# Exploratory Synthetic Studies Involving the Tricyclo[9.3.0.0$^{2,8}$]tetradecane Ring System Peculiar to the Cyathins

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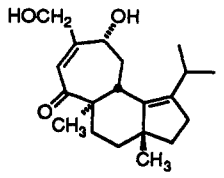
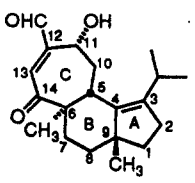
Following an improved preparation of 2-methylene-1,3-dithiolane, this ketene acetal was shown to undergo inverse-electron-demand Diels–Alder cycloaddition to tropone. Regiocontrolled copper hydride reduction and resolution via sulfoximine adducts was readily achieved to give (−)-**9**. Addition to **9** of the chiral nonracemic vinyl bromides **21** and **22** proceeded with endo capture of the nucleophilic vinyllithium to give carbinols that underwent anionic oxy-Cope rearrangement at somewhat elevated temperatures. The [3,3] sigmatropic event delivered *cis,syn,cis*-tricyclo[9.3.0.0$^{2,8}$]tetradecenones possessing structural frameworks related to the cyathins. Once **31** was in hand, it proved an easy matter to introduce added unsaturation and oxygen substituents. The tendency of certain derivatives for transannular cyclization was made quite apparent. Attempts to introduce a C(6)-$\alpha$-methyl substituent was not achieved, chiefly as the result of the overall molecular concavity of this class of intermediates. A variety of reactions aimed at enhancing the level of functionality in rings B and C was explored and processes conducive to the attainment of these goals were developed.

The structurally interesting diterpenes known collectively as the cyathins are produced by bird's nest fungi of the genus *Cyathis*, which can be found in a variety of habitats throughout the world.[1] The pronounced antimicrobial and antifungal properties of the original crude extracts[2] led in time to definitive structural characterization of the numerous individual constituents.[3] Cyathin $A_3$ (**1**) is the major metabolite of *C. heleneae*, while cyathins $B_3$ (**2**) and $C_3$ (**3**) exhibit the highest levels of biological activity. The unusual structural nature of **1**–**3** and their congeners has prompted Ayer[4] and Ward[5] to take up the attendant challenge of total synthesis. The most advanced




**1**

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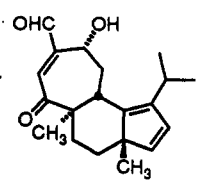
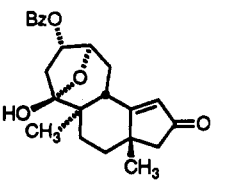



**3**

intermediate arrived at by either group is **4**. This compound features proper fusion of the three constituent rings in the appropriate stereochemical sense, but it is racemic and lacks the required C-3 isopropyl group and C-12,13 double bond.

This recorded experimentation provides some insight into the complications awaiting any program directed at the *de novo* elaboration of the cyathins. However, the




**4**

picture is far from complete. In particular, the progressive manner in which the tricyclo[9.3.0.0$^{2,8}$]tetradecane framework was assembled provided little opportunity to gauge the steric consequences of serially fusing 5-, 6-, and 7-membered rings together in this fashion, to determine the extent to which potentially interactive functional groups might contribute to instability, and to assess with some level of accuracy the feasibility of introducing stereocenters in a reasonably controlled manner.

In order to address these points and related issues, we considered it of interest to devise a process that would assemble the core cyathin ring system rapidly, thereby providing an unrivaled opportunity to examine the means for enhancing the level of resident functionality. Accordingly, the primary initial target of this investigation was ketone **31**.

## Synthesis of the Levorotary Bicyclo[3.2.2]nonenone 9

The plan adopted for arrival at **31** developed out of studies designed to demonstrate the unparalleled scaffolding power of anionic sigmatropy.[6,7] Since the bifunctional building block **9** was to play a key role in providing **31**, its preparation in a fully regiocontrolled manner was sought. In a first approach (Scheme 1), heating phenyl vinyl sulfide with tropone in the absence of solvent according to Rigby and co-workers[8] resulted in operation of an inverse-electron-demand Diels–Alder reaction to give

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(1) (a) Brodie, H. *Can. J. Chem.* **1966**, *44*, 1235. (b) Brodie, H. *Can. J. Bot.* **1967**, *45*, 1653. (c) Brodie, H. J. *The Bird's Nest Fungi*, University of Toronto Press: Toronto, Canada, 1975.

(2) Allbutt, A. D.; Ayer, W. A.; Brodie, H. J.; Johri, B. N.; Taube, H. *Can. J. Microbiol.* **1971**, *17*, 1401.

(3) (a) Ayer, W. A.; Taube, H. *Tetrahedron Lett.* **1972**, 1917. (b) Ayer, W. A.; Carstens, L. L. *Can. J. Chem.* **1973**, *51*, 3157. (c) Ayer, W. A.; Taube, H. *Can. J. Chem.* **1973**, *51*, 3842. (d) Ayer, W. A.; Browne, L. M.; Mercier, J. R.; Taylor, D. R.; Ward, D. E. *Can. J. Chem.* **1978**, *56*, 717. (e) Ayer, W. A.; Yoshida, T.; van Schie, D. M. J. *Can. J. Chem.* **1978**, *56*, 2113. (f) Ayer, W. A.; Lee, S. P. *Can. J. Chem.* **1979**, *57*, 3332. (g) Ayer, W. A.; Browne, L. M.; Fernandez, S.; Ward, D. E.; Yoshida, T. *Rev. Latinoamer. Quim.* **1978**, *9*, 177.

(4) Ayer, W. A.; Ward, D. E.; Browne, L. M.; Delbaere, L. T. J.; Hoyano, Y. *Can. J. Chem.* **1981**, *59*, 2665.

(5) Ward, D. E. *Can. J. Chem.* **1987**, *65*, 2380.

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

(7) Wilson, S. R. *Org. React.* **1993**, *43*, 93.

(8) (a) Rigby, J. H.; Sage, J.-M. *J. Org. Chem.* **1983**, *48*, 3591. (b) Rigby, J.-H.; Sage, J.-M.; Raggon, J. *J. Org. Chem.* **1982**, *47*, 4815.

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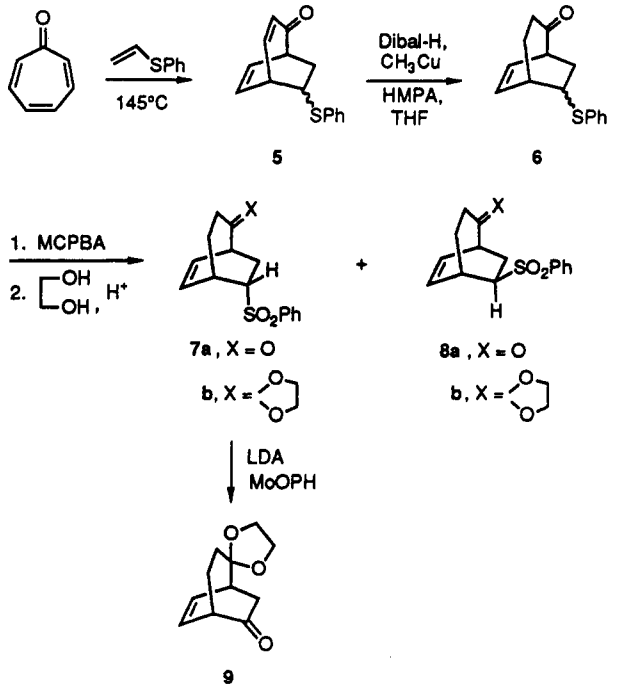
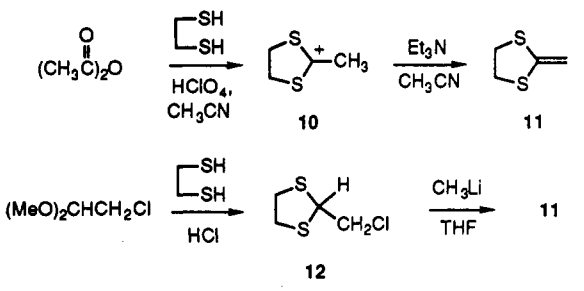
**Scheme 1**



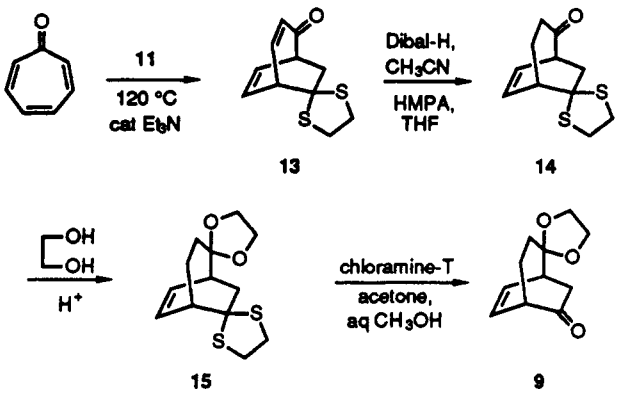

5 (67%), which was reduced regioselectively to deliver **6**. When initial attempts to accomplish this conversion with $Li(MeO)_3AlH{\cdot}CuBr$[9] failed to be more than 50% efficient, recourse was made instead to $i$-$Bu_2AlH/CH_3Cu/HMPA$.[10] Under these conditions, **6** was reproducibly formed in 75% yield. To reach **9**, keto sulfide **6** was sequentially oxidized with MCPBA and ketalized. For characterization purposes, the exo and endo isomers of **6** were carried separately through these two steps. Of a variety of methods surveyed for oxidative removal of the phenylsulfonyl group,[11,12] the only one that gave reproducible results involved MoOPH. However, the 32% maximum yield realized with this reagent was not acceptable.

An alternative dienophile was obviously required for the Diels–Alder reaction. From the tactical viewpoint, a ketene equivalent that was also symmetric would serve our purposes particularly well since the possibility of generating exo and endo isomers would be eliminated. A priori, 2-methylene-1,3-dithiolane (**11**) seemed to be a reasonable choice. The only reported synthesis of **11**[13] involved the condensation of acetic anhydride with ethanedithiol in the presence of perchloric acid, followed by isolation of perchlorate salt **10** (Scheme 2). This salt is then neutralized with triethylamine to afford **11** in 36% overall yield. The several drawbacks associated with this procedure, including the large amounts of dry $CH_3CN$ and $Et_3N$ required and the potentially explosive nature of **10**, could not be satisfactorily skirted. From among several other routes to **11** that were explored,[14] the most satisfactory for large-scale production involved transacetalization of chloroacetaldehyde dimethyl acetal to give **12**, dehydrochlorination of which with methyllithium

**Scheme 2**




**Scheme 3**




proceeded smoothly to deliver the desired dithiolane in 53% overall yield.[15] This reactive intermediate is very acid-sensitive; all glassware involving its use must be base-washed.

The projected use of **11** for the acquisition of **9** worked splendidly (Scheme 3).[16] Although the cycloaddition yield (56%) was comparable to that encountered previously with **5**, the subsequent conversion to **14** was markedly improved (>90%), formation of the dioxolane proceeded quantitatively, and chemoselective removal of the dithiolane was achievable with chloramine-T hydrate.[17,18]

Ketones **9** and **13** were both successfully resolved following adaptation of Johnson's sulfoximine technology.[19] In the first instance, three diastereomeric carbinols (**16–18**) were isolated in a ratio of approximately 2:1:1 (Scheme 4). These could be separated by simple column chromatography. The fourth carbinol was observed (low yield) but not characterized. The indicated absolute configurational assignments follow from an X-ray crystallographic analysis of **18**, expectations based on $\pi$-facial discrimination toward nucleophilic addition, and near-quantitative recovery of the enantiomeric dienones upon heating each carbinol individually in toluene. The proton spectra of **16** and **18** are very similar, whereas **16** and **17** are quite different with respect to the four olefinic proton absorptions. On the basis of this information, the structural assignment to **16** was made such that the sulfoximine

(9) Semmelhack, M. F.; Stauffer, R. D.; Yamashita, A. *J. Org. Chem.* **1977**, *42*, 3180.
(10) Tsuda, T.; Hayashi, T.; Satomi, H.; Kawamato, T.; Saegusa, T. *J. Org. Chem.* **1986**, *51*, 537.
(11) Little, R. D.; Myong, S. O. *Tetrahedron Lett.* **1980**, *21*, 3339.
(12) Hwu, J. R. *J. Org. Chem.* **1983**, *48*, 4433.
(13) (a) Okuyama, T. *Tetrahedron Lett.* **1982**, *23*, 2665. (b) Okuyama, T.; Fujiware, W.; Fueno, T. *Bull. Chem. Soc. Jpn.* **1986**, *59*, 453.
(14) Dahnke, K. R. Ph.D. Thesis, The Ohio State University, 1993.
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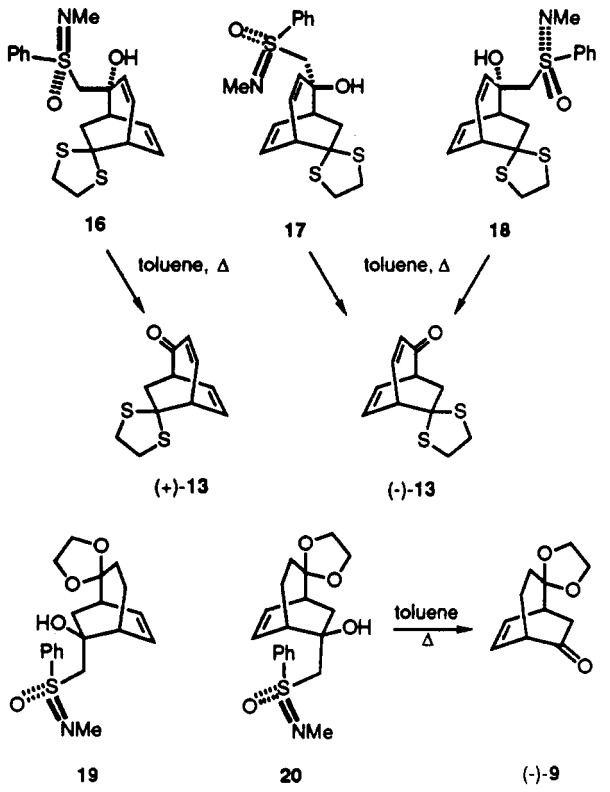
(17) (a) Emerson, D. W.; Wynberg, H. *Tetrahedron Lett.* **1971**, 3445. (b) Yoshida, H.; Yoshikane, M.; Ogata, T.; Inokawa, S. *Synthesis* **1976**, 551.
(18) Other methods for deprotecting dithiolanes in the presence of dioxolanes were examined and found to function less well: (a) Stork, G.; Zhao, K. *Tetrahedron Lett.* **1989**, *30*, 287. (b) Abdallah, M. A.; Shah, J. N. *J. Chem. Soc., Perkin Trans. 1* **1975**, 888. (c) Smith, A. B., III; Lupo, A. T., Jr.; Ohba, M.; Chen, K. *J. Am. Chem. Soc.* **1989**, *111*, 6648. (d) Chang, H.-L. *Tetrahedron Lett.* **1972**, 1989.
(19) (a) Johnson, C. R.; Zeller, J. R. *J. Am. Chem. Soc.* **1982**, *104*, 4021. (b) Johnson, C. R.; Schroeck, C. W.; Shanklin, J. R. *J. Am. Chem. Soc.* **1973**, *95*, 7424.

**Scheme 4**



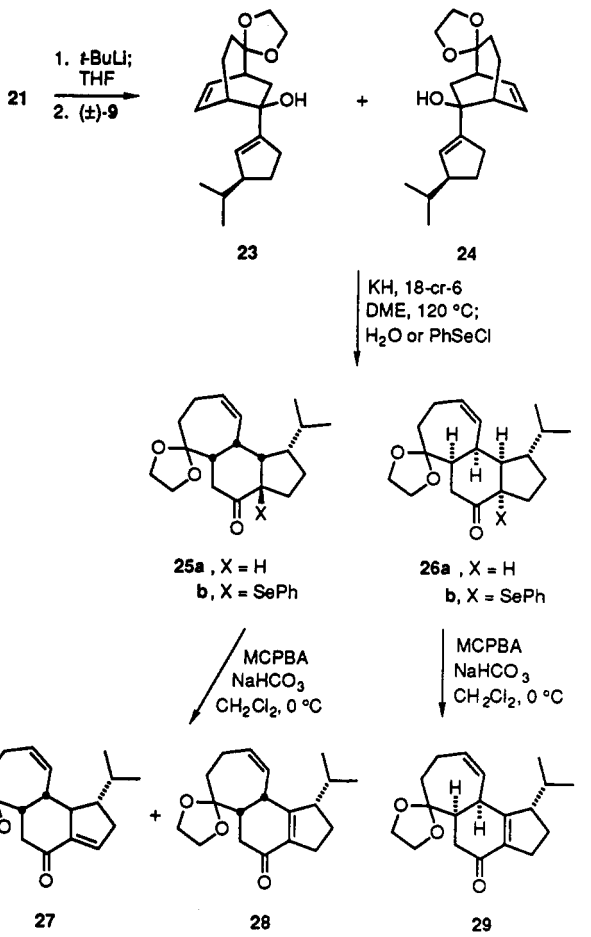

lies over the dithiolane side of the molecule as in 18. The difference in $R_f$s of 16–18 was conducive to their separation on a small scale. However, their highly crystalline nature and limited solubility caused considerable difficulty when operating with the large amounts needed. Consequently, recourse was ultimately made to the more soluble sulfoximine adducts 19 and 20, whose separation was realized by preparative HPLC. Levorotatory ketone 9 obtained in this manner was carried through the ensuing investigation.

## Stereocontrolled Access to the Tricyclo[9.3.0.0$^{2,8}$]-tetradecane Framework

In the context of Scheme 4, one sees that excellent $\pi$-face selectivity operates during the addition of the sulfoximine anion to 9. If such strict control over the endo trajectory is an inherent property of this ketone *and* high diastereoselectivity can be achieved during its condensation with an enantiopure organometallic reagent, net kinetic resolution would be realized and prior resolution of 9 would be unnecessary.[20] Synthetically useful levels of intermolecular recognition have earlier been observed during the coupling of optically active 5-substituted cyclopentenyllithiums to racemic 2-norbornenones and related ketones.[21]

The present goals require that 9 be condensed with 1-lithio-3-isopropylcyclo-pentene. The progenitor (*R*)-(+)-bromide 21 has previously been described.[22] In this study,

**Scheme 5**




the *S*-(-)-enantiomer 22 was prepared as well in identical fashion from (*S*)-(+)-carvone. Since the isopropyl sub-


stituent in these reagents is positioned somewhat remotely from the actual reaction center, the opportunities for imbalancing the energy demands of the two competing transition states were not expected to be especially high. This conclusion was borne out by the preliminary experiments described below.

Bromide 21 was readily transformed into a nucleophile by halogen–metal exchange with *tert*-butyllithium. The subsequent introduction of racemic 9 produced in 50% yield a 1:1 mixture of 23 and 24 (Scheme 5). Neither a change in solvent from THF to ether nor transmetalation to the cerate improved the reaction efficiency or altered the product distribution. Use of a 3-fold excess of 21 in an attempt to bias selectivity toward one of the diastereomers[21] was of no measurable consequence. Clearly, steric considerations have little or no impact on the distribution of carbinols in this instance.

