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Studies Directed toward the Total Synthesis of Cerorubenic Acid-III. 2. Analysis of the Inability To Realize D Ring Formation by Means of Extraannular Robinson Annulation[1]

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The possibility of achieving construction of the complete framework of cerorubenic acid-III by means of a highly convergent anionic oxy-Cope step followed by extraannular Robinson annulation has been probed. To this end, the dithiane **10** and iodides **14** were prepared and merged via S_N2 chemistry. The dianion derived from **15d** added smoothly to β,γ-unsaturated ketone **5**, and the resulting diastereomers **18b** and **19b** were separated and individually transformed into the diketone pairs **22** and **23**. When these advanced intermediates failed to undergo the cyclization required for assembly of ring D, the ability of parent ketone **28** to undergo nucleophilic addition with various classes of nucleophiles was assessed. Although somewhat attenuated, the carbonyl group in this peculiar structural setting gives evidence of being adequately reactive.

The possibility of employing the anionic oxy-Cope rearrangement for the expedient construction of the entire eastern sector of cerorubenic acid-III (**1**) is documented fact.[1,2] Despite this favorable early start toward the development of a practical synthesis of this insect kairomone, the approach earlier investigated required that ring D and its side chain be appended last. Due to the unique structural features of the ABC subunit in **1**, proper engineering of the requisite annulation process has not proven straightforward. In this report, we explore an alternative, more highly convergent option in which all but one of the 25 carbon atoms of this sesterterpene are preassembled in advance of the [3,3]sigmatropic event. Contemplated in this plan was the intermediacy of diketone **3**, cyclization of which would have the benefit of providing **2** and allowing for subsequent stereocontrolled 1,4-reduction and carbonyl-to-methyl homologation (Scheme I). It is noteworthy that **3** should be available from base-promoted isomerization of **4** as long as ponderal effects do not have detrimental consequences on the particular alignment of $p\pi$ orbitals required for the electronic reorganization. The final supposition was that **4** would result from coupling of the substantially functionalized vinyl organometallic **6** to the known ketone **5**.[1,3,4] The 1,3-dithiane unit in **6** was strategically selected to serve as the cornerstone for construction of this key building block.

Results and Discussion

The synthesis of **6** began by conversion of methyl cyclopropyl ketone (**7**) to bromide **8** by the method of Julia[5] (Scheme II). Treatment of **8** with selenium dioxide and *tert*-butyl hydroperoxide[6] in CH_2Cl_2 at rt resulted in oxidation of the less sterically congested allylic methyl group to give **9a** in 58% yield. The sensitivity of allylic alcohol **9a** demanded that its hydroxyl group be protected immediately. The MOM group[7] was construed to be well suited to our long-range goals, and **9b** was therefore prepared. Subsequent condensation of **9b** with 2-lithio-1,3-dithiane[8] at low temperatures resulted in smooth S_N2 displacement and the formation of **10** (78%).

Central to our plan was the availability of an efficient means for extending the chain in **10** so as to arrive at **6**. Attention was therefore directed to the stannylation of methyl propiolate (**11**) according to Piers and Morton[9] (Scheme III). Vinylstannane **12** was deprotonated with LDA[10] and the enolate allowed to react with 1,3-diiodopropane. This deconjugative alkylation sequence, when performed in an inverse addition mode, furnished **13** in 65% yield. At this stage, low-temperature (−40 °C) reduction with diisobutylaluminum hydride made available alcohol **14a**. From among the many blocking groups that could be utilized to mask the hydroxyl functionality in **14a** temporarily, three silyl groups of varying steric bulk were selected for evaluation. Since a "naked" alkoxide was ultimately to be generated at the point of oxy-Cope rearrangement and too rapid silyl transfer would arrest this reaction, the pragmatic ploy was to assess the levels of migratability as a function of the nature of SiR_3. The use of silyl chlorides for the preparation of **14b–d** had to be avoided because of competing displacement of iodide by chloride ion as in **16**. No similar complication was noted when recourse was made to the silyl triflates.

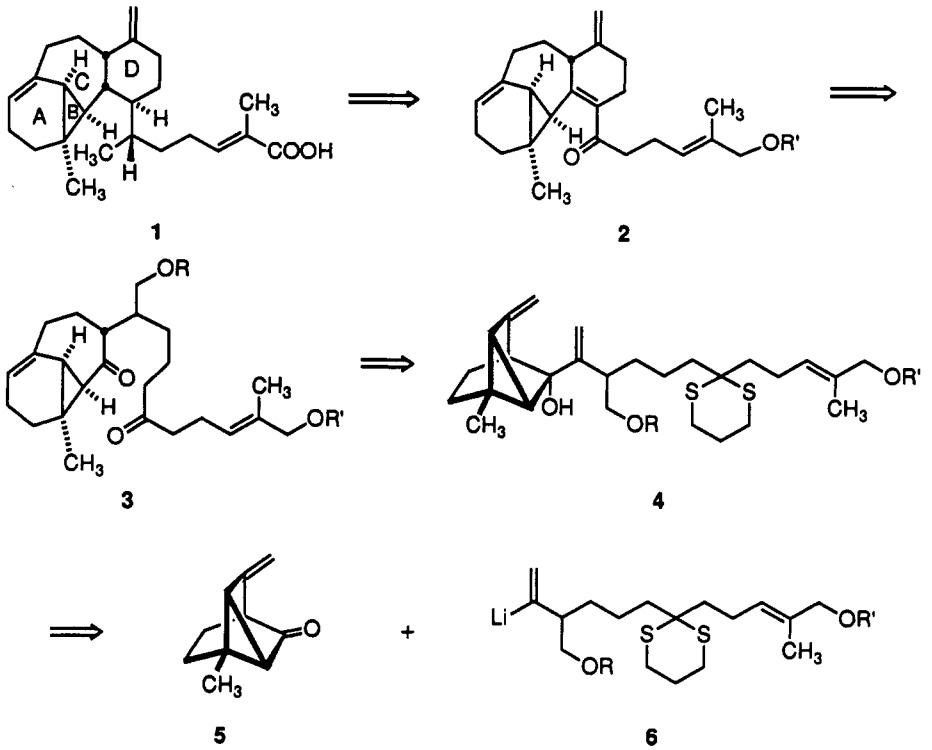
The coupling reactions that delivered **15a–c** involved the condensation of lithiated **10** with all three O-protected primary iodides. The high electrophilicity of the latter reagents was reflected in their rapid consumption by the dithianyl anion at −78 °C in THF solution.

A variety of attempts to achieve the transmetalation of **15a–c** by reaction with methyllithium in THF at different temperatures resulted either in silyl transfer from oxygen to carbon or in protonation of the vinyl anion prior to the introduction of ketone **5**. Following these developments, it was reasoned that the free alcohol **15d** might serve our purposes most advantageously in that it would be transformed directly into **17** upon treatment with 2 equiv of an

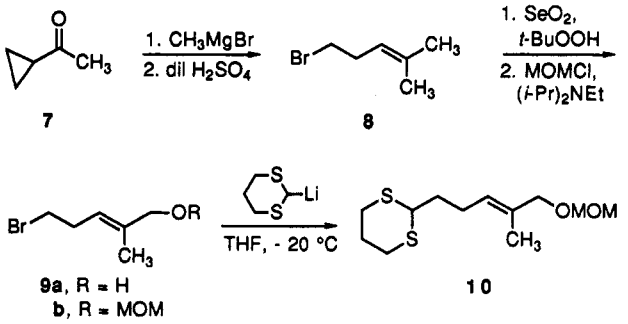
(1) Part 1. Preceding paper in this issue.
(2) Paquette, L. A.; Poupart, M. A. *Tetrahedron Lett.* **1988**, *29*, 273.
(3) Poupart, M.-A. *Tetrahedron Lett.* **1988**, *29*, 269.
(4) Poupart, M.-A.; Lassalle, G.; Paquette, L. A. *Org. Synth.* **1990**, *69*, 173.
(5) Biernacki, W.; Gdula, A. *Synthesis* **1979**, 37.
(6) Umbreit, M.-A.; Sharpless, K. B. *J. Am. Chem. Soc.* **1977**, *99*, 5526.
(7) Stork, G.; Takahashi, T. *J. Am. Chem. Soc.* **1977**, *99*, 1275.
(8) Seebach, D.; Corey, E. J. *J. Org. Chem.* **1975**, *40*, 231.
(9) Piers, E.; Morton, H. E. *J. Org. Chem.* **1980**, *45*, 4263.
(10) Piers, E.; Karumaratne, V. *J. Org. Chem.* **1983**, *48*, 1774.

