

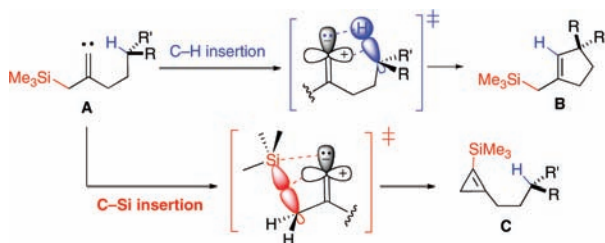
Cyclopropenation of Alkylidene Carbenes Derived from α -Silyl Ketones

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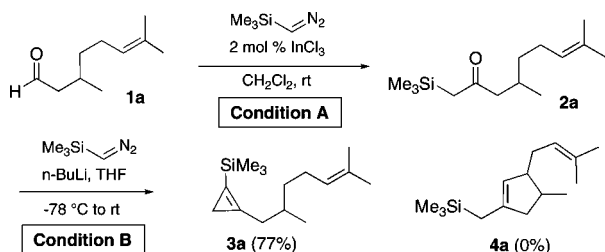
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Insertion of alkylidene carbenes into C–H bonds is a powerful tool for constructing carbocycles containing quaternary carbon centers with defined stereochemistry.¹ We envisioned that the prowess of this C–H insertion reaction can be extended to the silyl-substituted alkylidene carbene **A**, which should constitute an effective entry into the synthesis of functionalized cyclopentene derivatives of type **B**. In a preliminary study, however, we found that alkylidene carbene **A** preferentially provided cyclopropene **C** instead of cyclopentene derivative **B**, except for substrates with strongly activated $C\gamma$ –H bonds.² This is probably due to a more favorable interaction of the empty p orbital of the carbenic carbon with the nearby C–Si bond than with the rather remote $C\gamma$ –H bond. Since cyclopropenes are unusual yet versatile substrates for a variety of synthetic transformations,³ the development of efficient methods for their preparation is highly desirable. Herein we report a new cyclopropenation that involves selective insertion into the $C\alpha$ –Si bond of α -silyl ketones.



Our investigation commenced with a search for an efficient method for the preparation of α -silyl ketones.⁴ We found that the indium chloride-catalyzed reaction between trimethylsilyldiazomethane and aldehydes provided an efficient preparation of α -silyl ketones (condition A in Scheme 1).⁵ With this secure method, citronellal **1a** was converted into **2a**, which was then treated with lithiated trimethylsilyldiazomethane⁶ without purification (condition B in Scheme 1), delivering a product in 77% yield. To our surprise, the identity of this compound was established to be silylcyclopropene **3a**,⁷ and the expected cyclopentene derivative **4a** was not detected.

Scheme 1. Selective Insertion into the $C\alpha$ –Si Bond Rather Than the $C\gamma$ –H Bond



The generality of cyclopropene formation via $C\alpha$ –Si insertion was further examined using a variety of aldehydes with γ,δ -

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Table 1. Formation of Cyclopropenes via $C\alpha$ –Si Bond Insertion of Alkylidene Carbenes Derived from α -Silyl Ketones^a

entry	aldehyde	cyclopropene	yield (%) ^b
1	1b	3b	81
2	1c	3c	78
3	1d	3d	71
4	1e	3e	69
5	1f	3f	75
6	1g	3g	81
7	1h	3h	54
8	1i	3i	65
9	1j	3j	51
10	1k	3k	82
11	1l	3l	71
12	1m	3m	75

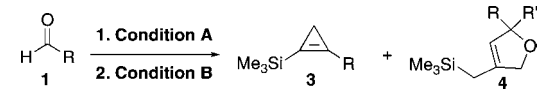
^a Conditions A and B are shown in Scheme 1. ^b Isolated yield.

