Development of a New Carbon−Carbon Bond Forming Reaction. New Organic Chemistry of Sulfur Dioxide. Asymmetric Four-Component Synthesis of Polyfunctional Sulfones

Vera Narkevitch, Sophie Megevand, Kurt Schenk, and Pierre Vogel*

Section de Chimie, Université de Lausanne, BCH, CH-1015 Lausanne-Dorigny, Switzerland, and Institut de Cristallographie, BSP, Université de Lausanne, CH-1015 Lausanne-Dorigny, Switzerland

pierre.vogel@ico-unil-ch

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At low temperature 1-alkoxy-1,3-dienes add to sulfur dioxide activated by a Lewis or Brønstedt acid and generate zwitterionic intermediates that can be quenched by enoxysilanes. The resulting β,γ-unsaturated silyl sulfinates can be desilylated and reacted with methyl iodide to provide polyfunctional sulfones. Exploratory studies of this four-component synthesis of sulfones are reported. Enantiomerically pure derivatives containing up to three new stereogenic centers can be obtained using enantiomerically pure (*E*,*E*)-1-alkoxy-2-methylpenta-1,3-dienes derived from α-methyl benzyl alcohols, including the Greene's chiral auxiliary. The stereochemistry of the reactions is consistent with a mechanism involving the suprafacial hetero-Diels−Alder addition of sulfur dioxide to the 1-alkoxy-1,3-dienes that are rapidly ionized into zwitterionic intermediates.

Introduction

The organic chemistry of sulfur dioxide has been limited to the formation of arenesulfinic acids (Friedel−Crafts sulfinylation[1]), the copolymerization of SO_2 with alkenes or alkynes (polysulfone synthesis[2]), the synthesis of sulfinates by reaction with organometallic compounds,[3,4] the ring opening of oxiranes and oxetanes[4,5] leading to polysulfites,[4,6] the synthesis of sulfones,[4,7] the isomerization of alkenes via ene reaction/sigmatropic shift/retro-ene elimination sequence,[8] and the cheletropic additions of conjugated polyenes[9,10] forming cyclic sulfones, as the [ω2s+π4s] addition of SO_2 to isoprene producing 2,5-dihydro-3-methylthiophene-1,1-dioxide (sulfolene), a reaction known since 1914.[11,12] Our group has shown that simple alkyl-substituted 1,3-dienes can undergo hetero-Diels−Alder additions with SO_2 giving the corresponding 3,6-dihydro-1,2-oxathiin-2-oxides (sultines).[13] These cycloadducts are unstable above −50 °C and undergo fast cycloreversions liberating the starting dienes and SO_2.[14,15] Both the hetero-Diels−Alder and cycloreversion are catalyzed by protic or Lewis acids and by SO_2 itself.[16,17] Electron-rich 1,3-dienes such as (*E*)-1-methoxybutadiene (**1**) adds SO_2 below −60 °C without catalyst, giving sulfolene **2** exclusively (Scheme 1).[18] No trace of the corresponding sultine **3** could be detected for Lewis acid catalyzed reactions, even at −110 °C. When diene **1** and enoxysilane **4** are mixed in SO_2 precomplexed with a Lewis acid such as $Yb(OTf)_3$ or (*t*-Bu)Me_2SiOTf, a carbon−carbon bond is formed between the electron-rich alkene and the electron-rich diene to give the silyl sulfinate **5**. At −78 °C the reaction is terminated in 4−5 h. The sulfinate **5** can be converted either into alkene **6** by hydrolysis and retro-ene elimination of SO_2 or into sulfone **7** by desilylation with Bu_4NF and reaction with methyl iodide.[19] Mixtures of sulfolene **2**, enoxysilane **4**, SO_2, and Lewis acids do not lead to the formation of the corresponding sulfinate **5** but are polymerized above −20

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(10) Homoconjugated dienes that cannot be rearranged into conjugated 1,3-dienes via ene reactions add to SO_2, giving sulfones via homocheletropic additions. De Lucchi, O.; Lucchini, V. *J. Chem. Soc., Chem. Commun.* **1982**, 1105. Roulet, J.-M.; Deguin, B.; Vogel, P. *J. Am. Chem. Soc.* **1994**, *116*, 3639. Roulet, J.-M.; Vogel, P. *Bull. Soc. Chim. Fr.* **1994**, *131*, 822. Roulet, J.-M.; Vogel, P.; Wieseman, F.; Pinkerton, A. A. *Tetrahedron* **1995**, *51*, 1685.
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(13) Earlier examples involve extremely reactive dienes (1,4,5,6-tetramethyl-2,3-dimethylidenetricyclo[2.1.1.$0^{5,6}$]hexane and *o*-quinodimethane): Heldeweg, R. F.; Hogeveen, H. *J. Am. Chem. Soc.* **1976**, *98*, 2341. Durst, T.; Tétreault-Ryan, L. *Tetrahedron Lett.* **1978**, *26*, 2353.
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(17) For rare examples of photoinduced [2 + 2]-cycloadditions of SO_2, see: Dunkin, I. R.; MacDonald, J. G. *J. Chem. Soc., Perkin Trans. 2* **1984**, 2079. Sianesi, D.; Bernardi, G. C.; Moggi, G. *Tetrahedron Lett.* **1970**, *16*, 1313.
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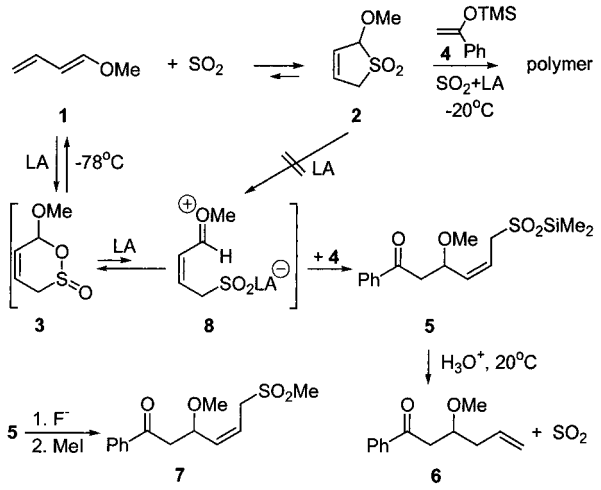
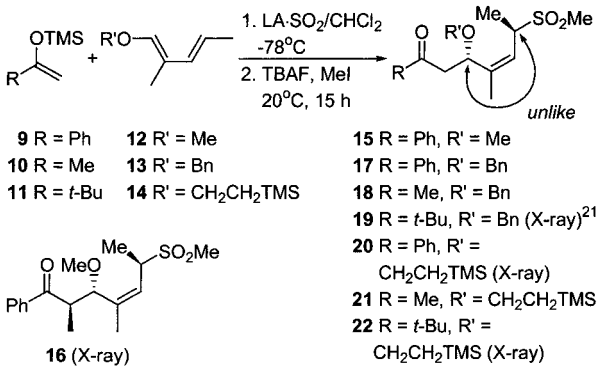
Scheme 1



Scheme 2



9 R = Ph **12** R' = Me
10 R = Me **13** R' = Bn
11 R = *t*-Bu **14** R' = CH_2CH_2TMS

15 R = Ph, R' = Me
17 R = Ph, R' = Bn
18 R = Me, R' = Bn
19 R = *t*-Bu, R' = Bn (X-ray)[21]
20 R = Ph, R' = CH_2CH_2TMS (X-ray)
21 R = Me, R' = CH_2CH_2TMS
22 R = *t*-Bu, R' = CH_2CH_2TMS (X-ray)

16 (X-ray)

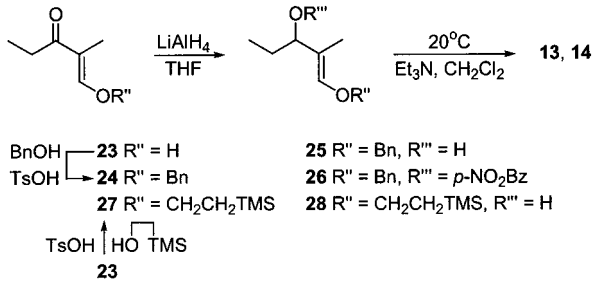
°C, thus demonstrating that sulfolene **2** is not able to generate any electrophilic species responsible for the oxyallylation of enoxysilane **4** at low temperature. We have assumed that sultine **3** is formed faster than sulfolene **2** and is quickly heterolyzed into a zwitterionic intermediate of type **8** able to add to the enoxysilane.

Preliminary experiments with enantiomerically pure 1-alkoxy-2-methyl-1,3-dienes has opened an asymmetric version of our new four-component synthesis of allyl methyl sulfones.[20] We report further exploratory studies on this reaction and shall show that enantiomerically pure polyfunctional sulfones containing up to three stereogenic centers and a (*Z*)-allylic moiety can be prepared readily. The results shed light on the mechanism of the reaction cascade involved in the new carbon−carbon bond forming reaction we have discovered.[21]

Results and Discussion

The first series of experiments were designed to evaluate the best possible 1-alkoxy-2-methylpenta-1,3-diene for optimal yields in the four-component synthesis of polyfunctional alkyl methyl sulfones (Scheme 2). We explored a number of conditions with enoxysilanes **9**−**11** and (*E*,*E*)-1-alkoxy-2-methylpenta-1,3-dienes **12**−**14**.

Scheme 3



Pure (1*E*,3*E*)-1-methoxy-2-methylpenta-1,3-diene (**12**) was prepared following Mikami's procedure.[22] Attempts to prepare diene **12** through O-methylation of the lithium or sodium enolate of 2-methylpent-2-enal, the product of crotonalization of propanal, all failed. Similarly, attempts to prepare diene **13** by O-benzylation of enolates of 2-methylpent-2-enal were not met with success. We thus turn to the method developed by Danishefsky and coworkers[23] for the synthesis of electron-rich 1,3-dienes.[24] Pentan-3-one was condensed with ethyl formate to give **23**, which reacted with benzyl alcohol in the presence of *p*-toluenesulfonic acid to furnish **24**. Reduction of **24** with $LiAlH_4$ in THF generated allylic alcohol **25**. It was esterified with *p*-nitrobenzoyl chloride, giving ester **26**, which eliminated *p*-nitrobenzoic acid at room temperature to provide diene **13** (60%). The same procedure (Scheme 3) applied to **23** and 2-(trimethylsilyl)ethanol furnished diene **14** (40%).

When a 1:1 mixture of diene **12** and enoxysilane **9**, **10**, or **11** was added to a 1:4 solution of SO_2/CH_2Cl_2 containing 0.2−0.8 equiv of $Yb(OTf)_3$, a deep yellow solution was immediately formed at −78 °C (probably charge-transfer complexes of alkenes, dienes with SO_2). After 12 h at −78 °C, the yellow color faded. Evaporation of SO_2, followed by the addition of Bu_4NF and an excess of methyl iodide, led to a complicated mixture from which a single, pure compound could be isolated in 6% yield by column chromatography on silica gel. This compound was identified as **16** by its spectral data and by single-crystal X-ray radiocrystallography. This product resulted from the diastereoselective α-methylation (by MeI, Bu_4NF) of the expected ketone **15**. Attempts, including changing concentrations, mode of addition and the nature of the Lewis acid, to improve the yield of the reaction cascade **9** + **12** + SO_2 + MeI → **15** all failed. With (*t*-Bu)Me_2SiOTf, $Sn(OTf)_2$, $MgBr_2$, $TiCl_4$, $ZnCl_2$, $ZnBr_2$, $Ti(OEt)_4$, Bu_3BOTf, BCl_3, and $BF_3{\cdot}OEt_2$ only polymeric materials were formed. No better results were obtained using enoxysilanes **10** or **11**.

We then explored the reactivity of the 1-benzyloxydiene **13** and enoxysilane **9**. Under conditions similar to those described above for the preparation of **16** and using $Yb(OTf)_3$ as Lewis acid promoter, we obtained the expected methyl sulfone **17** in 6% yield, together with products of benzyl alcohol elimination from **17**. Testing a number of alternative acid promoters, we finally discovered that $(CF_3SO_2)NH$[25] led to the formation of **17** with a better

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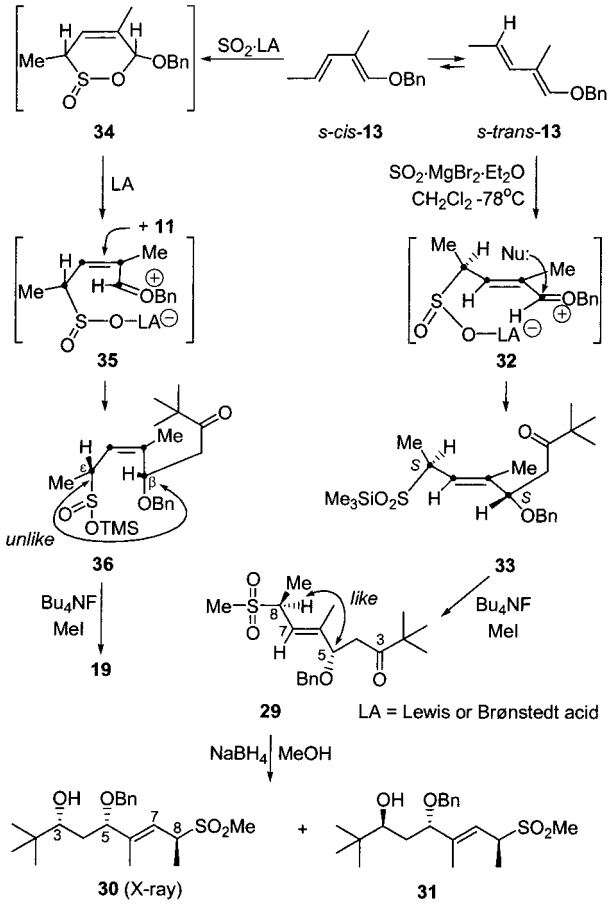
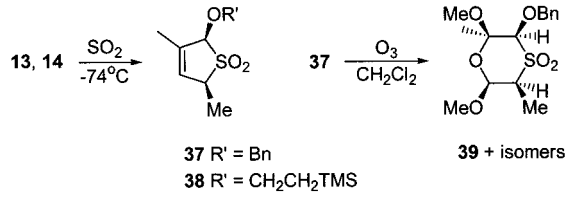
Scheme 4



yield (45%). Under similar conditions the reaction cascades involving enoxysilanes **10** and **11** gave sulfones **18** and **19**, respectively, in 69% and 62% yield, respectively. By using $Yb(OTf)_3$ instead of $(Tf)_2NH$, **18** and **19** were isolated in 71% and 32% yield, respectively. For the combination **11** + **13** + SO_2 + MeI the best promoter appeared to be (*t*-Bu)Me_2SiOTf, giving methyl sulfone **19** in 77% yield. These exploratory studies show that the choice of the acid promoter must take into account the nature of the starting diene and that of the enoxysilane. All experiments using $TiCl_4$ or $TiBr_4$ as Lewis acid led to polymerization. With $MgBr_2{\cdot}OEt_2$, the condensation was slower than with other acid promoters and gave mostly polymeric material. Nevertheless, in the case of enoxysilane **11** reacting with **13**, a low yield of a mixture of the expected methyl sulfone **19** and its (*E*)-isomer **29** was obtained, from which pure **29** could be isolated in 8% yield (Scheme 4). The structures of **17**−**19** and **29** were established by their spectral data (2D NOESY ^1H NMR). That of **19** was confirmed by single-crystal X-ray diffraction studies.[21] Reduction of **29** with $NaBH_4$ in MeOH led to a 4:1 mixture of diastereomeric alcohols **30** and **31**. Single-crystal X-ray diffraction studies on **30** confirmed the structure of **29**. The (*Z*)-alkene **19** was not isomerized into **29** in the presence of SO_2 and $MgBr_2{\cdot}OEt_2$ at −78 °C (2 weeks). When diene **13** and enoxysilane **11** were allowed to react first with SO_2/(*t*-Bu)-Me_2SiOTf and then with $SO_2/MgBr_2{\cdot}OEt_2$, subsequent SO_2 evaporation and treatment with Bu_4NF and MeI gave **19** exclusively. These results demonstrated that the formation of the (*E*)-alkene **29** follows a different route than the formation of its (*Z*)-isomer **19**. As for a large

Scheme 5



number of Diels−Alder additions, competitive Michael additions can occur, especially if the difference in stability between the *s-cis*-diene (necessary for the Diels−Alder addition) and the *s-trans* conformer (most stable conformer) is high.[26] We propose that the formation of **29** arises from a concurrent Michael addition of the more stable *s-trans* conformer of diene **13** with SO_2, leading to the (*E*)-zwitterionic intermediate **32** (Scheme 4), which reacts with the enoxysilane **11**. This implies that the competition between the hetero-Diels−Alder addition and the Michael addition of dienes with SO_2 depends on the nature of the acid promoter. This statement implies that the (*Z*)-alkenes (e.g., **19**, Scheme 4) formed in our four-component synthesis of sulfones arise exclusively from the corresponding (*Z*)-zwitterionic intermediates (e.g., **35**) and that the latter are formed by ionization of the corresponding sultines (e.g., **34**) arising from the suprafacial hetero-Diels−Alder addition of SO_2 to the starting 1-oxy-1,3-dienes. These hypotheses are confirmed by the *β,ϵ-unlike* relative configuration found for all of our ketones with (*Z*)-alkene moieties[21] (X-ray of **16**, **19**, **20**). The *β,ϵ-like* relative configuration observed for **29** can be interpreted in terms of the formation of zwitterionic intermediate **32**, which adds to the enoxysilane **11** on the face *anti* with respect to that occupied by the sulfinate moiety, as in the case of **35**.

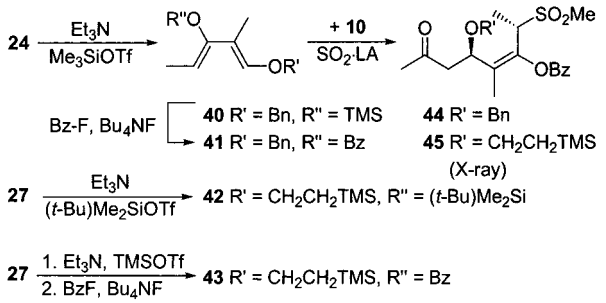
The condensation of diene **14** with enoxysilanes **9**, **10**, and **11** ($SO_2/Yb(OTf)_3$), followed by methylation (MeI) of the intermediate silyl sulfinates, generated the methyl sulfones **20**, **21**, and **22**, respectively, which were isolated in 47%, 20%, and 50% yield, respectively. Lower yields were obtained using acid promoters ($(Tf)_2NH$, (*t*-Bu)-Me_2SiOTf) different from $Yb(OTf)_3$. The structures of **20**−**22** were deduced from their spectral data. That of **20** was confirmed by single-crystal X-ray diffraction studies.

