Asymmetric Synthesis of 3-Oxacarbacyclin and 3-Oxaisocarbacyclin by a Common Enantioselective Deprotonation Based Route

Irene Vaulont, Hans-Joachim Gais*, Norbert Reuter, Elmar Schmitz, and Rainer K. L. Ossenkamp

Institut für Organische Chemie der Rheinisch-Westfälischen Technischen Hochschule Aachen,
Professor-Pirlet-Straße 1, D-52056 Aachen, Germany
Fax: (internat.) +49(0)241/8888127
E-mail: Gais@RWTH-Aachen.de

Received December 22, 1997

Keywords: (+)-3-Oxacarbacyclin / (+)-3-Oxaisocarbacyclin / Chiral base / Chiral phosphonoacetate / Asymmetric synthesis

Asymmetric total syntheses of 3-oxacarbacyclin (**4**) and 3-oxaisocarbacyclin (**5**) have been achieved by a new and common route. The key step of these syntheses is an enantioselective deprotonation of the prochiral ketone **25** with lithium (*R*,*R*)-bis(phenylethyl)amide (**12**) in the presence of LiCl. Treatment of the thus formed enolate **26** with $ClSiEt_3$ gave the enol ether **27** of 92% *ee* in 94% yield. Deprotonation of the analogous prochiral ketone **9** with **12** in the presence of LiCl followed by reaction of the enolate **13** with $ClSiEt_3$ led to isolation of the silyl enol ether **8b** of 92% *ee* in 95% yield. A study of the deprotonation of **9** with the chiral lithium amides **14**−**19** showed that **12** in combination with LiCl is the optimal base in terms of enantioselectivity and accessibility. The ω-side chain in **4** and **5** was established by a Mukaiyama reaction of **27** with the unsaturated aldehyde **28**, leading to ketone **39** of 90% *de*, in combination with a stereoselective Pd-catalyzed allylic rearrangement of acetate **47** to the isomeric acetate **48** and a Mitsunobu reaction of the allylic alcohol **49**. The key step in the construction of the α-side chain in **4** is a Horner-Wadsworth-Emmons reaction of ketone **7c** with the 8-phenylnormenthol-containing phosphonoacetate **56** which gave ester **60** of 90% *de*. Ester **60** was obtained diastereomerically pure by chromatography in 72% yield from **7c**. Reduction of **60** furnished the allylic alcohol **62** which was converted to **4** in a standard fashion. It is at the stage of the α,ß-unsaturated ester **60** where divergence into synthesis of **5** was made. Selective isomerization of **60** to the ß,γ-unsaturated ester **66** of 97% ie in 91% yield was accomplished by deprotonation of **60** with **12** to enolate **65** and its subsequent regioselective protonation. By a similar reaction sequence the isomeric α,ß-unsaturated ester **61** was converted to the ß,γ-unsaturated ester **69** of 97% ie in 88% yield. Reduction of **66** afforded the homoallylic alcohol **71** which was converted to **5** in a standard fashion.

Introduction

Prostacyclin (PGI_2) (**1**)[1] (Figure 1) is the most potent endogenous inhibitor of blood platelet aggregation known and a strong vasodilator[2]. The characteristic modes of action of this important regulator of the cardiovascular system are mediated by specific cell-surface receptors[3] which are apparently widespread expressed not only in peripheral organs but also in the central nervous system[4]. The latter finding suggests that **1** plays also an important role in neuronal activity. The medicinal application of **1** is, however, severely hampered by a short in vivo half-life which is mainly due to the hydrolytic sensitivity of the enol ether moiety and the enzymatic degradation of the α-side chain. The intensive search for stable analogs of **1**[2a][5][6] has culminated in the synthesis of the 3-oxacarbacyclin derivative **2**[7] and the 3-oxaisocarbacyclin derivative **3**[8]. The formal exchange between the ring oxygen atom and the methylene group in **1** as well as the modification of the ω-side chains not only convey high biological activity but also high chemical and metabolic stability to **2** and **3**. Because of the oxygen atom in 3-position, enzymatic β-hydroxylation, which is the first step of a rapid degradation of the α-side chain in **1**, is prevented. Prostacyclin analogs **2** and **3** are orally active and their anti-aggregatory potency exceeds that of **1** considerably. Intensive studies of cicaprost **2** revealed, in addition to a nephroprotective activity[9], a high in vivo potency for the inhibition of metastasis development[10][11]. Thus, **2** is also an interesting candidate for a medicinal anti-metastatic therapy. Furthermore, cicaprost was shown recently to have a suppressing effect on the tumor necrosis factor-α production in human peripheral blood mononuclear cells[12][13]. Asymmetric syntheses of **2**[7][14][15][16] and **3**[8] as well as of the parent compounds **4**[17][18] and **5**[8][19] have been described by Skuballa et al., Shibasaki et al., Kojima et al. and by us. Because of the considerable medicinal potential of 3-oxacarbacyclins and 3-oxaisocarbacyclins, it was our intention to provide for a new asymmetric entry to these prostacyclin analogs by using the prochiral ketone **9** as starting material (cf. Scheme 2). This entry should permit for the attachment of a segment containing carbon atoms 13 to 20(21) to **9** in one step and allow for the synthesis of 3-oxacarbacyclins as well as of 3-oxaisocarbacyclins through divergence at a late stage of the synthesis of the former. We report in this paper such an entry to **4** and **5** which is based on enantioselective deprotonation.

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Figure 1. Prostacyclin and its 3-oxaanalogs

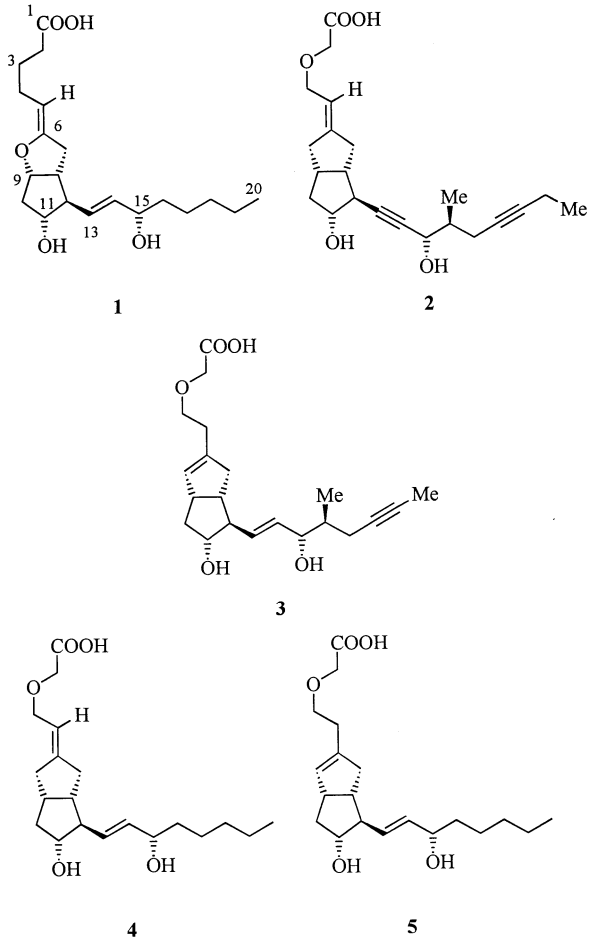
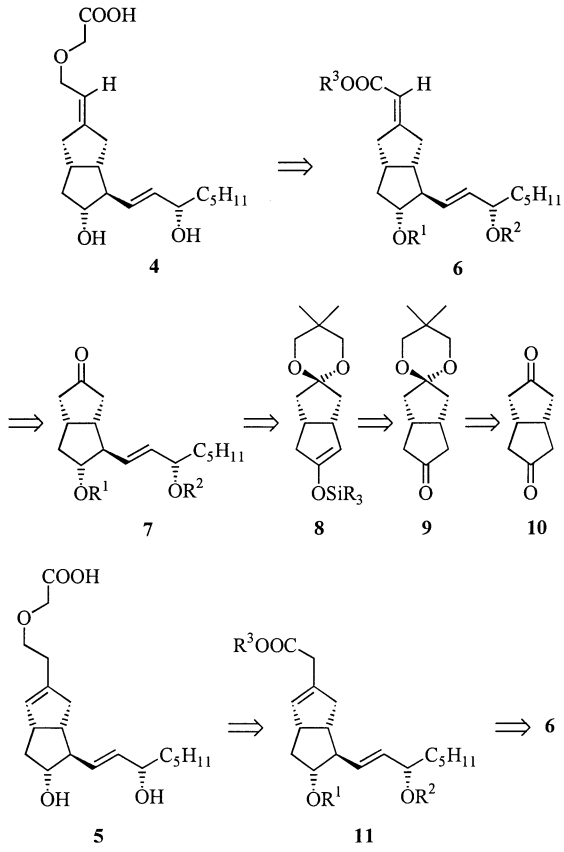


Figure 2. Retrosyntheses of 3-oxacarbacyclin (**4**) and 3-oxaisocarbacyclin (**5**)



Results and Discussion

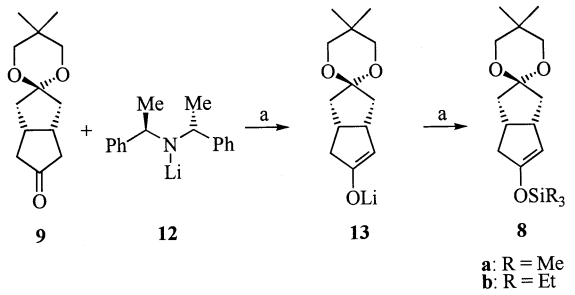
Retrosynthetic Analysis: The choice of ketone **9**, which is readily accessible from diketone **10**[20][21][22], as starting material for the synthesis of **4** and **5** poses two challenges[5][6][17][18]. The first is the enantioselective introduction of the ω-side chain and the second challenge is the stereoselective introduction of the α-side side chain as well as of the endocyclic double bond. Because of their bicyclic structure, chiral derivatives of **9**, containing either the α- or the ω-side chain, e. g. **7**, provide in general only a low asymmetric induction in the functionalization of the respective cyclopentanone ring[23].

Figure 2 shows the retrosynthetic analysis of **4** and **5** on which the synthetic strategy was based. Thus, disassembly of the ether moiety in **4** and oxidation of the allylic alcohol derived thereof led, retrosynthetically, to ester **6**. Retrosynthetic oxidative cleavage of the double bond gave ketone **7**, a known intermediate in the synthesis of carbacyclin[5][6][24][25]. Protection of the carbonyl group and disassembly of the ω-side chain allowed for the generation of the enol ether **8**. Work on the enantioselective deprotonation of prochiral cyclohexanone derivatives with chiral bases[26][27] suggested the possibility of a similar reaction of **9** and, thus, its enantioselective conversion to **8**. The enol ether **8** should allow for the stereoselective introduction of the ω-side chain via a Mukaiyama aldol reaction[28a] with (*E*)-2-octenal in combination with a Pd-catalyzed transposition of the allylic hydroxy group[29][30][31][32]. Such a sequence was successfully applied by Danishefski et al.[31] for the construction of the ω-side chain of the prostaglandin $F_{2\alpha}$. Alternatively, an aldol reaction[28b] of the lithium enolate derived from **9** with (*E*)-2-octenal can be envisaged. We were confident that a stereoselective HWE reaction of **7** under formation of ester **6** could be accomplished by using a chiral phosphonoacetate like the one we[15][17] and others[33] have successfully introduced for the stereoselective olefination of **9** and ketones of type **7**. It is at the point of ester **6** where divergence into 3-oxaisocarbacyclin (**5**) will be made. Precedent exists, suggesting that the pivotal selective rearrangement of the α,ß-unsaturated ester **6** to the ß,γ-unsaturated ester **11** should be feasible[8][34][35][36].

Enantioselective Deprotonation: At the beginning of our investigation of the synthesis of **8** from **9** the enantioselective deprotonation of a variety of prochiral mono- and bicyclic ketones had been studied by using chiral lithium amides[26][27]. From the large number of lithium amides investigated the C_2-symmetrical amide **12** (Scheme 1) seemed to be the most promising one. We therefore began our investi-

gation of the enantioselective deprotonation of ketone **9** with this base[37].

Scheme 1



Reagents and conditions: see Table 1.

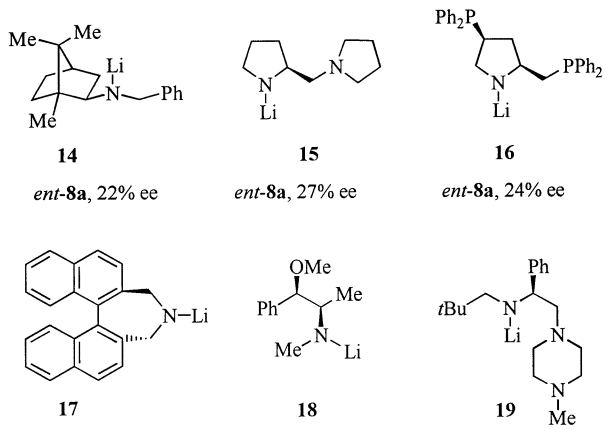
Amide **12** is readily accessible on a large scale in three steps from (*R*)-α-phenylethylamine[38] and shows a high enantioselectivity in deprotonation reactions[26][27][39]. Treatment of **12** in THF at low temperatures with ketone **9** and trapping of the lithium enolate **13** formed by reaction with $ClSiMe_3$ gave the enol ether **8a** which had, however, only a low *ee* value (Table 1, entry 1). Deprotonation proceeded with a significantly higher enantioselectivity if $ClSiMe_3$ was added to **12** prior to the addition of ketone **9** (Table 1, entry 2). Previous studies of the deprotonation of ketones with **12** have shown that a high enantioselectivity can only be attained with this base if $ClSiMe_3$ is present in the deprotonation step[26][27][40]. This has been attributed to the formation of a mixed aggregate[41] between LiCl, formed by reaction of the respective lithium enolate with $ClSiMe_3$, and **12**[42] which is more reactive and selective than the monomer or dimer of **12**[43]. Thus in another experiment **12** was treated first with LiCl, to generate **12**·LiCl, followed by the sequential addition of **9** and $ClSiMe_3$. In this case **8a** was isolated with a high *ee* value (Table 1, entry 3). In case LiCl was added before the deprotonation step the sequence of the addition of **9** and $ClSiMe_3$ had almost no bearing upon the enantioselectivity (Table 1, entries 3 and 4). Because of the ready hydrolysis of **8a** on silica gel, which made its chromatographic purification on a preparative scale exceedingly difficult, the triethylsilyl ether **8b** was prepared. Deprotonation of **9** was carried out with **12**·LiCl, which was prepared directly by treatment of (*R*,*R*)-bis(phenylethyl)ammonium chloride[38] with 2 equivalents of *n*BuLi[40][41]. Reaction of thus formed **13** with $ClSiEt_3$ gave **8b** with an *ee* value of 92% in 95% yield (Table 1, entry 5). Silyl ether **8b** proved to be hydrolytically much more stable than **8a**. Reaction of **13** with $ClSiEt_3$ required higher temperatures than that with $ClSiMe_3$. Our results support the previously put forward notion that the actual chiral base in deprotonations with **12** in the presence of $ClSiR_3$ is the mixed aggregate **12**·LiCl, which has a higher reactivity and selectivity than monomeric or dimeric **12**. Besides **12** we have studied the chiral lithium amides **14**[44], **15**[45], **16**[46], **17**[47] and **18**[48] in the deprotonation of **9** and recorded invariably lower enantioselectivities in the formation of *ent*-**8a**, **8a** and **8b**, respectively[49][50][51]. Whereas deprotonation of **9** with **18** was carried out in the presence of $ClSiMe_3$ deprotonations of the ketone with **14**–**17** were run without $ClSiMe_3$. Koga et al.[52] have studied the deprotonation of **9** with various phenyl glycine derived asymmetric lithium amides and reported on the synthesis of *ent*-**8a**, having an *ee* value of 94%, by using *ent*-**19** in THF the presence of HMPA. Leonhard et al.[53] have investigated the deprotonation of the monoethylene ketal derivative of **10** by using **12** as well as lithium (α-phenylethyl)isopropylamide and recorded *ee* values of 48% and 72%, respectively, for the corresponding silyl enol ether. However, in our hands deprotonation of **9** with **19** in THF the presence of HMPA led to **8a** of only 84% *ee*. In the present work determination of the *ee* values of **8a**, *ent*-**8a** and **8b** was made directly and not indirectly[52][53] by ^{1}H-NMR spectroscopy of the silyl enol ethers in the presence of $Pr(tfc)_3$/Ag(fod) (tfc = tris-[3-(trifluoromethylhydroxymethylene)]-d-camphorato, fod = 6,6,7,7,8,8,8-heptafluor-2,2-dimethyl-3,5-octandionato)[54] [$\Delta\Delta\delta$ (=CH−R) = 0.04 and 0.06, respectively].

Table 1. Deprotonation of ketone **9** with the lithium amide **12**

Entry	Method[a]	Product	*ee* [%]	Yield [%]
1	A: 1. **12**, 2. **9**, 3. $ClSiMe_3$	**8a**	30	62
2	B: 1. **12**, 2. $ClSiMe_3$, 3. **9**	**8a**	86	80
3	C: 1. **12**, 2. LiCl, 3. $ClSiMe_3$, 4. **9**	**8a**	92	88
4	D: 1. **12**, 2. LiCl, 3. **9**, 4. $ClSiMe_3$	**8a**	93	83
5	E: 1. (*R*,*R*)-bis(phenylethyl)-ammonium chloride, 2. 2 *n*BuLi, 3. **9**, 4. $ClSiEt_3$[b]	**8b**	92	95

[a] Reactions were run at −100°C. − [b] At −78°C.

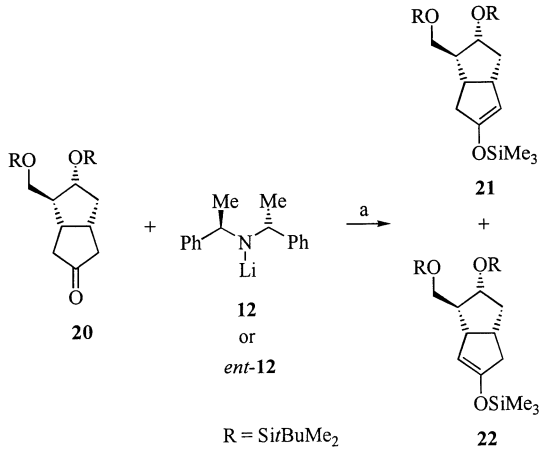
Figure 3. Synthesis of **8a**, *ent*-**8a** and **8b** from **9** with chiral lithium amides



The absolute configurations of **8a** and **8b** were determined in an indirect manner by comparison with the silyl enol ethers **21** and **22** formed via deprotonation of the chiral ketone **20**[15] with **12** and *ent*-**12** (Scheme 2).

Because of their roof-shaped structures, ketones **20** and **9** resemble each other closely in regard to the cyclopentanone rings. The stereogenic centers in **20** are expected to exert only a minor asymmetric induction in the deprotonation with **12** and *ent*-**12**. Thus, it is safe to assume that at least

Scheme 2



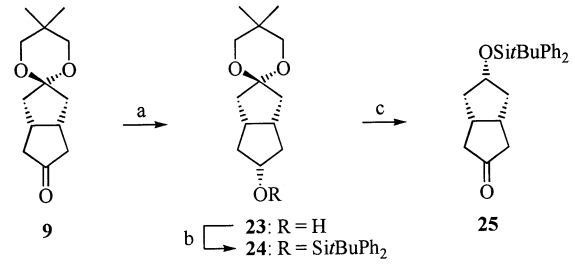
Reagents and conditions: (a) 1. **12**, THF; 2. **20**, −95°C; 3. $ClSiMe_3$, −90°C.

the sense of asymmetric induction in the deprotonation of **9** and **20** with **12** should be the same. Treatment of **12** with $ClSiMe_3$ followed by addition of **20** led to isolation of a mixture of **21** and **22** in a ratio of 95:5 in 87% yield. The use of *ent*-**12** in the deprotonation of **20** gave a mixture of **21** and **22** in an opposite ratio of 14:86 in 85% yield. The lower selectivity in the deprotonation of **20** by using *ent*-**12** can be attributed to a steric effect of the silyloxymethyl group. The structure of **21** and, thus, of **22** was unequivocally established by NOE experiment after a complete assignment of its signals in the ^{1}H-NMR spectrum. On the basis of the above considerations and results the absolute configurations of **8a** and **8b** were assigned as depicted in Scheme 1. This is in accordance with the results of an independent assignment by chemical correlation[52].

Because of the possible interference of the ketal group in **8a** and **8b** with the Lewis acid necessary for the planned Mukaiyama reaction of the silyl enol ether we included in the deprotonation studies ketone **25** which carries a less sensitive silyloxy group instead of the ketal group (Scheme 3). Reduction of **9** with $NaBH_4$ in EtOH at −45°C proceeded highly stereoselective and afforded alcohols **23** and *epi*-**23**[55] in a ratio of 98:2 in 98% yield. Although both alcohols **23** and *epi*-**23** could be used in principle for the syntheses of **4** and **5**, *epi*-**23** was removed by chromatography in order to simplify analysis of the products in the subsequent steps. Ketone **25** was prepared in two steps in 96% overall yield from **23** via silylation with $tBuPh_2SiCl$, yielding the silyl ether **24**, followed by the *p*TsOH-catalyzed cleavage of the ketal group in the latter in acetone.

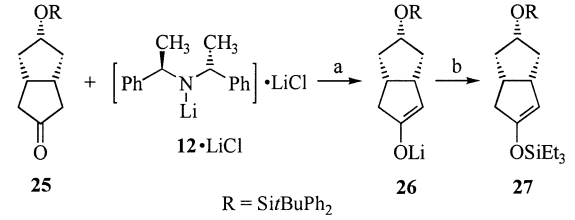
Following the optimal protocol developed for the deprotonation of **9** (cf. Table 1), (*R*,*R*)-bis(phenylethyl)ammonium chloride was treated with two equivalents of *n*BuLi, providing **12**·LiCl, followed by addition of **25** at −100°C (Scheme 4). The thus formed lithium enolate **26** was treated at −78°C with Et_3SiCl. This led to isolation of the stable silyl ether **27** in 94% yield, which had an *ee* value of 92%, according to ^{1}H-NMR spectroscopy in the presence of $Pr(tfc)_3$/Ag(fod), [$\Delta\Delta\delta$ (=CHR) = 0.08].

Scheme 3



Reagents and conditions: (a) $NaBH_4$, EtOH, −45°C; (b) $tBuPh_2SiCl$, ImH, DMF, 0°C; (c) *p*TsOH, acetone, H_2O, room temp.

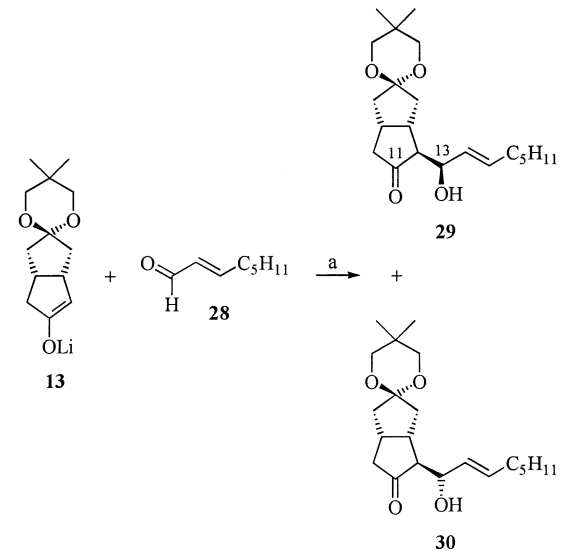
Scheme 4



Reagents and conditions: (a) THF, −100°C; (b) $ClSiEt_3$, −78°C.

Construction of the ω-Side Chain: According to the retrosynthetic scheme a segment containing carbon atoms 12 to 20 of the ω-side chain was going to be attached to **8a** or **8b** in one step followed by a transposition of the allylic hydroxy group. In pursuing this goal we began with a study of the aldol reaction of **13** with (*E*)-aldehyde **28** (Scheme 5). Treatment of **13**, which was prepared by deprotonation of **9** with **12**·LiCl (cf. Table 1, entry 5), with **28** in THF at −78°C gave a mixture of the aldol products **29** and **30** in a ratio of 2:1 in 95% yield. Thus, the aldol reaction had occurred with high stereoselectivity in regard to C-12 (prostaglandin numbering) but with a low selectivity in regard to

Scheme 5

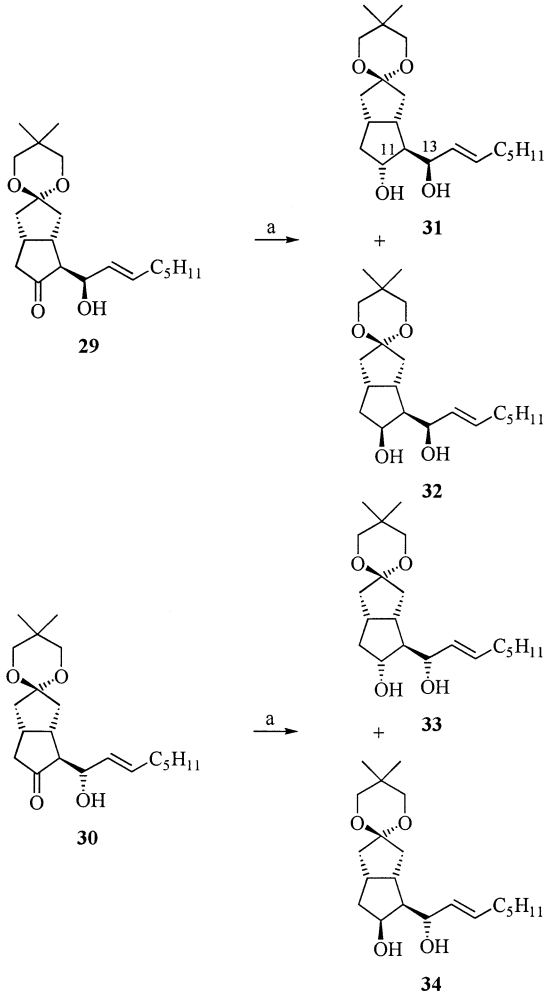


Reagents and conditions: (a) THF, hexanes, −78°C.

