Facile 1,3-Hydride Transfer in a Cycloheptyl Cation

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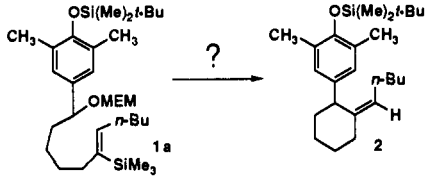
Abstract: The intramolecular addition of a benzylic cation to a vinylsilane was studied. The benzylic (methoxyethoxy)methyl ether **1** was shown to undergo an unusual cyclization to afford a substituted cycloheptene (**12**) upon treatment with a Lewis acid. Following cyclization, the molecule undergoes a formal 1,3-hydride shift, followed by elimination to give styrene **12**.

Introduction

As part of our continuing studies of the scope and limitations of cyclization reactions initiated by *p*-quinone methides[1] and related cations,[2] we report a cyclization of a benzylic cation with a vinylsilane in which the major product is formed via a 1,3-hydride transfer. This takes place within a 7-membered ring and occurs under extremely mild conditions with no competing 1,2-hydride transfer reactions.[3] To our knowledge, this is the first example of a 1,3-hydride transfer in a cycloheptyl cation.

The intramolecular addition of cations to vinylsilanes is well documented. Vinylsilanes normally react with electrophiles to initially afford a β-silyl cation, which then loses the silyl group to afford an alkene.[4] We examined the cyclization of benzylic ether/vinylsilane **1a** with the expectation that the cyclization would proceed through a sterically demanding transition state to afford



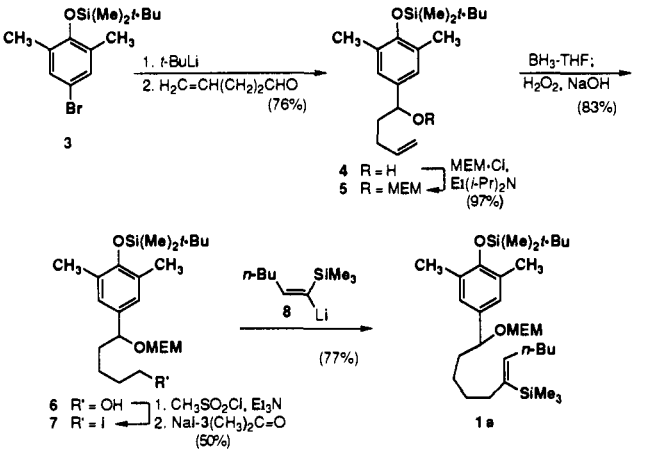
(1)

methylenecyclohexane **2**, which should experience a substantial $A^{1,3}$-interaction between the aryl and butyl groups (eq 1).[5] This study was designed to push our benzylic cation cyclization methodology and ascertain whether the intermediate could hold its configuration and undergo stereospecific elimination in the face of substantial steric interactions.

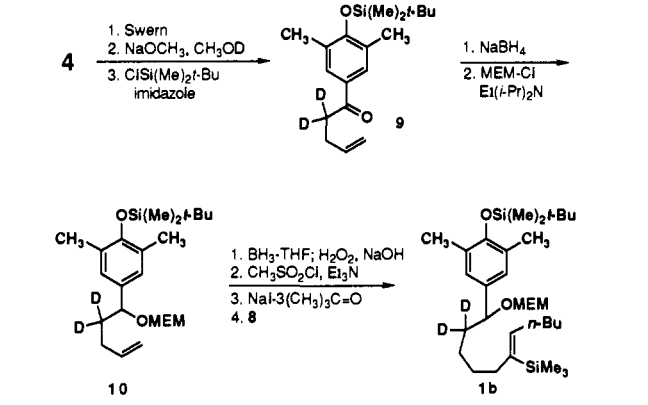
Results and Discussion

Synthesis of Benzylic Ether/Vinylsilanes 1. Substrates **1** were prepared in a straightforward manner. Halogen/metal exchange of protected phenol **3**, followed by condensation with 4-propenal,[6] afforded benzylic alcohol **4** in 76% yield (Scheme I). Treatment of the alcohol with MEM-Cl in the presence of Hünig's base afforded MEM-ether **5** in 97% yield.[7] Hydroboration of **5**, followed by oxidation with basic hydrogen peroxide, afforded alcohol **6**, which was converted to the iodide **7** via the mesylate. Condensation of **7** with (*Z*)-1-lithio-1-(trimethylsilyl)-1-hexene[8] (**8**) afforded **1a** in 77% yield.

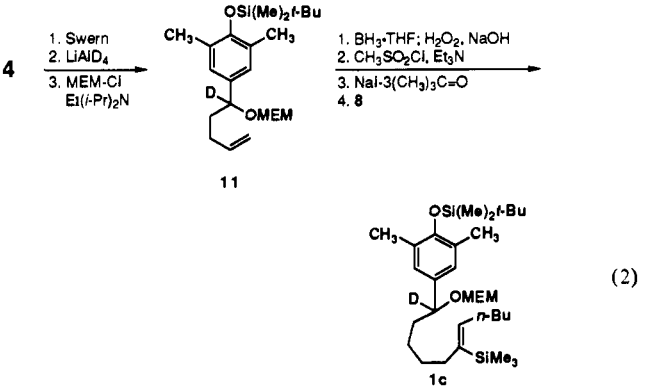
Scheme I. Synthesis of **1a**



Scheme II. Synthesis of **1b**



The deuterium-labeled substrates **1b** and **1c** were prepared from alcohol **4** as shown in Scheme II and eq 2. The vinylsilane was introduced in the same manner as above.



(2)

Cyclization Studies. Treatment of **1a** with $TiCl_4$ (4 equiv, CH_2Cl_2, 0.01 M, 10 min, −78 °C) afforded cycloheptene **12a** as

(1) (a) Angle, S. R.; Turnbull, K. D. *J. Am. Chem. Soc.* **1989**, *111*, 1136. (b) Angle, S. R.; Louie, M. S.; Mattson, H. L.; Yang, W. *Tetrahedron Lett.* **1989**, *30*, 1193.

(2) (a) Angle, S. R.; Louie, M. S. *Tetrahedron Lett.* **1989**, *30*, 5741. (b) Angle, S. R.; Louie, M. S. *J. Org. Chem.* **1991**, *56*, 2853.

(3) For a review on intramolecular hydride shifts in carbonium ions, see: (a) Fry, J. L.; Karabatsos, G. J. In *Carbonium Ions*; Olah, G. A.; Schleyer, P. v. R., Eds.; John Wiley and Sons: New York, 1970; Vol. 2, Chapter 14. For a leading reference to the work of Sorensen on hydride shifts, see: (b) Kirchen, R. P.; Okazawa, N.; Ranganayakulu, K.; Rauk, A.; Sorensen, T. S. *J. Am. Chem. Soc.* **1981**, *103*, 597. For a leading reference to gas-phase ion chemistry, see: (c) Hall, D. G.; Morton, T. H. *J. Am. Chem. Soc.* **1980**, *102*, 5686.

(4) For a review on the chemistry of vinylsilanes, see: Blumenkopf, T. A.; Overman, L. E. *Chem. Rev.* **1986**, *86*, 857.

(5) If **2** were formed, it would likely adopt a conformation with the phenyl group axial. For reviews on allylic strain, see: (a) Jonhnson, F. *Chem. Rev.* **1968**, *68*, 374. (b) Hofmann, R. W. *Chem. Rev.* **1989**, *89*, 1841.

