a capillary column containing the phase Phe-3-*O*-TA dispersed in OV-101.

Polarimetric measurements were performed with an Autopol III (Rudolph Research) automatic polarimeter, using a 10-cm path cell. Melting points were obtained on an Electrotermal melting point apparatus and are uncorrected.

Preparation of the Chiral Stationary Phase Phe-3-*O*-TA (1). The chiral stationary phase Phe-3-*O*-TA was prepared as described in the literature,[9] optically and chemically pure. ^{1}H chemical shifts in $CDCl_3$ and in CD_3OD are reported in Table I. ^{13}C NMR ($CDCl_3$): δ 28.47 (C_1), 38.8 (C_β), 51.19 (C_2), 54.6 (C_α), 70.44 (C_7), 70.55 (C_9), 71.02 (C_{10}), 126.74 ($C_{4'}$), 128.47 ($C_{2'}$, $C_{6'}$), 129.36 ($C_{3'}$, $C_{5'}$), 137.02 ($C_{1'}$), 169.34 (C_4), 169.50 (C_6) ppm. ^{13}C NMR (CD_3OD): δ 28.77 (q, J = 124.91 Hz, C_1), 39.79 (t, J = 130.59 Hz, C_β), 52.07 (s, C_2), 55.59 (d, J = 141.94 Hz, C_α), 71.08 (t, J = 141.94 Hz, C_{10}), 71.48 (t, J = 141.94 Hz, C_9), 71.98 (t, J = 141.94 Hz, C_7), 127.82 ($C_{4'}$), 129.36 ($C_{2'}$, $C_{6'}$), 130.62 ($C_{3'}$, $C_{5'}$), 138.07 ($C_{1'}$), 171.99 (C_4), 171.98 (C_6) ppm.

Preparation of (*S*)-(−)- and (*R*)-(+)-Methyl *N*-(Trifluoroacetyl)phenylalaninate (2a, 2b) and (*S*)-(−)- and (*R*)-(+)-*n*-Butyl *N*-(Trifluoroacetyl)phenylalaninate (3a, 3b). (*R*)- and (*S*)-*N*-(trifluoroacetyl)phenylalanine, prepared as described in the literature,[17] were esterified by addition of methyl or *n*-butyl iodide to a suspension of equimolar amounts of the free acid and $NaHCO_3$ in DMF.[18] The mixture was stirred at room temperature for 24 h; then water was added to remove DMF. The products were isolated by extraction with ethyl acetate, dried over Na_2SO_4, and concentrated by evaporation under reduced pressure. Last traces of DMF were eliminated by percolation on a silica gel column, using hexane as eluent. The products were purified on preparative TLC (Merck silica gel), using a mixture of hexane and ethyl acetate (85:15) as the mobile phase.

Optical purity, checked by GC using Phe-3-*O*-TA, was 100% in all cases.

2a: mp 53–54°C; $[\alpha]^{25}_D$ = −9.9 (c = 1, EtOH 95%) (lit.[19] −7.2, c = 1, EtOH). **2b**: mp 52–53 °C; $[\alpha]^{25}_D$ = +10.7° (c = 1, EtOH 95%). ^{1}H NMR ($CDCl_3$, c = 0.1 M): δ 3.19 (d, J = 6 Hz, 1 H), 3.20 (d, J = 6 Hz, 1 H), 3.78 (s, 3 H), 4.88 (m, 1 H), 6.77 (d, 1 H), 7.04–7.08 (m, 2 H), 7.25–7.35 (m, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ 37.44, 52.74, 53.67, 116 (q, J_{C-F} = 280 Hz), 127.68, 128.91, 129.25, 134.74, 156.5 (q, J_{C-F} = 32 Hz), 170.44 ppm. IR (KBr): 3270, 3100, 2950, 1750, 1700, 1580, 1555, 1440, 1330, 1280, 1180 cm^{-1}. Anal. Calcd for $C_{12}H_{12}NO_3F_3$: C, 52.36; H, 4.39; N, 5.09. Found: C, 52.34; H, 4.48; N, 4.88. **3a**: mp 42–43 °C (lit.[20] mp 35.5–36.5 °C); $[\alpha]^{25}_D$ = −19.38 (c = 1, EtOH 95%). **3b**: mp 41–42 °C; $[\alpha]^{25}_D$ = +19.68 (c = 1, EtOH 95%). ^{1}H NMR ($CDCl_3$, c = 0.1 M): δ 0.93 (t, J = 7 Hz, 3 H), 1.35 (m, J = 7 Hz, 2 H), 1.62 (m, J = 6.5 Hz, 2 H), 3.17–3.22 (m, 2 H), 4.16 (t, J = 6 Hz, 2 H), 4.85 (m, 1 H), 6.79 (d, 1 H), 7.06–7.09 (m, 2 H), 7.25–7.33 (m, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ 13.67, 19.1, 30.43, 37.39, 53.69, 66.12, 115.84 (q, J_{C-F} = 280 Hz), 127.57, 128.86, 129.27, 134.88, 156.67 (q, J_{C-F} = 38 Hz), 170.21 ppm. IR (KBr): 3300, 2940, 1750, 1710, 1560, 1460–1450, 1080 cm^{-1}. Anal. Calcd for $C_{15}H_{18}NO_3F_3$: C, 56.78; H, 5.72; N, 4.41. Found: C, 56.46; H, 5.85; N, 4.15.

^{1}H NMR Studies and Titration and Variable-Temperature Experiments. Samples for ^{1}H NMR studies were prepared by using $CDCl_3$ or CD_3OD with tetramethylsilane as internal standard. Titration experiments were performed by adding directly in a 5-mm tube increasing amounts of a 1 M solution of the amino acid derivative to a 0.1 M solution of 1 and stirring with a Maxy Mixer apparatus. Molar ratios were checked by integration of the α-protons of the selector and of the amino acid derivative. In the variable-temperature experiments care was taken to allow equilibrium of sample temperature before acquiring the FID. Variable-concentration experiments were performed by using samples made by dilution of the same standard solution (0.3 M for the selector and 1 M for the amino acid derivative).

^{13}C NMR T_1 Measurements. Relaxation times were measured by the inversion–recovery method.

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Registry No. 1, 104608-19-7; **2a**, 23635-30-5; **2b**, 65638-78-0; **3a**, 52574-47-7; **3b**, 73366-06-0; methyl, 74-88-4; *n*-butyl iodide, 542-69-8.

(17) Weygand, F.; Geiger, R. *Chem. Ber.* **1956**, *89*, 647.
(18) Bocchi, V.; Casnati, G.; Dossena, A.; Marchelli, R. *Synthesis* **1979**, 961.
(19) Weygand, F.; Geiger, R. *Chem. Ber.* **1959**, *92*, 2099.
(20) *CRC*: *Handbook of Biochemistry*, 2nd ed.; 1973.

