

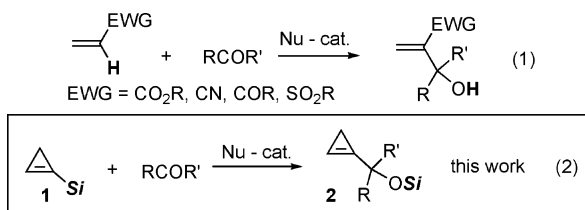
## Sila Morita–Baylis–Hillman Reaction of Cyclopropenes

Stepan Chuprakov, Denis A. Malyshev, Alexander Trofimov, and Vladimir Gevorgyan\*

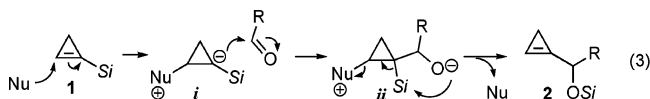
Department of Chemistry, University of Illinois at Chicago, Chicago, Illinois 60607

Received September 26, 2007; E-mail: vlad@uic.edu

The Morita–Baylis–Hillman (MBH) reaction<sup>1</sup> is an attractive and powerful tool for carbon–carbon bond formation (eq 1). This protocol involves amine- or phosphine-catalyzed coupling of Michael-acceptors with carbonyl compounds or their equivalents. Herein, we report the phosphine-catalyzed sila-MBH reaction of 1-silyl-cyclopropenes **1** with carbonyl compounds, which produces 1-(silyloxymethyl)cyclopropenes **2** in good to excellent yields (eq 2).



Cyclopropenes<sup>2</sup> are the smallest unsaturated carbocycles, possessing a highly strained<sup>3</sup> double bond, which readily undergoes a wide array of addition reactions.<sup>4,5</sup> We hypothesized that 1-silyl-substituted cyclopropenes might be suitable substrates for a sila-MBH reaction on the basis of the following reasoning. It was thought that the high reactivity of the cyclopropene double bond, together with the ability of silyl group to stabilize  $\alpha$ -carbanion,<sup>6</sup> could allow for the formation of  $\alpha$ -silylcyclopropyl anion **i**<sup>7</sup> upon addition of nucleophilic catalyst<sup>4a–d</sup> to 1-silylcyclopropene **1** (eq 3). If long-lived, intermediate **i** may undergo an addition to carbonyl group to produce alkoxide **ii**, which was reasoned to be an ideal substrate for a subsequent 1,3-Brook rearrangement<sup>8</sup>/elimination cascade to furnish 1-(silyloxymethyl)cyclopropene **2** (eq 3).



To this end, we examined the reaction of 1-(trimethylsilyl)-cyclopropene-3,3-dicarboxylate **1a** with benzaldehyde in the presence of various nucleophilic catalysts (Table 1). We were pleased to find that in the presence of 25 mol % of DABCO **1a**, indeed, underwent the sila-MBH reaction to produce the expected cyclopropene **2a** in 42% yield (entry 1).<sup>9</sup> Next, it was found that electron-rich tris(2,4,6-trimethoxyphenyl)phosphine (TTMPP) was more efficient than other N- and P-based catalysts (entries 1–7). However, the yield of **2a** produced in the presence of 25 mol % of TTMPP in DMF at ambient temperature remained moderate (entry 7). Change of temperature did not improve the reaction yield (entries 8–9). To our delight, it was found that reducing the catalyst loading, together with the use of 1,4-dioxane as a solvent, allowed for a dramatic increase in the yield of the sila-MBH reaction, producing **2a** in 79% yield (entry 15).<sup>10</sup>

Naturally, with optimized conditions in hand, we examined the scope of this novel transformation with respect to the aldehyde component (Table 2). Gratifyingly, a wide selection of aryl and heteroaryl aldehydes (entries 1–7) reacted smoothly with **1a** to produce 1-(silyloxymethyl)cyclopropenes **2** in good yields. Ester-, methoxy-, and halo-substituents were well tolerated in this transformation. Notably, cinnamyl aldehyde, a compound possessing

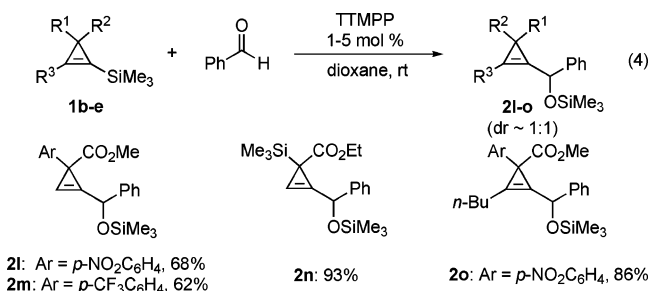
**Table 1.** Optimization of the Reaction Conditions<sup>a</sup>

entry	catalyst <sup>b</sup>	mol %	solvent	temp	time, h	yield <sup>c</sup> , %
1	DABCO	25	DMF	rt	3	42
2	DBU	25	DMF	rt	3	0
3	DMAP	25	DMF	rt	3	28
4	P( <i>t</i> -Bu) <sub>3</sub>	25	DMF	rt	3	5
5	PPh <sub>3</sub>	25	DMF	rt	3	12
6	PCy <sub>3</sub>	25	DMF	rt	3	5
7	TTMPP	25	DMF	rt	3	57
8	TTMPP	25	DMF	0 °C	3	33
9	TTMPP	25	DMF	50 °C	3	42
10	TTMPP	5	DMF	rt	4.5	62
11	TTMPP	5	DMA	rt	4.5	62
12	TTMPP	5	DMSO	rt	4.5	64
13	TTMPP	5	1,4-dioxane	rt	4.5	68
14	TTMPP	5	THF	rt	4.5	66
15	TTMPP	1	1,4-dioxane <sup>d</sup>	rt	6	79

