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Enantioselective Cyclization/Hydrosilylation of 1,6-Enynes Catalyzed by a Cationic Rhodium Bis(phosphine) Complex

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ABSTRACT

Reaction of 4,4-dicarbomethoxy-1-octene-6-yne (1) with triethylsilane and a catalytic 1:1 mixture of $[Rh(COD)_2]^+$ SbF_6^- and (*R*)-BIPHEMP (5 mol %) at 70 °C for 90 min gave (*Z*)-1,1-dicarbomethoxy-3-(1-triethylsilyl)ethylidene-4-methylcyclopentane (2) in 81% isolated yield with 98% de and 92% ee.

Substituted carbocycles represent one of the most prevalent structural features of naturally occurring and biologically active compounds.[1] For this reason, considerable effort has been directed toward the development of new and effective methods for the synthesis of functionalized carbocycles. In this area, transition metal-catalyzed approaches have shown particular utility due to the high levels of selectivity and efficiency often realized by transition metal catalysis.[2] However, enantioselective transformations represent only a small subset of the known transition metal-catalyzed cyclization reactions,[3] which is unfortunate given the propensity of the naturally occurring carbocycles to display optical activity.

Cyclization/hydrosilylation of dienes,[4,5] enynes,[6] and diynes[7,8] has emerged as an effective route to the synthesis of functionalized carbocycles. However, as is the case with catalytic cyclization reactions in general, examples of asymmetric cyclization/hydrosilylation remain quite limited. In fact, the only examples of asymmetric cyclization/hydrosilylation are the cyclization/hydrosilylation of 1,6-dienes catalyzed by palladium pyridine−oxazoline complexes (Scheme 1).[4] Unfortunately, the cyclopentanes generated via asymmetric diene cyclization/hydrosilylation are relatively unfunctionalized. Because of this, we sought to develop an effective procedure for the cyclization/hydrosilylation of enynes to form the more functionalized alkylidenecyclopentanes. Here we report the first examples of the asymmetric

Scheme 1

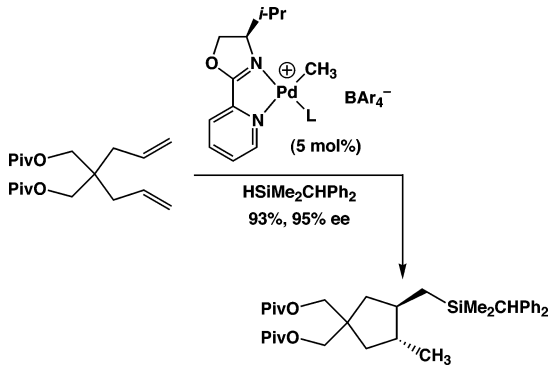

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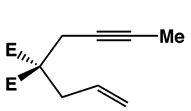
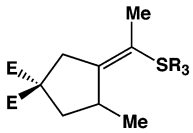
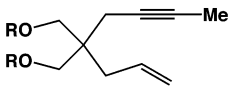
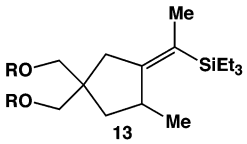
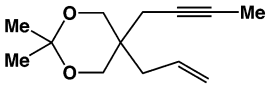
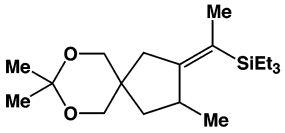
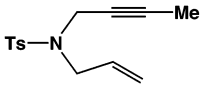
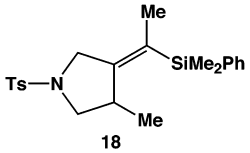
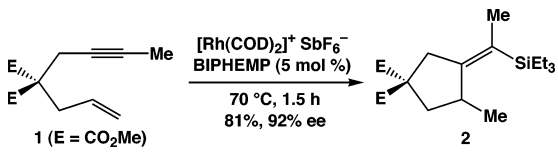
Table 1. Asymmetric Cyclization/Hydrosilylation of 1,6-Enynes Catalyzed by a 1:1 Mixture of $[Rh(COD)_2]^+$ $[SbF_6]^-$ and (*R*)-BIPHEMP (5 mol %) in DCE at 70 °C

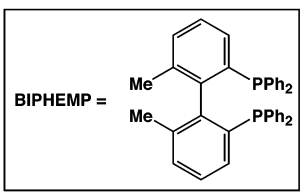
entry	enyne	silane	carbocycle	yield (%)	ee (%)
					
1	1 (E = CO_2Me)	$HSiMe_2Bn$	3	70	89
2		$HSiMePh_2$	4	71	77
3		$HSiMe_2Ph$	5	77	77
4		$HSiMe_2$*n*-octyl	6	74	82
5		$HSiMe_2Et$	7	75	82
6		$HSiMeEt_2$	8	76	88
					
7	9 (R = Me)	$HSiEt_3$	13	65	80
8	10 (R = Ac)		14	58	83
9	11 (R = COEt)		15	48	87
10				48	81
	12		16		
11		$HSiMePh_2$			
	17		18	73	80

cyclization/hydrosilylation of functionalized enynes to form silylated alkylidenecyclopentanes with up to 92% ee.

