# Synthesis of Terpenoids Using a Free Radical Fragmentation/ Elimination Sequence

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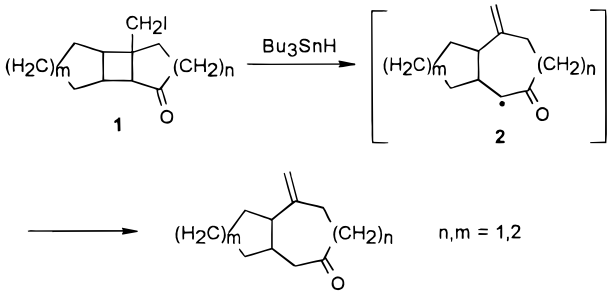
Total syntheses of the guaiane alismol **8** and the trinor-guaiane dictamnol **18** are reported. In both syntheses the initial [2+2] photoadduct is transformed into an iodo xanthate **14** or a diiodide **27**, respectively. In the critical step, the strained bifunctional substrate undergoes a very efficient free radical fragmentation/elimination sequence to give the requisite seven-membered ring with regioselective placement of the two double bonds in that ring. This first alismol synthesis was accomplished in eight steps while the dictamnol synthesis required only six steps. Clarification of the structure of dictamnol is also described.

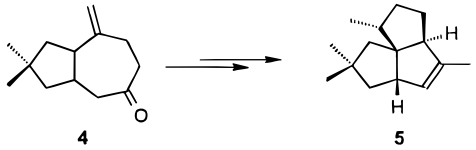
## Introduction

In previous investigations we showed that free radical fragmentation of appropriate photoadduct derivatives **1** leads to bicyclo[*m*.*n*.0]carbon skeletons **3** that are present in terpenoids (Scheme 1).[1,2] For example, this methodology was employed in the preparation of **4**,[2] an important relay in the synthesis of the angular triquinane pentalenene **5**[3] (Scheme 2). Other research groups have also used free radical fragmentations in their approaches to natural product syntheses.[4] In the partial mechanism outlined in Scheme 1, free radical **2** formed after the fragmentation is reduced by the chain-transfer reagent $Bu_3SnH$. We wished to extend this methodology by including a leaving group (Y) on the carbon adjacent to this radical (**6** in Scheme 3) and thereby facilitating the regioselective introduction of a second double bond to give **7**. Herein we describe the total syntheses of the guaiane alismol[5a] and the trinor-guaiane dictamnol[5b] using this free radical fragmentation/elimination sequence as a key step.

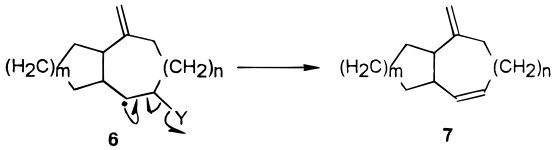
**Scheme 1**




**Scheme 2**




**Scheme 3**




## Results and Discussion

**Synthesis of Alismol.** Alismol **8** is a naturally occurring guaiane first isolated from the rhizome of *Alisma plantago-aquatica* var. *orientale*.[6] The rhizome has been used in the preparation of a drug known as "takusha", employed in traditional Oriental medicine for its diuretic and antiinflammatory activity. **8** has also been isolated from Australian soft corals *Nephthea chabrolii* and *Lemnalia africana*[7a] and Okinawan soft coral *Xenia* sp.[7b] The structure originally proposed[6] was revised recently to one in which the ring-fusion is *trans*-**8**[8] rather than *cis*-**8**. No other synthesis of **8** has been reported prior to or since our communication.[5a]

The essential features of our approach involved conversion of a photoadduct to a difunctional substrate which then underwent the critical fragmentation/elimination sequence (Scheme 4). Adduct **11** was prepared by [2+2]

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(1) Lange, G. L.; Gottardo, C. *Tetrahedron Lett.* **1990**, *31*, 5985.
(2) Lange, G. L.; Gottardo, C. *J. Org. Chem.* **1995**, *60*, 2183.
(3) Pattenden, G.; Teague, S. T. *Tetrahedron* **1987**, *43*, 5637.
(4) (a) Dowd, P.; Zhang, W. *Chem. Rev.* **1993**, *93*, 2091. (b) Pattenden, G.; Schultz, D. J. *Tetrahedron Lett.* **1993**, *34*, 6787. (c) Rawal, V. H.; Dufour, C.; Iwasa, S. *Tetrahedron Lett.* **1995**, *36*, 19. (d) Dowd, P.; Zhang, W. *Tetrahedron Lett.* **1996**, *37*, 957. (e) Crimmins, M. T.; Huang, S.; Guise-Zawacki, L. E. *Tetrahedron Lett.* **1996**, *37*, 6519.
(5) Preliminary accounts of these syntheses have been reported. (a) Lange, G. L.; Gottardo, C. *Tetrahedron Lett.* **1994**, *35*, 8513. (b) Lange, G. L.; Merica, A.. Chimanikire, M. *Tetrahedron Lett.* **1997**, *38*, 6371.
(6) Oshima, Y.; Iwagawa, T.; Hikino, H. *Phytochemistry* **1983**, *22*, 183.
(7) (a) Bowden, B. F.; Iwagawa, T.; Mitchell, J. *Aust. J. Chem.* **1980**, *33*, 1833. (b) Kitagawa, I.; Kobayashi, M.; Cui, Z.; Kiyota, Y.; Ohnishi, M. *Chem. Pharm. Bull.* **1986**, *34*, 4590.
(8) Yoshikawa, M.; Yamaguchi, S.; Matsuda, H.; Kohda, Y.; Ishigawa, H.; Tanaka, N.; Yamahara, J.; Mukarani, N. *Chem. Pharm. Bull.* **1994**, *42*, 1813.

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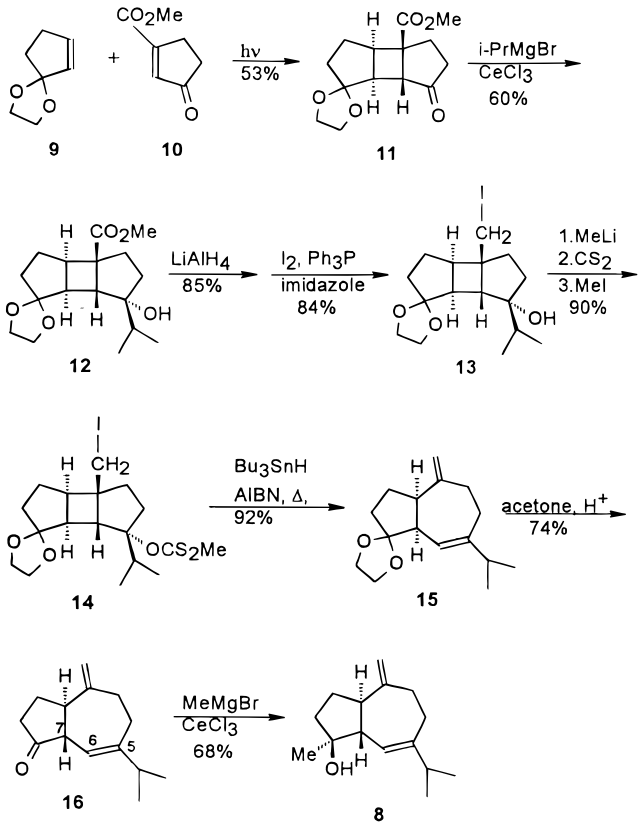
**Scheme 4**



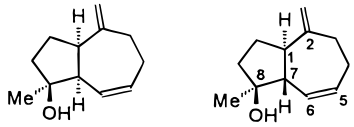

photoaddition of an excess of alkene **9**[9] with enone **10**[10] in methylene chloride solvent. Ketals such as **9** generally give exclusively or predominantly head-to-head adducts,[11,12] particularly in nonpolar solvents.[13] Adduct **11** was contaminated by about 20% of an inseparable regioisomer which was tentatively assigned a head-to-tail structure. This impurity was removed in the next step. Regio- and stereoselective reaction of **11** with isopropyl Grignard gave addition product **12**. $CeCl_3$ was included in the reaction mixture to minimize the enolization side reaction.[14] Reduction of the ester group in **12** with $LiAlH_4$ followed by conversion of the resultant primary alcohol to an iodide using our standard protocol ($Ph_3P$, $I_2$, imidazole)[15] gave **13** in good yield. The tertiary alcohol did not react under these $S_N2$-type iodination conditions.

