Desymmetrization of Cyclohexa-1,4-dienes − A Straightforward Route to Cyclic and Acyclic Polyhydroxylated Systems

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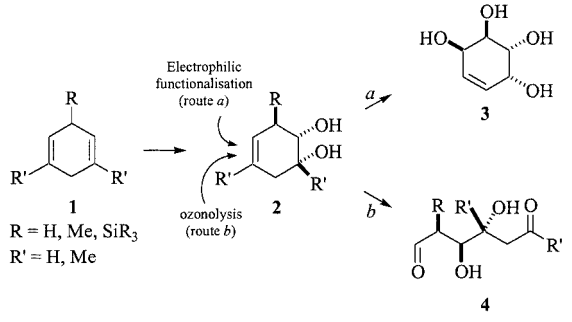
A straightforward route to polyols, amino polyols, polysubstituted lactols and lactones from readily available arenes has been devised. It uses a three- or four-step sequence involving a Birch reduction of the arene, followed by desymmetrization through dihydroxylation or aminohydroxylation and, lastly, ozonolysis of the remaining olefin. Depending on the ozonolysis workup conditions, cyclic or acylic synthons were obtained in generally high overall yields and with excellent levels of stereocontrol.

Introduction

During the course of our ongoing efforts to develop straightforward and stereocontrolled routes to useful synthons from readily available organosilanes, we have recently reported an efficient access to various types of cyclitols, ranging from conduritols (**3**, Scheme 1) to carba-sugars and carba-C-disaccharides.[1] The methodology is based on the desymmetrization of simple and easily accessible cyclohexa-1,4-dienes such as **1**, through asymmetric Sharpless dihydroxylation and aminohydroxylation. The diastereoselective and enantioselective dihydroxylation of a single double bond thus offered an entry to homochiral allylic systems, which could be functionalized further. The most remarkable results were obtained with silylcyclohexa-2,5-dienes, which upon desymmetrization afforded new optically active allylsilanes. These could then be converted into an array of useful polysubstituted cyclohexanes.[1] The second double bond was functionalized by epoxidation or cyclopropanation (route *a*, Scheme [2] It was then envisioned that cleavage of the double bond of **2** by ozonolysis (route *b*, Scheme 1) might also provide ready access to acyclic synthons such as **4**, possessing several contiguous stereogenic centers. Such an approach would also create useful additional functionalities (such as carbonyl or hydroxy groups), permitting further elaboration of these intermediates. Although acyclic stereocontrol[3] has been used as a method of choice for the setting up of chains with adjacent stereogenic centers of determined relative configurations, functionalization and subsequent ring opening of cyclic precursors may offer a very attractive alternative.[4] Such an approach, as pioneered by Woodward and Corey,[5] relies on the conformational preferences that exist in six-membered ring systems, allowing the construction of highly substituted rings possessing several adjacent stereocenters in a highly stereocontrolled manner. The ring opening can then be carried out by mild and efficient processes such as ozonolysis[6] or Baeyer−Villiger rearrangement.[7] Organometallic processes have also recently been used for the same purpose.[8] We provide here a full account of our investigations into the desymmetrization of cyclic dienes by various asymmetric processes and the subsequent elaboration of the resulting intermediates by ozonolysis.[9] These studies have been carried out with cyclohexadienylsilanes and have been extended to non-silylated analogs, thus offering access to a wider range of useful synthons.



Scheme 1

Results and Discussion

Preparation of the Precursors

The diene precursors (**1**, Scheme 1) were prepared by two different and complementary routes. The first one relied on the Birch reduction of the corresponding arenes **5**.[10] In the

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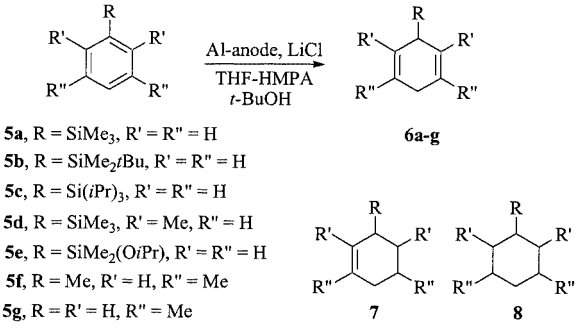
second approach, silylated dienes were prepared by metalation of cyclohexa-1,4-dienes, followed by silylation with the appropriate chlorosilanes.[11] In our preliminary studies,[1a] Birch chemical reduction (Li, NH_3) was successfully used to provide the desired dienes in good yields. The same method was employed with arenes **5a**−**b** and gave the desired dienes **6a**−**b** in good yield.[1f] The use of these conditions with arylsilane **5c**, however, provided the over-reduced products **7c** and **8c**, which could not be separated from the desired diene **6c** (Scheme 2). Moreover, the Birch reduction requires large quantities of NH_3, a method unsuitable for laboratory scaling up (Table 1, Scheme 2). Hence, an alternative method involving electrochemical reduction was successfully developed on precursors **5a**−**b**[1f,12] and then extended to other arenes (Scheme 2, Table 1). This reduction was carried out in an undivided cell equipped with a sacrificial aluminum anode[13] and a stainless steel grid cathode. The reactions were performed by means of an intensiostatic method (0.1 A in small cells) in a THF/HMPA mixture (8:2) and with anhydrous LiCl as supporting electrolyte. Under such conditions, HMPA-solvated electrons reduced the arenes, while *t*BuOH − which is not reduced at this potential − acted as a proton donor. It is interesting to notice that, as the reaction proceeds, the amount of aluminum salts increases, thus improving the conductivity of the medium. The amount of LiCl necessary (4 equiv.) was therefore limited, the aluminum salts working as co-supporting electrolytes. After extensive experimental studies, conditions **A** were found to be the most appropriate for the reduction of arylsilanes (Entries 1 and 3, Table 1), while conditions **B** were found to be the best for non-silylated arenes (Entries 12−14, Table 1). The regioselectivity of the reaction was excellent, only cyclohexa-1,4-dienes being observed. As summarized in Table 1 (Scheme 2), the desired dienes were obtained under the appropriate conditions in high yields and with no over-reduction products, in all cases except for that of **5c**. It is interesting to note that for the non-silylated arenes **5f**−**g** (Entries 12 and 14) or the alkyl-substituted arylsilanes (**5d**, Entry 8), a larger amount of *t*BuOH had to be employed (conditions B). For **5f**−**g** this may be explained by the absence of the silyl group, known to activate the arene towards reduction.[10a] The first step of a Birch reduction involves the formation of a radical anion, which exists in equilibrium with the arene. The reduction then evolves with the protonation of the radical anion either by the solvent (NH_3) or by a proton source (*t*BuOH), forming a new radical that is further reduced. The rate of the Birch reduction depends on this first step and thus on the concentration of the radical anion. With alkyl substituents, which are electron-donating groups, the concentration of radical anion must be less important and therefore the equilibrium probably lies to the left (towards the arene). A larger amount of protonating agent in the medium is thus required in order to shift the equilibrium. On the other hand, with arylsilanes such as **5a**−**b**, in which the radical anion is stabilized by the silyl group, the addition of a larger amount of *t*BuOH results in the formation of over-reduction products (Entries 2 and 4). If the quantity of proton donor increases the rate of the reaction with certain substrates, a larger quantity of alcohol will then slow the reaction down, by decreasing the conductivity. Nevertheless, the results summarized in Table 1 demonstrate that the electrochemical Birch reduction can be a valuable tool, and it was found to be particularly attractive for sensitive substrates, as shown by the clean reduction of siloxane **5e** (Entry 9). Moreover, we did not observe any desilylation,[12] which may occasionally occur under the basic conditions of the Birch reduction. Finally, through the use of a tubular flow cell, we were able to extend the method to a large-scale preparative reduction of **5f** (Entry 13, conditions C).[14] Under these conditions, up to 20 g of mesitylene **5f** could be reproducibly transformed into **6f** in very high yield. Conditions C were very similar to conditions A and B described above, except that the electrolysis was carried out at a constant current of 1 A and that Me_3SiCl was added to the medium to remove residual water originating from the technical grade solvents used in the pilot scale cell.



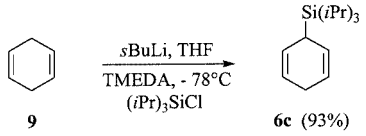
Scheme 2

Table 1. Electrochemical Birch reduction of arenes **5a**−**g** (Scheme 2)

Entry	Precursor	Product	Cond.[a]	Ratio (%)[b] **5/6/7/8**	Yield (%)[c]
1	**5a**	**6a**	A	0:*100*:0:0	90
2	**5a**	**6a**	B	5:*30*:50:15	25
3	**5b**	**6b**	A	0:*100*:0:0	87
4	**5b**	**6b**	B	0:*70*:0:30	60
5	**5c**	**6c**	A	1:*85*:2:12	50
6	**5c**	**6c**	D	2:*85*:5:8	30
7	**5d**	**6d**	A	50:*50*:0:0	50
8	**5d**	**6d**	B	0:*100*:0:0	75
9	**5e**	**6e**	B	0:*100*:0:0	99
11	**5f**	**6f**	A	50:*50*:0:0	45
12	**5f**	**6f**	B	0:*100*:0:0	98
13	**5f**	**6f**	C	0:*100*:0:0	94
14	**5g**	**6g**	B	0:*100*:0:0	80

[a] Conditions A: *t*BuOH (4 equiv.), I = 0.1 A; conditions B: *t*BuOH (22 equiv.), I = 0.1 A; conditions C: tubular flow cell, THF/HMPA (8:2), LiCl (4 equiv.), *t*BuOH (22 equiv.), I = 1 A; conditions D: *t*BuOH (3 equiv.), I = 0.1 A. [b] Estimated from ^{1}H NMR (250 MHz) and GC analysis of the crude reaction mixture. [c] Isolated yields of dienes **6** after purification through column chromatography.

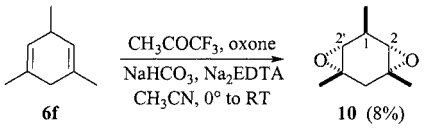
As shown in Table 1, arylsilane **5c** gave varying amounts of over-reduced products whatever the conditions used (Entries 5−6). Monitoring of the progress of the reaction by GC showed that over-reduced products **7c** and **8c** were formed simultaneously with the diene **6c**, indicating that they probably have very similar reduction potentials. Compound **6c** was therefore more conveniently prepared by metalation of cyclohexa-2,4-diene **9** with *s*BuLi and silylation of the resulting carbanion with iPr$_3$SiCl (Scheme 3).[11] This simple procedure also worked well for other silanes such as **5a**−**b**, but is not applicable to polysubstituted arenes such as **6f**. The two methods developed in these studies are thus complementary, and offer a rapid entry to cyclohexa-2,4-dienes.



Scheme 3

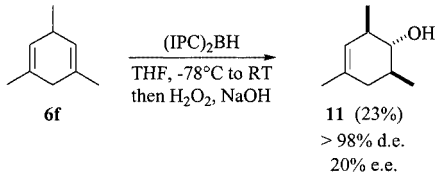
Desymmetrization of Precursors 6a−g

Our preliminary investigations into the desymmetrization of dienes **6a**−**g** were carried out by hydroboration and epoxidation. The former process has been used with success in the past in the desymmetrization of cyclopentadienes and cyclohexa-2,4-dienes,[15] while the latter has never been investigated in enantiopure series.[16] Epoxidation of **6f** was first performed in racemic series with reagents such as *m*CPBA, oxone®/CH_3COCF_3 or oxone®/acetone. None of these methods were able to provide the desired monoepoxide but mainly caused aromatization of the diene. Similarly, attempted asymmetric epoxidation under the chiral oxirane conditions recently reported by Shi[17] resulted in aromatization and no trace of monoepoxide. We were finally able to isolate the bis(epoxide) **10** as a single diastereomer with the relative configuration as shown (Scheme 4), albeit in low yield, by the use of an oxirane produced in situ from the mixture oxone®/CH_3COCF_3.[18,19]



Scheme 4

In view of the poor results obtained with epoxidations, we next turned our attention to asymmetric hydroboration. Our preliminary investigations were carried out with precursors **6d** and **6f** and Brown's dilongifoleneborane[20] and diisopinocampheylboranes.[15c] While **6d** either was recovered unchanged or simply decomposed under the hydroboration conditions, diene **6f** was converted into an alcohol, the structure and relative configuration of which were tentatively assigned as **11** from ^{1}H NMR studies (Scheme 5).[21] An enantiomeric excess of 20% was finally determined by ^{19}F NMR investigation of the corresponding Mosher's ester. The structure of **11** is attractive, as ozonolysis of the double bond should provide a polypropionate fragment with three contiguous stereocenters. However, although the regio- and the diastereocontrol were high, the poor yield and enantioselectivity precluded the use of such an approach for the preparation of homochiral synthons.



Scheme 5

We thus turned our attention towards Sharpless asymmetric dihydroxylation, which was found to be more promising in terms both of yield and of stereoselectivity.[1,22] As summarized in Table 2, yields and stereoselectivities largely depend on the nature of the ligands used during the dihydroxylation. When we compared the behavior of silylated and non-silylated dienes **6a**−**e** and **6f**−**g**, respectively, we noticed, as before, that the silyl group controlled the diastereofacial selectivity more efficiently than a methyl group did[1a,1f] (compare Entries 1−10 and 13−17, Table 2, see also Scheme 6), the osmium reagent approaching in an *anti* fashion in both cases.[23] This is not too surprising in view of the steric hindrance and the electronic effect of the silyl group. The best enantioselectivities for silyldienes **6c**−**e** (Entries 4, 6 and 12) were obtained with $(DHQ)_2PYR$, known to be the best ligand for the dihydroxylation of (*Z*)- and cyclic dienes,[22a] in good agreement with our own results reported earlier with analogs **6a**−**b** (Entries 1−2).[1]

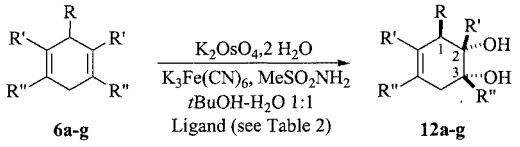
It is noteworthy that precursor **6c**, bearing the large triisopropylsilyl (TIPS) group, behaves quite differently from its analogs. Large amounts of *meso*-tetrol (vide infra), isolated as the acetonide **13b**, were formed upon bis(dihydroxylation) (Scheme 7). This had been observed earlier with **6b**, but not to such an extent. A 6:4 ratio of **12c**/tetrol was observed with quinuclidine as a ligand (Entry 3), while an 8:2 ratio was obtained with $(DHQ)_2PYR$ (Entry 4). The large amount of tetrol formed in this case may be attributed both to the size of the TIPS group and, more importantly, to its lipophilicity relative to the analogs **6a**−**b**. This would then imply that the smaller amounts detected with the analogs **6a**−**b** were due to the polar nature of the tetrol, which may remain in the aqueous layer after workup. Although this has not been firmly established, the presence of the tetrol could be indicative of a kinetic amplification effect.[24] It is also interesting to notice that according to ^{1}H NMR studies, the tetrol possesses a *meso* configuration, indicating that the second dihydroxylation again occurred *anti* relative to the silyl group.

During dihydroxylation of non-silylated dienes, it was found that the nature of the ligands had a profound effect not only on the enantioselectivity but also on the diastereoselectivity of the process. The best results in terms of diastereofacial selectivity were obtained with achiral quinuclid-

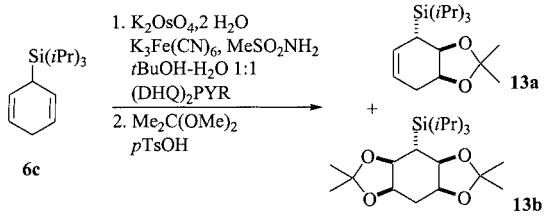
Table 2. Asymmetric dihydroxylation of dienes **6a**−**f** (Scheme 6)

Entry	Precursor	Diols	Ligand	Conditions	*de* (%)[a]	*ee*$_{maj.}$ (%)	*ee*$_{min.}$ (%)	Configuration[b]	Yield (%)[c]
1	**6a**	**12a**	$(DHQ)_2PYR$	0 °C, 12 h	> 98	60[d]	–	(1*S*,2*S*,3*S*)	85[1f]
2	**6b**	**12b**	$(DHQ)_2PYR$	0 °C, 12 h	> 98	71[b]	–	(1*S*,2*S*,3*S*)	80[1f]
3	**6c**	**12c**	quinuclidine	2 °C, 4 h	> 98	–	–	–	65[e]
4	**6c**	**12c**	$(DHQ)_2PYR$	2 °C, 4 h	> 98	40[d]	–	(1*S*,2*S*,3*S*)	75[e]
5	**6d**	**12d**	quinuclidine	2 °C, 48 h	> 98	–	–	–	84
6	**6d**	**12d**	$(DHQ)_2PYR$	2 °C, 72 h	> 98	47[d]	–	(1*S*,2*S*,3*S*)	84
7	**6d**	**12d**	$(DHQ)_2PHAL$	0 °C, 96 h	> 98	5[d]	–	(1*S*,2*S*,3*S*)	73
8	**6d**	**12d**	$(DHQD)_2PHAL$	0 °C, 72 h	> 98	27[d]	–	(1*R*,2*R*,3*R*)	87
9	**6d**	**12d**	$(DHQ)_2AQN$	0 °C, 96 h	–	–	–	–	0
10	**6d**	**12d**	$(DHQD)_2AQN$	0 °C, 96 h	–	–	–	–	0
11	**6e**	**12e**	quinuclidine	2 °C, 12 h	> 98	–	–	–	57
12	**6e**	**12e**	$(DHQ)_2PYR$	2 °C, 12 h	> 98	53[d]	–	–	70
13	**6f**	**12f**	quinuclidine	10 °C, 8 h	88	–	–	–	36[f]
14	**6f**	**12f**	$(DHQ)_2PYR$	r.t., 96 h	–	–	–	–	0
15	**6f**	**12f**	$(DHQ)_2PHAL$	10 °C, 16 h	60	60[g]	50[g]	(1*R*,2*S*,3*R*)	52
16	**6f**	**12f**	$(DHQD)_2PHAL$	10 °C, 14 h	40	70[g]	18[g]	(1*S*,2*R*,3*S*)	55
17	**6f**	**12f**	$(DHQ)_2AQN$	10 °C, 24 h	70	30[g]	32[g]	(1*R*,2*S*,3*R*)	40
18	**6f**	**12f**	$(DHQD)_2AQN$	0 °C, 96 h	–	–	–	–	0
19	**6g**	**12g**	quinuclidine	0 °C, 72 h	–	–	–	–	61

[a] Estimated from the ^1H NMR spectrum (250 MHz) of the crude reaction mixture. [b] See text. [c] Isolated yields after purification by column chromatography. [d] Estimated from the ^1H and ^{19}F NMR (250 MHz) spectra of the corresponding Mosher's esters. [e] Estimated yield of the diol in the diol/tetrol mixture. [f] Isolated yield of major diastereomer after recrystallization. [g] Determined by HPLC analysis on a Chiralcel OD® column (hexane/*i*PrOH, see Exp. Sect. for details).



