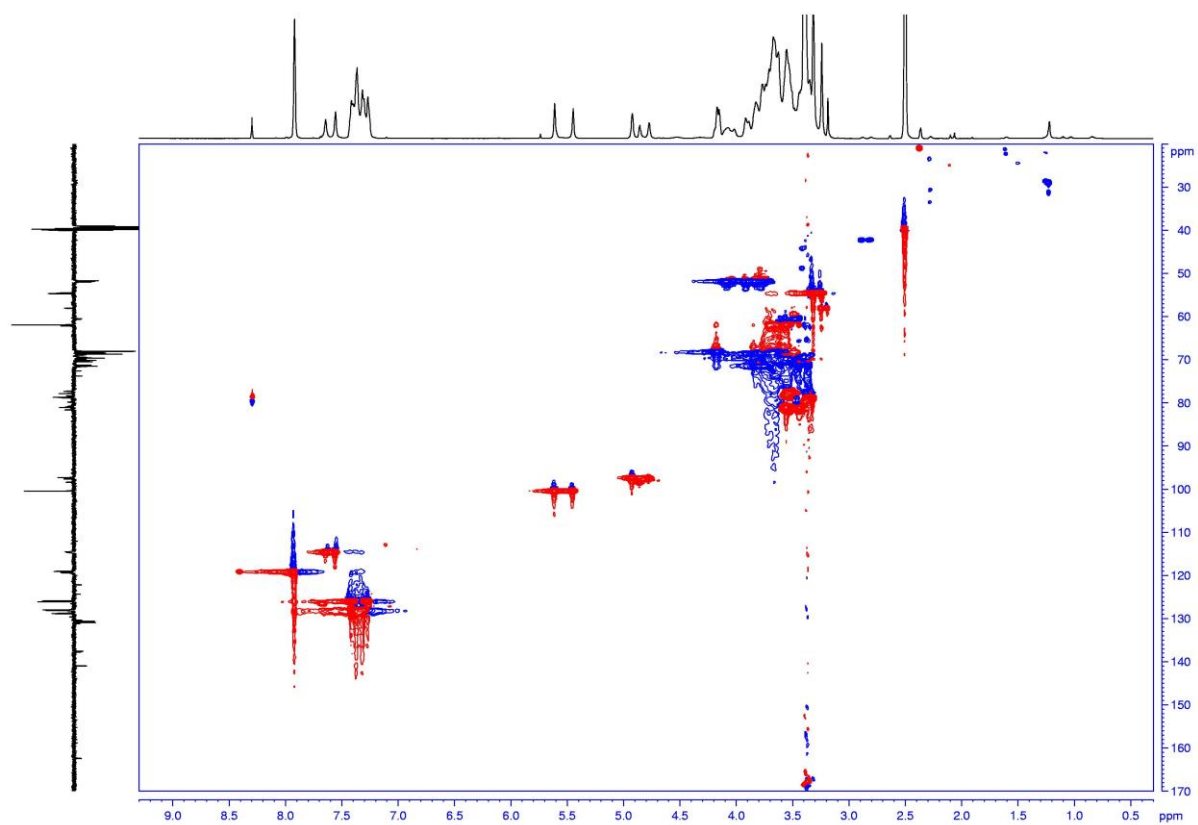
**Figure S55.**  $^1\text{H}$ -gs-COSY NMR spectrum of catalyst **G5** ( $\text{DMSO-d}_6$ )



