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Novel DMAP-Catalyzed Skeletal Rearrangement of 5-*exo*-(2-Hydroxyethylene)oxasilacyclopentanes

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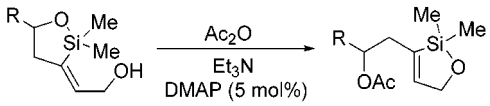
ABSTRACT



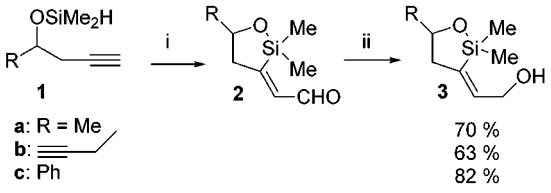
5-*exo*-(Hydroxyethylene)-2-oxa-1-silacyclopentanes are found to undergo a novel DMAP-catalyzed skeletal rearrangement through silicon–oxygen exchange during acetylation to yield the corresponding 5-(2-acetoxyalkyl)-2-oxa-1-silacyclopent-4-enes exclusively. The mechanism for this unprecedented rearrangement is proposed.

Highly functionalized 3-substituted 5-*exo*-(formylmethylene)-oxasilacyclopentanes, which serve as useful intermediates in organic syntheses, are readily obtained through intramolecular silylformylation of *ω*-dimethylsiloxyalkynes[1] and dimethylsiloxyalkadiynes.[2]

In the course of our studies on various transformations of these *exo*-(formylmethylene)oxasilacyclopentanes (**2**), especially for the syntheses of polyhydroxy compounds of medicinal interest, we found an unexpectedly facile and novel DMAP-catalyzed (DMAP = 4-(dimethylamino)pyridine) skeletal rearrangement of *exo*-(hydroxyethylene)oxasilacyclopentanes (**3**). We would like to report here the novel DMAP-catalyzed rearrangement of 5-*exo*-(hydroxyethylene)-2-oxa-1-silacyclopentanes (**3**) to 5-(2-acetoxyalkyl)-2-oxa-1-silacyclopent-4-enes (**4**) in the presence of acetic anhydride, triethylamine, and a catalytic amount of DMAP. A mechanism for this novel process is also proposed.

5-*exo*-(Hydroxyethylene)-1,1-dimethyl-2-oxa-1-silacyclopentanes (**3a**−**c**) were prepared by $NaBH_4$ reduction of 5-*exo*-(formylmethylene)-1,1-dimethyl-2-oxa-1-silacyclopentanes (**2a**−**c**), which were obtained through Rh-catalyzed intramolecuar silylformylation of the corresponding *ω*-dimethylsiloxyalkynes (**1a**−**c**) (Scheme 1). 3-(2-Hydroxymethyl-3-silylprop-2-enyl)-5-*exo*-(hydroxyethylene)-1,1-dimethyl-2-oxa-1-silacyclopentanes (**3d**−**e**) were prepared in a similar manner from 4-dimethylsiloxy-1,6-heptadiyne using our sequential double silylformylation protocol, followed by $NaBH_4$ reduction.[2]

Scheme 1. Synthesis of 5-*exo*-(2-Hydroxyethylene)oxasilacyclopentanes **3a**−**c**[a]



[a] (i) $Rh(acac)(CO)_2$ (2 mol %), CO (10 atm), toluene, rt, 16 h; (ii) $NaBH_4$ (1 equiv), MeOH, 0 °C, 45 min.

When we tried to acetylate the hydroxyl group of the *exo*-2-hydroxylethylene moiety of **3a**−**c** with acetic anhydride and triethylamine in the *presence* of a catalytic amount of DMAP at room temperature, **3a**−**c** underwent a facile skeletal rearrangement to afford **4a**−**c** exclusively, i.e., no acetylation product of **3a**−**c** was detected (Scheme 2). Release of the ring strain in **3a**−**c** accounts for the

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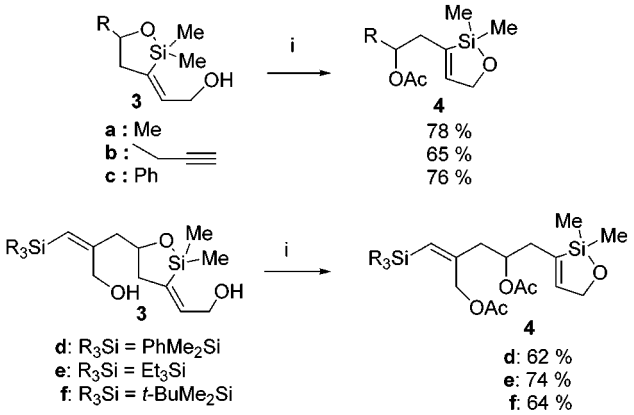
Scheme 2. DMAP-Catalyzed Skeletal Rearrangement of **3** to Oxasilacyclopentene **4**[a]