0022-3263/93/1958-4254$04.00/0

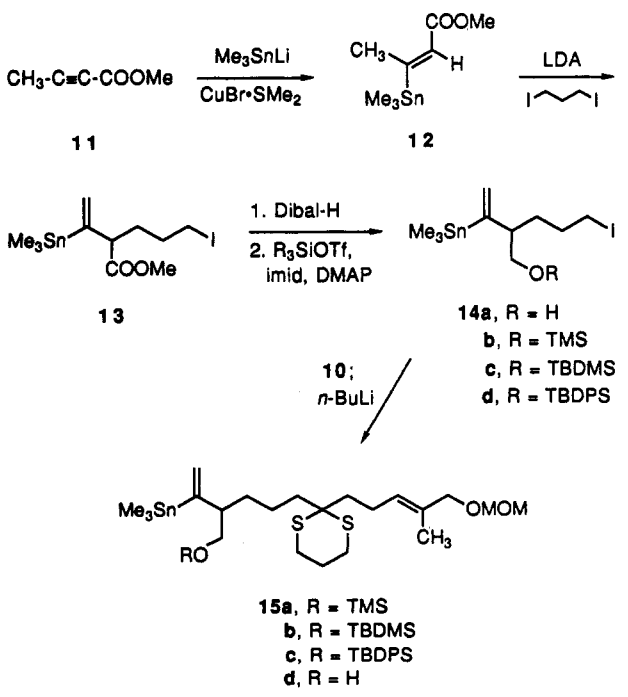
Scheme I



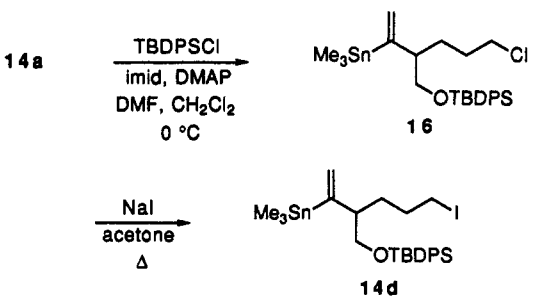
Scheme II



Scheme III

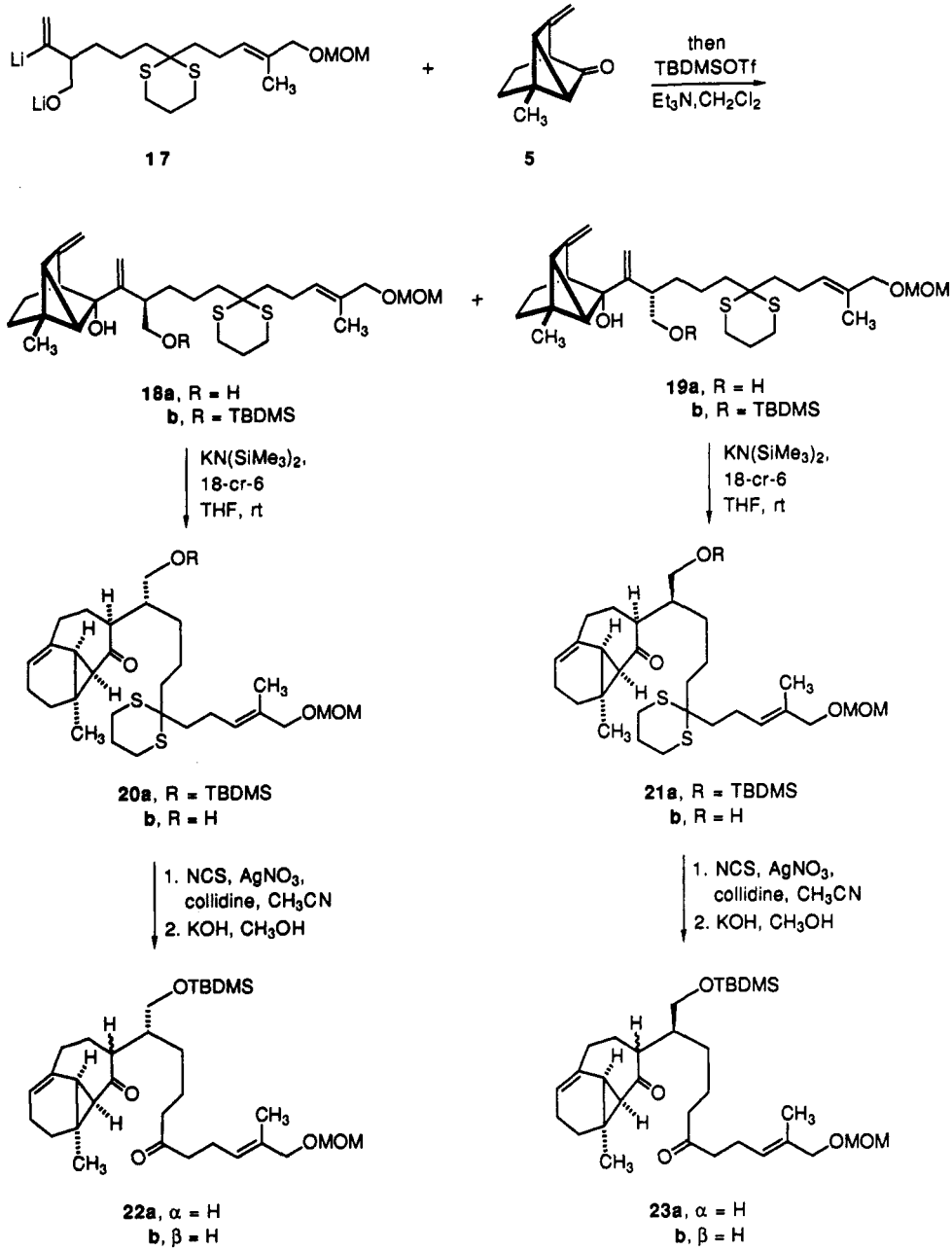


alkyllithium. In the event, compound **15d** did react with methyllithium (2.3 equiv) in THF at −78 to −35 °C to give presumably **17**, since the subsequent addition of **5** afforded the pair of diastereomers **18a** and **19a** in 81% combined yield. A very small amount of diol resulting from opposite π-facial attack was also detected. Since the adducts could be separated following their O-silylation, full characterization was undertaken once **18b** and **19b** (ratio 1:1.1) had been obtained chromatographically pure. Their ^1H and ^{13}C NMR spectra, while fully supportive of the structural assignments and diastereomeric interrelationship, did not allow for unequivocal definition of the relative stereochemical orientation of the $CH_2OTBDMS$ group. This was not of great concern since this substituent was destined to become the exocyclic methylene unit in cerorubenic acid-III (*cf.* **4** → **3** → **2** → **1**).



The stage was now set to explore the anionic oxy-Cope rearrangement step. The best conditions uncovered involved treatment of either **18b** or **19b** with a slight excess of potassium hexamethyldisilazide and 18-crown-6 in THF at rt for 1 h. More elevated temperatures induced undesirable degradation. The two diastereomers exhibited closely parallel behavior in that the isomerized ketones **20a** and **21a** were produced in 72% yield alongside 7% of the desilylated rearrangement products **20b** and **21b** and 12–13% of the deprotected starting materials **18a** and **19a**.

Scheme IV



Consideration of the mechanistic events associated with the successful conversions to **20** and **21** requires that the enolate anions of these ketones be generated regiospecifically as the penultimate products. Subsequent proton delivery to **A** (Figure 1) should, for steric reasons, occur from that direction exocyclic to the reactive double bond. However, kinetically controlled quenching along this reaction channel delivers a product (**B**) having the larger pendant side chain projected pseudoaxially. The nonbonded steric compression is released following epimerization to **C**. Detailed NOE, DEPT, and COSY studies performed on **20a**[11] revealed unequivocally that the less thermodynamically stable stereoisomer had been obtained following workup and chromatographic purification. The spectral similarities between **20a** and **21a** are such that these diastereomers clearly have the same configuration α to carbonyl.

(11) We thank Dr. Dirk Friedrich for performing these measurements.

Deprotection of the second carbonyl group was achieved efficiently by making recourse to NCS and silver nitrate in acetonitrile solution containing collidine.[12] When exposed to KOH in methanol, **22a** and **23a** were equilibrated with **22b** and **23b**, respectively. We had now arrived at the point where ring D cyclization had to be implemented. Although the Robinson annulation has long seen utility as a direct route to fused ring ketones,[13] the heavy predominance of examples are of the intraannular variety, e.g., **24** to **25**.[14] This classification encompasses those numerous cases where the enolate (or enol) activating group eventually becomes a carbonyl substituent on the newly formed ring. Those cyclizations that deliver products

(12) Corey, E. J.; Erickson, B. W. *J. Org. Chem.* **1971**, *36*, 3553.
(13) (a) House, H. O. *Modern Synthetic Reactions*, 2nd ed.; W. A. Benjamin, Inc.: Menlo Park, CA, 1972; Chapter 9. (b) Gawley, R. *Synthesis* **1976**, 777. (c) Jung, M. E. *Tetrahedron* **1976**, *32*, 3.
(14) For example: (a) Tsuji, J.; Shimizu, I.; Suzuki, H.; Naito, Y. *J. Am. Chem. Soc.* **1979**, *101*, 5070. (b) Sisko, J.; Balog, A.; Curran, D. P. *J. Org. Chem.* **1992**, *57*, 4341.

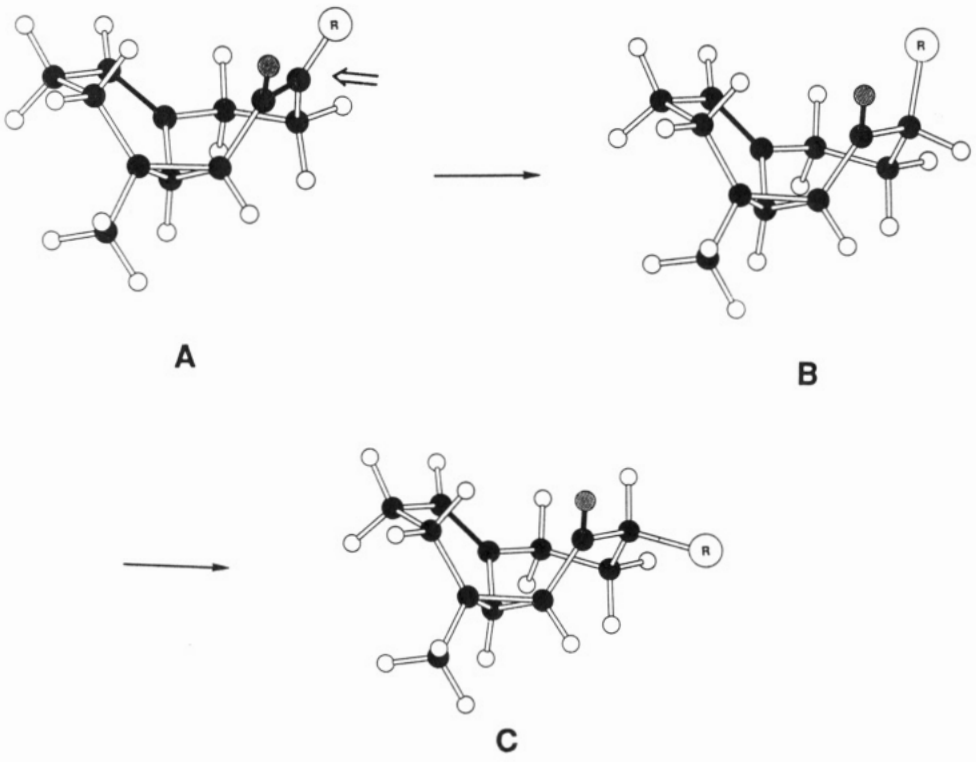
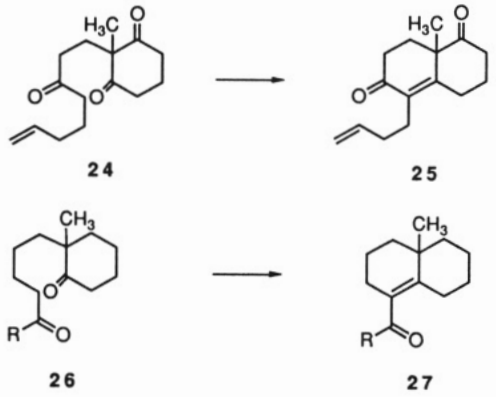