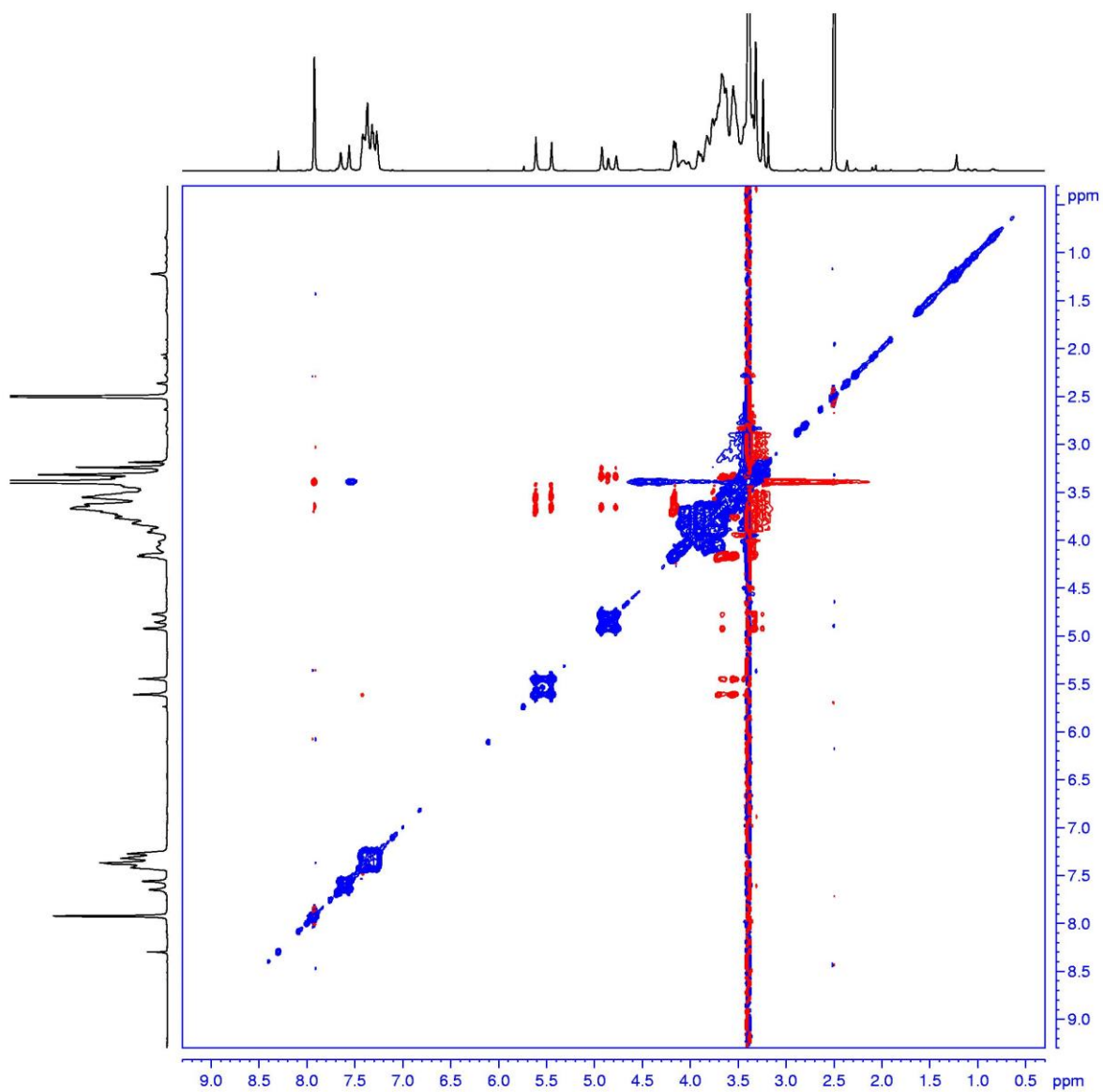
**Figure S56.**  $^{13}\text{C}$  DEPTQ NMR spectrum of catalyst **G5** ( $\text{DMSO-d}_6$ )



**Figure S57.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HMBC NMR spectrum of catalyst **G5** ( $\text{DMSO-d}_6$ )