A Short, Oxetane-Based Synthesis of (±)-Sarracenin

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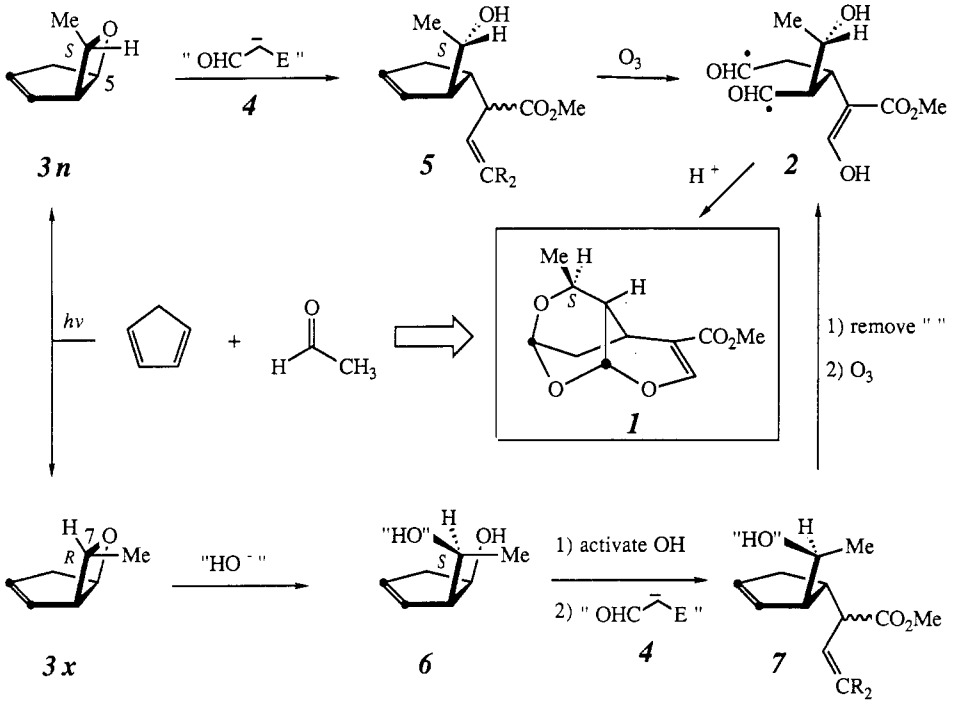
(±)-Sarracenin (1) was synthesized in nine steps and six pots from the simple precursors acetaldehyde and cyclopentadiene. Paterno–Büchi photocycloaddition of this pair yielded two diastereomeric oxetanes (**3x**, **3n**). The major, exo isomer underwent highly regioselective acid-catalyzed methanolysis at the methyl-bearing oxetane center to give a 3-cyclopentenol derivative (**8**). Attachment of a methyl 2-(2-phenylethenyl)ethanoate moiety, a 3-oxopropanoate equivalent, with inversion of the toluenesulfonate **9** derived from **8** gave a diene (**11**) containing all of the necessary carbon atoms. Following decarbomethoxylation, both olefins were simultaneously ozonized to an in situ equivalent of a trialdehyde (**2**) which has played a role in previous synthetic studies and biosynthetic postulates in this area. Spontaneous dehydration of **2** produced (±)-sarracenin in 18% overall yield from the tosylate **9**, the first purified intermediate in the sequence.

(−)-Sarracenin (1) is a tricyclic secoiridoid (i.e., lacks the cyclopentane ring found in iridoids) first isolated from the roots and leaves of *Sarracenia flava* (golden trumpet). Its structure was described in 1976 by Miles, Atwood, and Bryson.[2] In the same paper it was proposed that sarracenin is a likely component of a biosynthetic manifold connecting it and other secoiridoids (secologanin and morronoside) with certain indole alkaloids via the intermediacy of the trialdehyde equivalent **2** and the latter's

(1) Fellow of the Alfred P. Sloan Foundation, 1985–9.
(2) Miles, D. H.; Kokpol, U.; Bhattacharyya, J.; Atwood, J. L.; Stone, K. E.; Bryson, T. A.; Wilson, C. *J. Am. Chem. Soc.* **1976**, *98*, 1569.

0022-3263/89/1954-0688$01.50/0

Scheme I



condensation with tryptamine. The notion of reversible, acid-catalyzed interconversion of **1** and **2** has been exploited to varying extents in each of the previous four syntheses of sarracenin.[3]

We were attracted by the extremely concise access (see Scheme I) to the trialdehyde **2** (potentially three steps) which would arise by the nucleophilic opening of **3n** (the endo diastereomer of the bicyclic oxetane which should be available via Paterno–Büchi union of acetaldehyde and cyclopentadiene) by some equivalent of methyl formylacetate enolate anion (**4**). An ideal equivalent would be the enolate anion derived from a methyl crotonate derivative since both olefins in, say, **5** would be oxidatively cleaved in one operation—the projected ozonolytic generation of **2**. The success of this strategy required access to the endo isomer **3n**, a regioselective opening of the 2,4-disubstituted oxetane ring in **3n** at C(5), and the identification of an equivalent of **4** with suitable stability under conditions sufficient to nucleophilically open **3n**. Since none of these prerequisites was assured, we also recognized that it might be possible to use the exo oxetane isomer **3x** in a slightly longer sequence. Thus, opening at C(7) of **3x** with an oxygen nucleophile with inversion of configuration, conversion of the free, cyclopentyl alcohol in **6** to a leaving group, displacement with an equivalent of **4**, and deprotection (–" ") of the latent hydroxyl in **7** would provide **5**.

In the event, irradiation through quartz of acetaldehyde and freshly cracked cyclopentadiene in methylene chloride at <10 °C (to minimize the thermal dimerization of the diene) gave a mixture of hydrocarbons and oxetanes (~1:1) whose separation by distillation was complicated by continual and annoying contamination of the more volatile oxetanes through background cracking of (photochemically generated)[4] dicyclopentadiene present among the hydrocarbons. Repeated fractionation concluding with spinning band distillation allowed the isolation of a 5:1 mixture of oxetanes **3x** and **3n** (Me's at δ 1.51 and 1.46 respectively) but in only 5–10% yield.[5] Nonetheless, this mixture of isomers was subjected to an extensive battery of conditions[6] designed to effect oxetane ring-opening by *any* carbon nucleophile—no such process was ever observed.[7] We are unaware of any documented examples of ring-opening reactions of 2,4-disubstituted oxetanes induced by carbon nucleophiles.

In light of the difficulties just described, it was gratifying to learn that either of the oxetanes **3n** or **3x** underwent acid-catalyzed, highly regioselective methanolysis with predominant attack by solvent at the methylated oxetane carbon, C(7). We assumed this process was occurring with inversion of configuration and thus assigned the structure **8** to the major product derived from the major oxetane **3x**. It was operationally much more convenient to treat the crude photolysate with 0.05 M methanolic camphorsulfonic acid at room temperature for 1 week. The crude product

(3) (a) Whitesell, J. K.; Mathews, R. S.; Helbling, A. M. *J. Org. Chem.* **1978**, *43*, 784. (b) Whitesell, J. K.; Mathews, R. S.; Minton, M. A.; Helbling, A. M. *J. Am. Chem. Soc.* **1981**, *103*, 3468. (c) Tietze, L. F.; Glusenkamp, K.-H.; Nakane, M.; Hutchinson, C. R. *Angew. Chem., Int. Ed. Engl.* **1982**, *21*, 70. (d) Baldwin, S. W.; Crimmins, M. T. *J. Am. Chem. Soc.* **1982**, *104*, 1132. (e) Takano, S.; Morikawa, K.; Hatakeyama, S. *Tetrahedron Lett.* **1983**, *24*, 401.

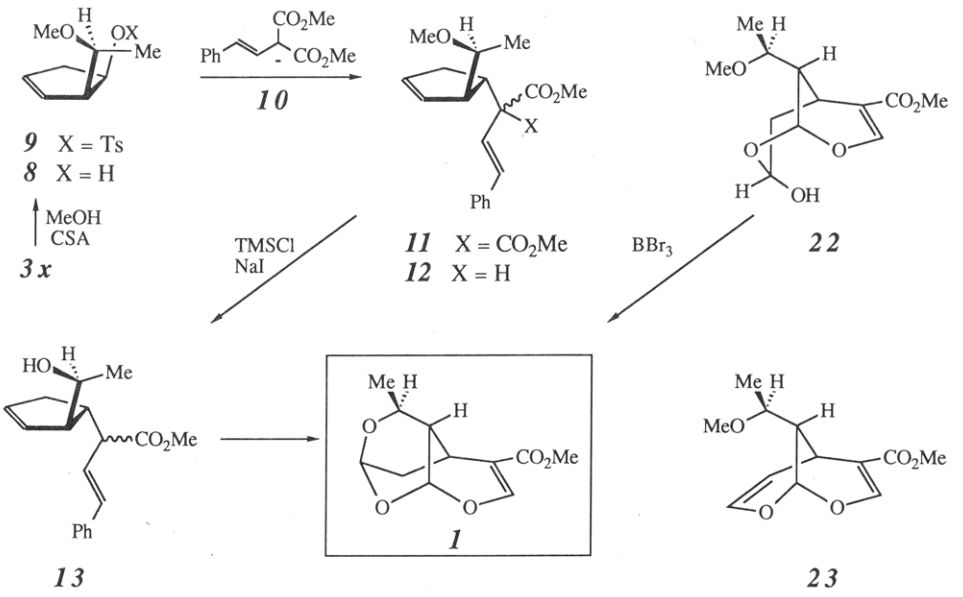
(4) Gold, E. H.; Ginsburg, D. *Angew. Chem., Int. Ed. Engl.* **1966**, *5*, 246.

