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Reaction of δ-silyl-γ,δ-epoxy-α,β-unsaturated acylsilanes with cyanide ion: possibility of the formation of silicate intermediate in anion-induced ring opening of epoxysilanes

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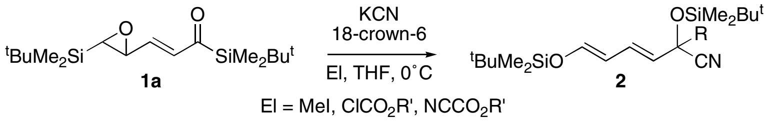
Abstract—Reaction of *trans*- and *cis*-δ-silyl-γ,δ-epoxy-α,β-unsaturated acylsilanes **1** and **9** with cyanide ion in the presence of an electrophile affords double Brook rearrangement products **10** in an *E*/*Z* ratio depending on the cis/trans geometry of the epoxysilanes.

During our investigation of chirality transfer in twofold Brook rearrangement-mediated tandem reactions of δ-silyl-γ,δ-epoxy-α,β-unsaturated acylsilanes **1a**[1] with a cyanide ion (**1a**→**2**) (Scheme 1), we observed that generation of an alkoxide, a possible intermediate in the reaction, by treatment of α-silyl alcohol (2*Z*,4*E*)-**3**[1] with $KN(SiMe_3)_2$ (KHMDS) in the presence of MeI afforded *O*-silyl cyanohydrin derivatives **4** in 78% yield with an 5*E*:5*Z* ratio of 1:5.0, in sharp contrast to the fact that only (3*E*,5*E*)-**2** was obtained from the reaction of **1a** with KCN/MeI (Scheme 2).[1,2] A similar trend was also observed for other bases and for the addition of 18-crown-6. Interestingly, the *E*/*Z* ratio in **4** was dependent upon the olefin geometries in **3**. Thus, (2*E*,4*E*)-**3** afforded **4** in an 5*E*:5*Z* ratio of 1:33. These striking results prompted us to study this in some detail.[3,4]

The observed *Z*-selectivities can be rationalized in terms of the ground-state conformation at C6 and the transition structures in the Brook rearrangement[5] (Scheme 3). X-ray analysis of (2*Z*,4*E*)-**3** indicates that a ground-state conformation has a silyl group aligned almost perpendicularly to the plane of the olefin and an OH group in an inside position (Fig. 1).[6,7] Assuming that the conformation in the solid state is similar to the conformation in solution, the most plausible pathway from **3** to **4** may involve the formation of a silicate intermediate **6a**,[8] which can be directly derived from the most stable conformation of **3**, and the C–Si bond adopts a coplanar arrangement with the π-orbitals of the double bond, followed by Brook rearrangement and reaction with an electrophile. These findings are in good agreement with those reported by Panek[9] on the catalytic osmylation of C1-oxygenated allylsilanes and with those described in the literature for allylsilanes.[10]

On the other hand, the result for epoxysilane **1a**, in which only (*E*)-**2** was formed, suggests that an alkoxide



Scheme 1. Tandem reaction of **1a** with an electrophile.

Keywords: Brook rearrangement; Tandem reactions; Epoxysilanes; Allyl silanes; Electrophilic substitution.

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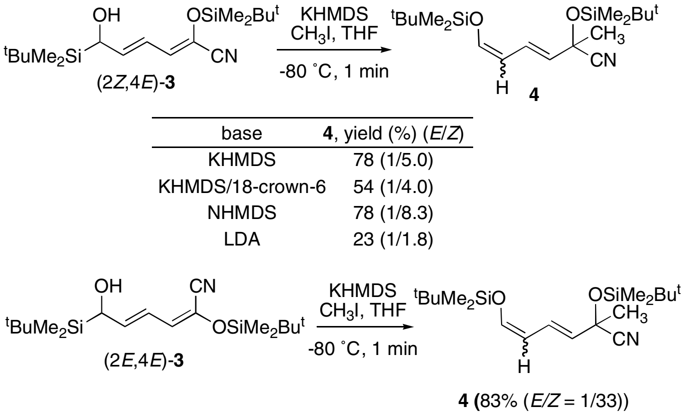
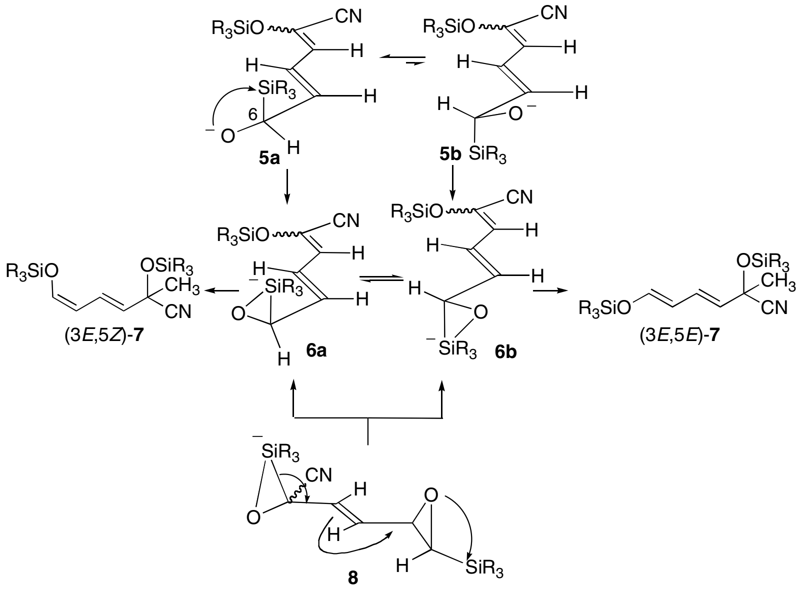


base	**4**, yield (%) (*E*/*Z*)
KHMDS	78 (1/5.0)
KHMDS/18-crown-6	54 (1/4.0)
NHMDS	78 (1/8.3)
LDA	23 (1/1.8)

Scheme 2. Treatment of **3** with a base.