**Figure S58.**  $^1\text{H}$ ,  $^{13}\text{C}$ -gs-HSQC NMR spectrum of intermediate **G5** ( $\text{DMSO-d}_6$ )



**Figure S59.**  $^1\text{H}$ ,  $^1\text{H}$ -gs-ROESY NMR spectrum of intermediate **G5** ( $\text{DMSO-d}_6$ )

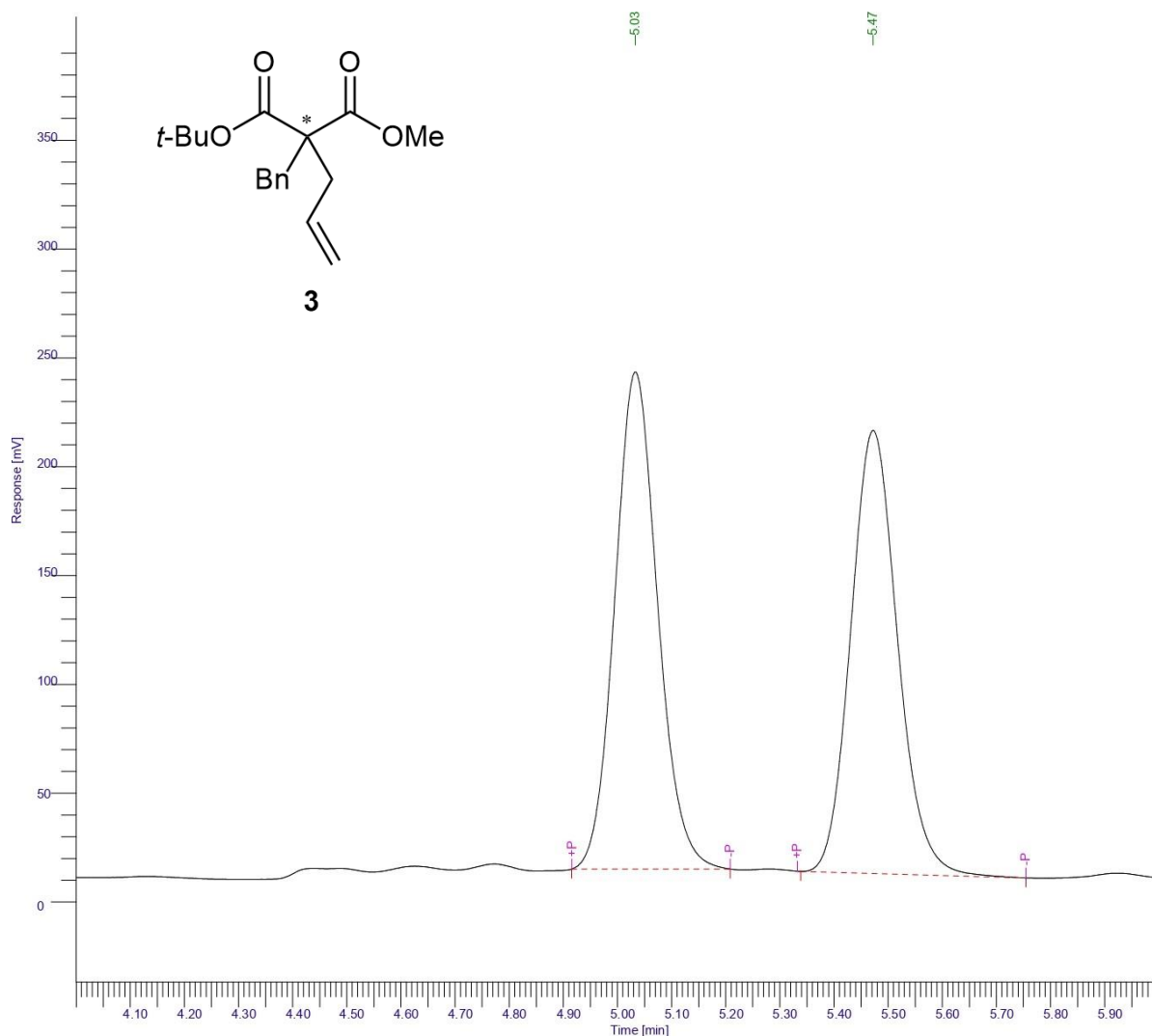


## 2. HPLC chromatograms

Product **3** of  $\alpha$ -alkylation reaction

Method: Phenomenex Lux<sup>®</sup> 5  $\mu$ m Cellulose-2 (250  $\times$  4.6 mm ID), hexane/ethanol 95:5, 0.8 mL min<sup>-1</sup>, 20 °C,  $\lambda$ =254 nm