(6) Montgomery, L. K.; Matt, J. W. *J. Am. Chem. Soc.* **1967**, *89*, 6556.

(7) Corey, E. J.; Gras, J.-L.; Ulrich, P. *Tetrahedron Lett.* **1976**, *117*, 809.

(8) (a) Overman, L. E.; Malone, T. C. *J. Org. Chem.* **1982**, *47*, 5297. (b) Zweifel, G.; Lewis, W. *J. Org. Chem.* **1978**, *43*, 2739.

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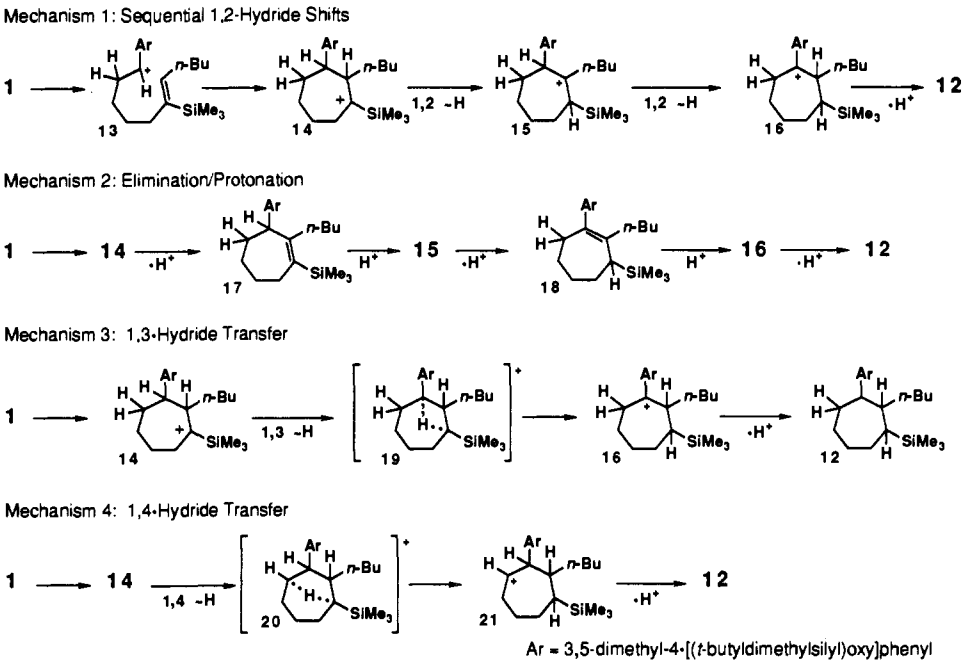
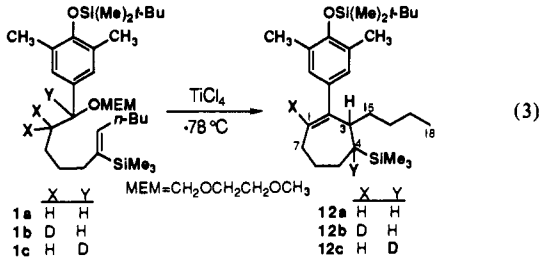
Scheme III. Possible Mechanisms for the Conversion of **1** to **12**



a single diastereoisomer, comprising >85% (^{1}H NMR) of the crude reaction mixture (eq 3).[9] Styrene **12a** was isolated in 50%



(3)

yield after flash chromatography. The expected product **2** was not observed. The formation of **12a** was surprising; it is unusual for a vinylsilane to retain silicon upon reaction with a carbon electrophile.[10,11]

This novel result has led us to consider possible mechanisms for the formation of **12a**. The logical first step is the formation of benzylic cation **13**, followed by cyclization to α-silyl cation **14** (Scheme III). There are four reasonable pathways for the conversion of cation **14** to styrene **12a**: (1) two sequential 1,2-hydride shifts, to afford benzylic cation **16**, followed by elimination to **12a**;[12] (2) a series of elimination/protonation reactions, to move the alkene into conjugation with the aryl group; (3) a 1,3-hydride transfer, to afford benzylic cation **16**;[3,13,14] and (4) a 1,4-hydride transfer, to afford homobenzylic cation **21**, followed by elimination to the styrene.[15] Mechanisms 1 and 2 invoke the intermediacy of β-silyl cation **15**, which under normal circumstances would be expected to lose silicon to afford an alkene.[10] Indeed, this is what led us to consider the 1,3- and 1,4-hydride transfer mechanisms 3 and 4.

To ascertain which of these mechanisms is operating, the two deuterated analogs **1b** and **1c** were studied. Substrate **1b** should allow mechanism 4 to be distinguished from mechanisms 1, 2, and 3. Mechanism 4 predicts that the product should completely retain the label; one deuterium should be transferred to the carbon bearing the trimethylsilyl group, C(4), and the second deuterium should be retained on the alkene at C(1) (see eq 3 for numbering system).

Treatment of **1b** with $TiCl_4$ (4 equiv, CH_2Cl_2, 0.01 M, 10 min, −78 °C) afforded **12** in 61% isolated yield. Analysis of the ^{1}H NMR spectrum of the crude product showed it to have >95% deuterium at C(1). Mass spectrometry analysis of the product after flash chromatography showed it to be 70% d_1 (**12b**) and 30% d_0 (**12a**).[16] The loss of deuterium upon storage and handling is consistent with the instability of this electron-rich styrene.[9] These results show that mechanism **4** is not responsible for product formation, but they do not distinguish between the other three possible mechanisms.

Substrate **1c** should afford products that allow mechanisms 1, 2, and 3 to be distinguished for each other. Mechanism 1, two sequential 1,2-hydrogen migrations, should afford a product with

(9) The structure assigned to **12a** is consistent with the spectral data. The assignment of the relative stereochemistry in **12** has not been possible to date; X-ray quality crystals have not been obtained. The stability of **12a** is consistent with the low isolated yield; stored neat or as a concentrated solution, **12a** polymerized readily. Stored in dilute solution at low temperature (hexane, 0.1 M, 0 °C), it is stable for several weeks with little or no decomposition.

(10) We are aware of five reports of reactions of vinylsilanes that retain silicon upon reaction with a carbon electrophile. All but ref (a) have some overriding steric and/or electronic effect that inhibits loss of silicon: (a) Overman, L. E.; Castañeda, A.; Blumenkopf, T. A. *J. Am. Chem. Soc.* **1986**, *108*, 1303. (b) Hoflack, J.; De Clerq, P. J. *Bull. Soc. Chim. Belg.* **1983**, *92*, 407. (c) Fleming, I.; Pearce, A. *J. Chem. Soc., Perkin Trans. 1* **1980**, 2485. (d) Brook, M. A.; Sebastian, T.; Jueschke, R.; Dallaire, C. *J. Org. Chem.* **1991**, *56*, 2273. (e) Blumenkopf, T. A.; Bratz, M.; Castañeda, A.; Look, G. C.; Overman, L. E.; Rodriguez, D.; Thompson, A. S. *J. Am. Chem. Soc.* **1990**, *112*, 4386.

(11) Unless steric restrictions are present, the following order of cation stability is predicted (Mikami, K.; Kishi, N.; Nakai, T. *Tetrahedron Lett.* **1983**, *24*, 795): tertiary trialkyl > secondary β-silyl > tertiary α-silyl > primary β-silyl. In the absence of steric interactions, the secondary β-silyl cation that would be an intermediate in the formation of **3** is predicted to be more stable than the α-silyl cation **5**. However, steric congestion between the aryl group and substituents on the alkene might preclude formation of a six-membered ring, leading to the preferential formation of a seven-membered ring via a less sterically congested transition state.