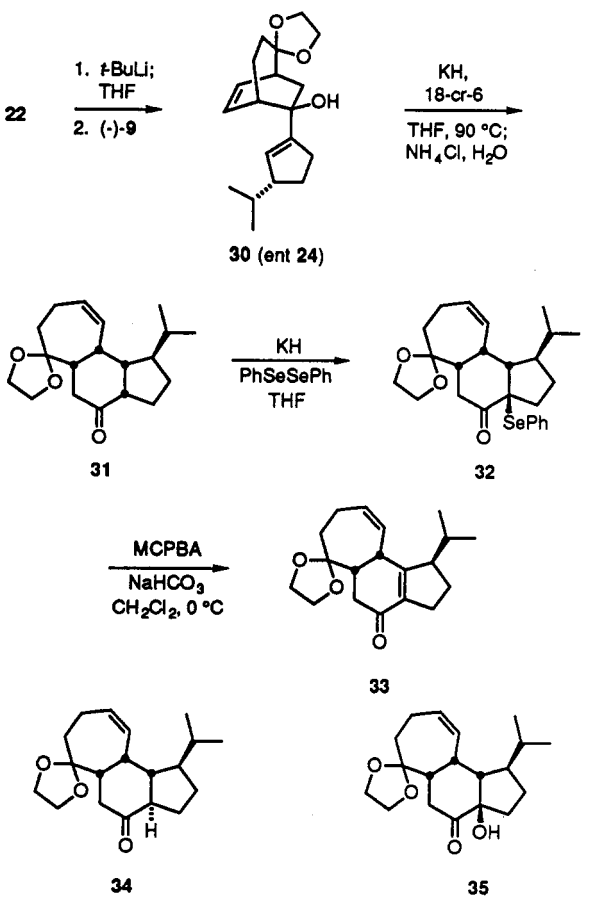
Notwithstanding, the availability of 23 and 24 as an inseparable mixture permitted preliminary exploration of the oxyanionic Cope rearrangement and transformations

(20) Paquette, L. A. In *Organic Synthesis: Modern Trends*, Chizov, O., Ed.; Blackwell Scientific Publications: Oxford, 1988, pp 1–12.

(21) (a) Paquette, L. A.; Learn, K. S. *J. Am. Chem. Soc.* **1986**, *108*, 7873. (b) Paquette, L. A.; Learn, K. S.; Romine, J. L.; Lin, H.-S. *J. Am. Chem. Soc.* **1988**, *110*, 879. (c) Paquette, L. A.; Learn, K. S.; Romine, J. L. *Synth. Commun.* **1987**, *17*, 1141; *Tetrahedron* **1987**, *43*, 4989. (d) Paquette, L. A.; DeRussy, D. T.; Cottrell, C. E. *J. Am. Chem. Soc.* **1988**, *110*, 890. (e) Paquette, L. A.; Oplinger, J. A. *Tetrahedron* **1989**, *45*, 107. (f) Paquette, L. A.; DeRussy, D. T.; Gallucci, J. C. *J. Org. Chem.* **1989**, *54*, 2278. (g) Paquette, L. A.; He, W.; Rogers, R. D. *J. Org. Chem.* **1989**, *54*, 22291. (h) Paquette, L. A.; Doyon, J. Manuscript in preparation.

(22) Paquette, L. A.; Dahnke, K.; Doyon, J.; He, W.; Wyant, K.; Friedrich, D. *J. Org. Chem.* **1991**, *56*, 6199.

**Scheme 6**




immediately to follow. Despite the accelerating effects normally associated with the [3,3] sigmatropic rearrangement of a 1,5-dien-3-ol following its conversion to the potassium alkoxide in the presence of 18-crown-6,[23] **23** and **24** proved rather un-responsive to oxy-Cope rearrangement. However, when recourse was ultimately made to heating these salts in DME at 120 °C (sealed tube), the desired sigmatropic event did take place. The rather drastic conditions utilized also promoted decomposition since the combined yields of **25a/26a** (following protonation) or of **25b/26b** (following addition of PhSeCl) did not exceed 40%. The stereochemical assignments to the pair of seleno ketones were derived from X-ray crystallographic analyses of each.

Upon exposure of **26b** to an excess of MCPBA, rapid reaction ensued to deliver **29** quantitatively. When **25b** was comparably processed, oxidative elimination took place with equal efficiency to give a 2:1 mixture of **27** and **28**. At this stage, it became quite apparent that our inability to produce **28** exclusively was a serious drawback that had to be circumvented.

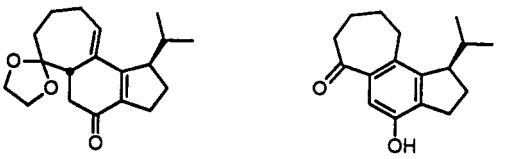
We therefore next addressed the coupling of (*R*)-(−)-bromide **22** with enantiopure (-)-**9**. In light of previous precedents, it seemed reasonable to anticipate that the resultant carbinol **30** (= ent **24**) would rearrange to ketone **31**, whose $\alpha$-face is sterically blockaded by the cycloheptene ring and associated ketal functionality. Therefore, selenation of the derived enolate anion formed under thermodynamic control and elimination was expected to furnish only **32** (Scheme 6). This series of key reactions was smoothly accomplished once the efficiency of each step was appropriately upgraded.

(23) Evans, D. A.; Golob, A. M. *J. Am. Chem. Soc.* **1975**, *97*, 4765.

Alternative anionic oxy-Cope conditions were the first to be improved. An important advance was made by performing the rearrangement in the presence of 3 equiv of KH and 18-crown-6 in THF at 90 °C (sealed tube). Inverse quenching of the enolate anion solution so produced into aqueous $NH_4Cl$ was found to yield **31** reproducibly in excess of 80%. If the quench was not performed in the inverse mode, some loss of stereocontrol was noted as indicated by the co-formation of **34** (up to 23%). Deoxygenation of the $NH_4Cl$ solution was also necessary in order to skirt oxidation[24] to **35** (up to 17%). Treatment of **31** with KH and diphenyl diselenide led unidirectionally to **32** with remarkable regiocontrol. As expected, the conversion of **32** to **33** proceeded exclusively with introduction of the double bond internal to the 6-membered ring.

## Angular Methylation and Carbonyl Reduction Studies

Two observations made at the outset of this phase of the investigation guided our thinking as to which intermediate (**31** or **33**) would be most serviceable. Under a variety of conditions involving basic reagents, **33** exhibited a tendency for migration of its distal double bond into conjugation. For example, **36** was isolated in 54% yield when an attempt was made to effect cyclopropanation with Corey's sulfur ylide reagent.[25] The second development centered around the use of NBS in aqueous DME to accomplish planned conversion of the cycloheptenyl double bond into a bromohydrin. Phenol **37** was isolated instead.

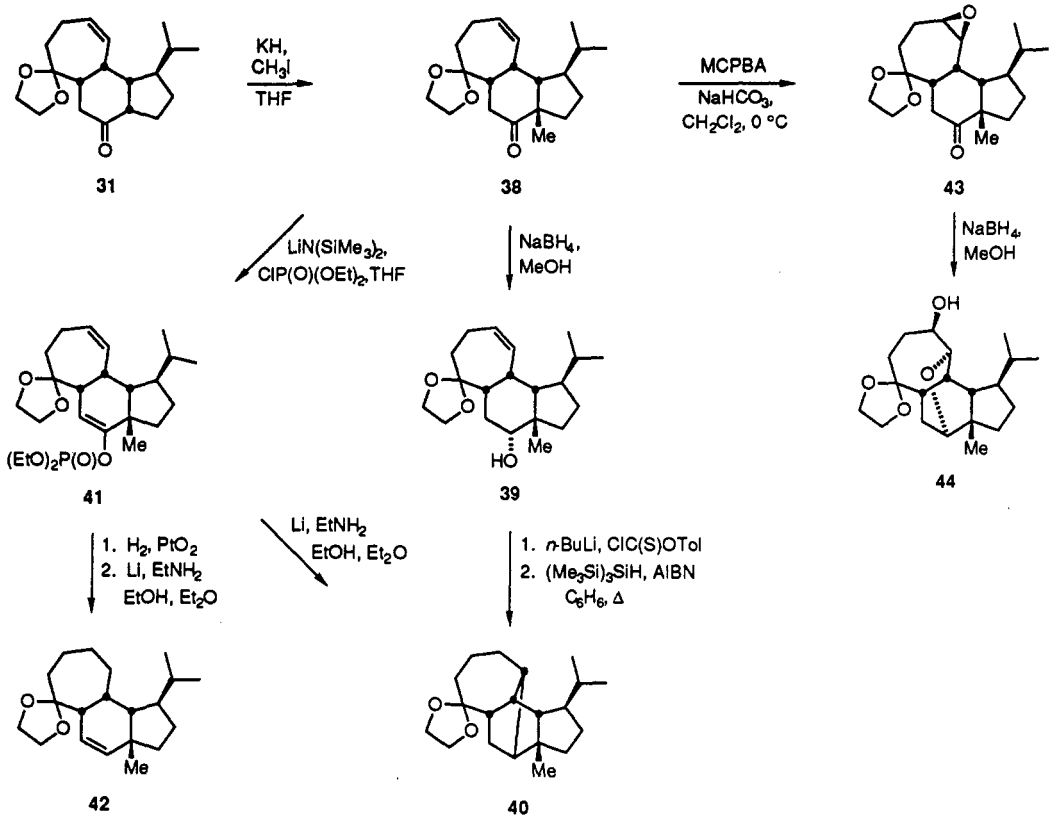



**36** **37**

Comparable complications did not surface with **31**, which could be directly methylated as in **38** (Scheme 7) in an efficient manner. Electrophilic capture from the $\beta$-face was anticipated in light of pronounced folding present within the enolate anion that sterically blockades its $\alpha$-surface. Confirmation of this conclusion followed quickly. With the first of two angular methyl groups properly installed, the time had arrived to remove the carbonyl group. Borohydride reduction proceeded stereoselectively to give alcohol **39**. When the tosylate of **39** was recognized to be particularly subject to 1,2-Wagner–Meerwein shifting of the neighboring methyl substituent,[14] recourse was made instead to thionocarbonate formation[26] for the purpose of reductive C–O bond cleavage under free-radical conditions.[27] Heating of this intermediate with $(Me_3Si)_3SiH$ and AIBN in benzene resulted in rapid transformation into **40**, a product that had not only lost the oxygen functionality but the C(10,11) double bond on the opposite side of the molecule as well. Evidently, the

(24) Paquette, L. A.; DeRussy, D. T.; Pegg, N. A.; Taylor, R. T.; Zydowsky, T. M. *J. Org. Chem.* **1989**, *54*, 4576.
(25) Corey, E. J.; Chaykovsky, M. *J. Am. Chem. Soc.* **1965**, *87*, 1353.
(26) (a) Barton, D. H. R.; McCombie, S. W. *J. Chem. Soc., Perkin Trans. 1* **1975**, 1574. (b) Barton, D. H. R.; Subramaniam, R. *J. Chem. Soc., Perkin Trans. 1* **1975**, 1574.
(27) Jackson, R. A.; Malek, F. *J. Chem. Soc., Perkin Trans. 1* **1980**, 1207.

**Scheme 7**




olefinic center can position itself in sufficient proximity to the radical center to capture it before hydrogen atom transfer can occur. Molecular models of the free radical indicate this to be eminently feasible.

The identical transannular product was formed following the conversion of **38** to enol phosphate **41**[28] and subsequent reduction of **41** with lithium in ethylamine.[29] The proclivity of these cis,syn,cis tricyclic systems for transannular bonding could, of course, be arrested by prior saturation of the olefinic linkage as reflected in the production of **42**. Conversion to epoxide **43** and regiocontrolled reduction of its carbonyl group with $NaBH_4$ was accompanied by intramolecular oxirane cleavage and the formation of **44** (83%).

## The Consequences of Conformational Flattening

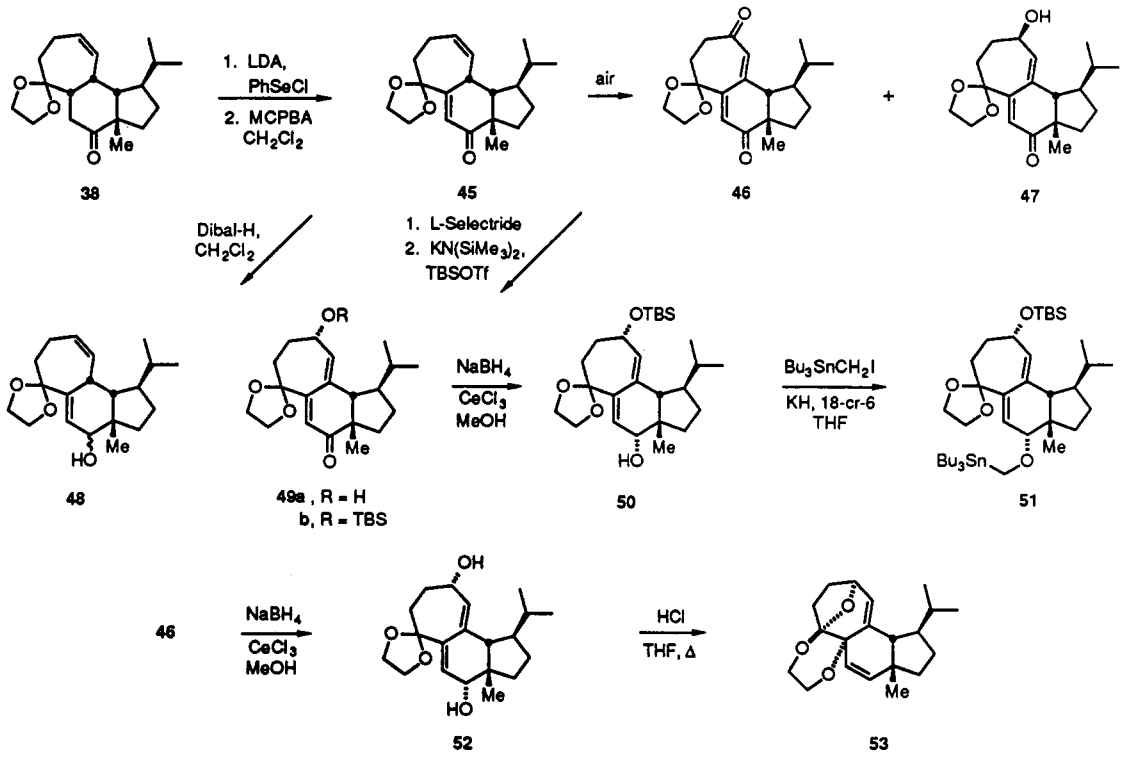
In reconsidering our tactical approach, we were cognizant that the concavity of molecules such as **38** disfavors approach of an electrophile from the $\alpha$-face. Since the C(6)-methyl in **1** is $\alpha$-configured, removal of H(6) and stereocontrolled [2,3]-Wittig rearrangement[30] were viewed as a potential intramolecular solution to the dilemma. It was soon discovered that conversion of **38** into **45** was possible via an $\alpha$-(phenylseleno) ketone (Scheme 8). This dienone proved unexpectedly to be quite air-sensitive. When allowed to stand in contact with the atmosphere, conversion to **46** and **47** occurred. Although the precise factors governing this quite unusual reactivity are not known, it will be recognized that an especially facile means for introducing needed oxygen substitution at C(11) (see **1–3**) had been serendipidously uncovered.

The additional double bond in **45** had the expected consequence of lowering diastereofacial control during reduction to dienol **48** ($\alpha$:$\beta$ = 1:2). For this reason and because these alcohols were not much more stable than their precursor **45**, efforts were directed instead to the controlled functionalization of **46**. Its reduction with L-Selectride in THF at −78 °C proceeded regioselectively to give **49a**, the C(11) epimer of **47**. No evidence was uncovered for concurrent attack at C(8). Protection of **49a** as its *tert*-butyldimethylsilyl ether set the stage for stereocontrolled conversion to $\alpha$-carbinol **50** (90%) and subsequently to the stannane **51**.[31] With this functionalized intermediate in hand, its potential for [2,3]-Wittig rearrangement was vigorously pursued. Unfortunately, **51** proved to be a remarkably inert compound. For example, upon being heated with 25 equiv of *n*-butyllithium in hexane for 4 h,[30] **51** was found to be largely unchanged (85% recovery). This lack of reactivity can be attributed to the substantial steric congestion that exists in that region of the stannyl ether where chemistry must operate.[32]

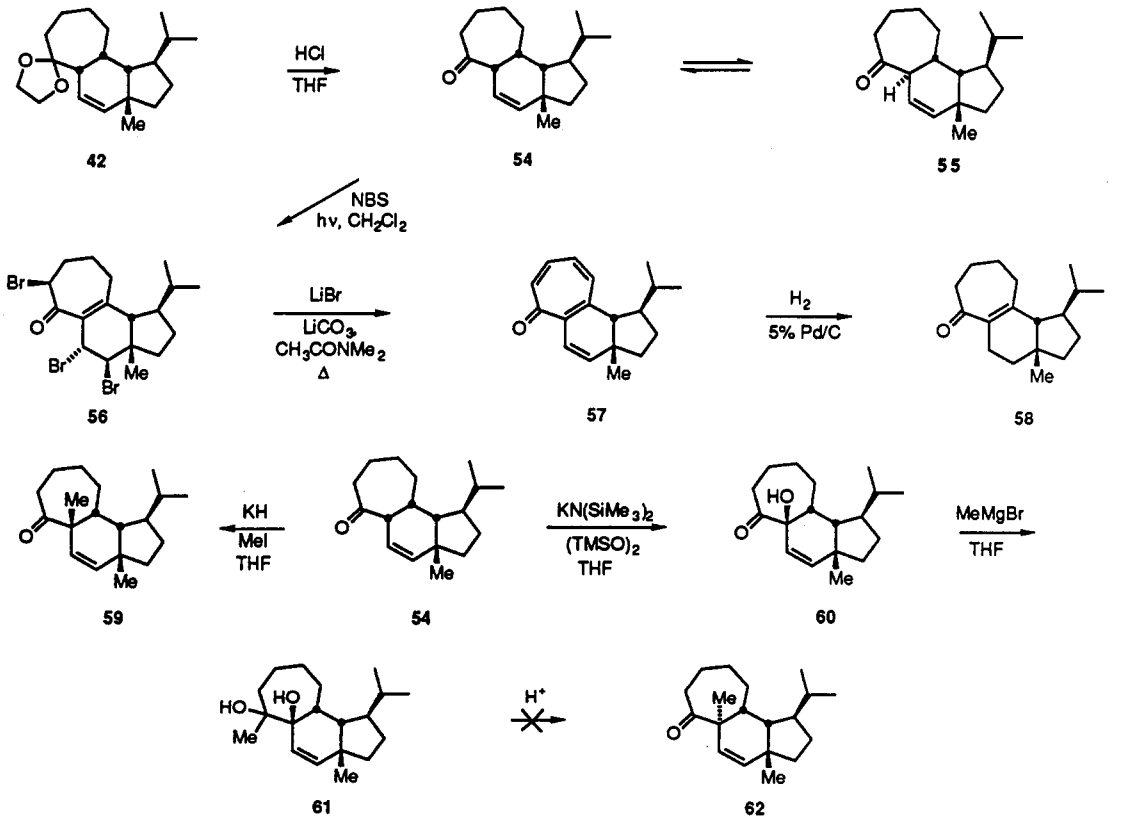
The dioxolane unit in **51** certainly contributes to the overall steric crowding and is itself subject to strain release. During a survey of selected reactions aimed at its hydrolytic removal, the occasion presented itself to heat **52** with aqueous hydrochloric acid in THF.[33] Diol **52** had earlier been produced by reduction of **46** under Luche conditions.[34] The attempted hydrolysis did not result in deketalization. Rather, the dioxane **53** was produced as a consequence of the loss of water with 1,2-migration of oxygen.

