(m, 2 H), 1.72 (t, J = 2.0 Hz, 3 H), 1.47 (tm, J = 7.7 Hz, 2 H), 1.01 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 213.14, 129.79, 129.57, 62.92, 50.10, 48.47, 39.47, 33.21, 31.64, 26.57 23.80, 15.25; MS m/z (M^+) calcd 194.1307, obsd 194.1323.

Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 73.92; H, 9.35.

For **25**: oil; IR ($CHCl_3$, cm^{-1}) 3600, 1715; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.04 (s, 2 H), 3.31 (t, J = 3.0 Hz, 1 H) 2.53 (br, 1 H), 2.12-2.03 (m, 4 H), 1.88-1.75 (m, 2 H), 1.67 (dd, J = 1.5, 1.3 Hz, 3 H), 1.50-1.28 (m, 2 H), 1.02 (s, 3 H); ^{13}C NMR (75 MHz) ppm 213.36, 130.54, 130.45, 62.43, 49.95, 48.07, 40.77, 33.12, 31.69, 26.56, 24.20, 16.39; MS m/z (M^+) calcd 194.1307, obsd 194.1298.

Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 74.19; H, 9.20.

Acknowledgment. We are grateful to the National Institutes of Health for their financial support of this work (Grant GM-30827).

Functionalization Reactions of a Medium-Ring Bridgehead Enone That Skirt Transannular Bond Formation

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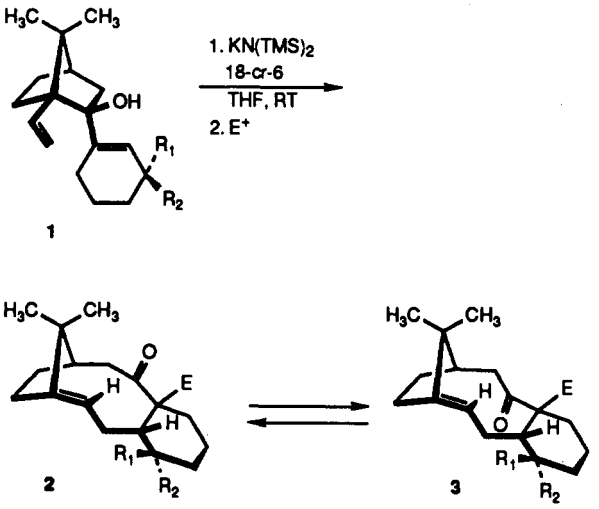
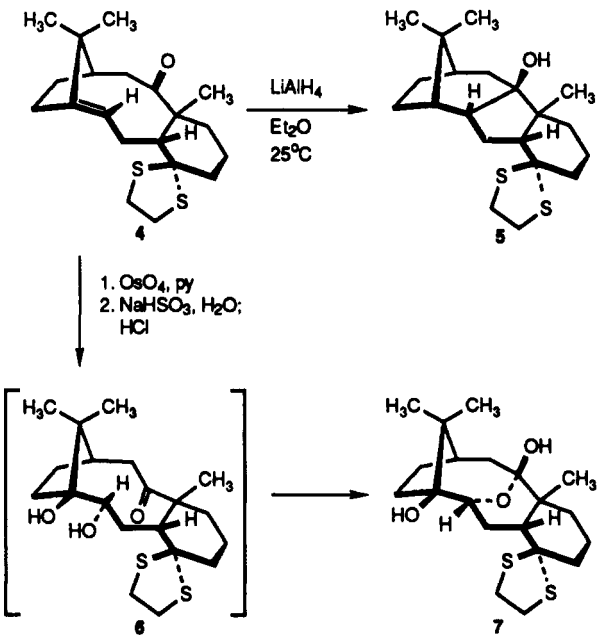
As a consequence of the close proximity of the olefinic and carbonyl centers in ketone **4**, the molecule participates readily in transannular reactions. Sequences have been developed for enhancing the level of functionality in both of these sectors within the central medium-sized ring without incurring ring closure. Osmate ester **10** is especially serviceable, permitting direct access to triol **11** and to the olefinic hydroxy acetate **17**. In a companion study, acetals **19a** and **19b** were prepared from **11** and dehydrated with the Burgess reagent. The trans cycloalkene generated in each instance was shown to possess the topography found in **21**, a conclusion that was further supported by deuterium labeling experiments. Access to this diastereomer made possible the acquisition of diacetates **23a** and **23b**, where seven of the nine carbon atoms of the central ring are stereogenic and have well-defined absolute stereochemistry.

Optically pure 1-vinyl-2-alkenyl-7,7-dimethyl-*exo*-norbornan-2-ols typified by **1** undergo anionic oxy-Cope rearrangement[1,2] with strict adherence to an endo-chair transition state to deliver *E*,syn ketones such as **2** rapidly at room temperature.[3-5] This notably efficient transformation is often atropselective and can lead to the "carbonyl up" conformer **2** or its "carbonyl down" diastereomer **3** depending upon the nature of R_1, R_2, and E.[3,4] The rate at which **2** and **3** interconvert and the magnitude and sign of K_{eq} are likewise sensitive to these substituents.[4,6]



Scheme I



The central ring in **2** and **3** is of the previously unknown[9] 5(*E*)-cyclononenone type. The minimum energy conformations of **2** and **3** (where R_1, R_2 = dithiolane and E = CH_3) have been estimated by molecular mechanics calculations (MODEL KS 2.93)[7] and are depicted in Figure 1. Despite many differing aspects of structure, both molecules

(1) (a) Paquette, L. A. *Angew. Chem.* **1990**, *102*, 642; *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 609. (b) Paquette, L. A. *Synlett* **1990**, 67.

(2) (a) Hill, R. K. in *Asymmetric Synthesis*; Morrison, J. D., Ed.; Academic Press: New York, 1984; Vol. 3A, p 503. (b) Hill, R. K. In *Comprehensive Organic Synthesis*; Pergamon Press: New York, in press.

(3) Paquette, L. A.; Pegg, N. A.; Toops, D.; Maynard, G. D.; Rogers, R. D. *J. Am. Chem. Soc.* **1990**, *112*, 277.

(4) Paquette, L. A.; Combrink, K. D.; Elmore, S. W.; Rogers, R. D., submitted for publication.

(5) Elmore, S. W.; Paquette, L. A., submitted for publication.

(6) Paquette, L. A.; DeRussy, D. T.; Pegg, N. A.; Taylor, R. T.; Zydowsky, T. M. *J. Org. Chem.* **1989**, *54*, 4576.

(7) We thank Professor W. C. Still (Columbia University) for making his program available to us and Professor K. Steliou (University of Montreal) for providing us with updates of this software package.

(8) Cope, A. C.; Martin, M. M.; McKervey, M. A. *Q. Rev. Chem. Soc.* **1966**, *20*, 119.

(9) A search of CAS ONLINE uncovered only two citations under cyclononenone, neither of which dealt with the 5-isomer: (a) Mehta, G. *Org. Prep. Proced.* **1970**, *2*, 245. (b) Baldwin, J. E.; Adlington, R. M.; Robertson, J. *Tetrahedron* **1989**, *45*, 909.

0022-3263/91/1956-2461$02.50/0

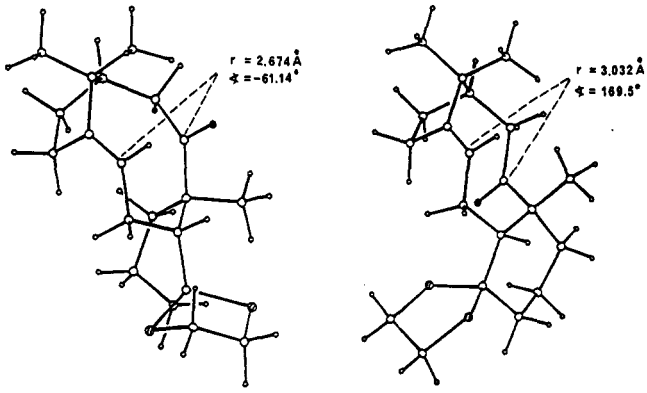
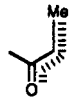


Figure 1. Energy-minimized conformations of 2 (left) and 3 (right) (R_1, R_2 = dithiolane and E = Me) showing the magnitudes of the transannular olefin-carbonyl gap (r) and dihedral angle



share in common the feature that the less substituted transannularly positioned olefinic carbon resides in close proximity to the carbonyl carbon. At 2.674 Å, the distance in the *E*,syn,up structure is somewhat shorter than the gap seen in its atropisomer. Nevertheless, the nonbonded carbon atoms in question in both atropisomers are sufficiently proximate that heightened transannular reactivity can be anticipated.[8] In an effort to gain insight into the reactivity of these molecules, particularly as a prelude to a synthetic thrust in the taxane area, we have examined reactions involving 4 with the objective of increasing the level of functionalization while maintaining the cyclononanoid core intact.