Next we wished to convert the tertiary alcohol in **13** into a free radical leaving group prior to our attempted fragmentation/elimination reaction. Xanthates, halides, and groups such as SPh, SOPh, $SO_2Ph$, and SePh have previously served as effective radical leaving groups.[16] The xanthate was chosen for this purpose, and alcohol **13** was converted to derivative **14**. Generation of the tertiary alkoxide of **13** prior to reaction with $CS_2$ required the very strong base methyllithium.[17] Treatment of iodo xanthate **14** under the usual free radical conditions with $Bu_3SnH$ gave in excellent yield the desired fragmentation/elimination product **15** (Scheme 4). In this reaction the 5/7 ring system was formed and both double bonds present in the target alismol were introduced regioselectively.

To complete the synthesis, the ketal protective group in **15** was removed in the presence of acidic acetone. Apparently, during this reaction acid-catalyzed epimerization at C-7 also took place to give the *trans*-fused product **16**. Reaction of **16** with methyl Grignard resulted in stereoselective attack from the α-face to give in good yield (±)-alismol **8**. This reaction was conducted in the presence of $CeCl_3$ to minimize enolization and prevent possible isomerization of the $C_5-C_6$ double bond into conjugation with the carbonyl group at $C_8$. This highly regio- and stereoselective synthesis of the sesquiterpenoid alismol was accomplished in only eight steps. It should also be possible to synthesize **8** in an optically enriched form and establish its absolute configuration by using our previously reported asymmetric induction methodology[12] with a chiral ketal in the initial photoaddition step.

Now that the efficacy of the fragmentation/elimination sequence in the formation of a 5/7 ring system had been established, we wished to investigate a more direct approach to the preparation of the required bifunctional substrate. That is, could a diiodide rather than an iodo xanthate be used in the free radical tandem process? Removal of one iodide would initiate the fragmentation reaction, and the other iodide would serve as the leaving group in the last stage of the sequence. Below we report our investigation of a model system and the total synthesis of the natural product dictamnol using a diiodide as the substrate for the free radical sequence.

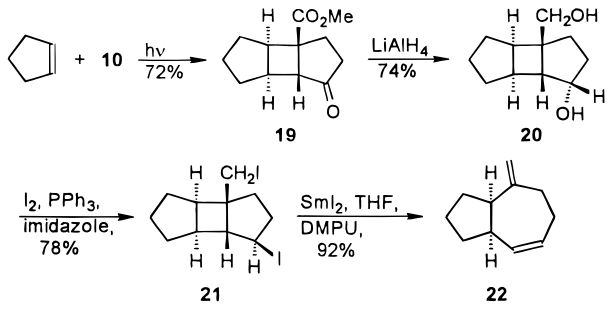
**Synthesis of Dictamnol and Model Studies.** Dictamnol is a trinor-guaiane isolated from the roots of *Dictamnus dasycarpus* TURCZ.[18] The *cis*-fused structure **17** was initially proposed for the natural product on the basis of a detailed NMR spectroscopy study,[18] and a total synthesis of the compound was claimed.[19] A second research group reported a stereoselective synthesis of **17** and discovered the spectral data differed from those of dictamnol.[20] On the basis of further NMR studies the latter group suggested that dictamnol possessed structure **18** with a *trans* ring fusion. **18** was prepared in low yield by air oxidation of pregeijerene.[20] Below we outline model studies followed by stereoselective syntheses of both **17** and **18**. Support is offered for the revised structure of dictamnol **18**.



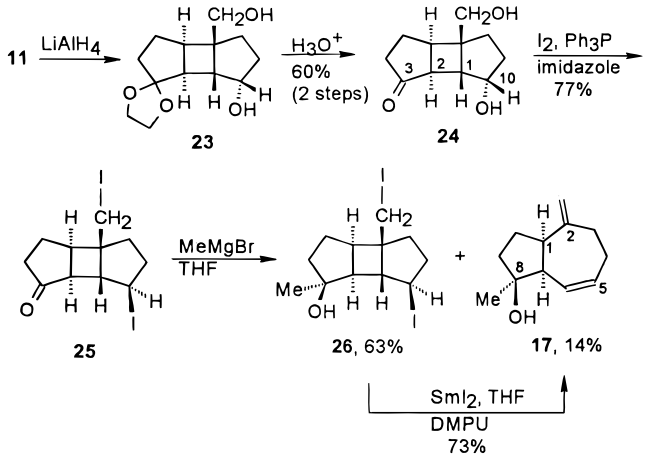

In the model study, cyclopentene was used as the alkene component in the photoaddition step rather than

(9) Garbisch, E. W. *J. Org. Chem.* **1965**, *30*, 2109.
(10) Lange, G. L.; Decicco, C. P.; Willson, J.; Strickland, L. A. *J. Org. Chem.* **1989**, *54*, 1805.
(11) Challand, B. D.; Hikino, H.; Kornis, G.; Lange, G.; de Mayo, P. *J. Org. Chem.* **1969**, *34*, 794.
(12) Lange, G. L.; Decicco, C. P. *Tetrahedron Lett.* **1988**, *29*, 2613.
(13) Challand, B. D.; de Mayo, P. *J. Chem. Soc., Chem. Commun.* **1968**, 982.
(14) Imamoto, T.; Takiyama, N.; Nakamura, K.; Hatajima, T.; Kamiya, Y. *J. Am. Chem. Soc.* **1989**, *111*, 4392.
(15) Lange, G. L.; Gottardo, C. *Synth. Commun.* **1990**, *20*, 1473.
(16) Motherwell, W. B.; Crich, D. *Free Radical Chain Reactions in Organic Synthesis*; Academic Press: San Diego, CA, 1992; pp 131–145.
(17) Barton, D. H. R.; Parekh, S. I.; Tse, C.-L. *Tetrahedron Lett.* **1993**, *34*, 2733.
(18) Takeuchi, N.; Fujita, T.; Goto, K.; Morisaki, N.; Osone, N.; Tobinaga, S. *Chem. Pharm. Bull.* **1993**, *41*, 923.
(19) Koike, T.; Yamazaki, K.; Fukumoto, N.; Yashiro, K.; Takeuchi, N.; Tobinaga, S. *Chem. Pharm. Bull.* **1996**, *44*, 646.

**Scheme 5**




**Scheme 6**




the corresponding unsaturated ketal, which will be required in the approach to dictamnol. Irradiation of enone **10** with excess cyclopentene gave the known adduct **19**,[10] which upon reduction with $LiAlH_4$ gave diol **20** (Scheme 5). Facial selectivity in this reduction was improved from 3:1 to greater than 6:1 by starting the reduction at 0 °C rather than room temperature. Conversion of **20** to diiodide **21** was achieved in good yield using our iodination protocol[15] with excess reagents and heating to reflux. The more vigorous conditions were required because of the limited solubility of the diol **20** in methylene chloride and the sluggish conversion of the secondary alcohol to the inverted iodide under these $S_N2$ conditions.