(28) Ireland, R. E.; Kowalski, C. J.; Tilley, J. W.; Walba, D. M. *J. Org. Chem.* **1975**, *40*, 990.
(29) Ireland, R. E.; McKenzie, T. C.; Trust, R. I. *J. Org. Chem.* **1975**, *40*, 1007.
(30) Still, W. C. *J. Am. Chem. Soc.* **1978**, *100*, 1481.
(31) Seyferth, D.; Andrews, S. B. *J. Organomet. Chem.* **1971**, *30*, 151.
(32) Sugimura, T.; Paquette, L. A. *J. Am. Chem. Soc.* **1987**, *109*, 3017.
(33) Highet, R. J.; Wildman, W. C. *J. Am. Chem. Soc.* **1955**, *77*, 4399.
(34) Gemal, A. L.; Luche, J.-L. *J. Am. Chem. Soc.* **1981**, *103*, 5454.

**Scheme 8**




**Scheme 9**




## Further Chemical Modification of Ring C

In contrast to the resistance of **52** to deketalization, **42** lost its protecting group simply by stirring with HCl in THF at 0 °C. Under these conditions, the $\beta,\gamma$-double bond contained in **54** did not migrate into conjugation (Scheme 9). Although being heated in an acidic environment did induce the equilibration of **54** with **55**, it was most efficacious to effect the isomerization with rhodium trichloride in ethanol at 100 °C[35] or potassium carbonate in methanol at reflux. Under either set of conditions, **55** dominated the equilibrium (ratio 1:1.5). Since the more useful conjugated enone **58** was not produced in any of these experiments, an alternate means for obtaining this isomer was investigated.

(35) Grieco, P. A.; Nishizawa, M.; Marinovic, N.; Ehmann, W. J. *J. Am. Chem. Soc.* **1976**, *98*, 7102.

Toward this end, **54** was irradiated in $CH_2Cl_2$ solution containing 3.5 equiv of *N*-bromocsuccinimide. Photoinduced halogenation occurred to give **56** in 56% yield, alongside three isomeric tribromides which were not further characterized. When **56**, either alone or as the unpurified mixture, was exposed to lithium bromide and lithium carbonate in *N,N*-dimethylacetamide at 100 °C, the tropone derivative **57** resulted. The overall yield of **57** from **54** when intermediate purification was not attempted was 76%.

Catalytic hydrogenation of **57** at atmospheric pressure afforded **58**. Unfortunately, **58** did not respond well to efforts aimed at its regioselective deprotonation. This behavior is not shared by **54**, which undergoes highly directed methylation to give **59** and $\alpha$-hydroxylation in the presence of bis(trimethylsilyl) peroxide[36,37] with formation of **60**.

Addition of methylmagnesium bromide to **60** resulted in conversion to the 1,2-diol **61**. Although **61** was a single diastereomer, the relative stereochemistry of the newly formed hydroxyl group could not be convincingly ascertained by means of NMR spectroscopy. Our purpose in generating **61** was to engage this compound in a pinacol-like rearrangement and arrival at ketone **62**. Unfortunately, **61** exhibited only a tendency to form triene mixtures when processed under a variety of acidic conditions.

## Overview

It can be stated with a high degree of assurance that a cis,cis arrangement of the pivotal stereogenic centers at C(4), C(5), and C(9) is not conducive to electrophilic capture at C(6) from the $\alpha$ face. Neither is **51** well suited to intramolecular delivery of anionic carbon from the structural underside. These features are particularly exacerbated in cis,syn,cis tricyclic systems such as **31**, **38**, and **43** because of the pronounced concave topography adopted by their frameworks. The apparent inability to flex significantly into more extended arrangements effectively brings groups that are transannularly disposed into close proximity. The compounds that have distinguished themselves in this manner, viz. **40**, **44**, and **53**, have entered into more advanced bonding in different ways. It is expected that ring closure along these channels results in the relief of nonbonded steric strain.

None of these reactions is well suited to the acquisition of the cyathins. Despite this, several potentially useful synthetic observations have emanated from this study. First, an efficient synthesis of 2-methylene-1,3-dithiolane has been developed. This ketene acetal gives evidence of being a quite reputable $2\pi$ reaction partner in inverse-electron-demand Diels–Alder reactions. Second, the use of copper hydride to distinguish between the reactive double bonds in tropone adducts such as **5** and **13** is noteworthy. The utilization of these bicyclo[3.2.2]-nonenones as building blocks in anionic oxy-Cope rearrangement sequences represent a particularly expedient way to elaborate tricyclic ketones akin to those found in the cyathins.

By different tactics, it has proven possible to aromatize either the B-ring (as the phenol) or the C-ring (as a tropone). In the latter instance, controlled hydrogenation of **57** provided a convenient three-step means for "migrating" the C(7)–C(8) double bond into the tetrasubstituted C(5)–C(6) locale.

Finally, the remarkably facile air oxidation of **45** to **46** and **47** has little or no precedence. This conversion constitutes a notably expedient approach for introduction of oxygen functionality into C(11) as required of the cyathin substitution plan.

## Experimental Section

Melting points are uncorrected. $^1H$ and $^{13}C$ NMR spectra were recorded at 300 and 75 MHz, respectively. High resolution mass spectra were recorded at The Ohio State University Chemical Instrumentation Center. Elemental analyses were performed at the Scandinavian Microanalytical Laboratory, Herlev, Denmark. All reactions were carried out under a nitrogen atmosphere and the ensuing separations were effected under flash chromatography conditions on Merck silica gel $HG_{254}$. The organic extracts were dried over anhydrous magnesium sulfate. Solvents were reagent grade and in many cases dried before use.

***exo*- and *endo*-(1*R**,5*R**)-9-(Phenylthio)bicyclo[3.2.2]non-6-en-2-one (6).** Into a 500-mL round-bottomed flask were placed copper(I) iodide (1.14 g, 6.0 mmol) and THF (250 mL). The suspension was cooled to −50 °C and methyllithium (4.2 mL of 1.4 M, 6.0 mmol) was added, followed by HMPA (60 mL) and diisobutylaluminum hydride in hexanes (66 mL of 1.0 M, 66 mmol). After 30 min, a solution of **5** (14.5 g, 59.8 mmol) was added in THF (50 mL) via cannula over 5 min. After an additional 1.5 h, the mixture was quenched with 1 N HCl (100 mL), allowed to warm to rt, and diluted with ether (500 mL). The organic layer was separated and washed with 1 N HCl (200 mL), water (3 × 200 mL), and brine (100 mL) and then dried. Concentration and chromatography of the residue on silica gel (elution with 10% ether–petroleum ether) afforded 6.89 g (47%) of *exo*-**6** followed by 4.11 g (28%) of *endo*-**6** as colorless oils.

For the exo isomer: IR ($CHCl_3$, $cm^{-1}$) 2940, 1700; $^1H$ NMR (300 MHz, $C_6D_6$) $\delta$ 7.23 (m, 2H), 6.97 (m, 3H), 5.79 (t, $J$ = 8.1 Hz, 1H), 5.68 (t, $J$ = 8.0 Hz, 1H), 3.25 (m, 1H), 2.84 (t, $J$ = 7.1 Hz, 1H), 2.68 (dt, $J$ = 15.4, 7.7 Hz, 1H), 2.39 (ddd, $J$ = 15.4, 7.5, 5.1 Hz, 1H), 2.20 (m, 2H), 1.96 (ddd, $J$ = 14.9, 11.0, 6.8 Hz, 1H), 1.57 (dd, $J$ = 14.9, 7.4 Hz, 1H), 1.31 (m, 1H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 204.7, 136.8, 135.9, 131.9, 129.2, 127.7, 127.1, 49.4, 45.3, 38.8, 35.5, 30.5, 24.5.

For the endo isomer: IR ($CHCl_3$, $cm^{-1}$) 2970, 1720; $^1H$ NMR (300 MHz, $C_6D_6$) $\delta$ 7.20 (m, 2H), 6.99 (m, 3H), 5.90 (t, $J$ = 8.0 Hz, 1H), 5.82 (t, $J$ = 8.1 Hz, 1H), 3.34 (dd, $J$ = 9.3, 5.6 Hz, 1H), 2.79 (dd, $J$ = 7.0, 5.9 Hz, 1H), 2.51 (dt, $J$ = 7.5, 4.0 Hz, 1H), 2.27 (ddd, $J$ = 14.7, 8.0, 6.6 Hz, 1H), 2.11 (m, 2H), 1.53 (dt, $J$ = 14.6, 5.6 Hz, 1H), 1.32 (dddd, $J$ = 13.7, 8.0, 6.9, 4.3 Hz, 1H), 1.13 (dddd, $J$ = 10.7, 10.0, 7.0, 3.8 Hz, 1H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 205.9, 137.2, 133.6, 130.7, 129.2, 129.0, 126.6, 49.2, 45.3, 39.2, 37.5, 32.8, 30.1.

**(1*R**,5*R**,9*R**)-9-(Phenylsulfonyl)bicyclo[3.2.2]non-6-en-2-one (7a).** To a solution of *endo*-**6** (0.80 g, 3.27 mmol) in $CH_2Cl_2$ (10 mL) at −30 °C was added dropwise a solution of 80% *m*-chloroperbenzoic acid (1.41 g, 6.54 mmol) in $CH_2Cl_2$ (30 mL). After 1.5 h, a saturated $NaHCO_3$ solution (200 mL) and $CH_2Cl_2$ (60 mL) were added. The organic layer was separated, washed with water (3 × 30 mL), and dried. Concentration and chromatography of the residue on silica gel (elution with 40% ethyl acetate–petroleum ether) afforded 0.80 g (89%) of **7a** as fine white needles, mp 118–118.5 °C (from $CH_2Cl_2$–hexane): IR ($CH_2Cl_2$, $cm^{-1}$) 2950, 1705, 1150; $^1H$ NMR (300 MHz, $C_6D_6$) $\delta$ 7.68 (m, 2H), 6.96 (m, 3H), 5.71 (t, $J$ = 8.0 Hz, 1H), 5.61 (t, $J$ = 8.2 Hz, 1H), 3.19 (dd, $J$ = 9.9, 7.3 Hz, 1H), 3.06 (dt, $J$ = 7.1, 3.9 Hz, 1H), 2.71 (br t, $J$ = 5.4 Hz, 1H), 2.17 (ddd, $J$ = 14.6, 8.0, 6.0 Hz, 1H), 1.92 (m, 2H), 1.76 (ddd, $J$ = 14.3, 9.9, 2.0 Hz, 1H), 1.31 (dddd, $J$ = 11.0, 10.0, 7.8, 3.9 Hz, 1H), 1.09 (dddd, $J$ = 11.1, 10.3, 6.0, 4.1 Hz, 1H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 204.9, 139.1, 133.2,

(36) Taddei, M.; Ricci, A. *Synthesis* **1986**, 633.

(37) Alternative means were examined to accomplish this oxidation. Of these, the action of sulfonyloxaziridines [Davis, F. A.; Vishwakarma, L. C.; Billmers, J. M.; Finn, J. *J. Org. Chem.* **1984**, *49*, 3241] and molecular oxygen on the enolate and of MCPBA on the silyl enol ether [Rubottom, G. M.; Gruber, J. M.; Juve, H. D., Jr.; Charleson, D. A. *Org. Synth.* **1986**, *64*, 118] proved less efficient.

132.9, 129.2, 129.0, 128.6, 64.0, 48.4, 39.1, 31.4, 30.5, 27.4; MS *m/z* ($M^+$) calcd 276.0820, obsd 276.0840

Anal. Calcd for $C_{15}H_{16}O_3S$: C, 65.19; H, 5.83. Found: C, 65.26; H, 5.90.

**(1*R**,5*R**,9*S**)-9-(Phenylsulfonyl)bicyclo[3.2.2]non-6-en-2-one (8a).** To a solution of *exo*-**6** (1.11 g, 4.54 mmol) in $CH_2Cl_2$ (15 mL) at −30 °C was added dropwise a solution of 80% *m*-chloroperbenzoic acid (1.96 g, 9.08 mmol) in $CH_2Cl_2$ (40 mL). After 1.5 h, a saturated $NaHCO_3$ solution (250 mL) and $CH_2Cl_2$ (80 mL) were added. The organic layer was separated, washed with water (3 × 40 mL), and dried. Concentration and chromatography of the residue on silica gel (elution with 40% ethyl acetate–petroleum ether) afforded 1.03 g (82%) of **8a** as colorless crystals, mp 139–141 °C (from $CH_2Cl_2$–hexane): IR ($CH_2Cl_2$, $cm^{-1}$) 3050, 2940, 1700, 1305, 1145, 1085; $^1H$ NMR (300 MHz, $C_6D_6$) δ 7.38 (m, 2H), 6.97 (m, 3H), 5.77 (t, *J* = 8.2 Hz, 1H), 5.57 (t, *J* = 8.1 Hz, 1H), 3.22 (m, 1H), 2.83 (m, 3H), 2.46 (m, 2H), 2.17 (dd, *J* = 14.7, 8.1 Hz, 1H), 1.40 (m, 1H), 1.19 (m, 1H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 203.3, 140.4, 136.4, 133.2, 129.1, 128.4, 128.1, 62.1, 48.2, 39.3, 32.5, 26.4, 24.1; MS *m/z* ($M^+$) calcd 276.0820, obsd 276.0816.

Anal. Calcd for $C_{15}H_{16}O_3S$: C, 65.19; H, 5.83. Found: C, 64.90; H, 5.89.

**(1*R**,5*R**,9*R**)-9-(Phenylsulfonyl)spiro[bicyclo[3.2.2]non-6-ene-2,2′-[1,3]dioxolane] (7b).** A solution **7a** (0.50 g, 1.81 mmol), ethylene glycol (3 mL), and *p*-toluenesulfonic acid (0.1 g) in benzene (15 mL) contained in a 50 mL round-bottomed flask fitted with a Dean–Stark trap was heated to reflux. After 5.5 h, the mixture was cooled, benzene (35 mL) was added, and the organic layer was washed with water (3 × 35 mL) and brine (35 mL) and then dried. Concentration under reduced pressure and chromatography on silica gel (elution with 35% petroleum ether–ethyl acetate) afforded 0.56 g (97%) of **7b** as a colorless oil which solidified on standing, mp 102–104 °C: IR ($CH_2Cl_2$, $cm^{-1}$) 2930, 1300, 1145, 1090; $^1H$ NMR (300 MHz, $C_6D_6$) δ 7.76 (m, 2H), 6.93 (m, 3H), 5.94 (t, *J* = 8.2 Hz, 1H), 5.82 (t, *J* = 8.0 Hz, 1H), 3.50 (dd, *J* = 9.5, 7.0 Hz, 1H), 3.33 (m, 3H), 3.23 (m, 1H), 3.09 (m, 1H), 2.26 (m, 2H), 2.04 (ddd, *J* = 12.3, 8.9, 5.4 Hz, 1H), 1.72–1.38 (series of m, 3H), 1.20 (m, 1H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 138.0, 133.4, 131.6, 130.0, 129.0, 128.8, 108.4, 64.5, 64.1, 63.9, 41.2, 33.5, 30.3, 27.8, 25.3; MS *m/z* ($M^+$) calcd 320.1082, obsd 320.1109.

**(1*R**,5*R**,9*S**)-9-(Phenylsulfonyl)spiro[bicyclo[3.2.2]non-6-ene-2,2′-[1,3]dioxolane] (8b).** A solution of **8a** (0.98 g, 3.55 mmol), ethylene glycol (7.5 mL), and *p*-toluenesulfonic acid (0.18 g) in benzene (25 mL) contained in a 100-mL round-bottomed flask fitted with a Dean–Stark trap was heated at reflux. After 4.5 h, the mixture was cooled, benzene (100 mL) was added, and the organic layer was washed with water (3 × 100 mL) and brine (50 mL) and then dried. Concentration under reduced pressure afforded 1.10 g (97%) of **8b** as a colorless oil: IR ($CH_2Cl_2$, $cm^{-1}$) 2910, 1140, 1090, 1080; $^1H$ NMR (300 MHz, $C_6D_6$) δ 7.73 (m, 2H), 6.94 (m, 3H), 5.91 (m, 2H), 3.44 (m, 4H), 3.04 (m, 2H), 2.72 (m, 2H), 2.43 (dddd, *J* = 10.2, 9.7, 5.8, 4.5 Hz, 1H), 2.30 (br t, *J* = 7.1 Hz, 1H), 1.89 (dt, *J* = 14.8, 5.9 Hz, 1H), 1.57 (m, 1H), 1.42 (ddd, *J* = 14.3, 11.3, 7.5 Hz, 1H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 140.9, 134.5, 132.8, 130.6, 129.0, 128.5, 109.8, 64.5, 64.2, 63.9, 41.5, 33.7, 32.3, 23.1, 22.9; MS *m/z* ($M^+$) calcd 320.1082, obsd 320.1077.

Anal. Calcd for $C_{17}H_{20}O_4S$: C, 63.73; H, 63.84. Found: C, 6.29; H, 6.40.

**(±)-Spiro[bicyclo[3.2.2]non-8-ene-2,2′-[1,3]dioxolan]-6-one (9).** To a solution of diisopropylamine (39 mL, 0.278 mmol) in THF (90 mL) at −78 °C was added *n*-butyllithium in hexanes (175 mL of 1.6 M, 0.280 mmol). After 30 min, the mixture was warmed to 0 °C and added via cannula over 15 min to a solution of **7b** (24.0 g, 74.9 mmol) in THF (200 mL) at −78 °C. After 5 min a solution of oxodiperoxymolybdenum-(pyridine)(hexamethylphosphoramide) (65 g, 150 mmol) in THF (700 mL) was added via cannula over 15 min. After 4 h, a saturated $Na_2SO_3$ solution (400 mL) and water (400 mL) were sequentially introduced, the aqueous layer was separated and extracted with ether (2 × 500 mL), and the combined organic layers were washed with water (500 mL) and brine (300 mL). Concentration under reduced pressure and chromatography on silica gel (elution with 20% ethyl acetate–petroleum ether) afforded 4.71 g (32%) of **9** as a colorless oil which solidified on standing, mp 41–42 °C: IR ($CHCl_3$, $cm^{-1}$) 2950, 1710, 1200; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.02 (t, *J* = 8.0 Hz, 1H), 5.75 (t, *J* = 7.8 Hz, 1H), 3.38 (m, 3H), 3.30 (m, 1H), 2.78 (dddd, *J* = 6.5, 4.4, 3.4, 1.2 Hz, 1H), 2.62 (dd, *J* = 18.7, 0.8 Hz, 1H), 2.28 (t, *J* = 6.5 Hz, 1H), 2.12 (dd, *J* = 18.7, 5.7 Hz, 1H), 1.79 (m, 2H), 1.55 (m, 1H), 1.44 (m, 1H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 211.0, 131.9, 130.4, 107.8, 64.4, 64.1, 49.2, 41.7, 38.1, 34.0, 24.3; MS *m/z* ($M^+$) calcd 194.0943, obsd 194.0967.

Anal. Calcd for $C_{11}H_{14}O_3$: C, 68.02; H, 7.27. Found: C, 67.94; H, 7.31.

