

## Supporting Information

### **Air/Water-Stable Tridentate NHC-Pd<sup>II</sup> Complex: Catalytic C-H Activation of Hydrocarbons *via* H/D Exchange Process in D<sub>2</sub>O**

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## **General information**

All commercially available reagents and solvents were used as received by Aldrich and Acros chemical without further purification. Prior to use, dichloromethane was distilled from calcium hydride.  $^1\text{H}$  and  $^{13}\text{C}$  NMR spectra were recorded on a 250 and 63MHz Bruker instrument and H/D exchange experiment were recorded on a 400MHz Varian instrument. Chemical shifts were reported in ppm relative to TMS for  $^1\text{H}$ - and  $^{13}\text{C}$ -NMR spectra and  $\text{CD}_3\text{OD}$ ,  $\text{CDCl}_3$  and  $\text{D}_2\text{O}$  were used as the NMR solvent. Thin-layer chromatography (TLC) was performed using commercially prepared 60 mesh silica gel plates visualized with short-wavelength UV light (254 nm). Silica gel 60 (9385, 230-400 mesh) was used for column chromatography. The reported yields are isolated yields. Elemental analysis was performed by Atlantic Microlab, Inc. (Norcross, GA). HRMS analyses were performed by the Analytical Chemistry Instrumentation Facility at University of California Riverside.

## **Preparation of Ligand and Pd-Complex**

**2-Benzimidazol-1-yl-*N*-(2-methoxy-ethyl)acetamide (5a) and 2-Benzimidazol-1-yl-*N*-(1-benzyloxymethyl-2-methyl-propyl)acetamide (5b).** Bromoacetyl bromide (0.92 mL, 10.6 mmol) was added to a mixture of 2-methoxyethyl amine (**4a**) (0.92 mL, 10.6 mmol) and TEA (2.94 mL, 21.1 mmol) in  $\text{CH}_2\text{Cl}_2$  (30 mL) at 0 °C. After stirring for 4 hours at 0 °C, the reaction mixture was washed with water, and the separated aqueous layer was extracted with  $\text{CH}_2\text{Cl}_2$  (50 mL). The combined organic layers were washed with brine, dried over anhydrous  $\text{Na}_2\text{SO}_4$  and evaporated to give the corresponding  $\alpha$ -bromoacetyl amide compound, which was used for the next step without further purification. To a solution of benzimidazole (1.03 g, 8.69 mmol) in DMF (10 mL) was added  $\alpha$ -bromoacetyl amide compound (1.70 g, 8.69 mmol) followed by KOH (730 mg, 13.03 mmol). After stirring the reaction mixture for 16 h at room temperature, EtOAc (70 mL) was added. Subsequently, a precipitated solid was removed by filtration. The filtrated organic layers were washed with brine twice, dried over anhydrous  $\text{Na}_2\text{SO}_4$  and then concentrated under reduced pressure to give a crude oil, which was purified by column chromatography on silica gel using EtOAc followed by MeOH as an eluent to afford **5a** as a white solid (1.62 g, 80 % yield).  $^1\text{H}$ -NMR ( $\text{CDCl}_3$ ):  $\delta$  8.14 (s, 1H), 7.71-7.68 (m, 1H), 7.45-7.43 (m, 1H), 7.31-7.27 (m, 2H), 4.96 (s, 1H), 4.91 (s, 2H), 3.45-3.37 (m, 4H), 3.32 (s, 3H);  $^{13}\text{C}$ -NMR ( $\text{CD}_3\text{OD}$ ):  $\delta$  168.9, 145.6, 143.7, 135.2, 124.3, 123.6, 120.0, 111.2, 71.6, 58.8, 48.0, 40.3; HRMS-ESI (m/z) [ $\text{M}^+$ ] calcd. for  $\text{C}_{12}\text{H}_{15}\text{N}_3\text{O}_2$ : 233.1164, found: 233.1159

Following the above procedure with **4b** (2.0 g, 10.3 mmol) and bromoacetyl bromide (0.90 mL, 10.3 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (30 mL) to afford  $\alpha$ -bromoacetyl amide compound (2.46 g, 7.83 mmol, 76 % yield for **4b**) and N-alkylation with benzimidazole (925 mg, 7.83 mmol) to give desired product **5b** (2.28 g, 83 % yield). <sup>1</sup>H-NMR (CDCl<sub>3</sub>):  $\delta$  7.88 (s, 1H), 7.85-7.81 (m, 1H), 7.35-7.26 (m, 6H), 7.10-7.06 (m, 2H), 5.74 (brd, 1H), 4.83 (s, 2H), 4.27 (s, 2H), 3.85 (m, 1H), 3.46-3.41 (ABX,  $J = 4.0$  Hz, 9.5 Hz, 2H), 3.32-3.27 (ABX,  $J = 3.5$  Hz, 9.25 Hz, 2H), 1.75 (m, 1H), 0.80 (d,  $J = 7.0$  Hz, 3H), 0.73 (d,  $J = 7.0$  Hz, 3H); HRMS-ESI (m/z) [M<sup>+</sup>] calcd. for C<sub>21</sub>H<sub>25</sub>N<sub>3</sub>O<sub>2</sub>: 351.1947, found: 351.1950

**3-[(2-Methoxy-ethylcarbamoyl)-methyl]-1-methyl-3H-benzimidazole iodide (6a) and 3-[(1-Benzyloxymethyl-2-methyl-propylcarbamoyl)-methyl]-1-methyl-3H-benzimidazole iodide (6b).** To a 300 mL round-bottom flask **5a** (1.50 g, 6.43 mmol), iodomethane (1.20 mL, 19.3 mmol) and THF (70 mL) were added. The reaction mixture was stirred under refluxing for 16 h. After cooling the mixture solution at room temperature, a white solid was filtrated and then washed with THF to give the desired product **6a** (2.01 g, 83 % yield). <sup>1</sup>H-NMR (CD<sub>3</sub>OD):  $\delta$  9.56 (s, 1H), 7.98 (d,  $J = 8.8$  Hz, 1H), 7.89 (d,  $J = 8.8$  Hz, 1H), 7.74-7.71 (m, 2H), 5.35 (s, 2H), 4.19 (s, 3H), 3.53-3.50 (m, 2H), 3.46-3.44 (m, 2H), 3.37 (s, 3H); <sup>13</sup>C-NMR (CD<sub>3</sub>OD):  $\delta$  168.9, 145.6, 143.7, 135.2, 124.4, 123.7, 123.6, 120.1, 111.2, 71.7, 58.8, 48.0, 40.3; HRMS-ESI (m/z) [M+H<sup>+</sup>] calcd. for C<sub>13</sub>H<sub>19</sub>IN<sub>3</sub>O<sub>2</sub><sup>+</sup> [M+H<sup>+</sup>]: 376.0522, found: 376.0515

Following the above procedure with **5b** (800 mg, 2.28 mmol) and iodomethane (425  $\mu$ L, 6.83 mmol) in THF (70 mL) to afford desired product **6b** (889 mg, 79 % yield) as white solid. <sup>1</sup>H-NMR (CD<sub>3</sub>OD):  $\delta$  9.54 (s, 1H), 8.49 (br, 1H), 7.96 (d,  $J = 8.5$  Hz, 1H), 7.79 (d,  $J = 8.5$  Hz, 1H), 7.70 (t,  $J = 7.5$  Hz, 1H), 7.59 (t,  $J = 7.5$  Hz, 1H), 7.34-7.29 (m, 5H), 5.36 (d,  $J = 7.2$  Hz, 2H), 4.53 (d,  $J = 2.25$  Hz, 2H), 4.16 (s, 3H), 3.91 (m, 1H), 3.59 (m, 2H), 1.93 (m, 1H), 0.97 (d,  $J = 2.5$  Hz, 3H), 0.94 (d,  $J = 2.5$  Hz, 3H); HRMS-ESI (m/z) calcd. for C<sub>22</sub>H<sub>29</sub>IN<sub>3</sub>O<sub>2</sub><sup>+</sup> [M+H<sup>+</sup>]: 494.1305, found: 494.1301

**Pd(II)-Ligand Complex 7a and 7b:** The suspension of benzimidazolium salt **6a** (500 mg, 1.33 mmol) and silver(I) oxide (154 mg, 0.66 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (30 mL) was stirred for 2 hours with exclusion of light at room temperature. The reaction mixture was concentrated under reduced pressure to give a dark-red solid. To a suspension of the silver complex in CH<sub>3</sub>CN (50 mL) was added PdCl<sub>2</sub>(CH<sub>3</sub>CN)<sub>2</sub> (345 mg, 1.33 mmol) with exclusion of light at room temperature. Then, the resulting suspension was stirred for 2 hours and filtered through a plug of glass fiber filter paper. The filtrate was evaporated to dryness in vacuo to afford product **7a** (409 mg, 79 % yield) as orange

color solid.;  $^1\text{H-NMR}$  ( $\text{CD}_3\text{OD}$ ):  $\delta$  7.63 (d,  $J = 7.2$  Hz, 1H), 7.51 (d,  $J = 7.2$  Hz, 1H) 7.40-7.36 (m, 2H), 5.62 (s, 2H), 4.35 (s, 3H), 3.45 (m, 2H), 3.39 (m, 2H), 3.32 (s, 3H);  $^{13}\text{C-NMR}$  ( $\text{CD}_3\text{OD}$ ):  $\delta$  167.3, 139.5, 134.7, 134.4, 123.6, 117.8, 110.6, 110.2, 70.2, 57.6, 50.6, 39.1, 34.2; HRMS-ESI ( $m/z$ ) [ $\text{M}^+$ ] calcd. for  $\text{C}_{13}\text{H}_{16}\text{ClN}_3\text{O}_2\text{Pd}$ : 386.9966, found: 386.9938

