## 1,2-DIALKYLVINYLSILANES FROM α-SILYL EPOXIDES VIA ORGANOLITHIUM REAGENTS

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**Abstract.** The reactions of cis- $\alpha$ -epoxystlanes (1) with an excess of alkyllithium reagents were found to cleanly provide 1,2-dialkylvinylstlanes (3). A model for this reductive alkylation is advanced which explains the role of substituents in determining the product stereochemistry.

Over two decades ago, Crandall<sup>2</sup> discovered that epoxides could undergo a reductive alkylation with organolithium reagents, a reaction believed to proceed through  $\alpha$ -lithiation followed by decomposition through a carbenoid process.<sup>24</sup> By incorporating  $\alpha$ -heteroatoms into the starting epoxide (*e.g.* 1), Eisch achieved the efficient formation of 2 under conditions which avoid its decomposition, and developed a protocol which demonstrated the synthetic importance of such species.<sup>3</sup> Recently, Molander<sup>4</sup> found that *cis*-silyl epoxides (1) undergo deprotonation much faster than their *trans* counterparts, and like Eisch, found that, at low temperature, 2 retains its configuration in reactions with electrophiles,<sup>3,4</sup> except in one case where  $Z \rightarrow E$  isomenzation was observed (2: R = *t*-Bu, R<sup>1</sup> = Me).<sup>4</sup> The decomposition of 2 at higher temperatures is thought, as has been proposed for its non-silylated counterparts,<sup>2,34</sup> to occur *via*  $\alpha$ -elimination, to give a carbenoid (*i.e.* LiOCHR<sup>1</sup>(R<sub>3</sub>Si)C:) which adds LiR<sup>2</sup> and eliminates the elements of Li<sub>2</sub>O, ultimately giving the vinylsilane (*i.e.* 3).<sup>3</sup> For 1, the stereochemistry of this reductive alkylation is unknown (*i.e.* R<sup>1</sup>  $\neq$  H) except for a  $\beta$ -deuterated case which proved to be stereorandom.<sup>36</sup>



Our interest in the chemistry of both  $1^5$  and  $3^6$  led us to view the above process as a potentially versatile entry to bulky vinylsilanes which are either unknown or are nontrivial to prepare.<sup>7</sup> Epoxysilanes (**1a-f**) were added to 4 equiv of LiR<sup>2</sup> in an ethercal cosolvent (cf. Footnote a, Table 1) at -78°C, which, after a slow warm-up, led to the clean formation of **3** in most cases.<sup>8</sup> The stereochemistry of **3** regularly changes with systematic increases in the size of either SiR<sub>3</sub> or R<sup>1</sup> from a predominantly Z-selective process (*i.e.* R = Me, Et, R<sup>1</sup> = 1° alkyl) to >95% E for the Si(*i*-Pr)<sub>3</sub> derivatives (Table 1).

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Entry	1	$\mathbf{R}^{1}$	R	R <sup>2</sup>	3	Yield*	E:Z <sup>a</sup>
1	а	n-Pr	Ме	n-Bu	a	28 <sup>b</sup>	1:99
2	Ъ	n-Bu	Me	t-Bu	Ъ	93	16:84
3	c	Me	Et	n-Bu	с	81	8:92
4	с	Me	Et	t-Bu	đ	97	5:95
5	с	Me	Et	"Ce( <i>t</i> -Bu) <sub>4</sub> "	$\mathbf{d}^{c}$	100	5:95
6	đ	n-Bu	Et	n-Bu	e	80	24:76
7	đ	<i>n</i> -Bu	Et	"Ce( <i>n</i> -Bu) <sub>4</sub> "	e°	97	27:73
8	đ	n-Bu	Et	$CH_2TMS$	f	89	25:75
9	đ	n-Bu	Et	"Ce(CH <sub>2</sub> TMS) <sub>4</sub> "	f	62	30:70
10	đ	n-Bu	Et	t-Bu	g	100	12:88
11	е	ı-Pr	Et	n-Bu	h	79	62:38
12	е	ı-Pr	Et	n-Bu	$\mathbf{h}^{d}$	79	75:25
13	е	i-Pr	Et	n-Bu	ħ۴	50	70:30
14	е	i-Pr	Et	$CH_2TMS$	i	45	60:40
15	e	i-Pr	Et	t-Bu	j	57	95:5
16	f	Me	ı-Pr	Me	k	85	95:5
17	f	Me	ı-Pr	n-Bu	1	82	99:1
18	f	Me	i-Pr	$CH_2TMS$	m	90	96:4
19	f	Me	i-Pr	t-Bu	n	89	99:1

Table 1. 1,2-Disubstituted Vinylsilanes (3) from 1.

