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# A CONCISE ROUTE TO THE TETRACYCLIC CORE OF PHORBOL

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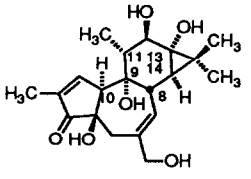
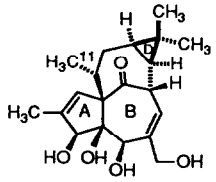
**Abstract:** The tetracyclic ketone **17**, which possesses a framework closely related to phorbol, has been prepared in enantiomerically pure condition. Condensation of the dichlorocerate derived from **3** with 2-chlorocyclohexanone leads to chlorohydrins **4** and **5** in a 1:1 ratio. Treatment of **5** with excess vinylmagnesium bromide delivers **7**, thereby setting the stage for anionic oxy-Cope rearrangement to **9**. Epoxidation of **9** and base-promoted cyclization of the α-isomer (**15**) under kinetically controlled conditions eventuates in the formation of **17**. A companion set of reactions was performed on **4** with the result that hemiketal **11** is formed following transannular ring closure. Lastly, one of the first intramolecularly competitive anionic oxy-Cope rearrangements is described.

The complex structure and striking tumor-promoter properties[2] of phorbol esters have prompted others to devise means for constructing the phorbol skeleton[3] and phorbol (**1**) itself.[4] Our own efforts aimed at the elaboration of ingenol (**2**),[5] a co-occurring substance, which in esterified form is likewise capable of strongly activating protein kinase C,[6] have led us to examine the possibility of devising a unified synthetic approach of sufficient breadth to access both promoters.



**1**

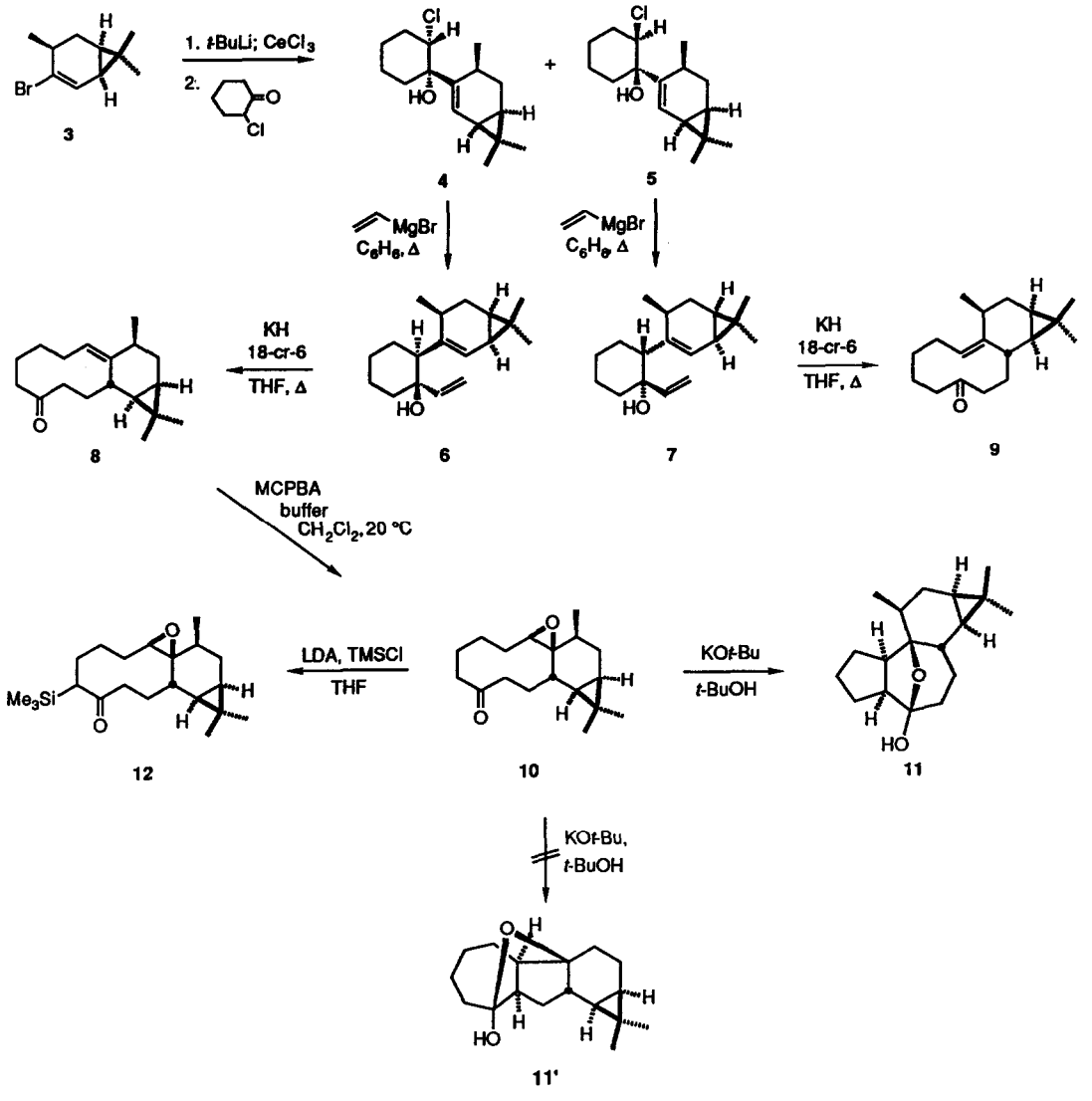


**2**

We report here the results of a pilot investigation that has culminated in the acquisition of an enantiomerically pure tetracyclic compound having the phorbol framework. The end product is relatively unadorned of hydroxyl substituents and carries an 11β-methyl group. However, these structural elements appear amenable to proper modification in more advanced work. Importantly, **17** possesses absolute configuration in common with phorbol at five key ring juncture carbons (C-8, 9, 10, 13, and 14).

At the outset, advantage was taken of the ready availability of (+)-vinyl bromide **3** from (+)-carvone.[7,8] Halogen-metal exchange within **3** by exposure to *tert*-butyllithium, in situ conversion to the dichlorocerate to reduce nucleophile basicity,[9] and condensation with 2-chlorocyclohexanone resulted in the formation of a 1:1 mixture of chlorohydrins **4** and **5** (Scheme I). These readily separable diastereomers were distinguished by X-ray crystallographic analysis of the less polar **4**

**Scheme I**




(see Figure 1 and Supplementary Material). Treatment of the individual chlorohydrins with excess vinylmagnesium bromide promoted antiperiplanar 1,2-shift of the 2-carenyl component and ensuing capture of the ketone functionality so liberated with a second equivalent of the Grignard reagent from the less sterically hindered π-surface. Anionic oxy-Cope rearrangement[10] of **6** by heating with potassium hydride and 18-crown-6 in THF afforded the *cis*-cyclodecenone **8** (87%). Comparable charge-accelerated sigmatropy within **7** led to **9**.

The double bond geometry in these medium-ring ketones could be easily distinguished by comparison of the chemical shifts of the carbonyl signals in their $^{13}C$ NMR spectra.[11] As seen in Table I, the carbonyl carbons present in the cis isomers invariably appear downfield of those in the corresponding trans series ($\Delta\delta$ = 2.5-5.1 ppm). The assignment of *Z*-stereochemistry to **8** was initially based on nOe experiments. The 3% enhancement in the vinyl proton signal observed upon double irradiation of the secondary methyl absorption is particularly noteworthy. In contrast, the *E*-isomer **9** does not display any measurable interaction between these protons because of their significantly increased distance. Ultimate corroboration of these conclusions derives from X-ray crystallographic analysis of the highly crystalline α-methoxy congener of **9** included in Table 1 (see Figure 2 and Supplementary Material). Thus, the chirality transfer observed in the transformation of **6** into **8** and of **7** into **9** completely mirrors precedent.[11b]

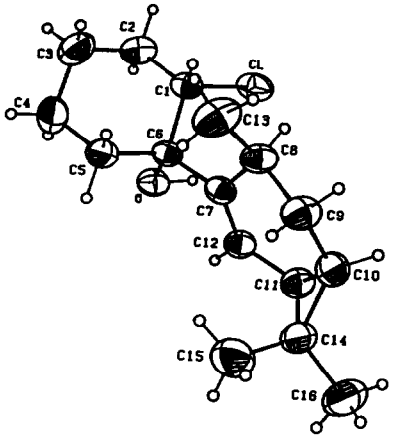



Figure 1. Computer-generated perspective drawing of the final X-ray model of **4**.