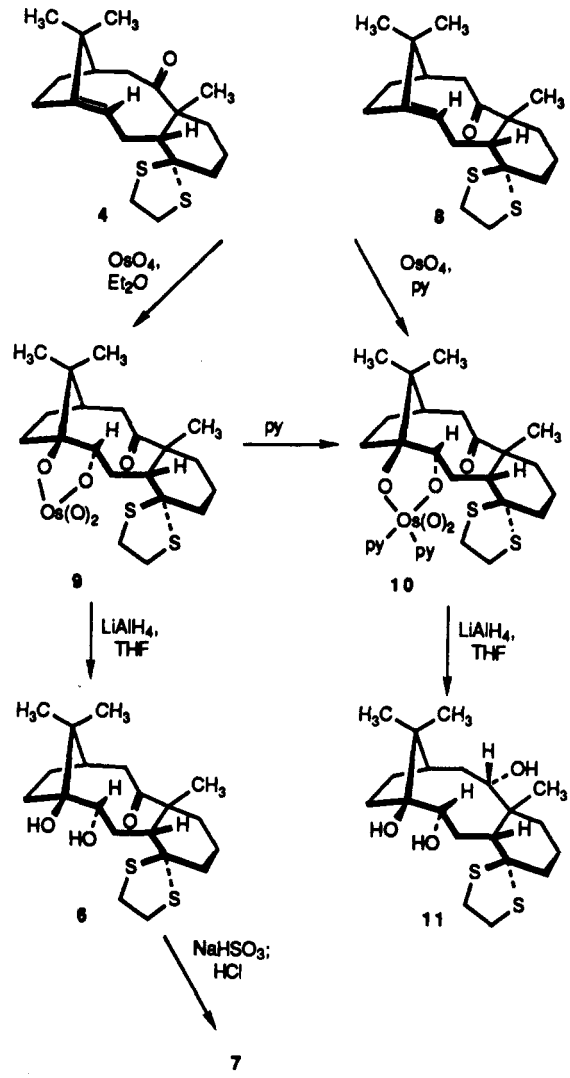
Results and Discussion

The Undesired Transannular Phenomenon. In a series of early experiments, we sought to determine if the carbonyl group in 4 is subject to stereocontrolled reduction. Consequently, ketone 43 was exposed to Dibal-H in refluxing THF, $LiAlH_4$ at −23 °C,[10] SmI_2,[11] and the ate complex derived from *n*-BuLi–Dibal-H.[12] Under these conditions, only the very slow formation of a *tertiary* alcohol was observed, if any reaction occurred at all. When recourse was made instead to ethereal $LiAlH_4$ at room temperature, 4 was entirely consumed after 24 h and 5 was isolated in an unoptimized yield of 22% (Scheme I). This singular observation made evident from the outset the facility with which transannular bonding can materialize in such systems.

The structural assignment to 5, which is fully corroborated by its ^1H and ^{13}C NMR spectra, follows logically from proximity considerations (see Figure 1), from the *E* geometry about the double bond in 4, and from the favorable thermodynamics attending formation of a cis (rather than trans) bicyclo[4.3.0]nonanol. The alternative highly congested diastereomer bearing the fusion point H and OH substituents on the α-face would require prior stereochemical inversion in both the front and rear sectors of the central ring, an unlikely scenario in light of the substantial energy of activation associated merely with orienting the carbonyl oxygen downward.[4]

Transannular reactivity also surfaced in the context of preliminary studies involving osmylation of the double bond in 4. Direct bisulfite reduction of the osmate ester

Scheme II



that is formed efficiently in pyridine solution gave rise not to 6, but the bridged ether 7 (70%). Since 6 was not detected, hemiketal formation was evidently rapid during the workup procedure (see below). Furthermore, the cyclized tautomer 7 does not revert readily to 6 when subjected to further reaction. Acetylation, for example, provides the unrearranged tertiary acetate derived from 7.[13]

The outcome of the above reactions is clearly unsatisfactory relative to our goals. In what follows, these problems are overcome through adaptation of suitable procedures.

Controlled Functionalization about the Double Bond. When the osmylation of 4 or its atropisomer 8 was carried out with stoichiometric amounts of OsO_4 in ether solution, the resulting osmate ester 9 could be reductively cleaved to 6 by short exposure (3 h) to $LiAlH_4$ at room temperature (Scheme II). Thus, saturation of the double bond in 4 and 8 reduces the barrier to atropisomerization sufficiently such that bond rotation to orient the carbonyl oxygen in the thermodynamically preferred "down" position operates readily at room temperature. The ease with which 6 can be isolated is equally notable. However, in the presence of aqueous $NaHSO_3$, or weakly acidic or basic reagents in general, the previously observed conversion to 7 occurs rapidly.

When the osmylation of 4 or 8 is performed instead in pyridine, ester 10 is formed efficiently. The same product, which is amenable to purification by column chromatog-

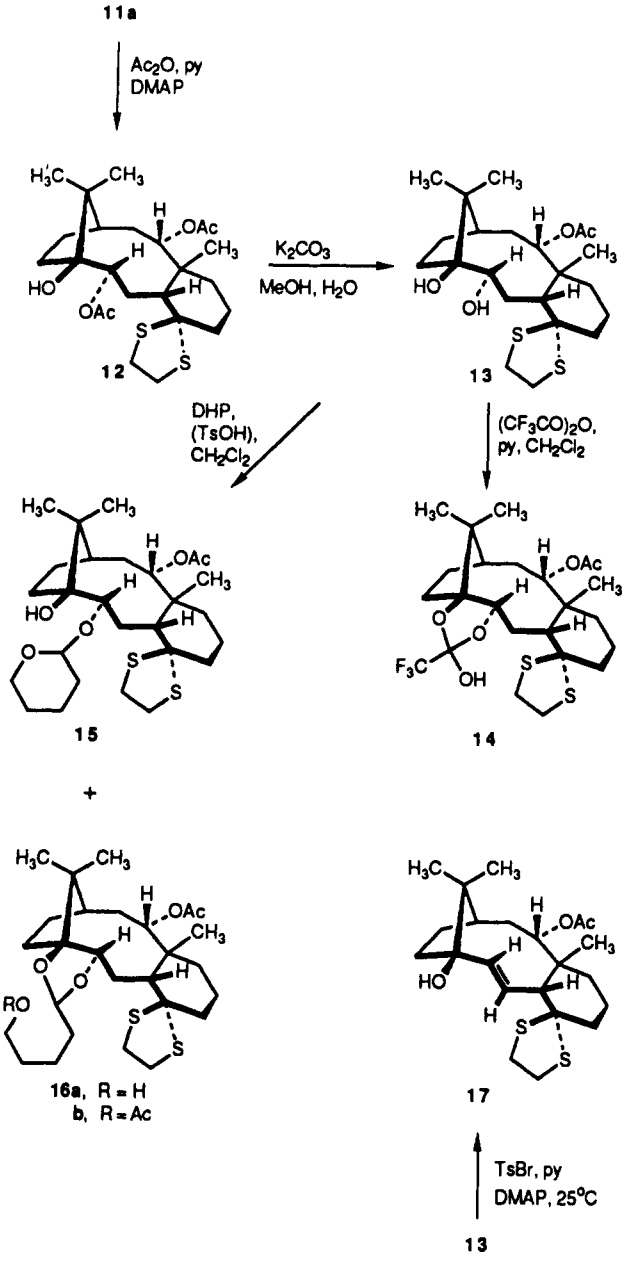
(10) (a) Girard, P.; Nany, J.-L.; Kagan, H. B. *J. Am. Chem. Soc.* **1980**, *102*, 2693. (b) Singh, A. K.; Bakshi, R. K.; Corey, E. J. *Ibid.* **1987**, *109*, 6187.

(11) Paquette, L. A.; Colapret, J. A.; Andrews, D. A. *J. Org. Chem.* **1985**, *50*, 201 and relevant references cited therein.

(12) Kim, S.; Ahn, K. H. *J. Org. Chem.* **1984**, *49*, 1717.

(13) Elmore, S. W., unpublished results.

Scheme III



raphy on silica gel, is arrived at by dissolution of **9** in pyridine. The reduction of **10** with $LiAlH_4$ proceeds more slowly than in the case of **9**. Consequently, triol **11** is formed.

To establish beyond doubt the configurations of the newly introduced stereogenic centers in **11**, a single-crystal X-ray analysis was undertaken. The ORTEP diagram resulting from this study (Figure 2) discloses further that the carbinol carbon (labeled as C-6) prefers to remain remote to the *gem*-dimethyl substituted bridge, at least in the solid state. Our illustration of **11** in Scheme II does not reflect this conformational feature of the triol in order to achieve maximum clarity in depicting configuration.

Although the ease of conversion of **6** to **7** precluded its serviceability as a useful intermediate, this was not the case with **11**. Its treatment with acetic anhydride in pyridine containing a catalytic quantity of DMAP afforded **12** (79%). As seen in Scheme III, selective hydrolysis to provide **13** (96%) was possible with potassium carbonate in aqueous methanol.

