

New Carbon-Nitrogen Bond-Forming Reactions of Palladium

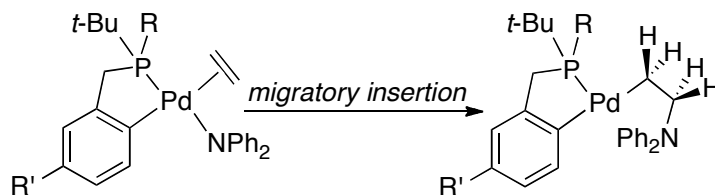
Patrick S. Hanley

Thesis Defense

November 8, 2012

My work at the University of Illinois has included the development of two new fundamental organometallic C-N bond-forming reactions of palladium: the migratory insertion of an unactivated olefin into a palladium-nitrogen bond, and the reductive elimination of an alkylamine from an isolated alkylpalladium amido complex. These two reactions have been proposed as steps in the catalytic cycle of a number of palladium catalyzed reactions. However, isolated metal-amido complexes that undergo either of these C-N bond-forming reactions are rare.¹⁻⁴

Here we report the discovery of a series of amidopalladium complexes ligated by a cyclometallated benzylphosphine that react with unactivated alkenes to generate enamine products (Scheme 1).⁵ Kinetic and stereochemical analysis indicate that these complexes react by migratory insertion of an alkene into the palladium-nitrogen bond. At low temperature (-65°C), an olefin amido complex was observed by ³¹P and ¹³C NMR spectroscopy from the reaction of an isolated amido complex and ethylene. Upon warming to -40 °C, these complexes underwent migratory insertion followed by β-hydride elimination to generate the enamine products.

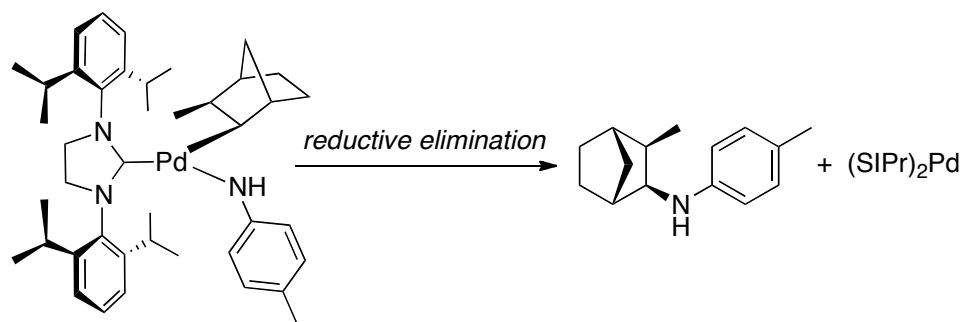


Scheme 1. Migratory insertion of ethylene into a palladium-nitrogen bond

Reactions of a family of these complexes containing ancillary ligands having systematically varied electronic and steric properties allowed us to map the effect these properties have on the binding of the alkene and the rate of migratory insertion.⁶ The relative binding affinity of ethylene vs. THF is larger for the less sterically hindered amido complex than for the more sterically hindered amido complex, but the less hindered amido complex undergoes the migratory insertion step slower than the more hindered amido complex. Reactions of complexes containing electronically varied ancillary ligands showed that the more electron-poor complexes underwent the migratory insertion step faster than the more electron-rich complexes. Reactions

of Pd-amides with functionalized vinylarenes indicated that electron-poor vinylarenes reacted with the amido complex slightly faster than electron-rich vinylarenes. These are the first detailed studies of the steric and electronic effects on the migratory insertion step of the reaction of well-defined amido complexes with alkenes.

In addition, we report the first alkylpalladium amido complexes that undergo C(sp³)-N bond-forming reductive elimination of alkylamines (Scheme 2).⁷ Three-coordinate norbornylpalladium anilido complexes ligated by bulky monodentate *N*-heterocyclic carbene (NHC) ligands undergo thermal reductive elimination to generate alkylamine products. The stereochemistry of the norbornylamine product suggests that the reductive elimination occurs by a concerted mechanism. The experimentally determined free energy barrier for the concerted reductive elimination of norbornylamine (26 kcal/mol) is similar to the computed free energy barrier for the concerted reductive elimination of norbornylamine (23.9 kcal/mol). Although the reductive elimination of an alkylamine to form a C(sp³)-N bond is proposed to occur in several palladium catalyzed reactions, these reactions are the first examples of reductive elimination from an isolated low-valent amido complex.



Scheme 2. Reductive elimination of norbornylamine from an SIPr-ligated alkylpalladium amido complex

References

- (1) Casalnuovo, A. L.; Calabrese, J. C.; Milstein, D. *J. Am. Chem. Soc.* **1988**, *110*, 6738.
- (2) Koo, K.; Hillhouse, G. L. *Organometallics* **1995**, *14*, 4421.
- (3) Zhao, P. J.; Krug, C.; Hartwig, J. F. *J. Am. Chem. Soc.* **2005**, *127*, 12066.
- (4) Pawlikowski, A. V.; Getty, A. D.; Goldberg, K. I. *J. Am. Chem. Soc.* **2007**, *129*, 10382.
- (5) Hanley, P. S.; Markovic, D.; Hartwig, J. F. *J. Am. Chem. Soc.* **2010**, *132*, 6302.
- (6) Hanley, P. S.; Hartwig, J. F. *J. Am. Chem. Soc.* **2011**, *133*, 15661.
- (7) Hanley, P. S.; Marquard, S. L.; Cundari, T. R.; Hartwig, J. F. *J. Am. Chem. Soc.* **2012**, *134*, 15281.