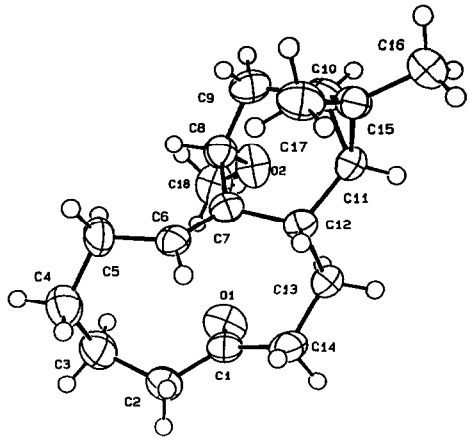
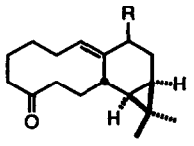
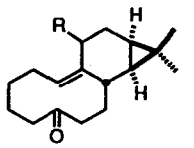



Figure 2. Computer-generated perspective drawing of the final X-ray model of the α-methoxy congener of **9** (see Table 1).

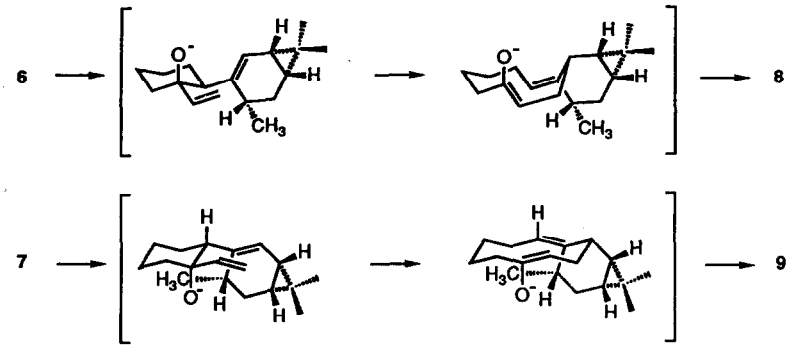
The sigmatropic pathway available to each divinylcarbinol is consistent with these stereochemical findings (Scheme II). Thus, in order to avoid the sterically encumbered β-face of the carene moiety, **6** adopts a boat-like transition state topography so as to bond from the relatively open α-direction. This restriction locks the double bond into a cis geometry. Dienol **7** can, on the other hand, adopt a chair-like geometry having no adverse steric interactions. This favorable conformation is therefore adopted and gives rise to the observed trans isomer. Both processes orient the allylic ring *juncture proton* β.

**Table 1.** Carbonyl Chemical Shifts in Norcarenyl-Fused 5-Cyclodecenones (75 MHz, $C_6D_6$ solutions, values in ppm).

| A. Cis series | | B. Trans series | |
|---|---|---|---|
|  | |  | |
| R = H | 211.9 | R = H | 206.8 |
| R = α-$OCH_3$ | 212.4 | R = α-$OCH_3$ | 209.9 |
| R = β-$CH_3$ | 211.9 | R = β-$CH_3$ | 208.3 |

Although the olefinic functionality in **8** undergoes peracid oxidation relatively slowly (23% complete after 48 h at 20 °C), a single epoxide is produced provided that the reaction mixture is suitably buffered. Failure to take this precaution results instead in conversion to **14** because of

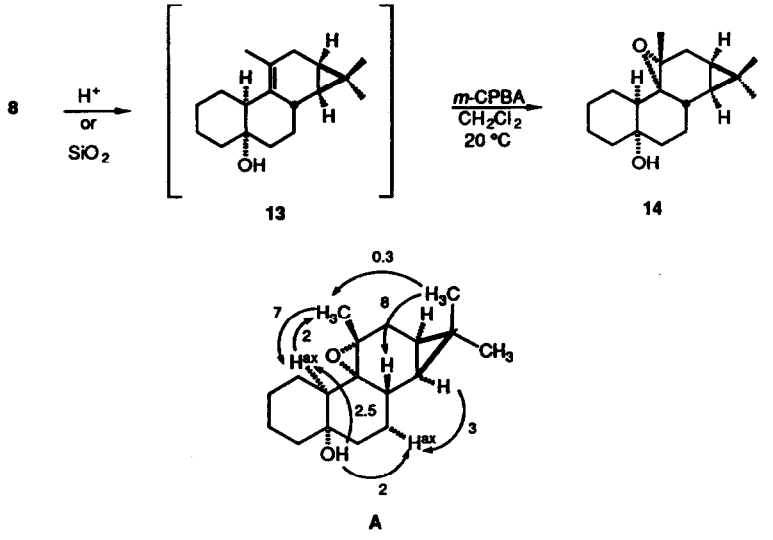
**Scheme II**



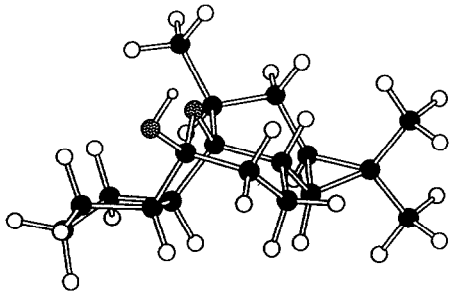
preliminary acid-catalyzed rearrangement to **13** (Scheme III). The transannular cyclization step can be accomplished independently by merely exposing **8** to silica gel. The assignment to structure **13** is based on chemical correlation with epoxide **14**. Although this epoxy alcohol exhibits considerable overlap of $^1H$ NMR signals in both $CDCl_3$ and $C_6D_6$, the combined results of nOe experiments performed in these two solvents make possible unequivocal confirmation of its relative stereochemistry. The key enhancements are illustrated in **A**. The α-oxirane configuration may stem from hydroxyl-directed kinetic acceleration.[12]

At this juncture, the base-promoted closure[13] of epoxide **10** was undertaken. Molecular models of the two *E/Z* enolate pairs accessible to this system clearly reveal that only one possesses the ability to attack the secondary carbon atom of the epoxide in the appropriate manner.[14] Indeed, heating **10** with potassium *tert*-butoxide in *tert*-butyl alcohol led exclusively to a hemiketal ultimately defined as **11**. A distinction between **11** and **11'** was not possible on spectroscopic grounds alone. Consequently, it was necessary to define unequivocally the behavior of **10** under both kinetically- and

**Scheme III**



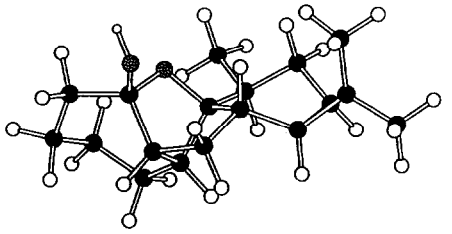

thermodynamically-controlled conditions. Following precedent set by Corey and Gross,[15,16] **10** was treated with LDA *in the presence of* chlorotrimethylsilane. These conditions led smoothly to the production of **12** in unoptimized 78% yield. Note that transannular cyclization does *not* occur under these kinetically-controlled conditions. Information gained from extensive decoupling studies as well as DQF-COSY and one-bond H,C-COSY experiments allowed for assignment of the resolved resonances. Several protons in the overlapping δ 1.90-1.50 region could be recognized by selective nulling of methine and methylene protons, respectively, in appropriate inversion-recovery experiments. Two contiguous proton networks could be assembled from this information. Long-range $^{1}H,^{13}C$ connectivities were derived from an inverse ($^{1}H$-detected) HMBC experiment, which revealed the attachment or $Me_3Si$ to C(4) by showing a correlation via $^{3}J_{C,H}$ between $(\underline{H}_3C)_3Si$ and $\underline{C}(4)$.