(12) For a recent report of and leading reference to 1,2-hydride transfer, see: Sorensen, T. S.; Whitworth, S. M. *J. Am. Chem. Soc.* **1990**, *112*, 6647.

(13) (a) Cope, A. C.; Berchtold, G. A.; Peterson, P. E.; Sharman, S. H. *J. Am. Chem. Soc.* **1960**, *82*, 6366. For a reaction in a steroid system that has been proposed to invole a 1,3-hydride shift, see: (b) Jacquesy, R.; Narbonne, C. *J. Chem. Soc., Chem. Commun.* **1979**, 765. For a biochemical pathway that has been proposed to involve a 1,3-hydride shift, see; (d) Hirota, A.; Nakagawa, M.; Sakai, H.; Isogai, A.; Furihata, K.; Seto, H. *Tetrahedron Lett.* **1985**, *26*, 3845.

(14) Boelema, E.; Wieringa, J. H.; Wynberg, H.; Strating, J. *Tetrahedron Lett.* **1973**, *14*, 2377.

(15) For a discussion of 1,4-hydride transfers, see ref 3a, pp 555–557.

(16) Products **12a–c** are unstable, undergoing polymerization readily and slowly decomposing upon chromatography. All yields are of analytically pure products. Analysis of the crude reaction mixture by ^{1}H NMR showed **12b** to be >90% d_1. The loss of deuterium from **12b**, detected in the MS and ^{1}H NMR spectra, must arise via reaction of **12b** with trace amounts of acid upon standing in $CDCl_3$ or during handling and chromatography.

a deuterium at C(3).[12] Mechanism 2, a series of addition/elimination reactions, should lead to loss and scrambling of the deuterium label. Mechanism 3, a 1,3-hydride shift, should afford product **12c**, with deuterium at C(4).[14]

Treatment of **1c** with $TiCl_4$ (4 equiv, CH_2Cl_2, 0.01 M, 10 min, −78 °C), followed by flash chromatography, afforded an analytical sample of cycloheptene **12**.[17] Mass spectrometry showed the product **12c** to be >98% d_1. Analysis of the ^1H NMR spectrum of the product showed that the deuterium that is retained is found exclusively at C(4); hence, the deuterium-containing product is **12c**.

The labeling studies are consistent with mechanism 3, a 1,3-hydride shift. Cation **14** may be a discreet α-silyl cation, or it may better be described as corner protonated cyclopropane **22**. Cation **14** (or **22**) can undergo a 1,3-hydride transfer via an edge-protonated cyclopropane/transition state **19**.

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The relatively mild conditions and efficiency of this 1,3-hydride transfer make it noteworthy. Intramolecular 1,3-hydride transfers have been documented as minor processes, competing with other more favorable hydrogen migrations (e.g., 1,2 and 1,5) in propyl,[3] norbornyl,[3] and cyclooctyl cations.[13] There is a single report in which a 1,3-hydride transfer has been shown to be the major reaction pathway, and this was in a rigid adamantane system.[14] All of these transformations employ extremely harsh conditions (e.g., HF–SbF_5, 50% H_2SO_4 at 100 °C). By comparison, our reaction conditions are extremely mild.

Conclusion

A mechanism involving two sequential 1,2-hydride transfers would usually be preferred over a 1,3-hydride shift. Our results show that even in a cycloheptyl cation, a 1,3-hydride transfer can be extremely facile, and this type of mechanism should not be dismissed without careful consideration. The results of further studies on the chemistry of benzylic cations and an examination of the generality of the 1,3-hydride transfer in other ring systems will be reported in due course.

Experimental Section

General Information. NMR spectra were recorded on a General Electric QE-300 NMR or a General Electric GN-500 NMR; coupling constants J are reported in hertz and refer to apparent peak multiplicities and not true coupling constants. Abbreviations used are as follows: s = singlet, bs = broad singlet, d = doublet, t = triplet, q = quartet, p = pentuplet. Mass spectra were recorded at the UCR-MS facility on a VG-7070EHF or a VG-ZAB1FHF and are reported as relative intensity to the parent peak. IR spectra were recorded on a Nicolet-5DX FT-IR. Flash chromatography was done on E. Merck silica gel #60, 230–400 mesh, and analytical TLC was performed on E. Merck glass-backed silica gel 60 plates, 0.250-mm thickness, with a 254-nm fluorescent indicator. Capillary GC was carried out on a Hewlett-Packard 5890 equipped with a HP-3393A computing integerator. THF and ether were distilled from sodium/benzophenone. Dichloromethane was distilled from CaH_2. Solvents for chromatography were distilled prior to use. In cases where synthetic intermediates or products were isolated by aqueous workup (aqueous solution, organic solvent), the procedure was to quench the reaction mixture with the indicated aqueous solution, dilute with the indicated organic solvent, separate the organic layer, extract the aqueous layer several times with the organic solvent, wash the combined organic extracts with brine, dry them over $MgSO_4$, and remove the solvent under reduced pressure with a rotary evaporator. The pH 6 buffer was prepared by dissolving 23.2 g of KH_2PO_4 and 4.3 g of Na_2HPO_4 (anhydrous) in water and diluting to a volume of 1.00 L. Unless stated otherwise, all reactionws were run under an atmosphere of nitrogen or argon in oven-dried glassware.

(*Z*)-1-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-1-[((methoxyethoxy)methyl)oxy]-6-(trimethylsilyl)-6-undecene (1a). According to the general procedure of Overman and Malone,[8a] *sec*-BuLi (4.7 mL of a 1.1 M solution in cyclohexane, 5.2 mmol) was added dropwise to a stirring solution of (*E*)-vinyl bromide[8b] (1.10 g, 4.68 mmol) and dry THF (9.4 mL) at −78 °C. After 33 min, a solution of iodide **7** (515 mg, 0.960 mmol) and dry THF (3 mL) was added dropwise. After 45 min, the resulting solution was allowed to warm to room temperature and was stirred for 1 h. Aqueous workup (pH 6 buffer, ether) afforded 953 mg of crude **1a**. Flash chromatography (gradient 98:2 (3 volumes), 95:5 (4), 0:100 (1) hexane/ethyl acetate) gave 419 mg (77%) of **1a** as a colorless oil: ^1H NMR (300 MHz, $CDCl_3$) δ 6.87 (s, 2 H, ArH), 5.89 (t, J = 7.4 Hz, 1 H, CH=CSi), 4.60 (ABq, J = 7.2 Hz, $\Delta\nu$ = 3.9 Hz, 2 H, OCH_2O), 4.42 (t, J = 6.8 Hz, 1 H, ArC(H)O), 3.82–3.78 (m, 1 H, OC*H*HCH_2O), 3.57–3.49 (m, 3 H, $OCHHCH_2O$), 3.38 (s, 3 H, OCH_3), 2.19 (s, 6 H, $ArCH_3$), 2.06 (apparent q, J = 7.1 Hz, 2 H, $SiC{=}CCH_2$), 1.99 (t, J = 7.1 Hz, 2 H, $CH_2(Si)C{=}$), 1.84–1.77 (m, 1 H, ArCCH*H*), 1.66–1.58 (m, 1 H, ArCC*H*H), 1.41–1.16 (m, 8 H, $CH_2CH_2CH_2CH_2$, $CH_2CH_2CH_2CH_3$), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.90 (t, J = 6.8 Hz, 3 H, CH_2CH_3), 0.18 (s, 6 H, $Si(CH_3)_2C(CH_3)_3$), 0.10 (s, 9 H, $Si(CH_3)_3$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 151.3, 143.0, 138.8, 134.4, 128.1, 127.4, 92.9, 77.9, 71.8, 66.8, 58.9, 38.3, 37.5, 32.3, 31.7, 30.9, 26.1, 25.8, 22.4, 18.7, 17.8, 14.0, 0.3, −3.0; IR (CCl_4) 2956, 2933, 2860, 1473, 1303, 1249, 1232, 1152 cm^{-1}; MS (EI, 20 eV) m/z 564 (M^+, 2), 353 (17), 249 (13), 89 (100), 59 (11); HRMS calcd for $C_{32}H_{60}O_4Si_2$ 564.4030, found 564.4042.

