Asymmetric Synthesis of Isocarbacyclin Based on the Olefination-Isomerization-Coupling Process with Chiral Sulfoximines

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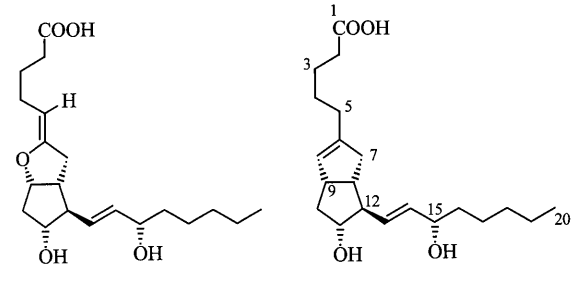
An asymmetric synthesis of isocarbacyclin (**2**) was achieved from ketone **7** by the olefination-isomerization-coupling process with chiral sulfoximines. The vinylic sulfoximine **6** (≥98% de) was prepared from ketone **7** and lithiosulfoximine **8** by an asymmetric olefination via an addition-elimination process. Model experiments, aiming at a rationalization of the asymmetric induction in the elimination of β-hydroxysulfoximines, with ketone **12** and lithiosulfoximine *ent*-**8** revealed formation of the silyl ether **15** as an intermediate which eliminated $LiOSiMe_3$ upon reaction with *n*BuLi under formation of (*S*,*Z*)-alkene **17** (≥98% de). Reaction of the C,O-dilithiosulfoximine **19** with $ClSiMe_3$ led to elimination of $LiOSiMe_3$ and also gave **17** (≥98% de). Methylation of **19**, however, furnished the corresponding α-methyl-substituted β-hydroxysulfoximines, **20** and **21**, in a ratio of 75:25. Isomerization of sulfoximine **6** gave the allylic sulfoximine **5** (96% de) whose absolute configuration was determined by X-ray structure analysis. Cross-coupling reaction of **5** with cuprate **23** delivered with high regioselectivity alkene **25**. A similar reaction of **5** with the organocopper reagent **26**, which was prepared from (benzyloxy)methylmagnesium chloride, in the presence of $BF_3 \cdot OEt_2$ and halide afforded alkene **27**. Ketone **28** is a potential starting material for the asymmetric synthesis of 3-oxaisocarbacyclin. Besides alkenes **25** and **27** sulfinamide **24** (97% ee), whose conversion to **8** has been already described, was isolated in 90% yield. The key step in the sequence leading to the construction of the ω-side chain was the deprotonation of ketone **4b** with a complex of lithium (*R*,*R*)-bis(α-phenylethyl)amide and lithium chloride, **29** · LiCl, which gave enolate **3**. The use of *ent*-**29** · LiCl in the deprotonation of **4b** afforded the isomeric enolate **30**. Enolates **3** and **30** were trapped as the silyl ethers **31** (90% ie) and **32** (92% ie), respectively. The aldol reaction of **3** with (*E*)-octenal proceeded highly selective in regard to C-12 but unselective in regard to C-13 and gave aldols **34** (42%) and *epi*-**34** (36%). It was at the stage of the aldol reaction of **3** where the unwanted diastereomers **35** and *epi*-**35**, stemming from **30**, could be separated. Reduction of ketones **34** and *epi*-**34** afforded diols **36** (≥98% de) and **37** (93% de), respectively. The Pd-catalyzed rearrangement of the allylic diacetates **39** and **41** was highly stereoselective (≥98% de) but incomplete and led to formation of mixtures of **40** and **39** as well as of **42** and **41** in ratios of 84:16 and 86:14, respectively. A two-step oxidation of alcohol **43**, contaminated by 5% of the isomeric alcohol stemming from acetate **39**, via aldehyde **44** gave after purification by crystallization isocarbacyclin (**2**) in 38% yield. Diol **45**, having the undesired (15*R*) configuration, was selectively oxidized with dichlorodicyanobenzoquinone to enone **46** (81%).

Introduction

Prostacyclin (**1**) (Figure 1) is an extremely potent vasodilator and inhibitor of blood platelet aggregation[1], which has been implicated in the regulation of vascular tone and haemostasis[2]. Recent studies have revealed that the prostacyclin receptor[3] is not only expressed in peripheral organs but also in the central nervous system[4]. This finding suggests that **1** has also important roles in neuronal activity. Due to the inherent chemical instability of **1** clinical application of prostacyclin is, however, severely hampered. This experience has stimulated intensive efforts towards the identification of chemically and metabolically stable analogs of **1** for development as clinically effective antithrombic agents[5]. Amongst the most potent analogs is isocarbacyclin (**2**)[6] which is currently being developed as a highly active liposome formulation for application in myocardial infarction, cerebrovascular disorder and chronical arterial obstruction[7][5b]. Isocarbacyclin and its side chain-modified derivatives have found recently much use as chemically stable and selective agents for a study of the role of prostacyclin in the brain[4][8]. Due to its high chemical stability and antiaggregatory potency **2** has been the

Figure 1. Prostacyclin (**1**) and isocarbacyclin (**2**)



  1434–193X/98/0707–1319 $ 17.50+.50/0

target of considerable synthetic efforts which have led to several total syntheses[6][9]. We now report in continuation of our previous efforts in this field[10] an asymmetric synthesis of **2** from *cis*-bicyclo[3.3.0]octan-2,5-dione[11] by a new route which is based on the olefination-isomerization-coupling process with chiral sulfoximines[10b][12]. A special feature of this route is that access to the very potent 3-oxaisocarbacyclins[10c][13] is provided as well.

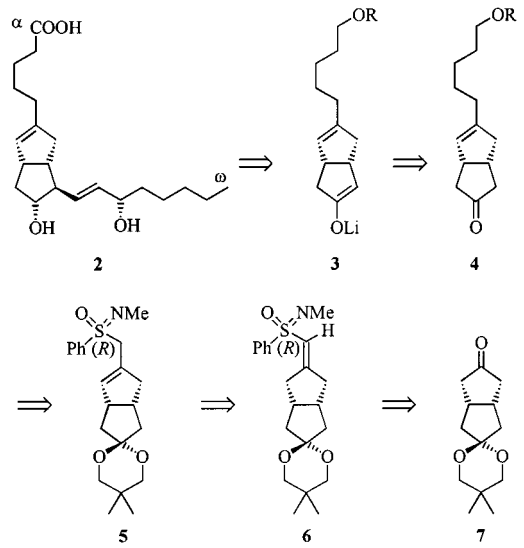
Results and Discussion

Retrosynthetic Analysis

The choice of the readily available ketone **7**[11] as the starting material for the synthesis of **2** poses three challenges. The main challenge is the enantioselective attachment of either the α- or the ω-side chain to the bicyclic skeleton and the other challenges are the regioselective introduction of the respective other side chain and of the endocyclic double bond. Figure 2 shows the retrosynthetic analysis of **2** on which the synthetic strategy was based. Thus, disassembly of the ω-side chain in **2** at C-12 (prostaglandin numbering) led, retrosynthetically, to the lithium enolate **3** and from there to ketone **4**. The highly regioselective deprotonation of an analogous chiral bicyclic ketone, carrying the double bond in the exocyclic position, by using lithium (*R*,*R*)-bis(α-phenylethyl)amide[14] suggested the possibility of a similar reaction of **4** and, thus, its selective conversion to **3**. Enolate **3** should allow for the stereoselective introduction of the ω-side chain in two steps via an aldol reaction with (*E*)-2-octenal and a Pd-catalyzed transposition of the allylic hydroxy group in the aldol from C-13 to C-15[15]. We have successfully applied such a sequence in asymmetric syntheses of 3-oxacarbacyclin and 3-oxaisocarbacyclin[10c]. Disassembly of the α-side chain in **4** gave the allylic sulfoximine **5**. Because of the highly selective cross-coupling reaction of allylic sulfoximines with cuprates in the α-position[10b][12], we were confident that reaction of **5** with a suitable cuprate would furnish the ketal derivative of **4**[10a]. Isomerization of the double bond in **5** led, retrosynthetically, to the vinylic sulfoximine **6** and oxidative cleavage of the double bond in the latter finally gave the prochiral ketone **7**. The highly stereoselective three-step conversion of an analogous but chiral bicyclic ketone to the corresponding allylic sulfoximine by using (*R*)-*S*-lithiomethyl-*N*-methyl-*S*-phenylsulfoximine[10b][16] as reagent (cf. Figure 3) suggested that the asymmetric synthesis of intermediate **5** from **7** should be feasible[17]. The conversion of **7** to **5** is closely related to the more general theme of the asymmetric olefination of ketones which has attracted much attention in recent years[14a][18].

We have already described a "chemical-enzymatic" asymmetric synthesis of **4** from dimethyl *cis*-1,2-cyclohexene dicarboxylate which relies on a radical-initiated 5-*exo*-*dig*-cyclization for the construction of the bicyclic frame-work and on a cross-coupling reaction of an allylic acetate for the construction of the α-side chain[10a]. However, because of the step-wise construction of the bicyclic ring skeleton from the cyclohexanoid precursor, this synthesis of **4** requires too many steps to be useful for the large scale synthesis of **4**. Because of the availability of *cis*-bicyclo[3.3.0]-octan-2,5-dione in two steps from glyoxal and dimethyl acetonedicarboxylate on a large scale[11], synthesis of **4** from **7**, as outlined above, would be more attractive.

Figure 2. Retrosynthetic analysis of **2**



Asymmetric Olefination and Synthesis of the Allylic Sulfoximine

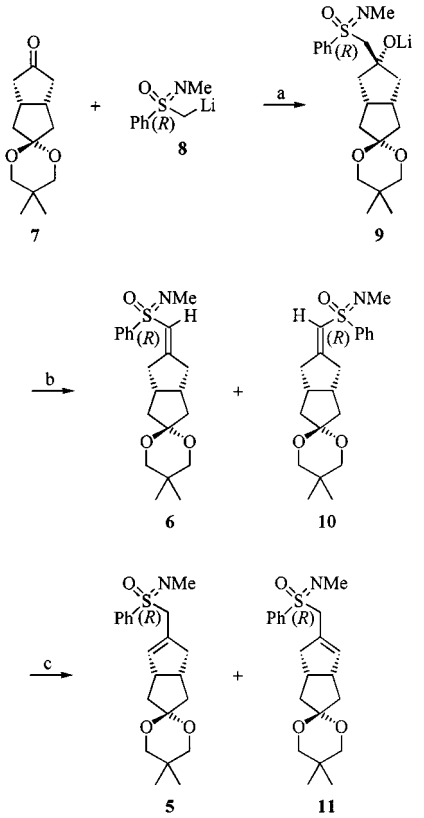
Reaction of ketone **7** with lithiosulfoximine **8**[19], which was prepared from readily available (*R*)-*N*,*S*-dimethyl-*S*-phenylsulfoximine[20], in THF at −78°C gave the lithium alkoxide **9**, which was not isolated but consecutively treated with $ClSiMe_3$ and *n*BuLi to afford, after chromatography, the vinylic sulfoximine **6** (≥98% de) in 86% yield and the allylic sulfoximines **5** and **11** in 3% and 1% yield, respectively (Scheme 1). Formation of the diastereomeric alkene **10** could not be detected by ^{1}H-NMR spectroscopy.

The (*E*) configuration was assigned to **6** in analogy to that of the vinylic sulfoximine **II** (Figure 3), which was obtained from **I** and **8** in a similar manner as **6** with high diastereoselectivity and whose configuration was unequivocally determined by NOE experiments[10b][16].

Isomerization of **6** upon treatment with 5 equivalents of LiOMe in a toluene/THF/*n*-hexane mixture delivered a mixture of the allylic sulfoximine **5** and **11** in a ratio of 50:1 (HPLC) in 94% yield. MPLC of this mixture afforded the key intermediate **5** in 73% yield from **7**. Isolation and purification of **6** are not required for the synthesis of **5**. The conversion of **7** to **5** can be carried out instead with equal success in a one-pot version. The structure of **5** was determined by X-ray analysis[21] (Figure 4) which showed the bicyclic alkene to have the absolute configuration necessary for the synthesis of **2**.

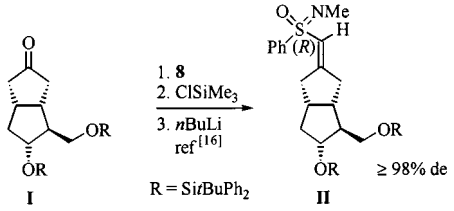
The highly selective conversion of **6** to **5** by LiOMe can be explained by a prior coordination of LiOMe to the N atom of the sulfoximine group in **6** followed by an intramolecular deprotonation in syn position under formation of the corresponding sulfonimidoyl-stabilized allylic carbanion[22]

Scheme 1



Reagents and conditions: (a) THF, −78°C; (b) 1. $ClSiMe_3$, −90°C → room temp.; 2. *n*BuLi, −90°C; (c) LiOMe, THF, toluene, 0°C → room temp.

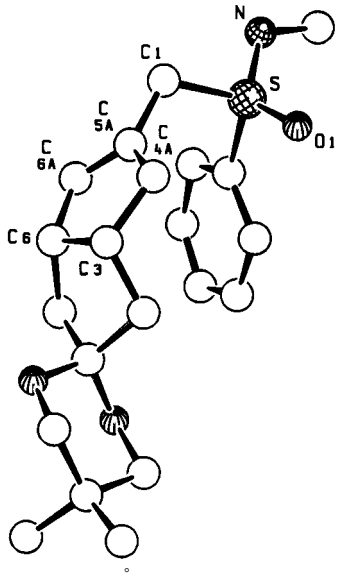
Figure 3. Stereoselective olefination of the chiral ketone **I** by using **8**



which is protonated by MeOH at the α-position. Crucial for the selectivity of the isomerization is the use of a non-polar solvent. In polar solvents isomerization of **6** to **5** is much less selective.

Because of the current interest in asymmetric olefination[18], we studied the course of the transformation of **7** to **6** in somewhat more detail in the case of the olefination of the analogous ketone **12**[11] by using lithiosulfoximine *ent*-**8**. Reaction of ketone **12** with *ent*-**8**, which was obtained from (*S*)-*N*,*S*-dimethyl-*S*-phenylsulfoximine[20], in THF at −78°C afforded β-hydroxysulfoximine **13** as a single crystalline diastereomer (≥98% de) in 92% yield (Scheme 2). The structure of **13** was secured by NOE experiments. Not surprisingly, because of the convex-concave structure of **12**, addition of *ent*-**8** had occurred to the carbonyl group exclusively from the convex side[23]. The consecutive treatment of *ent*-**8** with **12**, $ClSiMe_3$ and *n*BuLi led to isolation

Figure 4. Crystal structure of the allylic sulfoximine **5**[a]

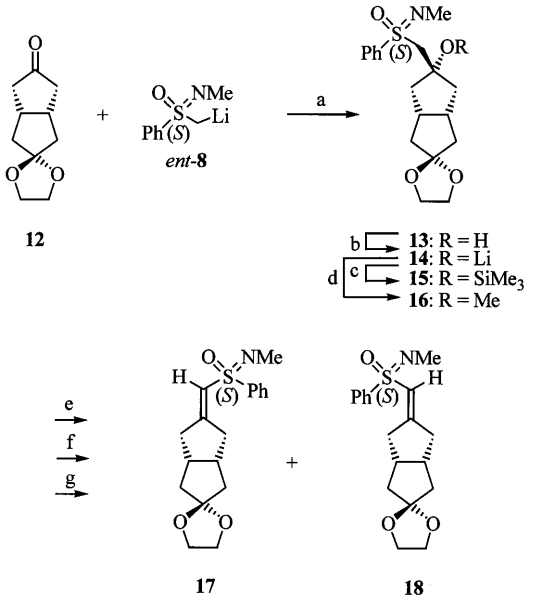


[a] Selected bond lengths [A]: C5A−C6A 1.336(7), C4A−C5A 1.500(8), C1−C5A 1.493(7), C3−C6 1.540(8), C6−C6A 1.485(7), C3−C4A 1.555(7), C1−S 1.800(6), S−O1 1.467(5), S−N 1.512(4).

of a mixture of the vinylic sulfoximine **17** (≥98% de) and the corresponding allylic sulfoximines in a ratio of 91:9 in 99% yield. Formation of the diasteromeric alkene **18** could not be detected by ^{1}H-NMR spectroscopy. We assumed that alkoxide **14** reacted with $ClSiMe_3$ under formation of the silyl ether **15** which eliminated $LiOSiMe_3$ upon reaction with *n*BuLi to give selectively (*S*,*Z*)-alkene **17**.

Indeed, the consecutive treatment of alcohol *rac*-**13** with *n*BuLi and $ClSiMe_3$, under the conditions applied in the one-pot elimination of **13**, afforded the hydrolysisprone silyl ether *rac*-**15** in 92% yield. Methylation of the sterically hindered alkoxy group in **14** proved to be possible as well. Treatment of **14**, which is stable in THF solution at room temperature, with MeI in THF in the presence of HMPA furnished the methyl ether **16** in 73% yield. Elimination of the silyl ether *rac*-**15** with *n*BuLi in THF at −78°C afforded a mixture of alkene *rac*-**17** (≥98% de) and the corresponding allylic sulfoximines in a ratio of 90:10 in 90% yield. Thus, the one-pot elimination of **13** and that of *rac*-**15** proceeded with the same sense and degree of asymmetric induction. Finally, elimination of the methyl ether *rac*-**16** was studied. Treatment of *rac*-**16** with *n*BuLi in THF at −78°C afforded a mixture of *rac*-**17** and *rac*-**18** in a ratio of 92.5:7.5 and a mixture of the corresponding diastereomeric racemic allylic sulfoximines in a ratio of 80:20 in 82% yield. Thus, eliminations of *rac*-**15** and *rac*-**16** with *n*BuLi proceeded with the same sense of asymmetric induction. As a side reaction in the formation of *rac*-**17** and *rac*-**18** from *rac*-**15** and *rac*-**16**, respectively, isomerization of the exocyclic alkenes to the corresponding endocyclic alkenes occurred (cf. Scheme 1). We ascribe this isomerization to the lithium alkoxides formed. Isomerization was more distinct with LiOMe than with $LiOSiMe_3$. In another series of experiments we wanted to see whether dilithiosulfoximine **19** could be

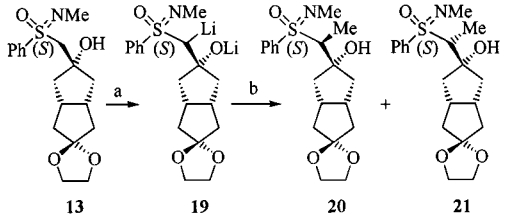
Scheme 2



Reagents and conditions: (a) 1. THF, −78°C; 2. H_3O^+; (b) 1 equiv. *n*BuLi, THF, −78°C; (c) $ClSiMe_3$, THF, −78°C → room temp.; (d) THF, HMPA, MeI, 0°C; (e) 1. **14**, $ClSiMe_3$, THF, −90°C → room temp.; 2. *n*BuLi, −90°C; (f) *rac*-**15**, *n*BuLi, THF, −78°C; (g) *rac*-**16**, *n*BuLi, THF, −78°C.

prepared from **13** (Scheme 3) and if a stereoselective elimination of the dilithiosulfoximine would occur upon reaction with MeI and $ClSiMe_3$. Treatment of **13** with 2 equivalents of *n*BuLi in THF at −78°C gave dilithiosulfoximine **19**. Reaction of **19** with MeI in the presence of HMPA took place at the C atom and furnished a mixture of α-methyl hydroxysulfoximines, **20** and **21**, in a ratio of 75:25 in 89% yield. MPLC of this mixture afforded the pure diastereomers **20** and **21** whose configuration at the α-position has not been determined.