**11**

$\Delta E_{strain}$ 50.9 kcal/mol

$\Delta E_{total}$ 58.2 kcal/mol



**11'**

$\Delta E_{strain}$ 56.1kcal/mol

$\Delta E_{total}$ 63.3 kcal/mol

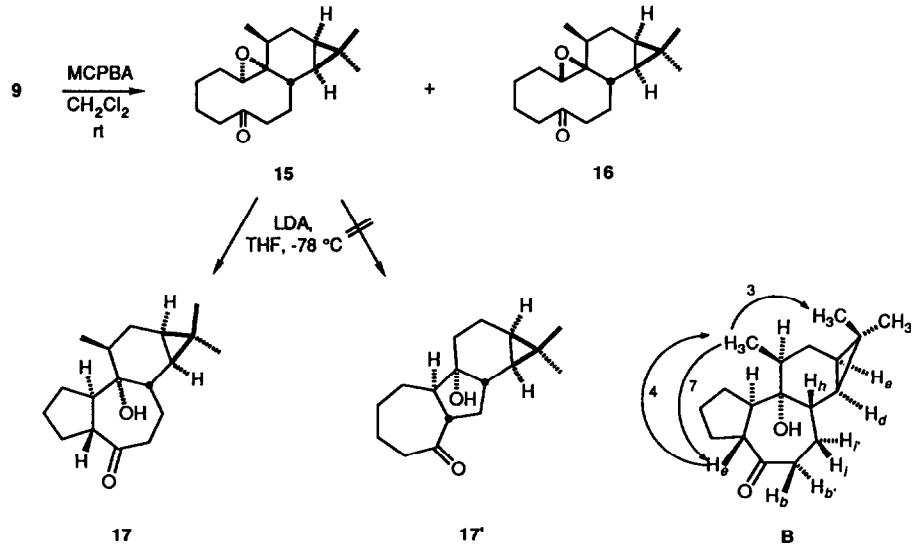
Figure 3. Global minimum energy conformations of **11** (left) and **11'** (right) as determined by molecular mechanics calculations (Chem-3D output).

As noted above, the formation of **11'** was not considered likely on stereoelectronic grounds. The more highly distorted topography and heightened strain energy of **11'** are reflected in its calculated $\Delta E_{strain}$ and $\Delta E_{total}$ values of 56.1 and 63.3 kcal/mol, respectively (Figure 3). Analogous evaluation of **11** by means of the MODEL software package (version KS 2.99) indicates that when the desired transannular cyclization transpires, the appreciably more stable (> 5 kcal/mol) isomer is formed. Thus, the **10** → **11** transformation is favored both kinetically and thermodynamically.

The elaboration of **11** was considered to be a significant advance in that it showed a tigliane-related framework to be attainable in only five steps from 2-chlorocyclohexanone. However, attempts to open the hemiketal ring of **11** under basic or acidic conditions have not proven successful.[17] An alternative means for accomplishing this goal was therefore sought.

Reversal in the relative stereochemistry of the C-O bonds was clearly necessary to achieve the proper match with phorbol (**1**). Since attempts to alter the stereoselectivity of the epoxidation of **8** were without success, attention was focused on the epoxidation of **9**. This cyclododecenone was more reactive than **8**, oxidation occurring rapidly from both faces at room temperature to form **15** and **16** in a 1:1 ratio (86% combined, Scheme IV). After chromatographic separation, **15** was cyclized with LDA in THF at -78 °C to give **17** (71%). Through a combination of COSY 90 (see Figure 4) and nOe experiments (see **B**), it was possible to confirm the gross structural features and relative stereochemistry of **17**, and to definitively rule out the conversion to **17'**. Assignment of the doublet of doublets centered at δ 0.46 to $H_d$ was evident from its chemical shift and coupling pattern. Similarly, the absorption furthest downfield was considered diagnostic of a methine proton α to a cycloheptane carbonyl. This conclusion was confirmed by a DEPT measurement and a C-H correlation. Consequently, the δ 2.76 signal was assigned to $H_a$. Similar tests allowed the δ 2.60 absorption to be associated with one of the $H_b$'s, and the other $H_b$ to lie under the multiplet at δ 2.32. The coupling of

**Scheme IV**



$H_d$ to $H_h$ is quite clear in the COSY spectrum (Figure 4). Phase-sensitive C-H correlation confirmed that $H_h$ is responsible for the δ 1.49 signal. Although $H_h$ appears close to other peaks, the $^1H^1H$ COSY 90 spectrum provides a set of cross-couplings which are independent of other assignments. As a consequence, $H_h$ can be used to identify $H_i$ and $H_{i'}$ (δ2.06, 2.17). The more downfield of these signals was not helpful because the multiplet superimposed on it contains other protons which give complicated cross-couplings with many other protons. However, the other at δ 2.06 gives only four cross-coupling peaks (to $H_h$, $H_i$, and the two $H_b$'s). These data are not compatible with the proton sequencing in **17'**. The absence of coupling to $H_a$ is especially telltale.

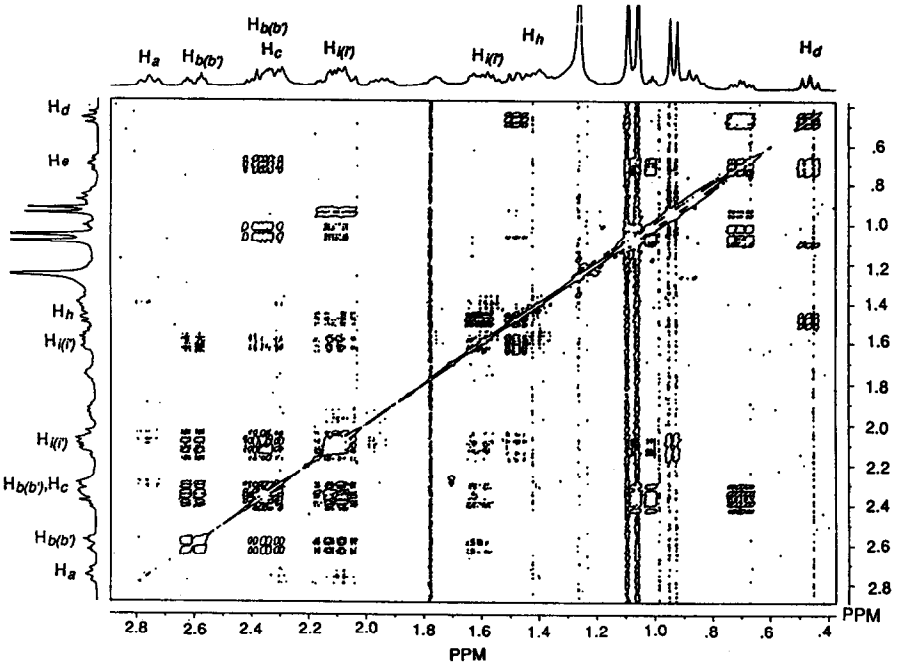
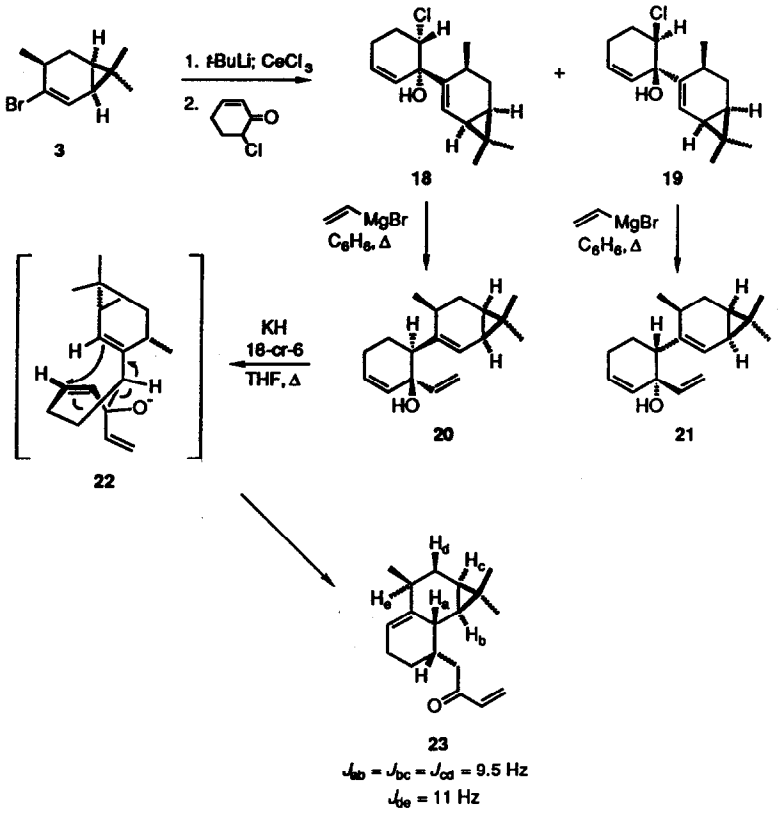



Figure 4. $^1H^1H$ COSY 90 spectrum of **17**.