C-13. Unfortunately the major diastereomer **29** has, in synthetic terms, the wrong configuration at C-13. Thus, its use for the synthesis of **4** and **5** would require an additional stereochemical correction step at a latter stage. The diastereomers **29** and **30** were readily separated by chromatography. Since we did not determine the enantiomeric composition of **29** and **30** independently we assume that the aldol products have the same *ee* value as the silyl ethers **8a** and **8b**.

Reduction of ketone **29** with $NaBH_4$ in EtOH at −45°C gave diols **31** and **32** in a ratio of 96:4 in 84% yield (Scheme 6). A similar reduction of ketone **30** afforded diols **33** and **34** in a ratio of 96:4 in 84% yield.

Scheme 6

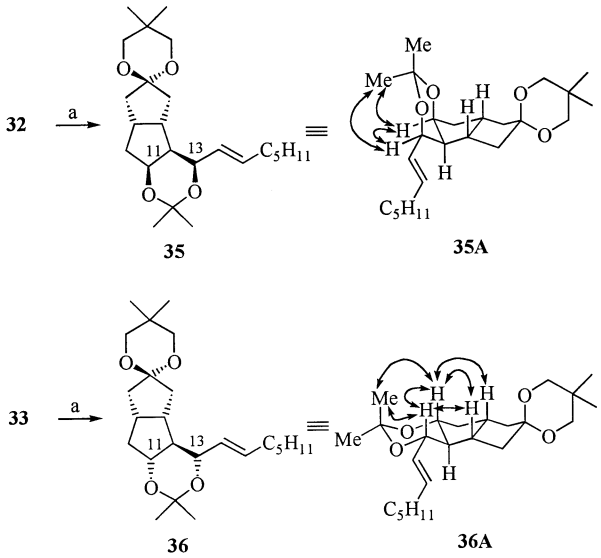


Reagents and conditions: (a) $NaBH_4$, EtOH, −45°C.

Diols **31**−**34** were readily obtained diastereomerically pure by chromatography. In order to assign the configurations of diols **31**−**34** at C-11 to C-13 diols **32** and **33** were converted to acetonides[56] **35** and **36**, respectively, which were isolated in 66% and 96% yield (Scheme 7).

Conversion of diol **31** to the corresponding acetonide could not be achieved under these conditions. This is presumably due to a 1,3-diaxial interaction between the methyl group and the alkenyl group in the transition state of acetonide formation of **31**. The configurations at C-11 to C-13

Scheme 7



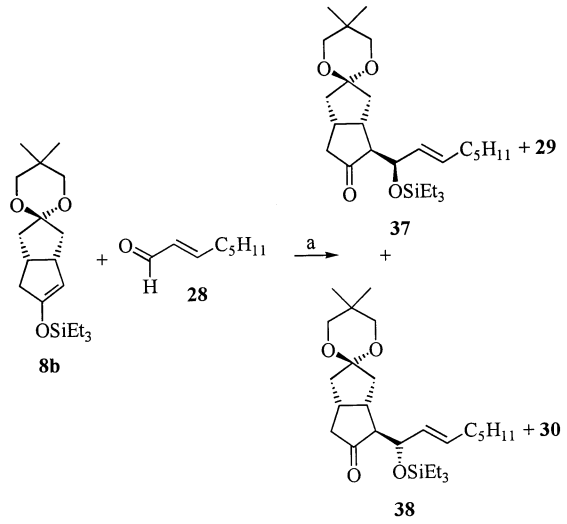
Reagents and conditions: (a) acetone, $Me_2C(OMe)_2$, ω-camphorsulfonic acid, room temp.

of **35** and **36** were established by NOE experiments on the basis of a complete assignment of the signals in the ^{1}H- and ^{13}C-NMR spectra by APT-, (H,H)-COSY-, (H,C)-COSY and H-delayed-(H,H)-COSY-experiments. The more important details of the NOE experiments are summarized in formulas **35A** and **36A**. Thus, aldehyde **28** had attacked the double bond in **13** exclusively from the sterically less hindered convex side but giving the *syn* aldol product with low diastereoselectivity. Because of the low selectivity of the aldol reaction leading to **29** and **30** in regard to the configuration of C-13, we studied, as planned, the reaction of the silyl enol ether **8b** (92% *ee*) with aldehyde **28** in the presence of $TiCl_4$. However, with this Lewis acid a mixture of several products was formed. Analysis of the reaction products revealed a competing reaction of $TiCl_4$ with the ketal group[57] in **8b** as well as in the aldol products formed. These side reactions could be avoided completely, however, by using BF_3 as the Lewis acid. Reaction of **8b** of 92% *ee* with **28** in the presence of $BF_3{\cdot}OEt_2$ in CH_2Cl_2 at −95°C gave under a partial transfer of the silyl group[31] a mixture of the silyl ethers **37** and **38** in a ratio of 4:1 in 62% yield and a mixture of alcohols **29** and **30** in a ratio of 4:1 in 15% yield (Scheme 8).

The configurations of **37** and **38** were determined by their desilylation to diols **29** and **30**, respectively. Although the diastereoselectivity of the aldol reaction could be improved by an increase of the reaction temperature and a decrease of the reaction time, the yields of **37** and **38** became unacceptably low. Thus we turned our attention to the Mukaiyama reaction of the silyl enol ether **27**, being devoid of the ketal group, with **28** (Scheme 9).

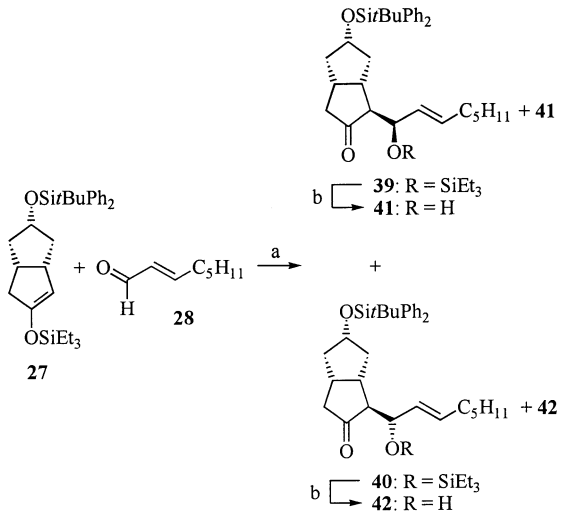
A mixture of aldehyde **28** and $BF_3{\cdot}Et_2O$ was prepared at room temperature, cooled immediately to −78°C and treated with **27** of 92% *ee*. After a reaction time of 1 h, a mixture of the silyl ethers **39** and **40** in a ratio of 95:5 was

Scheme 8



Reagents and conditions: (a) $BF_3{\cdot}OEt_2$, CH_2Cl_2, −78°C.

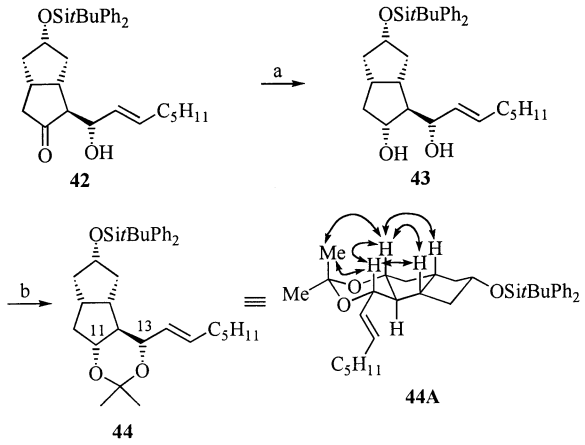
Scheme 9



Reagents and conditions: (a) $BF_3{\cdot}OEt_2$, CH_2Cl_2, −78°C; (b) AcOH, H_2O, THF, room temp.

isolated in 69% yield. Obviously, aldehyde **28** had entered preferentially with the *Si*-side the enol ether **27** from the convex side under formation of the *syn* aldol product under silyl group transfer. As side products alcohols **41** and **42** were obtained in an opposite ratio of 1:2 in 15% yield. Selective cleavage of the silyl ethers **39** and **40** with aqueous AcOH gave a mixture of alcohols **41** and **42** in a ratio of 95:5 in 80% yield. Alcohols **41** and **42** were obtained diastereomerically pure by chromatography. The configurational assignment of **41** and **42** was made by NMR spectroscopy of acetonide **44** derived from the reduction product of the minor alcohol **42**, **43** (Scheme 10). Thus, reduction of **42** with $NaBH_4$ in EtOH at −45°C afforded diol **43** of 98% *de* in 86% yield. Ketalization of **43** with 2,2-dimethoxypropane in acetone led to isolation of ketal **44** in 99% yield. The configurations at C-11 to C-13 in **44** were determined by NOE experiments on the basis of a complete assignment of the signals in the ^1H- and ^{13}C-NMR spectra by ATP-, (H,H)-COSY-, (H,C)-COSY and H-delayed-(H,H)-COSY-experiments. The more important details of the NOE experiments are summarized in formula **44A**.

Scheme 10

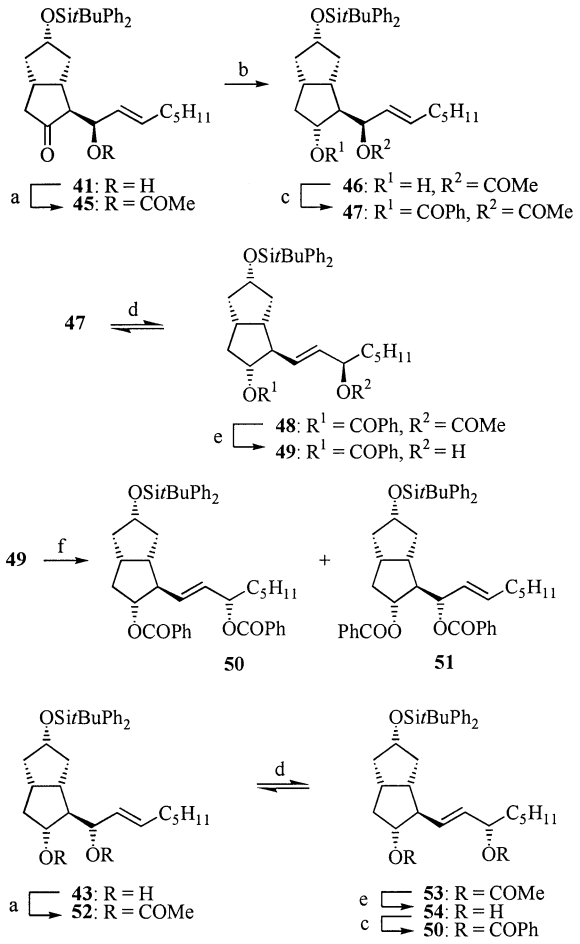


Reagents and conditions: (a) $NaBH_4$, EtOH, −45°C; (b) acetone, $Me_2C(OMe)_2$, ω-camphorsulfonic acid, room temp.

Having attached a unit containing C-13 to C-20 enantioselectively to **9**, we turned our attention to the structural adjustment of the side chain in **41** according to the ω-side chain in the target compounds **4** and **5**. We therefore envisaged a reduction of the carbonyl group of **41**, or of a derivative thereof, followed by a transposition of the allylic hydroxy group in the resulting diol from the 13- into the 15-position by a Pd-catalyzed rearrangement[29][30][31][32]. Protection of the hydroxy group in **41** by treatment with acetyl chloride and pyridine gave acetate **45** (Scheme 11).

Reduction of ketone **45** with $NaBH_4$ in EtOH at −45°C led to isolation of a mixture of alcohols **46** and *epi*-**46** in a ratio of 91:9 in 84% yield. A higher selectivity in the reduction of **45** was achieved by using $Zn(BH_4)_2$ in ether at −30°C, which delivered a mixture of alcohols **46** and *epi*-**46** in a ratio of 97.5:2.5 in 87% yield. Chromatography afforded the diastereomerically pure alcohol **46** (85%) which was benzoylated to give benzoate **47** in 96% yield. The introduction of two different protecting groups for the hydroxy groups at C-11 and C-13 in **47** was deemed necessary because of the inversion of configuration at C-15 which has to be carried out after the allylic rearrangement. Treatment of **47** with a catalytic amount of $Pd(MeCN)_2Cl_2$ in THF at room temperature gave the isomeric acetate **48** as a single diastereomer. Unfortunately the allylic rearrangement of **47** could not be brought to completion. An equilibrium consisting of 75% of **48** and 25% of **47** was established instead. The same observation was made in the case of the Pd-catalyzed rearrangement of the allylic diacetate derived from diol **31**[51] and of a similar bicyclic allylic diacetate[32a]. These results are in contrast to reports of unidirectional Pd-catalyzed rearrangements of analogous monocyclic allylic acetates[31]. Fortunately, a separation of both isomers could be achieved by chromatography, affording **48**

Scheme 11

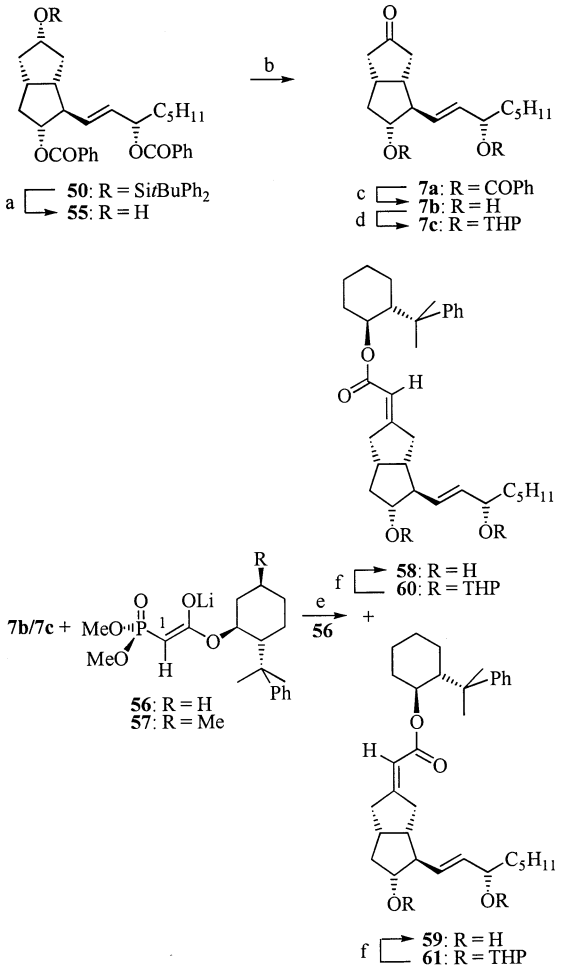


Reagents and conditions: (a) MeCOCl, pyridine, THF, room temp.; (b) $Zn(BH_4)_2$, ether, −30°C; (c) PhCOCl, pyridine, 0°C; (d) $Pd(MeCN)_2Cl_2$, THF, room temp.; (e) MeOH, K_2CO_3, room temp.; (f) PPh_3, EtOOC−N=N−COOEt, PhCOOH, THF, −30°C.

in 71% yield besides **47** in 24% yield. The acetoxy group in **48** was cleaved selectively with 1% K_2CO_3 in MeOH. Deacetylation was stopped before it had gone to completion in order to prevent the concomitant cleavage of the benzoyloxy group. Thus, alcohol **49** was obtained in 79% yield besides a 12% recovery of **48**. The final step of the completion of the ω-side chain consisted in the inversion of configuration at C-15 in **49**. Mitsunobu reaction[58] of **49** with diethyl azodicarboxylate, triphenylphosphane and benzoic acid at −30°C delivered the epimeric benzoate **50** in 83% yield. As a side product the isomeric benzoate **51** was isolated in 4% yield. Finally, a configurational correlation between diol **43** (cf. Scheme 10) and dibenzoate **50** was made through acetylation of the former to give diacetate **52** which was submitted to the Pd-catalyzed rearrangement to afford a 75:25 mixture of **53** and **52** in 95% yield. Cleavage of the acetoxy groups in **53** followed by a benzoylation of **54** gave dibenzoate **50** in 95% yield.

3-Oxacarbacyclin: According to the synthetic plan, we envisaged the stereoselective attachment of the α-side chain in **4** and **5** via reaction of ketone **7** with the chiral lithium phosphonoaceates **56** or **57**[15][17][33][59] (Scheme 12). We have recently introduced **56** for the diastereoselective olefination of ketone **9**[17]. Phosphonoacetate **56** contains as chiral auxiliary (1*S*-*trans*)-8-phenylnormenthol, which is much more readily accessible than (1*S*,2*R*,5*S*)-8-phenylmenthol[60]. The highest selectivity in the olefination of **9** with **56** was obtained in THF at low temperatures in the presence of LiCl. With LiCl as additive the yield and diastereoselectivity increased noticeably[17].

Scheme 12



Reagents and conditions: (a) $Bu_4NF{\cdot}H_2O$, THF, room temp.; (b) $(COCl)_2$, DMSO, NEt_3, CH_2Cl_2, −60°C; (c) MeOH; NaOH, room temp.; (d) 3,4-dihydro-2*H*-pyran, pyridinium *p*-toluenesulfonate, CH_2Cl_2, room temp.; (e) THF, LiCl, −62°C; (f) MeOH, pyridinium *p*-toluenesulfonate, room temp.

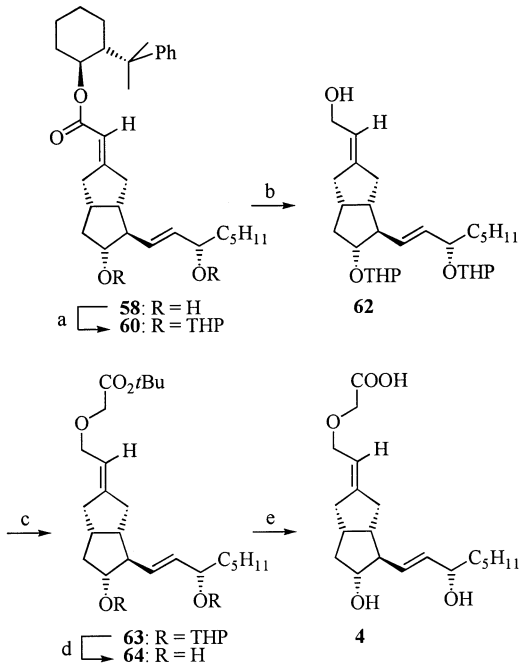
The required ketone **7b** was prepared in a straight forward manner from the silyl ether **50** in three steps. Desilylation of **50** with Bu_4NF gave alcohol **55**, which, upon Swern oxidation with DMSO, $(COCl)_2$ and NEt_3 at −60°C, afforded ketone **7a**. Finally, cleavage of the benzoyloxy groups in **7a** with NaOH in MeOH delivered **7b**[24][25] in 76% overall yield from **50**. In order to study the influence of the hydroxy groups in **7b** upon the stereoselectivity of the olefination reaction with **56**[33] we prepared as a further substrate the bis-THP ether **7c** from **7b**[24][25] by treatment of the latter with 3,4-dihydro-2*H*-pyran in the presence of

pyridinium *p*-toluenesulfonate in 99% yield. Reaction of ketone **7b** with 3 equivalents of **56** in THF gave, after a reaction time of 7 d at −62°C, a mixture of esters **58** and **59** in a ratio of 93:7 in 72% yield, according to HPLC analysis and NMR spectroscopy. LiCl had almost no effect upon the rate and selectivity of the reaction of **7b** with **56**. In accordance with previous observations in the case of **9**[17] the reaction of **7b** with **56** showed a linear temperature−diastereoselectivity relationship[61]. The reaction of the bis-THP ether **7c** with **56** in THF at −62°C took a similar course. In this case, however, addition of LiCl slightly raised the diastereoselectivity of the olefination. Cleavage of the THP groups in the thus obtained mixture of esters **60** and **61** gave a mixture of diols **58** and **59** in a ratio of 95:5 in 82% overall yield from **7c**. MPLC allowed for the removal of the unwanted diastereomer **59** and afforded **58** in 72% yield as a single stereoisomer, according to HPLC analysis and NMR spectroscopy. It was presumably at this stage where the second unwanted diastereomer of **58**, stemming from *ent*-**27**, was separated as well.

The preferential formation of **58** and **60** can be rationalized by assuming a highly selective and irreversible addition of (*E*)-phosphonoenolate **56** from its least hindered *Re*-side (C-1) to ketones **7b** and **7c** from the convex side[17]. A comparison with the olefination of the prochiral ketone **9** shows that the side chains in the chiral ketones **7b** and **7c** have almost no influence upon the stereoselectivity of the olefination with **56**.

The α-side chain in **4** starting from **58** was completed following an established protocol[7][8][14][18]. Treatment of diol **58** with 3,4-dihydro-2*H*-pyran and pyridinium *p*-toluenesulfonate gave the bis-THP ether **60** in 99% yield, which, upon reduction with DIBAL-H, afforded the allylic alcohol **62** in 86% yield (Scheme 13). In addition to **62** (1*S*-*trans*)-8-phenylnormenthol was formed. (1*S*-*trans*)-8-phenylnormenthol was not isolated but its recovery in high yield should pose no problems. Etherification of **62** by reaction with *tert*-butyl bromoacetate in the presence of NaOH provided ester **63** in 85% yield. Cleavage of the bis-THP ether **63** with pyridinium *p*-toluenesulfonate in EtOH delivered diol **64** in 94% yield. Finally, saponification of ester **64** under basic conditions gave (+)-3-oxacarbacyclin (**4**) in 85% yield. The NMR spectroscopic data and the optical rotation of **4** ($[\alpha]_D^{22}$ = +64.2 (*c* = 0.30, MeOH), ref[18] $[\alpha]_D^{20}$ = +62.3 (*c* = 0.40, MeOH) matched those reported in the literature[18].

Scheme 13



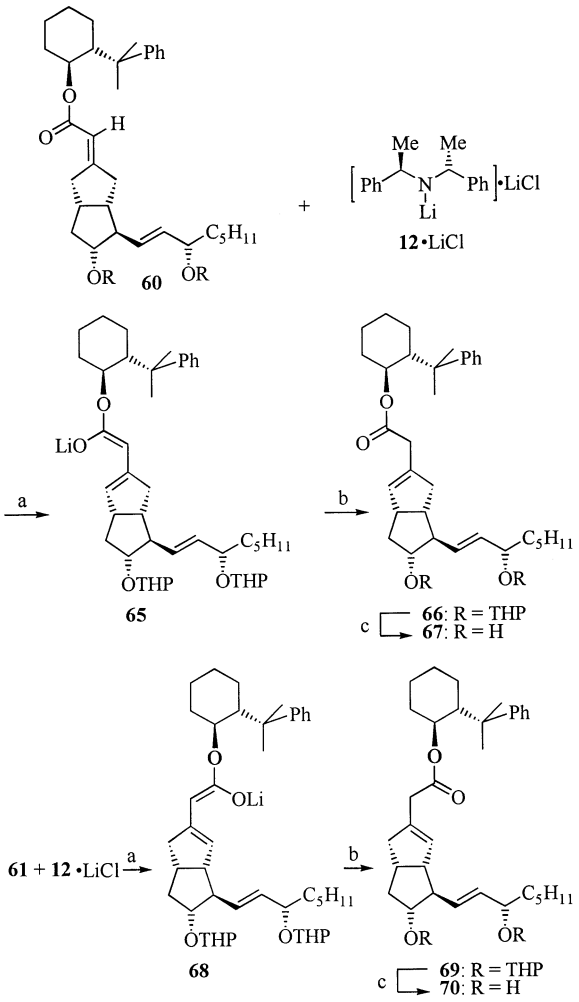
Reagents and conditions: (a) 3,4-dihydro-2*H*-pyran, pyridinium *p*-toluenesulfonate, CH_2Cl_2, room temp.; (b) DIBAL−H, THF, 0°C → room temp.; (c) $BrCH_2COOtBu$, Bu_4NHSO_4, CH_2Cl_2, NaOH-H_2O, room temp; (d) EtOH, pyridinium *p*-toluenesulfonate, room temp.; (e) MeOH, NaOH-H_2O, room temp.

3-Oxaisocarbacyclin: According to the retrosynthetic scheme the synthesis of 3-oxaisocarbacyclin (**5**) will be carried out by divergence of the synthesis of **4** at a late stage. This called for the isomerization of the α,β-unsaturated ester **60** to the β,γ-unsaturated ester **66** (Scheme 14).

This transformation requires two selective steps[8][34][35][36], deprotonation at the methylene group *cis* to the ester group under formation of the vinylogous enolate **65**, and, secondly, protonation of **65** at the α-position. Because of the highly selective deprotonation of **9** with **12**, we choose this chiral base for the regioselective deprotonation of **60**. (*R*,*R*)-Bis(phenylethyl)ammonium chloride was treated with two equivalents of *n*BuLi, providing **12**·LiCl, which was treated with **60** at −100°C. Subsequent protonation of the thus formed lithium enolate **65**, whose configuration was not determined, with saturated aqueous $NaHCO_3$ at −78°C led to isolation of the β,γ-unsaturated ester **66** in 91% yield. ^{1}H-NMR spectroscopy of the alcohol **67**, obtained by cleavage of crude **66**, showed the admixture of only 1.5% of the isomeric alcohol **70**. Deprotonation of the isomeric α,ß-unsaturated ester **61** with **12**·LiCl gave enolate **68**, whose configuration was not determined. Subsequent protonation of **68** afforded ester **69** in 88% yield. ^{1}H-NMR spectroscopy of alcohol **70**, obtained by cleavage of crude **69**, showed the admixture of only 1.5% of the isomeric alcohol **67**. The structures of alcohols **67** and **70** were determined by NOE experiments. Thus, neither the chirality of **12** nor of the ester group apparently have any influence upon the selectivity of the deprotonation of **60** and **61**. Thus it seems reasonable to assume that an achiral base like LDA could be used as well[35][36]. The highly selective deprotonations of **60** and **61** can be best explained by a coordination of **12** to the carbonyl groups in the esters followed by an intramolecular deprotonation[34d].