Given the ready availability of **13**, the stage was set for investigating the proximity effects offered by the vicinal hydroxyl substitution plan. The action of excess tri-

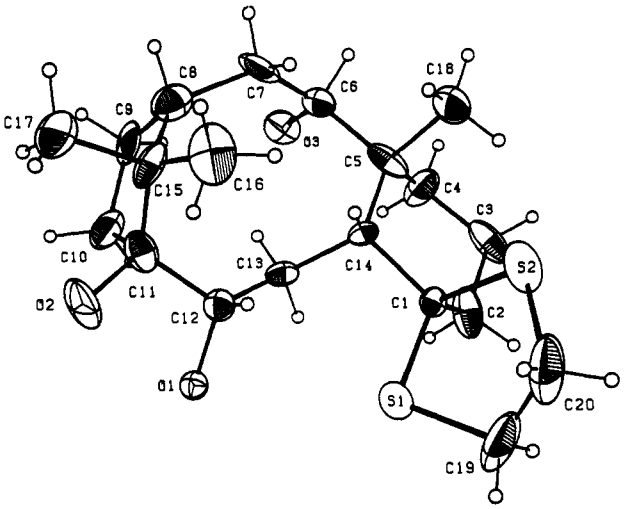
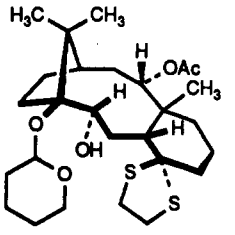


Figure 2. Computer-generated perspective drawing of **11** as determined by X-ray analysis.

fluoroacetic anhydride and pyridine on **13** presumably resulted in initial conversion to the secondary trifluoroacetate. However, the electron deficiency induced by the fluorine atoms flanking the carbonyl carbon provides a driving force adequate for fostering subsequent internal attack by the vicinal tertiary hydroxyl group to afford **14** (a 2:1 mixture of epimers). The latter could be chromatographed on silica gel without event.

The acid-catalyzed condensation of **13** with dihydropyran in CH_2Cl_2 at room temperature afforded a 4:1 mixture of **15** and **16a**. Extension of the reaction time to 4 h gave **16a** as the predominant product. The spectral properties of **16a** did not unequivocally rule out the possibility that the compound was actually **18**, in which the tetrahydropyranyl group had completely migrated to the tertiary site. Further consideration of **18** could be dismissed, however, by virtue of the ease with which acetylation can be realized. The acetate must be primary as in **16a** since **13** is not acetylated under the conditions employed. We would expect the reactivity of **18** to be comparable. The ^1H and ^{13}C NMR spectra of **16a** and **16b** are so similar that the possibility of further equilibration during acetate formation can be dismissed.

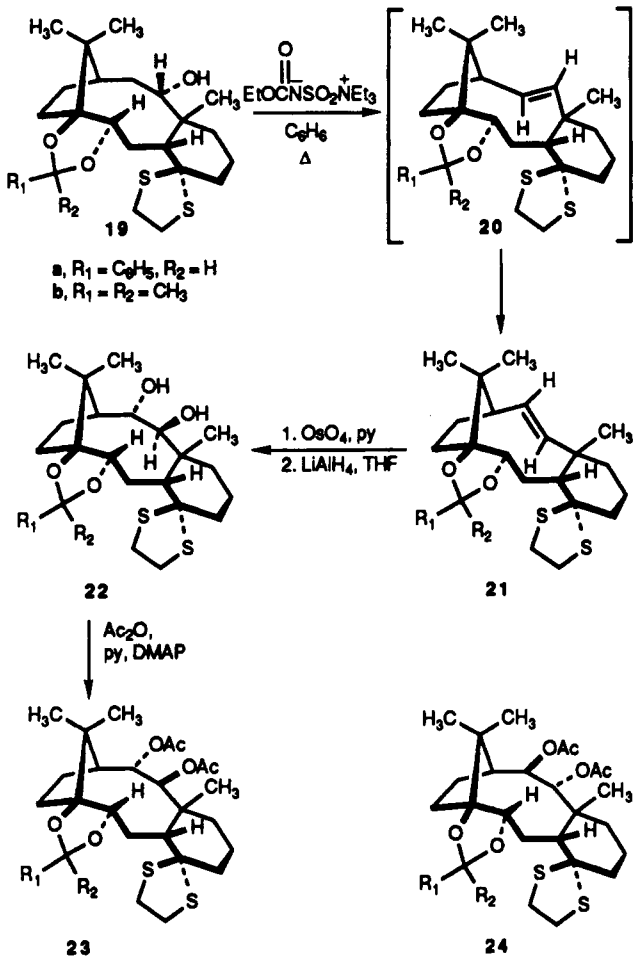


18

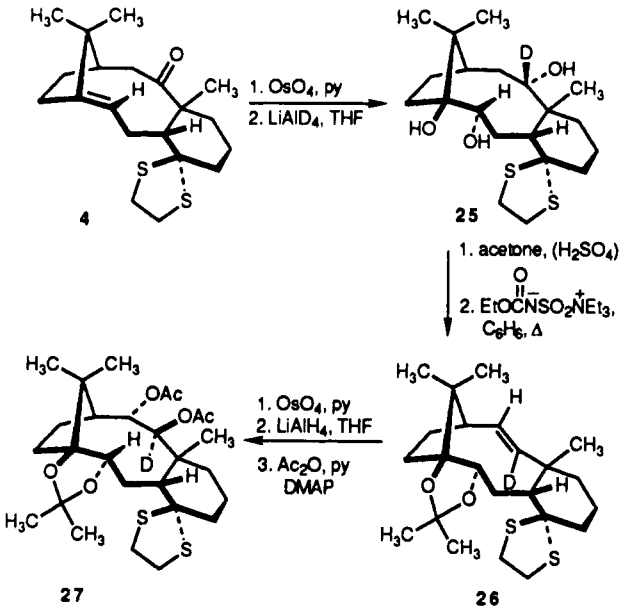
In view of the reluctance of **13** to undergo acylation, we were not surprised to find that its reactivity toward sulfonyl halides and anhydrides was also quite low. This sluggishness can be exemplified by the complete recovery of **13** following exposure to 10 equiv of methanesulfonic anhydride in pyridine containing DMAP at 70 °C for 24 h. However, a useful advance materialized when **13** was stirred overnight with the more reactive tosyl bromide[14] under identical conditions except for a lower temperature (25 °C). This strategy provided for the isolation of allylic alcohol **17** (42%) along with a minor second nonsulfuraceous product that has not been characterized. The *E*

(14) Effenberger, F.; Huthmacher, K. *Chem. Ber.* **1976**, *109*, 2315.

Scheme IV

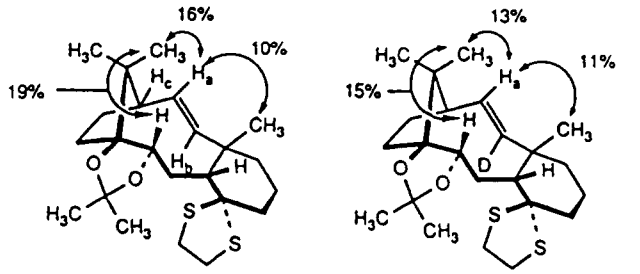


Scheme V



geometry of **17** was readily established by the large coupling constant observed for the alkene protons (J = 15.9 Hz). Furthermore, formation of the specific E isomer shown was confirmed by NOE and COSY measurements made on $CDCl_3$ solutions of this white foamy solid.

Chemical Manipulation in the Rear Sector. With a successful procedure established for introducing unsaturation and a bridgehead hydroxyl group along the leading edge of the central ring, the goal of the next phase of this study was to accomplish comparably heightened functionalization in the rear sector of this ring. Initially, **11** was transformed into both **19a** and **19b** (Scheme IV). The benzylidene acetal was obtained as one essentially pure diastereomer. The configuration of the benzylic carbon was not established, although the strong likelihood exists that the aryl group is β-oriented. Heating either **19a** or **19b** in benzene with the Burgess inner salt[15] led in good yield to an E-cycloalkene in each instance (J = 16.9 or 17.0 Hz). A detailed examination of molecular models of **19** show convincingly that the residual hydroxyl group does not reside syn to either neighboring hydrogen. A modest amount of σ bond rotation does, however, establish a geometric relationship such that syn elimination becomes kinetically feasible. This process leads uniquely to **20**. However, the NOE spectra recorded for the pair of alkenes obtained from **19a** and **19b** suggested that rotamer **21** and not **20** was actually in hand. This conclusion rests on the accuracy of the assignments made to the olefinic signals arising from H_a and H_b. Only one of these resonances is seen to experience added spin–spin interaction (J = 2.9 Hz). This less pronounced coupling could be the result of J_{AC}. The possibility that a W-plan coupling of the J_{BC} type was responsible was given less credence because of the almost orthogonal relationship to H_B and H_C, as established by an examination of molecular models. When attempts to grow X-ray quality crystals of either cycloalkene were to no avail, recourse was made to deuterium labeling.



H_a: δ 5.67 (dd, J = 17.0, 2.9 Hz)
H_b: δ 5.46 (d, J = 17.0 Hz)

21b

H_a: δ 5.66 (dd, J = 17.0 Hz)

28

Following osmylation of **4** in pyridine and reduction with $LiAlD_4$, the monodeuterated triol **25** was obtained (Scheme V). The subsequent conversion of **25** into **26** was performed in a manner analogous to that described for the preparation of **21**. The spectral features of this E-olefin confirmed that **21** had in fact been formed exclusively in the reaction of **19** with the Burgess inner salt.