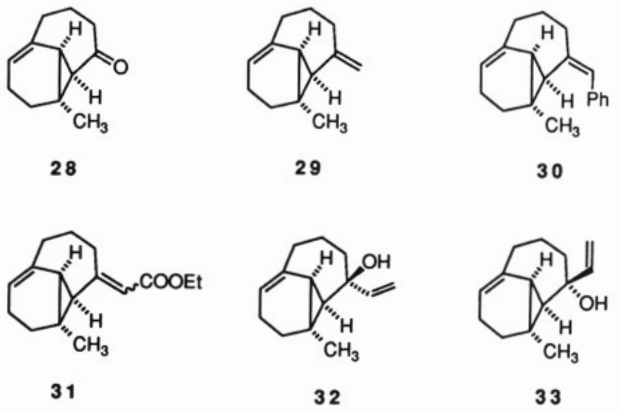
Figure 1. Chem-3D representations of the regiospecifically generated enolates (**A**) derived by isomerization of **18b** and **19b** together with their exo- (**B**) and endo-protonated (**C**) products.



where the carbonyl is posited extraannularly as in **26** to **27** are far less prevalent and decidedly rare.[15]

Many attempts to close the six-membered ring were to no avail. Under mild conditions (e.g., pyrrolidine in refluxing benzene), **22a** and **23a** could be recovered unchanged. With stronger bases (e.g., KO-*t*-Bu in *tert*-butyl alcohol), only epimerization to **22b** and **23b** was encountered. Recourse neither to conventional conditions (e.g., Triton B, CH_3OH, reflux) nor to unusually forcing conditions [KO-*t*-Bu, *t*-BuOH, 100 000 psi or $KN(SiMe_3)_2$, 18-crown-6, DME, 3 days] gave indication that a tetracyclic enone structurally related to **2** had been generated from any of the four available diketone precursors.

This pivotal cyclization may have been thwarted by stereoelectronic features or by an unanticipated lack of reactivity of the cyclopropyl-conjugated ketone toward nucleophiles. Independent investigation of the second probable factor has shown that while the electrophilicity of the C-ring carbonyl is somewhat attentuated, it might well be sufficiently high for our intended purposes. In an earlier phase of this investigation,[1] ketone **28** was shown to condense readily with (methoxymethylene)triphenylphosphorane. In like fashion, exposure of **28** to the parent phosphorus ylide furnished **29** in 82% yield. The potassium salt of diethyl benzylphosphonate acted on **28** in THF at rt to afford the styrene **30** (93%). Ester-derived phosphonates reacted more sluggishly (43% conversion to **31**) but keto phosphonates not at all. Highly stabilized anions such as those derived from diethyl malonate or its bis(diethyl phosphonate) equivalent also gave no evidence of reaction. In contrast, organometallics typified by vinylmagnesium bromide added smoothly to give a predominance of the β-carbinol **32** (62%) relative to **33** (7%).



The requirement of good stereoelectronic overlap during the intramolecular attack is another matter. While this generic question falls outside the scope of this investigation, there exists no doubt that complications do not usually surface when the two carbonyls are arranged as in **24**.

(15) Miyao, Y.; Tanaka, M.; Suemune, H.; Sakai, K. *J. Chem. Soc., Chem. Commun.* **1989**, 1535.

Consequently, the following paper examines the issue of cerorubenic acid-III synthesis from this perspective.[16]

Experimental Section

See ref 1 for a listing of generic experimental details.

(*E*)-5-Bromo-2-methyl-2-penten-1-ol (9a). A solution of selenium dioxide (5.5 g, 0.05 mol) in dry CH_2Cl_2 (75 mL) was added at rt to 90% *tert*-butyl hydroperoxide (22 mL, 0.2 mol) and the mixture stirred for 30 min. Neat 8 (16.3 g, 0.1 mol) was introduced dropwise, and stirring was continued for 2.5 h before dilution with benzene (50 mL). The solvents were removed under reduced pressure, the residue was dissolved in ether (100 mL) and washed with 10% KOH (6 × 25 mL) and brine (25 mL), and the organic phase was dried and evaporated. The residue was chromatographed on silica gel (elution with 5% ethyl acetate in petroleum ether) to afford 2.46 g (14%) of the aldehyde and 10.34 g (58%) of **9a** as a colorless oil: IR (neat, cm^{-1}) 3600–3100; ^1H NMR (300 MHz, $CDCl_3$) δ 5.44 (dt, J = 1.3, 7.2 Hz, 1 H), 4.03 (br s, 2 H), 3.38 (t, J = 7.1 Hz, 2 H), 2.63 (q, J = 7.1 Hz, 2 H), 1.68 (s, 3 H), 1.48 (br s, 1 H); ^{13}C NMR (20 MHz, $CDCl_3$) ppm 137.7, 121.4, 67.6, 32.2, 30.9, 13.5; MS m/z (M^+) calcd 179.9973, obsd 179.9977.

[[(*E*)-5-Bromo-2-methyl-2-pentenyl]methoxymethane (9b). To a solution of **9a** (8.60 g, 48.03 mmol) in dry CH_2Cl_2 (144 mL) was added at 0 °C diisopropylethylamine (20.9 mL, 120 mmol) and chloromethyl methyl ether (8.20 mL, 108 mmol) dropwise. The reaction mixture was left overnight in a refrigerator and diluted with water (50 mL) and saturated NH_4Cl solution (50 mL) and the aqueous phase separated and extracted with ether (2 × 100 mL). The combined organic solutions were washed with 1 M HCl (2 × 100 mL), water (100 mL), and brine (100 mL) prior to drying and evaporation. The residue was purified by Kugelrohr distillation to give 9.96 g (93%) of **9b** as a colorless oil: ^1H NMR (300 MHz, $CDCl_3$) δ 5.46 (dt, J = 1.2, 7.1 Hz, 1 H), 4.63 (s, 2 H), 3.95 (s, 2 H), 3.38 (t, J = 7.1 Hz, 2 H), 3.38 (s, 3 H), 2.63 (q, J = 7.0 Hz, 2 H), 1.69 (s, 3 H); ^{13}C NMR (20 MHz, $CDCl_3$) ppm 135.0, 124.1, 95.6, 72.7, 55.3, 32.0, 31.4, 14.2; MS m/z (M^+ – HBr) calcd 142.0994, obsd 142.1022.

Anal. Calcd for $C_8H_{15}BrO_2$: C, 43.07; H, 6.78. Found: C, 43.12; H, 6.62.

2-[(*E*)-5-(Methoxymethoxy)-4-methyl-3-pentenyl]-*m*-dithiane (10). A solution of 1,3-dithiane (6.0 g, 49.9 mmol) in dry THF (120 mL) was added at –20 °C to a 1.6 M solution of *n*-butyllithium in hexanes (31.2 mL, 49.9 mmol). Stirring was maintained for 90 min at –20 °C before a solution of **9b** (10.12 g, 45.4 mmol) in THF (15 mL) was introduced dropwise during 30 min. After 20 h at –20 °C and 48 h at 0 °C, the reaction mixture was quenched by the addition of saturated NH_4Cl solution (50 mL) and brine (100 mL). The separated aqueous phase was extracted with ether (3 × 150 mL), and the combined organic solutions were dried and evaporated. The residue was chromatographed on silica gel (elution with 5–10% ethyl acetate in petroleum ether) to give 9.37 g (78%) of **10** as a colorless viscous oil: ^1H NMR (300 MHz, $CDCl_3$) δ 5.41 (dt, J = 1.1, 7.3 Hz, 1 H), 4.61 (s, 2 H), 4.02 (t, J = 6.9 Hz, 1 H), 3.93 (s, 2 H), 3.37 (s, 3 H), 2.87–2.82 (m, 4 H), 2.27 (q, J = 7.6 Hz, 2 H), 2.17–1.05 (m, 1 H), 1.95–1.78 (m, 3 H), 1.68 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 133.1, 126.5, 95.4, 73.1, 55.2, 46.9, 35.1, 30.3, 26.0, 24.8, 14.1; MS m/z ($M^+ - CH_2OCH_3$) calcd 217.0721, obsd 217.0734.

Anal. Calcd for $C_{12}H_{22}O_2S_2$: C, 54.92; H, 8.45. Found: C, 55.01; H, 8.54.