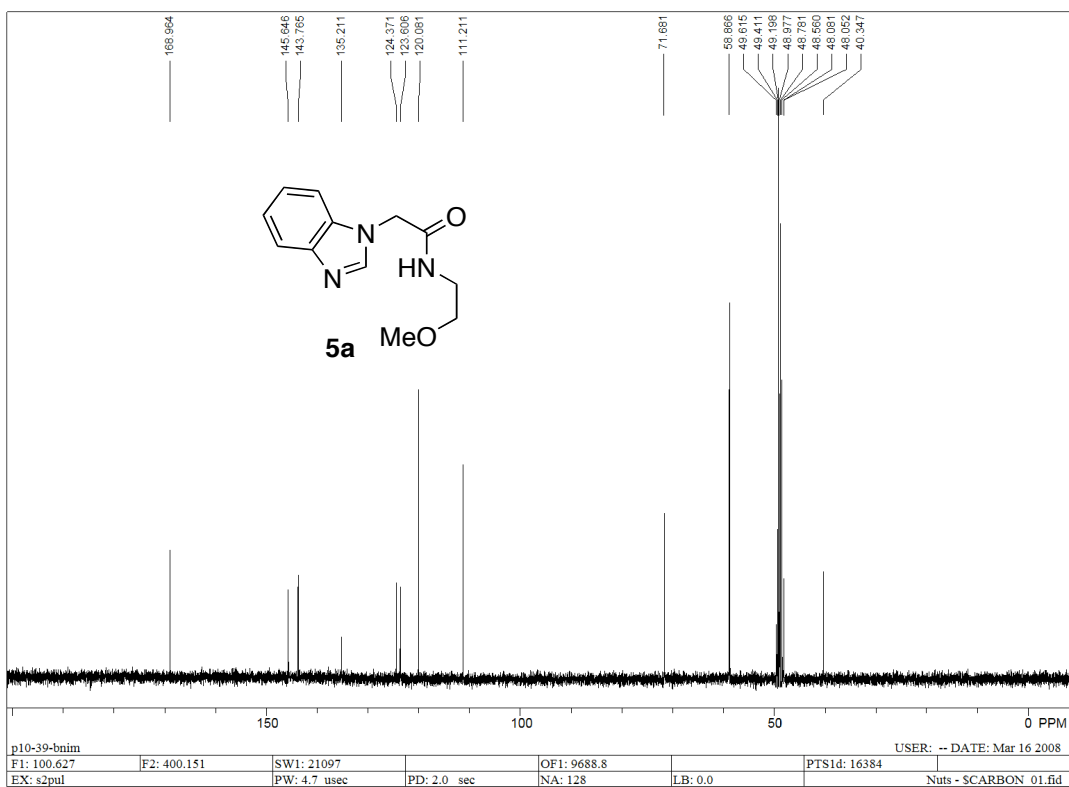
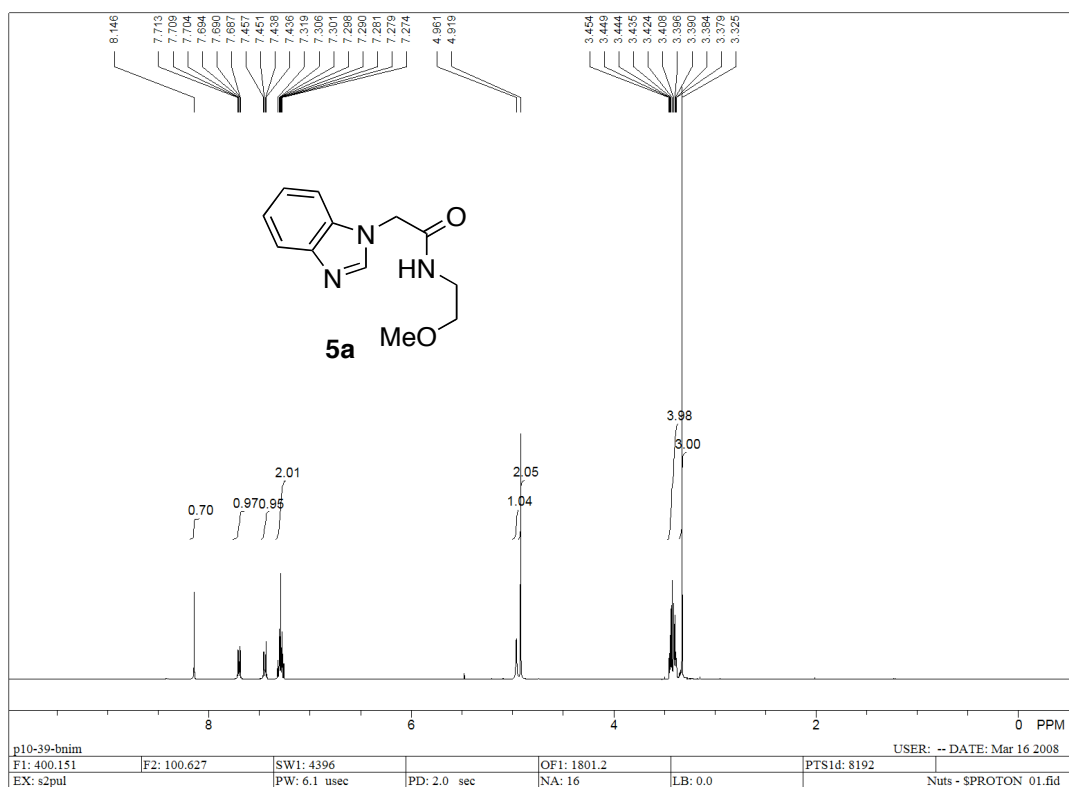
Following the above procedure with **6b** (800 mg, 1.62 mmol) and silver oxide (188 mg, 0.81 mmol) to give silver complex, then added  $\text{PdCl}_2(\text{CH}_3\text{CN})_2$  (420 mg, 1.62 mmol) to afford Pd-ligand complex **7b** (592 mg, 72 % yield) as an orange solid.;  $^1\text{H-NMR}$  ( $\text{CD}_3\text{OD}$ ):  $\delta$  7.56 (d,  $J = 7.5$  Hz, 1H), 7.48 (d,  $J = 7.5$  Hz, 1H), 7.39-7.21 (m, 7H), 5.64 (s, 2H), 4.32 (s, 3H), 4.30 (d,  $J = 6.0$  Hz, 2H), 3.87 (m, 1H), 3.47 (m, 2H), 1.86 (m, 1H), 0.85 (d,  $J = 7.0$  Hz, 3H), 0.82 (d,  $J = 7.0$  Hz, 3H); HRMS-ESI ( $m/z$ ) [ $\text{M}^+$ ] calcd. for  $\text{C}_{22}\text{H}_{26}\text{ClN}_3\text{O}_2\text{Pd}$ : 505.0748, found: 505.0731