unsaturation (**1b**–**i**) and branched chains (**1j**–**m**) with electronic and steric variation (Table 1). Both *cis*- and *trans*-dodecal (**1b** and **1c**) afforded the corresponding cyclopropenes **3b** and **3c** in 81 and 78% yield (entries 1 and 2). Symmetrical *cis*-dialdehyde⁸ **1d** also gave the corresponding bicyclopropene **3d** in good yield (entry 3). Aldehydes **1e**–**g** with trisubstituted γ,δ -double bonds behaved similarly, affording cyclopropenes **3e**–**g** in good yields (entries 4–6). An alkyne or aromatic substituent at this position in **1h** and **1i** did not interfere with the $C\alpha$ –Si insertion, which provided **3h** and **3i** in 54 and 65% yield, respectively. Although the addition of alkylidene carbenes to γ,δ -double bonds is well-precedented,⁹ the addition reaction was not observed with these systems. The

selectivity of insertion into the C γ -H bond versus the C α -Si bond was also examined with aldehydes **1j**-**m**¹⁰ containing methylene and methine protons as well as an oxygen atom at the C γ position.^{1c} Quite surprisingly, no competing insertion into the C γ -H protons or oxygen moiety¹¹ was observed, and only cyclopropenes **3j**-**m** were isolated in good yields.

Next, a variety of substrates carrying more strongly activated C γ -H bonds were explored (Table 2). Because of the especially strong activating role of the α -oxygen in the tether for C γ -H insertion,^{1c} the formation of both cyclopropene **3** via C α -Si bond insertion and dihydrofuran **4** via C γ -H insertion were expected. When subjected to condition A followed by condition B, aldehyde **1n** with C γ -methylene protons provided a mixture of cyclopropene **3n** and allylic silane-containing dihydrofuran **4n** in a 1.2:1 ratio in 75% yield (entry 1). Similarly, aldehyde **1o** afforded a mixture of cyclopropene **3o** and C-H insertion product **4o** in a slightly higher ratio (2.4:1) in 84% yield (entry 2). Surprisingly, aldehyde **1p** with allylic methylene protons yielded cyclopropene **3p** and C-H insertion product **4p** in only a 2:1 ratio, despite the fact that allylic C-H bonds are generally more activated toward carbene insertion (entry 3). The effect of an alkyl substituent was examined using methine-proton-containing substrate **1q**, which, contrary to our expectation, provided an even higher ratio (3.2:1) of cyclopropene **3q** to C-H insertion product **4q** (entry 4). Substrate **1r** containing a methine proton on a six-membered ring provided cyclopropane **3r** and a slightly increased relative amount of insertion product **4r** (**3r/4r** ratio of 1.5:1) in 69% yield (entry 5).

Table 2. Selectivity for Cyclopropenation of α -Silyl Ketones Containing Activated Protons at the C γ Position^a



entry	aldehyde	cyclopropene / insertion product ^b	yield (%) ^c
1		1.2 : 1	75
2		2.4 : 1	84
3		2 : 1	83
4		3.2 : 1	75
5		1.5 : 1	69

^a Conditions A and B are shown in Scheme 1. ^b Ratio determined by ¹H NMR analysis of the crude products. ^c Combined isolated yield of products **3** and **4**. ^d A pure sample of **4q** could not be obtained for full characterization.

In conclusion, we have developed a new cyclopropenation reaction involving C α -Si bond insertion of alkylidene carbenes derived from α -silyl ketones. This unprecedented alkylidene carbene

reactivity features an excellent selectivity for C α -Si bond insertion rather than C γ -H bond insertion or addition to γ,δ -double or -triple bonds. The selectivity trend in Table 2 clearly indicates that the α -oxygen in the tether significantly promotes C γ -H insertion, although the C α -Si bond insertion still competes effectively. It is noteworthy that the reactivity of the C-H bond toward carbene insertion depends intricately on electronic and steric factors and cannot be predicted by the simple additive effect of contributing factors.

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Supporting Information Available: General procedures and characterization data for representative compounds. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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