(*Z*)-1-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-2,2-dideuterio-1-[((methoxyethoxy)methyl)oxy]-6-(trimethylsilyl)-6-undecene (1b). The same procedure given previously for the preparation of **6** was carried out with **10** (109 mg, 0.266 mmol) to afford 121 mg of crude alcohol. Flash chromatography (gradient 90:10 (2 volumes), 80:20 (3), 70:30 (2) 50:50 (1), 30:70 (1), 0:100 (1) hexane/ethyl acetate) gave 95.9 mg (84%) of 1-[4-*tert*-butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-2,2-dideuterio-1-[((methoxyethoxy)methyl)oxy]-5-pentanol as a viscous colorless oil: ^1H NMR (300 MHz, $CDCl_3$) δ 6.86 (s, 2 H, ArH), 4.58 (ABq, J = 7.2 Hz, $\Delta\nu$ = 3.9 Hz, 2 H, OCH_2O), 4.43 (s 1 H, ArC*H*), 3.82 (m, 1 H, OC*H*HCH_2O), 3.59 (t, J = 6.5, 2 H CH_2OH), 3.51 (m, 3 H, $OCHHCH_2O$), 3.36 (s, 3 H, CH_3O), 2.17 (s, 6 H, CH_3Ar), 1.94 (bs, 1 H, CH_2OH), 1.61–1.10 (m, 4 H, $CH_2CH_2CH_2OH$), 1.01 (s, 9 H, $SiC(CH_3)_3$), 0.16 (s, 6 H, $SiCH_3$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 151.4, 134.2, 128.2, 127.3, 92.9, 77.4, 71.7, 66.9, 62.6, 58.9, 32.4, 26.0, 22.0, 18.7, 17.8, −3.0. The same procedure given previously for the preparation of **7** was carried out with the above alcohol (95.9 mg, 0.224 mmol) and afforded 98.8 mg of crude alkyl iodide. Flash chromatography (neutral alumina, 98:2 hexane/ethyl acetate) gave 86.7 mg (72%) of 1-[4-((*tert*-butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-2,2-dideuterio-1-[((methoxyethoxy)methyl)oxy-5-iodopentane: ^1H NMR (300 MHz, $CDCl_3$) δ 6.87 (s, 2 H, ArH), 4.59 (ABq, J = 7.2 Hz, $\Delta\nu$ = 3.9 Hz, 2 H, OCH_2O), 4.43 (s, 1 H, ArCH), 3.81 (m, 1 H, OC*H*HCH_2O), 3.55 (m, 3 H, $OCHHCH_2$), 3.39 (s, 3 H, CH_3O), 3.16 (t, J = 7.0 Hz, 2 H, CH_2CH_2I), 2.19 (s, 6 H, CH_3Ar), 1.88–1.28 (m, 6 H, $CHCH_2CH_2CH_2$), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.18 (s, 6 H, $Si(CH_3)_2$). The same procedure given previously for the preparation of **1a** was carried out with the above alkyl iodide (202 mg, 0.382 mmol) to afford 280 mg of crude **1b**. Flash chromatography (gradient 98:2 (2 volumes), 95:5 (3), 90:10 (2) 50:50 (1), 0:100 (1) hexane/ethyl acetate) gave 113 mg (47%) of **1b** as a colorless oil: ^1H NMR (300 MHz, $CDCl_3$) δ 6.87 (s, 2 H, ArH), 5.89 (t, J = 7.4 Hz, 1 H, CH=CSi), 4.60 (ABq, J = 7.2 Hz, $\Delta\nu$ = 3.9 Hz, 2 H, OCH_2O), 4.42 (s, 1 H, ArC(H)O), 3.82–3.78 (m, 1 H, OC*H*HCH_2O), 3.57–3.49 (m, 3 H, $OCHHCH_2O$), 3.38 (s, 3 H, OCH_3), 2.19 (s, 6 H, $ArCH_3$), 2.06 (q, J = 7.1 Hz, 2 H, $SiC{=}CCH_2$), 1.99 (t, J = 7.1 Hz, 2 H, $CH_2(Si)C{=}$), 1.41–1.16 (m, 8 H, $CH_2CH_2CH_2CH_2$, $CH_2CH_2CH_2CH_3$), 1.02 (s, 9 H, SiC $(CH_3)_3$), 0.90 (t, J = 6.8 Hz, 3 H, CH_2CH_3), 0.18 (s, 6 H, $Si(CH_3)_2C(CH_3)_3$), 0.10 (s, 9 H, $Si(CH_3)_3$); MS (EI, 70 eV) m/z 566 (M^+, 3), 460 (4), 353 (9), 89 (100), 73 (29); HRMS calcd for $C_{32}H_{58}D_2O_4Si$ 566.4156, found 566.4169; deuterium analysis 91.9% d_2, 8.1% d_1.

(*Z*)-1-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-1-deuterio-1-[((methoxyethoxy)methyl)oxy]-6-(trimethylsilyl)-6-undecene (1c). The same procedure given previously for the preparation of **6** was carried out with **11** (820 mg, 2.00 mmol) to afford 850 mg (99%) of crude 1-[4-((*tert*-butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-1-deuterio-1-[((methoxyethoxy)methyl)oxy]-5-pentanol. The crude material was taken on to the next step without purification: ^1H NMR (300 MHz, $CDCl_3$) δ 6.87 (s, 2 H, ArH), 4.59 (ABq, J = 7.2 Hz, $\Delta\nu$ = 3.9 Hz, 2 H, OCH_2O), 3.86 (m, 1 H, OC*H*HCH_2O), 3.61 (t, J = 6.3 Hz, 2 H, CH_2CH_2OH), 3.58–3.47 (m, 3 H, $OCHHCH_2$), 3.38 (s, 3 H, CH_3O), 2.18 (s, 6 H, CH_3Ar), 1.91–1.22 (m, 6 H, $CDCH_2CH_2CH_2$), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.18 (s, 6 H, $Si(CH_3)_2$). The same procedure given previously for the preparation of **7** was carried out with the above alcohol (793 mg, 1.85 mmol) to afford 787 mg of the crude iodide as a yellow oil. Flash chromatography (neutral alumina, 98:2 hexane/ethyl acetate) gave 164.1 mg (17%) of 1-[4-((*tert*-butyldimethylsilyl)oxy)-

(17) The lower yield for **12c** is of no significance; the chromatography fractions were combined to ensure maximum purity of **12c**. The mass recovery of crude material prior to chromatography was >95%.