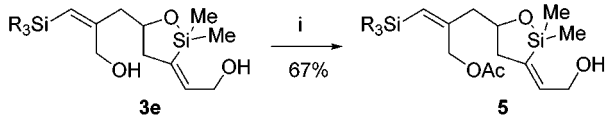


[a] (i) Ac_2O (1.2 equiv), Et_3N (1.2 equiv), DMAP (5 mol %), THF, rt, 4 h.

unprecedented facile skeletal rearrangement and exclusive formation of **4a**−**c**. In a similar manner, the reaction of **3d**−**f** under the same conditions gave diacetate **4d**−**f** via the same skeletal rearrangement (Scheme 2).

Reaction of diol **3e** with acetyl chloride and NEt_3 in the *absence* of DMAP gave only monoacetylated product **5** in 67% yield, but no rearrangement was observed (Scheme 3).

Scheme 3. Acetylation of **3e** with Acetyl Chloride in the Absence of DMAP[a]



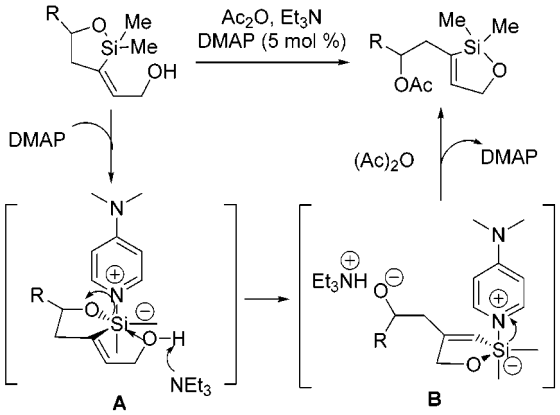
[a] (i) AcCl (3 equiv), Et_3N (3 equiv), THF, rt, overnight.

This result clearly indicates that DMAP is a requisite for the skeletal rearrangement. It should be also noted that only the allylic alcohol moiety in the C-3-side chain of **3e** was acetylated; acetylation of the allylic alcohol group at the C-5 *exo*-hydroxyethylene moiety did not take place at all. This is most likely due to the ligation of the oxygen of the C-5 allylic alcohol group to the silicon atom of the oxasilacyclopentane ring, which should substantially decrease the nucleophilicity of the alcohol oxygen. For the same reason, **3a** and **3b** were not acetylated with AcCl/NEt_3 in the *absence* of DMAP.

A plausible mechanism for this novel skeletal rearrangement is proposed in Scheme 4. This mechanism involves a nucleophilic attack of DMAP to the silicon atom of the oxasilacyclopentane ring, forming 6-coordinated silicate-like intermediate **A**, which facilitates the base-promoted oxygen−silicon exchange through intermediate **B** to give the rearranged product **4** and regenerate DMAP (Scheme 4).

The formation of 5-coordinated silicon involving DMAP has a precedent in a paper by Martin et al. on the reactivity

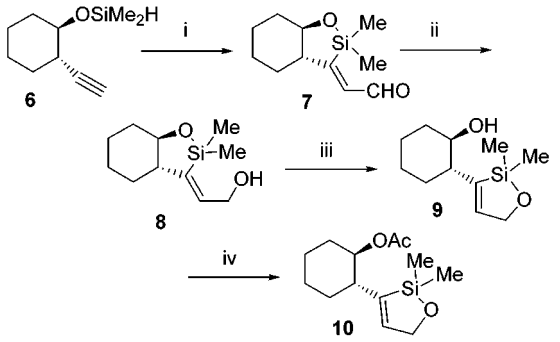
Scheme 4. Mechanism of the DMAP-Catalyzed Skeletal Rearrangement of **3** through Si−O Bond Exchange



of 3,3,3′,3′-terakis(trifluoromethyl)-1,1′(3*H*,3′*H*)-spiro-bis-[2,1-benzoxasilole].[3] More recently, Leighton et al. proposed a 5-coordinated 2,8-dioxa-1-silabicyclo[3.3.0]octane, involving the coordination of an aldehyde oxygen to the silicon metal in a tandem silylformylation−allylsilylation process.[4] However, the DMAP-catalyzed skeletal rearrangement of *exo*-alkylideneoxasilacyclopentane to alkyloxasilacyclopentene involving Si−O bond exchange is unprecedented.