With the substrate required for the fragmentation/elimination sequence now in hand, diiodide **21** was treated with $SmI_2$ in THF and 1,3-dimethyl-3,4,5,6-tetrahydro-2(1*H*)-pyrimidone (DMPU)[21] to give in excellent yield diene **22**. $SmI_2$[22] was used in this study rather than *n*-$Bu_3SnH$ because of the former's convenience, lower toxicity, and ease of product purification. This transformation established that the more efficient method via the diiodide could be used to generate the 5/7 ring system present in dictamnol with regioselective introduction of both double bonds. We then turned to the synthesis of dictamnol and related epimers using this more efficient methodology.

Photoadduct **11**, which was used previously in the synthesis of alismol (Scheme 4), was also the starting material for the dictamnol sequence. The ketal function in **11** will be used to introduce the methyl carbinol moiety at C-8 in the target molecule. This ketal group may be removed before or after the free radical fragmentation reaction to form the 5/7 ring system, but we will see that the order of these steps will have important stereochemical consequences.

In the event, the ester and ketone groups in **11** were reduced with $LiAlH_4$ to give diol **23** (Scheme 6). Removal of the ketal with aqueous acid gave ketone **24** in 60% yield from **11**. A small amount of the head-to-tail regioisomer of **24** (derived from the corresponding photoadduct as discussed earlier) could be separated at this point and accounted for the modest yield of **24**. It should be noted that reduction of the ketone function proceeded stereoselectively from the top face to give the α-alcohol **23** or **24**. The same iodination conditions that were used for the conversion **20** → **21** were employed for the preparation of diiodide **25** from **24** with inversion at C-10 as expected. Reaction of **25** with methyl Grignard gave the desired β-alcohol **26**, but to our surprise a small amount (14%) of the fragmentation product **17** was also formed. Presumably the Grignard reagent promoted the formation of either a carbanionic or free radical intermediate at the primary iodide site and initiated the fragmentation sequence. Attempts to improve the yield of the direct conversion of **25** → **17** using additional Grignard reagent and heating to reflux were not successful. Treatment of **26** with $SmI_2$ resulted in the desired fragmentation/elimination sequence and gave diene **17** in good yield.

Comparison of the $^1H$ and $^{13}C$ NMR data of **17** and dictamnol showed the compounds were different, but the data for **17** were the same as those reported previously for this compound.[20] In our approach to **17** there can be no question that the ring fusion is *cis* as the carbonyl group in **25** was reacted before the fragmentation and thus the possibility of epimerization was avoided. The sequence outlined in Scheme 6 provided an efficient unambiguous synthesis of **17** but did not give the desired natural product.

A different approach to the synthesis of dictamnol was investigated as a result of the above-mentioned outcome. In developing this new approach, it was assumed that **17** and dictamnol differed either at the ring fusion or the configuration at C-8. Because of the significant differences in the $^{13}C$ NMR chemical shifts of the two compounds, the ring fusion (*cis* vs *trans*) seemed the more likely possibility. In this approach we planned to react at the C-8 carbonyl *after* the fragmentation to allow for the possibility of epimerization. The previously prepared diol **23** was converted in good yield to diiodide **27**, which was treated with $SmI_2$ to initiate the fragmentation/elimination sequence, and gave in excellent yield diene ketal **28** (Scheme 7). Hydrolysis of the ketal in **28** gave ketone **29** in which C-7 had apparently been epimerized under the acidic conditions. Molecular mechanics calculations indicated that the *trans*-isomer (**29**) was more stable than the *cis*-fused ketone by about 1.4 kcal/mol.[23] The $^1H$ NMR spectrum of **29** was very similar to the supposedly *cis*-fused ketone reported previously,[19] but the absence of a reported $^{13}C$ NMR spectrum made the

(20) Piet, D. P.; Orru, R. V. A.; Jenniskens, L. H. D.; van de Haar, C.; van Beek, T. A.; Franssen, M. C. R.; Wijnberg, J. B. P. A.; de Groot, A. *Chem. Pharm. Bull.* **1996**, *44*, 1400.

(21) (a) Molander, G. A.; Shakya, S. R. *J. Org. Chem.* **1994**, *59*, 3445. (b) Shabangi, M.; Sealy, J. M.; Fuchs, J. R.; Flowers, R. A. *Tetrahedron Lett.* **1998**, *39*, 4429.

(22) (a) Molander, G. A. *Chem. Rev.* **1992**, *92*, 29. (b) Molander, G. A.; Harris, C. R. *Chem. Rev.* **1996**, *96*, 307. (c) Molander, G. A.; Harris, C. R. *Tetrahedron* **1998**, *54*, 3321.

(23) Difference in heats of formation using PS Spartan and the AM1 semiempirical method.

**Scheme 7**

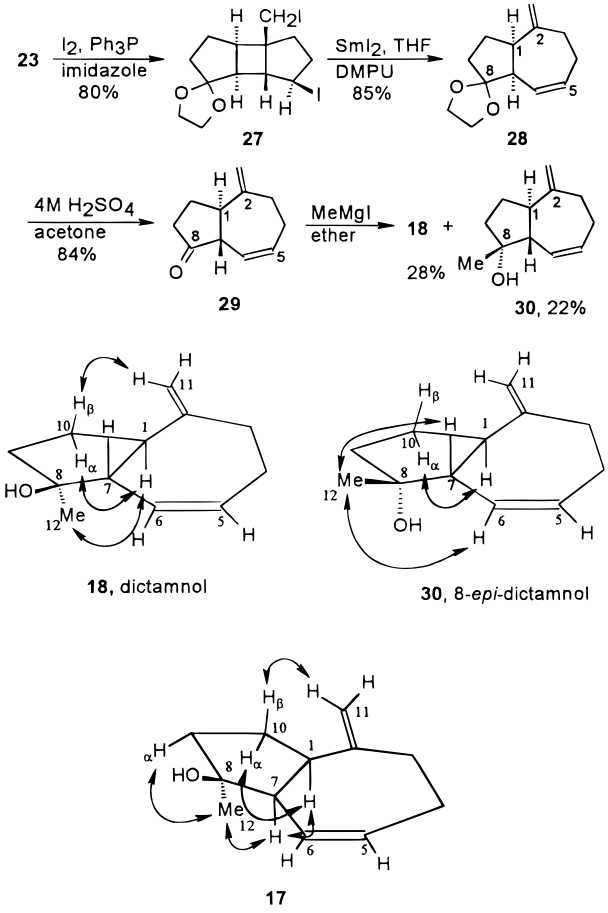



**Figure 1.**

comparison tentative. Reaction of **29** with methylmagnesium iodide gave a mixture of **18** and 8-*epi*-dictamnol **30**. A lack of stereoselectivity in this reaction is not surprising from examination of a molecular model of **29**. The spectral data for **18** were the same as those reported previously for dictamnol.[18,20]

As samples of **17**, **18**, and **30** were now in hand, a detailed NOESY study of these three isomers was undertaken. This was deemed necessary to clarify the ambiguity in structural assignments described above. Figure 1 outlines the significant NOESY cross-peaks that were found for each isomer. This analysis clearly supports the stereochemistry assigned in this paper to each of the isomers and in particular is in agreement with the revised *trans*-fused structure proposed for dictamnol, **18**.[20]

## Conclusions

A free radical fragmentation/elimination sequence has been developed and employed in the synthesis of several terpenoid systems containing a 5/7 fused ring skeleton. The methodology employs either an iodo xanthate, in which case the iodide (upon reaction with *n*-$Bu_3SnH$ or $SmI_2$) initiates the fragmentation step and the xanthate serves as a leaving group in the elimination step, or, more efficiently, a diiodide is used and the iodides serve both roles. In these sequences two double bonds are introduced in the seven-membered ring in a very regioselective manner and in high yield. The first reported synthesis of the sesquiterpenoid alismol (**8**) was accomplished in eight steps using an iodo xanthate, and the trinorsesquiterpenoid dictamnol (**18**) was synthesized in only six steps using a diiodide. The ambiguity concerning the structures of dictamnol and related isomers was clarified.

