A Highly Stereospecific Procedure for the Transformation of Allylic Alcohols into 1,3-Dienes[1)]

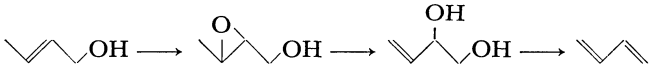
Arata YASUDA,*,† Shin TANAKA, Hisashi YAMAMOTO,†† and Hitosi NOZAKI

Department of Industrial Chemistry, Kyoto University Yoshida, Kyoto 606

(Received December 6, 1978)

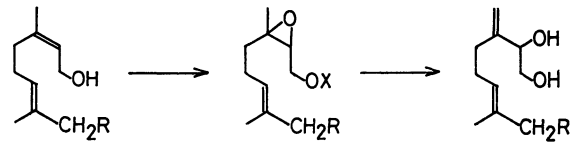
The title synthesis involves (1) epoxidation of allylic alcohols with *t*-butyl hydroperoxide in the presence of vanadium catalyst followed by trimethylsilylation, (2) specific oxirane ring opening by means of diethylaluminum 2,2,6,6-tetramethylpiperidide and subsequent desilylation producing 3-ene-1,2-diols, and (3) removal of both hydroxyl groups through bromination with a mixture of phosphorus tribromide and copper(I) bromide and the successive zinc debromination. The sequence of reactions has been extended with considerable success to the preparations of β-myrcene from nerol, *trans*-β-ocimene from geraniol in a specific way, and α- and β-farnesenes from their biological precursors. A C_{12} sex pheromone of red bollworm moth has been prepared efficiently by this method with cyclododecene as a starting material.

The high regio- and stereospecific isomerization of oxiranes into allylic alcohols has recently been accomplished by means of aluminum amides, especially diethylaluminum 2,2,6,6-tetramethylpiperidide(DATMP).[2)] To explore the applicability of this technique, we have undertaken an investigation of the reactions with a variety of oxirane derivatives.

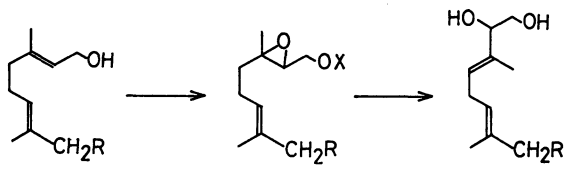


Of particular interest among them should be the conversion of 2,3-epoxy alcohols to 3-ene-1,2-diols. The recent development of effective methods of catalytic epoxidation of allylic alcohols with *t*-butyl hydroperoxide has made 2,3-epoxy alcohol species readily available for synthetic purpose.[3)] Furthermore, it could be envisioned that such ene-diols would provide us with the chance of success in the stereocontrolled synthesis of 1,3-dienes.[4)]

Epoxidation of nerol (**1a**) with the Sharpless reagent ($VO(acac)_2$–*t*-BuOOH) furnished epoxy alcohol **2a** in quantitative yield. Although the direct transformation of **2a** into 3-ene-1,2-diol **4a** by means of DATMP did not proceed smoothly, the problem was easily solved by protection of the hydroxyl group with either trimethylsilyl ether or 1-ethoxyethyl group. Of the two protecting groups, the trimethylsilyl group was more favorable for our purpose for ease of both introduction and removal. Thus, the epoxy alcohol **2a** was converted *in situ* to the epoxy silyl ether **3a** by the successive addition of pyridine, hexamethyldisilazane, and chlorotrimethylsilane at 0 °C. The crude product was immediately subjected to the action of DATMP, followed by desilylation with potassium fluoride in aqueous methanol, to furnish **4a** in 79% overall yield from **1a**. A striking feature is that none of the vinyl silyl ether was detected in the crude reaction mixture before KF treatment. As anticipated from the previous results,[2)] geraniol (**5a**) gave the isomeric diol **8a** as a predominant product. The detailed product distribution in the reaction of **7a** with DATMP and diethylaluminum diisopropylamide



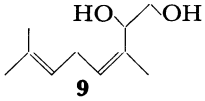
1a R=H **2a** R=H, X=H **4a** R=H
2b R=Me_2C=$CHCH_2$, X=H
1b R=Me_2C=$CHCH_2$ **3a** R=H, X=$SiMe_3$ **4b** R=Me_2C=$CHCH_2$
3b R=Me_2C=$CHCH_2$, X=$SiMe_3$