Completion of the α-side chain in **5** starting from **66** was accomplished in a similar manner as described above in the synthesis of **4**. Reduction of **66** with DIBAL-H afforded the allylic alcohol **71** in 71% yield (Scheme 15). In addition to **71** (1*S*-*trans*)-8-phenylnormenthol was formed. (1*S*-*trans*)-8-phenylnormenthol was not isolated but its recovery in high yield should be possible. Etherification of **71** by reac-

Scheme 14



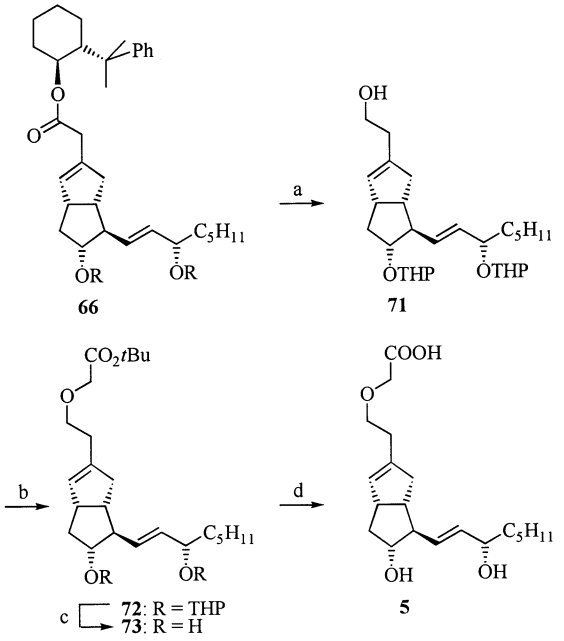
Reagents and conditions: (a) 1. THF, −100°C; 2. **60**, −100°C; (b) $NaHCO_3$, H_2O, −78°C; (c) MeOH, pyridinium *p*-toluenesulfonate, room temp.

tion with *tert*-butyl bromoacetate in the presence of NaOH provided ester **72** in 85% yield. Cleavage of the bis-THP ether **72** with pyridinium *p*-toluenesulfonate in EtOH delivered diol **73** in 85% yield. Finally, saponification of ester **73** under basic conditions gave (+)-3-oxaisocarbacyclin (**5**) in 87% yield. The NMR spectroscopic data and the optical rotation of **5** ($[\alpha]_D^{22}$ = +6.9 (*c* = 4.60, MeOH), ref.[8] $[\alpha]_D^{20}$ = +6.2 (*c* = 0.40, MeOH) matched those reported in the literature[8].

Conclusion

In this article, we have described new asymmetric syntheses of 3-oxacarbacyclin (**4**) and 3-oxaisocarbacyclin (**5**) from **9** by a common route which is characterized by divergence at a late stage and which should allow for the synthesis of other 3-oxacarbacyclins and 3-oxaisocarbacyclins as well. We are currently exploring the synthesis of **2** and of **3** from **27** by using, for the construction of the ω-side chains[7][14][62], (*E*,*S*)-2-bromo-4-methylnon-6-yn-2-enal and (*E*,*S*)-4-methyloct-5-yn-2-enal, respectively.

Scheme 15



Reagents and conditions: (a) DIBAL−H, THF, 0°C → room temp.; (b) $BrCH_2COOtBu$, Bu_4NHSO_4, CH_2Cl_2, NaOH-H_2O, room temp.; (c) EtOH, pyridinium *p*-toluenesulfonate; (d) MeOH, NaOH-H_2O, room temp.

Financial support of this research by the *Deutsche Forschungsgemeinschaft*, the *Schering AG*, Berlin, and the *Fonds der Chemischen Industrie* is gratefully acknowledged. The authors are indebted to Professor Dr. *H. Vorbrüggen* and Dr. *W. Skuballa* for stimulating discussions. The authors further acknowledge Dr. *H. Dahl* for a generous supply of ketone **9** and Dr. *J. Runsink* for NOE experiments.

Experimental Section

All reactions were carried out in oven-dried glassware under an argon atmosphere unless otherwise noted. Diethyl ether and THF were distilled from sodium/benzophenone, CH_2Cl_2 and DMF were distilled from CaH_2, EtOH was distilled from sodium, and pyridine was distilled from KOH. *n*BuLi was standardized by titration with diphenylacetic acid. − TLC analysis was performed with Merck silica gel coated aluminum foil. − Chromatography was performed with Merck silica gel 60 (0.063−0.100 mm). − MPLC was performed with Impaq silica gel (particle size 1.61 μm) on a Kronwald apparatus. − HPLC analysis was performed with a Chiracel OD (Baker) column. − IR spectra were recorded on a Perkin-Elmer PE 1760 spectrometer. Only peaks of $\tilde{\nu} > 900$ cm^{-1} in the IR spectra are listed. − ^{1}H-NMR spectra and ^{13}C-NMR spectra were recorded on a Varian VXR 300 or a Varian Unity 500 spectrometer. Chemical shifts 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. − Optical rotations were measured with a Perkin-Elmer Model 241 polarimeter at 22°C. − Mass spectra were obtained with a Finnigan MAT 212 spectrometer (EI, 70 eV). Only peaks of *m*/*z* >100 and an intensity of >10% in the MS

spectra are listed. – Elemental analyses were performed by the Institut für Organische Chemie Microanalytical Laboratory. – ^{1}H NMR shift experiments with Eu(tfc)$_3$ and Ag(fod) were carried out with freshly prepared solutions of the reagents.

Deprotonation of **9** *with* **12.** – *Method A:* A solution of (*R*,*R*)-bis(phenylethyl)amine (1.34 mmol) in THF (5 ml) was cooled to −78°C and *n*BuLi (1.55 M in hexanes, 1.33 mmol) was added dropwise. The mixture was warmed to 0°C and recooled to −100°C. A solution of the ketone (0.67 mmol) in THF (5 ml) was added dropwise and the mixture was stirred for 15 min. After addition of $ClSiR_3$ (3.34 mmol), the mixture was stirred for 60 min. at −100°C. The mixture was treated with saturated aqueous $NaHCO_3$ (5 ml), warmed to ambient temp. and extracted with ether (3 × 30 ml). The organic phase was dried ($MgSO_4$) and concentrated in vacuo. Chromatography (hexanes/EtOAc, 1:1) of the residue gave the silyl enol ether.

Method B: A solution of (*R*,*R*)-bis(phenylethyl)amine (2 mmol) in THF (10 ml) was cooled to −90°C and *n*BuLi (1.58 M in hexanes, 1.98 mmol) was added dropwise. The mixture was warmed to ambient temp. and recooled to −95°C. A solution of $ClSiR_3$ (5 mmol) in THF (4 ml) was added dropwise and the mixture was stirred for 5 min. After addition of a solution of the ketone (1 mmol) in THF (4 ml), the mixture was stirred for 30 min. at −90°C. The mixture was treated with saturated aqueous $NaHCO_3$ (10 ml) and warmed to ambient temp. After work up as described above (method A), the silyl enol ether was obtained.

Method C: A solution of (*R*,*R*)-bis(phenylethyl)amine (1.34 mmol) in THF (5 ml) was cooled to −78°C, and *n*BuLi (1.55 M in hexanes, 1.33 mmol) was added dropwise. The mixture was warmed to 0°C, treated with a solution of LiCl (43 mg, 1.01 mmol) in THF (2 ml) and recooled to −100°C. Subsequently $ClSiR_3$ (3.34 mmol) was added dropwise. After addition of a solution of the ketone (0.67 mmol) in THF (5 ml), the mixture was stirred for 60 min. at −100°C. The mixture was treated with saturated aqueous $NaHCO_3$ (5 ml) and warmed to ambient temp. After work up as described above (method A), the silyl enol ether was isolated.

Method D: A solution of (*R*,*R*)-bis(phenylethyl)amine (1.34 mmol) in THF (5 ml) was cooled to −78°C and *n*BuLi (1.55 M in hexanes, 1.33 mmol) was added dropwise. The mixture was warmed to 0°C, treated with a solution of LiCl (43 mg, 1.01 mmol) in THF (2 ml) and recooled to −100°C. A solution of the ketone (0.67 mmol) in THF (5 ml) was added dropwise and the mixture was stirred for 15 min. After addition of $ClSiR_3$ (3.34 mmol), the mixture was stirred for 60 min. at −100°C. The mixture was treated with saturated aqueous $NaHCO_3$ (5 ml) and warmed to ambient temp. After work up as described above (method A), the silyl enol ether was isolated.

Method E: A suspension of (*R*,*R*)-bis(phenylethyl)ammonium chloride (1.67 mmol) in THF (10 ml) was cooled to −78°C and *n*BuLi (1.44 M in hexanes, 3.26 mmol) was added dropwise. The mixture was warmed to 0°C, recooled to −105°C and treated dropwise with a solution of the ketone (1.11 mmol) in THF (5 ml). After stirring the mixture for 30 min. at −105°C, it was warmed to −78°C and treated with $ClSiEt_3$ (1.45 mmol). After stirring the mixture for 15 min., saturated aqueous $NaHCO_3$ (5 ml) was added and the mixture was warmed to ambient temp. After work up as described above (method A), the silyl enol ether was obtained.

(3′aR-cis)-Trimethyl-[[3′,3′a,4′,6′a-tetrahydro-5,5-dimethylspiro[1,3-dioxane-2,2′(1′H)-pentalen]-5′-yl]oxy]silane (**8a**): Following method D, **9** (150 mg, 0.67 mmol) in THF (5 ml) gave **8a** (165 mg, 83%, 92% *ee*) as a colorless oil, $[\alpha]_D$ = +16.9 (*c* = 10.1, acetone). – IR (neat): $\tilde{\nu}$ = 3060 (s), 1645 (s), 1325 (s), 1250 (s), 1195 (s), 1115 (s). – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.20 (s, 9 H), 0.95 (s, 3 H), 0.97 (s, 3 H), 1.50−1.60 (m, 2 H), 1.96−2.05 (m, 1 H), 2.24−2.40 (m, 2 H), 2.49−2.69 (m, 2 H), 3.01−3.14 (m, 1 H), 3.46 (s, 2 H), 3.49 (s, 2 H), 4.59−4.62 (m, 1 H). – ^{1}H NMR (300 MHz, $CDCl_3$, 100 mol% Ag(fod)/(+)-Pr(tfc)$_3$): δ (=CH-R) (*ent*-**8a**) = 4.43, δ (=CH-R) (**8a**) = 4.47. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 0.04 (d), 22.53 (d), 22.55 (d), 30.09 (u), 35.51 (d), 39.88 (u), 40.16 (u), 41.19 (u), 43.18 (d), 71.40 (u), 72.73 (u), 107.18 (d), 108.86 (u), 152.71 (u). – MS; *m*/*z* (%): 296 [M$^+$] (30), 209 (72), 206 (63), 167 (94), 128 (96), 73 (100). – $C_{16}H_{28}O_3Si$: calcd. 296.18077, found 296.1805 (MS).

(3′aR-cis)-Triethyl-[[3′,3′a,4′,6′a-tetrahydro-5,5-dimethylspiro-[1,3-dioxane-2,2′(1′H)-pentalen]-5′-yl]oxy]silane (**8b**): Following method E, **9** (2.00 g, 8.90 mmol) in THF (40 ml) gave **8b** (2.87 g, 95%, 92% *ee*) as a colorless oil, $[\alpha]_D$ = +0.6 (*c* = 9.8, THF). – IR (neat): $\tilde{\nu}$ = 3060 (w), 2960 (s), 2910 (s), 2880 (s) 1740 (w), 1645 (s), 1465 (m), 1415 (w), 1395 (w), 1325 (s), 1280 (w), 1250 (s), 1195 (s), 1115 (s), 1005 (s), 930 (m). – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.67 (q, *J* = 8.0 Hz, 6 H), 0.95 (s, 6 H), 0.97 (t, *J* = 8.0 Hz, 9 H), 1.51−1.63 (m, 2 H), 1.99−2.05 (m, 1 H), 2.31 (ddd, *J* = 13.1, *J* = 8.7, *J* = 2.0 Hz, 1 H), 2.36 (ddd, *J* = 12.7, *J* = 7.7, *J* = 2.0 Hz, 1 H), 2.51−2.66 (m, 2 H), 3.05−3.09 (m, 1 H), 3.45 (s, 2 H), 3.49 (s, 2 H), 4.61 (q, *J* = 1.8 Hz, 1 H). – ^{1}H NMR (300 MHz, $CDCl_3$, 100 mol% Ag(fod)/(+)-Pr(tfc)$_3$): δ (=CH-R) (*ent*-**8b**) = 4.44, δ (=CH-R) (**8b**) 4.51. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 4.81 (u), 6.62 (d), 22.55 (d), 22.57 (d), 30.13 (u), 35.60 (d), 39.97 (u), 40.09 (u), 41.20 (u), 43.19 (d), 71.42 (u), 72.83 (u), 106.97 (d), 108.90 (u), 153.00 (u). – MS; *m*/*z* (%): 338 [M$^+$] (30), 252 (18), 251 (54), 223 (13), 210 (17), 209 (40), 207 (14), 206 (70), 129 (26), 128 (100), 115 (48), 103 (18). – $C_{19}H_{34}O_3Si$ (338.5): calcd. C 67.40, H 10.12; found C 67.77, H 10.37.

[1S-(1α,2β,3aα,6aα)]-(1,1-Dimethylethyl)-[2-[1,2,3,3a,6,6a-hexahydro-1-[[[(1,1-dimethylethyl)dimethylsilyl]oxy]methyl]-5-[(trimethylsilyl)oxy]pentalenyl]oxy]dimethylsilane (**21**) *and [1S-(1α,2β,3aα,6aα)]-(1,1-Dimethylethyl)-[2-[1,2,3,3a,4,6a-hexahydro-1-[[[(1,1-dimethylethyl)dimethylsilyl]oxy]methyl]-5-[(trimethylsilyl)oxy]pentalenyl]oxy]dimethylsilane* (**22**): Following method B, **20** (586 mg, 2.22 mmol) in THF (4 ml) and **12** gave after chromatography (hexanes/EtOAc, 9:1) 900 mg (87%) of an unseparable mixture of **21** and **22** in a ratio of 95:5 as a colorless oil.

21: ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.04 (t, *J* = 2.1 Hz, 9 H), 0.19 (s, 12 H), 0.87 (s, 9 H), 0.89 (s, 9 H), 1.22−1.29 (m, 1 H), 1.58 (ddt, *J* = 9.5, *J* = 5.3, *J* = 3.4 Hz, 1 H), 2.06−2.12 (m, 1 H), 2.12−2.17 (m, 1 H), 2.34 (m, 1 H), 2.51 (ddt, *J* = 16.0, *J* = 9.5, *J* = 2.0 Hz, 1 H), 2.86 (m, 1 H), 3.61 (dd, *J* = 10.0, *J* = 5.0 Hz, 1 H), 3.69 (dd, *J* = 10.0, *J* = 3.5 Hz, 1 H), 3.82 (dt, *J* = 9.5, *J* = 7.0 Hz, 1 H), 4.63 (q, *J* = 1.8 Hz, 1 H). – ^{13}C NMR (125 MHz, $CDCl_3$): δ = −5.55 (d), −5.40 (d), −4.83 (d), −4.43 (d), 0.10 (d), 18.08 (u), 18.35 (u), 25.88 (d), 25.98 (d), 37.33 (d), 39.57 (u), 41.64 (d), 41.88 (u), 56.53 (d), 61.78 (u), 73.11 (d), 107.58 (d), 152.52 (u).

22: ^{1}H NMR (300 MHz, $CDCl_3$, in part) δ = 4.69 (q, *J* = 1.8 Hz, 1 H). – ^{13}C NMR (75 MHz, $CDCl_3$, in part): δ = −5.55 (d), −5.41 (d), −4.83 (d), −4.43 (d), 0.05 (d), 18.05 (u), 18.33 (u), 25.88 (d), 25.98 (d), 33.90 (d), 40.67 (u), 43.03 (u), 46.96 (d), 56.86 (d), 63.33 (u), 73.59 (d), 106.82 (d), 152.05 (u).

By the same procedure but using *ent*-**12**, **20** gave a mixture of **21** and **22** in a ratio of 14:86 in 85% yield.

(3′aα,5′β,6′aα)-Hexahydro-5,5-dimethylspiro[1,3-dioxane-2,2′-(1′H)-pentalen]-5′-ol (**23**) *and (3′aα,5′a,6′aα)-Hexahydro-5,5-di-*

methylspiro[1,3-dioxane-2,2′(1′H)-pentalen]-5′-ol (*epi*-**23**): A solution of **9** (20.00 g, 89.17 mmol) in EtOH (250 ml) was cooled to −45°C and $NaBH_4$ (6.75 g, 178.32 mmol) was added. After stirring the mixture for 4 h, saturated aqueous NH_4Cl (20 ml) was added. The mixture was warmed to ambient temp. and extracted with diethyl ether. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. Chromatography (hexanes/EtOAc, 1:1) of the residue gave **23** (19.37 g, 96%) and *epi*-**23** (395 mg, 2%) as white waxy solids.

23: IR (KBr): $\tilde{\nu}$ = 3290 (br), 2950 (s), 2860 (s), 1470 (s), 1395 (m), 1360 (s), 1310 (s), 1270 (s), 1255 (s), 1220 (s), 1330 (s), 1125 (s), 1110 (s), 1045 (s), 1015 (s), 995 (s), 980 (s), 950 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.96 (s, 6 H), 1.52 (ddd, *J* = 13.1, *J* = 5.7, *J* = 5.7 Hz, 2 H), 1.89 (dd, *J* = 13.4, *J* = 5.7 Hz, 2 H), 2.09 (ddd, *J* = 13.1, *J* = 5.9, *J* = 5.9 Hz, 2 H), 2.22 (dd, *J* = 13.4, *J* = 9.4 Hz, 2 H), 2.48 (s, 1H), 2.45−2.59 (m, 2 H), 3.47 (s, 2 H), 3.50 (s, 2 H), 4.20 (m, 1 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 22.5 (d), 30.1 (u), 38.5 (d), 40.8 (u), 42.5 (u), 71.9 (u), 72.2 (u), 75.5 (d), 110.5 (u). − MS; *m*/*z* (%): 226 [M^+] (31), 183 (79), 181 (12), 155 (37), 141 (57), 131 (13), 128 (43), 124 (15), 123 (45), 122 (17). − $C_{13}H_{22}O_3$ (226.3): calcd. C 68.99, H 9.80; found C 69.37, H 9.77.

epi-**23**: IR (KBr): $\tilde{\nu}$ = 3290 (br), 2960 (s), 2860 (s), 1470 (s), 1435 (m), 1395 (m), 1335 (s), 1295 (s), 1225 (s), 1120 (s) 1020 (s), 975 (m), 945 (m), 910 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.96 (s, 6 H), 1.46 (s, 1 H), 1.57−1.68 (m, 4 H), 1.81 (ddd, *J* = 13.1, *J* = 8.4, *J* = 4.4 Hz, 2 H), 2.23 (dd, *J* = 13.4, *J* = 9.3 Hz, 2 H), 2.66−2.74 (m, 2 H), 3.46 (s, 2 H), 3.47 (s, 2 H), 4.41 (m, 1 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 22.5 (d), 30.1 (u), 38.0 (d), 40.2 (u), 42.2 (u), 71.8 (u), 72.3 (u), 74.8 (d), 110.0 (u). − MS; *m*/*z* (%): 226 [M^+] (74), 183 (74), 155 (41), 141 (74), 128 (45), 96 (44). − $C_{13}H_{22}O_3$ (226.3): calcd. C 68.99, H 9.80;. found C 69.16, H 10.01.

(3′aα,5′β,6′aα)-(1,1-Dimethylethyl)-[hexahydro-5,5-dimethylspiro[1,3-dioxane-2,2′(1′H)-pentalen]-5′-yloxy]diphenylsilane (**24**): A solution of **23** (18.44 g, 81.46 mmol) in DMF (350 ml) was cooled to 0°C and imidazole (13.87 g, 203.64 mmol) was added, followed by the dropwise addition of $ClSitBuPh_2$ (24.63 g, 89.60 mmol). After stirring the mixture for 30 min. at 0°C, it was warmed to ambient temp. and concentrated in vacuo. Chromatography (hexanes/EtOAc, 10:1) of the residue provided **24** (37.50 g, 99%) as a colorless oil. − IR ($CHCl_3$): $\tilde{\nu}$ = 3070 (w), 2950 (s), 2860 (s), 1590 (w), 1470 (m), 1430 (m), 1395 (m), 1365 (m), 1335 (m), 1310 (w), 1255 (m), 1240 (m), 1220 (m), 1110 (s), 1045 (m), 995 (m), 905 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.96 (s, 6 H), 1.05 (s, 9 H), 1.57 (ddd, *J* = 12.9, *J* = 5.5, *J* = 5.5 Hz, 2 H), 1.78−1.91 (m, 4 H), 2.25−2.37 (m, 4 H), 3.47 (s, 2 H), 3.50 (s, 2 H), 4.21 (m, 1 H), 7.32−7.42 (m, 6 H), 7.65−7.69 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 19.1 (u), 22.6 (d), 26.9 (d), 30.1 (u), 37.9 (d), 40.5 (u), 41.8 (u), 71.5 (u), 72.7 (u), 77.0 (d), 110.2 (u), 127.5 (d), 129.5 (d), 134.4 (u), 135.8 (d). − MS; *m*/*z* (%): 464 [M^+] (2), 407 (29), 322 (29), 321 (100), 200 (12), 199 (64), 139 (15). − $C_{29}H_{40}O_3Si$ (464.7): calcd. C 74.95, H 8.68; found C 75.14, H 8.78.

(3aα,5β,6aα)-Hexahydro-5-[(1,1-dimethylethyl)diphenylsilyloxy]-2(1H)-pentalenone (**25**): A solution of **24** (37.50 g, 80.69 mmol) in acetone (600 ml) was treated with water (8 ml) and *p*TsOH (0.9 g, 5.23 mmol). The clear solution was stirred for 3 h at ambient temp., treated with saturated aqueous $NaHCO_3$ (3 ml) and concentrated in vacuo. Chromatography (hexanes/EtOAc, 5:1) of the residue gave **24** (1.02 g, 3%) and **25** (29.71 g, 97%) as colorless oils.

25: IR (neat): $\tilde{\nu}$ = 3070 (m), 2960 (s), 2930 (s), 2860 (s), 1740 (s), 1590 (w), 1470 (m), 1430 (s), 1175 (m), 1110 (s), 1025 (s), 935 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.03 (s, 9 H), 1.61 (ddd, *J* = 13.7, *J* = 4.7, *J* = 4.7 Hz, 2 H), 2.01 (ddd, *J* = 13.7, *J* = 7.7, *J* = 6.0 Hz, 2 H), 2.35 (dd, *J* = 18.7, *J* = 4.3 Hz, 2 H), 2.50 (dd, *J* = 18.9, *J* = 9.6 Hz, 2 H), 2.57−2.68 (m, 2 H), 4.33 (m, 1 H), 7.34−7.45 (m, 6 H), 7.63−7.67 (m, 4 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 19.0 (u), 26.9 (d), 37.8 (d), 42.8 (u), 45.3 (u), 76.2 (d), 127.6 (d), 129.6 (d), 134.0 (u), 135.8 (d), 221.0 (u). − MS; *m*/*z* (%): 322 (28), 321 (100), 200 (17), 243 (9), 199 (89), 139 (28). − $C_{24}H_{30}O_2Si$ (378.6): calcd. C 76.14, H 7.99; found C 75.81, H 7.92.

[2S-(2α,3aβ,6aβ)]-(1,1-Dimethylethyl)-[2-[1,2,3,3a,4,6a-hexahydro-5-[(triethylsilyl)oxy]pentalenyl]oxy]diphenylsilane (**27**): Following method E (vide supra), **25** (15.00 g, 39.62 mmol) in THF (225 ml) gave **27** (18.36 g, 94%, 92% *ee*) as a colorless oil, $[\alpha]_D$ = +6.4 (*c* = 13.2, THF). − IR (neat): $\tilde{\nu}$ = 3070 (m), 2960 (s), 2880 (s), 1645 (s), 1590 (m), 1460 (m), 1430 (m), 1375 (m), 1340 (m), 1330 (m), 1285 (m), 1240 (m), 1220 (m), 1190 (m), 1110 (s), 975 (m), 925 (m), 900 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.68 (q, *J* = 7.9 Hz, 6 H), 0.98 (t, *J* = 7.9 Hz, 9 H), 1.04 (s, 9 H), 1.30−1.54 (m, 2 H), 1.94−2.10 (m, 3 H), 2.30 (m, 1 H), 2.49 (dd, *J* = 15.8, *J* = 9.4 Hz, 1 H), 2.78 (m, 1 H), 4.04 (m, 1 H), 4.62 (d, *J* = 1.7 Hz, 1 H), 7.33−7.44 (m, 6 H), 7.65−7.70 (m, 4 H). − ^{1}H NMR (300 MHz, $CDCl_3$, 100 mol% Ag(fod)/(+)-Pr(tfc)$_3$): δ (= CH-R) (*ent*-**27**) = 4.47, δ (=CH-R) (**27**) = 4.55. − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 4.85 (u), 6.67 (d), 19.12 (u), 26.90 (d), 35.38 (d), 40.51 (u), 41.91 (u), 43.19 (u), 43.32 (d), 74.77 (d), 107.32 (d), 127.47 (d), 129.43 (d), 134.62 (u), 135.75 (d), 152.48 (u). − MS; *m*/*z* (%): 492 [M^+] (0.4), 437 (13), 436 (36), 435 (100), 199 (19), 135 (7), 115(5), 87 (21). − $C_{30}H_{44}O_2Si_2$ (492.9): calcd. C 73.11, H 9.00; found C, 73.18, H 9.08.