Scheme 3

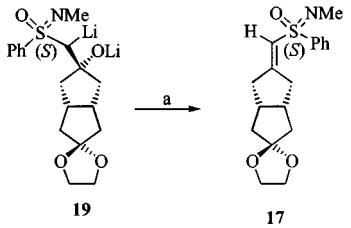


Reagents and conditions: (a) 2 equiv. *n*BuLi, THF, −78°C; (b) HMPA, MeI, 0°C.

Reaction of *rac*-**19** with $ClSiMe_3$, however, took a different and most interesting course, delivering a mixture of alkene *rac*-**17** (≥98% de) and a mixture of the corresponding diastereomeric racemic allylic sulfoximines in a ratio of 95:5 in 69% yield (Scheme 4). Formation of the diastereomeric alkene **18** could not be detected by ^{1}H-NMR spectroscopy. In this experiment, hydroxysulfoximine *rac*-**13** was isolated in 28% yield besides *rac*-**17**.

We ascribe the highly selective formation of (*S*,*Z*)-alkene **17** from the silyl ether **15** as well as from dilithiosulfoximine

Scheme 4



Reagents and conditions: (a) $ClSiMe_3$, THF, −70°C.

19, by taking into account the crystal structure[19b][22][24] and the configurational stability of lithiosulfoximines[16][22a][25] as well as the nucleofugacity of a OR group[26], to the following factors (Scheme 5):

1. An initial metallation of **15** to give lithiosulfoximine **22**, which is also formed upon silylation of **19** at the O atom or, alternatively, via C/O silyl migration following *C*-silylation.

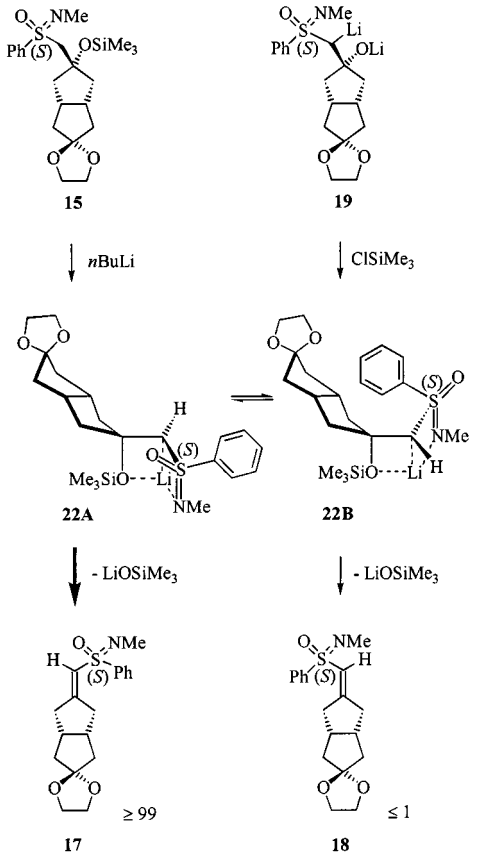
2. A structure of **22** which is characterized by a coordination of the Li atom to the N atom as well as to the Cα atom.

3. The establishment of a rapid equilibrium between diastereomers **22A** and **22B** at low temperatures via Cα−S-bond rotation and Cα-inversion on account of the low energy barriers for both processes in lithiosulfoximines and the poor nucleofugacity of a OR group[26].

4. A more rapid elimination of $LiOSiMe_3$ in **22A** than in **22B**, because of the steric interaction between the phenyl group and the γ-methylene group in the latter, which hinders the achievement of coplanarity of the C−Li bond and the C−O bond in the transition state.

Support for the above proposed E1cB mechanism for the elimination of **15** comes from a study of the elimination of β-alkoxysulfones where the operation of such a mechanism has been demonstrated[26a][26b][26c][27]. The crucial intermediate in Scheme 5 is the lithiosulfoximine **22**. β-Silyloxy carbanions of type **22** have been invoked and even occasionally proven as intermediates in the Peterson olefination of aldehydes and ketones with stabilized α-silyl carbanions[28]. We have shown some time ago that vinylic sulfoximines can also be synthesized by the Peterson reaction using α-silylsulfoximines[29][24a]. Indirect experimental evidence for **22** and an equilibrium between **22A** and **22B** comes from the elimination of **19** which occurs upon treatment of the dilithiosulfoximine with $ClSiMe_3$. Silylation of **19** can take place either at the O atom or at the C atom. *O*-Silylation of the dilithiosulfoximine must necessarily lead to **22**. Because of the likely existence of **19** as a mixture of diastereomers, *O*-silylation of **19** should yield **22A** and **22B**. Thus, the highly selective formation of **17** would only be compatible with an equilibrium between **22A** and **22B**. *C*-Silylation of **19** is expected to be in a similar manner unselective as the *C*-methylation, giving both diastereomeric *C*-trimethylsilyl derivatives of **19**. C/O-Silyl migration in these derivatives would again result in formation of **22A** and **22B**.

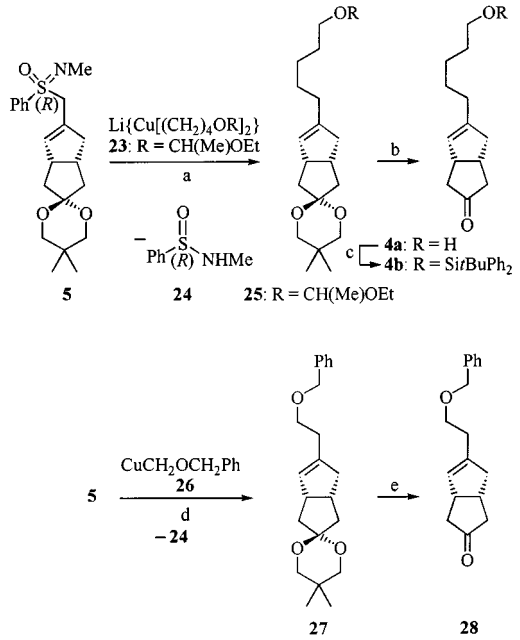
Scheme 5



Cross-Coupling Reactions of the Allylic Sulfoximine

Reaction of the allylic sulfoximine **5** with cuprate **23**[30] in ether/Me_2S proceeded highly selective at the α-position and afforded alkene **25** in 95% yield (Scheme 6). Formation of the isomeric γ-substitution product could not be detected by NMR spectroscopy. Because of the high biological potency of 3-oxaisocarbacyclin and its derivatives[10c][13], we were interested to see whether alkene **27**[10a], a potential starting material for the synthesis of these analogs, could be obtained from **5** as well. Synthesis of **27** would require the replacement of the sulfoximine group in **5** by a benzyloxymethyl group. To this end **5** was treated with the organocopper reagent **26**[31], which was prepared from (benzyloxy-)methylmagnesium chloride[32] and CuI, in the presence of $BF_3 \cdot OEt_2$ in THF at −78°C to give the α-substitution product **27**, uncontaminated by the corresponding γ-substitution product, in 87% yield. The synthesis of **27** from **5** is another example for the surprising ability of **26** to react with allylic sulfoximines in the presence of $BF_3 \cdot OEt_2$ and halide under formation of the α-substitution product rather than the γ-substitution product[10b]. Normally, allylic sulfoximines react with homocuprates in the α-position and with organocopper reagents in the presence of $BF_3 \cdot OEt_2$ and halide in the γ-position[12]. Besides alkenes **25** and **27** sulfinamide **24**[32] was isolated in 90% yield. The sulfinamide has the (*R*) configuration and an ee-value of 97%, according to ^{1}H-NMR spectroscopy in the presence of $Eu(tfc)_3$ [$\Delta\Delta\delta$ (Me) = 0.66 ppm]. Because of the known conversion of **24** to sulfoximine **8**[33], isolation of the sulfinamide in high enantiomeric purity means that recycling of the chiral auxiliary **8** is possible.

Scheme 6



Reagents and conditions: (a) ether, Me_2S, −45°C; (b) acetone, H_2O, *p*TsOH, room temp.; (c) $ClSitBuPh_2$, imidazol, DMF, 0°C; (d) THF, Me_2S, $BF_3 \cdot Et_2O$, −78°C; (e) acetone, *p*TsOH, room temp.

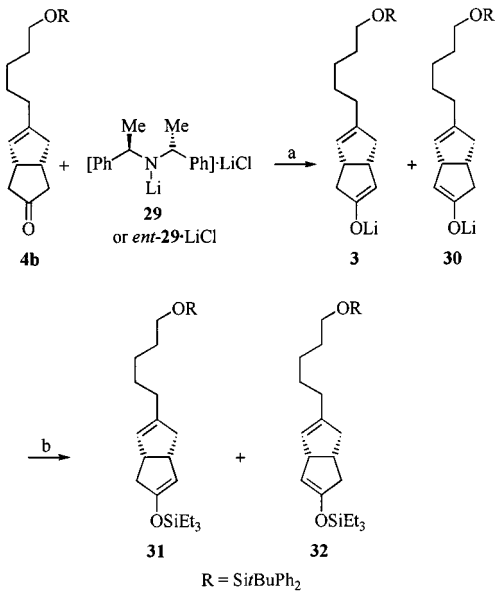
Cleavage of ketals **25** and **27** with *p*TsOH in acetone gave ketone **4a** in 77% yield and ketone **28** in 85% yield, respectively. Protection of the hydroxy group in **4a** by treatment with $ClSitBuPh_2$ afforded the silyl ether **4b**[10a] in 80% yield.

Selective Deprotonation of the Bicyclic Ketone with a Chiral Base

The construction of the ω-side chain required the regioselective deprotonation of ketone **4b** under formation of enolate **3**. Because of the high local symmetry about the carbonyl group of **4b**, the induction provided by the substrate is expected to be insufficient and a chiral base must be applied. We and others have used for the regioselective deprotonation of an analogous chiral bicyclic ketone, having the double bond in the exocyclic position[14], and the enantioselective deprotonation[34a][35] of **7**[10a][10c][34] with much success a complex of the lithium amide **29**[35][36] with lithium chloride[36]. Treatment of **29**·LiCl, which was prepared in situ from (*R*,*R*)-bis(α-phenylethyl)ammonium chloride[36e][37] and 2 equivalents of *n*BuLi, in THF at −105°C with ketone **4b** gave enolates **3** and **30** which were trapped by the subsequent addition of $ClSiEt_3$ at −78°C (Scheme 7). This led to isolation of a mixture of the silyl enol ethers **31** and **32** in a ratio of 19:1 in 91% yield. By the same sequence but using *ent*-**29** · LiCl ketone **4b** afforded a mixture of **31** and **32** in an opposite ratio of 1:27 in 94% yield from **4b**. The structures of **31** and **32** were unequivocally established by NOE experiments in combination with a

complete assignment of the signals of the bicyclic ring systems in the ^{1}H-NMR spectra.

Scheme 7



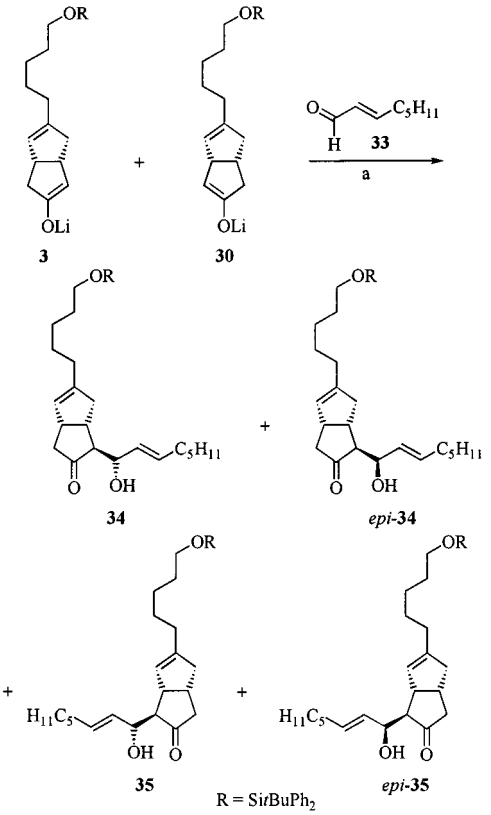
Reagents and conditions: (a) THF, −105°C, (b) $ClSiEt_3$, −78°C.

Construction of the ω-Side Chain

According to the synthetic plan the ω-side chain was going to be attached to enolate **3** by an aldol reaction with **33** followed by a transposition of the allylic hydroxy group in the aldol product from C-13 to C-15 through a Pd-catalyzed allylic rearrangement. Treatment of a mixture of enolates **3** and **30**, which was prepared as described above from **4b** and **29**·LiCl, with aldehyde **33** gave a mixture of the aldol products **34**, *epi*-**34**, **35**, and *epi*-**35** in a ratio of 52:44:3:1 in 95% yield (Scheme 8). The pure β-hydroxyketones **34** and *epi*-**34** were isolated in 42% yield and 36% yield, respectively, by chromatography. Thus, the aldol reaction had occurred, as observed in a related case[10c], highly stereoselectively in regard to C-12 but almost unselectively in regard to C-13. Reduction of ketone **34** with $NaBH_4$ in EtOH at low temperatures afforded diol **36** as a single diastereomer in 84% yield (Scheme 9). A similar reduction of ketone *epi*-**34** with $NaBH_4$ gave diol **37** in 88% yield and diol *epi*-**37** in 3% yield. In order to assign the configurations of diols **36** and **37** at C-11 to C-13 diol **36** was converted to acetonide **38** which was isolated in 87% yield. The configurations at C-11 to C-13 in **38** were established by NOE experiments on the basis of a complete assignment of the signals in the ^{1}H- and ^{13}C-NMR spectra. The more important details of the NOE experiments are summarized in formula **38A**. Conversion of diol **37** to the corresponding acetonide could not be achieved presumably because of an unfavorable 1,3-diaxial interaction between the methyl group and the heptenyl group in the transition state of acetonide formation[10c].

Having achieved the regioselective attachment of the C-12 to C-20 unit in **2** to **4b** and the stereoselective reduction

Scheme 8



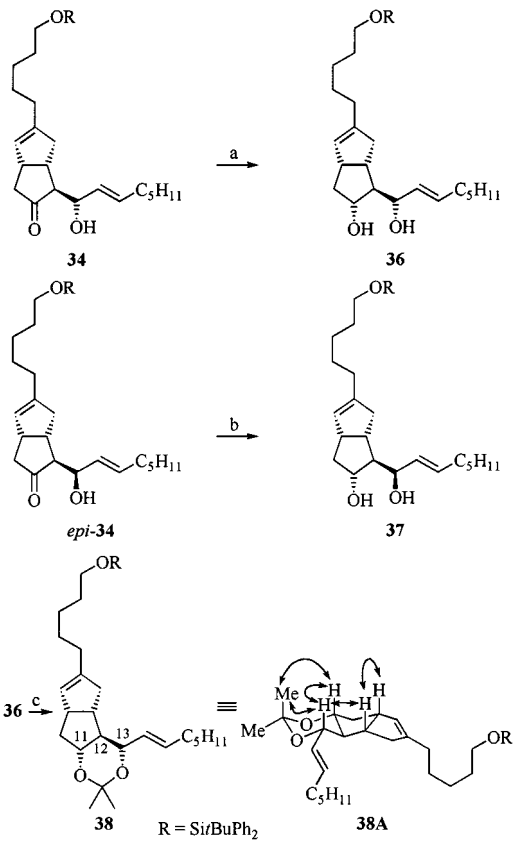
Reagents and conditions: (a) THF, −82°C.

of the carbonyl group in **34**, we turned our attention to the completion of the ω-side chain and the transposition of the hydroxy group in **36**. Treatment of diacetate **39**, which was obtained from diol **36** in 97% yield, with $Pd(MeCN)_2Cl_2$ in THF at room temperature gave the isomeric diacetate **40** as a single diastereomer (Scheme 10). Unfortunately, the allylic rearrangement of **36** to **40** could not brought to completion. An equilibrium consisting of 84% of **40** and 16% of **39** was established instead. The same observation was made in the case of the Pd-catalyzed rearrangement of a related bicyclic allylic acetate[10c][15e]. These results are in contrast to reports of an unidirectional Pd-catalyzed rearrangement of analogous monocyclic allylic acetates[15c][15d]. MPLC of the mixture of the isomeric diacetates gave **40**, contaminated with 5% of **39**, in 70% yield. The Pd-catalyzed rearrangement of the epimeric diacetate **41**, which was obtained from diol **37** in 98% yield, took a similar course as that of **36**. Treatment of **41** with $Pd(MeCN)_2Cl_2$ in THF at room temperature gave a mixture of **42** and **41** in a ratio of 86:14. Gravitation chromatography of the mixture of the isomeric diacetates gave **42**, contaminated with 5% of **41**, in 70% yield.

Completion of the α-Side Chain

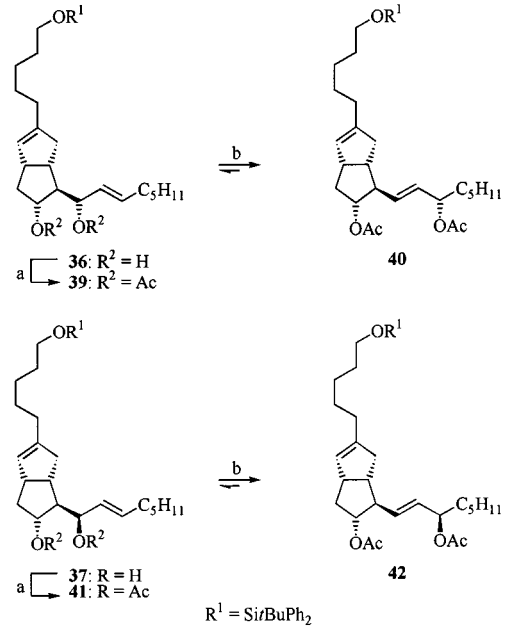
Desilylation of the silyl ether **40** with nBu$_4$NF·3 H_2O in THF at room temperature afforded alcohol **43** in 96% yield (Scheme 11). Conversion of **43** to **2** was conducted in two

Scheme 9



(a) $NaBH_4$, EtOH, −66°C → −50°C; (b) $NaBH_4$, EtOH, −66°C → −40°C; (c) acetone, $Me_2C(OMe)_2$, ω-camphorsulfonic acid, room temp.