5a R=H **6a** R=H, X=H **8a** R=H
6b V=Me_2C=$CHCH_2$, X=H
5b R=Me_2C=$CHCH_2$ **7a** R=H, X=$SiMe_3$ **8b** R=Me_2C=$CHCH_2$
7b R=Me_2C=$CHCH_2$, X=$SiMe_3$

Table 1. Product distribution in the reaction of **7** with aluminum amides

Aluminum amide[a)]	Isomer distribution[b)] **8a : 9* : 4a**	Yield (%)[c)]
DATMP	90 : 5 : 5	65
Et_2Al–$N(i\text{-}Pr)_2$	44 : 48 : 8	64

*) 

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a) Aluminum amide reagents were prepared as previously reported.[2)] b) Isomer ratio was determined as follows. After KF treatment, the resulting crude 1,2-diols were converted to the corresponding aldehydes by the reaction with sodium periodate in ethanol. The chemical shifts ($CDCl_3$, TMS) of aldehyde protons appeared at δ 9.3 (the aldehyde derived from **8a**); 10.1 (the aldehyde derived from **9**); 9.5 (the aldehyde derived from **4a**). The ratio was determined by their intensities. c) Yields are based on material isolated by preparative TLC.

† Present Address: The Institute for Molecular Science, Myodaiji, Okazaki 444.

†† Present Address: Department of Chemistry, University of Hawaii at Manoa, Honolulu, Hawaii 96822.

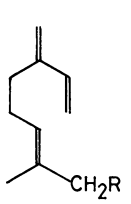
are listed in Table 1. In addition to the previous observation, Table 1 shows following points of interest:

(1) This transformation can be believed to involve initial complex formation where aluminum amides approach the oxirane so as to enable a greater orbital overlap. Then the presence of the bulky trimethylsiloxyl group should make the attack of aluminum amides even more selective so that the reagents attack the oxirane group exclusively on the less hindered side (on the same side as hydrogen of oxirane) to produce trisubstituted olefinic diol **8a** or the isomer **9**.

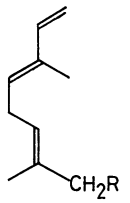
(2) Substitution of diisopropylamide for tetramethylpiperidide moiety results in the complete lack of the (*E*) preference, which supports that the bulk of the extremely large TMP group did play an even more significant role in determining the course of elimination. Thus, in the abstraction stage of hydrogen, the favored direction is to be strictly arranged so as to minimize the severe nonbonded interactions. It should be added that using *t*-butyldimethylsilyl protecting group[5] in place of trimethylsilyl moiety even more improved the selectivity (**4a**: **8a**: **9**=2: 96: 2).

A similar sequence was extended to transform (2*Z*,6*E*)-farnesol (**1b**) to ene-diol **4b** (71% yield) and the isomer **5b** to **8b** (70% yield), respectively.

Now the remaining step toward 1,3-dienes consists in selective transformation of 1,2-diol group into vinyl moiety. Attempted application of the Eastwood method[6] proved to be disappointing. Treatment of the diol **4a** with *N*,*N*-dimethylformamide dimethyl acetal and the subsequent heating of the resulting dioxolane derivative in acetic anhydride at 110 °C afforded myrcene (**10a**)[7] in less than 20% yield.[8] Reaction of the benzaldehyde acetal of the diol with butyllithium was also tested without any success.[9] We therefore developed the following alternative route. The diol **4a** was initially brominated with a mixture of copper(I) bromide (2.5 equiv) and phosphorus tribromide (1.2 equiv) at 0 °C for 1 h and then successively treated with excess zinc dust at room temperature for 2 h to furnish myrcene (**10a**) in 58% yield. Similarly, the following terpenes were prepared efficiently from the corresponding ene-diols: *trans*-*β*-ocimene (**11a**),[10] from diol **8a**; *β*-farnesene (**10b**),[11] from **4b**; *trans*-*α*-farnesene (**11b**),[12] from **8b**. The homogeneity of each product was attested by the NMR analysis. Although the role of excess copper(I) bromide in this process is still obscure, it