**2-(Chloromethyl)-1,3-dithiolane (12).** Into a 500-mL round-bottomed flask were placed 1,2-ethanedithiol (66.8 g, 59.5 mL, 709 mmol) and concentrated hydrochloric acid (50 mL). After this mixture was cooled to 0 °C, chloroacetaldehyde dimethyl acetal (97.4 g, 89 mL, 782 mmol) was added dropwise over 2 h. After an additional 30 min, the mixture was warmed to rt and stirred for an additional 3 h. To the mixture were added $CH_2Cl_2$ (200 mL) and water (100 mL). The aqueous layer was separated and extracted with $CH_2Cl_2$ (100 mL). The combined organic layers were washed with water (100 mL), saturated $NaHCO_3$ solution (100 mL), and brine (100 mL) and then dried. Concentration under reduced pressure and bulb-to-bulb distillation at 20–120 °C and 0.1 mm yielded 65.0 g (59%) of **12** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 3000, 2910, 1430, 1260; $^1H$ NMR (300 MHz, $CDCl_3$) δ 4.63 (t, *J* = 7.2 Hz, 1H), 3.61 (d, *J* = 7.2 Hz, 2H), 3.22 (s, 4H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 54.2, 49.6, 38.4.

**2-Methylene-1,3-dithiolane (11).** A solution of **12** (33.0 g, 213 mmol) in ether (400 mL) at 0 °C was treated dropwise with methyllithium–lithium bromide complex in diethyl ether (156 mL of 1.5 M, 0.235 mol) over 2 h. After an additional 30 min, the mixture was allowed to warm gradually to rt. After 2 h when methane evolution had ceased, the mixture was recooled to 0 °C and quenched by dropwise addition of saturated $NH_4Cl$ solution (50 mL) followed by sufficient water to just dissolve the salts. The organic layer was separated, washed with water (3 × 100 mL), saturated $NaHCO_3$ solution (100 mL), and brine (100 mL) and then dried. The solvent was removed under reduced pressure and the residue was distilled through a base-washed short path distillation apparatus (37–40 °C, 1.0 mmHg) to give 20.4 g (89%) of **11** as a light yellow oil: IR ($CHCl_3$, $cm^{-1}$) 3000, 2930, 1675, 1575, 1525, 1425, 1285; $^1H$ NMR (300 MHz, $CDCl_3$) δ 5.13 (s, 2H), 3.37 (s, 4H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 144.5, 99.6, 38.5.

**(±)-Spiro[bicyclo[3.2.2]nona-3,8-diene-6,2′-[1,3]dithiolan]-2-one (13).** Tropone (74.0 g, 697 mmol), triethylamine (2 mL), and **11** (82.4 g, 697 mmol) were sequentially added to a 250-mL round-bottomed flask and the solution was heated at 110–120° C for 12 h. The cooled mixture was poured into ether (750 mL), and after decanting, the residue was rinsed with ether (2 × 350 mL). The ether extracts were concentrated and distilled, first up to 100 °C and 0.1 mm to remove impurities, then at 110–160 °C and 0.1 mm to give 87.2 g (56%) of **13** as an orange oil that solidified on standing, mp 63–64 °C: IR ($CHCl_3$, $cm^{-1}$) 2930, 1665, 1630, 1380, 1165; $^1H$ NMR (300 MHz, $CDCl_3$) δ 6.92 (dd, *J* = 11.0, 8.5 Hz, 1H), 6.60 (dt, *J* = 0.8, 7.7 Hz, 1H), 6.13 (t, *J* = 7.8 Hz, 1H), 5.77 (dd, *J* = 11.0, 2.0 Hz, 1H), 5.61 (t, *J* = 8.2 Hz, 1H), 3.66 (t, *J* = 7.7 Hz, 1H), 3.45–3.21 (m, 5H), 2.87 (dd, *J* = 15.5, 6.8 Hz, 1H), 2.72 (d, *J* = 15.5 Hz, 1H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 196.3, 150.6, 139.4, 129.4, 126.5, 70.8, 52.1, 51.9, 42.9, 40.6, 40.2; MS *m/z* ($M^+$) calcd 224.0330, obsd 224.0334.

Anal. Calcd for $C_{11}H_{12}OS_2$: C, 58.89; H, 5.39. Found: C, 58.80; H, 5.41.

**(±)-Spiro[bicyclo[3.2.2]non-8-ene-6,2′-[1,3]dithiolan]-2-one (14).** Into a 500-mL round-bottomed flask were placed copper(I) iodide (0.80 g, 4.2 mmol) and THF (150 mL). The suspension was cooled to −50 °C and methyllithium (3.2 mL of 1.4 M, 4.5 mmol) was added, followed by HMPA (40 mL) and diisobutylaluminum hydride (50 mL of 1.0 M, 50 mmol). After 1.5 h, a solution of **13** (7.40 g, 32.7 mmol) was added in THF (30 mL) via cannula over 10 min. After an additional 4 h, during which the reaction mixture was gradually warmed to 0° C, 1.6 N HCl (75 mL) was introduced. The aqueous layer was separated and extracted with ether (3 × 100 mL). The combined organic layers were washed with water (3 × 150 mL) and brine (150 mL) and then dried. Concentration and chromatography of the residue on silica gel (elution with $CH_2Cl_2$) afforded 6.81 g (92%) of **14** as a pale yellow solid, mp 70.5–72.5 °C: IR ($CHCl_3$, $cm^{-1}$) 2930, 2860, 1700, 1425; $^1H$ NMR (300 MHz, $CDCl_3$) δ 6.51 (t, *J*

= 8.2 Hz, 1H), 6.14 (t, $J$ = 7.9 Hz, 1H), 3.48–3.22 (m, 4H), 3.10 (t, $J$ = 7.3, 1H), 2.94–2.83 (m, 2H), 2.70–2.52 (m, 3H), 2.33 (m, 1H), 1.88 (dddd, $J$ = 12.2, 10.0, 7.6, 4.7 Hz, 1H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 206.9, 137.3, 127.3, 69.9, 49.1, 46.8, 42.9, 39.8, 39.4, 38.1, 27.1; MS $m/z$ ($M^+$) calcd 226.0486, obsd 226.0483.

Anal. Calcd for $C_{11}H_{14}OS_2$: C, 58.37; H, 6.23. Found: C, 58.80; H, 6.19.

**(±)-Dispiro[1,3-dioxolane-2,2′-bicyclo[3.2.2]non[8]ene-6′,2″-[1,3]dithiolane] (15).** A solution of **14** (1.50 g, 6.63 mmol), ethylene glycol (7.50 g, 121 mmol), and *p*-toluenesulfonic acid (0.1 g) in benzene (75 mL) was heated at reflux in a 200-mL recovery flask fitted with a Dean–Stark trap. After 4 h, the mixture was cooled, benzene (100 mL) was added, and the organic layer was washed with water (3 × 100 mL) and brine (100 mL) and then dried. Concentration and chromatography of the residue on silica gel (elution with dichloromethane) afforded 1.75 g (98%) of **15** as colorless rods, mp 95.5–96.5 °C (from $CH_2Cl_2$–petroleum ether): IR ($CHCl_3$, $cm^{-1}$) 2930, 1100, 1080; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 6.37 (dt, $J$ = 0.8, 8.0 Hz, 1H), 6.12 (t, $J$ = 8.1 Hz, 1H), 3.89 (m, 4H), 3.30 (m, 4H), 2.80 (d, $J$ = 15.7 Hz, 1H), 2.74 (m, 1H), 2.62 (dd, $J$ = 15.7, 7.2 Hz, 1H), 2.47 (dt, $J$ = 0.5, 7.2 Hz, 1H), 2.01 (m, 2H), 1.82 (m, 1H), 1.64 (m, 1H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 139.0, 129.8, 109.4, 71.4, 64.4, 63.9, 46.4, 42.6, 42.0, 39.4, 39.2, 33.7, 25.1; MS $m/z$ ($M^+$) calcd 270.0748, obsd 270.0731.

Anal. Calcd for $C_{13}H_{18}O_2S_2$: C, 57.74; H, 6.71. Found: C, 57.64; H, 6.73.

**Regiocontrolled Hydrolysis of 15.** A solution of **15** (0.50 g, 1.85 mmol) in acetone (5 mL) was cooled to 0 °C. A solution of chloramine-T·3$H_2O$ (1.11 g, 4.16 mmol) in 80:20 methanol–water (10 mL) was introduced dropwise over 5 min. After an additional 10 min, brine (5 mL) was added followed by 50% NaOH (0.25 mL), and the mixture was extracted with $CH_2Cl_2$ (3 × 25 mL). Concentration and chromatography of the residue on silica gel (elution with 20% ether–petroleum ether) afforded 0.20 g (56%) of **9** as a colorless oil which solidified on standing, identical in all respects to the ketone produced earlier.

**Sulfoximine Adducts 16–18.** To a −78 °C solution of (+)-(*S*)-*N*-methyl-*S*-phenylsulfoximine (7.78 g, 46.0 mmol) in THF (120 mL) was slowly added *n*-butyllithium in hexanes (38 mL of 1.45 M, 55.1 mmol). After 35 min, a solution of **13** (9.64 g, 43.0 mmol) in THF (100 mL) was introduced. After 1 h, the mixture was poured into saturated $NH_4Cl$ solution (100 mL) and extracted with $CH_2Cl_2$ (2 × 200 mL). The organic layers were dried and concentrated to obtain 16.7 g (99%) of the crude sulfoximine adducts. Repeated chromatography of the adducts on silica gel (elution with 25–30% ethyl acetate–petroleum ether) afforded approximately a 2:1:1 mixture of diastereomeric products.

Higher $R_f$ isomer **16**: colorless solid, mp 166.5–168 °C; IR ($CHCl_3$, $cm^{-1}$) 3200, 3000, 1445, 1240, 1210, 1155, 1085; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 7.89 (m, 2H), 7.60 (m, 3H), 7.05 (br s, 1H), 6.47 (m, 2H), 5.81 (dd, $J$ = 11.1, 8.2 Hz, 1H), 5.11 (dd, $J$ = 11.1, 2.6 Hz, 1H), 3.39–3.08 (series of m, 9H), 2.60 (m, 4H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 138.7, 138.6, 133.2, 133.1, 131.2, 130.4, 129.6, 128.9, 75.0, 74.3, 60.2, 47.8, 42.0, 40.0, 39.3, 28.8; MS $m/z$ ($M^+$) calcd 393.0981, obsd 393.0867; $[\alpha]^{23}_D$ −223.5° (*c* 1.8, $CHCl_3$)

Anal. Calcd for $C_{18}H_{23}NO_2S_3$: C, 57.98; H, 5.89. Found: C, 58.09; H, 5.90.

Middle $R_f$ isomer **17**: colorless solid, mp 143.5–144 °C; IR ($CHCl_3$, $cm^{-1}$) 3170, 3000, 1445, 1245, 1210, 1150, 1085; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 7.86 (m, 2H), 7.60 (m, 3H), 7.21 (br s, 1H), 6.53 (t, $J$ = 7.6 Hz, 1H), 5.89 (m, 2H), 5.70 (t, $J$ = 7.5 Hz, 1H), 3.38–3.10 (series of m, 8H), 2.65 (s, 3H), 2.55 (m, 2H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 140.9, 138.9, 133.2, 132.5, 129.7, 129.6, 128.9, 127.9, 74.4, 73.7, 62.8, 48.0, 43.8, 40.1, 39.7, 39.3, 28.8; MS $m/z$ ($M^+$) calcd 393.0981, obsd 393.0914; $[\alpha]^{23}_D$ +113.2° (*c* 1.8, $CHCl_3$).

Anal. Calcd for $C_{18}H_{23}NO_2S_3$: C, 57.98; H, 5.89. Found: C, 57.90; H, 5.92.

Lower $R_f$ isomer **18**: colorless solid, mp 163.5–164.5 °C; IR ($CHCl_3$, $cm^{-1}$) 3200, 3000, 1445, 1245, 1210, 1145, 1085; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 7.91 (m, 2H), 7.62 (m, 3H), 6.96 (s, 1H), 6.59 (dt, $J$ = 0.8, 7.8 Hz, 1H), 6.22 (t, $J$ = 7.6 Hz, 1H), 6.10 (dd, $J$ = 11.0, 8.4 Hz, 1H), 5.09 (dd, $J$ = 10.9, 2.4 Hz, 1H), 3.83 (m, 1H), 3.39–3.13 (series of m, 7H), 2.81 (m, 2H), 2.63 (s, 3H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 140.9, 138.9, 133.2, 132.5, 129.7, 129.6, 128.9, 127.9, 74.6, 73.7, 62.8, 48.0, 43.8, 40.1, 39.7, 39.3, 28.8; MS $m/z$ ($M^+$) calcd 393.0981, obsd 393.0961; $[\alpha]^{23}_D$ −122.8° (*c* 1.8, $CHCl_3$).

**(−)-(1*S*,5*R*)-Spiro[bicyclo[3.2.2]nona-3,8-diene-6,2′-[1,3]-dithiolan]-2-one [(−)-13].** A solution of **17** (113 mg, 286 μmol) in toluene (2 mL) was heated to reflux. After 3 h, the cooled solution was concentrated and subjected to column chromatography on silica gel (elution with 50% ethyl acetate–petroleum ether) to afford 69 mg (100%) of (−)-**13**: $[\alpha]^{23}_D$ −144.6° (*c* 0.4, $CHCl_3$).

**(*S*)-*S*-[[(1*S*,5*S*,6*R*)-6-Hydroxyspiro[bicyclo[3.2.2]non-8-ene-2,2′-[1,3]dithiolan]-6-yl]methyl]-*N*-methyl-*S*-phenylsulfoximine (19) and (*S*)-*S*-[[(1*R*, 5*R*, 6*S*)-6-Hydroxyspiro-[bicyclo[3.2.2]non-8-ene-2,2′-[1,3]dithiolan]-6-yl]methyl]-*N*-methyl-*S*-phenylsulfoximine (20).** To a −78 °C solution of (+)-(*S*)-*N*-methyl-*S*-phenylsulfoximine (7.60 g, 41.3 mmol) in THF (175 mL) was slowly added *n*-butyllithium in hexanes (29.5 mL of 1.4 M, 41.3 mmol). After 30 min, a solution of **9** (6.60 g, 34.0 mmol) was added in THF (100 mL). After 5 h, the mixture was poured into saturated $NH_4Cl$ solution (400 mL) and extracted with $CH_2Cl_2$ (2 × 200 mL). The combined organic layers were washed with brine, dried, and concentrated. Chromatography on silica gel (elution with 1:1 ether–petroleum ether + 1% methanol) yielded 10.93 g (89%) of a 1:1 mixture of diastereomers. These were in turn separated on a Waters Prep 500 HPLC (2 × 500 g cartridges) with 1:1 ether–petroleum ether containing 1.25% methanol as eluant.

Higher $R_f$ isomer **20**: colorless solid, mp 123–124.5 °C; IR ($CHCl_3$, $cm^{-1}$) 3210, 2930, 1445, 1225, 1145, 1115, 1085; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 7.84 (m, 2H), 7.57 (m, 3H), 7.19 (br s, 1H), 6.04 (t, $J$ = 8.0 Hz, 1H), 5.93 (t, $J$ = 7.9 Hz, 1H), 3.90 (m, 1H), 3.25 ($AB_q$, $J$ = 13.6 Hz, $\Delta\nu$ = 14.0 Hz, 2H), 2.72 (dd, $J$ = 15.1, 6.7 Hz, 1H), 2.63 (s, 3H), 2.09 (ddd, $J$ = 13.9, 10.9, 5.4 Hz, 1H), 1.77 (dt, $J$ = 14.2, 5.5 Hz, 1H), 1.44 (dddd, $J$ = 13.8, 10.4, 5.7, 3.3 Hz, 1H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 139.2, 133.1, 133.0, 130.7, 129.6, 128.9, 109.4, 75.7, 67.4, 64.5, 63.9, 43.4, 42.2, 36.1, 33.9, 28.9, 22.2; MS $m/z$ ($M^+$) calcd 363.1504, obsd 363.1527; $[\alpha]^{23}_D$ -66.2° (*c* 1.2, $CHCl_3$).

Anal. Calcd for $C_{19}H_{25}NO_4S$: C, 62.79; H, 6.93. Found: C, 62.90; H, 7.02.

Lower $R_f$ isomer **19**: colorless viscous oil; IR ($CHCl_3$, $cm^{-1}$) 3220, 2930, 1445, 1225, 1150, 1100, 1085; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 7.83 (m, 2H), 7.56 (m, 3H), 6.70 (br s, 1H), 6.26 (t, $J$ = 8.1 Hz, 1H), 5.94 (t, $J$ = 8.1 Hz, 1H), 3.86 (m, 4H), 3.35 (dt, $J$ = 7.7, 4.0 Hz, 1H), 3.22 ($AB_q$, $J$ = 8.5 Hz, $\Delta\nu$ = 10.9 Hz, 2H), 2.58 (s, 3H), 2.31 (t, $J$ = 7.1 Hz, 1H), 2.17 (m, 3H), 1.78 (dt, $J$ = 14.0, 5.8 Hz, 1H), 1.51 (m, 1H), 1.44 (dd, $J$ = 15.3, 7.2 Hz, 1H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 138.8, 135.2, 133.1, 129.5, 129.0, 128.4, 109.4, 76.5, 65.3, 64.5, 63.9, 41.7, 40.1, 38.8, 33.5, 28.7, 22.1; MS $m/z$ ($M^+$) calcd 363.1504, obsd 363.1517; $[\alpha]^{23}_D$ +79.5° (*c* 2.7, $CHCl_3$).

**(1*S*,5*S*)-Spiro[bicyclo[3.2.2]non-8-ene-2,2′-[1,3]dioxolan]-6-one [(−)-9].** A solution of **20** (5.64 g, 15.5 mmol) in toluene (50 mL) was heated to reflux. After 36 h, the cooled solution was concentrated and the residue was subjected to column chromatography on silica gel (elution with 25–40% ether–petroleum ether) to afford 2.94 g (98%) of (−)-**9** as a colorless solid; $[\alpha]^{23}_D$ −325.3° (*c* 5.1, $CHCl_3$).

Analogous heating of **19** (0.50 g) for 28 h afforded 150 mg (55%) of (+)-**9**, $[\alpha]^{23}_D$ +327° (*c* 1.6 $CHCl_3$).

(1*S*,5*S*,6*R*)-6-[(*S*)-3-Isopropyl-1-cyclopenten-1-yl]spiro[bicyclo-[3.2.2]non-8-ene-2,2′-[1,3]dioxolan]-6-ol (**23**). To a solution of (−)-**21** (1.00 g, 5.32 mmol) in THF (50 mL) at −78 °C was added *tert*-butyllithium in pentane (6.57 mL of 1.7 M, 31.6 mmol). After 1 h, (-)-**9** (0.94 g, 4.83 mmol) dissolved in THF (25 mL) was added dropwise. The mixture was allowed to warm slowly to 0 °C over 2 h, recooled to −78 °C, and treated with water (10 mL). After warming, the mixture was evaporated, water (50 mL) was added, and the mixture was extracted with $CH_2Cl_2$ (3 × 50 mL). The organic layers were evaporated to leave an oily solid, recrystallization of which from petroleum ether led to the isolation of 462 mg (31%) of **23** as a colorless solid, mp 108–110 °C: IR ($CHCl_3$, $cm^{-1}$) 3590, 3500, 2950, 1095, 1075; $^1$H NMR (300 MHz, $C_6D_6$) $\delta$ 6.00 (dd, $J$ = 15.5, 8.0 Hz, 1H), 5.94 (ddd, $J$ = 9.6, 2.4, 0.9 Hz, 1H), 5.45 (dd, $J$ = 3.7, 1.9 Hz, 1H), 3.48 (m, 4H), 2.40 (m, 4H), 2.33–2.13 (series of m, 4H), 2.08 (dd, J = 14.3, 6.3 Hz, 1H),

1.93 (m, 2H), 1.79 (s, 1H), 1.48 (m, 3H), 0.89 (d, $J$ = 6.7 Hz, 3H), 0.84 (d, $J$ = 6.7 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 153.2, 133.9, 129.5, 126.3, 110.1, 75.7, 64.3, 63.9, 52.7, 43.2, 42.3, 38.2, 34.2, 33.1, 32.3, 28.2, 22.1, 20.7, 20.3; MS $m/z$ ($M^+$) calcd 304.2038, obsd 304.2020; $[a]^{23}_D$ −77.2° ($c$ 1.1, $CHCl_3$).

