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Yttrocene-catalyzed asymmetric cyclization–hydrosilylation of α,ω-dienes

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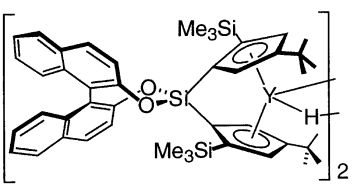
Abstract

(*R*,*S*)-BnBpY-H (BnBp = {$(OC_{10}H_6C_{10}H_6O)Si(C_5H_2$-2-$SiMe_3$-4-$CMe_3)_2$}) is an effective catalyst for the cyclization–hydrosilylation of α,ω-dienes. The cyclization of 1,5-hexadienes and 1,6-heptadienes results in the formation of five- and six-membered rings, respectively, with low to moderate enantioselectivities. Deuterium labeling studies revealed that β-hydride elimination of the cycloalkylmethyl intermediate prior to σ-bond metathesis with the silane did not occur. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: asymmetric catalysis; cyclization; dienes; hydrosilylation; yttrium.

We recently reported the synthesis of enantiomerically pure, C_2-symmetric yttrocene (*R*,*S*)-BnBpY-H (**1**).[1] Studies aimed at understanding the stereocontrol mechanisms for isotactic polymerizations of α-olefins by metallocene catalysts revealed that olefin insertion into a metal–alkyl bond proceeds with >95% ee, whereas the insertion into a metal–hydride bond proceeds with only 34% ee.[2] Because of the poor olefin facial discrimination observed in the M–H insertion step, it was anticipated that olefin hydrogenations,[3] hydrosilylations,[4] and hydroborations[5] would be poor candidates for asymmetric catalysis. An attractive transformation for investigation, however, is Molander's cyclization–hydrosilylation of α,ω-dienes,[6] since the stereochemistry-determining step involves olefin insertion into an M–C bond.



[(*R*,*S*)-BnBpY-H]$_2$ (**1**$_2$)

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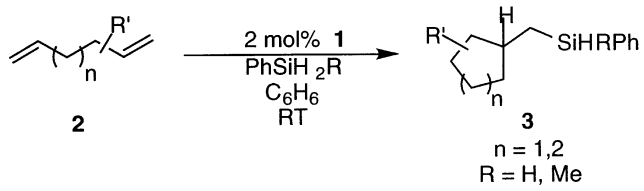
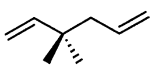
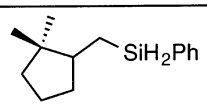
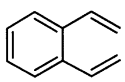
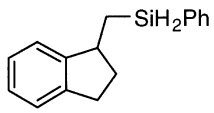
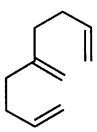
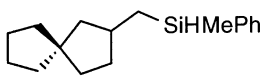
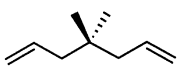
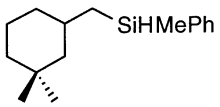
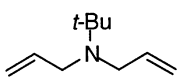
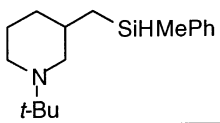
Yttrocene **1** proved to be an effective catalyst for the cyclization–hydrosilylation of α,ω-dienes.[7] Reactions were effected with 2 mol% of **1** and were complete after 3–10 h at room temperature. When $PhSiH_3$ was employed in the reaction, **1** could be generated in situ from (*R*,*S*)-BnBpYCH($SiMe_3$)$_2$. Reactions employing the more hindered $PhSiH_2Me$ required initial treatment of (*R*,*S*)-BnBpYCH($SiMe_3$)$_2$ with dihydrogen.

The results of the hydrosilylation–cyclization reactions are shown in Table 1. Hexadiene **2a**[8] cyclized regioselectively to form carbocycle **3a** in 95% yield and 50% ee. Reaction of *ortho*-divinylbenzene[9] resulted in the isolation of **3b** in 84% yield with low enantioselectivity (10% ee). Triene **2c**[10] cyclized cleanly to yield spirocyle **3c** (72% yield, 23% ee). In the case of **2c**, and of substrates that furnish six-membered ring products, it is necessary to employ $PhSiH_2Me$ to avoid olefin hydrosilylation. Heptadiene **2d**[11] reacted cleanly to afford cyclohexane **3d** in 80% yield and 14% ee. *N*,*N*-Diallyl-*tert*-butylamine[6c] cyclized to form piperidine **3e** in 74% yield as a racemic mixture.