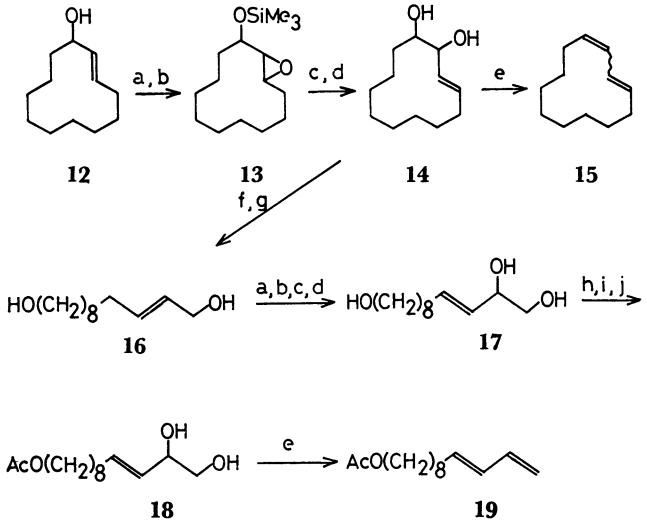
10a R=H
10b R=Me_2C=CHCH$_2$



11a R=H
11b R=Me_2C=CHCH$_2$

appears to facilitate both bromination and debromination and is essential for securing good yields. The synthesis of **10b** and **11b** should be monitored by TLC assay, since the longer reaction time causes cyclization induced by zinc bromide at the expense of the desired product.

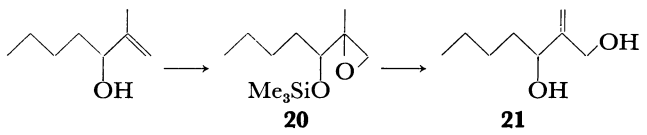
The present method permitted the facile synthesis of the following 1,3-diene compounds. 1,3-Cyclododecadiene (**15**) was prepared from (*E*)-2-cyclododecen-1-ol (**12**).[13] In addition, (*E*)-9,11-dodecadienyl acetate (**19**), which was known as the major sex pheromone of the red bollworm moth,[14] was prepared smoothly from the diol **14** as a starting material. Thus, **14** was converted to the open chain diol **16** by sodium periodate oxidation followed by sodium tetrahydroborate reduction. The same series of reactions transformed **16** into the triol **17**. The terminal alcohol (C-12) was converted to the



a, VO(acac)$_2$–*t*-BuOOH; b, Me_3SiCl–$(Me_3Si)_2NH$–C_5H_5N; c, DATMP; d, KF; e, PBr_3–Cu_2Br_2–Zn; f, $NaIO_4$; g, $NaBH_4$; h, $Me_2C(OMe)_2$–*p*-TsOH; i, Ac_2O–C_5H_5N; j, $(CH_2OH)_2$–*p*-TsOH.

acetate **18** as follows. Treatment of **17** with 2,2-dimethoxypropane with a catalytic amount of *p*-toluenesulfonic acid followed by acetylation (acetic anhydride-pyridine) afforded acetonide acetate, which was transformed to diol **18** using ethylene glycol and trace *p*-toluenesulfonic acid. The desired diene **19** was obtained by the similar treatment with PBr_3–Cu_2Br_2–Zn.

Finally a further extension of the sequence should be added. Reaction of an epoxy silyl ether **20** with DATMP and then KF gave 2-methylene-1,3-diol **21**. Although this class of compounds are potential intermediates for



the synthesis of substituted trimethylenemethane and other related compounds, there exist few synthetic routes available.[15]

Experimental

The infrared spectra were determined on a Shimadzu IR-27-G spectrometer; the mass spectra on a Hitachi RMU-6L mass machine; and NMR spectra on a JNM-PMX 60 or

Varian EM-360 spectrometer. The chemical shifts are given in δ in ppm with TMS as the internal standard. Splitting patterns are designated as s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet. The microanalyses were carried out by the staffs at the Elemental Analyses Center of Kyoto University. All experiments were carried out under an atmosphere of dry argon. In experiments requiring dry solvents, tetrahydrofuran was distilled from sodium-benzophenone. Ether and benzene were dried over sodium metal. During workup, drying of the organic solution was performed over anhydrous sodium sulfate. Thin layer or preparative thick layer plates were made of E. Merck PF-254, and preparative column chromatography on silica gel E. Merck Art. 7734.