Methyl 2-(3-Iodopropyl)-3-(trimethylstannyl)-3-butenoate (13). To a solution of freshly distilled diisopropylamine (0.81 mL, 5.77 mmol) in dry THF (15 mL) was added at 0 °C a 1.51 M solution of *n*-butyllithium in hexanes (3.82 mL, 5.77 mmol). After 15 min, the reaction mixture was cooled to –78 °C, and **12** (1.265 g, 4.81 mmol) dissolved in dry THF (3 mL) was introduced dropwise. After 1 h at –78 °C and 1 h at 0 °C, the mixture was returned to –78 °C and added during 30 min to a cold (–78 °C) solution of 1,3-diiodopropane (2.85 g, 9.62 mmol) in dry THF (15 mL). Stirring was continued for 3 h at –78 °C, and warming to –40 °C took place during 2 h prior to the addition of saturated NH_4Cl solution (4 mL) and brine (20 mL). The separated aqueous phase was extracted with ether (3 × 30 mL), and the combined organic solutions were washed with brine (2 × 40 mL), dried, and evaporated. Chromatography of the residue on silica gel (elution with 0.5% ethyl acetate in petroleum ether) furnished 1.36 g (65%) of **13** as a colorless oil: IR ($CHCl_3$, cm^{-1}) 1727; ^1H NMR (300 MHz, $CDCl_3$) δ 5.75 (dd, J = 2.2, 0.6 Hz, 1 H with additional coupling to Sn: $^3J_{H-^{119}Sn}$ = 146.2 Hz), 5.33 (d, J = 2.2 Hz, 1 H with additional coupling to Sn: $^3J_{H-^{119}Sn}$ = 65.0 Hz), 3.67 (s, 3 H), 3.22–3.04 (m, 3 H), 1.94–1.55 (series of m, 4 H), 0.17 (s, 9 H, with additional coupling to Sn: $^3J_{H-^{119}Sn}$ = 55.0, 52.8 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 174.4, 153.1, 128.1, 55.5, 51.7, 33.4, 31.2, 5.9, 5.7; MS m/z ($M^+ - CH_3$) calcd 416.9374, obsd 416.9379.

2-(3-Iodopropyl)-3-(trimethylstannyl)-3-buten-1-ol (14a). A solution of **13** (4.40 g, 10.2 mmol) in dry CH_2Cl_2 (60 mL) was treated dropwise at –40 °C with 1 M diisobutylaluminum hydride in hexanes (22.47 mL, 22.47 mmol), stirred for 30 min, and quenched by the dropwise addition of dry methanol (0.41 mL, 10.2 mmol) and 0.7 M potassium sodium tartrate in water (96 mL, 3 equiv). After 3 h of stirring at 0 °C, the separated aqueous phase was extracted with ether (2 × 50 mL), and the combined organic layers were dried and evaporated. The crude residue was subjected to MPLC (silica gel, elution with 15% ethyl acetate in petroleum ether) to afford 3.73 g (91%) of **14a** as a colorless oil: IR ($CHCl_3$, cm^{-1}) 3420 (br); ^1H NMR (300 MHz, $CDCl_3$) δ 5.78 (dd, J = 2.5, 0.8 Hz, 1 H with additional coupling to Sn: $^3J_{H-^{119}Sn}$ = 146.4 Hz), 5.37 (d, J = 2.5 Hz, 1 H with additional coupling to Sn: $^3J_{H-^{119}Sn}$ = 69.1 Hz), 3.60–3.38 (m, 2 H), 3.22–3.11 (m, 2 H), 2.48–2.42 (m, 1 H), 1.86–1.33 (series of m, 5 H), 0.19 (s, 9 H with additional coupling to Sn: ^2J = 53.9, 51.4 Hz), ^{13}C NMR (75 MHz, $CDCl_3$) ppm 156.5, 128.3, 65.5, 53.5, 32.1, 31.3, 6.5, 5.9; MS m/z ($M^+ - CH_3$) calcd 388.9479, obsd 388.9453.

***tert*-Butyl[[2-(3-Iodopropyl)-3-(trimethylstannyl)-3-butenyl]oxy]dimethylsilane (14c).** To a cold (0 °C), magnetically stirred solution of **14a** (229 mg, 0.57 mmol) in dry CH_2Cl_2 (2.5 mL) was added sequentially dry triethylamine (0.119 mL, 0.85 mmol) and *tert*-butyldimethylsilyl triflate (0.168 mL, 0.68 mmol). The reaction mixture was stirred for 3 h at 0 °C and quenched with 1 M NaOH solution (5 mL). The separated aqueous phase was extracted with ether (2 × 10 mL), and the combined organic solutions were washed with water, dried, and evaporated. MPLC of the residue (neutral alumina, elution with 0.5% ether in petroleum ether) furnished 294 mg (100%) of **14c** as a colorless oil: ^1H NMR (300 MHz, $CDCl_3$) δ 5.69 (d, J = 2.4 Hz, 1 H with additional coupling to Sn: $^3J_{H-^{119}Sn}$ = 151.1 Hz), 5.24 (d, J = 2.5 Hz, 1 H, additional coupling to Sn: $^3J_{H-^{119}Sn}$ = 71.5 Hz), 3.55–3.43 (m, 2 H), 3.23–3.10 (m, 2 H), 2.65–2.25 (m, 1 H), 1.87–1.65 (m, 2 H), 1.34–1.21 (m, 2 H), 0.89 (s, 9 H), 0.16 (s, 9 H with additional coupling to Sn: ^2J = 53.6, 51.5 Hz), 0.05 (s, 6 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 156.2, 126.9, 67.1, 53.3, 32.4, 31.6, 26.0, 18.4, 7.0, –5.2, –8.2; MS m/z ($M^+ - CH_3$) calcd 503.0252, obsd 503.0270.

[[2-(3-Iodopropyl)-3-(trimethylstannyl)-3-butenyl]oxy]trimethylsilane (14b). A 414-mg (1.03 mmol) sample of **14a** was silylated as above with trimethylsilyl triflate to give after MPLC (neutral alumina, elution with petroleum ether) 416 mg (85%) of **14b** as a colorless oil; ^1H NMR (300 MHz, $CDCl_3$) δ 5.69 (d, J = 2.3 Hz, 1 H with additional coupling to Sn: $^3J_{H-^{119}Sn}$ = 151.0 Hz), 5.25 (d, J = 2.3 Hz, 1 H with additional coupling to Sn: $^3J_{H-^{119}Sn}$ = 71.5 Hz), 3.55–3.43 (m, 2 H), 3.23–3.11 (m, 2 H), 2.62–2.40 (m, 1 H), 1.90–1.26 (series of m, 4 H), 0.15 (s, 9 H with additional coupling to Sn: ^2J = 53.6, 51.6 Hz), 0.11 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 156.5, 126.6, 66.6, 52.9, 32.4, 31.6, 6.9, –0.4, –7.9; MS m/z ($M^+ - CH_3$) calcd 460.9820, obsd 460.9799.

***tert*-Butyl[[2-(3-iodopropyl)-3-(trimethylstannyl)-3-butenyl]oxy]diphenylsilane (14d).** A solution of **14a** (803 mg, 2 mmol), imidazole (204 mg, 3 mmol), and 4-(dimethylamino)-pyridine (24 mg, 0.2 mmol) in dry DMF (10 mL) was cooled to 0 °C and treated dropwise with *tert*-butyldiphenylsilyl chloride (0.768 mL, 3 mmol). The reaction mixture was stored in a refrigerator for 43 h and poured into brine and ether (40 mL, 1:1). The separated aqueous phase was extracted with ether (4 × 20 mL), and the combined organic layers were washed with brine (2 × 30 mL), dried, and evaporated. Chromatography of

(16) Paquette, L. A.; Deaton, D. N.; Endo, Y.; Poupart, M.-A. Following paper in this issue.

the residue on silica gel (elution with 1% ethyl acetate in petroleum ether) provided 1.058 g (83%) of **16** as a viscous, colorless oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.85–7.78 (m, 4 H), 7.59–7.36 (m, 6 H), 5.82 (dd, J = 2.5, 0.7 Hz, 1 H with additional coupling to Sn: $^3J_{^1H-^{119}Sn}$ = 150.7 Hz), 5.39 (d, J = 2.5 Hz, 1 H with additional coupling to Sn: $^3J_{^1H-^{119}Sn}$ = 71.5 Hz), 3.74–3.58 (m, 4 H), 2.64–2.41 (m, 1 H), 2.03–1.70 (m, 3 H), 1.48–1.32 (m, 1 H), 1.20 (s, 9 H), 0.21 (s, 9 H with additional coupling to Sn: ^2J = 63.6, 51.4 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 155.9, 135.6-(2 C), 133.9, 133.8, 129.6, 127.6, 127.1, 67.6, 53.4, 45.1, 30.6, 28.6, 27.0, 19.3, –8.4; MS m/z (M^+ – t-Bu) calcd 493.0776, obsd 493.0778.

A mixture of **16** (402 mg, 0.73 mmol) and dry sodium iodide (440 mg, 2.92 mmol) in dry acetone (5 mL) was refluxed for 48 h, cooled, and evaporated. The residue was partitioned between ether (10 mL) and water (10 mL), and the separated aqueous layer was extracted with ether (2 × 20 mL). The combined organic solutions were washed with brine (20 mL), dried, and evaporated to leave an oil that was purified by MPLC on silica gel (elution with 0.5% ethyl acetate in petroleum ether) to provide 412 mg (88%) of **14d** as a colorless oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.68–7.64 (m, 4 H), 7.43–7.36 (m, 6 H), 5.67 (d, J = 2.3 Hz, 1 H with additional coupling to Sn: $^3J_{^1H-^{119}Sn}$ = 150.7 Hz), 5.24 (d, J = 2.5 Hz, 1 H with additional coupling to Sn: $^3J_{^1H-^{119}Sn}$ = 71.4 Hz), 3.59–3.46 (m, 2 H), 3.20–3.08 (m, 2 H), 2.58–2.42 (m, 1 H), 1.86–1.59 (m, 3 H), 1.29–1.19 (m, 1 H), 1.07 (s, 9 H), 0.08 (s, 9 H with additional coupling to Sn: ^2J = 53.3, 51.6 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 155.9, 135.7, 135.6, 133.9, 129.6, 127.6, 127.1, 67.5, 53.1, 32.3, 31.4, 27.0, 19.3, 6.9, –8.4; MS m/z (M^+ – CH_3) calcd 626.0602, obsd 626.0603.

***tert*-Butyl[[2-[3-[2-[(*E*)-5-(methoxymethoxy)-4-methyl-3-pentenyl]-*m*-dithian-2-yl]propyl]-3-(trimethylstannyl)-3-butenyl]oxy]diphenylsilane (15c).** To a cold (–20 °C), magnetically stirred solution of **10** (169 mg, 0.64 mmol) in dry THF (2 mL) was added n-butyllithium in hexanes (0.425 mL of 1.51 M, 0.64 mmol). The reaction mixture was stirred for 2 h at –78 °C prior to the addition of **14d** (412 mg, 0.64 mmol) dissolved in THF (1 mL) and quenched 3 h later with saturated NH_4Cl solution (1 mL) and brine (4 mL). After return to rt, the separated aqueous phase was extracted with ether (3 × 20 mL) and the combined organic solutions were washed with brine (30 mL), dried, and evaporated. The residue was purified by chromatography on silica gel (elution with 5% ethyl acetate in petroleum ether) to provide 220 mg (44%) of **15c** as a colorless oil: IR ($CHCl_3$, cm^{-1}) 1580; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.67–7.63 (m, 4 H), 7.43–7.33 (m, 6 H), 5.68 (d, J = 2.6 Hz, 1 H with additional coupling to Sn: $^3J_{^1H-^{119}Sn}$ = 152.8 Hz), 5.43 (tq, J = 7.1, 1.6 Hz, 1 H), 5.23 (d, J = 2.6 Hz, 1 H with additional coupling to Sn: $^3J_{^1H-^{119}Sn}$ = 62.3 Hz), 4.62 (s, 2 H), 3.92 (s, 2 H), 3.53 (dd, J = 10.0, 6.9 Hz, 1 H), 3.47 (dd, J = 10.1, 3.5 Hz, 1 H), 3.38 (s, 3 H), 2.81–2.77 (m, 4 H), 2.49–2.44 (m, 1 H), 2.20–2.11 (m, 2 H), 1.98–1.14 (series of m, 10 H), 1.73 (d, J = 1.0 Hz, 3 H), 1.04 (s, 9 H), 0.6 (s, 9 H with additional coupling to Sn: ^2J = 53.6, 51.1 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 156.2, 135.7, 134.0, 132.4, 129.5, 127.6, 127.3, 127.0, 95.4, 73.2, 67.7, 55.2, 53.9, 53.2, 38.5, 37.7, 31.5, 27.0, 26.1, 25.5, 22.9, 21.8, 19.3, 14.1, –8.3; MS m/z (M^+ – CH_3) calcd 761.2540, obsd 761.2548.

***tert*-Butyl[[2-[3-[2-[(*E*)-5-(methoxymethoxy)-4-methyl-3-pentenyl]-*m*-dithian-2-yl]propyl]-3-(trimethylstannyl)-3-butenyl]oxy]diphenylsilane (15b).** By analogous means, **10** (141 mg, 0.54 mmol) was alkylated with **14c** (277 mg, 0.54 mmol). MPLC purification (silica gel) afforded 188 mg (54%) of **15b**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.71 (d, J = 2.3 Hz, 1 H with additional coupling to Sn), 5.44 (tm, J = 6.9 Hz, 1 H), 5.24 (d, J = 2.5 Hz, 1 H, with additional coupling to Sn), 4.62 (s, 3 H), 3.93 (s, 2 H), 3.54–3.42 (m, 2 H), 3.38 (s, 3 H), 2.82–2.74 (m, 4 H), 2.43–2.39 (m, 1 H), 2.20–2.13 (m, 2 H), 1.99–1.19 (series of m, 9 H), 1.68 (s, 3 H), 0.89 (s, 9 H), 0.15 (s, 9 H with additional coupling to Sn: ^2J = 53.5, 51.4 Hz), 0.04 (s, 6 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 156.5, 132.4, 127.2, 126.7, 95.3, 73.1, 67.2, 55.2, 54.1, 53.1, 38.5, 37.6, 31.4, 26.0, 25.5, 22.8, 21.8, 18.4, 14.0, –5.2, –8.2; MS m/z (M^+ – CH_3) calcd 637.2227, obsd 637.2229.

[[2-[3-[2-[(*E*)-5-(methoxymethoxy)-4-methyl-3-pentenyl]-*m*-dithian-2-yl]propyl]-3-(trimethylstannyl)-3-butenyl]oxy]trimethylsilane (15a). By analogous means, **10** (777 mg, 2.96 mmol) was alkylated with **14b** (1.406 g, 2.96 mmol). MPLC purification (neutral alumina, elution with 5% ethyl acetate in petroleum ether) furnished 1.40 g (78%) of **15a** as a colorless oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.70 (d, J = 2.6 Hz, 1 H with additional coupling to Sn: $^3J_{^1H-^{119}Sn}$ = 153.2 Hz), 5.42 (tm, J = 6.6 Hz, 1 H), 5.23 (d, J = 2.6 Hz, 1 H with additional coupling to Sn: $^3J_{^1H-^{119}Sn}$ = 72.0 Hz), 4.61 (s, 2 H), 3.91 (s, 2 H), 3.53–3.41 (m, 2 H), 3.36 (s, 3 H), 2.81–2.73 (m, 4 H), 2.42–2.34 (m, 1 H), 2.25–2.02 (m, 2 H), 1.97–1.17 (series of m, 9 H), 1.67 (s, 3 H), 0.13 (s, 9 H with additional coupling to Sn: ^2J = 53.0 Hz), 0.09 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 156.9, 132.4, 127.3, 126.7, 126.4, 126.2, 95.4, 73.1, 66.7, 65.8, 55.2, 53.6, 53.4, 38.5, 37.6, 31.5, 26.0, 25.5, 22.9, 21.8, 14.0, –0.5, –7.9; MS m/z (M^+ – CH_3) calcd 595.1757, obsd 595.1760.

2-[(*E*)-5-(Methoxymethoxy)-4-methyl-3-pentenyl]-β-[(trimethylstannyl)vinyl]-*m*-dithian-2-pentanol (15d). By analogous means, **10** (566 mg, 2.15 mmol) was alkylated with **14b** (1.024 g, 2.15 mmol). After completion of the reaction, a 1.0 M solution of tetra-n-butylammonium fluoride in THF (3.23 mL, 3.23 mmol) was introduced, and the mixture was stirred at rt for 2 h. MPLC of the residue on silica gel (elution with 35% ethyl acetate in petroleum ether) gave 822 mg (71%) of **15d** as a colorless oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.81 (d, J = 2.5 Hz, 1 H with additional coupling to Sn), 5.44 (tm, J = 7.0 Hz, 1 H), 5.38 (d, J = 2.5 H, 1 H with additional coupling to Sn), 4.62 (s, 2 H), 3.93 (s, 2 H), 3.59–3.37 (m, 2 H), 3.38 (s, 3 H), 2.85–2.74 (m, 4 H), 2.49–2.44 (m, 1 H), 2.20–2.12 (m, 2 H), 1.98–1.80 (series of m, 6 H), 1.68 (s, 3 H), 1.58–1.23 (series of m, 5 H), 0.18 (s, 9 H with additional coupling to Sn: ^2J = 52.8 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 156.8, 132.4, 128.3, 127.1, 95.3, 73.1, 65.6, 55.1, 54.3, 53.0, 38.3, 37.6, 31.4, 26.0, 25.4, 22.8, 21.8, 14.0, –7.7; MS m/z (M^+ – CH_3) calcd 523.1363, obsd 523.1365.

(1*R,2*S**,5*R**,6*R**,7*R**)-6-[1-[(1*S**)-1-[(*tert*-Butyldimethylsiloxy)methyl]-4-[2-[(*E*)-5(methoxymethoxy)-4-methyl-3-pentenyl]-*m*-dithian-2-yl]butyl]vinyl]-2-methyl-8-methylenetricyclo[3.2.1.0^{2,7}]octan-6-ol and (1*R**,2*S**,5*R**,6*R**,7*R**)-6-[1-[(1*R**)-1-[(*tert*-Butyldimethylsiloxy)methyl]-4-[2-[(*E*)-5-(methoxymethoxy)-4-methyl-3-pentenyl]-*m*-dithian-2-yl]-butyl]vinyl]-2-methyl-8-methylenetricyclo[3.2.1.0^{2,7}]octan-6-ol (18b and 19b).** A solution of **15d** (822 mg, 1.53 mmol) in dry THF (5 mL) was treated at –78 °C with methyllithium (3.165 mL of 1.11 M in ether, 3.51 mmol), stirred for 1 h at –35 °C, recooled to –78 °C, and treated dropwise with **5** (432 mg, 3.06 mmol) dissolved in THF (2 mL). After 2 h at –78 °C, the mixture was allowed to warm to rt, stirred for 90 min, and quenched with brine (5 mL). The separated aqueous phase was extracted with ether (4 × 15 mL), and the combined organic solutions were dried and evaporated. MPLC of the residue on silica gel (elution with 60% ethyl acetate in petroleum ether) provided 635 mg (81%) of a mixture of **18a** and **19a** as a colorless viscous oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.50–5.40 (m, 1 H), 5.24 and 5.20 (2s, total 1 H), 4.97 and 4.95 (2s, total 1H), 4.64–4.58 (m, 2 H), 4.62 (s, 2 H), 3.92 (s, 2 H), 3.79–3.68 (m, 1 H), 3.51–3.37 (m, 1 H), 3.37 (s, 3 H), 2.84–2.26 (series of m, 5 H), 2.16–2.05 (m, 4 H), 2.05–0.83 (series of m, 17 H), 1.67 (s, 3 H), 1.05 and 1.04 (2s, total 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 153.7, 153.0, 152.5, 132.3, 132.2, 127.2, 110.0, 109.9, 101.6, 101.0, 95.3, 80.0, 79.9, 73.1, 69.2, 67.9, 55.2, 55.1, 53.0, 45.7, 45.4, 42.1, 41.6, 38.9, 38.7, 37.74, 37.68, 37.1, 36.9, 35.2, 34.9, 33.9, 33.1, 28.0, 27.4, 26.0, 25.4, 25.0, 24.5, 23.6, 23.4, 22.8, 22.1, 22.0, 14.0; MS m/z (M^+ – H_2O) cacld 504.2738, obsd 504.2735.

The diol mixture (106 mg, 0.205 mmol) in dry CH_2Cl_2 (3 mL) was cooled to 0 °C and treated sequentially with triethylamine (0.043 mL, 0.308 mmol) and *tert*-butyldimethylsilyl triflate (0.056 mL, 0.226 mmol). After 2 h at rt, the reaction mixture was quenched with 1 M NaOH (4 mL) and the separated aqueous layer was extracted with ether (3 × 10 mL). The combined organic phases were washed with brine, dried, and evaporated. MPLC of the residue on silica gel (elution with 15% ethyl acetate in petroleum ether) gave **18b** (54 mg, 43%) and **19b** (59 mg, 47%). (NOTE: these assignments may be reversed).

For **18b**: colorless oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.43 (tm, J = 7.1 Hz, 1 H), 5.14 (s, 1 H), 4.90 (s, 1 H), 4.62 (s, 2 H), 4.60 (d, J = 1.4 Hz, 1 H), 4.54 (s, 1 H), 4.08 (d, J = 2.6 Hz, 1 H), 3.92 (s, 2 H), 3.75 (dd, J = 4.9, 8.6 Hz, 1 H), 3.38 (s, 3 H), 3.33 (dd, J = 8.8, 10.3 Hz, 1 H), 2.86–2.75 (m, 4 H), 2.71–2.60 (m, 1 H), 2.18–0.77 (series of m, 19 H), 1.67 (s, 3 H), 1.03 (s, 3 H), 0.90 (s, 9 H), 0.07 (s, 6 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 153.9, 153.2,

132.2, 127.1, 109.1, 101.0, 95.3, 79.3, 73.0, 70.5, 55.1, 52.9, 46.9, 41.0, 38.9, 37.8, 37.7, 35.3, 32.8, 27.4, 25.9, 25.8, 25.4, 24.5, 23.6, 22.8, 22.0, 18.3, 13.9, -5.48, -5.54; MS *m/z* (M^+) calcd 636.3702, obsd 636.3704.

Anal. Calcd for $C_{35}H_{60}O_4S_2Si$: C, 65.99; H, 9.49. Found: C, 66.03; H, 9.52.

For **19b**: colorless oil; ^1H NMR (300 MHz, $CDCl_3$) δ 5.43 (tm, J = 7.0 Hz, 1 H), 5.23 (s, 1 H), 4.85 (s, 1 H), 4.63 (d, J = 1.1 Hz, 1 H), 4.62 (s, 2 H), 4.60 (s, 1 H), 3.92 (s, 2 H), 3.72 (s, 1 H), 3.71 (dd, J = 5.3, 8.9 Hz, 1 H), 3.37 (s, 3 H), 3.33 (dd, J = 9.2, 9.2 Hz, 1 H), 2.86–2.71 (m, 5 H), 2.34–0.86 (series of m, 19 H), 1.67 (s, 3 H), 1.02 (s, 3 H), 0.87 (s, 9 H), 0.04 (s, 3 H), 0.03 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 155.0, 153.9, 133.3, 127.0, 108.9, 99.9, 95.2, 78.9, 73.0, 69.6, 55.1, 53.0, 46.3, 41.7, 38.8, 37.7, 37.6, 34.2, 33.2, 28.2, 25.9, 25.8, 25.4, 24.3, 23.4, 22.8, 22.2, 18.2, 13.9, -5.6, -5.7; MS *m/z* (M^+) calcd 636.3702, obsd 636.3724.

Anal. Calcd for $C_{35}H_{60}O_4S_2Si$: C, 65.99; H, 9.49. Found: C, 66.09; H, 9.58.

A very small amount of diol resulting from opposite π-facial attack was also isolated: ^1H NMR (300 MHz, $CDCl_3$) δ 5.43 (br t, J = 6.0 Hz, 1 H), 5.27 (s, 1 H), 5.09 (s, 1 H), 4.87 (d, J = 1.0 Hz, 1 H), 4.78 (s, 1 H), 4.60 (s, 2 H), 3.91 (s, 2 H), 2.60 (ABq, J_{AB} = 9.8 Hz, J_{AX} = 5.6 Hz, J_{BX} = 4.2 Hz, $\Delta\nu_{AB}$ = 27.5 Hz, 2 H), 3.36 (s, 3 H), 2.80–2.76 (m, 4 H), 2.54–2.50 (m, 1 H), 2.24–0.86 (series of m, 19 H), 1.67 (d, J = 0.7 Hz, 3 H), 1.02 (s, 3 H), 0.88 (s, 9 H), 0.03 (s, 3H), 0.02 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 154.0, 151.3, 132.3, 127.4, 112.4, 103.3, 95.3, 83.6, 73.2, 66.3, 55.2, 53.3, 48.4, 42.3, 40.9, 38.7, 37.7, 33.4, 32.0, 30.2, 26.01, 25.97, 25.88, 25.5, 23.8, 22.9, 22.8, 21.7, 18.3, 14.0, -5.4; MS *m/z* (M^+) calcd 636.3702, obsd 636.3707.

(1*R,2*R**,4*S**,11*S**)-4-[(1*S**)-1-[(*tert*-Butyldimethylsiloxy)methyl]-4-[2-[(*E*)-5-(methoxymethoxy)-4-methyl-3-pentenyl]-*m*-dithian-2-yl]butyl]-11-methyltricyclo[5.4.0.0^{2,11}]undec-7-en-3-one (20a).** A solution of **18b** (563 mg, 0.884 mmol) and 18-crown-6 (257 mg, 0.972 mmol) in dry THF (15 mL) was treated with potassium hexamethyldisilazide (1.94 mL of 0.5 M in toluene, 0.972 mmol), stirred at rt for 1 h, cooled to -78 °C, and quenched with dry methanol (1 mL). The reaction mixture was allowed to warm to rt, saturated NH_4Cl solution (10 mL) was added, and the aqueous layer was extracted with ether (3 × 10 mL). The combined organic solutions were dried and evaporated, and the residue was chromatographed on silica gel (elution with 5–35% ethyl acetate in petroleum ether) to afford **20a** (405 mg, 72%), **20b** (31 mg, 7%), and **18a** (60 mg, 13%).

For **20a**: IR (CH_2Cl_2, cm^{-1}) 1702, 1650; ^1H NMR (300 MHz, $CDCl_3$) δ 5.70 (br d, J = 6.6 Hz, 1 H), 5.43 (br t, J = 7.0 Hz, 1 H), 4.60 (s, 2 H), 3.91 (s, 2 H), 3.54 (ABq, J_{AB} = 10.1 Hz, J_{AX} = 4.9 Hz, J_{BX} = 3.8 Hz, $\Delta\nu_{AB}$ = 23.9 Hz, 2 H), 3.36 (s, 3 H), 2.81–2.69 (m, 6H), 2.36–2.31 (m, 1 H), 2.20–0.82 (series of m, 19 H), 1.67 (s, 3 H), 1.12 (s, 3 H), 0.87 (s, 9 H), 0.02 (s, 3 H), 0.01 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 210.1, 138.4, 132.4, 127.7, 127.2, 95.4, 73.1, 62.8, 55.2, 55.1, 53.1, 42.9, 41.4, 38.8, 37.8, 34.9, 32.4, 28.7, 27.5, 26.7, 26.2, 26.0, 25.9, 25.4, 24.7, 23.2, 22.9, 21.6, 18.2, 14.0, -5.4, -5.5; MS *m/z* (M^+) calcd 636.3702, obsd 636.3696.

Anal. Calcd for $C_{35}H_{60}O_4S_2Si$: C, 65.99; H, 9.49. Found: C, 66.10; H, 9.66.

For **20b**: IR ($CHCl_3$, cm^{-1}) 1705; ^1H NMR (300 MHz, $CDCl_3$) δ 5.70 (br d, J = 6.8 Hz, 1 H), 5.41 (br t, J = 6.9 Hz, 1 H), 4.59 (s, 2 H), 3.89 (s, 2 H), 3.80–3.70 (m, 1 H), 3.59–3.53 (m, 1 H), 3.34 (s, 3 H), 3.05–2.95 (m, 1 H), 2.85–2.74 (m, 4 H), 2.40–2.35 (m, 1 H), 2.18–0.80 (series of m, 22 H), 1.65 (s, 3 H), 1.13 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 212.0, 138.0, 132.5, 128.1, 127.1, 95.4, 73.1, 61.5, 57.0, 55.2, 53.2, 43.1, 42.9, 38.6, 37.9, 34.7, 33.8, 29.5, 27.5, 27.0, 26.1, 26.0, 25.4, 24.8, 23.1, 22.9, 21.9, 14.0; MS *m/z* ($M^+ - H_2O$) calcd 504.2731, obsd 504.2731.

For pure **18a**: ^1H NMR (300 MHz, $CDCl_3$) δ 5.42 (br t, J = 7.1 Hz, 1 H), 5.20 (s, 1 H), 4.97 (s, 1 H), 4.625 (d, J = 0.5 Hz, 1 H), 4.616 (s, 2 H), 4.61 (d, J = 3.1 Hz, 1 H), 3.91 (s, 2 H), 3.76 (dd, J = 4.5, 9.3 Hz, 1 H), 3.46–3.37 (m, 1 H), 3.37 (s, 3 H), 2.83–2.74 (m, 4 H), 2.54–2.45 (m, 1 H), 2.20–1.99 (m, 4 H), 1.99–0.86 (series of m, 17 H), 1.66 (s, 3 H), 1.05 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 153.1, 152.6, 132.3, 127.2, 110.1, 101.8, 95.4, 80.1, 73.1, 69.3, 55.2, 53.0, 45.8, 41.6, 38.9, 37.7, 37.1, 35.3, 33.2, 27.5, 26.0, 25.4, 24.6, 24.4, 23.7, 22.9, 22.1, 14.0; MS *m/z* ($M^+ - H_2O$) calcd 504.2731, obsd 504.2705.

(1*R,2*R**,4*S**,11*S**)-4-[(1*R**)-1-[(*tert*-Butyldimethylsiloxy)methyl]-4-[2-[(*E*)-5-(methoxymethoxy)-4-methyl-3-pentenyl]-*m*-dithain-2-yl]butyl]-11-methyltricyclo[5.4.0.0^{2,11}]undec-7-en-3-one (21a).** Analogous treatment of **19b** (259 mg, 0.406 mmol) gave **21a** (186 mg, 72%), **21b** (25 mg, 7%), and **19a** (25 mg, 12%).

For **21a**: ^1H NMR (300 MHz, $CDCl_3$) δ 5.70 (br d, J = 6.3 Hz, 1 H), 5.42 (br t, J = 7.2 Hz, 1 H), 4.61 (s, 2 H), 3.91 (s, 2 H), 3.62 (d, J = 3.8 Hz, 2 H), 3.37 (s, 3 H), 2.80–2.73 (m, 6 H), 2.37–2.32 (m, 1 H), 2.20–0.82 (series of m, 21 H), 1.67 (d, J = 0.6 Hz, 3 H), 1.14 (s, 3 H), 0.89 (s, 9 H), 0.06 (s, 6 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 210.4, 138.4, 132.4, 127.6, 127.2, 95.4, 73.2, 61.6, 55.7, 55.2, 53.2, 43.3, 41.3, 38.5, 38.0, 34.8, 32.2, 29.6, 27.5, 26.8, 26.2, 26.0, 25.9, 25.4, 24.8, 23.2, 22.8, 22.0, 18.2, 14.0, -5.48, -5.54; MS *m/z* (M^+) calcd 636.3702, obsd 636.3705.

Anal. Calcd for $C_{35}H_{60}O_4S_2Si$: C, 65.99; H, 9.49. Found: C, 65.48; H, 9.70.

For **21b**: ^1H NMR (300 MHz, $CDCl_3$) δ 5.73 (br d, J = 6.5 Hz, 1 H), 5.44 (br t, J = 6.9 Hz, 1 H), 4.62 (s, 2 H), 3.93 (s, 2 H), 3.61–3.56 (m, 2 H), 3.38 (s, 3 H), 2.87–2.74 (m, 6 H), 2.45–2.35 (m, 1 H), 2.21–0.87 (series of m, 22 H), 1.68 (s, 3 H), 1.16 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 212.2, 138.2, 136.8, 132.4, 127.9, 127.6, 127.1, 95.4, 73.1, 63.6, 62.1, 56.6, 55.2, 53.0, 44.0, 42.9, 40.9, 40.6, 38.6, 38.4, 37.9, 34.6, 30.6, 30.4, 27.5, 26.7, 26.1, 25.9, 25.3, 24.6, 23.5, 23.1, 22.8, 22.2, 20.6, 14.0; MS *m/z* ($M^+ - H_2O$) calcd 504.2731, obsd 504.2731.

For pure **19a**: ^1H NMR (300 MHz, $CDCl_3$) δ 5.43 (br t, J = 6.2 Hz, 1 H), 5.23 (s, 1 H), 4.94 (s, 1 H), 4.63 (s, 1 H), 4.61 (s, 2 H), 4.57 (s, 1 H), 3.91 (s, 2 H), 3.70 (dd, J = 5.2, 10.2 Hz, 1 H), 3.50–3.43 (m, 1 H), 3.37 (s, 3 H), 2.84–2.40 (m, 6 H), 2.18–2.08 (m, 4 H), 1.96–0.90 (series of m, 16 H), 1.67 (s, 3 H), 1.04 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 153.7, 152.9, 132.3, 127.2, 110.0, 100.9, 95.2, 79.8, 73.0, 67.9, 55.1, 53.0, 45.4, 42.1, 38.7, 36.9, 34.8, 33.8, 28.0, 25.9, 25.3, 25.0, 24.3, 23.3, 22.8, 22.1, 14.0; MS *m/z* (M^+H_2O) calcd 504.2731, obsd 504.2736.

(1*R,2*R**,4*S**,11*S**)-4-[(1*R**,8*E*)-1-[(*tert*-Butyldimethylsiloxy)methyl]-10-(methoxymethoxy)-9-methyl-5-oxo-8-decenyl]-11-methyltricyclo[5.4.0.0^{2,11}]undec-7-en-3-one (22a).** To a solution of *N*-chlorosuccinimide (219 mg, 1.64 mmol), silver nitrate (313 mg, 1.84 mmol), and collidine (0.432 mL, 3.28 mmol) in 80% aqueous acetonitrile (50 mL) was added **20a** (261 mg, 0.409 mmol) dissolved in acetonitrile (3 mL). After 3 min of stirring at rt, the reaction mixture was treated successively with saturated Na_2SO_3 solution, saturated $NaHCO_3$ solution, and brine (10 mL each) at 1 min intervals, then diluted with a 1:1 mixture of CH_2Cl_2 and hexane (30 mL) and filtered through celite/silica gel. The filter pad was rinsed with the same solvent mixture and the filtrate was dried and evaporated. MPLC of the residue (silica gel, elution with 15% ethyl acetate in petroleum ether) afforded 195 mg (87%) of **22a**: IR (neat, cm^{-1}) 1706; ^1H NMR (300 MHz, $CDCl_3$) δ 5.71 (br d, J = 6.9 Hz, 1 H), 5.38 (br t, J = 6.5 Hz, 1H), 4.60 (s, 2 H), 3.90 (s, 2 H), 3.54 (ABq, J_{AB} = 10.1 Hz, J_{BX} = 5.2 Hz, J_{AX} = 4.3 Hz, $\Delta\nu_{AB}$ = 30.2 Hz, 2 H), 3.36 (s, 3 H), 2.77–2.70 (m, 1 H), 2.48–2.26 (m, 7 H), 2.14–1.51 (series of m, 10 H), 1.87 (d, J = 10.5 Hz, 1 H), 1.67 (s, 3H), 1.49–1.21 (m, 3 H), 1.13 (s, 3 H), 0.88 (s, 9 H), 0.02 (s, 3 H), 0.01 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 210.3, 138.5, 133.0, 127.8, 126.6, 95.4, 73.1, 63.0, 55.2, 54.9, 43.1, 42.9, 42.3, 41.4, 34.9, 32.2, 28.1, 27.6, 26.7, 26.2, 25.9, 24.7, 23.2, 22.1, 21.4, 18.3, 14.0, -5.4, -5.5; MS *m/z* (M^+) calcd 546.3740, obsd 546.3743.

Anal. Calcd for $C_{32}H_{54}O_5Si$: C, 70.28; H, 9.95. Found: C, 70.38; H, 10.03.

(1*R,2*R**,4*S**,11*S**)-4-[(1*S**,8*E*)-1-[(*tert*-Butyldimethylsiloxy)methyl]-10-(methoxymethoxy)-9-methyl-5-oxo-8-decenyl]-11-methyltricyclo[5.4.0.0^{2,11}]undec-7-en-3-one (23a).** Treatment of **21a** (13 mg) in an entirely comparable manner gave 11 mg (98%) of **23a**: IR (neat, cm^{-1}) 1705; ^1H NMR (300 MHz, $CDCl_3$) δ 5.70 (br d, J = 7.1 Hz, 1 H), 5.37 (br t, J = 7.1 Hz, 1 H), 4.60 (s, 2 H), 3.90 (s, 2 H), 3.59 (d, J = 3.9 Hz, 1 H), 3.36 (s, 3 H), 2.80–2.73 (m, 1 H), 2.46–2.25 (m, 7 H), 2.14–1.63 (series of m, 10 H), 1.82 (d, J = 10.3 Hz, 1 H), 1.66 (s, 3 H), 1.60–1.41 (m, 1 H), 1.27–1.24 (m, 1 H), 1.14 (s, 3 H), 1.14–1.08 (m, 1 H), 0.93–0.87 (m, 1 H), 0.88 (s, 9 H), 0.03 (s, 6 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 210.5, 210.2, 138.4, 132.8, 127.6, 126.6, 95.4, 73.1, 61.7, 55.7, 55.2, 43.3, 42.9, 42.2, 41.2, 34.8, 32.2, 29.7,

29.2, 27.5, 26.8, 26.2, 25.9, 24.8, 23.2, 22.1, 21.8, 18.2, 14.0, −5.5, −5.6; MS m/z (M^+) calcd 546.3740, obsd 546.3755.

Anal. Calcd for $C_{32}H_{54}O_5Si$: C, 70.28; H, 9.95. Found: C, 70.43; H, 10.01.

(1*R,2*R**,4*R**,11*S**)-4-[(1*R**,8*E*)-1-[(*tert*-Butyldimethylsiloxy)methyl]-10-(methoxymethoxy)-9-methyl-5-oxo-8-decenyl]-11-methyltricyclo[5.4.0.0^{2,11}]undec-7-en-3-one (22b).** The β isomer was isolated from attempts to cyclize diketone **22a**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.69 (br d, J = 7.1 Hz, 1 H), 5.38 (br t, J = 6.2 Hz, 1 H), 4.60 (s, 2 H), 3.90 (s, 2 H), 3.49 (s, 1 H), 3.47 (d, J = 1.5 Hz, 1 H), 3.37 (s, 3 H), 2.52–2.23 (series of m, 10 H), 2.22–1.80 (m, 2 H), 1.80–0.87 (series of m, 10 H), 1.67 (s, 3 H), 1.18 (s, 3 H), 0.87 (s, 9 H), 0.03 (s, 3 H), 0.02 (s, 3 H); MS m/z (M^+ − t-Bu) calcd 489.3037, obsd 489.3059.