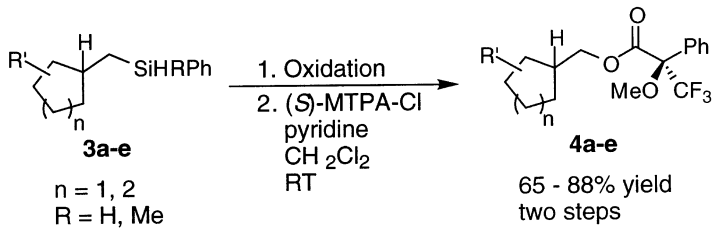
Table 1
Asymmetric cyclization–hydrosilylation of α,ω-dienes with (*R*,*S*)-BnBpY-H (**1**)



Reactant		Product		yield,%	ee, %[a]
2a		3a		95[b]	50
2b		3b		84[b]	10
2c		3c		72[c]	23
2d		3d		80[c]	14
2e		3e		74[c]	<5

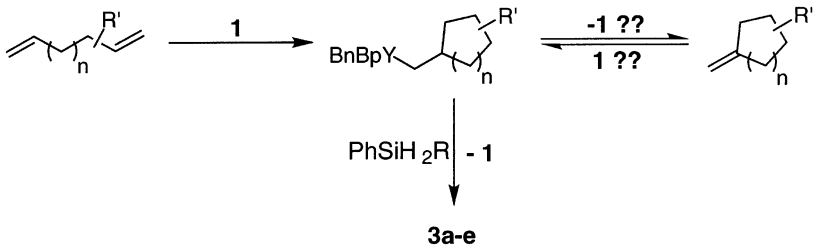
[a]%ee was determined by oxidation of the C-Si bond to the alcohol followed by acylation with (*S*)-MTPA-Cl. [b]$PhSiH_3$ used in reaction. [c]$PhSiH_2Me$ used in reaction.

Enantioselectivities were determined by conversion of the silanes into the corresponding MTPA esters (Scheme 1). Oxidation of the Si–C bond yielded the desired alcohols.[12] Acylation with (*S*)-MTPA-Cl[13] afforded esters **4a–e**, which were analyzed by ^{1}H NMR or GC.



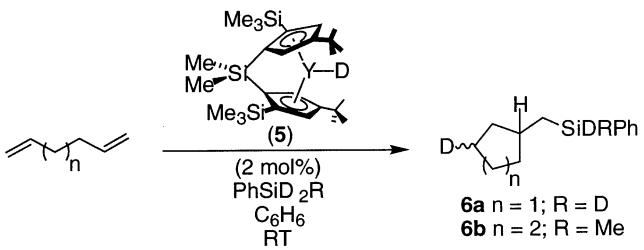
Scheme 1.

We were concerned that side reactions might be eroding the enantiomeric excesses of the products. If the yttrium alkyl resulting from intramolecular cyclization reacts slowly with silane, reversible β-hydride elimination to the methylenecycloalkane and **1** may occur (Scheme 2). Since M–H insertion of methylenecycloalkanes into **1** proceeds with low facial selectivity,[14] one would anticipate low enantioselectivity in the formation of **3a–e** by this pathway.



Scheme 2.

To test for this possibility, we performed experiments with 1,5-hexadiene using BpY-D[15] (**5**) and $PhSiD_3$ (Scheme 3). Examination of the ^2H NMR spectrum of carbocycle **6a** revealed that no deuterium had been incorporated at the methine carbon.[16] Analogously, no deuterium incorporation at the methine position was observed in **6b**. If β-hydride elimination and olefin dissociation were to occur prior to reaction with the silane, incorporation of deuterium into the methine positions would have been observed.



Scheme 3.

In conclusion, we have investigated the asymmetric cyclization–hydrosilylation of α,ω-dienes to afford substituted five- and six-membered rings in good yield. The low enantioselectivities observed do not occur through rapid, reversible β-hydride elimination and unselective M–H insertion into the resulting methylenecycloalkane. It is believed that the competing transition states of the cyclization are far different from the analogous Ziegler–Natta transition states, and that the BnBp-ligand array does not effectively discriminate between them. Preliminary MM3 calculations (CaChE™) using the diastereomeric olefin adducts as transition state models appear to support this conclusion. While the olefin side chain and growing polymer side chain orient in

a *trans* fashion in the preferred Ziegler–Natta transition state,[2] the five-membered ring forming reactions appear to proceed via a *cis*-like transition state.[17] The six-membered ring forming reactions have both chair- and boat-like transition structures that are energetically comparable.

Acknowledgements

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7. **General procedure for cyclization/hydrosilylation of α,ω-dienes (1 mmol scale)**: (*R*,*S*)-BnBpYCH$(SiMe_3)_2$ (19 mg, 0.02 mmol, 0.02 equiv.) was added as a solid to a 25 mL Schlenck tube in a nitrogen-filled glove box. The tube was affixed to a high vacuum line, evacuated, and cyclohexane (5 mL) was vacuum-transferred into the vessel. After warming to room temperature, dihydrogen (1 atm) was admitted into the vessel and the solution was stirred for five minutes. After three freeze–pump–thaw cycles, $PhSiH_2Me$ (151 μL, 1.1 mmol, 1.1 equiv.) and the diene (1.0 mmol, 1.0 equiv.) were added to the reaction vessel by vacuum transfer. The resulting mixture was warmed to room temperature and stirred for 3–10 h. The reaction was quenched by addition of saturated $NH_4Cl_{(aq)}$. The mixture was diluted with Et_2O (25 mL) and washed once each with 25 mL of saturated $NH_4Cl_{(aq)}$, water, and brine. The organic layer was dried over $MgSO_4$, filtered, concentrated in vacuo, and flash-chromatographed to yield the desired product.
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