*Synthesis of Myrcene (**10a**). 2-Methyl-*r*-2-(4-methyl-3-pentenyl)-*c*-3-trimethylsiloxymethyloxirane (**3a**).* The epoxy alcohol **2a** was prepared as previously reported.[3a] A solution of *t*-butyl hydroperoxide (300 mg, 3.0 mmol) in benzene (3 ml) was added at 0 °C dropwise to a mixture of nerol (**1a**) (308 mg, 2.0 mmol) and oxobis(2,4-pentanedionato-*O*,*O'*)vanadium-(IV) (16 mg, 0.06 mmol) in benzene (10 ml). Stirring was continued at room temperature for 3 h (TLC analysis indicated the absence of starting material). The epoxy alcohol **2a** was converted *in situ* to the epoxy silyl ether **3a** by the successive addition of pyridine (4.0 ml), hexamethyldisilazane (0.8 ml), and chlorotrimethylsilane (0.4 ml) at 0 °C. The reaction was completed in 1 h at room temperature, then saturated sodium sulfite was added and the whole mixture was vigorously stirred at ambient temperature for 20 min. The separated organic phase was washed with saturated copper(II) sulfate and water, dried, and concentrated *in vacuo*. The crude product was immediately subjected to the next reaction.

A sample was purified by column chromatography on silica gel (20: 1 hexane–ether) followed by bulb-to-bulb distillation: bp 92—94 °C (bath temp, 1 Torr); TLC, R_f 0.49 (2: 1 hexane–ether); IR (neat), 1450 (m), 1245 (s), 1122 (s), 1080 (s), and 845 cm^{-1} (s); NMR (CCl_4), 0.11 (9H, s, CH_3–Si), 1.25 (3H, s, CH_3–CO), 1.59 (3H, s, CH_3–C=), 1.65 (3H, s, CH_3–C=), 2.63 (1H, t, J=6 Hz, CH–O), 3.54 (2H, dd, CH_2–O), and 5.00 (1H, bt, CH=); MS (*m/e*), 242 (1), 181 (8), 173 (10), 160 (100), and 145 (44).

Found: C, 64.4; H, 10.7 %. Calcd for $C_{13}H_{26}O_2Si$: C, 64.4; H, 10.8 %.

*7-Methyl-3-methylene-6-octene-1,2-diol (**4a**).* To a benzene solution (20 ml) of diethylaluminum 2,2,6,6-tetramethylpiperide (8.0 mmol) a solution of crude **3a** (*ca.* 2.0 mmol) in benzene (2 ml) was added at 0 °C dropwise and the mixture was stirred at the same temperature for 1 h. The reaction mixture was quenched with dil. hydrochloric acid at 0 °C and the resulting organic phase was separated. The aqueous layer was extracted with ether, and the combined organic solutions were washed with saturated brine, dried, and freed of the solvent. The residue was dissolved in 80 % aqueous methanol (5 ml) and potassium fluoride (1.2 g, 20.0 mmol) was added at 0 °C. After stirring at room temperature for 3 h, the volatile material was removed under reduced pressure. The residue was partitioned between saturated brine and ethyl acetate, and the aqueous phase was extracted several times with ethyl acetate. The combined organic phase was washed with saturated brine, dried, and concentrated *in vacuo*. The remaining liquid was submitted to preparative TLC (1: 1 hexane–ethyl acetate) to give pure **4a** (269 mg, 79% yield from **1a**) as a clear oil: bp 130 °C (bath temp, 1 Torr); TLC, R_f 0.41 (ether); IR (neat), 3350—3440 (s), 1440—1455 (m), 1065—1090 (s), and 905 cm^{-1}(m); NMR ($CDCl_3$), 1.61 (3H, s, CH_3–C=), 1.69 (3H, s, CH_3–C=), 4.00—4.33 (1H, m, CH–O), and 4.83—5.27 (3H, bd, CH= and CH_2–); MS (*m/e*), 170 (1), 152 (4), 127 (9), 109 (18), and 69 (100).

Microanalysis was performed after converting the 1,2-glycol group to isopropylidene acetal group by treating the glycol with 2,2-dimethoxypropane in dichloromethane in the presence of a catalytic amount of *p*-toluenesulfonic acid:

Found: C, 74.4; H, 10.7%. Calcd for $C_{13}H_{22}O_2$: C, 74.2; H, 10.5%.

*Myrcene (**10a**).*[7] To an ethereal solution (10 ml) of diol **4a** (200 mg, 1.2 mmol), copper(I) bromide (860 mg, 3.0 mmol) and phosphorus tribromide (0.09 ml, 0.5 mmol) were successively added at −78 °C, and the whole mixture was stirred at 0 °C for 1 h. Zinc dust (392 mg, 6.0 mmol) was added at 0 °C and stirring was continued at room temperature for 2 h. Dilution of the mixture with pentane, folowed by workup and short-path column chromatography (pentane as an eluent), furnished myrcene (**10a**) (98 mg, 58 % yield) as a colorless oil: TLC, R_f 0.80 (hexane); IR (neat), 1600 (s), 1435—1450 (m), 1365 (m), 990 (s), and 890 cm^{-1} (s); NMR (CCl_4), 1.53 (3H, s, CH_3–C=), 1.62 (3H, s, CH_3–C=), 2.20 (4H, d, CH_2–C=), 4.98 (2H, s, CH_2= on C-3), 4.81—5.46 (3H, m, CH_2= on C-1 and CH= on C-6), and 6.35 (1H, dd, J=18 and 10 Hz, CH= on C-2); MS (*m/e*), 136 (8), 121 (7), 107 (5), 93 (100), and 69 (99).