Following this demonstration that anionic oxy-Cope sigmatropy can be adapted to concise, convergent construction of the phorbol skeleton, the strategy was extended to 6-chloro-2-cyclohexen-1-one.[7] As outlined in Scheme V, chlorohydrins **18** and **19** (ratio 2.5:1)could be obtained in analogous fashion and separated chromatographically. Addition of excess vinylmagnesium bromide to each diastereomer was accomplished operationally as before. However, the direct parallelism between the two series stops here because the added cyclohexenyl double bond in **20** provides to its potassium alkoxide an alternative pathway for charge-promoted [3,3] sigmatropy.[18] In fact, **20** skirts completely the reaction pathway followed by **6** (Scheme II). Instead, the dehydro derivative prefers to

**Scheme V**




isomerize entirely via **22** to give **23**. The cyclohexenyl double bond is engaged to the exclusion of the vinyl substituent, presumably because less nonbonded steric compression is encountered in **22**. Introduction of the third double bond into **20** so rigidifies the alkoxide-substituted six-membered ring that proper alignment of the carenyl and vinyl π-systems cannot be realized as readily as with **6**. This case of intramolecularly competitive oxyanionic sigmatropy represents one of only two presently known examples.[18]

In summary, a highly abbreviated means for elaborating a phorbol model system has been described. The condensation of an optically pure carenyl anion with 2-chlorocyclohexanone provides a convenient means for assembling the two structural components that constitute > 90% of the total carbon content of the target compound. Further applications of this methodology to the elaboration of **1** and **2** are expected to be forthcoming.

## Experimental Section

Melting points were determined in open capillaries with a Thomas-Hoover apparatus and are uncorrected. Infrared spectra were recorded on a Perkin-Elmer Model 1320 spectrometer. $^1$H NMR

spectra were recorded at 300 MHz and $^{13}C$ spectra at 75 MHz on a Bruker AC-300 instrument as denoted. Mass spectra were recorded at The Ohio State University Chemical Instrument Center. Elemental analyses were performed by Scandinavian Microanalytical Laboratory, Herlev, Denmark. All solvents were pre-dried by standard methods. All reactions involving non-aqueous solutions were performed under an inert atmosphere. Unless indicated otherwise, all separations were carried out under flash chromatography conditions on silica gel 60 (230-400 mesh, 60 Å) using the indicated solvents. The organic extracts were dried over anhydrous sodium sulfate.

**Condensation of 3 with 2-Chlorocyclohexanone.** *tert*-Butyllithium (4.13 mL of 1.7 M, 7.02 mmol) was added dropwise to a solution of **3**[7] (1.01 g, 4.68 mmol) in anhydrous THF (15 mL) at -78 °C. After 30 min, this solution was transferred via cannula to a suspension of anhydrous (dried at 140 °C for 18 h) $CeCl_3$ (1.54 g, 6.23 mmol) in the same solvent (30 mL) at -78 °C and the mixture was stirred for 1 h. A solution of 2-chlorocyclohexanone (0.67 g, 5.15 mmol) in THF (10 mL) was introduced dropwise via cannula and stirring was maintained for 2 h at -78 °C prior to removal of the cooling bath and addition of 20 mL of water. The resulting mixture was partitioned between water (100 mL) and ether (100 mL), and the aqueous layer was extracted with ether (3 x 75 mL). The combined organic phases were washed with brine (50 mL), dried, and concentrated. The resulting residue was purified by silica gel chromatography (5% ethyl acetate in petroleum ether) and MPLC (1% ethyl acetate in petroleum ether) to provide 368 mg (30%) of less polar **4** and 368 mg (30%) of more polar **5**.

For **4**: colorless needles; IR (film, $cm^{-1}$) 3540; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.17 (d, $J$ = 2.4 Hz, 1 H), 4.20 (dd, $J$ = 11.7, 4.6 Hz, 1 H), 2.65-2.45 (m, 1 H), 2.25-2.00 (m, 2 H), 1.97 (br s, 1 H), 1.95-1.70 (m, 3 H), 1.65-1.40 (m, 2 H), 1.35-1.15 (m, 2 H), 1.05 (s, 3 H), 0.99 (d, $J$ = 7.1 Hz, 3 H), 0.94 (s, 3 H), 0.90-0.80 (m, 3 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 145.7, 122.1, 76.8, 66.7, 38.8, 33.1, 30.0, 28.2, 27.8, 26.3, 24.1, 23.8, 23.5, 21.6, 21.2, 15.8; MS *m/z* ($M^+$) calcd 268.1594, obsd 268.1600; $[\alpha]_D^{22}$ +14.1° (*c* 1.41, benzene).

*Anal.* Calcd for $C_{16}H_{25}ClO$: C, 71.49; H, 9.37. Found: C, 71.53; H, 9.49.

For **5**: colorless syrup; IR (film, $cm^{-1}$) 3560; $^1H$ NMR (300 MHz, $C_6D_6$) δ 5.95 (m, 1 H), 4.28 (dd, $J$ = 11.7, 4.5 Hz, 1 H), 2.45-2.30 (m, 1 H), 2.25-2.05 (m, 3 H), 2.00-1.80 (m, 3 H), 1.70-1.35 (m, 3 H), 1.35-1.25 (m, 1 H), 1.24 (d, $J$ = 7.1 Hz, 3 H), 1.17 (s, 3 H), 1.11 (s, 3 H), 1.10-1.00 (m, 3 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 145.1, 121.7, 77.0, 68.6, 38.3, 33.1, 30.2, 29.3, 28.2, 26.3, 24.2, 24.0, 22.3, 21.9, 20.8, 16.0; MS *m/z* ($M^+$) calcd 268.1594, obsd 268.1602; $[\alpha]_D^{22}$ +49.6° (*c* 1.68, benzene).

*Anal.* Calcd for $C_{16}H_{25}ClO$: C, 71.49; H, 9.37. Found: C, 71.44; H, 9.37.

**(1*R*,2*S*)-2-[(1*S*,4*S*,6*R*)-4,7,7-Trimethylbicyclo[4.1.0]hept-2-en-3-yl]-1-vinylcyclohexanol (6).** A solution of vinylmagnesium bromide (3.83 mL of 1 M solution in THF, 3.8 mmol) was added to a solution of **4** (257 mg, 0.96 mmol) in 30 mL of anhydrous benzene at 0-5 °C. The mixture was stirred at 0 °C for 15 min, heated to 85 °C in a preheated oil bath for 20 min, quenched with saturated $NH_4Cl$ solution (5 mL) at 0 °C, poured into 50 mL of 50% saturated brine, and extracted with ether (2 x 50 mL). The combined organic layers were washed with brine, dried and concentrated. The residue was purified by silica gel chromatography (5% ethyl acetate in petroleum ether) to yield 227

mg (91%) of **6**; colorless syrup; IR (film, $cm^{-1}$) 3540; $^1H$ NMR (300 MHz, $C_6D_6$) δ 5.80 (dd, $J$ = 17.1, 10.6 Hz, 1 H), 5.51 (m, 1 H), 5.27 (dd, $J$ = 17.1, 1.7 Hz, 1 H), 4.91 (dd, $J$ = 10.6, 1.7 Hz, 1 H), 2.34 (dd, $J$ = 12.8, 3.3 Hz, 1 H), 2.30-2.15 (m, 1 H), 2.00-1.80 (m, 5 H), 1.75-1.60 (m, 1 H), 1.55-1.05 (m, 5 H), 1.01 (s, 3 H), 0.89 (s, 3 H), 0.82 (d, $J$ = 7.1 Hz, 3 H), 0.79-0.72 (m, 2 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 147.2, 146.8, 121.8, 111.0, 72.5, 46.2, 38.0, 31.7, 30.6, 28.6, 27.7, 26.8, 23.2, 23.0, 21.7, 20.8, 19.9, 15.3; MS *m/z* ($M^+$) calcd 260.2140, obsd 260.2156; $[\alpha]_D^{21}$ +105.0° (*c* 2.61, cyclohexane).