Anal. Calcd for $C_{19}H_{28}O_3$: C, 74.96; H, 9.27. Found: C, 74.72; H, 9.18.

**(1*S*,3a*S*,5a*S*,10a*R*,10b*S*)-1,2,3,3a,5,5a,7,8,10a,10b-Decahydro-1-isopropylspiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (25a).** To **23** (349 mg, 1.15 mmol), KH (138 mg, 3.44 mmol), and 18-crown-6 (908 mg, 3.44 mmol) in an oven-dried no. 15 Ace pressure tube was added THF (20 mL). After 1 h, the nitrogen-purged tube was sealed and immersed below the level of the contents in an oil bath preheated to 95 °C. After 3 h, the cooled mixture was cannulated into saturated $NH_4Cl$ solution (30 mL) (which had been degassed and placed under nitrogen) at 0 °C. The aqueous layer was separated and extracted with ether (3 × 50 mL). The combined organic layers were concentrated and the residue was chromatographed on silica gel (elution with 20–25% ether–petroleum ether) to afford 128 mg (37%) of **25a** as a colorless oil: IR ($CHCl_3$, cm$^{-1}$) 2950, 1685, 1255; $^1$H NMR (300 MHz, $C_6D_6$) $\delta$ 5.67 (dddd, $J$ = 11.0, 8.5, 5.0, 2.5 Hz, 1H), 5.49 (ddd, $J$ = 10.9, 4.5, 2.5 Hz, 1H), 3.48 (m, 4H), 3.12 (br s, 1H), 2.63–2.40 (series of m, 3H), 2.35–2.15 (series of m, 3H), 2.03 (dd, $J$ = 10.9, 6.2 Hz, 1H), 1.80–1.18 (series of m, 8H), 0.89 (d, $J$ = 6.3 Hz, 3H), 0.77 (d, $J$ = 6.6 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 211.1, 132.0, 131.6, 111.8, 64.5, 64.4, 53.2, 52.4, 48.2, 47.5, 38.0, 34.1, 30.8, 29.8, 28.8, 27.6, 23.1, 22.5, 22.2; MS $m/z$ ($M^+$) calcd 304.2038, obsd 304.2036; $[\alpha]^{23}_D$ +6.5° ($c$ 0.3, $CHCl_3$).

**(1*S*,3a*R*,5a*S*,10a*S*,10b*S*)-1,2,3,3a,5,5a,7,8,10a,10b-Decahydro-1-isopropyl-3a-(phenylselenyl)spiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (25b) and (1*S*,3a*S*,5a*R*,10a*R*,10b*R*)-1,2,3,3a,5,5a,7,8,10a,10b-Decahydro-1-isopropyl-3a-(phenylselenyl)spiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (26b).** Into an oven-dried no. 15 Ace pressure tube was placed KH (420 mg, 10.5 mmol). To this was added the diastereomeric mixture **23** and **24** (0.48 g, 1.58 mmol) and 18-crown-6 (2.70 g, 10.2 mmol) in DME (10 mL). After 1 h, the nitrogen-purged tube was sealed and immersed below the level of the contents in an oil bath preheated to 95 °C. After 3.5 h, the mixture was cooled to −50 °C and PhSeCl (0.60 g, 3.15 mmol) in DME (4 mL) was added dropwise over 10 min. After 30 min, the mixture was warmed to rt and saturated $NH_4Cl$ solution (5 mL) was added, followed by water (50 mL) and ether (25 mL). The aqueous layer was separated and extracted with ether (25 mL), and the combined organic layers were dried. Concentration and HPLC chromatography of the residue on silica gel (elution with 10% ethyl acetate–petroleum ether) led to the isolation of **25b** and **26b**.

For **25b**: 88 mg (12%), crystalline solid, mp 132–132.5 °C; IR ($CHCl_3$, cm$^{-1}$)

2960, 1780, 1110; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 7.50 (m, 2H), 7.31 (m, 3H), 5.82 (dddd, $J$ = 10.7, 8.2, 5.5, 2.3 Hz, 1H), 5.32 (ddd, $J$ = 10.5, 4.9, 2.0 Hz, 1H), 3.96 (m, 4H), 2.99 (br s, 1H), 2.93 (m, 1H), 2.54 (m, 2H), 2.30–1.93 (series of m, 6H), 1.79 (m, 1H), 1.64 (m, 1H), 1.56 (m, 2H), 1.31 (m, 1H), 1.00 (d, $J$ = 6.3 Hz, 3H), 0.88 (d, $J$ = 6.5 Hz, 3H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 206.0, 136.7, 132.6, 129.9, 129.3, 128.8, 128.5, 111.6, 64.5, 64.4, 61.3, 54.5, 51.8, 45.2, 36.2, 35.1, 33.7, 30.5, 30.3, 28.0, 23.0, 22.1, 21.8; MS $m/z$ ($M^+$) calcd 460.1517, obsd 460.1525; $[\alpha]^{23}_D$ +5.0° ($c$ 0.2, $CHCl_3$).

For **26b**: 162 mg (22%), crystalline solid, mp 127–128 °C; IR ($CHCl_3$, cm$^{-1}$) 2960, 1680, 1110; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 7.46–7.27 (series of m, 5H), 5.92 (dddd, $J$ = 10.8, 8.2, 5.5, 2.5 Hz, 1H), 5.23 (ddd, $J$ = 10.5, 4.9, 2.0 Hz, 1H), 3.99 (m, 4H), 3.02 (dd, $J$ = 18.2, 6.8 Hz, 1H), 2.90 (s, 1H), 2.43 (dd, $J$ = 11.9, 6.9 Hz, 1H), 2.23 (dd, $J$ = 18.2, 11.9 Hz, 1H), 2.04 (m, 2H), 1.74 (m, 7H), 1.61 (m, 2H), 0.99 (d, $J$ = 6.0 Hz, 3H), 0.94 (d, $J$ = 6.1 Hz, 3H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 206.6, 137.2, 133.9, 129.6, 129.0, 128.91, 128.85, 111.8, 64.6, 64.5, 63.6, 56.2, 50.5, 45.6, 36.1, 35.9, 34.6, 32.4, 30.5, 26.7, 22.2, 22.1, 20.3; MS $m/z$ ($M^+$) calcd 460.1517, obsd 460.1541; $[\alpha]^{23}_D$ −18.7° ($c$ 0.3, $CHCl_3$).

Anal. Calcd for $C_{25}H_{32}O_3Se$: C, 65.35; H, 7.02. Found: C, 65.26; H, 7.00.

**(1*R*,5a*R*,10a*S*,10b*R*)-1,2,5,5a,7,8,10a,10b-Octahydro-1-isopropylspiro-[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (27) and (1*R*,5a*R*,10a*R*)-1,2,3,5,5a,7,8,10a-Octahydro-1-isopropylspiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (28).** To **25b** (56 mg, 122 $\mu$mol) and $NaHCO_3$ (51 mg, 610 $\mu$mol) in $CH_2Cl_2$ (3 mL) at 0 °C was added dropwise a solution of $m$-chloroperbenzoic acid (52 mg, 303 $\mu$mol) in $CH_2Cl_2$ (1 mL). After 30 min, saturated $NaHCO_3$ solution (2 mL) and water (2 mL) were added, and the separated aqueous layer was extracted with $CH_2Cl_2$ (5 mL). The combined organic layers were concentrated and the residue was subjected to chromatography on silica gel (elution with 1–3% ether–$CH_2Cl_2$) to afford 17 mg (46%) of **27** followed by 14 mg (37%) of **28** as colorless oils.

For **27**: IR ($CHCl_3$, cm$^{-1}$) 2950, 1650, 1100; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 6.25 (t, $J$ = 2.1 Hz, 1H), 5.73 (dddd, $J$ = 11.0, 8.5, 4.9, 2.5 Hz, 1H), 5.22 (dt, $J$ = 10.8, 3.4 Hz, 1H), 3.44 (m, 4H), 3.39 (br s, 1H), 2.83 (m, 2H), 2.36 (m, 1H), 2.34 (dd, $J$ = 16.9, 14.0 Hz, 1H), 2.12 (m, 2H), 1.73 (m, 4H), 1.42 (m, 2H), 0.89 (d, $J$ = 6.0 Hz, 3H), 0.61 (d, $J$ = 6.2 Hz, 3H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 198.5, 146.3, 135.0, 132.2, 130.9, 127.9, 111.6, 64.4, 53.4, 49.3, 48.2, 39.9, 38.3, 36.2, 31.0, 28.9, 23.3, 22.4, 21.9; MS $m/z$ ($M^+$) calcd 302.1882, obsd 302.1884; $[\alpha]^{23}_D$ +77.0° ($c$ 1.7, $CHCl_3$).

For **28**: IR ($CHCl_3$, cm$^{-1}$) 2950, 1650, 1100; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 5.73 (dddd, $J$ = 13.6, 6.0, 4.7, 2.8 Hz, 1H), 5.23 (dt, $J$ = 10.7, 3.2 Hz, 1H), 3.42 (m, 5H), 2.82 (ddd, $J$ = 16.6, 3.3, 1.1 Hz, 1H), 2.59 (m, 3H), 2.46 (m, 1H), 2.33 (m, 2H), 1.81 (m, 2H), 1.50 (m, 4H), 0.78 (d, $J$ = 6.8 Hz, 3H), 0.61 (d, $J$ = 6.7 Hz, 3H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 196.3, 168.6, 138.1, 133.2, 129.4, 111.2, 64.5, 64.4, 57.3, 50.0, 37.6, 36.8, 32.5, 29.3, 29.2, 23.2, 22.5, 22.4, 17.1; MS $m/z$ ($M^+$) calcd 302.1882, obsd 302.1884; $[\alpha]^{23}_D$ +110.5° ($c$ 0.6, $CHCl_3$).

**(1*S*,5a*R*,10a*R*)-1,2,3,5,5a,7,8,10a-Octahydro-1-isopropylspiro[cyclohept-[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (29).** To a solution of **26b** (70 mg, 151 $\mu$mol) and $NaHCO_3$ (151 mg, 1.80 mmol) in $CH_2Cl_2$ (5 mL) at 0 °C was added dropwise a solution of $m$-chloroperbenzoic acid (52 mg, 303 $\mu$mol) in $CH_2Cl_2$ (2.5 mL). After 10 min, saturated $NaHCO_3$ solution (2 mL) was added and the aqueous layer was separated and extracted with $CH_2Cl_2$ (2 × 10 mL). The organic layers were concentrated and subjected to chromatography on silica gel (elution with 9:1 petroleum ether–ethyl acetate) to afford 39 mg (85%) of **29** as a colorless oil: IR ($CHCl_3$, cm$^{-1}$) 2960, 1650, 1110; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 5.91 (dddd, $J$ = 11.4, 8.4, 4.1, 3.0 Hz, 1H), 5.11 (ddd, $J$ = 11.3, 2.9, 2.3 Hz, 1H), 3.95 (m, 4H), 3.38 (br s, 1H), 2.91 (ddd, $J$ = 10.7, 6.9, 4.0 Hz, 1H), 2.44 (m, 4H), 2.29 (m, 2H), 2.11 (m, 2H), 1.88 (m, 1H), 1.67 (m, 3H), 0.96 (d, $J$ = 6.9 Hz, 3H), 0.72 (d, $J$ = 6.8 Hz, 3H); $^{13}$C NMR (75 MHz, $CDCl_3$) ppm 197.7, 171.1, 137.7, 133.1, 127.6, 110.9, 64.44, 64.42, 52.9, 47.4, 36.8, 34.5, 32.0, 28.2, 27.8, 22.5, 22.2, 21.1, 16.6; MS $m/z$ ($M^+$) calcd 302.1882, obsd 302.1940; $[\alpha]^{23}_D$ −84.9° ($c$ 1.3, $CHCl_3$).

**(1*S*,5*S*,6*R*)-6-[(*R*)-3-Isopropyl-1-cyclopenten-1-yl]spiro-[bicyclo[3.2.2]non-8-ene-2,2′-[1,3]dioxolan]-6-ol (30).** To freshly prepared **22** (2.97 g, 15.8 mmol) in THF (100 mL) at −78 °C was added *tert*-butyllithium in pentane (18.6 mL of 1.7 M, 31.6 mmol). After 45 min, (−)-**9** (2.44 g, 12.6 mmol) in THF (50 mL) was added dropwise. The mixture was allowed to warm slowly to 0 °C over 12 h, recooled to −78 °C, and treated with water (10 mL). On warming to rt, the mixture was evaporated, water (100 mL) was added, and the mixture was extracted with $CH_2Cl_2$ (3 × 100 mL). The organic layers were evaporated to leave an oily solid, chromatography of which on silica gel (gradient elution with 95:4.5:0.5–90:9.5:0.5 petroleum ether–ether–triethylamine) afforded 1.93 g (51%) of **30** as a colorless solid, mp 97.5–98.5 °C: IR ($CHCl_3$, cm$^{-1}$) 3580, 1940, 1090; $^1$H NMR (300 MHz, $C_6D_6$) $\delta$ 5.98 (m, 2H), 5.47 (dd, $J$ = 3.6, 1.8 Hz, 1H), 3.48 (m, 4H), 2.46–1.85 (series of m, 11H), 1.69 (s, 1H), 1.48 (m, 3H), 0.89 (d, $J$ = 6.7 Hz, 3H), 0.85 (d, $J$ = 6.7 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 153.2, 133.8, 129.5, 126.2, 110.1, 75.7, 64.3, 63.9, 52.7, 43.2, 42.6, 38.1, 34.2, 33.2, 32.2, 28.1, 22.1, 20.7, 20.4; MS $m/z$ ($M^+$) calcd 304.2038, obsd 304.2036; $[\alpha]^{23}_D$ −141.4° ($c$ 1.2, $CHCl_3$).

**(1*R*,3a*S*,5a*S*,10a*R*,10bS)-1,2,3,3a,5,5a,7,8,10a,10b-Decahydro-1-isopropylspiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (31).** To **30** (0.96 g, 3.15 mmol), KH (383 mg, 9.56 mmol), and 18-crown-6 (2.53 g, 9.56 mmol) in an oven-dried no.15 Ace pressure tube was added THF (20 mL). After 1 h, the nitrogen-purged tube was sealed and immersed below the level of the contents in an oil bath preheated to 90 °C. After 3 h, the cooled mixture was cannulated into saturated $NH_4Cl$ solution

(100 mL) (which had been degassed and placed under nitrogen) at 0 °C. The aqueous layer was separated and extracted with ether (4 × 100 mL). The combined organic layers were concentrated and the residue was chromatographed on silica gel (elution with 20–25% ether–petroleum ether) to afford 0.80 g (83%) of **31** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 2950, 1690; $^1H$ NMR (300 MHz, $C_6D_6$) δ 5.72 (dddd, $J$ = 10.9, 8.4, 5.4, 2.5 Hz, 1H), 5.33 (ddd, $J$ = 10.6, 4.9, 2.4 Hz, 1H), 3.50 (m, 4H), 3.07 (br s, 1H), 2.55–2.17 (series of m, 5H), 2.08 (ddd, $J$ = 12.3, 8.4, 5.4 Hz, 1H), 1.85 (m, 3H), 1.49 (m, 4H), 1.35 (dt, $J$ = 13.3, 6.7 Hz, 1H), 0.96 (m, 1H), 0.84 (d, $J$ = 6.7 Hz, 3H), 0.74 (d, $J$ = 6.7 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 212.0, 132.9, 130.3, 112.0, 64.5, 51.4, 49.3, 48.9, 47.8, 38.4, 36.2, 32.2, 30.6, 29.6, 28.5, 22.3, 22.0, 20.2; MS $m/z$ ($M^+$) calcd 304.2038, obsd 304.2036; $[\alpha]^{23}_D$ +13.2° (c 0.3, $CHCl_3$).

**(1*R*,3a*R*,5a*S*,10a*S*,10b*S*)-1,2,3,3a,5,5a,7,8,10a,10b-Decahydro1-isopropyl-3a-(phenylselenyl)spiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (32).** Selenenylation of **31** in the manner predescribed for **26b** afforded **32** in 38% yield. The $^1H$ and $^{13}C$ NMR spectra were identical to those of **26b**: $[\alpha]^{23}_D$ +20.4° (c 2.2, $CHCl_3$).

Oxidation of this intermediate (238 mg) as described above furnished **33** (154 mg, 98%): colorless oil, $[\alpha]^{23}_D$ +86° (c 1.3, $CHCl_3$).

**(1*R*,3a*R*,5a*S*,10a*R*,10bS)-1,2,3,3a,5,5a,7,8,10a,10b-Decahydro-1-isopropylspiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (34).** If an inverse quench is not used in the preparation of **31**, undesired epimerization on workup can afford up to 23% of **34** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 2960, 1710, 1260, 1090; $^1H$ NMR (300 MHz, $C_6D_6$) δ 5.85 (dddd, $J$ = 11.6, 8.4, 3.9, 3.1 Hz, 1H), 5.35 (ddd, $J$ = 11.4, 2.7, 2.4 Hz, 1H), 3.40 (m, 4H), 3.04 (d, $J$ = 2.7 Hz, 1H), 2.65 (ddd, $J$ = 12.9, 3.1, 1.0 Hz, 1H), 2.35 (m, 1H), 2.20 (m, 2H), 1.87 (m, 3H), 1.63–1.33 (series of m, 7H), 1.18 (m, 1H), 0.76 (d, $J$ = 6.0 Hz, 3H), 0.64 (d, $J$ = 6.0 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 207.7, 133.2, 128.2, 111.4, 64.5, 64.3, 54.2, 53.1, 52.5, 46.7, 40.7, 34.6, 31.8, 29.4, 24.6, 22.9, 21.6, 21.4, 18.3; MS $m/z$ ($M^+$) calcd 304.2038, obsd 304.2032; $[\alpha]^{23}_D$ +35.7° (c 1.2, $CHCl_3$).

Anal. Calcd for $C_{19}H_{28}O_3$: C, 74.96; H, 9.27. Found: C, 74.91; H, 9.36.

**(1*R*,3a*R*,5a*S*,10a*S*,10bS)-3a-Hydroxy-1,2,3,3a,5,5a,7,8,10a,-10b-Decahydro-1-isopropylspiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (35).** If the saturated $NH_4Cl$ solution used in the preparation of **31** is not degassed, undesired oxygenation on workup can afford up to 17% of **35** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 3520, 2950, 1700, 1105; $^1H$ NMR (300 MHz, $CDCl_3$) δ 5.97 (dddd, $J$ = 12.8, 8.2, 4.8, 2.8 Hz, 1H), 5.36 (dt, $J$ = 11.1, 2.7 Hz, 1H), 3.95 (m, 4H), 3.05 (br s, 1H), 2.91 (br s, 1H), 2.53 (d, $J$ = 1.7 Hz, 1H), 2.51 (s, 1H), 2.48–1.46 (series of m, 12H), 0.95 (d, $J$ = 6.3 Hz, 3H), 0.90 (d, $J$ = 6.3 Hz, 3H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 213.1, 133.0, 129.8, 110.9, 85.3, 64.6, 64.5, 57.8, 50.4, 48.1, 39.5, 37.4, 36.3, 34.1, 31.4, 38.7, 22.2, 22.1, 21.0; MS $m/z$ ($M^+$) calcd 320.1988, obsd 320.1987; $[\alpha]^{23}_D$ +99.1° (c 1.0, $CHCl_3$).