## Experimental Section

**General Methods.** $^1H$ and $^{13}C$ NMR spectra were recorded on a 400-MHz spectrometer with $CDCl_3$ as solvent unless otherwise indicated. IR spectra were recorded on a FTIR spectrophotometer in the indicated solvent using NaCl liquid cells. Mass spectra were obtained on a high-resolution spectrometer (EI, 70 eV). Products were purified by flash chromatography (FC) using 230−400 mesh silica gel. A solvent mixture (by volume) of ethyl acetate and hexanes was chosen which gave the product of interest an $R_f$ of 0.25−0.35 on thin-layer chromatography (TLC). TLC analyses were performed on silica gel GF 254 plates with a thickness of 0.25 mm. Melting points are uncorrected. The irradiations were performed using a Hanovia 450-W light source with a Pyrex filter.

Solvents were prepared as follows. Benzene, diethyl ether, and $CH_2Cl_2$ were dried over 4 Å molecular sieves prior to use. THF was freshly distilled from $CaH_2$ and deoxygenated by bubbling argon into the flask for 1 min. DMPU was distilled under vacuum from $CaH_2$ and was stored over 4 Å molecular sieves. $CH_2I_2$ was distilled from a mixture of anhydrous $CaCl_2$ and copper powder and stored in the dark with some copper wire. Solvents employed for chromatographic purification were used as received. Other reagents were used without further purification. Reactions sensitive to air or moisture were conducted in flame-dried flasks under an argon atmosphere.

**General Procedure for the Preparation of the 0.1 M $SmI_2$ Solution.** The following procedure has been used throughout this paper for the preparation of $SmI_2$. A flame-dried 25-mL round-bottomed flask was flushed with argon, and samarium (Sm) powder (0.140 g, 0.935 mmol) was added. The flask was again flame dried, flushed with argon, and sealed with a serum cap. Freshly distilled and deoxygenated THF (6 mL) was added, and this stirred suspension was cooled to 0 °C before a solution of $CH_2I_2$ (0.200 g, 0.748 mmol) in dry THF (2 mL) was added dropwise. The suspension was stirred under argon at 0 °C for 40 min and at room temperature for 80 min. The solution turned green after 15−20 min of stirring at 0 °C and at the end of the preparation period was dark blue in color.

**Methyl (1*R*,2*R*,6*S*,7*R*)-5-(1,2-Ethylenedioxy)-8-oxotricyclo[5.3.0.0$^{2,6}$]decane-1-carboxylate (11).** The general irradiation procedure was described elsewhere.[24] A solution of enone **10** (0.300 g, 2.14 mmol) and ketal **9** (2.16 g, 17.1 mmol) in $CH_2Cl_2$ (8 mL) was placed into each of three Pyrex irradiation tubes. The oxygen was removed by bubbling argon through the solution for 2 min, and the tube was sealed with a serum cap. The mixture was irradiated in an ice bath, and the disappearance of enone **10** was followed by TLC (50% ethyl acetate/hexanes). After completion of the irradiation (75 min), the contents of the tubes were combined and the solvent was removed at reduced pressure. The residue was purified by FC (40% ethyl acetate/hexanes) to give fractions which contained a small amount of an inseparable regioisomer (~20% of mixture) along with photoadduct **11** (0.907 g, 53%) as a colorless oil: $R_f$ = 0.35 (60% ethyl acetate/hexanes); $^1H$ NMR ($CDCl_3$) $\delta$ 1.65−1.73 (2H, m), 1.80 (1H, m), 1.95 (1H, ddd, $J$ = 13.0, 7.6, 7.6 Hz), 2.16−2.23 (2H, m), 2.30 (2H, m), 2.57 (1H, m), 2.72 (1H, dd, $J$ = 7.6, 6.8 Hz), 2.97 (1H, d, $J$ = 4.4 Hz), 3.64 (3H, s), 3.75−3.89 (4H, m); $^{13}C$ NMR($CDCl_3$) $\delta$ 26.1, 32.6, 33.1, 37.0, 43.1, 45.9, 47.0, 48.9, 51.7, 64.0, 64.7, 117.2, 173.7, 217.0. Anal. Calcd for $C_{14}H_{18}O_5$: C, 63.14; H, 6.81. Found: C, 63.14; H, 7.02.

**Methyl (1*R*,2*R*,6*S*,7*R*,8*R*)-5-(1,2-Ethylenedioxy)-8-hydroxy-8-isopropyltricyclo[5.3.0.0$^{2,6}$]decane-1-carboxylate (12).** A freshly ground sample of $CeCl_3 \cdot 7H_2O$ (0.695 g, 2.82 mmol) was heated under vacuum (0.1 Torr) to 150 °C for 2.5

(24) Lange, G. L.; Organ, M. G. *J. Org. Chem.* **1996**, *61*, 5358.

h. The hot flask was flushed with argon and was cooled to 0 °C before THF (5 mL) was added. The suspension was stirred at room temperature for 3 h and cooled to 0 °C, and adduct **11** (0.500 g, 1.88 mmol) in THF (2 mL) was added slowly. Stirring was continued at room temperature for 0.5 h, and the reaction was cooled to 0 °C. Isopropylmagnesium bromide (0.424 g, 2.82 mmol) was added and stirring was continued for 3 h at 0 °C. The reaction was quenched by the addition of saturated $NH_4Cl$ (5 mL). The product was extracted into diethyl ether and washed with brine. The organic layer was dried over $MgSO_4$ and filtered and the solvent evaporated in vacuo. The product was isolated by FC (40% ethyl acetate/hexanes) to give **12** (0.349 g, 60%) as a yellow oil: $R_f$ = 0.23 (40% ethyl acetate/hexanes); IR($CHCl_3$) 3622, 3465, 1726, 1224 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 0.88 (3H, d, $J$ = 6.8 Hz), 0.94 (3H, d, $J$ = 6.8 Hz), 1.80−2.00(4H, m), 1.51−1.83 (5H, m), 2.00 (1H, m), 2.50 (2H, m), 2.76 (1H, d, $J$ = 3.7 Hz), 3.64 (3H, s) 3.87(4H, m); $^{13}C$ NMR ($CDCl_3$) $\delta$ 16.6 (2 x C), 26.3, 32.8, 33.4, 34.6, 34.7, 38.9, 44.2, 46.4, 51.3, 51.8, 63.8, 64.6, 83.4, 118.6, 175.3; HRMS calcd for $C_{17}H_{26}O_5$ 310.1780, found 310.1783.