(5) For some examples of previous Paterno–Büchi additions of aldehydes to cyclopentadiene, see: (a) Jones, G. In *Organic Photochemistry*; Marcel Dekker, Inc.: New York, 1981; Vol. 5, p 15. (b) Reference 4. Cyclohexadiene has been added to propionaldehyde to produce a 7:1 ratio of exo/endo diasteromers: Shima, K.; Kubota, T.; Sakurai, H. *Bull. Chem. Soc. Jpn.* **1976**, *44*, 2567.

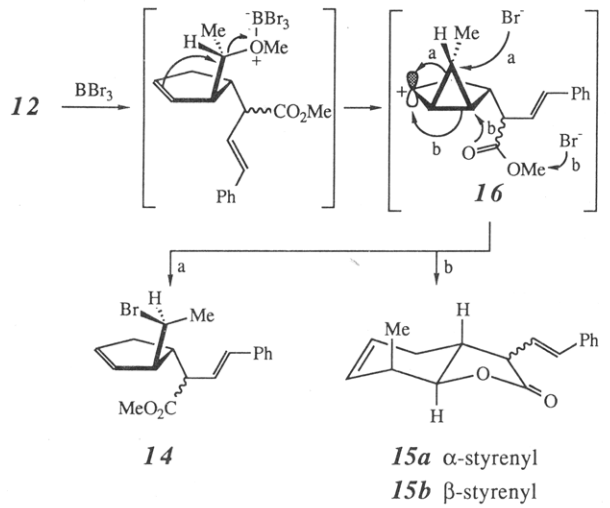
(6) Among the reagent systems tried were the following: MeMgBr [PhH, Et_2O, or THF with or without pretreatment with $AlMe_3$ or $TiCl_4$ (Felkin, H.; Swierczewski, G. *Tetrahedron* **1975**, 2735)], Me_2CuLi (with and without $BF_3{\cdot}OEt_2$), $Me_2Cu(CN)Li_2$ (with and without $BF_3{\cdot}OEt_2$), crotonate anion [from LDA-HMPA or Nozaki–Reformatsky (Maruoka, K.; Hashimoto, S.; Kitagawa, Y.; Yamamoto, H.; Nozaki, H. *J. Am. Chem. Soc.* **1977**, *99*, 7705)], $LiEt_3BH$ [which opens tetrasubstituted epoxides (Krishnamurthy, S.; Schubert, R. M.; Brown, H. C. *J. Am. Chem. Soc.* **1973**, *95*, 8486)], $NaCH(CO_2R)_2$, $LiCH_2CO_2$-*t*-Bu, and $LiCH_2CO_2Li$. Many of these reactions were eventually heated until extensive decomposition occurred, but in no instance was the desired product of ring-opening observed.

(7) For recent work on the use of $BF_3{\cdot}OEt_2$ to promote nucleophilic attack of oxetanes by acetylides and enolates, see: (a) Yamaguchi, M.; Nobayashi, Y.; Hirao, I. *Tetrahedron Lett.* **1983**, *24*, 5121. (b) Yamaguchi, M.; Shibato, K.; Hirao, I. *Tetrahedron Lett.* **1984**, *25*, 1159.

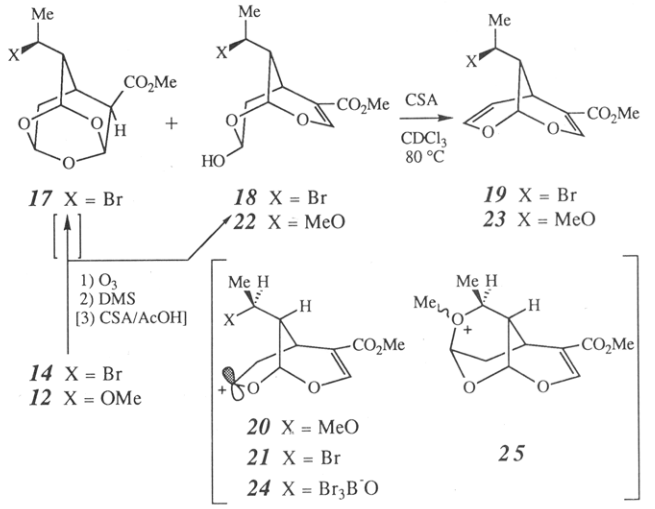
Scheme II



Scheme III



Scheme IV



of that process was exposed directly to *p*-toluenesulfonyl chloride in pyridine, which allowed isolation of the toluenesulfonate ester **9** in 11% yield based upon cyclopentadiene.

After examination of a number of potential equivalents for the formylacetate enolate **4**, we settled on the use of anion **10** prepared from dimethyl β-styrenylmalonate. The potassium salt of **10** in *tert*-butyl alcohol displaced tosylate **9** at room temperature, providing the substituted malonate **11** in 84% yield (Scheme II). Following decarbomethoxylation, a mixture of the diastereomeric monoesters **12** was subjected to boron tribromide treatment (−78 °C, CH_2Cl_2) in an attempt to deprotect the methyl ether. None of the desired alcohol, **13**, was observed; instead, one diastereomer of the bromide **14**[8] and the epimeric lactones **15a** and **15b** were isolated in 47, 2, and 17% yields, respectively (see Scheme III). These unexpected products may arise via the common cyclopropylcarbinyl cation **16**, which can collapse by direct attack of external bromide ion (see route a in Scheme III) or by a competitive internal addition of the carbomethoxy group (see route b) and subsequent transfer of methyl to bromide ion.

As a preliminary to the projected final oxidative cleavage of **13**, we subjected diene **14** to treatment with ozone in methanol in order to learn about this process with a substrate that did not contain the additional reactive hydroxyl functional group present in **13**. Reduction with dimethyl sulfide, concentration, and direct treatment with acetic acid containing camphorsulfonic acid (CSA) produced the trioxane **17** and acetal **18** in low yields (Scheme IV). The latter, when heated at 80 °C in $CDCl_3$ with CSA, was dehydrated cleanly to the interesting bisenol acetal **19**.

Rationalizing that the carbocation **20** analogous to **21**, the one presumably involved in the **18** to **19** dehydration, might be turned to advantage in the problematic ether demethylation, we turned to the study of ozonolytic cleavage of the methyl ether **12**. Purification of the mixture after DMS reduction provided the acetal **22** in 60% yield. However, dehydration, this time to **23**, was again the major event when **22** was heated with CSA in $CDCl_3$. Our first sample of synthetic (±)-sarracenin was obtained by the BBr_3-induced fragmentation of **22** (~30%). It is not clear if this demethylation proceeds via a species like **24** or **25**.

By this juncture we had discovered that it was possible to chemoselectively demethylate the ether in **12** with in

(8) The stereochemistry of the brominated carbon in **14** is assigned in view of the mechanism proposed in Scheme III.

situ generated trimethylsilyl iodide[9] to give the alcohol **13** in 51% yield (Scheme II). Low-temperature, methanolic ozonolysis; DMS reductive workup; and warming at 70 °C in acetic acid produced 60% of a white crystalline material, which after MPLC on silica gel gave (±)-sarracenin (47%) whose ^{1}H NMR,[2,3c] mass,[2] and infrared[2] spectra and melting point[3a] were entirely consistent with those reported in the literature. The overall sequence constitutes a nine-step, six-pot synthesis of (±)-sarracenin in 2% yield from the trivial molecules acetaldehyde and cyclopentadiene and in 18% yield from the first isolated intermediate, the tosylate **9**.