(1*R,2*R**,4*R**,11*S**)-4-[(1*S**,8*E*)-1-[(*tert*-Butyldimethylsiloxy)methyl]-10-(methoxymethoxy)-9-methyl-5-oxo-8-decenyl]-11-methyltricyclo[5.4.0.0^{2,11}]undec-7-en-3-one (23b).** The β isomer was isolated from attempts to cyclize diketone **23a**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.70 (br d, J = 6.2 Hz, 1 H), 5.38 (br t, J = 5.8 Hz, 1 H), 4.61 (s, 2 H), 3.91 (s, 2 H), 3.59 (dd, J = 4.8, 10.3 Hz, 1 H), 3.40 (dd, J = 8.1, 10.2 Hz, 1 H), 3.37 (s, 3 H), 2.56–1.90 (series of m, 12 H), 1.88–0.86 (series of m, 10 H), 1.68 (s, 3 H), 1.19 (s, 3 H), 0.87 (s, 9 H), 0.03 (s, 3 H), 0.02 (s, 3 H); MS m/z (M^+ − t-Bu) calcd 489.3037, obsd 489.3059.

(1*R,2*S**,11*R**)-11-Methyl-3-methylenetricyclo[5.4.0.0^{2,11}]undec-7-ene (29).** A suspension of methyltriphenylphosphonium bromide (82 mg, 0.229 mmol) in dry THF (3 mL) and anhydrous HMPA (0.1 mL) was cooled to 0 °C and treated dropwise with 0.5 M potassium hexamethyldisilazide (0.45 mL, 0.225 mmol). After 15 min of stirring at 0 °C, a solution of **28** (30 mg, 0.171 mmol) in THF (0.75 mL) was introduced dropwise. The reaction mixture was stirred for 2 h at 0 °C, quenched with saturated NH_4Cl solution (5 mL), and diluted with ether (10 mL). The separated aqueous phase was extracted with ether (2 × 10 mL), and the combined organic solutions were dried, filtered, and concentrated. The residue was purified by flash chromatography (silica gel, elution with petroleum ether) to give **29** (24 mg, 82%) as a colorless oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.64 (d, J = 7.3 Hz, 1 H), 5.01 (s, 1 H), 4.59 (dd, J = 2.3, 2.3 Hz, 1 H), 2.37–2.25 (m, 2 H), 2.10–1.70 (series of m, 5 H), 1.65–1.55 (m, 3 H), 1.26 (d, J = 6.9 Hz, 1 H), 1.18 (s, 3 H), 1.03 (d, J = 8.8 Hz, 1 H), 1.14–0.86 (m, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 147.0, 140.4, 125.8, 115.6, 38.0, 36.4, 36.3, 31.7, 28.8, 27.1, 26.5, 24.1, 23.6; MS m/z (M^+) 174.1409, obsd 174.1411.

(1*R,2*S**,11*S**)-3-[(*Z*)-Benzylidene]-11-methyltricyclo[5.4.0.0^{2,11}]undec-7-ene (30).** Diethyl benzylphosphonate (690 mg, 2.84 mmol) in dry THF (3 mL) was added dropwise to a magnetically stirred suspension of potassium hydride (114 mg, 2.84 mol) in dry THF (1 mL). The mixture was stirred at rt for 45 min before a solution of **28** (104 mg, 0.596 mmol) in the same solvent (1.5 mL) was introduced dropwise. After 26 h, water (5 mL) and ether (10 mL) were added, and the separated aqueous phase was extracted with ether (3 × 10 mL). The combined solutions were dried and concentrated to leave a residue that was filtered through a pad of silica gel (elution with petroleum ether) and subjected to Kugelrohr distillation to afford 140 mg (93%) of **30** as a colorless liquid: bp 155–165 °C (0.3 Torr); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.54–7.36 (m, 2 H), 7.34–7.20 (m, 2 H), 7.18–7.12 (m, 1 H), 5.62 (d, J = 7.2 Hz, 1 H), 2.49 (ddd, J = 13.7, 6.0, 2.0 Hz, 1 H), 2.32–2.15 (m, 2 H), 2.10–2.05 (m, 1 H), 2.03–1.91 (m, 1 H), 1.90–1.80 (m, 1 H), 1.70 (dd, J = 9.1, 2.0 Hz, 1 H), 1.60–1.50 (m, 2 H), 1.25 (s, 3 H), 1.30–1.16 (m, 1 H), 1.11 (br d, J = 9.0 Hz, 1 H), 0.96 (ddd, J = 13.5, 3.6, 2.5 Hz, 1 H), 0.67 (td, J = 13.2, 4.0 Hz, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) pm 140.8, 138.5, 129.2, 128.5, 127.5, 126.3, 126.0, 39.6, 36.4, 35.0, 31.4, 29.6, 26.7, 26.3, 24.6, 23.4; MS m/z (M^+) calcd 250.1722, obsd 250.1723.

The stereochemistry of **30** was assigned on the basis of NOE experiments. Double irradiation of the *o*-phenyl protons induced 5% intensity enhancement of both the styrenyl and external cyclopropyl hydrogens. Double irradiation of the vinylic proton caused a 3% intensity enhancement of the *o*-phenyl hydrogens and a 5% effect on the nearby β-methylene hydrogen.

Methyl (1*R,2*S**,11*S**)-11-Methyltricyclo[5.4.0.0^{2,11}]undec-7-ene-Δ$^{3,\alpha}$-acetate (31).** Oil-free potassium hydride (29 mg, 0.733 mmol) was suspended in dry THF (2 mL) under N_2, treated dropwise with triethylphosphonoacetate (0.16 mL, 0.733 mmol) via syringe, and stirred at rt for 1 h. Following the introduction of **28** (21 mg, 0.119 mmol) dissolved in THF (1.5 mL), the mixture was stirred at rt for 3 h and at reflux for 115 h, allowed to cool, and quenched with water (3 mL). After extraction with ether (4 × 5 mL), the combined organic layers were dried and concentrated to leave a residue that was chromatographed on silica gel (elution with 0–5% ethyl acetate in petroleum ether). There was isolated 13 mg (43%) of **31** and 11 mg (54%) of **28**.

For **31**: colorless oil (a 57:43 mixture of isomers); ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.84 (m, 0.6 H), 5.63 (br m, 1 H), 5.51 (br s, 0.4 H), 4.20–4.02 (m, 2 H), 3.24 (dd, J = 5.9, 13.6 Hz, 0.4 H), 2.36–2.31 (m, 0.6 H), 2.26–2.16 (m, 2 H), 2.10–1.91 (m, 3 H), 1.81–1.64 (m, 2 H), 1.61–1.47 (m, 2H), 1.30 (s, 1.4 H), 1.26 (s, 1.6 H), 1.29–1.18 (m, 3 H), 1.16 (d, J = 9.1 Hz, 1 H), 1.10 (ddd, J = 4.1, 13.1, 13.2 Hz, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 166.4, 166.2, 160.8, 159.8, 139.5, 139.2, 127.1, 126.5, 120.94, 120.87, 59.50, 59.46, 38.5, 37.7, 36.1, 35.9, 35.4, 33.4, 29.8, 328.5, 28.3, 28.1, 27.0, 26.7, 25.9, 24.8, 24.5, 23.4, 23.3, 14.4, 14.3; MS m/z (M^+) calcd 246.1620, obsd 246.1614.

(1*R,2*R**,3*S**,11*S**)-11-Methyl-3-vinyltricyclo[5.4.0.0^{2,11}]undec-7-en-3-ol (32).** A solution of vinylmagnesium bromide, prepared from vinyl bromide (720 mg, 6.73 mmol) and magnesium turnings (130 mg, 5.42 mmol) in dry THF (5 mL), was added via cannula to a solution of **28** (132 mg, 0.749 mmol) in THF (1 mL) at 0 °C. The mixture was stirred at 0 °C for 30 min and at rt for 1 h, quenched cautiously with water, and extracted with ether. The combined organic phases were dried and concentrated to leave a residue that was subjected to flash chromatography on silica gel (elution with 5% ethyl acetate in petroleum ether). There was isolated 95 mg (62%) of **32** and 7 mg (7%) of a 2:1 mixture of **33** and unreacted **28**. The latter fraction was not further purified.

For **32**: colorless oil; ^{1}H NMR (300 MHz, C_6D_6) δ 6.04 (ddd, J = 0.8, 10.7, 17.2 Hz, 1 H), 5.51 (d, J = 6.7 Hz, 1 H), 5.39 (dd, J = 1.7, 17.2 Hz, 1 H), 4.98 (dd, J = 1.7, 10.6 Hz, 1 H), 2.80 (ddd, J = 5.0, 12.7, 14.0 Hz, 1 H), 2.21 (dt, J = 12.3, 4.3 Hz, 1 H), 2.24–1.85 (m, 2 H), 1.78–1.38 (m, 7 H), 1.00 (s, 3 H), 0.75 (d, J = 9.6 Hz, 1 H), 0.55 (d, J = 9.6 Hz, 1 H); ^{13}C NMR (75 MHz, C_6D_6) ppm 148.1, 141.2, 124.6, 109.6, 76.5, 41.2, 37.2, 36.2, 29.1, 27.1, 26.7, 25.2, 24.9, 23.5; MS m/z (M^+) calcd 204.1514, obsd 204.1511.

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Supplementary Material Available: 300-MHz ^{1}H and 75-MHz ^{13}C NMR spectra of those compounds lacking combustion data (39 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.