Scheme 3.

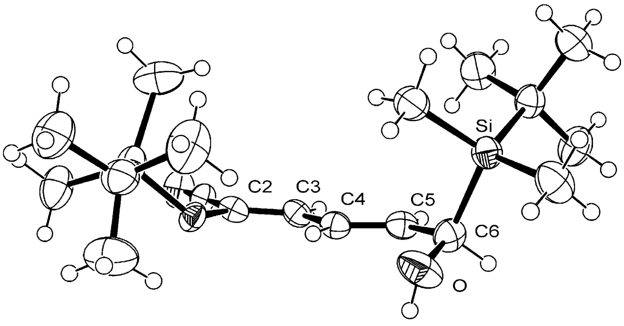
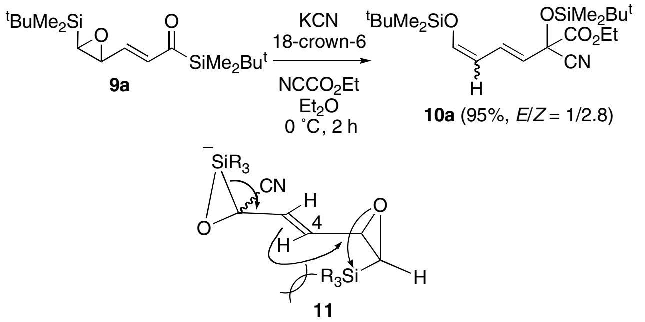


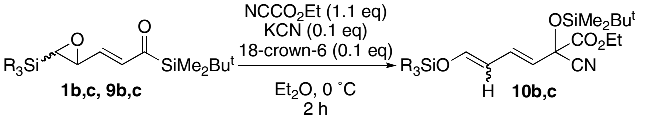
Figure 1. ORTEP drawing of (2*Z*,4*E*)-**3**.

5 was not involved as an intermediate in the major pathway or that it was involved but was too short-lived to change its conformation to the most stable one **5a**. One possible explanation of this result is that the C–O bond cleavage of epoxide and Si–O bond formation in silicate intermediate **8**, generated from addition of cyanide ion to **1a**, occur in a concerted fashion to provide silicates **6a** and **b**, leading to (5*Z*)-**7** and (5*E*)-**7**, respectively.[11] Although the migrating silyl groups in both **6a** and **b** are located in the position to ensure best overlap with the π-bond, the latter seems to be formed faster with rotation about the C5–C6 bond from **8**.[12] To test this possibility and to preclude the possibility that the difference in the stereochemical outcome between the reactions of **1a** and **3** is due to the difference in the reaction conditions used,[13] we conducted the reaction using *cis*-epoxide derivatives **9a**, which would give an (5*Z*)-**7** as a major product if the above assumption is true. When **9a** was treated with KCN/NCCO$_2$Et under the same conditions as those employed for **1a**, (5*Z*)-**10a** was obtained as a major isomer ($E/Z = 1/2.8$),[14] supporting our assumption mentioned above (Scheme 4). The lower selectivity observed for the cis derivative may be explained by eclipsing interaction between the hydrogen at C-4 and the *tert*-butyldimethylsilyl group in the formation of silicate as shown in **11**.

Next, to obtain further support for our assumption of silicate intermediacy, we carried out reactions using



Scheme 4. Reaction of **9a** with ethyl cyanoformate in the presence of KCN/18-crown-6.



	R_3Si	yield (%)	E/Z
1b	*i*-Pr_3Si	93	*E*
1c	*t*-$BuPh_2Si$	97	*E*
9b	*i*-Pr_3Si	96	1/3.3
9c	*t*-$BuPh_2Si$	99	1/1.5

Scheme 5. Reaction of **1b**,**c** and **9b**,**c** with ethyl cyanoformate in the presence of KCN/18-crown-6.

1b,**c** and **9b**,**c**, which bear electronically and sterically different silyl groups, with the expectation that in the case of **9c**, the silicate ion **6a** would have a sufficiently long lifetime for conversion to rotamer **6b**, leading to a thermodynamically stable *E*-isomer, by introduction of a phenyl group on the silyl group, and consequently the *E*/*Z* ratio in **10** would increase (Scheme 5).[15] While in the case of triisopropylsilyl derivatives **1b** and **9b**, more sterically demanding than *tert*-butyldimethylsilyl group, essentially the same stereochemical outcome as that observed for *tert*-butyldimethylsilyl derivatives **1a** and **9a** was observed, *tert*-butyldiphenylsilyl derivative **9c**, more sterically demanding but more silicate ion-stabilizing than the *tert*-butyldimethylsilyl group, afforded **10c** in an increased ratio (*E*/*Z*: 1/1.5 vs 1/2.8) of *E*-isomer to *Z*-isomer, supporting the above assumption.

In conclusion, we demonstrated the possibility that a γ-anion-induced ring opening in α,β-epoxysilanes provides an allylsilicate intermediate in a concerted fashion and demonstrated that the intermediate does not have a sufficient lifetime to allow it to rotate freely about the C(α)–C(β) bond and undergoes Brook rearrangement according to the least motion principle[16] to give products in an *E*/*Z* ratio depending on the geometry of the epoxysilanes.

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Supplementary data

Supplementary data associated with this article can be found, in the online version at doi:10.1016/j.tetlet.2005.07.120. Information available: full experimental details and spectral data.

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14. Reaction of **1a** with KCN/$NCCO_2Et$ provided (5*E*)-**10a** in 93% yield. See Ref. 1.
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