Synthesis of trans-*β-Ocimene (**11a**). 2-Methyl-r-2-(4-methyl-3-pentenyl)-t-3-trimethylsiloxymethyloxirane (**7a**).* The epoxy alcohol **6a**[3a] was converted to epoxy silyl ether **7a** as described above, and used for the next reaction without purification.

A small aliquot was purified by column chromatography (20: 1 hexane–ether) followed by evaporative distillation: bp 95 °C (bath temp, 1 Torr); TLC, R_f 0.50 (2: 1 hexane–ether); IR (neat), 1450 (m), 1240 (m), 1120 (s), 1065—1080 (s), and 840 cm^{-1} (s); NMR (CCl_4), 0.11 (9H, s, CH_3–Si), 1.19 (3H, s, CH_3–CO), 1.59 (3H, s, CH_3–C=), 1.65 (3H, s, CH_3–C=), 2.63 (1H, t, J=5 Hz, CH–O), 3.54 (2H, dd, CH_2–O), and 5.00 (1H, bt, CH=); MS (*m/e*), 242 (1), 181 (14), 160 (100), 145 (45), and 103 (76).

Found: C, 64.2; H, 10.7%. Calcd for $C_{13}H_{26}O_2Si$: C, 64.4; H, 10.8 %.

*(E)-3,7-Dimethyl-3,6-octadiene-1,2-diol (**8a**).* The title compound was prepared from the crude **7a** by treatment with DATMP (4 equiv) at 0 °C for 1.5 h in benzene and then with potassium fluoride (10 equiv) at room temperature for 3 h (59 % yield based on geraniol **5a**): bp 135 °C (bath temp, 1 Torr); TLC, R_f 0.37 (ether); IR (neat), 3250—3400 (s), 1430—1445 (s), 1035—1070 (s), and 880—890 cm^{-1} (m); NMR ($CDCl_3$), 1.64 (6H, s, CH_3–C=), 1.69 (3H, s, CH_3–C=), 2.52—2.94 (2H, t, J=8 Hz, CH_2–C=), 3.80—4.32 (1H, m, CH–O), 5.12 (1H, bt, CH= on C-6), and 5.46 (1H, bt, CH= on C-4); MS (*m/e*), 170 (6), 152 (11), 139 (36), 109 (60), and 81 (100).

Microanalysis was performed with the isopropylidene acetal derivative:

Found: C, 74.4; H, 10.5%. Calcd for $C_{13}H_{22}O_2$: C, 74.2; H, 10.5%.

trans-*β-Ocimene (**11a**).*[10] The title compound was prepared from sequential treatment of the diol **8a** with copper-(I) bromide, phosphorus tribromide, and zinc as described above. The desired triene **11a** (66 % yield) formed a clear oil: TLC, R_f 0.80 (hexane); IR (neat), 1650 (m), 1610 (s), 1380 (s), 990 (s), and 890 cm^{-1} (s); NMR (CCl_4), 1.65—1.72 (9H, m, CH_3–C=), 2.79 (2H, bt, CH_2–C=), 4.58—5.55 (4H, CH= on C-4 and C-6, CH_2=), and 6.26 (1H, dd, J=18 and 10 Hz, CH= on C-2); MS (*m/e*), 136 (13), 121 (24), 105 (18), 93 (100), and 79 (47).

*Synthesis of β-Farnesene (**10b**). r-2-[(3E)-4,8-Dimethyl-3,7-nonadienyl]-2-methyl-c-3-trimethylsiloxymethyloxirane (**3b**)*: Bp 135 °C (bath temp, 1 Torr); TLC, R_f 0.48 (5: 1 hexane–ether); IR (neat), 1450 (m), 1245 (s), 1120 (s), 1080 (s), and 845 cm^{-1} (s); NMR (CCl_4), 0.09 (9H, s, CH_3–Si), 1.23 (3H, s,

CH_3–CO), 2.67 (1H, t, CH–O), 3.54 (2H, d, J=6 Hz, CH_2–O), and 4.82—5.23 (2H, m, CH=); MS (*m/e*), 310 (M^+).