**(1*S*,2*R*,3*R*,6*R*,7*R*)-10-(1,2-Ethylenedioxy)-6-iodomethyl-3-isopropyltricyclo[5.3.0.0$^{2,6}$]decan-3-ol (13).** To a stirring solution of ester **12** (0.375 g, 1.21 mmol) in anhydrous diethyl ether (10 mL) was added $LiAlH_4$ (0.068 g, 1.80 mmol), and the mixture was refluxed overnight. The excess $LiAlH_4$ was quenched by the dropwise addition of water (10 mL). The aqueous layer was extracted with diethyl ether, and the organic layers were combined and washed with brine. The product was isolated by FC (50% ethyl acetate/hexanes) to give the corresponding alcohol as a yellow oil (0.290 g, 85%). To a solution of this alcohol (0.250 g, 0.890 mmol) in $CH_2Cl_2$ (5 mL) were added triphenylphosphine (0.348 g, 1.33 mmol), imidazole (0.091 g, 1.33 mmol), and iodine (0.338 g, 1.33 mmol). The suspension was stirred overnight, and a solution of 0.2 M $Na_2S_2O_3$ (10 mL) was added. The aqueous phase was extracted with $CH_2Cl_2$. The combined organic phases were dried over $MgSO_4$ and concentrated at reduced pressure. The product was purified FC (50% ethyl acetate/hexanes) to give iodide **13** (0.292 g, 84%) as a yellow oil: $R_f$ = 0.43 (50% ethyl acetate/hexanes); IR ($CHCl_3$) 3613, 3482 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 0.86 (3H, d, $J$ = 6.5 Hz), 0.89 (3H, d, $J$ = 6.5 Hz), 1.14 (1H, s), 1.48 (1H, m), 1.55−1.65 (1H, m), 1.70−1.85 (4H, m), 1.88−2.05 (3H, m), 2.10 (1H, d, $J$ = 4.4 Hz), 2.23 (1H, m), 2.39 (1H, m), 3.04−3.22 (2H, AB, $J$ = 9.6 Hz, $\Delta\nu_{AB}$ = 38.9 Hz), 3.84 (4H, m); $^{13}C$ NMR ($CDCl_3$) $\delta$ 14.3, 16.5, 16.7, 24.1, 33.8, 34.6, 34.9, 36.1, 39.3, 42.5, 45.3, 50.1, 64.4, 64.8, 84.2, 118.3; HRMS calcd for $C_{16}H_{25}IO_3$ − I 265.1788, found 265.1783.

**Xanthate of (1*R*,2*S*,3*R*,6*R*,7*R*)-10-(1,2-Ethylenedioxy)-6-iodomethyl-3-isopropyltricyclo [5.3.0.0$^{2,6}$]decan-3-ol (14).** To a solution of tertiary alcohol **13** (0.150 g, 0.382 mmol) in THF (5 mL) at −78 °C was added 1.4 M MeLi in hexanes (0.41 mL, 0.573 mmol). The solution was warmed to 0 °C, and stirring was continued for 1 h. Carbon disulfide (0.145 g, 1.91 mmol) was added, and the solution was warmed to room temperature. Stirring was continued for 3 h, and MeI (0.542 g, 3.82 mmol) was added. Stirring was continued overnight, and water (10 mL) was added. The aqueous phase was extracted with diethyl ether. The combined organic phases were dried over $MgSO_4$ and filtered, and the solvent was evaporated in vacuo. The product was not purified, and xanthate **14** (0.166 g, 90%) was obtained as a yellow oil: $R_f$ = 0.59 (10% ethyl acetate/hexanes); IR ($CCl_4$) 1656, 1450, 1225, 1117 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 0.89 (3H, d, $J$ = 3.6 Hz), 0.94 (3H, d, $J$ = 3.6 Hz), 1.60−2.05 (6H, m), 2.10−2.50 (4H, m), 2.55 (3H, s), 2.61 (1H, m), 2.72 (1H, m), 3.07−3.28 (2H, AB, $J$ = 9.6 Hz, $\Delta\nu_{AB}$ = 38.9 Hz), 3.90 (4H, m).

**(1*R*,7*S*)-10-(1,2-Ethylenedioxy)-3-isopropyl-6-methylenebicyclo[5.3.0]dec-2-ene (15).** A solution of iodide **14** (0.100 g, 0.207 mmol), $Bu_3SnH$ (0.090 g, 0.310 mmol), and AIBN (0.031 g, 0.020 mmol) in benzene (3 mL) was refluxed for 2 h. After cooling, DBU (0.573 g, 0.371 mmol) was added followed by a 0.1 M solution of $I_2$ in diethyl ether (5 mL). The solvent was removed in vacuo and the residue purified by FC (10% ethyl acetate/hexanes) to give diene **15** (0.047 g, 92%) as a yellow oil: $R_f$ = 0.55 (10% ethyl acetate/hexanes); IR ($CCl_4$) 1653, 1450, 1229, 882 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 0.93 (3H, d, $J$ = 6.6 Hz), 0.97 (3H, d, $J$ = 6.6 Hz), 1.50−2.00 (4H, m), 2.05−2.50 (5H, m), 2.75 (1H, m), 2.84 (1H, m), 3.91(4H, m), 4.70 (1H, s), 4.72 (1H, s), 5.35 (1H, s); $^{13}C$ NMR ($CDCl_3$) $\delta$ 16.4, 18.9, 21.3, 25.8, 28.6, 34.2, 36.7, 45.9, 47.5, 64.1, 64.7, 110.0, 118.1, 118.6, 135.4, 151.0; HRMS calcd for $C_{16}H_{24}O_2$ 248.1776, found 248.1769.

**(1*R*,7*R*)-5-Isopropyl-2-methylenebicyclo[5.3.0]dec-5-en-8-one (16).** A solution of ketal **15** (0.200 g, 0.81 mmol) and concentrated $H_2SO_4$ (15 $\mu$L) in acetone (4 mL) was stirred for 3 h at room temperature. Aqueous saturated $NaHCO_3$ (5 mL) was added, and the product was extracted into diethyl ether. The organic phases were washed with brine and dried over $MgSO_4$, and the solvent was removed in vacuo to give ketone **16** (0.122 g, 74%) as a yellow oil: $R_f$ = 0.35 (10% ethyl acetate/hexanes); IR ($CCl_4$) 1741, 1652, 884 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 0.93 (3H, d, $J$ = 6.5 Hz), 0.99 (3H, d, $J$ = 6.5 Hz), 1.50−2.00 (5H, m), 2.00−2.35 (5H, m), 2.41 (1H, m), 4.61 (1H, s), 4.77 (1H, s), 5.61 (1H, s); $^{13}C$ NMR ($CDCl_3$) $\delta$ 21.0, 21.2, 24.6, 36.8, 37.1, 37.4, 42.6, 47.7, 54.8, 107.6, 119.2, 148.3, 152.5, 215.6.

**(1*R*,7*R*,8*S*)-5-Isopropyl-8-methyl-2-methylenebicyclo-[5.3.0]dec-5-en-8-ol (Alismol) (8).** A freshly ground sample of $CeCl_3 \cdot 7H_2O$ (0.090 g, 0.37 mmol) was heated under vacuum (0.1 Torr) to 150 °C for 2.5 h. The hot flask was flushed with argon and was cooled to 0 °C before THF (5 mL) was added. The suspension was stirred at room temperature for 3 h and was cooled to 0 °C when ketone **16** (0.050 g, 0.24 mmol) in THF (2 mL) was added dropwise. Stirring was continued at room temperature for 0.5 h, and the reaction was cooled to 0 °C. A solution of 3.0 M MeMgBr (0.12 mL, 0.36 mmol) in diethyl ether was added slowly, and stirring was continued for 1 h at 0 °C. The reaction was quenched by the addition of saturated $NH_4Cl$ (5 mL). The product was extracted into diethyl ether and washed with brine. The organic layer was dried over $MgSO_4$ and filtered, and the solvent was evaporated in vacuo. The product was isolated by FC (25% ethyl acetate/hexanes) to give alismol (**8**) (0.035 g, 68%) as a yellow oil: $R_f$ = 0.52 (30% ethyl acetate/hexanes); the spectral data were similar to those reported previously.[6]

**(1*S*,2*R*,3*S*,6*R*,7*R*)-6-Hydroxymethyltricyclo[5.3.0.0$^{2,6}$]-decan-3-ol (20).** To a stirred solution of photoadduct **19**[10] (0.238 g, 1.14 mmol) in anhydrous diethyl ether (8 mL) was added slowly $LiAlH_4$ (0.087 g, 2.28 mmol). The mixture was stirred at 0 °C for 2 h and rt for 1 h and refluxed for 3 h under an argon atmosphere. Excess $LiAlH_4$ was quenched by the careful addition of water (5 mL). The product was extracted into 90:10 ether/THF (5 × 25 mL), and the combined organic extracts were dried over anhydrous $MgSO_4$. The solvent was removed in vacuo, and the resulting viscous oil was dissolved in methanol and purified by FC (50% ethyl acetate/hexanes) to afford diol **20** (0.154 g, 74%) as white crystals: mp 129−130 °C; $R_f$ = 0.22 (80% ethyl acetate/hexanes); $^1H$ NMR ($CDCl_3$) $\delta$ 1.47−1.54 (1H, m), 1.57 (3H, m), 1.70−1.91 (7H, m), 1.96−2.04 (2H, m), 2.26 (1H, dd, $J$ = 8.0, 8.0 Hz), 2.62 (1H, m), 3.40−3.57 (2H, AB, $J$ = 10.8 Hz, $\Delta\nu_{AB}$ = 55.6 Hz), 4.13 (1H, m); $^{13}C$ NMR ($CDCl_3$) $\delta$ 27.6, 29.3, 32.7, 33.4, 33.6, 34.5, 45.4, 47.2, 49.1, 64.5, 75.7; HRMS calcd for $C_{11}H_{18}O_2 - H_2O$ 164.1201, found 164.1203. Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95. Found: C, 72.56; H, 10.24.

**(1*S*,2*R*,3*R*,6*R*,7*R*)-3-Iodo-6-iodomethyltricyclo[5.3.0.0$^{2,6}$]-decane (21).** To a suspension of diol **20** (0.100 g, 0.550 mmol) in $CH_2Cl_2$ (8 mL) were added triphenylphosphine (0.576 g, 2.20 mmol), imidazole (0.150 g, 2.20 mmol), and iodine (0.558 g, 2.20 mmol) in that order, and the suspension was refluxed for 16 h under argon. A solution of 0.2 M sodium thiosulfate (5 mL) was added, and after 10 min of stirring, the layers were separated and the aqueous phase was extracted with $CHCl_3$. The combined organic phases were dried ($MgSO_4$) and concentrated. The product was purified by FC (hexanes) to give diiodide **21** (0.172 g, 78%) as white crystals: mp 51−52 °C; $R_f$ = 0.41 (hexanes); $^1H$ NMR ($CDCl_3$) $\delta$ 1.35−1.45 (2H, m), 1.48−1.61 (2H, m), 1.77−1.87 (2H, m), 1.96−2.01 (1H, m), 2.09 (1H, d, $J$ = 3.4 Hz), 2.12−2.22 (3H, m), 2.27 (1H, m), 2.39 (1H, d, $J$ = 4.4 Hz), 3.44 (2H, s), 4.84 (1H, d, $J$ = 4.4 Hz). $^{13}C$ NMR ($CDCl_3$) $\delta$ 14.5, 26.7, 27.7, 32.0, 35.6, 36.3, 41.0, 41.7, 44.1,

47.4, 59.0; HRMS calcd for $C_{11}H_{16}I_2$ 401.9345, found 401.9342. Anal. Calcd for $C_{11}H_{16}I_2$: C, 32.86; H, 4.01. Found: C, 33.16; H, 4.05.

**(1*R*,7*S*)-2-Methylenebicyclo[5.3.0]dec-5-ene (22).** To a solution of diiodide **21** (0.075 g, 0.187 mmol) in dry THF/DMPU (4.5/0.6 mL) was added the stock 0.1 M $SmI_2$ solution slowly at room temperature until a dark gray color persisted for about 1 min. The reaction mixture was stirred for an additional 30 min, and aqueous saturated $NaHCO_3$ (8 mL) was added. The product was extracted with diethyl ether, and the combined organic layer was washed with brine and dried over $MgSO_4$. Removal of the solvent at reduced pressure (no heat) and purification by FC (pentane) afforded olefin **22** (0.025 g, 92%) as a colorless oil: $R_f = 0.60$ (hexanes); IR ($CHCl_3$) 1653, 1636, 895 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.42−1.80 (6H, m), 2.21−2.32 (4H, m), 2.73 (1H, dd, $J = 8.0$, 8.0 Hz), 2.80 (1H, m), 4.66 (1H, t, $J = 1.6$ Hz), 4.72 (1H, br s), 5.33 (1H, d, $J = 14.5$ Hz), 5.46 (1H, m); $^{13}C$ NMR ($CDCl_3$) $\delta$ 23.6, 29.5, 29.8, 33.9, 34.3, 42.1, 49.4, 109.6, 128.0, 134.0, 152.5; HRMS calcd for $C_{11}H_{16}$ 148.1252, found 148.1247.

**(1*S*,2*R*,3*S*,6*R*,7*R*)-10-(1,2-Ethylenedioxy)-6-hydroxymethyltricyclo[5.3.0.0$^{2,6}$]decan-3-ol (23).** A mixture of photoadduct **11** (0.408 g, 1.53 mmol) and $LiAlH_4$ (0.116 g, 3.06 mmol) in dry diethyl ether (10 mL) was stirred at 0 °C (2 h) and rt (1 h) and refluxed (3.5 h) under argon. Saturated aqueous $NaHCO_3$ solution (10 mL) and water (5 mL) were added, and the aqueous layer was extracted with $CHCl_3$/THF (80:20) (4 × 30 mL). The organic layers were combined and dried ($MgSO_4$), and the solvent was removed in vacuo. The residue was dissolved in THF and was purified by FC (ethyl acetate) to afford diol **23** (0.231 g, 63%) as white crystals: mp = 104−106 °C; $R_f = 0.20$ (ethyl acetate); IR ($CHCl_3$) 3621, 3440, 1354, 1240, 1122, 1042 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.49 (1H, dd, $J = 12.8$, 6.8 Hz), 1.65−1.84 (5H, m), 1.94 (2H, m), 2.06 (1H, dd, $J = 6.6$, 4.0 Hz), 2.24 (1H, m), 2.33 (1H, dd, $J = 7.0$, 4.0 Hz), 2.78 (2H, br s, 2 × OH), 3.43−3.54 (2H, AB, $J = 11.2$ Hz, $\Delta\nu_{AB} = 35.2$ Hz, $CH_2OH$), 3.78−3.89 (4H, m), 4.13 (1H, dt, $J = 10.4$, 6.6 Hz); $^{13}C$ NMR ($CDCl_3$) $\delta$ 24.6, 31.5, 33.2, 34.6, 36.8, 42.0, 43.7, 46.0, 63.7, 64.4, 64.8, 74.1, 118.7; HRMS calcd for $C_{13}H_{20}O_4$ 240.1361, found 240.1361.

**(1*R*,2*S*,6*R*,7*R*,10*S*)-10-Hydroxy-7-hydroxymethyltricyclo[5.3.0.0$^{1,7}$]decan-3-one (24).** To a solution of photoadduct **11** (0.345 g, 2.58 mmol) in anhydrous diethyl ether (10 mL) was added $LiAlH_4$ (0.098 g, 2.58 mmol). The suspension was stirred at 0 °C (2 h) and rt (1 h) and refluxed (4 h) under an argon atmosphere. The reaction mixture was cooled in an ice bath, and excess $LiAlH_4$ was quenched by the dropwise addition of 1.5 M HCl (10 mL). Stirring of this two-phase system was continued for 16 h to hydrolyze the ketal of **23**, at which time solid $NaHCO_3$ was added until all HCl was neutralized. The ether layer was separated, and the aqueous layer was extracted with $CHCl_3$/THF (90:10) (4 × 25 mL). The combined organic layers were dried over anhydrous $MgSO_4$ and concentrated at reduced pressure. The residue was dissolved into THF and was purified by FC (ethyl acetate) to give diol **24** (0.152 g, 60%) as a colorless viscous oil: $R_f = 0.15$ (ethyl acetate); IR ($CHCl_3$) 3615, 3426, 1730, 1241, 1095 $cm^{-1}$; $^1H$ NMR ($CD_3OD$) $\delta$ 1.57 (1H, dd, $J = 13.2$, 6.4 Hz), 1.70 (1H, dt, $J = 13.0$, 6.4 Hz), 1.80−1.91 (1H, m), 2.00 (1H, dd, $J = 12.8$, 6.0 Hz), 2.08 (1H, m), 2.17 (1H, dd, $J = 6.8$, 3.2 Hz), 2.23 (1H, m), 2.30 (1H, ddt, $J = 10.0$, 10.0, 2.4 Hz), 2.54 (1H, dd, $J = 9.2$, 3.2 Hz), 2.60 (1H, m), 2.67 (1H, m), 3.54−3.69 (2H, AB, $J = 11.2$ Hz, $\Delta\nu_{AB} = 48.8$ Hz), 4.18 (1H, m), 4.88 (2H, br s, 2 × OH); $^{13}C$ NMR ($CD_3OD$) $\delta$ 23.8, 32.5, 34.5, 38.8, 40.7, 42.5, 47.9, 49.9, 65.9, 74.5, 225.9; HRMS calcd for $C_{11}H_{16}O_3$ 196.1099, found 196.1115.

**(1*R*,2*S*,6*R*,7*R*,10*R*)-10-Iodo-7-iodomethyltricyclo-[5.3.0.0$^{2,6}$]decan-3-one (25).** To diol **24** (0.250 g, 1.27 mmol) in $CH_2Cl_2$ (12 mL) were added $PPh_3$ (1.34 g, 5.10 mmol) and imidazole (0.347 g, 5.10 mmol) at room temperature. After 15 min of stirring, iodine (1.290 g, 5.10 mmol) was added slowly, and the mixture was refluxed for 22 h under argon. A solution of 0.2 M $Na_2S_2O_3$ (15 mL) was added, and after 10 min of stirring, the methylene chloride layer was separated. The aqueous phase was extracted with $CHCl_3$, and the combined organic layers were dried ($MgSO_4$) and concentrated in vacuo. The solid residue was dissolved into $CHCl_3$ and was purified by FC (hexanes and then 25% ethyl acetate/hexanes) to afford diiodide **25** (0.407 g, 77%) as white crystals: mp 96−97 °C; $R_f = 0.33$ (30% ethyl acetate/hexanes); IR ($CHCl_3$)1735, 1169 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.92 (1H, dd, $J = 12.8$, 4.0 Hz), 2.04 (1H, m), 2.18−2.27 (3H, m), 2.30 (1H, m), 2.36−2.50 (4H, m), 2.75 (1H, d, $J = 4.0$ Hz), 3.41−3.54 (2H, AB, $J = 10.0$ Hz, $\Delta\nu_{AB} = 43.6$ Hz), 4.50 (1H, br s); $^{13}C$ NMR ($CDCl_3$) $\delta$ 13.5, 22.0, 32.7, 35.8, 36.9, 40.5, 41.1, 47.6, 49.2, 56.7, 218.2; HRMS calcd for $C_{11}H_{14}I_2O$ 415.9138, found 415.9124. Anal. Calcd for $C_{11}H_{14}I_2O$: C, 31.75; H, 3.39. Found: C, 32.07; H, 3.46.

**(1*R*,2*S*,3*S*,6*R*,7*R*,10*R*)-10-Iodo-7-iodomethyl-3-methyltricyclo[5.3.0.0$^{2,6}$]decan-3-ol (26).** To a solution of iodide **25** (0.148 g, 0.357 mmol) in dry THF (8 mL) at 0 °C was added 3.0 M MeMgBr in diethyl ether (0.18 mL, 0.54 mmol) dropwise. Stirring was continued for 2 h at 0 °C and for 2 h at room temperature, when the reaction was quenched by the dropwise addition of water (6 mL). Diethyl ether (7 mL) was added, the organic layer was separated, and the aqueous layer was extracted with diethyl ether. The combined organic phases were washed with brine and dried over anhydrous $MgSO_4$, and the solvent was removed at reduced pressure. The residue was purified by FC (10%, followed by 20% ethyl acetate/hexanes) to give a mixture of the fragmented product **17** (8.7 mg, 14%) and the expected alcohol **26** (0.097 g, 63%) as a colorless oil: $R_f = 0.33$ (30% ethyl acetate/hexanes); IR ($CHCl_3$) 3608, 3459, 1173 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.17 (3H, s), 1.56−1.66 (4H, m), 1.74 (1H, dd, $J = 14.0$, 4.0 Hz), 1.83 (1H, d, $J = 6.4$ Hz), 2.02 (1H, dd, $J = 14.0$, 7.2 Hz), 2.10 (1H, dd, $J = 8.0$, 7.2 Hz), 2.13−2.23 (3H, m), 2.91 (1H, d, $J = 4.0$ Hz), 3.43−3.54 (2H, AB, $J = 9.6$ Hz, $\Delta\nu_{AB} = 33.2$ Hz), 4.43 (1H, d, $J = 3.6$ Hz); $^{13}C$ NMR ($CDCl_3$) $\delta$ 14.5, 24.6, 28.1, 35.0, 36.2, 39.6, 40.9, 42.8, 47.1, 50.6, 53.8, 78.8; HRMS calcd for $C_{12}H_{18}I_2O$ 431.9451, found 431.9458.

**(1*R*,7*S*,8*S*)-Methyl-2-methylenebicyclo[5.3.0]dec-5-en-8-ol (*cis*-Dictamnol) (17).** To a solution of iodide **26** (0.110 g, 0.254 mmol) in THF/DMPU (7.0/0.8 mL) was added slowly at room temperature a 0.1 M solution of $SmI_2$ in THF until a dark gray color persisted. The solution was stirred for 0.5 h and was quenched by the addition of saturated $NaHCO_3$ solution (5 mL) and water (10 mL). The product was extracted with diethyl ether, and the combined organic layers were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Purification by FC (10% ethyl acetate/hexanes) afforded diene **17** (0.0332 g, 73%) as a colorless oil: $R_f = 0.44$ (25% ethyl acetate/hexanes); All spectral data were identical to those reported earlier.[18,20]

**(1*S*,2*R*,3*R*,6*R*,7*R*)-10-(1,2-Ethylenedioxy)-3-iodo-6-iodomethyltricyclo [5.3.0.0$^{2,6}$]decane (27).** A solution of diol **23** (0.150 g, 0.624 mmol), $PPh_3$ (0.655 g, 2.50 mmol), imidazole (0.170 g, 2.50 mmol), and iodine (0.634 g, 2.50 mmol) in $CH_2Cl_2$ (9 mL) was refluxed for 16 h under argon. A solution of 0.2 M $Na_2S_2O_3$ (10 mL) was added, and after 10 min of stirring the methylene chloride layer was separated. The aqueous phase was extracted with $CHCl_3$, and the combined organic layers were dried ($MgSO_4$) and concentrated at reduced pressure. The solid residue was dissolved into $CHCl_3$ and was purified by FC (10% ethyl acetate/hexanes) to give diiodide **27** (0.229 g, 80%) as white crystals: mp = 144−145 °C; $R_f = 0.38$ (25% ethyl acetate/hexanes); IR ($CHCl_3$) 1204, 1105 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.67−1.75 (3H, m), 1.81 (2H, m), 2.03 (1H, dd, $J = 12.2$, 6.6 Hz), 2.09−2.18 (4H, m), 2.76 (1H, d, $J = 4.4$ Hz), 3.38−3.49 (2H, AB, $J = 9.6$ Hz, $Dn_{AB} = 37.6$ Hz, $CH_2I$), 3.71−3.85 (4H, m), 4.39 (1H, d, $J = 3.2$ Hz); $^{13}C$ NMR ($CDCl_3$) $\delta$ 14.5, 24.0, 34.5, 34.7, 36.1, 41.1, 42.1, 46.3, 47.6, 54.9, 64.2, 65.0, 117.5; MS *m*/*z* (rel intens) 333 ($M^+ - I$, 100), 207 (54); HRMS calcd for $C_{13}H_{18}I_2O_2 - I$ 333.0353, found 333.0355. Anal. Calcd for $C_{13}H_{18}I_2O_2$: C, 33.93; H, 3.94. Found: C, 34.22; H, 3.96.

**(1*R*,7*S*)-8-(1,2-Ethylenedioxy)-2-methylenebicyclo[5.3.0]-dec-5-ene (28).** A 0.1 M solution of $SmI_2$ in THF prepared according to the general procedure was added dropwise at room temperature to a solution of iodide **27** (0.123 g, 0.267 mmol) in THF/DMPU (5.0/0.7 mL) under argon until a dark

gray color persisted. After a further 0.5 h of stirring, aqueous saturated $NaHCO_3$ solution (10 mL) was added, and the product was extracted into diethyl ether. The combined organic layers were washed with brine and dried over anhydrous $MgSO_4$, and the solvent was removed at reduced pressure (no heat). Purification by FC (2% ethyl acetate/hexanes) afforded diene **28** (0.0468 g, 85%) as a slightly yellow oil: $R_f = 0.40$ (15% ethyl acetate/hexanes); IR ($CHCl_3$) 1654, 1635, 895 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.67−1.77 (3H, m), 1.87 (1H, m), 2.09−2.19 (2H, m), 2.27 (2H, m), 2.78 (1H, bd, $J = 8.0$ Hz), 3.00 (1H, dd, $J = 8.4$, 8.0 Hz), 3.84 (4H, m), 4.69 (1H, dd, $J = 2.0$, 2.0 Hz), 4.72 (1H, m), 5.52 (1H, dd, $J = 12.4$, 3.4 Hz), 5.56−5.62 (1H, ddd, $J = 12.4$, 7.2, 3.4 Hz); $^{13}C$ NMR ($CDCl_3$) $\delta$ 26.1, 30.6, 33.3, 33.8, 47.4, 47.9, 64.0, 64.8, 110.3, 118.1, 126.7, 130.1 151.9; HRMS calcd for $C_{13}H_{18}O_2$ 206.1307, found 206.1308.

**(1*R*,7*R*)-2-Methylenebicyclo[5.3.0]dec-5-en-8-one (29).** To a solution of ketal **28** (0.0452 g, 0.218 mmol) in acetone (4 mL) was added a solution of 4 M $H_2SO_4$ (40 $\mu$L) in acetone (1 mL) at room temperature. Disappearance of **28** was followed by TLC (10% ethyl acetate/hexanes) and was complete after 1 h of stirring. Saturated $NaHCO_3$ solution (8 mL) was added, and the product was extracted into diethyl ether. The combined ether extracts were washed with brine and dried ($MgSO_4$), and the solvent was removed in vacuo (no heat). The residue was purified by FC (5% ethyl acetate/hexanes), and ketone **29** (0.0297 g, 84%) was obtained as a slightly yellow oil: some spectral data for this compound, such as $^1H$ NMR (not detailed), IR (neat), and HRMS, were reported previously;[19] $R_f = 0.33$ (10% ethyl acetate/hexanes); IR ($CHCl_3$) 1735, 1641, 902 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.75−1.86 (1H, m), 2.03 (1H, m), 2.09−2.20 (3H, m), 2.26 (1H, m), 2.40 (1H, ddd, $J = 9.6$, 9.6, 1.2 Hz), 2.45−2.57 (3H, m), 4.74 (1H, br s), 4.82 (1H, dd, $J = 1.2$, 1.2 Hz), 5.87 (2H, m); $^{13}C$ NMR ($CDCl_3$) $\delta$ 24.9, 28.7, 36.4, 37.4, 47.4, 55.0, 108.0, 127.5, 132.6, 151.8, 217.5; MS *m*/*z* (rel intens) 162 ($M^+$, 51).

**(1*R*,7*R*,8*S*)-8-Methyl-2-methylenebicyclo[5.3.0]dec-5-en-8-ol (Dictamnol) (18) and (1*R*,7*R*,8*R*)-8-Methyl-2-methylenebicyclo[5.3.0]dec-5-en-8-ol (8-*epi*-Dictamnol) (30).** A slight modification of the published procedure[19] was followed. To a solution of ketone **29** (0.0433 g, 0.265 mmol) in dry diethyl ether (15 mL) was added a solution of 3.0 M MeMgI (0.30 mL, 2.12 mmol) in diethyl ether slowly at 0 °C. After 5 h of stirring at 0 °C, aqueous saturated $NH_4Cl$ (5 mL) was added, and the aqueous layer was extracted with $CHCl_3$. The combined organic layers were washed with saturated $NaHCO_3$ and brine, dried ($MgSO_4$), and concentrated. The residue was purified by FC (7% ethyl acetate/hexanes) to afford dictamnol **18** (0.0133 g, 28%) and 8-*epi*-dictamnol **30** (0.0104 g, 22%). Dictamnol **(18)**: $R_f = 0.27$ (25% ethyl acetate/hexanes); the other spectral data for **18** were identical to those reported previously.[18,20] 8-*epi*-Dictamnol **(30)**: $R_f = 0.32$ (25% ethyl acetate/ hexanes); IR ($CHCl_3$) 3609, 1635, 1379, 1097, 894 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.21 (1H, br s, OH), 1.28 (3H, s), 1.77 (3H, m), 1.89−1.95 (1H, m), 2.08 (2H, m), 2.16 (1H, dd, $J = 11.6$, 11.6 Hz), 2.28 (1H, m), 2.50 (1H, dd, $J = 11.6$, 11.6 Hz), 2.74 (1H, dd, $J = 10.4$, 10.4 Hz), 4.70 (1H, s), 4.77 (1H, s), 5.73 (1H, d, $J = 11.2$ Hz), 5.93 (1H, m); $^{13}C$ NMR ($CDCl_3$) $\delta$ 26.0, 26.9, 28.9, 36.8, 39.4, 47.7, 55.0, 80.5, 107.3, 128.6, 133.4, 153.9; MS *m*/*z* (rel intens) 178 ($M^+$, 5), 160 ($M^+ - H_2O$, 28); HRMS calcd for $C_{12}H_{18}O$ 178.1358, found 178.1365.

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**Supporting Information Available:** $^1H$ or $^{13}C$ NMR spectra for **8**, **12**, **13**, **14**, **15**, **17**, **18**, **22**, **23**, **24**, **26**, **28**, **29**, and **30**. This material is available free of charge via the Internet at http://pubs.acs.org.

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