Scheme 6



Scheme 7

ine. The major isomer **12f** was thus obtained with 88% *de* (Entry 13) and in 36% yield after crystallization. A good enantioselectivity but a poor diastereoselectivity in favor of the major isomer **12f** was obtained with commercially available $(DHQD)_2PHAL$ (Entry 16). Moreover, the minor isomer was obtained with a rather poor enantioselectivity (18% *ee*). Better diastereocontrol was observed with $(DHQ)_2AQN$, but the enantioselectivities for both isomers were low (Entry 17). It was noteworthy that the diastereomeric ligand $(DHQD)_2AQN$ gave no reaction either with **6f** (Entry 18) or with **6d** (Entry 9), indicating that a minor change in the nature of the ligand had an important effect on the rate of the reaction. The same holds for the ligand $(DHQ)_2PYR$, which was very efficient for silylation of dienes **6a**−**e** but did not give any reaction with non-silylated dienes. This may be explained by invoking a poor fitting of the substrate in the pocket formed by the complex osmium ligands.[1f] Finally, though, we were pleased to observe that dihydroxylation of **6f** with $(DHQ)_2PHAL$ gave a good compromise, **12f** being obtained in reasonable yield with 60% *de* and 60% *ee* for both diastereomers (Entry 15).

The absolute configurations of diols **12c**−**e** obtained with $(DHQ)_2PYR$ as a ligand were assumed to be the same as those of the diols **12a**−**b**, previously determined unambiguously through chemical correlations.[1a,1c,1f] For non-silylated analogs **12f**−**g**, assumption of the absolute configurations was made by use of the Sharpless mnemonic device[22] (quadrant method, Figure 1), and these were found to be in good agreement with results obtained from dihydroxylation on related dienes.[25]

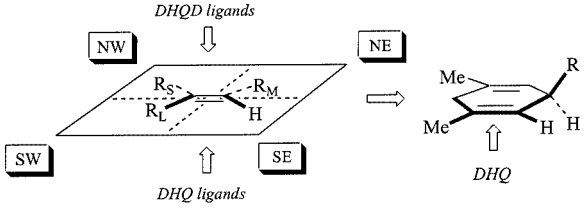
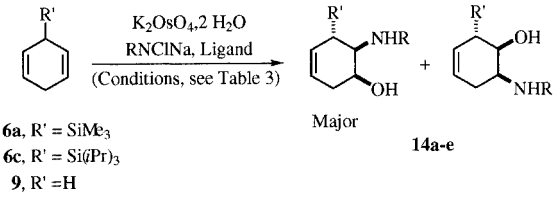


Figure 1. Quadrant method for rationalization of asymmetric dihydroxylation (AD) enantiofacial selectivity

Such encouraging results obtained during the dihydroxylation of precursors **6c**−**g** prompted us to investigate the analogous aminohydroxylation, which would give rise to useful amino alcohol intermediates for organic synthesis.[26] As summarized in Table 3 (Scheme 8), the influence of various parameters such as the nature of the ligands, the amino group and the solvents were studied. The

best results were obtained with mesyl- and tosyl-protected amino groups, acetyl protection providing only dihydroxylation products.[26e] The carbamate group ($NHCO_2Et$), used successfully in our previous studies,[1b,1f] was not a good candidate in this context, due to the lability of this amino protecting group under the reductive ozonolysis conditions (vide infra). It is noteworthy that the mesyl and tosyl groups were introduced with the aid of the easily handled chloramine-M (MsNClNa) and chloramine-T (TsNClNa). The latter reagent is commercially available and does not require the chlorination of the amino group prior to the aminohydroxylation process. Aminohydroxylation of **6a** thus afforded the amino alcohol **14a** as an inseparable mixture of two regioisomers, **14aa** and **14ab**, in low yield but with complete diastereocontrol (Entry 1, Table 3). A similar trend was observed with the TIPS analogs **6c** (Entry 2). Better results were obtained with cyclohexa-1,4-diene **9**, which gave the desired amino alcohol **14c** in reasonable yield and with 36% *ee* (Entry 3). When we turned our attention towards sterically more demanding amino groups such as tosylamine, we were pleased to find that even better enantioselectivity could be attained (Entry 4). Although the yields were moderate, complete regio- and diastereocontrol was also observed with precursor **6c**, with chloramine-T as a source of amine and oxidizing agent (Entries 5−9). It is noteworthy that the enantioselectivity varies according to the nature of the solvent. With the chiral ligand $(DHQ)_2PYR$, for instance, the amino alcohol **14e** was obtained with a 20% *ee* in CH_3CN/H_2O (Entry 5) but with 54% *ee* and a better yield in *n*PrOH/H_2O (Entry 7). This probably reflects the lipophilicity of **6c** and its low solubility in acetonitrile and water. Better solubility of the diene is observed in alcoholic media, explaining the better results in these solvents. However, the degree of conversion of the starting diene is generally low, due to slow turnover rates.[26] Further addition of osmium salt and ligand to the reaction mixture was shown to improve the level of conversion slightly. The high lipophilicity of diene **6c** probably retards the hydrolysis of the osmium azaglycolate and thus limits the turnover rate of the reaction.[22a,26,27] The moderate corrected yields are due to the sensitivity of diene **6c** towards the silica gel used for purification, since the crude yield was generally high and no byproducts were detected during the reaction.



Scheme 8

The structure of the major regioisomer **14e** was determined by ^1H NMR experiments (COSY), which unambiguously showed that the aminohydroxylation of **6c** gave the regioisomer with the most hindered substituent close to the silyl group, in good agreement with previous observations on closely related analogs.[1b,1f] The origin of the regioselectivity was explained in terms of specific coordination of the diene inside the U-shaped binding pocket provided by the $(DHQ)_2PYR$−osmium complex, preceding the [3+2] addition process involved in asymmetric aminohydroxylation (AA) and AD reactions.[1f,28] Finally, with reference to earlier studies,[1f] the absolute configuration of **14e** was assumed to be the same as that of diols **12a**−**e**, obtained by use of the same chiral ligand [i.e., (1*S*,2*S*,3*S*) when $(DHQ)_2PYR$ was used].

Functionalization of Diols and Amino Alcohols by Ozonolysis

As mentioned above, functionalization of allylsilanes **12a**−**e** and **14a**−**e** can be carried out in a number of ways. We have shown previously that epoxidation, dihydroxylation and cyclopropanation can afford useful intermediates for organic synthesis.[1] It was anticipated that ox-

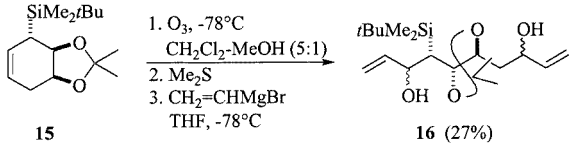
Table 3. Asymmetric aminohydroxylation of dienes **6** and **9** (Scheme 8)

Entry	Precursor	Product	Conditions[a]	Ligand	R in NHR group	Regioselectivity (%)[b]	*de* (%)[c]	$ee_{maj.}$ (%)[d]	Yield (%)
1	**6a**	**14aa** + **14ab**	A	$(DHQ)_2PYR$	Ms	50:50	> 98	23	28
2	**6c**	**14ba** + **14bb**	A	$(DHQ)_2PYR$	Ms	66:33	> 98	15	10
3	**9**	**14c**	A	$(DHQ)_2PHAL$	Ms	−	−	36	57
4	**9**	**14d**	B	$(DHQ)_2PHAL$	Ts	−	−	66	46
5	**6c**	**14e**	B	$(DHQ)_2PYR$	Ts	> 98	> 98	20	30
6	**6c**	**14e**	C	$(DHQD)_2PYR$	Ts	> 98	> 98	60	46
7	**6c**	**14e**	C	$(DHQ)_2PYR$	Ts	> 98	> 98	54	52
8	**6c**	**14e**	D	$(DHQ)_2PYR$	Ts	> 98	> 98	66	30[e]
9	**6c**	**14e**	D	$(DHQ)_2PHAL$	Ts	> 98	> 98	28	24[e]

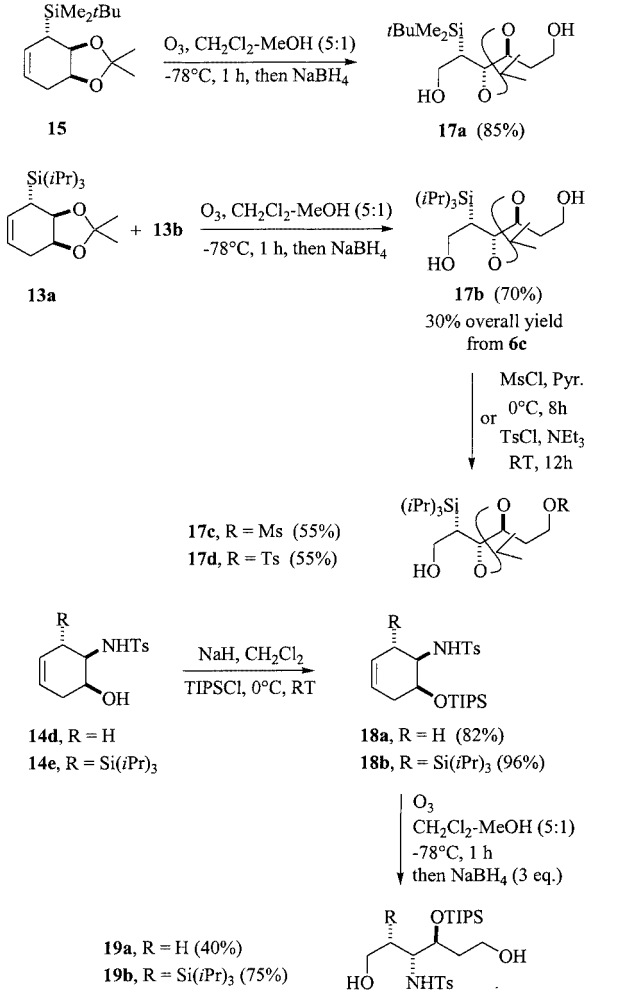
[a] Conditions A: MsNClNa (3 equiv.); $K_2OsO_4{\cdot}2H_2O$ (0.04 equiv.), *n*PrOH/H_2O (1:1), ligand (0.05 equiv.); conditions B: TsNClNa (3 equiv.); $K_2OsO_4{\cdot}2H_2O$ (0.04 equiv.), CH_3CN/H_2O (1:1), ligand (0.05 equiv.); conditions C: TsNClNa (3 equiv.); $K_2OsO_4{\cdot}2H_2O$ (0.04 equiv.), *n*PrOH/H_2O (1:1), ligand (0.05 equiv.); conditions D: TsNClNa (3 equiv.); $K_2OsO_4{\cdot}2H_2O$ (0.04 equiv.), *t*BuOH/H_2O (1:1), ligand (0.05 equiv.). [b] As measured after purification of the regioisomers. [c] Estimated by ^1H NMR (250 MHz). [d] Determined by HPLC analysis on a Chiralcel OD® column (hexane/*i*PrOH, 9:1). [e] Corrected yield after purification by chromatography and recovery of the starting diene.

idative cleavage (i.e., ozonolysis or Baeyer−Villiger reaction) of the remaining double bond of **12a−g** and **14a−e** should ideally give rise to intermediates possessing useful functionalities that could be functionalized further. In view of the sensitivity of our diols **12a−e** and amino alcohols **14a** and **14e** towards desilylation, it was expected that ozonolysis of the remaining double bond should be the mildest process with which to open our cyclic systems. Careful control of the workup conditions after ozonolysis should also ensure the introduction of functionalities such as diols or lactols.[6b−6g]

The first attempts were made on the diacetate of **12b**. Unfortunately, ozonolysis in CH_2Cl_2/MeOH with subsequent reduction of the ozonide resulted only in decomposition of the diacetate. In order to establish whether the dialdehyde (i.e., α-silyl aldehyde) was effectively formed upon ozonolysis workup, a second attempt was made with the more robust acetonide **15** and, immediately after the workup, an excess of a vinyl Grignard reagent was added at low temperature to the intermediate (Scheme 9). This resulted in the formation, albeit in low yield, of **16** as a mixture of stereoisomers, thus indicating that the dialdehyde had been effectively formed but probably decomposed during the workup due to the lability of the silyl group α to the aldehyde function.[29]



Scheme 9

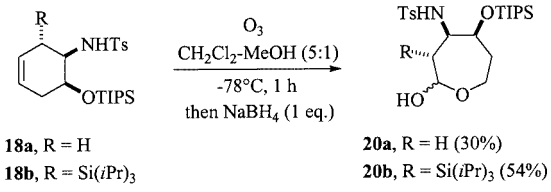


Scheme 10

It was thus decided that the reduction of the ozonide should be followed by complete reduction of the sensitive dialdehyde into a diol.[6b,30] The acetonide **15** was subjected to ozonolysis (conditions A), as above, followed by addition of an excess of $NaBH_4$, which afforded the diol **17a** in excellent yield (Scheme 10). Similarly, the inseparable mixture of mono- and bis(acetonide) **13a** and **13b** (Scheme 7) provided the diol **17b** in 30−34% overall yield from diene **6c**. The steric hindrance induced by the TIPS group was deliberately used to differentiate the two ends of the chain in **17b**. For instance, treatment of **17b** in the presence of MsCl and *p*TsCl selectively afforded mesylate **17c** and tosylate **17d**, respectively. It is noteworthy that the same reactions performed on the analog **17a** gave mixtures of mono- and diprotected tosylates and mesylates, demonstrating the unique properties of the TIPS group as compared with the less hindered silyl groups. Finally, the aminohydroxylation products **14d−e** were submitted to the same conditions (A) after TIPS protection of their alcohol functions. The desired amino polyols **19a−b** were thus obtained in moderate to good yields from **18a−b** (Scheme 10).

Interestingly, the result of the ozonolysis process could be modified by simply reducing the amount of $NaBH_4$ added at the end of the reaction (conditions B). When only 1 equiv. of $NaBH_4$ was added to the ozonides generated from olefins **18a−b**, partial reduction occurred to afford the oxepane lactols **20a−b** in moderate yield after chromatography (Scheme 11). This unexpected result is noteworthy and constitutes a straightforward means to differentiate the two ends of the amino polyol chains of **19a−b**. We have not been able to establish the origin of the complete regioselectivity of this process firmly, although it appears to be mainly steric, the less hindered end of the system (away from the TIPS group) being attacked by the reducing agent first.

The above results encouraged us to apply our methodology to the synthesis of simple polypropionate fragments, the goal being that the stereochemistry of such synthons would be installed by dihydroxylation of suitable precursors. Dienes such as **6d** and **6f**, containing resident methyl groups present in the polypropionate targets, were thought to constitute suitable candidates.[6c−6e] The qua-

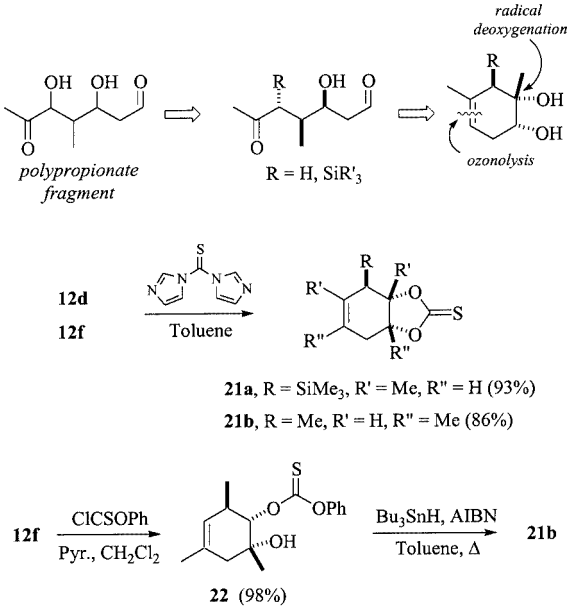


18a, R = H
18b, R = Si(*i*Pr)$_3$

20a, R = H (30%)
20b, R = Si(*i*Pr)$_3$ (54%)

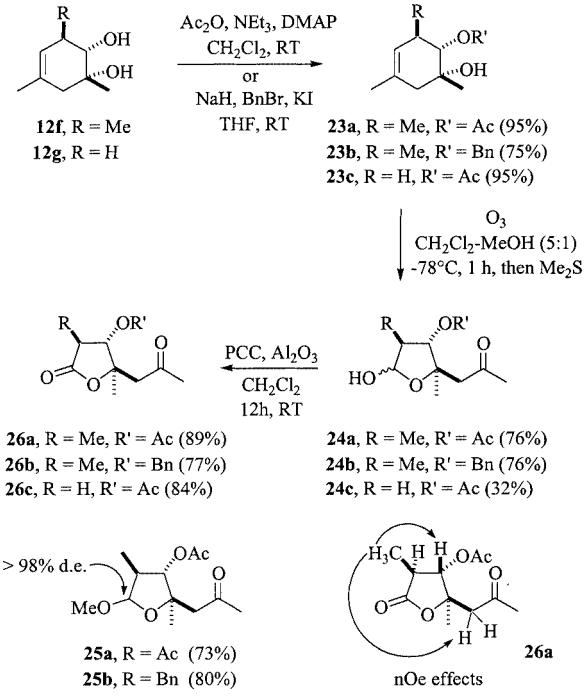
Scheme 11

ternary OH group would then be removed by Barton−McCombie deoxygenation[31] starting from thiocarbonate intermediates (Scheme 12). It was anticipated that a tertiary radical could then be formed and trapped stereoselectively by use of a tin hydride. Compounds **12d** and **12f** were thus converted into the desired cyclic thiocarbonates **21a**−**b** in excellent yields and submitted to Barton−McCombie conditions.[31,32] Unfortunately, the silylated precursor **21a** gave degradation products under these conditions, while **21b** was recovered unchanged. Interestingly, a similar attempt with thiocarbonate **22**, prepared in 98% yield from **12f**, gave the carbonate **21b** through nucleophilic displacement of the thiocarbonyl group.



Scheme 12

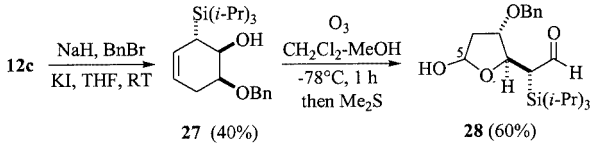
Having established the viability of our strategy of transformation of dienes into acyclic polyols and amino polyols, we then focused our attention towards the formation of related cyclic systems such as lactols and lactones. It was envisioned that a partial reduction of the dialdehyde intermediate should offer a rapid route to five-membered ring lactones,[6b] one of the resident hydroxy groups preventing complete reduction through the formation of a hemiacetal. This was first tested on diols **12f**−**g**, which were protected either as monoacetates **23a** and **23c** or as benzyl ether **23b** before being subjected to ozonolysis (Scheme 13). Reduction of the ozonide with Me_2S at 0 °C (conditions C) then produced the desired lactols **24a**−**c**, in each case as a 6:4 mixture of diastereomers. It is interesting to note that when ozonolysis of **23a**−**b** was followed by treatment with Me_2S between 0 °C and room temperature (conditions D), acetals **25a**−**b** were formed instead of lactols **24a**−**b**. Acetal **25a** was obtained as a single diastereomer, the stereochemistry of which at the lactol center was not determined. Lactols **24a**−**c** were oxidized with PCC on alumina[33] to afford the corresponding lactones **26a**−**c** in 64% and 44% overall yield from mesitylene **12f** and 26% overall yield from **12g**, respectively. NOE experiments carried out on lactone **26a** unambiguously established the relative configurations of the lactones as well as those of the cyclohexene precursors **12f**−**g**.