Experimental Section

General Methods. Melting and boiling points are uncorrected. Reactions requiring anhydrous conditions were performed under an atmosphere of nitrogen. MPLC refers to chromatography with E. Merck (No. 9385, 230–400 mesh) silica gel packed in Ace Michel-Miller columns at pressures of 10–50 psi using a Fluid Metering Inc. pump and refractive index detector.

(±)-(1α,5α,7α)- and (±)-(1α,5α,7β)-7-Methyl-6-oxabicyclo[3.2.0]hept-2-ene (3x and 3n). Freshly distilled cyclopentadiene (16.0 mL, 0.2 mol) and acetaldehyde (20.0 mL, 0.35 mol) in methylene chloride (150 mL) were irradiated through a quartz immersion apparatus with a 450-W Hanovia high-pressure mercury lamp. The solution was kept at <10 °C by circulating ice-cooled water through the cooling jacket and blowing dry air past the lamp. After 7 h, GC analysis (SE-30 at 80 °C) indicated a 4:1 mixture of oxetanes **3x** and **3n** and an approximately equal amount of cyclopentadiene dimers. The oxetane could be isolated by distillation (bp ~35–40 °C, 25 mmHg) with ~95% purity by using a spinning band column (~5% yield) or with ~75% purity by using a Vigreux column (~25% yield). Solutions of pure oxetane could easily be obtained by MPLC (10:1 hexanes/EtOAc), but separation of the volatile oxetanes from the elution solvents proved troublesome. In practice it was more convenient to carry out the next two transformations on the crude material before purification. An analytical sample of the major isomer **3x** was purified by preparative GC (SE-30, 50 °C): ^{1}H NMR (80 MHz, $CDCl_3$) δ 5.96 (dddd, J = 5.8, 1.2, 1.2, and 1.2 Hz, C=C*H*), 5.88 (dddd, J = 5.8, 2.3, 2.3, and 2.3 Hz, *H*C=C), 5.35 (m, J values include 5, 4, 1.5, and 1.5 Hz, R_2CHOR), 4.42 (dq, J = 3.1 and 6.2 Hz, MeC*H*), 3.20 (m, J values include 5.4, 3, and 1.5 Hz, =CC*H*R_2), 2.57 (m, 2 H, J values include 4.2 Hz, =CCH_2R), and 1.51 (d, J = 6.3 Hz, CH_3); IR ($CDCl_3$) 3060, 2960, 2920, 1195, and 1160 cm^{-1}. Anal. Calcd for $C_7H_{10}O$: C, 76.33; H, 9.15. Found: C, 76.07; H, 9.28. **3n**: ^{1}H NMR (80 MHz, $CDCl_3$, differentiated hydrogens from mixture) δ 3.5 (m, =CC*H*R_2) and 1.45 (d, J = 6 Hz, CH_3).[10a,b]

(±)-[1α,2α(S*)]-2-(1-Methoxyethyl)-3-cyclopenten-1-ol (8). The crude irradiation mixture of **3x** and **3n** (~30 mL after concentration at 0 °C to remove most of the CH_2Cl_2) was dissolved in methanol (30 mL), and camphorsulfonic acid (0.4 g) was added. The mixture was stirred at room temperature for 7 days. Dilution with ether, washing (0.5 N NaOH and brine), drying ($MgSO_4$), and concentration left a crude, dark oil. A portion of this was purified by MPLC (3:1 hexanes/EtOAc) to give an analytical sample of the alcohol **8**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.8 (m, *H*C=C*H*), 4.48 (ddd, J = 2.0, 6, and 6 Hz, C*H*OH), 3.75 (dq, J = 4.2 and 6.3 Hz, C*H*OMe), 3.35 (s, OCH_3), 2.71 (m, J values include 4.2 and 6.3 Hz, =CC*H*R_2), 2.64 (ddddd, J = 16.9, 6.2, 2.2, 2.2, and 2.2 Hz, =CC*H*HR), 2.36 (dddd, J = 17, 3.8, 1.5, and 1.5, =CCH*H*R), and 1.31 (d, J = 6.3 Hz, CH_3); IR ($CDCl_3$) 3500, 2980, 2940, and 1070 cm^{-1}. Anal. Calcd for $C_8H_{14}O_2$: C, 67.57; H, 9.92. Found: C, 67.67; H, 9.70.

(±)-[1α,2α(S*)]-2-(1-Methoxyethyl)-3-cyclopentenyl 4-Methylbenzenesulfonate (9). Pyridine (6 mL, 74 mmol) and *p*-toluenesulfonyl chloride (12.8 g, 67 mmol) were added at 0 °C to the crude preparation of alcohol **8**. After 24 h at 0 °C, ethyl acetate was added, and the solution was washed (0.1 N HCl and brine) and dried ($MgSO_4$). Sequential MPLC (4:1 and then 9:1 hexanes/EtOAc) gave the tosylate ester **9** (8.05 g, 11% based upon cyclopentadiene): ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.2 (d, 2 H, J = 8.2 Hz, Ar*H*), 7.8 (d, 2 H, J = 8.3, Ar*H*), 5.82 (dddd, J = 6.1, 2, 2, and 2 Hz, C=C*H*), 5.73 (dddd, J = 6.1, 2, 2, and 2, *H*C=C), 5.05 (ddd, J = 4.4, 6.4, and 6.4 Hz, C*H*OTs), 3.49 (dq, J = 6.2 and 6.2 Hz, C*H*OMe), 3.31 (s, OCH_3), 2.72 (m, J values include 6.4 and 4.4 Hz, =CC*H*R_2), 2.45 (s, ArCH_3), 2.45 (m, =CCH_2R), and 1.14 (d, J = 6.2 Hz, CH_3); MS (EI), m/z (relative intensity) 297 (0.1), 172 (12), 155 (5), 124 (9), 91 (20), 66 (53), and 59 (100).[10b]

Dimethyl (E)-(2-Phenylethenyl)propanedioate (10). Pyridine (13 mL, 0.16 mol) was added to a mixture of malonic acid (16.0 g, 0.152 mol) and phenylacetaldehyde (18.5 mL, 0.16 mol), and the bright yellow solution was warmed to 110 °C. After 24 h, EtOAc and water were added. The organic layer was washed with 10% HCl and extracted with 1 N NaOH solution. The base layer was then reacidified (concentrated H_2SO_4) and extracted with EtOAc. The organic extracts were dried ($MgSO_4$) and concentrated to leave 4-phenyl-3-butenoic acid (20 g) as a white solid. This material was dissolved in MeOH (75 mL) and H_2SO_4 (0.5 mL), and the solution was refluxed for 24 h. Addition of ether, washing (1 N NaOH and brine), drying ($MgSO_4$), concentration, and distillation (bp 104–106 °C, 1.7 mmHg) gave (*E*)-methyl 4-phenyl-3-butenoate as a colorless oil (17.8 g, 67%): ^{1}H NMR (80 MHz, $CDCl_3$) δ 7.4–7.2 (m, 5 H, Ar*H*), 6.50 (d, J = 16 Hz, =C*H*Ar), 6.19 (dt, J = 16 and 6 Hz, =C*H*R), 3.68 (s, OCH_3), and 3.20 (d, J = 6 Hz, CH_2); IR ($CDCl_3$) 3040, 2960, 1740, 1170, 965, 745, and 690 cm^{-1}; MS (EI), m/z (relative intensity) 176 (25.9), 117 (100), and 91 (15.6). Anal. Calcd for $C_{11}H_{12}O_2$: C, 74.98; H, 6.86. Found: C, 74.83; H, 6.78.