*Anal.* Calcd for $C_{18}H_{28}O$: C, 83.02; H, 10.84. Found: C, 83.05; H, 10.87.

**(1*S*,2*R*)-2-[(1*S*,4*S*,6*R*)-4,7,7-Trimethylbicyclo[4.1.0]hept-2-en-3-yl]-1-vinylcyclohexanol (7).** A solution of vinylmagnesium bromide in anhydrous THF (7.2 mL of 1 M solution, 17.2 mmol) was added to a solution of **5** (464 mg, 1.72 mmol) in 50 mL of anhydrous benzene at 0-5 °C. The mixture was stirred at 0 °C for 15 min, heated to 80 °C in a preheated oil bath for 30 min, quenched with saturated $NH_4Cl$ solution (2 mL) at 0 °C, and diluted with ether (50 mL). The separated aqueous phase was extracted with ether (3 x 100 mL) and the combined organic layers were washed with saturated $NaHCO_3$ solution (50 mL) and brine (50 mL), then dried, and concentrated. The residue was purified by silica gel chromatography (1% triethylamine and 2% ethyl acetate in hexanes) to yield 269 mg (60%) of **7**; colorless syrup; IR ($C_6H_6$, $cm^{-1}$) 3560; $^1H$ NMR (300 MHz, $C_6D_6$) δ 5.93 (m, 1 H), 5.78 (dd, $J$ = 17.3, 10.7 Hz, 1 H), 5.16 (dd, $J$ = 17.3, 1.6 Hz, 1 H), 4.90 (dd, $J$ = 10.7, 1.6 Hz, 1 H), 2.40-2.25 (m, 1 H), 2.17 (dd, $J$ = 12.4, 3.4 Hz, 1 H), 1.95-1.65 (m, 4 H), 1.65-1.30 (m, 5 H), 1.25-1.05 (m, 3 H), 1.02 (s, 3 H), 0.96 (s, 3 H), 0.91-0.89 (m, 1 H), 0.86 (d, $J$ = 7.2 Hz, 3 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 147.6, 145.6, 122.6, 110.9, 73.7, 46.3, 39.6, 30.7, 30.5, 30.2, 27.9, 26.9, 24.1, 23.5, 21.6, 21.4, 19.7, 15.9; MS *m/z* ($M^+$) calcd 260.2140, obsd 260.2134; $[\alpha]_D^{21}$ +24.6° (*c* 1.23, cyclohexane).

*Anal.* Calcd for $C_{18}H_{28}O$: C, 83.02; H, 10.84. Found: C, 82.85; H, 10.82.

**(1a*R*,3*S*,3a*Z*,11a*S*,11b*R*)-1,1a,2,3,5,6,7,8,10,11,11a,11b-Dodecahydro-1,1,3-trimethyl-9*H*-cyclopropa[3,4]benzo[1,2]cyclodecen-9-one (8).** To a suspension of KH (206 mg, 5.14 mmol, pretreated with enough 0.5 M $I_2$/THF to maintain a yellow color for several min) in anhydrous THF (20 mL) was added, via cannula, a solution composed of **6** (275 mg, 1.06 mmol) and 18-crown-6 (1.12 g, 4.24 mmol) in anhydrous THF (20 mL). The reaction mixture was heated to reflux for 2.5 h under $N_2$, cooled to -78 °C, quenched with ethanol (3 mL), poured into brine (50 mL), and extracted with ether (3 x 100 mL). The combined organic phases were washed with brine (3 x 50 mL), dried, and concentrated. The residue was purified by chromatography (neutral alumina, 5% ethyl acetate in petroleum ether) to yield 239 mg (87%) of **8**; colorless syrup; IR (film, $cm^{-1}$) 1705; $^1H$ NMR (300 MHz, $C_6D_6$) δ 4.88 (d, $J$ = 12.1 Hz, 1 H), 3.16 (dd, $J$ = 11.5, 4.9 Hz, 1 H), 2.70-2.20 (m, 3 H), 2.15-2.00 (m, 3 H), 2.00-1.80 (m, 1 H), 1.80-1.60 (m, 2 H), 1.60-1.35 (m, 5 H), 1.15-1.00 (m, 1 H), 0.99 (s, 3 H), 0.95 (d, $J$ = 6.9 Hz, 3 H), 0.93 (s, 3 H), 0.90-0.75 (m, 1 H), 0.53 (d, $J$ = 9.0 Hz, 1 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 211.9, 144.9, 122.1, 45.4, 34.5, 32.3, 31.0, 30.8, 29.7, 29.3 (2 C), 29.1, 28.9, 24.8, 23.6, 20.4, 18.2, 14.6; MS *m/z* ($M^+$) calcd 260.2140, obsd 260.2149; $[\alpha]_D^{21}$ +98.8° (*c* 1.20, cyclohexane).

*Anal.* Calcd for $C_{18}H_{28}O$: C, 83.02; H, 10.84. Found: C, 83.33; H, 11.02.

**(1a*R*,3*S*,3a*E*,11a*S*,11b*R*)-1,1a,2,3,5,6,7,8,10,11,11a,11b-Dodecahydro-1,1,3-trimethyl-9*H*-cyclopropa[3,4]benzo[1,2]cyclodecen-9-one (9).** To a suspension of KH (38 mg, 0.95 mmol, pretreated with 1 drop of 0.5 M $I_2$/THF) in anhydrous THF (15 mL) was added, via cannula, a solution composed of **7** (44 mg, 0.17 mmol) and 18-crown-6 (250 mg, 0.95 mmol) in anhydrous THF (15 mL). The reaction mixture was heated to reflux for 2 h under $N_2$, cooled to -78 °C, quenched with ethanol (2 mL), diluted with petroleum ether (30 mL), poured into brine (50 mL), and extracted with ether (2 x 25 mL). The combined organic phases were washed with brine (3 x 25 mL), dried, and concentrated. The residue was purified by chromatography (neutral alumina, 5% ethyl acetate in petroleum ether) to yield 34 mg (77%) of **9**; colorless syrup; IR (film, $cm^{-1}$) 1710; $^1H$ NMR (300 MHz, $C_6D_6$) δ 4.82 (dd, $J$ = 11.9, 3.5 Hz, 1 H), 2.65-2.50 (m, 2 H), 2.40-2.25 (m, 1 H), 2.15-1.75 (m, 9 H), 1.65-1.50 (m, 1 H), 1.50-1.40 (m, 2 H), 1.25 (d, $J$ = 6.9 Hz, 3 H), 1.16 (dt, $J$ = 13.4, 4.2 Hz, 1 H), 1.02 (s, 3 H), 0.97 (s, 3 H), 0.80 (dt, $J$ = 9.1, 4.2 Hz, 1 H), 0.29 (d, $J$ = 9.1 Hz, 1 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 208.3, 145.6, 124.4, 48.2, 45.5, 43.6, 34.3, 33.8, 32.3, 30.9, 29.1, 28.8, 28.2, 23.5, 22.0, 21.5, 18.6, 15.2; MS *m/z* ($M^+$) calcd 260.2140, obsd 260.2142; $[\alpha]_D^{22}$ +63.7° (*c* 1.37, cyclohexane).

*Anal.* Calcd for $C_{18}H_{28}O$: C, 83.02; H, 10.84. Found: C, 83.21; H, 10.87.