We have recently shown that cationic rhodium (±)-BINAP complexes catalyze the cyclization/hydrosilylation of 1,6-diynes to form silylated 1,2-dialkylidienecyclopentanes.[8] In addition, enantiomerically enriched cationic rhodium (BINAP) complexes catalyze a number of highly enantioselective cyclization reactions, including intramolecular olefin hydrosilylation,[9] intramolecular olefin hydroacylation,[10] and enyne cycloisomerization.[11] For these reasons, we targeted cationic rhodium BINAP complexes as catalysts for asymmetric enyne cyclization/hydrosilylation. Although rhodium BINAP complexes were not effective catalysts for enyne cyclization/hydrosilylation, the closely related BIPHEMP [BIPHEMP = 6,6′-bis-(diphenylphosphino)-2,2′-dimethylbiphenyl] complexes proved effective. For example, treatment of 4,4-dicarbomethoxy-1-octene-6-yne (**1**) with triethylsilane and a catalytic 1:1 mixture of $[Rh(COD)_2]^+$ SbF_6^- and (*R*)-BIPHEMP (5 mol %) at 70 °C for 90 min led to the isolation of the silylated alkylidene cyclopentane **2** in 81% yield with 98% de and 92% ee (Scheme 2).

Scheme 2





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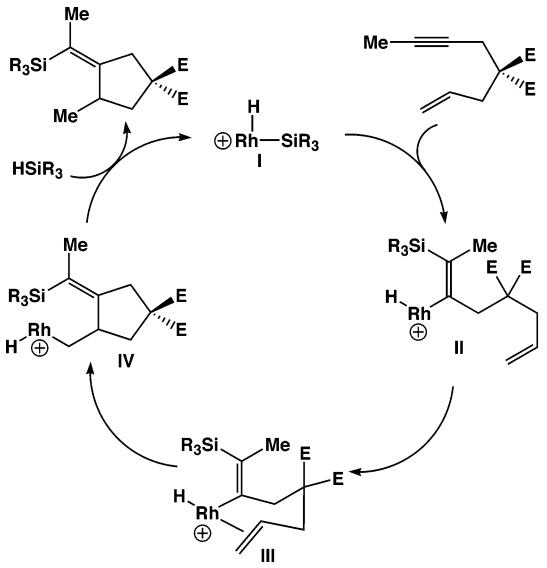
Scheme 3



Mixtures of $[Rh(COD)_2]^+$ SbF_6^- and (*R*)-BIPHEMP catalyzed the cyclization/hydrosilylation of enyne **1** with a number of tertiary silanes to form silylated alkylidene cyclopentanes **3**−**8** in 70−76% yield with 77−89% ee (Table 1, entries 1−6). In addition to enyne **1**, several 1,6-enynes underwent rhodium-catalyzed asymmetric cyclization/hydrosilylation to generate the silylated alkylidenecyclopentanes **13**−**16** in moderate yield with ≥80% ee (Table 1, entries 7−10). Asymmetric enyne cyclization/hydrosilylation was also applied to the synthesis of silylated pyrrolidine derivative **18** (Table 1, entry 11).

On the basis of the proposed mechanism for rhodium-catalyzed alkyne hydrosilylation[12] and diyne cyclization/hydrosilylation,[6c,8] we propose a working mechanism for rhodium-catalyzed enyne cyclization/hydrosilylation (Scheme 3). Oxidative addition of the H−Si bond of the silane to a Rh(I) species could form the Rh(III) silyl hydride species **I**. Coordination and β-migratory insertion of the triple bond of the enyne into the Rh−Si bond of **I** could form the rhodium alkenyl complex **II**. Coordination of the pendant olefin followed by β-migratory insertion into the Rh−C bond of alkenyl olefin complex **III** could form the rhodium alkyl complex **IV**. Formal C−H reductive elimination from **IV**, coupled with H−Si oxidative addition, could release the silylated alkylidenecyclopentane with regeneration of the cationic Rh(I) complex **I** (Scheme 3).

In summary, we have presented the first examples of asymmetric enyne cyclization/hydrosilylation catalyzed by a cationic, rhodium (*R*)-BIPHEMP complex. We are currently working toward the identification of more active and more stereoselective enyne cyclization/hydrosilylation catalysts.

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Supporting Information Available: Experimental procedures and spectroscopic data for new compounds and determination of enantiomeric excess. This material is available free of charge via the Internet at http://pubs.acs.org.

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