3,5-dimethylphenyl]-1-deuterio-1-[((methoxyethoxy)methyl)oxy]-5-iodopentane as a colorless oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.87 (s, 2 H, ArH), 4.59 (ABq, J = 7.2 Hz, $\Delta\nu$ = 3.9 Hz, 2 H, OCH_2O), 3.81 (m, 1 H, OC*H*HCH$_2$O), 3.59–3.49 (m, 3 H, OCH*HC*H$_2$), 3.38 (s, 3 H, CH_3O), 3.15 (t, J = 7.0 Hz, 2 H, CH_2CH_2I), 2.18 (s, 6 H, CH_3Ar), 1.87–1.31 (m, 6 H, $CHCH_2CH_2CH_2$), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.18 (s, 6 H, $Si(CH_3)_2$). The same procedure given previously for the preparation of **1a** was carried out with the above alkyl iodide (61.7 mg, 0.155 mmol) to afford 97.9 mg of crude **1c**. Flash chromatography (gradient 98:2 (3 volumes), 95:5 (4), 0:100 (1) hexane/ethyl acetate) gave 41.8 mg (64%) of **1c** as a colorless oil: ^{1}H NMR (300 MHz (300 MHz, $CDCl_3$) δ 6.87 (s, 2 H, ArH), 5.89 (t, J = 7.4 Hz, 1 H, CH=CSi), 4.59 (bs, 2 H, OCH_2O), 3.83–3.77 (m, 1 H, OC*H*HCH$_2$O), 3.58–3.49 (m, 3 H, OCH*HC*H$_2$O), 3.38 (s, 3 H, OCH_3), 2.19 (s, 6 H, $ArCH_3$), 2.06 (q, J = 7.1 Hz, 2 H, SiC=CHC*H*$_2$), 1.99 (t, J = 7.2 Hz, 2 H, C*H*$_2$(Si)C=), 1.82–1.76 (m, 1 H, ArCCH*H*), 1.65–1.57 (m, 1 H, ArCC*H*H), 1.33–1.28 (m, 8 H, $CH_2CH_2CH_2CH_2$, $CH_2CH_2CH_2CH_3$), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.90 (t, J = 6.9 Hz, 3 H, CH_2CH_3), 0.18 (s, 6 H, $Si(CH_3)_2C(CH_3)_3$), 0.11 (s, 9 H, $Si(CH_3)_3$); ^{13}C NMR (125 MHz, $CDCl_3$) δ 151.4, 143.0, 138.9, 134.4, 128.2, 127.4, 92.9, 71.8, 66.8, 59.0, 38.3, 37.4, 32.4, 31.8, 31.0, 26.1, 25.8, 22.4, 18.7, 17.9, 14.1, 0.4, -2.9; IR (CCl_4) 2957, 2931, 2859, 2359, 2337, 1473, 1249 cm^{-1}; MS (EI, 70 eV) m/z 565 (M$^+$, 3), 459 (4), 354 (11), 89 (100), 73 (30); HRMS calcd for $C_{32}H_{59}DO_4Si_2$ 565.4094, found 565.4079; deuterium analysis 98.8% d_1.

1-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]pent-4-en-1-ol (4). *t*-BuLi (37.4 mL of a 1.6 M solution in pentane, 59.8 mmol) was added dropwise to a stirred solution of 1-((*tert*-butyldimethylsilyl)-oxy)-4-bromo-2,6-dimethylbenzene (18.87 g, 59.85 mmol) and dry THF (400 mL) at -78 °C. After 75 min, 4-pentenal[6] (4.58 g, 54.4 mmol) was added dropwise, and the resulting solution was allowed to warm to room temperature. After 1 h, aqueous workup (pH 6 buffer, ether) afforded 20.6 g of crude **4**. Flash chromatography (gradient 95:5 (3 volumes), 90:10 (4), 70:30 (1) hexane/ethyl acetate) gave 13.4 g (76%) of **4** as a yellow oil. An analytical sample was prepared by a second flash chromatography (9:1 hexane/acetone) to afford **41** as a pale yellow oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.88 (s, 2 H, ArH), 5.82 (ddt, J = 17.1, 10.4, 6.4 Hz, 1 H, CH_2=C*H*CH$_2$), 5.00 (d, J = 17.6 Hz, 1 H, C*H*H=CH), 4.95 (d, J = 10.7 Hz, 1 H, CH*H*=CH), 4.52 (t, J = 6.0 Hz, 1 H, ArC*H*(OH)), 2.22 (s, 6 H, CH_3Ar), 2.19–2.00 (m, 2 H, C*H*$_2$CH=CH$_2$), 1.92–1.71 (m, 2 H, ArCH(OH)C*H*$_2$), 1.05 (s, 9 H, $SiC(CH_3)_3$), 0.91 (s, 1 H, OH), 0.20 (s, 6 H, $SiCH_3$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 151.4, 138.3, 137.1, 128.4, 126.3, 114.6, 73.6, 37.9, 30.2, 26.1, 18.7, 17.8, -3.0; IR (neat) 3352, 2955, 2930, 2858, 1484, 1473, 1304, 1255, 1231, 1151, 910, 890, 840, 823 cm^{-1}; MS (EI, 20 eV) m/z 320 (M$^+$, 16), 302 (12), 266 (21), 265 (100), 263 (10), 245 (22), 191 (11), 180 (11), 179 (66), 105 (11), 75 (16), 73 (14), 67 (16), 57 (7); HRMS (EI 70 eV) calcd for $C_{19}H_{32}O_2Si$ 320.2172, found 320.2186.

1-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-1-[((methoxyethoxy)methyl)oxy]-4-pentene (5). According to the general procedure of Corey and co-workers[7] *N,N*-diisopropylethylamine (17.5 mL, 100 mmol) was added dropwise to a stirred solution of benzyl alcohol **4** (10.72 g, 33.44 mmol) and CH_2Cl_2 (42 mL) at 24 °C. A room temperature water bath was applied, and (2-methoxyethoxy)methyl chloride (11.5 mL, 100 mmol) was added dropwise. After 4 h, aqueous workup (pH 6 buffer, ether) afforded 13.31 g (97%) of crude **5** (93% pure by GC, t_R = 14.76 min) as a bright yellow oil. An analytical sample was prepared by flash chromatography (9:1 hexanes/acetone) to afford **5** as a colorless oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.88 (s, 2 H, ArH), 5.82 (ddt, J = 17.1, 10.4, 6.4 Hz, 1 H, CH_2=C*H*CH$_2$), 5.00 (d, J = 17.6 Hz, 1 H, C*H*H=CH), 4.95 (d, J = 10.7 Hz, 1 H, CH*H*=CH), 4.60 (ABq, J = 7.2 Hz, $\Delta\nu$ = 3.9 Hz, 2 H, OCH_2O), 4.46 (t, J = 6.6 Hz, 1 H, ArCH), 3.84–3.77 (m, 1 H, OC*H*HCH$_2$O), 3.60–3.46 (m, 3 H, OCH*HC*H$_2$O), 3.38 (s, 3 H, CH_3O), 2.19 (s, 6 H, CH_3Ar), 2.13–1.66 (m, 4 H, CHC*H*$_2$C*H*$_2$), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.18 (s, 6 H, $Si(CH_3)_2$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 151.4, 138.2, 134.1, 128.2, 127.4, 114.5, 92.9, 77.2, 71.7, 66.8, 58.9, 36.8, 30.2, 26.0, 18.7, 17.8, -3.0; IR (neat) 2954, 2931, 2886, 2860, 1483, 1474, 1255, 1232, 1039, 908, 840 cm^{-1}; MS (EI 20 eV) m/z 408 (M$^+$, 6), 303 (100), 249 (10), 205 (15); HRMS calcd for $C_{23}H_{40}O_4Si$ 408.2696, found 408.2672.