To a solution of this methyl ester (2.02 g, 11.5 mmol) in dry THF (10 mL) at −78 °C was added a solution of lithium diisopropylamide [from $(i\text{-Pr})_2$NH (1.61 mL, 11.5 mmol) and *n*-BuLi (2.1 N in hexanes, 5.48 mL, 11.5 mmol)] in THF (16 mL), and the mixture was stirred for 5 min. Carbon dioxide was bubbled through the solution until the color changed from red to pale yellow and a precipitate appeared (~5 min). Quenching at −78 °C (10% H_2SO_4), extraction (EtOAc), drying ($MgSO_4$), concentration, and MPLC (EtOAc) gave the monoester monoacid (1.78 g, 70%) as a colorless oil: ^{1}H NMR (80 MHz, $CDCl_3$) δ 7.4–7.1 (m, 5 H, Ar*H*), 6.63 (d, J = 16 Hz, =C*H*Ar), 6.25 (dd, J = 16.6 and 6 Hz, =C*H*R), 4.20 (d, J = 6, R_3CH), and 3.75 (s, OCH_3); IR ($CDCl_3$) 3500–2500, 1750 (br), 1500, 1450, and 1000 cm^{-1}. Anal. Calcd for $C_{12}H_{12}O_4$: C, 65.45; H, 5.49. Found: C, 65.46; H, 5.54.

The crude acid (1.78 g, 8.1 mmol) was dissolved in MeOH (10 mL) and concentrated H_2SO_4 (0.25 mL), and the solution was refluxed for 24 h. Addition of EtOAc, washing (0.5 N NaOH and brine), drying ($MgSO_4$), concentration, and MPLC (9:1 hexanes/EtOAc) gave diester **10** (1.9 g, 90%) as a colorless oil: ^{1}H NMR (80 MHz, $CDCl_3$) δ 7.4–7.1 (m, 5 H, Ar*H*), 6.58 (d, J = 16 Hz, =C*H*Ar), 6.26 (dd, J = 16 and 8 Hz, =C*H*R), 4.15 (d, J = 8, R_3CH), and 3.74 (s, OCH_3); IR ($CDCl_3$) 3000, 2800, 1725, 1440, 1435, and 1250 cm^{-1}; MS (EI), m/z (relative intensity) 262 (17.6), 189 (18), 115 (100), and 103 (79).[10a,b]

Dimethyl (±)-[1α,2β(R*)]-(E)-[2-(1-Methoxyethyl)-3-cyclopentenyl](2-phenylethenyl)propanedioate (11). Diester **10** (240 mg, 1.0 mmol) was added to a solution of potassium *tert*-butoxide in *tert*-butyl alcohol (1 M, 1 mL). After 5 min, the tosylate **9** (210 mg, 0.7 mmol) in *tert*-butyl alcohol (1 mL) was added, and the mixture was stirred at room temperature for 48 h. Addition of EtOAc, washing (10% H_2SO_4 and brine), drying ($MgSO_4$), concentration, and MPLC (9:1 hexanes/EtOAc) gave **11** (319 mg, 82%) as a colorless oil. The analytical sample was prepared from the corresponding diethyl ester, which was made by an entirely analogous set of reactions: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.38–7.20 (m, 5 H, Ar*H*), 6.52 (d, J = 16.6 Hz, =C*H*Ar), 6.43 (d, J = 16.6 Hz, ArC=C*H*), 5.72 (dddd, J = 6.5, 2, 2, and 2 Hz, =C*H*R), 5.61 (dddd, J = 6.5, 2, 2, and 2 Hz, =C*H*R), 4.23 (q, J = 7.1 Hz, OCH_2), 4.22 (q, J = 7.1 Hz, OCH_2), 3.40 (dq, J = 3.3 and 6.3 Hz, C*H*OR), 3.30 (s, OCH_3), 3.06 [ddd, J = 8.9, 3, and 3 Hz, $R_2CHCR(CO_2R)_2$], 2.80 (m, J values include 2.3 and 3.0 Hz, =C*H*R_2), 2.71 (ddddd, J = 17.5, 8.9, 2.6, 2.6, and 2.6 Hz, =CC*H*HR), 2.36 (dddd, J = 17.5, 2.5, 2.5, and 2.5 Hz, =CCH*H*R), 1.27 (t, J = 7 Hz, 6 H, CH_2CH_3), and 1.12 (d, J = 6.3 Hz, CH_3R); IR ($CDCl_3$) 2940, 2860, 1730, 1470, 1450, and 1200 cm^{-1}. Anal.

(9) Bhatt, M. V.; Kulkarni, S. U. *Synthesis* **1983**, 249.

(10) Purity of this compound was judged to be (a) ≥98% by gas chromatography and/or (b) ≥95% by ^{1}H NMR spectroscopy.

Calcd for $C_{23}H_{30}O_5$: C, 71.47; H, 7.82. Found: C, 71.18; H, 7.73.

Methyl (±)-[1α(S*),2β(R*)]- and (±)-[1α(R*),2β(R*)]-(E)-α-(2-Phenylethenyl)-2-(1-methoxyethyl)-3-cyclopentene-1-ethanoate (12). The diester **11** (145 mg, 0.40 mmol) and KOH (0.38 g, 6.7 mmol) were dissolved in 95% ethanol (0.5 mL) and refluxed for 4 h. Dilution with water, extraction with EtOAc, washing (10% H_2SO_4 and brine), drying ($MgSO_4$), and concentration gave an ~1:1 mixture of decarboxylated monoacids: ^{1}H NMR (of the mixture, 80 MHz, $CDCl_3$) δ 9.88 (br s, CO_2H), 7.4–7.1 (m, 5 H, Ar*H*), 6.53 (d, *J* = 16.1 Hz, =C*H*Ar), 6.14 (dd, *J* = 15.7 and 8.7 Hz, ArC=C*H*R), 5.66 (m, R*H*C=C*H*R), 3.31 (s, OCH_3), 3.26 (s, OCH_3), 3.13 (m, C*H*COOH), 2.7–2.1 (m, 4 H), 1.13 (d, *J* = 5 Hz, CH_3R), and 1.08 (d, *J* = 6 Hz, CH_3R).[10b]

The crude acids were dissolved in MeOH (5 mL) and concentrated H_2SO_4 (0.3 mL) and stirred at reflux overnight. Extraction with EtOAc, washing (1 N NaOH, water, and brine), drying ($MgSO_4$), and concentration gave an ~1:1 mixture of **12** (190 mg, 90%). Careful MPLC (19:1 hexanes/EtOAc) allowed separation of the epimers to give (in order of elution) isomers I and II. Isomer I: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.4–7.2 (m, 5 H, Ar*H*), 6.47 (d, *J* = 15.8 Hz, =C*H*Ar), 6.17 (dd, *J* = 15.8 and 9.6 Hz, ArC=C*H*R), 5.73 (dddd, *J* = 5.9, 2, 2, and 2 Hz, =C*H*R), 5.62 (dddd, *J* = 5.9, 2, 2, and 2 Hz, =C*H*R), 3.70 (s, CO_2CH_3), 3.27 (s, $ROCH_3$), 3.22 (m, C*H*OR), 3.07 (dd, *J* = 9.2 and 9.2 Hz, C*H*CO_2R), 2.71 (m, =CC*H*R_2), 2.60 (m, =CC*H*HR and R_2C*H*CHRCO_2R), 2.08 (m, *J* values include 14.2 Hz, =CCH*H*R), and 1.08 (d, *J* = 6.3 Hz, CH_3R); IR ($CDCl_3$) 3060, 3000–2900, 1720, 1440, 1425, 1250, 1155, 1075, and 960 cm^{-1}; MS (EI), *m*/*z* (relative intensity) 300 (2.1), 268 (7.2), 209 (3.3), 176 (19.3), 144 (5.0), 155 (10.5), 77 (3.2), and 59 (100).[10b] Isomer II: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.4–7.2 (m, 5 H, Ar*H*), 6.47 (d, *J* = 15.8 Hz, =C*H*Ar), 6.17 (dd, *J* = 15.8 and 9.5 Hz, ArC=C*H*R), 5.73 (dddd, *J* = 6.0, 2, 2, and 2 Hz, =C*H*R), 5.64 (dddd, *J* = 6.0, 2, 2, and 2 Hz, =C*H*R), 3.70 (s, CO_2CH_3), 3.33 (s, $ROCH_3$), 3.28 (dq, *J* = 3.2 and 6.3 Hz, C*H*OR), 3.11 (dd, *J* = 9.3 and 8.1 Hz, C*H*CO_2R), 2.60 (m, =CC*H*R_2 and R_2C*H*CHRCO_2R), 2.49 (m, *J* values include 17.8 Hz, =CC*H*HR), 2.23 (m, *J* values include 17 Hz, =CCH*H*R), and 1.14 (d, *J* = 6.3 Hz, CH_3R); IR ($CDCl_3$) 3060, 3000–2920, 1720, 1440, 1425, 1250, 1150, 1075, and 960 cm^{-1}; MS (EI), *m*/*z* (relative intensity) 300 (1.0), 268 (3.5), 209 (2.0), 176 (11.5), 144 (3.5), 115 (15.9), 77 (4.3), and 59 (100). Anal. Calcd for $C_{19}H_{24}O_3$: C, 75.97; H, 8.05. Found: C, 76.09; H, 7.98.