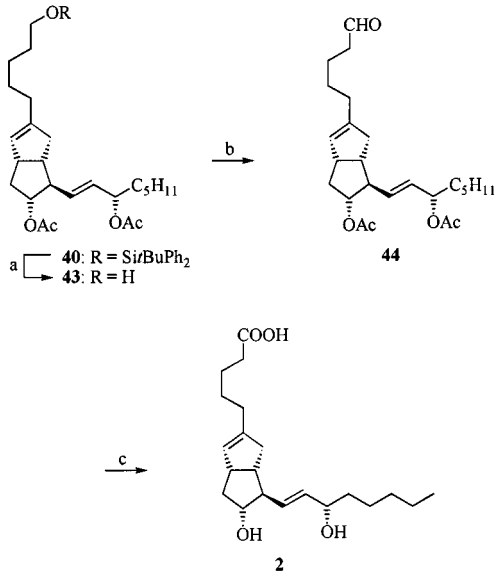
Scheme 10



Reagents and conditions: (a) THF, pyridine, MeCOCl, room temp.; (b) $Pd(MeCN)_2Cl_2$, THF, room temp.

steps[10a]. Oxidation of alcohol **43** with DMSO, $SO_3 \cdot$ pyridine, and NEt_3 delivered aldehyde **44** in 91% yield. Upon treatment of **44** with $AgNO_3$ in aqueous NaOH solution an oxidation of the aldehyde group and a cleavage of the acetoxy groups occurred to give isocarbacyclin (**2**), which was contaminated by 5% of the isomeric acid derived from acetate **39**, in 91% yield. Recrystallization of the mixture of the two isomers gave pure **2** in 37%. The NMR spectroscopic and further physical data of **2** matched those reported in the literature[10a][38]. After completion of the synthesis of **2** we could achieve a complete separation of the allylic acetates **39** and **40** by HPLC. Thus, the use of pure **40** for the synthesis of **2** should improve the total yield of isocarbacyclin by the route described considerably.

Scheme 11

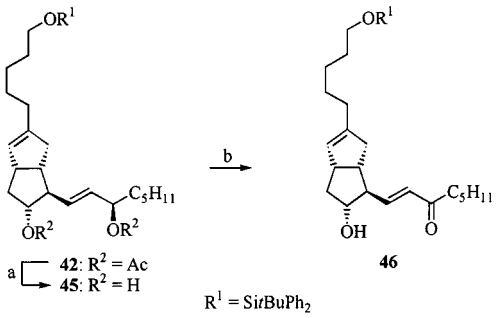


Reagents and conditions: (a) $n Bu_4NF \cdot 3\ H_2O$, THF, room temp.; (b) DMSO, NEt_3, $SO_3 \cdot$pyridine, room temp.; (c) $AgNO_3$, EtOH, H_2O, NaOH, room temp.

The final synthetic efforts were devoted to the potential utilization of diol **45** (Scheme 12) for the synthesis of **2**. Two likely solutions for this problem are conceivable: selective protection of the hydroxy group at C-11 in **45** and inversion of configuration at C-15 in the corresponding allylic alcohol by Mitsunobu reaction or a selective oxidation of the allylic hydroxy group in **45** followed by a stereoselective reduction of the corresponding enone. We have used successfully both versions, the inversion and the reduction, in our syntheses of 3-oxaisocarbacyclin[10c], 3-oxacarbacyclin[14], and isocarbacyclin[10a]. Because of the difficulties encountered in the selective protection of **45**, we have chosen the selective oxidation-reduction process. Saponification of diacetate **42**, which was contaminated by 5% of **41**, gave a mixture of diols **45** and **37** in a ratio of 95:5. Chromatography of this mixture afforded the pure diol **45**. The selective oxidation of diol **45** was accomplished with dichlorodicyanobenzoquinone[39] in dioxane at room temperature which afforded enone **46** in 81% yield. Oxidation of **45** in THF was less efficient, affording besides **46** as a side product the tetra-

hydrofuranyl ether of the latter. Because of the ample precedence for the stereoselective reduction of related enones[40][10a] we did not pursue the reduction of **46** to the corresponding diol.

Scheme 12



Reagents and conditions: (a) K_2CO_3, MeOH, room temp.; (b) dichlorodicyanobenzoquinone, dioxane, room temp.

Conclusion

An enantioselective route to isocarbacyclin (**2**) from *cis*-bicyclo[3.3.0]octan-2,5-dione was developed, which should allow for the synthesis of its ω-side chain modified derivatives as well. The flexibility of this route was demonstrated by the synthesis of the potential 3-oxaisocarbacyclin precursor **28**. The conversion of ketone **7** to the vinylic sulfoximine **6**, which may be termed an inverse Peterson olefination, is a further example for an asymmetric olefination of a ketone by an addition-elimination process using a chiral carbanion[14a]. The stereoselective substitution of the sulfonimidoyl group in **6** through a Ni-catalyzed cross-coupling reaction with zinkorganyls[18a][18b] should allow for the facile enantioselective synthesis of alkyl and aryl derivatives of **6** and, thus, provide an entry to carbacyclins. In the course of the study leading to **2**, the scope of the cross-coupling reaction of allylic sulfoximines and of the stereoselective deprotonation of ketones with lithium bis(α-phenylethyl)amide/lithium chloride were delineated further.

Financial support of this research by the *Deutsche Forschungsgemeinschaft* and the *Fonds der Chemischen Industrie* is gratefully acknowledged. The authors thank Dr. *H. Dahl*, Schering AG Berlin, for a generous supply of ketone **7** and Dr. *J. Runsink* for NOE experiments.

Experimental Section

All reactions were carried out in oven-dried glassware under an argon atmosphere using syringe technique unless otherwise noted. THF was distilled from sodium benzophenone ketyl. CH_2Cl_2, MeCN, DMSO, and DMF were distilled from CaH_2. EtOH was distilled from sodium, and MeOH was distilled from Mg tunings. Dioxane was distilled from KOH. *n*BuLi was standardized by titration with diphenylacetic acid. LiCl was dried at 120°C/0.01 Torr for 10 h. − TLC analysis was performed with Merck silica gel coated aluminum foil. Column chromatography was performed with Merck silica gel 60 (0.063−0.100 mm). MPLC was performed on a LiChroprep Si 60 (15−25 μm) column. HPLC was performed on a silica gel 120 A (5μ) column. − Only peaks of ν ≥ 900 in the IR spectra and only peaks of *m/z* ≥90 in the MS spectra (EI, 70 eV) are listed. − Chemical shifts in the NMR spectra are reported relative to TMS (δ = 0.00) as the internal standard. Splitting patterns in the ^{1}H-NMR spectra are designated as s, singlet; d, doublet; dd, double doublet; t, triplet; q, quartet; quin, quintet; m, multiplet. Peaks in the ^{13}C-NMR spectra are denoted as "u" for carbons with zero or two attached protons or as "d" for carbons with one or three attached protons, as determined from the APT puls sequence.

[3′aR-(3′aα,5′E(R),6′aα)]-N-Methyl-S-phenyl-S-[{tetrahydro-5,5-dimethylspiro[1,3-dioxan-2,2′(1′H)-pentalen]-5′(3′H)-yliden}-methyl]sulfoximine* (**6**): To a solution of (*R*)-*N,S*-dimethyl-*S*-phenylsulfoximine (1.110 g, 6.6 mmol) in THF (18 ml) was added at −60°C *n*BuLi (4.2 ml of 1.54 M in *n*-hexane, 6.5 mmol). The mixture was warmed to room temperature, cooled to −78°C and treated dropwise with a solution of **7** (1.439 g, 6.4 mmol) in THF (10 ml). After stirring the mixture for 30 min. at this temperature, it was cooled to −90°C and $ClSiMe_3$ (1.3 ml, 10.2 mmol) was added. The mixture was warmed to room temperature. After stirring the mixture for 3 h at room temperature, it was cooled to −90°C and *n*BuLi (4.2 ml of 1.54 M in *n*-hexane, 6.5 mmol) was added dropwise. Stirring was continued for 30 min. at −90°C and the cold mixture was poured into saturated aqueous $NaHCO_3$. The aqueous phase was extracted with ether and the combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (EtOAc/MeOH, 98:2) afforded **6** (2.06 g, 86%), **5** (72 mg, 3%), and **11** (20 mg, 1%) as colorless oils (HPLC: *n*-hexane/THF, 77:23, R_t (**5**) = 23.7 min., R_t (**11**) = 21.4 min., R_t (**6**) = 20.6 min.). − $[\alpha]_D^{21}$ = +76.9 (*c* = 3.06, THF). − ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.85 (s, 3 H), 0.91 (s, 3 H), 1.55 (dd, *J* = 6.4, *J* = 13.4 Hz, 1 H), 1.60 (dd, *J* = 13.4, *J* = 6.4 Hz, 1 H), 2.08−2.23 (m, 2 H), 2.25−2.69 (m, 5 H), 2.60 (s, 3 H), 2.80 (m, 1 H), 3.22−3.48 (m, 4 H), 6.20 (quin, *J* = 1.8 Hz, 1 H), 7.35−7.59 (m, 3 H), 7.71−7.90 (m, 2 H). − ^{13}C NMR (100 MHz, $CDCl_3$): δ = 22.36 (d), 22.45 (d), 29.21 (d), 29.95 (d), 35.80 (u), 38.87 (d), 41.10 (d), 40.03 (u), 40.85 (u), 41.69 (u), 71.73 (u), 72.33 (u), 109.76 (u), 122.23 (d), 128.56 (d), 129.01 (d), 132.14 (d), 140.56 (u), 164.03 (u). − MS; *m/z* (%): 376 [M^+ + 1] (16), 375 [M^+] (68), 259 (15), 250 (40), 246 (60), 241 (14), 221 (70), 220 (29), 211 (13), 210 (12), 209 (25), 167 (19), 164 (34), 154 (14), 135 (34), 134 (18), 129 (57), 128 (28), 109 (18), 107 (75), 105 (30), 93 (63), 91 (58). − $C_{21}H_{29}NO_3S$ (375.5): calcd. C 67.16, H 7.78, N 3.70; found C 67.06, H 7.63, N 3.70.

[3′aR-(3′aα,5′(R),6′aα)]-N-Methyl-S-phenyl-S-[{3′,3′a,4′,6′a-tetrahydro-5,5-dimethylspiro[1,3-dioxan-2,2′(1′H)-pentalen]-5′-yl}methyl]sulfoximine* (**5**) *and [3′aS-(3′aα,5′(S*),6′aα)]-N-Methyl-S-phenyl-S-[{3′,3′a,4′,6′a-tetrahydro-5,5-dimethylspiro[1,3-dioxan-2,2′(1′H)-pentalen]-5′-yl}methyl]sulfoximine* (**11**): To a solution of *n*BuLi (3.1 ml of 1.61 M in *n*-hexane, 5.0 mmol) in THF (10 ml), containing phenantroline (1 mg), was added at −35°C MeOH (10 ml of 0.5 M in toluene, 5.0 mmol) until the color of the solution changed from red to yellow. After stirring the solution for 30 min. at 0°C, it was treated with **6** (375 mg, 1.0 mmol) in THF (5 ml). The mixture was warmed within 10 h to room temperature. After stirring the mixture for 2 d at room temperature, it was treated with saturated aqueous $NaHCO_3$. The mixture was extracted with EtOAc and the combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (EtOAc/MeOH, 94:6) gave a mixture of **5** and **11** (352 mg, 94%) in a ratio of 50:1. MPLC (EtOAc/MeOH, 99.25:0.75) gave **5** (333 mg, 88%) and **11** (4 mg, 1%) as colorless crystals. HPLC: *n*-hexane/THF, 77:23, R_t (**5**) = 23.7 min., R_t (**11**) = 21.4 min., R_t (**6**) = 20.6 min.

5: m.p. 101°C, $[\alpha]_D^{20} = -37.3$ (c = 0.67, THF). – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.87 (s, 3 H), 0.94 (s, 3 H), 1.22 (dd, J = 6.75, J = 13.1 Hz, 1 H), 1.38 (dd, J = 13.1, J = 9.4 Hz, 1 H), 2.08–2.23 (m, 2 H), 2.23–2.38 (m, 1 H), 2.40–2.52 (m, 1 H), 2.54–2.70 (m, 1 H), 2.67 (s, 3 H), 3.00 (m, 1 H), 3.25–3.55 (m, 4 H), 3.78 (s, 2 H), 5.13 (s, 1 H), 7.40–7.65 (m, 3 H), 7.65–7.90 (m, 2 H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 22.45 (d), 22.61 (d), 29.85 (d), 30.09 (u), 38.48, (d), 39.15 (u), 39.85 (u), 41.26 (u), 47.13 (d), 59.34 (u), 71.43 (u), 72.87 (u), 108.77 (u), 129.08 (d), 129.78 (d), 132.83 (d), 138.81 (d), 136.93 (u). – MS; *m/z* (%): 375 [M^+], (8), 368 (6), 250 (63), 221 (100), 191 (18), 164 (43), 135 (39), 107 (88), 93 (84), 91 (41). – IR (KBr): ν = 3450 (w, br), 3076 (w), 3063 (w), 3049 (w), 2989 (m), 2977 (m), 2954 (s), 2928 (s), 2909 (s), 2870 (s), 2795 (m), 2111 (w), 1961 (w), 1896 (w), 1647 (w), 1584 (w), 1469 (m), 1446 (s), 1398 (m), 1360 (m), 1330 (m), 1310 (s), 1249 (s), 1220 (s), 1202 (m), 1183 (m), 1158 (s), 1126 (s), 1110 (s), 1084 (s), 1067 (m), 1052 (m), 1036 (w), 1018 (m), 1007 (m), 998 (s), 947 (w), 926 (w), 908 (w). – $C_{21}H_{29}NO_3S$ (375.5): calcd. C 67.16, H 7.78, N 3.70; found C 67.25, H 7.75, N 3.72.

11: m.p. 87°C, $[\alpha]_D^{20} = -41.4$ (c = 0.36, THF). – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.86 (s, 3 H), 0.90 (s, 3 H), 1.25–1.45 (m, 2 H), 1.90–2.05 (m, 1 H), 2.05–2.30 (m, 2 H), 2.50–2.75 (m, 2 H), 2.66 (s, 3 H), 2.96 (m, 1 H), 3.25–3.50 (m, J = 7.5, J = 10.5 Hz, 4 H), 3.85 (m, 2 H), 5.20 (s, 1 H), 7.35–7.60 (m, 3 H), 7.70–7.86 (m, 2 H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 22.46 (d), 22.56 (d), 29.78 (d), 30.08 (u), 38.25 (d), 38.83 (u), 40.26 (u), 41.61 (u), 47.35 (d), 58.38 (u), 71.45 (u), 72.80 (u), 108.80 (u), 129.06 (d), 129.28 (d), 129.80 (u), 137.08 (u), 132.8 (d), 138.48 (d). – IR (KBr): ν = 3450 (w, br), 3066 (w), 3051 (w), 2953 (s), 2926 (s), 2859 (s), 2794 (m), 2373 (w), 2097 (w), 1775 (w), 1736 (w), 1719 (w), 1702 (w), 1686 (w), 1655 (w), 1638 (w), 1626 (w), 1584 (w), 1561 (w), 1543 (w), 1509 (w), 1470 (m), 1445 (s), 1394 (m), 1361 (m), 1352 (m), 1322 (m), 1311 (s), 1236 (s), 1152 (s), 1108 (s), 1083 (s), 1068 (s), 1041 (m), 1016 (m), 1007 (m), 987 (m), 946 (w), 922 (m), 907 (m). – $C_{21}H_{29}O_3NS$ (375.5): calcd. C 67.16, H 7.78, N 3.70; found C 67.35, H 7.74, N 3.58.

[5′(S)-(3′aα,5′β,6′aα)]-Hexahydro-5′-[(N-methyl-S-phenylsulfonimidoyl)methyl]spiro[1.3-dioxolan-2.2′-(1′H)-pentalene]-5′-ol (**13**): To a solution of (*S*)-*N*,*S*-dimethyl-*S*-phenylsulfoximine (2.030 g, 12 mmol) in THF (10 ml) was added at −60°C *n*BuLi (7.5 ml of 1.6 M in *n*-hexane, 12 mmol). The mixture was warmed to room temperature, cooled to −78°C and treated dropwise with a solution of **12** (2.180 g, 12 mmol) in THF (10 ml). After stirring the mixture for 3 h at this temperature, it was poured into saturated aqueous NH_4Cl. The mixture was extracted with EtOAc and the combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 1:2) gave **13** (3.880 g, 92%) as colorless needles. – M.p. 132–133°C, $[\alpha]_D^{20} = +36.4$ (c = 1.6, acetone). – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.70 (dd, J = 9, J = 13.5 Hz, 1 H), 1.83 (dd, J = 6, J = 13.5 Hz, 1 H), 1.88–2.10 (m, 5 H), 2.42–2.55 (m, 2 H), 2.63 (s, 3 H), 2.68 (ddd, J = 2, J = 8, J = 15 Hz, 1 H), 3.06 (dd, J = 14 Hz, 1 H), 3.46 (d, J = 14 Hz, 1 H), 3.90 (m, sym, 4 H), 6.43 (s, 1 H). 7.55–7.70 (m, 3 H), 7.84–7.93 (m, 2 H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 28.99 (d), 37.81 (d), 39.10 (d), 41.61 (u), 41.68 (u), 44.29 (u), 47.00 (u), 63.69 (u), 63.91 (u), 64.75 (u), 81.83 (u), 118.89 (u), 129.07 (d), 129.65 (d), 133.18 (d), 139.07 (u). – MS; *m/z* (%): 351 [M^+] (13), 196 (17), 182 (12), 169 (14), 156, 100), 154 (37), 140 (36), 139, 24), 135 (14), 125 (85), 113 (38), 112 (32), 107 (40), 106 (30), 99 (21), 95 (27), 91 (19). – $C_{18}H_{25}NO_4S$ (351.5): calcd. C 61.50, H 7.17, N 3.98; found C 61.50, H 7.22, N 3.98.

(±)-[3′aα,5′β,6′aα-S]-[{Hexahydro-5′-[(trimethylsilyl)oxy]-spiro[1,3-dioxolan-2,2′(1′H)-pentalen]5′-yl}methyl]-N-methyl-S-phenylsulfoximin (*rac*-**15**): To a solution of *rac*-**13** (265 mg, 0.75 mmol) in THF (20 ml) was added at 0°C *n*BuLi (0.5 ml of 1.5 M in *n*-hexane, 0.75 mmol). After stirring the mixture for 15 min. at 0°C, it was cooled to −78°C and treated with $ClSiMe_3$ (0.7 ml of 1.5 M in *n*-hexane, 1.05 mmol). Subsequently the mixture was warmed to room temperature. After stirring the mixture for 3 h at this temperature, it was concentrated in vaccum. The residue was suspended in $CHCl_3$ and the suspension was filtered. Concentration of the filtrate gave a mixture of *rac*-**15** and *rac*-**13** in a ratio of 92:8. – ^{1}H NMR (100 MHz, $CDCl_3$): δ = −0.17 (s, 9 H), 1.32–2.96 (m, 12 H), 2.50 (s, 3 H), 3.46 (s, 2 H), 3.81 (m, 4 H), 7.38–7.60 (m, 3 H), 7.72–7.90 (m, 2 H). – MS; *m/z* (%): 423 [M^+] (1), 408 (1), 351 (13), 228 (18), 156 (90), 140 (50), 125 (100), 107 (43).