The discrepancy between our formulation of the likely kinetic product, viz. **20**, and that actually observed (**21**) can be construed as an indicator that the σ bond rotation that gives rise to this diastereomerism may be thermodynamically driven. Accordingly, the global minimum energy conformations of **20b** and **21b** were determined using MODEL (KS 2.93) in conjunction with its companion program BAKMDL.[7] Of note were the particularly distinctive conformational differences in the six-membered rings of the low-energy conformations of **20b** and **21b**. As seen in Figure 3, orientation of the double bond as in **20** has the net effect of forcing the fused cyclohexane to adopt a boat conformation. Evidently, this specific π-bond arrangement cannot readily accommodate the external diheral angles demanded by the chair geometry. This is not

(15) Burgess, E. M.; Penton, H. R., Jr.; Taylor, E. A. *J. Org. Chem.* 1973, *38*, 26.

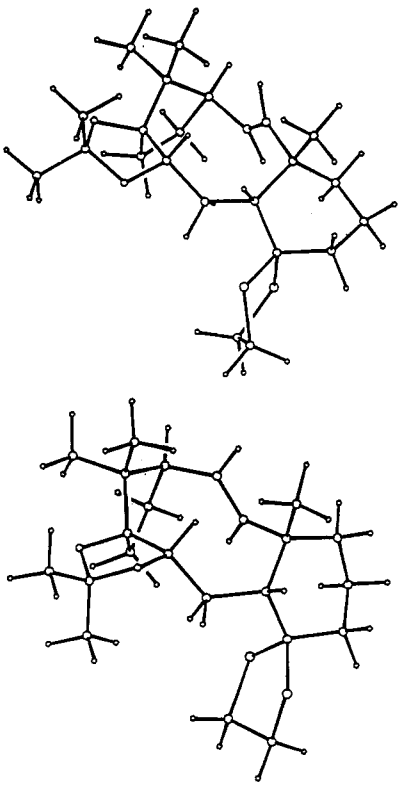
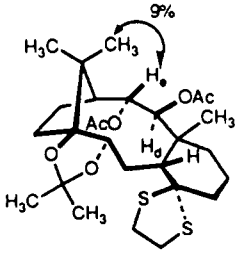


Figure 3. Energy-minimized conformations of **20b** (top) and **21b** (bottom) showing the differing spatial arrangements of the six-membered ring.

the case in **21** where a chairlike disposition of the cyclohexane ring is comfortably tolerated.

This distinguishing characteristic is also present in the atropisomeric ketones **2** (boatlike) and **3** (chairlike) as seen upon close examination of Figure 1. The important insight provided by these models leads us to the tentative working assumption that the extent to which the cyclohexane ring controls structural thermodynamics may be greater than previously appreciated. In the future, we hope to provide a more detailed frame of reference against which these considerations can be examined in a more sophisticated way. In the interim, the conformational diagrams contained in Figures 1 and 3 constitute a useful tool for gauging the preferred direction of topographical change in these molecules.

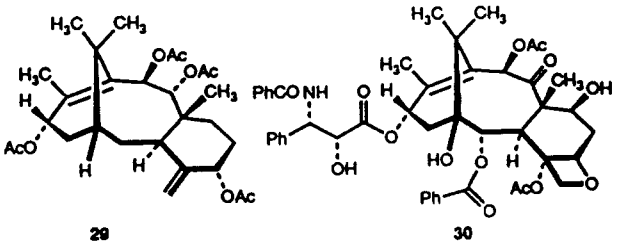
Osmylation of **21a** and **21b** led to diols having the stereochemistry depicted in **22**. Acetylation subsequently provided **23**. Engagement of d_1 derivative **26** in the same reaction sequence furnished **27**. The latter diacetate lacked a signal at δ 5.51 (in C_6D_6) present in **23b**, thereby identifying the chemical shift of H_d in **23b**. NOE studies on



23b

23b indicated that H_d was not proximate to either of the key methyl groups, which would have been expected if the alternative stereochemistry defined in **24** had been obtained. On the other hand, the intense NOE to H_e (δ 5.64) is quite apparent.

The preceding experiments make available an intermediate, viz. **21**, that is amenable to cis hydroxylation and stereocontrolled conversion to **23**. The high level of oxygenation present in these intermediates and the fully stereocontrolled manner in which these centers are established are noteworthy. In a more general sense, reactions of the type described herein should be adaptable for use in the elaboration of taxanes represented by taxusin (**29**) and taxol (**30**). Developments along these lines will be reported in due course.



29 **30**

Experimental Section

Melting points are uncorrected. Mass spectra were recorded by Mr. Dick Weisenberger at The Ohio State University Chemical Instrument Center. Elemental analyses were performed at the Scandinavian Microanalytical Laboratory, Herlev, Denmark. All separations were carried out under flash chromatography conditions on Merck silica gel HF_{254}. In all reactions, the organic extracts were dried over anhydrous magnesium sulfate. Solvents were reagent grade and in many cases were dried prior to use.

(4′a*R*,4′b*R*,6′*R*,9′*S*,9′a*R*,10′a*R*)-Decahydro-4′a,11′,11′-trimethylspiro[1,3-dithiolane-2,1′(2*H*)-[6,9]methanobenz[*a*]azulen]-4′b(3′*H*)-ol (5). A mixture of lithium aluminum hydride (14 mg, 2.6 equiv) in anhydrous ether (1 mL) was treated with a solution of **4** (50 mg, 0.142 mmol) in ether (1 mL) under argon. The mixture was stirred for 24 h at room temperature, quenched with 10% NaOH solution (4 mL), and extracted with ether (3 × 10 mL). The combined organic phases were washed with water (10 mL) and brine (10 mL) prior to drying and solvent removal. Purification of the residue by chromatography on silica gel gave 3.1 mg (22%) of **5** as a white solid: IR ($CHCl_3$, cm^{-1}) 3610, 3020–2800, 1490–1400, 975; ^1H NMR (300 MHz, C_6D_6) δ 3.05–2.75 (m, 4 H), 2.60 (ddd, J = 5.9, 9.9, 15.7 Hz, 1 H), 2.25–0.85 (series of m, 18 H), 1.53 (s, 3 H), 1.20 (s, 3 H), 1.04 (s, 3 H); ^{13}C NMR (75 MHz, C_6D_6) ppm 81.91, 70.71, 54.32, 50.73, 49.63, 46.25, 43.25, 40.10, 39.51, 38.62, 37.14, 34.16, 29.56, 28.07, 27.22, 23.34, 22.20, 21.67, 20.00 (one C not observed); MS m/z (M^+) calcd 352.1894, obsd 352.1897.

(4′a*R*,5′*S*,7′*R*,10′*S*,11′*S*,12′a*R*)-Decahydro-4′a,14′,14′-trimethylspiro[1,3-dithiolane-2,1′(2′*H*)-[5,11]epoxy[7,10]methanobenzocyclodecene]-5′,10′-diol (7). A solution of **4** (200 mg, 0.57 mmol) in pyridine (5 mL) was treated with osmium tetroxide in pyridine (1.44 mL of a solution containing 1 g OsO_4 per 10 mL, 1 equiv), and the mixture was stirred overnight at room temperature. Aqueous 5% $NaHSO_3$ solution (35 mL) was introduced, and stirring was continued for an additional 24 h. The resulting mixture was filtered through Celite and rinsed with ethyl acetate (50 mL). The filtrate was extracted further with ethyl acetate (3 × 30 mL), and the combined organic phases were washed with 2 M HCl (2 × 30 mL) and brine (30 mL) prior to drying and solvent removal. Silica gel chromatographic purification of the residue gave **7** (153 mg, 70%) as a white solid: IR ($CHCl_3$, cm^{-1}) 3600, 3040–2800, 1500–1440, 1390, 1335, 1285, 1250–1200, 1135, 1100–1030; ^1H NMR (300 MHz, C_6D_6) δ 3.93 (d, J = 10.8 Hz, 1 H), 2.90–2.60 (m, 5 H), 2.36 (dd, J = 7.0, 15.1 Hz, 1 H), 2.25–1.80 (m, 10 H), 1.75–1.40 (m, 4 H), 1.47 (s, 3 H), 1.20–0.90 (m, 2 H), 1.11 (s, 3 H), 0.89 (s, 3 H); ^{13}C NMR (75 MHz, C_6D_6) ppm 101.05, 84.00, 79.85, 73.94, 49.23, 46.80, 43.88, 42.31, 39.85, 38.59, 37.73, 36.00, 35.74, 28.11, 25.08, 23.66, 20.84, 20.53, 19.11; MS m/z (M^+) calcd 384.1793, obsd 384.1811.

Anal. Calcd for $C_{20}H_{32}O_3S_2$: C, 62.46; H, 8.39. Found: C, 62.36; H, 8.52.