Methyl (±)-[1α(S*),2β(R*)]- and (±)-[1α(R*),2β(R*)]-(E)-α-(2-Phenylethenyl)-2-(1-hydroxyethyl)-3-cyclopentene-1-ethanoate (13). To a solution of the esters **12** (82 mg, 0.273 mmol) in dry acetonitrile (0.5 mL) were added chlorotrimethylsilane (52 μL, 0.41 mmol) and NaI (61.5 mg, 0.41 mmol). After 24 h, the mixture was filtered, concentrated, and purified by MPLC (5:1 hexanes/EtOAc) to give (in order of elution) the alcohols **13**: isomer I (14.5 mg, 19%) and isomer II (24.6 mg, 32%). Isomer I: ^{1}H NMR (60 MHz, $CDCl_3$) δ 7.25–7.15 (m, 5 H, Ar*H*), 6.42 (d, *J* = 15 Hz, =C*H*Ar), 6.03 (dd, *J* = 15 and 9 Hz, ArC=C*H*R), 5.62 (m, R*H*C=C*H*R), 3.63 (s, CO_2CH_3), 3.6–2.0 (m, 6 H), and 1.13 (d, *J* = 6 Hz, CH_3R).[10b] Isomer II: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.4–7.2 (m, 5 H, Ar*H*), 6.49 (d, *J* = 15.8 Hz, =C*H*Ar), 6.13 (dd, *J* = 15.8 and 9.5 Hz, ArC=C*H*R), 5.63 (dddd, *J* = 6.1, 2, 2, and 2 Hz, =C*H*R), 5.61 (dddd, *J* = 6.1, 2, 2, and 2 Hz, =C*H*R), 3.79 (dq, *J* = 4.0 and 6.4 Hz, C*H*OH), 3.71 (s, CO_2CH_3), 3.08 (dd, *J* = 9.3 and 9.3 Hz, C*H*CO_2R), 2.65 (ddd, *J* = 9.2, 9.2, 3.3 and 3.3 Hz, R_2C*H*CR_2CO_2R), 2.55 (m, =CC*H*R_2), 2.48 (m, *J* values include 17.4, 8.5, and 2.6 Hz, =CC*H*HR), 2.22 (m, *J* values include 17.0 and 2.5 Hz, =CCH*H*R), and 1.17 (d, *J* = 6.4 Hz, CH_3R); IR ($CDCl_3$) 3500 (br), 3060, 3035, 2980, 1730, 1450, 1435, 1270, 1200, 1160, 1030, and 970 cm^{-1}; MS [of the mixture, CI (NH_3)], *m*/*z* (relative intensity) negative ion 285 (M – H$^+$, 100), 233 (22.1), and 175 (14.5), positive ion 304 (M + NH_4^+, 8.0), 287 (M + H$^+$, 3.9), and 269 (2.2); HRMS calcd for $C_{18}H_{22}O_3$ 286.1569, found 286.1571.[10b]

Methyl (±)-[1α(S*),2β(S*)]- and (±)-[1α(R*),2β(S*)]-(E)-α-(2-Phenylethenyl)-2-(1-bromoethyl)-3-cyclopentene-1-ethanoate (14) and (±)-(3α,3aβ,7β,7aα)- and (±)-(3α,3aα,7α,7aβ)-3a,4,7,7a-Tetrahydro-3-(2-phenylethenyl)-7-methyl-2(3*H*)-benzofuranone (15a and 15b). A mixture of esters **12** (104 mg, 0.347 mmol) was dissolved in CH_2Cl_2 (1 mL) and cooled to –45 °C. Boron tribromide (0.36 mL, 0.36 mmol) was added, and the resulting red solution was stirred for 3 h. Quenching (saturated NH_4Cl solution), warming to room temperature, extraction (EtOAc), drying (Na_2SO_4), concentration, and MPLC (9:1 hexanes/EtOAc) gave bromide **14** (57 mg, 47%) and lactones **15a** (1.8 mg, 2%), and **15b** (15.0 mg, 17%). **14**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.4–7.2 (m, 5 H, Ar*H*), 6.50 (d, *J* = 15.8 Hz, =C*H*Ar), 6.18 (dd, *J* = 15.7 and 9.7 Hz, ArC=C*H*R), 5.83 (m, =C*H*R), 5.62 (m, =C*H*R), 4.16 (dq, *J* = 4.4 and 6.9 Hz, C*H*Br), 3.71 (s, CO_2CH_3), 3.10 (dd, *J* = 9.2 and 9.2 Hz, C*H*CO_2R), 2.88 (m, =CC*H*R_2), 2.60 (m, *J* values include 13.8 Hz, =CC*H*HR and R_2C*H*CR_2CO_2R), 2.09 (m, *J* values include 13.9 Hz, =CCH*H*R), and 1.64 (d, *J* = 6.8 Hz, CH_3R); IR ($CDCl_3$) 3000, 2930, 1720, 1445, 1365, 1225, 1165, and 970 cm^{-1}; MS (EI), *m*/*z* (relative intensity) 285 (0.7), 348 (0.9), 237 (3.9), 209 (44.3), 176 (35.7), 144 (25.5), 115 (100), 91 (80.1), and 77 (46.3); HRMS calcd for $C_{18}H_{21}BrO_2$ 348.0725, found 348.0695.[10b] **15a**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.4–7.2 (m, 5 H, Ar*H*), 6.63 (d, *J* =16.0 Hz, =C*H*Ar), 6.13 (dd, *J* = 16.0 and 8.1 Hz, ArC=C*H*R), 5.66 (br s, R*H*C=C*H*R), 4.50 (dd, *J* = 11.7 and 6.1 Hz, C*H*OR), 3.50 (dd, *J* = 7.9 and 7.9 Hz, C*H*CO_2R), 2.82 (m, *J* values include 7.0 Hz, C*H*CH_3), 2.58 (dddd, *J* = 11.4, 9.8, 7.6, and 7.3 Hz, R_2C*H*CR_2CO_2R), 2.18 (m, =CCH_2R), and 1.08 (d, *J* = 6.9 Hz, CH_3R); IR ($CDCl_3$) 3040, 2980, 2910, 1780, 1200, 1165, 1037, and 690 cm^{-1}; MS (EI), *m*/*z* (relative intensity) 254 (22.9), 210 (38.9), 155 (45.9), 130 (100), 119 (61.5), 115 (42.4), 106 (33.8), 91 (90.4), and 77 (12.1); HRMS calcd for $C_{17}H_{18}O_2$ 254.1307, found 254.1298.[10b] **15b**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.3–7.2 (m, 5 H, Ar*H*), 6.54 (d, *J* = 16.1 Hz, =C*H*Ar), 6.24 (dd, *J* = 16.1 and 7.3 Hz, ArC=C*H*R), 5.7 (m, R*H*C=C*H*R), 4.28 (dd, *J* = 11.0 and 6.1 Hz, C*H*OR), 3.14 (dd, *J* = 12.0 and 7.5 Hz, C*H*CO_2R), 2.83 (m, *J* values include 6.5 and 3.2 Hz, C*H*CH_3), 2.45 (ddd, *J* = 16.0, 4.8, and 4.8 Hz, =CC*H*HR), 2.32 (ddd, *J* = 4.8, 11.4 and 11.4, R_2C*H*CR_2CO_2R), 2.10 (m, *J* values include 16 and 11 Hz, =CC*H*HR), 2.32 (ddd, *J* = 4.8, 11.4 and 11.4, R_2C*H*CR_2CO_2R), 2.10 (m, *J* values include 16 and 11 Hz, =CCH*H*R), and 1.08 (d, *J* = 7.2 Hz, CH_3R); IR ($CDCl_3$) 3040, 2980, 2920, 1780, 1455, 1448, 1165, 1025, and 690 cm^{-1}; MS (EI), *m*/*z* (relative intensity) 254 (10.5), 210 (11.7), 155 (26.7), 130 (68.6), 119 (43.3), 105 (100), 91 (95.2), and 77 (82.7). Anal. Calcd for $C_{17}H_{18}O_2$: C, 80.29; H, 7.13. Found: C, 80.14; H, 7.14.