<sup>a</sup> 0.1 mmol scale; 1 M concentration; rt = room temperature. <sup>b</sup> DABCO = 1,4-diazabicyclo[2.2.2]octane; DBU = 1,8-diazabicyclo[5.4.0]undec-7-ene; DMAP = 4-(dimethylamino)pyridine; TTMPP = tris(2,4,6-trimethoxyphenyl)phosphine. <sup>c</sup> GC yield. <sup>d</sup> Reaction run using 2 M concentration, 0.5 mmol scale.

an activated double bond, reacted with **1a** highly chemo- and regioselectively<sup>11</sup> to produce 1,4-diene **2h** in good yield (entry 8). Remarkably, primary, secondary, and tertiary aliphatic aldehydes were equally efficient in sila-MBH reaction (entries 9–11), suggesting a low sensitivity of this reaction to steric hindrance at the  $\alpha$ -position of aldehyde.

Next, we tested a series of unsymmetrically substituted 1-silyl-cyclopropenes **1b–e** in the reaction with benzaldehyde (eq 4). Both 3-aryl and 3-silyl substrates, as well as tetrasubstituted cyclopropene, produced the corresponding sila-MBH products **2l–o** in good to excellent yields, though as nearly equimolar mixtures of diastereomers. It was also found that the reaction was limited to cyclopropenes possessing electron-withdrawing groups at C-3. Presumably, this was required to decrease the energy of the cyclopropene's LUMO<sup>12</sup> for a more facile addition of nucleophilic catalyst.



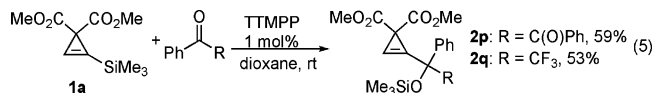
Encouraged by the successful sila-MBH reaction of **1** with aldehydes, we then attempted the analogous reaction with activated ketones (eq 5). To our delight, we found that cyclopropene **1a**

**Table 2.** Phosphine-Catalyzed Sila-MBH Reaction of 1-silylcyclopropene **1a**<sup>a</sup>

<div><div><div><div><div></div><div>E</div><div>E</div></div><div><div></div><div>SiMe<sub>3</sub></div></div></div><div><div></div><div></div><div></div></div></div><div>+ R-C(=O)H</div><div><div>TTMPP</div><div>1 mol %</div><div>dioxane, rt</div></div><div><div><div><div><div></div><div>E</div><div>E</div></div><div><div></div><div>OSiMe<sub>3</sub></div></div></div><div><div></div><div></div><div></div></div><div>R</div></div></div><div>E = CO<sub>2</sub>Me (<b>1a</b>)</div><div><b>2</b></div></div>			
#	R	product	yield <sup>b</sup> , %
1	Ph		<b>2a</b> 75
2	<i>p</i> -Tol		<b>2b</b> 75
3	<i>p</i> -OMeC <sub>6</sub> H <sub>4</sub>		<b>2c</b> 65
4	<i>p</i> -CO <sub>2</sub> MeC <sub>6</sub> H <sub>4</sub>		<b>2d</b> 60
5	<i>m</i> -ClC <sub>6</sub> H <sub>4</sub>		<b>2e</b> 80
6	<i>m</i> -BrC <sub>6</sub> H <sub>4</sub>		<b>2f</b> 58
7	2-Furyl		<b>2g</b> 50
8		<b>2h</b> 76	
9	<i>n</i> -Pr		<b>2i</b> 72
10	<i>i</i> -Pr		<b>2j</b> 76
11		<b>2k</b> 69	

<sup>a</sup> Reaction conditions: **1a** (0.5 mmol), aldehyde (1.0 mmol), TTMPP (0.005 mmol), dioxane (0.25 mL). <sup>b</sup> Isolated yield.

reacted smoothly with 1,2-dicarbonyl compound to form  $\alpha$ -silyloxyketone **2p**. Moreover,  $\alpha,\alpha,\alpha$ -trifluoroacetophenone underwent reaction with **1a** to produce cyclopropene **2q** in reasonable yield (eq 5).<sup>13</sup> It deserves mentioning that, prior to the development of this protocol, there were no direct approaches toward 1-(silyloxymethyl)cyclopropene-3-carboxylates **2**. Indeed, these synthetically



useful building blocks<sup>14</sup> may not be obtained through the direct Rh(II)-catalyzed addition of diazocompounds to secondary propargyl alcohol derivatives, as this route is known to lead to the corresponding allenes.<sup>15</sup> An alternative dianion approach<sup>16</sup> requires hydrolysis of ester group and reesterification.

In summary, we developed a sila Morita–Baylis–Hillman reaction of readily available<sup>17</sup> 1-silylcyclopropene-3-carboxylates with aldehydes and activated ketones, involving a 1,3-Brook rearrangement/elimination sequence. This novel protocol allows for

the direct and efficient synthesis of 1-(silyloxymethyl)cyclopropenes, which are not easily available through existing methods. Further studies on expanding the scope<sup>9</sup> and elucidation of the precise mechanism of sila-MBH reaction are underway in our laboratories.

**Acknowledgment.** The financial support of National Science Foundation (Grant CHE-0710749) is gratefully acknowledged.

**Supporting Information Available:** Experimental procedures and spectral data. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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JA077437S