Scheme 13

We have thus shown that highly functionalized five-membered ring lactones possessing three contiguous stereogenic centers could be prepared in high overall yield from inexpensive arenes. It is noteworthy that this approach also allowed the creation of an otherwise difficult to install quaternary stereogenic center. It was then envisioned that a similar strategy could be applied to the silylated analogs.[34] In view of the poor stability of α-silyl aldehydes obtained from precursors such as **15**,[29] the sterically more hindered TIPS analog **12c** was deemed to constitute a more suitable candidate for our purposes. The unique steric hindrance provided by the TIPS group in **12c** was used to protect selectively the hydroxy group on the position remote from the silyl group. The monobenzyl ether **27**, obtained in moderate yield, was then subjected to ozonolysis (conditions C), providing the α-silyl aldehyde **28** in 60% yield as a single diastereomer after treatment with Me_2S (Scheme 14). Surprisingly, **28** was found to be remarkably stable and could be

purified by chromatography on silica gel. α-Silyl aldehydes are valuable intermediates for organic synthesis and can be elaborated further in a stereocontrolled manner into allylsilanes by means of Wittig reactions[35a] or into β-hydroxysilanes[35b] through addition of organometallic reagents. Moreover, the lactol function may also serve for the introduction of an additional chain at C-5, which should give rise to useful intermediates for the synthesis of ubiquitous naturally occurring 2,4,5-trisubstituted tetrahydrofurans.



Scheme 14

Conclusion

We have reported here on a straightforward route to polyols, amino polyols, polysubstituted lactols and lactones, in four steps starting from readily available arenes. The methodology relies on a sequence of three key steps: Birch reduction of the arene, followed by desymmetrization through dihydroxylation or aminohydroxylation, and final ozonolysis of the remaining double bond. Depending on the ozonolysis workup conditions, cyclic or acylic synthons were obtained in generally high overall yield. This strategy represents an attractive alternative to acyclic stereocontrol and should find interesting applications in total synthesis of natural compounds.

Experimental Section

General Remarks: ^{1}H and ^{13}C NMR spectra were recorded with Bruker AC 250 (^{1}H: 250 MHz, ^{13}C: 83 MHz), Bruker AC 200 (^{1}H: 200 MHz, ^{13}C: 67 MHz) and Bruker DPX 200 instruments, with $CDCl_3$ as internal reference unless otherwise indicated. The chemical shifts (δ) and coupling constants (*J*) are expressed in ppm and Hz, respectively. IR spectra were recorded with a Perkin−Elmer Paragon 1000 FT-IR spectrophotometer. High- and low-resolution mass spectra were recorded with a Micromass autospec-Q mass spectrophotometer (EI, 70 eV, LSIMS with a 3-nitrobenzyl alcohol matrix). Elemental analyses were performed by the CNRS laboratory at Vernaison (France). Melting points were not corrected and determined by use of a Stuart Scientific apparatus (SMP3). Gas chromatography was run with a Hewlett Packard Instruments, 48490 series equipped with an SPB-1 column. HPLC was performed with a Waters 600 machine equipped with a 996 photodiode array detector and a Chiralcel OD® column. Kugelrohr distillations were performed with a Büchi GKR-50 apparatus. Merck silica gel 60 (70−230 mesh) and (0.063−0.200 mm) were used for flash chromatography. CH_2Cl_2 and Et_3N were distilled from CaH_2. THF, diethyl ether, hexane and DME were distilled from sodium/benzophenone. Chlorosilanes were distilled from magnesium. *t*BuOH was dried with CaO, and MeOH was distilled from magnesium.

General Procedure for the Preparation of Cyclohexa-2,5-dienes 6a−g. Conditions A. (Cyclohexa-2,5-dienyl)trimethylsilane (6a): THF (70 mL), HMPA (18 mL), *t*BuOH (2.16 mL, 26 mmol) and trimethylphenylsilane (**5a**, 1 g, 6.5 mmol) were introduced under nitrogen into a one-compartment cell, fitted with a sacrificial anode of aluminum and a cylindrical stainless grid, and containing LiCl (0.86 g, 20.6 mmol) as supporting electrolyte. Electrolysis (constant current 0.1 A) was then initiated and maintained for 5 h. Stirring was then continued for 3 h until the starting material had disappeared (monitored by GC). The mixture was then diluted with pentane (80 mL) and treated dropwise at −78 °C with a 10% solution of HCl (100 mL). The organic layer was decanted. The aqueous layer was extracted with diethyl ether (3 × 10 mL), and the combined extracts were washed with HCl (10%, 5 × 100 mL), and then with a saturated solution of $NaHCO_3$ (3 × 50 mL) and with brine (2 × 30 mL). The solution was dried with $MgSO_4$ and the solvents were removed in vacuo to afford **6a** as a colorless oil (0.88 g, 90%), used in the next step without further purification. Spectroscopic data for **6a** were consistent with those described in the literature.[1f,12]

Metalation of Cyclohexa-1,4-diene 9. (Cyclohexa-2,5-dienyl)triisopropylsilane (6c): A solution of *s*BuLi in hexane (1.6 M, 6.2 mL, 10 mmol) and TMEDA (1.5 mL, 10 mmol) were added dropwise at −78 °C to a solution of cyclohexa-1,4-diene (0.94 mL, 10 mmol) in anhydrous THF (15 mL). The pale yellow solution was stirred for 3 h at −45 °C, and treated with a solution of chlorotriisopropylsilane (2.16 mL, 10 mmol) in THF (4 mL). After 0.5 h at −45 °C, the mixture was allowed to warm to room temp. and quenched with a saturated solution of NH_4Cl (20 mL). The organic layer was decanted and the aqueous layer was extracted with diethyl ether (3 × 20 mL). The combined extracts were washed with brine (2 × 20 mL) and dried with $MgSO_4$, and the solvent was removed in vacuo. Chromatography on silica gel (cyclohexane) afforded **6c** as white crystals (2.22 g, 93%), which were recrystallized from cyclohexane; m.p. 37 °C. IR (film, KBr): $\tilde{\nu}_{max}$ = 2935 cm^{-1}, 2873, 1625 (C=C), 1546, 1501, 1380, 1251, 1100, 830, 818, 702. ^{1}H NMR ($CDCl_3$): δ = 5.84−5.78 (m, 2 H, C*H*=CH), 5.75−5.52 (m, 2 H, CH=C*H*), 2.83−2.69 (m, 3 H, C*H*Si, CH_2), 1.18 [sept, *J* = 7.1 Hz, 3 H, *H*C(CH$_3$)$_2$], 1.15 [br. s, 18 H, HC(CH_3)$_2$] ppm. ^{13}C NMR ($CDCl_3$): δ = 127.98 (*C*H=CH), 122.02 (CH=*C*H), 27.48 (*C*HSi), 27.10 (*C*H$_2$), 19.72 [HC(*C*H$_3$)$_2$], 18.54 [HC(*C*H$_3$)$_2$], 13.35 [H*C*(CH$_3$)$_2$], 12.26 [H*C*(CH$_3$)$_2$] ppm. $C_{15}H_{28}Si$ (236.47): calcd. C 76.19, H 11.93, Si 11.88; found C 75.53, H 12.33, Si 12.14 ppm.

General Procedure for the Preparation of Cyclohexa-2,5-dienes 6a−g. Conditions B. (2,6-Dimethylcyclohexa-2,5-dienyl)trimethylsilane (6d): Conditions B were identical to conditions A except for the amount of *t*BuOH (22 equiv. instead of 4). Compound **5d** (2 g, 11.2 mmol) was treated according to conditions B for 8 h, and afforded diene **6d** (1.51 g, 75%), which was used in the next step without further purification. IR (film, KBr): $\tilde{\nu}_{max}$ = 3019 cm^{-1}, 2961, 1932, 1681 (C=C), 1445, 1246, 1190, 1104, 1049, 1025, 836, 755, 693, 622. ^{1}H NMR ($CDCl_3$): δ = 5.33 (m, 2 H, =C*H*), 2.57 (m, 2 H, CH_2), 2.31 (s, 1 H, SiC*H*), 1.74 (m, 6 H, =CCH_3), 0.06 [s, 9 H, Si(CH_3)$_3$] ppm. ^{13}C NMR ($CDCl_3$): δ = 136.02 (=*C*CH$_3$), 116.79 (=*C*H), 42.28 (*C*H$_2$), 28.17 (H*C*Si), 23.65 (=C*C*H$_3$), −0.60 [Si(*C*H$_3$)$_3$] ppm.

(Cyclohexa-2,5-dienyl)isopropoxydimethylsilane (6e): On subjection to conditions B, arylsilane **5e** (1 g, 5.1 mmol), after 5 h, gave the diene **6e** (1 g, 99%) as a colorless oil, used in the next step without further purification. IR (film, KBr): $\tilde{\nu}_{max}$ = 3025 cm^{-1}, 2969, 2925, 2637, 2368, 1939, 1741, 1623 (C=C), 1463, 1449, 1380, 1367, 1257, 1100, 1029, 938, 881, 798, 654. ^{1}H NMR ($CDCl_3$): δ = 5.57−5.66 (m, 4 H, C*H*=C*H*), 4.03 (sept, *J* = 6.1 Hz, 1 H, OC*H*(CH$_3$)$_2$], 2.70 (m, 2 H, CH_2), 2.39 (m, 1 H, SiC*H*), 1.15 (d, *J* = 6.1 Hz, 6 H,

OCH(CH_3)$_2$], 0.13 [s, 3 H, Si(CH_3)$_2$], 0.06 [s, 3 H, Si(CH_3)$_2$] ppm. ^{13}C NMR ($CDCl_3$): δ = 123.5 (*C*H=CH), 122.6 (CH=*C*H), 67.12 [H*C*(CH_3)$_2$], 31.80 (H*C*Si), 31.01 (*C*H$_2$), 26.15 [HC(*C*H$_3$)$_2$], −2.19, −2.22 [Si(*C*H$_3$)] ppm.

2,4,6-Trimethylcyclohexa-1,4-diene (6f): On subjection to conditions B, mesitylene (**5f**, 3 g, 25 mmol), after 53 h, gave the diene **6f** (3 g, 98%) as a colorless oil, used in the next step without further purification. IR (film, KBr): $\tilde{\nu}_{max}$ = 3922 cm^{-1}, 2958, 2548, 2341, 1853, 1697, 1607, 1451, 1384, 1260, 1068, 1055, 1017, 927, 869, 823, 687, 656. ^{1}H NMR ($CDCl_3$): δ = 5.24 (m, 2 H, =C*H*), 2.65 (m, 1 H, CH$_3$C*H*), 2.36 (br. s, 1 H, C*H*$_2$), 1.61 (s, 6 H, =CC*H*$_3$), 0.93 (d, *J* = 7.1 Hz, 3 H, CHC*H*$_3$) ppm. ^{13}C NMR ($CDCl_3$): δ = 130.13 (=*C*CH$_3$), 125.12 (=*C*H), 35.84 (*C*H$_2$), 32.22 (*C*HCH$_3$), 23 (=C*C*H$_3$), 22.47 (CH*C*H$_3$) ppm.

2,4,6-Trimethylcyclohexa-1,4-diene (6f). Conditions C: LiCl (28 g, 0.67 mol) was dissolved in a mixture of THF (600 mL), HMPA (320 mL) and *t*BuOH (360 mL, 3.7 mol). After homogenization, the solution was poured into the tubular flow cell,[14] and mesitylene (**5f**, 23 mL, 0.17 mol) was added, followed by chlorotrimethylsilane (4 mL). Electrolysis (constant current 1 A) was then initiated and maintained for 24 h. The mixture was diluted with pentane (800 mL) and then treated dropwise at −78 °C with a 10% solution of HCl (800 mL), and the organic layer was decanted. The aqueous layer was extracted with diethyl ether (3 × 500 mL) and the combined extracts were washed with HCl (10%, 5 × 500 mL), a saturated solution of $NaHCO_3$ (3 × 200 mL) and brine (2 × 300 mL). The solution was dried with $MgSO_4$ and the solvents were removed in vacuo to afford **6f** as a colorless oil (20.3 g, 94%), used in the next step without further purification. The spectroscopic data for **6f** were consistent with those described above.

1,5-Dimethylcyclohexa-1,4-diene (6g): On subjection to conditions B, *m*-xylene (**5g**, 2 g, 18.8 mmol) gave, after 72 h, the diene **6g** (1.65 g, 80%) as a colorless oil, used in the next step without further purification. IR (film, KBr): $\tilde{\nu}_{max}$ = 2962 cm^{-1}, 2925, 2866, 2660, 2360, 1853, 1696, 1447, 1387, 1375, 1261, 1096, 1015, 928, 807. ^{1}H NMR ($CDCl_3$): δ = 5.43 (m, 2 H, =C*H*), 2.70 (m, 2 H, C*H*$_2$), 2.30 (m, 2 H, C*H*$_2$), 1.67 (s, 6 H, C*H*$_3$) ppm. ^{13}C NMR ($CDCl_3$): δ = 130.15 (=*C*CH$_3$), 125.18 (=*C*H), 35.9 (*C*H$_2$), 32.3 (*C*H$_2$), 23.11 (=C*C*H$_3$) ppm.

Bis(epoxide) (10): Trifluoroacetone (0.81 mL, 8.9 mmol) was added dropwise at 0 °C to a mixture of a solution of Na_2EDTA (4 × 10^{-4} M, 4 mL, 1.63 μmol) and diene **6f** (0.1 g, 0.81 mmol) in CH_3CN (6 mL). A mixture of $NaHCO_3$ (0.53 g, 6.3 mmol) and oxone® (2.51 g, 0.1 mmol) was then added to the reaction medium in portions so as to maintain the pH at 7. The medium was then allowed to warm to room temp. and the reaction mixture was poured into water. The layers were decanted and the aqueous layer was extracted with CH_2Cl_2. The combined organic layers were then dried with $MgSO_4$ and the solvents were evaporated under vacuum to give **10** as a solid (10 mg, 8%), which was recrystallized from petroleum ether; m.p. 70 °C (petroleum ether). IR (film, KBr): $\tilde{\nu}_{max}$ = 3000 cm^{-1}, 1428, 1300, 1150, 952 (C−O), 890, 775, 740. ^{1}H NMR ($CDCl_3$): δ = 3.10 (q, *J* = 7.6 Hz, 1 H, CH$_3$C*H*), 3.08 (s, 2 H, C*H*O), 2.85 (d, *J* = 16.8 Hz, 1 H, C*H*$_a$H$_b$), 2.39 (d, *J* = 16.8 Hz, 1 H, CH$_a$*H*$_b$), 1.85 (s, 6 H, C*H*$_3$CO), 1.51 (d, *J* = 7.6 Hz, 3 H, C*H*$_3$CH) ppm. ^{13}C NMR ($CDCl_3$): δ = 61.63 (*C*HO), 55.02 (O*C*CH$_3$), 32.94 (*C*H$_2$), 28.80 (OC*C*H$_3$), 23.74 (HC*C*H$_3$), 15.26 (*C*H$_3$CH) ppm. $C_9H_{14}O_2$ (154.21): calcd. C 70.10, H 9.15, O 20.25; found C 70.10, H 9.11, O 20.29.

(1*R,2*R**,6*S**)-2,4-6-Trimethylcyclohex-3-enol (11):** 2,4,6-Cyclohexa-1,4-diene (**6f**, 0.3 g, 2.46 mmol) was added at 0 °C to a solution of diisopinocampheylborane[15c] (2.21 mmol) in THF (20 mL). The reaction mixture was stirred at 0 °C for 24 h and then oxidized by addition of distilled water (3 mL), an aqueous solution of NaOH (3 M, 2.3 mL, 6.9 mmol) and a solution of H_2O_2 (50%, 0.5 mL, 7.4 mmol). The organic layer was decanted and the aqueous layer was extracted with diethyl ether (3 × 10 mL). The combined extracts were washed with brine (10 mL) and dried with $MgSO_4$, and the solvents were removed in vacuo. The brown residue (0.73 g) was purified by chromatography on silica gel (cyclohexane/EtOAc, 80:20), to afford the crystalline alcohol of pinene (0.5 g) and the alcohol **11** as a colorless oil (0.08 g, 23%, 20% *ee* as estimated from ^{19}F NMR of the corresponding Mosher's ester). IR (film, KBr): $\tilde{\nu}_{max}$ = 3608 cm^{-1}, 3355, 2922, 2360, 1452, 1394, 1366, 1260, 1039, 1004, 928, 784, 761. ^{1}H NMR ($CDCl_3$): δ = 5.04 (m, 1 H, =CH), 3.50 (s, 1 H, O*H*), 2.91 (d, *J* = 7.5 Hz, 1 H, *H*COH), 2.20−1.92 (m, 4 H, C*H*$_2$, 2 × *H*CCH$_3$), 1.71 (s, 3 H, =CC*H*$_3$), 1.08 (m, 3 H, HCC*H*$_3$), 0.92 (m, 3 H, HCC*H*$_3$) ppm. ^{13}C NMR ($CDCl_3$): δ = 130.1 (=*C*CH$_3$), 126.12 (=*C*H), 79.09 (*C*HOH), 44.15 (*C*H$_2$), 35.27 (H*C*CH$_3$), 32.20 (H*C*CH$_3$), 26.44 (=C*C*H$_3$), 20.20 (HC*C*H$_3$), 18.13 (HC*C*H$_3$) ppm. $C_9H_{16}O$ (140.22): calcd. C 77.09, H 11.50, O 11.41; found C 76.63, H 11.31, O 12.06.