<sup>6</sup> GC yields employing an internal hydrocarbon standard A LiR<sup>2</sup>/1 ratio of 4 was used except as noted in footnotes c and e. 1,2-Dimethoxyethane (DME) was employed as the reaction solvent except for the Li(t-Bu) reactions and Entry 12 where a 1.3 ether/THF solvent system was used. The amount of added ethereal solvent was adjusted to result in solutions which were *ca*. 0.4 M in LiR<sup>2</sup>. In most cases, the mixtures were allowed to warm over *ca* 3.5 h to room temperature. However, in some cases, they were allowed to reach cither -45°C (Entries 2,4,5,15) or -25°C (Entries 1,3,11,12,13) and held at this temperature for 2 h, quenched and judged to be complete by the absence of 1 Entry 14 required 4 h at 0°C. *E/Z* ratios were determined from capillary GC and/or the <sup>13</sup>C NMR peaks heights for the α-alkylsilyl carbons, both of which were in good agreement with the ratios obtained from the integrated vinylic proton region in cases which gave significant amounts of both isomers. <sup>b</sup> 62% 4-nonene (*Z/E* = 4) was formed <sup>c</sup> LiR<sup>2</sup>/CeCl<sub>a</sub>/1 = 8.2.1 <sup>d</sup> 1:3 ether/THF.

The rate of this reductive alkylation proved to be quite variable (cf. 4 h, 0°C (Entry 14) vs. <2 h, -25°C (Entry 11)). Quenching this latter reaction after 2 h at -78°C gives **3h** (25%, E/Z = 60:40) and recovered **1e** (70%) as a c/t mixture (71:29). With TMEDA (2 equiv) added to the Li(*n*-Bu), quenching with D<sub>2</sub>O produced a similar product distribution with the c/t mixture of **1e** being  $\alpha$ -deuterated.<sup>9</sup> Replacing DME with the ether/THF solvent system slightly increased the *E*-selectivity (Entry 12) without affecting the yield of **3h**. However, reducing the amount of LiR<sup>2</sup> to 2 equiv, did lower its yield (50%, E/Z = 70:30) and convert **1e** to a 70:30 c/t mixture (Entry 13).



As is illustrated above, each system was rigorously characterized by NMR. Where necessary, the amount of minor isomer was increased by the photoisomerization of **3** in  $C_6D_6$ . The vinylic proton for the *Z* isomer is consistently downfield from its *E* counterpart. As expected, the <sup>13</sup>C NMR resonances for the allylic carbons were quite dependent upon the geometry of **3**. For **3h**, the relief of the  $\gamma$ -cis interaction with the *i*-Pr group upon changing from *E* to *Z*, results in a downfield shift for C-5 (*i.e.*  $\delta$  29.8 vs 37.8 ppm). With an exchange of one such interaction for another (*e.g.* **3h** (C-2), *n*-Bu vs TES) the shift is less and, in the TIPS derivatives, the shift is upfield (*e.g.* **3i**: Me(C-1)  $\delta$  14.7(*E*) vs 13.0(*Z*) ppm).

In the reaction of **1f** with LiMe (Entry 16), we noted that any recovered epoxide had the pure *trans* configuration indicating that the  $Z\rightarrow E$  isomerization of **2** can be an important process in these systems. The reaction of LiMe with the corresponding TES epoxide (**1c**) led to TESMe, rather than to **3**, suggesting that Si/Li exchange had occurred. Similarly, Li(*n*-Bu) reacts with **1a** to produce **3a** in low yield (28%), but with remarkable Z-selectivity (99:1) (Entry 1). The major products, 4-nonene (c/t = 4) and *n*-BuTMS, evidently arise from reaction at silicon with the formation of *cis*-1,2-epoxy-1-pentyllithium. As for SiPh<sub>3</sub> or SnR<sub>3</sub> derivatives,<sup>3,4</sup> these exchanges with unencumbered LiR<sup>2</sup> can also occur with TMS or TES systems. This probably accounts for the fact that Li(*s*-Bu) proved superior to its straightchain counterpart for the formation of **2** from **1** (R = Me).<sup>4</sup> "LiCeR<sub>4</sub>" reagents<sup>10</sup> appear to give LiR<sup>2</sup>-based chemistry rather than from any cerium species (*cf*. Entries 5, 7, 9).

Taking advantage of the information available on this reductive alkylation,<sup>2-4</sup> our results led us to consider a number of reaction models for this interesting conversion.<sup>12</sup> We found the following mechanistic picture, wherein the organolithium aggregates are represented by encircled  $LiR^2$ , to be consistent with all of the available data.