1-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-1-[((methoxyethoxy)methyl)oxy]-5-pentanol (6). Borane–tetrahydrofuran (20.4 mL of a 1.0 M solution in THF, 20.4 mmol) was added dropwise to a stirred solution of alkene **5** (7.95 g, 19.5 mmol) and THF (114.5 mL) at 0 °C. The reaction mixture was allowed to warm to room temperature. After 4.7 h, the mixture was cooled to 0 °C, and a solution of NaOH (34.3 mL of a 1.7 M aqueous solution, 58.3 mmol) and H_2O_2 (20.4 mL of a 30% aqueous solution) were added dropwise. The cooling bath was removed, and after 1 h, aqueous workup (pH 6 buffer, ether) afforded 9.23 g of crude **6** as a pale yellow oil. Flash chromatography (gradient 70:30 (3 volumes), 50:50 (3), 40:60 (2), 0:100 (1) hexane/ethyl acetate) gave 6.88 g (83%) of **6** as a colorless viscous oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.87 (s, 2 H, ArH), 4.59 (ABq, J = 7.2 Hz, $\Delta\nu$ = 3.9 Hz, 2 H, OCH_2O), 4.45 (dd, J = 5.7, 7.9 Hz, 1 H, ArCH), 3.86 (m, 1 H, OC*H*HCH$_2$O), 3.61 (t, J = 6.3 Hz, 2 H, CH_2CH_2OH), 3.58–3.47 (m, 3 H, OCH*HC*H$_2$), 3.38 (s, 3 H, CH_3O), 2.18 (s, 6 H, CH_3Ar), 1.91–1.79 (m, 1 H, CHCH*H*CH$_2$CH$_2$), 1.70–1.52 (m, 3 H, CHCH*H*CH$_2$C*H*$_2$), 1.51–1.22 (m, 2 H, CHCH$_2$C*H*$_2$), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.18 (s, 6 H, $Si(CH_3)_2$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 151.2, 134.2, 128.0, 127.2, 92.7, 77.6, 71.6, 66.7, 62.2, 58.7, 37.2, 32.3, 25.9, 22.1, 18.5, 17.7, -3.1; IR ($CDCl_3$) 3629, 2932, 1475, 1256, 1234 cm^{-1}.

1-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-1-[((methoxyethoxy)methyl)oxy]-5-iodopentane (7). Triethylamine (0.46 mL, 3.3 mmol) was added dropwise to a stirred solution of alcohol **6** (1.07 g, 2.52 mmol) in CH_2Cl_2 (7.8 mL) at 20 °C. The solution was cooled to 0 °C, and methanesulfonyl chloride (0.2 mL, 2.6 mmol) was added dropwise. After 3 h, aqueous workup (pH 6 buffer, CH_2Cl_2; combined organic layers washed with saturated aqueous $CuSO_4$) afforded 1.21 g (95%) of crude mesylate. Sodium iodide–triacetone (23.8 g, 73.4 mmol) was added to a solution of the above mesylate (1.21 g, 2.39 mmol) in acetone (10 mL) at 20 °C. The flask was covered with aluminum foil. After 5 h, aqueous workup (H_2O, ethyl acetate) afforded 1.12 g of crude iodide **7**. Flash chromatography (98:2 hexane/ethyl acetate) gave 0.642 g (50%) of **7**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.87 (s, 2 H, ArH), 4.59 (ABq, J = 7.2, $\Delta\nu$ = 3.9 Hz, 2 H, OCH_2O), 4.44 (dd, J = 5.8, 7.6 Hz, 1 H, ArCH), 3.81 (m, 1 H, OC*H*HCH$_2$O), 3.59–3.49 (m, 3 H, OCH*HC*H$_2$), 3.38 (s, 3 H, CH_3O), 3.15 (t, J = 7.0 Hz, 2 H, CH_2CH_2I), 2.18 (s, 6 H, CH_3Ar), 1.87–1.16 (m, 6 H, CHC*H*$_2$C*H*$_2$C*H*$_2$), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.18 (s, 6 H, $Si(CH_3)_2$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 151.3, 134.0, 128.1, 127.2, 92.8, 77.3, 71.3, 66.8, 58.8, 36.4, 33.2, 26.9, 26.0, 18.6, 17.8, 6.5, -3.0; IR (neat) 2957, 2931, 2896, 2860, 1474, 1251, 1232, 1040, 840 cm^{-1}; MS (FAB$^+$, nitrobenzyl alcohol) 536 (M$^+$, 12), 431 (100), 307 (20), 154 (39), 136 (32); HRMS calcd for $C_{23}H_{41}O_4ISi$ 536.1819, found 536.1833.

1-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-2,2-dideuteriopent-4-en-1-one (9). According to the general procedure of Swern and co-workers,[18] a solution of oxalyl chloride (0.35 mL, 4.1 mmol) and CH_2Cl_2 (20 mL) was added dropwise to a stirred solution of dimethylsulfoxide (0.33 mL, 4.7 mmol) and CH_2Cl_2 (5 mL) at -75 °C. After 15 min, a solution of alcohol **7** (1.01 g, 3.15 mmol) and CH_2Cl_2 (6 mL) was added dropwise. The resulting solution was allowed to stir for 20 min, and then triethylamine (2.7 mL, 19 mmol) was added dropwise. After 15 min, the reaction mixture was allowed to warm to room temperature. After 2.5 h, aqueous workup (pH 6 buffer, ether) afforded 1.06 g of crude ketone. Flash chromatography (98:2 hexane/ethyl acetate) gave 796.6 mg (79%) of 1-[4-((*tert*-butyldimethylsilyl)-oxy)-3,5-dimethylphenyl]pent-4-en-1-one as a colorless viscous oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.62 (s, 2 H, ArH), 5.88 (ddt, J = 16.8, 10.3, 6.5 Hz, 1 H, CH_2=C*H*CH$_2$), 5.06 (dd, J = 1.6, 17.1 Hz, 1 H, C*H*H=CH), 4.97 (dd, J = 1.2, 10.2 Hz, 1 H, CH*H*=CH), 2.99 (t, J = 7.4 Hz, 2 H, ArC(O)C*H*$_2$), 2.45 (apparent q, J = 7.1 Hz, 2 H, C*H*$_2$CH=CH$_2$), 2.24 (s, 6 H, CH_3Ar), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.20 (s, 6 H, $SiCH_3$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 198.3, 156.6, 137.4, 130.2, 129.0, 128.6, 114.9, 37.2, 28.3, 25.9, 18.7, 17.8, -3.0. The above ketone (865 mg, 2.72 mol) and methanol-d_1 (0.5 mL) were added dropwise to a stirred solution of sodium methoxide/methanol-d_1 (from 71.8 mg, 3.12 mmol sodium and 3 mL of methanol-d_1) at room temperature.[19] After 15 h, acetic acid-d_4 (0.2 mL) was added. Aqueous workup (pH 6 buffer, ether) afforded 699.2 mg (125%) of crude 2,2-dideuterio-1-[3,5-dimethyl-4-hydroxyphenyl]pent-4-en-1-one as a pale yellow oil. The crude material was taken on to the next step without purification: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.62 (s, 2 H, ArH), 6.70–6.30 (bs, 1 H, OH), 5.89 (ddt, J = 16.8, 10.2, 6.5 Hz, 1 H, CH_2=C*H*CH$_2$), 5.05 (dd, J = 17.1, 1.6 Hz, 1 H, C*H*H=CH), 4.97 (dd, J = 10.2, 1.2 Hz, 1 H, CH*H*=CH), 2.43 (d, J = 6.4 Hz, 2 H, C*H*$_2$CH=CH$_2$), 2.24 (s, 6 H, CH_3Ar). Imidazole (461 mg, 6.78 mmol) was added to a solution of the above phenol (699 mg, 3.39 mmol) and CH_2Cl_2 (6.8 mL) at 23 °C. After the imidazole had dissolved, the solution was cooled to 0 °C, and *tert*-butyldimethylsilyl chloride (566 mg, 3.73 mmol) was added. The resulting solution was allowed to warm to 23 °C and was stirred for 2.7 h. Aqueous workup (pH 6 buffer, ether) afforded 0.910 mg of crude **9**. Flash chromatography (gradient 98:2 (1 volume), 95:5 (3), 50:50 (1), 0:100 (1) hexane/ethyl acetate) gave 385 mg (35%) of **9** as a colorless viscous oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.62 (s, 2 H, ArH), 5.89 (ddt, J = 16.8, 10.3, 6.5 Hz, 1 H, CH_2=