[3′aS-[3′aα,4′α(1S,2E),6′aα]]-Tetrahydro-4′-(1-hydroxy-2-octenyl)-5,5-dimethylspiro[1,3-dioxane-2,2′(1′H)-pentalen]-5′(3′H)-one* (**29**) *and [3′aS-[3′aα,4′α(1R*,2E),6′aα]]-Tetrahydro-4′-(1-hydroxy-2-octenyl)-5,5-dimethylspiro[1,3-dioxane-2,2′(1′H)-pentalen]-5′(3′H)-one* (**30**): A suspension of (*R*,*R*)-bis(phenylethyl)ammonium chloride (3.04 g, 11.60 mmol) in THF (65 ml) was cooled to −78°C, and *n*BuLi (1.44 M in hexanes, 15.7 ml, 22.6 mmol) was added dropwise. The mixture was warmed to ambient temp. until it became a clear yellow solution. The solution was cooled to −105°C, treated dropwise with a solution of **9** (2.00 g, 8.90 mmol) in THF (35 ml) and stirred for a further 30 min. at −105°C. Subsequently, the mixture was warmed to −78°C and treated with **28** (1.69 g, 13.40 mmol). After stirring the mixture for 3 h, saturated aqueous $NaHCO_3$ (25 ml) was added. The mixture was warmed to ambient temp. and extracted with ether. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. MPLC (hexanes/EtOAc, 2:1) of the residue provided **29** (1.98 g, 63%) and **30** (0.99 g, 32%) as colorless oils.

29: $[\alpha]_D$ = −30.0 (*c* = 9.9, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3460 (s, br), 2960 (s), 2930 (s), 2860 (s), 1735 (s), 1670 (w), 1470 (m), 1400 (m), 1350 (m), 1330 (m), 1295 (m), 1240 (m), 1210 (m), 1115 (s), 1050 (m), 1010 (m), 975 (m), 910 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 6.9 Hz, 3 H), 0.95 (s, 3 H), 0.97 (s, 3 H), 1.24−1.43 (m, 6 H), 1.71 (dd, *J* = 13.4, *J* = 5.7 Hz, 1 H), 1.92 (dd, *J* = 14.1, *J* = 3.4 Hz, 1 H), 2.04 (dt, *J* = 7.0, *J* = 7.0 Hz, 2 H), 2.20−2.35 (m, 5 H), 2.45 (dd, *J* = 18.8, *J* = 9.1 Hz, 1 H), 2.77 (m, 2 H), 3.43 (s, 2 H), 3.48 (s, 2 H), 4.51 (m, 1 H), 5.44 (ddt, *J* = 15.3, *J* = 6.5, *J* = 1.3 Hz, 1 H), 5.71 (dtd, *J* = 15.3, *J* = 6.7, *J* = 1.0 Hz, 1 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.05 (d), 22.44 (d), 22.50 (u), 28.84 (u), 30.07 (u), 31.35 (u), 32.16 (u), 35.20 (d), 37.86 (d), 41.06 (u), 41.51 (u), 45.35 (u), 60.01 (d), 71.92 (d), 72.07 (u), 72.18 (u), 109.64 (u), 129.66 (d), 133.02 (d), 221.49 (u). − MS; *m*/*z* (%): 350 [M^+] (4), 224 (29), 181 (19), 155 (23), 154 (17),141 (15), 139 (12), 138 (15), 129 (17), 128 (36), 95 (30), 91 (24). −

$C_{21}H_{34}O_4$ (350.5): calcd. C 71.96, H 9.78; found C 71.98, H 10.06.

30: $[\alpha]_D$ = +2.6 (*c* = 10.9, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3460 (m, br), 2960 (s), 2860 (m), 1725 (m), 1115 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 6.7 Hz, 3 H), 0.97 (s, 6 H), 1.18−1.43 (m, 6 H), 1.73 (dd, *J* = 13.4, *J* = 7.4 Hz, 1 H), 1.98 (dd, *J* = 14.1, *J* = 4.1 Hz, 1 H), 2.05 (dt, *J* = 6.8, *J* = 6.8 Hz, 2 H), 2.18−2.56 (m, 6 H), 2.74 (m, 1 H), 3.45 (s, 2 H), 3.47 (s, 2 H), 3.75 (s, br, 1 H), 4.13 (dd, *J* = 8.1, *J* = 8.1 Hz, 1 H), 5.41 (dd, *J* = 15.1, *J* = 6.8 Hz, 1 H), 5.71 (dt, *J* = 15.1, *J* = 6.8 Hz, 1 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.04 (d), 22.44 (d), 22.52 (u), 28.79 (u), 30.07 (u), 31.42 (u), 32.18 (u), 34.67 (d), 40.23 (d), 41.19 (u), 44.76 (u), 59.22 (d), 72.08 (u), 72.21 (u), 74.37 (d), 109.35 (u), 129.28 (d), 134.42 (d), 222.86 (u). − MS; *m/z* (%): 350 [M^+] (8), 224 (55), 223 (11), 181 (26), 155 (26), 141 (20), 139 (13), 138 (25), 129 (34), 128 (43), 109 (11), 95 (36), 91 (14). − $C_{21}H_{34}O_4$ (350.5): calcd. C 71.96, H 9.78; found C 71.87, H 9.95.

[3′aS-[3′aα,4′α(1S,2E),5′β,6′aα]]-Hexahydro-4′-(1-hydroxy-2-octenyl)-5,5-dimethylspiro[1,3-dioxane-2,2′(1′H)-pentalen]-5′-ol* (**31**) *and [3′aS-[3′aα,4′α(1S*,2E),5′α,6′aα]]-Hexahydro-4′-(1-hydroxy-2-octenyl)-5,5-dimethylspiro[1,3-dioxane-2,2′(1′H)-pentalen]-5′-ol* (**32**): A solution of **29** (1.01 g, 2.89 mmol) in EtOH (60 ml) was cooled to −45°C and treated with $NaBH_4$ (0.22 g, 5.78 mmol). After stirring the mixture for 3 h, saturated aqueous NH_4Cl (20 ml) was added. The mixture was warmed to ambient temp. and extracted with ether. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. Chromatography (hexanes/EtOAc, 1:1) of the residue afforded **31** (827 mg, 81%) and **32** (32 mg, 3%) as colorless oils.

31: $[\alpha]_D$ = +15.2 (*c* = 4.8, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3400 (s, br), 2960 (s), 2930 (s), 2870 (s), 1735 (s), 1665 (w), 1625 (w), 1470 (m), 1435(m), 1400 (m), 1380 (m), 1365 (m), 1350 (m), 1330 (m), 1315 (m), 1290 (m), 1260 (m), 1240 (w), 1220 (m), 1175 (m), 1110 (s), 1045 (s), 975 (m), 930 (w), 910 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 7.0 Hz, 3 H), 0.94 (s, 3 H), 0.96 (s, 3 H), 1.23−1.40 (m, 6 H), 1.48 (ddd, *J* = 12.1, *J* = 9.6, *J* = 9.6 Hz, 1 H), 1.74−1.91 (m, 3 H), 2.05 (dt, *J* = 6.8, *J* = 6.8 Hz, 2 H), 2.10−2.41 (m, 7 H), 3.46 (s, 2 H), 3.48 (s, 2 H), 4.00 (ddd, *J* = 9.4, *J* = 9.4, *J* = 6.4 Hz, 1 H), 4.20 (dd, *J* = 7.0, *J* = 5.0 Hz, 1 H), 5.55 (dd, *J* = 15.5, *J* = 7.4 Hz, 1 H), 5.70 (dt, *J* = 15.1, *J* = 6.7 Hz, 1 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.11 (d), 22.55 (u), 22.60 (d), 28.93 (u), 30.15 (u), 31.47 (u), 32.31 (u), 35.89 (d), 39.54 (d), 40.05 (u), 40.24 (u), 41.67 (u), 58.69 (d), 72.05 (u), 72.23 (u), 74.29 (d), 75.18 (d), 110.48 (u), 130.36 (d), 133.97 (d). − MS; *m/z* (%): 352 [M^+] (25), 281 (32), 267 (15), 249 (12), 248 (13), 225 (37), 223 (30), 208 (13), 183 (18), 181 (12), 177 (15), 169 (13), 168 (11), 155 (15), 141 (18), 139 (18), 129 (35), 128 (100) 127 (24), 125 (30), 123 (15), 122 (22), 121 (14), 115 (13), 109 (17).

32: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 6.7 Hz, 3 H), 0.95 (s, 3 H), 0.96 (s, 3 H), 1.22−1.43 (m, 6 H), 1.55 (ddd, *J* = 13.1, *J* = 9.4, *J* = 3.4 Hz, 1 H), 1.68−1.72 (m, 1 H), 1.74−1.84 (m, 2 H), 1.92 (dd, *J* = 13.4, *J* = 7.4 Hz, 1 H), 2.04 (dt, *J* = 7.0, *J* = 7.0 Hz, 2 H), 2.06−2.19 (m, 2 H), 2.65−2.88 (m, 4 H), 3.45 (s, 2 H), 3.48 (s, 2 H), 4.39 (dd, *J* = 3.2, *J* = 3.2 Hz, 1 H), 4.53 (dd, *J* = 6.2, *J* = 3.9 Hz, 1 H), 5.53 (ddt, *J* = 15.4, *J* = 6.7, *J* = 1.2 Hz, 1 H), 5.69 (dtd, *J* = 15.4, *J* = 6.5, *J* = 0.8 Hz, 1 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.12 (d), 22.59 (u), 22.66 (d), 28.99 (u), 30.14 (u), 31.50 (u), 32.23 (u), 37.91 (d), 38.94 (d), 39.40 (u), 40.46 (u), 42.58 (u), 56.72 (d), 72.00 (u), 72.19 (u), 73.39 (d), 79.36 (d), 110.79 (u), 131.45 (d), 131.92 (d).

[3′aS-[3′aα,4′α(1R,2E),5′β,6′aα]]-Hexahydro-4′-(1-hydroxy-2-octenyl)-5,5-dimethylspiro[1,3-dioxane-2,2′(1′H)-pentalen]-5′-ol* (**33**) *and [3′aS-[3′aα,4′α(1R*,2E),5′α,6′aα]]-Hexahydro-4′-(1-hydroxy-2-octenyl)-5,5-dimethylspiro[1,3-dioxane-2,2′(1′H)-pentalen]-5′-ol* (**34**): Following the procedure described for the preparation of **31**, **30** (159 mg, 0.45 mmol) in EtOH (10 ml) and $NaBH_4$ (34 mg, 0.90 mmol) gave after chromatography (hexanes/EtOAc, 1:1) **33** (120 mg, 76%) and a mixture of **34** and **33** (7 mg, 4%, ratio 2:1) as colorless oils.

33: $[\alpha]_D$ = +17.0 (*c* = 9.7, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3400 (s, br), 2960 (s), 2930 (s), 2860 (s), 1735 (w), 1670 (w), 1470 (m), 1435 (m), 1395 (m), 1365 (m), 1330 (m), 1310 (m), 1290 (m), 1255 (m), 1240 (m), 1220 (m), 1190 (m), 1110 (s), 990 (m), 925 (w), 910 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 6.9 Hz, 3 H), 0.93 (s, 3 H), 0.98 (s, 3 H), 1.27−1.41 (m, 6 H), 1.49 (ddd, *J* = 11.4, *J* = 11.4, *J* = 11.4 Hz, 1 H), 1.64−1.74 (m, 3 H), 1.93−2.12 (m, 4 H), 2.16−2.28 (m, 2 H), 2.32−2.43 (m, 1 H), 2.62 (s, br, 1 H), 3.39 (s, br, 1 H), 3.41 (d, *J* = 11.1 Hz, 1 H), 3.44 (d, *J* = 11.1 Hz, 1 H), 3.47 (d, *J* = 11.1 Hz, 1 H), 3.50 (d, *J* = 11.1 Hz, 1 H), 3.93−4.01 (m, 2 H), 5.45 (ddt, *J* = 15.4, *J* = 7.9, *J* = 1.2 Hz, 1 H), 5.67 (dt, *J* = 15.4, *J* = 6.7 Hz, 1 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.04 (d), 22.52, 22.59, 28.90 (u), 30.07 (u), 31.45 (u), 32.14 (u), 35.68 (d), 39.40 (u), 40.50 (d), 40.84 (u), 41.07 (u), 58.37 (d), 71.86 (u), 72.29 (u), 79.26 (d), 79.61 (d), 110.16 (u), 131.77 (d), 133.37 (d). − MS; *m/z* (%): 352 [M^+] (53), 281 (33), 267 (24), 249 (13), 248 (13), 223 (33), 208 (17), 183 (17), 181 (12), 177 (10), 169 (13), 168 (10), 155 (14), 141 (15), 139 (17), 129 (39), 128 (100), 127 (15), 125 (28), 123 (12), 122 (18), 121 (13), 115 (13), 109 (13). − $C_{21}H_{36}O_4$ (352.5): calcd. C 71.55, H 10.29; found C 71.39, H 10.63.

[4′R-[4′α(E),4′aβ,4′bα,7′aα,8′aα]-Hexahydro-4′-(1-heptenyl)-2′,2′,5,5-tetramethylspiro[1,3-dioxane-2,6′(5′H)-4′H-pentaleno[2,1-d]-1,3-dioxine] (**35**): Following the procedure described for the preparation of **44** (vide infra), **32** (32 mg, 0.09 mmol) in acetone (4.0 ml) and 2,2-dimethoxypropane (1.0 ml) gave in the presence of ω-camphorsulfonic acid (3 mg) after chromatography (hexanes/EtOAc, 1:1) **35** (24 mg, 66%) as a colorless oil, $[\alpha]_D$ = +31.3 (*c* = 6.1, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 2960 (s), 2930 (s), 2860 (s), 1470 (m), 1435 (m), 1380 (s), 1365 (m), 1350 (m), 1310 (m), 1250 (m), 1220 (m), 1200 (s), 1130 (s), 1105 (s), 1050 (m), 1030 (m), 1000 (m). − ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 7.0 Hz, 3 H), 0.93 (s, 3 H), 0.98 (s, 3 H), 1.23−1.32 (m, 4 H), 1.38 (s, 3 H), 1.37−1,41 (m, 2 H), 1.45 (s, 3 H), 1.51 (ddd, *J* = 13.4, *J* = 8.9, *J* = 3.4 Hz, 1 H), 1.64 (ddd, *J* = 8.5, *J* = 3.0, *J* = 3.0 Hz, 1 H), 1.70−1.74 (m, 1 H), 1.76−1.80 (m, 1 H), 1.98 (dd, *J* = 13.4, *J* = 7.8 Hz, 1 H), 2.02−2.08 (m, 4 H), 2.75−2.83 (m, 2 H), 3.41 (d, *J* = 11.2 Hz, 1 H), 3.45 (d, *J* = 11.2 Hz, 1 H), 3.48 (d, *J* = 11.2 Hz, 1 H), 3.49 (d, *J* = 11.2 Hz, 1 H), 4.31 (dd, *J* = 3.3, *J* = 3.3 Hz, 1 H), 4.53 (dd, *J* = 6.9, *J* = 2.5 Hz, 1 H), 5.44 (ddt, *J* = 15.4, *J* = 7.0, *J* = 1.5 Hz, 1 H), 5.73 (dtd, *J* = 15.4, *J* = 6.7, *J* = 1.0 Hz, 1 H). − ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.06 (d), 19.48 (d), 22.56 (u), 22.57 (d), 22.68 (d), 28.87 (u), 30.09 (u), 30.10 (d), 31.55 (u), 32.34 (u), 37.43 (d), 38.89 (d), 40.63 (u), 50.40 (d), 70.11 (d), 71.85 (u), 72.28 (u), 75.62 (d), 97.95 (u), 110.78 (u), 129.23 (d), 132.65 (d). − MS; *m/z* (%): 392 [M^+] (29), 377 (12), 335 (19), 334 (49), 321 (19), 263 (11), 250 (11), 249 (22), 248 (11), 231 (26), 213 (13), 209 (12), 208 (56), 207 (13), 206 (11), 155 (11), 141 (19), 129 (34), 128 (100), 122 (28), 121 (12), 105 (10). − $C_{24}H_{40}O_4$ (392.6): calcd. C 73.43, H 10.27; found C 73.44, H 10.22.

[4′S-[4′α(E),4′aα,4′bβ,7′aβ,8′aβ]]-Hexahydro-4′-(1-heptenyl)-2′,2′,5,5-tetramethyl-5,5-dimethylspiro[1,3-dioxane-2,6′(5′H)-4′H-pentaleno[2,1-d]-1,3-dioxine] (**36**): Following the procedure described for the preparation of **44** (vide infra), **33** (106 mg, 0.30 mmol) in acetone (12.8 ml) and 2,2-dimethoxypropane (3.2 ml) gave in the presence of ω-camphorsulfonic acid (8 mg) after chromatography (hexanes/EtOAc, 1:1) **36** (114 mg, 96%) as a colorless

oil, $[\alpha]_D = +23.2$ (c = 22.1, THF). − IR (neat): $\tilde{\nu}$ = 3000 (m), 2960 (s), 2930 (s), 2860 (m), 1465 (m), 1380 (m), 1365 (w), 1335 (m), 1265 (m), 1220 (m), 1195 (m), 1165 (m), 1115 (s), 1040 (m), 1000 (m), 957 (m). − ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.89 (t, J = 6.9 Hz, 3 H), 0.93 (s, 3 H), 0.98 (s, 3 H), 1.28−1.32 (m, 4 H), 1.35−1.42 (m, 4 H), 1.45 (s, 3 H), 1.48 (s, 3 H), 1.63 (dd, J = 13.1, J = 7.6 Hz, 1 H), 1.67−1.73 (m, 1 H), 1.99−2.08 (m, 4 H), 2.19 (ddd, J = 11.0, J = 7.9, J = 6.1 Hz, 1 H), 2.29 (dd, J = 13.1, J = 8.7 Hz, 1 H), 2.38−2.46 (m, 1 H), 3.45 (d, J = 11.3 Hz, 1 H), 3.46 (d, J = 11.3 Hz, 1 H), 3.48 (d, J = 11.3 Hz, 1 H), 3.49 (d, J = 11.3 Hz, 1 H), 3.60 (ddd, J = 10.9, J = 10.9, J = 6.1 Hz, 1 H), 4.07 (dd, J = 10.1, J = 7.9 Hz, 1 H), 5.43 (ddt, J = 15.4, J = 7.8, J = 1.5 Hz, 1 H), 5.73 (dt, J = 15.4, J = 6.7 Hz, 1 H). − ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.63 (d), 20.96 (d), 23.05 (d), 23.12 (u), 23.14 (d), 29.33 (u), 30.58 (d), 30.64 (u), 32.06 (u), 32.84 (u), 35.74 (d), 37.96 (u), 38.39 (d), 39.70 (u), 39.86 (u), 54.16 (d), 72.41 (u), 72.86 (u), 75.14 (d), 78.93 (d), 100.33 (u), 110.97 (u), 129.61 (d), 134.71 (d). − MS; *m/z* (%): 392 [M^+] (11), 334 (24), 317 (75), 263 (13), 231 (41), 208 (66), 128 (100). − $C_{24}H_{40}O_4$ (392.6): calcd. C 73.43, H 10.27; found C 73.36, H 10.14.

[3′aS-[3′aα,4′α(1S,2E),6′aα]]-Tetrahydro-4′-(1-triethylsilyloxy-2-octenyl)-5,5-dimethylspiro[1,3-dioxane-2,2′(1′H)-pentalen]-5′(3′H)-one* (**37**) *and [3′aS-[3′aα,4′α(1R*,2E),6′aα]]-Tetrahydro-4′-(1-triethylsilyloxy-2-octenyl)-5,5-dimethylspiro[1,3-dioxane-2,2′(1′H)-pentalen]-5′(3′H)-one* (**38**): A solution of **28** (69 mg, 0.55 mmol) in CH_2Cl_2 (4 ml) was treated at room temp. with $Et_2O{\cdot}BF_3$ (78 mg, 0.55 mmol), and the resulting mixture was cooled immediately to −95°C. After the addition of a solution of **8b** (169 mg, 0.50 mmol) (92% *ee*) in CH_2Cl_2 (100 ml), the resultant orange mixture was stirred for 1 h. The mixture was treated with saturated aqueous $NaHCO_3$ (6 ml), warmed to ambient temp. and extracted with ether. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. Chromatography (hexanes/EtOAc, 1:1) of the residue provided a mixture of **37** and **38** (144 mg, 62%, ratio 4:1), **29** (21 mg, 12%) and **30** (5 mg, 3%) as colorless oils. Data for **37** and **38**: $[\alpha]_D = -30.8$ (c = 3.30, THF). − IR (neat): $\tilde{\nu}$ = 3010 (w), 2960 (s), 2930 (s), 2880 (s), 1740 (s), 1460 (m), 1360 (w), 1330 (w), 1240 (m), 1215 (m), 1110 (s), 1050 (m), 975 (m), 910 (w). − ^{1}H NMR (300 MHz, $CDCl_3$) (**37**): δ = 0.51 (q, J = 8.1 Hz, 6 H), 0.89 (t, J = 7.9 Hz, 12 H), 0.95 (s, 3 H), 0.96 (s, 3 H), 1.22−1.43 (m, 6 H), 1.65 (dd, J = 13.1, J = 7.4 Hz, 1 H), 1.81 (dd, J = 13.3, J = 4.6 Hz, 1 H), 2.01 (dt, J = 7.0, J = 7.0 Hz, 2 H), 2.18 (dd, J = 18.8, J = 4.2 Hz, 1 H), 2.23−2.31 (m, 3 H), 2.39 (dd, J = 18.8, J = 9.4 Hz, 1 H), 2.75 (m, 1 H), 3.00 (m, 1 H), 3.41 (s, 2 H), 3.48 (s, 2 H), 4.63 (dd, J = 6.6, J = 1.2 Hz, 1 H), 5.42 (ddt, J = 15.4, 6.6, J = 1.4 Hz, 1 H), 5.63 (dtd, J = 15.4, J = 6.7, J = 1.0 Hz, 1 H). − ^{1}H NMR (300 MHz, $CDCl_3$) (**38**, in part): δ = 4.43 (dd, J = 6.0, J = 6.0 Hz, 1 H). − ^{13}C NMR (75 MHz, $CDCl_3$) (**37**): δ = 4.89 (u), 6.80 (d), 14.07 (d), 22.45 (d), 22.53 (u), 28.87 (u), 30.06 (u), 31.38 (u), 32.06 (u), 35.67 (d), 37.17 (d), 41.14 (u), 41.87 (u), 45.54 (u), 61.91 (d), 71.99 (u), 72.21 (u), 72.86 (d), 109.67 (u), 131.27 (d), 220.93 (u). − MS; *m/z* (%): 464 [M^+] (4), 436 (34), 435 (100), 350 (17), 349 (55), 338 (27), 291 (15), 242 (14), 241 (70), 171 (11), 115 (18), 103 (80).

[1S-(1α(1S,2E),3aα,5β,6aα)]-5-[(1,1-Dimethylethyl)diphenylsilyloxy]hexahydro-1-(1-triethylsilyloxy-2-octenyl)-2(1H)-pentalenone* (**39**) *and [1S-(1α(1R*,2E),3aα,5β,6aα)]-5-[(1,1-Dimethylethyl)diphenylsilyloxy]hexahydro-1-(1-triethylsilyloxy-2-octenyl)-2(1H)-pentalenone* (**40**): A solution of **28** (42 mg, 0.33 mmol) in CH_2Cl_2 (3 ml) was treated with $Et_2O{\cdot}BF_3$ (47 mg, 0.33 mmol), and the resulting mixture was cooled immediately to −78°C. After the addition of a solution of **27** (148 mg, 0.30 mmol) (92% *ee*) in CH_2Cl_2 (1.5 ml), the resultant orange mixture was stirred for 1 h. The mixture was treated with saturated aqueous $NaHCO_3$ (5 ml), warmed to ambient temp. and extracted with ether. The organic phase was concentrated in vacuo. Chromatography (hexanes/EtOAc, 4:1) of the residue gave a mixture of **39** and **40** (128 mg, 69%, ratio 95:5) as a colorless oil. Data for **39** and **40**: $[\alpha]_D = -33.2$ (c = 10.3, THF). − IR (neat): $\tilde{\nu}$ = 3170 (w), 3150 (m), 2960 (s), 2930 (s), 2880 (s), 2860 (s), 1740 (s), 1590 (w), 1460 (w), 1430 (s), 1375 (m), 1240 (m), 1110 (s), 1005 (s), 975 (m), 940 (m), 900 (m). − ^{1}H NMR (300 MHz, $CDCl_3$) (**39**): δ = 0.51 (q, J = 8.1 Hz, 6 H), 0.88 (t, J = 7.9 Hz, 9 H), 0.90 (t, J = 7.0 Hz, 3 H), 1.01 (s, 9 H), 1.20−1.40 (m, 6 H), 1.45−1.63 (m, 2 H), 1.93−2.90 (m, 9 H), 4.31 (m, 1 H), 4.66 (d, J = 5.7 Hz, 1 H), 5.41 (ddt, J = 15.4, J = 6.4, J = 1.3 Hz, 1 H), 5.62 (dtd, J = 15.4, J = 6.7, J = 1.0 Hz, 1 H), 7.33−7.45 (m, 6 H), 7.60−7.65 (m, 4 H). − ^{1}H NMR (300 MHz, $CDCl_3$) (**40**, in part): δ = 4.47 (dd, J = 6.0, J = 6.0 Hz, 1 H). − ^{13}C NMR (75 MHz, $CDCl_3$) (**39**): δ = 4.98 (u), 6.89 (d), 14.15 (d), 19.05 (u), 22.58 (u), 26.94 (d), 28.94 (u), 31.46 (u), 32.13 (u), 36.69 (d), 38.42 (d), 43.18 (u), 43.35 (u), 46.48 (u), 62.79 (d), 72.98 (d), 76.51 (d), 127.64 (d), 129.64 (d), 131.03 (d), 131.61 (d), 134.21 (u), 135.87 (d), 221.95 (u). − MS; *m/z* (%): 619 [M^+] (0.5), 590 (20), 589 (42), 563 (18), 562 (49), 561 (100), 435 (11), 333 (23), 241 (39), 200 (11), 199 (51), 189 (15), 187 (23), 135 (14), 115 (27), 103 (17).