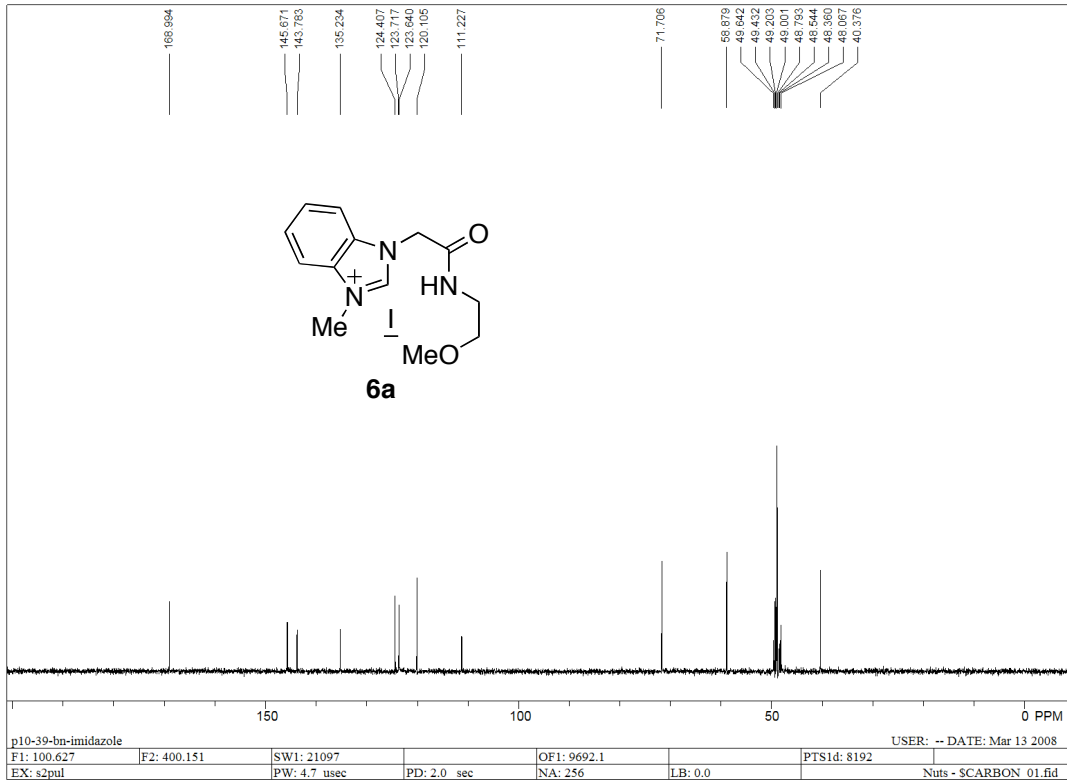
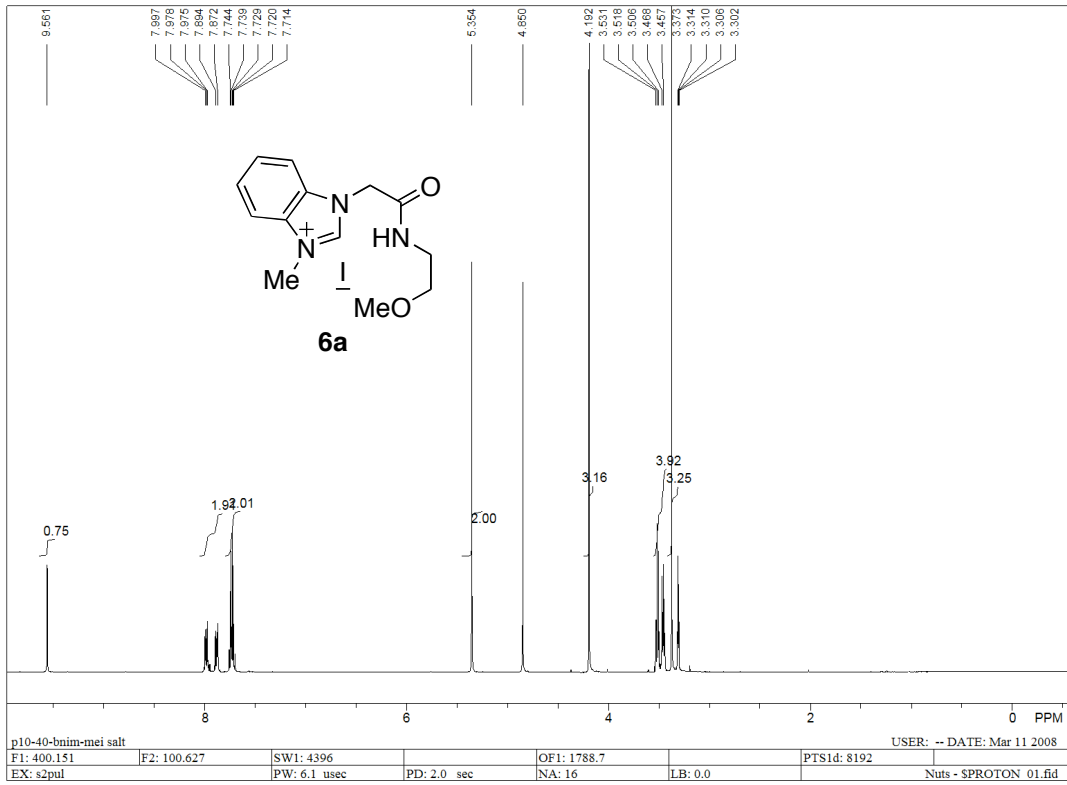
**1-(2-Hydroxyl-ethyl)-3-phenylcarbamoylmethyl-3H-benzimidazole iodide (10).** To a solution of benzimidazole (525 mg, 4.44 mmol) in DMF (10 mL) was added  $\alpha$ -bromoacetyl amide compound **9** (950 mg, 4.44 mmol) followed by KOH (500 mg, 8.89 mmol). After stirring the reaction mixture for 16 h at room temperature, EtOAc (50 mL) was added. Subsequently, a precipitated solid was removed by filtration. The filtrated organic layers were washed with brine twice, dried over anhydrous  $\text{Na}_2\text{SO}_4$  and then concentrated under reduced pressure to give a crude oil, which was purified by column chromatography on silica gel using EtOAc followed by MeOH as an eluent to afford benzimidazole amide compound as a white solid. And then, to a solution of benzimidazole amide compound (905 mg, 3.6 mmol, 81 % yield for **9**) in THF (120 mL), iodoethane (562  $\mu\text{L}$ , 7.2 mmol) was added. The reaction mixture was stirred under refluxing for 16 h. After cooling the solution at room temperature, a white solid, which is the desired product **10**, was filtrated and then washed with THF (1.17 g, 77 % yield).  $^1\text{H-NMR}$  ( $\text{CD}_3\text{OD}$ ):  $\delta$  8.27 (s, 1H), 6.68 (m, 1H), 6.57 (m, 1H), 6.35 (m, 2H), 6.22 (d,  $J = 7.2$  Hz, 2H), 5.96 (t,  $J = 7.5$  Hz, 2H), 5.76 (t,  $J = 7.5$  Hz, 1H), 4.17 (s, 2H), 3.31 (t,  $J = 4.8$  Hz, 2H), 2.64 (t,  $J = 5.0$  Hz, 2H);  $^{13}\text{C-NMR}$  ( $\text{CD}_3\text{OD}$ ):  $\delta$  164.6, 144.4, 138.9, 133.1, 132.5, 129.9, 128.3, 128.1, 125.7, 121.1, 114.8, 114.4, 60.2, 51.1, 50.4; HRMS-ESI ( $m/z$ ) [ $\text{M}+\text{H}^+$ ] calcd. for  $\text{C}_{17}\text{H}_{19}\text{IN}_3\text{O}_2^+$ : 424.0522, found: 424.0514

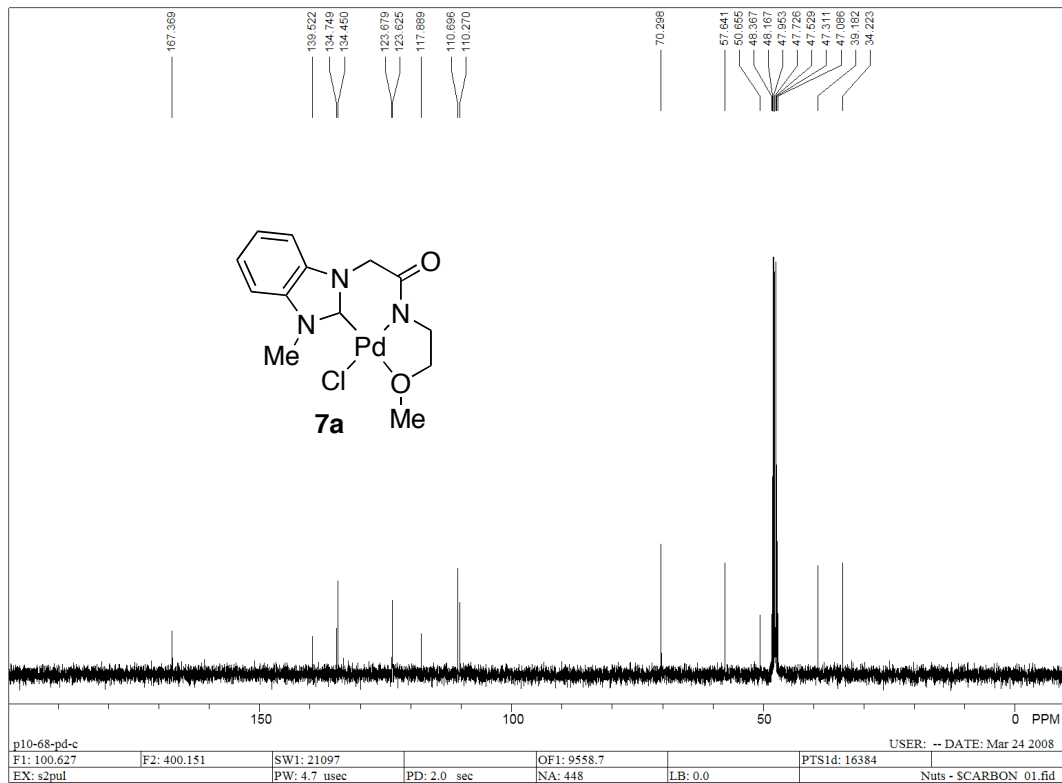
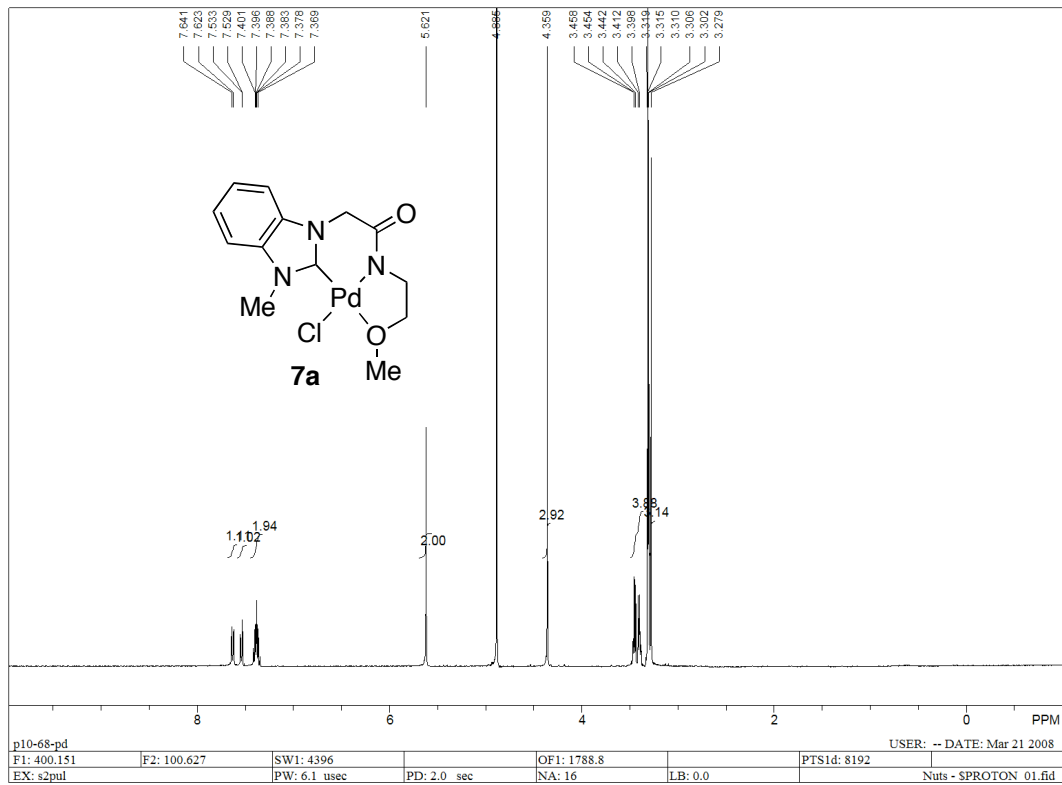
**Pd(II)-Ligand Complex 11.** The suspension of benzimidazolium salt **10** (500 mg, 1.18 mmol) and silver(I) oxide (136 mg, 0.59 mmol) in  $\text{CH}_2\text{Cl}_2$  (30 mL) was stirred for 2 hours with exclusion of light at room temperature. The reaction mixture was concentrated under reduced pressure to give a dark-red solid. To a suspension of the silver complex in  $\text{CH}_3\text{CN}$  (30 mL) was added  $\text{PdCl}_2(\text{CH}_3\text{CN})_2$  (361 mg, 1.18 mmol)