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$CHCH_2$), 5.07 (dd, J = 1.5, 17.2 Hz, 1 H, CHH=CH), 4.98 (dd, J = 1.2, 10.2 Hz, 1 H, CHH=CH), 2.45 (d, J = 6.3 Hz, 2 H, CH_2CH=CH_2), 2.24 (s, 6 H, CH_3Ar), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.21 (s, 6 H, $SiCH_3$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 198.8, 156.7, 137.4, 130.2, 129.1, 128.6, 115.0, 28.2, 25.9, 18.7, 17.8, -2.9.

1-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-2,2-dideuterio-1-[((methoxyethoxy)methyl)oxy]-4-pentene (10). Sodium borohydride (42.3 mg, 1.12 mmol) was added to a stirred solution of ketone **9** (133 mg, 0.414 mmol) and methanol (10 mL) at 23 °C. After 20 min, aqueous workup (pH 6 buffer, ether) afforded 129 mg (97%) of crude 1-[4-((*tert*-butyldimethylsilyl)oxy)-3,5-dimethylphenyl-2,2-dideuteriopent-4-en-1-ol as an oil. The crude material was taken on to the next step without purification: ^1H NMR (300 MHz, $CDCl_3$) δ 6.95 (s, 2 H, ArH), 5.85 (ddt, J = 16.9, 10.3, 6.7 Hz, 1 H, CH_2=$CHCH_2$), 5.02 (m, 2 H, CH_2=CH), 4.53 (s, 1 H, $ArCH$), 2.23 (s, 6 H, CH_3Ar), 2.18 (m, 2 H, CH_2CH=CH_2), 1.06 (s, 9 H, $SiC(CH_3)_3$), 0.21 (s, 6 H, $SiCH_3$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 151.4, 138.3, 137.1, 128.4, 126.3, 114.7, 73.6, 30.0, 26.0, 18.7, 17.9, -3.0. The same procedure given previously for the preparation of **5** was carried out with the above alcohol (129 mg, 0.400 mmol) to afford 118 mg of crude **10** as a bright yellow oil. Flash chromatography (9:1 hexanes/acetone) gave 109 mg (67%) of **10** as a colorless oil: ^1H NMR (300 MHz, $CDCl_3$) δ 6.88 (s, 2 H, ArH), 5.81 (ddt, J = 16.8, 10.3, 6.5 Hz, 1 H, CH_2=$CHCH_2$), 4.98 (m, 2 H, CH_2=CH), 4.60 (ABq, J = 7.2 Hz, $\Delta\nu$ = 3.9 Hz, 2 H, OCH_2O), 4.46 (s, 1 H, $ArCH$), 3.80 (m, 1 H, $OCHHCH_2O$), 3.59-3.45 (m, 3 H, $OCHHCH_2O$), 3.37 (s, 3 H, OCH_3), 2.19 (s, 6 H, CH_3Ar), 2.07 (m, 2 H, CH_2CH=CH_2), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.18 (s, 6 H, $SiCH_3$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 151.4, 138.3, 134.1, 128.2, 127.4, 114.5, 92.9, 77.2, 71.7, 66.8, 58.9, 30.0, 26.1, 18.7, 17.8, -3.0.

1-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-1-deuterio-1-[((methoxyethoxy)methyl)oxy]-4-pentene (11). Lithium aluminum deuteride (150 mg, 3.50 mmol) was added to a solution of 1-[4-((*tert*-butyldimethylsilyl)oxy)-3,5-dimethylphenyl]pent-4-en-1-one (797 mg, 2.50 mmol) and ether (5 mL) at 0 °C. The reaction was allowed to warm to room temperature for 25 min, recooled to 0 °C, and quenched by the sequential addition of water (0.15 mL), 15% NaOH solution (0.15 mL), and water (0.45 mL). The resulting suspension was stirred for 1 h. The precipitate was filtered off and washed with ether. The filtrate was dried ($MgSO_4$) and concentrated to afford 723 mg (90%) of crude 1-[4-((*tert*-butyldimethylsilyl)oxy)-3,5-dimethylphenyl-1-deuterio-pent-4-en-1-ol as a colorless oil. The crude material was taken on to the next step without purification: ^1H NMR (300 MHz, $CDCl_3$) δ 6.88 (s, 2 H, ArH), 5.82 (ddt, J = 17.1, 10.4, 6.4 Hz, 1 H, CH_2=$CHCH_2$), 5.00 (d, J = 17.6 Hz, 1 H, CHH=CH), 4.95 (d, J = 10.7 Hz, 1 H, CHH=CH), 2.22 (s, 6 H, CH_3Ar), 2.19-2.00 (m, 2 H, CH_2CH=CH_2), 1.92-1.71 (m, 2 H, $CD(OH)CH_2$), 1.05 (s, 9 H, $SiC(CH_3)_3$), 0.20 (s, 6 H, $SiCH_3$). The same procedure given previously for the preparation of **5** was carried out with the above alcohol (723 mg, 2.25 mmol) to afford 820 mg (89%) of crude **11** as a bright yellow oil. The crude material was taken on to the next step without purification: ^1H NMR (300 MHz, $CDCl_3$) δ 6.88 (s, 2 H, ArH), 5.82 (ddt, J = 17.1, 10.4, 6.4 Hz, 1 H, CH_2=$CHCH_2$), 5.00 (d, J = 17.6 Hz, 1 H, CHH=CH), 4.95 (d, J = 10.7 Hz, 1 H, CHH=CH), 4.60 (ABq, J = 7.2 Hz, $\Delta\nu$ = 3.9 Hz, 2 H, OCH_2O), 3.84-3.77 (m, 1 H, $OCHHCH_2O$), 3.60-3.46 (m, 2 H, $OCHHCH_2O$), 3.38 (s, 3 H, CH_3O), 2.19 (s, 6 H, CH_3Ar), 2.13-1.66 (m, 4 H, $CDCH_2CH_2$), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.18 (s, 6 H, $Si(CH_3)_2$).