Reaction of *O*-dimethylsilyl-*trans*-2-ethynylcyclohexanol (**6**) under the standard conditions gave the fused bicyclic silylformylation product **7**,[1] which was reduced by $NaBH_4$ to afford fused bicyclic (2-hydroxylethylene)oxasilacyclopentane **8** in 90% yield for the two steps as a white solid (Scheme 5). Since **8** was a solid, recrystallization was carried

Scheme 5. Formation of **8** and Facile Rearrangement to **9**[a]



[a] (i) $Rh(acac)(CO)_2$ (2 mol %), CO (10 atm), toluene, rt, 24 h, quantitative; (ii) $NaBH_4$ (1 equiv), MeOH, 0 °C, 45 min, 90%; (iii) crystallization from Et_2O; (iv) $(Ac)_2O$ (1.5 equiv), Et_3N (1.5 equiv), DMAP (5 mol %), THF, rt, 5 h, 76%.

out from ether (3 weeks at 25 °C), which gave good single crystals for X-ray analysis. To our surprise, the X-ray crystallographic data showed that the crystalline product obtained from recrystallization was not **8** but was 5-(2-hydroxycyclohex-1-yl)-2-oxa-1-silacyclopent-4-ene **9**, arising from the skeletal rearrangement similar to the DMAP-

catalyzed process discussed above. This facile skeletal rearrangement of **8** can be attributed to the high strain energy of the 7-*exo*-alkylene-*trans*-bicyclo[4.3.0]-2-oxa-1-silanonane system. Thus, the forced coordination of the alcohol oxygen to the Si metal during crystallization process is, apparently, sufficient to drive the skeletal rearrangement via trigonal bipyramidal silicate-like intermediate to release the strain energy, yielding thermodynamically favorable **9** (Figure 1).

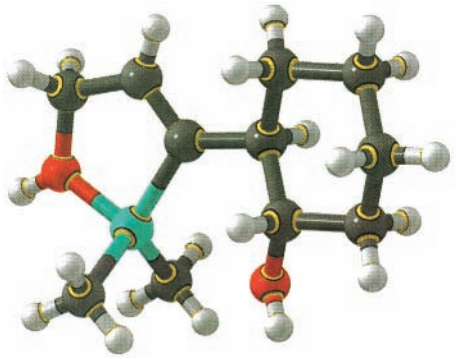


Figure 1. X-ray crystal structure of **9**.

It may be worthy of note that the attempted acetylation of **9** with AcCl/NEt_3 at room temperature in THF, followed by reflux for 3 h, did not give the acetylated product **10**. However, the reaction of **9** with Ac_2O/NEt_3 in the presence of a catalytic amount of DMAP (5 mol %) afforded **10** in 76% yield (Scheme 5). The observed low reactivity of the hydroxyl group in **9** can be ascribed to the steric hindrance and a possible attractive interaction of the oxygen of the hydroxyl group with the silicon metal, which requires the reactive acetylating species Ac-$DMAP^+$. This result also implies that DMAP is involved in the generation of the Ac-$DMAP^+$ species in the acetylation of the secondary alcohols formed by the DMAP-catalyzed skeletal rearrangement of **3** in Scheme 4.

In conclusion, 5-*exo*-(hydroxyethylene)-2-oxa-1-silacyclopentanes **3** undergo an unprecedented DMAP-catalyzed facile skeletal rearrangement via silicon−oxygen exchange to give the corresponding oxasilacyclopent-4-enes **4** exclusively. This novel rearrangement is likely to include 5-coordinated and 6-coordinated silicate-like intermediates. Noncatalyzed spontaneous skeletal rearrangement was observed upon crystallization of highly strained fused bicyclic *exo*-(hydroxyethylene)oxasilacyclopentane **8**, which should include 5-coordinated silicon intermediate in a condensed phase. The rearrangement products **4a**−**f** and **10** serve as useful intermediates in organic syntheses.

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Supporting Information Available: The characterization data of compounds **2a**−**c**, **3a,c**, **4a**−**f**, **5**, **8**, **9**, and **10**. This material is available free of charge via the Internet at http://pubs.acs.org.

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