with exclusion of light at room temperature. Then, the resulting suspension was stirred for 2 hours and filtered through a plug of glass fiber filter paper. The filtrate was evaporated to dryness in vacuo to afford product **11** (361 mg, 70 % yield) as orange color solid.  $^1\text{H-NMR}$  ( $\text{CD}_3\text{OD}$ ):  $\delta$  7.69 (m, 1H), 7.58-7.55, (m, 3H), 7.35-7.30 (m, 2H), 7.27 (t,  $J = 8.2$  Hz, 2H), 7.08 (t,  $J = 8.0$  Hz, 1H), 5.83 (s, 2H), 4.99 (t,  $J = 5.7$  Hz, 2H), 4.34, (t,  $J = 5.7$  Hz, 2H);  $^{13}\text{C-NMR}$  ( $\text{CD}_3\text{OD}$ ):  $\delta$  166.5, 158.5, 139.1, 136.0, 129.7, 129.2, 125.5, 124.8, 124.7, 121.5, 112.5, 111.9, 62.1, 52.8, 51.7; HRMS-ESI ( $m/z$ ) [ $\text{M}^+$ ] calcd. for  $\text{C}_{17}\text{H}_{16}\text{ClN}_3\text{O}_2\text{Pd}$ : 434.9966, found: 434.9957

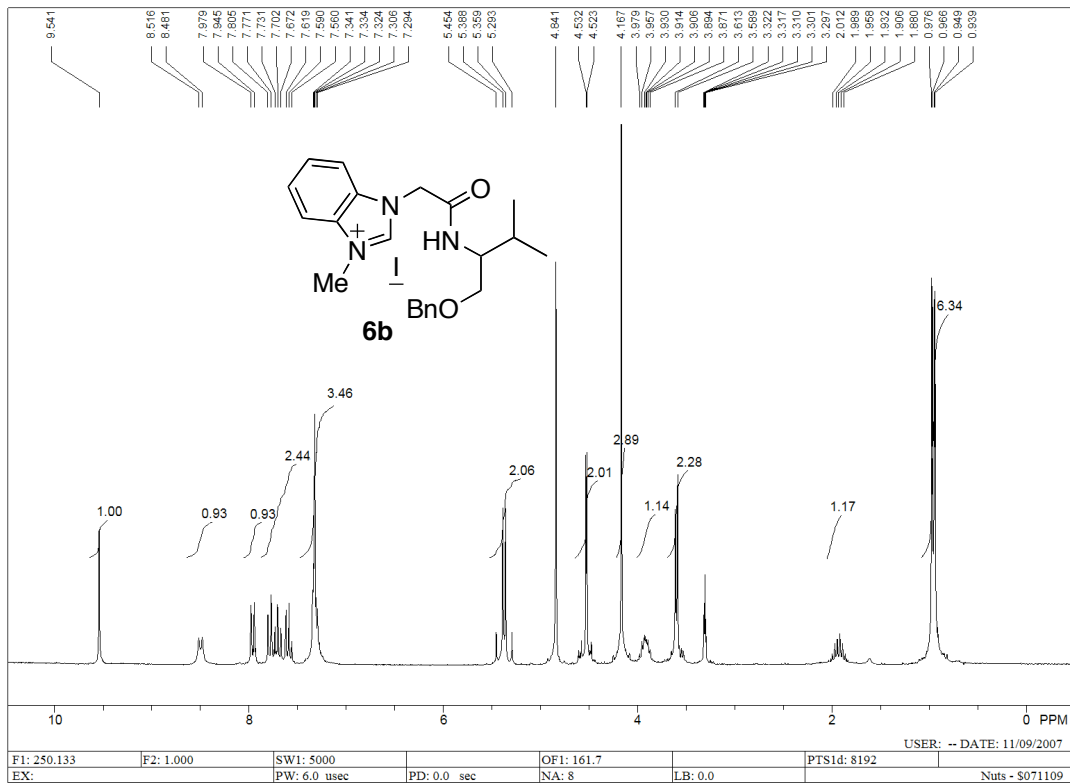
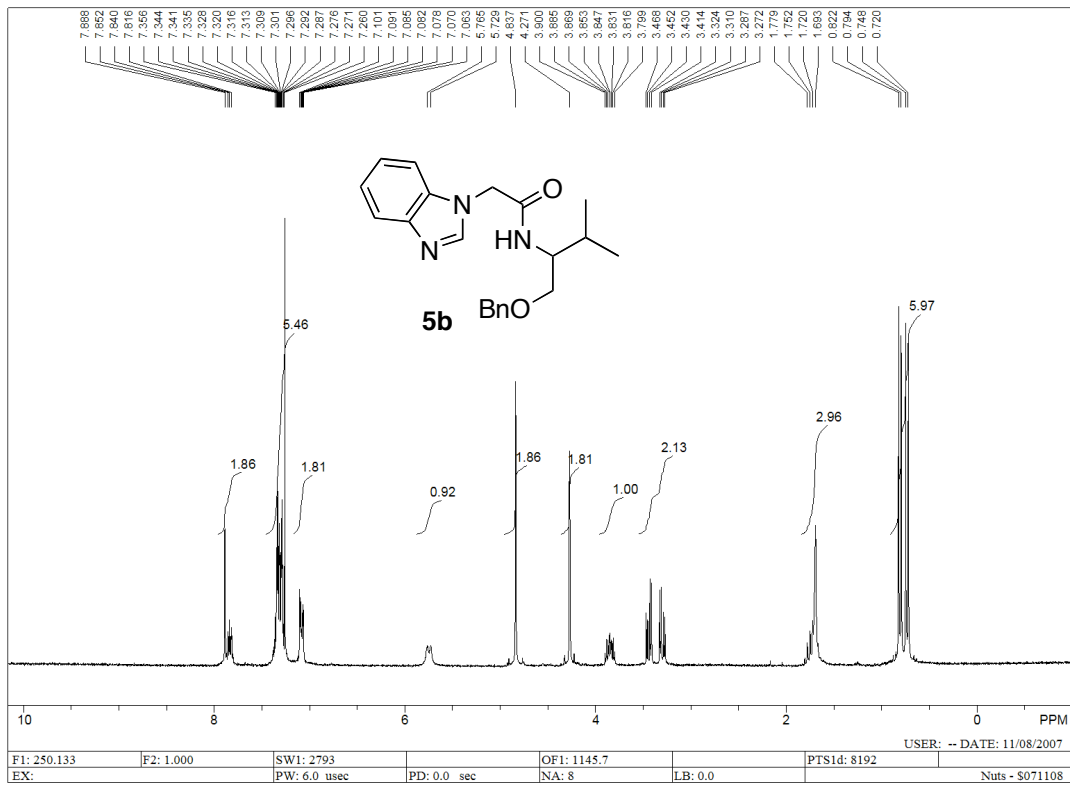
***1H, 13C NMR spectra for compounds***