HPLC chromatogram of racemic mixture



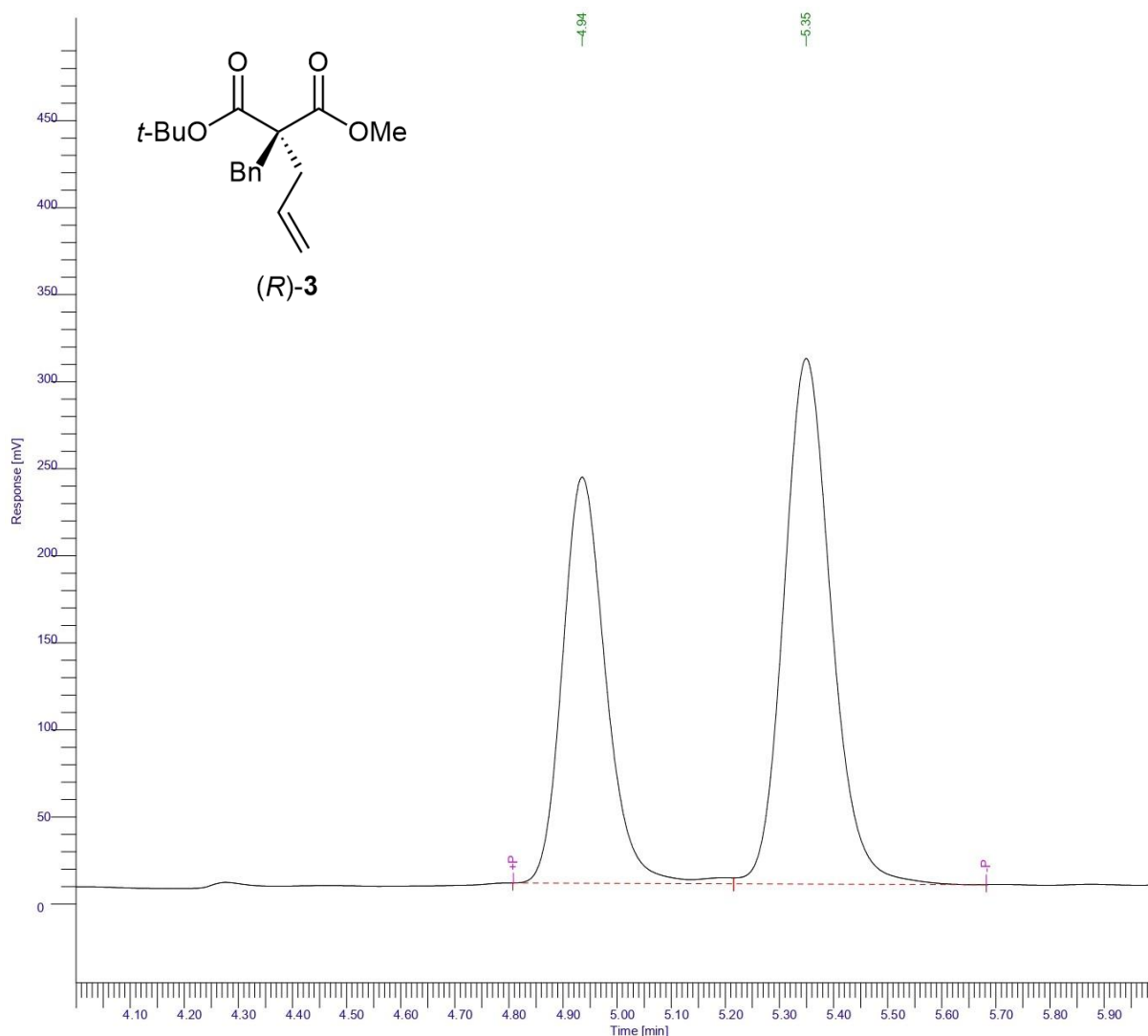
**Figure S60.** HPLC chromatogram of the racemic mixture of product **3**

**Table S1.** HPLC chromatogram peaks of the racemic mixture of product **3**

Peak #	Time [min]	Area [ $\mu$ V·s]	Height [ $\mu$ V]	Area [%]
1	5.033	1255114.36	228333.54	50.70
2	5.472	1220626.56	203554.28	49.30
		2475740.92	431887.81	100.00

HPLC chromatogram of product **3** with catalyst **C5** (17% ee)

Reaction conditions: *tert*-butyl methyl  $\alpha$ -benzylmalonate (1 eq), allyl iodide reagent (1.2 eq), **C5** catalyst (10 mol%), 50% aq. KOH base (50 eq), 2.4 mL DCM solvent, 0 °C, 24 h reaction time.