General Procedure for the Sharpless Asymmetric Dihydroxylation of Dienes 6. 1,3,5-Trimethylcyclohex-4-ene-1,2-diol (12f): AD-mix {$K_3[Fe(CN)_6]$ (9.8 g, 30 mmol), K_2CO_3 (4.12 g, 30 mmol), quinuclidine (11.2 mg, 0.1 mmol), K_2OsO_4·2H_2O (34 mg, 0.1 mmol)}, H_2O (50 mL) and *t*BuOH (50 mL) were placed in a 250-mL flask. The solution was stirred for 5 min and methanesulfonamide (0.95 g, 10 mmol) was added. The orange solution was cooled to 10 °C and **6f** (1.22 g, 10 mmol) was introduced with vigorous stirring. After the mixture had been kept for 0.5 h at room temp., sodium sulfite (10 g) was added and the solution was stirred at room temp. for 0.75 h. The aqueous layer was extracted with EtOAc (3 × 50 mL) and the combined extracts were washed with an NaOH solution (10%, 20 mL) and brine (20 mL). The organic layer was dried with $MgSO_4$ and the solvents were evaporated in vacuo to give the crude diol **12f** as a yellow solid (0.85 g, 54%, 88% *de*). The major diastereoisomer **12f** was obtained pure after recrystallization from petroleum ether (0.56 g, 36%); m.p. 110 °C. IR (film, KBr): $\tilde{\nu}_{max}$ = 3582 cm^{-1} (OH), 2959, 2359, 1549 (C=C), 1461, 1378, 1256, 1006, 784. ^{1}H NMR ($CDCl_3$): δ = 5.20 (m, 1 H, =C*H*), 3.15 (m, 1 H, *H*COH), 2.15−2.30 (m, 3 H, C*H*$_2$, C*H*CH$_3$), 1.92 (s, 1 H, O*H*), 1.80 (s, 1 H, O*H*), 1.69 (m, 3 H, =CC*H*$_3$), 1.34 (s, 3 H, C*H*$_3$COH), 1.16 (d, *J* = 6.6 Hz, 3 H, CHC*H*$_3$) ppm. ^{13}C NMR ($CDCl_3$): δ = 129.82 (=*C*CH$_3$), 125.44 (=*C*H), 78.81 (H*C*OH), 71.27 (HO*C*CH$_3$), 43.74 (*C*H$_2$), 35.53 (H*C*CH$_3$), 25.65 (=C*C*H$_3$), 22.76 (HOC*C*H$_3$), 18.46 (HC*C*H$_3$) ppm. MS (EI): *m*/*z* (%) = 138 (37) [M$^{+\cdot}$ − 18], 123 (75) [M$^{+\cdot}$ − 18 − CH$_3$], 101 (30), 74 (64) [$CH_3COCH_2OH^+$], 55 (32), 43 (100) [CH_3CO^+]. $C_9H_{16}O_2$ (156.22): calcd. C 69.19, H 10.32, O 20.49; found C 68.81, H 10.92, O 20.27.

Sharpless Dihydroxylation of Diene 6f in the Presence of (DHQD)$_2$PHAL. 1,3,5-Trimethylcyclohex-4-ene-1,2-diol (12f): Upon treatment according to the general procedure above, **6f** (0.3 g, 2.45 mmol), when treated at 10 °C for 14 h with (DHQD)$_2$PHAL, afforded the diol **12f** as a yellow solid (0.21 g, 55%, 40% *de*). $ee_{maj.}$ = 70%, $ee_{min.}$ = 18% as measured by HPLC (chiral column Chiracel OD®): 1 mL/min, 220 nm, hexane/*i*PrOH (97:3), t_R (min) = 7, 8, 11, 13.

Sharpless Dihydroxylation of Diene 6f in the Presence of (DHQ)$_2$PHAL. 1,3,5-Trimethylcyclohex-4-ene-1,2-diol (12f): Upon treatment according to the general procedure above, **6f** (0.3 g, 2.45 mmol), when treated at 10 °C for 16 h with (DHQ)$_2$PHAL,

afforded the diol **12f** as a yellow solid (0.20 g, 52%, 60% *de*). $ee_{maj.}$ = 60%, $ee_{min.}$ = 50% measured by HPLC as above.

Sharpless Dihydroxylation of Diene 6f in the Presence of $(DHQ)_2$AQN. 1,3,5-Trimethylcyclohex-4-ene-1,2-diol (12f): Upon treatment according to the general procedure above, **6f** (0.3 g, 2.45 mmol), when treated at 10 °C for 24 h with $(DHQD)_2$PHAL, afforded the diol **12f** as a yellow solid (0.15 g, 40%, 70% *de*). $ee_{maj.}$ = 30%, $ee_{min.}$ = 32% measured by HPLC as above.

Sharpless Dihydroxylation of Diene 6c in the Presence of $(DHQ)_2$PYR. (3-Triisopropylsilyl)cyclohex-4-ene-1,2-diol (12c): Upon treatment according to the general procedure above, **6c** (0.20 g, 0.84 mmol), when treated at 0 °C for 4 h, afforded a mixture (0.27 g) containing diol **12c** [40% *ee*, measured from ^{1}H and ^{19}F NMR of the corresponding Mosher bis(ester)] and the corresponding tetrol as a minor product (80:20, measured after protection as acetonide). This oil was used in the next step without further purification. IR (film, KBr): $\tilde{\nu}_{max}$ = 3569 cm^{-1} (OH), 2945, 2884, 1625 (C=C), 1553, 1499, 1379, 1251, 1103, 829, 820, 700. ^{1}H NMR ($CDCl_3$): δ = 5.78−5.42 (m, 2 H, C*H*=C*H*), 4.09 (m, 1 H, C*H*OH), 3.94−3.73 (m, 1 H, C*H*OH), 3.50 (s, 2 H, O*H*), 2.72−2.63 (m, 3 H, CH_2, C*H*Si), 1.13−1.20 [sept, 3 H, C*H*(CH_3)$_2$], 1.10 [br. s, 18 H, HC(CH_3)$_2$] ppm. ^{13}C NMR ($CDCl_3$): δ = 127.61 (*C*H=CH), 121.53 (CH=*C*H), 70.82 (*C*HOH), 69.02 (*C*HOH), 30.10 (*C*HSi), 27.00 (*C*H_2), 19.40 [HC(*C*H_3)$_2$], 12.12 [H*C*(CH_3)$_2$] ppm. MS (LSIMS): *m*/*z* (%) = 293.2 (100) [M + Na]. HRMS: calcd. for $C_{15}H_{30}OSi$ [M + Na] 293.191279; found 293.192143.

Sharpless Dihydroxylation of Diene 6c in the Presence of Quinuclidine. (3-Triisopropylsilyl)cyclohex-4-ene-1,2-diol (12c): Upon treatment according to the general procedure above, **6c** (0.20 g, 0.84 mmol), when treated at 2 °C for 4 h, afforded a mixture (0.23 g) containing diol **12c** and the corresponding tetrol as a minor product (60:40, measured after protection as acetonide). This oil was used in the next step without further purification.

Sharpless Dihydroxylation of Diene 6d in the Presence of $(DHQD)_2$PHAL. (2,4-Dimethyl-3-trimethylsilyl)cyclohex-4-ene-1,2-diol (12d): Upon treatment according to the general procedure above, **6d** (0.3 g, 1.67 mmol), when treated at 0 °C for 72 h with $(DHQD)_2$PHAL, afforded the diol **12d** as a yellow solid (0.31 g, 87%, > 98% *de*), used in the next step without further purification. *ee* = 27% estimated from ^{1}H and ^{19}F NMR of the corresponding Mosher ester. IR (film, KBr): $\tilde{\nu}_{max}$ = 3422 cm^{-1} (OH), 2956, 1550 (C=C), 1438, 1380, 1304, 1251, 1197, 1144, 1105, 1053, 972, 923, 838, 784, 761, 685. ^{1}H NMR ($CDCl_3$): δ = 5.35 (m, 1 H, =C*H*), 3.52 (t, *J* = 5.2 Hz, 1 H, *H*COH), 2.52−2.22 (m, 2 H, CH_2), 1.85 (s, 1 H, SiC*H*), 1.52 (m, 3 H, =CCH_3), 1.35 (s, 3 H, CH_3COH), 0.10 [br. s, 9 H, Si(CH_3)$_3$] ppm. ^{13}C NMR ($CDCl_3$): δ = 130.00 (=*C*CH$_3$), 118.72 (=*C*H), 76.52 (HO*C*H), 71.14 (HO*C*CH$_3$), 46.67 (H*C*Si), 33.32 (*C*H_2), 25.17 (=C*C*H$_3$), 24.29 (HOC*C*H$_3$), 1.21 [Si(*C*H_3)$_3$], 1.03 [Si(*C*H_3)$_3$] ppm. MS (EI): *m*/*z* (%) = 214 (6) [M$^{+\cdot}$], 196 (9) [M$^{+\cdot}$ − 18], 181 (12) [M$^{+\cdot}$ − 18 − CH_3], 124 (45) [M$^{+\cdot}$ − Si(CH_3)$_3$−OH], 109 (64) [124 −CH_3], 91 (18) [124 − H_2O], 73 (100) [Si(CH_3)$_3^+$], 43 (39) [CH_3CO^+]. HRMS: calcd. for $C_{11}H_{22}O_2Si$ [M + Na]: 214.138910; found 214.138550.

Sharpless Dihydroxylation of Diene 6c in the Presence of Quinuclidine. (2,4-Dimethyl-3-trimethylsilyl)cyclohex-4-ene-1,2-diol (12d): Upon treatment according to the general procedure above, **6c** (0.3 g, 1.67 mmol), when treated at 2 °C for 48 h with quinuclidine, afforded the diol **12d** as an oil (0.30 g, 84%, > 98% *de*), used in the next step without further purification.

Sharpless Dihydroxylation of Diene 6c in the Presence of $(DHQ)_2$PHAL. (2,4-Dimethyl-3-trimethylsilyl)cyclohex-4-ene-1,2-diol (12d): Upon treatment according to the general procedure above, **6c** (0.3 g, 1.67 mmol), when treated at 0 °C for 96 h with $(DHQ)_2$PHAL, afforded the diol **12d** as an oil (0.26 g, 73%, > 98% *de*), used in the next step without further purification. *ee* = 5% measured from ^{1}H and ^{19}F NMR of the corresponding Mosher ester.

Sharpless Dihydroxylation of Diene 6c in the Presence of $(DHQ)_2$PYR. (2,4-Dimethyl-3-trimethylsilyl)cyclohex-4-ene-1,2-diol (12d): Upon treatment according to the general procedure above, **6c** (0.3 g, 1.67 mmol), when treated at 2 °C for 72 h with $(DHQ)_2$PYR, afforded the diol **12d** as an oil (0.30 g, 84%, > 98% *de*), used in the next step without further purification. *ee* = 47% measured from ^{1}H and ^{19}F NMR of the corresponding Mosher ester.

Sharpless Dihydroxylation of Diene 6e in the Presence of Quinuclidine. 3-(Dimethylisopropoxysilyl)cyclohex-4-ene-1,2-diol (12e): Upon treatment according to the general procedure above, **6e** (0.3 g, 1.53 mmol), when treated at 0 °C for 12 h with quinuclidine, afforded the diol **12e** as an oil (0.20 g, 57%, > 98% *de*), used in the next step without further purification. IR (film, KBr): $\tilde{\nu}_{max}$ = 3435 cm^{-1} (OH), 2973, 2252, 1587 (C=C), 1383, 1255, 1118, 1012, 907, 827, 732, 650. ^{1}H NMR ($CDCl_3$): δ = 5.59−5.42 (m, 2 H, C*H*=C*H*), 4.02 [sept, *J* = 6.1 Hz, 1 H, OC*H*(CH_3)$_2$], 3.98 (m, 1 H, *H*COH), 3.90 (dd, *J* = 2.1, *J* = 7.6 Hz, 1 H, *H*COH), 3.36 (s, 2 H, O*H*), 2.37−2.16 (m, 2 H, CH_2), 1.88 (m, 1 H, SiC*H*), 1.16 [d, *J* = 6.1 Hz, 6 H, OCH(CH_3)$_2$], 0.22 [s, 3 H, Si(CH_3)$_2$], 0.13 [s, 3 H, Si(CH_3)$_2$] ppm. ^{13}C NMR ($CDCl_3$): δ = 123.48 (H*C*=*C*H), 122.63 (H*C*=*C*H), 70.00 (H*C*OH), 67.45 (H*C*OH), 67.00 [O*C*H(CH_3)$_2$], 31.94 (Si*C*H), 31.08 (*C*H_2), 25.71 [OCH(*C*H_3)$_2$], −2.18 [Si(*C*H_3)$_2$] ppm.

Sharpless Dihydroxylation of Diene 6e with $(DHQ)_2$PYR. 3-(Dimethylisopropoxysilyl)cyclohex-4-ene-1,2-diol (12e): Upon treatment according to the general procedure above, **6e** (1.93 g, 9.84 mmol), when treated at 0 °C for 12 h with $(DHQ)_2$PYR, afforded the diol **12e** as an oil (1.58 g, 70%, > 98% *de*), used in the next step without further purification. *ee* = 53% measured from ^{1}H and ^{19}F NMR of the corresponding Mosher ester.

1,5-Dimethylcyclohex-4-ene-1,2-diol (12g): According to the general procedure described above for the Sharpless dihydroxylation, diene **6g** (1 g, 9.2 mmol), when treated at 0 °C for 72 h with quinuclidine, afforded diol **12g** as an oil (0.80 g, 61%), used in the next step without further purification. IR (film, KBr): $\tilde{\nu}_{max}$ = 3425 cm^{-1} (OH), 2967, 2912, 2249, 1630 (C=C), 1451, 1379, 1261, 1105, 1048, 907, 731, 649. ^{1}H NMR ($CDCl_3$): δ = 5.23 (m, 1 H, =C*H*), 3.58 (t, *J* = 5.1 Hz, 1 H, *H*COH), 2.28−2.04 (m, 6 H, 2 × CH_2, 2 × O*H*), 1.96 (d, *J* = 1.5 Hz, 3 H, =CCH_3), 1.65 (s, 3 H, CH_3COH) ppm. ^{13}C NMR ($CDCl_3$): δ = 132.48 (=*C*CH$_3$), 116.97 (=*C*H), 72.37 (H*C*OH), 72.00 (HO*C*CH$_3$), 41.92 (CH*C*H$_2$), 31.75 (*C*H_2CH), 24.77 (=C*C*H$_3$), 23.26 (HOC*C*H$_3$) ppm.

Acetonide 13a and Bis(acetonide) 13b: *p*TsOH (catalytic amount) was added to a solution of **12c** (0.24 g, 0.89 mmol) in 2,2-dimethoxypropane (10 mL). The reaction mixture was stirred for 12 h at room temp. and the solvent was removed under vacuum. A saturated solution of $NaHCO_3$ (10 mL) was then added, and the aqueous layer was extracted with diethyl ether (3 × 5 mL). The combined extracts were washed with brine (5 mL) and dried with $MgSO_4$, and the solvent was removed in vacuo. Column chromatography of the residue (cyclohexane) afforded a 60:40 mixture (0.28 g) of **13a** and the corresponding bis(acetonide) **13b**. **13a:** IR (film, KBr): $\tilde{\nu}_{max}$ = 3054 cm^{-1}, 2918, 2978, 2900, 1412, 1415, 1365, 1288, 1215, 1051, 1041, 835, 805, 698. ^{1}H NMR ($CDCl_3$): δ = 6.12−6.08 (m, 1 H, C*H*=CH), 5.93−5.87 (m, 1 H, CH=C*H*), 4.77

(dd, J = 2.1, 5.8 Hz, 1 H, SiCC*H*O), 4.65 (ddd, J = 4.6, 5.8 Hz, 1 H, CH_2CHO), 2.69−2.51 (m, 3 H, CH_2, C*H*Si), 1.80 [s, 3 H, $O_2C(CH_3)_2$], 1.68 [s, 3 H, $O_2C(CH_3)_2$], 1.44 [m, 3 H, $HC(CH_3)_2$], 1.06 [s, 18 H, $CH(CH_3)_2$] ppm. ^{13}C NMR ($CDCl_3$): δ = 128.32 (*C*H=CH), 121.55 (CH=*C*H), 108.23 [$O_2C(CH_3)_2$], 74.61 (H*C*O), 73.62 (H*C*O), 32.17 (CH_2), 29.03 (*C*HSi), 28.05 [$O_2C(CH_3)_2$], 25.15 [$O_2C(CH_3)_2$], 20.18 [$HC(CH_3)_2$], 12.20 [$HC(CH_3)_2$]. **13b:** IR (film, KBr): $\tilde{\nu}_{max}$ = 2945 cm^{-1}, 2899, 1586, 1511, 1401, 1150, 1112, 835, 799, 700. ^{1}H NMR ($CDCl_3$): δ = 4.53 (dd, J = 11.3, 7.0 Hz, 2 H, SiCC*H*O), 4.36 (m, 2 H, CH_2CHO), 2.56 (m, 3 H, CH_2, C*H*Si), 1.78 [s, 6 H, $O_2C(CH_3)_2$], 1.62 [s, 6 H, $O_2C(CH_3)_2$], 1.44 [sept, 3 H, $HC(CH_3)_2$], 1.06 [s, 18 H, $HC(CH_3)_2$] ppm. ^{13}C NMR ($CDCl_3$): δ = 109.00 [$O_2C(CH_3)_2$], 73.77 (*C*HO), 73.76 (*C*HO), 32.14 (CH_2), 28.08 [$O_2C(CH_3)_2$], 27.02 (*C*HSi), 25.08 [$O_2C(CH_3)_2$], 20.10 [$HC(CH_3)_2$], 12.93 [Si*C*H$(CH_3)_2$] ppm. $C_{21}H_{40}O_4Si$ (384.63): calcd. C 65.58, H 10.48, O 16.64, Si 7.30; found C 65.71, H 10.35, O 16.24, Si 7.70.

Preparation of CH_3SO_2NClNa: Solid NaOH (2 g, 0.05 mol) was added to a solution of methanesulfonamide (4.81 g, 0.05 mol) in water (40 mL), followed by *tert*-butyl hypochlorite (5.63 mL). The mixture was stirred overnight. Water and *t*BuOH were then evaporated under reduced pressure to afford the chloramine salt as a white solid (7.5 g, 98%), used in the next step without further purification.

General Procedure for the Sharpless Asymmetric Aminohydroxylation of Dienes 6a−c and 9. *N*-(2-Trimethylsilyl)(6-hydroxycyclohex-3-enyl)methanesulfonamide (14aa), and *N*-(2-Trimethylsilyl)(2-hydroxycyclohex-3-enyl)methanesulfonamide (14ab). Conditions A: In a 100-mL flask equipped with a magnetic stirrer and a thermometer, a solution of $(DHQ)_2PYR$ (0.057 g, 0.065 mmol) in *n*-propanol (8 mL) was added to a solution of CH_3SO_2NClNa (0.60 g, 3.93 mmol) in water (8 mL). After homogenization, $K_2OsO_4{\cdot}2H_2O$ (0.017 g, 0.05 mmol) and then diene **6a** (0.2 g, 1.31 mmol) were added at room temp. and the reaction mixture rapidly turned green. The mixture was stirred for 0.5 h (the color had turned brown at the end of the reaction), sodium sulfide (1.97 g, 15.7 mmol) was then added, and the resulting mixture was stirred for 0.3 h. The aqueous layer was extracted with EtOAc (3 × 50 mL) and the combined extracts were washed with water (20 mL) and brine (2 × 20 mL), and then dried with $MgSO_4$. The solvents were evaporated in vacuo to afford a residue, which was purified by chromatography on silica gel (cyclohexane/EtOAc, 60:40 to 0:100). This afforded a 1:1 mixture of the two regioisomers **14aa** and **14ab** (0.097 g, 28%, > 98% *de*). *ee* = 27% and 3% measured by HPLC (chiral column Chiracel OD®): 0.4 mL/min, 220 nm, hexane/*i*PrOH (9:1), t_R (min) = 16, 23, 28 and 34. IR (film, KBr): $\tilde{\nu}_{max}$ = 3575 cm^{-1} (OH), 1627 (C=C), 1400, 1302, 1250 (S=O), 978, 694 (C−S). ^{1}H NMR ($CDCl_3$): δ = 5.48 (m, 2 H, C*H*=C*H*), 5.01 (s, 1 H, N*H*), 3.97−3.68 (m, 2 H, C*H*OH, C*H*NH), 3.05 (s, 3 H, SO_2CH_3), 3.00 (s, 3 H, SO_2CH_3), 1.82 (m, 3 H, CH_2, C*H*Si), 0.04 [s, 6 H, Si$(CH_3)_3$], 0.03 [s, 3 H, Si$(CH_3)_3$] ppm. ^{13}C NMR ($CDCl_3$): δ = 125.56, 125.3, 121.66, 121.16 (2 × *C*=*C*, 2 isomers), 70.72, 66.98 (2 × *C*HOH, 2 isomers), 57.79, 52.58 (2 × *C*HNH, 2 isomers), 43.60, 42.10 (2 × SO_2CH_3, 2 isomers) 36.48 (*C*HSi), 30.48 (CH_2), 27.21 (CH_2), −2.00 (SiCH_3) ppm. MS (LSIMS): *m*/*z* (%) = 286.0 (100), 240.1 (43). HRMS: calcd. for $C_{10}H_{21}NO_3SSi$ [M + Na] 286.090914; found 286.091633.