**(1a*R*,3*S*,3a*S*,4*R*,11a*S*,11b*R*)-3a,4-Epoxytetradecahydro-1,1,3-trimethyl-9*H*-cyclopropa-[3,4]benzo[1,2]cyclodecen-9-one (10).** A solution of **8** (56 mg, 0.22 mmol) in anhydrous $CH_2Cl_2$ (5 mL) was treated with $NaH_2PO_4 \cdot H_2O$ (91 mg, 0.66 mmol), $Na_2HPO_4$ (94 mg, 0.66 mmol), and MCPBA (53 mg, 0.22 mmol). The resultant suspension was stirred at rt for 48 h, diluted with ether (20 mL), and washed with 10% sodium bisulfite solution (20 mL), 10% $NaHCO_3$ solution (2 x 20 mL), and brine (20 mL) prior to drying and concentration. The residue was purified by chromatography (Florisil) to yield 35 mg (63% recovery) of **8** and 14 mg (23%, 63% based on recovered starting material) of **10**; colorless syrup; IR (film, $cm^{-1}$) 1707, 1458; $^1H$ NMR (300 MHz, $C_6D_6$) δ 2.68 (dd, $J$ = 10.4, 1.5 Hz, 1 H), 2.35-2.25 (m, 1 H), 2.05-1.90 (m, 4 H), 1.90-1.50 (m, 6 H), 1.50-1.45 (m, 2 H), 1.42 (s, 3 H), 1.35-1.15 (m, 2 H), 1.03 (s, 3 H), 1.00-0.90 (m, 1 H), 0.86-0.78 (dt, $J$ = 9.3, 4.7 Hz, 1 H), 0.66 (d, $J$ = 6.5 Hz, 3 H), 0.39 (d, $J$ = 9.3 Hz, 1 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 210.7, 65.4, 59.6, 42.2, 40.1, 33.1, 30.0, 29.7, 29.2, 27.7, 27.0, 25.7, 25.1, 24.8, 19.9, 18.7, 15.1, 13.9; MS, *m/z* ($M^+$) calcd 276.2089, obsd 276.2086; $[\alpha]_D^{22}$ +81.8° (*c* 1.5, cyclohexane).

**(1a*R*,1b*S*,4*R*,4a*S*,7a*R*,7b*S*,8*S*,9a*R*)-Dodecahydro-1,1,8-trimethyl-4,7b-epoxy-7b*H*-cyclopropa[3,4]benz[1,2-*e*]azulen-4-(4a*H*)-ol (11).** A solution composed of **10** (15.7 mg, 0.057 mmol), potassium *tert*-butoxide (22 mg, 0.2 mmol) and *tert*-butyl alcohol (6 mL) was heated at reflux under $N_2$ for 19 h, cooled, diluted with ether (25 mL), washed with saturated $NH_4Cl$ solution (15 mL) and brine (3 x 15 mL), dried and concentrated to yield a yellow syrup. This material was purified by silica gel chromatography (10% ethyl acetate in petroleum ether) to give 8 mg (51%) of **11**; colorless oil; IR (film, $cm^{-1}$) 3473; $^1H$ NMR (300 MHz, $CDCl_3$) δ 2.58 (s, 1 H), 2.49 (ddd, $J$ = 8, 8, 8 Hz, 1 H), 2.36 (ddd, $J$ = 9, 8, 8 Hz, 1 H), 1.97-1.82 (m, 1 H), 1.81-1.36 (series of m, 11 H), 1.34-1.24 (m, 1 H), 1.03 (s, 3 H), 1.00 (s, 3 H), 0.95 (d, $J$ = 7.2 Hz, 3 H), 0.90-0.81 (m, 1 H), 0.56 (ddd, $J$ = 9, 8, 8 Hz, 1 H), 0.12 (t, $J$ = 9.0 Hz, 1 H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 103.3, 83.7, 50.2, 49.8, 37.3, 35.9, 34.6,

30.3, 28.8, 28.4, 28.2, 27.6, 26.4, 25.9, 22.7, 17.9, 17.8, 15.0; MS *m/z* ($M^+$) calcd 276.2089, obsd 276.2064; $[\alpha]_D^{21}$ +4.8° (*c* 0.79, cyclohexane).

**C-Silylation of 10.** LDA was prepared in a dry flask by the addition of diisopropylamine (24 μL, 0.17 mmol) and *n*-butyllithium (150 μL of 1.1M, 0.17 mmol) to 2 mL of THF at -78 °C. A solution of chlorotrimethylsilane (22 μL, 0.17 mmol), **10** (29 mg, 0.11 mmol), and THF (10 mL) was cooled to -78 °C and added via cannula to the LDA solution. The reaction mixture was stirred for 1h at -78 °C, quenched by the addition of 250 μL of $Et_3N$, diluted with ether (100 mL), washed with saturated $NaHCO_3$ solution (2 x 5 mL) and brine (5 mL), dried, and concentrated. The residue was purified on a Florisil column to yield 30 mg (78%) of **12** as a colorless solid, mp 144-145 °C; IR (film, $cm^{-1}$) 1681; $^1H$ NMR (300 MHz, $C_6D_6$) δ 2.66 (dd, *J* = 11.4, 2.3 Hz, 1 H), 2.26-2.08 (m, 2 H), 1.99 (br d, *J* = 11.4 Hz, 1 H), 1.87-1.20 (series of m, 12 H), 1.30 (s, 3 H), 0.98 (s, 3 H), 0.81 (td, *J* = 9.2, 4.6 Hz, 1 H), 0.73-0.60 (m, 1 H), 0.67 (d, *J* = 6.6 Hz, 3 H), 0.38 (d, *J* = 9.2 Hz, 1 H), -0.03 (s, 9 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 212.8, 66.9, 59.5, 47.8, 44.9, 34.1, 32.5, 29.7, 29.1, 28.4 (2 C), 27.8, 27.0, 25.9, 20.6, 18.8, 15.4, 14.3, -2.9; MS *m/z* ($M^+$) calcd 348.2484, obsd 348.2483; $[\alpha]_D^{21}$ +73.6° (*c* 0.97, cyclohexane).

**Epoxide 14.** A solution of **8** (110 mg, 0.42 mmol) in anhydrous $CH_2Cl_2$ (25 mL) was treated with MCPBA (150 mg, 0.87 mmol). The resultant suspension was stirred at rt for 48 h and worked up as before. The residue was purified by chromatography (Florisil) to yield 80 mg (69%) of **14**; colorless oil; IR (film, $cm^{-1}$) 3580; $^1H$ NMR (300 MHz, $CDCl_3$) δ 3.39 (s, 1 H), 2.15 (dd, *J* = 16.3, 9.6 Hz, 1 H), 2.05-1.82 (m, 2 H), 1.81-1.61 (series of m, 5 H), 1.55-1.15 (series of m, 8 H), 1.25 (s, 3 H), 0.98 (s, 3 H), 0.69 (s, 3 H), 0.49 (dt, *J* = 9.4, 3.1 Hz, 1 H), 0.07 (dd, *J* = 9.4, 2.3 Hz, 1 H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 73.2, 66.1, 60.2, 47.0, 39.6, 31.7, 28.2, 27.7, 26.8, 26.3, 25.8, 25.6, 23.3, 22.0, 18.6, 16.0, 15.8, 15.3; MS *m/z* ($M^+$) calcd 276.2089, obsd 276.2083; $[\alpha]_D^{21}$ -52.4° (*c* 1.42, chloroform).