Found: C, 69.7; H, 11.2 %. Calcd for $C_{18}H_{34}O_2Si$: C, 69.6; H, 11.0 %.

*(6E)-7,11-Dimethyl-3-methylene-6,10-dodecadiene-1,2-diol (**4b**).* The title compound (169 mg, 71 % yield) was prepared from **1b** employing a series of reactions as aforementioned: TLC, R_f 0.53 (ether); IR (neat), 3330—3420 (s), 1438—1454 (m), 1065—1090 (s), and 905 cm^{-1} (s); NMR ($CDCl_3$), 1.61 (6H, s, CH_3–C= on C-7 and C-11), 1.69 (3H, s, CH_3–C= on C-11), 3.39—3.91 (2H, m, CH_2–O), 4.00—4.36 (1H, m, CH–O), and 4.70—5.34 (4H, bd, CH_2= and CH=).

Microanalysis was performed with its isopropylidene acetal derivative:

Found: C, 77.9; H, 10.9 %. Calcd for $C_{18}H_{30}O_2$: C, 77.7; H, 10.8 %.

*β-Farnesene (**10b**).*[11] The preparation of the diene **10a** was repeated, except stirring was stopped in 1.5 h to suppress the formation of by-products. β-Farnesene (**10b**) (78 mg) was obtained from the diol **4b** (238 mg) in 38 % yield as a colorless liquid: TLC, R_f 0.80 (hexane); IR (neat), 1600 (s), 1440—1465 (s), 990 (s), 910 (sh), and 895 cm^{-1} (s); NMR (CCl_4), 1.60 (6H, s, CH_3–C=), 1.69 (3H, s, CH_3–C=), 4.82—5.41 (6H, m, CH_2= and CH= on C-6, C-10), and 6.32 (1H, dd, J=18 and 11 Hz, CH= on C-2); MS (*m/e*), 204 (8), 161 (10), 133 (20), 93 (59), and 69 (100).

Synthesis of trans-α-*Farnesene (**11b**).* r-2-[*(3E)-4,8-Dimethyl-3,7-nonadienyl*]-2-*methyl*-t-3-*trimethylsiloxymethyloxirane (**7b**)*: Bp 135 °C (bath temp, 1 Torr); TLC, R_f 0.53 (5:1 hexane–ether); IR (neat), 1450 (m), 1250 (s), 1120 (s), 1060—1080 (s), and 835 cm^{-1} (s); NMR (CCl_4), 0.09 (9H, s, CH_3–Si), 1.19 (3H, s, CH_3–CO), 2.67 (1H, t, CH–O), 3.54 (2H, d, J=6 Hz, CH_2–O), and 4.82—5.23 (2H, m, CH=); MS (*m/e*), 310 (M^+).

Found: C, 69.6; H, 11.1 %. Calcd for $C_{18}H_{34}O_2Si$: C, 69.6; H, 11.0 %.

*(3E,6E)-3,7,11-Trimethyl-3,6,10-dodecatriene-1,2-diol (**8b**).* The same sequence as aforementioned furnished the diol **8b** (168 mg, 70 % yield) from (*E,E*)-farnesol (**5b**) (222 mg) as a clear oil: TLC, R_f 0.48 (ether); IR (neat), 3340—3420 (s), 1440—1455 (m), 1060—1080 (m), and 890 cm^{-1} (w); NMR ($CDCl_3$), 1.61 (6H, s, CH_3–C= on C-7 and C-11), 1.65 (3H, s, CH_3–C= on C-3), 1.69 (3H, s, CH_3–C= on C-11), 2.72 (2H, t, J=7 Hz, CH_2–C= on C-4), 3.92—4.31 (1H, m, CH–O), 5.12 (2H, bt, CH= on C-6 and C-10), and 5.46 (1H, bt, CH= on C-4).

Microanalysis was performed with its isopropylidene acetal derivative:

Found: C, 77.9; H, 11.1 %. Calcd for $C_{18}H_{30}O_2$: C, 77.7; H, 10.8 %.

trans-α-*Farnesene (**11b**).*[12] The title compound was obtained in 45 % yield from **8b**: TLC, R_f 0.80 (hexane); IR (neat), 1610 (m), 1440—1455 (s), 1380 (s), 990 (s), 910 (sh), and 895 cm^{-1} (s); NMR (CCl_4), 1.50—1.74 (12H, m, CH_3–C=), 2.80 (2H, bt, CH_2–C= on C-4), 4.60—5.66 (5H, m, CH_2= and CH= on C-4, C-6, and C-10), and 6.32 (1H, dd, J=18 and 11 Hz, CH= on C-2); MS (*m/e*), 204 (9), 135 (14), 119 (48), 107 (43), and 93 (100).