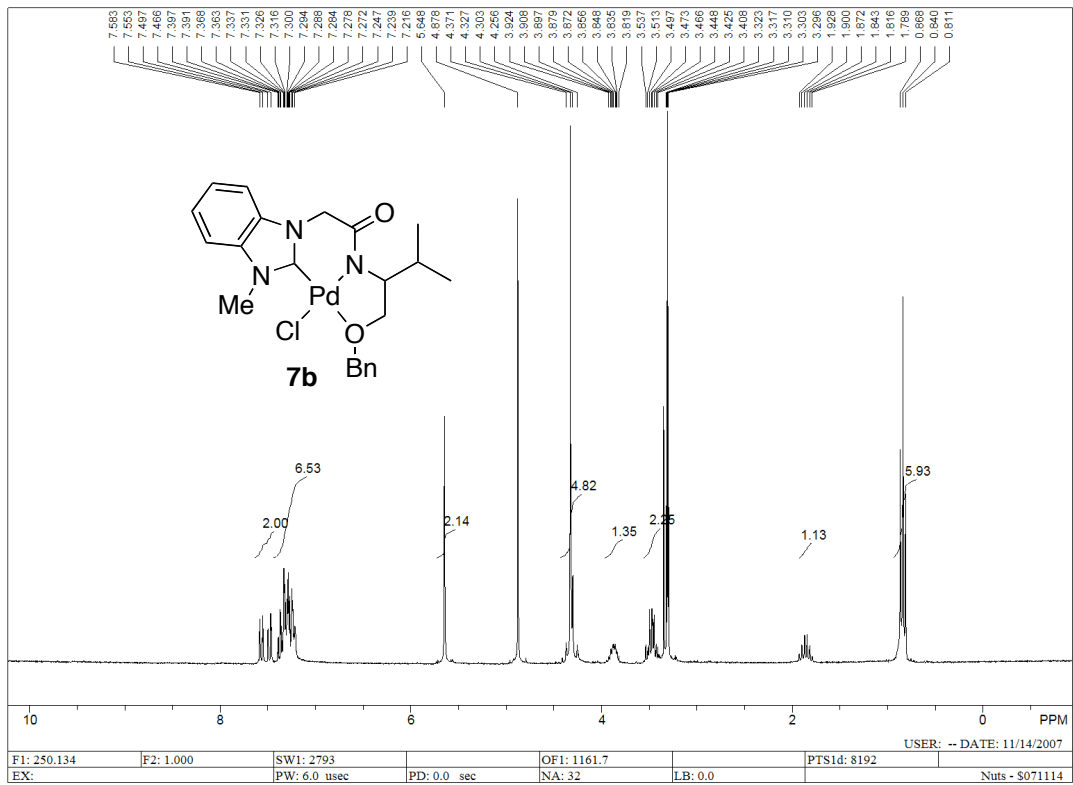


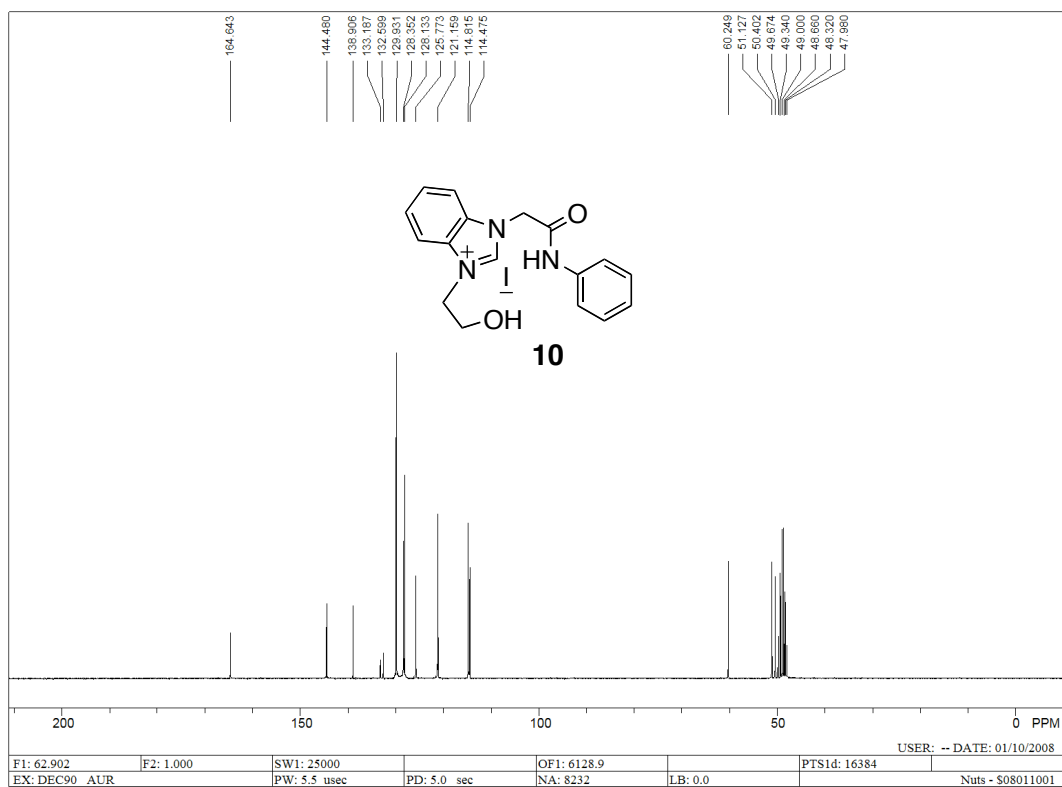
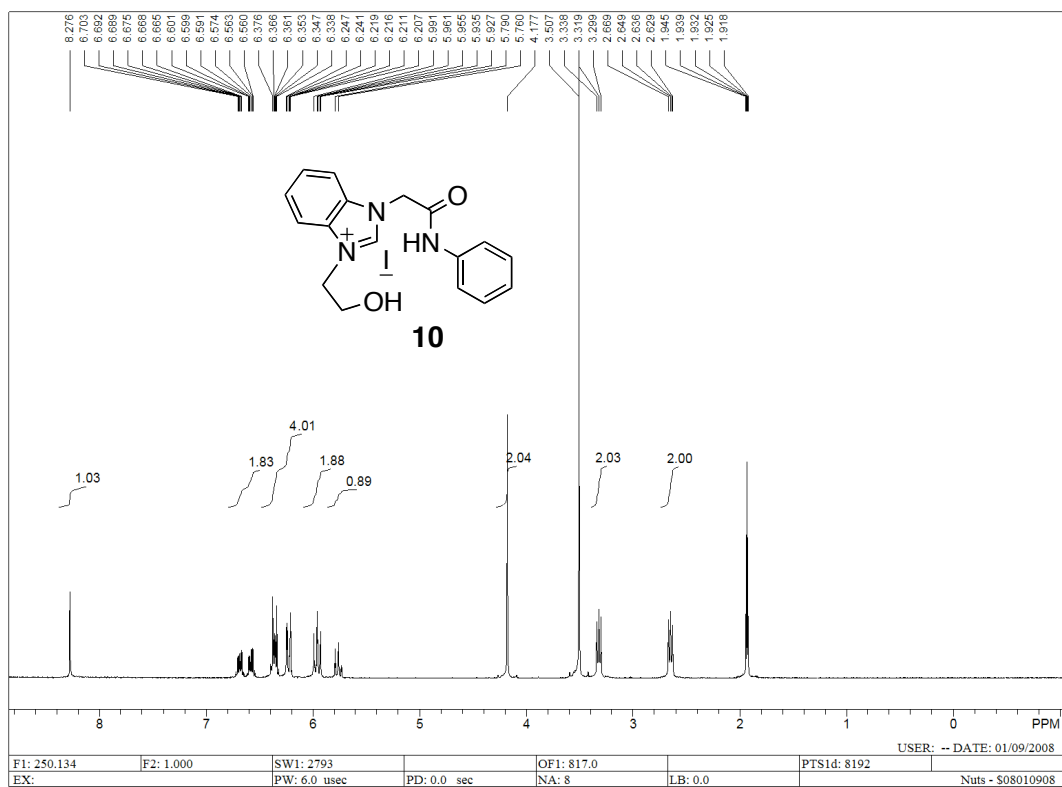


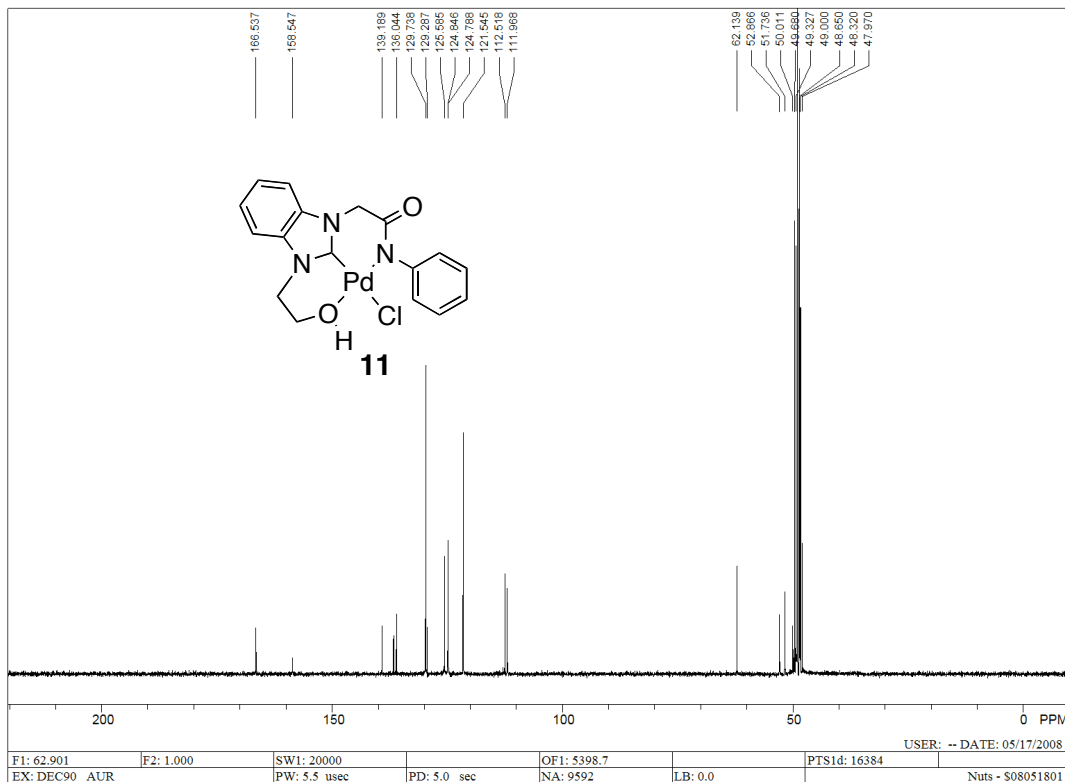
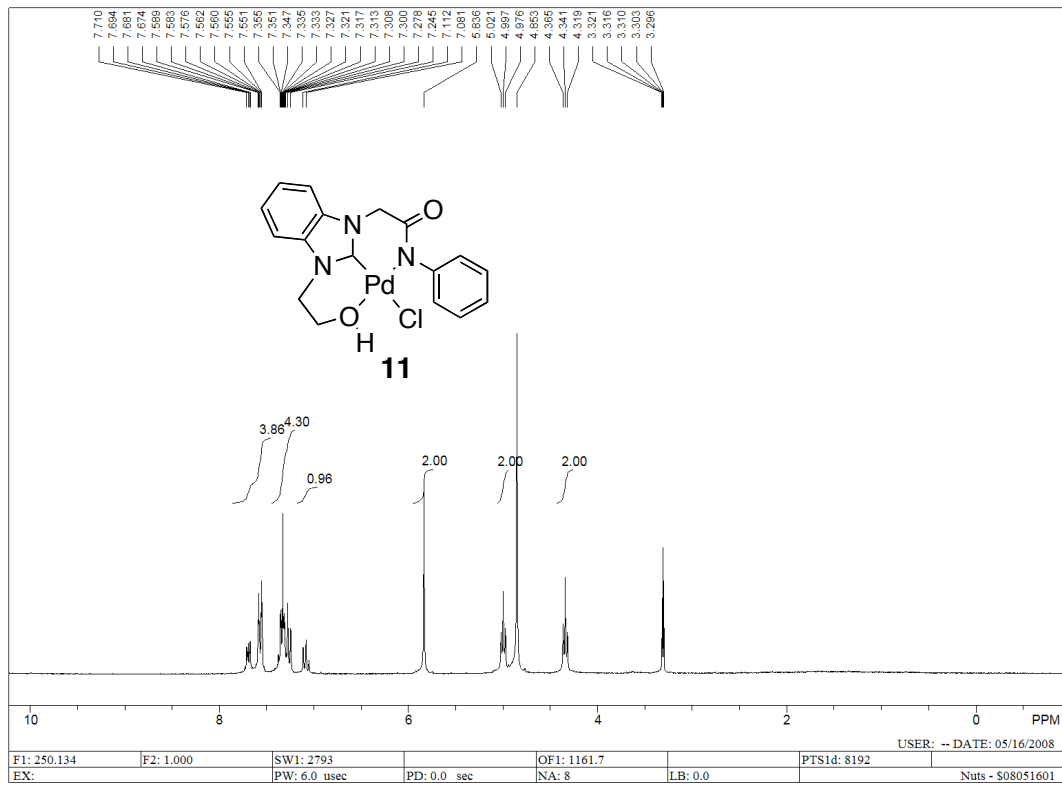