***N*-(2-Triisopropylsilyl)(6-hydroxycyclohex-3-enyl)methanesulfonamide (14ba) and *N*-(3-Triisopropylsilyl)(2-hydroxycyclohex-4-enyl)-methanesulfonamide (14bb):** On subjection to conditions A, diene **6c** (0.1 g, 0.42 mmol), after 1 h at room temp. and purification by column chromatography on silica gel (cyclohexane/EtOAc, 70:30 to 0:100), afforded a 66:33 mixture of two regioisomers **14ba** and **14bb** (14 mg, 10%, > 98% *de*). $ee_{maj.}$ = 15% and $ee_{min.}$ < 2% measured by HPLC (chiral column Chiracel OD®): 0.4 mL/min, 220 nm, hexane/*i*PrOH (9:1), t_R (min) = 18, 20, 24 and 27. IR (film, KBr): $\tilde{\nu}_{max}$ = 3595 cm^{-1} (OH), 1725 (C=C), 1399, 1283 (S=O), 962, 903 (C−S). ^{1}H NMR ($CDCl_3$): δ = 5.64 (m, 1 H, C*H*=CH), 5.40 (m, 1 H, CH=C*H*), 4.99 (dd, J = 8.8, 3.9 Hz, 1 H, N*H*), 4.76 (d, J = 8.5 Hz, 1 H, N*H*), 4.09 (m, 1 H, C*H*OH), 3.99 (m, 1 H, C*H*OH), 3.90 (m, 1 H, C*H*NH), 3.69 (m, 0.33 H, C*H*NH), 3.04 (s, 1 H, CH_3), 2.97 (s, 2 H, CH_3), 2.44 (m, 2 H, O*H*, CH_aH_b), 2.04 (m, 2 H, SiC*H*, CH_aH_b), 1.07 [m, 21 H, SiC*H*CH_3)] ppm. ^{13}C NMR ($CDCl_3$): δ = 127.84, 126.92, 121.31, 120.49 (*C*=*C*), 70.06, 67.48 (*C*HOH), 55.89, 52.97 (*C*HNH), 42.52, 42.42 (CH_3), 33.77 (Si*C*H), 30.32, 27.27 (CH_2), 19.43, 19.38 (SiCH*C*H_3), 11.95 (Si*C*HCH_3) ppm. MS (LSIMS): *m*/*z* (%) = 370.1 (100), 304.1 (71), 252.1 (56). HRMS: calcd for $C_{16}H_{33}NO_3SSi$ [M + Na] 370.184814; found 370.184565.

***N*-(6-Hydroxycyclohexyl-3-enyl)methanesulfonamide (14c):** On subjection to conditions A, diene **9** (0.2 g, 2.5 mmol) in the presence of $(DHQ)_2PHAL$, after 4 h at room temp. and purification by column chromatography on silica gel (cyclohexane/EtOAc, 60:40 to 0:100), afforded compound **14c** as a white solid, which was recrystallized from cyclohexane (0.28 g, 57%). *ee* = 36% measured by HPLC (chiral column Chiracel OD®): hexane/*i*PrOH (9:1), 0.4 mL/min, 220 nm, t_R (min) = 46 and 48; m.p. 91 °C (cyclohexane). IR (film, KBr): $\tilde{\nu}_{max}$ = 3565 cm^{-1} (OH), 1689 (C=C), 1406, 1299, 1274 (S=O), 1158 (S=O), 895, 689 (C−S). ^{1}H NMR ([D$_6$]DMSO): δ = 6.42 (s, 1 H, N*H*), 5.14 (m, 2 H, C*H*=C*H*), 4.37 (m, 1 H, C*H*NH), 3.48 (m, 1 H, C*H*OH), 2.56 (s, 3 H, SO_2CH_3), 1.93−1.66 (m, 2 H, CH_2) ppm. ^{13}C NMR ([D$_6$]DMSO): δ = 125.33−125.08 (*C*H=*C*H), 67.33 (H*C*OH), 53.58 (*C*HNH), 40.45 (CH_3SO_2), 33.53 (C_aH_2), 29.02(C_bH_2) ppm. MS (EI): *m*/*z* (%) = 191 (1.4) [M$^+$], 160 (0.6), 136 (16), 95 (58), 80 (100), 58 (20), 30 (45). HRMS: calcd. for $C_7H_{13}O_3NS$ [M$^+$] 191.061615; found 191.061665.

***N*-(6-Hydroxycyclohex-3-enyl)-4-methylbenzenesulfonamide (14d). Conditions B:** On subjection to conditions B, diene **9** (0.5 g, 6.25 mmol) in CH_3CN (45 mL) and water (45 mL) in the presence of $(DHQ)_2PHAL$, after 4 h at room temp. and purification by column chromatography on silica gel (CH_2Cl_2/EtOAc, 95:5 to 80:20), afforded compound **14d** as a white solid, which was recrystallized from cyclohexane (0.77 g, 46%). *ee* = 66% measured by HPLC (chiral column Chiracel OD®): hexane/*i*PrOH (9:1), 0.4 mL/min, 220 nm, t_R (min) = 38 and 40. The spectroscopic data are consistent with those described in the literature.[26]

General Procedure for the Sharpless Asymmetric Aminohydroxylation of Dienes 6c. Conditions D. *N*-[6-Hydroxy-2-(triisopropylsilyl)-cyclohex-3-enyl]-4-methylbenzenesulfonamide (14e): A solution of $(DHQ)_2PYR$ (0.018 g, 0.02 mmol) in *t*BuOH (3 mL) was added to a solution of TsNClNa $3H_2O$ (0.35 g, 1.48 mmol) in water (3 mL) in a 500-mL flask equipped with a magnetic stirrer and a thermometer. After homogenization, $K_2OsO_4{\cdot}2H_2O$ (5.6 mg, 0.017 mmol) and then diene **6c** (0.1 g, 0.42 mmol) were added at room temp. and the reaction mixture rapidly turned green. The mixture was stirred for 1 h (the color had turned brown at the end of the reaction), solid sodium sulfide (0.63 g, 5.04 mmol) was added, and the resulting mixture was stirred for 0.3 h. The aqueous layer was extracted with EtOAc (3 × 50 mL) and the combined extracts were washed with water (20 mL) and brine (2 × 20 mL) and then dried with $MgSO_4$. The solvents were evaporated in vacuo to afford a residue, which was purified by chromatography on silica gel (cyclohexane/EtOAc, 85:15). This afforded the starting diene **6c** and the desired compound **14e** as a colorless oil (0.122 g, 30% corrected

yield, > 98% *de*). *ee* = 66% measured by HPLC (chiral column Chiracel OD®): hexane/*i*PrOH (9:1), 0.4 mL/min, 220 nm, t_R (min) = 26 and 28. IR (film, KBr): $\tilde{\nu}_{max}$ = 3612 cm^{-1} (NH), 1731, 1394, 1257 (S=O), 947, 899 (C−S). ^1H NMR ($CDCl_3$): δ = 7.79 (d, *J* = 8.2 Hz, 2 H, Ph), 7.31 (d, *J* = 8.2 Hz, 2 H, Ph), 5.52 (m, 2 H, C*H*=C*H*), 4.90 (d, *J* = 8.5 Hz, 1 H, N*H*), 3.87 (m, 1 H, C*H*OH), 3.63 (m, 1 H, C*H*NH), 2.45 (m, 2 H, CH_aH_b, O*H*), 2.42 (s, 3 H, PhCH_3), 2.10 (m, 1 H, CH_aH_b), 2.01 (m, 1 H, C*H*Si), 0.95 (m, 21 H, SiC*H*CH_3) ppm. ^{13}C NMR ($CDCl_3$): δ = 143.70, 137.22 (*C*SO_2, *C*CH_3), 129.71 (C_{ar}), 127.28 (*C*=C), 125.83 (C_{ar}), 121.69 (C=*C*), 66.71 (*C*HOH), 55.15 (*C*HNH), 32.91 (*C*HSi), 30.66 (*C*H_2), 21.39 (Ph*C*H_3), 18.74, 18.66 (SiCH*C*H_3), 11.35 (Si*C*HCH$_3$) ppm. MS (LSIMS): *m*/*z* (%) = 446.2 (100), 423.2 (6), 380.1 (32), 328.1 (54), 284.1 (11). HRMS: calcd. for $C_{22}H_{37}NO_3SSi$ [M + Na] 446.216114; found 446.215587.

β-Hydroxysilane 16: Ozone was bubbled at −78 °C through a solution of alkene **15** (0.14 g, 0.52 mmol) in a 1:1 mixture of CH_2Cl_2 (1.5 mL) and MeOH (1.5 mL). After few minutes, the mixture turned deep blue. When no trace of the starting material could be detected by TLC, excess ozone was purged with nitrogen until the blue color had totally disappeared. Me_2S (0.25 mL, 2.63 mmol) was then added, and the solvents were evaporated at 0 °C under reduced pressure. The residue was dissolved in dry THF (10 mL) and a solution of vinylmagnesium bromide in THF (1 M, 1.15 mL, 1.15 mmol) was added dropwise at 0 °C. The reaction mixture was then stirred at room temp. for 12 h and the excess of Grignard reagent was hydrolysed with a saturated solution of NH_4Cl. The organic layer was decanted and the aqueous layer was extracted with EtOAc (4 × 10 mL). The combined extracts were washed with brine (20 mL) and dried with $MgSO_4$, and the solvents were evaporated under vacuum to give an oil, which was purified by chromatography on silica gel (cyclohexane/EtOAc, 70:30), affording **16** as a mixture of stereoisomers (50 mg, 27%). IR (film, KBr): $\tilde{\nu}_{max}$ = 3601 cm^{-1} (OH), 1749, 1257 (C−O), 1021 (C−O). ^1H NMR ($CDCl_3$): δ = 5.83 (m, 2 H, C*H*=CH_2), 5.16 (m, 4 H, CH=CH_2), 4.32 (m, 4 H, C*H*O*H*), 3.74 (m, 2 H, C*H*O), 1.60 (m, 3 H, CH_2, C*H*Si), 1.27 [s, 3 H, C(CH_3)$_2$], 1.21 [s, 3 H, C(CH_3)$_2$], 0.89 [s, 9 H, SiC(CH_3)$_3$], 0.10 [s, 3 H, Si(CH_3)$_2$], 0.08 [s, 3 H, Si(CH_3)$_2$] ppm. ^{13}C NMR ($CDCl_3$): δ = 142.17, 141.35 (CH_2=*C*H), 115.14, 114.42 (*C*H_2=CH), 106.26 [*C*(CH$_3$)$_2$], 76.20, 72.68 (*C*HOH), 70.63, 61.72 (*C*HO), 30.54 (*C*HSi), 30.07 (*C*H_2), 28.34 [C(*C*H$_3$)$_2$], 26.10 [SiC(*C*H$_3$)$_3$], 16.20 [Si*C*(CH$_3$)$_3$], −3.02, −3.63 (Si*C*H$_3$) ppm. MS (LSIMS): *m*/*z* (%) = 379.2 (38) [M + Na], 268.1 (100), 228.1 (63). HRMS: calcd. for $C_{19}H_{36}NaO_4Si$ [M^+ + Na] 379.228058; found 379.226167.

General Procedure for the Ozonolysis of Allylsilanes. Conditions A. Diol 17a: Ozone was bubbled at −78 °C through a solution of alkene **15** (0.54 g, 2.01 mmol) in a 1:1 mixture of CH_2Cl_2 (5 mL) and MeOH (5 mL). After a few minutes, the mixture turned deep blue. When no trace of the starting material could be detected by TLC, excess ozone was purged with nitrogen until the blue color had totally disappeared. Solid $NaBH_4$ (76 mg, 2 mmol) was then added, and the mixture was allowed to warm to room temp. An excess of $NaBH_4$ (0.076 g, 2 mmol) was then introduced, and the mixture was stirred for 12 h. The reaction mixture was then hydrolyzed with a saturated solution of NH_4Cl (5 mL). The organic layer was decanted and the aqueous layer was extracted with EtOAc (5 × 5 mL). The combined extracts were washed with a saturated solution of NH_4Cl (5 mL) and brine (2 × 10 mL), and then dried with $MgSO_4$. The solvents were removed in vacuo and the residue was purified by column chromatography on silica gel (cyclohexane/EtOAc, 70:30), affording the diol **17a** as white crystals, which were recrystallized from a cyclohexane/diethyl ether 95:5 mixture (0.52 g, 85%). M.p. 114 °C (cyclohexane/diethyl ether, 95:5). IR (film, KBr): $\tilde{\nu}_{max}$ = 3225 cm^{-1} (OH), 3154 (OH), 2252, 1793, 1562, 1469, 1381 (C−O), 1095 (C−O), 912, 794, 742, 684. ^1H NMR ($CDCl_3$): δ = 4.37−4.30 (m, 1 H, OC*H*CH$_2$), 4.20 (dd, *J* = 5.1, 10.3 Hz, 1 H, C*H*OCHSi), 3.76−3.90 (m, 2 H, CH_2OH), 3.74−3.66 (m, 2 H, CH_2OH), 1.70 (m, 1 H, SiC*H*), 1.55 (m, 2 H, CH_2), 1.41 [s, 3 H, C(CH_3)$_2$], 1.28 [s, 3 H, C(CH_3)$_2$], 0.89 [s, 9 H, C(CH_3)$_3$], 0.03 [s, 3 H, Si(CH_3)$_2$], 0.00 [s, 3 H, Si(CH_3)$_2$] ppm. ^{13}C NMR ($CDCl_3$): δ = 105.90 [*C*(CH$_3$)$_2$], 89.45 (*C*H_2OH), 78.93 (*C*H_2OH), 61.59 (*C*HO), 61.08 (*C*HO), 31.95 (*C*HSi), 27.91 (*C*H_2), 27.10 [C(*C*H$_3$)$_3$], 25.24 [*C*(CH$_3$)$_2$], 16.82 [*C*(CH$_3$)$_3$], −6.77 [Si(*C*H$_3$)$_2$] ppm. $C_{15}H_{32}O_4Si$ (304.50): calcd. C 58.78, H 11.18, O 20.88, Si 9.16; found C 58.48, H 10.44, O 22.48, Si 8.60.

Diol 17b: On subjection to the ozonolysis conditions A reported for **15**, a 60:40 mixture of **13a** and bis(acetonide) **13b** (0.19 g), after column chromatography on silica gel (cyclohexane/EtOAc, 70:30), afforded recovered bis(acetonide) **13b** (46 mg, 57%) and diol **17b** (86 mg, 30%, 3 steps from **6c**) as a colorless oil. IR (film, KBr): $\tilde{\nu}_{max}$ = 3758 cm^{-1}, 3517, 2893, 2607, 2268, 1973, 1899, 1747, 1694, 1193, 1156, 1093, 1057, 802, 697. ^1H NMR ($CDCl_3$): δ = 4.34 (m, 2 H, 2 × CH_2OH), 4.18 (m, 2 H, 2 × CH_2OH), 3.76 (m, 2 H, 2 × C*H*O), 3.40 (m, 2 H, O*H*), 1.85 (m, 3 H, CH_2, C*H*Si), 1.36 [s, 3 H, O$_2$C(CH_3)$_2$], 1.26 [s, 3 H, O$_2$C(CH_3)$_2$], 1.05 [m, 21 H, *H*C(CH_3)$_2$] ppm. ^{13}C NMR ($CDCl_3$): δ = 107.07 [O$_2$*C*(CH$_3$)$_2$], 81.57 (*C*HO), 80.31 (*C*HO), 63.68 (*C*H_2OH), 61.87 (*C*H_2OH), 33.58 (*C*H_2), 29.40 [O$_2$C(*C*H$_3$)$_2$], 27.90 (*C*HSi), 26.81 [O$_2$C(*C*H$_3$)$_2$], 20.22 [HC(*C*H$_3$)$_2$], 13.12 [H*C*(CH$_3$)$_2$] ppm. MS (LSIMS): *m*/*z* (%) = 369 (63) [M + Na], 310 (10), 281 (5), 271 (34), 227 (100). HRMS: calcd. for $C_{18}H_{38}O_4Si$ [M^+ + Na] 369.240565; found 369.243535.

Diol 17b: On subjection to the ozonolysis conditions A reported for **15**, an 80:20 mixture of **13a** and bis(acetonide) **13b** (0.19 g), after column chromatography on silica gel (cyclohexane/EtOAc, 70:30), afforded recovered bis(acetonide) **13b** (50 mg, 36%) and diol **17b** (0.10 mg, 34%, 3 steps from **6c**) as a colorless oil. Spectroscopic data are identical to those of the sample obtained above.

Mesylate 17c: Methanesulfonyl chloride (23.6 μL, 0.29 mmol) was added at 0 °C to a solution of **17b** (0.1 g, 0.29 mmol) in anhydrous pyridine (5 mL). The mixture was stirred for 8 h at 0 °C and an additional quantity of methanesulfonyl chloride (23.6 μL, 0.29 mmol) was then added to complete the reaction. The mixture was allowed to warm to room temp. and the solvents were evaporated under reduced pressure. The residue was purified by column chromatography on silica gel (cyclohexane/EtOAc, 70:30), affording **17c** as a colorless oil (67 mg, 55%). IR (film, KBr): $\tilde{\nu}_{max}$ = 3788 cm^{-1} (OH), 3534, 2904, 2637, 1779, 1697, 794, 702. ^1H NMR ($CDCl_3$): δ = 4.49 (m, 1 H, CH_aH_bOMs), 4.38 (m, 1 H, CH_aH_b-OMs), 4.29 (m, 2 H, C*H*OH), 3.95 (dd, *J* = 10.5, 3.4 Hz, 1 H, C*H*O), 3.79 (d, *J* = 10.5 Hz, 1 H, CH$_2$C*H*O), 3.01 (s, 3 H, SO$_2$CH_3), 2.26 (m, 2 H, CH_2), 1.75 (m, 1 H, C*H*Si), 1.58 (m, 1 H, O*H*), 1.39 [s, 3 H, C(CH_3)$_2$], 1.31 [s, 3 H, C(CH_3)$_2$], 1.20 (m, 3 H, SiC*H*CH$_3$), 1.08 (m, 18 H, SiCHCH_3) ppm. ^{13}C NMR ($CDCl_3$): δ = 106.35 [*C*(CH$_3$)$_2$], 80.35 (*C*HOCH$_2$), 76.16 (*C*HO), 68.32 (*C*H_2OH), 62.77 (*C*H_2OMs), 37.28 (*C*H_2), 30.52 (*C*H$_3$SO$_2$), 28.60, 26.75 [C(*C*H$_3$)$_2$], 25.80 (*C*HSi), 19.25 (SiCH*C*H$_3$), 12.10 (Si*C*HCH$_3$).