[1S-(1α(1S,2E),3aα,5β,6aα)]-5-[(1,1-Dimethylethyl)diphenylsilyloxy]hexahydro-1-(1-hydroxy-2-octenyl)-2(1H)-pentalenone* (**41**) *and [1S-(1α(1R*,2E),3aα,5β,6aα)]-5-[(1,1-Dimethylethyl)diphenylsilyloxy]hexahydro-1-(1-hydroxy-2-octenyl)-2(1H)-pentalenone* (**42**): A solution of **28** (6.02 g, 47.73 mmol) in CH_2Cl_2 (200 ml) was treated with $Et_2O{\cdot}BF_3$ (6.77 g, 47.73 mmol) and the resulting mixture was cooled immediately to −78°C. After the addition of a solution of **27** (21.38 g, 43.39 mmol) (92% *ee*) in CH_2Cl_2 (100 ml), the resultant orange mixture was stirred for 1 h. The mixture was treated with saturated aqueous $NaHCO_3$ (100 ml), warmed to ambient temp. and extracted with ether. The organic phase was concentrated in vacuo and the residue was dissolved in a mixture of AcOH (300 ml), water (100 ml) and THF (100 ml). The mixture was stirred for 12 h at room temp. and concentrated in vacuo. Chromatography (hexanes/EtOAc, 3:1) of the residue gave **41** (14.48 g, 66%) and **42** (2.97 g, 14%) as colorless oils.

41: $[\alpha]_D = -15.8$ (c = 14.4, THF). − IR (neat): $\tilde{\nu}$ = 3440 (br), 3070 (m), 2960 (s), 2930 (s), 2860 (m), 1735 (s), 1590 (w), 1470 (m), 1430 (s), 1380 (s), 1110 (s), 1025 (s), 900 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.8 Hz, 3 H), 1.02 (s, 9 H), 1.23−1.41 (m, 6 H), 1.52−1.70 (m, 2 H), 1.95−2.06 (m, 4 H), 2.25 (d, J = 5.4 Hz, 1 H), 2.42−2.67 (m, 5 H), 4.35 (m, 1 H), 4.53 (m, 1 H), 5.42 (ddt, J = 15.3, J = 6.7, J = 1.3 Hz, 1 H), 5.70 (dtd, J = 15.3, J = 6.7, J = 1.3 Hz, 1 H), 7.34−7.46 (m, 6 H), 7.62−7.65 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.12 (d), 19.04 (u), 22.55 (u), 26.95 (d), 28.89 (u), 31.42 (u), 32.22 (u), 36.22 (d), 39.15 (d), 42.93 (u), 43.10 (u), 46.17 (u), 60.97 (d), 72.03 (d), 76.62 (d), 127.68 (d), 129.72 (d), 129.81 (d), 132.91 (d), 134.08 (u), 135.84 (d), 222.43 (u). − MS; *m/z* (%): 503 [$M^+ - 1$] (0.1), 370 (11), 369 (37), 322 (13), 321 (44), 243 (11), 213 (18), 201 (11), 200 (20), 199 (100), 189 (11), 183 (11), 181 (36), 139 (63), 135 (17), 129 (11), 121 (12), 105 (17). − $C_{32}H_{44}O_3Si$ (504.8): calcd. C 76.14, H 8.79; found C 76.40, H 8.94.

42: $[\alpha]_D = -7.2$ (c = 12.0, THF). − IR (neat): $\tilde{\nu}$ = 3460 (br), 3070 (m), 3050 (m), 2960 (s), 2930 (s), 2860 (s), 1725 (s), 1590 (w), 1460 (s), 1430 (s), 1310 (w), 1260 (w), 1110 (s), 1025 (s), 975 (m), 940 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.5 Hz, 3 H), 1.04 (s, 9 H), 1.20−1.40 (m, 6 H), 1.56−1.76 (m, 2 H), 1.86−2.05 (m, 4 H), 2.28−2.61 (m, 5 H), 3.95 (s, 1 H), 4.11 (dd,

J = 8.1 Hz, 1 H), 4.35 (m, 1 H), 5.38 (dd, J = 15.5, J = 7.7 Hz, 1 H), 5.68 (dt, J = 15.5, J = 6.7 Hz, 1 H), 7.34−7.46 (m, 6 H), 7.63−7.67 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.14 (d), 19.04 (u), 22.58 (u), 26.99 (d), 28.81 (u), 31.48 (u), 32.20 (u), 35.71 (d), 41.61 (d), 42.64 (u), 43.19 (u), 45.72 (u), 60.03 (d), 74.66 (d), 76.52 (d), 127.71 (d), 127.73 (d), 129.63 (d), 129.76 (d), 129.89 (d), 134.00 (u), 134.18 (d), 135.84 (d), 135.87 (d), 223.97 (u). − MS; *m/z* (%): 447 (19), 431 (12), 430 (30), 429 (77), 369 (25), 325 (15), 323 (32), 322 (77), 321 (100), 243 (28), 231 (17), 225 (14), 201 (24), 200 (68), 199 (90), 197 (39), 183 (41), 182 (11), 181 (59), 165 (16), 140 (10),139 (76), 137 (11), 135 (30), 123 (13), 121 (22), 117 (11), 105 (32). − $C_{32}H_{44}O_3Si$ (504.8): calcd. C 76.14, H 8.79; found C 76.00, H 8.85.

[1R-(1α(1S,2E),2β,3aα,5β,6aα)]-5-[(1,1-Dimethylethyl)-diphenylsilyloxy]octahydro-1-(1-hydroxy-2-octenyl)-2-pentalenol* (**43**): A solution of **42** (120 mg, 0.23 mmol) in EtOH (5 ml) was cooled to −45°C and treated with $NaBH_4$ (18 mg, 0.48 mmol). After stirring the reaction mixture for 2 h, saturated aqueous NH_4Cl (2 ml) was added. The mixture was warmed to ambient temp. and extracted with ether. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. Chromatography (hexanes/EtOAc, 4:1) of the residue afforded **43** (104 mg, 86%) as a colorless oil, $[\alpha]_D$ = +2.3 (c = 10.0, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3360 (br), 3070 (s), 3050 (s), 2940 (s), 2860 (s), 1960 (w), 1890 (w), 1825 (w), 1670 (w), 1590 (w), 1460 (s), 1430 (s), 1375 (s), 1340 (s), 1220 (m), 1190 (m), 1110 (s), 1025 (s), 975 (s) − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.9 Hz, 3 H), 1.06 (s, 9 H), 1.23−1.39 (m, 6 H), 1.48−2.03 (m, 9 H), 2.12−2.28 (m, 2 H), 2.52 (s, 1 H), 3.22 (s, 1 H), 3.91−4.00 (m, 2 H), 4.19 (m, 1 H), 5.40 (ddt, J = 15.4, J = 7.7, J = 1.3 Hz, 1 H), 5.60 (dt, J = 15.4, J = 6.7 Hz, 1 H), 7.33−7.44 (m, 6 H), 7.65−7.70 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.05 (d), 19.09 (u), 22.49 (u), 26.96 (d), 28.79 (u), 31.44 (u), 32.07 (u), 36.60 (d), 41.74 (d), 42.00 (u), 42.13 (u), 58.51 (d), 77.14 (d), 79.56 (d), 79.93 (d), 127.50 (d), 129.49 (d), 132.00 (d), 132.96 (d), 134.27 (u), 134.39 (u), 135.82 (d). − MS; *m/z* (%): 504 [M^+] (0.02), 431 (18), 233 (27), 217 (30), 216 (20), 215 (96), 200 (19), 199 (100), 197 (13), 183 (10), 181 (12), 149 (15), 145 (13), 139 (33), 135 (27), 131 (19), 127 (18), 125 (18), 121 (13), 117 (17), 109 (19), 107 (24), 106 (12), 105 (19). $C_{32}H_{46}O_3Si$ (506.8): calcd. C 75.84, H 9.15; found C 76.18, H 9.14.

[4S-[4α(E),4aα,4bβ,6α,7aβ,8aβ]]-(1,1-Dimethylethyl)-[[octahydro-4-(1-heptenyl)-2,2-dimethyl-4H-pentaleno[2,1-d]-1,3-dioxine-6-yl]oxy]diphenylsilane (**44**): A solution of **43** (146 mg, 0.29 mmol) in acetone (12.8 ml) containing 2,2-dimethoxypropane (3.2 ml) was treated with ω-camphorsulfonic acid (8 mg) and stirred for 1 h. After the addition of NEt_3 (0.02 ml), the mixture was concentrated in vacuo. Chromatography (hexanes/EtOAc, 10:1) of the residue gave **44** (158 mg, 99%) as a colorless oil, $[\alpha]_D$ = +10.1 (c = 10.8, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3070 (w), 3050 (w), 2990 (m), 2930 (s), 2860 (s), 1590 (w), 1460 (s), 1430 (s), 1380 (s), 1360 (s), 1260 (w), 1195 (s), 1165 (s), 1110 (s), 1050 (s), 1025 (s), 970 (m), 940 (m). − ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.89 (t, J = 7.0 Hz, 3 H), 1.07 (s, 9 H), 1.25−1.39 (m, 6 H), 1.46 (s, 3 H), 1.47 (s, 3 H), 1.52 (ddd, J = 13.4, J = 4.8, J = 4.8 Hz, 1 H), 1.55−1.68 (m, 3 H), 1.73−1.89 (m, 3 H), 1.95−2.08 (m, 2 H), 2.17 (m, 1 H), 2.25 (m, 1 H), 3.57 (ddd, J = 10.9, J = 10.9, J = 5.7 Hz, 1 H), 4.03 (dd, J = 9.8, J = 7.9 Hz, 1 H), 4.25 (m, 1 H), 5.40 (ddt, J = 15.4, J = 7.8, J = 1.5 Hz, 1 H), 5.68 (dt, J = 15.4, J = 6.7 Hz, 1 H), 7.34−7.43 (m, 6 H), 7.65−7.69 (m, 4 H). − ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.07 (d), 19.09 (u), 20.46 (d), 22.52 (u), 26.98 (d), 28.78 (u), 30.15 (d), 31.52 (u), 32.27 (u), 36.29 (d), 38.01 (u), 39.45 (d), 40.20 (u), 41.86 (u), 53.51 (d), 74.76 (d), 77.50 (d), 78.74 (d), 99.65 (u), 127.55 (d), 127.57 (d), 129.47 (d), 129.54 (d), 129.56 (d), 133.81 (d), 134.37 (u), 135.90 (d). − MS; *m/z* (%): 546 [M^+] (0.1), 471 (5), 431 (35), 353 (12), 215 (100), 199 (49), 149 (14). − $C_{35}H_{50}O_3Si$ (546.9): calcd. C 76.87, H 9.22; found C 77.10, H 9.46.

[1S-(1α(1S,2E),3aα,5β,6aα)]-5-[(1,1-Dimethylethyl)-diphenylsilyloxy]hexahydro-1-(1-acetyloxy-2-octenyl)-2(1H)-pentalenone* (**45**): To a solution of **41** (94 mg, 0.19 mmol) in THF (7.5 ml) were added pyridine (90 mg, 1.14 mmol) and acetyl chloride (89 mg, 1.14 mmol). The suspension was stirred for 16 h at ambient temp. and then concentrated in vacuo. Chromatography (hexanes/EtOAc, 4:1) of the residue gave **45** (87 mg, 85%) as a colorless oil, $[\alpha]_D$ = −24.7 (c = 12.7, THF). − IR (neat): $\tilde{\nu}$ = 3070 (w), 3050 (w), 2960 (s), 2930 (s), 2860 (s), 1750 (s), 1590 (w), 1465 (m), 1430 (m), 1370 (m),1235 (s), 1110 (s), 1020 (s), 970 (m), 940 (w), 900 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.9 Hz, 3 H), 1.02 (s, 9 H), 1.23−1.40 (m, 6 H), 1.51−1.74 (m, 2 H), 1.98 (s, 3 H), 1.96−2.07 (m, 4 H), 2.41−2.74 (m, 5 H), 4.36 (m, 1 H), 5.39 (ddt, J = 15.4, J = 6.7, J = 1.3 Hz, 1 H), 5.60 (dd, J = 6.7, J = 2.3 Hz, 1 H), 5.69 (dtd, J = 15.4, J = 6.7, J = 1.0 Hz, 1 H), 7.34−7.46 (m, 6 H), 7.62−7.65 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.11 (d), 19.03 (u), 21.16 (d), 22.52 (u), 26.95 (d), 28.65 (u), 31.40 (u), 32.20 (u), 36.09 (d), 39.96 (d), 42.90 (u), 43.04 (u), 45.62 (u), 59.16 (d), 73.58 (d), 76.50 (d), 126.02 (d), 127.69 (d), 129.73 (d), 134.02 (u), 134.55 (d), 135.84 (d), 169.68 (u), 218.43 (u). − MS; *m/z* (%): 547 [M^+] (0.2), 447 (28), 431 (11), 430 (35), 429 (100), 411 (12), 370 (22), 369 (84), 241 (13), 231 (19), 213 (23), 199 (84), 197 (13), 189 (11), 183 (14), 181 (37), 139 (30), 135 (17), 105 (13). − $C_{34}H_{46}O_4Si$ (546.8): calcd. C 74.68, H 8.48; found C 74.52, H 8.47.

[1R-(1α(1R,2E),2β,3aα,5β,6aα)]-1-(1-Acetyloxy-2-octenyl)-5-[(1,1-dimethylethyl)diphenylsilyloxy]octahydro-2-pentalenol* (**46**) *and [1R-(1α(1R*,2E),2α,3aα,5β,6aα)]-1-(1-Acetyloxy-2-octenyl)-5-[(1,1-dimethylethyl)diphenylsilyloxy]octahydro-2-pentalenol* (*epi*-**46**): To a solution of **41** (11.20 g, 22.30 mmol) in THF (500 ml) were added pyridine (10.57 g, 133.70 mmol) and acetyl chloride (10.49 g, 133.70 mmol). After 5 min. a white solid separated. The suspension was stirred for 16 h at ambient temp., concentrated in vacuo and the residue, containing **45**, dissolved in ether (500 ml). The solution was cooled to −30°C and a solution of $Zn(BH_4)_2$ (8.47 g, 89.2 mmol) in ether (50 ml) was added. After stirring the mixture for 6 h, saturated aqueous NH_4Cl (150 ml) was added. The mixture was warmed to ambient temp. and extracted with ether. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. Chromatography (hexanes/EtOAc, 2:1) of the residue gave **46** (10.40 g, 85%) and *epi*-**46** (0.27 g, 2%) as colorless oils.

46: $[\alpha]_D$ = −11.7 (c = 10.1, THF). − IR (neat): $\tilde{\nu}$ = 3470 (br), 3070 (w), 3050 (w), 2960 (s), 2930 (s), 2830 (s), 1735 (s), 1590 (w), 1460 (m), 1430 (s), 1370 (s), 1240 (s), 1110 (s), 1040 (s), 970 (m), 945 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.9 Hz, 3 H), 1.06 (s, 9 H), 1.22−1.42 (m, 6 H), 1.54−1.67 (m, 2 H), 1.71−1.87 (m, 3 H), 1.99−2.22 (m, 6 H), 2.03 (s, 3 H), 2.40 (s, 1 H), 3.74 (m, 1 H), 4.22 (m, 1 H), 5.38 (dd, J = 7.6, J = 4.5 Hz, 1 H), 5.45 (ddt, J = 14.8, J = 7.7, J = 1.3 Hz, 1 H), 5.75 (dt, J = 14.6, J = 6.7 Hz, 1 H), 7.33−7.46 (m, 6 H), 7.66−7.70 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.11 (d), 19.15 (u), 21.35 (d), 22.53 (u), 27.01 (d), 28.70 (u), 31.47 (u), 32.26 (u), 36.49 (d), 40.70 (d), 41.08 (u), 42.16 (u), 42.26 (u), 58.39 (d), 75.15 (d), 75.75 (d), 77.38 (d), 127.04 (d), 127.61 (d), 129.60 (d), 134.28 (u), 134.36 (u), 134.97 (d), 135.92 (d), 170.82 (u). − MS; *m/z* (%): 431 (30), 353 (11), 216 (22), 215 (100), 200 (12), 199 (64), 183 (10), 181 (36), 159 (10), 149 (17), 145 (15), 139 (20), 135 (19), 131 (15), 117 (18), 105 (15). − $C_{34}H_{48}O_4Si$ (548.8): calcd. C 74.42, H 8.82; found C 74.39, H 9.10.

epi-**46**: $[\alpha]_D$ = +10.1 (*c* = 14.2, THF). − IR (neat): $\tilde{\nu}$ = 3470 (br), 3070 (m), 3050 (m), 2960 (s), 2930 (s), 2860 (s), 1740 (s), 1590 (w), 1460 (s), 1370 (s), 1240 (s), 1110 (s), 1035 (s), 975 (m), 905 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.7 Hz, 3 H), 1.04 (s, 9 H), 1.25−1.40 (m, 6 H), 1.46−1.88 (m, 6 H), 1.97 (s, 3 H), 1.98−2.07 (m, 3 H), 2.25 (ddd, *J* = 9.2, *J* = 9.2, *J* = 3.3 Hz, 1 H), 2.36 (m, 1 H), 2.67 (m, 1 H), 4.22−4.32 (m, 2 H), 5.40 (dd, *J* = 9.3, *J* = 7.7 Hz, 1 H), 5.50 (ddt, *J* = 15.1, *J* = 7.7, *J* = 1.4 Hz, 1 H), 5.80 (dt, *J* = 14.9, *J* = 6.8 Hz, 1 H), 7.33−7.44 (m, 6 H), 7.65−7.70 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.64 (d), 19.66 (u), 21.98 (d), 23.05 (u), 27.54 (d), 29.24 (u), 31.93 (u), 32.79 (u), 40.66 (d), 41.96 (u), 42.42 (u), 43.45 (d), 44.42 (u), 57.35 (d), 77.13 (d), 77.36 (d), 78.38 (d), 128.13 (d), 128.16 (d), 128.66 (d), 130.16 (d), 134.76 (u), 134.98 (u), 135.29 (d), 136.41 (d), 136.46 (d), 170.87 (u). − MS; *m/z* (%): 432 (12), 241 (11), 216 (19), 215 (100), 200 (13), 199 (66), 183 (12), 182 (11), 181 (75), 159 (11), 149 (17), 145 (16), 139 (24), 135 (27), 131 (15), 121 (14), 119 (10), 117 (18), 107 (10), 105 (17). − $C_{34}H_{48}O_4Si$ (548.8): calcd. C 74.42, H 8.82; found C 74.35, H 8.98.

[1R-(1α(1R,2E),2β,3aα,5β,6aα)]-1-(1-Acetyloxy-2-octenyl)-5-[(1,1-dimethylethyl)diphenylsilyloxy]octahydro-2-pentalenyl Benzoate* (**47**): A solution of **46** (8.14 g, 14.83 mmol) in pyridine (200 ml) was cooled to 0°C and treated with benzoyl chloride (12.51g, 89.00 mmol). After stirring the mixture for 3 h, it was concentrated in vacuo. Chromatography (hexanes/EtOAc, 4:1) of the residue gave **47** (9.35 g, 96%) as a colorless oil, $[\alpha]_D$ = −29.3 (*c* = 8.3, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3070 (s), 2960 (s), 2930 (s), 2860 (s), 1730 (s), 1605 (m), 1590 (m), 1450 (s), 1430 (s), 1370 (s), 1315 (s), 1275 (s), 1240 (s), 1110 (s), 1070 (s), 1030 (s), 985 (s), 950 (s), 900 (s). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.83 (t, *J* = 6.9 Hz, 3 H), 1.10 (s, 9 H), 1.10−1.27 (m, 6 H), 1.66−1.99 (m, 7 H), 1.94 (s, 3 H), 2.25 (m, 1 H), 2.34−2.49 (m, 2 H), 2.71 (ddd, *J* = 8.7, *J* = 8.7, *J* = 6.1 Hz, 1 H), 4.31 (m, 1 H), 5.17 (ddd, *J* = 9.1, *J* = 9.1, *J* = 6.4 Hz, 1 H), 5.28 (dd, *J* = 7.7, *J* = 6.1 Hz, 1 H), 5.42 (ddt, *J* = 15.1, *J* = 7.7, *J* = 1.3 Hz, 1 H), 5.68 (dt, *J* = 15.1, *J* = 6.7 Hz, 1 H), 7.33−7.46 (m, 8 H), 7.55 (tt, *J* = 7.4, *J* = 1.3 Hz, 1 H), 7.66−7.73 (m, 4 H), 8.04−8.07 (m, 2 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.01 (d), 19.11 (u), 21.26 (d), 22.41 (u), 26.97 (d), 28.41 (u), 31.38 (u), 32.14 (u), 37.45 (d), 38.81 (u), 41.46 (d), 41.93 (u), 42.01 (u), 54.82 (d), 76.10 (d), 76.87 (d), 77.19 (d), 126.30 (d), 126.42 (d), 127.57 (d), 128.26 (d), 129.60 (d), 130.54 (u), 132.78 (d), 134.08 (u), 134.18 (u), 135.30 (d), 135.82 (d), 135.88 (d), 165.94 (u), 170.07 (u). − MS; *m/z* (%): 652 [M^+] (0.013), 535 (7), 473 (23), 303 (25), 244 (14), 243 (75), 216 (16), 215 (83), 199 (42), 181 (51), 135 (11), 131 (11), 117 (14), 106 (10), 105 (100). − $C_{41}H_{52}O_5Si$ (652.9): calcd. C 75.42, H 8.03; found C 75.44, H 8.29.

[1S-(1α(1E,3S),2β,3aα,5β,6aα)]-1-(3-Acetyloxy-1-octenyl)-5-[(1,1-dimethylethyl)diphenylsilyloxy]octahydro-2-pentalenyl Benzoate* (**48**): A solution of **47** (24.49 g, 37.51 mmol) in THF (500 ml) was treated with $Pd(MeCN)_2Cl_2$ (175 mg, 0.67 mmol) at room temp. After stirring the mixture for 16 h, it was concentrated in vacuo. MPLC (hexanes/EtOAc, 10:1) of the residue afforded **47** (5.82 g, 24%) and **48** (17.45 g, 71%) as colorless oils. Data for **48**: $[\alpha]_D$ = −18.3 (*c* = 11.6, THF). − IR (neat): $\tilde{\nu}$ = 3070 (m), 2960 (s), 2930 (s), 2860 (s), 1720 (s), 1605 (w), 1585 (w), 1450 (s), 1430 (s), 1370 (s), 1315 (s), 1275 (s), 1240 (s), 1175 (m), 1110 (s), 1070 (s), 1025 (s), 965 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.77 (t, *J* = 6.4 Hz, 3 H), 1.11 (m, 15 H), 1.35−1.56 (m, 2 H), 1.66−2.00 (m, 5 H), 2.01 (s, 3 H), 2.22 (m, 1 H), 2.41−2.51 (m, 2 H), 3.04 (ddd, *J* = 8.9, *J* = 8.9, *J* = 8.9 Hz, 1 H), 4.35 (m, 1 H), 5.06 (ddd, *J* = 9.4, *J* = 9.4, *J* = 6.1 Hz, 1 H), 5.16 (dt, *J* = 7.0, *J* = 7.0 Hz, 1 H), 5.44 (dd, *J* = 15.4, *J* = 7.4 Hz, 1 H), 5.61 (dd, *J* = 15.4, *J* = 8.3 Hz, 1 H), 7.33−7.46 (m, 8 H), 7.55 (tt, *J* = 7.4, *J* = 1.3 Hz, 1 H), 7.66−7.72 (m, 4 H), 8.02−8.06 (m, 2 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.95 (d), 19.12 (u), 21.41 (d), 22.35 (u), 24.64 (u), 26.99 (d), 31.46 (u), 34.40 (u), 37.43 (d), 38.35 (u), 40.02 (u), 42.37 (u), 44.89 (d), 54.83 (d), 74.85 (d), 77.24 (d), 79.48 (d), 127.58 (d), 128.26 (d), 129.55 (d), 129.59 (d), 129.97 (d), 130.54 (u), 132.76 (d), 134.05 (u), 134.17 (u), 134.59 (d), 135.84 (d), 135.85 (d), 166.19 (u), 170.26 (u). − MS; *m/z* (%): 535 (18), 473 (23), 303 (25), 244 (12), 243 (60), 216 (18), 215 (100), 199 (22), 181 (41), 135 (10), 117 (11), 105 (99). − $C_{41}H_{52}O_5Si$ (652.9): calcd. C 75.42, H 8.03: found C 75.06, H 8.10.