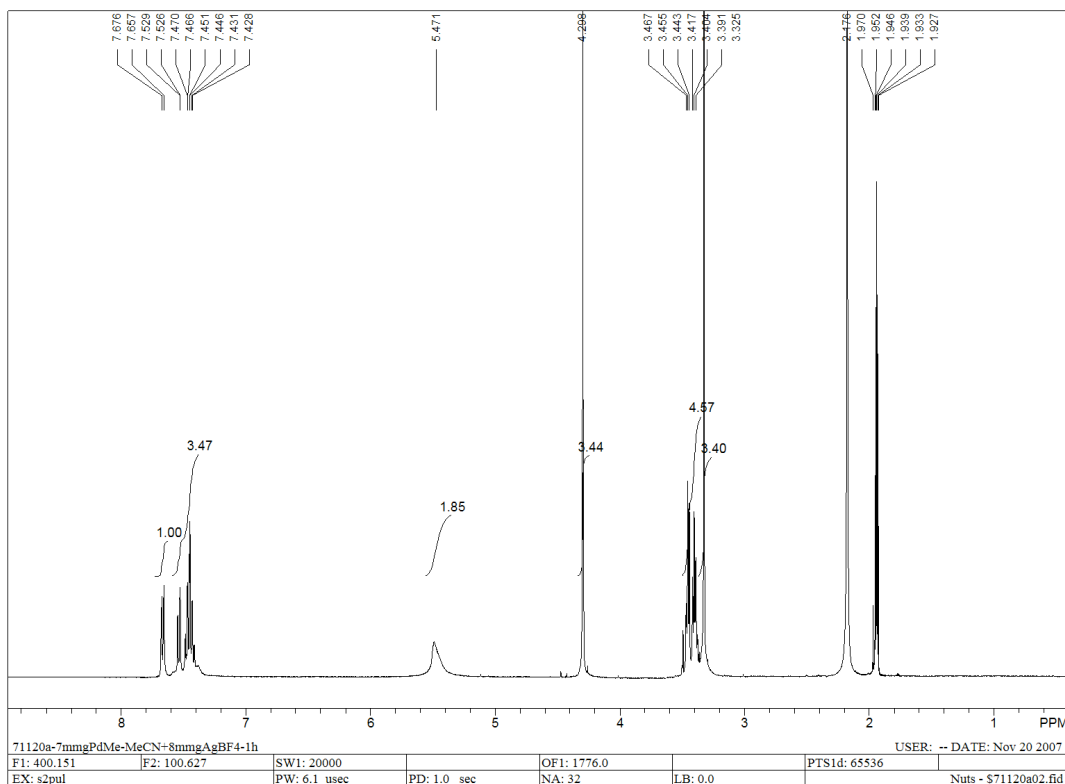




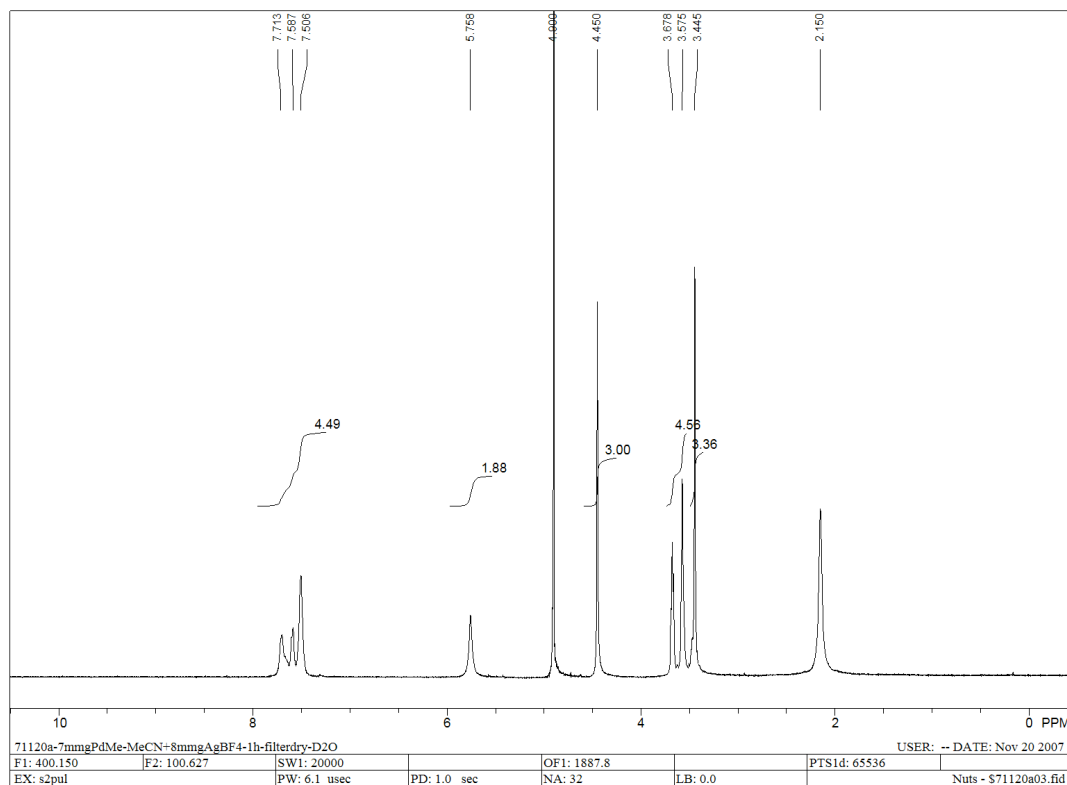
## General Procedure for H/D Exchange Reactions

**Preparation of Cationic Palladium complex 8a:** Catalyst **7a** and 1.5 equivalent of  $\text{AgBF}_4$  were stirred in 2 mL of MeCN solution for 30 minutes. Then filtrate was dried in vacuo after passing through celite column.