2-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-3-butyl-4-(trimethylsilyl)-1-cycloheptene (12a). Titanium tetrachloride (3.5 mL of a 1 M solution in CH_2Cl_2, 3.5 mmol) was added dropwise to a stirring solution of vinylsilane **1a** (490 mg, 0.867 mmol) and CH_2CH_2 (87 mL) at -78 °C. After 10 min, aqueous workup ($NaHCO_3$, CH_2Cl_2) afforded 432 mg of crude **12a**. Flash chromatography (98:2 hexane/ethyl acetate) gave 202 mg (51%) of **12a** as a clear oil: ^1H NMR (300 MHz, $CDCl_3$) δ 6.92 (s, 2 H, ArH), 5.79 (dd, J = 4.9, 8.8 Hz, 1 H, CH=CAr), 2.78 (dt, J = 5.5, 7.0 Hz, 1 H, $ArCCHCH_2$), 2.47-2.32 (m, 1 H, =$CHCHH$), 2.20 (s, 6 H, $ArCH_3$), 2.14 (m, 1 H, C=$CHCHH$), 1.99-1.47 (m, 6 H, $C(Si)HCH_2CH_2$, $CH_2CH_2CH_2CH_3$), 1.31-1.15 (m, 4 H, $CH_2CH_2CH_2CH_3$), 1.03 (s, 9 H, $SiC(CH_3)_3$), 0.95 (m, 1 H, $SiCHCH_2$), 0.86 (t, J = 6.9 Hz, 3 H, CH_2CH_3), 0.18 (s, 6 H, $Si(CH_3)_2C(CH_3)_3$), 0.001 (s, 9 H, $Si(CH_3)_3$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 150.6, 147.0, 139.3, 127.7, 126.7, 126.3, 43.4, 33.1, 30.1, 27.5, 27.4, 26.3, 26.1, 25.8, 22.8, 18.8, 18.0, 14.2, -0.9, -3.0; IR (neat) 2956, 2930, 2857, 1483, 1472, 1248, 909, 838 cm^{-1}; MS (EI, 70 eV) m/z 458 (M^+, 59), 271 (13), 115 (13), 73 (100); HRMS calcd for $C_{28}H_{50}OSi_2$ 458.3400, found 458.3398.

2-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-3-butyl-1-deuterio-4-(trimethylsilyl)-1-cycloheptene (12b). Titanium tetrachloride (0.35 mL of a 1 M solution in CH_2Cl_2, 0.35 mmol) was added dropwise to a solution of vinylsilane **1b** (52.1 mg, 0.0882 mmol) and CH_2Cl_2 (8.8 mL) at -78 °C. After 10 min, aqueous workup ($NaHCO_3$, CH_2Cl_2) afforded 52.0 mg of crude **12b** as an oil. Flash chromatography (98:2 hexane/ethyl acetate) gave 24.6 mg (61%) of **12b** and **12a** as a 7:3 mixture (MS): ^1H NMR (300 MHz, $CDCl_3$) δ 6.92 (s, 2 H, ArH), 5.79 (dd, J = 4.9, 8.8 Hz, 1 H, CH=CAr), 2.78 (dt, J = 5.5, 7.0 Hz, 1 H, $ArCCHCH_2$), 2.47-2.32 (m, 1 H, =$CHCHH$), 2.20 (s, 6 H, $ArCH_3$), 2.14 (m, 1 H, C=$CDCHH$), 1.99-1.47 (m, 6 H, $CH_2CHC(Si)HCH_2CH_2$, 1.31-1.15 (m, 4 H, $CH_2CH_2CH_2CH_3$), 1.03 (s, 9 H, $SiC(CH_3)_3$), 0.95 (m, 1 H, $SiCHCH_2$), 0.86 (t, J = 6.9 Hz, 3 H, CH_2CH_3), 0.18 (s, 6 H, $Si(CH_3)_2C(CH_3)_3$), 0.001 (s, 9 H, $Si(CH_3)_3$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 150.5, 147.0, 146.9, 139.2, 127.7, 126.6, 126.3, 43.3, 43.3, 33.0, 30.1, 27.4, 27.3, 26.2, 26.1, 25.7, 22.8, 18.8, 18.0, 14.2, -0.9, -3.0; MS (EI, 70 eV) m/z 459 (M^+, 27), 272 (12), 115 (13), 73 (100); HRMS calcd for $C_{28}H_{49}DOSi_2$ 459.3463, found 459.3498; deuterium analysis 70.0% d_1, 30.0% d_0.

2-[4-((*tert*-Butyldimethylsilyl)oxy)-3,5-dimethylphenyl]-3-butyl-4-deuterio-4-(trimethylsilyl)-1-cycloheptene (12c). Titanium tetrachloride (0.11 mL of a 1 M solution in CH_2Cl_2, 0.11 mmol) was added dropwise to a solution of vinylsilane **1c** (15.4 mg, 0.0272 mmol) and CH_2Cl_2 (2.7 mL) at -78 °C. After 10 min, aqueous workup ($NaHCO_3$, CH_2Cl_2) afforded 11.4 mg of crude **12c** as a yellow oil. Flash chromatography (silica gel, hexane center fractions only) gave 4.2 mg (34%) of **12c**: ^1H NMR (300 MHz, $CDCl_3$) δ 6.92 (s, 2 H, ArH), 5.78 (dd, J = 4.6, 8.6 Hz, 1 H, CH=CAr), 2.76 (t, J = 7.3 Hz, 1 H, $ArCCHCH_2$), 2.46-2.33 (m, 1 H, =$CHCHH$), 2.19 (s, 6 H, $ArCH_3$), 2.14 (m, 1 H, C=$CHCHH$), 1.91-1.87 (m, 1 H, $CHCHH$), 1.84-1.44 (m, 5 H, $CHCH$, $CDCH_2CH_2$), 1.30-1.15 (m, 4 H, $CH_2CH_2CH_2CH_3$), 1.02 (s, 9 H, $SiC(CH_3)_3$), 0.84 (t, J = 6.9 Hz, 3 H, CH_2CH_3), 0.18 (s, 6 H, $Si(CH_3)_2C(CH_3)_3$), -0.004 (s, 9 H, $Si(CH_3)_3$); ^{13}C NMR (125 MHz, $CDCl_3$) δ 150.5, 147.0, 139.2, 127.7, 126.7, 126.3, 43.3, 33.0, 30.1, 27.4, 26.1, 25.7, 22.8, 18.8, 18.0, 14.2, -0.9, -3.0; MS (EI, 70 eV) m/z 459 (M^+, 61), 387 (14), 330 (16), 272 (26), 115 (18), 73 (100); HRMS calcd for $C_{28}H_{49}DOSi_2$ 459.3463, found 459.3460; deuterium analysis 99.8% d_1, 0.2% d_0.

Acknowledgment. We thank Dr. Dan Borchardt and Dr. Robert Lee for discussions and assistance with 500-MHz NMR experiments, Dr. Richard Kondrat, Mr. Ronald New, and Mr. Viet Nguyen of the UCR Mass Spectrometry Laboratory for the mass spectra, Ms. Dorothy Nguyen for expert technical assistance, and Professor Thomas Morton for stimulating discussions. We gratefully acknowledge the National Institutes of Health (GM-39354) and the UCR Graduate Division (Fellowship to H.L. M.-A.) for financial support of this work.

Supplementary Material Available: Summary of NOE enhancements, decoupling data, and the 500-MHz double quantum COSY ^1H NMR spectrum for **12a** (1 page). Ordering information is given on any current masthead page.