(4′a*R*,7′*R*,10′*S*,11′*S*,12′a*R*)-Dodecahydro-10′,11′-dihydroxy-4′a,13′,13′-trimethylspiro[1,3-dithiolane-2,1′(5′*H*)-

[7,10]methanobenzocyclodecen]-5′-one (6). A solution of **4** (128 mg, 0.366 mmol) in ether (3 mL) was treated with a solution of osmium tetroxide in ether (4.1 mL of 0.25 g of OsO_4 per 10 mL, 1.1 equiv) and the mixture was stirred at room temperature under argon for 2 days. The ether was removed in vacuo, and anhydrous tetrahydrofuran (20 mL) was added. The mixture was cooled in an ice bath, and $LiAlH_4$ (43 mg, 3 equiv) was introduced portionwise. After 3 h of stirring at 25 °C, ethyl acetate (5 mL) was slowly added followed by water (10 mL). The resulting mixture was filtered through Celite, washed with brine (20 mL), dried, and evaporated. Silica gel chromatographic purification of the residue gave 92 mg (66%) of pure **6** as a white solid: mp 181–184 °C; IR ($CHCl_3$, cm^{-1}) 3700–3400, 3100–2800, 1690, 1450, 1365, 1280, 1260–1190, 1075, 1030, 1010, 910; ^1H NMR (300 MHz, $CDCl_3$) δ 4.08 (dd, J = 2.8, 7.3 Hz, 1 H), 3.50–3.15 (m, 4 H), 3.10–2.95 (m, 2 H), 2.63 (d, J = 8.5 Hz, 1 H), 2.45–2.30 (m, 1 H), 2.20–1.05 (series of m, 14 H), 1.30 (s, 3 H), 1.18 (s, 3 H), 1.15 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 215.16, 85.55, 75.77, 73.17, 54.24, 49.18, 47.94, 43.53, 40.22, 39.65, 38.26, 36.62, 34.85, 31.52, 31.44, 27.11, 23.14, 21.09, 20.69, 20.00; MS m/z (M^+) calcd 384.1793, obsd 384.1814; $[\alpha]^{20}_D$ +35.9° (c 0.22, $CHCl_3$).

Anal. Calcd for $C_{20}H_{32}O_3S_2$: C, 62.46; H, 8.39. Found: C, 62.46; H, 8.51.

Conversion of 6 to 7. A solution of **6** (5 mg, 0.013 mmol) in pyridine (0.5 mL) was vigorously stirred overnight with 5% aqueous $NaHSO_3$ solution (5 mL). The product was extracted into ether (3 × 10 mL), and the combined organic phases were washed with 2 M HCl (2 × 10 mL) and brine (10 mL), dried, and evaporated. TLC and ^1H NMR analysis confirmed complete and clean conversion to **7**.

Osmate Ester 10. A solution of **4** (206 mg, 0.59 mmol) in pyridine (6 mL) was treated with a solution of osmium tetroxide in pyridine (1.5 mL of 1 g of OsO_4 per 10 mL, 1 equiv). The mixture was stirred overnight under argon at room temperature, filtered through Celite, and evaporated. The residue was subjected to silica gel chromatography to give 347 mg (83%) of **10**: IR ($CHCl_3$, cm^{-1}) 3100–2800, 1690, 1610, 1480, 1450, 1260–1190, 1070, 980, 830, 720–650; ^1H NMR (300 MHz, $CDCl_3$) δ 8.79 (d, J = 5.1 Hz, 4 H), 7.90–7.80 (m, 2 H), 7.50–7.40 (m, 4 H), 4.87 (d, J = 8.1 Hz, 1 H), 3.45–3.15 (m, 5 H), 2.87 (d, J = 7.8 Hz, 1 H), 2.60–2.40 (m, 2 H), 2.25–1.25 (series of m, 12 H), 1.36 (s, 3 H), 1.28 (s, 3 H), 1.25 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 216.07, 149.82, 139.60, 128.26, 124.88, 99.76, 94.09, 74.15, 54.59, 49.03, 47.74, 44.87, 40.28, 39.34, 38.59, 36.44, 35.04, 31.38, 30.42, 27.17, 23.17, 20.71, 20.54, 20.39; MS molecular ion too fleeting for accurate mass measurement.

(4′a*R*,5′*S*,7′*R*,10′*S*,11′*S*,12′a*R*)-Decahydro-4′a,13′,13′-trimethylspiro[1,3-dithiolane-2,1′(2′*H*)-[7,10]methanobenzocyclodecene]-5′,10′,11′(5′*H*)-triol (11)). A solution of **4** (20 mg, 0.057 mmol) in pyridine (1 mL) was treated with a solution of osmium tetroxide in pyridine (0.14 mL of 1 g of OsO_4 per 10 mL, 1 equiv), and the mixture was stirred overnight under argon at room temperature. The pyridine was removed in vacuo, and the residue was taken up in anhydrous tetrahydrofuran (5 mL) and stirred overnight in the presence of $LiAlH_4$ (22 mg, 10 equiv). Ethyl acetate (1 mL) and water (3 mL) were added in sequence, the insoluble byproducts were separated by filtration through Celite, and the organic phase was washed with 2 M HCl (10 mL) prior to drying and solvent evaporation. Purification by column chromatography on silica gel gave **11** (11.0 mg, 50% overall) as a white solid: mp 193–194 °C; IR ($CHCl_3$, cm^{-1}) 3630, 3620–3360, 3050–2500, 1480, 1465, 1385, 1370, 1260–1200, 1065, 1030, 1015, 990, 920; ^1H NMR (300 MHz, $CDCl_3$) δ 3.92 (dd, J = 2.4, 7.4 Hz, 1 H), 3.70 (dd, J = 2.4, 7.4 Hz, 1 H), 3.40–3.15 (m, 4 H), 3.11 (d, J = 3.0 Hz, 1 H), 2.88 (m, 2 H), 2.50–2.30 (m, 2), 2.30–1.95 (series of m, 5 H), 1.95–1.55 (series of m, 7 H), 1.50–1.35 (m, 1 H), 1.16 (s, 3 H), 1.10 (s, 6 H), 1.00–0.85 (m, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 86.37, 85.12, 77.98, 74.83, 50.68, 48.89, 47.27, 43.99, 39.78, 39.73, 37.16, 34.83, 32.67, 31.96, 30.30, 27.52, 27.36, 22.15, 20.94, 20.31; MS m/z (M^+) calcd 386.1949, obsd 386.1913; $[\alpha]^{20}_D$ −43.5° (c 0.046, $CHCl_3$).

Anal. Calcd for $C_{20}H_{34}O_3S_2$: C, 62.13; H, 8.86. Found: C, 62.30; H, 8.86.

(4′a*R*,5′*S*,7′*R*,10′*S*,11′*S*,12′a*R*)-Decahydro-4′a,13′,13′-trimethylspiro[1,3-dithiolane-2,1′(2′*H*)-[7,10]methanobenzocyclodecene]-5′,10′,11′(5*H*)-triol 5′,11′-Diacetate (12). A solution of **11** (100 mg, 0.26 mmol) in anhydrous pyridine (6 mL) and acetic anhydride (3 mL) was stirred overnight under argon at room temperature in the presence of DMAP (3 crystals). The mixture was diluted with ethyl acetate (20 mL) and washed in turn with water (10 mL), 0.12 N HCl (2 × 10 mL), saturated $NaHCO_3$ solution (2 × 10 mL), and brine (10 mL) prior to drying and evaporation. The residue, when subjected to silica gel chromatography, gave **12** (80 mg, 66%) as a white solid: mp 94–96 °C; IR ($CHCl_3$, cm^{-1}) 3525, 3080–2800, 1725, 1455, 1375, 1245, 1055, 1030, 990; ^1H NMR (300 MHz, $CDCl_3$) δ 5.24 (d, J = 7.4 Hz, 1 H), 4.92 (d, J = 8.9 Hz, 1 H), 3.40–3.10 (m, 4 H), 2.10 (s, 3 H), 2.09 (s, 3 H), 2.60–0.9 (series of m, 17 H), 1.31 (s, 3 H), 1.18 (s, 3 H), 1.07 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 173.39, 169.93, 87.55, 84.04, 81.25, 73.28, 50.65, 48.31 (2 C), 44.42, 39.91, 39.43, 37.50, 33.65, 32.88, 31.18, 29.89, 27.63, 25.50, 21.54, 21.37, 20.45, 20.00 (1C not observed); MS m/z (M^+) calcd 470.2161, obsd 470.2169; $[\alpha]^{20}_D$ −30.0° (c 0.05, $CHCl_3$).

Anal. Calcd for $C_{24}H_{38}O_5S_2$: C, 61.24; H, 8.14. Found: C, 61.05; H, 8.14.