First, the initial O-complexation of 1 with  $LiR^2$  has been proposed for the formation of  $2^{2\cdot4}$  and a similar species has been suggested to explain the efficient trapping of a carbene-type intermediate.<sup>3d 12a</sup> With a large excess of  $LiR^2$ , we suggest that **2Z** forms an adduct **A** with ( $LiR^2$ )<sub>x</sub> involving both its oxygen and lithium atoms. Li assists its ringopening to produce a carbenoid **B** which can lead to **3Z** through an addition/*syn*elimination ( $\mathbb{R}^2$ /LiOLi) process.<sup>12b</sup> which is enhanced by an excess of LiR<sup>2</sup> (*cf.* Entries 11 *vs* 13). Assuming that a significant energy barrier to the **B/C** interconversion exists, smaller groups in **1** lead to a *Z*-selective process. However, as the size of SiR<sub>3</sub> is increased, this collapse is slowed, and driven, by SiR<sub>3</sub>-R<sup>1</sup> repulsions, to the **C** side of the reaction manifold where either **2E** or **3E** can be formed. More **3E** is observed with an incremental increase in the size of either SiR<sub>3</sub> or R<sup>1</sup> and, as noted above, we also observed  $Z \rightarrow E$  isomerization in the recovered epoxide. In **B** us **C**, the steric bulk of  $(\text{LiR}^2)_{x*}$  rather than that of R<sup>2</sup> alone must be considered. Since larger R<sup>4</sup> groups generally lead to a lower value for x in  $(\text{LiR}^2)_{x*}$ .<sup>13</sup> it is not surprising that no clear-cut stereochemical consequence emerges in the E/Zproducts ratios with a change in the size of R<sup>2</sup> in the organolithium reagent. Finally, this model can also explain the observed preference for *trans* alkenes from bulky epoxides as well as the "memory effect" in other systems wherein the geometry of the lithnated epoxide is partially reflected in the alkene products formed (*cf.* Entry 1: 4-nonene, c/t = 4).<sup>2,3c,10</sup>

## **REFERENCES AND NOTES**

 $1\,$  The support provided by the (a) NIH-MBRS Program (RR08102) and (b) Department of Education (P200A90203) is gratefully acknowledged

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8. As expected, the nucleophilic ring-opening of 1, reactivity which has been observed for less basic organolithium reagents, was not detected under our conditions (cf. Zhang, Y; Miller, J. A. Negishi, E.-I. J. Org Chem. 1989, 54, 2043). The procedure for 3g is representative. Under a nitrogen atmosphere, to a stirred solution of Li(t-Bu) (13.6 mL 1 47 M, 20.0 mmol) in pentane at -78°C was added, dropwise, dry ether (15 mL) and THF (5 mL) followed by 1d (0.94 g, 4.4 mmol) The mixture was allowed to warm to 25°C over 3.5 h, carefully poured onto an ice/NH<sub>4</sub>Cl (sat.) mixture (20 g/35 mL) Pentane (20 mL) was added, and after separation, the aqueous layer was washed with pentane (3 x 15 mL), and the combined organic layers were dried (K<sub>2</sub>CO<sub>3</sub>), concentrated in vacuo Distillation of the residue provided 0.87 g (78%, Z/E = 12:88 (by <sup>13</sup>C NMR); 96% GC purity) of 3g (bp 94-5 °C at 0.35 Torr) (See footnotes, Table 1) Preparative GC provided 3 in pure form for smaller GC scale reactions. Satisfactory analytical and complete spectroscopic data were obtained in each case.

9 TMEDA = N,N,N',N'-tetramethylethylenediamine Under our general reaction conditions (*i.e.* no added TMEDA), the aggregation of LiR<sup>2</sup> or **2** is probably more extensive Surprisingly, repeated attempts to incorporate deuterium into **1e** were unsuccessful Lithium salts (LiBr) alone do not effect the c/t isomerization of **1e**. At present, we do not understand this phenomenon

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12. (a) No C-H insertion or related products attributable to a free carbone were observed in our systems. (b) While we cannot rule out the possibility that the  $R^2$  group adds from below the  $\alpha$ -Li, model studies on a variety of known LiR aggregates<sup>11,13</sup> suggest that the illustrated top-side attack is more likely. Moreover, no evidence for nucleophilic attack by LiR<sup>2</sup> of 1 as has been observed for less basic organolithium reagents was detected in our systems (cf. Zhang, Y., Miller, J A., Negishi, E -I J. Org. Chem. 1989, 54, 2043)

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