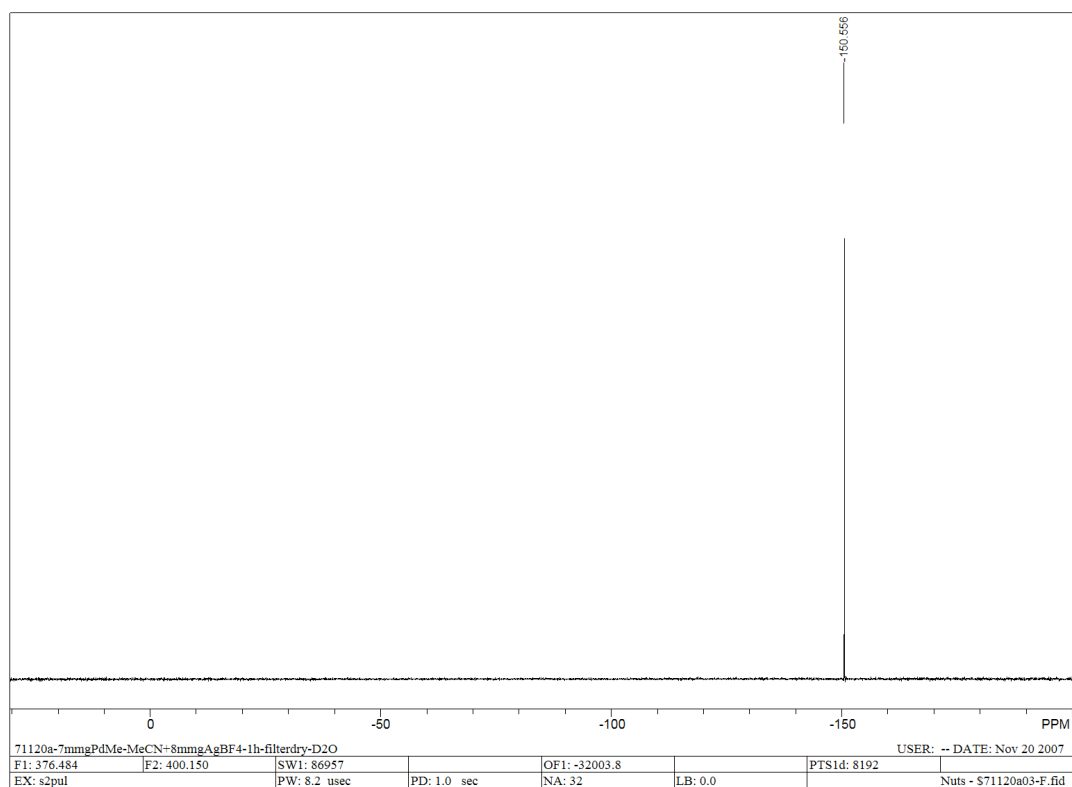
$^1\text{H-NMR}$  for **8a** in  $\text{CD}_3\text{CN}$



$^1\text{H-NMR}$  for **8a** in  $\text{D}_2\text{O}$

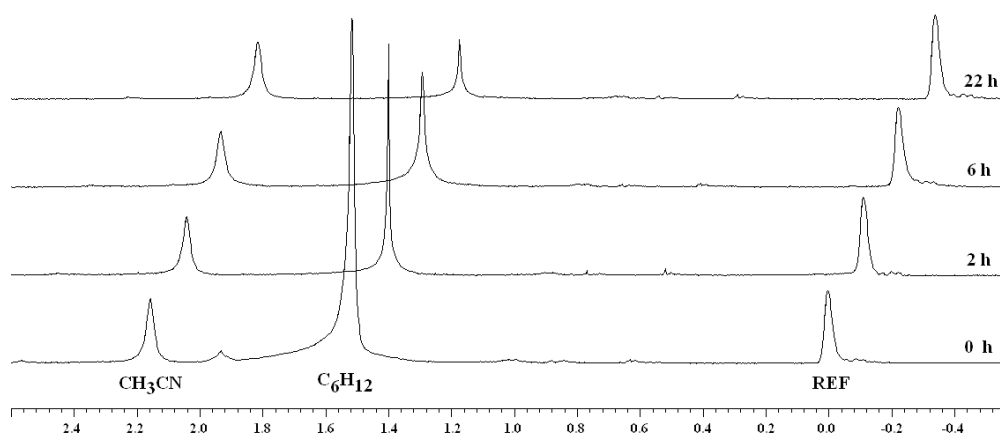


$^{19}\text{F-NMR}$  for **8a** in  $\text{D}_2\text{O}$



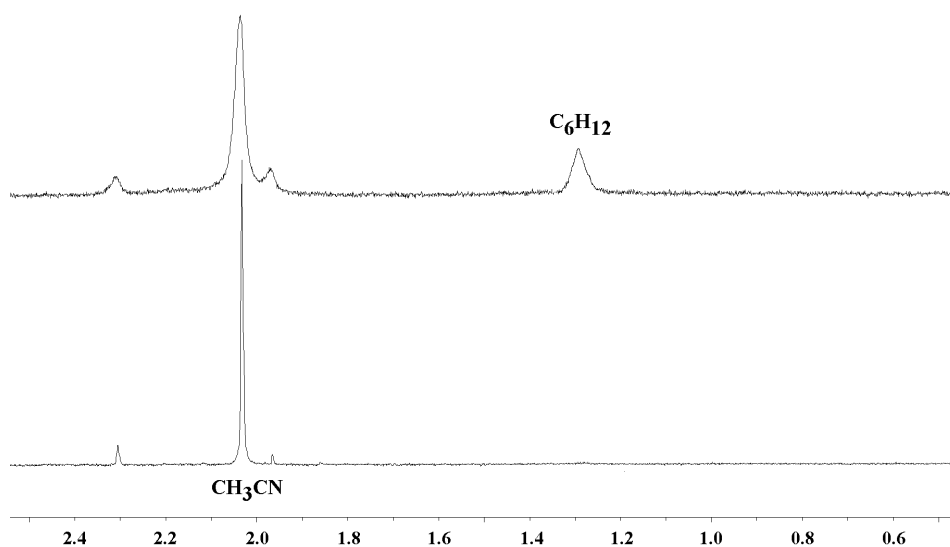
### Catalytic H/D Exchange of Cyclohexane

*H/D Exchange of cyclohexane:* Cationic Palladium complex **8a** (3.36  $\mu\text{mol}$ ) was dissolved in 0.7 mL of  $\text{D}_2\text{O}$  and placed in a J-Young NMR tube with an external standard capillary consisting of poly(dimethyl siloxane) in hexafluorobenzene. To a solution of **8a** in  $\text{D}_2\text{O}$ , cyclohexane (20  $\mu\text{L}$ ) was added. The resulting mixture was heated at 55  $^\circ\text{C}$  or 100  $^\circ\text{C}$ . Through comparing intensity between cyclohexane and external standard in  $^1\text{H}$ -NMR spectra, decrement of cyclohexane signal ( $\delta$  1.51 ppm) was monitored (Figure 1).



**Figure 1.**

*H/D Exchange of cyclohexane- $d_{12}$ :* Following the above procedure with **8a** (3.36  $\mu\text{mol}$ ) and cyclohexane- $d_{12}$  (20  $\mu\text{L}$ ) in  $\text{H}_2\text{O}$  (0.7 mL). The resulting mixture heated at 50  $^\circ\text{C}$  for 22 hours. Increasing cyclohexane signal in  $^1\text{H}$ -NMR spectra was monitored (Figure 2).



**Figure 2.**

### Equilibrium between Monomeric and Dimeric NHC-Pd Complex

We prepared tridentate Pd complex **1** and its dimeric complex **1'** [Angew. Chem. Int. Ed. **2008**, *47*, 9326]. As shown in Figure 3, monomeric Pd complex **1** was converted into dimeric Pd complex **1'** under aqueous basic conditions and dimeric complex also reconverted to monomeric Pd complex **1** by cleavage of the Pd<sub>2</sub>O<sub>2</sub> core in the presence of HCl (coordinating anion).

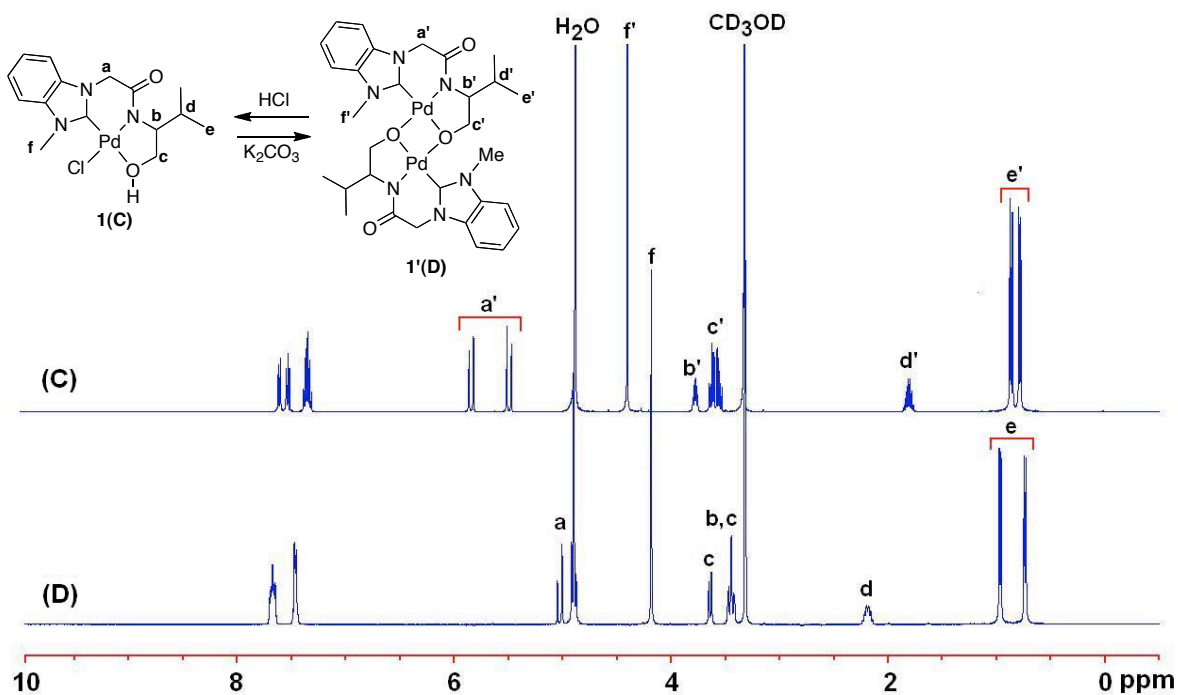
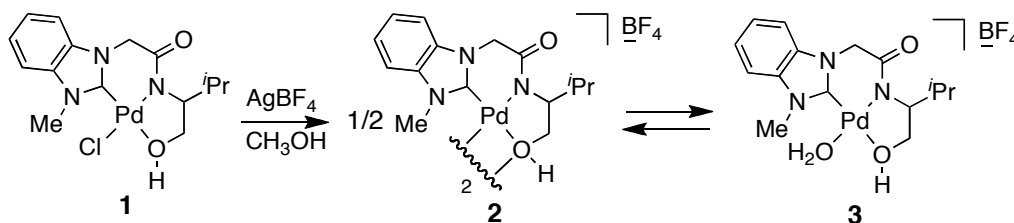


Figure 3



As similar manner, to a solution of **1** in CH<sub>3</sub>OH, AgBF<sub>4</sub> (3 eq.) was added to give corresponding **2**. After stirring 30 minutes, Ag salt and unreacted AgBF<sub>4</sub> were removed by passing the solution through a celite column, and volatiles in filtrate was removed by rotary-evaporator to give product **2** [Figure 4 (A)] as a solid. Subsequently, a solution of **2** in D<sub>2</sub>O was heated at 90 °C for 19 hours, and we observed a mixture of **2** (dimeric)



and **3** (monomeric) (1: 9 ratio) [Figure 4 (B)], as seen in the resulting  $^1\text{H}$  NMR spectra, which were analogous to those for complex **1** and **1'**.