As already demonstrated in the case of the reaction cascade involving 1-methoxybutadiene **1** (Scheme 1),[18] dienes **13** and **14** reacted with pure SO_2 in $CFCl_3/CD_2Cl_2$ at −74 °C, giving the corresponding sulfolenes **37** and **38**, respectively (Scheme 5). These unstable compounds were polymerized when mixed with enoxysilane **9**, **10**, or **11** and an acid promoter ($Yb(OTf)_3$, (*t*-Bu)-Me_2SiOTf or $(Tf)_2NH$). The structures of sulfolenes **37** and **38** were given by their ^1H and ^{13}C NMR data. That of **37** was confirmed by its ozonolysis in CH_2Cl_2/SO_2 followed by workup with anhydrous MeOH and $CeCl_3$, which gave a mixture from which **39** was isolated and characterized by its ^1H and ^{13}C NMR spectra.

We have also explored the possibility to prepare methyl sulfones containing an oxy-substituted alkene moiety

(26) See, for example: Bargagna, A.; Schenone, P.; Badavalli, F.; Lugobradi, M. *J. Heterocycl. Chem.* **1980**, *17*, 1201. Clever, H. A.; Wang, G.; Mollberg, W. C.; Padias, A. B.; Hall, H. K., Jr. *J. Org. Chem.* **1992**, *57*, 6837. Kataoka, F.; Shimizu, N.; Nishida, S. *J. Am. Chem. Soc.* **1980**, *102*, 711. Gompper, R.; Heinemann, U. *Angew. Chem., Int. Ed. Engl.* **1980**, *19*, 216.

Scheme 6



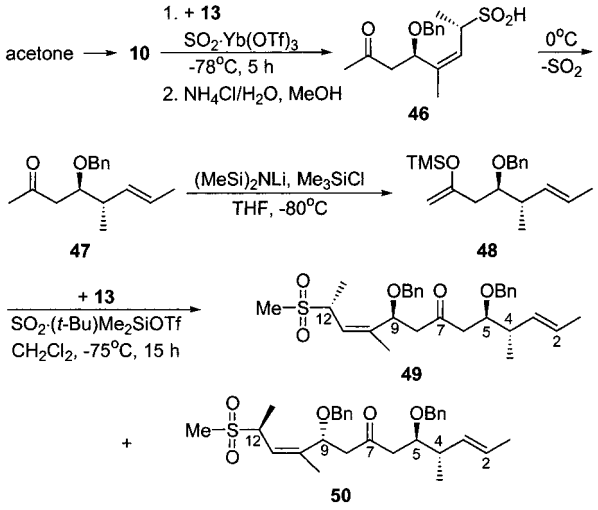
(Scheme 6). With this goal in mind we prepared the (*E*,*E*)-1-alkoxy-3-oxy-2-methylpenta-1,3-dienes **40**−**43**. Diene **40** (97%) was derived from **24** following Danishefsky's method.[23] Diene **40** was reacted with benzoyl fluoride in the presence of Bu_4NF[27] to give **41** in 72% yield. Similarly, **27** was converted into **42** (93%) and **43** (31%). Attempts to carry out oxyallylations with the 3-silyloxydienes **40** and **42** were not met with success. With the more stable 3-benzoyloxydienes **41** and **43**, their condensation with enoxysilane **10**, SO_2, and MeI following procedures similar to those described above provided sulfones **44** and **45** in 67% and 42% yield, respectively. Their structures were deduced from their spectral data, and that of **45** was confirmed by single-crystal X-ray radiocrystallography.

Iterative Oxyallylations. The condensation of enoxysilane **10** with 1-benzyloxydiene **13** and SO_2 in the presence of $Yb(OTf)_3$ (−78 °C, 5 h) generated a silyl sulfinate that was converted into the corresponding β,γ-unsaturated sulfinic acid **46** on treatment with NH_4Cl in 1:1 $MeOH/H_2O$. At 0 °C **46** underwent a retro-ene elimination of SO_2[28] in about 15 h, giving oct-6-en-2-one **47** in 71% yield.[19] The kinetic lithium enolate of **47** was quenched with Me_3SiCl to give enoxysilane **48** in quantitative yield. When **48** was reacted with 1-benzyloxydiene **13** and SO_2 in the presence of (*t*-Bu)Me_2SiOTf (−78 °C, 15 h), a mixture of silyl sulfinates was formed. After SO_2 evaporation, treatment with Bu_4NF and MeI (0 °C, 4 h) a 1:1 mixture of sulfones **49** and **50** was obtained and isolated in 47% yield. Although the yield of this reaction remains modest, this experiment demonstrates the possibility to run two successive oxyallylations of acetone (Scheme 7).

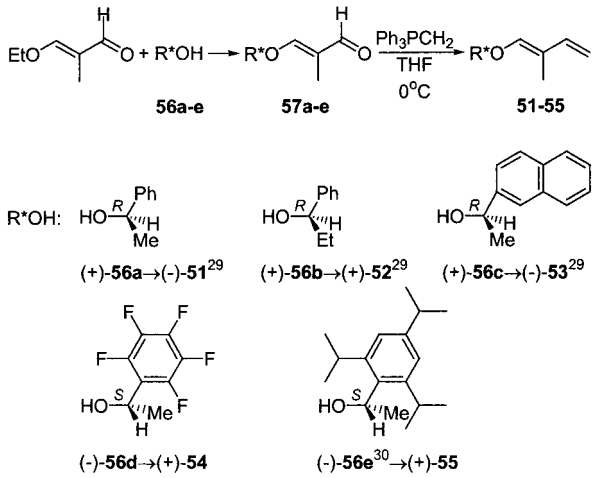
Asymmetric Version of the Four-Component Synthesis of Sulfones. In a first series of experiments we explored the behavior of enantiomerically pure (>99% ee) 1-benzyloxy-2-methylbutadienes **51**−**55**, which were prepared (Scheme 8) following Breitmaier's diene synthesis[29] and using readily available enantiomerically pure secondary alcohols **56a**−**e**.[29,30]

In the case of the synthesis of (+)-**55** bearing the Greene's chiral auxiliary,[30] we found that acidic transal-

Scheme 7



Scheme 8



coholysis of 3-ethoxy-2-methylacrolein[29] led to racemization. We thus used basic conditions for that transalcoholysis, reacting 3-ethoxy-2-methylacrolein with the sodium alcoholate derived from (−)-(*S*)-1-(2,4,6-triisopropylphenyl)ethanol. This gave enal (−)-**57e** in 79% yield. It was then reacted with methyltriphenylphosphonium bromide and lithium diisopropylamide giving (+)-**55** in 87% yield.

Dienes (−)-**51**, (+)-**52**, (−)-**53**, (+)-**54**, and (+)-**55** mixed with 1-phenyl-1-(trimethylsilyloxy)ethene (**9**) were allowed to react with a large excess of SO_2 precomplexed with $Yb(OTf)_3$ in CH_2Cl_2. After disappearance of the starting diene (yellow complex with SO_2) (−90 to −78 °C, 5−24 h) the solvents were evaporated at −78 °C (0.1 Torr), and then at 0 °C a solution of Bu_4NF in THF and an excess of MeI were added. After 16−24 h at 0−20 °C the products were isolated by flash chromatography on silica gel. The fraction containing the methyl sulfones were analyzed by ^1H and ^{13}C NMR; the results are shown in Table 1. The best diastereoselectivity was observed for the reaction of diene (+)-**55**, which provided a 25:1 mixture of sulfones (−)-**66** and **67** (79% yield, recovery of 20% of (+)-**55**). The structure of (−)-**66** was established by X-ray radiocrystallography.[20] The trifluoroacetolysis[31] (Scheme 9) of sulfone mixtures **58** + **59**, **60** + **61**, and **62**

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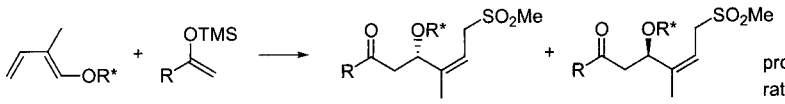
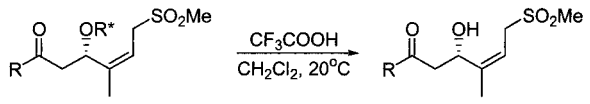
Table 1. Asymmetric Four-Component Synthesis of Sulfones with (*E*)-1-Benzyloxy-2-methylbutadienes[a]



(-)-**51**	**9** (R = Ph)	(1′*R*,3*S*)-**58**	(1′*R*,3*R*)-**59**[f)]	1:5.4	89%
(+)-**52**	**9**	(1′*R*,3*S*)-**60**	(1′*R*,3*R*)-**61**[f)]	1:6.7	54%
(-)-**53**	**9**	(1′*R*,3*S*)-**62**	(1′*R*,3*R*)-**63**[f)]	1:4.1	82%
(+)-**54**	**9**	(1′*S*,3*S*)-**64**	(1′*S*,3*R*)-**65**	6.2:1[i)]	22%
(+)-**55**	**9**	(-)-(1′*S*,3*S*)-**66**[h)]	(1′*S*,3*R*)-**67**	25:1[i)]	99%[c)]
(-)-**51**	**10** (R = Me)	(1′*R*,4*S*)-**69**	(1′*R*,4*R*)-**70**[f)]	1:2.9	99%
(+)-**52**	**10**	(1′*R*,4*S*)-**71**	(1′*R*,4*R*)-**72**[f)]	1:5.0	51%
(+)-**55**	**10**	(-)-(1′*S*,4*S*)-**73**[h)]	(-)-(1′*S*,4*R*)-**74**	5.2:1[i)]	86%
(+)-**55**	**10**	(-)-(1′*S*,4*S*)-**73**	(-)-(1′*S*,4*R*)-**74**	7.0:1[i)]	80%[d)]
(±)-**55**	**11** (R = *t*-Bu)	(1′*RS*,5*RS*)-**76**[g)]	(1′*RS*,5*SR*)-**77**[g)]	3.3:1	27%
(+)-**55**	**78** (R = *c*-C_3H_5)	(-)-(1′*S*,3*S*)-**79**[h)]	(-)-(1′*S*,3*R*)-**80**	10.5:1[i)]	79%
(+)-**55**	**82** (R = H)	(-)-(1′*S*,3*S*)-**83**[h)]	[e)]	>20:1[i)]	48%[c)]

[a] Standard conditions: 10- to 20-fold excess of SO_2, 0.5−1 equiv of Yb(OTf)$_3$, −78 °C; then evaporation, Bu_4NF, MeI, 20 °C. Ee (>99%) of sulfones determined by Mosher's esters on derivatives; see text and ref 20. [b] By ^{1}H NMR of the mixture of sulfones, after flash chromatography. Similar product ratios were found from the ^{1}H NMR spectra of crude reaction mixture, when analyzable. [c] Considering the recovery of the starting diene. [d] Using (Tf)$_2$NH at −100 °C, instead of Yb(OTf)$_3$ at −78 °C. [e] Minor compound is the (*E*)-alkene **84**. [f] Structure by chemical correlation with aldols obtained by trifluoroacetolyis (Scheme 9). [g] Racemic diene use in this experiment. [h] Structure by single-crystal X-ray radiocrystallography. [i] The change over of diastereoselectivity is due to the fact that chiral auxiliaries (−)-**51**, (+)-**52**, and (−)-**53** have the (1*R*) configuration, whereas (+)-**54** and (+)-**55** have the (1*S*) configuration.

Scheme 9



(-)-**66** R = Ph
(-)-**73** R = Me
(-)-**79** R = *c*-C_3H_5

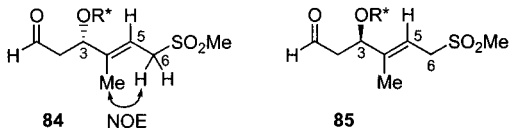
(-)-**68** R = Ph
(-)-**75** R = Me
(-)-**81** R = *c*-C_3H_5

+ **63** (homogeneous mixtures after flash chromatography on silica gel) (Table 1) gave aldol (+)-**68** (with $[\alpha]_D^{25}$ = +30 ± 2, 35 ± 3 and 23 ± 3, respectively. Pure (−)-**66** gave (−)-**68** with $[\alpha]_D^{25} = -52 \pm 2$.

By using the silyl enol ether of acetone **10** for the oxyallytion with dienes (−)-**51**, (+)-**52**, and (+)-**55**, mixtures of sulfones **69** + **70**, **71** + **72**, and **73** + **74**, respectively, were obtained (Table 1). In this case too, the best diastereoselectivity was observed with diene (+)-**55** bearing the Greene's chiral auxiliary. When the oxyallylation is promoted with Yb(OTf)$_3$ at −78 °C, the product ratio (**73**/**74**) reaches 5.2:1. Using (Tf)$_2$NH as acid promoter and running the reaction at −100 °C, the product ratio increases to 7.0:1. The structure of the major sulfone (−)-**73** was established by X-ray radiocrystallography. The structures of sulfones **69**−**72** were deduced from their spectral data and by their trifluoroacetolysis (Scheme 9).[31] The mixture of **69** + **70** gave (+)-**75** ($[\alpha]_D^{25}$ = +4.6 ± 1). That of **71** + **72** furnished (+)-**75** ($[\alpha]_D^{25}$ = +8.8 ± 1). Pure (−)-**73** gave aldol (−)-**75** ($[\alpha]_D^{25}$ = −11.0 ± 1).

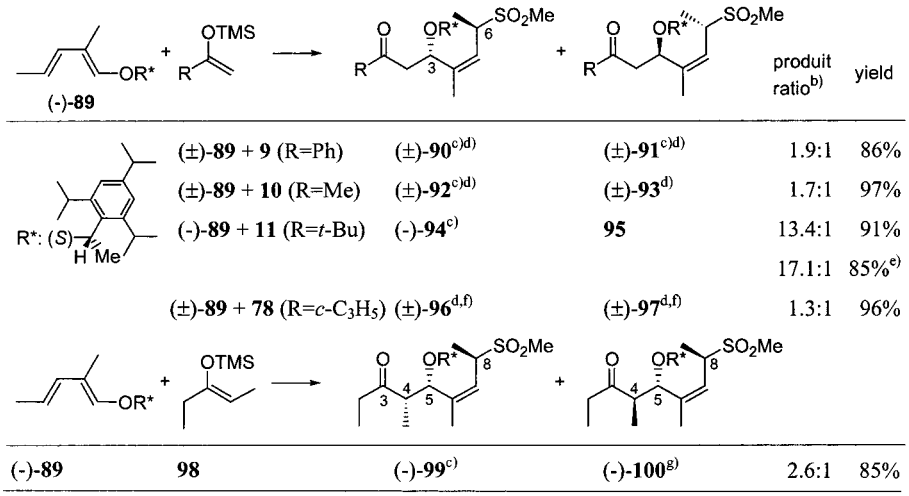
These interesting results led us to apply our asymmetric four-component synthesis of sulfones to other enoxysilanes. With 1-(tertiobutyl)-1-(trimethylsilyloxy)-ethene and diene (+)-**55** a 3.3:1 mixture of sulfones **76** + **77** was obtained in mediocre yield. This observation suggested that sterically hindered enoxysilanes are too slow in their quenching of the zwitterionic sulfinate intermediates. The structures of **76** and **77** were not established unambiguously. We turned then to the electron-rich 1-cyclopropyl-1-(trimethylsilyloxy)ethene (**78**). Its reaction with (+)-**55**, SO_2, and then MeI provided a 10.5:1 mixture of sulfones (−)-**79** and (−)-**80** in good yield. The major product (−)-**79** was isolated pure, and its structure was established by X-ray radiocrystallography. Trifluoroacetoylsis of pure (−)-**79** provided aldol (−)-**81** (85%).

We have also tested the reactivity of the less electron-rich vinyloxytrimethylsilane (**82**) and were surprised that it was able to quench the zwitterionic intermediate assumed to be formed in the reactions of diene (+)-**55** with SO_2 in the presence of acid promoters. Using Yb(OTf)$_3$ (−78 °C, 16 h) a 6.1:1 mixture of sulfones (−)-**83** and **84** was obtained in 31% yield (56% yield considering the recovery of unreacted (+)-**55**). Pure (±)-**83** derived from (±)-**55** gave crystals suitable for X-ray radiocrystallography. The structure of the minor sulfone **84** was deduced from its ^{1}H NMR spectrum (2D NOESY): it contains an (*E*)-alkene moiety. Unfortunately we could not establish whether it has the (1′*S*,3*S*) or (1′*S*,3*R*) configuration. A similar experiment using (Tf)$_2$NH as acid promoter (−78 °C, 2 h) led to a 4:1 mixture of sulfones **84** and **85** isolated in 23% yield. The major sulfone crystallized, but the crystals were not suitable for X-ray radiocrystallography. In the latter experiment, the isomeric (*Z*)-sulfone (−)-**83** was not observed!



R* = (*S*)-Greene's chiral auxiliary

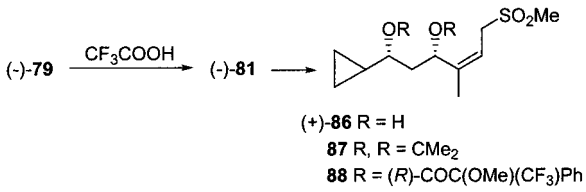
Table 2. Asymmetric Four-Component Synthesis of Sulfones with Diene (−)-89[a]



	(±)-**89** + **9** (R=Ph)	(±)-**90**[c)d)]	(±)-**91**[c)d)]	1.9:1	86%
	(±)-**89** + **10** (R=Me)	(±)-**92**[c)d)]	(±)-**93**[d)]	1.7:1	97%
	(-)-**89** + **11** (R=*t*-Bu)	(-)-**94**[c)]	**95**	13.4:1	91%
				17.1:1	85%[e)]
	(±)-**89** + **78** (R=*c*-C_3H_5)	(±)-**96**[d,f)]	(±)-**97**[d,f)]	1.3:1	96%
(-)-**89**	**98**	(-)-**99**[c)]	(-)-**100**[g)]	2.6:1	85%

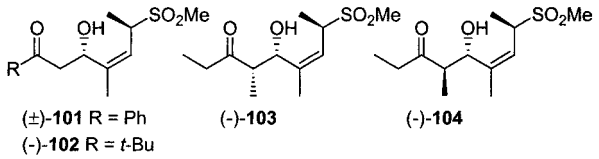
[a] Standard conditions: $(Tf_2)NH$, −78 °C (3−5 h); then evaporation at −78 °C, Bu_4NF/THF + MeI, −78 to 20 °C (15 h); purification by column chromatography on silica gel. [b] By ^1H NMR of the crude reaction mixture. [c] Structure by single-crystal X-ray radiocrystallography. [d] Experiments described for the reactions with (±)-**89** derived from (+)-**56e**. [e] Using (*t*-Bu)Me_2SiOTf as acid promotor. [f] Structure not established unambiguously. [g] Assumed structure; diastereomeric structure with the (4*S*,5*R*,6*Z*,8*S*) configuration cannot be ruled out.

The enantiomeric purity of the pure sulfones isolated above was established by converting aldols (−)-**68** and (−)-**75** into *cis*- or *trans*-1,3-diols and by ^{19}F NMR of the corresponding Mosher's diesters.[20] The method is illustrated for aldol (−)-**81**. Its reduction under Nasaraka's conditions[32] ($Et_2BMe/NaBH_4$) afforded diol (+)-**86** (83%). The *syn* relationship of the diol was confirmed by the ^{13}C NMR spectrum of its acetonide **87** (δ_C = 30.2, 19.5 ppm, for $Me_2C(2)$).[33] The ^{19}F NMR spectrum of Mosher's diester[34] **88** ($\delta(^{19}F) = -71.406, -71.652$ ppm) showed (^{13}C satellites) that (+)-**86** has an ee >99%.



Asymmetric Four-Component Synthesis of Sulfones Using a Enantiomerically Pure (*E*,*E*)-1-Alkoxy-2-methylpent-1,3-diene. The Wittig olefination of enal (−)-**57e** (Scheme 8) with ethyltriphenylphosphonium bromide and lithium diisopropylamide was highly stereoselective and afforded diene (−)-**89** in 93% yield. Its condensation with various enoxysilanes, SO_2, and MeI were explored, and the results are presented in Table 2. The best yield of methyl sulfones were observed when using $(Tf)_2NH$ as acid promoter. The best diastereoselectivity was found for the reaction involving the most sterically hindered enoxysilane **11**, which led to a 13.4:1 mixture (91% yield) of sulfones (−)-**94**/**95** using $(Tf)_2NH$ as acid promoter. With (*t*-Bu)Me_2SiOTf, the diastereoselectivity was increased to 17.1:1. Except for the sulfones **96** and **97** derived from enoxysilane **78**, all other sulfones of Table 2 have their structure established unambiguously by X-ray radiocrystallography of the major isomers obtained pure by column chromatography on silica gel. Except for reaction **11** + (−)-**89** + SO_2 + MeI → (−)-**94** the diastereoselectivities observed with the other enoxysilanes are lower with diene (−)-**89** (Table 2) than with diene (+)-**55**. These observations are not explained readily. Nevertheless they demonstrate that steric hindrance between the zwitterionic intermediate (arising from the reaction of the 1-oxydiene with SO_2 and the acid promoter) and the enoxysilane is not the unique factor affecting yield and diastereoselectivity of the oxyallylation.

The reaction of diene (−)-**89** with the (*Z*)-enoxysilane **98** derived from pentan-3-one[35] led to a 2.6:1 mixture of isomeric sulfones (−)-**99** and (−)-**100**, which were separated in 63% and 22% yield, respectively. The structure of (−)-**99** was established by X-ray radiocrystallography. Since other diastereomers represented less than 5% of the reaction mixture, we can state that the diastereoselectivity (1′*S*,5*S*) is better than 15:1 in the case of (−)-**99** and better than 4.4:1 for the formation of (−)-**100**. As for the other sulfones of Table 2, trifluoroacetolysis of pure (±)-**90**, (−)-**94**, (−)-**99**, and (−)-**100** (Table 2) furnished the unprotected aldols (±)-**101** (90%), (−)-**102** (95%), (−)-**103** (99%), and (−)-**104** (86%), respectively, in good yields. Unfortunately, the chiral auxiliary (Greene's alcohol **56e**) was completely racemized during these reactions.



Toward a Mechanism for the Oxyallylation. Although more work is required to approach a global view of the overall processes intervening in our four-component synthesis of sulfones, we think that all of the results

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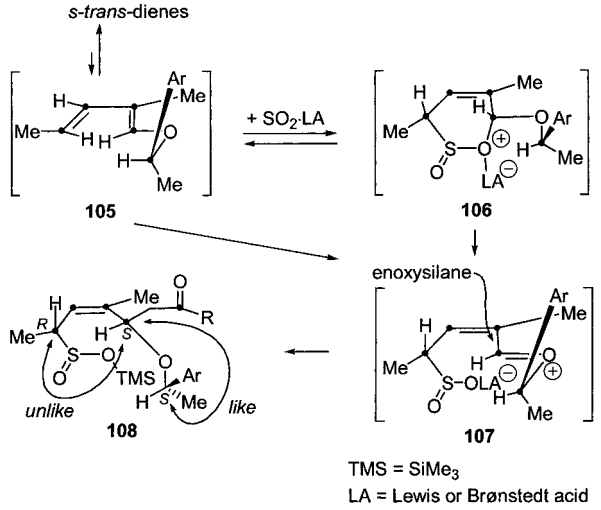
Scheme 10



presented so far can be interpreted in terms of the mechanisms proposed in Schemes 1 and 4. In particular, the diastereoselectivity (*like* configuration for the center of the chiral benzyl ethers and the β-center of the final ketones) can be explained by assuming that SO_2 is activated by the acid promoter and that it reacts with a *s-cis*-conformer of the 1,3-diene, placing the C−H bond of the chiral auxiliary in the plane of the diene moiety as shown with **105** in Scheme 10. This conformer reduces $A^{1,2}$-allylic strain and gauche interactions.[36] For steric reasons, the face of the diene *syn* to the large aromatic moiety of the chiral auxiliary is less prone to the attack by the SO_2−LA complex. This hypothesis is corroborated by the observation that the oxyallylation of enoxysilane **9** is more diastereoselective with diene (+)-**55** with the largest aromatic substituent than with the other dienes (Table 1). Thus dienes **105** undergo face-selective, suprafacial hetero-Diels−Alder additions with SO_2, giving the corresponding sultines of type **106**, which are ionized by the acid promoter into zwitterions of type **107**. Alternatively, direct reaction of acid−SO_2 complex with **105** giving **107** in one step cannot be ruled out. If quenching of zwitterions of type **107** by an enoxysilane should be rapid, i.e., if it does not allow for **107** to equilibrate with diastereomeric zwitterionic species or sultines, a good diastereoselectivity is obtained for the oxyallylation reaction. It implies the addition of the enoxysilane on the face of the zwitterion *anti* with respect to that occupied by the sulfinate moiety (Scheme 10). This is confirmed firmly by the fact that all oxyallylations give major products with β,ϵ-*unlike* configuration of the final ketones. At this moment, we cannot exclude an alternative hypothesis that implies concerted reactions of enoxysilanes with sultine intermediates of type **106**. The latter hypothesis is consistent with our observation that the least electron-rich enoxysilane **82** (vinyloxytrimethylsilane) did not react much more slowly than the electron-richer derivatives such as **9** (Ph(TMSO)C=CH_2) and **78** (cyclopropyl(TMSO)C=CH_2). As already discussed for the reaction of achiral 1-alkoxy-2-methylpenta-1,3-dienes (Scheme 4), the path **105** = **106** = **107** → **108** or **105** = **107** → **108** or **105** = **106** → **108** are all consistent with the 1′,β-*like* and β,ϵ-*unlike* configurations found for all the ketones obtained in this work.

Conclusion

Our four-component sulfone synthesis can be applied to generate a variety of polyfunctional methyl sulfones with one (*Z*)-alkene unit and containing up to three new stereogenic centers. Enantiomerically pure derivatives can be obtained using enantiomerically pure (*E*)-1-alkoxy-2-methylbutadienes or (*E*,*E*)-1-alkoxy-2-methylpenta-1,3-dienes derived from readily available enantiomerically pure α-methyl benzyl alcohols. The best diastereoselectivities have been found with dienes bearing the Greene's chiral auxiliary [(−)-(*S*)−(2,4,6-triisopropylphenyl)ethanol].[30] The methyl sulfones derived from (*E*,*E*)-1-alkoxy-2-methylpenta-1,3-dienes are γ,δ-unsaturated ketones with an allylic sulfone moiety and *unlike* β,ϵ-disubstitution. Using the trimethylsilyl ether of the (*Z*)-enol of diethyl ketone, enantiomerically pure (4*S*,5*S*,6*Z*,8*R*)- and (4*R*,5*S*,6*Z*,8*R*)-5-hydroxy-4,6-dimethyl-8-(methylsulfonyl-)non-6-en-3-one have been prepared. In this case the α,β-diastereoselectivity of the oxyallylation (face selectivity of the enoxysilane addition) does not surpass 2.6:1 (4*R*,5*S* vs 4*S*,5*S*). Further exploratory studies will have to be undertaken in order to find suitable dienes and enoxysilanes for better control of the α,β-diastereoselectivity in the ketone formation.

Experimental Section

General Remarks. See ref 37. None of the procedures were optimized. Flash column chromatography (FC) was performed on Merck silica gel (230−400 mesh).[38] Thin-layer chromatography (TLC) was carried out on silica gel (Merck aluminum foils). ^{1}H NMR signal assignments were confirmed by double irradiation experiments and, when required, by 2D NOESY and COSY spectra; *J* values are given in hertz. Dry SO_2 was prepared by passing through a column of alkaline alumina (Merck, act. I) and redistilled twice under vacuum (vacuum line, degassing by freeze/thaw cycles).

(*E*,*E*)-1-Methoxy-2-methylpenta-1,3-diene (12). A 1:1 mixture of (*E*,*E*)- and (*Z*,*E*)-1-methoxy-2-methylpentadiene was obtained according to the procedure of Mikami.[22] FC separated the two dienes. Data for **12**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.04 (dqd, 1H, J = 15.4, 1.4, 1.3), 5.47 (dd, 1H, J = 15.4, 6.6), 3.62 (s, 3H), 1.76 (ddd, 1H, J = 6.6, 1.4, 0.5), 1.69 (d, 3H, J = 1.3).

(*E*)-1-(Benzyloxy)-2-methylpent-1-en-3-one (24). A mixture of 1-hydroxy-2-methylpent-1-en-3-one (**23**) (9.91 g, 86.9 mmol),[23] benzyl alcohol (10.5 mL, 100 mmol), toluene (150 mL), and *p*-toluenesulfonic acid (2 mg) was heated under reflux in a Dean−Stark apparatus for 3 h. After the mixture cool to 20 °C, $NaHCO_3$ (1 g) was added, and the mixture was washed with a saturated aqueous solution of $NaHCO_3$ (50 mL). The aqueous layer was extracted with CH_2Cl_2 (150 mL, 5 times). The combined organic extracts were dried ($MgSO_4$), and the solvent was evaporated in vacuo (0.3 Torr, 80 °C) giving a colorless oil (13.8 g, 77%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34−7.40 (m, 6H), 5.06 (s, 2H), 2.51 (q, 2H, J = 7.3), 1.78 (d, 2H, J = 1.1), 1.08 (t, 3H, J = 7.3).

(*E*,*E*)-1-(Benzyloxy)-2-methylpenta-1,3-diene (13). A solution of **24** (5.5 g, 29.2 mmol) in anhydrous THF (50 mL) was added dropwise to a stirred suspension of $LiAlH_4$ (1.2 g, 31.6 mmol) in anhydrous THF (200 mL) cooled to −78 °C. The mixture was stirred overnight, and the temperature was allowed to reach 25 °C. After the mixture cooled to 0 °C, an

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(38) Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

ice-cold saturated aqueous solution of NH_4Cl (50 mL) and ice (50 g) were added under vigorous stirring. The mixture was extracted with CH_2Cl_2 (200 mL, 4 times). The combined organic extracts were dried ($MgSO_4$), and the solvent was evaporated in vacuo. The residue was taken up in anhydrous CH_2Cl_2 (150 mL) and cooled to −10 °C. After the addition of triethylamine (16 mL, 114 mmol), *p*-nitrobenzoyl chloride (15.8 g, 85 mmol), and 4-(dimethylamino)pyridine (10 mg), the mixture was stirred at 20 °C for 56 h. The mixture was washed with saturated aqueous solution of $NaHCO_3$ (100 mL). The aqueous layer was extracted with CH_2Cl_2 (200 mL, 5 times). The combined organic extracts were dried ($MgSO_4$). The solvent was evaporated in vacuo. The residue was taken up with pentane (200 mL). The precipitate was filtered off, and the solvent was evaporated. FC (Florisil, 1:2 CH_2Cl_2/light petroleum ether) gave a yellowish oil (3.3 g, 60%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39−7.27 (m, 5H), 6.19 (dqd, 1H, J = 1.4, 0.9, 0.5), 5.93 (dqd, 1H, J = 15.4, 1.4, 1.4), 5.47 (dqd, 1H, J = 15.4, 6.5, 0.5), 4.83 (s, 2H), 1.76 (d, 3H, J = 0.9), 1.74 (dd, 3H, J = 6.5, 1.4).

(*E*)-2-Methyl-1-[2-(trimethylsilyl)ethoxy]pent-1-en-3-one (27). The procedure was the same as for the preparation of **24**, using 1-hydroxy-2-methylpent-1-en-3-one (**23**, 1.18 g, 10.4 mmol), 2-(trimethylsilyl)ethanol (1.78 mL, 1.47 g, 12.5 mmol), toluene (15 mL), and *p*-TsOH (2 mg). Purification by distillation (Kugelrohr, Büchi, 10 Torr, 50−120 °C) gave a yellowish oil (1.49 g, 67%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.28 (q, 1H, J = 1.0), 4.05 (m, 2H), 2.48 (q, 2H, J = 7.4), 1.65 (d, 3H, J = 1.0), 1.03 (t, 1H, J = 7.4), 1.02 (m, 2H), 0.00 (s, 9H).

(*E*,*E*)-2-Methyl-1-[2-(trimethylsilyl)ethoxy]penta-1,3-diene (14). The procedure was the same as for the preparation of **13**, using **27** (1.65 g, 7.73 mmol), $LiAlH_4$ (316 mg, 8.5 mmol). Yellowish oil (500 mg, 40%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.09 (br. s, 1H), 5.95 (dq, 1H, J = 15.4, 1.5). 5.44 (dq, 1H, J = 15.4, 6.6), 3.96 (m, 2H), 1.76 (dd, 3H, J = 6.6, 1.5), 1.71 (d, 3H, J = 1.1), 1.01 (m, 2H), 0.04 (s, 9H).

(2*RS*,3*SR*,4*Z*,6*RS*)-2,4-Dimethyl-6-methylsulfonyl-3-methoxy-1-phenylhept-4-en-1-one (16). SO_2 (1 mL) was transferred (vacuum line) to a frozen solution of $Yb(OTf)_3$ (15 mg) in anhydrous CH_2Cl_2 (2 mL). The mixture was allowed to melt and to warm to −78 °C. After 15 min, **10** (39 mg, 0.2 mmol) and 1-phenyl-1-(trimethylsilyloxy)ethene (**9**, 41 μL, 0.22 mmol) were added (syringe) slowly (Ar atmosphere, −78 °C, stirring). After stirring at −78 °C for 12 h, the solvent was evaporated at −78 °C (0.1 Torr). Acetone (1 mL) and then 1 M Bu_4NF in THF (1.5 mL) and MeI (0.5 mL) were added. The mixture was stirred at 20 °C for 22 h and washed with a saturated aqueous solution of $NaHCO_3$ (30 mL). The aqueous layer was extracted with CH_2Cl_2 (30 mL, 3 times). The combined organic extracts were concentrated under reduced pressure. FC (1:3 EtOAc/light petroleum ether) gave a colorless oil (7 mg, 6%, R_f = 0.45) that crystallizes from ether/light petroleum ether): mp 104−106 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91−7.40 (m, 5H), 5.22 (br.d, 1H, J = 10.7), 4.30 (d, 1H, J = 9.7), 4.26 (dq, 1H, J = 10.7, 6.7), 3.84 (dq, 1H, J = 9.7, 6.8), 3.34 (s, 3H), 1.70 (d, 3H, J = 1.4), 1.39 (d, 3H, J = 6.7), 1.36 (d, 3H, ^3J = 6.8).

(3*RS*,4*Z*,6*SR*)-3-(Benzyloxy)-4-methyl-6-methylsulfonyl-1-phenylhept-4-en-1-one (17). In a two-necked round-bottom flask, anhydrous CH_2Cl_2 (1 mL) and 0.5 M $(CF_3SO_2)_2NH$ in CH_2Cl_2 (0.1 mL) were degassed on the vacuum line (−196 °C). Then dry SO_2 (1 mL) (basic alumina column, two distillations on the vacuum line) was transferred. The system was pressurized with Ar (1 atm) and allowed to warm to −78 °C. After 15 min at −78 °C, a mixture of **9** (102 mg, 0.53 mmol) and **13** (50 mg, 0.26 mmol) was added dropwise (automatic syringe) to the stirred mixture maintained at −78 °C. The stirring was continued at −78 °C for 15 h (oxyallytion step). The solvents were evaporated (−78 °C, 0.1 Torr). Acetone (1 mL), 1 M Bu_4NF in THF (1.5 mL), and MeI (0.3 mL) were added, and the mixture was stirred at 20 °C for 15 h. A saturated aqueous solution of $NaHCO_3$ (30 mL) was added, and the mixture was extracted with CH_2Cl_2 (30 mL, 3 times). The combined organic extracts were dried ($MgSO_4$) and the solvent was evaporated in vacuo. FC gave a colorless oil (45.8 mg, 45%, R_f = 0.62, 1:1 EtOAc/light petroleum ether): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96−7.25 (m, 5H), 5.40 (dd, 1H, ^3J = 10.8, 1.4), 4.97 (dd, 1H, J = 6.8, 6.2), 4.50 (m, 2H), 4.33 (dq, 1H, J = 10.8, 6.7), 3.53 (dd, 1H, J = 16.6, 6.2), 3.20 (dd, 1H, J = 16.2, 6.8), 2.82 (s, 3H), 1.89 (d, 3H, J = 1.4), 1.42 (d, 3H, J = 6.7).

(4*RS*,5*Z*,7*SR*)-4-(Benzyloxy)-5-methyl-7-(methylsulfonyl)oct-5-en-2-one (18). The procedure was the same as for the preparation of **16**, starting with **13** (37 mg, 0.19 mmol) and 2-(trimethylsilyloxy)propene (**10**, 70 μL, 0.38 mmol) and using $Yb(OTf)_3$ (0.19 mmol) as acid promoter. FC (1:3 EtOAc/light petroleum ether) gave a colorless oil (13 mg, 70%, R_f = 0.07): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35−7.28 (m, 5H), 5.40 (dq, 1H, J = 10.7, 1.2), 4.75 (dd, 1H, J = 7.1, 5.8), 4.43 (m, 2H), 4.24 (dq, 1H, J = 10.7, 6.7), 2.97 (dd, 1H, J = 7.1, 16.6), 2.81 (s, 3H), 2.57 (dd, 3H, J = 16.6, 5.8), 2.17 (s, 3H), 1.84 (d, 3H, J = 1.2), 1.43 (d, 3H, J = 6.7).

(5*RS*,6*Z*,8*SR*)-5-(Benzyloxy)-2,2,6-trimethyl-8-(methylsulfonyl)non-6-en-3-one (19). The procedure was the same as for the preparation of **16**, starting from **13** (37 mg, 0.19 mmol) and 1-(*tert*-butylvinyloxy)trimethylsilane (**11**, 50 μL, 0.19 mmol) and using (*t*-Bu)$Me_2SiOSO_2CF_3$ (0.04 mmol) as acid promoter. FC (1:3 EtOAc/light petroleum ether) gave a yellowish oil (32 mg, 77%, R_f = 0.28) that crystallized from Et_2O/pentane: mp 101.5−103 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35−7.27 (m, 5H), 5.37 (dq, 1H, J = 11.0, 1.4), 4.83 (dd, 1H, J = 6.7, 6.2), 4.47−4.39 (m, 2H), 4.33 (dq, 1H, J = 11.0, 6.7), 3.00 (dd, 1H, J = 11.0, 6.7), 2.81 (s, 3H), 2.72 (dd, 1H, J = 11.0, 6.2), 1.84 (d, 3H, J = 1.4), 1.42 (d, 3H, J = 6.7), 1.12 (s, 9H).

(3*RS*,4*Z*,6*SR*)-4-Methyl-6-(methylsulfonyl)-1-phenyl-3-[2-(trimethylsilyl)-ethoxy]hept-4-en-1-one (20). In a two necked-round-bottom flask dried in a flame under vacuum (vacuum line)were placed anhydrous CH_2Cl_2 (10 mL) and $Yb(OSO_2CF_3)_3$ (615 mg) under an Ar atmosphere. After freezing (−196 °C) and evacuation (vacuum line) SO_2 (4 mL) was transferred. The system was pressurized with Ar (1 atm) and allowed to warm to −86 °C (EtOH/liquid N_2 bath). After stirred at −86 °C for 15 min, **1** (0.2 g, 1 mmol) and **9** (192 mg, 1 mmol) were added (syringe) dropwise. After stirring at −86 °C for 3 h, the solvents were evaporated. A 1 M solution of Bu_4NF in THF (6 mL) and MeI (1.2 mL) were added, and the mixture was stirred at 20 °C for 15 h. A saturated aqueous solution of $NaHCO_3$ (30 mL) was added, and the mixture was extracted with CH_2Cl_2 (20 mL, 5 times). The combined organic extracts were dried ($MgSO_4$), and the solvent was evaporated. The residue was taken in 1:1 Et_2O/light petroleum ether. The precipitate was filtered off, and the solution was concentrated in vacuo. FC (1:3 Et_2O/light petroleum ether) gave a colorless oil (174 mg, 47%) that crystallized from EtOAc/pentane: mp 62−64 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96−7.46 (m, 5 H), 5.35 (dq, 1H, J = 10.8, 1.3), 4.79 (dd, 1H, J = 6.4, 6.3), 4.39 (dq, 1H, J = 10.8, 6.7), 3.52, 3.39 (m, 3H), 3.10 (dd, 1H, J = 16.6, 6.4), 2.85 (s, 3H), 1.82 (d, 3H, J = 1.3), 1.41 (d, 3H, J = 6.7), 0.97−0.80 (m, 3H), 0.10 (s, 9H).

(4*RS*,5*Z*,7*SR*)-5-Methyl-7-(methylsulfonyl)-4-[2-(trimethylsilyl)ethoxy]oct-5-en-2-one (21). The procedure was the same as for the preparation of **20**, starting from **14** (0.2 g, 1 mmol) and **10** (131 mg) and using $Yb(OSO_2CF_3)_3$ as acid promoter (615 mg). FC (1:3 EtOAc/light petroleum ether) gave a colorless oil (61 mg, 20%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.34 (dq, 1H; J = 10.7, 1.3), 4.55 (dd, 1H, J = 7.5, 5.5), 4.30 (dq, 1H, J = 10.7, 6.8), 3.47−3.31 (m, 2H), 2.88 (dd, 1H, J = 16.5, 7.5), 2.83 (s, 3H), 2.48 (dd, 1H, J = 16.5, 5.5), 2.17 (s, 3H), 1.76 (d, 3H, J = 1.3), 1.42 (d, 3H, J = 6.8), 0.95−0.78 (m, 3H), −0.01 (s, 9H).

(5*RS*,6*Z*,8*SR*)-2,2,6-Trimethyl-8-(methylsulfonyl)-5-[2-(trimethylsilyl)ethoxy]non-6-en-3-one (22). The procedure was the same as for the preparation of **20**, starting from **14** (0.2 g, 1 mmol) and **11** (327 mg, 1.9 mmol) and using $Yb(OSO_2CF_3)_3$ (615 mg) as acid promoter. FC (1:4 EtOAc/light petroleum ether) gave a colorless oil (173 mg, 50%) that crystallizes from Et_2O/pentane: mp 63−64 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.29 (br.d, 1H, J = 10.8), 4.59 (dd, 1H, J = 6.6, 6.4), 4.34 (dq, 1H, J = 10.8, 6.8), 3.43−3.29 (m, 2H), 2.87 (dd, 1H, J =

17.0, 6.4), 2.80 (s, 3H), 2.59 (dd, 1H, J = 17.0, 6.6), 1.73 (d, 3H, J = 1.3), 1.77 (d, 3H, J = 6.8), 1.08 (s, 9H), 0.92−0.75 (m, 2H), −0.04 (s, 9H).

(5*RS*,6*E*,8*RS*)-5-(Benzyloxy)-2,2,6-trimethyl-8-(methylsulfonyl)non-6-en-3-one (29). The procedure was the same as for the preparation of **19** starting from **11** (425 mg, 2.7 mmol) and **13** (0.5 g, 2.7 mmol) and using $MgBr_2$ (666 mg, 2.7 mmol) as acid promoter (instead of (*t*-Bu)$Me_2SiOSO_2CF_3$). FC (1:3 EtOAc/light petroleum ether) gave a fraction from which a white solid was obtained (80 mg, 8%) that was recrystallized from Et_2O/pentane, giving thin needles: mp 76−78 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35−7.27 (m, 5H), 5.37 (dq, 1H, J = 11.0, 1.4), 4.83 (dd, 1H, J = 6.7, 6.2), 4.47−4.39 (m, 2H), 4.33 (dq, 1H, J = 11.0, 6.7), 3.00 (dd, 1H, J = 11.0, 6.7), 2.81 (s, 3H), 2.72 (dd, 1H, J = 11.0, 6.2), 1.84 (d, 3H, J = 1.4), 1.42 (d, 3H, J = 6.7), 1.12 (s, 9H).

(3*RS*,5*SR*,6*E*,8*SR*)- (30) and (3*RS*,5*RS*,6*E*,8*RS*)-5-(Benzyloxy)-2,2,6-trimethyl-8-(methylsulfonyl)non-6-en-3-ol (31). A mixture of **29** (50 mg, 0.14 mmol), anhydrous MeOH (2 mL), and $NaBH_4$ (10 mg, 0.56 mmol) was stirred at 20 °C for 2 h. EtOAc (1 mL) was added, and the solvent was evaporated to dryness. The residue was washed with water (50 mL) and then extracted with CH_2Cl_2 (50 mL, 4 times). Drying ($MgSO_4$), solvent evaporation, and FC (1:3 EtOAc/light petroleum ether) gave a first fraction (38.4 mg) of **30** and a second (10.1 mg) of **31**. Overall yield: 97%. Diol **30** crystallized from Et_2O/pentane. Data for **30**: colorless crystals; mp 116−118 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37−7.29 (m, 5H), 5.48 (d, 1H, J = 10.0), 4.50 (d, 1H, J = 11.3), 4.34 (d, 1H, J = 11.3), 4.05 (d, 1H, J = 9.1), 3.93 (dq, 1H, J = 10.0, 6.9), 3.43 (br. s, 1H), 3.36 (d, 1H, J = 9.4), 2.84 (s, 3H), 1.80−1.62 (m, 2H), 1.80 (s, 3H), 1.50 (d, 3H, J = 6.9), 0.89 (s, 9H). Data for **31**: colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38−7.29 (m, 5H), 5.50 (d, 1H, J = 10.2), 4.54 (d, 1H, J = 11.9), 4.33 (d, 1H, J = 11.9), 4.06 (dd, 1H, J = 8.7, 3.0), 3.93 (dq, 1H, J = 10.2, 6.8), 3.43 (d, 1H, J = 10.3), 2.82 (s, 3H), 1.80 (m, 1H), 1.78 (d, 3H, J = 1.1), 1.50 (d, 3H, J = 6.9), 1.43 (ddd, 1H, J = 14.0, 3.0, 10.3), 0.89 (s, 9H).

2-(Benzyloxy)-3,5-dimethyldihydrothiophene-1,1-dioxide (37). On the vacuum line, SO_2 (0.4 mL) was condensed onto a degassed mixture of CD_2Cl_2 (0.5 g), **13** (24.4 mg, 0.13 mmol), and $CFCl_3$ (0.1 g). The mixture was allowed to stand at −74 °C for 6 h. ^{1}H NMR demonstrated the disappearance of diene **13** and the exclusive formation of sulfolene **37**, unstable above −20 °C: ^{1}H NMR (400 MHz, $CDCl_3$, −65 °C) δ 7.47−7.32 (m, 5H), 5.88 (s, 1H), 5.04 and 4.69 (2d, 2H, J = 11.5), 4.72 (s, 1H), 3.66 (m, 1H), 1.83 (s, 3H), 1.35 (d, 3H, J = 7.1). ^{13}C NMR (100.6 MHz, $CDCl_3$, −65 °C) δ 136.6, 134.6 (2s), 129.6, 129.5, 128.6 (3d), 93.5 (d, ^1J(C,H) = 165), 78.6 (t, ^1J(C,H) = 144), 59.9 (d, ^1J(C,H) = 145), 17.0, 15.8 (2q).

3,5-Dimethyl-2-[2-(trimethylsilyl)ethoxy]dihydrothiophene-1,1-dioxide (38). The procedure was the same as for the preparation of **37**: ^{1}H NMR (400 MHz, CD_2Cl_2, −75 °C) δ 5.81 (m, 1H), 4.64 (s, 1H), 4.07 (m, 1H), 3.65 (m, 2H), 1.84 (s, 3H), 1.30 (d, 3H, J = 7.1), 1.03 (m, 2H); ^{13}C NMR (100.6 MHz, CD_2Cl_2, −75 °C) δ 135.4 (s), 128.4 (d, ^1J(C,H) = 169), 95.5 (d, ^1J(C,H) = 159), 71.7 (t, ^1J(C,H) = 143), 60.2 (d, ^1J(C,H) = 143), 18.8 (t, ^1J(C,H) = 121), 17.8, 15.6 (2q), −0.8 (q, ^1J(C,H) = 119).

(2*RS*,3*SR*,5*SR*,6*SR*)-3-(Benzyloxy)-2,5-dimethyl-2,6-dimethoxy-1,4-oxathiane-4,4-dioxide (39). SO_2 (2 mL) was condensed onto frozen (−196 °C) CH_2Cl_2 (4 mL) and Yb(OSO_2CF_3)$_3$ (100 mg). The mixture was allowed to stand at −78 °C for 15 min. Diene **13** (120 mg, 0.63 mmol) was added slowly (syringe) to the stirred solution at −78 °C. After stirring at −78 °C for 5 h, O_3 (2% in O_2) was bubbled through the solution until persistence of the blue color. SO_2 (1 mL) was transferred to the mixture. After stirring at −78 °C for 30 min, the solvents were half-evaporated at −60 °C (0.5 Torr), ethyl orthoformiate (940 mg, 6.3 mmol), $CeCl_3$ (160 mg, 0.63 mmol), and anhydrous MeOH (1 mL) were added, and the mixture was stirred at −78 °C for 15 min and then at 20 °C for 15 h. A saturated aqueous solution of $NaHCO_3$ (30 mL) was added, and the mixture was extracted with CH_2Cl_2 (30 mL, 3 times). Drying ($MgSO_4$), solvent evaporation, and FC (1:3 EtOAc/light petroleum ether) gave a colorless oil (37 mg, 18%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−7.27 (m, 5H), 4.65 (d, 1H, J = 11.6), 4.37 (d, 1H, J = 11.6), 4.25 (d, 1H, J = 8.1), 4.00 (d, 1H, J = 3.9), 3.31 (s, 3H), 3.26 (s, 3H), 2.26 (ddq, 1H, J = 8.1, 3.9, 7.0), 2.17 (s, 3H), 0.93 (d, 3H, J = 7.0). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 137.6 (s), 128.4, 127.9 (2d), 127.8 (s), 105.9 (s), 105.1 (d, ^1J(C,H) = 165), 85.0 (d, ^1J(C,H) = 142), 72.9 (t), 54.3 (q), 52.4 (q), 38.9 (d, ^1J(C,H) = 128), 26.7 and 9.95 (2q, ^1J(C,H) = 128).

(1*E*,3*Z*)-1-(Benzyloxy)-2-methyl-3-(trimethylsilyloxy)-penta-1,3-diene (40). $Me_3SiOSO_2CF_3$ (3.2 mL) was added dropwise to a stirred solution of **24** (3.2 g, 15.7 mmol) in anhydrous Et_3N (5 mL) containing $ZnCl_2$ (50 mg) cooled to 10 °C. After stirring at 10 °C for 15 h, the solid was extracted with pentane (50 mL, 6 times). The combined organic extracts were washed with a saturated aqueous solution of $NaHCO_3$ (100 mL), then with H_2O (200 mL), and finally with a solution of citric acid (7.2 g) in H_2O (200 mL). Drying ($MgSO_4$) and solvent evaporation gave a colorless oil (4.2 g, 97%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37−7.30 (m, 5H), 6.46 (s, 1H), 4.86 (s, 2H), 4.75 (q, 1H, J = 6.9), 1.75 (d, 3H, J = 1.1), 1.62 (d, 3H, J = 6.9), 0.12 (s, 9H).

(1*E*,3*Z*)-3-Benzoyloxy-1-(benzyloxy)-2-methylpenta-1,3-diene (41, (1*E*,3*Z*)-1-(benzyloxy)-2-methylpenta-1,3-dien-3-yl benzoate). A mixture of **40** (4 g, 14.5 mmol), anhydrous THF (15 mL), benzoyl fluoride (1.58 mL, 14.5 mmol), and 1 M tetrabutylammonium trihydrate in THF (0.3 mL, 0.29 mmol) was stirred at 20 °C for 15 h. The solvent was evaporated in vacuo. FC (CH_2Cl_2) gave a colorless oil (3.22 g, 72%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.17−7.26 (m, 10 H), 6.40 (s, 1H), 5.34 (q, 1H, J = 7.0), 4.79 (s, 1.86 (s, 3H), 1.61 (d, 3H, J = 7.0).

(1*E*,3*Z*)-3-[(*tert*-Butyl)dimethylsilyloxy]-2-methyl-1-[2-(trimethylsilyl)ethoxy]penta-1,3-diene (42). (*t*-Bu)$Me_2SiOSO_2CF_3$ (0.57 mL) was added dropwise to a stirred solution of **27** (530 mg, 2.5 mmol) in anhydrous Et_3N (2 mL) and Et_2O (2 mL) cooled to 0 °C. After stirring at 20 °C for 5 h the solvent was evaporated in vacuo. A saturated aqueous solution of $NaHCO_3$ (50 mL) was added, and the mixture was extracted with pentane (50 mL, 4 times). The combined organic extracts were washed with H_2O (50 mL) and then with a 2 M solution of citric acid in H_2O (100 mL). Drying ($MgSO_4$) and solvent evaporation gave a colorless oil (763 mg, 93%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.39 (s, 1H), 4.69 (q, 1H, J = 6.9), 3.87 (t, 2H, J = 8.4), 1.69 (s, 1H), 1.61 (d, 3H, J = 6.9), 1.00 (m, 11H).

(1*E*,3*Z*)-2-Methyl-1-[2-(trimethylsilyl)ethoxy]penta-1,3-dien-3-yl Benzoate (43). $Me_3SiOSO_2CF_3$ (3.86 mL) was added dropwise to a stirred solution of **42** (4 g, 18.7 mmol) in anhydrous Et_3N (5 mL). After stirring at 20 °C for 15 h the solid was extracted with pentane (100 mL, 5 times). The combined organic extracts were washed with a saturated aqueous solution of $NaHCO_3$ (100 mL), then with H_2O (100 mL), and finally with a solution of citric acid (3.6 g) in H_2O (100 mL). After drying ($MgSO_4$) and solvent evaporation in vacuo, the residue was dissolved in anhydrous THF (18.5 mL) and cooled to 0 °C. Benzoyl fluoride (2 mL, 18.7 mmol) and then 1 M Et_4NF in THF (0.4 mL, 0.37 mmol) were added. After stirring at 20 °C for 15 h the solvent was evaporated in vacuo. FC (CH_2Cl_2) gave a colorless oil (1.82 g, 31%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.21−7.50 (m, 5H), 6.27 (s, 1H), 5.29 (q, 1H, J = 6.9), 3.81 (m, 2H), 1.80 (s, 3H), 1.60 (d, 3H, J = 6.9), 0.96 (m, 2H), 0.00 (s, 9H).

(4*RS*,5*Z*,7*SR*)-6-Benzoyloxy-4-benzyloxy-5-methyl-7-(methylsulfonyl)oct-5-en-2-one (44, (2*RS*,3*Z*,5*SR*)-5-benzyloxy-4-methyl-2-(methylsulfonyl)-7-oxooct-3-en-3-yl benzoate). The procedure was the same as for the preparation of **16** using anhydrous CH_2Cl_2 (2 mL), SO_2 (0.6 mL), **41** (163 mg, 0.53 mmol), 2-(trimethylsilyloxy)propene (**10**, 104 mg, 0.8 mmol), and (*t*-Bu)$Me_2SiOSO_2CF_3$ as acid promoter (0.1 mL). FC (1:2 EtOAc/light petroleum ether) gave a colorless oil (157 mg, 67%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13−7.28 (m, 10H), 4.86 (dd, 1H, J = 6.6, 6.5), 4.66 (q, 1H, J = 6.9), 4.56 (AB, 2H), 3.00 (dd, 1H, J = 16.8, 6.6), 2.95 (s, 3H), 2.80 (dd, 1H, J = 16.8, 6.5), 2.23 (s, 3H), 1.69 (s, 3H), 1.54 (d, 3H, J = 6.9).

(4*RS*,5*Z*,7*SR*-6-Benzoyloxy-5-methyl-7-(methylsulfonyl)-4-[2-trimethylsilyl)ethoxy]oct-5-en-2-one (45, (2*RS*,3*Z*,5*SR*)-4-methyl-2-(methylsulfonyl)-5-[2-(trimethylsilyl)ethoxy]-7-oxooct-3-en-3-yl benzoate). SO_2 (0.6 mL) was condensed in vacuo (vacuum line) onto frozen (−196 °C) anhydrous CH_2Cl_2 (2 mL) containing $(CF_3SO_2)_2NH$ (0.2 mL). The mixture was melted at −78 °C. After 15 min at −78 °C, **43** (163 mg, 0.53 mmol) and **10** (104 mg, 0.8 mmol) were added slowly (syringe) under stirring. After stirring at −78 °C for 15 h, the solvent was evaporated (−78 °C, 0.1 Torr). Then, 1 M Bu_4NF in THF (2 mL) and MeI (0.5 mL) were added, and the mixture was stirred at 0 °C for 3.5 h. A saturated aqueous solution of $NaHCO_3$ (50 mL) was added, and the mixture was extracted with CH_2Cl_2 (30 mL, 4 times). The combined extracts were dried ($MgSO_4$), and the solvent was evaporated in vacuo. The residue was taken up in 1:3 EtOAc/light petroleum ether. The precipitate was filtered off. The solvent was evaporated. FC (1:2 EtOAc/light petroleum ether) gave a colorless oil (102 mg, 42%) that crystallized from Et_2O/pentane: mp 93−95 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11−7.48 (m, 5H), 4.68 (q, 1H, J = 6.9), 4.66 (t, 1H, J = 6.6), 3.60, 3.47 (2m, 2H), 2.98 (s, 3H), 2.92 (dd, 1H, J = 16.7, 6.6), 2.70 (dd, 1H, J = 16.7, 6.6), 2.22 (s, 3H), 1.61 (s, 3H), 1.54 (d, 3H, J = 6.9), 0.95, 0.87 (2m, 2H), 0.03 (s, 9H).

(4*RS*,5*SR*,6*E*)-4-(Benzyloxy)-5-methyloct-6-en-2-one (47). In a two-necked round-bottom flask dried under vacuum in a flame were placed anhydrous CH_2Cl_2 (40 mL) and $Yb(OSO_2CF_3)_3$ (3.2 g) under an Ar atmosphere. After complete dissolution, the mixture was frozen (liquid N_2), and the flask was evacuated (vacuum line). Dry SO_2 (16 mL) was condensed, and the mixture was allowed to warm slowly to −78 °C. After 15 min at −78 °C and pressurizing (1 atm) with Ar, **13** (1 g, 5.3 mmol) and **10** (2.4 g, 18.4 mmol) were added slowly (syringe) under stirring. After stirring at −78 °C for 5 h the solvents were evaporated (−78 °C, 0.1 Torr). A 1:1 mixture of MeOH and saturated aqueous solution of NH_4Cl (40 mL) was added, and the mixture was stirred at 0 °C for 1 h and then at 20 °C for 15 h. A saturated aqueous solution of $NaHCO_3$ (300 mL) was added, and the mixture was extracted with CH_2Cl_2 (300 mL, 3 times). Drying ($MgSO_4$), solvent evaporation, and FC (1:2 light petroleum ether/CH_2Cl_2) gave a colorless oil (1.09 g, 71%, R_f = 0.27): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35−7.24 (m, 5H), 5.47 (dqd, 1H, J = 15.3, 6.0, 0.8), 5.38 (dd, 1H, J = 15.3, 7.1, 1.3), 4.53 (m, 2H), 3.91 (ddd, 1H, J = 8.5, 4.0, 3.9), 2.67 (dd, 1H, J = 16.2, 8.5), 2.47−2.50 (m, 1H), 2.44 (dd, 1H, J = 16.2, 4.0), 2.14 (s, 3H), 1.68 (ddd, 3H, J = 6.0, 1.3, 0.9), 1.03 (d, 3H, J = 6.9).

(4*RS*,5*RS*,6*E*)-4-(Benzyloxy)-5-methyl-2-(trimethylsilyloxy)octa-1,6-diene (48). A 1.6 M solution of BuLi in hexane (0.95 mL, 1.52 mmol) was added dropwise to a stirred solution of $(Me_3Si)NH$ (0.32 mL, 1.52 mmol) in anhydrous THF (2 mL) cooled to −20 °C. After cooling to −78 °C, $(CH_3)_3SiCl$ (0.93 mL) in anhydrous THF (2 mL) was added (cannulated) and then a solution of **46** (183 mg, 0.74 mmol) in anhydrous THF (2 mL). Both solutions were cooled to −78 °C before the addition. After stirring at −78 °C for 5 min, anhydrous Et_3N (2 mL) was added. The mixture was poured into a saturated aqueous solution of $NaHCO_3$ (50 mL) under vigorous stirring. The mixture was extracted with pentane (100 mL, 4 times). The combined organic extracts were washed with H_2O and then with a solution of citric acid (0.48 g) in H_2O (50 mL). Drying ($MgSO_4$) and solvent evaporation gave a colorless oil (239 mg, 100%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35−7.25 (m, 5H), 5.49−5.39 (m, 2H), 4.61 and 4.50 (2d, 2H, J = 11.6), 4.13 and 4.10 (2d, 2H, J = 0.5), 3.55 (ddd, 1H, J = 7.0, 5.5, 3.7), 2.41 (m, 1H), 2.26 (dd, 1H, J = 14.1, 7.0), 2.17 (dd, 1H, J = 14.1, 5.5), 1.68 (dd, 1H, J = 4.6, 0.4), 1.01 (d, 3H, J = 6.9), 0.21 (s, 9H).

1:1 Mixture of (2*E*,4*RS*,5*SR*,9*RS*,10*Z*,12*SR*)- (49) and (2*E*,4*RS*,5*SR*,9*SR*,10*Z*,12*RS*)-5,9-Di(benzyloxy)-4,10-dimethyl-12-(methylsulfonyl)trideca-2,10-dien-7-one (50). The procedure was the same as for the preparation of **45**, using **13** (0.1 g, 0.54 mmol) and **48** (110 mg, 0.35 mmoL) and (*t*-Bu)-$Me_2SiOSO_2CF_3$ (0.1 mL) as acid promoter. FC (1:3 EtOAc/light petroleum ether) gave a colorless oil (84 mg, 47%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33−7.25 (m, 5H), 5.44 (m, 1H), 5.36 (m, 2H), 4.77 and 4.75 (2dd, 1H, J = 6.3, 6.4), 4.58−4.37 (m, 2H), 4.24 (m, 1H), 3.90 (m, 1H), 2.98 (dd, 0.5H, J = 17.0, 7.3), 2.94 (dd, 0.5H, J = 17.0, 7.2), 2.79 and 2.78 (2s, 3H), 2.67 (dd, 0.5H, J = 16.0, 8.5), 2.63 (dd, 0.5H, J = 16.2, 8.9), 2.58 (dd, 0.5H, J = 17.0, 1.4), 2.56 (dd, 0.5H, J = 17.0, 1.4), 2.48 (m, 1H), 2.44 (dd, 0.5H, J = 16.2, 3.5), 2.41 (dd, 0.5H, J = 16.2, 3.8), 1.80 (d, 1.5H, J = 1.4), 1.78 (d, 1.5H, J = 1.1), 1.66 (m, 3H), 1.42 (d, 1.5H, J = 6.7), 1.39 (d, 1.5H, J = 6.8), 1.1 (d, 3H, J = 6.8).

(+)-(1′*S*,1*E*)-2-Methyl-1-[1-(pentafluorophenyl)ethoxy]-butadiene ((+)-54). A mixture of 3-ethoxy-2-methylacrolein (0.6 mL, 5 mmol), (−)-(*S*)-1-(pentafluorophenyl)ethanol (**56d**), and *p*-toluenesulfonic acid (16 mg) was stirred at 20 °C for 14 h under vacuum (1 Torr). This gave 2-methyl-3-{1-(*S*)-[pentafluorophenyl)ethoxy}prop-2-enal (**57d**). In another flask, 1.6 M BuLi in hexane (4.7 mL) was added dropwise to a stirred solution of $(i\text{-Pr})_2NH$ in anhydrous THF (20 mL) cooled to −78 °C. After stirring at 0 °C for 1.5 h, methyltriphenylphosphonium bromide (2.65 g, 7.5 mmol) was added. After stirring at 20 °C for 2 h, the mixture was cooled to 0 °C, and **57d** obtained above was added. After stirring at 0 °C for 1.5 h, ice-cold H_2O (30 mL) was added, and the mixture was extracted with light petroleum ether (20 mL, 3 times). The combined organic extracts were dried (anhydrous Na_2SO_4), and the solvent was evaporated. The residue was distilled (Kugelrohr, Büchi) under reduced pressure, giving a yellowish oil (bp 80 °C, 1 Torr), 2:1 mixtures of (*E*)- and (*Z*)-diene (0.408 g, 20%). $[\alpha]_D^{25}$ = +66 (c = 1.0, $CHCl_3$). Data for the major diene (+)-**54**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.20 (dd, 1H, J = 17.0, 10.5), 6.18 (q, 1H, J = 1.2), 5.23 (q, 1H, J = 6.8), 5.02 (dd, 1H, J = 17.0, 1.2), 4.84 (dd, 1H, J = 10.5, 1.2), 1.733 (d, 3H, J = 1.2), 1.70 (d, 3H, J = 6.8). Data for the minor diene (1*Z*): ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.19 (dd, 1H, J = 17.0, 10.5), 6.16 (q, 1H, J = 1.2), 5.27 (q, 1H, J = 6.8), 4.98 (dd, 1H, J = 17.0, 1.2), 4.87 (dd, 1H, J = 10.5, 1.2), 1.730 (d, 3H, J = 1.2), 1.70 (d, 3H, J = 6.8).

(−)-2-Methyl-3-[1-(*S*)-(2,4,6-triisopropylphenyl)ethoxy]-prop-2-enal ((−)-57e). A solution of (−)-(*S*)-1-(2,4,6-triisopropylphenyl)ethanol[30] (1.89 g, 7.6 mmol) in anhydrous THF (10 mL, dried with 4 Å molecular sieves) was added slowly to a stirred solution of activated NaH (0.36 g, 8.36 mmol) in anhydrous THF (5 mL). After stirring at 20 °C for 3 h, the solution was cooled to 0 °C, and 3-ethoxy-2-methylacrolein (1.03 mL, 8.36 mmol) in anhydrous THF (5 mL, dried over 4 Å molecular sieves, 20 °C, 2 h) was added. After stirring at 20 °C for 20 h a saturated aqueous solution of NH_4Cl (20 mL) was added. The mixture was extracted with CH_2Cl_2 (40 mL, 3 times). The combined organic extracts were washed with H_2O (50 mL, twice) and dried ($MgSO_4$). Solvent evaporation and FC (CH_2Cl_2) gave a white solid (1.9 g, 79%, R_f = 0.13): mp 87.5−89 °C; $[\alpha]_D^{25}$ = −27 (c = 0.98, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.14 (s, 1H), 7.05−7.00 (m, 2H), 6.96 (q, 1H, J = 0.9), 5.69 (q, 1H, J = 6.9), 3.40 (m, 1H), 2.88 (sept. 3H, J = 6.9), 1.76 (d, 3H, J = 6.9), 1.72 (d, 3H, J = 0.9), 1.31−1.09 (m, 6H), 1.26 (d, 3H, J = 6.9).

(+)-1,3,5-Triisopropyl-2-{1-(*S*)-{(1*E*)-2-methylbuta-1,3-dienyloxy]ethyl}benzene ((+)-55). A 1.6 M solution of BuLi in hexane (3.6 mL, 5.74 mmol) was added dropwise to a stirred solution of $(i\text{-Pr})_2NH$ (0.85 mL, 5.74 mmol) in anhydrous THF (20 mL) cooled to −78 °C under an Ar atmosphere. After stirring at 0 °C for 1 h, methyltriphenylphosphonium bromide (1.865 g, 5.2 mmol) was added portionwise. After stirring at 20 °C for 45 min the mixture was cooled to 0 °C. A solution of (−)-**57e** (1.5 g, 4.74 mmol) in anhydrous THF (15 mL) was added, and the mixture stirred at 0 °C for 1 h. Ice-cold H_2O (50 mL) was added, and the mixture was extracted with light petroleum ether (30 mL, 3 times). The combined organic extracts were dried ($MgSO_4$), and the solvent was evaporated. The residue was taken up with pentane, and the precipitate (Ph_3PO) was filtered off. Solvent evaporation gave a white solid (1.3 g, 87%): mp 39.5−41 °C; $[\alpha]_D^{25}$ = +17 (c = 1.02, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.03−7.01 (m, 2H), 6.22 (q, 1H, J = 1.2), 6.20 (dd, 1H, J = 17.2, 10.8), 5.41 (q, 1H, J = 6.9), 4.92 (dd, 1H, J = 17.2, 1.1), 4.76 (dd, 1H, J = 10.8, 1.1), 3.48

(m, 2H), 2.87 (sept, 1H, J = 6.9), 1.73 (d, 3H, J = 1.2), 1.64 (d, 3H, J = 6.9), 1.35−1.21 (m, 6H), 1.25 (d, 3H, J = 6.9).

1:5.4 Mixture of (3*S*,4*Z*)- and (3*R*,4*Z*)-4-Methyl-6-(methylsulfonyl)-1-phenyl-3-[(*R*)-1-phenylethoxy]hex-4-en-1-one ((1′*R*,3*S*)-58 and (1′*R*,3*R*)-59). The procedure was the same as for the preparation of **16**, starting from (−)-{1-(*R*)-[(1*E*)-2-methylbuta-1,3-dienyloxy]ethyl}benzene[29] ((−)-**51**, 56 mg, 0.3 mmol) and 1-phenyl-1-trimethylsilyloxyethene (**9**, 130 mg, 0.75 mmmol) and using $Yb(OSO_2CF_3)_3$ (0.132 g, 0.2 mmol) as acid promoter in anhydrous CH_2Cl_2 (2 mL). FC (24:1 CH_2Cl_2/Et_2O) gave a colorless oil, 1:5.4 mixture of (1′*R*,3*S*)-**58** and (1′*R*,3*R*)-**59** (103 mg, 89%): ^{1}H NMR (400 MHz, $CDCl_3$) of (1′*R*,3*R*′)-**59** (major) δ 7.99−7.40 (m, 5H), 7.40−7.10 (m, 5H), 5.61 (tq, 1H, J = 8.0, 1.2), 4.59 (t, 1H, J = 6.5), 4.35 (q, 1H, J = 6.5), 3.61 (dd, 1H, J = 13.3, 8.0), 3.50 (dd, 1H, J = 13.3, 8.0), 3.37 (dd, 1H, J = 16.5, 6.5), 3.22 (dd, 1H, J = 16.5, 6.5), 2.79 (s, 3H), 1.89 (d, 3H, J = 1.2), 1.377 (d, 3H, J = 6.5); ^{1}H NMR (400 MHz, $CDCl_3$) (1′*R*,3*S*)-**58** (minor) δ 7.99−7.10 (m, 10H), 5.29 (tq, 1H, J = 6.9, 1.0), 4.87 (dd, 1H, J = 7.4, 5.4), 4.52 (q, 1H, J = 6.4), 3.50−2.80 (m, 4H), 2.72 (s, 3H), 1.79 (d, 3H, J = 1.0), 1.374 (d, 3H, J = 6.4).

1:6.7 Mixture of (3*S*,4*Z*)- and (3*R*,4*Z*)-4-Methyl-6-(methylsulfonyl)-1-phenyl-3-[(*R*-1-phenylpropoxy]hex-4-en-1-one ((1′*R*,3*S*)-60 and (1′*R*,3*R*)-61). The procedure was the same as for the preparation of **16**, starting from (+)-{1-(*R*)-[(1*E*)-2-methylbuta-1,3-dienyloxy]propyl}benzene[29] ((+)-**52**, 59 mg, 0.3 mmol), **9** (95 mg, 0.55 mmol), and $Yb(OSO_2CF_3)_3$ (132 mg, 0.2 mmol). FC (39:1 CH_2Cl_2/Et_2O) gave a colorless oil containing a 1:6.7 mixture of (1′*R*,3*S*)-**60** and (1′*R*,3*R*)-**61** (65 mg, 54%): ^{1}H NMR (400 MHz, $CDCl_3$) of (1′*R*,3*R*)-**61** (major) δ 7.99−7.40 (m, 5H), 7.40−7.10 (m, 5H), 5.60 (tq, 1H, J = 8.3, 1.0), 4.58 (t, 1H, J = 6.6), 4.05 (t, 1H, J = 6.7), 3.55 (dd, 1H, J = 14.8, 8.3), 3.44 (dd, 1H, J = 14.8, 8.3), 3.36 (dd, 1H, J = 16.3, 6.6), 3.20 (dd, 1H, J = 16.3, 6.6), 2.78 (s, 3H), 1.89 (d, 3H, J = 1.0), 1.78 (dqd, 1H, J = 13.9, 7.4, 6.7), 1.61 (dqd, 1H, J = 13.9, 7.4, 6.7), 0.85 (t, 3H, J = 7.4). ^{1}H NMR (400 MHz, $CDCl_3$) of (1′*R*,3*S*)-**60** (minor) δ 8.0−7.0 (m, 10H), 5.48 (tq, 1H, J = 7.7, 1.1), 4.82 (dd, 1H, J = 6.9, 5.4), 4.28 (t, 1H, J = 6.6), 3.66−3.25 (m, 2H), 3.24−3.06 (m, 2H), 2.68 (s, 3H), 1.76 (d, 3H, J = 1.1), 1.82−1.54 (m, 2H), 0.76 (t, 3H, J = 7.4).

1:4.1 Mixture of (3*S*,4*Z*)- and (3*R*,4*Z*)-4-Methyl-6-(methylsulfonyl)-3-[(*R*)-(2-naphthyl)ethoxy]-1-phenylhex-4-en-1-one ((1′*R*,3*S*)-62 and (1′*R*,3*R*)-63). The procedure was the same as for the preparation of **16** starting from (−)-2-{1-(*R*)-[(1*E*)-2-methylbuta-1,3-dienyloxy]ethyl}naphthalene[29] ((−)-**53**, 71 mg, 0.3 mmol), **9** (95 mg, 0.55 mmol), and $Yb(OSO_2CF_3)_3$ (132 mg, 0.2 mmol). FC (24:1 CH_2Cl_2/Et_2O) gave a colorless oil (107 mg, 82%), a 1:4.1 mixture of (1′*R*,3*S*)-**62** and (1′*R*,3*R*)-**63**: ^{1}H NMR (400 MHz, $CDCl_3$) of (1′*R*,3*R*)-**63** (major) δ 8.00−7.40 (m, 12H), 5.66 (tq, 1H, J = 7.5, 1.2), 4.62 (t, 1H, J = 6.6), 4.52 (q, 1H, J = 6.7), 3.59 (dd, 1H, J = 18.1, 7.5), 3.58 (dd, 1H, J = 18.1, 7.5), 3.40 (dd, 1H, J = 16.0, 6.6), 3.22 (dd, 1H, J = 16.0, 6.6), 2.71 (s, 3H), 1.95 (d, 3H, J = 1.2), 1.46 (d, 3H, J = 6.7). ^{1}H NMR (400 MHz, $CDCl_3$) of (1′*R*,3S)-**62** (minor) δ 8.0−7.4 (m, 12 H), 5.26 (tq, 1H, J = 7.6, 1.2), 4.95 (dd, 1H, J = 7.6, 5.2), 4.73 (q, 1H, J = 6.4), 3.65 (dd, 1H, J = 15.1, 7.6), 3.55−3.48 (m, 1H), 3.15 (dd, 1H, J = 17.2, 7.6), 3.12 (dd, 1H, J = 17.2, 5.2), 2.58 (s, 3H), 1.81 (d, 3H, J = 1.2), 1.45 (d, 3H, J = 6.4).

3.8:1 Mixture of (3*S*,4*Z*)- and (3*R*,4*Z*)-4-Methyl-6-(methylsulfonyl)-3-[(*S*)-1-(pentafluorophenyl)ethoxy]-1-phenylhex-4-en-1-one (1′*S*,3*S*)-64 and (1′*S*,3*R*)-65). The procedure was the same as for the preparation of **16**, starting from (+)-**54** (83 mg, 0.3 mmol) and **9** (95 mg, 0.55 mmol) and using $Yb(OSO_2CF_3)_3$ (40 mg, 0.06 mmol) as acidic promoter. FC (34:1 CH_2Cl_2/Et_2O) gave a colorless oil (32 mg, 22%), 3.8:1 mixture of (1′*S*,3*S*)-**64** and (1′*S*,3*R*)-**65**: ^{1}H NMR (400 MHz, $CDCl_3$) of (1′*S*,3*S*)-**64** (major) δ 7.99−7.40 (m, 5H), 5.68 (ddq, 1H, J = 7.1, 6.3, 1.4), 4.75 (q, 1H, J = 6.7), 4.62 (dd, 1H, J = 7.0, 5.6), 3.97 (dd, 1H, J = 14.3, 7.1), 3.80 (dd, 1H, J = 14.3, 6.3), 3.40 (dd, 1H, J = 16.8, 7.0), 3.15 (dd, 1H, J = 16.8, 5.6), 2.88 (s, 3H), 1.90 (d, 3H, J = 1.4), 1.53 (d, 3H, J = 6.7). ^{1}H NMR (400 MHz, $CDCl_3$) of (1′*S*,3*R*)-**65** (minor) δ 7.99−7.40 (m, 5H), 5.35 (tq, 1H, J = 6.1, 1.1), 4.97 (q, 1H, J = 6.7), 4.95 (dd, 1H, J = 5.8, 4.4), 3.94 (m, 1H), 3.83 (m, 1H), 3.53 (dd, 1H, J = 17.0, 5.8), 3.34 (dd, 1H, J = 17.0, 4.4), 2.77 (s, 3H), 1.68 (d, 3H, J = 1.1), 1.60 (d, 3H, J = 6.7).

(−)-(3*S*,4*Z*)-4-Methyl-6-(methylsulfonyl)-1-phenyl-3-[(*S*)-1-(2,4,6-triisopropylphenyl)ethoxy]hex-4-en-1-one ((−)-(1′*S*,3*S*)-66). In a 25 mL round-bottom flask were dissolved in anhydrous CH_2Cl_2 (6 mL) (+)-**55** (192 mg, 0.6 mmol), **9** (0.3 mL, 3 mmol), and $Yb(OSO_2CF_3)_3$ (292 mg, 0.48 mmol). After degassing and freezing (−196 °C, vacuum line), SO_2 (1.28 mg, 20 mmol, dried by basic alumina and two distillations on the vacuum line) was transferred. The mixture was stirred at −90 °C for 24 h. The solvents were evaporated at −90 °C (0.1 Torr). After pressuring with Ar (1 atm), 1 M Bu_4NF in THF (6 mL, 6 mmol) and MeI (1.2 mL, 20 mmol) were added. The mixture was stirred at 20 °C for 16 h. H_2O (30 mL) was added, and the mixture was extracted with CH_2Cl_2 (20 mL, 5 times). Drying ($MgSO_4$), solvent evaporation, and FC (24:1 CH_2Cl_2/Et_2O) gave (−)-**66** as colorless crystals (244 mg, 79%) and (+)-**55** (36 mg, 20%). Data for (−)-**66**: mp 116−118 °C (MeOH); $[\alpha]_D^{25}$ = −0.7 (c = 1.02, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86−7.41 (m, 5H), 7.06−6.98 (m, 2H), 5.55 (ddq, 1H, J = 9.4, 4.7, 1.3), 5.01 (q, 1H, J = 6.7), 4.70 (dd, 1H, J = 8.8, 4.0), 4.03 (dd, 1H, J = 15.2, 9.4), 3.93 (m, 1H), 3.47 (dd, 1H, J = 17.3, 8.8), 3.25 (dd, 1H, J = 15.2, 4.7), 3.19 (dd, 1H, J = 17.3, 4.0), 3.12 (m, 1H), 2.85 (sept, 1H, J = 6.9), 2.78 (s, 3H), 1.88 (d, 3H, J = 1.3), 1.54 (d, 3H, J = 6.7), 1.40−1.13 (m, 6H), 1.26 (d, 3H, J = 6.9).

1:2.9 Mixture of (4*S*,5*Z*)- and (4*R*,5*Z*)-5-Methyl-7-(methylsulfonyl)-4-[(*R*)-1-phenylethoxy]hept-5-en-2-one ((1′*R*,4*S*)-69 and (1′*R*,4*R*)-70). A mixture of (−)-**51** (56 mg, 0.3 mmol), (isopropenyloxy)trimethylsilane (**10**, 0.1 mL, 0.55 mmol) and $Yb(OSO_2CF_3)_3$ (132 mg, 0.2 mmol) in anhydrous CH_2Cl_2 (2 mL) was degassed and cooled to −196 °C. SO_2 (0.64 g, 10 mmol, dried on basic Al_2O_3, Merck, act. I, degassed 3 times on the vacuum line) was transferred (vacuum line). The mixture was stirred at −78 °C for 5 h. Solvent evaporation (−78 °C, 0.1 Torr) was followed by addition of 1 M Bu_4NF in THF (1.5 mL, 1.5 mmol) and MeI (0.3 mL, 5 mmol), stirring at 0 °C for 16 h, addition of H_2O (100 mL), and extraction with CH_2Cl_2 (60 mL, 3 times). The combined organic extracts were washed with H_2O (100 mL, twice) and dried (Na_2SO_4), and the solvent was evaporated. FC (9:1 CH_2Cl_2/EtOAc) gave a colorless oil (96 mg, 99%), a 1:2.9 mixture of (1′*R*,4*S*)-**69** and (1′*R*,4*R*)-**70**: ^{1}H NMR (400 MHz, $CDCl_3$) of (1′*R*,4*R*)-**70** (major) δ 7.40−7.10 (m, 5H), 5.55 (tq, 1H, J = 7.8, 1.3), 4.41 (dd, 1H, J = 7.7, 5.2), 4.25 (q, 1H, J = 6.5), 3.50 (d, 2H, J = 7.8), 2.83 (dd, 1H, J = 16.2, 7.7), 2.75 (s, 3H), 2.58 (dd, 1H, J = 16.2, 5.2), 2.10 (s, 3 H), 1.83 (d, 3H, J = 1.3), 1.38 (d, 3H, J = 6.5). ^{1}H NMR (400 MHz, $CDCl_3$) of (1′*R*,4*S*)-**69** (minor) δ 7.40−7.10 (m, 5H), 5.25 (tq, 1H, J = 7.4, 1.3), 4.68 (dd, 1H, J = 8.1, 4.5), 4.45 (q, 1H, J = 6.4), 3.62 (dd, 1H, J = 15.9, 7.4), 3.54 (dd, 1H, J = 15.9, 7.4), 2.95 (dd, 1H, J = 16.7, 8.1), 2.70 (s, 3H), 2.57 (dd, 1H, J = 16.7, 4.5), 2.20 (s, 3H), 1.72 (d, 3H, J = 1.3), 1.38 (d, 3H, J = 6.4).

1:5.0 Mixture of (4*S*,5*Z*)- and (4*R*,5*Z*)-5-Methyl-7-(methylsulfonyl)-4-[(*R*)-1-phenylpropoxy]hept-5-en-2-one ((1′*R*,4*S*)-71 and (1′*R*,4*R*)-72). The procedure was the same as for the preparation of **69** + **70**, starting from (+)-**52** (59 mg, 0.3 mmol) and **10** (100 mg, 0.55 mmol) and using $Yb(OSO_2CF_3)_3$ (40 mg, 0.06 mmol) as acid promoter. FC (14:1 CH_2Cl_2/EtOAc) gave a colorless oil (52 mg, 51%), a 1:5.0 mixture of (1′*R*,4*S*)-**71** and (1′*R*,4*R*)-**72**: ^{1}H NMR (400 MHz, $CDCl_3$) of (1′*R*,4*R*)-**72** (major) δ 7.38−7.18 (m, 5H), 5.55 (tq, 1H, J = 7.2, 1.1), 4.39 (dd, 1H, J = 7.7, 5.3), 3.98 (t, 1H, J = 6.8), 3.45 (dd, 1H, J = 14.7, 7.2), 3.41 (dd, 1H, J = 14.7, 7.2), 2.84 (dd, 1H, J = 16.1, 7.7), 2.75 (s, 3H), 2.56 (dd, 1H, J = 16.1, 5.3), 2.10 (s, 3H), 1.84 (d, 3H, J = 1.1), 1.75 (dqd, 1H, J = 13.9, 7.6, 6.8), 1.60 (dqd, 1H, J = 13.9, 7.6, 6.8), 0.84 (t, 3H, J = 7.6). ^{1}H NMR (400 MHz, $CDCl_3$) of (1′*R*,4*S*)-**71** (minor) δ 7.40−7.18 (m, 5H), 5.16 (tq, 1H, J = 7.9, 1.4), 4.62 (dd, 1H, J = 7.9, 4.5), 4.22 (t, 1H, J = 6.5), 3.55 (dd, 1H, J = 13.8, 7.9), 3.48−3.38 (m, 1H), 2.94 (dd, 1H, J = 16.7, 7.9), 2.67 (s, 3H), 2.55 (dd, 1H, J = 16.7, 4.5), 2.20 (s, 3H), 1.81−1.54 (m, 2H), 1.68 (d. 3H, J = 1.4), 0.79 (t, 3H, J = 7.4).

(−)-(4*S*,5*Z*)- and (−)-(4*R*,5*Z*)-5-Methyl-7-(methylsulfonyl)-3-[(*S*)-1-(2,4,6-triisopropylphenyl)ethoxy]hept-5-en-2-one ((−)-(1′*S*,4*S*)-73 and (−)-1′*S*,4*R*)-74). Dry SO_2 (1.28 g, 20 mmol) was transferred (vacuum line) to a frozen (liquid N_2) solution of $Yb(OSO_2CF_3)_3$ (315 mg, 0.51 mmol) in anhydrous CH_2Cl_2 (2 mL). The mixture was stirred at −78 °C for 30 min and cooled to −90 °C. A solution of (+)-**55** (200 mg, 0.64 mmol) and **10** (0.48 mL, 3 mmol) in anhydrous CH_2Cl_2 (4 mL) was added slowly to the mixture and stirred at −90 °C for 21 h. The solvents were evaporated at −78 °C (0.1 Torr). After pressurizing (1 atm) with Ar, 1 M Bu_4NF in THF (6 mL, 6 mmol) and MeI (1.2 mL, 20 mmol) were added. The mixture was stirred at 20 °C for 15 h. H_2O (30 mL) was added, and the mixture was extracted with CH_2Cl_2 (20 mL, 5 times). The combined organic extracts were dried ($MgSO_4$), and the solvent was evaporated. FC (24:1 CH_2Cl_2/Et_2O) gave a first fraction of (−)-(1′*S*,4*S*)-**73** (196 mg, 68%, R_f = 0.13) and a second of (−)-(1′*S*,4*R*)-**74** (52 mg, 18%). The same procedure using 0.5 M $(CF_3SO_2)_2NH$ in CH_2Cl_2 (0.24 mL, 0.12 mmol) (instead of $Yb(OTf)_3$), (+)-**55** (197 mg, 0.626 mmol), and **10** (0.48 mL, 3 mmol) in anhydrous CH_2Cl_2 (1 mL) at −100 °C provided (−)-**73** (198 mg, 70%) and (−)-**74** (28 mg, 10%), overall yield of 80%. Data for (−)-(1′*S*,4*S*)-**73**: colorless crystals, mp 121.5−123 °C (MeOH); $[\alpha]_D^{25} = -12$ (c = 1.05, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.05−6.95 (m, 2H), 5.54 (ddq, 1H, J = 9.3, 4.8, 1.4), 4.93 (q, 1H, J = 6.8), 4.48 (dd, 1H, J = 7.8, 4.9), 3.93 (m, 1H), 3.84 (dd, 1H, J = 14.9, 9.3), 3.30 (dd, 1H, J = 14.9, 4.8), 3.08 (m, 1H), 2.88 (sept, 1H, J = 7.2), 2.87 (dd, 1H, J = 17.1, 7.8), 2.84 (s, 3H), 2.75 (dd, 1H, J = 17.1, 4.9), 2.05 (s, 3H), 1.85 (d, 3H, J = 1.4), 1.50 (d, 3H, J = 6.8), 1.35−1.04 (m, 12 H), 1.25 (d, 6H, J = 7.2). Data for (−)-(1′*S*,4*R*)-**74**: colorless solid, mp 84−86 °C; $[\alpha]_D^{25} = -62.4$ (c = 1.1, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.00−6.92 (m, 2H), 5.41 (tq, 1H, J = 7.9, 1.1), 4.95 (q, 1H, J = 6.7), 4.77 (dd, 1H, J = 7.9, 4.6), 3.71 (dd, 1H, J = 14.4, 7.9), 3.70 (m, 1H), 3.58 (dd, 1H, J = 14.4, 7.9), 3.13 (m, 1H), 2.89 (dd, 1H, J = 16.5, 7.9), 2.83 (sept, 1H, J = 6.9), 2.69 (s, 3H), 2.58 (dd, 1H, J = 16.5, 4.6), 2.21 (s, 3H), 1.69 (d, 3H, J = 1.1), 1.49 (d, 3H, J = 6.7), 1.26−1.16 (m, 12H), 1.23 (d, 6H, J = 6.9).

(5*RS*,6*Z*)- and (5*SR*,6*Z*)-2,2,6-Trimethyl-8-(methylsulfonyl)-5-[(*RS*)-1-(2,4,6-triisopropylphenyl)ethoxy)oct-6-en-3-one ((1′*RS*,5*RS*)-76) and (1′*RS*,5*SR*)-77). The procedure was the same as for the preparation of (−)-**73** and (−)-**74** starting from (±)-**55** (50 mg, 0.16 mmol), **11** (0.15 mL, 0.67 mmol), and 0.5 M $(CF_3SO_2)_2NH$ in CH_2Cl_2 (60 μL, 0.03 mmol). FC (1:4 EtOAc/light petroleum ether) gave a first fraction of a colorless oil (15 mg of 1′*RS*,5*RS*-**76**, 19%). Then with 1:3 EtOH/light petroleum ether a second fraction delivered another oil (6 mg of 1′*RS*,5*SR*)-**77**, 8%). Data for (1′*RS*,5*RS*)-**76** (major): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.28−6.96 (m, 2H), 5.54 (ddq, 1H, J = 9.5, 4.4, 1.2), 4.93 (q, 1H, J = 6.8), 4.50 (dd, 1H, J = 9.4, 3.7), 3.98 (dd, 1H, J = 15.2, 9.5), 3.92 (m, 1H), 3.21 (dd, 1H, J = 15.2, 4.4), 3.07 (m, 1H), 3.04 (dd, 1H, J = 17.9, 9.4), 2.86 (sept, 3H, J = 6.9), 2.77 (s, 3H), 2.70 (dd, 1H, J = 17.9, 3.7), 1.83 (d, 3H, J = 1.2), 1.51 (d, 3H, J = 6.8), 1.31−1.17 (m, 12H), 1.21 (d, 6H, J = 6.9), 1.04 (s, 9H). Data for (1′*RS*,5*SR*)-**77**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.00−6.92 (m, 2H), 5.54 (tq, 1H, J = 7.8, 1.4), 4.94 (q, 1H, J = 6.6), 4.80 (dd, 1H, J = 7.2, 5.2), 3.72 (m, 1H), 3.72 (dd, 1H, J = 14.8, 7.8), 3.63 (dd, 1H, J = 14.8, 7.8), 3.17 (sept, 1H, J = 6.6), 3.04 (dd, 1H, J = 17.2, 7.2), 2.86 (sept, 1H, J = 6.9), 2.63 (s, 3H), 2.60 (dd, 1H, J = 17.2, 5.2), 1.70 (d, 3H, J = 1.4), 1.50 (d, 1H, J = 6.6), 1.27−1.15 (m, 6H), 1.24 (d, 6H, J = 6.6), 1.17 (d, 6H, J = 6.9), 1.15 (s, 9H).

(−)-(3*S*,4*Z*)- and (3*R*,4*Z*)-1-Cyclopropyl-4-methyl-6-(methylsulfonyl)-3-[(1*S*)-1-(2,4,6-triisopropylphenyl)-ethoxy]hex-4-en-1-one ((−)-(1′*S*,3*S*)-79 and (1′*S*,3*R*)-80). The procedure was the same as for the preparation of (−)-**73** and (−)-**74** starting from (+)-**55** (102 mg, 0.32 mmol), 1-cyclopropyl-1-(trimethylsilyloxy)ethene (**78**, 0.3 mL, 1.5 mmol), and $Yb(OSO_2CF_3)_3$ (121 mg, 0.19 mmol). FC (24:1 CH_2Cl_2/Et_2O) gave (−)-(1′*S*,3*S*)-**79** (R_f = 0.24, 106 mg, 69%) and a 1:2 mixture of (−)-**79** and (1′*S*,3*R*)-**80**. A second FC gave pure (1′*S*,3*R*)-**80** as a colorless oil (R_f = 0.14). Data for (−)-(1′*S*,3*S*)-**79**: colorless crystals, mp 97−98 °C (CH_2Cl_2/light petroleum ether); $[\alpha]_D^{25} = -23$ (c = 1.02, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.05−6.96 (m, 2H), 5.53 (ddq, 1H, J = 9.2, 5.0, 1.3), 4.94 (q, 1H, J = 6.7), 4.50 (dd, 1H, J = 8.3, 4.4), 3.91 (dd, 1H, J = 15.1, 9.2), 3.90 (m, 1H), 3.30 (dd, 1H, J = 15.1, 5.0), 3.10 (m, 1H), 2.96 (dd, 1H, J = 17.2, 8.3), 2.86 (dd, 1H, J = 17.2, 4.4), 2.85 (sept, 1H, J = 6.9), 2.76 (s, 3H), 1.85 (d, 3H, J = 1.3), 1.82 (m, 1H), 1.50 (d, 3H, J = 6.7), 1.35−1.12 (m, 12H), 1.25 (d, 6H, J = 6.9), 0.90−0.80 (m, 4H). Data for (1′*S*,3*R*)-**80**: colorless oil; $[\alpha]_D^{25} = -24$ (c = 0.65, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.07−6.92 (m, 2H), 5.42 (tq, 1H, J = 7.6, 1.3), 4.94 (q, 1H, J = 6.7), 4.76 (dd, 1H, J = 7.8, 4.9), 3.76 (m, 1H), 3.72 (dd, 1H, J = 14.3, 7.6), 3.58 (dd, 1H, J = 14.3, 7.6), 3.11 (m, 1H), 3.03 (dd, 1H, J = 16.0, 7.8), 2.84 (sept, 1H, J = 6.9), 2.69 (dd, 1H, J = 16.0, 4.9), 2.65 (s, 3H), 2.00 (m, 1H), 1.72 (d, 3H, J = 1.3), 1.48 (d, 3H, J = 6.7), 1.35−1.15 (m, 12 H), 1.24 (d, 6H, J = 6.9), 0.96−0.83 (m, 4H).

(−)-(3*S*,4*Z*)-4-Methyl-6-(methylsulfonyl)-3-[(*S*)-1-(2,4,6-triisopropylphenyl)ethoxy]hex-4-enal ((−)-(1′*S*,3*S*)-83). The procedure was the same as for the preparation of (−)-**73** and (−)-**74**, starting from (+)-**55** (48 mg, 0.15 mmol) and vinyloxytrimethylsilane (**82**, 0.11 mL, 0.75 mmol) and using $Yb(OSO_2CF_3)_3$ (73 mg, 0.12 mmol) as promoter. Reaction time was 16 h at −78 °C. FC (24:1 CH_2Cl_2/Et_2O) gave a first fraction (20 mg) containing a 6.1:1 mixture of (−)-**83**/**84** + **85**. A second fraction gave (+)-**55** (18 mg). Crystallization of the first fraction from Et_2O/pentane gave pure (−)-**83** (48% yield, considering the recovery of (+)-**55**): colorless solid, mp 111.5−112 °C; $[\alpha]_D^{25} = -30$ (c = 1.0, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.69 (t, 1H, J = 1.9), 7.08−6.92 (m, 2H), 5.52 (tq, 1H, J = 7.9, 1.2), 4.95 (q, 1H, J = 6.8), 4.56 (t, 1H, J = 6.5), 3.86 (m, 1H), 3.45 (dd, 1H, J = 14.6, 7.9), 3.32 (dd, 1H, J = 14.6, 7.9), 3.10 (m, 1H), 2.86 (sept, 1H, J = 6.9), 2.76 (s, 3H), 2.75 (dd, 1H, J = 6.5, 1.9), 2.73 (dd, 1H, J = 6.5, 1.9), 1.87 (d, 3H, J = 1.2), 1.52 (d, 3H, J = 6.8), 1.35−1.04 (m, 12H), 1.25 (d, 6H, J = 6.9).

(3*S*,4*E*)- and (3*R*,4*E*)-4-Methyl-6-(methylsulfonyl)-3-[(*S*)-1-[2,4,6-triisopropylphenyl)ethoxy]hex-4-enal (84 and 85). The procedure was the same as for the preparation of (−)-**73** + (−)-**74** starting from (+)-**75** (100 mg, 0.318 mmol) and **82** (0.7 mL, 4.8 mmol) and using $(CF_3SO_2)_2NH$ (0.5 M in CH_2Cl_2, 0.12 mL, 0.06 mmol) as promoter (−78 °C, 2 h). FC (29:1 CH_2Cl_2/Et_2O) gave a colorless oil containing a 4:1 mixture (32 mg, 32%) of **84** and **85**. Crystallization from Et_2O/pentane gave pure **84** (or **85**). Major diastereomer: mp 105−107 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.83 (t, 1H, J = 2.0), 7.05−6.90 (m, 2H), 5.72 (tq, 1H, J = 8.4, 1.2), 4.97 (q, 1H, J = 6.7), 4.54 (dd, 1H, J = 8.4, 4.4), 3.72 (m, 1H), 3.72 (d, 1H, J = 8.4), 3.71 (d, 1H, J = 8.4), 3.07 (m, 1H), 2.83 (sept, 1H, J = 6.9), 2.76 (ddd, 1H, J = 16.1, 8.4, 2.0), 2.75 (s, 3H), 2.55 (ddd, 1H, J = 16.1, 4.4, 2.0), 1.63 (d, 3H, J = 1.2), 1.51 (d, 3H, J = 6.7), 1.29−1.16 (m, 12 H), 1.27 (d, 6H, J = 6.9). Minor diastereomer: ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.62 (t, 1H, J = 2.4), 7.05−6.90 (m, 2H), 5.66 (tq, 1H, J = 8.6, 1.2), 5.00 (q, 1H, J = 6.7), 4.18 (t, 1H, J = 6.5), 3.86 (m, 1H), 3.77 (d, 1H, J = 8.6), 3.75 (d, 1H, J = 8.6), 3.15 (m, 1H), 2.82 (sept, 1H, J = 6.9), 2.83 (s, 3H), 2.85−2.74 (m, 2H), 1.81 (d, 3H, J = 1.2), 1.52 (d, 3H, J = 6.7), 1.29−1.16 (m, 18H).

(−)-(3*S*,4*Z*)-1-Cyclopropyl-3-hydroxy-4-methyl-6-(methylsulfonyl)hex-4-en-1-one ((−)-81). A mixture of (−)-**79** (46 mg, 0.096 mmol), CD_2Cl_2 (1.5 mL), and CF_3COOH (0.1 mL) was stirred at 20 °C for 25 min (control by ^{1}H NMR). A saturated aqueous solution of $NaHCO_3$ (30 mL) was added, and the mixture was extracted with CH_2Cl_2 (20 mL, 3 times). The combined organic extracts were dried ($MgSO_4$), and the solvent was evaporated. FC (1:10 EtOAc/CH_2Cl_2) gave a white solid (20 mg, 85%, R_f = 0.19): mp 78−80 °C; $[\alpha]_D^{25} = -18$ (c = 1.0, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.39 (tq, 1H, J = 8.2, 1.5), 4.89 (dd, 1H, J = 8.4, 4.0), 3.90 (d, 2H, J = 8.2), 3.23 (s, 1H), 2.87 (dd, 1H, J = 17.5, 8.4), 2.82 (s, 3H), 2.81 (dd, 1H, J = 17.5, 4.0), 1.96 (m, 1H), 1.84 (d, 3H, J = 1.5), 1.04−0.90 (m, 4H).

(+)-(1*R*,3*S*,4*Z*)-1-Cyclopropyl-4-methyl-6-(methylsulfonyl)hex-4-en-1,3-diol ((+)-86). A 1 M solution of Et_2BOMe in THF (0.1 mL, 0.1 mmol) was added slowly (syringe) to a

stirred solution of (−)-**81** (17 mg, 0.035 mmol) in anhydrous 4:1 THF/MeOH (0.5 mL) cooled to −78 °C under an Ar atmosphere. After stirring at −78 °C for 15 min, $NaBH_4$ (3 mg, 0.1 mmol) was added. After stirring at −78 °C for 5 h, AcOH (0.3 mL) was added, and the mixture was allowed to warm to 0 °C. A saturated aqueous solution of NH_4Cl (5 mL) was added, and the mixture was extracted with CH_2Cl_2 (5 mL, twice). The combined organic extracts were dried ($MgSO_4$), and the solvent was evaporated to dryness. The residue was taken up in MeOH (10 mL) and heated under reflux for 45 min. Solvent evaporation and FC (EtOAc) gave a colorless oil (8 mg, 83%, $R_f = 0.20$): $[\alpha]_D^{25} = +2.0$ ($c = 0.75$, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.39 (q, 1H, J = 8.2, 1.3), 4.66 (dd, 1H, J = 9.2, 3.8), 3.99 (dd, 1H, J = 14.2, 8.2), 3.90 (dd, 1H, J = 14.2, 8.2), 3.55 (br. s, 1H), 3.06 (ddd, 1H, J = 10.8, 8.6, 2.5), 2.90 (s, 3H), 2.90 (br. s, 1H), 1.90 (ddd, 1H, J = 14.3, 10.8, 9.2), 1.82 (d, 3H, J = 1.3), 1.80 (ddd, 1H, J = 14.3, 3.8, 2.5), 0.95 (m, 1H), 0.54 (m, 2H), 0.33−0.22 (m, 2H).

10:1 Mixture of (2′*Z*,4*S*,6*S*)- and (2′*Z*,4*S*,6*R*)-6-Cyclopropyl-2,2-dimethyl-4-[(4-methylsulfonyl)but-2-en-2-yl]-1,3-dioxane ((2′*Z*,4*S*,6*S*)-87 and (2′*Z*,4*S*,6*R*)-87). A mixture of $Me_4NBH(OAc)_3$ (265 mg, 1 mmol), MeCN (0.4 mL), and AcOH (0.15 mL) was stirred at 20 °C for 15 min. After cooling to −40 °C a solution of (−)-**81** (25 mg, 0.1 mmol) in MeCN (1.5 mL) was added slowly. After stirring at −40 °C for 48 h, H_2O (10 mL) and CH_2Cl_2 (10 mL) were added. The organic layer was washed with a saturated aqueous solution of $NaHCO_3$ (10 mL, twice). The aqueous layers were extracted with CH_2Cl_2 (10 mL, 5 times). The combined organic extracts were dried ($MgSO_4$). Solvent evaporation and FC (EtOAc) gave a colorless oil (16 mg, 64%, $R_f = 0.10$), a 10:1 mixture of *anti*- and *syn*-1,3-diol. A total of 7 mg (0.028 mmol) of this mixture was dissolved in 2,2-dimethoxypropane (0.8 mL) and acetone (0.2 mL). After the addition of pyridinium *p*-toluenesulfonate (2 mg) the mixture was stirred at 20 °C for 2 h. The mixture was poured into a saturated aqueous solution of $NaHCO_3$ (10 mL) and extracted with CH_2Cl_2 (10 mL, 3 times). The combined organic extracts were dried ($MgSO_4$). Solvent evaporation and FC (12:1 CH_2Cl_2/EtOAc) gave a colorless oil (7 mg, 86%, R_f = 0.30), a 10:1 mixture of *anti*- and *syn*-1,3-diol acetonide, which are hydrolyzed in a few hours in $CDCl_3$ solution. Data for (2′*Z*,4*S*,6*S*)-**87**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.40 (tq, 1H, J = 8.5, 1.1), 4.62 (dd, 1H, J = 8.8, 7.3), 4.02 (dd, 1H, J = 14.3, 8.5), 3.88 (dd, 1H, J = 14.3, 8.5), 3.11 (dt, 1H, J = 8.7, 7.0), 2.86 (s, 3H), 1.90 (m, 2H), 1.88 (d, 3H, J = 1.1), 1.41, 1.36 (2s, 6H), 0.95 (m, 1H), 0.57 (m, 2H), 0.31−0.20 (m, 2H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 145.2, 112.4, 100.5, 72.0, 66.8, 54.1, 39.3, 36.4, 24.9 (Me-C(2)), 24.8 (Me-C(2)) 20.3, 15.5, 3.4, 2.0. Data for (2′*Z*,4*S*,6*R*)-**87**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.43 (tq, 1H, J = 8.5, 1.1), 4.56 (dd, 1H, J = 11.3, 2.6), 4.11 (dd, 1H, J = 14.4, 8.5), 3.97 (dd, 1H, J = 14.4, 8.5), 3.20 (td, 1H, J = 8.5, 3.1), 2.87 (s, 3H), 2.03 (dd, 1H, J = 14.4, 11.3, 3.1), 1.86 (d, 3H, J = 1.1), 1.72 (ddd, 1H, J = 14.4, 8.5, 2.6), 1.47, 1.43 (2s, 6H), 0.95 (m, 1H), 0.57 (m, 2H), 0.34 (m, 2H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 145.0, 113.5, 99.9, 74.0, 68.1, 53.4, 39.4, 34.7, 30.2 (Me-C(2)), 20.8, 19.5 (Me-C(2)), 16.1, 3.3, 2.3.

10:1 Mixture of (1*S*,3*S*,4*R*)- and (1*R*,3*S*,4*Z*)-1-Cyclopropyl-4-methyl-6-(methylsulfonyl)hex-4-en-1,3-diyl bis{[(*R*)-α-methoxy-α-trifluoromethylphenyl]acetate} ((1*S*,3*S*,4*Z*)-88 and (1*R*,3*S*,4*Z*)-88). The 10:1 mixture of 1,3-diols obtained above (5 mg, 0.02 mmol) was mixed with pyridine (0.5 mL), 4-(dimethylamino)pyridine (2 mg), and (*S*)-(α-methoxy-α-trifluoromethylphenyl)acetyl chloride (25 mg, 0.11 mmol). After stirring at 20 °C for 40 min, the solvent was evaporated in vacuo to dryness. FC (CH_2Cl_2) gave a colorless oil (13 mg, 96%, $R_f = 0.20$): ^{19}F NMR (376.7 MHz, $CDCl_3$, CCl_3F) δ −71.375 (s), −71.580 (s).

(−)-1,3,5-Triisopropyl-2-{1-(*S*)-[(1*E*)-2-methylpenta-1,3-dienyloxy]ethyl}benzene ((−)-89). A 1.6 M solution of BuLi in hexane (6.44 mL, 9.35 mmol) was added dropwise to a stirred solution of $(i\text{-Pr})_2NH$ (1.54 mL, 0.35 mmol) in anhydrous THF (30 mL) cooled to −78 °C under an Ar atmosphere. After stirring at 0 °C for 1 h, ethyltriphenylphosphonium bromide (3.21 g, 8.5 mmol) was added portionwise. After stirring at 20 °C for 2 h the mixture was cooled to 0 °C, and (−)-**57e** (2.45 g, 7.74 mmol) was added. After stirring at 0 °C for 2 h, ice-cold H_2O (100 mL) was added, and the mixture was extracted with light petroleum ether (50 mL, 3 times). The combined organic extracts were dried ($MgSO_4$), and the solvent was evaporated to dryness. The residue was taken up in light petroleum ether (50 mL). The precipitate (Ph_3PO) was filtered off. Solvent evaporation gave a white solid (2.365 g, 93%): mp 68−69.5 °C; $[\alpha]_D^{25} = -17$ ($c = 1.08$, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.03−7.01 (m, 2H), 6.11 (q, 1H, J = 1.2), 5.88 (dq, 1H, J = 15.2, 1.4), 5.41 (dq, 1H, J = 15.2, 6.6), 5.35 (q, 1H, J = 6.7), 3.54 (2m, 2H), 2.86 (sept, 1H, J = 6.9), 1.73 (d, 3H, J = 1.2), 1.70 (dd, 3H, J = 6.6, 1.4), 1.62 (d, 3H, J = 6.7), 1.28−1.20 (m, 12H), 1.25 (d, 6H, J = 6.9).

(3*RS*,4*Z*,6*SR*)- and (3*SR*,4*Z*,6*RS*)-4-Methyl-6-(methylsulfonyl)-1-phenyl-3-[(*RS*)-1-(2,4,6-triisopropylphenyl)-ethoxy]hept-4-en-1-one ((±)-90) and (±)-91). The procedure was the same as for the preparation of **17** starting from (±)-**9** (0.2 mL, 1 mmol) and (±)-**89** (50 mg, 0.15 mmol, made from (±)-**56e**) and using $(CF_3SO_2)_2NH$ (0.5 M in CH_2Cl_2, 60 μL, 0.03 mmol) and 0.5 g of SO_2 (−78 °C, 90 min for the oxyallylation step). FC (1:3 EtOAc/light petroleum ether) gave (±)-**90** (39 mg, 55%, $R_f = 0.22$) and (±)-**91** (22 mg, 31%, $R_f = 0.16$). Data for (±)-**90** (major): white crystals, mp 132−133.5 °C (Et_2O/pentane); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76−7.37 (m, 5H), 7.05−6.94 (m, 2H), 5.25 (dq, 1H, J = 10.7, 1.3), 5.17 (q, 1H, J = 6.8), 4.91 (t, 1H, J = 6.5), 4.40 (dq, 1H, J = 10.7, 6.8), 3.88, 3.21 (2m, 2H), 3.20 (d, 2H, J = 6.5), 2.90 (s, 3H), 2.86 (sept, 1H, J = 7.0), 1.88 (d, 3H, J = 1.3), 1.54 (d, 3H, J = 6.8), 1.43 (d, 3H, J = 6.8), 1.29−1.19 (m, 12 H), 1.24 (d, 6H, J = 7.0). Data for (±)-**91** (minor): white crystals, mp 138−140 °C (Et_2O/pentane); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00−7.42 (m, 5H), 6.98−6.91 (m, 2H), 5.20 (dq, 1H, J = 10.8, 1.3), 5.01 (q, 1H, J = 6.7), 4.93 (t, 1H, J = 7.4), 4.17 (dq, 1H, J = 10.8, 6.7), 3.65 (sept, 1H, J = 6.8), 3.54 (dd, 1H, J = 15.9, 7.4), 3.12 (sept, 1H, J = 6.8), 3.06 (dd, 1H, J = 15.9, 7.4), 2.83 (sept, 1H, J = 6.9), 2.42 (s, 3H), 1.78 (d, 3H, J = 1.3), 1.47 (d, 3H, J = 6.7), 1.27 (d, 3H, J = 6.7), 1.25−1.06 (m, 18H).

(4*RS*,5*Z*,7*SR*)- and (4*SR*,5*Z*,7*RS*)-5-Methyl-7-(methylsulfonyl)-4[(*RS*)-1-(2,4,6-triisopropylphenyl)ethoxy]oct-5-en-2-one ((±)-92) and (±)-93). The procedure was the same as for the preparation of **17** starting from **10** (0.3 mL, 1.9 mmol) and (±)-**89** (56 mg, 0.17 mmol), SO_2 (0.5 g) and using $(CF_3SO)_2NH$ (0.03 mmol), oxyallylation step at −78 °C for 2 h. FC (1:2 EtOAc/light petroleum ether) gave (±)-**92** (48 mg, 60%, $R_f = 0.24$) and (±)-**93** (29 mg, 37%, $R_f = 0.12$). Data for (±)-**92** (major): white crystals, mp 134−136 °C (Et_2O/pentane); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.21−6.94 (m, 2H), 5.27 (dq, 1H, J = 10.8, 1.4), 5.08 (q, 1H, J = 6.8), 4.66 (dd, 1H, J = 7.4, 5.6), 4.40 (dq, 1H, J = 10.8, 6.8), 3.83, 3.18 (2m, 2H), 2.89 (s, 3H), 2.84 (sept, 1H, J = 6.6), 2.73 (dd, 1H, J = 16.7, 5.6), 2.65 (dd, 1H, J = 16.7, 7.4), 2.01 (s, 3H), 1.84 (d, 3H, J = 1.4), 1.50 (d, 3H, J = 6.8), 1.48 (d, 3H, J = 6.8), 1.28−1.22 (m, 12H), 1.25 (d, 6H, J = 6.6). Data for (±)-**93** (minor): white crystals, mp 129−131 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.00−6.91 (m, 2H), 5.23 (dq, 1H, J = 10.5, 1.3), 4.98 (q, 1H, J = 6.8), 4.79 (dd, 1H, J = 7.1, 5.9), 4.12 (dq, 1H, J = 10.5, 6.8), 3.73, 3.14 (2 sept, 2H, J = 6.8), 2.93 (dd, 1H, J = 16.3, 7.1), 2.84 (sept, 1H, J = 6.8), 2.54 (dd, 1H, J = 16.3, 5.9), 2.51 (s, 3H), 2.22 (s, 3H), 1.69 (d, 3H, J = 1.3), 1.49 (d, 3H, J = 6.8), 1.24 (d, 3H, J = 6.8), 1.26−1.17 (m, 12 H), 1.22 (d, 6H, J = 6.8).

(−)-(5*S*,6*Z*,8*R*)- and (5*R*,6*Z*,8*S*)-2,2,6-Trimethyl-8-(methylsulfonyl)-5-[(*S*)-1-(2,4,6-triisopropylphenyl)ethoxy]-non-6-en-3-one ((−)-94) and 95). The procedure was the same as for the preparation of **17**, starting from (−)-**89** (48 mg, 0.15 mmol) and **11** (0.15 mL, 0.67 mmol) and using 0.5 M $(CF_3SO_2)NH$ (6 μL, 0.03 mmol) in CH_2Cl_2 and 0.5 g of SO_2. Oxyallylation was at −100 to −92 °C for 2 h. FC (EtOAc/light petroleum ether 1:4) gave (−)-**94** (55 mg, 74%, $R_f = 0.14$) and a 1:1 mixture of (−)-**94** + **95** (9 mg). Pure **95** was obtained by FC (1:4 EtOAc/light petroleum ether): 4 mg (5%). Data for (−)-**94**: colorless crystals, mp 101−103 °C (Et_2O/pentane); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.03−6.93 (m, 2H), 5.23 (dq, 1H, J = 10.8, 1.4), 5.08 (q, 1H, J = 6.8), 4.75 (dd, 1H, J = 8.6, 4.3),

4.45 (dq, 1H, J = 10.7, 6.8), 3.87, 3.20 (2m, 2H), 2.89 (s, 3H), 2.87 (sept, 1H, J = 6.9), 2.79 (dd, 1H, J = 17.6, 8.6), 2.62 (dd, 1H, J = 17.6, 4.3), 1.83 (d, 3H, J = 1.4), 1.50 (d, 3H, J = 6.8), 1.46 (d, 3H, J = 6.8), 1.29−1.15 (m, 12H), 1.25 (d, 6H, J = 6.9), 0.95 (s, 9H). Data for **95**: colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.00−6.92 (m, 2H), 5.16 (dq, 1H, J = 10.6, 1.3), 4.95 (q, 1H, J = 6.6), 4.82 (t, 1H, J = 6.3), 4.18 (dq, 1H, J = 10.6, 6.7), 3.76, 3.15 (2 sept, 2H, J = 6.8), 3.05 (dd, 1H, J = 17.1, 6.3), 2.84 (sept, 1H, J = 6.8), 2.63 (dd, 1H, J = 17.1, 6.3), 2.42 (s, 3H), 1.72 (d, 3H, J = 1.3), 1.50 (d, 3H, J = 6.6), 1.29 (d, 3H, J = 6.7), 1.27−1.14 (m, 18H), 1.16 (s, 9H).

(3*RS*,4*Z*,6*SR*)- and (3*SR*,4*Z*,6*RS*)-1-Cyclopropyl-4-methyl-6-(methylsulfonyl)-3-[(*RS*)-1-(2,4,6-triisopropylphenyl)-ethoxy]hept-4-en-1-one ((±)-96) and (±)-97). The procedure was the same as for the preparation of **17** starting from (±)-**89** (56 mg, 0.17 mmol) and **78** (0.1 mL, 0.5 mmol) and using 5 M $(CF_3SO_2)NH$ in CH_2Cl_2 (60 μL, 0.03 mmol) 0.5 g SO_2. Oxyallylation was at −78 °C for 1 h. FC (1:3 EtOAc/light petroleum ether) gave (±)-**96** (47 mg, 56%, R_f = 0.16) and (±)-**97** (33 mg, 40%, R_f = 0.09). Data for (±)-**96** (major): white crystals, mp 120−122 °C (Et_2O/pentane); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.03−6.94 (m, 2H), 5.26 (dq, 1H, J = 10.8, 1.4), 5.09 (q, 1H, J = 6.7), 4.71 (dd, 1H, J = 7.8, 5.3), 4.40 (dq, 1H, J = 10.8, 6.8), 3.84, 3.18 (2m, 2H), 2.89 (s, 3H), 2.88 (sept, 1H, J = 6.9), 2.83 (dd, 1H, J = 16.3, 5.3), 2.77 (dd, 1H, J = 16.3, 7.8), 1.86 (d, 3H, J = 1.4), 1.77 (m, 1H), 1.50 (d, 3H, J = 6.7), 1.45 (d, 3H, J = 6.8), 1.28−1.22 (m, 12H), 1.24 (d, 6H, J = 6.9), 1.12−0.74 (m, 4H). Data for (±)-**97** (minor): colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.00−6.91 (m, 2H), 5.22 (dq, 1H, J = 10.7, 1.2), 4.97 (q, 1H, J = 6.6), 4.79 (dd, 1H, J = 7.3, 5.7), 4.13 (dq, 1H, J = 10.7, 6.8), 3.78, 3.08 (2 sept, 2H, J = 6.8), 3.06 (dd, 1H, J = 15.8, 7.3), 2.84 (sept, 1H, J = 6.8), 2.63 (dd, 1H, J = 15.8, 5.7), 2.47 (s, 3H), 2.03 (m, 1H), 1.72 (d, 3H, J = 1.2), 1.48 (d, 3H, J = 6.6), 1.26 (d, 3H, J = 6.8), 1.25−1.15 (m, 12H), 1.21 (d, 6H, J = 6.8), 1.09−0.95 (m, 4H).

(−)-(4*S*,5*S*,6*Z*,8*R*)- and (−)-(4*R*,5*S*,6*Z*,8*R*)-4-Dimethyl-8-(methylsulfonyl)-5-[(*S*)-1-(2,4,6-triisopropylphenyl)-ethoxy]non-6-en-3-one ((−)-99) and (−)-100). The procedure was the same as for the preparation of **17** starting from (−)-**89** (52 mg, 0.16 mmol) and (*Z*)-3-trimethylsilyloxypent-3-ene[35] (**98**, 77 mg, 0.48 mmol) and using $(CF_3SO_2)_2NH$ (0.03 mmol) and SO_2 (0.5 g). Oxyallylation was at −90 °C for 1h, then −78 °C for 3 h. FC (1:3 EtOAc/light petroleum ether) gave (−)-**99** (49 mg, 63%, R_f = 0.16) and (−)-**100** (17 mg, 22%, R_f = 0.09). Data for (−)-**99**: colorless crystals, mp 144−146 °C (MeOH); $[\alpha]_D^{25}$ = −107 (c = 0.75, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.03−6.92 (m, 2H), 5.18 (dq, 1H, J = 10.7, 1.1), 5.12 (q, 1H, J = 6.7), 4.25 (d, 1H, J = 9.6), 4.19 (dq, 1H, J = 10.7, 6.8), 3.81, 3.17 (2 sept, 2H, J = 6.9), 2.88 (s, 3H), 2.87 (sept, 1H, J = 6.9), 2.87 (m, 1H), 2.47 (dq, 1H, J = 18.5, 7.2), 2.31 (dq, 1H, J = 18.5, 7.2), 1.91 (d, 3H, J = 1.1), 1.51 (d, 3H, J = 6.7), 1.43 (d, 3H, J = 6.8), 1.27−1.20 (m, 12H), 1.25 (d, 6H, J = 6.9), 0.98 (d, 3H, J = 6.9), 0.95 (t, 3H, J = 7.2). Data for (−)-**100**: colorless crystals, mp 143−145 °C (Et_2O/light petroleum ether); $[\alpha]_D^{25}$ = −19 (c = 0.45, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.27−6.89 (m, 2H), 5.40 (dq, 1H, J = 10.8, 1.1), 4.96 (q, 1H, J = 6.7), 4.39 (d, 1H, J = 9.7), 4.23 (dq, 1H, J = 10.8, 6.9), 3.72, 3.11 (2 sept, 2H, J = 6.9), 2.91 (s, 3H), 2.89 (sept, 1H, J = 6.9), 2.81 (dq, 1H, J = 9.7, 7.1), 2.20 (dq, 1H, J = 18.6, J = 7.1), 2.09 (dq, 1H, J = 18.9, 7.1), 1.91 (d, 3H, J = 1.1), 1.50 (d, 3H, J = 6.9), 1.49 (d, 3H, J = 6.7), 1.26−1.11 (m, 12H), 1.22 (d, 6H, J = 6.9), 0.79 (d, 3H, J = 7.1), 0.49 (t, 3H, J = 7.1).

(3*RS*,4*Z*,6*SR*)-3-Hydroxy-4-methyl-6-(methylsulfonyl)-1-phenylhept-4-en-1-one ((±)-101). The procedure was the same as for the preparation of (−)-**81** starting from (±)-**90** (29 mg, 0.057 mmol). FC (1:1 EtOAc/CH_2Cl_2) gave a colorless oil (15 mg, 95%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.17 (dq, 1H, J = 10.0, 1.0), 4.92 (dd, 1H, J = 7.3, 5.6), 4.33 (dq, 1H, J = 10.0, 6.8), 3.17 (br. s, 1H), 2.90 (dd, 1H, J = 17.8, 7.3), 2.86 (s, 3H), 2.74 (dd, 1H, J = 17.8, 5.6), 1.81 (d, 3H, J = 1.0), 1.49 (d, 3H, J = 6.8), 1.16 (s, 9H).

(−)-(5*S*,6*Z*,8*R*)-5-Hydroxy-2,2,6-trimethyl-8-(methylsulfonyl)non-6-en-3-one ((−)-102). The procedure was the same as for the preparation of (−)-**81** starting from (−)-**94** (29 mg, 0.057 mmol). FC (1:1 EtOAc/CH_2Cl_2) gave a colorless oil (15 mg, 95%, R_f = 0.40): $[\alpha]^{25}_D$ = −72 (c = 0.85, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.17 (dq, 1H, J = 10.0, 1.0), 4.92 (dd, 1H, J = 7.3, 5.6), 4.33 (dq, 1H, J = 10.0, 6.8), 3.17 (br. s, 1H), 2.90 (dd, 1H, J = 17.8, 7.3), 2.86 (s, 3H), 2.74 (dd, 1H, J = 17.8, 5.6), 1.81 (d, 3H, J = 1.0), 1.49 (d, 3H, J = 6.8), 1.16 (s, 9H).

(−)-(4*S*,5*S*,6*Z*,8*R*)-5-Hydroxy-4,6-dimethyl-8-(methylsulfonyl)non-6-en-3-one ((−)-103). The procedure was the same as for the preparation of (−)-**81** starting from (−)-**99** (9 mg, 0.018 mmol). FC (1:1 EtOAc/CH_2Cl_2) gave a colorless oil (5 mg, 99%, R_f = 0.32): $[\alpha^{25}_D$ = −91 (c = 0.85, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.08 (dq, 1H, J = 9.7, 0.8), 4.62 (d, 1H, J = 9.2), 4.28 (dq, 1H, J = 9.7, 6.8), 2.92 (dq, 1H, J = 9.2, 7.0), 2.85 (s, 3H), 2.58 (dq, 1H, J = 21.8, 7.3), 2.36 (dq, 1H, J = 21.8, 7.3), 1.79 (d, 3H, J = 0.8), 1.64 (br. s, 1H), 1.49 (d, 3H, J = 6.8), 1.26 (d, 3H, J = 7.0), 1.03 (t, 3H, J = 7.3).

(−)-(4*R*,5*S*,6*Z*,8*R*)-5-Hydroxy-4,6-dimethyl-8-(methylsulfonyl)non-6-en-3-one ((−)-104). The procedure was the same as for the preparation of (−)-**81** starting from (−)-**100** (15 mg, 0.030 mmol). FC (1:1 EtOAc/CH_2Cl_2) gave a colorless oil (7 mg, 89%, R_f = 0.28): $[\alpha^{25}_D$ = −40 (c = 1.3, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.25 (dq, 1H, J = 10.0, 1.3), 4.59 (d, 1H, J = 10.0), 4.14 (dq, 1H, J = 10.0, 6.8), 2.86 (m, 1H), 2.61 (m, 2H), 1.84 (d, 1H, J = 1.3), 1.63 (br. s, 1H), 1.50 (d, 3H, J = 6.8), 1.08 (t, 3H, J = 7.3), 0.87 (d, 3H, J = 7.1).

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Supporting Information Available: Detailed ^{1}H and ^{13}C NMR spectra and signal assignments, further optical rotation data, and UV, IR, and MS spectra as well as the ORTEP representations of all structures reported in this work. This material is available free of charge via the Internet at http://pubs.acs.org. Complete X-ray data has been deposited with the Cambridge Crystallographic Data Centre for **16**, CCDC-157582; **19**, CCDC-140985; **20**, CCDC-157583; **22**, CCDC-157584; **30**, CCDC-157585; **45**, CCDC-157586; (−)-**66**, CCDC-134999; (−)-**73**, CCDC-135000; (−)-**79**, CCDC-157575; (±)-**83**, CCDC-157576; (±)-**90**, CCDC-157577; (±)-**91**, CCDC-157578; (±)-**92**, CCDC-157579; (−)-**94**, CCDC-157580; (−)-**99**, CCDC-157581.

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