Anal. Calcd for $C_{19}H_{28}O_4 \cdot {}^1/_2\, Et_2O$: C, 70.70; H, 8.90. Found: C, 70.56; H, 9.30.

**(1*R*,5a*S*)-1,2,3,5,5a,7,8,9-Octahydro-1-isopropylspiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolane-4-one (36).** To a solution of trimethylsulfoxonium iodide (26 mg, 116 μmol) and KH (5 mg, 116 μmol) in DMSO (0.5 mL) was added (+)-**33** (32 mg, 106 μmol) in DMSO (1 mL). After 12 h, the mixture was poured into water (10 mL) and extracted with ether (2 × 15 mL). The extracts were concentrated and the residue was subjected to column chromatography on silica gel (elution with 25% ethyl acetate–petroleum ether) to afford 17.3 mg (54%) of **36** as a white crystalline solid, mp 128–130 °C: IR ($CHCl_3$, $cm^{-1}$) 2950, 1655, 1140, 1120; $^1H$ NMR (300 MHz, $CDCl_3$) δ 6.21 (dd, $J$ = 7.2, 6.2 Hz, 1H), 4.00 (m, 1H), 3.83 (m, 3H), 3.48 (d, $J$ = 7.9 Hz, 1H), 3.12 (ddd, $J$ = 8.8, 5.1, 2.8 Hz, 1H), 2.72 (dd, $J$ = 16.4, 1.3 Hz, 1H), 2.66–2.29 (series of m, 5H), 2.09 (dddd, $J$ = 13.7, 10.1, 3.6, 3.3 Hz, 1H), 1.99–1.56 (series of m, 6H), 0.98 (d, $J$ = 6.9 Hz, 3H), 0.69 (d, $J$ = 6.9 Hz, 3H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 197.2, 158.4, 136.3, 133.3, 132.3, 110.1, 65.6, 64.5, 51.6, 43.8, 36.7, 36.2, 30.4, 29.3, 25.9, 22.4, 21.9, 21.2, 16.1; MS $m/z$ ($M^+$) calcd 302.1882, obsd 302.1871; $[\alpha]^{23}_D$ +144.3° (c 0.9, $CHCl_3$).

Anal. Calcd for $C_{19}H_{26}O_3 \cdot {}^1/_2\, Et_2O$: C, 74.30; H, 9.20. Found: C, 74.65; H, 8.94.

**(1*R*)-4-Hydroxy-2,3,7,8-tetrahydro-1-isopropylcyclohept-[*e*]inden-6(1*H*)-one (37).** To a solution of (+)-**33** (38 mg, 125 μmol) in 9:1 DME–water (4 mL) was added dropwise a solution of *N*-bromosuccinimide (49 mg, 273 μmol) in DME (1.5 mL). After 1 h, a saturated $Na_2SO_3$ solution (1 mL) was introduced and the mixture was concentrated. A saturated $NaHCO_3$ solution (5 mL) was added and the mixture was extracted with $CH_2Cl_2$ (2 × 25 mL). The organic layers were evaporated to leave a residue which was chromatographed on silica gel (elution with 3:1 petroleum ether–ethyl acetate) to afford 13 mg (39%) of **37** as a colorless crystalline solid, mp 160–162 °C dec: IR ($CHCl_3$, $cm^{-1}$) 3580, 3380, 2950, 1650, 1575; $^1H$ NMR (300 MHz, $CDCl_3$) δ 7.37 (s, 1H), 6.52 (d, $J$ = 11.7 Hz, 1H), 6.41 (br s, 1H), 6.10 (dt, $J$ = 11.6, 5.8 Hz, 1H), 3.30 (m, 1H), 2.87 (m, 4H), 2.45 (m, 2H), 2.07 (m, 3H), 1.03 (d, $J$ = 6.9 Hz, 3H), 0.63 (d, $J$ = 6.8 Hz, 3H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 204.0, 151.2, 149.4, 137.2, 135.5, 130.1, 127.7, 125.3, 114.8, 50.5, 43.5, 32.1, 29.3, 25.0, 23.5, 22.1, 16.4; MS $m/z$ ($M^+$) calcd 256.1464, obsd 256.1466; $[\alpha]^{23}_D$ +7.5° (c 0.9, $CHCl_3$).

Anal. Calcd for $C_{17}H_{20}O_2 \cdot H_2O$: C, 74.42; H, 8.08. Found: C, 74.86; H, 7.93.

**(1*R*,3a*S*,5a*S*,10a*R*,10b*S*)-1,2,3,3a,5,5a,7,8,10a,10b-Decahydro-1-isopropyl-3a-methylspiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (38).** To a suspension of dry KH (137 mg, 3.42 mmol) in THF (25 mL, warm from distillation) was added methyl iodide (1.21 g, 532 μL, 8.54 mmol). Ketone **31** (866 mg, 2.85 mmol) was added slowly in warm THF (30 mL) over 2 min. The solution bubbled and rapidly became turbid. After 45 min, the suspension was cooled to 0 °C, and a saturated $NH_4Cl$ solution (2 mL) was slowly added. After sufficient water was added to dissolve the salts, the aqueous layer was separated and extracted with $CH_2Cl_2$ (25 mL). The organic layers were concentrated and the residue was subjected to chromatography on silica gel (elution with 10–40% ether–petroleum ether) to afford 792 mg (87%) of **38** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 2950, 2860, 1690, 1105, 1040; $^1H$ NMR (300 MHz, $CDCl_3$) δ 5.89 (dddd, $J$ = 11.0, 8.2, 5.4, 2.5 Hz, 1H), 5.28 (ddd, $J$ = 10.6, 4.9, 2.2 Hz, 1H), 4.00 (m, 4H), 2.91 (br s, 1H), 2.52 (dd, $J$ = 17.1, 6.2 Hz, 1H), 2.30 (dd, $J$ = 12.1, 6.1 Hz, 1H), 2.18 (m, 2H), 2.01 (m, 1H), 1.84–1.50 (series of m, 8H), 1.29 (m, 1H), 1.17 (s, 3H), 0.95 (d, $J$ = 6.6 Hz, 3H), 0.89 (d, $J$ = 6.5 Hz, 3H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 218.6, 133.3, 129.6, 111.9, 64.5, 56.6, 55.2, 50.4, 46.3, 36.8, 36.6, 36.4, 32.7, 30.1, 29.2, 27.1, 22.2, 22.0, 20.2; MS $m/z$ ($M^+$) calcd 318.2195, obsd 318.2174; $[\alpha]^{23}_D$ +106.5° (c 1.7, $CHCl_3$).

Anal. Calcd for $C_{20}H_{30}O_3$: C, 75.43; H, 9.49. Found: C, 75.28; H, 9.51.

**(1*R*,3a*S*,4*S*,5a*S*,10a*R*,10b*S*)-2,3,3a,4,5,5a,7,8,10a,10b-Decahydro-1-isopropyl-3a-methylspiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-ol (39).** To a solution of **38** (74 mg, 231 μmol) in methanol (5 mL) was added an excess of sodium borohydride (ca 100 mg). After 2 h, water (100 μL) was added and the mixture was concentrated. The residue was extracted from water (5 mL) with $CH_2Cl_2$ (3 × 10 mL). Concentration and chromatography of the residue on silica gel (elution with 3:1 petroleum ether–ether) afforded 73 mg (98%) of **39** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 3620, 3480, 2970, 2880, 1460, 1440, 1385, 1370, 1100, 1040; $^1H$ NMR (300 MHz, $CDCl_3$) δ 5.79 (dddd, $J$ = 12.3, 7.6, 4.4, 2.8 Hz, 1H), 5.56 (ddd, $J$ = 11.4, 3.0, 2.9 Hz, 1H), 3.93 (m, 4H), 3.59 (m, 1H), 2.56 (m, 1H), 2.06 (m, 1H), 1.93 (m, 2H), 1.79–1.46 (series of m, 11H), 1.34 (m, 1H), 1.07 (s, 3H), 0.92 (d, $J$ = 5.8 Hz, 3H), 0.85 (d, $J$ = 5.8 Hz, 3H); $^{13}C$ NMR (75 MHz, $CDCl_3$) ppm 133.0, 130.2, 112.0, 78.8, 64.4, 64.2, 54.9, 51.8, 48.0, 47.8, 39.4, 35.7, 32.5, 31.7, 29.1, 29.0, 28.3, 22.6, 22.1, 21.6; MS $m/z$ ($M^+$) calcd 320.2351, obsd 320.2390; $[\alpha]^{23}_D$ +22.6° (c 1.0, $CHCl_3$).

Anal. Calcd for $C_{20}H_{32}O_3$: C, 74.96; H, 10.06. Found: C, 74.85; H, 10.40.

**(3′*R*,3′a*S*,3′b*R*,4′*S*,8′a*S*,9′*R*,9′a*R*)-Dodecahydro-3′-isopropyl-9′a-methyl-spiro[1,3-dioxolane-2,5′-[4,9]methano[5*H*]cyclopent[*a*]azulene] (40).** To a solution of **39** (19 mg, 58 μmol) in THF (2 mL) was added dropwise *n*-butyllithium (56 μL of 1.3 M, 72 μmol). After 15 min, *p*-tolyl chlorothionocarbonate (13 mg, 11 μL, 69 μmol) was added. After an additional 30 min, the solution was concentrated to leave a crude oil, chromatography of which on silica gel (elution with petroleum ether) afforded 20 mg (75%) of the thiocarbonate as a pale yellow oil. A solution of the thiocarbonate (11 mg, 23 μmol), tris(trimethylsilyl)silane

(17 mg, 21 μL, 68 μmol), and a small amount of AIBN (ca. 5 mg) in benzene (10 mL) was heated at reflux. After 1 h, the solution was cooled and concentrated. Chromatography of the residue on silica gel (elution with 0–2% ether–petroleum ether) afforded 5 mg (78%) of **40** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 2955, 1725, 1265, 1110, 1075; $^1H$ NMR (300 MHz, $C_6D_6$) δ 3.54 (m, 4H), 2.26 (s, 1H), 2.10 (dd, $J$ = 10.4, 1.3 Hz, 1H), 1.8 (m, 5H), 1.60 (m, 3H), 1.45 (m, 3H), 1.32 (m, 3H), 1.18 (m, 1H), 1.09 (m, 2H), 1.01 (d, $J$ = 6.6 Hz, 3H), 0.92 (s, 3H), 0.87 (d, $J$ = 6.6 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 112.6, 64.4, 64.4, 63.1, 55.1, 52.2, 51.2, 49.9, 46.5, 42.6, 39.8, 37.3, 35.2, 30.8, 27.9, 26.1, 25.7, 22.4, 22.0, 21.9; MS $m/z$ ($M^+$) calcd 304.2403, obsd 304.2400; $[\alpha]^{23}_D$ +4.9° ($c$ 1.1, $CHCl_3$).

Anal. Calcd for $C_{20}H_{32}O_2$: C, 78.90; H, 10.59. Found: C, 78.99; H, 10.67.

**Diethyl (1*R*,3a*S*,5a*R*,10a*R*,10b*S*)-2,3,3a,5a,7,8,10a,10b-Octahydro-1-isopropyl-3a-methylspiro[cyclohept[*e*]indene-6(1*H*),2′-[1,3]dioxolan]-4-yl Phosphate (41).** Into a 200-mL round-bottomed flask containing THF (30 mL) at -78 °C wwew sequentially added lithium hexamethyldisilazide (9.42 mL of 1.0 M, 9.42 mmol), *N,N,N′,N′-tetramethylethylenediamine (5.0 mL), and freshly distilled diethyl chlorophosphate (1.63 g, 1.36 mL, 9.42 mmol). After 10 min, 38* (1.03 g, 3.14 mmol) was added in THF (20 mL) and the mixture was allowed to warm to rt. After 1.5 h, the mixture was recooled to −78 °C, water (5 mL) was added, and the mixture was allowed to warm to rt. Water (25 mL) was added and the mixture was extracted with ether (3 × 75 mL). The organic layers were washed with saturated $CuSO_4$ solution (3 × 50 mL), the $CuSO_4$ layers were back-extracted with ether (50 mL), and the combined organic layers were concentrated to leave a viscous oil. Chromatography of this residue (elution with 50–75% ether–petroleum ether) afforded 1.28 g (87%) of **41** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 3020, 2960, 2390, 1210, 1040; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.07 (s, 1H), 5.85 (m, 2H), 4.07 (m, 4H), 3.57 (m, 4H), 3.02 (br s, 1H), 2.81 (br s, 1H), 2.47 (tt, $J$ = 14.9, 2.0 Hz, 1H), 2.07 (m, 1H), 1.97–1.66 (series of m, 7H), 1.37 (m, 2H), 1.32 (s, 3H), 1.12 (t, $J$ = 7.1 Hz, 3H), 1.11 (t, $J$ = 7.1 Hz, 3H), 0.95 (d, $J$ = 6.6 Hz, 3H), 0.87 (d, $J$ = 6.6 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 155.0, 154.9, 133.1, 130.8, 112.1, 108.4, 108.3, 64.7, 64.4, 64.0, 63.90, 63.85, 63.78, 57.5, 50.3, 49.2, 47.46, 47.38, 38.4, 37.6, 35.8, 33.3, 29.5, 28.6, 22.4, 22.1, 21.1, 16.25, 16.22, 16.17, 16.14; MS $m/z$ ($M^+$) calcd 454.2484, obsd 454.2501; $[\alpha]^{23}_D$ +58.5° ($c$ 0.8, $CHCl_3$).

Anal. Calcd for $C_{24}H_{39}O_6P$: C, 63.41; H, 8.65. Found: C, 63.04; H, 8.88.

**Dissolving Metal Reduction of 41.** Into a nitrogen-flushed 100-mL round-bottomed flask fitted with a dry ice condenser was condensed ethylamine (25 mL). Lithium (ca. 300 mg) was added and the mixture was warmed to rt to give a blue solution. A solution of **41** (325 mg, 715 μmol) and ethanol (14 drops) in ether (10 mL) was added dropwise over 5 min. After 35 min, the mixture was cooled to −78 °C and ethanol (20 mL) was added. After the unreacted lithium pieces had been removed, the mixture was warmed to rt and the ethylamine was removed under reduced pressure. Sufficient saturated $NH_4Cl$ solution (50 mL) was added to make the solution slightly acidic, and the mixture was extracted with $CH_2Cl_2$ (3 × 50 mL). The extracts were concentrated and subjected to chromatography on silica gel (gradient elution with 0–10% ether–petroleum ether) to afford 144 mg (66%) of **40** as a colorless oil.

**(1*R*,3a*R*,5a*S*,10a*R*,10b*S*)-2,3,3a,5a,7,8,10a,10b-Octahydro-1-isopropyl-3a-methylspiro[cyclohept[*e*]indene-6(1*H*),2′-[1,3]dioxolane] (42).** To **41** (426 mg, 937 μmol) in ethyl acetate (25 mL) was added a catalytic amount of $PtO_2$ (20 mg). The mixture was hydrogenated on a Parr apparatus at 50 psi for 12 h, filtered, and concentrated. Chromatography on silica gel (elution with 50–100% ether–petroleum ether) afforded 383 mg (90%) of the dihydro derivative as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 2950, 1260, 1040; $^1H$ NMR (300 MHz, $C_6D_6$) δ 5.99 (s, 1H), 4.01 (m, 4H), 3.52 (m, 4H), 2.82 (s, 1H), 2.08 (m, 1H), 1.95–1.51 (series of m, 13H), 1.35 (m, 2H), 1.21 (s, 3H), 1.07 (ddt, $J$ = 7.1, 2.5, 0.8 Hz, 6H), 0.88 (d, $J$ = 6.5 Hz, 3H), 0.82 (d, $J$ = 6.5 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 155.1, 155.0, 112.6, 107.84, 107.80, 64.7, 64.1, 63.9, 63.8, 63.7, 56.8, 49.8, 49.4, 46.6, 46.5, 41.6, 40.0, 36.3, 32.7, 29.4, 27.5, 26.8, 23.9, 22.4, 21.31, 21.27, 16.24, 16.16; MS $m/z$ ($M^+$) calcd 456.2641, obsd 456.2656; $[\alpha]^{23}_D$ +11.7° ($c$ 0.7, $CHCl_3$).

Anal. Calcd for $C_{24}H_{41}O_6P$: C, 63.14; H, 9.05. Found: C, 62.90; H, 9.27.

Into a nitrogen-flushed 100-mL round-bottomed flask fitted with a dry ice condenser was condensed ethylamine (20 mL). Lithium (ca. 50 mg) was added and the mixture was warmed to rt to give a blue solution. A solution of dihydro-**41** (317 mg, 838 μmol) and ethanol (12 drops) in ether (8 mL) was added dropwise over 5 min. After an additional 10 min, the mixture was cooled to −78 °C and ethanol (10 mL) was added. After removal of the unreacted lithium pieces, the mixture was warmed to rt and the ethylamine removed under reduced pressure. Sufficient saturated $NH_4Cl$ solution (25 mL) was added to make the solution slightly acidic, and the mixture was extracted with ether (3 × 50 mL). The extracts were concentrated and subjected to chromatography on silica gel (gradient elution with 0–10% ether–petroleum ether) to afford 202 mg (95%) of **42** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 2960, 1460, 1090; $^1H$ NMR (300 MHz, $C_6D_6$) δ 5.94 (ddd, $J$ = 9.9, 1.9, 1.1 Hz, 1H), 5.75 (dd, $J$ = 9.9, 2.9 Hz, 1H), 3.51 (m, 4H), 2.71 (br s, 1H), 1.96 (m, 2H), 1.87–1.29 (series of m, 14H), 0.99 (s, 3H), 0.94 (d, $J$ = 6.5 Hz, 3H), 0.87 (d, $J$ = 6.5 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 137.2, 124.3, 112.9, 64.6, 64.0, 55.1, 50.1, 49.8, 44.1, 41.5, 39.2, 36.4, 32.7, 30.1, 29.5, 26.9, 24.3, 22.6, 21.4, 21.3; MS $m/z$ ($M^+$) calcd 304.2401, obsd 304.2402; $[\alpha]^{23}_D$ +45.4° ($c$ 1.3, $CHCl_3$).

**(1*R*,3a*S*,5a*S*,9*R*,10*S*,10a*R*,10b*S*)-9,10-Epoxydodecahydro-1-isopropyl-3a-methylspiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (43).** To **38** (43 mg, 134 μmol) in $CH_2Cl_2$ (2 mL) was added $NaHCO_3$ (56 mg, 667 μmol) followed by dropwise addition of a solution of MCPBA (29 mg, 167 μmol) in $CH_2Cl_2$ (1 mL). After 17 h, a saturated $NaHCO_3$ solution (3 mL) was added and the mixture was extracted with $CH_2Cl_2$ (2 × 15 mL). Concentration of the combined organic layers and chromatography of the residue on silica gel (gradient elution with 25–50% ether–petroleum ether) afforded 39 mg (87%) of **43** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 2960, 1700, 1460, 1100; $^1H$ NMR (250 MHz, $CDCl_3$) δ 3.94 (m, 4H), 2.98 (ddd, $J$ = 8.1, 6.4, 4.6 Hz, 1H), 2.74 (m, 1H), 2.38–2.07 (series of m, 5H), 1.93–1.41 (series of m, 9H), 1.31 (m, 1H), 1.22 (s, 3H), 1.00 (d, $J$ = 6.7 Hz, 3H), 0.92 (d, $J$ = 6.7 Hz, 3H); $^{13}C$ NMR (62.5 MHz, $CDCl_3$) ppm 217.9, 111.2, 64.8, 64.6, 55.9, 55.1, 53.6, 50.9, 46.4, 38.0, 37.1, 36.9, 31.5, 29.7, 28.7, 26.5, 23.7, 22.3, 19.7; MS $m/z$ ($M^+$) calcd 334.2144, obsd 334.2126; $[\alpha]^{23}_D$ +50.4° ($c$ 1.4, $CHCl_3$).