*Synthesis of 1,3-Cyclododecadiene (**15**).* trans-*1,2-Epoxy-3-trimethylsiloxycyclododecane (**13**)*: Bp 110—112 °C (bath temp, 1 Torr); TLC, R_f 0.59 (3:1 hexane–ether); IR (neat), 1240 (s), 1105 (m), 950 (w), 865 (m), and 840 cm^{-1} (s); NMR (CCl_4), 0.10 (9H, s, CH_3–Si), 2.42—2.90 (2H, m, CH–O on C-1 and C-2), and 3.83—4.16 (1H, m, CH–O on C-3); MS (*m/e*), 270 (1), 255 (48), 185 (6), 129 (100), and 95 (38).

Found: C, 66.9; H, 11.4 %. Calcd for $C_{15}H_{30}O_2Si$: C, 66.6; H, 11.2 %.

*(E)-3-Cyclododecene-1,2-diol (**14**).* This compound was prepared from **12** in 63 % yield: mp 89—91 °C (benzene–hexane); TLC, R_f 0.68 (ether); IR (Nujol), 3300—3410 (s), 1450 (s), 1030 (s), 980 (s), and 915 cm^{-1} (m); NMR ($CDCl_3$), 3.20—3.98 (2H, m, CH–O), and 5.39—5.83 (2H, m, CH=).

Found: C, 72.7; H, 11.3 %. Calcd for $C_{12}H_{22}O_2$: C, 72.7; H, 11.2 %.

*1,3-Cyclododecadiene (**15**).*[16] The diol **14** was transformed to the title compound in 70 % yield: TLC, R_f 0.80 (hexane); IR (neat), 1470—1485 (s), 1445 (m), 980 (s), and 950 cm^{-1} (m); NMR (CCl_4), 5.00—6.59 (4H, m, CH=); MS (*m/e*), 164 (37), 121 (25), 93 (37), 79 (100), and 67 (100).

*Synthesis of (E)-9,11-Dodecadienyl Acetate (**19**). (E)-2-Dodecene-1,12-diol (**16**).* Sodium periodate (3.08 g, 14.4 mmol) was added at 0 °C to a solution of diol **14** (1.42 g, 7.2 mmol) in 80 % aqueous ethanol (26 ml). After stirring at 0 °C for 1.5 h, the solid was filtered off and the filtrate was concentrated *in vacuo*. The residue was partitioned between saturated brine and ether, then the ethereal solution was washed with saturated brine, dried, and freed of the solvent to yield dialdehyde: TLC, R_f 0.60 (2:1 ether–hexane); IR (neat), 1720—1730 (s), 1690 (s), 1460—1470 (m), and 980 cm^{-1} (m); NMR (CCl_4), 6.00 (1H, dd, J=16 and 8 Hz, CH= on C-2), 6.80 (1H, dt, J=16 and 7 Hz, CH= on C-3), 9.43 (1H, d, J=7 Hz, CH=O on C-1), and 9.70 (1H, t, CH=O on C-12); MS (*m/e*), 196 (3), 98 (48), 83 (76), 70 (74), and 55 (100).

The crude product was treated with sodium tetrahydroborate (274 mg, 7.2 mmol) in methanol (10 ml) at room temperature for 1 h. Acetic acid was then added dropwise to hydrolyze the excess hydride and the volatile material was removed *in vacuo*. The residue was diluted with ethyl acetate and the organic phase was washed with saturated brine, dried, and concentrated *in vacuo*. Purification by column chromatography (1:1 benzene–ethyl acetate) furnished the diol **16** (1.05 g, 73 % yield from **14**) as a semi-solid: TLC, R_f 0.13 (1:2 hexane–ether); IR (neat), 3350—3450 (s), 1480 (m), 1470 (s), 1090 (s), and 970 cm^{-1} (s); NMR ($CDCl_3$), 3.60 (2H, t, CH_2–O on C-12), 4.05 (2H, d, CH_2–O on C-1), and 5.41—5.73 (2H, m, CH=).

Microanalysis was performed after trimethylsilylation of both hydroxyl groups:

Found: C, 63.0; H, 12.0 %. Calcd for $C_{18}H_{40}O_2Si_2$: C, 62.8; H, 11.7 %.

*(E)-9,11-Dodecadienyl Acetate (**19**).*[14] The sequence as described above converted the diol **16** to the triol **17** in 75 % yield: TLC, R_f 0.31 (ethyl acetate); IR (neat), 3300—3450 (s), 1450—1480 (m), 1050—1070 (s), and 970 cm^{-1} (s); NMR ($CDCl_3$), 3.20—4.05 (5H, m, CH_2–O and CH–O), and 5.51—5.73 (2H, m, CH=).

Before the synthesis of diene **19**, the terminal alcohol (C-12) was converted to the acetate as follows. To a mixture of triol **17** (80 mg, 0.37 mmol), 2,2-dimethoxypropane (0.07 ml, 0.55 mmol), and THF (3 ml) was added *p*-toluenesulfonic acid (4 mg, 0.02 mmol) at 0 °C, and the solution was stirred at room temperature for 4 h. A drop of pyridine was added and the mixture was diluted with ether. The organic solution was washed with saturated brine, dried, and freed of the solvent. The residue was treated with acetic anhydride (0.5 ml) in pyridine (0.5 ml) at ambient temperature for 5 h. Aqueous workup in the usual manner, drying, and concentrating *in vacuo* gave acetonide acetate, which was treated with *p*-toluenesulfonic acid (4 mg, 0.02 mmol) in ethylene glycol (2 ml) at room temperature for 4 h to furnish diol **18** (89 % yield based on **17**) after purification by preparative TLC (2:1 ether–hexane): TLC, R_f 0.53 (2:1 ether–hexane); IR (neat), 3400—3450 (s), 1740 (s), 1370 (m), 1235—1255 (s), and 970 cm^{-1} (m); NMR ($CDCl_3$), 1.96 (3H, s, CH_3–CO), 3.59 (2H, t, CH_2–OAc), 3.87—4.38 (3H, m, CH–O and CH_2–O), and

5.18—6.09 (2H, m, CH=).

The diol **18** was converted to the desired diene **19** with the Cu_2Br_2–PBr_3–Zn system in 75 % yield: TLC, R_f 0.38 (5: 1 hexane–ether); IR (neat), 1740 (s), 1260 (s), 1005 (m), 960(w), and 900 cm^{-1} (m); NMR ($CDCl_3$, 100 MHz), 2.02 (3H, s, CH_3–CO), 1.95—2.21 (2H, m, CH_2–C=), 4.06 (2H, t, J=7 Hz, CH_2–O), and 4.85—6.50 (5H, m, CH= and CH_2=, 5.00, 5.15, 5.61, 5.69, 5.75, 5.82, 5.92, 6.03, 6.15, 6.24, 6.30, 6.40, and 6.50); MS (*m/e*), 224 (7), 164 (18), 135 (15), 121 (20), and 67 (100).

*2-Methyl-2-(1-trimethylsiloxypentyl)oxirane (**20**)*: Bp 60 °C (bath temp, 1 Torr); TLC, R_f 0.68 (1: 1 hexane–ether); IR (neat), 1450—1700 (w), 1245 (s), 1090 (s), 940 (m), 865 (sh), and 840 cm^{-1} (s); NMR (CCl_4), 0.53 (9H, s, CH_3–Si), 1.67 (3H, s, CH_3–CO), 2.68—3.16 (2H, dd, CH_2–O), and 3.50—3.90 (1H, bt, CH–O); MS (*m/e*), 216 (2), 201 (25), 160 (43), 131 (34), and 75 (100).

Found: C, 61.3; H, 11.3 %. Calcd for $C_{11}H_{24}O_2Si$: C, 61.1; H, 11.2 %.

*2-Methylene-1,3-heptanediol (**21**)*. Treatment of **20** (216 mg, 1.0 mmol) with DATMP (4.0 mmol) and then with KF furnished the diol **21** (108 mg) in 75 % yield: TLC, R_f 0.33 (ether); IR (neat), 3340—3400 (s), 1655 (w), 1010—1060 (s), and 905 cm^{-1} (m); NMR ($CDCl_3$), 3.84—4.48 (3H, m, CH–O and CH_2–O), and 5.09 (2H, s, CH_2=).

Found: C, 66.5; H, 11.5 %. Calcd for $C_8H_{16}O_2$: C, 66.6; H, 11.2 %.

The authors wish to thank the Ministry of Education, Japan, for a Grant-in-Aid (No. 011010, 110309, 203014, and 303023).

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