**Acid-Catalyzed Rearrangement of 8.** Chromatography of **8** (275 mg, 1.06 mmol) on silica gel resulted in conversion to **13** (190 mg, 69%); colorless oil; IR (film, $cm^{-1}$) 3469; $^1H$ NMR (300 MHz, $C_6D_6$) δ 2.56 (dd, *J* = 12.5, 3.3 Hz, 1 H), 2.22 (dd, *J* = 18.2, 7.8 Hz, 1 H), 1.97-1.86 (complex m, 3 H), 1.81-1.66 (series of m, 4 H), 1.64 (s, 1 H), 1.53 (s, 3 H), 1.51-1.10 (series of m, 7 H), 1.04 (s, 3 H), 0.80 (s, 3 H), 0.65 (t, *J* = 9.2 Hz, 1 H), 0.33 (d, *J* = 9.2 Hz, 1 H); $^{13}C$ NMR (75 MHz, $C_6D_6$, ppm) 131.8, 125.8, 72.2, 48.1, 40.3, 32.4, 32.2, 28.8, 28.5, 28.3, 28.2, 26.7, 25.3, 24.3, 18.8, 18.3, 16.6, 13.7; MS *m/z* ($M^+$) calcd 260.2140, obsd 260.2133; $[\alpha]_D^{21}$ -43.9° (*c* 2.49, cyclohexane).

**Epoxidation of 9.** A solution of **9** (8.8 mg, 0.034 mmol) in anhydrous $CH_2Cl_2$ (5 mL) was treated with $NaH_2PO_4 \cdot H_2O$ (8 mg, 0.06 mmol), $Na_2HPO_4$ (8 mg, 0.06 mmol), and MCPBA (7 mg, 0.04 mmol). The resultant suspension was stirred at rt for 18 h and processed in the predescribed manner. The residue was purified by chromatography on neutral alumina (elution with 10% ethyl acetate in petroleum ether) to yield pure **15** (4 mg, 43%) and **16** (4 mg, 43%).

For **15**: colorless oil; IR ($CHCl_3$, $cm^{-1}$) 1698; $^1H$ NMR (300 MHz, $C_6D_6$) δ 2.86 (dd, $J$ = 1.8, 9.5 Hz, 1 H), 2.24-2.04 (m, 4H), 2.01-1.67 (m, 5 H), 1.66-1.22 (m, 7 H), 0.98 (s, 3 H), 0.96 (s, 3 H), 0.90 (d, $J$ = 7 Hz, 3 H), 0.77-0.71 (m, 2 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 211.3, 66.7, 61.6, 44.4, 44.2, 34.4, 33.5, 30.0, 28.4, 27.2, 27.0, 26.7, 25.8, 21.9, 20.4, 18.5 (2 C), 15.2; MS *m/z* ($M^+$) calcd 276.2086, obsd 276.2083; $[\alpha]_D^{22}$ +52.5° (*c* 0.44, $CHCl_3$).

For **16**: colorless solid, mp 93-94 °C; IR ($CHCl_3$, $cm^{-1}$) 1703; $^1H$ NMR (300 MHz, $C_6D_6$) δ 2.45 (m, 1 H), 2.31 (dd, $J$ = 2.9, 6.8 Hz, 1 H), 2.23 (m, 1 H), 2.06 (m, 2 H), 1.93-1.65 (m, 6 H), 1.60-1.42 (m, 2 H), 1.40 (s, 3H), 1.37-1.21 (m, 2 H), 1.16-1.03 (s, 3 H), 0.80 (d, $J$ = 6.7 Hz, 3 H), 0.88-0.78 (m, 1 H), 0.23 (d, $J$ = 9.5 Hz, 1 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 209.2, 65.6, 65.2, 44.2, 42.8, 42.4, 30.3, 30.0, 29.8, 29.6, 29.3, 28.8, 27.9, 23.9, 21.4, 18.4, 17.2, 15.5; MS *m/z* ($M^+$) calcd 276.2086, obsd 276.2091; $[\alpha]_D^{22}$ +34.2° (*c* 1.91, $CHCl_3$).

**Cyclization of 15.** A solution of **15** (11 mg, 0.036 mmol) in dry THF (6 mL) was blanketed with $N_2$, cooled to -78 °C, and treated with freshly prepared LDA (0.25 mL of 0.26 M in THF) via syringe. After 120 min, an additional 2.0 mL of the LDA solution was introduced and stirring was maintained 60 min longer. The reaction mixture was quenched with water (5 mL) and ether (50 mL) was added. The separated aqueous phase was extracted with ether (2 x 25 mL) and the combined organic layers were washed with 5% HCl (20 mL) and brine (2 x 25 mL), then dried and concentrated. The residue was purified by flash chromatography on silica gel (elution with 15% ethyl acetate in hexanes) to give 8 mg (71%) of **17** as a colorless waxy solid; IR ($CHCl_3$, $cm^{-1}$) 1690; $^1H$ NMR (300 MHz, $CDCl_3$) δ 2.76 (ddd, $J$ = 9.1, 9.1, 1.9 Hz, 1 H), 2.60 (ddd, $J$ = 3.7, 3.7, 14.7 Hz, 1 H), 2.42-2.24 (m, 3 H), 2.17-2.06 (m, 3 H), 2.04-1.91 (m, 1 H), 1.78-1.70 (m, 1H), 1.66-1.30 (m, 5 H), 1.09 (s, 3 H), 1.06 (s, 3 H), 1.21-1.00 (m, 1 H), 0.93 (d, $J$ = 7.4 Hz, 3 H), 0.90-0.83 (m, 1 H), 0.70 (ddd, $J$ = 3.8, 9.4, 9.4 Hz, 1 H), 0.46 (dd, $J$ = 7.4, 8.8 Hz, 1 H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 210.6, 75.0, 50.3, 49.7, 44.7, 35.7, 34.9, 29.7, 28.7, 28.6, 28.2, 26.3, 26.1, 25.4, 19.1, 18.5, 18.2, 16.0; MS *m/z* ($M^+$) calcd 276.2089, obsd 276.2084; $[\alpha]_D^{22}$ +105° (*c* 0.2, $CHCl_3$).

**Condensation of 3 with 6-Chloro-2-cyclohexen-1-one.** *tert*-Butyllithium (3.6 mL of 1.7 M, 6.11 mmol) was added dropwise to a solution of **3** (0.66 g, 3.06 mmol) in anhydrous THF (20 mL) at -90 °C. After 30 min, this solution was transferred via cannula to a suspension of anhydrous (dried at 140 °C for 18 h) $CeCl_3$ (5 mmol) in the same solvent (20 mL) at -90 °C, and the mixture was stirred for 45 min. A solution of 6-chloro-2-cyclohexen-1-one[7] (0.78 g, 6 mmol) in THF (25 mL) was introduced dropwise via cannula and stirring was maintained for 2 h at -90 °C prior to removal of the cooling bath and addition of 10 mL of water. The resulting mixture was partitioned between water (100 mL) and ether (100 mL), and the aqueous layer was extracted with ether (3 x 50 mL). The combined organic phases were washed with brine (3 x 50 mL), dried, and concentrated. The residue was purified by silica gel chromatography (3% ethyl acetate in petroleum ether) to yield 333 mg of a mixture of **18** and **19** (41%). MPLC (2% ethyl acetate in petroleum ether) was utilized to separate the mixture thus affording 194 mg of the less polar **18** and 78 mg of the more polar **19**.

For **18**: colorless syrup; IR (film, $cm^{-1}$) 3540; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.07 (dd, $J$ = 3.9, 2.9 Hz, 1 H), 5.59-5.38 (m, 2 H), 4.43 (dd, $J$ = 8.0, 2.9 Hz, 1 H), 2.56-2.47 (m, 1 H), 2.37 (s, 3 H), 2.06-1.81 (m, 4 H), 1.66-1.53 (m 1 H), 1.14 (ddd, $J$ = 14.8, 9.5, 4.4 Hz, 1 H), 1.03 (d, $J$ = 7.1 Hz, 1 H), 1.01 (s, 1 H), 0.98 (ddd, $J$ = 8.8, 4.4, 1.5 Hz, 1 H), 0.85 (s, 3 H), 0.82 (ddd, $J$ = 18.0, 9.5, 4.4 Hz, 1 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 143.5, 132.9, 127.5, 125.8, 75.1, 65.5, 30.1, 28.6, 27.8, 27.6, 27.0, 24.1, 23.3, 22.2, 20.7, 15.6; MS *m/z* ($M^+$) calcd 266.1437, obsd 266.1444; $[\alpha]_D^{21}$ +100.1° (*c* 0.92, cyclohexane).