**Figure S61.** HPLC chromatogram of product (*R*)-**3** (17% ee)

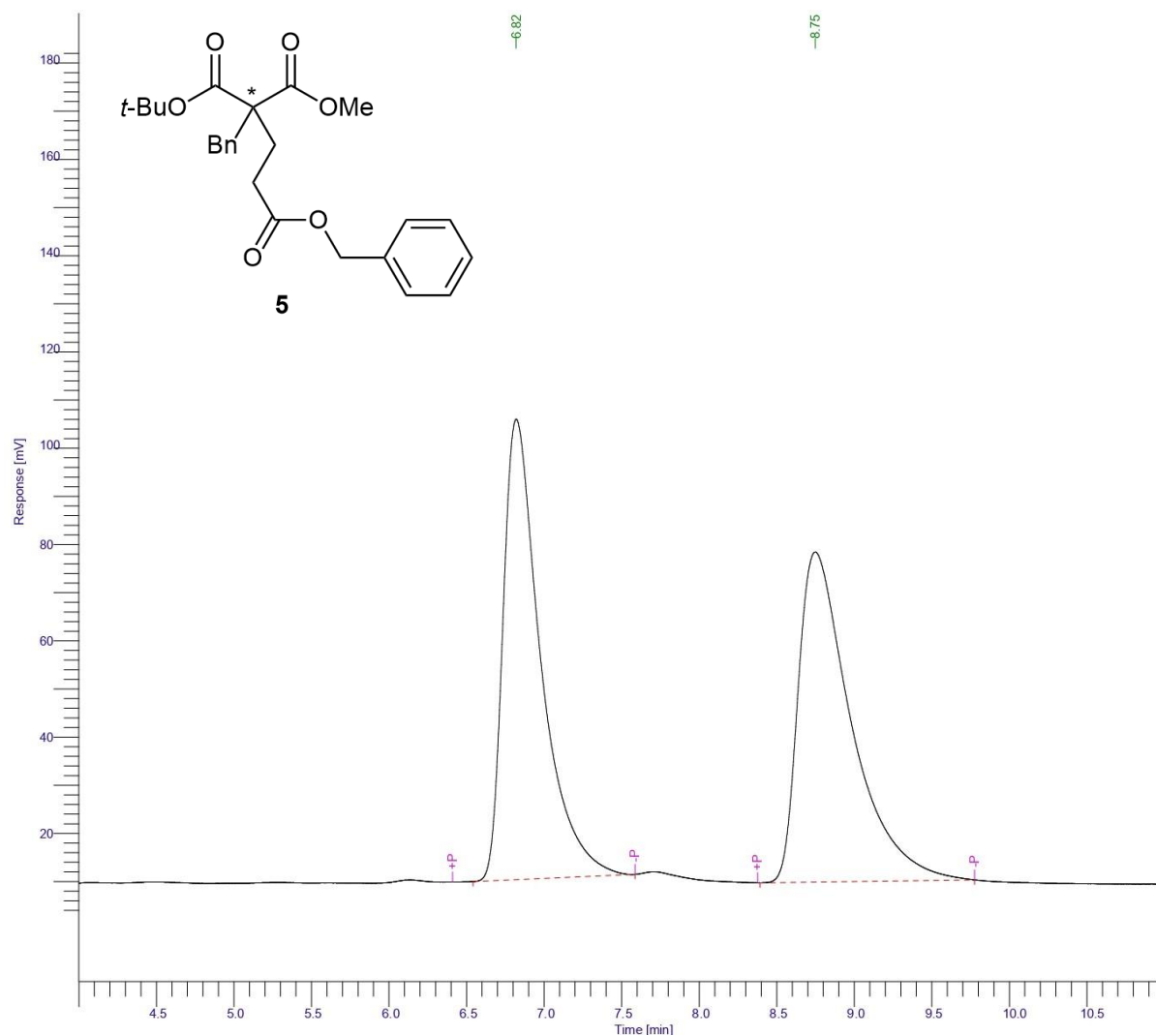
**Table S2.** HPLC chromatogram peaks of product (*R*)-**3** (17% ee)

Peak #	Time [min]	Area [ $\mu\text{V}\cdot\text{s}$ ]	Height [ $\mu\text{V}$ ]	Area [%]
1	4.935	1299138.74	233277.90	41.47
2	5.349	1833377.33	301912.66	58.53
		3132516.08	535190.57	100.00

## Product **5** of *Michael* addition reaction

Method: Kromasil® 5 µm AmyCoat® (250 × 4.6 mm ID), hexane/ethanol 85:15, 0.8 mL min<sup>-1</sup>, 20 °C, λ=254 nm

HPLC chromatogram of racemic mixture



**Figure S62.** HPLC chromatogram of the racemic mixture of product **5**

**Table S3.** HPLC chromatogram peaks of the racemic mixture of product **5**

Peak #	Time [min]	Area [µV·s]	Height [µV]	Area [%]
1	6.820	1609853.73	95671.16	49.79
2	8.749	1623189.02	68560.60	50.21
		3233042.75	164231.76	100.00