Anal. Calcd for $C_{20}H_{30}O_4$: C, 71.82; H, 9.04. Found: C, 71.62; H, 9.14.

**(1′*R*,3′a*S*,4′*R*,5′a*S*,9′*R*,10′*R*,10′a*R*,10′b*S*)-Dodecahydro-1-isopropyl-3′a-methylspiro[1,3-dioxolane-2,6′(1′*H*)-[4,10]epoxycyclohept[*e*]inden]-9′-ol (44).** To **43** (23 mg, 70 μmol) in absolute methanol (3 mL) at 0 °C was added $NaBH_4$ (5 mg, 140 μmol). After 12 h at rt, water (100 μL) was added and the mixture was concentrated. Chromatography of the residue on silica gel (elution with 50% ether–petroleum ether) afforded 20 mg (83%) of **44** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 3600, 3480, 2950, 1455, 1255, 1100, 1035; $^1H$ NMR (300 MHz, $C_6D_6$) δ 4.14 (s, 1H), 3.93 (m, 1H), 3.48 (m, 5H), 2.23 (m, 1H), 2.11–1.69 (series of m, 10H), 1.43-1.17 (series of m, 5H), 0.92 (d, $J$ = 6.6 Hz, 3H), 0.92 (d, $J$ = 6.6 Hz, 3H), 0.77 (s, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 112.8, 76.2, 75.5, 73.0, 64.3, 57.1, 50.4, 46.5, 45.2, 35.5, 35.2, 32.7, 29.5, 29.1, 28.1, 27.8, 27.2, 22.2, 21.4; MS $m/z$ ($M^+$) calcd 336.2301, obsd 336.2305; $[\alpha]^{23}_D$ +5.0° ($c$ 1.5, $CHCl_3$).

Anal. Calcd for $C_{20}H_{32}O_4 \cdot {}^1/_2\,Et_2O$: C, 70.74; H, 9.98. Found: C, 70.51; H, 9.64.

**(1*R*,3a*S*,10a*R*,10b*S*)-1,2,3,3a,7,8,10a,10b-Octahydro-1-isopropyl-3a-methylspiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (45).** To a solution of diisopropylamine (254 mg, 352 μL, 2.51 mmol) in THF (10 mL) at 0 °C was added *n*-butyllithium (1.00 mL of 2.5 M, 2.51 mmol). This solution was stirred for 30 min and cannulated into a solution of **38** (727 mg, 2.28 mmol) in THF (10 mL) at 0 °C. After 45 min, this solution was transferred into a solution of PhSeCl (524 mg, 2.74 mmol) in THF (10 mL) at 0 °C. After an additional 1 h, water (1 mL) was added and the mixture was concentrated to leave an oily solid. Chromatography of this residue on silica gel (gradient elution with 15–50% ether–petroleum ether) afforded 596 mg of

β-(phenylseleno) ketone as a colorless oil, followed by 308 mg of recovered **38** (96% yield based on recovered starting material): IR ($CHCl_3$, $cm^{-1}$) 2960, 1685, 1260, 1100; $^1H$ NMR (300 MHz, $C_6D_6$) δ 7.87 (m, 2H), 7.03 (m, 3H), 5.68 (dddd, $J$ = 10.8, 8.0, 5.1, 2.6 Hz, 1H), 5.32 (ddd, $J$ = 10.9, 4.6, 2.1 Hz, 1H), 4.00 (d, $J$ = 10.7 Hz, 1H), 3.77 (m, 4H), 3.56 (m, 2H), 3.45 (m, 2H), 3.12 (br s, 1H), 2.54 (d, $J$ = 10.6 Hz, 1H), 2.26 (m, 1H), 1.97 (ddd, $J$ = 13.6, 13.3, 5.7 Hz, 1H), 1.80–1.53 (series of m, 7H), 1.50 (s, 3H), 1.36 (m, 1H), 1.11 (m, 1H), 0.88 (d, $J$ = 6.7 Hz, 3H), 0.77 (d, $J$ = 6.5 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 211.1, 135.8, 134.1, 131.6, 129.7, 129.4, 129.3, 129.2, 129.1, 129.0, 128.9, 128.8, 128.7, 128.1, 127.8, 127.4, 112.0, 64.8, 64.2, 57.3, 55.5, 53.5, 51.1, 46.3, 38.5, 38.1, 34.0, 31.9, 27.7, 22.7, 22.1, 20.7; MS $m/z$ ($M^+$) calcd 474.1673, obsd 474.1692; $[\alpha]^{23}_D$ +18.3° ($c$ 1.3, $CHCl_3$).

Anal. Calcd for $C_{26}H_{34}O_3Se$: C, 65.95; H, 7.24. Found: C, 65.35; H, 7.39.

Oxidation of 63 mg (132 μmol) of the above intermediate with MCPBA as described above gave 19 mg (45%) of **45** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 2950, 1660, 1100, 1040; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.42 (d, $J$ = 1.4 Hz, 1H), 5.59 (m, 2H), 3.45 (m, 3H), 3.30 (m, 2H), 2.23 (m, 1H), 2.10–1.75 (series of m, 6H), 1.57 (m, 3H), 1.32 M, 1H), 1.11 (s, 3H), 0.82 (d, $J$ = 6.7 Hz, 3H), 0.73 (d, $J$ = 6.7 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 203.4, 160.1, 132.3, 129.1, 122.5, 109.7, 64.5, 64.5, 53.8, 51.9, 48.3, 38.6, 38.2, 37.1, 33.4, 26.4, 26.0, 22.7, 22.4, 18.4; MS $m/z$ ($M^+$) calcd 318.2195, obsd 318.2174; $[\alpha]^{23}_D$ +262.7° ($c$ 1.4, $CHCl_3$).

This material undergoes oxidation when allowed to stand in the air (see below).

**(1*R*,3a*S*,10b*S*)-2,3,3a,7,8,10b-Hexahydro-1-isopropyl-3a-methylspiro[cyclohept[*e*]indene-6(1*H*),2′-[1,3]dioxolane]-4,9-dione (46) and (1*R*,3a*S*,9*R*,10b*S*)-1,2,3,3a,7,8,9,10b-Octahydro-9-hydroxy-1-isopropyl-3a-methylspiro[cyclohept-[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (47).** To the preceding α-(phenylseleno) ketone (596 mg, 1.26 mmol) and $NaHCO_3$ (528 mg, 6.29 mmol) in $CH_2Cl_2$ (20 mL) at 0 °C was added dropwise a solution of MCPBA (434 mg, 2.52 mmol) in $CH_2Cl_2$ (10 mL). After 20 min, saturated $NaHCO_3$ solution (10 mL) was added and the mixture was extracted with $CH_2Cl_2$ (2 × 50 mL). The organic layers were concentrated and the residue was allowed to stand in air for 7 d. The resulting oil was then subjected to chromatography on silica gel (gradient elution within 5–60% ether–petroleum ether) to afford 29 mg (7%) of **45**, 236 mg (57%) of **46**, and 66 mg (16%) of **47**.

For **46**: light yellow crystalline solid, mp 72–73.5 °C; IR ($CHCl_3$, $cm^{-1}$) 2960, 1665, 1260, 1100, 1040; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.34 (d, $J$ = 1.1 Hz, 1H), 6.17 (s, 1H), 3.21 (m, 4H), 2.55 (m, 2H), 2.31 (ddd, $J$ = 15.1, 8.4, 6.8 Hz, 1H), 2.08 (d, $J$ = 10.6 Hz, 1H), 1.88 (m, 2H), 1.71 (m, 2H), 1.48 (m, 2H), 1.15 (m, 2H), 0.99 (s, 3H), 0.73 (d, $J$ = 6.9 Hz, 3H), 0.77 (d, $J$ = 6.7 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 202.6, 198.1, 151.4, 145.6, 132.6, 124.1, 108.2, 64.5, 63.9, 61.3, 56.3, 50.2, 37.7, 35.1, 33.2, 29.3, 24.0, 22.2, 21.4, 16.8; MS $m/z$ ($M^+$) calcd 330.1831, obsd 330.1828; $[\alpha]^{23}_D$ −277.8° ($c$ 1.2, $CHCl_3$).

Anal. Calcd for $C_{20}H_{26}O_4$: C, 72.70; H, 7.93. Found: C, 72.34; H, 7.93.

For **47**: light yellow crystalline solid, mp 131–132 °C; IR ($CHCl_3$, $cm^{-1}$) 3610, 2950, 1660, 1365, 1025; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.28 (s, 1H), 6.05 (d, $J$ = 1.4 Hz, 1H), 4.48 (d, $J$ = 10.0 Hz, 1H), 3.38 (m, 2H), 3.24 (m, 2H), 2.73 (t, $J$ = 8.9 Hz, 1H), 2.10 (d, $J$ = 10.7 Hz, 1H), 1.91 (m, 2H), 1.76–1.43 (series of m, 5H), 1.22 (m, 3H), 1.11 (s, 3H), 0.81 (d, $J$ = 6.8 Hz, 3H), 0.77 (d, $J$ = 6.6 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 203.7, 151.7, 142.2, 131.7, 122.7, 110.0, 69.0, 64.5, 64.0, 61.1, 55.5, 49.0, 35.1, 34.9, 34.2, 29.3, 23.5, 22.6, 22.1, 16.7; MS $m/z$ ($M^+$) calcd 332.1988, obsd 332.1990; $[\alpha]^{23}_D$ −290.6° ($c$ 1.5, $CHCl_3$).

Anal. Calcd for $C_{20}H_{28}O_4$: C, 72.26; H, 8.49. Found: C, 71.96; H, 8.49.

**(1*R*,3a*S*,4*R* and *S*,10a*R*,10b*S*)-2,3,3a,4,7,8,10a,10b-Octahydro-1-isopropyl-3a-methylspiro[cyclohept[*e*]indene-6(1*H*),2′-[1,3]dioxolan]-4-ols (48).** To freshly prepared **45** (86 mg, 271 μmol) in $CH_2Cl_2$ (10 mL) was added dropwise Dibal-H (571 μL of 1.0 M, 571 μmol) at −78 °C. After 2 h, saturated Rochelle's salt solution (1 mL) was added and the mixture was warmed to rt. Water (2 mL) was added and the aqueous layer was separated and extracted with $CH_2Cl_2$ (2 × 10 mL). The organic layers were concentrated and the residue was subjected to chromatography on silica gel (gradient elution with 25–50% ether–petroleum ether) to afford 23 mg (26%) of the α-alcohol, followed by 48 mg (55%) of the β-epimer as colorless oils.

For the α-isomer: IR ($CHCl_3$, $cm^{-1}$) 3600, 3520, 2960, 1110, 1050; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.31 (d, $J$ = 5.7 Hz, 1H), 5.96 (ddd, $J$ = 11.0, 3.0, 1.1 Hz, 1H), 5.53 (dddd, $J$ = 11.6, 5.9, 5.0, 2.6 Hz, 1H), 3.80 (br s, 1H), 3.54 (m, 3H), 3.44 (m, 2H), 2.34–1.99 (series of m, 4H), 1.89–1.57 (series of m, 5H), 1.35 (m, 3H), 0.92 (d, $J$ = 6.9 Hz, 3H), 0.91 (s, 3H), 0.83 (d, $J$ = 6.7 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 144.9, 134.4, 129.1, 125.8, 110.1, 72.3, 64.9, 64.0, 54.4, 50.2, 47.9, 38.1, 37.2, 34.5, 31.8, 30.4, 27.7, 23.9, 22.5, 18.9; MS $m/z$ ($M^+$) calcd 318.2195, obsd 318.2199; $[\alpha]^{23}_D$ +60.9° ($c$ 0.4, $CHCl_3$).

For the β-isomer: IR ($CHCl_3$, $cm^{-1}$) 3610, 2960, 1265, 1040; $^1H$ NMR (300 MHz, $C_6D_6$) δ 5.92 (d, $J$ = 1.8 Hz, 1H), 5.87 (dd, $J$ = 10.7, 4.9 Hz, 1H), 5.56 (dddd, $J$ = 10.2, 6.4, 6.2, 2.6 Hz, 1H), 4.02 (s, 1H), 3.57 (m, 2H), 3.46 (m, 3H), 2.29–2.05 (m, 3H), 1.88 (m, 1H), 1.85–1.27 (series of m, 8H), 0.98 (s, 3H), 0.89 (d, $J$ = 6.7 Hz, 3H), 0.79 (d, $J$ = 6.7 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 141.6, 132.5, 129.2, 127.2, 110.4, 75.3, 64.7, 64.1, 52.4, 49.5, 48.9, 39.8, 39.1, 37.2, 32.2, 27.8, 23.8, 23.8, 22.3, 19.3; MS $m/z$ ($M^+$) calcd 318.2195, obsd 318.2190; $[\alpha]^{23}_D$ +160.6° ($c$ 0.9, $CHCl_3$).

**(1*R*,3a*S*,9*S*,10b*S*)-1,2,3,3a,7,8,9,10b-Octahydro-9-hydroxy-1-isopropyl-3a-methylspiro[cyclohept[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (49a).** To **46** (90 mg, 273.6 μmol) in THF (10 mL) at −78 °C was added L-Selectride (274 μL of 1.0 M, 274 μmol) dropwise. After 15 min, water (10 mL) was added and the mixture was extracted with $CH_2Cl_2$ (2 × 50 mL). Concentration and chromatography on silica gel (elution with 50% ether–petroleum ether) afforded 80 mg (88%) of **49a** as a colorless oil: IR ($CHCl_3$, $cm^{-1}$) 3500, 2950, 1655, 1005; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.22 (d, $J$ = 1.3 Hz, 1H), 5.98 (dd, $J$ = 6.2, 1.0 Hz, 1H), 4.23 (m, 1H), 3.33 (m, 1H), 3.19 (m, 4H), 2.63 (m, 1H), 2.18 (m, 1H), 2.05 (d, $J$ = 10.4 Hz, 1H), 1.93 (m, 2H), 1.66 (m, 2H), 1.48 (m, 2H), 1.22 (m, 2H), 1.05 (s, 3H), 0.82 (d, $J$ = 6.8 Hz, 3H), 0.77 (d, $J$ = 6.6 Hz, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 203.5, 152.6, 136.8, 133.8, 122.9, 109.7, 68.0, 64.5, 64.3, 61.7, 56.2, 49.1, 35.5, 34.4, 30.2, 29.8, 24.2, 22.6, 22.0, 17.4; MS $m/z$ ($M^+$) calcd 332.1988, obsd 332.1987; $[\alpha]^{23}_D$ −278.2° ($c$ 1.5, $CHCl_3$).

Anal. Calcd for $C_{20}H_{28}O_4$: C, 72.26; H, 8.49. Found: C, 71.89; H, 8.63.

**(1*R*,3a*S*,9*S*,10b*S*)-9-(*tert*-Butyldimethylsiloxy)-1,2,3,-3a,7,8,9,10b-octahydro-1-isopropyl-3a-methylspiro[cyclohept-[*e*]indene-6(4*H*),2′-[1,3]dioxolan]-4-one (49b).** To **49a** (80 mg, 242 μmol) in THF (10 mL) at −78 °C was added lithium hexamethyldisilazide (266 μL of 1.0 M, 266 μmol). After 30 min, *tert*-butyldimethylsilyl triflate (70 mg, 61 μL, 266 μmol) was added and after an additional 30 min, water (100 μL) was introduced. The mixture was concentrated and subjected to chromatography on silica gel (elution with 10% ether–petroleum ether) to afford 74 mg (69%) of **49b** as a colorless oil and 10 mg (12.8%) of unreacted **49a**.

For **49b**: IR ($CHCl_3$, $cm^{-1}$) 2960, 1660, 1080; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.36 (d, $J$ = 1.1 Hz, 1H), 5.99 (t, $J$ = 1.2 Hz, 1H), 4.50 (ddd, $J$ = 12.9, 2.8, 0.9 Hz, 1H), 3.38 (m, 3H), 3.26 (m, 1H), 2.64 (m, 1H), 2.24 (m, 1H), 2.08 (m, 2H), 1.93-1.59 (series of m, 4H), 1.50 (m, 1H), 1.25 (m, 2H), 1.14 (s, 3H), 0.98 (s, 9H), 0.86 (d, $J$ = 6.8 Hz, 3H), 0.75 (d, $J$ = 6.7 Hz, 3H), 0.09 (s, 3H), 0.06 (s, 3H); $^{13}C$ NMR (75 MHz, $C_6D_6$) ppm 203.7, 154.1, 139.2, 131.9, 123.4, 107.6, 71.7, 65.1, 64.2, 62.9, 56.5, 49.1, 35.9, 35.4, 32.4, 30.1, 26.0, 24.6, 24.5, 22.0, 18.3, 17.6, −4.5, −4.6; $[\alpha]^{23}_D$ −233.5° ($c$ 1.0, $CHCl_3$).

Anal. Calcd for $C_{26}H_{42}O_4Si$: C, 69.91; H, 9.48. Found: C, 69.96; H, 9.54.

**(1*R*,3a*S*,4*R*,9*S*,10b*S*)-9-(*tert*-Butyldimethylsiloxy)-2,3,-3a,4,7,8,9,10b-octahydro-1-isopropyl-3a-methylspiro[cyclohept[*e*]indene-6(1*H*),2′-[1,3]dioxolan]-4-ol (50).** To **49b** (64 mg, 144 μmol) and cerium trichloride heptahydrate (59 mg, 159 μmol) in methanol (5 mL) at 0 °C was added excess sodium borohydride (ca. 50 mg). After 30 min, the mixture was warmed to rt and water was added (5 mL). The mixture was extracted with $CH_2Cl_2$ (2 × 20 mL) and the organic layers were concentrated to afford 61 mg (90%) of **50** as a colorless solid, mp 126–128 °C (from petroleum ether): IR ($CHCl_3$, $cm^{-1}$) 3620, 2960, 1255, 1070; $^1H$ NMR (300 MHz, $C_6D_6$) δ 6.16 (d, $J$ = 0.8 Hz, 1H), 5.59 (dd, $J$ = 1.0, 0.8 Hz, 1H), 4.37 (dt, $J$ = 9.2, 2.7 Hz, 1H), 3.73 (br s, 1H),

3.53 (m, 5H), 2.23 (m, 2H), 2.06–1.82 (series of m, 4H), 1.58–1.40 (series of m, 4H), 1.20 (m, 1H), 1.05 (s, 3H), 1.01 (d, $J$ = 6.9 Hz, 3H), 0.96 (s, 9H), 0.87 (d, $J$ = 6.8 Hz, 3H), 0.07 (s, 3H), 0.04 (s, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 139.4, 135.1, 132.1, 132.1, 107.7, 85.2, 72.4, 65.1, 64.0, 59.8, 54.3, 49.5, 36.9, 35.5, 33.3, 28.7, 27.3, 26.1, 28.2, 22.9, 18.3, 17.6, –4.4, –4.5; MS $m/z$ ($M^+$) calcd 448.3009, obsd 448.3045; $[\alpha]^{23}_D$ –136.5° ($c$ 1.0, $CHCl_3$).