For **19**: colorless solid; IR (film, $cm^{-1}$) 3550; $^1H$ NMR (300 MHz, $C_6D_6$) δ 5.99 (t, $J$ = 2.9 Hz, 1 H), 5.53-5.44 (m, 2 H), 4.39 (dd, $J$ = 8.3, 2.9 Hz, 1 H), 2.33 (s, 1 H), 2.30-2.20 (m, 1 H), 2.03-1.89 (m, 3 H), 1.82-1.74 (m, 1 H), 1.67-1.55 (m, 1 H), 1.33 (ddd, $J$ = 14.7, 10.3, 4.5 Hz, 1 H), 1.13 (d, $J$ = 7.0 Hz, 3 H), 1.03 (s, 3 H), 1.01 (s, 3 H), 0.97-0.82 (m, 2 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 143.0, 131.9, 128.2, 126.6, 75.1, 65.8, 31.3, 29.9, 28.1, 27.9, 24.1, 24.0, 23.6, 21.5, 21.2, 15.8; MS *m/z* ($M^+$) calcd 266.1437, obsd 266.1446; $[\alpha]_D^{21}$ +1.3° (*c* 0.80, cyclohexane).

**(1*S*,2*S*)-6-[(1*S*,4*S*,6*R*)-4,7,7-Trimethylbicyclo[4.1.0]hept-2-en-3-yl]-1-vinyl-2-cyclohexen-1-ol (20).** A solution of vinylmagnesium bromide in anhydrous THF (2.9 mL of 1 M solution, 2.9 mmol) was added to a solution of **18** (190 mg, 0.71 mmol) in 35 mL of anhydrous benzene at 0-5 °C. The mixture was stirred at 0 °C for 30 min, heated to 82 °C in a preheated oil bath for 30 min, quenched with saturated $NH_4Cl$ solution (5 mL) at 0 °C, poured into 25 mL of 50% saturated brine, and extracted with ether (3 x 50 mL). The combined organic layers were washed with brine, dried, and concentrated. The residue was purified by silica gel chromatography (5% ethyl acetate in petroleum ether) to yield 110 mg (60%) of **21**; colorless syrup; IR (film, $cm^{-1}$) 3520; $^1H$ NMR (300 MHz, $C_6D_6$) δ 5.90 (dd, $J$ = 17.1, 10.5 Hz, 1 H), 5.77-5.67 (m, 2 H), 5.60 (m, 1 H), 5.37 (dd, $J$ = 17.1, 1.7 Hz, 1 H), 4.98 (dd, $J$ = 10.5, 1.7 Hz, 1 H), 2.55-2.51 (m, 1 H), 2.26-2.16 (m, 1 H), 2.03 (s, 1 H), 1.99-1.76 (m, 4 H), 1.32-1.22 (m, 1 H), 1.18-1.04 (m, 1 H), 1.01 (s, 3 H), 0.90 (s, 3 H), 0.81 (d, $J$ = 7.1 Hz, 3 H), 0.80-0.75 (m, 2 H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 145.8, 145.7, 132.4, 129.5, 123.7, 112.2, 71.1, 45.1, 31.3, 30.5, 27.7, 26.7, 25.4, 23.3, 23.2, 20.7, 19.9, 15.4; MS *m/z* ($M^+$) calcd 258.1984, obsd 258.1984; $[\alpha]_D^{21}$ +102.6° (*c* 1.18, cyclohexane).

*Anal.* Calcd for $C_{18}H_{26}O$: C, 83.67; H, 10.14. Found: C, 83.49; H, 10.18.

**(1*R*,2*R*)-6-[(1*S*,4*S*,6*R*)-4,7,7-Trimethylbicyclo[4.1.0]hept-2-en-3-yl]-1-vinyl-2-cyclohexen-1-ol (21).** A solution of vinylmagnesium bromide (0.6 mL of 1 M solution in THF 0.6 mmol) was added to a solution of **19** (60 mg, 0.23 mmol) in 5 mL of anhydrous benzene at 0-5 °C. The mixture was stirred at 0 °C for 20 min, heated to 80 °C in a preheated oil bath for 25 min, quenched with saturated $NH_4Cl$ solution (5 mL) at 0 °C, and partitioned between ether (20 mL) and 50% saturated brine (20 mL). The aqueous layer was separated and extracted with ether (3 x 20 mL). The combined organic layers were washed with brine, dried, and concentrated. The residue was purified by silica gel chromatography (5% ethyl acetate in petroleum ether) to yield 15.3 mg (40%) of **21**; colorless syrup; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.11 (t, $J$ = 2.8 Hz, 1 H), 5.96 (dd, $J$ = 17.2, 10.6 Hz, 1 H), 5.69-5.60 (m, 2 H), 5.35 (dd, $J$ = 17.2, 1.7 Hz, 1 H), 5.03 (dd, $J$ = 10.6, 1.7 Hz, 1 H), 2.50 (dd, $J$ = 3.3, 3.2 Hz, 1 H),

2.33-2.30 (m, 1 H), 1.99 (s, 1 H), 1.96-1.56 (m 5 H), 1.26-1.15 (m, 1 H), 1.06 (s, 3 H), 1.00 (s, 3 H), 0.92-0.89 (m, 2 H), 0.85 (d, $J$ = 7.1 Hz, 3 H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 146.0, 143.5, 133.3, 129.3, 123.4, 112.6, 72.3, 44.7, 30.5, 30.3, 27.8, 25.5, 25.1, 24.1, 23.4, 21.2, 19.7, 15.8; MS $m/z$ ($M^+$) calcd 258.1984, obsd 258.1966; $[\alpha]_D^{21}$ +7.3° ($c$ 0.88, cyclohexane).

**Anionic Oxy-Cope Rearrangement of 20.** To a suspension of KH (16 mg, 0.4 mmol, pretreated with one drop 0.5 M $I_2$/THF) in anhydrous THF (25 mL) was added via cannula a solution composed of **20** (20 mg, 0.08 mmol) and 18-crown-6 (106 mg, 0.4 mmol) in anhydrous THF (25 mL). The reaction mixture was heated to reflux for 2 h under argon, cooled to -78 °C, quenched with ethanol (2 mL), poured into brine (20 mL), and extracted with ether (3 x 20 mL). The combined organic phases were washed with brine (3 x 20 mL), dried, and concentrated. The residue was purified by chromatography (neutral alumina, 5% ethyl acetate in petroleum ether) to yield 5 mg (25%) of **23**; colorless syrup; $^1$H NMR (300 MHz, $C_6D_6$) δ 6.15 (dd, $J$ = 17.7, 10.5 Hz, 1 H), 5.93 (dd, $J$ = 17.7, 1.4 Hz, 1 H), 5.50-5.45 (m, 1 H), 5.22 (dd, $J$ = 10.5, 1.4 Hz, 1 H), 2.58-2.31 (m, 3 H), 2.28-2.15 (m, 1 H), 2.12-1.92 (m, 2 H), 1.78-1.69 (m, 2 H), 1.46-1.38 (m, 1 H), 1.33-1.18 (m, 1 H), 0.98 (d, $J$ = 6.9 Hz, 3 H), 0.93 (s, 3 H), 0.90 (s, 3 H), 0.69 (ddd, $J$ = 14.5, 11, 9.5 Hz, 1 H), 0.55 (ddd, $J$ = 9.5, 9.5, 7 Hz, 1 H), 0.29 (dd, $J$ = 9.5, 9.5 Hz, 1 H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 198.3, 144.9, 137.4, 126.5, 119.6, 43.8, 35.5, 32.8, 32.3, 28.4, 27.5, 27.1, 25.7, 24.9, 23.1, 22.3, 19.1, 15.2; $[\alpha]_D^{21}$ +22.9 ($c$ 0.47, cyclohexane).

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**Supplementary Material Available:** Crystal data, summary of X-ray data collection, tables of bond distances and angles, final fractional coordinates, thermal parameters, and observed and calculated structure factors for **4** and the α-methoxy congener of **9**, as well as the final fractional coordinates for **11** and **11'** (33 pages). The crystallographic information can be obtained on request from The Director, Cambridge Crystallographic Data Centre, University Chemical Laboratory, Lensfield Road, Cambridge CB2 1EW, U.K.

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