[1S-(1α(1E,3S),2β,3aα,5β,6aα)]-5-[(1,1-Dimethylethyl)diphenylsilyloxy]-octahydro-1-(3-hydroxy-1-octenyl)-2-pentalenyl 2-Benzoate* (**49**): To a solution of **48** (12.25 g, 18.76 mmol) in MeOH (400 ml) was added K_2CO_3 (3.16 g). After stirring the mixture for 100 min., it was extracted with hexane and the organic phase was concentrated in vacuo. Chromatography (hexanes/EtOAc, 4:1) of the residue provided **48** (1.45 g, 12%) and **49** (9.01 g, 79%) as colorless oils. Data for **49**: $[\alpha]_D$ = −37.5 (*c* = 12.6, THF). − IR (neat): $\tilde{\nu}$ = 3480 (br), 3070 (m), 2960 (s), 2930 (s), 2860 (s), 1720 (s), 1605 (m), 1585 (m), 1450 (s), 1430 (s), 1375 (s), 1315 (s), 1275 (s), 1110 (s), 1070 (s), 1025 (s), 970 (s), 940 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.78 (t, *J* = 6.9 Hz, 3 H), 1.11 (s, 9 H), 1.04−1.28 (m, 6 H), 1.30−1.50 (m, 2 H), 1.67−2.01 (m, 6 H), 2.22 (m, 1 H), 2.39−2.52 (m, 2 H), 3.06 (m, 1 H), 4.02 (m, 1 H), 4.37 (m, 1 H), 5.07 (ddd, *J* = 9.6, *J* = 9.6, *J* = 6.0 Hz, 1 H), 5.47−5.61 (m, 2 H), 7.33−7.46 (m, 8 H), 7.54 (tt, *J* = 7.4, *J* = 1.5 Hz, 1 H), 7.67−7.72 (m, 4 H), 8.03−8.06 (m, 2 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.07 (d), 19.21 (u), 22.53 (u), 25.05 (u), 27.08 (d), 31.77 (u), 37.26 (u), 37.50 (d), 38.47 (u), 40.13 (u), 42.46 (u), 45.08 (d), 54.94 (d), 73.12 (d), 77.39 (d), 79.65 (d), 127.68 (d), 127.69 (d), 128.36 (d), 129.64 (d), 129.70 (d), 130.65 (u), 132.51 (d), 132.86 (d), 134.20 (u), 134.74 (d), 135.94 (d), 135.96 (d), 166.38 (u). − MS; *m/z* (%): 535 (2), 431 (7), 303 (27), 243 (95), 215 (88), 199 (49), 105 (100). − $C_{39}H_{50}O_4Si$ (610.9): calcd. C 76.68, H 8.25; found C 76.37, H 8.34.

[1S-(1α(1E,3R),2β,3aα,5β,6aα)]-1-(3-Benzoyloxy-1-octenyl)-5-[(1,1-dimethylethyl)diphenylsilyloxy]octahydro-2-pentalenyl Benzoate* (**50**) *and [1R-(1α(1S*,2E),2β,3aα,5β,6aα)]-1-(1-benzoyloxy-2-octenyl)-5-[(1,1-dimethylethyl)diphenylsilyloxy]-octahydro-2-pentalenyl Benzoate* (**51**): A solution of **49** (6.72 g, 10.99 mmol), triphenylphosphane (5.70 g, 13.19 mmol) and benzoic acid (2.66 g, 13.19 mmol) in THF (55 ml) was treated dropwise at −30°C with a solution of diethylazodicarboxylate (2.30 g, 13.19 mmol) in THF (23 ml). After stirring the mixture for 1 h, saturated aqueous $NaHCO_3$ (5 ml) was added. The mixture was warmed to ambient temp. and extracted with ether. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. MPLC (hexanes/EtOAc, 10:1) of the residue gave **50** (6.53 g, 83%) and **51** (0.31 g, 4%) as colorless oils.

50: $[\alpha]_D$ = −33.7 (*c* = 9.0, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3070 (m), 2960 (s), 2930 (s), 2860 (m), 1720 (s), 1605 (w), 1585 (w), 1450 (m), 1430 (m), 1365 (w), 1315 (m), 1275 (s), 1175 (m), 1110 (s), 1070 (m), 1025 (s), 970 (m), 940 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.82 (t, *J* = 7.0 Hz, 3 H), 1.10 (s, 9 H), 1.17−1.33 (m, 6 H), 1.55−1.98 (m, 7 H), 2.20 (m, 1 H), 2.41−2.53 (m, 2 H), 3.07 (ddd, *J* = 8.6, *J* = 8.6, *J* = 8.6 Hz, 1 H), 4.35 (m, 1 H), 5.07 (ddd, *J* = 9.3, *J* = 9.3, *J* = 5.9 Hz, 1 H), 5.45 (dt, *J* = 6.5, *J* = 6.5 Hz, 1 H), 5.57 (dd, *J* = 15.1, *J* = 6.4 Hz, 1 H), 5.72 (dd, *J* = 15.1, *J* = 7.9 Hz, 1 H), 7.32−7.45 (m, 10 H), 7.47−7.55 (m, 2 H), 7.66−7.71 (m, 4 H), 7.94−8.02 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.05 (d), 19.21 (u), 22.53 (u), 24.78 (u), 27.08 (d), 31.62 (u), 34.54 (u), 37.53 (d), 38.42 (u), 40.11 (u), 42.51 (u), 44.86 (d), 54.78 (d),

74.89 (d), 77.31 (d), 79.67 (d), 127.66 (d), 128.30 (d), 129.62 (d), 130.66 (u), 130.89 (u), 132.68 (d), 134.05 (d), 134.19 (u), 134.25 (u), 135.93 (d), 165.83 (u), 166.31 (u). − MS; *m/z* (%): 303 (17), 243 (50), 215 (31), 199 (13), 105 (100). − $C_{46}H_{54}O_5Si$ (715.0): calcd. C 77.27, H 7.61; found C 77.66, H 7.78.

51: $[\alpha]_D$ = −42.4 (*c* = 9.1, THF). − IR (neat): $\tilde{\nu}$ = 3070 (w), 2960 (s), 2930 (s), 2860 (s), 1720 (s), 1605 (m), 1585 (m), 1455 (s), 1430 (s), 1370 (s), 1315 (s), 1275 (s), 1110 (s), 1070 (s), 1025 (s), 970 (s), 940 (m). − ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.82 (t, *J* = 6.9 Hz, 3 H), 1.09 (s, 9 H), 1.15−1.32 (m, 6 H), 1.68−2.03 (m, 7 H), 2.28 (m, 1 H), 2.35−2.56 (m, 2 H), 2.88 (ddd, *J* = 8.3, *J* = 8.3, *J* = 5.6 Hz, 1 H), 4.31 (m, 1 H), 5.37 (ddd, *J* = 8.7, *J* = 8.7, *J* = 6.4 Hz, 1 H), 5.47−5.60 (m, 2 H), 5.77 (dt, *J* = 14.4, *J* = 6.7 Hz, 1 H), 7.28−7.42 (m, 10 H), 7.42−7.56 (m, 2 H), 7.65−7.70 (m, 4 H), 7.95−8.04 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.11 (d), 19.22 (u), 22.52 (u), 27.08 (d), 28.62 (u), 31.49 (u), 32.32 (u), 37.75 (d), 39.00 (u), 41.47 (u), 41.92 (d), 42.29 (u), 54.90 (d), 76.21 (d), 77.12 (d), 77.88 (d), 126.35 (d), 127.68 (d), 128.30 (d), 129.70 (d), 130.56 (u), 132.80 (d), 134.25 (u), 135.30 (d), 135.92 (d), 165.83 (u), 166.08 (u). − MS; *m/z* (%): 470 (10), 415 (10), 414 (37), 413 (100), 379 (6), 335 (13), 303 (24), 244 (12), 243 (55), 215 (22), 214 (44), 199 (46), 135 (12), 131 (12), 129 (11), 117 (19), 105 (92). − $C_{46}H_{54}O_5Si$ (715.0): calcd. C 77.27, H 7.61; found C 77.03, H 7.98.

Synthesis of **50** from **54:** A solution of **54** (2.30 g, 4.54 mmol) in pyridine (50 ml) was cooled to 0°C and treated with benzoyl chloride (3.83 g, 27.24 mmol). After stirring the mixture for 3 h, it was concentrated in vacuo. Chromatography (hexanes/EtOAc, 4:1) of the residue gave **50** (3.24 g, 99%) as a colorless oil.

[1R-(1α(1S,2E),2β,3aα,5β,6aα)]-1-(1-Acetyloxy-2-octenyl)-5-[(1,1-dimethylethyl)diphenylsilyloxy]-octahydro-2-pentalenyl Acetate* (**52**): A solution of **43** (3.58 g, 7.08 mmol) in THF (250 ml) was treated with acetyl chloride (3.33 g, 42.48 mmol) and pyridine (3.36 g, 42.48 mmol). After stirring the mixture for 3 h, it was concentrated in vacuo. Chromatography (hexanes/EtOAc, 2:1) of the residue gave **52** (3.90 g, 93%) as a colorless oil, $[\alpha]_D$ = −8.0 (*c* = 0.87, THF). − IR (neat): $\tilde{\nu}$ = 3070 (w), 3050 (w), 2960 (s), 2930 (s), 2860 (s), 1740 (s), 1590 (w), 1465 (m), 1430 (s), 1370 (s), 1250 (s), 1110 (s), 1025 (s), 970 (m), 905 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.87 (t, *J* = 6.9 Hz, 3 H), 1.07 (s, 9 H), 1.22−1.39 (m, 6 H), 1.57−2.40 (m, 10 H), 2.00 (s, 3 H), 2.05 (s, 3 H), 2.51 (ddd, *J* = 8.6, *J* = 8.6, *J* = 6.0 Hz, 1 H), 4.27 (m, 1 H), 4.94 (ddd, *J* = 9.1, *J* = 9.1, *J* = 6.4 Hz, 1 H), 5.25 (dd, *J* = 6.9, *J* = 6.9 Hz, 1 H), 5.36 (ddt, *J* = 15.1, *J* = 7.7, *J* = 1.3 Hz, 1 H), 5.67 (dt, *J* = 15.1, *J* = 6.7 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 = 14.12 (d), 19.17 (u), 21.33 (d), 21.36 (d), 22.53 (u), 27.00 (d), 28.65 (u), 31.45 (u), 32.30 (u), 37.51 (d), 38.81 (u), 41.07 (d), 42.02 (u), 42.14 (u), 54.40 (d), 75.85 (d), 77.09 (d), 77.42 (d), 126.07 (d), 127.64 (d), 129.66 (d), 134.26 (u), 135.39 (d), 135.89 (d), 170.22 (u), 170.64 (u). − MS; *m/z* (%): 473 (14), 241 (14), 216 (13), 215 (76), 199 (45), 182 (14), 181 (100), 149 (11), 145 (12), 139 (20), 135 (16), 131 (15), 117 (18), 105 (12), 91 (15). − $C_{36}H_{50}O_5Si$ (590.9): calcd. C 73.18, H 8.53; found C 73.18, H 8.68.

[1S-(1α(1E,3R),2β,3aα,5β,6aα)]-1-(3-Acetyloxy-1-octenyl)-5-[(1,1-dimethylethyl)diphenylsilyloxy]-octahydro-2-pentalenyl Acetate* (**53**): A solution of **52** (3.85 g, 6.52 mmol) in THF (80 ml) was treated with $Pd(CH_3CN)_2Cl_2$ (34 mg, 0.13 mmol) at room temp. After stirring the mixture for 16 h, it was concentrated in vacuo. MPLC (hexanes/EtOAc, 4:1) of the residue afforded **52** (0.92 g, 24%) and **53** (2.73 g, 71%) as colorless oils. Data for **53**: $[\alpha]_D$ = −27.0 (*c* = 0.71, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3070 (m), 3050 (w), 2960 (s), 2930 (s), 2860 (s), 1740 (s), 1590 (w), 1460 (m), 1430 (m), 1370 (s), 1245 (s), 1110 (s), 1050 (m), 1025 (s), 970 (w), 900 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.7 Hz, 3 H), 1.07 (s, 9 H), 1.24−1.31 (m, 6 H), 1.49−2.41 (m, 10 H), 2.03 (s, 3 H), 2.05 (s, 3 H), 2.82 (ddd, *J* = 9.4, *J* = 9.4, *J* = 8.1 Hz, 1 H), 4.32 (m, 1 H), 4.79 (ddd, *J* = 9.7, *J* = 9.7, *J* = 6.4 Hz, 1 H), 5.21 (dt, *J* = 6.7, *J* = 6.7 Hz, 1 H), 5.40 (dd, *J* = 15.4, *J* = 6.7 Hz, 1 H), 5.55 (dd, *J* = 15.4, *J* = 7.7 Hz, 1 H), 7.34−7.46 (m, 6 H), 7.65−7.69 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.00 (d), 19.11 (u), 21.13 (d), 21.37 (d), 22.54 (u), 24.74 (u), 26.95 (d), 31.53 (u), 34.36 (u), 37.13 (d), 38.24 (u), 39.96 (u), 42.41 (u), 44.66 (d), 54.43 (d), 74.38 (d), 77.25 (d), 78.91 (d), 127.56 (d), 129.44 (d), 133.98 (d), 129.57 (d), 134.16 (u), 135.84 (d), 170.29 (u), 170.85 (u). − MS; *m/z* (%): 473 (22), 241 (18), 216 (17), 215 (87), 199 (47), 183 (10), 182 (15), 181 (100), 149 (11), 145 (11), 139 (20), 135 (16), 131 (15), 117 (18), 105 (11). − $C_{36}H_{50}O_5Si$ (590.9): calcd. C 73.18, H 8.53; found C 73.19, H 8.71.

[1S-(1α(1E,3R),2β,3aα,5β,6aα)]-5-[(1,1-Dimethylethyl)-diphenylsilyloxy]octahydro-1-(3-hydroxy-1-octenyl)-2-pentalenol* (**54**): To a solution of **53** (2.84 g, 4.80 mmol) in MeOH (125 ml) was added K_2CO_3 (1.00 g). After stirring the mixture for 6 h, it was concentrated in vacuo. Chromatography (hexanes/EtOAc, 1:1) of the residue provided **54** (2.34 g, 96%) as a colorless oil, $[\alpha]_D$ = −10.1 (*c* = 1.17, THF). − IR (ether): $\tilde{\nu}$ = 3350 (s, br), 3070 (s), 3050 (s), 2940 (s), 2860 (s), 1960 (w), 1890 (w), 1825 (w), 1775 (w), 1670 (w), 1590 (m), 1460 (s), 1430 (s), 1375 (s), 1330 (s), 1260 (m), 1190 (m), 1110 (s), 1020 (s), 970 (s), 940 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 6.7 Hz, 3 H), 1.06 (s, 9 H), 1.26−1.36 (m, 6 H), 1.44−2.31 (m, 10 H), 2.45 (ddd, *J* = 9.4, *J* = 9.4, *J* = 8.0 Hz, 1 H), 2.59 (s, 2 H), 3.71 (ddd, *J* = 9.4, *J* = 9.4, *J* = 6.0 Hz, 1 H), 4.03 (dt, *J* = 6.7, *J* = 6.7 Hz, 1 H), 4.27 (m, 1 H), 5.44 (dd, *J* = 15.1, *J* = 8.1 Hz, 1 H), 5.53 (dd, *J* = 15.1, *J* = 6.7 Hz, 1 H), 7.33−7.45 (m, 6 H), 7.65−7.69 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.12 (d), 19.17 (u), 22.71 (u), 25.26 (u), 27.07 (d), 31.81 (u), 36.74 (d), 37.25 (u), 39.92 (u), 41.47 (u), 42.68 (u), 45.34 (d), 58.60 (d), 73.30 (d), 77.36 (d), 78.26 (d), 127.61 (d), 129.61 (d), 133.96 (d), 135.11 (d), 134.31 (u), 135.92 (d). − MS; *m/z* (%): 233 (67), 216 (15), 215 (75), 200 (15), 199 (80), 149 (21), 145 (16), 139 (25), 135 (27), 131 (23), 121 (16), 119 (100), 105 (24). − $C_{32}H_{46}O_3Si$ (506.8): calcd. C 75.84, H 9.15; found C 75.96, H 9.49.

[1S-(1α(1E,3R),2β,3aα,5β,6aα)]-1-(3-Benzoyloxy-1-octenyl)-octahydro-2,5-pentalendiol 2-Benzoate* (**55**): A solution of **50** (9.30 g, 13.01 mmol) in THF (200 ml) was treated with a solution of Bu_4NF (6.16 g, 19.51 mmol) in THF (50 ml). After stirring the mixture for 16 h, it was concentrated in vacuo. Chromatography (hexanes/EtOAc, 3:1) of the residue provided **55** (6.13 g, 99%) as a colorless oil, $[\alpha]_D$ = −32.3 (*c* = 12.1, THF). − IR (ether): $\tilde{\nu}$ = 3500 (br), 2930 (s), 2860 (m), 1720 (s), 1600 (w), 1585 (w), 1490 (w), 1450 (m), 1315 (s), 1275 (s), 1175 (m), 1115 (s), 1070 (m), 1030 (m), 975 (m), 935 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.82 (t, *J* = 6.9 Hz, 3 H), 1.16−1.35 (m, 6 H), 1.55−1.78 (m, 6 H), 1.96−2.12 (m, 2 H), 2.26 (m, 1 H), 2.38−2.56 (m, 2 H), 2.82 (ddd, *J* = 9.1, *J* = 9.1, *J* = 7.7 Hz, 1 H), 4.38 (m, 1 H), 5.04 (ddd, *J* = 9.4, *J* = 9.4, *J* = 6.0 Hz, 1 H), 5.44 (dt, *J* = 6.4, *J* = 6.4 Hz, 1 H), 5.62 (dd, *J* = 15.4, *J* = 6.4 Hz, 1 H), 5.73 (dd, *J* = 15.4, 7.4 Hz, 1 H), 7.31−7.41 (m, 4 H), 7.46−7.55 (m, 2 H), 7.94−8.02 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.09 (d), 22.56 (u), 24.81 (u), 31.64 (u), 34.55 (u), 37.54 (d), 38.48 (u), 40.36 (u), 42.76 (u), 44.67 (d), 55.14 (d), 74.96 (d), 76.03 (d), 79.73 (d), 128.31 (d), 128.35 (d), 129.61 (d), 129.63 (d), 129.88 (d), 130.52 (u), 130.83 (u), 132.76 (d), 132.80 (d), 133.71 (d), 165.87 (u), 166.42 (u). − MS; *m/z* (%): 354 (9), 232 (46), 199 (12), 106 (10), 105 (100).- $C_{30}H_{36}O_5$ (476.6): calcd. C 75.60, H 7.61; found C 76.00, H 7.94.

[3aS-(3aα,4α(1E,3R),5β,6aα)]-5-Benzoyloxy-4-(3-benzoyloxy-1-octenyl)hexahydro-2(1H)-pentalenone* (**7a**): A solution of $(COCl)_2$ (1.82 g, 14.30 mmol) in CH_2Cl_2 (32.5 ml) was cooled to −60°C and treated with DMSO (2.44 g, 31.20 mmol). After stirring the mixture for 10 min. a solution of **55** (6.20 g, 13.00 mmol) in CH_2Cl_2 (13 ml) was added and stirring was continued for 15 min. The mixture was treated with NEt_3 (6.58 g, 65.00 mmol) and warmed to ambient temp. After treatment of the mixture with water (39 ml), it was extracted with CH_2Cl_2. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. Chromatography (hexanes/EtOAc, 3:1) of the residue gave **7a** (5.91 g, 96%) as a white waxy solid, $[\alpha]_D = -63.8$ (c = 11.2, THF). − IR (ether): $\tilde{\nu}$ = 3060 (w), 2930 (m), 2860 (m), 1740 (s), 1720 (s), 1600 (w), 1585 (w), 1455 (m), 1315 (m), 1275 (s), 1175 (m), 1115 (s), 1070 (m), 1030 (m), 970 (w). − ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.84 (t, J = 7.0 Hz, 1 H), 1.21−1.27 (m, 4 H), 1.28−1.36 (m, 2 H), 1.60−1.79 (m, 3 H), 2.17 (ddd, J = 19.2, J = 7.0, J = 1.5 Hz, 1 H), 2.28 (d, J = 18.9 Hz, 1 H), 2.50 (ddd, J = 18.9, J = 9.2, J = 1.2 Hz, 1 H), 2.52−2.76 (m, 4 H), 2.85 (m, 1 H), 5.21 (ddd, J = 7.4, J = 7.4, J = 7.4 Hz, 1 H), 5.47 (dt, J = 6.4, J = 6.4 Hz, 1 H), 5.66 (dd, J = 15.6, J = 6.4 Hz, 1 H), 5.75 (dd, J = 15.4, J = 7.6 Hz, 1 H), 7.34−7.44 (m, 4 H), 7.49−7.55 (m, 2 H), 7.92−8.00 (m, 4 H). − ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.05 (d), 22.53 (u), 24.80 (u), 31.58 (u), 34.46 (u), 35.93 (d), 38.68 (u), 42.81 (u), 42.94 (d), 45.65 (u), 54.52 (d), 74.64 (d), 79.92 (d), 128.40 (d), 128.43 (d), 129.59 (d), 129.64 (d), 130.09 (u), 130.69 (u), 131.18 (d), 132.10 (d), 132.87 (d), 133.07 (d), 165.81 (u), 166.24 (u), 219.21 (u). − MS; *m/z* (%): 352 (1), 247 (4), 230 (6), 105 (100). − $C_{30}H_{34}O_5$ (474.6): calcd. C 75.92, H 7.22; found C 75.65, H 7.54.

[3aS-(3aα,4α(1E,3R),5β,6aα)]-Hexahydro-5-hydroxy-4-(3-hydroxy-1-octenyl)-2(1H)-pentalenone* (**7b**): To a solution of **7a** (248 mg, 0.52 mmol) in MeOH (10 ml) was added NaOH (0.08 g). After stirring the mixture for 16 h at ambient temp., it was concentrated in vacuo. Chromatography (hexanes/EtOAc, 1:10) of the residue gave **7b** (111 mg, 80%) as a colorless oil, $[\alpha]_D = -18.7$ (c = 9.4, THF). − IR (neat): $\tilde{\nu}$ = 3380 (br), 2960 (s), 2930 (s), 2860 (s), 1740 (s), 1670 (w), 1460 (m), 1405 (m), 1380 (m), 1340 (m), 1250 (w), 1165 (m), 1095 (m), 1020 (m), 970 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.6 Hz, 3 H), 1.23−1.62 (m, 9 H), 1.95−2.20 (m, 3 H), 2.34−2.78 (m, 5 H), 3.27 (s, 1 H), 3.84−3.94 (m, 2 H), 4.02 (dt, J = 6.7, J = 6.7 Hz, 1 H), 5.43 (dd, J = 15.1, J = 8.0 Hz, 1 H), 5.53 (dd, J = 15.1, J = 7.0 Hz, 1 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.11 (d), 22.69 (u), 25.26 (u), 31.76 (u), 34.76 (d), 37.18 (u), 41.13 (u), 42.35 (u), 42.94 (d), 46.04 (u), 57.85 (d), 73.25 (d), 77.59 (d), 132.47 (d), 136.30 (d), 220.21 (u). − MS; *m/z* (%): 248 (47), 204 (26), 191 (20), 177 (100), 152 (62), 135 (39), 117 (32), 107 (29), 96 (60). − $C_{16}H_{26}O_3$ (226.4): calcd. C 72.14, H 9.84; found C 72.08, H 10.02.

[3aS-(3aα,4α(1E,3R),5β,6aα)]-Hexahydro-5-[(tetrahydro-2H-pyran-2-yl)oxy]-4-[3-(tetrahydro-2H-pyran-2-yl)oxy-1-octenyl)-2(1H)-pentalenone* (**7c**): A solution of **7b** (450 mg, 1.69 mmol) in CH_2Cl_2 (6 ml) was treated with 3,4-dihydro-2*H*-pyran (1.42 g, 16.90 mmol) and pyridinium *p*-toluenesulfonate (20 mg, 0.08 mmol). After stirring the mixture for 16 h, it was concentrated in vacuo. Chromatography (hexanes/EtOAc, 1:1) of the residue gave **7c** (740 mg, 99%) as a colorless oil, $[\alpha]_D$ −32.7 (c = 10.2, THF). − IR (neat): $\tilde{\nu}$ = 2940 (s), 2870 (s), 1740 (s), 1670 (w), 1455 (s), 1440 (s), 1405 (m), 1380 (m), 1350 (m), 1320 (m), 1285 (m), 1260 (m), 1200 (s), 1185 (m), 1160 (s), 1130 (s), 1080 (s), 1020 (s), 975 (s), 915 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.85−0.90 (m, 3 H), 1.23−1.35 (m, 6 H), 1.42−1.87 (m, 16 H), 2.07−2.80 (m, 7 H), 3.39−3.58 (m, 2 H), 3.75−4.12 (m, 4 H), 4.55−4.97 (m, 2 H), 5.26−5.68 (m, 2 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.15 (d), 18.83 (u), 18.88 (u), 19.63 (u), 19.69 (u), 19.73 (u), 19.90 (u), 22.69 (u), 24.91 (u), 25.42 (u), 25.54 (u), 25.62 (u), 25.62 (u), 30.78 (u), 30.87 (u), 30.93 (u), 31.84 (u), 31.90 (u), 34.76 (u), 34.85 (u), 35.48 (d), 35.70 (u), 35.78 (d), 35.87 (d), 36.03 (d), 37.95 (u), 40.24 (u), 40.31 (u), 42.73 (u), 42.89 (u), 43.00, 43.04, 43.19, 43.26 (d), 45.88 (u), 45.93 (u), 54.99 (d), 55.14 (d), 55.44 (d), 55.58 (d), 61.53 (u), 62.06 (u), 62.18 (u), 62.35 (u), 62.62 (u), 62.71 (u), 75.77 (d), 75.85 (d), 77.16 (d), 77.29 (d), 80.26 (d), 80.74 (d), 83.49 (d), 83.68 (d), 94.52 (d), 95.75 (d), 95.85 (d), 97.20 (d), 97.40 (d), 98.92 (d), 99.26 (d), 131.47 (d), 131.52 (d), 132.28 (d), 132.61 (d), 132.85 (d), 133.28 (d), 134.43 (d), 219.90 (u), 220.15 (u). − MS; *m/z* (%): 248 (21), 204 (4), 177 (6), 152 (14), 96 (10), 85 (100). − $C_{26}H_{42}O_5$ (434.6): calcd. C 71.85, H 9.74, found C 71.67, H 9.76.