(4′a*R*,5′*S*,7′*R*,10′*S*,11′*S*,12′a*R*)-Decahydro-4′a,13′,13′-trimethylspiro[1,3-dithiolane-2,1′(2′*H*)-[7,10]methanobenzocyclodecene]-5′,10′,11′(5′*H*)-triol 5′-Acetate (13). A solution of **12** (60 mg, 0.128 mmol) in methanol (4 mL) and water (1 mL) was stirred overnight at room temperature in the presence of potassium carbonate (40 mg, 2.25 equiv). The methanol was removed in vacuo, and the residue was partitioned between ethyl acetate (10 mL) and water (5 mL). The aqueous phase was extracted with more ethyl acetate (2 × 10 mL), and the combined organic phases were washed with brine (10 mL), dried, and evaporated. Compound **13** (45 mg, 82%) was isolated as white crystals: mp 84–86 °C (from ether); IR ($CHCl_3$, cm^{-1}) 3530, 3100–2800, 1725, 1460, 1390, 1375, 1300–1190, 1055, 1040, 1015, 1000; ^1H NMR (300 MHz, $CDCl_3$) δ 4.89 (d, J = 9.0 Hz, 1 H), 3.95 (d, J = 7.5 Hz, 1 H), 3.40–3.10 (m, 6 H), 2.07 (s, 3 H), 2.60–0.90 (series of m, 16 H), 1.28 (s, 3 H), 1.11 (s, 3 H), 1.10 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 169.96, 86.14, 83.93, 77.73, 74.45, 50.32, 48.26, 47.11, 44.36, 39.81, 39.57, 37.12, 35.62, 32.64, 31.77, 29.70, 27.49, 25.20, 21.82, 21.33, 20.71, 20.22; MS m/z (M^+) calcd 428.2055, obsd 428.2049; $[\alpha]^{20}_D$ −11.4° (c 0.14, $CHCl_3$).

Anal. Calcd for $C_{22}H_{36}O_4S_2$: C, 61.64; H, 8.47. Found: C, 61.67; H, 8.50.

Trifluoroorthoacetic Acid, Cyclic 10′,11′-Ester with (4′a*R*,5′*S*,7′*R*,10′*S*,11′*S*,12′a*R*)-Decahydro-4′a,13′,13′-trimethylspiro[1,3-dithiolane-2,1′(2′*H*)-[7,10]methanobenzocyclodecene]-5′,10′,11′(5′*H*)-triol 5′-Acetate (14). A solution of **13** (3 mg, 7 × 10^{-3} mmol) in CH_2Cl_2 (1 mL) was cooled to 0 °C under argon and treated with pyridine (5.7 μL, 10 equiv) and trifluoroacetic anhydride (4.9 μL, 5 equiv). The reaction mixture was allowed to warm to room temperature and after 2.5 h was diluted with ether (10 mL) and washed with water (5 mL) and brine (5 mL). Drying and solvent evaporation provided a residue that was purified by column chromatography on silica gel. Compound **14** (2 mg, 60%) was obtained as a colorless oil consisting of a 2:1 mixture of isomers: ^1H NMR (300 MHz, $CDCl_3$, major isomer) δ 4.99 (d, J = 10.6 Hz, 1 H), 4.55 (d, J = 9.5 Hz, 1 H), 3.50–3.10 (m, 5 H), 2.90–2.75 (m, 1 H), 2.14 (s, 3 H), 2.50–0.90 (series of m, 15 H), 1.28 (s, 3 H), 1.20 (s, 3 H), 1.17 (s, 3 H); ^{19}F NMR ($CDCl_3$) −85.37, −86.22 (ratio 1:2), MS m/z (M^+) calcd 524.1878, obsd 524.1844.

(3′a*S*,6′*R*,8′*S*,8′a*R*,12′a*R*,13′a*S*)-Decahydro-8′-hydroxy-8′a,14′,14′-trimethylspiro[1,3-dithiolane-2,12′(9′*H*)-[4*H*-3a,6]methanobenzo[4,5]cyclodeca[1,2-*d*][1,3]dioxole]-2′-butanol 8′-Acetate (16a). A solution of **13** (5 mg, 1.2 × 10^{-5} mol) in dry CH_2Cl_2 (1 mL) was cooled to 0 °C under argon and treated with *p*-toluenesulfonic acid (1 crystal) and dihydropyran (1.2 μL, 1.1 equiv). The mixture was stirred at 25 °C for 1 h whereupon the solvent was removed in vacuo. Purification by silica gel chromatography gave first **15** (4 mg, 67%) and then the more polar **16a** (1 mg, 17%).

When the reaction was allowed to proceed at 25 °C for 4 h, 30 mg of **13** furnished lesser amounts of **15** (8 mg, 22%) relative to **16a** (13 mg, 36%).

For **15**: IR ($CHCl_3$, cm^{-1}) 3010–2800, 1730, 1460, 1390, 1370, 1270–1190, 1140, 1040; ^1H NMR (300 MHz, C_6D_6) δ 5.25–5.15 (m, 1 H), 4.62 (br s, 1 H), 4.50–4.40 (m, 1 H), 3.95–3.70 (m, 2 H), 3.50–3.30 (m, 2 H), 3.05–2.40 (series of m, 6 H), 2.30–1.50 (series

of m, 13 H), 1.78 (s, 3 H), 1.50–1.20 (m, 6 H), 1.35 (s, 3 H), 1.33 (s, 3 H), 1.24 (s, 3 H).

For **16a**: IR ($CHCl_3$, cm^{-1}) 3610, 3050–2800, 1725, 1460, 1385, 1365, 1270–1190, 1140, 1055, 1040; ^1H NMR (300 MHz, C_6D_6) δ 5.25–5.15 (m, 2 H), 4.47 (d, J = 7.0 Hz, 1 H), 3.38 (t, J = 6.1 Hz, 2 H), 3.05–2.60 (m, 5 H), 2.58 (d, J = 6.2 Hz, 1 H), 2.55–2.40 (m, 1 H), 2.25–1.70 (series of m, 12 H), 1.78 (s, 3 H), 1.60–1.30 (m, 6 H), 1.34 (s, 3 H), 1.33 (s, 3 H), 1.24 (s, 3 H), 1.00–0.60 (m, 2 H); ^{13}C NMR (75 MHz, C_6D_6) ppm 169.35, 101.73, 92.09, 84.86, 82.22, 75.59, 62.54, 50.54, 49.65, 45.87, 44.56, 40.22, 39.90, 36.01, 35.49, 34.33, 33.08, 31.56, 30.01, 29.57, 27.30, 24.27, 23.67, 21.10 (2 C), 20.88, 20.71; MS m/z (M^+) calcd 512.2630, obsd 512.2615.

(3′a*S*,6′*R*,8′*S*,8′a*R*,12′a*R*,13′a*S*)-Decahydro-8′-hydroxy-8′a,14′,14′-trimethylspiro[1,3-dithiolane-2,12′(9′*H*)-[4*H*-3a,6]methanobenzo[4,5]cyclodeca[1,2-*d*][1,3]dioxole]-2′-butanol Diacetate (16b). A solution of **16a** (6 mg, 1.2×10^{-5} mol) in dry pyridine (1 mL) containing acetic anhydride (0.5 mL) was stirred overnight at 25 °C under argon in the presence of DMAP (1 crystal). The mixture was diluted with ethyl acetate (5 mL) and water (3 mL), and the aqueous phase was further extracted with ethyl acetate (5 mL). The combined organic phases were washed with saturated $NaHCO_3$ solution (2 × 5 mL) and brine (5 mL) prior to drying and solvent evaporation. The crude product was purified by chromatography on silica gel to give 6 mg (92%) of **16b** as a colorless oil: IR ($CHCl_3$, cm^{-1}) 3040–2800, 1725, 1385, 1365, 1280–1190, 1145, 1050; ^1H NMR (300 MHz, C_6D_6) δ 5.70–5.60 (m, 2 H), 4.42 (d, J = 8.6 Hz, 1 H), 3.93 (br s, 2 H), 3.00–2.60 (series of m, 4 H), 2.60–2.50 (m, 1 H), 2.45–2.35 (m, 1 H), 2.20–1.55 (series of m, 11 H), 1.72 (s, 3 H), 1.62 (s, 3 H), 1.50–1.10 (m, 8 H), 1.29 (s, 3 H), 1.27 (s, 3 H), 1.18 (s, 3 H), 0.95–0.85 (m, 1 H); MS m/z (M^+) calcd for 554.2736, obsd 554.2728.

(4′a*R*,5′*S*,7′*R*,10′*R*,11′*E*,12′a*R*)-3′,4′,4′a,6′,7′,8′,9′,12′a-Octahydro-4′a,13′,13′-trimethylspiro[1,3-dithiolane-2,1′-(2′*H*)-[7,10]methanobenzocyclodecene]-5′,10′(5′*H*)-diol 5′-Acetate (17). A solution of **13** (25 mg, 0.058 mmol) in dry pyridine (5 mL) was treated with DMAP (1 crystal) and cooled to −25 °C under argon. The mixture was treated with *p*-toluenesulfonyl bromide (1.375 g, 100 equiv) and stirred at −25 °C overnight. Dilution with ethyl acetate (30 mL) was followed by washing with water (2 × 10 mL) and brine (10 mL), drying, and solvent removal in vacuo. Purification of the residue by chromatography on silica gel gave 6 mg of a mixture of components followed by **17** (10 mg, 42%), a colorless solid with mp 85–100 °C dec: IR ($CHCl_3$, cm^{-1}) 3600, 3050–2800, 1720, 1455, 1365, 1260–1200, 1035, 1015, 960; ^1H NMR (300 MHz, $CDCl_3$) δ 5.78 (dd, J = 1.6, 15.9 Hz, 1 H), 5.70 (dd, J = 11.2, 15.8 Hz, 1 H), 5.07 (d, J = 9.0 Hz, 1 H), 3.45–3.30 (m, 2 H), 3.20–3.05 (m, 2 H), 2.56 (d, J = 10.4 Hz, 1 H), 1.98 (s, 3 H), 2.20–0.90 (series of m, 14 H), 1.20 (s, 3 H), 1.19 (s, 3 H), 1.01 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 169.50, 132.49, 128.91, 81.74, 80.81, 70.42, 58.29, 48.40, 45.86, 43.29, 40.62, 40.53, 39.59, 35.39, 33.47, 29.28, 28.64, 27.01, 24.46, 21.20, 20.31, 18.12; MS m/z (M^+) calcd 410.1950, obsd 410.1987; $[\alpha]^{20}_D$ +81.8° (c 0.55, $CHCl_3$).