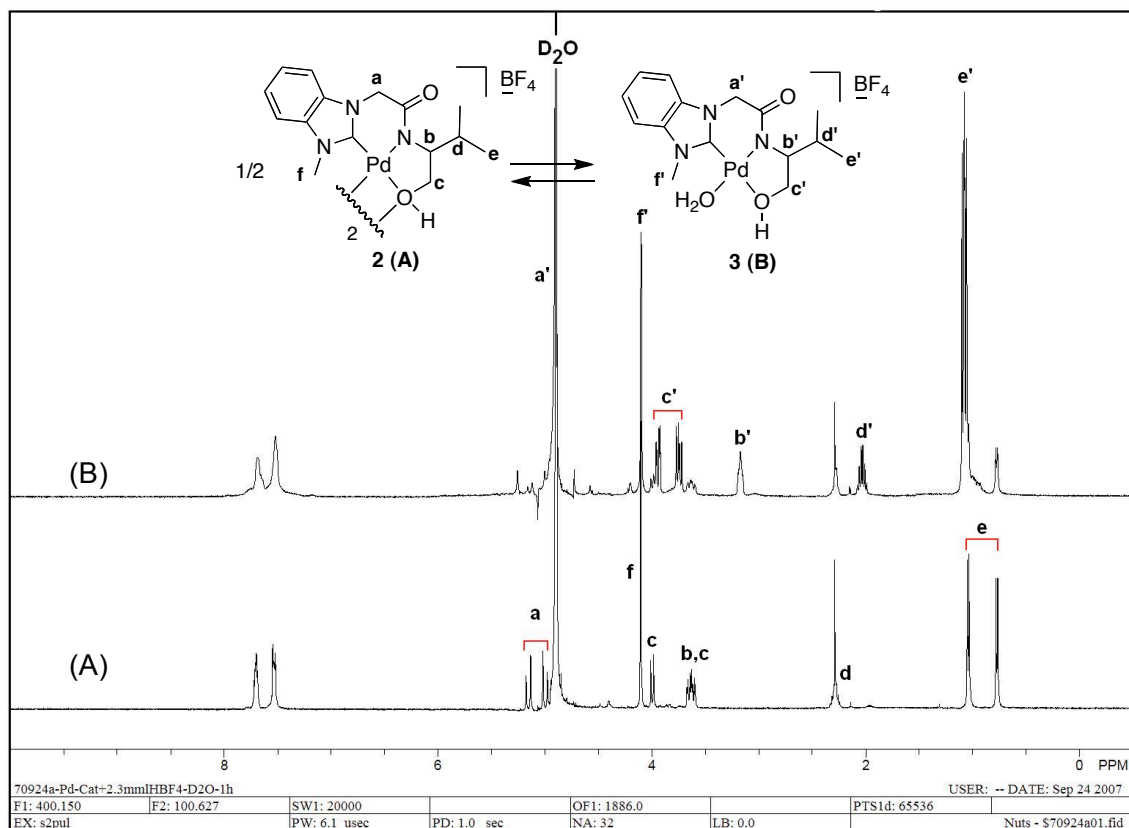
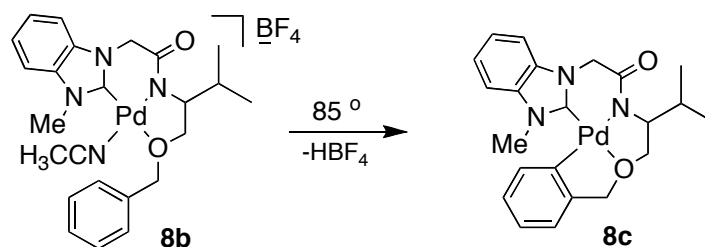


Figure 4

### Deactivation of NHC-Pd Complex 8b



The Pd complex **8b** was dissolved in  $\text{CD}_3\text{CN}$  and placed in a J-Young NMR tube. Then, the resulting solution was heated at  $85\text{ }^\circ\text{C}$  for 5 hours and the change in chemical structure was monitored by use of  $^1\text{H}$  NMR spectra. As predicted in Figure 5, we observed a change in the chemical shift for the benzyl aromatic proton C-H(#16) [down

field H(16) to H(16')] and reducing of proton integration value due to the aromatic C-H activation with palladium metal. In addition, we detected a new aromatic C-H(20') proton peak at  $\delta$  7.67 ppm. With this information, we were able to confirm that Pd complex **8b** was converted to the product of benzyl aromatic intramolecular activation, structure **8c**, at an elevated temperature. In addition, when the H/D exchange reaction of benzene was examined in D<sub>2</sub>O at 100°C [Table 1, entry 5], the structure of **8c** was observed by <sup>1</sup>H NMR spectra.

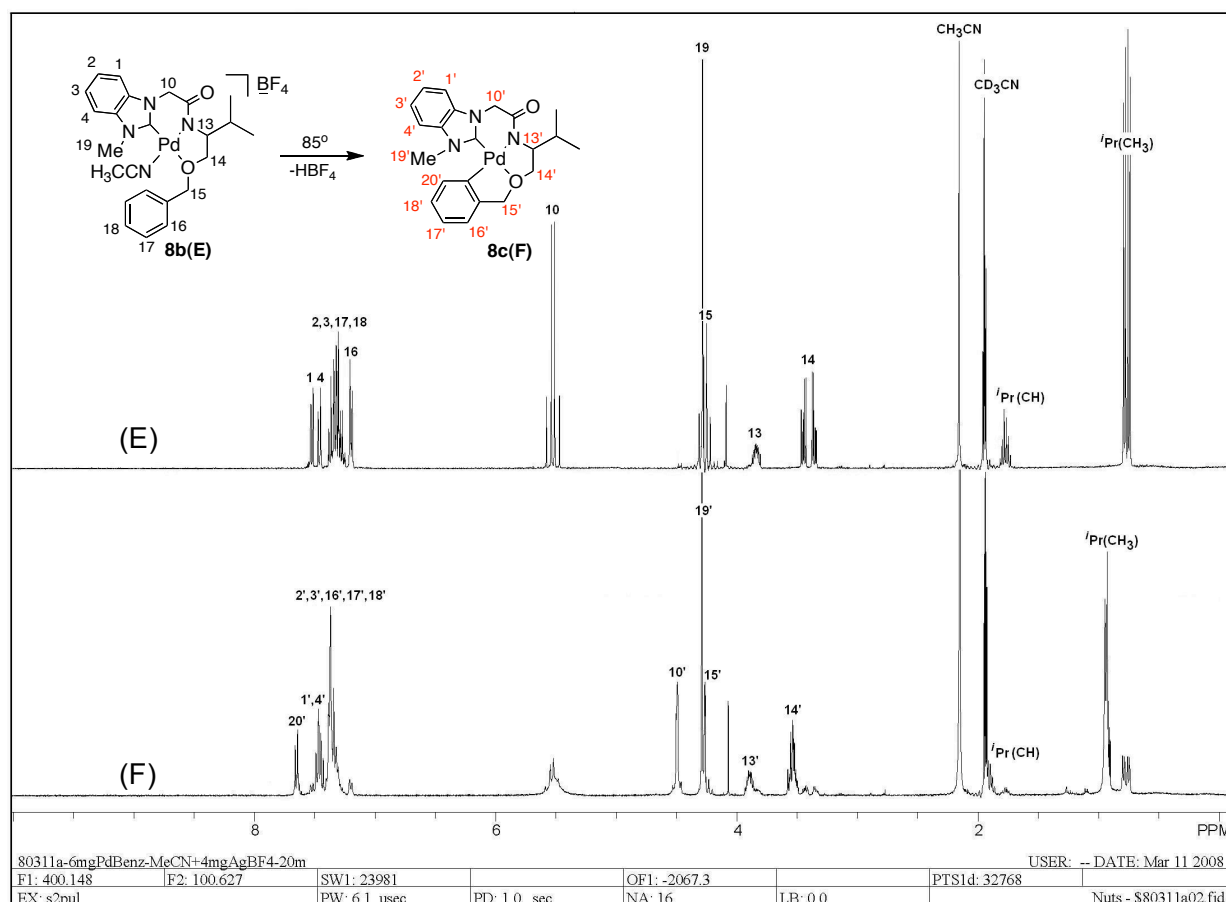


Figure 5