[5′(S)-(3′aα,5′β,6′aα)]-S-[{Hexahydro-5′-methoxyspiro[1,3-dioxo-lan-2,2′(1′H)-pentalen]-5′-yl}methyl]-N-methyl-S-phenylsulfoximine (**16**): To a solution of **13** (316 mg, 0.9 mmol) in THF (20 ml) were consecutively added at 0°C *n*BuLi (0.6 ml of 1.5 M in *n*-hexane, 0.9 mmol) and HMPA (0.32 ml). After stirring the mixture for 20 min. at this temperature, MeI (0.5 ml, 9 mmol) was added. The mixture was stirred for 24 h at 0°C and brine was added. The mixture was extracted with EtOAc and the combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (EtOAc) gave **16** (240 mg, 73%) as a colorless oil. – $[\alpha]_D^{20} = +43.9$ (c = 0.6, acetone). – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.63 (dd, J = 6, J = 13 Hz, 1 H), 1.70 (dd, J = 6, J = 13 Hz, 1 H), 1.76–1.96 (m, 5 H), 2.35 (dd, J = 9, J = 13 Hz, 1 H), 2.45 (dquin, J = 6, J = 9 Hz, 1 H), 2.58 (m, 1 H), 2.61 (s, 3 H), 2.77 (s, 3 H), 3.39 (d, J = 15 Hz, 1 H), 3.48 (d, J = 15 Hz, 1 H), 3.84 (s, 4 H), 7.45–7.60 (m, 3 H), 7.82–7.91 (m, 2 H). – ^{13}C NMR (20 MHz, $CDCl_3$): δ = 29.29 (d), 37.74 (d), 38.04 (d), 40.98 (u), 41.39 (u), 41.55 (u), 50.31 (d), 59.91 (u), 64.00 (u), 64.69 (u), 86.52 (u), 118.84 (u), 129.12 (d), 129.69 (d), 132.57 (d), 139.38 (u). – MS; *m/z* (%): 365 [M^+] (3), 339 (5), 287 (13), 210 (38), 179 (34), 156 (58), 140 (61), 125 (53), 109 (100), 91 (38). – $C_{19}H_{27}NO_4S$ (365.5): calcd. C 62.44, H 7.45, N 3.83; found C 62.32, H 7.43, N 3.78.

[3′aα,5′Z(S),6′aα]-N-Methyl-S-phenyl-S-[{tetrahydrospiro-[1,3-dioxolan-2,2′(1′H)-pentalen]-5′(4′H)-yliden}methyl]-sulfoximine* (**17**): To a solution of (*S*)-*N*,*S*-dimethyl-*S*-phenylsulfoximine (850 mg, 5 mmol) in THF (30 ml) was added at −60°C *n*BuLi (3.3 ml of 1.5 M in *n*-hexane, 5 mmol). The mixture was warmed to room temperature, cooled to −78°C and treated dropwise with a solution of **12** (910 mg, 5 mmol) in THF (5 ml). After stirring the mixture for 30 min. at this temperature, it was cooled to −90°C and $ClSiMe_3$ (0.63 ml, 5 mmol) was added. The mixture was warmed to room temperature. After stirring the mixture for 3 h at room temperature, it was cooled to −90°C and *n*BuLi (3.3 ml of 1.5 M in *n*-hexane, 5 mmol) was added dropwise. Stirring was continued for 30 min. at −90°C and the cold mixture was poured into saturated aqueous $NaHCO_3$. The aqueous phase was extracted with ether and the combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (EtOAc) afforded a mixture of **17** (≥98% de) and the corresponding allylic sulfoximines (1.660 g, 99%) in a ratio of 91:9 as a colorless oil. – $[\alpha]_D^{20} = -64.9$ (c = 1.5, CH_2Cl_2). – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.56–1.70 (2× dd, J = 8, J = 15 Hz, 2 H), 1.96–2.10 (2× dd, J = 8, J = 15 Hz, 2 H), 2.23–3.17 (m, 6 H), 2.69 (s, 3 H), 3.86 (s, 4 H), 6.28 (quin, J = 2 Hz, 1 H), 7.48–7.63 (m, 3 H), 7.80–7.94 (m, 2 H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 29.22 (d), 35.86 (u), 39.20 (u), 41.19 (u), 41.66 (u),

41.69 (u), 42.05 (u), 63.94 (u), 64.53 (u), 118.46 (u), 122.42 (d), 128.53 (d), 129.01 (d), 132.13 (d), 140.97 (u), 163.72 (u). – MS; *m/z* (%): 333 [M^+] (100), 246 (55), 208 (32), 179 (38). – $C_{18}H_{23}NO_3S$ (333.4): calcd. C 64.83, H 6.95, N 4.20; found C 64.83, H 6.96, N 4.06.

(±)-[3′aα,5′Z(S),6′aα]-N-Methyl-S-phenyl-S-[{tetrahydrospiro[1,3-dioxolan-2,2′(1′H)-pentalen]-5′(4′H)-yliden}-methyl]-sulfoximine* (*rac*-**17**): From *rac*-**15**: To a solution of *rac*-**15** (527 mg, 1.5 mmol) was added at −90°C dropwise *n*BuLi (1 ml of 1.5 M in *n*-hexane, 1.5 mmol). Stirring of the mixture was continued for 30 min. at −90°C until it was poured into saturated aqueous $NaHCO_3$. The aqueous phase was extracted with ether and the combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (EtOAc) afforded a mixture of *rac*-**17** (≥98% de) and the corresponding allylic sulfoximines (449 mg, 90%) in a ratio of 90:10 as a colorless oil.

From *rac*-**16**: To a solution of *rac*-**16** (240 mg, 0.66 mmol) in THF (20 ml) was added at −70°C *n*BuLi (0.43 ml of 1.5 M in *n*-hexane, 0.66 mmol). After stirring the mixture for 2 h at −70°C, it was poured into saturated aqueous NH_4Cl. The mixture was extracted with EtOAc and the combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (EtOAc) gave a mixture of *rac*-**17**, *rac*-**18**, and the corresponding allylic sulfoximines in a ratio of 74:6:20 (180 mg, 82%). Data for *rac*-**18**: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.32−1.55 (2× dd, *J* = 6.5, *J* = 13.5 Hz, 2 H), 1.90−2.10 (m, 2 H), 2.32−2.43 (ddd, *J* = 2, *J* = 5, *J* = 16 Hz, 1 H), 2.43−2.55 (ddd, *J* = 2, *J* = 5, *J* = 18 Hz, 1 H), 2.55−2.80 (m, 3 H), 2.68 (s, 3 H), 2.96−3.10 (ddt, *J* = 2, *J* = 9, *J* = 18 Hz, 1 H), 3.74−3.86 (m, 2 H), 6.29 (quin, *J* = 2 Hz, 1 H), 7.49 7.52 (m, 3 H), 7.86−7.95 (m, 2 H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 29.23 (d), 36.02 (u), 39.16 (d), 41.10 (d), 41.79 (u), 41.84 (u), 42.12 (u), 63.98 (u), 64.49 (u), 118.45 (u), 122.59 (d), 128.63 (d), 129.02 (d), 132.10 (d), 141.02 (u), 163.74 (u). For the NMR-spectroscopic identification of *rac*-**18** a 3:1-mixture of *rac*-**18** and *rac*-**17** was prepared in 37% yield by the consecutive treatment of *rac*-**8** with 1 equivalent of *n*BuLi, 1 equivalent of $ClTi(OiPr)_3$ and 1 equivalent of **12**[41].

From *rac*-**19**: To a solution of *rac*-**13** (1.050 g, 3 mmol) in THF (30 ml) was added at −30°C *n*BuLi (4 ml of 1.5 M in *n*-hexane, 6 mmol). After stirring the yellow solution for 1 h at −30°C, it was cooled to −70°C and treated with $ClSiMe_3$ (0.76 ml, 6 mmol). The mixture was stirred for 2 h at −70°C and poured into saturated aqueous NH_4Cl. The aqueous phase was extracted with EtOAc and the combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (EtOAc) gave *rac*-**13** (290 mg, 28%) and *rac*-**17** (685 mg, 69%) (≥98 de) which contained 5% of the corresponding allylic sulfoximines.

[5′(S)-(1S,3′aα,5′β,6′aα)]-Hexahydro-5′-[1-(N-methyl-S-phenylsulfonimidoyl)ethyl]spiro[1.3-dioxolan-2.2′(1′H)pentalen]-5′-ol and [5′(S)-(1R*,3′aα,5′β,6′aα)]-Hexahydro-5′-[1-(N-methyl-S-phenylsulfonimidoyl)ethyl]spiro[1.3-dioxolan-2.2′(1′H)-pentalen]-5′-ol* (**20** and **21**): To a solution of **13** (740 mg, 2.1 mmol) in THF (15 ml) were added at 0°C consecutively *n*BuLi (2.8 ml of 1.5 M in *n*-hexane, 4.2 mmol) and HMPA (0.73 ml). After stirring the mixture for 1 h at this temperature, MeI (450 mg, 3.15 mmol) was added. Stirring was continued for 1 h at 0°C and the mixture was poured into saturated aqueous NH_4Cl. The aqueous was extracted with EtOAc and the combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (EtOAc) gave a mixture of **20** and **21** (670 mg, 89%). The two diastereomer were obtained in a ratio of 75:25, R_f (minor diastereomer) > R_f (major diastereomer) (EtOAc/*n*-hexane, 2:1). Repeated chromatography (EtOAc) of the mixture gave pure **20** and **21**.

Data for minor diastereomer (**20** or **21**): m.p. 110°C, $[\alpha]_D^{20}$ = +45.3 (*c* = 0.5, acetone). – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.21 (d, *J* = 7 Hz, 3 H), 1.59 (dd, *J* = 9, *J* = 13 Hz, 1 H), 1.84 (dt, *J* = 2, *J* = 13 Hz, 1 H), 1.90−2.12 (m, 3 H), 2.18 (dd, *J* = 9, *J* = 13 Hz, 1 H), 2.33 (ddd, *J* = 13, *J* = 2, *J* = 3 Hz, 1 H), 2.42 (dd, *J* = 9, *J* = 13 Hz, 1 H), 2.57 (dquin, *J* = 2, *J* = 9 Hz, 1 H), 2.68 (s, 3 H), 2.78 (dquin, *J* = 9, *J* = 3 Hz, 1 H), 2.84 (q, *J* = 7 Hz, 1 H), 3.92 (s, 4 H), 5.86 (s, 1 H), 7.54−7.69 (m, 3 H), 7.75−7.84 (m, 2 H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 13.85 (d), 28.96 (d), 38.14 (d), 40.12 (d), 41.91 (u), 41.97 (u), 45.38 (u), 46.04 (u), 63.84 (u), 64.82 (u), 67.19 (d), 84.87 (u), 118.85 (u), 129.34 (d), 130.28 (d), 133.14 (d), 136.61 (u). – $C_{19}H_{27}NO_4S$ (365.5): calcd. C 62.44, H 7.45, N 3.83; found C 62.52, H 7.50, N 3.82.

Data for major diastereomer (**21** or **20**): m. p. 142°C, $[\alpha]_D^{20}$ = +78.4 (*c* = 0.8, acetone). – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.14 (d, *J* = 7 Hz, 3 H), 1.71 (dt, *J* = 13, *J* = 2 Hz, 1 H), 1.85 (dd, *J* = 13, *J* = 9 Hz, 1 H), 1.94 (ddd, *J* = 2, *J* = 9, *J* = 13 Hz, 1 H), 2.03 (ddd, *J* = 2, *J* = 9, *J* = 13 Hz, 1 H), 2.09−2.27 (m, 4 H), 2.50−2.64 (m, 1 H), 2.60 (s, 3 H), 2.72 (dquin, *J* = 3, *J* = 9 Hz, 1 H), 3.48 (q, *J* = 7 Hz, 1 H), 3.82 (s, 4 H), 7.10 (s, 1 H), 7.54−7.68 (m, 3 H), 7.82−7.90 (m, 2 H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 10.90 (d), 29.45 (d), 39.26 (d), 40.09 (d), 40.91 (u), 41.85 (u), 42.38 (u), 44.33 (u), 63.85 (u), 64.83 (u), 66.17 (d), 85.79 (u), 118.91 (u), 129.48 (d), 129.74 (d), 133.05 (d), 137.51 (u). – $C_{19}H_{27}NO_4S$ (365.5): calcd. C 62.44, H 7.45, N 3.83; found C 62.37, H 7.41, N 3.73.

Data for the mixture of **20** and **21**: MS; *m/z* (%): 365 [M^+] (10), 156 (70), 139 (42), 125 (90), 113 (45), 107 (70), 95 (40).

[3′aR-(3′aα,6′aα)]-3′,3′a,4′,6′a-Tetrahydro-5′-[5-(1-ethoxyethoxy)pentyl]spiro[5,5-dimethyl-1,3-dioxan-2,2′(1′H)-pentalene] (**25**): To a solution of **23**, which was prepared from CuI (190 mg, 1.0 mol) and 4-(1-ethoxyethoxy)butyllithium (2.25 ml of 0.85 M in ether, 1.9 mmol) in ether (3 ml) and Me_2S (3 ml) at −65°C to −35°C, was added at −45°C a solution of **5** (113 mg, 0.3 mmol) in ether (5 ml). After stirring the mixture for 6 h at this temperature, it was treated with a mixture of saturated aqueous NH_4C1 and conc. NH_4OH (35 ml, 10:1). The mixture was extracted with ether and the combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 7:1, and EtOAc) gave **25** (105 mg, 95%) as a colorless oil, contaminated a small amount of an imputity stemming from the synthesis of **23**, and **24** (45 mg, 90%) as a colorless oil.

25: ^{1}H NMR (400 MHz, $CDCl_3$): 6 = 0.90 (s, 6 H), 1.15 (t, *J* = 6.9 Hz, 3 H), 1.26 (d, *J* = 5.5 Hz, 3 H), 1.20−1.60 (m, 9 H), 1.90−2.05 (t, *J* = 6.9 Hz, 2 H), 2.20−2.32 (m, 2 H), 2.35−2.50 (m, 1 H), 2.65 (m, *J* = 2.5, *J* = 8.7 Hz, 1 H), 3.08 (m, 1 H), 3.30−3.55 (m, 8 H), 4.63 (q, *J* = 5.5 Hz, 1 H), 5.17 (m, 1 H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 15.36 (d), 19.92 (d), 22.59 (d), 22.60 (d), 26.06 (u), 27.60 (u), 29.78 (u), 30.12 (u), 30.99 (u), 38.18 (d), 39.37 (u), 40.99 (u), 41.49 (u), 47.18 (d), 60.68 (u), 65.29 (u), 71.46 (u), 72.82 (u), 99.56 (u), 109.33 (u), 127.47 (d), 142.47 (u). – MS: *m/z* (%); 320 (0.5) , 275 (1.5) , 199 (5) , 171 (2), 111 (3). – $C_{22}H_{38}O_4$: calcd. 366.2772, found 366.2775 (MS).

24: $[\alpha]_D^{20}$ = −166 (*c* = 0.6, acetone), 97% ee [^{1}H NMR, 400 MHz, $CDCl_3$, 17 mol% Eu(tfc)$_3$]: δ (**24**) = 3.48 (Me), δ (*ent*-**24**) = 4.14 (Me). – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 2.56 (d, *J* = 6 Hz, 3 H), 4.22 (q, *J* = 6 Hz, 1 H), 7−47−7.57 (m, 3 H), 7.65−7.75 (m, 2 H).

[3aR-cis]-3,3a,4,6a-Tetrahydro-5-(5-hydroxypentyl)-2(1H)-pentalenone (**4a**): To a solution of impure **25** (11.60 g, 31 mmol) in acetone (310 ml) are added at room temperature *p*TsOH (500 mg) and water (1 ml). After stirring the mixture for 1 d at room temperature, it was filtered through silica gel (*n*-hexane/EtOAc/MeOH, 33:64:2). Concentration of the filtrate in vacuum gave **4a** (5.070 g, 77%) as a colorless oil which crystallized in the refrigerator. − M. p. 29°C, $[\alpha]_D^{20}$ = −88.2 (*c* = 1.2, THF). − ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.20−1.70 (m, 7 H), 1.93 (dd, *J* = 7.5, *J* = 18 Hz, 1 H), 2.02 (t, *J* = 7.3 Hz, 1 H), 1.97−2.10 (m, 1 H), 2.18 (d, *J* = 18 Hz, 1 H), 2.30−2.52 (m, 2 H), 2.52−2.70 (m, 1 H), 2.82−2.98 (m, 1 H), 3.36 (m, 1 H), 3.60 (t, *J* = 6 Hz, 2 H), 5.18 (m, 1 H). − ^{13}C NMR (100 MHz, $CDCl_3$): δ = 25.59 (u), 27.41 (u), 31.03 (u), 32.60 (u), 37.52 (d), 42.71 (u), 43.21 (u), 45.19 (u), 46.21 (d), 62.87 (u), 126.89 (d), 144.75 (u), 220.83 (u). − MS; *m*/*z* (%): 208 [M$^+$] (9), 190 (11), 148 (28), 133 (72), 121 (24), 105 (43), 93 (50), 91 (100). − IR (neat): ν = 3423 (m, br), 3037 (w), 2931 (s), 2858 (s), 1739 (s), 1647 (w), 1461 (w), 1445 (m), 1400 (m), 1314 (w), 1286 (w), 1260 (w), 1160 (m), 1109 (w), 1072 (m), 1052 (m), 958 (w). − $C_{13}H_{20}O_2$ (208.3): calcd. C 74.96, H 9.67; found C 74.76, H 9.59.

[3aR-cis]-3,3a,4,6a-Tetrahydro-5-[5-{[(1,1-dimethylethyl)-diphenylsilyl]oxy}pentyl]-2(1H)-pentalenone] (**4b**): To a solution of **4a** (3.16 g, 15.2 mmol) in DMF (70 ml) were added at 0°C imidazol (2.65 g, 39.0 mmol) and Cl*Si*t*Bu*Ph_2 (4.85 g, 4.58 ml, 17.6 mmol). After stirring the mixture for 40 min. at 0°C, it was concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 4:1, 10:1) gave **4b** (5.390 g, 80%) as a colorless oil. − R_f = 0.18 (*n*-hexane/EtOAc, 10:1), $[\alpha]_D^{19}$ = −40.8 (*c* = 1.70, THF). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.05 (s, 9 H), 1.29−1.47 (m, 4 H), 1.56 (m, 2 H), 1.95 (ddd, *J* = 1.7, *J* = 7.4, *J* = 19.1 Hz, 1 H), 2.02 (t, br, *J* = 5.7 Hz, 2 H), 2.05 (d, br, *J* = 15.4 Hz, 1 H), 2.18 (ddd, *J* = 2.3, *J* = 2.3, *J* = 18.8 Hz, 1 H), 2.40 (ddd, *J* = 1.7, *J* = 9.4, *J* = 18.8 Hz, 1 H), 2.47 (ddd, *J* = 1.6, *J* = 9.5, *J* = 19.1 Hz, 1 H), 2.62 (ddm, *J* = 7.7, *J* = 16.1 Hz, 1 H), 2.91 (m, 1 H), 3.36 (m, 1 H), 3.66 (t, *J* = 6.6 Hz, 2 H), 5.19 (m, 1 H), 7.33−7.44 (m, 6 H), 7.64−7.69 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 19.22 (u), 25.64 (u), 26.87 (d), 27.36 (u), 31.03 (u), 32.38 (u), 37.50 (d), 42.68 (u), 43.12 (u), 45.11 (u), 46.15 (d), 63.85 (u), 126.71 (d), 127.57 (d), 129.50 (d), 134.11 (u), 135.56 (d), 144.81 (u), 220.47 (u). − IR (neat): ν = 3070 (m), 3047 (w), 2998 (w), 2931 (s), 2895 (s), 2857 (s), 1961 (w), 1890 (w), 1823 (w), 1742 (s), 1648 (w), 1589 (w), 1472 (m), 1462 (m), 1445 (m), 1428 (s), 1400 (m), 1390 (m), 1361 (w), 1310 (w), 1260 (w), 1156 (m), 1111 (s), 1008 (w), 999 (w), 939 (w), 917 (w). − MS; *m*/*z* (%): 392 (2), 391 (8), 390 (32), 389 (100), 345 (2), 331 (2), 311 (4), 267 (2), 253 (2), 239 (2), 201 (4), 200 (13), 199 (76), 183 (9), 174 (10), 173 (28), 139 (13), 131 (14), 105 (10), 91 (16). − $C_{29}H_{38}O_2Si$ (446.7): calcd. C 77.97, H 8.57; found C 77.91, H 8.45.

[3′aR-(3′aα,6′aα)]-3′,3′a,4′,6′a-Tetrahydro-5′-[2-(phenylmethoxy)ethyl]spiro[5,5-dimethyl-1,3 dioxan-2,2′(1′H)-pentalene] (**27**): To a solution of **26**, which was prepared from CuI (152 mg, 0.8 mmol) and a suspension of (benzyloxy)methylmagnesium chloride in THF (3.0 ml, 0.8 mmol) in Me_2S (2.5 ml) and THF (4 ml) at −60°C to −45°C, were added at −78°C consecutively **5** (86 mg, 0.23 mmol) in THF (3 ml) and $BF_3{\cdot}Et_2O$ (28 μL, 0.23 mmol). After stirring the mixture for 1.5 h at this temperature, a mixture of saturated aqueous NH_4Cl and conc. NH_4OH (25 ml, 10:1) was added and the mixture extracted with ether. The combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by MPLC (*n*-hexane/EtOAc, 8:1) gave **27** (68 mg, 87%) as a colorless oil. − ^{1}NMR (400 MHz, $CDCl_3$): δ = 0.94 (2 s, 6 H), 1.40, 1.58 (m, 2 H), 2.00 (d, *J* = 1.5 Hz, 1 H), 2.20−2.45 (m, 4 H), 2.45−2.58 (m, 1 H), 2.60−2.78 (m, 1 H), 3.12 (m, 1 H), 3.42, 3.49 (s, 4 H), 3.55 (t, *J* = 6.8 Hz, 2 H), 4.50 (s, 2 H), 5.29 (m, 1 H), 7.20−7.40 (m, 5 H). − ^{13}C NMR (100 MHz, $CDCl_3$): δ = 22.62 (d), 22.65 (d), 30.18 (u), 31.48 (u), 38.17 (d), 39.32 (u), 40.94 (u), 41.89 (u), 47.33 (d) 68.96 (u), 71.52, 72.88 (u), 72.96 (u, CH_2Ph), 109.33 (u), 127.61 (d), 127.76 (d), 128.44 (d), 129.64 (d), 138.58 (u), 139.31 (u). − MS; *m*/*z* (%): 342 [M$^+$] (21), 251 (10), 236 (5), 165 (136), 135 (49), 129 (19), 128 (48), 123 (18), 107 (14), 91. − IR (film): ν = 3025, 2850, 1470, 1460, 1360, 1310, 1220, 1110, 700. − $C_{22}H_{30}O_3$ (342.5): calcd. C 77.22, H 8.64; found C 77.15, H 8.80.

[3aR-(3aα,6aα)]-3,3a,4,6aTetrahydro-5-[2-(phenylmethoxy)-ethyl]2(1H)-pentalenone (**28**): To a solution of **27** (69 mg, 0.20 mmol) in acetone (2 ml) was added at room temperature *p*TsOH (5 mg). After stirring the mixture for 1.5 h at room temperature, it was filtered throgh silica gel (*n*-hexane/EtOAc, 3:1). Concentration of the filtrate in vacuum gave **28** (43 mg, 85%) as a colorless oil. − $[\alpha]_D^{20}$ = −72.31 (*c* = 0.32, THF). − ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.90−2.28 (m, 3 H), 2.30−2.56 (m, 4 H), 2.60−2.72 (m, 1 H), 2.92 (m, 1 H), 3.40 (m, 1 H), 3.54 (t, *J* = 6.8 Hz, 2 H), 4.50 (s, 2 H), 5.28 (m, 1 H), 7.20−7.40 (m, 5 H). − ^{13}C NMR (100 MHz, $CDCl_3$) : δ = 31.46 (u) , 37.55 (d) , 42.98 (u), 43.08 (u), 45.17 (u), 46.34 (d), 68.61 (u), 73.04 (u), 127.70 (d), 127.78 (d), 128.47 (d), 138.40 (d), 41.67 (u). − MS; *m*/*z* (%): 256 [M$^+$] (3), 226 (4), 165 (18), 123 (24), 105 (9), 91 (100). − IR (film): ν = 2900, 2850, 1735, 1450, 1360, 1175, 1100. − $C_{17}H_{20}O_2$ (256.3): calcd. C 79.65, H 7.94; found C 79.41, H 7.86.

[3aR-cis]-(1,1-Dimethylethyl)[{[5-{1,3a,4,6a-tetrahydro-5-[(triethylsilyl)oxy]-2-pentalenyl-}]pentyl}oxy]diphenylsilane (**31**): To a suspension of (*R*,*R*)-bis(α-phenylethyl)ammonium chloride (74.6 mg, 0.29 mmol) in THF (2 ml) was added at −70°C dropwise *n*BuLi (0.34 ml of 1.57 M in *n*-hexane, 0.53 mmol). After stirring the suspension for 5 min. at −70°C, it was warmed to room temperature. The yellow solution formed was cooled to −105°C and a solution of **4b** (93 mg, 0.21 mmol) in THF (2 ml) was added under film cooling within 40 min. The suspension formed was warmed to −78°C, kept at this temperature for 50 min and subsequently treated with $ClSiEt_3$ (0.1 ml, 0.60 mmol). After stirring the mixture for 1.5 h at −78°C, saturated aqueous $NaHCO_3$ (2 ml) was added and the mixture was warmed to room temperature. Water (5 ml) was added and the mixture extracted with ether. The organic phase was dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 4:1) gave a mixture of **31** and **32** (108 mg, 91%) in a ratio of 19:1 as a colorless oil. − $[\alpha]_D^{22}$ = +7.8 (*c* = 1.70, THF). − ^{1}H NMR (500 MHz, C_6D_6): δ = 0.67 (q, *J* = 7.9 Hz, 6 H), 0.99 (t, *J* = 8.0 Hz, 9 H), 1.19 (s, 9 H), 1.28−1.41 (m, 4 H), 1.56 (m, *J* = 6.9 Hz, 2 H), 1.97 (t, br, *J* = 7.2 Hz, 2 H), 2.01 (dm, *J* = 16.0 Hz, 1 H), 2.16 (ddt, *J* = 1.4, *J* = 2.5, *J* = 15.8 Hz, 1 H), 2.44 (ddm, *J* = 0.8, *J* = 8.6, *J* = 15.9 Hz, 1 H), 2.63 (dddt, *J* = 0.6, *J* = 2.1, *J* = 9.1, *J* = 15.8 Hz, 1 H), 3.25 (m, 1 H), 3.34 (m, 1 H), 3.66 (t, *J* = 6.5 Hz, 2 H), 4.60 (m, *J* = 1.7 Hz, 1 H), 5.13 (m, *J* = 1.8 Hz, 1 H), 7.23−7.26 (m, 6 H), 7.76−7.82 (m, 4 H). − ^{13}C NMR (126 MHz, C_6D_6): δ = 5.28 (u), 6.92 (d), 19.48 (u), 25.98 (u), 27.13 (d), 27.90 (u), 31.44 (u), 32.90 (u), 39.80 (u), 41.99 (u), 44.68 (d), 46.12 (d), 64.25 (u), 107.51 (d), 128.07 (d), 128.14 (d), 129.94 (d), 134.55 (u), 136.05 (d), 142.96 (u), 153.81 (u). − IR (neat): ν = 3070 (m), 3050 (m), 2955 (s), 2932 (s), 2876 (s), 2858 (s), 1955 (w), 1885 (w), 1825 (w), 1725 (w), 1646 (s), 1590 (w), 1461 (s), 1428 (s), 1389 (m), 1361 (m), 1334 (s), 1295 (m), 1245 (s), 1194 (s), 1111 (s), 1007 (s), 976 (m), 939 (m), 918 (m). − MS; *m*/*z* (%): 560 [M$^+$] (1.1), 504 (2), 503 (5), 482 (0.1), 387 (1.3), 353 (0.7), 324 (0.6), 322 (0.5), 320 (0.6), 319 (0.8), 313 (1), 311 (2), 292 (1), 279 (2), 278 (2), 252 (2), 251 (2), 250 (2), 217 (41), 200 (18), 199 (100), 189 (21), 161 (12), 105 (48), 103 (13).

− $C_{35}H_{52}O_2Si_2$ (560.9): calcd. C 74.94, H 9.34; found C 75.29, H 9.56.

[3aS-cis]-(1,1-Dimethylethyl)[{[5-{1,3a,6,6a-tetrahydro-5-[(triethylsilyl)oxy]-2-pentalenyl-}]pentyl}oxy]diphenylsilane (**32**): To a suspension of LiCl (28.2 mg, 0.67 mmol) and (*S*,*S*)-bis(α-phenylethyl)amine (77.7 mg, 0.35 mmol) in THF (2 ml) was added at −70°C dropwise *n*BuLi (0.22 ml of 1.55 M in *n*-hexane, 0.34 mmol) within 2 min. After stirring the solution for 10 min. at −70°C, it was warmed to room temperature, cooled to −102°C and kept at this temperature for 15 min. Subsequently a solution of **4b** (93 mg, 0.21 mmol) in THF (2 ml) was added at −102°C under film cooling within 35 min. After stirring the mixture for 1 h at −88°C, it was warmed to −78°C and $ClSiEt_3$ (0.1 ml, 0.60 mmol) was added. After being kept for 30 min. at −70°C, the mixture was treated with saturated aqueous $NaHCO_3$ (2 ml) and warmed to room temperature. Water (5 ml) was added and the mixture extracted with ether. The organic phase was dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 4:1) gave a mixture of **32** and **31** (111 mg, 94%) in a ratio of 27:1 as a colorless oil. − $[\alpha]_D^{23}$ = −15.3 (*c* = 1.67, THF). − ^{1}H NMR (500 MHz, C_6D_6): δ = 0.67 (q, *J* = 8.0 Hz, 6 H), 1.00 (t, *J* = 7.9 Hz, 9 H), 1.18 (s, 9 H), 1.28−1.41 (m, 4 H), 1.55 (m, *J* = 6.9 Hz, 2 H), 1.95 (t, br, *J* = 7.3 Hz, 2 H), 2.01 (dm, *J* = 16.3 Hz, 1 H), 2.20 (dm, *J* = 16.0 Hz, 1 H), 2.49 (ddm, *J* = 9.4, *J* = 16.1 Hz, 1 H), 2.69 (dddd, *J* = 1.2, *J* = 1.9, *J* = 9.5, *J* = 16.0 Hz, 1 H), 2.84 (m, 1 H), 3.66 (t, *J* = 6.5 Hz, 2 H), 3.71 (m, 1 H), 4.78 (q, *J* = 2.0 Hz, 1 H), 5.35 (m, *J* = 1.8 Hz, 1 H), 7.22−7.26 (m, 6 H), 7.76−7.81 (m, 4 H). − ^{13}C NMR (126 MHz, C_6D_6): δ = 5.24 (u), 6.92 (d), 19.48 (u), 25.98 (u), 27.13 (d), 27.87 (u), 31.44 (u), 32.89 (u), 37.40 (d), 42.63 (u), 43.84 (u), 54.63 (d), 64.25 (u), 105.29 (d), 127.04 (d), 128.07 (d), 129.93 (d), 134.54 (u), 136.04 (d), 143.27 (u), 154.20 (u). − IR (neat): ν = 3070 (m), 3050 (m), 2955 (s), 2933 (s), 2876 (s), 2858 (s), 1955 (w), 1885 (w), 1825 (w), 1725 (w), 1638 (s), 1590 (w), 1461 (s), 1428 (s), 1389 (m), 1361 (w), 1336 (s), 1306 (m), 1241 (s), 1188 (m), 1111 (s), 1007 (s), 976 (m), 916 (s). − MS; *m*/*z* (%): 560 [M^+] (0.5), 503 (2), 482 (0.2), 387 (0.2), 353 (0.6), 338 (0.7), 324 (1.4), 319 (2), 279 (2), 259 (6), 222 (12), 220 (20), 219 (12), 218 (19), 217 (100), 206 (11), 205 (55), 190 (11), 189 (56), 161 (28), 133 (11), 105 (29), 103 (15). − $C_{35}H_{52}O_2Si_2$ (560.9): calcd. C 74.94, H 9.34; found C 74.66, H 9.66.

{3S-[3α(1S,2E),3aα,6aα]}-5-[5-{[(1,1-Dimethylethyl)-diphenylsilyl]oxy}pentyl]-3,3a,4,6a-tetrahydro-3-(1-hydroxy-2-octenyl)-2(1H)-pentalenone* (*epi*-**34**), *{3S-[3α(1R*,2E),3aα,-6aα]}-5-[5-{[(1,1-Dimethylethyl)diphenylsilyl]oxy}pentyl]-3,3a,4,6a-tetrahydro-3-(1-hydroxy-2-octenyl)-2(1H)-pentalenone* (**34**), *{3R-[3α(1S*,2E),3aα,6aα]}-5-[5-{[(1,1-Dimethylethyl)-diphenylsilyl]oxy}pentyl]-3,3a,6,6a-tetrahydro-3-(1-hydroxy-2-octenyl)-2(1H)-pentalenone* (*epi*-**35**), *and {3R-[3α(1R*,2E),3aα,6aα]}-5-[5-{[(1,1-Dimethyl-ethyl)diphenylsilyl]-oxy}pentyl]-3,3a,6,6a-tetrahydro-3-(1-hydroxy-2-octenyl)-2(1H)-pentalenone* (**35**): To a suspension of (*R*,*R*)-bis(α-phenylethyl)ammonium chloride (1.383 g, 5.3 mmol) in THF (32 ml) was added at −72°C within 15 min. *n*BuLi (6.2 ml of 1.63 M in *n*-hexane, 10.1 mmol). After stirring the suspension for 10 min. at −72°C, it was warmed to room temperature and stirred for 20 min. whereby a yellow solution was formed. After stirring the solution for 2 h at −100°C, it was cooled to −108°C and treated dropwise under film cooling with a solution of **4b** (1.984 g, 4.4 mmol) in THF (10 ml) within 2 h. After stirring the suspension formed for 35 min. at −104°C, it was warmed to −82°C and a solution of **33** (838.5 mg, 6.6 mmol) in THF (5 ml) was added under film cooling within 2 min. After stirring the mixture for 3 h at −70°C, saturated aqueous $NaHCO_3$ (100 ml) was added at this temperature and the mixture was subsequently warmed to room temperature. The aqueous phase was extracted with ether and the combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 4:1) gave a mixture of **34**, *epi*-**34**, **35**, and *epi*-**35** in a ratio of 52:44:1:3 in 95% yield. Chromatography (*n*-hexane/EtOAc, 4:1) of this mixture gave **34** (1.05 g, 42%), *epi*-**34** (910 mg, 36%) and a mixture of *epi*-**35** and **35** as colorless oils.

epi-**34**: $[\alpha]_D^{22}$ = −33.8 (*c* = 1.49, THF). − ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 7.1 Hz, 3 H), 1.05 (s, 9 H), 1.25−1.32 (m, 4 H), 1.32−1.44 (m, 6 H), 1.56 (m, 2 H), 2.01 (m, 2 H), 2.04 (m, 2 H), 2.07 (m, 2 H), 2.28 (ddd, *J* = 1.7, *J* = 2.4, *J* = 19.2 Hz, 1 H), 2.39 (dd, *J* = 9.3, *J* = 19.1 Hz, 1 H), 2.65 (ddm, *J* = 7.4, *J* = 16.1 Hz, 1 H), 2.71 (s, br, 1 H), 2.91 (q, br, *J* = 7.5 Hz, 1 H), 3.30 (m, 1 H), 3.66 (t, *J* = 6.4 Hz, 2 H), 4.50 (dd, *J* = 2.9, *J* = 6.3 Hz, 1 H), 5.18 (m, 1 H), 5.47 (ddt, *J* = 1.4, *J* = 6.8, *J* = 15.4 Hz, 1 H), 5.71 (ddt, *J* = 1.2, *J* = 6.8, *J* = 15.3 Hz, 1 H), 7.33−7.42 (m, 6 H), 7.65−7.69 (m, 4 H). − ^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.06 (d), 19.18 (u), 22.48 (u), 25.62 (u), 26.86 (d), 27.33 (u), 28.82 (u), 31.05 (u), 31.31 (u), 32.14 (u), 32.35 (u), 38.79 (d), 42.93 (u), 43.95 (u), 44.46 (d), 60.51 (d), 63.83 (u), 71.71 (d), 127.04 (d), 127.59 (d), 129.53 (d), 129.91 (d), 132.73 (d), 134.08 (u), 135.57 (d), 144.92 (u), 221.90 (u). − IR ($CHCl_3$): ν = 3453 (w, br), 3071 (w), 3050 (m), 2956 (m), 2930 (s), 2858 (s), 1960 (w), 1890 (w), 1825 (w), 1732 (m), 1590 (w), 1472 (m), 1463 (m), 1428 (m), 1391 (w), 1362 (w), 1344 (w), 1309 (w), 1158 (w), 1111 (s), 1008 (w), 975 (w), 939 (w). − MS; *m*/*z* (%): 499 (2), 498 (6), 497 (20), 391 (8), 390 (34), 389 (98), 345 (2), 331 (2), 311 (6), 293 (2), 267 (3), 253 (3), 251 (2), 249 (2), 239 (2), 225 (2), 215 (2), 213 (2), 210 (2), 201 (5), 200 (21), 199 (100), 183 (11), 181 (15), 174 (10), 173 (49), 145 (17), 139 (22), 135 (10), 133 (12), 131 (31), 117 (17), 105 (20), 93 (13), 91 (36). − $C_{37}H_{52}O_3Si$ (572.9): calcd. C 77.57, H 9.15; found C 77.73, H 9.50. − $C_{33}H_{41}O_3Si$ (M^+ − C_4H_{11}): calcd. 513.2825, found 513.2820 (MS).

34: $[\alpha]_D^{29}$ = −16.0 (*c* = 1.73, THF). − ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 7.0 Hz, 3 H), 1.05 (s, 9 H), 1.25−1.44 (m, 10 H), 1.56 (m, 2 H), 1.99−2.09 (m, 5 H), 2.12 (d, br, *J* = 14.3 Hz, 1 H), 2.34 (ddd, *J* = 1.8, *J* = 3.0, *J* = 19.5 Hz, 1 H), 2.48 (dd, *J* = 9.4, *J* = 19.5 Hz, 1 H), 2.56−2.64 (m, 2 H), 3.30 (m, 1 H), 3.65 (t, *J* = 6.4 Hz, 2 H), 3.95 (s, br, 1 H), 4.17 (dt, *J* = 0.7, *J* = 8.0, *J* = 8.0 Hz, 1 H), 5.20 (m, 1 H), 5.42 (ddt, *J* = 1.5, *J* = 7.7, *J* = 15.3 Hz, 1-H), 5.72 (ddt, *J* = 0.9, *J* = 6.8, *J* = 15.3 Hz, 1 H), 7.35−7.44 (m, 6 H), 7.65−7.68 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.05 (d), 19.21 (u), 22.51 (u), 25.65 (u), 26.85 (d), 27.34 (u), 28.77 (u), 31.02 (u), 31.39 (u), 32.16 (u), 32.37 (u), 41.24 (d), 42.73 (u), 43.39 (u), 43.93 (d), 59.32 (d), 63.84 (u), 74.32 (d), 126.74 (d), 127.56 (d), 129.31 (d), 129.50 (d), 134.10 (u), 134.10 (d), 135.55 (d), 144.90 (u), 223.72 (u). − IR (neat): ν = 3475 (w, br), 3070 (m), 3047 (m), 2998 (w), 2954 (s), 2930 (s), 2857 (s), 1957 (w), 1889 (w), 1824 (w), 1733 (s), 1723 (s), 1668 (w), 1650 (w), 1590 (w), 1472 (m), 1462 (m), 1428 (s), 1403 (m), 1390 (m), 1361 (w), 1311 (w), 1281 (w), 1263 (w), 1188 (w), 1158 (m), 1111 (s), 1029 (m), 1008 (m), 998 (m), 977 (m), 939 (w), 917 (w). − MS; *m*/*z* (%): 515 [M^+ − C_4H_9] (2), 514 (2), 513 (3), 498 (2), 497 (4), 438 (2), 437 (6), 391 (8), 390 (29), 389 (88), 345 (3), 312 (2), 311 (9), 253 (2), 249 (2), 239 (2), 233 (2), 201 (4), 200 (11), 199 (66), 173 (34), 145 (10), 139 (19), 131 (22), 117 (10), 105 (11), 98 (12), 97 (15), 95 (11), 93 (17), 91 (22). − $C_{33}H_{41}O_3Si$ (M^+ − C_4H_{11}): calcd. 513.2825; found 513.2820 (MS).

epi-**35**: ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 7.0 Hz, 3 H), 1.04 (s, 9 H), 1.23−1.45 (m, 10 H), 1.56 (m, 2 H), 2.01−2.07 (m, 5 H), 2.11 (dddd, *J* = 0.4, *J* = 1.6, *J* = 7.6, *J* = 18.8 Hz, 1

H), 2.20 (s, br, 1 H), 2.25 (ddd, J = 1.6, J = 3.5, J = 4.7 Hz, 1 H), 2.49 (dd, J = 9.2, J = 18.8 Hz, 1 H), 2.61 (ddm, J = 8.0, J = 16.3 Hz, 1 H), 2.86 (m, 1 H), 3.28 (m, 1 H), 3.65 (t, J = 6.4 Hz, 2 H), 4.50 (m, 1 H), 5.23 (m, 1 H), 5.46 (ddt, J = 1.5, J = 6.5, J = 15.3 Hz, 1 H), 5.72 (ddt, J = 1.2, J = 6.8, J = 15.3 Hz, 1-H), 7.35−7.44 (m, 6 H), 7.65−7.68 (m, 4 H). − ^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.06 (d), 19.23 (u), 22.51 (u), 25.68 (u), 26.88 (d), 27.44 (u), 28.83 (u), 31.04 (u), 31.37 (u), 32.20 (u), 32.41 (u), 36.76 (d), 42.48 (u), 46.27 (u), 48.04 (d), 58.47 (d), 63.90 (u), 72.77 (d), 126.76 (d), 127.64 (d), 129.57 (d), 129.81 (d), 133.16 (d), 134.18 (u), 135.64 (d), 144.56 (u), 222.33 (u).

35: ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.88 (t, J = 7.0 Hz, 3 H), 1.04 (s, 9 H), 1.24−1.45 (m, 10 H), 1.56 (m, 2 H), 1.58 (s, br, 1 H), 1.97−2.10 (m, 5 H), 2.16−2.22 (m, 2 H), 2.54 (dd, J = 9.2, J = 19.2 Hz, 1 H), 2.62 (ddm, J = 8.2, J = 16.2 Hz, 1 H), 2.86 (m, 1 H), 3.06 (m, 1 H), 3.65 (t, J = 6.5 Hz, 2 H), 4.15 (t, J = 7.9 Hz, 1 H), 5.24 (m, 1 H), 5.41 (ddt, J = 1.4, J = 7.7, J = 15.3 Hz, 1-H), 5.72 (ddt, J = 0.8, J = 6.8, J = 15.3 Hz, 1-H), 7.35−7.44 (m, 6 H), 7.65−7.68 (m, 4 H).

{2R-[2α,3β(1S,2E),3aβ,6aβ]}-5-[5-{[(1,1-Dimethylethyl)-diphenylsilyl]oxy}pentyl]-1,2,3,3a,4,6a-hexahydro-3-(1-hydroxy-2-octenyl)-2-pentalenol* (**36**): To a solution of **34** (799 mg, 1.39 mmol) in EtOH (40 ml) was added at −66°C $NaBH_4$ (213 mg, 5.64 mmol). After stirring the mixture for 5 h at −50°C, it was treated with saturated aqueous NH_4Cl (60 ml) and warmed to room temperature. The aqueous phase was extracted with ether. The combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 2:1) gave **36** (677 mg, 84%) as a colorless oil. − R_f (*n*-hexane/EtOAc, 2:1) = 0.20, $[\alpha]_D^{23}$ = +10.1 (*c* = 1.09, THF). − ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.89 (t, J = 7.0 Hz, 3 H), 1.05 (s, 9 H), 1.24−1.43 (m, 11 H), 1.54 (q, J = 9.2 Hz, 1 H), 1.56 (m, J = 7.0 Hz, 2 H), 1.98 (t, br, J = 6.9 Hz, 2 H), 2.00−2.07 (m, 3 H), 2.15 (dq, J = 3.3, J = 9.4 Hz, 1 H), 2.26 (ddd, J = 6.6, J = 8.2, J = 12.0 Hz, 1 H), 2.39 (ddm, J = 9.4, J = 16.6 Hz, 1 H), 2.90 (s, br, 2 H), 2.94 (q, br, J = 9.5 Hz, 1 H), 3.65 (t, J = 6.5 Hz, 2 H), 3.95 (ddd, J = 6.6, J = 9.0, J = 10.3 Hz, 1 H), 4.03 (dd, J = 8.5, J = 8.5 Hz, 1 H), 5.26 (m, J = 1.8 Hz, 1 H), 5.48 (ddt, J = 1.4, J = 7.7, J = 15.3 Hz, 1 H), 5.66 (ddt, J = 0.7, J = 6.7, J = 15.3 Hz, 1-H), 7.35−7.43 (m, 6 H), 7.65−7.68 (m, 4 H). − ^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.05 (d), 19.21 (u), 22.52 (u), 25.66 (u), 26.88 (d), 27.53 (u), 28.87 (u), 30.89 (u), 31.41 (u), 32.13 (u), 32.45 (u), 40.61 (u), 41.20 (d), 42.56 (u), 46.08 (d), 59.18 (d), 63.95 (u), 78.31 (d), 79.72 (d), 127.12 (d), 127.62 (d), 129.54 (d), 132.01 (d), 132.90 (d), 134.18 (u), 135.61 (d), 142.27 (u). − IR ($CHCl_3$): ν = 3362 (m, br), 3071 (m), 3048 (m), 3013 (m), 2999 (m), 2955 (s), 2929 (s), 2857 (s), 1957 (w), 1890 (w), 1820 (w), 1670 (w), 1654 (w), 1590 (w), 1472 (m), 1462 (m), 1428 (s), 1390 (m), 1361 (w), 1330 (m), 1261 (w), 1217 (w), 1189 (w), 1148 (m), 1112 (s), 998 (m), 974 (m), 939 (w). − MS; *m/z* (%): 557 (0.4), 556 [$M^+ - H_2O$] (0.4), 539 (1), 538 (1), 501 (10), 500 (31), 499 (71), 481 (9), 455 (5), 421 (4), 284 (11), 283 (55), 227 (11), 213 (15), 200 (13), 199 (67), 187 (18), 185 (11), 183 (12), 175 (10), 173 (11), 171 (15), 159 (13), 157 (10), 149 (12), 147 (20), 145 (22), 143 (13), 139 (21), 135 (22), 133 (32), 131 (31), 129 (13), 123 (11), 121 (10), 119 (19), 117 (29), 109 (19), 107 (14), 105 (38), 97 (10), 95 (24), 93 (29), 92 (10), 91 (72). − $C_{37}H_{54}O_3Si$ (574.92): calcd. C 77.30, H 9.47; found C 77.47, H 9.40. − $C_{33}H_{43}O_2Si$ ($M^+ - C_4H_{11} - H_2O$): calcd. 499.3032, found 499.3031 (MS).

{2R-[2α,3β(1R,2E),3aβ,6aβ]}-5-[5-{[(1,1-Dimethylethyl)-diphenylsilyl]oxy}pentyl]-1,2,3,3a,4,6a-hexahydro-3-(1-hydroxy-2-octenyl)-2-pentalenol* (**37**) *and {2S-[2α,3α(1S*,2E),3aα,6aα]}-5-[5-{[(1,1-Dimethylethyl)diphenylsilyl]oxy}pentyl]-1,2,3,3a,4,6a-hexahydro-3-(1-hydroxy-2-octenyl)-2-pentalenol* (*epi*-**37**): To a solution of *epi*-**34** (566 mg, 0.99 mmol) in EtOH (30 ml) was added at −66°C $NaBH_4$ (153 mg, 4.06 mmol). After stirring the suspension for 4.5 h at −40°C, $NaBH_4$ (155.0 mg, 4.10 mmol) was added and the mixture was stirred for 2.5 h at −25°C. The mixture was treated with saturated aqueous NH_4Cl and warmed to room temperature. The aqueous phase was extracted with ether. The combined organic phases were dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 2:1) gave **37** (498 mg, 88%) and *epi*-**37** (15 mg, 3%) as colorless oils.

37: R_f (*n*-hexane/EtOAc, 2:1) = 0.17, $[\alpha]_D^{24}$ = +10.7 (*c* = 1.57, THF). − ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.89 (t, J = 7.0 Hz, 3 H), 1.05 (s, 9 H), 1.24−1.44 (m, 11 H), 1.56 (quin, J = 6.9 Hz, 2 H), 1.74 (dt, J = 4.6, J = 9.3 Hz, 1 H), 2.00 (t, br, J = 7.0 Hz, 2 H), 2.03−2.10 (m, 3 H), 2.21 (ddd, J = 6.7, J = 8.2, J = 12.2 Hz, 1 H), 2.31 (dq, J = 2.6, J = 9.3, 1 H), 2.47 (dd, br, J = 9.2, J = 16.5 Hz, 1 H), 2.60 (s, br, 2 H), 2.93 (q, br, J = 7.7 Hz, 1 H), 3.66 (t, J = 6.4 Hz, 2 H), 4.00 (ddd, J = 6.7, J = 9.2, J = 9.2 Hz, 1 H), 4.24 (dd, J = 4.6, J = 7.3 Hz, 1 H), 5.27 (m, br, J = 1.5 Hz, 1 H), 5.59 (ddt, J = 1.2, J = 7.3, J = 15.3 Hz, 1-H), 5.69 (dt, J = 6.6, J = 15.3 Hz, 1 H), 7.34−7.43 (m, 6 H), 7.65−7.68 (m, 4 H). − ^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.06 (d), 19.21 (u), 22.49 (u), 25.66 (u), 26.88 (d), 27.53 (u), 28.90 (u), 30.95 (u), 31.40 (u), 32.28 (u), 32.43 (u), 39.86 (d), 40.40 (u), 41.70 (u), 46.19 (d), 59.03 (d), 63.93 (u), 74.08 (d), 74.29 (d), 127.62 (d), 127.69 (d), 129.54 (d), 130.12 (d), 133.77 (d), 134.17 (u), 135.61 (d), 142.34 (u). − IR ($CHCl_3$): ν = 3371 (m, br), 3071 (m), 3048 (m), 3013 (m), 2998 (w), 2954 (s), 2929 (s), 2857 (s), 1956 (w), 1888 (w), 1823 (w), 1715 (w), 1651 (w), 1590 (w), 1472 (m), 1462 (m), 1428 (s), 1390 (m), 1361 (w), 1332 (w), 1305 (w), 1262 (w), 1217 (w), 1188 (w), 1111 (s), 1022 (m), 1008 (m), 974 (m), 939 (w). − MS; *m/z* (%): 556 [$M^+ - H_2O$] (0.4), 538 (0.8), 515 (0.8), 501 (6), 500 (24), 499 (58), 482 (3), 481 (7), 456 (2), 455 (3), 440 (2), 439 (5), 421 (3), 325 (2), 284 (11), 283 (49), 227 (11), 213 (13), 200 (11), 199 (62), 187 (17), 185 (14), 183 (11), 175 (14), 173 (10), 171 (13), 159 (11), 157 (10), 149 (12), 147 (18), 145 (19), 143 (12), 139 (20), 135 (21), 133 (22), 131 (29), 129 (16), 121 (10), 119 (17), 117 (26), 109 (16), 107 (12), 105 (29), 95 (21), 93 (24), 91 (43). − $C_{37}H_{54}O_3Si$ (574.9): calcd. C 77.30, H 9.47; found C 77.28, H 9.84.

epi-**37**: R_f (*n*-hexane/EtOAc, 2:1) = 0.28. − ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.88 (t, J = 7.0 Hz, 3 H), 1.04 (s, 9 H), 1.24−1.44 (m, 11 H), 1.56 (m, 2 H), 1.64 (dt, J = 3.9, J = 9.6 Hz, 1 H), 1.70−2.80 (s, br, 2 H), 1.94 (ddd, J = 1.5, J = 8.3, J = 13.5 Hz, 1 H), 1.98 (t, br, J = 7.5 Hz, 2 H), 2.00−2.07 (m, 3 H), 2.54 (ddm, J = 9.5, J = 16.6 Hz, 1 H), 2.99 (dq, J = 3.0, J = 9.4 Hz, 1 H), 3.38 (m, 1 H), 3.64 (t, J = 6.5 Hz, 2 H), 4.37 (m, 1 H), 4.56 (ddd, J = 0.5, J = 3.9, J = 6.8 Hz, 1 H), 5.33 (m, 1 H), 5.55 (ddt, J = 1.4, J = 6.9, J = 15.3 Hz, 1 H), 5.69 (ddt, J = 1.0, J = 6.7, J = 15.4 Hz, 1 H), 7.35−7.44 (m, 6 H), 7.64−7.68 (m, 4 H). − ^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.01 (d), 19.18 (u), 22.48 (u), 25.61 (u), 26.83 (d), 27.48 (u), 28.83 (u), 30.93 (u), 31.36 (u), 32.11 (u), 32.43 (u), 38.79 (d), 42.24 (u), 42.40 (u), 49.41 (d), 57.20 (d), 63.95 (u), 73.59 (d), 78.54 (d), 127.16 (d), 127.50 (d), 129.54 (d), 131.36 (d), 132.01 (d), 134.16 (u), 135.58 (d), 142.44 (u).

{4S-[4α(E),4aα,4bβ,7aβ,8aβ]}-(1,1-Dimethylethyl)[{5-[4a,4b,5,7a,8,8a-hexahydro-4-(1-heptenyl)-2,2-dimethyl-4H-pentaleno[2,1-d]-1,3-dioxin-6-yl]pentyl}oxy]diphenylsilane (**38**): To a solution of **36** (23 mg, 0.04 mmol) in acetone (1.5 ml) were added at room temperature 2,2-dimethoxypropane (0.4 ml, 3.25 mmol) and ω-camphorsulfonic acid (1 mg). After stirring the mixture for 15 min. at room temperature, NEt_3 (0.2 ml) was added and the

mixture was concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 4:1) gave **38** (22 mg, 87%) as a colorless oil. − R_f (*n*-hexane/EtOAc, 4:1) = 0.53, $[\alpha]_D^{25}$ = +16.6 (*c* = 1.11, THF). − ^{1}H NMR (500 MHz, C_6D_6): δ = 0.86 (t, *J* = 6.9 Hz, 3 H), 1.18−1.29 (m, 4 H), 1.20 (s, 9 H), 1.30−1.44 (m, 7 H), 1.42 (s, 3 H), 1.46 (dt, *J* = 8.2, *J* = 11.1 Hz, 1 H), 1.55 (quin, *J* = 6.9 Hz, 2 H), 1.62 (s, 3 H), 1.94 (m, 2 H), 2.00 (m, *J* = 6.7 Hz, 2 H), 2.05 (m, 1 H), 2.14 (m, 1 H), 2.22 (ddd, *J* = 6.4, *J* = 8.3, *J* = 11.2 Hz, 1 H), 2.40 (ddm, *J* = 8.9, *J* = 16.6 Hz, 1 H), 2.96 (m, 1 H), 3.50 (dt, *J* = 6.4, *J* = 10.7, *J* = 10.3 Hz, 1 H), 3.66 (t, *J* = 6.5 Hz, 2 H), 4.13 (dd, *J* = 7.1, *J* = 9.8 Hz, 1 H), 5.24 (m, *J* = 1.5 Hz, 1 H), 5.61 (ddt, *J* = 1.4, *J* = 7.0, *J* = 15.4 Hz, 1 H), 5.75 (ddt, *J* = 0.8, *J* = 6.8, *J* = 15.4 Hz, 1 H), 7.23−7.27 (m, 6 H), 7.77−7.82 (m, 4 H). − ^{13}C NMR (126 MHz, C_6D_6): δ = 14.25 (d), 19.51 (u), 20.57 (d), 22.91 (u), 26.08 (u), 27.16 (d), 27.93 (u), 29.32 (u), 30.54 (d)), 31.34 (u), 31.70 (u), 32.64 (u), 32.90 (u), 37.28 (u), 39.31 (d), 40.62 (u), 46.02 (d), 53.96 (d), 64.26 (u), 74.20 (d), 78.41 (d), 99.75 (u), 127.41 (d), 128.38 (d), 129.99 (d), 130.76 (d), 132.21 (d), 134.56 (u), 136.07 (d), 142.24 (u). − IR ($CHCl_3$): ν = 3071 (w), 2998 (w), 2957 (m), 2930 (s), 2858 (m), 1960 (w), 1890 (w), 1825 (w), 1730 (w), 1670 (w), 1590 (w), 1472 (w), 1462 (w), 1428 (w), 1382 (w), 1363 (w), 1332 (w), 1261 (w), 1217 (m), 1197 (w), 1159 (m), 1111 (m), 1050 (w), 1000 (w), 975 (w), 938 (w). − MS; *m*/*z* (%): 599 (0.03), 571 (0.5), 558 (0.5), 557 [M^+ − C_4H_9] (0.9), 556 (0.8), 542 (0.3), 541 (0.6), 540 (1.1), 539 (3.8), 538 (0.7), 515 (0.5), 502 (1.5), 501 (7), 500 (26), 499 (69), 482 (2), 481 (5), 456 (1), 455 (3), 422 (2), 421 (4), 403 (1), 283 (44), 199 (51), 187 (11), 185 (10), 183 (13), 173 (11), 171 (10), 147 (10), 145 (14), 139 (12), 135 (17), 133 (12), 131 (19), 129 (11), 117 (16), 105 (19), 95 (13), 93 (13), 91 (29). − $C_{33}H_{43}O_2Si$ (M^+ − C_4H_9 − C_3H_6O): calcd. 499.3032, found 499.3034 (MS).

{2R-[2α,3β(1S,2E),3aβ,6aβ]}-3-[1-(Acetyloxy)-2-octenyl]-5-[5-{[(1,1-dimethylethyl)diphenylsilyl]oxy}pentyl]-1,2,3,3a,4,6a-hexahydro-2-pentalenol Acetate* (**39**): To a solution of **36** (671 mg, 1.17 mmol) in THF (40 ml) were added at room temperature pyridine (0.38 ml, 4.68 mmol) and acetyl chloride (0.33 ml, 4.68 mmol). After stirring the mixture for 18 h at room temperature, it was concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane-EtOAc, 4:1) gave **39** (746 mg, 97%) as a colorless oil. − R_f (*n*-hexane/EtOAc, 1:1) = 0.40, $[\alpha]_D^{33}$ = −15.4 (*c* = 1.44, THF). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.9 Hz, 3 H), 1.05 (s, 9 H), 1.20−1.47 (m, 11 H), 1.57 (quin, *J* = 6.7 Hz, 2 H), 1.94−2.16 (m, 6 H), 1.98 (s, 3 H), 2.03 (s, 3 H), 2.33 (ddd, *J* = 6.7, *J* = 8.4, *J* = 12.8 Hz, 1 H), 2.40 (dq, *J* = 2.4, *J* = 8.7 Hz, 1 H), 2.53 (dd, br, *J* = 9.1, *J* = 16.1 Hz, 1 H), 3.02 (m, 1 H), 3.66 (t, *J* = 6.5 Hz, 2 H), 4.93 (q, *J* = 7.6 Hz, 1 H), 5.22 (m, *J* = 1.7 Hz, 1 H), 5.28 (dd, *J* = 6.1, *J* = 7.4 Hz, 1 H), 5.41 (ddt, *J* = 1.3, *J* = 7.4, *J* = 15.1 Hz, 1 H), 5.70 (dt, *J* = 6.7, *J* = 15.2 Hz, 1 H), 7.34−7.45 (m, 6 H), 7.64−7.69 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.03 (d), 19.23 (u), 21.20 (d), 21.28 (d), 22.46 (u), 25.64 (u), 26.88 (d), 27.51 (u), 28.59 (u), 30.87 (u), 31.37 (u), 32.23 (u), 32.44 (u), 37.60 (u), 40.81 (d), 42.45 (u), 46.85 (d), 55.29 (d), 63.91 (u), 75.55 (d), 76.82 (d), 126.03 (d), 127.19 (d), 127.57 (d), 129.51 (d), 134.14 (u), 135.42 (d), 135.57 (d), 142.38 (u), 170.13 (u), 170.52 (u). − IR ($CHCl_3$): ν = 3071 (w), 3025 (w), 2998 (w), 2955 (s), 2930 (s), 2857 (s), 1960 (w), 1890 (w), 1825 (w), 1739 (s), 1669 (w), 1590 (w), 1472 (m), 1462 (m), 1428 (m), 1370 (s), 1245 (s), 1189 (w), 1111 (s), 1051 (m), 1021 (m), 999 (m), 975 (m). − MS; *m*/*z* (%): 602 [M^+ + H − C_4H_9] (0.3), 601 (0.1), 543 (8), 542 (20), 541 (48), 500 (2), 499 (6) , 497 (3), 482 (3), 481 (9), 464 (3), 463 (7), 404 (3), 403 (8), 385 (14), 283 (30), 241 (34), 199 (44), 181 (30), 171 (10), 145 (12), 139 (13), 135 (10), 133 (11), 131 (15), 129 (12), 121 (12), 117 (17), 105 (17), 95 (13), 93 (13), 91 (23). − $C_{41}H_{58}O_5Si$ (659.0): calcd. C 74.73, H 8.87; found C 74.94, H 9.00. − $C_{35}H_{45}O_3Si$ (M^+ − C_4H_9 − CH_3COOH): calcd. 541.3138, found 541.3138 (MS).

{2R-[2α,3β(2E,3S),3aβ,6aβ]}-3-[3-(Acetyloxy)-2-octenyl]-5-[5-{[(1,1-dimethylethyl)diphenylsilyl]oxy}pentyl]-1,2,3,3a,4,6a-hexahydro-2-pentalenol Acetate* (**40**): To a solution of **39** (729 mg, 1.11 mmol) in THF (30 ml) was added at room temperature $Pd(MeCN)_2Cl_2$ (11 mg, 44 μmol). After stirring the solution for 18 h at room temperature, it was concentrated in vacuum. *n*-hexane (80 ml) were added to the residue. The suspension was filtered and the residue was washed with *n*-hexane (50 ml). The combined filtrates were concentrated in vacuum. Purification of the residue by MPLC (*n*-hexane/EtOAc, 10:1) gave **40** (515 mg, 71%), contaminated by 5% of **39** (R_f = 0.16, *n*-hexane/EtOAc, 10:1), HPLC (silica gel, 5 μm, *n*-hexane/EtOAc, 95:5): R_t (**39**) = 30.16 min., R_t (**40**) = 26.91 min. − R_f (*n*-hexane/EtOAc, 10:1) = 0.13, $[\alpha]_D^{30}$ = −24.0 (*c* = 0.90, THF). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.7 Hz, 3 H), 1.05 (s, 9 H), 1.21−1.47 (m, 11 H), 1.57 (m, 4 H), 1.94−2.07 (m, 3 H), 1.98 (s, 3 H), 2.04 (s, 3 H), 2.16 (dt, *J* = 7.7, *J* = 9.6, 1 H), 2.31 (m, 1 H), 2.36−2.49 (m, 2 H), 3.04 (m, 1 H), 3.66 (t, *J* = 6.5 Hz, 2 H), 4.80 (dt, *J* = 7.4, *J* = 9.4 Hz, 1 H), 5.21 (q, *J* = 6.7 Hz, 1 H), 5.23 (m, 1 H), 5.43 (dd, *J* = 6.7, *J* = 15.5 Hz, 1 H), 5.58 (dd, *J* = 7.7, *J* = 15.5 Hz, 1 H), 7.33−7.46 (m, 6 H), 7.65−7.69 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.99 (d), 19.23 (u), 21.06 (d), 21.34 (d), 22.53 (u), 24.75 (u), 25.67 (u), 26.89 (d), 27.51 (u), 30.92 (u), 31.53 (u), 32.44 (u), 34.39 (u), 36.67 (u), 39.82 (u), 43.56 (d), 45.74 (d), 54.16 (d), 63.93 (u), 74.37 (d), 78.13 (d), 127.58 (d), 127.58 (d), 129.51 (d), 129.98 (d), 133.30 (d), 134.15 (u), 135.58 (d), 142.09 (u), 170.28 (u), 170.81 (u). − ^{1}H NMR (500 MHz, C_6D_6): δ = 0.86 (t, *J* = 7.1 Hz, 3 H), 1.19 (s, 9 H), 1.17−1.35 (m, 10 H), 1.37 (ddd, *J* = 7.1, *J* = 9.4, *J* = 12.5 Hz, 1 H), 1.55 (m, 3 H), 1.64−1.71 (m, 1 H), 1.71 (s, 3 H), 1.74 (s, 3 H), 1.91 (m, br, 2 H), 2.01 (d, br, *J* = 16.3 Hz, 1 H), 2.14 (m, *J* = 1.7, *J* = 8.6, *J* = 10.2 Hz, 1 H), 2.27 (dt, *J* = 8.1, *J* = 9.8 Hz, 1 H), 2.32 (ddm, *J* = 8.6, *J* = 16.4 Hz, 1 H), 2.44 (ddd, *J* = 7.3, *J* = 9.0, *J* = 12.4 Hz, 1 H), 2.86 (m, 1 H), 3.66 (t, *J* = 6.4 Hz, 2 H), 5.01 (dt, *J* = 7.4, *J* = 9.6 Hz, 1 H), 5.15 (m, *J* = 1.4 Hz, 1 H), 5.47 (q, *J* = 6.7 Hz, 1 H), 5.57 (ddd, *J* = 0.8, *J* = 6.9, *J* = 15.4 Hz, 1 H), 5.71 (ddd, *J* = 0.8, *J* = 7.9, *J* = 15.4 Hz, 1 H), 7.23−7.27 (m, 6 H), 7.77−7.82 (m, 4 H). − ^{13}C NMR (75 MHz, C_6D_6): δ = 14.17 (d), 19.49 (u), 20.69 (d), 20.91 (d), 22.92 (u), 25.22 (u), 26.03 (u), 27.14 (d), 27.84 (u), 31.24 (u), 31.88 (u), 32.84 (u), 34.88 (u), 37.12 (u), 40.06 (u), 43.98 (d), 46.08 (d), 54.90 (d), 64.21 (u), 74.33 (d), 78.11 (d), 128.05 (d), 129.94 (d), 130.71 (d), 134.02 (d), 134.48 (u), 136.01 (d), 142.02 (u), 169.46 (u), 169.92 (u). − IR ($CHCl_3$): ν = 3071 (w), 3047 (w), 3028 (w), 2999 (w), 2931 (s), 2858 (s), 1960 (w), 1890 (w), 1825 (w), 1738 (s), 1649 (w), 1590 (w), 1472 (m), 1462 (m), 1428 (m), 1371 (m), 1243 (s), 1111 (s), 1066 (m), 1021 (m), 970 (m), 939 (w). − MS; *m*/*z* (%): 615 (0.6), 601 (0.7), 557 (0.6), 544 (1), 543 (4), 542 (18), 541 [M^+ − C_4H_9 − CH_3COOH] (39), 499 (4) , 497 (2), 483 (2), 482 (4), 481 (8), 464 (3), 463 (8), 404 (2), 403 (10), 385 (14), 283 (26), 241 (48), 199 (43), 183 (12), 181 (31), 171 (12), 147 (10), 145 (14), 143 (10), 139 (18), 135 (17), 133 (12), 131 (16), 129 (14), 121 (11), 119 (10), 117 (17), 107 (10), 105 (17), 95 (16), 93 (17), 91 (36). − $C_{35}H_{45}O_3Si$ (M^+ − C_4H_9 − CH_3COOH): calcd. 541.3138, found 541.3136 (MS).

{2R-[2α,3β(1R,2E),3aβ,6aβ]}-3-[1-(Acetyloxy)-2-octenyl]-5-[5-{[(1,1-dimethylethyl)diphenylsilyl]oxy}pentyl]-1,2,3,3a,4,6a-hexahydro-2-pentalenol Acetate* (**41**): To a solution of **37** (438 mg, 0.76 mmol) in THF (30 ml) were added at room temperature pyridine (0.25 ml, 3.09 mmol) and acetyl chloride (0.22 ml, 3.10 mmol). After stirring the mixture for 23 h, it was concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc,

4:1) gave **41** (491 mg, 98%) as a colorless oil. − R_f (*n*-hexane/EtOAc, 4:1) = 0.38, $[\alpha]_D^{24}$ = −16.3 (*c* = 1.02, THF). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.7 Hz, 3 H), 1.05 (s, 9 H), 1.22−1.47 (m, 11 H), 1.57 (quin, *J* = 6.7 Hz, 2 H), 1.94−2.07 (m, 5 H), 1.97 (s, 3 H), 2.04 (s, 3 H), 2.14 (d, br, *J* = 15.8 Hz, 1 H), 2.33 (ddd, *J* = 7.0, *J* = 8.5, *J* = 12.5 Hz, 1 H), 2.48 (dq, *J* = 2.0, *J* = 9.1 Hz, 1 H), 2.53 (dd, br, *J* = 9.1, *J* = 16.1 Hz, 1 H), 3.01 (m, *J* = 7.7 Hz, 1 H), 3.66 (t, *J* = 6.4 Hz, 2 H), 4.93 (ddd, *J* = 7.1, *J* = 8.7, *J* = 8.7 Hz, 1 H), 5.23 (m, 1 H), 5.29 (dd, *J* = 5.0, *J* = 7.7 Hz, 1 H), 5.42 (ddt, *J* = 1.3, *J* = 7.7, *J* = 15.1 Hz, 1 H), 5.71 (dt, *J* = 6.7, *J* = 15.1 Hz, 1 H), 7.33−7.45 (m, 6 H), 7.64−7.69 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.04 (d), 19.22 (u), 21.14 (d), 21.30 (d), 22.47 (u), 25.64 (u), 26.88 (d), 27.50 (u), 28.59 (u), 30.83 (u), 31.38 (u), 32.22 (u), 32.44 (u), 37.62 (u), 39.98 (d), 42.54 (u), 46.49 (d), 55.50 (d), 63.91 (u), 74.89 (d), 75.46 (d), 126.30 (d), 127.02 (d), 127.57 (d), 129.50 (d), 134.12 (u), 135.15 (d), 135.56 (d), 142.36 (u), 170.09 (u), 170.56 (u). − IR ($CHCl_3$): ν = 3071 (w), 3022 (w), 2955 (s), 2931 (s), 2858 (s), 1960 (w), 1890 (w), 1825 (w), 1739 (s), 1670 (w), 1589 (w), 1472 (m), 1461 (m), 1428 (m), 1370 (s), 1244 (s), 1189 (w), 1111 (s), 1020 (m), 975 (m). − MS; *m*/*z* (%): 614 (1), 602 [M^+ + 1 − C_4H_9] (1), 544 (3), 543 (12), 542 (41), 541 (100), 539 (3), 538 (3), 500 (7), 499 (15) , 497 (3), 482 (6), 481 (17), 464 (6), 463 (16), 403 (10), 385 (18), 283 (29), 242 (12), 241 (52), 199 (51), 183 (13), 181 (31), 139 (14), 135 (14), 133 (11), 131 (13), 129 (11), 117 (13), 105 (16), 95 (12), 93 (13), 91 (26). − $C_{37}H_{49}O_5Si$ (M^+ − C_4H_9): calcd. 601.3349, found 601.3351 (MS).

{2R-[2α,3β(2E,3R),3aβ,6aβ]}-3-[3-(Acetyloxy)-2-octenyl]-5-[5-{[(1,1-dimethylethyl)diphenylsilyl]oxy}pentyl]-1,2,3,3a,4,6a-hexahydro-2-pentalenol Acetate* (**42**): To a solution of **41** (477 mg, 0.725 mmol) in THF (20 ml) was added at room temperature $Pd(MeCN)_2Cl_2$ (8 mg, 29 μmol). After stirring the solution for 17 h at room temperature, it was concentrated in vacuum and *n*-hexane (45 ml) was added to the residue. The suspension was filtered and the residue washed with *n*-hexane (50 ml). The combined filtrates were concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 10:1) gave a mixture of **42** and **41** [R_f (*n*-hexane/EtOAc, 10:1) = 0.18] (288.1 mg, 60%) in a ratio of 95:5, a mixture of **42** and **41** (112 mg, 23%) in a ratio of 5:3 and a mixture of **42** and **41** (43 mg, 9%) in a ratio of 2:1. − R_f (*n*-hexane/EtOAc, 10:1) = 0.20, $[\alpha]_D^{29}$ = +9.6 (*c* = 1.78, THF) (**42**/**41** = 95:5). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.7 Hz, 3 H), 1.05 (s, 9 H), 1.21−1.45 (m, 11 H), 1.45−1.65 (m, 4 H), 1.94−2.06 (m, 3 H), 1.97 (s, 3 H), 2.04 (s, 3 H), 2.14 (dt, *J* = 8.1, *J* = 9.6 Hz, 1 H), 2.33 (m, 1 H), 2.33−2.49 (m, 2 H), 3.03 (m, 1 H), 3.66 (t, *J* = 6.6 Hz, 2 H), 4.80 (dt, *J* = 7.4, *J* = 9.6 Hz, 1 H), 5.19 (q, *J* = 6.9 Hz, 1 H), 5.23 (m, 1 H), 5.43 (dd, *J* = 7.0, *J* = 15.4 Hz, 1 H), 5.57 (dd, *J* = 8.1, *J* = 15.5 Hz, 1 H), 7.33−7.46 (m, 6 H), 7.64−7.70 (m, 4 H). − ^{13}CNMR (75 MHz, $CDCl_3$): δ = 14.00 (d), 19.23 (u), 21.05 (d), 21.39 (d), 22.53 (u), 24.75 (u), 25.67 (u), 26.89 (d), 27.51 (u), 30.93 (u), 31.55 (u), 32.44 (u), 34.48 (u), 36.66 (u), 39.77 (u), 43.64 (d), 45.70 (d), 54.42 (d), 63.94 (u), 74.64 (d), 78.03 (d), 127.52 (d), 127.58 (d), 129.51 (d), 130.24 (d), 133.80 (d), 134.16 (u), 135.58 (d), 142.12 (u), 170.33 (u), 170.81 (u). − ^{1}H NMR (500 MHz, C_6D_6): δ = 0.87 (t, *J* = 7.2 Hz, 3 H), 1.20 (s, 9 H), 1.19−1.34 (m, 10 H), 1.38 (ddd, *J* = 7.1, *J* = 9.5, *J* = 12.4 Hz, 1 H), 1.55 (m, 3 H), 1.64−1.72 (m, 1 H), 1.74 (s, 3 H), 1.75 (s, 3 H), 1.90 (m, br, 2 H), 2.00 (d, br, *J* = 16.5 Hz, 1 H), 2.14 (m, *J* = 1.7, *J* = 8.5, *J* = 10.2 Hz, 1 H), 2.24 (dt, *J* = 8.3, *J* = 9.9 Hz, 1 H), 2.32 (ddm, *J* = 8.5, *J* = 16.4 Hz, 1 H), 2.39 (ddd, *J* = 7.3, *J* = 9.0, *J* = 12.4, 1 H), 2.85 (m, 1 H), 3.67 (t, *J* = 6.4 Hz, 2 H), 4.98 (dt, *J* = 7.4, *J* = 9.7 Hz, 1 H), 5.15 (m, *J* = 1.4 Hz, 1 H), 5.45 (q, *J* = 6.7 Hz, 1 H), 5.56 (ddd, *J* = 0.6, *J* = 7.2, *J* = 15.3 Hz, 1 H), 5.68 (ddd, *J* = 0.6, *J* = 8.2, *J* = 15.3 Hz, 1 H), 7.23−7.27 (m, 6 H), 7.77−7.82 (m, 4 H). − ^{13}C NMR (75 MHz, C_6D_6): δ = 14.21 (d), 19.51 (u), 20.74 (d), 20.97 (d), 22.94 (u), 25.24 (u), 26.05 (u), 27.16 (d), 27.85 (u), 31.25 (u), 31.93 (u), 32.85 (u), 35.01 (u), 37.07 (u), 40.03 (u), 44.08 (d), 46.04 (d), 55.26 (d), 64.23 (u), 74.63 (d), 77.94 (d), 128.06 (d), 129.95 (d), 131.02 (d), 134.46 (d), 134.49 (u), 136.02 (d), 142.09 (u), 169.52 (u), 169.90 (u). − IR ($CHCl_3$): ν = 3071 (w), 3050 (w), 3018 (w), 2931 (s), 2858 (s), 1960 (w), 1890 (w), 1825 (w), 1738 (s), 1671 (w), 1589 (w), 1472 (m), 1462 (m), 1428 (m), 1372 (m), 1242 (s), 1111 (s), 1066 (m), 1048 (m), 1020 (m), 970 (m), 940 (w). − MS; *m*/*z* (%): 658 [M^+] (0.5), 603 (0.3), 602 (2), 601 (2), 543 (13), 542 (45), 541 (93), 499 (8) , 482 (10), 481 (21), 464 (6), 463 (15), 403 (13), 386 (8), 385 (23), 325 (9), 284 (12), 283 (48), 281 (7), 242 (13), 241 (71), 213 (7), 211 (11), 200 (13), 199 (63), (11), 183 (13), 181 (49), 173 (10), 171 (13), 149 (13), 147 (13), 145 (19), 143 (13), 139 (20), 135 (24), 133 (15), 131 (20), 129 (20), 119 (14), 117 (23), 115 (10), 105 (28), 95 (20), 93 (21), 91 (39). − $C_{41}H_{58}O_5Si$ (659.0): calcd. C 74.73, H 8.87; found C 74.99, H 8.90. − $C_{35}H_{45}O_3Si$ (M^+ − C_4H_9 − CH_3COOH): calcd. 541.3138, found 541.3139 (MS).

{3aS-[3aα,5β,6α(1E,3R),6aα]}-5-(Acetyloxy)-6-[(3-(acetyloxy)-1-octenyl)]-1,3a,4,5,6,6a-hexahydro-2-pentalenpentanol* (**43**): To a solution of **40** (483 mg, 0.73 mmol), contaminated by 5% of **39**, in THF (20 ml) was added at room temperature $nBu_4NF \cdot 3 H_2O$ (340 mg, 1.08 mmol). After stirring the mixture for 4 h at room temperature, it was concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 2:1) gave **43** (294 mg, 96%), contaminated by 5% of the isomeric alcohol stemming from **39**, as a colorless oil. − R_f (*n*-hexane/EtOAc, 2:1) = 0.15, $[\alpha]_D^{27}$ = −36.2 (*c* = 1.20, THF). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.7 Hz, 3 H), 1.22−1.65 (m, 15 H), 1.94−2.08 (m, 3 H), 1.99 (s, 3 H), 2.04 (s, 3 H), 2.17 (dt, *J* = 7.7, *J* = 9.7 Hz, 1 H), 2.27−2.51 (m, 4 H), 3.05 (m, 1 H), 3.62 (t, *J* = 6.6 Hz, 2 H), 4.80 (dt, *J* = 7.4, *J* = 9.5 Hz, 1 H), 5.20 (q, *J* = 6.6 Hz, 1 H), 5.25 (m, 1 H), 5.44 (dd, *J* = 6.6, *J* = 15.4 Hz, 1 H), 5.58 (dd, *J* = 7.6, *J* = 15.5 Hz, 1 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.99 (d), 21.08 (d), 21.35 (d), 22.53 (u), 24.75 (u), 25.57 (u), 27.53 (u), 30.89 (u), 31.53 (u), 32.61 (u), 34.36 (u), 36.64 (u), 39.76 (u), 43.57 (d), 45.74 (d), 54.15 (d), 62.94 (u), 74.38 (d), 78.14 (d), 127.71 (d), 130.01 (d), 133.23 (d), 141.96 (u), 170.35 (u), 170.86 (u). − IR ($CHCl_3$): ν = 3445 (m, br), 3020 (m), 2932 (s), 2860 (s), 1734 (s), 1650 (w), 1456 (m), 1442 (m), 1372 (s), 1246 (s), 1141 (w), 1050 (m), 1022 (m), 970 (m). − MS; *m*/*z* (%): 477 (0.7), 438 (0.7), 418 (0.7), 380 (0.7), 362 (0.7), 361 (0.7), 360 [M^+ − CH_3COOH] (2), 318 (3), 317 (2), 316 (2), 302 (2), 301 (13), 300 (48), 215 (10), 151 (11), 150 (15), 143 (14), 133 (13), 131 (12), 129 (15), 119 (13), 117 (16), 105 (15), 99 (10), 97 (10), 95 (12), 94 (10), 93 (11), 92 (10), 91 (30), 85 (13), 83 (12), 81 (19), 80 (14), 79 (26), 77 (13), 71 (24), 69 (16), 67 (30), 57 (23), 55 (25), 45 (13), 44 (26), 43 (100), 42 (15), 41 (29), 39 (15). − $C_{21}H_{32}O$ (M^+ − 2 CH_3COOH): calcd. 300.2453, found 300.2455 (MS). − $C_{25}H_{40}O_5$ (420.60): calcd. C 71.39, H 9.59; found C 71.00, H 9.74.

{3aS-[3aα,5β,6α(1E,3R),6aα]}-5-(Acetyloxy)-6-[3-(acetyloxy)1-octenyl]-1,3a,4,5,6,6a-hexahydro-2-pentalenpentanal* (**44**): To a solution of **43** (265 mg, 0.630 mmol), contaminated by 5% of the isomeric alcohol stemming from **39**, in DMSO (1.5 ml) and NEt_3 (1.1 ml, 7.89 mmol) was added at room temperature within 2 min. SO_3−pyridine (301 mg, 1.89 mmol). After stirring the mixture for 45 min. at room temperature, H_2O (10 ml) was added. The mixture was extracted with ether and the organic phase was concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 4:1) gave **44** (240 mg, 91%), contaminated by 5% of the isomeric aldehyde stemming from **39**, as a colorless oil. − R_f (*n*-hexane/EtOAc, 4:1) = 0.18, $[\alpha]_D^{24}$ = −40.4 (*c* = 1.81,

THF). – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.9 Hz, 3 H), 1.22–1.33 (m, 7 H), 1.44–1.51 (m, 2 H), 1.51–1.67 (m, 4 H), 1.97–2.08 (m, 3 H), 1.99 (s, 3 H), 2.04 (s, 3 H), 2.16 (m, 1 H), 2.33 (m, 1 H), 2.41 (ddd, *J* = 7.2, *J* = 9.0, *J* = 12.6 Hz, 1 H) 2.45 (m and dt, *J* = 1.8, *J* = 7.5 Hz, 3 H), 3.05 (m, 1 H), 4.79 (dt, *J* = 7.4, *J* = 9.3 Hz, 1 H), 5.20 (dq, *J* = 0.9, *J* = 6.6 Hz, 1 H), 5.26 (m, 1 H), 5.44 (ddd, *J* = 0.9, *J* = 6.7, *J* = 15.5 Hz, 1 H), 5.58 (ddd, *J* = 1.0, *J* = 7.9, *J* = 15.5 Hz, 1 H), 9.77 (t, *J* = 1.8 Hz, 1 H). – ^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.00 (d), 21.08 (d), 21.36 (d), 21.82 (u), 22.54 (u), 24.76 (u), 27.20 (u), 30.66 (u), 31.54 (u), 34.38 (u), 36.61 (u), 39.74 (u), 43.54 (d), 43.76 (u), 45.75 (d), 54.18 (d), 74.37 (d), 78.09 (d), 128.11 (d), 130.11 (d), 133.19 (u), 141.43 (u), 170.39 (u), 170.90 (u), 202.69 (C-5′). – IR ($CHCl_3$): ν = 2932 (s), 2860 (m), 2718 (w), 1738 (s), 1457 (m), 1442 (m), 1371 (s), 1244 (s), 1174 (w), 1141 (w), 1063 (m), 1049 (m), 1021 (m), 970 (m). – MS; *m*/*z* (%): 359 (2), 358 [M^+ – CH_3COOH] (9), 317 (7), 316 (34), 315 (6), 300 (4), 299 (27), 298 (97), 227 (14), 213 (14), 166 (11), 153 (11), 150 (19), 149 (10), 148 (11), 145 (12), 131 (15), 129 (10), 117 (16), 105 (14), 99 (19), 93 (15), 91 (18). – $C_{23}H_{34}O_3$ (M^+ – CH_3COOH): calcd. 358.2508, found 358.2509 (MS).

{3aS-[3aα,5β,6α(1E,3R),6aα]}-1,3a,4,5,6,6a-Hexahydro-5-hydroxy-6-(3-hydroxy-1-octenyl)-2-pentalenpentanoic Acid* (**2**): To a solution of **44** (220 mg, 0.53 mmol), contaning 5% of the isomeric aldehyde stemming from **39**, in EtOH (32 ml) were added at room temperature H_2O (6 ml) and $AgNO_3$ (358 mg, 2.11 mmol). After stirring the mixture for 10 min. at room temperature, aqueous NaOH (25%, 1 ml) was added dropwise. After stirring the mixture for 18 h at room temperature, aqueous HCl (0.2 M, 30 ml) was added and the mixture extracted with CH_2Cl_2 (100 ml). The organic phase was dried ($MgSO_4$) and concentrated in vacuum. There was obtained **2** (167 mg, 91%), contaminated by 5% of the isomeric acid stemming from **39**, as a colorless oil. The oil was treated with MeCN (4 ml) and the suspension formed was kept for 18 h at −24°C. The supernatant was removed with a syring and the residue dried in vacuum. Thereby pure **2** (66 mg, 38%) was obtained as colorless crystals. – M.p. 71°C, $[\alpha]_D^{23}$ = +9.0 (*c* = 0.78, CH_2Cl_2). – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 6.7 Hz, 3 H), 1.22–1.40 (m, 7 H), 1.41–1.53 (m, 3 H), 1.53–1.70 (m, 3 H), 1.89 (q, *J* = 9.5 Hz, 1 H), 1.96 (d, br, *J* = 16.2 Hz, 1 H), 2.05 (t, *J* = 7.0 Hz, 2 H), 2.22–2.41 (m, 5 H), 2.98 (m, 1 H), 3.73 (dt, *J* = 7.1, *J* = 9.7 Hz, 1 H), 4.03 (q, *J* = 6.9 Hz, 1 H), 4.9–6.6 (br, 3 H), 5.28 (s, br, 1 H), 5.45 (dd, *J* = 8.5, *J* = 15.3 Hz, 1 H), 5.52 (dd, *J* = 7.3, *J* = 15.3 Hz, 1 H). – ^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.05 (d), 22.63 (u), 24.36 (u), 25.22 (u), 26.96 (u), 30.38 (u), 31.71 (u), 33.93 (u), 36.84 (u), 39.21 (u), 39.36 (u), 44.21 (d), 45.49 (d), 57.97 (d), 73.53 (d), 77.12 (d), 128.72 (d), 133.66 (d), 135.60 (d), 141.17 (u), 178.65 (u). – IR (KBr): ν = 3388 (s, br), 3029 (s), 2930 (s), 2860 (s), 2639 (m), 1703 (s), 1661 (s), 1562 (w), 1544 (w), 1460 (s), 1409 (s), 1384 (s), 1346 (s), 1272 (s), 1256 (s), 1129 (m), 1087 (s), 1067 (s), 1021 (m), 996 (m), 972 (s), 901 (m). – MS; *m*/*z* (%): 334 (1), 333 (7), 332 [M^+ – H_2O] (30), 315 (6), 314 (27), 289 (19), 288 (78), 261 (23), 243 (17), 233 (13), 232 (10), 231 (15), 219 (11), 218 (35), 217 (10), 208 (11), 180 (13), 179 (24), 178 (10), 171 (10), 167 (15), 166 (61), 165 (19), 164 (16), 161 (12), 150 (13), 148 (15), 147 (11), 145 (15), 143 (11), 133 (14), 132 (12), 131 (38), 129 (16), 121 (10), 120 (10), 119 (24), 118 (10), 117 (37), 107 (18), 106 (26), 105 (42), 99 (50), 96 (10), 95 (20), 94 (17), 93 (34), 92 (16), 91 (58). – $C_{21}H_{32}O_3$ (M^+ – H_2O): calcd. 332.2351, found 332.2353 (MS).

{2R-[2α,3β(2E,3R),3aβ,6aβ]}-5-[5-{[(1,1-Dimethylethyl)-diphenylsilyl]oxy}pentyl]-1,2,3,3a,4,6a-hexahydro-3-(3-hydroxy-1-octenyl)-2-pentalenol* (**45**): To a solution of **42** (278 mg, 0.421 mmol), contaminated by 5% of **40**, in MeOH (10 ml) was added at room temperature K_2CO_3 (586 mg, 4.24 mmol). After stirring the mixture for 4 h at room temperature, aqueous HCl (2 M, 4 ml) was added and the mixture was extracted with ether. The organic phase was dried ($MgSO_4$) and concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 1:1) gave **45** (227 mg, 94%) and **43** (12 mg, 5%) (R_f = 0.32, *n*-hexane/EtOAc, 1:1). – R_f (*n*-hexane/EtOAc, 1:1) = 0.18, $[\alpha]_D^{18}$ = −2.4 (*c* = 1.00, THF). – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 6.7 Hz, 3 H), 1.05 (s, 9 H), 1.21–1.63 (m, 15 H), 1.94–2.06 (m, 4 H), 2.21–2.60 (m, 4 H), 2.98 (m, 1 H), 3.66 (t, *J* = 6.4 Hz, 2 H), 3.75 (dt, *J* = 7.2, *J* = 9.5 Hz, 1 H), 4.07 (m, 1 H), 5.25 (s, 1 H), 5.52–5.67 (m, *J* = 15.4, *J* = 15.4 Hz, 2 H), 7.32–7.44 (m, 6 H), 7.64–7.71 (m, 4 H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.20 (d), 19.33 (u), 22.75 (u), 25.35 (u), 25.79 (u), 27.00 (d), 27.64 (u), 31.11 (u), 31.91 (u), 32.56 (u), 37.32 (u), 39.83 (u), 40.00 (u), 44.34 (d), 45.68 (d), 57.88 (d), 64.04 (u), 72.41 (d), 77.21 (d), 127.70 (d), 127.94 (d), 129.62 (d), 132.01 (d), 135.04 (d), 134.23 (u), 135.68 (d), 142.13 (u). – IR ($CHCl_3$): ν = 3354 (m, br), 3071 (m), 3048 (m), 3012 (m), 2999 (m), 2930 (s), 2858 (s), 1957 (w), 1889 (w), 1823 (w), 1650 (w), 1590 (w), 1461 (m), 1428 (s), 1390 (m), 1361 (w), 1335 (w), 1306 (w), 1261 (w), 1217 (m), 1189 (w), 1111 (s), 1029 (m), 1008 (m), 998 (m), 973 (m), 939 (w), 916 (w). – MS; *m*/*z* (%): 594 (0.02), 573 [M^+ – 1] (0.02), 572 (0.02), 560 (0.03), 559 (0.07), 558 (0.2), 557 (0.5), 556 (1.0), 542 (0.4), 538 (0.7), 518 (0.9), 517 (2), 516 (1), 515 (3), 513 (1), 512 (2), 502 (9), 501 (28), 500 (38), 499 (90), 497 (5), 481 (9), 440 (5), 439 (16), 301 (8), 285 (22), 284 (11), 283 (55), 227 (10), 213 (10), 201 (15), 200 (19), 199 (100), 197 (13), 187 (37), 185 (15), 183 (26), 181 (12), 173 (13), 171 (10), 159 (11), 149 (10), 147 (14), 145 (22), 143 (10), 139 (16), 135 (26), 133 (17), 131 (25), 129 (12), 121 (12), 119 (13), 117 (21), 105 (27), 99 (18), 95 (16), 93 (16), 91 (37). – $C_{33}H_{43}O_2Si$ (M^+ – C_4H_9 – H_2O): calcd. 499.3032, found 499.3036 (MS).

{1S-[1α(1E),2β,3aα,6aα]}-1-{5-[5-{[(1,1-Dimethylethyl)-diphenylsilyl]oxy}pentyl]-1,2,3,3a,6,6a-hexahydro-2-hydroxypentalen1-yl}-1-octen-3-one (**46**): To a solution of **45** (123.4 mg, 0.22 mmol) in dioxane (10 ml) was added at room temperature dichlorodicyanobenzoquinone (196 mg, 0.87 mmol). After stirring the mixture for 22 h at room temperature, it was filtered and the residue was washed with *n*-hexane. The combined filtrates were concentrated in vacuum. Purification of the residue by chromatography (*n*-hexane/EtOAc, 1:1) gave **46** (100 mg, 81%) as a colorless oil. – R_f (*n*-hexane/EtOAc, 1:1) = 0.49, $[\alpha]_D^{23}$ = +9.1 (*c* = 1.44, THF). – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.90 (t, *J* = 7.1 Hz, 3 H), 1.05 (s, 9 H), 1.26–1.45 (m, 9 H), 1.57 (m, 2 H), 1.62 (m, 2 H), 1.74 (s, br, 1 H), 1.95–2.04 (m, 3 H), 2.15 (q, *J* = 9.0 Hz, 1 H), 2.34 (ddd, *J* = 7.0, *J* = 8.8, *J* = 12.4 Hz, 1 H), 2.40–2.49 (m, 2 H), 2.55 (m, 2 H), 3.06 (m, 1 H), 3.66 (t, *J* = 6.5 Hz, 2 H), 3.92 (m, 1 H), 5.27 (m, *J* = 1.6 Hz, 1 H), 6.19 (dd, *J* = 1.0, *J* = 15.8 Hz, 1 H), 6.76 (dd, *J* = 8.6, *J* = 15.8 Hz, 1 H), 7.35–7.44 (m, 6 H), 7.65–7.68 (m, 4 H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.03 (d), 19.31 (u), 22.56 (u), 23.92 (u), 25.73 (u), 26.95 (d), 27.56 (u), 30.97 (u), 31.57 (u), 32.49 (u), 40.09(u), 40.38 (u), 40.61 (u), 44.35 (d), 46.11 (d), 58.18 (d), 63.99 (u), 77.32 (d), 127.65 (d), 127.76 (d), 129.58 (d), 131.08 (d), 134.22 (u), 135.65 (d), 142.23 (u), 147.57 (d), 200.65 (d). – IR ($CHCl_3$): ν = 3416 (m, br), 3071 (m), 3047 (m), 3014 (w), 2998 (w), 2954 (s), 2930 (s), 2858 (s), 1959 (w), 1889 (w), 1823 (w), 1775 (w), 1669 (m), 1626 (m), 1590 (w), 1557 (w), 1472 (m), 1462 (m), 1428 (s), 1389 (m), 1362 (m), 1321 (m), 1259 (w), 1218 (w), 1189 (m), 1111 (s), 998 (m), 982 (m), 939 (w), 918 (w). – MS; *m*/*z* (%): 554 [M^+ – H_2O] (1.2), 529 (0.9), 518 (2), 517 (10), 516 (35), 515 (78), 514 (4), 513 (11), 499 (7), 498 (13), 497 (29), 439 (3), 438 (9), 437 (25), 401 (6), 389 (5), 311 (7), 300 (3), 299 (13), 297 (3), 281 (6), 201 (9), 200 (20), 199 (100), 197 (13), 185 (15), 183 (22), 173 (12), 151 (10), 147 (13), 145 (14), 139 (20), 135 (27), 133

(12), 131 (15), 129 (11), 117 (16), 105 (24), 99 (46), 95 (11), 93 (13), 91 (42). – $C_{37}H_{52}O_3Si$ (572.9): calcd. C 77.57, H 9.15; found C 77.69, H 9.25.

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