Tosylate 17d: Triethylamine (0.11 mL, 0.75 mmol), *p*TsCl (0.07 g, 0.37 mmol) and 4-DMAP (catalytic amount) were successively added to a solution of alcohol **17b** (0.13 g, 0.37 mmol) in anhydrous CH_2Cl_2 (10 mL). After 12 h at room temp., the reaction mixture was hydrolyzed with distilled water (10 mL). The organic layer was

decanted and the aqueous layer was extracted with CH_2Cl_2 (3 × 10 mL). The combined extracts were washed with brine (2 × 10 mL) and dried with $MgSO_4$, and the solvents were removed in vacuo. The residue was purified by column chromatography on silica gel (cyclohexane/EtOAc, 70:30), to afford **17d** as a colorless oil (0.101 g, 55%). IR (film, KBr): $\tilde{\nu}_{max}$ = 3758 cm^{-1} (OH), 3521, 2899, 2628, 1767, 1701, 1204, 798, 699. ^1H NMR ($CDCl_3$): δ = 7.81 (d, *J* = 8.3 Hz, 2 H, C*H*$_{ar}$), 7.35 (d, *J* = 8.3 Hz, 2 H, C*H*$_{ar}$), 4.27−4.17 (m, 4 H, C*H*$_2$OH, C*H*$_2$OTs), 3.92 (dd, *J* = 4.6, 10.6 Hz, 1 H, C*H*$_a$O), 3.75 (m, *J* = 10.6 Hz, 1 H, C*H*$_b$O), 2.46 (s, 3 H, C*H*$_3$Ph), 2.29−2.11 (m, 1 H, O*H*), 1.85−1.55 (m, 3 H, C*H*$_2$, C*H*Si), 1.30 [s, 3 H, $O_2C(CH_3)_2$], 1.27 [s, 3 H, $O_2C(CH_3)_2$], 1.17−1.10 [m, 21 H Si*CH*(C*H*$_3$)$_2$] ppm. ^{13}C NMR ($CDCl_3$): δ = 145.45 (*C*$_{ar}$CH$_3$), 134.31 (*C*$_{ar}$S), 130.66 (*C*$_{ar}$), 128.88 (*C*$_{ar}$), 107.17 [$O_2C(CH_3)_2$], 81.25 (*C*HO), 77.31 (*C*HO), 69.83 (*C*H$_2$OH), 53.55 (*C*H$_2$OTs), 31.42 (*C*H$_2$), 29.36 [$O_2C(CH_3)_2$], 26.71 [$O_2C(CH_3)_2$], 27.75 (H*C*Si), 22.49 (*C*H$_3$Ph), 20.17 [SiCH(*C*H$_3$)$_2$], 13.04 [Si*C*H(CH$_3$)$_2$].

4-Methyl-*N*-[6-(triisopropylsilyloxy)cyclohex-3-enyl]benzenesulfonamide (18a): A solution of **14d** (0.1 g, 0.37 mmol) in anhydrous THF (2 mL) was added at 0 °C to a suspension of NaH in mineral oil (60%, 60 mg, 1.5 mmol) in THF (10 mL). The reaction mixture was stirred for 0.5 h, chlorotriisopropylsilane (0.34 mL, 1.5 mmol) was then added dropwise at 0 °C, and the reaction mixture was allowed to warm to room temp. After 8 h at room temp., the reaction mixture was cooled to 0 °C and excess sodium hydride was hydrolyzed with a saturated solution of NH_4Cl (10 mL). The organic layer was decanted and the aqueous layer was extracted with diethyl ether (3 × 20 mL). The combined extracts were washed with a saturated solution of NH_4Cl (10 mL) and brine (10 mL) and then dried with $MgSO_4$, and the solvents were removed in vacuo. Column chromatography of the residue on silica gel (cyclohexane/EtOAc, 90:10) afforded **18a** as a colorless oil (0.13 g, 82%). IR (film, KBr): $\tilde{\nu}_{max}$ = 3622 cm^{-1} (NH), 1720, 1401, 1267 (S=O), 907 (C−S). ^1H NMR ($CDCl_3$): δ = 7.79 (d, *J* = 8.9 Hz, 2 H, Ph), 7.31 (d, *J* = 8.9 Hz, 2 H, Ph), 5.55 (br. s, 2 H, C*H*=C*H*), 4.75 (d, *J* = 8.0 Hz, 1 H, N*H*), 4.08 (m, 1 H, C*H*OSi), 3.45 (br. s, 1 H, NC*H*), 2.55 (s, 3 H, C*H*$_3$), 2.20 (m, 4 H, C*H*$_2$), 1.15 (m, 21 H, Si*CH*C*H*$_3$) ppm. ^{13}C NMR ($CDCl_3$): δ = 145.30, 137.25 (*C*$_{ar}$, *C*$_{ar}$CH$_3$), 131.62, 127.43 (*C*$_{ar}$), 124.68, 123.76 (*C*=*C*), 68.87 (*C*HOSi), 57.62 (*C*HNH), 32.22, 37.42 (*C*H$_2$), 22.45 (PhCH$_3$), 20.43, 20.01, 18.99, 18.94, 18.87 (OSi*CH*C*H*$_3$) ppm. MS (LSIMS): *m*/*z* (%) = 423.2 (100). HRMS: calcd. for $C_{22}H_{37}NO_3SSi$ [M^+] 423.226341; found 423.226312.

4-Methyl-*N*-[2-(triisopropylsilyl)-6-(triisopropylsilyloxy)cyclohex-3-enyl)]benzenesulfonamide (18b): A solution of **14e** (0.12 g, 0.28 mmol) in anhydrous THF (2 mL) was added at 0 °C to a suspension of NaH in mineral oil (60%, 45 mg, 1.12 mmol) in THF (10 mL). The reaction mixture was stirred for 0.5 h, chlorotriisopropylsilane (0.25 mL, 1.2 mmol) was then added dropwise at 0 °C, and the reaction mixture was allowed to warm to room temp. After 8 h at room temp., the reaction mixture was cooled to 0 °C and excess sodium hydride was hydrolyzed with a saturated solution of NH_4Cl (10 mL). The organic layer was decanted and the aqueous layer was extracted with diethyl ether (3 × 20 mL). The combined extracts were washed with a saturated solution of NH_4Cl (10 mL) and brine (10 mL) and then dried with $MgSO_4$, and the solvents were removed in vacuo. Column chromatography of the residue on silica gel (cyclohexane/EtOAc, 95:5) afforded **18b** as white crystals, which were recrystallized from cyclohexane (0.16 g, 96%). M.p. 101 °C (cyclohexane). IR (film, KBr): $\tilde{\nu}_{max}$ = 3624 cm^{-1} (NH), 1734, 1261 (S=O), 947, 895 (C−S). ^1H NMR ($CDCl_3$): δ = 7.76 (d, *J* = 8.2 Hz, 2 H, Ph), 7.24 (d, *J* = 8.2 Hz, 2 H, Ph), 5.41 (m, 2 H, C*H*=C*H*), 4.78 (d, *J* = 4.2 Hz, 1 H, N*H*), 4.09 (m, 1 H, C*H*OSi), 3.74 (br. s, 1 H, C*H*NH), 2.38 (m, 1 H, C*H*$_a$H$_b$), 2.39 (s, 3 H, PhC*H*$_3$), 2.13 (m, 1 H, CH$_a$*H*$_b$), 2.01 (m, 1 H, C*H*Si), 1.04 (m, 21 H, OSi-C*HCH*$_3$), 0.96 (m, 21 H, SiC*HCH*$_3$) ppm. ^{13}C NMR ($CDCl_3$): δ = 143.70, 137.20 (*C*$_{ar}$, *C*$_{ar}$CH$_3$), 130.28, 128.21 (*C*$_{ar}$), 127.68, 121.31 (*C*=*C*), 68.28 (*C*HOSi), 56.54 (*C*HNH), 32.22 (*C*H$_2$), 22.38 (PhCH$_3$), 20.03, 19.88, 18.94, 18.90, 18.85 (OSi*CH*C*H*$_3$), 13.27, 12.68 (Si*CH*C*H*$_3$) ppm. MS (LSIMS): *m*/*z* (%) = 579.3 (10), 536.2 (57), 409.3 (30), 328.1 (100), 284.1 (32). HRMS: calcd. for $C_{31}H_{57}NO_3SSi$ [M^+] 579.359774; found 579.359211.

Diol 19a: On subjection to the ozonolysis conditions A reported for **15**, allylsilane **18a** (0.36 g, 0.86 mmol), after column chromatography on silica gel (cyclohexane/EtOAc, 60:40), afforded diol **19a** (0.16 g, 40%) as a colorless oil. IR (film, KBr): $\tilde{\nu}_{max}$ = 3858 cm^{-1}, 3625 (NH), 3600 (OH), 1395 (C−O), 1076 (C−O), 946, 697. ^1H NMR ($CDCl_3$): δ = 7.73 (d, *J* = 8.2 Hz, 2 H, Ph), 7.28 (d, *J* = 8.2 Hz, 2 H, Ph), 4.98 (d, *J* = 8.8 Hz, 1 H, N*H*), 3.63 (m, 6 H, 2 × C*H*$_2$OH, C*H*NH, C*H*OSi), 2.75 (br. s, 1 H, O*H*), 2.38 (s, 3 H, PhC*H*$_3$), 2.09 (br. s, 1 H, O*H*), 1.71 (m, 4 H, 2 × C*H*$_2$), 0.93 (m, 21 H, Si*CH*C*H*$_3$) ppm. ^{13}C NMR ($CDCl_3$): δ = 143.45, 137.93 (*C*$_{ar}$, *C*$_{ar}$CH$_3$), 129.62, 126.80 (Ph), 73.07 (*C*HNH), 58.60, 58.34 (*C*H$_2$OH), 53.88 (*C*HOSi), 36.33, 30.31 (*C*H$_2$), 21.40 (*C*H$_3$), 18.03, 17.98 (SiCH*C*H$_3$), 12.54 (Si*C*HCH$_3$) ppm. MS (LSIMS): *m*/*z* (%) = 482.2 (100) [M + Na], 416.2 (6.8), 268.1 (10). HRMS: calcd. for $C_{22}H_{41}NO_5SSi$ [M^+ + Na] 482, 237244; found 482, 237421.

Diol 19b: On subjection to the ozonolysis conditions A reported for **15**, allylsilane **18b** (0.18 g, 0.31 mmol), after column chromatography on silica gel (cyclohexane/EtOAc, 60:40), afforded diol **19b** (0.143 mg, 75%) as a colorless oil. IR (film, KBr): $\tilde{\nu}_{max}$ = 3858 cm^{-1}, 3625 (NH), 3600 (OH), 1395 (C−O), 1076 (C−O), 946, 697. ^1H NMR ($CDCl_3$): δ = 7.73 (d, *J* = 8.2 Hz, 2 H, Ph), 7.28 (d, *J* = 8.2 Hz, 2 H, Ph), 4.95 (d, *J* = 8.8 Hz, 1 H, N*H*), 3.65 (m, 6 H, 2 × C*H*$_2$OH, C*H*NH, C*H*OSi), 2.80 (br. s, 1 H, O*H*), 2.42 (s, 3 H, PhC*H*$_3$), 2.00 (br. s, 1 H, O*H*), 1.66 (m, 3 H, SiC*H*, C*H*$_2$), 0.92 (m, 42 H, Si*CH*C*H*$_3$) ppm. ^{13}C NMR ($CDCl_3$): δ = 143.87, 138.01 (*C*$_{ar}$, *C*$_{ar}$CH$_3$), 129.96, 126.85 (Ph), 72.99 (*C*HNH), 58.75, 58.21 (*C*H$_2$OH), 54.01 (*C*HOSi), 36.01 (*C*H$_2$), 21.23 (*C*H$_3$), 19.25, 18.04 (SiCH*C*H$_3$), 12.54, 11.13 (Si*C*HCH$_3$, Si*C*H) ppm. MS (LSIMS): *m*/*z* (%) = 615.4 (100) [M + Na], 610.2 (8), 457.1 (25). HRMS: calcd. for $C_{31}H_{61}NO_5SSi_2$ [M^+ + Na] 615.380901; found 615.380954.

General Procedure for Ozonolysis of Olefins 18a−b. Conditions B. Oxepane 20a: Ozone was bubbled at −78 °C through a solution of alkene **18a** (0.158 g, 0.37 mmol) in a 1:1 mixture of CH_2Cl_2 (5 mL) and MeOH (5 mL). After a few minutes, the mixture turned deep blue. When no trace of the starting material could be detected by TLC, excess ozone was purged with nitrogen until the blue color had totally disappeared. Powdered $NaBH_4$ (14 mg, 0.37 mmol) was then added, and the mixture was allowed to warm to room temp. and stirred for 12 h. The reaction mixture was then hydrolyzed with a saturated solution of NH_4Cl (5 mL). The organic layer was decanted and the aqueous layer was extracted with EtOAc (5 × 5 mL). The combined extracts were washed with a saturated solution of NH_4Cl (5 mL) and brine (2 × 10 mL), and then dried with $MgSO_4$. The solvents were removed in vacuo and the residue was purified by column chromatography on silica gel (cyclohexane/EtOAc, 80:20), affording the lactol **20a** as a colorless oil (50 mg, 30%). IR (film, KBr): $\tilde{\nu}_{max}$ = 3886 cm^{-1} (OH), 3754 (NH), 1426 (C−O), 1267 (S=O), 904 (C−S), 762. ^1H NMR ($CDCl_3$): δ = 7.76 (d, *J* = 8.3 Hz, 2 H, Ph), 7.27 (d, *J* = 8.3 Hz, 2 H, Ph), 5.20 (t, *J* = 6.5 Hz, 1 H, NC*H*), 4.13 (t, *J* = 2.7 Hz, 1 H, C*H*OH), 4.02 (m, 1 H, N*H*), 3.75 (m, 3 H, OC*H*$_2$, C*H*OSi), 2.83 (br. s, 1 H, O*H*),

2.41 (s, 3 H, PhCH_3), 2.10 (dd, J = 3.0, 6.7 Hz, 2 H, CH_2CHN), 1.93 (m, 1 H, CH_aH$_b$), 1.65 (m, 1 H, CH$_a$$H_b$), 0.87 {m, 21 H, Si[C$H$(C$H_3$)$_2$]$_3$} ppm. ^{13}C NMR ($CDCl_3$): δ = 144.77, 135.93 ($CSO_2$, CCH$_3$), 130.69, 130.06, 129.38, 128.62 (CH_{ar}), 86.25 (CNH), 77.96 (CHOH), 77.33 (CHOSi), 67.77 (OCH$_2$), 42.56 (CH$_2$), 38.69 (CH$_2$CHN), 22.37 (PhCH_3), 18.77 {Si[CH(CH$_3$)$_2$]$_3$}, 12.58 {Si[CH(CH$_3$)$_2$]$_3$} ppm. MS (LSIMS): m/z (%) = 480.1 (30) [M + Na], 440.1 (100), 414 (13), 248 (7). HRMS: calcd. for $C_{22}H_{39}NO_5SSi$ [M^+ + Na] 480.221594; found 480.221085.

Oxepane 20b: On subjection to the ozonolysis conditions B reported for **18a**, allylsilane **18b** (0.159 g, 0.27 mmol), after column chromatography on silica gel (cyclohexane/EtOAc, 80:20), afforded lactol **20b** (90 mg, 54%) as a colorless oil. IR (film, KBr): $\tilde{\nu}_{max}$ = 3864 cm^{-1} (OH), 3789 (NH), 1410 (C−O), 1275 (S=O), 919 (C−S). ^{1}H NMR ($CDCl_3$): δ = 7.71 (d, J = 8.3 Hz, 2 H, Ph), 7.22 (d, J = 8.3 Hz, 2 H, Ph), 5.44 (m, 1 H, NCH), 4.32 (d, J = 3.0 Hz, 1 H, CHOH), 4.14 (d, J = 3.6 Hz, 1 H, NH), 3.92 (m, 2 H, OCH_2), 3.88 (d, J = 2.7 Hz, 1 H, CHOSi), 2.93 (m, 1 H, OH), 2.34 (s, 3 H, PhCH_3), 2.18 (m, 3 H, CH_2, CHSi), 1.10 (m, 21 H, OSiCHCH_3), 0.81 (m, 21 H, SiCHCH_3) ppm. ^{13}C NMR ($CDCl_3$): δ = 143.64, 134.51 (CSO$_2$, CCH$_3$), 129.61, 127.6 (Ph), 85.05 (CHNH), 74.70 (CHOH), 71.51 (CHOSi), 60.95 (OCH$_2$), 43.19 (CH$_2$), 34.73 (CHSi), 21.32 (PhCH$_3$), 19.20, 19.07, 17.83, 17.81 (SiCHCH$_3$), 12.37, 11.27 (SiCH) ppm. MS (LSIMS): m/z (%) = 636.3 (100) [M + Na], 354.2 (14). HRMS: calcd. for $C_{31}H_{59}NO_5SSi_2$ [M^+ + Na] 636.355023; found 636.355284.

Thionocarbonate 21a: A solution of thiocarbodiimidazole (0.17 g, 0.93 mmol) in dry toluene (25 mL) was added dropwise to a solution of diol **12d** (0.1 g, 0.46 mmol) in toluene (5 mL) and the mixture was stirred for 8 h at room temp. The solvent was then evaporated under vacuum and the residue was dissolved in EtOAc (20 mL). The yellow mixture was washed with HCl solution (10%), water (10 mL) and finally with brine (3 × 10 mL). The organic layer was dried with $MgSO_4$ and the solvent was removed in vacuo. Filtration of the residue through a short pad of silica gel (petroleum ether/EtOAc, 80:20) afforded **21a** as a brown solid, which was recrystallized from petroleum ether/diethyl ether (0.11 g, 93%). M.p. 103 °C (petroleum ether/diethyl ether, 95:5). IR (film, KBr): $\tilde{\nu}_{max}$ = 3787 cm^{-1}, 3150, 2784, 2223, 1657, 1547, 1310, 1238, 1194, 1163, 1072, 918, 784, 761. ^{1}H NMR ($CDCl_3$): δ = 5.48 (d, J = 6 Hz, 1 H, =CH), 4.80 (d, J = 4.9 Hz, 1 H, HCO), 2.41−2.28 (m, 2 H, CH_2), 2.18 (s, 1 H, SiCH), 1.75 (m, 3 H, =CCH_3), 1.71 (s, 3 H, CH_3C), 0.15 [s, 9 H, Si(CH_3)$_3$] ppm. ^{13}C NMR ($CDCl_3$): δ = 190.46 (C=S), 138.38 (=CCH$_3$), 113.94 (=CH), 94.24 (HCO), 85.55 (CH$_3$$C$O), 41.75 ($CH_2$), 28.35 (Si$C$H), 26.24 ($CH_3$CO), 24.58 (=C$CH_3$), 0.52 [Si($CH_3$)$_3$] ppm. MS (EI): m/z (%) = 256 (0.4), 179 (4), 107 (68), 91 (30), 73 (100), 45 (13). HRMS: calcd. for $C_{12}H_{20}O_2SSi$ [M^+] 256.095330; found 256.056230.

Thionocarbonate 21b: A solution of thiocarbodiimidazole (0.46 g, 1.86 mmol) in dry toluene (7 mL) was added dropwise to a solution of diol **12f** (0.1 g, 0.64 mmol) in toluene (5 mL) and the mixture was stirred for 8 h at room temp. The solvent was then evaporated under vacuum and the residue was dissolved in EtOAc (20 mL). The yellow mixture was washed with HCl solution (10%), water (10 mL) and finally brine (3 × 10 mL). The organic layer was dried with $MgSO_4$ and the solvent was removed in vacuo. Filtration of the residue through a short pad of silica gel (petroleum ether/EtOAc, 80:20) afforded **21b** as a yellow solid, which was recrystallized from petroleum ether/diethyl ether (0.11 g, 86%). M.p. 75 °C (petroleum ether/diethyl ether, 95:5). IR (film, KBr): $\tilde{\nu}_{max}$ = 2963 cm^{-1}, 2368, 2217, 1799, 1732, 1669, 1455, 1313, 1285, 1268, 1088, 1020, 953, 799, 699, 668. ^{1}H NMR ($CDCl_3$): δ = 5.38 (m, 1 H, =CH), 4.21 (d, J = 5.1 Hz, 1 H, HCO), 2.50 (m, 1 H, HCCH$_3$), 2.26 (s, 2 H, CH_2), 1.72 (m, 3 H, =CCH_3), 1.52 (s, 3 H, OCCH_3), 1.09 (d, J = 7.3 Hz, 3 H, HCCH_3) ppm. ^{13}C NMR ($CDCl_3$): δ = 191.12 (C=S), 133.55 (=CCH$_3$), 124.03 (=CH), 90.63 (HCO), 89.68 (CH$_3$$C$O), 36.65 ($CH_2$), 33.81 ($CH_3$CO), 27.26 (=C$CH_3$), 23.18 (H$CCH_3$), 16.63 (HC$CH_3$) ppm. MS (EI): m/z (%) = 198 (81), 138 (45), 121.0 (100), 95 (54), 43 (52). HRMS: calcd. for $C_{10}H_{14}O_2S$ [M^+] 198.071452; found 198.071144.

Thionocarbonate 22: Anhydrous pyridine (0.15 mL, 1.92 mmol) was added at room temp. to a solution of diol **12f** (0.1 g, 0.64 mmol) in dry CH_2Cl_2 (10 mL). The mixture was then cooled to 0 °C and a solution of PhOCSCl (0.2 mL, 1.28 mmol) in CH_2Cl_2 (2 mL) was added dropwise at 0 °C. The reaction mixture was stirred at room temp. for 12 h, and was then hydrolyzed with water (5 mL). The organic layer was decanted and the aqueous layer was extracted with CH_2Cl_2 (2 × 10 mL). The combined extracts were then washed with brine (10 mL) and dried with $MgSO_4$, and the solvents were evaporated under vacuum. The residue was purified by chromatography on silica gel (cyclohexane/EtOAc, 9:1) to afford **22** as a yellow oil (0.184 g, 98%), used in the next step without further purification. ^{1}H NMR ($CDCl_3$): δ = 6.81 (m, 5 H, Ar), 5.37 (m, 1 H, =CH), 4.18 (d, J = 5.2 Hz, 1 H, CHOCS), 2.72 (s, 1 H, OH), 2.43 (m, 3 H, CHCH$_3$, CH_2), 1.73 (s, 3 H, CH_3COH), 1.53 (s, 3 H, CH_3C=), 1.10 (d, J = 7.1 Hz, 3 H, CH_3CH) ppm. ^{13}C NMR ($CDCl_3$): δ = 191.7 (C=S), 157.2 (OC_{ar}), 141.5 (C=C), 130.2 (C_{ar}), 121.4 (C_{ar}), 124.5 (C=C), 116.7 (C_{ar}), 91.5 (CHO), 72.2 (CH$_3$$C$OH), 44.1 (CH$_2$), 24.3 ($CHCH_3$), 23.1, 22.4, 14.8 (CH$CH_3$, CH$_3$C=, CH$_3$COH).

General Procedure for Acetylation of Diols 12a−f. 6-Hydroxy-2,4,6-trimethylcyclohex-3-enyl Acetate (23a): DMAP (10 mg), triethylamine (0.26 mL, 1.92 mmol), and then acetic anhydride (0.18 mL, 1.92 mmol) were added to a solution of diol **12f** (0.1 g, 0.64 mmol) in anhydrous CH_2Cl_2 (20 mL). The reaction mixture was stirred for 2 h at room temp. and then hydrolyzed with water (10 mL). The organic layer was decanted and the aqueous layer was extracted with CH_2Cl_2 (3 × 20 mL). The combined extracts were washed with brine (20 mL) and dried with $MgSO_4$, and the solvent was removed in vacuo. Column chromatography on silica gel (cyclohexane/EtOAc, 70:30) afforded the acetate **23a** as a yellow oil (0.12 g, 95%), used in the next step without further purification. IR (film, KBr): $\tilde{\nu}_{max}$ = 3472 cm^{-1}, 2966, 2359, 1743, 1453, 1375, 1237, 1035, 915, 876, 786, 761. ^{1}H NMR ($CDCl_3$): δ = 5.11 (m, 1 H, =CH), 4.60 (d, J = 9.4 Hz, 1 H, HCOAc), 2.41 (s, 1 H, OH), 2.23−2.16 (m, 1 H, HCCH$_3$), 2.06 (s, 3 H, OCOCH_3), 2.00 (m, 2 H, CH_2), 1.58 (s, 3 H, =CCH_3), 1.09 (s, 3 H, HOCCH_3), 0.89 (d, J = 7.0 Hz, 3 H, HCCH_3) ppm. ^{13}C NMR ($CDCl_3$): δ = 170.98 (C=O), 130.40 (=CCH$_3$), 125.13 (=CH), 80.42 (HCOAc), 70.72 (HOCCH$_3$), 44.24 (CH$_2$), 32.78 (HCCH$_3$), 25.73 (=CCH$_3$), 22.90 (HOCCH$_3$), 20.90 (OCOCH$_3$), 18.10 (HCCH$_3$) ppm.

2-Benzyloxy-1,3,5-trimethylcyclohex-4-en-1-ol (23b): Diol **12f** (0.1 g, 0.64 mmol) and KI (0.2 g, 1.23 mmol) were added at 0 °C to a suspension of NaH in mineral oil (60%, 0.05 g, 1.25 mmol) in anhydrous THF (10 mL). After dropwise addition of a solution of benzyl bromide (0.23 mL, 1.92 mmol) in THF (5 mL), the reaction mixture was allowed to warm slowly to room temp. and stirred overnight. The flask was then cooled to 0 °C and excess sodium hydride was hydrolyzed by careful addition of a saturated solution of NH_4Cl (10 mL). The organic layer was decanted and the aqueous layer was extracted with diethyl ether (3 × 20 mL). The combined extracts were washed with brine (2 × 20 mL) and dried with $MgSO_4$, and the solvents were removed in vacuo. Column chromatography on silica gel (cyclohexane/EtOAc, 80:20) afforded **23b** as

a brown solid, which was recrystallized from cyclohexane (0.12 g, 75%). M.p. 140 °C (cyclohexane). IR (film, KBr): $\tilde{\nu}_{max}$ = 3576 cm^{-1}, 3013, 2931, 1498, 1452, 1502, 1116, 1057, 699. ^1H NMR ($CDCl_3$): δ = 7.43−7.22 (m, 5 H, H_{ar}), 5.22 (m, 1 H, C*H*=C), 4.74 (s, 2 H, OCH_2), 3.10 (d, *J* = 8.4 Hz, 1 H, C*H*O), 2.61−2.54 (s, 1 H, O*H*), 2.34 (m, 1 H, *H*CCH$_3$), 2.20 (s, 2 H, CH_2), 1.73 (s, 3 H, = CCH_3), 1.41 (s, 3 H, HOCCH_3), 1.18 (d, *J* = 7.9 Hz, 3 H, HCCH_3) ppm. ^{13}C NMR ($CDCl_3$): δ = 137.59 (C_{ar}CH$_2$), 131.23 (C_{ar}), 129.40 (H*C*=), 128.90 (C_{ar}), 126.99 (H*C*=), 124.69 (C_{ar}), 88.68 (*C*OCH$_2$), 74.50 (OCH$_2$Ph), 68.15 (CH$_3$*C*OH), 44.62 (CH$_2$), 35.43 (H*C*CH$_3$), 27.84 (=C*C*H$_3$), 23.99 (HOC*C*H$_3$), 19.91 (HC*C*H$_3$) ppm. MS (LSIMS): *m*/*z* (%) = 269.2 (100), 229.2 (73). HRMS: calcd. for $C_{16}H_{22}O_2$ [M^+ + Na] 269.151750; found 269.151769.

2-Hydroxy-2,4-dimethylcyclohex-3-enyl Acetate (23c): On subjection to the general acetylation procedure reported for the preparation of **23a**, diol **12g** (0.1 g, 0.69 mmol), after column chromatography (cyclohexane/EtOAc, 70:30), afforded the acetate **23c** as a yellow oil (0.12 g, 95%). IR (film, KBr): $\tilde{\nu}_{max}$ = 3458 cm^{-1}, 2964, 1742, 1372, 1260, 1101, 1031, 789, 762. ^1H NMR ($CDCl_3$): δ = 5.24 (m, 1 H, =C*H*), 4.81 (m, 1 H, *H*COAc), 2.24 (m, 3 H, = CH−CH_2), 2.13 [m, 2 H, =C(CH$_3$)−CH_2], 2.06 (s, 3 H, OCOCH_3), 1.63 (s, 3 H, =CCH_3), 1.18 (s, 3 H, HOCCH_3) ppm. ^{13}C NMR ($CDCl_3$): δ = 171.52(*C*=O), 131.52 (=*C*CH$_3$), 117.28 (=*C*H), 74.92 (H*C*OAc), 70.00 (HO*C*CH$_3$), 43.07 [=C(CH$_3$)−*C*H$_2$], 28.56 (=CH*C*H$_2$), 25.25 (=C*C*H$_3$), 23.13 (HOC*C*H$_3$), 21.22 (OCO*C*H$_3$) ppm.

General Procedure for the Ozonolysis of Alkenes 23a−c. Lactol 24a: Ozone was bubbled at −78 °C through a solution of **23a** (0.1 g, 0.50 mmol) in a 5:1 mixture of CH_2Cl_2 (15 mL) and MeOH (13 mL). After a few minutes, the solution turned deep blue. When no trace of the starting material could be detected by TLC, excess ozone was purged with nitrogen until the blue color had totally disappeared. Me_2S (0.18 mL, 2.5 mmol) was then added, and the mixture was allowed to warm to 0 °C. The solvents were evaporated under reduced pressure and the residue was purified by column chromatography on silica gel (cyclohexane/EtOAc, 70:30), affording the lactol **24a** as a brown oil (87 mg, 76%, 20% *de*). IR (film, KBr): $\tilde{\nu}_{max}$ = 3886 cm^{-1} (OH), 2927, 1742 (C=O), 1728 (C=O), 1567, 1424, 1396 (C−O), 1271 (C−O), 1045 (C−O), 791, 762. ^1H NMR ($CDCl_3$): δ = 5.13 (d, *J* = 10.3 Hz, 1 H, HOC*H*), 4.96 (d, *J* = 8.1 Hz, 1 H, *H*COAc), 4.42 (d, *J* = 9.1 Hz, 1 H, *H*COAc), 3.20 (m, 1 H, O*H*), 2.97 (d, *J* = 17.7 Hz, 1 H, CH_aH$_b$), 2.83 (d, *J* = 17.7 Hz, 1 H, CH$_a$$H_b$), 2.77 (d, *J* = 15.7 Hz, 1 H, CH_aH$_b$), 2.64 (d, *J* = 15.7 Hz, 1 H, CH$_a$$H_b$), 2.40 (m, 1 H, *H*CCH$_3$), 2.25 (m, 1 H, *H*CCH$_3$), 2.14 (s, 3 H, OCOC$H_3$), 2.12 (s, 3 H, OCOC$H_3$), 2.06 (s, 3 H, C$H_3$CO), 2.05 (s, 3 H, C$H_3$CO), 1.26 (s, 3 H, C$H_3$), 1.12 (d, *J* = 7.1 Hz, 3 H, CH_3CH), 1.06 (d, *J* = 6.8 Hz, 3 H, CH_3CH), 1.04 (s, 3 H, CH_3) ppm. ^{13}C NMR ($CDCl_3$): δ = 209.27 (CH$_3$*C*OCH$_2$), 171.25 (O*C*OCH$_3$), 98.19 (H*C*OH), 80.48 (H*C*OAc), 53.03 (CH$_3$*C*CH$_2$), 52.61 (*C*H$_2$), 42.93 (H*C*CH$_3$), 31.51 (*C*H$_3$COCH$_2$), 23.04 (*C*H$_3$CCH$_2$), 20.79 (OCO*C*H$_3$), 11.10 (*C*H$_3$CH) ppm. MS (EI): *m*/*z* (%) = 231 (3) [$M^{+\cdot}$ − OH], 170 (4.5), 152 (8), 130 (29), 113 (20), 101 (57), 82 (29), 43 (100). $C_{11}H_{18}O_5$ (230.26): calcd. C 57.38, H 7.88, O 34.74; found C 57.68, H 8.08, O 34.24.

Lactol 24b: On subjection to the ozonolysis conditions C, olefin **23b** (0.16 g, 0.64 mmol), after column chromatography on silica gel (cyclohexane/EtOAc, 80:20), afforded lactol **24b** as yellow crystals recrystallized from petroleum ether (0.13 g, 76%, 20% *de*). M.p. 81 °C (petroleum ether). IR (film, KBr): $\tilde{\nu}_{max}$ = 3886 cm^{-1} (OH), 2934, 1752 (C=O), 1610, 1557, 1520, 1494, 1400 (C−O), 1275 (C−O), 791, 762. ^1H NMR ($CDCl_3$): δ = 7.30 (m, 5 H, H_{ar}), 5.08 (dd, *J* = 7.9, 5.1 Hz, 1 H, *H*COH), 4.91 (dd, *J* = 6.4, 4.8 Hz, 1 H, *H*COH), 4.61 (d, *J* = 11.4 Hz, 1 H, OCH_aH$_b$), 4.48 (d, *J* = 11.4 Hz, 1 H, OCH$_a$$H_b$), 4.00 (d, *J* = 10.3 Hz, 1 H, *H*COBn), 3.70 (m, 2 H, *H*COBn, O*H*), 2.71 (d, *J* = 16.7 Hz, 1 H, CH_aH$_b$), 2.64 (d, *J* = 14.3 Hz, 1 H, CH_aH$_b$), 2.48 (d, *J* = 14.3 Hz, 1 H, CH$_a$$H_b$), 2.39 (d, *J* = 16.7 Hz, 1 H, CH$_a$$H_b$), 2.27 (m, 1 H, *H*CCH$_3$), 2.14 (s, 3 H, C$H_3$CO), 2.03 (s, 3 H, C$H_3$CO), 1.36 (s, 3 H, C$H_3CCH_2$), 1.14 (s, 3 H, C$H_3CCH_2$), 1.13 (d, *J* = 5.7 Hz, 3 H, HCCH_3), 1.11 (d, *J* = 7.0 Hz, 3 H, HCCH_3) ppm. ^{13}C NMR ($CDCl_3$): δ = 209.24 (*C*=O), 128.92, 128.81, 128.54, 128.39, 128.21, 128.13 (Ph), 102.75, 98.62 (*C*HOH), 88.45, 86.18 (H*C*OBn), 74.15, 73.61 (O*C*H$_2$), 66.91 (CH$_3$*C*CH$_2$), 53.70, 53.14 (*C*H$_2$C=O), 44.95, 44.42 (H*C*CH$_3$), 32.76, 32.12 (*C*HCH$_3$), 23.93, 23.75 (*C*H$_3$CO), 21.98 (*C*H$_3$CCH$_2$) ppm. $C_{16}H_{22}O_4$ (278.34): calcd. C 69.04, H 7.97, O 22.99; found C 69.05, H 8.12, O 22.83.

Lactol 24c: On subjection to the ozonolysis conditions C, olefin **23c** (0.1 g, 0.54 mmol), after column chromatography on silica gel (cyclohexane/EtOAc, 70:30), afforded lactol **24c** as a brown oil (36 mg, 32%, 20% *de*). IR (film, KBr): $\tilde{\nu}_{max}$ = 3890 cm^{-1} (OH), 2900, 1745 (C=O), 1732 (C=O), 1468, 1402 (C−O), 1287 (C−O), 1100 (C−O), 790, 782. ^1H NMR ($CDCl_3$): δ = 5.21 (dd, *J* = 3.4, 8.6 Hz, 1 H, *H*COH), 5.01 (dd, *J* = 1.9, 5.6 Hz, 1 H, *H*COAc), 4.94 (dd, *J* = 1.9, 5.6 Hz, 1 H, *H*COAc), 3.30 (s, 2 H, CH_2CO), 2.68 (m, 2 H, CH_2), 2.13 (s, 3 H, COCH_3), 2.04 (s, 3 H, OCOCH_3), 1.27 (s, 3 H, CH_3) ppm. ^{13}C NMR ($CDCl_3$): δ = 207.55 (CH$_2$*C*O), 171.77 (O*C*OCH$_3$), 84.73 (H*C*OH), 78.60 (H*C*OAc), 55.92 (CH$_3$*C*CH$_2$), 53.88 (*C*H$_2$CO), 39.79 (HC*C*H$_2$), 32.97 (*C*H$_3$CCH$_2$), 23.50 (*C*H$_3$COCH$_2$), 21.95 (OCO*C*H$_3$) ppm. $C_{11}H_{18}O_4$ (214.26): calcd. C 55.55, H 7.46, O 36.99; found C 55.30, H 7.66, O 37.04.