Methyl (±)-[1R*,3R*,5S*,6S*,7S*,8S*(R*)]-8-(1-Bromoethyl)-2,4,9-trioxatricyclo[3.3.1.1^{3,7}]decane-6-carboxylate (17) and Methyl (±)-[1R*,5S*,7R*,9R*(S*)]-9-(1-Bromoethyl)-7-hydroxy-2,8-dioxabicyclo[3.3.1]non-3-ene-4-carboxylate (18). A mixture of the esters **14** (57 mg, 0.16 mmol) was dissolved in MeOH (15 mL), cooled to –78 °C, and treated with a stream of ozone in oxygen until a blue color persisted. Dimethyl sulfide (4 mL) was added, and the reaction mixture was warmed to room temperature and stirred for 12 h. The solution was concentrated, and the residue was dissolved in 90% acetic acid (1 mL) and treated with camphorsulfonic acid (2 mg). The solution was heated at 70 °C for 1 h and concentrated under reduced pressure. MPLC (3:1 hexanes/EtOAc) gave **17** (4 mg, 8%) and **18** (7 mg, 14%). **17**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.62 [dd, *J* = 1.5 and 1.5 Hz, $(RO)_2$C*H*CHRCO_2R], 5.46 (br s, $(RO)_2$C*H*CHR$_2$), 5.22 [br s, $(RO)_2$C*H*CH_2R], 4.36 (dq, *J* = 10.8 and 6.8 Hz, C*H*Br), 3.79 (s, CO_2CH_3), 3.08 (dd, *J* = 2 and 2 Hz, C*H*CO_2R), 2.96 (m, *J* values include 1.7 Hz, R_3C*H*), 2.40 (br d, *J* = 10.9 Hz, R_2C*H*CBr), 2.19 (ddd, *J* = 13.5, 3, and 3 Hz, R_2C*H*H), 1.92 (br dd, *J* = 13.4 and 1.5 Hz, R_2CH*H*), and 1.82 (d, *J* = 6.8 Hz, RCH_3); IR ($CDCl_3$) 3010, 2985, 1738, 1450, 1435, 1295, 1180, 1125, 1115, 1090, 1085, 1030, 1020, and 870 cm^{-1}; MS [CI (NH_3)], *m*/*z* (relative intensity) negative ion 389 (M + Br$^-$, 2.4), 387 (M + Br$^-$, 4.8), 385 (M + Br$^-$, 2.5), 307 (M – H$^+$, 1.3), 305 (M – H$^+$, 0.9), 226 (6.3), 81 (65.9), and 79 (100), positive ion 326 (M + NH_4^+, 16.5) and 324 (M + NH_4^+, 17.5).[10b] **18**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.70 (s, =C*H*OR), 5.83 [br s, RC*H*$(OR)_2$], 5.20 (dd, *J* = 9.7 and 3.6 Hz, C*H*OH), 4.55 (dq, *J* = 10.9 and 6.8 Hz, C*H*CH_3), 3.75 (s, CO_2CH_3), 3.09 (m, *J* values include 6 and 3 Hz, =CC*H*R_2), 1.84 (d, *J* = 6.8 Hz, RCH_3), 1.8 (m, R_2C*H*H and R_2C*H*CBr), and 1.57 (ddd, *J* = 13.5, 9.8, and 3.7 Hz, R_2CH*H*); IR ($CDCl_3$) 3600, 3400 (br), 3000, 2960, 2940, 1705, 1635, 1440, 1300, 1264, 1225, 1190, 1170, 1140, 1120, 1093, 1062, and 900 cm^{-1}; MS [CI (NH_3)], *m*/*z* (relative intensity) negative ion 389 (M + Br$^-$, 1.9), 387 (M + Br$^-$, 3.7), 385 (M + Br$^-$, 2.0), 307 (M – H$^+$, 3.7), 305 (M – H$^+$, 3.0), 226 (33.5), 81 (75.1), and 79 (100), positive ion 326 (M + NH_4^+, 3.4), 324 (M + NH_4^+, 3.6), 308 (2.2), 306 (2.0), 244 (8.8), 226 (6.0), and 35 (100).[10b]

Methyl (±)-[1*R,5*R**,9*S**(*R**)]-9-(1-Bromoethyl)-2,8-dioxabicyclo[3.3.1]nona-3,6-diene-4-carboxylate (19).** Hemiacetal **18** (6 mg, 0.020 mmol) and CSA (5 mg, 0.022 mmol) in $CDCl_3$ were held at 80 °C for 7 h. The mixture was directly purified by MPLC (3:1 hexanes/EtOAc) to give the ester **19** (5.0 mg, 87%): ^1H NMR (300 MHz, $CDCl_3$) δ 7.59 (s, *H*C=CCO$_2$R), 6.42 (d, *J* = 5.8 Hz, HC=C*H*OR), 6.05 [dd, *J* = 2 and 2 Hz, (RO)$_2$C*H*], 5.15 (ddd, *J* = 7.0, 5.8, and 1.4 Hz, *H*C=CHOR), 4.06 (dq, *J* = 10.7 and 6.7 Hz, C*H*Br), 3.74 (s, CO$_2$C*H*$_3$), 3.34 [ddd, *J* = 6.9, 2.4, and 2.4 Hz, (=CR)$_2$C*H*], 2.01 (ddd, *J* = 10.8, 2, and 2 Hz, BrCC*H*), and 1.77 (d, *J* = 6.7 Hz, RC*H*$_3$); IR ($CDCl_3$) 2965, 2940, 1710, 1655, 1640, 1445, 1305, 1230, 1160, 1095, and 1055 cm^{-1}; MS [CI (NH_3)], *m/z* (relative intensity) negative ion 306 (M + NH_2^-, 11.6), 304 (M + NH_2^-, 11.3), 226 (38.3), 225 (38.3), 81 (96.8), and 79 (100), positive ion 308 (M + NH_4^+, 99.1), 306 (M + NH_4^+, 100), and 244 (94.3).[10b]

Methyl (±)-[1*R,5*S**,7*R**,9*S**(*S**)]-7-Hydroxy-9-(1-methoxyethyl)-2,8-dioxabicyclo[3.3.1]non-3-ene-4-carboxylate (22).** The diene esters **12** (109 mg, 0.36 mmol) were dissolved in MeOH (5 mL) and cooled to −78 °C. A stream of ozone in oxygen was bubbled through the solution until a blue color persisted. Dimethyl sulfide (3 mL) was added, and the reaction was allowed to stand at room temperature for 24 h. Concentration and purification by MPLC (2:1 hexanes/EtOAc) gave the hemiacetal **22** (56 mg, 60%) as a colorless oil: ^1H NMR (300 MHz, $CDCl_3$) δ 7.67 (s, =C*H*OR), 5.70 [dd, *J* = 2 and 2 Hz, RC*H*(OR)$_2$], 5.18 (dd, *J* = 9.7 and 3.6 Hz, C*H*OH), 3.74 (s, CO$_2$C*H*$_3$), 3.39 (s, ROC*H*$_3$), 2.89 (dq, *J* = 3 and 6.1 Hz, C*H*OCH$_3$), 2.9 (m, =CC*H*R$_2$), 2.1 (m, R$_2$C*H*COMe), 1.84 (ddd, *J* = 13.6, 3.6, and 3.6 Hz, R$_2$C*H*H), 1.57 (ddd, *J* = 13.6, 9.7, and 3.6 Hz, R$_2$CH*H*), and 1.24 (d, *J* = 6.2 Hz, RC*H*$_3$); IR ($CDCl_3$) 3500 (br), 3000, 2980, 2960, 2840, 1700, 1630, 1440, 1300, 1150, 1100, 1050, 1020, 948, 905, and 875 cm^{-1}; MS (EI), *m/z* (relative intensity) 258 (0.2), 226 (2.1), 181 (6.3), 180 (4.5), 165 (3.6, 139 (6.7), and 59 (100). Anal. Calcd for $C_{12}H_{18}O_6$: C, 55.81; H, 7.02. Found: C, 55.86; H, 7.05.

Methyl (±)-[1*R,5*R**,9*R**(*R**)]-9-(1-Methoxyethyl)-2,8-dioxabicyclo[3.3.1]nona-3,6-diene-4-carboxylate (23).** Ester **22** (5 mg, 0.02 mmol) and CSA (5 mg, 0.02 mmol) were warmed to 100 °C in $CDCl_3$ (0.5 mL) for 2 h. The mixture was directly purified by MPLC (4:1 hexanes/EtOAc) to give the ester **23** (3.0 mg, 63%): ^1H NMR (300 MHz, $CDCl_3$) δ 7.57 (s, *H*C=CCO$_2$R), 6.39 (d, *J* = 5.8 Hz, HC=C*H*OR), 5.96 [dd, *J* = 2.3 and 2.3 Hz, (RO)$_2$C*H*], 5.15 (dd, *J* = 6.4 and 6.4 Hz, *H*C=CHOR), 3.73 (s, CO$_2$C*H*$_3$), 3.33 (s, ROC*H*$_3$), 3.30 (dq, *J* = 10.2 and 6.0 Hz, C*H*OMe), 3.12 [ddd, *J* = 6.9, 2.7, and 2.2 Hz, (=CR)$_2$C*H*], 1.4 [m, R$_2$C*H*CH(OR)$_2$], and 1.18 (d, *J* = 6.1 Hz, RC*H*$_3$).[10b]

(±)-Sarracenin (1). Hemiacetal **22** (5 mg, 0.02 mmol) was dissolved in CH_2Cl_2 (50 μL) and treated with boron tribromide (20 μL, 0.02 mmol) at room temperature. After 4 h, the solution was concentrated and purified by MPLC (3:1 hexanes/EtOAc) to provide (±)-sarracenin (**1**, 1.4 mg, 31%).

As an alternative, the ester alcohol **13** (35 mg, 0.133 mmol) was dissolved in MeOH (5 mL), cooled to −78 °C, and treated with an ozone stream until a blue color persisted. Dimethyl sulfide (1 mL) was added, and the mixture was warmed to room temperature and allowed to stand for 12 h. The solution was concentrated, and the residue was dissolved in 90% AcOH (0.5 mL). After 1 h at 60 °C, the AcOH was removed under reduced pressure and the material purified by MPLC to provide **1** (14.1 mg, 47%). Recrystallization from hexanes/EtOAc gave the following: mp 108–109 °C (lit.[3a] mp 107–108 °C); ^1H NMR (300 MHz, $CDCl_3$) δ 7.46 (s, RO*H*C=CCO$_2$R), 5.78 [br s, RC*H*OR(OC=C)], 4.98 [d, *J* = 3.2 Hz, RC*H*(OR)$_2$], 4.21 (q, *J* = 6.4 Hz, R$_2$C*H*CH$_3$), 3.75 (s, CO$_2$C*H*$_3$), 2.97 (m, *J* values include 10.7 and 2 Hz, =CC*H*R$_2$), 2.37 (br dd, *J* = 13.9 and 10.6 Hz, R$_2$C*H*H), 1.71 [m, R$_2$CH*H* and R$_2$C*H*CH(OR)$_2$], and 1.34 (d, *J* = 6.5 Hz, RC*H*$_3$); IR ($CDCl_3$) 2900, 2600, 1709, 1647, 1442, 1303, 1254, 1174, 1111, 1097, 1080, 935, and 905 cm^{-1}; MS (EI), *m/z* (relative intensity) 227 (4.1), 226 (29.6), 180 (50.2), 165 (36.7), 148 (41.2), 139 (40.1), 137 (30.7), 123 (46.1), 121 (40.8), 109 (24.7), 96 (41.9), 95 (50.6), 69 (55.8), 59 (61.8), and 41 (100); HRMS calcd for $C_{11}H_{14}O_5$ 226.0841, found 226.0836. Anal. Calcd for $C_{11}H_{14}O_5$: C, 58.40; H, 6.24. Found: C, 57.96; H, 6.14.

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Iterative, Stereoselective Homologation of Chiral Polyalkoxy Aldehydes Employing 2-(Trimethylsilyl)thiazole as a Formyl Anion Equivalent. The Thiazole Route to Higher Carbohydrates[1]

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A new approach to long-chain sugars is demonstrated by the stereoselective conversion of D-glyceraldehyde acetonide (**2a**), L-threose acetonide (**2b**), and dialdogalactopyranose diacetonide (**2h**) into higher homologues up to C_9, C_7, and C_{10} terms, respectively, and with an all-anti configuration of vicinal hydroxy groups in the constructed chain. The methodology consists of the iterative repetition of a linear one-carbon chain extension that involves two very efficient (chemically and stereochemically) key operations: (A) the anti diastereoselective addition of 2-(trimethylsilyl)thiazole (**1a**) to the chiral alkoxy aldehyde; (B) the unmasking of the formyl group from the thiazole ring in the resulting adduct. The conversion of thiazole D-ribose **9a** into protected 2-deoxy- and 2,5-dideoxy-D-ribose (**28** and **30**) demonstrates the synthetic potential of thiazole masked sugars.

We report here a new and effective protocol[2] that is centered on the use of 2-(trimethylsilyl)thiazole (2-TST) (**1a**) as a synthetic equivalent to the formyl anion synthon[3] for the construction of long-chain polyhydroxylated aldehydes (carbohydrate-like materials) with high stereoselectivity and chemical efficiency starting from relatively simple and readily available chiral alkoxy aldehydes and dialdoses. The strategy, in essence, consists of repetition of sequence A and B (Scheme I), which involves as a whole a linear one-carbon chain elongation by creating a new chiral hydroxymethylene center. The chemical and stereochemical efficiency of this protocol is based on the high reactivity and stereoselectivity of **1a** in sequence A and the ready and effective aldehydic release in sequence B.

(1) Thiazole Route to Carbohydrates: Synthesis of Building Blocks or Precursors to Carbohydrates with the Use of Functionally Substituted Thiazoles as Auxiliaries.

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