2-(1-Methyl-1-phenylethyl)cyclohexyl [3aS-[2E(1R,2S*),3aα,4α,5β,6aα]]-[Hexahydro-5-hydroxy-4-(3-hydroxy-1-octenyl)-2(1H)-pentalenylidene]acetate* (**58**) *and 2-(1-Methyl-1-phenylethyl)cyclohexyl [3aS-[2Z(1R*,2S*),3aα,4α,5β,6aα]]-[Hexahydro-5-hydroxy-4-(3-hydroxy-1-octenyl)-2(1H)-pentalenylidene]acetate* (**59**): From **7c**: A solution of (1*S-trans*)-(dimethoxyphosphanyl)-2-(1-methyl-1-phenylethyl)cyclohexyl acetate (166 mg, 0.45 mmol) in THF (1 ml), containing LiCl (19 mg, 0.45 mmol), was cooled to −78°C, treated with *n*BuLi (1.52 M in hexanes, 0.29 ml, 0.44 mmol) and warmed to 0°C for 10 min. The mixture, containing **56**, was recooled to −62°C and treated with **7c** (65 mg, 0.15 mmol). After keeping the mixture at −62°C for 7 days without stirring, it was treated with saturated aqueous NH_4Cl (1 ml). The mixture was warmed to ambient temp., treated with water (0.5 ml) and extracted with EtOAc. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. The crude product, containing **60** and **61**, was dissolved in MeOH (2 ml) and the solution was treated with pyridinium *p*-toluenesulfonate (110 mg, 0.45 mmol). After stirring the mixture for 16 h at ambient temp., it was concentrated in vacuo to give a mixture of **58** and **59** in a ratio of 95:5 (HPLC, hexanes/isopropanol, 95:5, t_R(**58**) = 19.7 min., t_R(**59**) = 23.9 min.). MPLC (*n*-hexane/EtOAc, 1:3) of the residue afforded **58** (55 mg, 72%) and **59** (3 mg, 4%) as colorless oils.

58: $[\alpha]_D = +30.5$ (c = 16.8, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3380 (br), 2930 (s), 2860 (s), 1700 (s), 1655 (m), 1600 (w), 1495 (w), 1450 (m), 1420 (w), 1375 (m), 1220 (s), 1190 (m), 1130 (s), 1090 (m), 1030 (m), 970 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.90 (t, J = 6.7 Hz, 3 H), 1.02−1.39 (m, 18 H), 1.45−1.70 (m, 5 H), 1.80−1.95 (m, 2 H), 2.00−2.21 (m, 3 H), 2.34−2.58 (m, 4 H), 2.66−2.90 (m, 2 H), 3.80 (ddd, J = 9.4, J = 9.4, J = 7.4 Hz, 1 H), 4.07 (dt, J = 6.7, J = 6.7 Hz, 1 H), 4.79 (ddd, J = 10.3, J = 10.3, J = 4.0 Hz, 1 H), 5.14 (s, 1 H), 5.48 (dd, J = 15.1, J = 8.1 Hz, 1 H), 5.58 (dd, J = 15.1, J = 6.7 Hz, 1 H), 7.07−7.13 (m, 1 H), 7.22−7.29 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.04 (d), 22.63 (u), 24.77 (u), 25.22 (u), 25.59 (d), 26.03 (u), 27.17 (u), 27.30 (d), 31.72 (u), 33.63 (u), 37.25 (u), 38.55 (d), 39.42 (u), 39.97 (u), 41.23 (u), 45.06 (d), 51.21 (d), 56.83 (d), 73.14 (d), 73.90 (d), 77.67 (d), 113.68 (d), 124.70 (d), 125.53 (d), 127.88 (d), 132.81 (d), 135.76 (d), 151.73 (u), 165.77 (u), 166.01 (u). − MS; *m/z* (%): 389 (3), 290 (13), 273 (13), 272 (10), 200 (10), 120 (11), 119 (100), 118 (33), 105 (31), 91 (20). − $C_{33}H_{48}O_4$ (509.8): calcd. C 77.91, H 9.51; found C 77.62, H 9.54.

59: $[\alpha]_D = -23.4$ (c = 7.3, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3360 (br), 2930 (s), 2860 (s), 1700 (s), 1655 (s), 1600 (m), 1495 (m), 1450 (s), 1370 (s), 1280 (s), 1260 (s), 1205 (s), 1130 (s), 1090 (s), 1030 (s), 970 (s), 915 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, J = 6.9 Hz, 3 H), 1.00−1.39 (m, 18 H), 1.46−1.52 (m, 4 H), 1.81−2.07 (m, 4 H), 2.16−2.48 (m, 5 H), 2.61−2.87 (m, 3 H), 3.80 (ddd, J = 9.4, J = 9.4, J = 7.1 Hz, 1 H), 4.05 (dt, J = 6.2, J = 6.2 Hz, 1

H), 4.77 (ddd, J = 10.2, J = 10.2, J = 4.6 Hz, 1 H), 5.17 (s, 1 H), 5.45−5.59 (m, 2 H), 7.09−7.14 (m, 1 H), 7.21−7.28 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.05 (d), 22.61 (u), 24.79 (u), 25.18 (u), 26.01 (u), 26.19 (d), 26.78 (d), 27.24 (u), 31.72 (u), 33.66 (u), 35.58 (u), 36.77 (d), 37.35 (u), 40.04 (u), 40.47 (u), 43.15 (u), 46.88 (d), 51.22 (d), 57.63 (d), 72.98 (d), 73.91 (d), 77.73 (d), 113.48 (d), 124.85 (d), 125.51 (d), 127.85 (d), 132.32 (d), 135.54 (d), 151.55 (u), 165.80 (u), 166.16 (u). − MS; *m/z* (%): 389 (4), 290 (13), 273 (13), 200 (7), 119 (100), 105 (33), 91 (21). From **7b**: A solution of (1*S-trans*)-(dimethoxyphosphanyl)-2-(1-methyl-1-phenylethyl)-cyclohexyl acetate (166 mg, 0.45 mmol) in THF (1 ml) was cooled to −78°C, treated with *n*BuLi (1.52 M in hexanes, 0.29 ml, 0.44 mmol) and warmed to 0°C for 10 min. The mixture, containing **56**, was recooled to −62°C and treated with **7b** (40 mg, 0.15 mmol). After keeping the mixture at −62°C for 7 days without stirring, it was treated with saturated aqueous NH_4Cl (1 ml). The mixture was warmed to ambient temp., treated with water (0.5 ml) and extracted with EtOAc. The organic phase was dried ($MgSO_4$) and concentrated in vacuo to give a mixture of **58** and **59** in a ratio of 93:7 (HPLC, *n*-hexane/isopropanol, 95:5, t_R(**58**) = 19.7 min., t_R(**59**) = 23.9 min.). MPLC (hexanes/EtOAc, 1:3) of the residue afforded **58** (51 mg, 67%) and **59** (4 mg, 5%) as colorless oils.

2-(1-Methyl-1-phenylethyl)cyclohexyl [3aS-[2E(1R,2S*),3aα,4α,5β,6aα]]-[Hexahydro-5-[(tetrahydro-2H-pyran-2-yl)-oxy]-4-[3-(tetrahydro-2H-pyran-2-yl)oxy-1-octenyl]-2(1H)-pentalenylidene]acetate* (**60**): Following the procedure described for the preparation of **7c**, **58** (650 mg, 1.28 mmol) in CH_2Cl_2 (5 ml) and 3,4-dihydro-2*H*-pyran (1.07 g, 12.75 mmol) in the presence of pyridinium *p*-toluenesulfonate (15 mg, 0.06 mmol) gave after chromatography (hexanes/EtOAc, 4:1) **60** (870 mg, 99%) as a colorless oil, $[\alpha]_D$ = +12.6 (c = 9.5, THF). − IR (ether): $\tilde{\nu}$ = 2940 (s), 2860 (s), 1720 (s), 1655 (m), 1600 (w), 1495 (w), 1440 (m), 1375 (m), 1350 (m), 1320 (m), 1260 (m), 1200 (s), 1185 (s), 1125 (s), 1020 (s), 975 (s), 915 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.86−0.92 (m, 3 H), 1.00−1.35 (m, 16 H), 1.40−1.96 (m, 19 H), 1.99−2.27 (m, 4 H), 2.31−2.56 (m, 3 H), 2.67−2.94 (m, 2 H), 3.40−3.52 (m, 2 H), 3.77−4.13 (m, 4 H), 4.64−4.82 (m, 3H), 5.13 (s, 1 H), 5.28−5.65 (m, 2 H), 7.07−7.16 (m, 1 H), 7.22−7.32 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.06 (d), 14.09 (d), 18.67 (u), 18.73 (u), 19.51 (u), 19.61 (u), 19.68 (u), 19.82 (u), 22.63 (u), 24.78 (u), 24.86 (u), 25.41 (u), 25.50 (u), 25.60 (u), 26.05 (u), 27.17 (u), 27.28 (d), 27.38 (d), 27.51 (d), 30.77 (u), 30.84 (u), 31.80 (u), 31.77 (u), 31.86 (u), 31.89 (u), 33.63 (u), 34.73 (u), 34.86 (u), 35.79 (u), 35.88 (u), 37.78 (u), 37.83 (u), 38.73 (d), 38.81 (d), 39.15 (d), 39.21 (d), 39.39 (u), 39.49 (u), 39.64 (u), 39.82 (u), 39.94 (u), 40.26 (u), 40.30 (u), 44.87 (d), 44.95 (d), 45.02 (d), 51.19 (d), 53.50 (d), 53.81 (d), 54.46 (d), 54.66 (d), 61.18 (u), 61.99 (u), 62.18 (u), 62.39 (u), 62.51 (u), 63.36 (u), 73.76 (d), 75.80 (d), 75.90 (d), 77.09 (d), 77.18 (d), 79.58 (d), 80.03 (d), 83.46 (d), 83.68 (d), 94.47 (d), 95.42 (d), 95.58 (d), 96.92 (d), 97.15 (d), 99.07 (d), 99.37 (d), 113.43 (d), 113.55 (d), 124.73 (d), 124.79 (d), 125.50 (d), 127.89 (d), 131.90 (d), 132.15 (d), 132.25 (d), 132.43 (d), 132.79 (d), 135.25 (d), 135.30 (d), 151.63 (u), 151.70 (u), 151.74 (u), 165.71 (u), 165.75 (u), 166.23 (u), 166.33 (u), 166.55 (u), 166.69 (u). − MS; *m/z* (%): 490 (3), 371 (4), 290 (19), 272 (15), 201 (15), 200 (17), 119 (83), 105 (28), 91 (19). − $C_{43}H_{64}O_6$ (677.0): calcd. C 76.29, H 9.53; found C 76.43, H 9.85.

2-(1-Methyl-1-phenylethyl)cyclohexyl [3aS-[2Z(1R,2S*),3aα,4α(1E,3R*),5β,6aα]]-[Hexahydro-5-tetrahydro-2H-pyran-2-yl)-oxy]-4-(3-(tetrahydro-2H-pyran-2-yl)-oxy-1-octenyl)-2(1H)-pentalenylidene]acetate* (**61**): Following the procedure described for the preparation of **7c**, **59** (38 mg, 0.08 mmol) in CH_2Cl_2 (2 ml) and 3,4-dihydro-2*H*-pyran (620 mg, 0.79 mmol) in the presence of pyridinium *p*-toluenesulfonate (7.5 mg, 0.03 mmol) gave after chromatography (hexanes/EtOAc, 4:1) **61** (46 mg, 91%) as a colorless oil, $[\alpha]_D$ = −38.2° (c = 1.10, THF). − IR (ether): $\tilde{\nu}$ = 3090 (w), 3060 (w), 2940 (s), 2860 (s), 1710 (s), 1655 (m), 1600 (w), 1495 (m), 1465 (m), 1450 (s), 1370 (s), 1355 (s), 1320 (m), 1275 (m), 1260 (m), 1200 (s), 1160 (s), 1125 (s), 1080 (s), 1020 (s), 975 (s), 915 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.86−0.91 (m, 3 H), 0.95−2.95 (m, 44 H), 3.40−4.09 (m, 6 H), 4.59−4.98 (m, 3 H), 5.16 (s, 1 H), 5.24−5.69 (m, 2 H), 7.08−7.16 (m, 4 H), 7.22−7.30 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.12 (d), 18.64 (u), 19.47 (u), 19.57 (u), 19.77 (u), 22.63 (u), 24.79 (u), 25.43 (u), 25.60 (u), 26.02 (u), 26.24 (d), 26.32 (d), 26.66 (d), 26.73 (d), 27.26 (u), 30.80 (u), 31.80 (u), 31.86 (u), 33.67 (u), 34.74 (u), 34.87 (u), 35.90 (u), 36.16 (u), 37.14 (d), 37.30 (d), 37.44 (d), 39.54 (u), 40.05 (u), 43.01 (u), 46.71 (u), 46.90 (u), 51.22 (d), 54.41 (d), 54.70 (d), 55.30 (d), 55.50 (d), 61.14 (u), 62.14 (u), 62.59 (u), 62.69 (u), 73.83 (d), 75.87 (d), 75.98 (d), 76.87 (d), 77.05 (d), 79.70 (d), 80.05 (d), 83.59 (d), 83.88 (d), 94.51 (d), 95.39 (d), 96.75 (d), 97.06 (d), 99.17 (d), 99.48 (d), 113.24 (d), 113.36 (d), 124.85 (d), 125.52 (d), 127.86 (d), 131.60 (d), 131.80 (d), 132.20 (d), 132.46 (d), 135.18 (d), 151.56 (u), 165.75 (u), 166.37 (u), 166.73 (u). − MS: *m/z* (%) = 291 (13), 290 (40), 273 (17), 272 (24), 246 (13), 201 (22), 200 (11), 119 (75), 118 (12), 105 (26), 91 (12), 85 (100), 67 (12), 57 (13). − $C_{43}H_{64}O_6$ (676.9): calcd. C76.29, H 9.53; found C 76.39, H 9.74.

[3aS-(2E,3aα,4α(1E,3R),5β,6aα)]-2-[Hexahydro-5-[(tetrahydro-2H-pyran-2-yl)oxy]-4-[3-(tetrahydro-2H-pyran-2-yl)oxy-1-octenyl]-2(1H)-pentalenylidene]ethanol* (**62**): A solution of **60** (835 mg, 1.23 mmol) in THF (13 ml) was cooled to 0°C and a solution of DIBAL-H in CH_2Cl_2 (1.0 M, 3.72 ml, 3.72 mmol) added dropwise. The mixture was warmed to ambient temp. within 2 h and saturated aqueous NH_4Cl (15 ml) was added. The precipitated aluminum salts were dissolved by addition of water (15 ml) and saturated aqueous NH_4Cl (15 ml). The mixture was extracted with CH_2Cl_2. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. Chromatography (hexanes/EtOAc, 1:1) of the residue provided **62** (492 mg, 86%) as a colorless oil, $[\alpha]_D$ = +20.1 (c = 10.6, THF). − IR (ether): $\tilde{\nu}$ = 3430 (br), 2940 (s), 2870 (s), 1670 (w), 1455 (m), 1440 (m), 1380 (m), 1350 (m), 1320 (w), 1280 (w), 1260 (w), 1200 (m), 1180 (m), 1120 (s), 1075 (s), 1020 (s), 980 (s), 915 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.85−0.90 (m, 3 H), 1.07−1.92 (m, 22 H), 2.00−2.21 (m, 4 H), 2.30−2.50 (m, 4 H), 3.40−3.52 (m, 2 H), 3.68−3.93 (m, 3 H), 3.97−4.17 (m, 3 H), 4.61−4.75 (m, 2 H), 5.22−5.64 (m, 3 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.07 (d), 18.59 (u), 18.64 (u), 19.44 (u), 19.54 (u), 19.57 (u), 19.74 (u), 19.79 (u), 22.62 (u), 24.83 (u), 25.35 (u), 25.37 (u), 25.42 (u), 25.47 (u), 25.60 (u), 25.63 (u), 30.67 (u), 30.74 (u), 30.81 (u), 31.75 (u), 31.76 (u), 31.83 (u), 31.87 (u), 34.70 (u), 34.82 (u), 35.74 (u), 35.84 (u), 35.92 (u), 35.97 (u), 35.99 (u), 37.78 (d), 37.84 (d), 37.88 (u), 37.95 (u), 38.08 (u), 38.12 (u), 38.24 (u), 38.37 (u), 40.42 (u), 40.47 (u), 44.70 (d), 44.82 (d), 53.63 (d), 53.99 (d), 54.70 (d), 54.93 (d), 60.52 (u), 61.07 (u), 61.97 (u), 62.10 (u), 62.53 (u), 62.63 (u), 75.90 (d), 76.00 (d), 77.02 (d), 77.15 (d), 78.92 (d), 79.38 (d), 83.07 (d), 83.30 (d), 94.43 (d), 95.32 (d), 95.47 (d), 96.76 (d), 97.02 (d), 99.22 (d), 99.48 (d), 121.00 (d), 121.12 (d), 131.60 (d), 131.79 (d), 132.19 (d), 132.46 (d), 132.56 (d), 135.54 (d), 135.62 (d), 145.71 (u), 145.74 (u), 145.92 (u), 145.96 (u). − MS; *m/z* (%): 276 (9), 258 (12), 214 (15), 201 (26), 85 (100). − $C_{28}H_{46}O_5$ (462.7): calcd. C 72.69, H 10.02; found C 72.77, H 10.20.

1,1-Dimethylethyl [3aS-(2E,3aα,4α(1E,3R),5β,6aα)]-[2-[Hexahydro-5-[(tetrahydro-2H-pyran-2-yl)oxy]-4-[3-tetrahydro-2H-pyran-2-yl)oxy-1-octenyl]-2(1H)-pentalenylidene]-ethoxy]acetate* (**63**): A solution of **62** (468 mg, 1.01 mmol) and Bu_4NHSO_4 (258 mg, 0.78 mmol) in CH_2Cl_2 (6 ml) was treated with aqueous 50% NaOH (12 ml) and *tert*-butyl bromoacetate (303 mg, 1.55 mmol). The mixture was stirred for 2 h, cooled to 0°C, diluted with water (17 ml) and extracted with CH_2Cl_2. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. Chromatography (hexanes/

EtOAc, 4:1) of the residue gave **63** (496 mg, 85%) as a colorless oil, $[\alpha]_D = +31.0$ ($c = 9.5$, THF). – IR (ether): $\tilde{\nu}$ = 2940 (s), 2870 (s), 1750 (s), 1730 (m), 1455 (m), 1370 (s), 1300 (m), 1260 (m), 1225 (m), 1160 (s), 1130 (s), 1080 (s), 1035 (s), 1020 (s), 980 (s), 940 (w), 915 (m). – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.85–0.90 (m, 3 H), 1.12–1.85 (m, 30 H), 1.97–2.22 (m, 4 H), 2.29–2.51 (m, 4 H), 3.40–3.51 (m, 2 H), 3.70–4.10 (m, 8 H), 4.61–4.75 (m, 2 H), 5.23–5.64 (m, 3 H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.05 (d), 14.07 (d), 18.59 (u), 18.64 (u), 19.46 (u), 19.58 (u), 19.73 (u), 22.62 (u), 24.84 (u), 25.35 (u), 25.38 (u), 25.44 (u), 25.50 (u), 25.60 (u), 28.12 (d), 30.74 (u), 30.83 (u), 31.76 (u), 31.77 (u), 31.83 (u), 31.88 (u), 34.71 (u), 34.82 (u), 35.75 (u), 35.84 (u), 36.16 (u), 36.19 (u), 37.80, 37.89, 37.96, 38.08, 38.15, 38.19, 38.25, 38.40, 40.35 (u), 40.40 (u), 44.70 (d), 44.82 (d), 44.93 (d), 53.68 (d), 54.05 (d), 54.71 (d), 54.94 (d), 61.05 (u), 62.01 (u), 62.12 (u), 62.50 (u), 62.59 (u), 67.32 (u), 67.36 (u), 67.41 (u), 67.45 (u), 68.48 (u), 68.66 (u), 68.71 (u), 75.90 (d), 76.00 (d), 77.01 (d), 77.11 (d), 78.93 (d), 79.37 (d), 81.40 (u), 81.81 (u), 83.08 (d), 83.33 (d), 94.46 (d), 95.29 (d), 95.44 (d), 96.77 (d), 97.02 (d), 98.73 (d), 99.17 (d), 99.44 (d), 117.39 (d), 117.54 (d), 131.62 (d), 131.83 (d), 132.18 (d), 132.48 (d), 132.54 (d), 135.51 (d), 135.58 (d), 148.00 (u), 148.04 (u), 148.25 (u), 148.30 (u), 169.85 (u). – MS; *m/z* (%): 334 (4), 275 (4), 258 (11), 240 (6), 214 (7), 85 (100). – $C_{34}H_{56}O_7$ (576.8): calcd. C 70.80, H 9.79; found C 70.70, H 9.88.

1,1-Dimethylethyl [3aS-(2E,3aα,4α(1E,3R),5β,6aα)]-[2-[Hexahydro-5-hydroxy-4-(3-hydroxy-1-octenyl)-2(1H)-pentalenylidene]ethoxy]acetate* (**64**): A solution of **63** (460 mg, 0.80 mmol) in EtOH (6.5 ml) was treated with pyridinium *p*-toluenesulfonate (40 mg, 0.16 mmol). After stirring the mixture for 4 days at ambient temp., it was concentrated in vacuo. Chromatography (hexanes/EtOAc, 1:10) of the residue provided **64** (307 mg, 94%) as a colorless oil, $[\alpha]_D = +65.6$ ($c = 10.5$, THF). – IR (neat): $\tilde{\nu}$ = 3390 (br), 2930 (s), 2860 (s), 1745 (s), 1460 (s), 1430 (s), 1395 (s), 1370 (s), 1300 (s), 1250 (s), 1225 (s), 1160 (s), 1125 (s), 1035 (w), 970 (s). – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, J = 6.7 Hz, 3 H), 1.13–1.66 (m, 9 H), 1.49 (s, 9 H), 1.82 (ddd, J = 9.5, J = 9.5, J = 8.0 Hz, 1 H), 2.03–2.18 (m, 3 H), 2.27–2.50 (m, 4 H), 3.13 (s, 1 H), 3.35 (s, 1 H), 3.68 (ddd, J = 9.7, J = 9.7, J = 6.7 Hz, 1 H), 3.94 (s, 2 H), 3.98–4.11 (m, 3 H), 5.39–5.54 (m, 3 H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.13 (d), 22.70 (u), 25.26 (u), 28.22 (d), 31.82 (u), 36.18 (u), 37.18 (u), 37.60 (d), 38.22 (u), 41.36 (u), 44.94 (d), 57.26 (d), 67.51 (d), 68.72 (d), 73.30 (d), 77.22 (d), 81.70 (u), 117.60 (d), 133.62 (d), 135.65 (d), 148.19 (u), 170.06 (u). – MS; *m/z* (%): 372 (5), 333 (12), 316 (18), 275 (15), 258 (24), 241 (12), 214 (49), 187 (15), 159 (14), 145 (25), 144 (20), 134 (25), 117 (18), 106 (15), 105 (23), 99 (32).- $C_{24}H_{40}O_5$ (408.6): calcd. C 70.55, H 9.87; found C 70.26, H 9.96.

3-Oxacarbacyclin (**4**): A solution of **64** (256 mg, 0.63 mmol) in MeOH (40 ml) was treated with aqueous NaOH (1.0 M, 1.2 ml). After stirring the mixture for 4 h at ambient temp., saturated aqueous NH_4Cl (100 ml) and solid NaH_2PO_4 were added until a pH of 4–5 was reached, and the mixture was extracted with EtOAc. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. Dissolution of the residue in ether, filtration and concentration of the filtrate gave **4** (158 mg, 71%) as a colorless oil, $[\alpha]_D = +64.2$ ($c = 3.0$, MeOH). – IR (neat): $\tilde{\nu}$ = 3380 (br), 2930 (s), 2860 (s), 1740 (s), 1460 (m), 1430 (s), 1375 (s), 1240 (s), 1120 (s), 1045 (s), 970 (s). – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.91 (t, J = 7.0 Hz, 3 H), 1.20 (ddd, J = 12.5, J = 9.9, J = 7.5 Hz, 1 H), 1.26–1.60 (m, 8 H), 1.83 (ddd, J = 9.8, J = 9.8, J = 7.8 Hz, 1 H), 2.10–2.21 (m, 3 H), 2.30 (ddd, J = 12.5, J = 8.1, J = 7.0 Hz, 1 H), 2.41–2.54 (m, 3 H), 3.70 (ddd, J = 9.7, J = 9.7, J = 7.0 Hz, 1 H), 3.99 (dt, J = 6.6, J = 6.6 Hz, 1 H), 4.04 (s, 2 H), 4.03–4.13 (m, 2 H), 4.89 (s, 3 H), 5.44–5.48 (m, 1 H), 5.47 (dd, J = 15.4, J = 6.7 Hz, 1 H), 5.54 (dd, J = 15.4, J = 7.8 Hz, 1 H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.36 (d), 23.69 (u), 26.35 (u), 32.92 (u), 36.91 (u), 38.31 (u), 38.85 (d), 39.29 (u), 42.67 (u), 46.24 (d), 57.70 (d), 67.30 (u), 69.55 (u), 73.90 (d), 78.21 (d), 118.57 (d), 133.87 (d), 135.93 (d), 149.56 (u), 174.27 (u). – MS; *m/z* (%): 258 (14), 217 (14), 216 (48), 202 (10), 201 (41), 187 (29), 169 (11), 161 (13), 160 (10), 159 (27), 158 (14), 157 (18), 145 (38), 144 (48), 143 (69), 141 (10), 135 (21), 134 (29), 133 (19), 132 (14), 131 (37), 128 (13), 121 (15), 119 (23), 118 (33), 117 (50), 115 (12), 109 (13), 107 (20), 106 (42), 105 (61), 104 (17). – $C_{20}H_{32}O_5$ (352.5): calcd. C 68.15, H 9.15; found C 67.91, H 9.11.