Anal. Calcd for $C_{26}H_{44}O_4Si$: C, 69.60; H, 9.88. Found: C, 69.34; H, 9.98.

**(1*R*,3a*S*,4*S*,9*S*,10b*S*)-2,3,3a,4,7,8,9,10b-Octahydro-1-isopropyl-3a-methylspiro[cyclohept[*e*]indene-6(1*H*),2′-[1,3]dioxolane]-4,9-diol (52).** To **46** (200 mg, 605 μmol) and cerium trichloride heptahydrate (451 mg, 1.21 mmol) in methanol (20 mL) at 0 °C was added sodium borohydride (46 mg, 1.21 mmol). The mixture was slowly warmed to rt over 3 h and water (5 mL) was added. Concentration and chromatography of the residue on silica gel (elution with 50% ether–petroleum ether + 1% methanol) afforded 194 mg (97%) of **52** as a viscous colorless oil: IR ($CHCl_3$, cm$^{-1}$) 3620, 3480, 2960, 1255, 1070; $^1$H NMR (300 MHz, $C_6D_6$) δ 6.06 (d, $J$ = 0.8 Hz, 1H), 5.53 (d, $J$ = 4.7 Hz, 1H), 4.22 (br s, 1H), 3.69 (s, 1H), 3.46 (m, 2H), 3.37 (m, 2H), 2.34 (br s, 1H), 2.23 (m, 1H), 2.03 (m, 2H), 1.88 (m, 2H), 1.63–1.10 (series of m, 7H), 1.03 (s, 3H), 0.98 (d, $J$ = 6.9 Hz, 3H), 0.86 (d, $J$ = 6.8 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 138.4, 135.9, 131.3, 130.0, 109.5, 74.8, 69.2, 64.8, 64.2, 58.4, 54.8, 48.8, 36.2, 35.6, 31.2, 27.9, 27.3, 24.5, 23.1, 16.9; MS $m/z$ ($M^+$) calcd 334.2144, obsd 334.2143; $[\alpha]^{23}_D$ –153.6° ($c$ 1.1, $CHCl_3$).

**(3*R*,3a*R*,5*S*,7a*R*,11a*S*,13a*R*)-1,2,3,3a,5,6,7,9,10,13a-Decahydro-3-isopropyl-13a-methyl-5,7a-epoxy-7a*H*-indeno[5′,4′:1,7]-cyclohepta[1,2-*b*]-*p*-dioxin (53).** To **52** (48 mg, 143 μmol) in THF (10 mL) was added concentrated HCl (100 μL). The mixture was heated to reflux for 1 h and cooled to rt. Concentration and chromatography of the residue on silica gel (elution with 5–50% ether–petroleum ether) afforded 26 mg (57%) of **53** as a colorless oil: IR ($CHCl_3$, cm$^{-1}$) 2950, 1450, 1255, 1085, 1025, 1000; $^1$H NMR (300 MHz, $C_6D_6$) δ 6.23 (d, $J$ = 10.2 Hz, 1H), 5.61 (dd, $J$ = 10.2, 1.2 Hz, 1H), 5.37 (d, $J$ = 3.9 Hz, 1H), 4.44 (m, 2H), 3.88 (dt, $J$ = 3.2, 12.3 Hz, 1H), 3.26 (dd, $J$ = 11.1, 3.2 Hz, 1H), 3.17 (dd, $J$ = 12.0, 3.1 Hz, 1H), 2.73 (m, 1H), 1.91–1.51 (series of m, 7H), 1.47–1.21 (series of m, 3H), 1.03 (d, $J$ = 6.9 Hz, 3H), 0.90 (d, $J$ = 6.8 Hz, 3H), 0.87 (s, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 143.2, 137.1, 130.3, 121.6, 105.0, 75.0, 70.4, 62.9, 59.7, 56.6, 48.6, 47.1, 39.7, 32.1, 31.5, 30.5, 26.8, 25.9, 22.0, 18.6; MS $m/z$ ($M^+$) calcd 316.2039, obsd 316.2049; $[\alpha]^{23}_D$ +59.0° ($c$ 1.0, $CHCl_3$).

Anal. Calcd for $C_{20}H_{28}O_3$: C, 75.91; H, 8.92. Found: C, 75.41; H, 9.00.

**(1*R*,3a*R*,5a*S*,10a*R*,10b*S*)-2,3,3a,5a,7,8,9,10,10a,10b-Decahydro-1-isopropyl-3a-methylcyclohept[*e*]inden-6(1*H*)-one (54).** To **42** (687 mg, 2.26 mmol) in THF (150 mL) at 0 °C was added concentrated HCl (2 mL) dropwise. After 5 min, the solution was warmed to rt. After 1.5 h, the mixture was concentrated and the residue was subjected to chromatography on silica gel (elution with 0–5% ether–petroleum ether) to afford 584 mg (99%) of **54** as a colorless oil: IR ($CHCl_3$, cm$^{-1}$) 2960, 1690, 1260; $^1$H NMR (300 MHz, $C_6D_6$) δ 5.69 (dd, $J$ = 10.0, 2.0 Hz, 1H), 5.33 (ddd, $J$ = 10.0, 2.4, 1.1 Hz, 1H), 2.87 (dt, $J$ = 10.9, 2.1 Hz, 1H), 2.27 (m, 2H), 1.75–0.92 (series of m, 14H), 1.07 (s, 3H), 0.89 (d, $J$ = 6.8 Hz, 3H), 0.75 (d, $J$ = 6.8 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 212.6, 136.9, 126.0, 53.4, 50.2, 44.9, 44.3, 43.9, 40.6, 37.5, 37.3, 32.4, 28.8, 26.4, 24.1, 23.8, 23.0, 16.1; MS $m/z$ ($M^+$) calcd 260.2140, obsd 260.2135; $[\alpha]^{23}_D$ –78.9° ($c$ 1.1, $CHCl_3$).

Anal. Calcd for $C_{18}H_{28}O$: C, 83.02; H, 10.84. Found: C, 82.95; H, 10.80.

**(1*R*,3a*R*,10a*R*,10b*S*)-2,3,3a,4,7,8,9,10,10a,10b-Decahydro-1-isopropyl-3a-methylcyclohept[*e*]inden-6(1*H*)-one (55).** To **54** (8 mg, 32 μmol) dissolved in absolute ethanol (3 mL) and contained in a no.15 Ace pressure tube was added a catalytic amount of $RhCl_3{\cdot}3H_2O$ (ca. 1 mg). The mixture was sealed and heated in a 90°C oil bath for 15 h, concentrated, and subjected to chromatography on silica gel (elution with 0–5% ether–petroleum ether) to afford 7 mg (87%) of a 1.5:1 mixture of **55** and **54** as a colorless oil. The mixture could be partially separated by careful chromatography (elution with 0–50% dichloromethane–petroleum ether) for characterization of **55**: $^1$H NMR (300 MHz, $C_6D_6$) δ 6.60 (dd, $J$ = 6.9, 4.2 Hz, 1H), 2.42 (m, 2H), 2.25 (ddd, $J$ = 13.4, 11.3, 2.2 Hz, 1H), 1.84–1.43 (series of m, 7H), 1.42–1.06 (series of m, 9H), 0.88 (s, 3H), 0.85 (m, 1H), 0.79 (d, $J$ = 6.7 Hz, 3H), 0.73 (d, $J$ = 6.7 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 203.7, 143.4, 134.0, 52.7, 45.7, 43.4, 41.9, 40.2, 37.3, 35.3, 32.8, 30.9, 30.0, 27.3, 25.0, 22.8, 22.7, 15.5.

**(1*R*,3a*S*,4*R*,5*R*,7*S*,10b*S*)-4,5,7-Tribromo-2,3,3a,4,5a,7,8,9,-10,10b-decahydro-1-isopropyl-3a-methylcyclohept[*e*]inden-6(1*H*)-one (56).** Into a 250-mL round-bottomed flask were placed **54** (170 mg, 651 μmol), NBS (377 mg, 2.12 mmol), and $CH_2Cl_2$ (100 mL). The solution refluxed while being irradiated with a 150-W tungsten lamp at a distance of 10 cm. After 1.5 h, the solution was cooled to rt and concentrated. The residue was subjected to chromatography on silica gel (gradient elution with 0–10% ether–petroleum ether) to give 176 mg (56%) of **56**, followed by 100 mg (32%) of a mixture of three other tribromides all as light yellow solids. Recrystallization of **56** from petroleum ether furnished fine white needles, mp 138.5–140 °C dec: IR ($CHCl_3$, cm$^{-1}$) 2960, 1690; $^1$H NMR (300 MHz, $C_6D_6$) δ 5.70 (d, $J$ = 9.0 Hz, 1H), 4.52 (d, $J$ = 9.0 Hz, 1H), 4.40 (dd, $J$ = 5.7, 3.4 Hz, 1H), 2.61 (ddd, $J$ = 12.7, 6.5m 3.7 Hz, 1H), 2.35 (ddd, $J$ = 12.8, 11.4, 4.5 Hz, 1H), 2.23 (d, $J$ = 10.8 Hz, 1H), 1.93 (m, 3H), 1.73 (m, 1H), 1.52 (m, 2H), 1.36–0.79 (series of m, 4H), 0.97 (s, 3H), 0.68 (d, $J$ = 6.8 Hz, 3H), 0.59 (d, $J$ = 6.8 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 202.7, 141.4, 139.9, 127.9, 64.0, 56.8, 54.4, 53.5, 50.6, 44.7, 37.8, 34.7, 29.3, 22.5, 21.6, 21.4, 19.6, 14.9; FAB MS $m/z$ ($M^+$ + 1) calcd 500.14, obsd 500.17; $[\alpha]^{23}_D$ +155.7° ($c$ 2.6, $CHCl_3$).

Anal. Calcd for $C_{18}H_{25}Br_3O$: C, 43.49; H, 5.07. Found: C, 43.50; H, 5.11.

**(1*R*,3a*R*,10b*R*)-2,3,3a,10b-Tetrahydro-1-isopropyl-3a-methylcyclohept[*e*]inden-6(1*H*)-one (57).** A suspension of **56** (176 mg, 366 μmol), lithium carbonate (108 mg, 1.47 mmol), lithium bromide (111 mg, 1.28 mmol) and *N*,*N*-dimethylacetamide (15 mL) was placed in a 110 °C preheated oil bath. After 1 h, the mixture was cooled to rt. Extraction of the mixture from water (75 mL) with ether (3 × 50 mL) and concentration followed by chromatography of the residue on silica gel (elution with 0–20% ether–petroleum ether) afforded 78 mg (87%) of **57** as a bright yellow oil: IR ($CHCl_3$, cm$^{-1}$) 2950, 1560, 1470; $^1$H NMR (300 MHz, $C_6D_6$) δ 7.48 (d, $J$ = 9.8 Hz, 1H), 7.03 (d, $J$ = 11.8 Hz, 1H), 6.38 (d, $J$ = 11.2 Hz, 1H), 6.29 (ddd, $J$ = 11.8, 8.1, 1.1 Hz, 1H), 6.10 (ddd, $J$ = 11.1, 7.2, 1.0 Hz, 1H), 5.61 (dd, $J$ = 9.8, 1.0 Hz, 1H), 2.04 (m, 2H), 1.62 (m, 2H), 1.30 (m, 3H), 0.83 (s, 3H), 0.74 (d, $J$ = 6.8 Hz, 3H), 0.68 (d, $J$ = 6.8 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 184.5, 144.6, 142.0, 141.2, 140.8, 140.0, 133.7, 130.3, 123.8, 56.6, 53.5, 44.8, 40.7, 28.4, 24.4, 23.9, 22.6, 15.8; MS $m/z$ ($M^+$) calcd 254.1671, obsd 254.1647; $[\alpha]^{23}_D$ –50.4° ($c$ 0.9, $CHCl_3$).

**(1*R*,3a*R*,10b*R*)-2,3,3a,4,5,7,8,9,10,10b-Decahydro-1-isopropyl-3a-methylcyclohept[*e*]inden-6(1*H*)-one (58).** To **57** (25 mg, 98 μmol) in ethyl acetate (5 mL) was added 5 mg of 5% Pd/C. The mixture was hydrogenated at atmospheric pressure for 2 h, filtered, and concentrated under reduced pressure. Chromatography of the residue on silica gel (elution with 2–4% ether–petroleum ether) afforded 14 mg (55%) of **58** as a colorless oil: IR ($CHCl_3$, cm$^{-1}$) 2950, 1640; $^1$H NMR (300 MHz, $C_6D_6$) δ 2.60 (m, 1H), 2.37 (m, 3H), 1.71 (m, 3H), 1.56–1.15 (series of m, 9H), 1.09 (dt, $J$ = 13.0, 5.6 Hz, 1H), 0.85 (d, $J$ = 6.8 Hz, 3H), 0.85 (s, 3H), 0.79 (d, $J$ = 6.8 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 204.0, 151.7, 134.6, 56.6, 53.4, 41.6, 41.2, 39.2, 33.2, 31.6, 30.5, 26.5, 24.7, 23.1, 23.0, 22.9, 21.1, 16.1; MS $m/z$ ($M^+$) calcd 260.2140, obsd 260.2138; $[\alpha]^{23}_D$ –17.5° ($c$ 1.4, $CHCl_3$).

**(1*R*,3a*R*,5a*S*,10a*R*,10b*S*)-2,3,3a,5a,7,8,9,10,10a,10b-Decahydro-1-isopropyl-3a,5a-dimethylcyclohept[*e*]inden-6(1*H*)-one (59).** To KH (4 mg, 105 μmol) and freshly distilled methyl iodide (54 mg, 381 μmol, 24 μL) in THF (1 mL) was added **54** (25 mg, 95 μmol) in THF (2 mL). After 2 h, water (100 μL) was added and the mixture was concentrated. Chromatography of the residue on silica gel (elution with 0–4% ether–petroleum ether) followed by rechromatography on silica gel (elution with 5–15% $CH_2Cl_2$–petroleum ether) afforded 12 mg (44%) of **59** as a colorless oil. Some starting material (6 mg, 26%) was recovered, giving an overall yield based on unreacted **54** of 59%.

For **59**: IR ($CHCl_3$, cm$^{-1}$) 2940, 1690; $^1$H NMR (300 MHz, $C_6D_6$) δ 6.60 (dd, $J$ = 10.2, 1.3 Hz, 1H), 5.60 (d, $J$ = 10.2 Hz, 1H), 2.45 (ddd, $J$ = 13.4, 10.6, 2.8 Hz, 1H), 2.17 (m, 1H), 1.92 (d, $J$ = 1.6 Hz, 1H), 1.79–1.53 (series of m, 5H), 1.49-1.16 (series of m, 7H), 1.07 (s, 3H), 1.03 (m, 1H), 0.95 (d, $J$ = 5.9 Hz, 3H), 0.90 (s,

3H), 0.88 (d, $J$ = 5.9 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 213.4, 135.6, 127.1, 53.7, 50.3, 48.8, 47.1, 43.3, 39.1, 38.9, 36.9, 31.0, 30.1, 30.0, 29.7, 28.3, 24.6, 22.7, 21.8; $[\alpha]^{23}_D$ +4.7° (*c* 0.7, $CHCl_3$).

**(1*R*,3a*R*,5a*R*,10a*R*,10b*S*)-2,3,3a,5a,7,8,9,10,10a,10b-Decahydro-5a-hydroxy-1-isopropyl-3a-methylcyclohept[*e*]inden-6(1*H*)-one (60).** To **54** (26 mg, 99 μmol) in THF (3 mL) was added dropwise KHMDS in toluene (198 μL of 0.5 M, 99 μmol). After 15 min, bis(trimethylsilyl) peroxide (210 mg, 250 μL, 1.18 mmol) was added. After 45 min, the mixture was concentrated and the residue was chromatographed on silica gel (elution with 0–6% ether–petroleum ether) to afford 13 mg (46%) of **60** as a white crystalline solid, mp 88–89 °C: IR ($CHCl_3$, cm$^{-1}$) 3580, 3460, 2960, 1700, 1050; $^1$H NMR (300 MHz, $C_6D_6$) δ 5.78 (d, $J$ = 9.8 Hz, 1H), 5.72 (d, $J$ = 9.8 Hz, 1H), 3.31 (s, 1H), 2.41 (m, 3H), 1.74 (m, 1H), 1.65–1.07 (series of m, 12H), 1.02 (s, 3H), 0.95 (d, $J$ = 6.0 Hz, 3H), 0.85 (d, $J$ = 6.0 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 212.9, 141.3, 122.5, 77.9, 48.9 (2C), 48.0, 43.6, 38.6, 36.8, 36.6, 30.0, 29.6, 27.8, 26.8, 24.3, 22.6, 21.5; MS *m/z* ($M^+$) calcd 276.2089, obsd 276.2093; $[\alpha]^{23}_D$ +10.2° (*c* 1.1, $CHCl_3$).

**(1*R*,3a*R*,5a*S*,10a*R*,10b*S*)-2,3,3a,5a,7,8,9,10,10a,10b-Decahydro-5a,6-dihydroxy-1-isopropyl-3a,6-dimethylcyclohept[*e*]-inden-6(1*H*)-one (61).** To **60** (13 mg, 45 μmol) in ether (3 mL) at −78 °C was added dropwise a solution of methylmagnesium bromide in ether (90 μL of 3.0 M, 271 μmol). The mixture was allowed to warm slowly to rt and after an additional 1 h saturated $NH_4Cl$ solution (1 mL) was added. The aqueous layer was separated and extracted with ether (2 × 15 mL). The combined organic layers were concentrated and the residue was chromatographed on silica gel (elution with 0–6% ether–petroleum ether) to afford 13 mg (99%) of **61** as a white crystalline solid, mp 111–113 °C: IR ($CHCl_3$, cm$^{-1}$) 3600, 3540, 2940, 1450, 1360; $^1$H NMR (300 MHz, $C_6D_6$) δ 5.72 (d, $J$ = 10.0 Hz, 1H), 5.72 (dd, $J$ = 10.0, 1.2 Hz, 1H), 2.42 (t, $J$ = 4.4 Hz, 1H), 1.85 (m, 2H), 1.76-1.20 (series of m, 12H), 1.18 (s, 3H), 1.11 (m, 1H), 1.00 (d, $J$ = 6.2 Hz, 3H), 1.00 (s, 3H), 0.88 (d, $J$ = 6.3 Hz, 3H); $^{13}$C NMR (75 MHz, $C_6D_6$) ppm 142.9, 125.5, 77.8, 76.3, 49.5, 49.4, 48.1, 43.8, 38.8, 37.1, 33.9, 30.7, 30.0, 27.6, 26.4, 24.6, 22.7, 21.8, 19.8; MS *m/z* ($M^+$) calcd 292.2402, obsd 292.2401; $[\alpha]^{23}_D$ −1.20° (*c* 0.8, $CHCl_3$).

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**Supplementary Material Available:** Copies of the 300-MHz $^1$H NMR spectra of those compounds lacking combustion data as well as ORTEP, data collection, structure refinement details, and tables of bond distances and angles, final fractional coordinates, and thermal parameters for **18**, **25b**, and **26b** (33 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of this journal, and can be ordered from the ACS; see any current masthead page for ordering information. The authors have deposited atomic coordinates for **18**, **25b**, and **26b** with the Cambridge Crystallographic Data Cenre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK.