Hz, 12-H), and 6.78-7.25 (8 H, m, ArH); MS *m/e* 265 (M^+). Anal. Calcd for $C_{18}H_{19}NO{\cdot}CH_3CO_2H{\cdot}0.1H_2O$: C, 73.41; H, 7.15; N, 4.28. Found: C, 73.32; H, 7.15; N, 4.24.

11-*exo*-Hydroxy-5,12-iminomethano-5-methyl-5,6,11,12-tetrahydrodibenzo[*a*,*e*]cyclooctenacetic Acid (30). Compound **28** (0.1 g) was dissolved in glacial acetic acid (5 mL) and zinc dust (0.2 g) was added. The reaction mixture was heated at 65 °C under an atmosphere of nitrogen for 14 h, then cooled, filtered, and concentrated in vacuo. The crude product was purified by chromatography on silica gel using 30% methanol in dichloromethane as eluent to give, as a colorless solid, the title compound (0.107 g, 87%): mp 185 °C dec; ^{1}H NMR (360 MHz, DMSO) δ 1.57 (3 H, s, CH_3CO_2H), 1.87 (3 H, s, CH_3), 2.70 (1 H, d, J = 14.5 Hz, 6-H_{eq}), 2.79 (1 H, dd, J = 12.8 and 8.1 Hz, 14-H_{ax}), 3.27 (1 H, d, J = 14.5 Hz, 6-H_{ax}), 3.40 (1 H, m, 12-H), 3.54 (1 H, d, J = 12.8 Hz, 14-H_{eq}), 4.79 (1 H, d, J = 6.4 Hz, 11-H), and 6.89-7.12 (8 H, m, ArH); MS *m/e* 265 (M^+). Anal. Calcd for $C_{18}H_{19}NO{\cdot}CH_3CO_2H$: C, 73.82; H, 7.12; N, 4.30. Found: C, 74.06; H, 7.06; N, 4.39.

2,3:6,7-Dibenzo-1-methyl-8-aza-9-oxatricyclo[3.2.2.1]deca-2,6-diene (33). Sodium acetate (11.08 g, 0.135 mol) and dichloroacetic acid (16.8 mL, 0.203 mol) were dissolved in dichloromethane (17 mL) at room temperature with rapid stirring, and after 1 h formaldoxime hydrochloride (6.1 g, 0.045 mol) in dichloromethane (20 mL) was added. After a further 0.5 h, 5-hydroxy-5-methyldibenzo[*a*,*d*]cycloheptene (**32**)[8] (5 g, 0.0225 mol) was added to the reaction mixture and stirring was continued for 14 h. A sodium hydroxide solution (1 N, 100 mL) was added followed by dichloromethane (100 mL), and the organic layer was separated, dried (Na_2SO_4), filtered, and concentrated in vacuo to give a residue, which was purified by chromatography on silica gel, using 20% ethyl acetate in hexane as eluent, to give as a colorless foam **33** (0.49 g, 9%): ^{1}H NMR (360 MHz, $CDCl_3$) δ 2.18 (3 H, s, CH_3), 2.63 (1 H, d, J = 9.8 Hz, 10-H_{eq}), 3.57 (1 H, dd, J = 9.8 and 4.3 Hz, 10-H_{ax}), 4.19 (1 H, dd, J = 6.5 and 4.3 Hz, 5-H), 5.57 (1 H, d, J = 6.5 Hz, 4-H), and 6.92-7.31 (8 H, m, ArH); MS *m/e* (CI) 250 (M^+). Anal. Calcd for $C_{17}H_{15}NO$: C, 81.90; H, 6.06; N, 5.62. Found: C, 81.92; H, 6.17; N, 5.18.

11-*exo*-Hydroxy-5,10-iminomethano-5-methyl-5*H*-10,11-dihydrodibenzo[*a*,*d*]cycloheptene (34). Compound **33** (0.24 g) was dissolved in glacial acetic acid (25 mL) and zinc dust (0.48 g) was added. The reaction mixture was stirred and heated at 70 °C under an atmosphere of nitrogen for 36 h, then cooled, filtered, and concentrated in vacuo. The residue was partitioned between dichloromethane (50 mL) and sodium hydroxide solution (1 N, 50 mL) and the organic layer was separated, washed with brine, dried (Na_2SO_4), filtered, and evaporated under vacuum. The crude product was purified by chromatography on silica gel with 10% methanol in dichloromethane as eluent to give the title compound as a colorless solid (0.08 g, 33%): mp 261-264 °C; ^{1}H NMR (360 MHz, DMSO) δ 1.85 (3 H, s, CH_3), 2.87 (1 H, dd, J = 11.2 and 3.7 Hz, 12-H_{ax}), 3.19 (1 H, dd, J = 4.1 and 3.7 Hz, 10-H), 3.68 (1 H, d, J = 11.2 Hz, 12-H_{eq}), 4.71 (1 H, d, J = 4.1 Hz, 11-H), 5.58 (1 H, br, NH), and 7.08-7.41 (8 H, m, ArH); MS *m/e* found 251.13310, $C_{17}H_{17}NO$ requires 251.13101. Anal. Calcd for $C_{17}H_{17}NO{\cdot}0.9H_2O$: C, 76.32; H, 7.08; N, 5.24. Found: C, 75.98; H, 6.67; N, 5.02.

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Registry No. (±)-**3**, 125299-69-6; (±)-**5**, 125299-73-2; **8**, 89442-07-9; (±)-**13**, 120903-19-7; (±)-**14**, 125299-74-3; (±)-**15**, 125299-75-4; (±)-**16**, 125299-77-6; (±)-**16**·HCl, 34697-36-4; **17**, 125357-78-0; (±)-**23**·HCl, 125357-79-1; (±)-**24**, 125299-76-5; (±)-**25**, 125357-80-4; (±)-**27**, 120903-20-0; (±)-**28**, 120903-20-0; (±)-**29**·HOAc, 125411-78-1; (±)-**30**·HOAc, 125411-79-2; **32**, 18259-45-5; (±)-**33**, 125357-81-5; (±)-**34**, 125357-82-6.

Stereoselectivity in the Ortho Ester Claisen Rearrangements of the *E* and *Z* Isomers of γ-(1,3-Dioxan-4-yl)allyl Alcohols†,[1]

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The *E* and *Z* isomers of (2*R*,4*S*,5*R*)-5-hydroxy-4-(3-hydroxy-1-propenyl)-2-methyl-1,3-dioxane (**3Z** and **3E**), which were derived from 4,6-*O*-ethylidene-D-glucose (**1**), and their 5-*O*-*tert*-butyldimethylsilyl derivatives (**5Z**) and (**5E**) served as substrates for Claisen rearrangements with triethyl orthoacetate. The rearrangement employing **5Z** proceeds with moderate to high levels of diastereoselectivity. The chemically determined stereochemical assignments of the newly introduced stereogenic centers in the rearrangement products reveal that the diastereomer with an *R* configuration is the major rearrangement product. The results of the Claisen rearrangement of **5Z** with triethyl orthopropionate are also described.

Recent reports from these laboratories have described an efficient approach to the stereoselective quaternization of a skeletal carbon of some aldohexoses by means of the ortho ester Claisen (Johnson-Claisen) rearrangement.[2] Furthermore, the utility of the rearrangement product was demonstrated through the total syntheses of various natural products.[3] In the course of our ongoing investigations on the Claisen rearrangement of carbohydrate-derived enantiomeric allyl alcohols, we have studied the Claisen rearrangements of (2*R*,4*S*,5*R*)-5-hydroxy-4-(3-hydroxy-1-propenyl)-2-methyl-1,3-dioxane (**3Z** and **3E**) and their 5-*O*-*tert*-butyldimethylsilyl derivatives **5Z** and **5E** with triethyl orthoacetate and with triethyl orthopropionate.

Compared with our previous results which showed highly stereoselective Claisen rearrangement of bicyclic substrates

† This paper is dedicated to Professor Kenneth L. Rinehart in honor of his 60th birthday.

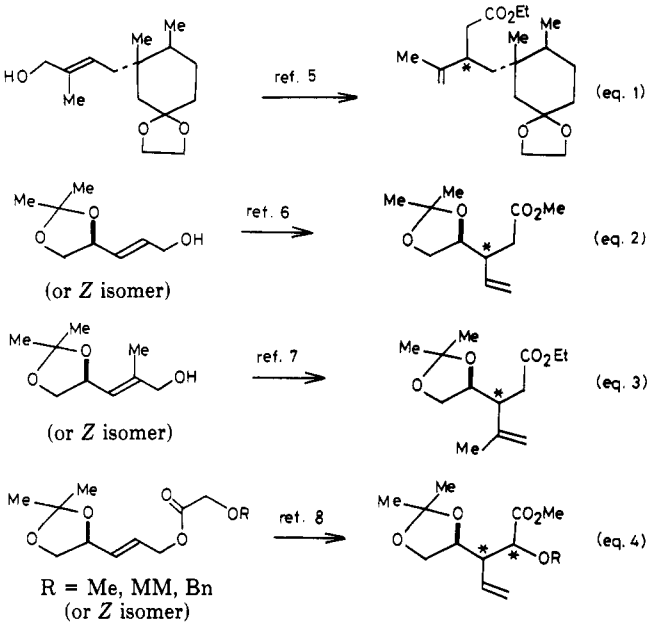
(1) This work was presented orally at the 58th National Meeting of the Chemical Society of Japan, Kyoto, April 1-4, 1989.

(2) Tadano, K.; Idogaki, Y.; Yamada, H.; Suami, T. *Chem. Lett.* **1985**, 1925; *J. Org. Chem.* **1987**, *52*, 1201. Tadano, K.; Ishihara, J.; Yamada, H.; Ogawa, S. *J. Org. Chem.* **1989**, *54*, 1223.

(3) Tadano, K.; Yamada, H.; Idogaki, Y.; Ogawa, S.; Suami, T. *Tetrahedron Lett.* **1988**, *29*, 655. Tadano, K.; Kanazawa, S.; Ogawa, S. *J. Org. Chem.* **1988**, *53*, 3868.

0022-3263/90/1955-2108$02.50/0

(e.g. cis-fused bicyclo[3.3.0] systems), the stereochemical outcome in the present case using six-membered substrates with an allyl alcohol side chain was not readily predictable. Although a number of the Claisen rearrangement protocols reported so far for the construction of complex carbon frameworks have been successful,[4] literature references dealing with the Claisen rearrangement of cyclic models similar to the present substrates reveal that predictability and high stereoselectivity are not always possible. For example, Ziegler[5] reported difficulty in achieving high stereoselectivity in the ortho ester Claisen rearrangement of an (*E*)-allyl alcohol, positioned as a side chain of a trisubstituted cyclohexanone ketal derivative (eq 1). No significant stereoselectivity was recorded in this case (3:2 diastereomeric mixture). The Claisen rearrangements (ortho ester–Claisen type or Ireland–Claisen type) of γ-(1,3-dioxolan-4-yl)allyl alcohol derivatives, derived from 1,2-*O*-isopropylidene-D-glyceraldehyde, were investigated recently[6,7] (eqs 2 and 3). In these studies, the ratios of the diastereomers obtained by the ortho ester Claisen rearrangements of both the (*E*)- and (*Z*)-allyl alcohols are not sufficiently high. One exception is the Ireland–Claisen rearrangement of hydroxy-protected glycolate esters of γ-(1,3-dioxolan-4-yl)allyl alcohol[8] (eq 4). For selected substrates, the Ireland–Claisen rearrangement provides one diastereomer with high stereoselectivity.[9] These previous observations prompted us to investigate the stereoselectivity of the Claisen rearrangement of other enantiomerically pure substrates.

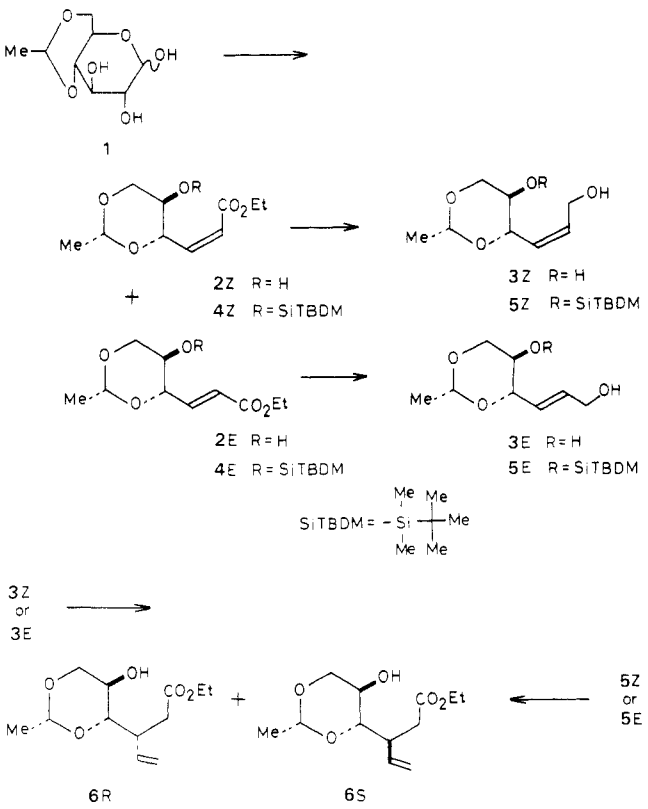


Preparation of the allyl alcohols, **3Z**, **3E**, **5Z**, and **5E**, were achieved as follows. Exhaustive glycol cleavage of 4,6-*O*-ethylidene-D-glucose (**1**)[10] with $NaIO_4$ in aqueous NaOH gave an aldehyde, which was directly subjected to Wittig reaction with [(ethoxycarbonyl)methylene]triphenylphosphorane in MeOH.[11] Chromatographic separation of the reaction mixture provided the *Z* isomer (**2Z**) and the *E* isomer (**2E**) in 62% and 24% yields, respectively.[12] Diisobutylaluminum hydride (Dibal-H) reduction of each α,β-unsaturated ester, **2Z** and **2E**, gave allyl alcohols **3Z** and **3E** in 83% and 94% yields. The 5-*O*-*tert*-butyldimethylsilyl derivatives, **5Z** and **5E**, were prepared from the mixture of the Wittig adducts. The mixture of **2Z** and **2E** was silylated in the usual manner. By chromatographic separation of the reaction mixture, silyl ethers **4Z** and **4E** were isolated in 53% and 22% yields from **1**. Dibal-H reduction of **4Z** and **4E** gave allyl alcohols **5Z** and **5E** in quantitative and 81% yields, respectively.

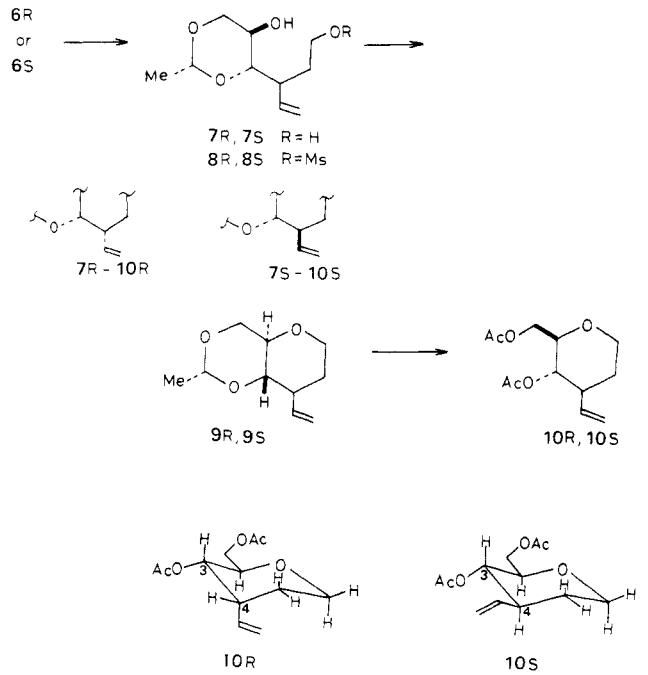
With allyl alcohols **3Z**, **3E**, **5Z**, and **5E** in hand, the Claisen rearrangement of each substrate with triethyl orthoacetate was executed under the standard conditions.[13] All four substrates smoothly furnished the rearrangement products as diastereomeric mixtures in moderate to high yields. Compound **3Z** gave diastereomers **6R** and **6S** in 52% and 10% yields, respectively. The stereochemical assignments of the newly introduced stereogenic centers in **6R** and **6S** were secured through chemical modifications (vide infra). In contrast, the Claisen rearrangement of **3E** gave an approximately 1:1.3 mixture of **6R** and **6S**, in a combined yield of 74%. A higher level of stereoselectivity was realized with **5Z**, in which the hydroxy group of **3Z** was replaced by a bulky (*tert*-butyldimethylsilyl)oxy group. Examination of the ^1H NMR spectrum (400 MHz) of the reaction mixture indicated that the rearrangement proceeded with greater than 10:1 diastereoselectivity. In fact, after desilylation of the rearrangement products followed by chromatographic separation, **6R** was isolated in 69% yield from **5Z** along with 6% yield of **6S**. Therefore, the diastereoselectivity in this case was 11.5:1 with preferred formation of **6R**. As similarly experienced in the case of **3E**, the rearrangement of **5E** proceeded less stereoselectivity, resulting in the formation of **6R** and **6S** in 31% and 21% yields, respectively, after desilylation of the rearrangement products.

The stereochemical assignment of the newly introduced stereogenic centers in **6R** and **6S** was achieved as follows. Both **6R** and **6S** were transformed into tetrahydropyran derivatives (**10R** and **10S**) by the following standard manipulations via **7R** and **7S**, **8R** and **8S**,[14] and **9R** and **9S**: (1) $LiAlH_4$ reduction, (2) selective methanesulfonylation of the primary hydroxyl group, (3) tetrahydropyran formation by base-mediated cyclization (MeONa), (4) deblocking of the ethylidene acetal with *p*-TsOH, and (5) acetylation. Compounds **10R** and **10S** were obtained in overal yields of 29% and 32%, respectively. The ^1H NMR spectrum of **10R** showed a doublet of doublets for H-3 at δ 4.82 with J = 9.3 and 4.9 Hz, indicating that H-3 and H-4 are in an axial–equatorial relationship. Therefore, the vinyl group in **10R** is of *R* configuration. On the other hand, H-3 of **10S** appeared at δ 4.74 as a doublet of doublets, each

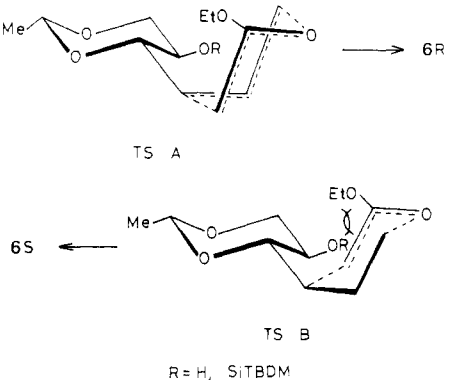
(4) A recent review on the Claisen rearrangement, see: Ziegler, F. D. *Chem. Rev.* **1988**, *88*, 1423.
(5) Ziegler, F. D.; Reid, G. R.; Studt, W. L.; Wender, P. A. *J. Org. Chem.* **1977**, *42*, 1991.
(6) Suzuki, T.; Sato, E.; Kamada, S.; Tada, H.; Unno, K.; Kametani, T. *J. Chem. Soc., Perkin Trans. 1* **1986**, 387.
(7) Takano, S.; Kurotani, A.; Takahashi, M.; Ogasawara, K. *J. Chem. Soc., Perkin Trans. 1* **1987**, 91.
(8) Cha, J. K.; Lewis, S. C. *Tetrahedron Lett.* **1984**, *25*, 5263.
(9) An account on the stereoselectivity of the Ireland–Claisen rearrangement by computational methods, see: Kahn, S. D.; Hehre, W. J. *J. Org. Chem.* **1988**, *53*, 301.
(10) Hockett, R. C.; Collins, D. V.; Scattergood, A. *J. Am. Chem. Soc.* **1951**, *73*, 599.
(11) When the Wittig reaction was carried out in benzene at room temperature, the α,β-unsaturated δ-lactone derived from **2Z** was obtained as a major product (30%) along with **2E** (20%) and **2Z** (4%). Therefore, the ratio of **2Z** to **2E** under the Wittig conditions was estimated to be 1.7:1.
(12) Substantial lactonization of **2Z** occurred upon prolonged contact of the Wittig adducts with SiO_2. Consequently, separation of the mixture **2Z** and **2E** by column chromatography on SiO_2 must be carried out rapidly.
(13) Johnson, W. S.; Werthemann, L.; Bartlett, W. R.; Brochsom, T. J.; Li, T.-t.; Faulkner, D. J.; Petersen, M. R. *J. Am. Chem. Soc.* **1970**, *92*, 741.
(14) Mesylates **8R** and **8S** were somewhat unstable. When they were left standing in $CHCl_3$ or CH_2Cl_2 solution overnight, partial decomposition was indicated by TLC analysis.



with J = 10.3 Hz, indicating that H-3 and H-4 are in a trans diaxial relationship. The structures of **10R** and **10S** (and therefore those of **6R** and **6S**) were thus established unequivocally.



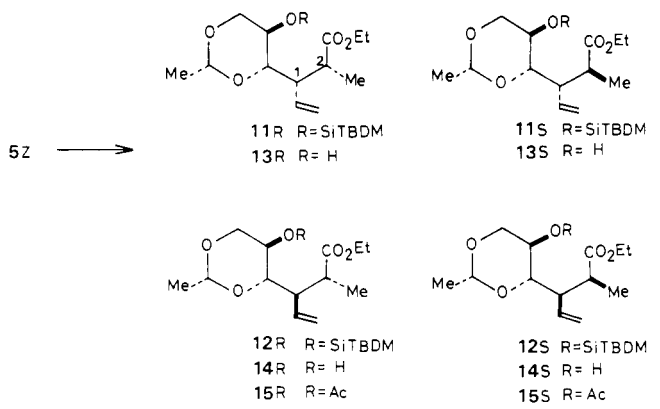
In order to account for the preferential formation of **6R** from both **3Z** and **5Z**, we considered two chair-like transition states A and B. Transition state (TS) A leads to **6R**, and TS B to **6S**, respectively. In the case of TS B, a nonbonded interaction between the allylic ketene acetal moiety and the substituent at C-5 (i.e. hydroxyl group or (*tert*-butyldimethylsilyl)oxy group) seems to be significant. In addition, this interaction should be proportional to the bulkiness of the C-5 substituent. The higher level of rearrangement stereoselectivity seen with **5Z** rather than **3Z** can be explained by considering this substituent effect. On the other hand, no such interaction is encountered in the TS A. Therefore, the rearrangement is likely to proceed through TS A leading to **6R** as a favorable product. Analysis of Dreiding models also indicates that the nonbonded interaction between the allylic ketene acetal and the C-5 substituent which is generated in each transition state is significantly reduced in the case of the *E* isomers, and thus no favorable transition state is expected. This steric factor accounts for the formation of the mixture of **6R** and **6S** with no special stereoselectivity from both **3E** and **5E**.



Encouraged by the high level of stereoselectivity obtained from **5Z**, we next carried out the rearrangement of **5Z** with triethyl orthopropionate. Substrate **5Z** was heated with triethyl orthopropionate in the presence of a catalytic amount of propionic acid for 4.5 h. A mixture of the four possible rearrangement products was obtained in a combined yield of 90%, from which one diastereomer **11R** could be separated cleanly in 32% yield from **4Z** by silica gel chromatography. Desilylation of the residual diastereomeric mixture, **11S**, **12R**, and **12S**, followed by chromatographic separation furnished pure **13S** in 37% yield from **4Z** along with inseparable mixture of **14R** and **14S** in a combined yield of 10% from **4Z**. The mixture of **14R** and **14S** was then acetylated to give **15R** and **15S**, both of which were cleanly separated by silica gel chromatography in 3.2% and 3.0% yields from **4Z**, respectively. This high diastereoselectivity at C-1 was also observed in the rearrangement of **3Z** with triethyl orthopropionate.[15] On the other hand, the diastereoselectivity at C-2 was improved when the (*E*)-allyl alcohols **3E** and **5E** were employed as substrates for the rearrangement, although the combined yields of the rearrangement products were too low.[15] The reason for this improvement remains unclear; however, the relatively high diastereoselectivity at C-1 in the cases of the (*Z*)-allyl alcohols **3Z** and **5Z** can be rationalized by invoking the transition state argument outlined above.

The stereochemical assignments for the stereogenic centers at C-1 and C-2 in each of **11R**, **11S**, **12R**, and **12S** were achieved after making the following chemical trans-

(15) The results of the Claisen rearrangement of substrates **3Z**, **3E**, and **5E** with triethyl orthopropionate were as follows: a 1:1.3 ratio of **11R** and **11S** was obtained from **3Z** in a combined yield of 38% (the rearrangement products were silylated to **11R** and **11S** for complete separation), and neither **12S** nor **12R** was detected in the reaction mixture. The rearrangement of **3E** provided **11R** (6% from **3E**) and **11S** (6%) after silylation, and **15R** (5%) and **15S** (20%) after acetylation, respectively. In the case of **5E**, the rearrangement products were completely separated as described for the other substrates, affording **11R** (9% from **4E**), **13S** (16%), **15R** (2%), and **15S** (27%). These results indicate that the diastereoselectivity at C-2 [(**11R** + **12R**)/(**11S** + **12S**)] achieved by employing **5E** was approximately 1:4 with preferential formation of the 2*S* diastereomers.

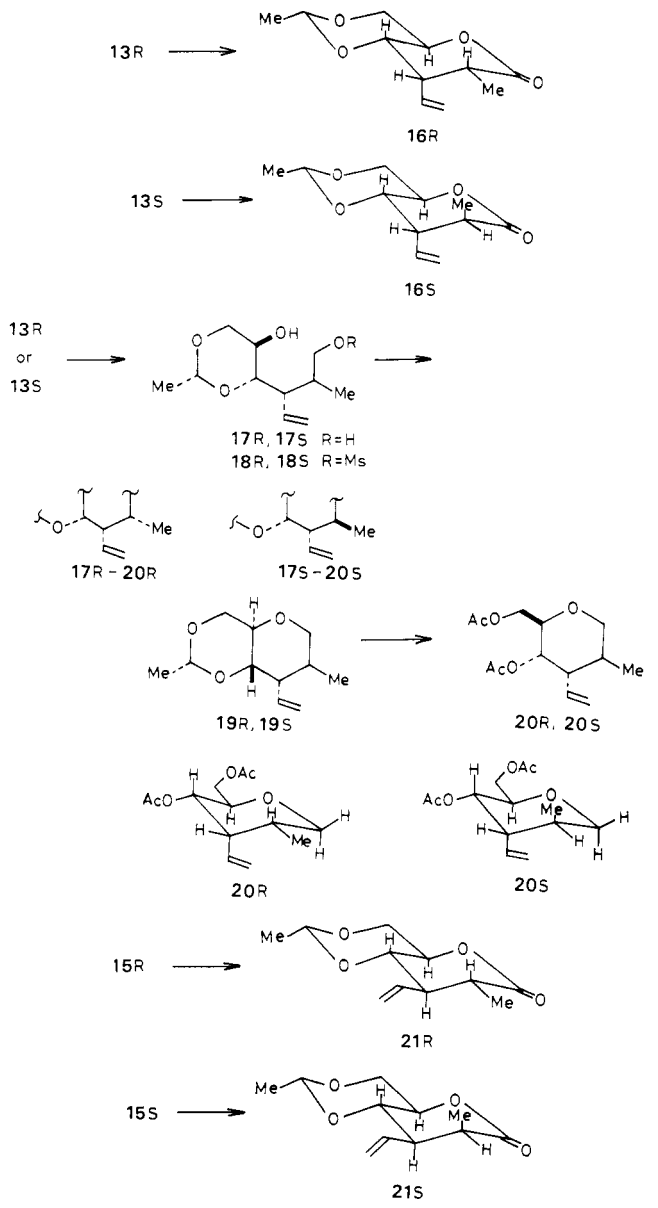


formations. Desilylation of **11R** gave **13R** in 97% yield. Saponification of **13R** and **13S** followed by dicyclohexylcarbodiimide (DCC) mediated lactonization of the resulting carboxylic acids provided δ-lactones **16R** and **16S** in 54% and 50% yields, respectively. The ^{1}H NMR spectra of **16R** and **16S** verified their 1*S* configurations (and hence, those of **11R** and **11S**). The configurational assignment at C-2 of **11R** and **11S** was established by the ^{1}H NMR spectral analysis of tetrahydropyran derivatives **20R** and **20S**. The preparation of **20R** from **13R** was achieved in an overall yield of 42% via **17R**, **18R**, and **19R**, by virtually the same reaction sequence employed for the transformation of **6R** into **10R**. Analogously, **13S** was transformed into tetrahydropyran derivative **20S** via **17S**, **18S**, and **19S**, in an overall yield of 32%. The stereochemistry at C-2 in **11R** or **11S** was established to be *R* or *S* configuration, respectively, based on the ^{1}H NMR analyses of **20R** and **20S**. The structural assignments of each of the other rearrangement products **12R** and **12S** were also confirmed by the ^{1}H NMR spectral analyses of δ-lactones **21R** and **21S** which were prepared from **15R** and **15S**.[16]

Experimental Section[17]

(*Z*)- and (*E*)-(2*R*,4*S*,5*R*)-4-[2-(Ethoxycarbonyl)-ethenyl]-5-hydroxy-2-methyl-1,3-dioxane (2Z and 2E). To a stirred solution of $NaIO_4$ (2.43 g, 11.0 mmol) in H_2O (10 mL) were added alternately a solution of **1** (1.03 g, 5.0 mmol) in H_2O (5 mL) and an aqueous 1 M NaOH solution to maintain the pH of the solution at 5–6. The mixture was then stirred for 1 h and concentrated in vacuo. The residue was dissolved in EtOH (100 mL), the solution was stirred for 30 min, and insoluble materials were removed by filtration through a Celite pad. The filtrate and EtOH washings were combined and concentrated in vacuo. The residue was partitioned between AcOEt (15 mL) and H_2O (10 mL). The aqueous phase was extracted with AcOEt (15 mL × 2). The combined organic phases were dried (Na_2SO_4) and concentrated in vacuo to give an aldehyde as a colorless oil, which was subjected to Wittig reaction without purification.

A solution of the aldehyde and [(ethoxycarbonyl)-methylene]triphenylphosphorane (3.6 g, 10.0 mmol) in MeOH (20 mL) was stirred for 30 min. After removal of the solvent by concentration in vacuo, the residue was stirred in 100 mL of petroleum ether. The insoluble triphenylphosphine oxide was removed by filtration and washed well with petroleum ether. The filtrate and washings were combined and concentrated in vacuo.



The residue was purified by flash column chromatography on silica gel (AcOEt/hexane, 1:8) to give **2Z** (0.67 g, 62%) and **2E** (0.26 g, 24%). **2Z** as a colorless oil: TLC R_f 0.25 (AcOEt/hexane, 1:4); $[\alpha]^{25}_D$ +52.4° (*c* 1.58, $CHCl_3$); IR (neat) ν_{max} 3450, 1720, 1690, 1650 cm^{-1}; ^{1}H NMR (270 MHz) δ 1.31 (t, 3 H, *J* = 7.0 Hz), 1.37 (d, 3 H, *J* = 5.1 Hz), 1.68 (s, 1 H), 3.47–3.52 (m, 2 H), 3.73 (d, 1 H, *J* = 6.6 Hz), 4.22 (q, 1 H, *J* = 7.0 Hz), 4.73 (q, 1 H, *J* = 5.1 Hz), 4.94 (dd, 1 H, *J* = 8.1 Hz), 6.07 (d, 1 H, *J* = 11.7 Hz), 6.24 (dd, 1 H, *J* = 11.7 and 8.1 Hz). Anal. Calcd for $C_{10}H_{16}O_5$: C, 55.55; H, 7.46. Found: C, 55.65; H, 7.25. **2E**: mp 59–60 °C; TLC R_f 0.15 (AcOEt/hexane, 1:4); $[\alpha]^{25}_D$ −35.2° (*c* 1.21, $CHCl_3$); IR (neat) ν_{max} 3450, 1710, 1660 cm^{-1}; ^{1}H NMR (270 Hz) δ 1.30 (t, 1 H, *J* = 7.0 Hz), 1.36 (d, 1 H, *J* = 5.1 Hz), 2.45 (d, 1 H, *J* = 5.1 Hz), 3.45–3.55 (m, 2 H), 3.98–4.04 (m, 1 H), 4.12–4.16 (m, 1 H), 4.21 (q, 2 H, *J* = 7.0 Hz), 4.75 (q, 1 H, *J* = 5.1 Hz), 6.16 (dd, 1 H, *J* = 15.8 and 1.8 Hz), 7.08 (dd, 1 H, *J* = 15.8 and 4.8 Hz). Anal. Calcd for $C_{10}H_{16}O_5$: C, 55.55; H, 7.46. Found: C, 55.83; H, 7.28.

(2*R*,4*S*,5*R*)-5-Hydroxy-4-[(*Z*)- and (*E*)-3-hydroxy-1-propenyl]-2-methyl-1,3-dioxane (3Z and 3E). To a solution of **2Z** (4.33 g, 20.0 mmol) in CH_2Cl_2 (100 mL) under an argon atmosphere was added Dibal-H (25 wt % solution in $PhCH_3$, 44 mL) at −30 °C. After the mixture was stirred for 2 h at −30 °C, H_2O (5 mL) was added. The resulting solids were removed by filtration and washed well with CH_2Cl_2. The combined filtrate and washings were concentrated in vacuo. The residue was chromatographed on SiO_2 (EtOH/$PhCH_3$, 1:40) to give **3Z** (2.89 g, 83%) as a colorless oil: TLC R_f 0.43 (EtOH/$PhCH_3$, 1:4); $[\alpha]^{26}_D$

(16) The δ-lactones **21R** and **21S** were prepared by saponification of the acetate **15R** and **15S** with aqueous NaOH followed by DCC-mediated lactonization. In the case of **15S**, partial epimerization (about 20%) at C-9 (adjacent to the ester group) occurred during the saponification. The resulting carboxylic acid mixture was lactonized to give a 5 to 1 mixture of **21S** and **21R**. We could not separate them cleanly.

(17) **General.** Reactions were carried out at room temperature unless otherwise specified. Melting points are uncorrected. Specific rotations were measured in a 10-mm cell. Column chromatography was performed with SiO_2 (Katayama Chemicals, K070), and TLC with glass plates coated with Kieselgel 60 GF_{254} (Merck). ^{1}H NMR spectra were recorded in $CDCl_3$ solutions.

+44.2° (*c* 1.23, $CHCl_3$); IR (neat) ν_{max} 3380 cm^{-1}; ^1H NMR (400 MHz) δ 1.34 (d, 3 H, J = 4.9 Hz), 2.87 (br s, 1 H), 3.36 (br s, 1 H), 3.41–3.50 (m, 2 H), 4.11–4.29 (m, 4 H), 4.74 (q, 1 H, J = 4.9 Hz), 5.63 (ddd, 1 H, J = 11.2, 8.3, and 1.0 Hz), 5.97–6.04 (m, 1 H).

By an analogous procedure and workup as that described for **2Z**, **2E** (2.03 g) was converted into **3E** (1.53 g, 94%). **3E** as a colorless oil: TLC R_f 0.36 (EtOH/$PhCH_3$, 1:4); $[\alpha]^{26}_D$ −11.3° (*c* 1.11, $CHCl_3$); IR (neat) ν_{max} 3380 cm^{-1}; ^1H NMR (400 MHz) δ 1.35 (d, 3 H, J = 4.9 Hz), 1.88 (br s, 1 H), 2.12 (br s, 1 H), 3.42 (dd, 1 H, J = 10.7 Hz), 3.50–3.55 (m, 1 H), 3.83 (dd, 1 H, J = 7.3 Hz), 4.17 (dd, 1 H, J = 10.7 and 4.9 Hz), 4.20–4.24 (m, 2 H), 4.74 (q, 1 H, J = 4.9 Hz), 5.80 (ddd, 1 H, J = 15.6, 7.3, and 1.5 Hz), 6.06 (ddd, 1 H, J = 15.6, 4.9, and 1.0 Hz).

(*Z*)- and (*E*)-(2*R*,4*S*,5*R*)-5-[(*tert*-Butyldimethylsilyl)oxy]-4-[2-(ethoxycarbonyl)ethenyl]-2-methyl-1,3-dioxane (4Z and 4E). Compound **1** (3.2 g, 15.5 mmol) was converted into a mixture of **2Z** and **2E** (2.75 g) as described above (the mixture of **2Z** and **2E** was rapidly passed through SiO_2 by flash chromatography to remove triphenylphosphine oxide). To a solution of the mixture (2.75 g) in DMF (30 mL) were added *tert*-butylchlorodimethylsilane (3.80 g, 25.3 mmol) and imidazole (3.50 g, 51.5 mmol). After being stirred for 18 h, the mixture was diluted with AcOEt (200 mL). This was washed with H_2O (100 mL × 2), 1 M aqueous HCl (100 mL × 2), and saturated aqueous $NaHCO_3$ (100 mL × 2) successively. The organic phase was dried (Na_2SO_4) and concentrated in vacuo. The residue was chromatographed on SiO_2 (AcOEt/hexane, 1:40) to give **4Z** (2.74 g, 53% from **1**) and **4E** (1.11 g, 22%). **4Z** as a colorless oil: TLC R_f 0.46 (AcOEt/hexane, 1:10); $[\alpha]^{29}_D$ +26.3° (*c* 1.07, $CHCl_3$); IR (neat) ν_{max} 1720, 1660 cm^{-1}; ^1H NMR (90 MHz) δ 0.02, 0.04 (each s, each 3 H), 0.84 (s, 9 H), 1.30 (t, 3 H, J = 7 Hz), 1.34 (d, 3 H, J = 5 Hz), 3.45–3.54 (m, 2 H), 4.03–4.09 (m, 1 H), 4.18 (q, 2 H, J = 7 Hz), 4.80 (q, 1 H, J = 5 Hz), 5.17–5.36 (m, 1 H), 5.98–6.06 (m, 2 H). Anal. Calcd for $C_{16}H_{30}O_5Si$: C, 58.13; H, 9.15. Found: C, 58.06; H, 8.94. **4E** as a colorless oil: TLC R_f 0.57 (AcOEt/hexane, 1:10); $[\alpha]^{29}_D$ −40.2° (*c* 1.29, $CHCl_3$); IR (neat) ν_{max} 1720, 1660 cm^{-1}; ^1H NMR (90 MHz) δ 0.04 (s, 6 H), 0.88 (s, 9 H), 1.28 (t, 3 H, J = 7 Hz), 1.35 (d, 3 H, J = 5 Hz), 3.37–3.46 (m, 2 H), 3.90–4.06 (m, 2 H), 4.20 (q, 2 H, J = 7 Hz), 4.70 (q, 1 H, J = 5 Hz), 6.09 (dd, 1 H, J = 16 and 1.5 Hz), 7.04 (dd, 1 H, J = 16 and 4 Hz). Anal. Calcd for $C_{16}H_{30}O_5Si$: C, 58.13; H, 9.15. Found: C, 58.25; H, 8.95.

(2*R*,4*S*,5*R*)-5-[(*tert*-Butyldimethylsilyl)oxy]-4-[(*Z*)- and (*E*)-3-hydroxy-1-propenyl]-2-methyl-1,3-dioxane (5Z and 5E). Compound **4Z** (1.24 g, 3.75 mmol) was treated with Dibal-H (25 wt % solution in $PhCH_3$ 10.6 mL, 15.6 mmol) in CH_2Cl_2 (25 mL) at −60 °C for 1.5 h. Quenching with H_2O (3 mL) and extractive workup (AcOEt) gave **5Z** (1.01 g, 100%) as a colorless oil: TLC R_f 0.44 (EtOH/$PhCH_3$, 1:10); $[\alpha]^{30}_D$ +59.5° (*c* 0.98, $CHCl_3$); IR (neat) ν_{max} 3440 cm^{-1}; ^1H NMR (400 MHz) δ 0.05, 0.07 (each s, each 3 H), 0.86 (s, 9 H), 1.34 (d, 3 H, J = 4.9 Hz), 2.12 (br s, 1 H), 3.42 (dd, 1 H, J = 10.3 Hz), 3.50 (ddd, 1 H, J = 10.3, 7.3, and 4.8 Hz), 4.05 (dd, 1 H, J = 10.3 and 4.8 Hz), 4.21–4.27 (m, 2 H), 4.30 (ddd, 1 H, J = 8.3, 7.3, and 1.0 Hz), 4.74 (q, 1 H, J = 4.9 Hz), 5.53 (ddd, J = 11.2, 8.3, and 1.5 Hz), 5.91 (dddd, 1 H, J = 11.2, 5.4, 5.4, and 1.0 Hz).

Dibal-H reduction of **4E** (1.06 g) as described for **4Z** gave 0.74 g (81%) of **5E** after SiO_2 chromatographic purification. **5E** as a colorless oil: TLC R_f 0.33 (EtOH/$PhCH_3$, 1:10); $[\alpha]^{30}_D$ −34.2° (*c* 0.98, $CHCl_3$); IR (neat) ν_{max} 3440 cm^{-1}; ^1H NMR (400 MHz) δ 0.03, 0.04 (each s, each 3 H), 0.86 (s, 9 H), 1.35 (d, 3 H, J = 4.9 Hz), 3.39 (dd, 1 H, J = 10.3 Hz), 3.46 (ddd, 1 H, J = 10.3, 7.8, and 4.4 Hz), 3.83 (dd, 1 H, J = 7.8 and 6.8 Hz), 4.01 (dd, 1 H, J = 10.3 and 4.4 Hz), 4.18 (br s, 2 H), 4.72 (q, 1 H, J = 4.9 Hz), 5.76 (ddd, 1 H, J = 15.6, 6.8, and 1.5 Hz), 5.99 (dddd, 1 H, J = 15.6, 4.9, 4.9, and 1.5 Hz).

Claisen Rearrangement of 3Z and 3E with Triethyl Orthoacetate. (2*R*,4*S*,5*R*)-4-[(1*R*)- and (1*S*)-1-[(Ethoxycarbonyl)methyl]-2-propenyl]-5-hydroxy-2-methyl-1,3-dioxane (6R and 6S). A solution of **3Z** (1.14 g, 6.6 mmol) in freshly distilled triethyl orthoacetate (10 mL) was heated at 135 °C in the presence of propionic acid (0.1 mL). The mixture was heated for 12 h, during which time 0.1-mL aliquots of propionic acid were added every 2 h. The EtOH formed was removed by distillation. The mixture was concentrated in vacuo with the aid of $PhCH_3$. The residue was purified by repeated chromatography on SiO_2 (AcOEt/hexane, 1:6), 834 mg (52%) of **6R** and 157 mg (10%) of **6S** were obtained as colorless oils. **6R**: TLC R_f 0.85 (EtOH/$PhCH_3$, 1:8); $[\alpha]^{26}_D$ −15.9° (*c* 1.88, $CHCl_3$); IR (neat) ν_{max} 3470, 1740, 1650 cm^{-1}; ^1H NMR (400 MHz) δ 1.27 (t, 3 H, J = 7.1 Hz), 1.30 (d, 3 H, J = 4.9 Hz), 2.33 (dd, 1 H, J = 16.6 and 5.9 Hz), 2.80 (dd, 1 H, J = 16.6 and 6.8 Hz), 2.85 (d, 1 H, J = 3.9 Hz), 2.96–3.02 (m, 1 H), 3.35–3.41 (m, 2 H), 3.44–3.51 (m, 1 H), 4.10 (dd, 1 H, J = 10.7 and 4.9 Hz), 4.15 (q, 2 H, J = 7.1 Hz), 4.64 (q, 1 H, J = 4.9 Hz), 5.12 (dd, 1 H, J = 10.3 and 1.5 Hz), 5.21 (ddd, 1 H, J = 17.6 and 1.5 Hz), 5.92 (ddd, 1 H, J = 17.6, 10.3, and 8.3 Hz). Anal. Calcd for $C_{12}H_{20}O_5$: C, 59.00; H, 8.25. Found: C, 59.16; H, 7.99. **6S**: TLC R_f 0.82 (EtOH/$PhCH_3$, 1:8), $[\alpha]^{26}_D$ −3.1° (*c* 2.04, $CHCl_3$); IR (neat) ν_{max} 3450, 1730, 1640 cm^{-1}; ^1H NMR (400 MHz) δ 1.25 (t, 3 H, J = 7.3 Hz), 1.30 (d, 3 H, J = 4.9 Hz), 2.10 (br s, 1 H), 2.47–2.57 (m, 2 H), 3.02–3.08 (m, 1 H), 3.32–3.39 (m, 2 H), 3.68 (ddd, 1 H, J = 10.7 and 5.4 Hz), 4.09 (dd, 1 H, J = 10.7 and 5.4 Hz), 4.13 (q, 2 H, J = 7.3 Hz), 4.62 (q, 1 H, J = 4.9 Hz), 5.14–5.20 (m, 2 H), 5.83 (ddd, 1 H, J = 17.1, 10.3, and 10.3 Hz). Anal. Calcd for $C_{12}H_{20}O_5$: C, 59.00; H, 8.25. Found: C, 59.07; H, 8.03.

As described for **3Z**, **3E** (1.38 g) was treated with triethyl orthoacetate (13 mL) for 10 h in the presence of catalytic propionic acid. Repeated SiO_2 chromatography of the reaction mixture gave 610 mg (32%) of **6R** and 810 mg (42%) of **6S**.

Claisen Rearrangement of 5Z and 5E and Successive Desilylation. Compound **5Z** (120 mg, 0.42 mmol) was treated with triethyl orthoacetate (1 mL) for 27 h in the presence of catalytic propionic acid as described for **3Z**. The reaction mixture was purified by chromatography on SiO_2 (AcOEt/hexane, 1:60) to give an oil, which consisted predominantly of *R* rearrangement product [133 mg, 89%, TLC R_f 0.84 (AcOEt/hexane, 1:2)]. This mixture (133 mg) was dissolved in THF (3 mL), and tetrabutylammonium fluoride (1.0 M solution in THF, 0.4 mL) was added. The solution was stirred for 45 min and concentrated in vacuo. The residue was chromatographed repeatedly on SiO_2 (EtOH/$PhCH_3$, 1:150) to give **6R** (70 mg, 69% from **5Z**) and **6S** (6 mg, 6%).

Claisen rearrangement of **5E** (213 mg) followed by desilylation of the rearrangement products as described for **5Z** gave **6R** (56 mg, 31%) and **6S** (37 mg, 21%).

Claisen Rearrangement of 5Z with Triethyl Orthopropionate. Separation of Four Diastereomers. Dibal-H (6.3 mL) reduction of **4Z** (1.29 g) in CH_2Cl_2 at −60 °C, quenching the reaction mixture, and extractive workup gave 1.12 g of **5Z**. A solution of **5Z** (1.12 g) in freshly distilled triethyl orthopropionate (10 mL) was heated at 135 °C in the presence of a catalytic amount of propionic acid. The mixture was heated at 135 °C for 4.5 h and then concentrated in vacuo. The residue was chromatographed on SiO_2 (AcOEt/hexane, 1:60). Fractions corresponding to R_f 0.58 (AcOEt/hexane, 1:10) were combined and concentrated in vacuo to give an inseparable mixture of **11S**, **12R**, and **12S** (844 mg, 58% of combined yield from **4Z**) as a colorless oil. Fractions corresponding to R_f 0.49 were combined and concentrated to give pure **11R** (462 mg, 32% yield from **4Z**) as a colorless oil. **11R**: $[\alpha]^{23}_D$ −37.2° (*c* 1.25, $CHCl_3$); IR (neat) ν_{max} 1740, 1640 cm^{-1}; ^1H NMR (400 MHz) δ 0.07, 0.10 (each s, each 3 H), 0.87 (s, 9 H), 1.16 (d, 3 H, J = 6.8 Hz), 1.25 (t, 3 H, J = 7.0 Hz), 1.26 (d, 3 H, J = 4.9 Hz), 2.53–2.58 (m, 1 H), 2.76–2.82 (m, 1 H), 3.29 (dd, 1 H, J = 10.3 Hz), 3.47 (dd, 1 H, J = 9.3 and 4.4 Hz), 3.75 (ddd, 1 H, J = 10.3, 9.3, and 4.9 Hz), 4.02 (dd, 1 H, J = 10.3 and 4.9 Hz), 4.03–4.15 (m, 2 H), 4.59 (q, 1 H, J = 4.9 Hz), 5.06 (dd, 1 H, J = 17.1 and 2.0 Hz), 5.09 (dd, 1 H, J = 10.3 and 2.0 Hz), 6.04 (ddd, 1 H, J = 17.1, 10.3, and 9.8 Hz). Anal. Calcd for $C_{19}H_{36}O_5Si$: C, 61.25; H, 9.74. Found: C, 60.98; H, 9.37.

The mixture of **11S**, **12R**, and **12S** was desilylated as follows. A solution of the mixture (844 mg) in THF (12 mL) was stirred in the presence of tetrabutylammonium fluoride (1.0 M solution in THF, 2.6 mL). After 30 min, the mixture was concentrated in vacuo. The residue was chromatographed on SiO_2 (AcOEt/hexane, 1:5). Fractions corresponding to R_f 0.42 (EtOH/$PhCH_3$, 1:15) were combined and concentrated to give **13S** (373 mg, 37% from **4Z**) as a colorless oil. Fractions corresponding to R_f 0.35 were combined and concentrated in vacuo to give an inseparable mixture of **14R** and **14S** (96 mg) as a colorless oil: **13S**: $[\alpha]^{23}_D$ −12.3° (*c* 1.82, $CHCl_3$); IR (neat) ν_{max} 3460, 1730, 1640 cm^{-1}; ^1H

NMR (400 MHz) δ 1.09 (d, 3 H, J = 6.8 Hz), 1.27 (t, 3 H, J = 7.3 Hz), 1.30 (d, 3 H, J = 4.9 Hz), 2.39 (d, 1 H, J = 2.7 Hz), 2.85–2.91 (m, 2 H), 3.32–3.38 (m, 2 H), 3.52–3.58 (m, 1 H), 4.09 (dd, 1 H, J = 10.7 and 5.4 Hz), 4.13 (q, 2 H, J = 7.3 Hz), 4.62 (q, 1 H, J = 4.9 Hz), 5.20 (dd, 1 H, J = 9.8 and 2.0 Hz), 5.27 (dd, 1 H, J = 17.1 and 2.0 Hz), 5.88 (ddd, 1 H, J = 17.1, 9.8, and 9.8 Hz). Anal. Calcd for $C_{13}H_{22}O_5$: C, 60.45; H, 8.58. Found: C, 60.22; H, 8.44.

The mixture of **14R** and **14S** (96 mg) was acetylated with acetic anhydride (1 mL) in pyridine (1 mL). Repeated chromatography of the reaction mixture on SiO_2 (AcOEt/hexane, 1:15) gave **15R** (38 mg, 3.2% from **4Z**) and **15S** (35 mg, 3.0% from **4Z**) as colorless oils. **15R**: TLC R_f 0.44 (AcOEt/hexane, 1:4); $[\alpha]^{24}_D$ +13.5° (*c* 1.19, $CHCl_3$); IR (neat) ν_{max} 1750, 1730, 1640 cm^{-1}; ^1H NMR (400 MHz) δ 1.12 (d, 3 H, J = 6.8 Hz), 1.28 (t, 3 H, J = 7.3 Hz), 1.31 (d, 3 H, J = 5.4 Hz), 2.05 (s, 3 H), 2.46 (ddd, 1 H, J = 2.0 and 10.3 Hz), 2.67–2.75 (m, 1 H), 3.32 (dd, 1 H, J = 10.3 Hz), 3.57 (dd, 1 H, J = 9.8 and 2.0 Hz), 4.17 (q, 2 H, J = 7.3 Hz), 4.20 (dd, 1 H, J = 10.3 and 5.4 Hz), 4.58 (q, 1 H, J = 5.4 Hz), 4.70 (ddd, 1 H, J = 10.3, 9.8, and 5.4 Hz), 5.03 (dd, 1 H, J = 17.1 and 2.0 Hz), 5.24 (dd, 1 H, J = 10.3 and 2.0 Hz), 5.67 (ddd, 1 H, J = 17.1, 10.3, and 10.3 Hz). Anal. Calcd for $C_{15}H_{24}O_6$: C, 59.98; H, 8.05. Found: C, 60.08; H, 7.67. **15S**: TLC R_f 0.39 (AcOEt/hexane, 1:4); $[\alpha]^{24}_D$ +1.5° (*c* 1.02, $CHCl_3$); IR (neat) ν_{max} 1750, 1730, 1640 cm^{-1}; ^1H NMR (400 MHz) δ 1.19 (d, 3 H, J = 7.3 Hz), 1.23 (t, 3 H, J = 7.3 Hz), 1.31 (d, 3 H, J = 4.9 Hz), 2.05 (s, 3 H), 2.40 (ddd, 1 H, J = 9.8, 9.8, and 2.0 Hz), 2.68–2.75 (m, 1 H), 3.35 (dd, 1 H, J = 10.3 Hz), 3.73 (dd, 1 H, J = 9.8 and 2.0 Hz), 4.08 (q, 2 H, J = 7.3 Hz), 4.24 (dd, 1 H, J = 10.3 and 5.4 Hz), 4.64 (q, 1 H, J = 4.9 Hz), 4.71 (ddd, 1 H, J = 10.3, 9.8, and 5.4 Hz), 4.96 (dd, 1 H, J = 17.1 and 2.0 Hz), 5.14 (dd, 1 H, J = 10.3 and 2.0 Hz), 5.82 (ddd, 1 H, J = 17.1, 10.3, and 9.8 Hz). Anal. Calcd for $C_{15}H_{24}O_6$: C, 59.98; H, 8.05. Found: C, 59.96; H, 8.00.

Desilylation of 11R. (2*R*,4*S*,5*R*)-4-[(1*S*,2*R*)-2-(Ethoxycarbonyl)-1-vinylpropyl]-5-hydroxy-2-methyl-1,3-dioxane (13R). A solution of **11R** (345 mg, 0.93 mmol) in THF (6 mL) was stirred in the presence of tetrabutylammonium fluoride (1.0 M solution in THF, 1.0 mL) for 50 min and then concentrated in vacuo. The residue was chromatographed on SiO_2 (AcOEt/hexane, 1:5) to give **13R** (233 mg, 97%) as a colorless oil: TLC R_f 0.42 (EtOH/$PhCH_3$, 1:15); $[\alpha]^{24}_D$ −19.2° (*c* 0.88, $CHCl_3$); IR (neat) ν_{max} 3460, 1730, 1640 cm^{-1}; ^1H NMR (400 MHz) δ 1.13 (d, 3 H, J = 6.8 Hz), 1.27 (t, 3 H, J = 7.3 Hz), 1.30 (d, 3 H, J = 5.3 Hz), 2.17 (d, 1 H, J = 2.9 Hz), 2.51–2.57 (m, 1 H), 2.92–2.98 (m, 1 H), 3.34 (dd, 1 H, J = 10.7 and 9.9 Hz), 3.53 (dd, 1 H, J = 8.8 Hz), 3.59–3.66 (m, 1 H), 4.08 (dd, 1 H, J = 10.7 and 5.4 Hz), 4.13 (q, 2 H, J = 7.3 Hz), 4.61 (q, 1 H, J = 5.3 Hz), 5.26 (dd, 1 H, J = 10.3 and 2.0 Hz), 5.31 (dd, 1 H, J = 17.1 and 2.0 Hz), 6.06 (ddd, 1 H, J= 17.1, 10.3, and 10.3 Hz). Anal. Calcd for $C_{13}H_{22}O_5$: C, 60.45; H, 8.58. Found: C, 60.25; H, 8.26.

(1*S*,3*R*,6*R*,9*R*,10*S*)- and (1*S*,3*R*,6*R*,9*S*,10*S*)-3,9-Dimethyl-10-vinyl-2,4,7-trioxabicyclo[4.4.0]decan-8-one (16R and 16S). A solution of **13R** (70 mg, 0.27 mmol) in a mixture of MeOH (1 mL) and 1 M aqueous NaOH (2 mL) was stirred for 1 h. The solution was acidified to pH 2 by addition of 1 M aqueous HCl, diluted with H_2O (5 mL), and extracted with CH_2Cl_2 (10 mL × 3). The combined organic phases were dried (Na_2SO_4) and concentrated. A solution of the residue (carboxylic acid) in pyridine (2 mL) was stirred in the presence of DCC (70 mg, 0.34 mmol) and 4-(dimethylamino)pyridine (DMAP) (35 mg, 0.29 mmol) for 12 h and then concentrated in vacuo. The residue was chromatographed on SiO_2 (AcOEt/hexane, 1:12) to give **16R** (31 mg, 54%): mp 94–95.5 °C; TLC R_f 0.77 (EtOH/$PhCH_3$, 1:5); $[\alpha]^{23}_D$ +55.1° (*c* 1.46, $CHCl_3$); IR (neat), ν_{max} 1740, 1640, 1620 cm^{-1}; ^1H NMR (400 MHz) δ 1.25 (d, 3 H, J = 6.8 Hz), 1.35 (d, 3 H, J = 4.9 Hz), 2.79–2.89 (m, 2 H), 3.60 (dd, 1 H, J = 10.3 Hz), 3.80 (dd, 1 H, J = 9.8 and 3.9 Hz), 4.22 (dd, 1 H, J = 10.3 and 4.9 Hz), 4.32 (ddd, 1 H, J = 10.3, 9.8, and 4.9 Hz), 4.80 (q, 1 H, J = 4.9 Hz), 5.28 (dd, 1 H, J = 17.1 and 1.5 Hz), 5.38 (dd, 1 H, J = 10.3 and 1.5 Hz), 5.70 (ddd, 1 H, J = 17.1, 10.3, and 8.8 Hz). Anal. Calcd for $C_{11}H_{16}O_4$: C, 62.25; H, 7.60. Found: C, 62.07; H, 7.46.

As described for **13R**, 71 mg of **13S** was saponified and then lactonized to **16S** (29 mg) in 50% yield: mp 80–81 °C; TLC R_f 0.79 (EtOH/$PhCH_3$, 1:5); $[\alpha]^{23}_D$ +70.8° (*c* 1.45, $CHCl_3$); IR (neat) ν_{max} 1750, 1640, 1620 cm^{-1}; ^1H NMR (400 MHz) δ 1.27 (d, 3 H, J = 6.4 Hz), 1.35 (d, 3 H, J = 5.1 Hz), 2.53–2.62 (m, 2 H), 3.58 (dd, 1 H, J = 10.3 and 9.8 Hz), 3.71 (dd, 1 H, J = 9.3 and 5.4 Hz), 4.24 (dd, 1 H, J = 9.8 and 5.4 Hz), 4.30 (ddd, 1 H, J = 10.3, 9.3, and 5.4 Hz), 4.73 (q, 1 H, J = 5.1 Hz), 5.11 (dd, J = 17.1 and 1.0 Hz), 5.26 (dd, 1 H, J = 10.3 and 1.0 Hz), 5.87 (ddd, 1 H, J = 17.1, 10.3, and 8.3 Hz). Anal. Calcd for $C_{11}H_{16}O_4$: C, 62.25; H, 7.60. Found: C, 62.42; H, 7.59.

(1*S*,3*R*,6*R*,9*R*,10*R*)- and (1*S*,3*R*,6*R*,9*S*,10*R*)-3,9-Dimethyl-10-vinyl-2,4,7-trioxabicyclo[4.4.0]decan-8-one (21R and 21S). A solution of **15R** (23 mg, 0.08 mmol) in a mixture of MeOH (0.5 mL) and 1 M aqueous NaOH (1 mL) was stirred for 2.5 h. The solution was acidified with 1 M aqueous HCl and diluted with H_2O (5 mL). The aqueous solution was extracted with CH_2Cl_2 (5 mL). The organic phase was dried (Na_2SO_4) and concentrated. The residue was dissolved in pyridine (0.5 mL), and then DCC (23 mg) and DMAP (10 mg) were added. The mixture was stirred for 8.5 h and concentrated in vacuo. The residue was chromatographed on SiO_2 (AcOEt/hexane, 1:12) to give **21R** (8 mg, 47%): mp 73.5–75 °C; TLC R_f 0.81 (EtOH/$PhCH_3$, 1:5); $[\alpha]^{23}_D$ +20.5° (*c* 0.64, $CHCl_3$); IR (neat) ν_{max} 1740, 1640 cm^{-1}; ^1H NMR (400 MHz) δ 1.36 (d, 3 H, J = 4.9 Hz), 1.38 (d, 3 H, J = 7.3 Hz), 2.38 (ddd, 1 H, J = 10.3 and 8.8 Hz), 2.47 (dq, 1 H, J = 7.3 and 10.3 Hz), 3.47 (dd, 1 H, J = 10.3 and 9.3 Hz), 3.57 (dd, 1 H, J = 10.3 Hz), 4.08 (ddd, 1 H, J = 10.3, 9.3, and 4.9 Hz), 4.22 (dd, 1 H, J = 10.3 and 4.9 Hz), 4.76 (q, 1 H, J = 4.9 Hz), 5.23 (dd, 1 H, J = 17.1 and 1.2 Hz), 5.27 (dd, 1 H, J = 10.7 and 1.2 Hz), 5.57 (ddd, 1 H, J = 17.1, 10.7, and 8.8 Hz). Anal. Calcd for $C_{11}H_{16}O_4$: C, 62.25; H, 7.60. Found: C, 62.06; H, 7.69.

As described for **15R**, **15S** (19 mg) was saponified and lactonized to give an approximately 5:1 inseparable mixture of **21S** and **21R** (7 mg, 50%) as white crystals: TLC R_f 0.81 (EtOH/$PhCH_3$, 1:5); IR (neat) ν_{max} 1760, 1640 cm^{-1}; ^1H NMR (400 MHz) for the major compound **21S** δ 1.12 (d, 3 H, J = 6.8 Hz), 1.37 (d, 3 H, J = 4.9 Hz), 2.77 (ddd, 1 H, J = 9.8, 9.3, and 6.8 Hz), 3.02 (dq, J = 9.3 and 6.8 Hz), 3.34 (dd, 1 H, J = 9.3 and 6.8 Hz), 3.60 (dd, 1 H, J = 10.3 Hz), 4.21 (ddd, 1 H, J = 10.3, 9.3, and 4.9 Hz), 4.32 (dd, 1 H, J = 10.3 and 4.9 Hz), 4.72 (q, 1 H, J = 4.9 Hz), 5.19 (dd, 1 H, J = 16.1 and 1.2 Hz), 5.22 (dd, 1 H, J = 9.8 and 1.2 Hz), 5.51 (ddd, 1 H, J = 16.6, 9.8, and 9.8 Hz).

Supplementary Material Available: Experimental details of the transformation of compounds **6R** and **6S** into **10R** and **10S** and of compounds **13R** and **13S** into **20R** and **20S**, spectral and analytical data for these and certain intermediates, and also ^1H NMR spectra for compounds **3E**, **3Z**, **5E**, **5Z**, and **21S** (16 pages). Ordering information is given on any current masthead page.