2-(1-Methyl-1-phenylethyl)cyclohexyl [3aS-[2(1R,2S*),3aα,5β,6α(1E,3R*),6aα]]-[1,3a,4,5,6,6a-Hexahydro-5-[(tetrahydro-2H-pyran-2-yl)oxy]-6-[3-(tetrahydro-2H-pyran-2-yl)oxy-1-octenyl]-2-pentalenyl]acetate* (**66**): A suspension of (*R*,*R*)-bis(phenylethyl)ammonium chloride (68 mg, 0.26 mmol) in THF (5 ml) was cooled to –78°C, and *n*BuLi (1.51 M in hexanes, 0.34 ml, 0.5 mmol) was added dropwise. The mixture was warmed to ambient temp. until it became a clear yellow solution. The solution was cooled to –105°C and treated dropwise with a solution of **60** (85 mg, 0.13 mmol) in THF (2 ml). After stirring the mixture for 30 min. at –105°C, it was warmed to –78°C, and saturated aqueous $NaHCO_3$ (2 ml) was added. After warming the mixture to ambient temp., it was extracted with ether. The organic phase was dried ($MgSO_4$) and concentrated in vacuo. Chromatography (hexanes/EtOAc, 4:1) of the residue provided a mixture of **66** and **69** (77 mg, 91%, ratio 98.5:1.5) as a colorless oil. Data for **66** and **69**: $[\alpha]_D = -19.9$ ($c = 10.0$, THF). – IR (neat): $\tilde{\nu}$ = 2930 (s), 2860 (s), 1730 (s), 1600 (w), 1440 (s), 1260 (s), 1200 (s), 1130 (s), 1080 (s), 1020 (s), 980 (s), 915 (m). – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.84–0.94 (m, 3 H), 0.96–2.56 (m, 43 H), 2.88–3.04 (m, 1 H), 3.40–4.02 (m, 6 H), 4.62–4.82 (m, 3 H), 5.24–5.64 (m, 3 H), 7.09–7.17 (m, 1 H), 7.19–7.35 (m, 4 H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.17 (d), 18.70 (u), 19.52 (u), 19.72 (u), 22.74 (u), 24.78 (u), 24.97 (d), 25.50 (u), 25.73 (u), 26.05 (u), 27.11 (u), 28.06 (d), 30.89 (u), 31.89 (u), 33.47 (u), 34.86 (u), 34.97 (u), 35.74 (u), 35.91 (u), 35.99 (u), 36.94 (u), 38.33 (u), 39.38 (u), 39.60 (u), 39.94 (u), 43.89 (d), 44.07 (d), 45.45 (d), 45.63 (d), 50.87 (d), 54.51 (d), 54.81 (d), 55.54 (d), 55.72 (d), 61.13 (u), 62.15 (u), 62.25 (u), 62.42 (u), 62.52 (u), 74.77 (d), 76.05 (d), 76.17 (d), 76.73 (d), 77.15 (d), 78.30 (d), 78.72 (d), 82.82 (d), 83.07 (d), 94.56 (d), 95.26 (d), 95.39 (d), 96.75 (d), 97.00 (d), 99.34 (d), 99.58 (d), 125.11 (d), 125.49 (d), 126.86 (d), 128.04 (d), 131.79 (d), 132.07 (d), 132.33 (d), 132.51 (d), 132.68 (d), 133.90 (u), 134.00 (u), 134.09 (u), 135.68 (d), 151.72 (u), 170.55 (u). – MS; *m/z* (%): 676 [M^+ – 1] (0.1), 490 (12), 446 (11), 291 (28), 290 (90), 289 (10), 272 (14), 246 (12), 201 (21), 119 (63), 105 (40), 91 (17). – $C_{43}H_{64}O_6$ (677.0): calcd. C 76.29, H 9.53; found C 76.03, H 9.57.

2-(1-Methyl-1-phenylethyl)cyclohexyl [3aS-[2(1R,2S*),3aα,5β,6α(1E,3R*),6aα]]-[1,3a,4,5,6,6a-Hexahydro-5-hydroxy-6-(3-hydroxy-1-octenyl)-2-pentalenyl]acetate* (**67**): A solution of **66** (77 mg, 0.11 mmol) in MeOH (2 ml) was treated with pyridinium *p*-toluenesulfonate (80 mg, 0.33 mmol). After stirring the mixture for 12 h at ambient temp., it was concentrated in vacuo. Chromatography (hexanes/EtOAc, 1:10) of the residue gave **67** (44 mg, 76%), containing 1.5% of **70**, as a colorless oil. Data for **67** and **70**: $[\alpha]_D = +12.3$ ($c = 7.7$, THF). – IR ($CHCl_3$): $\tilde{\nu}$ = 3380 (br), 2930 (s), 2860 (s), 1730 (s), 1600 (w), 1495 (m), 1445 (s), 1390 (m), 1370 (m), 1320 (m), 1300 (m), 1245 (s), 1170 (m), 1130 (s), 1090 (s), 1025 (s), 970 (s). – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, J = 6.9 Hz, 3 H), 1.06 (dddd, J = 12.5, J = 12.5, J = 12.5, J = 2.7 Hz, 1 H), 1.20 (s, 3 H), 1.31 (2s, 3 H), 1.11–1.40 (m, 10 H), 1.42–1.50 (m, 1 H), 1.54–1.61 (m, 1 H), 1.65–1.71 (m, 2 H), 1.71–1.77 (m, 1 H), 1.83–1.88 (m, 1 H), 1.88–1.95 (m, 2 H), 2.07 (ddd, J = 12.0, J = 10.5, J = 3.6 Hz, 1 H), 2.23–2.31 (m, 2 H), 2.39 (dd, J = 16.4, J = 8.7 Hz, 1 H), 2.46 (s, 2 H), 2.76 (s, 2 H), 2.95–3.02 (m, 1 H), 3.73 (ddd, J = 9.4, J = 9.4, J = 7.0 Hz, 1 H), 4.04 (dt, J = 6.7, J = 6.7 Hz, 1 H), 4.77 (ddd, J =

10.4, J = 10.4, J = 4.6 Hz, 1 H), 5.32 (d, J = 1.1 Hz, 1 H), 5.46 (dd, J = 15.3, J = 8.3 Hz, 1 H), 5.52 (dd, J = 15.3, J = 7.1 Hz, 1 H), 7.11−7.16 (m, 1 H), 7.26−7.29 (m, 4 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.06 (d), 22.65 (u), 24.54 (d), 24.69 (u), 25.24 (u), 25.94 (u), 26.96 (u), 28.27 (d), 31.75 (u), 33.37 (u), 36.73 (u), 37.18 (u), 39.03 (u), 39.55 (u), 39.80 (u), 44.56 (d), 45.74 (d), 50.72 (d), 58.01 (d), 73.24 (d), 74.77 (d), 77.07 (d), 125.05 (d), 125.42 (d), 128.01 (d), 132.60 (d), 133.39 (d), 134.00 (u), 135.58 (d), 151.72 (u), 170.63 (u). − MS; *m/z* (%): 446 (4), 290 (33), 246 (9), 201 (9), 120 (10), 119 (100), 105 (53), 91 (30). − $C_{33}H_{48}O_4$ (509.8): calcd. C 77.91, H 9.51; found C 77.66, H 9.56.

2-(1-Methyl-1-phenylethyl)cyclohexyl [3aS-[2(1S,2R*),3aα,4α(1E,3S*),5β,6aα]]-[1,3a,4,5,6,6a-Hexahydro-5-[(tetrahydro-2H-pyran-2-yl)oxy]-4-[3-(tetrahydro-2H-pyran-2yl)-oxy-1-octenyl]-2-pentalenyl]acetate* (**69**): Following the procedure described for the preparation of **66**, (*R*,*R*)-bis(phenylethyl)ammonium chloride (68 mg, 0.26 mmol) in THF (5 ml), *n*BuLi (1.51 M in hexanes, 0.34 ml, 0.26 mmol) and **61** (85 mg, 0.13 mmol) in THF (2 ml) gave after chromatography (hexanes/EtOAc, 1:1) a mixture of **69** and **66** (74 mg, 88%, ratio 98.5:1.5) as a colorless oil. Data for **69** and **66**: $[\alpha]_D$ = +12.3 (c = 10.2, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 2940 (s), 2860 (m), 1730 (s), 1600 (w), 1495 (w), 1445 (m), 1390 (m), 1370 (m), 1350 (m), 1340 (m), 1320 (m), 1260 (m), 1215 (m), 1200 (m), 1180 (m), 1160 (m), 1130 (s), 1080 (s), 1025 (s), 975 (m), 910 (w). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.85−0.90 (m, 3 H), 0.99−2.84 (m, 44 H), 3.40−4.09 (m, 6H), 4.61−4.81 (m, 3 H), 5.47−5.75 (m, 3 H), 7.10−7.18 (m, 1 H), 7.24−7.30 (m, 4 H), ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.08 (d), 14.09 (d), 18.67 (u), 19.44 (u), 19.65 (u), 22.63 (u), 24.69 (u), 24.70 (d), 24.86 (u), 25.35 (u), 25.39 (u), 25.47 (u), 25.52 (u), 25.60 (u), 25.63 (u), 25.67 (u), 25.94 (u), 28.10 (d), 30.79 (u), 30.84 (u), 31.78 (u), 31.80 (u), 31.85 (u), 31.90 (u), 33.29 (u), 34.66 (u), 34.79 (u), 35.75 (u), 35.86 (u), 36.26 (d), 36.32 (d), 36.39 (d), 36.48 (d), 36.73 (u), 38.28 (u), 38.35 (u), 39.82 (u), 41.07 (u), 42.53 (u), 50.75 (d), 53.85 (d), 53.89 (d), 54.04 (d), 54.31 (d), 54.85 (d), 55.17 (d), 61.07 (u), 62.10 (u), 62.18 (u), 62.35 (u), 62.44 (u), 74.66 (d), 75.90 (d), 76.00 (d), 76.87 (d), 77.05 (d), 78.82 (d), 79.20 (d), 83.01 (d), 83.32 (d), 94.49 (d), 95.28 (d), 95.40 (d), 96.69 (d), 96.97 (d), 99.12 (d), 99.42 (d), 125.00 (d), 125.39 (d), 127.94 (d), 129.82 (d), 130.05 (d), 130.11 (d), 130.41 (d), 131.07 (d), 131.22 (d), 131.67 (d), 131.90 (d), 133.17 (d), 133.20 (d), 134.46 (u), 134.68 (u), 134.90 (u), 136.02 (d), 136.15 (d), 151.67 (u), 170.44 (u), 170.47 (u). − MS; *m/z* (%): 490 (6), 447 (16), 446 (43), 290 (27), 289 (22), 247 (12), 246 (56), 201 (21), 175 (8), 119 (61), 105 (58), 95 (11), 91 (14). − $C_{43}H_{64}O_6$ (677.0): calcd. C 76.29, H 9.53; found C 76.19, H 9.62.

2-(1-Methyl-1-phenylethyl)cyclohexyl [3aR-[2(1S,2R*),3aα,4α(1E,3S*),5β,6aα]]-[1,3a,4,5,6,6a-Hexahydro-5-hydroxy-4-(3-hydroxy-1-octenyl)-2-pentalenyl]acetate* (**70**): A solution of **69** (77 mg, 0.11 mmol) in MeOH (2 ml) was treated with pyridinium *p*-toluenesulfonate (80 mg, 0.33 mmol). After stirring the mixture for 12 h at ambient temp., it was concentrated in vacuo. Chromatography (hexanes/EtOAc, 1:10) of the residue gave **70** (48 mg, 83%), containing 1.5% of **67**, as a colorless oil. Data for **70** and **67**: $[\alpha]_D$ = +34.3 (c = 8.5, THF). − IR ($CHCl_3$): $\tilde{\nu}$ = 3370 (br), 2930 (s), 2860 (s), 1725 (s), 1600 (w), 1495 (m), 1450 (s), 1390 (m), 1370 (m), 1320 (m), 1255 (m), 1215 (m), 1165 (m), 1130 (m), 1090 (m), 1025 (m), 970 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, J = 7.0 Hz, 3 H), 1.05 (ddd, J = 12.5, J = 12.5, J = 2.7 Hz, 1 H), 1.20 (s, 3 H), 1.31 (s, 3 H), 1.11−1.38 (m, 10 H), 1.42−1.49 (m, 1 H), 1.52−1.59 (m, 1 H), 1.65−1.76 (m, 3 H), 1.84−1.89 (m, 1 H), 1.97−2.09 (m, 3 H), 2.28 (ddd, J = 12.3, J = 8.3, J = 5.9 Hz, 1 H), 2.45 (s, 2 H), 2.51 (dd, J = 16.0, J = 9.3 Hz, 1 H), 2.59 (m, 1 H), 2.79 (m, 1 H), 3.70 (ddd, J = 9.5, J = 8.3, J = 5.9 Hz, 1 H), 4.03 (dt, J = 6.6, J = 6.6, 1 H), 4.77 (ddd, J = 10.3, J = 10.3, J = 4.6 Hz, 1 H), 5.36 (d, J = 1.9 Hz, 1 H), 5.46−5.55 (m, 2 H), 7.11−7.15 (m, 1 H), 7.26−7.29 (m, 4 H), ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.06 (d), 22.63 (u), 24.66 (d), 24.69 (u), 25.18 (u), 25.93 (u), 26.97 (u), 28.15 (d), 31.74 (u), 33.32 (u), 36.48 (d), 36.55 (u), 37.20 (u), 39.82 (u), 42.03 (u), 42.76 (u), 50.75 (d), 54.67 (d), 57.38 (d), 73.18 (d), 74.83 (d), 77.54 (d), 125.06 (d), 125.42 (d), 127.98 (d), 130.47 (d), 133.62 (d), 134.66 (d), 135.07 (u), 151.72 (u), 170.62 (u). − MS; *m/z* (%): 446 (11), 290 (14), 289 (22), 246 (23), 201 (9), 119 (100), 105 (65), 91 (34).

[3aS-[3aα,5β,6α(1E,3R),6aα]]-2-[1,3a,4,5,6,6a-Hexahydro-5-[(tetrahydro-2H-pyran-2-yl)oxy]-6-[3-(tetrahydro-2H-pyran-2-yl)-oxy-1-octenyl]-2-pentalenyl]ethanol* (**71**): Following the procedure described for the preparation of **62**, **66** (240 mg, 0.36 mmol) in THF (4 ml) and DIBAL-H in CH_2Cl_2 (1.0 M, 1.07 ml, 1.07 mmol) gave after chromatography (hexanes/EtOAc, 1:1) **71** (116 mg, 71%) as a colorless oil, $[\alpha]_D$ = −15.3 (c = 9.5, THF). − IR (neat): $\tilde{\nu}$ = 3460 (br), 2940 (s), 2870 (s), 1740 (w), 1670 (w), 1455 (s), 1440 (s), 1385 (m), 1350 (m), 1320 (m), 1285 (m), 1260 (m), 1200 (s), 1120 (s), 1080 (s), 1020 (s), 980 (s), 915 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.86−0.90 (m, 3 H), 1.20−2.51 (m, 29 H), 2.98−4.08 (m, 9 H), 4.62−4.75 (m, 2 H), 5.25−5.71 (m, 3 H). − ^{13}C NMR (75 MHz, $CDCl_3$) δ 14.06 (d), 18.69 (u), 18.80 (u), 19.48 (u), 19.58 (u), 19.72 (u), 22.63 (u), 24.85 (u), 25.39 (u), 25.48 (u), 25.60 (u), 30.71 (u), 30.76 (u), 30.83 (u), 31.78 (u), 31.84 (u), 34.27 (u), 34.77 (u), 34.86 (u), 35.78 (u), 35.87 (u), 36.09 (u), 36.15 (u), 38.55 (u), 39.64 (u), 39.76 (u), 39.87 (u), 40.06 (u), 43.83 (d), 43.93 (d), 45.79 (d), 45.88 (d), 46.00 (d), 46.12 (d), 54.92 (d), 55.10 (d), 55.21 (d), 55.78 (d), 55.99 (d), 60.51 (u), 60.55 (u), 61.20 (u), 61.30 (u), 62.01 (u), 62.16 (u), 62.51 (u), 75.94 (d), 76.05 (d), 77.18 (d), 77.22 (d), 78.71 (d), 79.28 (d), 83.06 (d), 83.21 (d), 94.46 (d), 95.40 (d), 95.64 (d), 96.87 (d), 97.08 (d), 99.30 (d), 99.52 (d), 130.81 (d), 130.90 (d), 130.96 (d), 131.56 (d), 131.85 (d), 132.12 (d), 132.46 (d), 132.58 (d), 132.62 (d), 135.58 (d), 137.89 (u), 138.02 (u), 138.10 (u). − MS; *m/z* (%): 462 [M^+] (0.02), 316 (7), 277 (22), 276 (8), 258 (13), 246 (13), 232 (29). − $C_{28}H_{46}O_5$ (462.7): calcd. C 72.69, H 10.02; found C 72.71, H 10.12.

1,1-Dimethylethyl [3aS-[3aα,5β,6α(1E,3R),6aα]]-[2-[1,3a,4,5,6,6a-Hexahydro-5-[(tetrahydro-2H-pyran-2-yl)oxy]-6-[3-(tetrahydro-2H-pyran-2-yl)oxy-1-octenyl]-2-pentalenyl]ethoxy]acetate* (**72**): Following the procedure described for the preparation of **63**, **71** (110 mg, 0.24 mmol) in CH_2Cl_2 (1.5 ml), Bu_4NHSO_4 (61 mg, 0.18 mmol), aqueous 50% NaOH (2.8 ml) and *tert*-butyl bromoacetate (71 mg, 0.36 mmol) gave after chromatography (hexanes/EtOAc, 4:1) **72** (117 mg, 85%) as a colorless oil, $[\alpha]_D$ = −16.4 (c = 9.8, THF). − IR (ether): $\tilde{\nu}$ = 2940 (s), 2870 (m), 1750 (s), 1730 (m), 1455 (m), 1440 (m), 1390 (m), 1370 (s), 1300 (m), 1260 (m), 1225 (m), 1200 (m), 1160 (s), 1135 (s), 1080 (s), 1035 (s), 1025 (s), 1020 (s), 980 (m), 920 (m). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.85−0.91 (m, 3 H), 1.10−2.54 (m, 37H), 2.92−3.06 (m, 1 H), 3.40−4.10 (m, 10 H), 4.62−4.76 (m, 2 H), 5.27−5.70 (m, 3 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.06 (d), 18.60 (u), 19.45 (u), 19.63 (u), 22.63 (u), 24.85 (u), 25.39 (u), 25.52 (u), 25.62 (u), 25.69 (u), 28.13 (d), 30.72 (u), 30.82 (u), 31.28 (u), 31.78 (u), 31.84 (u), 34.77 (u), 34.87 (u), 35.80 (u), 35.88 (u), 35.97 (u), 36.04 (u), 38.58 (u), 39.93 (u), 40.25 (u), 43.56 (d), 43.70 (d), 45.50 (d), 45.69 (d), 54.60 (d), 54.96 (d), 55.64 (d), 55.88 (d), 61.04 (u), 62.10 (u), 62.35 (u), 68.50 (u), 68.80 (u), 70.18 (u), 75.99 (d), 76.10 (d), 77.07 (d), 78.37 (d), 78.80 (d), 81.48 (u), 81.82 (u), 82.84 (d), 83.08 (d), 94.47 (d), 95.17 (d), 95.32 (d), 96.73 (d), 96.97 (d), 99.23 (d), 99.48 (d), 129.62 (d), 129.69 (d), 131.60 (d), 132.15 (d), 132.49 (d), 132.65 (d), 135.64 (d), 137.92 (u), 138.05 (u), 169.03 (u), 169.72 (u). − MS; *m/z* (%): 346 (13), 334 (14), 290 (11), 258 (12), 214 (31). − $C_{34}H_{56}O_7$ (576.8): calcd. C 70.80, H 9.79; found C 70.40, H 9.61.

1,1-Dimethylethyl [3aS-[3aα,5β,6α(1E,3R),6aα]]-[2-[1,3a,4,5,6,6a-Hexahydro-5-hydroxy-6-(3-hydroxy-1-octenyl)-2-penta-*

lenyl]ethoxy]acetate (**73**): Following the procedure described for the preparation of **64**, **72** (98 mg, 0.17 mmol) in EtOH (1.5 ml) and pyridinium *p*-toluenesulfonate (34 mg, 0.14 mmol) gave after chromatography (hexanes/EtOAc, 1:10) **73** (59 mg, 85%) as a colorless oil, $[\alpha]_D$ = +1.7 (*c* = 9.8, THF). − IR (neat): $\tilde{\nu}$ = 3380 (br), 2930 (s), 2870 (s), 1750 (s), 1670 (w), 1460 (m), 1430 (m), 1395 (m), 1370 (s), 1300 (m), 1255 (s), 1225 (s), 1165 (s), 1135 (s), 1095 (s), 1025 (m), 970 (s). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 6.7 Hz, 3 H), 1.18−1.69 (m, 9 H), 1.48 (s, 9 H), 1.91 (ddd, *J* = 9.5, *J* = 9.5, *J* = 8.0 Hz, 1 H), 2.01 (d, *J* = 17.3 Hz, 1 H), 2.23−2.53 (m, 5 H), 2.50−3.00 (s, br, 2 H), 2.94−3.08 (m, 1 H), 3.62 (t, *J* = 6.9 Hz, 2 H), 3.73 (ddd, *J* = 9.5, *J* = 9.5, *J* = 7.0 Hz, 1 H), 3.96 (s, 2 H), 4.04 (dt, *J* = 6.5, *J* = 6.5 Hz, 1 H), 5.38 (s, 1 H), 5.43−5.58 (m, 2 H). − ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.05 (d), 22.62 (u), 25.21 (u), 28.14 (d), 31.24 (u), 31.74 (u), 37.16 (u), 39.46 (u), 39.91 (u), 44.23 (d), 45.76 (d), 58.15 (d), 68.78 (u), 70.06 (u), 73.24 (d), 77.11 (d), 81.58 (u), 129.70 (d), 133.43 (d), 135.49 (d), 138.21 (u), 169.78 (u). − MS; *m/z* (%): 346 (11), 334 (17), 316 (10), 290 (39), 258 (21), 214 (41), 187 (20), 166 (17), 159 (16), 150 (15), 145 (22), 144 (25), 143 (41), 134 (26), 131 (19), 117 (20), 106 (25), 105 (35). − $C_{24}H_{40}O_5$ (408.6): calcd. C 70.55, H 9.87; found C 70.52, H 10.14.

3-Oxaisocarbacyclin (**5**): Following the procedure described for the preparation of **4**, **73** (40 mg, 0.10 mmol) in MeOH (6 ml) and NaOH (1.0 M, 0.2 ml) gave **5** (30 mg, 87%) as a colorless oil, $[\alpha]_D$ = +6.9 (*c* = 4.6, MeOH). − IR ($CHCl_3$): $\tilde{\nu}$ = 3360 (br), 2930 (s), 2860 (s), 1735 (s), 1445 (s), 1380 (m), 1345 (m), 1220 (s), 1130 (s), 970 (s). − ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 6.7 Hz, 3 H), 1.24−1.37 (m, 7 H), 1.42−1.50 (m, 1 H), 1.54−1.63 (m, 1 H), 1.97 (ddd, *J* = 9.3, *J* = 9.3, *J* = 9.3 Hz, 1 H), 2.08 (d, *J* = 16.2 Hz, 1 H), 2.25−2.34 (m, 3 H), 2.37−2.47 (m, 2 H), 3.01 (d, *J* = 7.9 Hz, 1 H), 3.66 (t, *J* = 6.4 Hz, 2 H), 3.75 (ddd, *J* = 9.5, *J* = 9.5, *J* = 7.2 Hz, 1 H), 4.04 (dt, *J* = 6.9, *J* = 6.9 Hz, 1 H), 4.05 (d, *J* = 16.6 Hz, 1 H), 4.11 (d, *J* = 16.6 Hz, 1 H), 5.24 (s, br, 3 H), 5.39 (s, 1 H), 5.45 (dd, *J* = 15.2, *J* = 8.4 Hz, 1 H), 5.52 (dd, *J* = 15.2, *J* = 7.6 Hz, 1 H). − ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.04 (d), 22.61 (u), 25.21 (u), 30.99 (u), 31.67 (u), 36.72 (u), 39.05 (u), 39.44 (u), 44.20 (d), 45.69 (d), 57.73 (d), 67.98 (u), 70.12 (u), 73.59 (d), 77.27 (d), 130.30 (d), 133.61 (d), 135.36 (d), 138.31 (u), 172.96 (u). − MS; *m/z* (%): 334 (11), 316 (6), 290 (26), 187 (15), 159 (18), 145 (21), 144 (28), 143 (43), 134 (22), 131 (37), 129 (30), 119 (20), 118 (17), 117 (41), 115 (17), 107 (19), 106 (30), 105 (72). − $C_{20}H_{32}O_5$ (352.5): calcd. C 68.15, H 9.15; found C 68.33, H 9.31.

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