Anal. Calcd for $C_{22}H_{34}O_3S_2$: C, 64.35; H, 8.35. Found: C, 63.94; H, 8.22.

(3′a*S*,6′*R*,8′*S*,8′a*R*,12′a*R*,13′a*S*)-Decahydro-8′a,14′,14′-trimethyl-2′-phenylspiro[1,3-dithiolane-2,12′(9′*H*)-[14*H*-3a,6]methanobenzo[4,5]cycloodeca[1,2-*d*][1,3]dioxol]-8′-ol (19a). A solution of **11** (117 mg, 0.303 mmol) and benzaldehyde (34 μL, 1.1 equiv) in dry benzene (5 mL) containing *p*-toluenesulfonic acid (63 mg, 1.1 equiv) and activated 4A molecular sieves (120 mg) was stirred at room temperature under argon. After 3 h, the mixture was diluted with ethyl acetate (10 mL) and filtered. The filtrate was washed with saturated $NaHCO_3$ solution (10 mL) and brine (10 mL) prior to drying and solvent evaporation. The residue was purified by silica gel chromatography to give 122 mg (85%) of **19a** as a colorless oil; IR ($CHCl_3$, cm^{-1}) 3640, 3040–2800, 1460, 1385, 1110, 1095, 1070, 1050, 1030; ^1H NMR (300 MHz, $CDCl_3$) δ 7.60–7.40 (m, 2 H), 7.40–7.20 (m, 3 H), 5.75 (s, 1 H), 4.26 (d, J = 8.9 Hz, 1 H), 3.77 (d, J = 9.4 Hz, 1 H), 3.45–3.05 (m, 6 H), 2.60–0.90 (series of m, 15 H), 1.21 (s, 3 H), 1.18 (s, 3 H), 1.16 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 139.79, 128.56, 128.07, 126.94, 100.44, 93.07, 85.35, 84.17, 75.46, 50.31, 49.66, 45.90, 43.89, 40.15, 39.43, 35.44, 33.93, 31.34, 29.76, 28.48, 27.00, 25.68, 23.54, 21.11, 20.74; MS m/z (M^+) calcd 474.2262, obsd 474.2285.

(3′a*S*,6′*R*,8′a*R*,12′a*R*,13′a*S*)-Decahydro-2′,2′,8′a,14′,14′-pentamethylspiro[1,3-dithiolane-2,12′(9′*H*)-[4*H*-3a,6]-methanobenzo[4,5]cyclodeca[1,2-*d*][1,3]dioxol]-8′-ol (19b). A solution of **11** (33 mg, 0.086 mmol) in dry acetone (6 mL) containing 1 drop of concentrated H_2SO_4 was refluxed under argon for 3.5 h. Solid $NaHCO_3$ (0.2 g) was introduced, and the acetone was removed in vacuo. The residue was treated with water (2 mL) and extracted with ether (3 × 5 mL). The combined ethereal layers were dried and concentrated to leave a residue that was chromatographed on silica gel to give 24.5 mg (67%) of **19b** as a white solid: mp 124–126 °C; IR ($CHCl_3$, cm^{-1}) 3630, 3000–2800, 1460, 1380, 1370, 1250–1190, 1075, 1045; ^1H NMR (300 MHz, C_6D_6) δ 4.45 (d, J = 9.0 Hz, 1 H), 3.30–3.15 (m, 2 H), 2.90–2.40 (m, 7 H), 2.15–1.00 (series of m, 13 H), 1.54 (s, 3 H), 1.50 (s, 3 H), 1.33 (s, 3 H), 1.24 (s, 3 H), 1.14 (s, 3 H); ^{13}C NMR (75 MHz, C_6D_6) ppm 103.27, 93.32, 84.19, 82.47, 76.06, 50.77, 49.68, 46.08, 44.10, 40.21, 39.78, 35.25, 33.12, 31.57, 29.80, 28.91, 28.09, 27.32, 26.83, 25.92, 23.93, 21.13, 20.98; MS m/z (M^+) calcd 426.2262, obsd 426.2228; $[\alpha]^{20}_D$ +91.0° (c 0.1, $CHCl_3$).

Anal. Calcd for $C_{23}H_{38}O_3S_2$: C, 64.74; H, 8.98. Found: C, 65.08; H, 8.99.

(3′a*S*,6′*R*,7′*E*,8′a*S*,12′a*R*,13′a*S*)-5′,6′,8′a,10′,11′,12′a,13′,-13′a-Octahydro-8′a,14′,14′-trimethyl-2′-phenylspiro[1,3-dithiolane-2,12′(9′*H*)-[4*H*-3a,6]methanobenzo[4,5]cyclodeca-[1,2-*d*][1,3]dioxole] (21a). Unpurified **19a** (26 mg, 5.48×10^{-5} mol) in dry benzene (20 mL) was refluxed overnight under argon in the presence of Burgess reagent (41 mg, 3 equiv). The cooled reaction mixture was diluted with ethyl acetate (20 mL), washed with brine (4 × 20 mL), dried, and evaporated. Chromatography of the residue on silica gel gave **21a** (13 mg, 55% from **11**, 75% per step) as a white solid: mp 200–202 °C; IR ($CHCl_3$, cm^{-1}) 3100–2800, 1460, 1400, 1100, 1065, 1050, 1025, 1010, 985; ^1H NMR (300 MHz, $CDCl_3$) δ 7.50–7.40 (m, 2 H), 7.40–7.30 (m, 3 H), 5.70 (dd, J = 16.9, 2.7 Hz, 1 H), 5.61 (s, 1 H), 5.56 (d, J = 17.7 Hz, 1 H), 4.12 (d, J = 8.3 Hz, 1 H), 3.40–3.10 (m, 4 H), 2.35–1.10 (series of m, 14 H), 1.44 (s, 3 H), 1.23 (s, 3 H), 1.18 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) ppm 143.51, 138.95, 128.87, 128.76, 128.15, 126.87, 99.66, 92.45, 86.87, 75.17, 62.74, 51.44, 48.84, 40.14, 39.05, 38.51, 36.91, 36.09, 33.96, 32.16, 28.34, 24.13, 22.84, 21.02, 20.90; MS m/z (M^+) calcd 456.2157, obsd 456.2155; $[\alpha]^{20}_D$ −166.6° (c 0.19, $CHCl_3$).

Anal. Calcd for $C_{27}H_{36}O_2S_2$: C, 71.01; H, 7.95. Found: C, 70.98; H, 7.99.

(3′a*S*,6′*R*,7′*E*,8′a*S*,12′a*R*,13′a*S*)-5′,6′,8′a,10′,11′,12′a,13′,-13′a-Octahydro-2′,2′,8′a,14′,14′-pentamethylspiro[1,3-dithiolane-2,12′(9′*H*)-[4*H*-3a,6]methanobenzo[4,5]cyclodeca-[1,2-*d*][1,3]dioxole] (21b). A solution of **19b** (265 mg, 0.62 mmol) in dry benzene (80 mL) was refluxed in the presence of Burgess reagent (470 mg, 3 equiv) under argon overnight. After the workup described above, compound **21b** (140 mg, 55%) was isolated as a white solid: mp 186–188 °C; IR ($CHCl_3$, cm^{-1}) 3000–2800, 1450, 1380, 1260–1190, 1170, 1040, 1030, 890; ^1H NMR (300 MHz, C_6D_6) δ 5.67 (dd, J = 2.9, 17.0 Hz, 1 H), 5.46 (d, J = 17.0 Hz, 1 H), 4.16 (d, J = 8.2 Hz, 1 H), 2.85–2.60 (m, 4 H), 2.25–0.90 (series of m, 14 H), 1.61 (s, 3 H), 1.39 (s, 3 H), 1.37 (s, 3 H), 1.23 (s, 3 H), 0.97 (s, 3 H); ^{13}C NMR (75 MHz, C_6D_6) ppm 143.23, 129.39, 102.25, 92.63, 84.13, 75.71, 62.56, 50.86, 48.40, 40.20, 39.37, 38.87, 37.53, 35.98, 33.95, 31.40, 28.43, 28.14, 27.04, 24.39, 23.16, 21.42, 20.01; MS m/z (M^+) calcd 408.6702, obsd 408.6686; $[\alpha]^{20}_D$ −132.5° (c 0.197, $CHCl_3$).

Anal. Calcd for $C_{23}H_{36}O_2S_2$: C, 67.60; H, 8.88. Found: C, 67.59; H, 8.96.

(3′a*S*,6′*S*,7′*S*,8′*S*,8′a*R*,12′a*R*,13′a*S*)-Decahydro-2′,2′,8′a,14′,14′-pentamethylspiro[1,3-dithiolane-2,12′(9′*H*)-[4*H*-3a,6]methanobenzo[4,5]cyclodeca[1,2-*d*][1,3]dioxole]-7′,8′-diol (22b). A solution of **21b** (93 mg, 0.228 mmol) in pyridine (3 mL) was treated with a solution of osmium tetroxide in pyridine (1.5 mL of 0.25 g of OsO_4 per 5 mL, 1.2 equiv), and the mixture was stirred at room temperature under argon for 24 h. The pyridine was removed in vacuo, the residue was taken up in anhydrous tetrahydrofuran, and this solution was stirred with $LiAlH_4$ (90 mg, 10 equiv) for 24 h. The reaction mixture was quenched with ethyl acetate (5 mL) and 1 M aqueous sodium hydroxide (5 mL), filtered through Celite, and concentrated in vacuo. Purification by chromatography on silica gel afforded **22b** (81 mg, 80%) as a white solid, mp 221–223 °C; IR ($CHCl_3$, cm^{-1})

3600-3300, 3000-2800, 1350, 1300-1100, 1075; ^{1}H NMR (250 MHz, $CDCl_3$) δ 4.05 (d, J = 8.3 Hz, 1 H), 3.80 (d, J = 5.6 Hz, 1 H), 3.48 (d, J = 7.0 Hz, 1 H), 3.45-3.10 (m, 4 H), 2.80 (d, J = 6.7 Hz, 1 H), 2.20-1.65 (series of m, 12 H), 1.60-1.5 (m, 2 H), 1.32 (s, 6 H), 1.30-1.15 (m, 1 H), 1.17 (s, 3 H), 1.16 (s, 3 H); ^{13}C NMR (62 MHz, $CDCl_3$) ppm 102.64, 91.81, 80.80, 75.64, 72.07, 65.76, 57.65, 49.98, 45.62, 42.27, 40.29, 38.77, 35.33, 32.66, 31.82, 30.73, 28.28, 27.50, 26.51, 22.34,. 20.67, 19.81, 17.15; MS m/z (M^+) calcd 442.2211, obsd 442.2190; $[\alpha]^{20}_D$ +10.9° (c 0.22, $CHCl_3$).

Anal. Calcd for $C_{23}H_{38}O_4S_2$: C, 62.40; H, 8.65. Found: C, 62.48; H, 8.67.

(3′a*S*,6′*S*,7′*S*,8′*S*,8′a*R*,12′a*R*,13′a*S*)-Decahydro-8′a,14′,14′-trimethyl-2′-phenylspiro[1,3-dithiolane-2,12′-(9′*H*)-[4*H*-3a,6]methanobenzo[4,5]cyclodeca[1,2-*d*]dioxole]-7′,8′-diol Diacetate (23a). A solution of **21a** (13 mg, 2.85 × 10^{-5} mol) in pyridine (1 mL) was treated with a solution of osmium tetroxide in pyridine (0.17 mL of 0.25 g of OsO_4 per 5 mL, 1.2 equiv), stirred at room temperature overnight, and processed as described above. The significant insolubility of the diol prompted direct conversion in unpurified form to the diacetate.

The crude diol **22b** in anhydrous pyridine (0.6 mL) containing acetic anhydride (0.3 mL) and DMAP (3 crystals) was stirred under argon at room temperature overnight. The mixture was diluted with ethyl acetate (5 mL), washed in turn with water (5 mL), 0.12 N HCl (2 × 5 mL), saturated $NaHCO_3$ solution (2 × 5 mL), and brine (5 mL), and then dried and evaporated. Purification by silica gel chromatography gave **23a** (1 mg, unoptimized): IR ($CHCl_3$, cm^{-1}) 3020-2800, 1730, 1370, 1270-1150, 1095, 1050, 1025; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.50-7.40 (m, 2 H), 7.40-7.30 (m, 3 H), 5.76 (s, 1 H), 5.22 (s, 1 H), 5.19 (s, 1 H), 4.28 (d, J = 9.6 Hz, 1 H), 3.45-3.15 (m, 5 H), 2.13 (s, 3 H), 2.04 (s, 3 H), 2.50-1.00 (series of m, 13 H), 1.35 (s, 3 H), 1.26 (s, 3 H), 1.20 (s, 3 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.59, 169.36, 139.07, 128.93, 128.25, 126.81, 100.20, 91.82, 84.11, 74.87, 73.42, 68.41, 56.10, 50.24, 46.51, 43.12, 40.41, 38.67, 35.91, 32.96, 32.61, 30.77, 29.71, 22.38, 21.33, 20.94, 20.58, 20.48, 17.54; MS m/z (M^+) calcd 574.2423, obsd 574.2416; $[\alpha]^{20}_D$ -41.7° (c 0.35, $CHCl_3$).

(3′a*S*,6′*S*,7′*S*,8′*S*,8′a*R*,12′a*R*,13′a*S*)-Decahydro-2′,2′,8′a,14′,14′-pentamethylspiro[1,3-dithiolane-2,12′(9′*H*)-[4*H*-3a,6]methanobenzo[4,5]cyclodeca[1,2-*d*][1,3]dioxole]-7′,8′-diol Diacetate (23b). A solution of **22b** (23 mg, 5.2 × 10^{-5} mol) in dry pyridine (2 mL) containing acetic anhydride (1 mL) was stirred at room temperature under argon in the presence of DMAP (3 crystals) for 24 h. The usual workup and chromatographic purification gave **23b** (20 mg, 73%) as a white solid: mp 226-228 °C; IR ($CHCl_3$, cm^{-1}) 3030-2800, 1730, 1460, 1375, 1280-1200, 1140, 1075-1000, 955; ^{1}H NMR (300 MHz, C_6D_6) δ 5.64 (br s, 1 H), 5.51 (br s, 1 H), 4.53 (d, J = 9.4 Hz, 1 H), 2.85-2.60 (m, 5 H), 2.60-1.00 (series of m, 13 H), 1.81 (s, 3 H), 1.75 (s, 3 H), 1.60 (s, 3 H), 1.52 (s, 3 H), 1.46 (s, 3 H), 1.44 (s, 3 H), 1.30 (s, 3 H); ^{13}C NMR (75 MHz, C_6D_6) ppm 169.86, 168.67, 103.11, 92.04, 81.46, 75.43, 73.77, 68.75, 56.47, 50.81, 46.74, 43.65, 40.37, 39.01, 35.74, 33.26, 32.21, 30.90, 28.24, 27.82, 26.88, 22.92, 20.99, 20.92, 20.48, 20.42, 18.18; MS m/z (M^+) calcd 526.2323, obsd 526.2364; $[\alpha]^{20}_D$ -17.5° (c 0.2, $CHCl_3$).

Anal. Calcd for $C_{27}H_{42}O_6S_2$: C, 61.57; H, 8.04. Found: C, 61.75; H, 8.24.

Deuterium Labeling Studies. The preparations of **25-27** were carried out along lines entirely parallel to those outlined above. The chemical shift effects and NOE data of greatest relevance are provided in the illustrated formulas.

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Supplementary Material Available: Tables of X-ray crystal data, bond distances and angles, final fractional coordinates, and thermal parameters for **11** as well as the 300-MHz ^{1}H NMR spectra of those compounds for which elemental analyses are not available (11 pages). Ordering information is given on any current masthead page.

(*Z*)-α-(Trimethylsilyl) α,β-Unsaturated Esters. Their Stereoselective Conversion into α,β- and β,γ-Unsaturated Esters and β,γ-Unsaturated Ketene Acetals

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Deprotonation of methyl (*Z*)-α-(trimethylsilyl) α,β-unsaturated esters with lithium diisopropylamide (LDA) or with lithium hexamethyldisilazide (LHMDS) in the presence of hexamethylphosphoramide (HMPA) as an activator, followed by protonation of the intermediate dienolates with methanol, produces stereoselectively the desilylated (*E*)-3-alkenoic esters. Trapping the dienolates with chlorotrimethylsilane instead of methanol and then treatment of the resultant ketene acetals with aqueous hydrochloric acid affords (*E*)-α-(trimethylsilyl)-β,γ-alkenoic esters in 98% isomeric purities. In the absence of HMPA, (*Z*)-α-(trimethylsilyl)-α,β-alkenoic esters undergo a Michael-type addition with LDA to furnish, after methanol-mediated elimination of the diisopropylamine moiety, (*E*)-α-(trimethylsilyl)-α,β-alkenoic esters. In contrast to the behavior with the corresponding *Z* esters, deprotonation of the *E* esters with LDA does not require an activator. Treatment of the dienolate intermediates formed with chlorotrimethylsilane yields *O*-methyl-*C*,*O*-bis(trimethylsilyl)ketene acetals, and alkylation furnishes (*E*)-α-alkyl β,γ-unsaturated esters. Protodesilylation of the latter compounds with tetra-*n*-butylammonium fluoride followed by hydrolytic workup provides trisubstituted 2-alkenoates.

The protonative deconjugation of α,β-unsaturated esters has been extensively investigated and represents an important method for preparing stereodefined β,γ-unsaturated esters.[1] It thus occurred to us that subjecting the

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