General Procedure for the Ozonolysis of Alkenes 23a−c. Conditions D. Acetal 25a: Ozone was bubbled at −78 °C through a solution of alkene **23a** (0.1 g, 0.50 mmol) in a 5:1 mixture of CH_2Cl_2 (2.5 mL) and MeOH (0.5 mL). When no trace of the starting material could be detected by TLC, excess ozone was purged with nitrogen until the blue color had totally disappeared. Me_2S (0.19 mL, 2.5 mmol) was added and the mixture was allowed to warm to room temp. The solvents were evaporated under reduced pressure and the residue was purified by column chromatography on silica gel (cyclohexane/EtOAc, 70:30), affording the acetal **25a** as a colorless oil (90 mg, 73%, > 98% *de*). IR (film, KBr): $\tilde{\nu}_{max}$ = 1739 cm^{-1} (C=O), 1732 (C=O), 1572, 1403, 1278 (C−O), 795, 754. ^1H NMR ($CDCl_3$): δ = 4.89 (d, *J* = 6.8 Hz, 1 H, C*H*OH), 4.57 (d, *J* = 3.9 Hz, 1 H, C*H*OAc), 3.31 (s, 3 H, OCH_3), 2.75 (d, *J* = 15 Hz, 1 H, CH_aH$_b$), 2.61 (d, *J* = 15 Hz, 1 H, CH$_a$$H_b$), 2.20 (m, 1 H, CH$_3$C*H*), 2.15 (s, 3 H, OCOCH_3), 2.05 (s, 3 H, CH_3CO), 1.25 (s, 3 H, CH_3), 1.13 (d, *J* = 7.1 Hz, 3 H, CH_3CH) ppm. ^{13}C NMR ($CDCl_3$): δ = 207.1 (*C*=O), 171.0 (O*C*=O), 109.28 (CH$_3$O*C*), 82.42(*C*OAc), 82.26 (*C*CH$_2$), 55.46 (*C*H$_2$), 53.46 (OCH$_3$), 45.25 (CH$_3$*C*H), 31.94 (*C*H$_3$C=O), 22.43 (OCO*C*H$_3$), 21.04 (*C*H$_3$CCH$_2$), 15.45 (CH*C*H$_3$) ppm.

Acetal 25b: On subjection to the ozonolysis conditions D, olefin **23b** (0.1 g, 0.40 mmol), after column chromatography on silica gel (cyclohexane/EtOAc, 70:30), afforded the acetal **25b** as a colorless oil (95 mg, 80%, 20% *de*). IR (film, KBr): $\tilde{\nu}_{max}$ = 2954 cm^{-1} (C−H_{ar}), 1764 (C=O), 1400 (C−O), 1275 (C−O), 789. ^1H NMR ($CDCl_3$): δ = 7.29 (m, 5 H, Ph), 4.58 (s, 2 H, OCH_2Ph), 4.45 (d, *J* = 4.5 Hz, 1 H, MeOC*H*), 3.61 (d, *J* = 7.9 Hz, 1 H, C*H*OBn), 3.32 (s, 3 H, OCH_3), 2.57 (d, *J* = 13.7 Hz, 1 H, CH_aH$_b$), 2.46 (d, *J* = 13.7 Hz, 1 H, CH$_a$$H_b$), 2.16 (s, 3 H, C$H_3$CO), 2.17 (m, 4 H, C$H_3$CO, C*H*CH$_3$), 1.30 (s, 3 H, C$H_3$), 1.24 (s, 3 H, C$H_3$), 1.09 (d, *J* = 7.0 Hz, 3 H, CH_3CH), 1.03(d, *J* = 6.7 Hz, 3 H, CH_3CH) ppm. ^{13}C NMR ($CDCl_3$): δ = 207.40 (*C*=O), 137.20 (OCH$_2$$C_{ar}$), 128.15,

127.45 (Ph), 109.06 (*C*HOCH$_3$), 88.35 (*C*HOBn), 72.89 (O*C*H$_2$), 56.13 (CH$_3$*C*CH$_2$), 55.34 (O*C*H$_3$), 53.41 (*C*H$_2$C=O), 44.86 (*C*H$_3$CH), 32.10 (CH$_3$*C*H), 22.45 (*C*H$_3$C=O), 15.81 (*C*H$_3$CCH$_2$) ppm. MS (LSIMS): *m*/*z* (%) = 315 (80) [M$^+$ + Na], 261 (100). HRMS: calcd. for $C_{17}H_{24}O_4$ [M$^+$ + Na] 315.157229; found 315.157494.

General Procedure for the Oxidation of Lactols 24a−c. Lactone 26a: A solution of lactol **24a** (55 mg, 0.23 mmol) in dry CH_2Cl_2 (2 mL) was added with vigorous stirring to a suspension of PCC (0.17 g, 0.76 mmol) and neutral alumina (0.34 g) in CH_2Cl_2 (2 mL). The reaction mixture, which turned dark brown, was stirred overnight and then filtered through a short pad of Florisil. The solid residue was washed several times with diethyl ether. The solvents were removed under reduced pressure, and the residue was purified by column chromatography (cyclohexane/EtOAc, 70:30), affording **26a** as a yellow oil (48 mg, 89%). IR (film, KBr): $\tilde{\nu}_{max}$ = 2927 cm^{-1}, 1789 (C=O), 1741 (C=O), 1557, 1454, 1372 (C−O), 1237 (C−O) 1044 (C−O), 794, 760. ^{1}H NMR (CDCl$_3$): δ = 5.25 (d, *J* = 8.2 Hz, 1 H, *H*COAc), 2.97 (d, *J* = 18.0 Hz, 1 H, CH$_a$*H*$_b$), 2.82 (d, *J* = 18.0 Hz, 1 H, C*H*$_a$H$_b$), 2.79 (dq, *J* = 8.2, 7.3 Hz, 1 H, *H*CCH$_3$), 2.10 (s, 3 H, COC*H*$_3$), 2.07 (s, 3 H, OCOC*H*$_3$), 1.37 (d, *J* = 7.3 Hz, 3 H, C*H*$_3$CH), 1.24 (s, 3 H, C*H*$_3$CCH$_2$) ppm. ^{13}C NMR (CDCl$_3$): δ = 205.45 (CH$_3$*C*OCH$_2$), 176.12 (CH$_3$*C*OO), 172.13 (CH*C*OO), 82.48 (*C*HOAc), 79.27 (CH$_3$*C*CH$_2$), 51.40 (*C*H$_2$CO), 40.48 (CH$_3$*C*H), 30.99 (*C*H$_3$COCH$_2$), 29.69 (*C*H$_3$CCH$_2$), 21.29 (*C*H$_3$COO), 13.10 (*C*H$_3$CH) ppm. MS (LSIMS): *m*/*z* (%) = 251.0 [M + Na], 229.0 [M$^{+\cdot}$ + 1]. HRMS: calcd. for $C_{11}H_{17}O_5$ [M$^+$ + 1] 229.108063; found 229.107599.

Lactone 26b: On subjection to the oxidation conditions reported for lactol **24a**, lactol **24b** (0.13 g, 0.46 mmol), after column chromatography on silica gel (cyclohexane/EtOAc, 70:30), afforded lactone **26b** as a colorless oil (97 mg, 77%). IR (film, KBr): $\tilde{\nu}_{max}$ = 1795 cm^{-1} (C=O), 1732 (C=O), 1562, 1485 (C−O), 1223 (C−O) 752, 770. ^{1}H NMR (CDCl$_3$): δ = 7.30 (m, 5 H, Ph), 4.63 (d, *J* = 11.6 Hz, 1 H, OC*H*$_a$H$_b$), 4.53 (d, *J* = 11.6 Hz, 1 H, OCH$_a$*H*$_b$), 4.09 (d, *J* = 8.8 Hz, 1 H, C*H*OBn), 2.83 (d, *J* = 16 Hz, 1 H, C*H*$_a$H$_b$), 2.71 (m, 1 H, C*H*CH$_3$), 2.48 (d, *J* = 16 Hz, 1 H, CH$_a$*H*$_b$), 2.09 (s, 3 H, C*H*$_3$CO), 1.35 (s, 3 H, C*H*$_3$), 1.32 (d, *J* = 7.1 Hz, 3 H, CHC*H*$_3$) ppm. ^{13}C NMR (CDCl$_3$): δ = 206.25 (CH$_2$*C*=O), 176.47 (C=O), 138.52 (CH$_2$*C*$_{ar}$), 129.5, 128.8 (Ph), 85.73 (*C*HOBn), 84.08 (O*C*CH$_3$), 74.61 (*C*H$_2$Ph), 52.29 (*C*H$_2$C=O), 42.05 (*C*HCH$_3$), 32.73 (*C*H$_3$C=O), 22.29 (OC*C*H$_3$), 14.74 (CH*C*H$_3$) ppm. $C_{16}H_{20}O_4$ (276.33): calcd. C 69.54, H 7.30, O 23.16; found C 69.38, H 7.48, O 23.14.

Lactone 26c: On subjection to the oxidation conditions reported for lactol **24a**, lactol **24c** (36 mg, 0.16 mmol), after column chromatography on silica gel (cyclohexane/EtOAc, 70:30), afforded lactone **26c** as a brown oil (30 mg, 84%). IR (film, KBr): $\tilde{\nu}_{max}$ = 3100 cm^{-1}, 2982, 1767 (C=O), 1723 (C=O), 1471, 1399 (C−O), 1321 (C−O), 1084 (C−O), 800, 764. ^{1}H NMR (CDCl$_3$): δ = 4.94 (dd, *J* = 1.9, 5.6 Hz, 1 H, *H*COAc), 3.38 (s, 2 H, C*H*$_2$CO), 2.71 (m, 2 H, C*H*$_2$), 2.15 (s, 3 H, COC*H*$_3$), 2.09 (s, 3 H, OCOC*H*$_3$), 1.31 (s, 3 H, C*H*$_3$) ppm. ^{13}C NMR (CDCl$_3$): δ = 207.85 (CH$_2$*C*O), 172.01 (O*C*OCH$_3$), 170.11 (CH$_2$*C*OO), 80.00 (H*C*OAc), 54.92 (CH$_3$*C*CH$_2$), 53.88 (*C*H$_2$CO), 39.82 (HC*C*H$_2$), 33.18 (*C*H$_3$CCH$_2$), 22.30 (*C*H$_3$COCH$_2$), 20.99 (OCO*C*H$_3$) ppm. $C_{10}H_{14}O_5$ (214.22): calcd. C 56.07, H 6.59, O 37.34; found C 55.79, H 6.51, O 37.70.

6-(Benzyloxy)-2-(triisopropylsilyl)cyclohex-3-en-1-ol (27): Diol **12c** (0.1 g, 0.37 mmol) and KI (36 mg, 0.22 mmol) were successively added at 0 °C to a suspension of NaH in mineral oil (60%, 60 mg, 1.48 mmol) in anhydrous THF (5 mL). After dropwise addition of a solution of benzyl bromide (44 μL, 0.37 mmol) in THF (1 mL), the reaction mixture was allowed to warm slowly to room temp. and stirred overnight. The flask was then cooled to 0 °C and excess sodium hydride was hydrolyzed by careful addition of a saturated solution of NH_4Cl (5 mL). The organic layer was decanted and the aqueous layer was extracted with diethyl ether (3 × 10 mL). The combined extracts were washed with brine (2 × 10 mL) and dried with $MgSO_4$, and the solvents were removed in vacuo. Column chromatography on silica gel (cyclohexane/EtOAc, 90:10) afforded **27** as a pale yellow oil (54 mg, 40%). IR (film, KBr): $\tilde{\nu}_{max}$ = 3487 cm^{-1} (OH), 3019, 2975, 2210, 1689, 1500, 1347, 1081, 827, 767, 691. ^{1}H NMR (CDCl$_3$): δ = 7.35 (m, 5 H, Ph), 5.61 (m, 1 H, C*H*=CH), 5.47 (m, 1 H, CH=C*H*), 4.66 (d, *J* = 12.2 Hz, 1 H, OC*H*$_a$H$_b$), 4.57 (d, *J* = 12.2 Hz, 1 H, OCH$_a$*H*$_b$), 4.22 (m, 1 H, C*H*OH), 3.70 (m, 1 H, C*H*OBn), 2.15 (m, 3 H, C*H*$_2$, C*H*Si), 1.69 (s, 1 H, O*H*), 1.07 (m, 21 H, SiC*H*C*H*$_3$) ppm. ^{13}C NMR (CDCl$_3$): δ = 138.68 (CH$_2$*C*$_{ar}$), 128.83, 128.19 (Ph), 127.15, 120.29 (*C*=*C*), 75.12 (*C*HOH), 70.50 (O*C*H$_2$Ph), 63.39 (*C*HOBn), 32.12 (Si*C*H), 24.44 (SiCH*C*H$_3$), 19.32 (Si*C*HCH$_3$), 11.88 ppm.

α-Silyl Aldehyde 28: On subjection to the ozonolysis conditions C, olefin **27** (60 mg, 0.16 mmol), after column chromatography on silica gel (cyclohexane/EtOAc, 80:20), afforded lactol **28** as a colorless oil (40 mg, 60%, > 98% *de*). IR (film, KBr): $\tilde{\nu}_{max}$ = 3754 cm^{-1} (OH), 1784 (C=O), 1421 (C−O), 1283 (C−O), 789. ^{1}H NMR (CDCl$_3$): δ = 9.69 (d, *J* = 4.4 Hz, 1 H, *H*C=O), 7.28 (m, 5 H, Ph), 4.93 (dd, *J* = 5.9, 1.9 Hz, 1 H, C*H*OH), 4.68 (dd, *J* = 10.9, 4.9 Hz, 1 H, C*H*OBn), 4.88 (s, 2 H, OC*H*$_2$Ph), 3.64 (m, 1 H, OC*H*), 2.78 (dd, *J* = 15.6, 4.4 Hz, 1 H, *H*CC=O), 2.21 (m, 2 H, C*H*$_a$H$_b$), 1.90 (m, 2 H, O*H*, CH$_a$*H*$_b$), 1.22 (m, 21 H, SiC*H*C*H*$_3$) ppm. ^{13}C NMR (CDCl$_3$): δ = 201.22 (*C*=O), 138.23 (*C*$_{ar}$CH$_2$), 128.78, 128.72, 128.45, 128.13 (Ph), 105.84, 104.92 (*C*HOH), 83.75 (*C*HOBn), 72.24 (O*C*H$_2$), 51.89 (O*C*HCH), 38.44 (*C*H$_2$), 19.32 (CH*C*HSi), 12.67 (SiCH*C*H$_3$), 1.14 (Si*C*HCH$_3$) ppm. $C_{22}H_{36}O_4Si$ (392.63): calcd. C 67.30, H 9.24, O 16.30, Si 7.15; found C 67.10, H 9.01, O 16.54, Si 7.35.

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[1] [1a] R. Angelaud, Y. Landais, *J. Org. Chem.* **1996**, *61*, 5202−5203. [1b] R. Angelaud, Y. Landais, K. Schenk, *Tetrahedron Lett.* **1997**, *38*, 1407−1411. [1c] R. Angelaud, Y. Landais, *Tetrahedron Lett.* **1997**, *38*, 8841−8844. [1d] R. Angelaud, Y. Landais, L. Parra-Rapado, *Tetrahedron Lett.* **1997**, *38*, 8845−8848. [1e] Y. Landais, *Chimia* **1998**, *52*, 104−111. [1f] R. Angelaud, O. Babot, T. Charvat, Y. Landais, *J. Org. Chem.* **1999**, *64*, 9613−9624. [1g] Y. Landais, L. Parra-Rapado, *Eur. J. Org. Chem.* **2000**, *2*, 401−418.

[2] I. Fleming, A. Barbero, D. Walter, *Chem. Rev.* **1997**, *97*, 2063−2192.

[3] [3a] J. Mulzer, in *Comprehensive Asymmetric Catalysis* (Eds.: E. N. Jacobsen, A. Pfaltz, H. Yamamoto), Springer-Verlag, Berlin, **1999**, vol. 1, pp. 33−97. [3b] R. S. Atkinson, *Stereoselective Synthesis*, John Wiley & Sons, New York, **1995**. [3c] R. W. Hoffmann, *Angew. Chem. Int. Ed.* **2000**, *39*, 2054−2070.

[4] [4a] A. M. Misske, R. W. Hoffmann, *Chem. Eur. J.* **2000**, *6*, 3313−3320. [4b] P. Vogel, J. Cossy, J. Plumet, O. Arjona, *Tetra-*

hedron **1999**, *55*, 13521−13642. [4c] P. Chiu, M. Lautens, *Top. Curr. Chem.* **1997**, *190*, 1−85. [4d] S. Woo, B. A. Keay, *Synthesis* **1996**, 669−686. [4e] M. Lautens, *Synlett* **1993**, 177−185. [4f] I. Paterson, M. M. Mansuri, *Tetrahedron* **1985**, *41*, 3569−3624.

[5] [5a] R. B. Woodward, E. Logusch, K. P. Nambiar, K. Sakan, D. E. Ward, B. W. Au-Yeung, P. Balaram, L. J. Browne, P. J. Card, C. H. Chen, *J. Am. Chem. Soc.* **1981**, *103*, 3210−3212. [5b] E. J. Corey, X.-M. Cheng, *The Logic of Chemical Synthesis*, Wiley Interscience, Toronto, **1989**.

[6] [6a] D. G. Lee, T. Chen, "Cleavage reactions" in *Comprehensive Organic Synthesis* (Eds.: B. M. Trost, I. Fleming); Pergamon Press, Oxford, **1991**, vol. 7, pp. 541−591. [6b]S. L. Schreiber, R. E. Claus, J. Reagan, *Tetrahedron Lett.* **1982**, *23*, 3867−3870. [6c] J. L. Acena, O. Arjona, M. Leon, J. Plumet, *Tetrahedron Lett.* **1996**, *37*, 8957−8960. [6d] O. Arjona, A. Martin-Domenech, J. Plumet, *J. Org. Chem.* **1993**, *58*, 7929−7931. [6e] O. Arjona, R. Menchaca, J. Plumet, *J. Org. Chem.* **2001**, *66*, 2400−2413. [6f] T. J. Donohoe, A. Raoof, I. D. Linney, M. Helliwell, *Org. Lett.* **2001**, *3*, 861−864. [6g] D. F. Taber, K. Nakajima, *J. Org. Chem.* **2001**, *66*, 2515−2517. [6h] C.R. Johnson, A. Golebioski, H. Sundram, M. W. Miller, R. L. Dwaihy, *Tetrahedron Lett.* **1995**, *36*, 653−654. [6i] B. A. Johns, Y. T. Pan, A. D. Elbein, C. R. Johnson, *J. Am. Chem. Soc.* **1997**, *119*, 4856−4865.

[7] G. R. Krow, "The Baeyer−Villiger Reaction" in *Comprehensive Organic Synthesis* (Eds.: B. M. Trost, I. Fleming), Pergamon Press, Oxford, **1991**, vol. 7, pp. 671−688.

[8] [8a] D. B. Millward, G. Sammis, R. M. Waymouth, *J. Org. Chem.* **2000**, *65*, 3902−3909. [8b] M. Lautens, T. Rovis, *J. Am. Chem. Soc.* **1997**, *119*, 11090−11091. [8c] M. Lautens, W. Klute, *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 442−445.

[9] For a preliminary account, see: Y. Landais, E. Zekri, *Tetrahedron Lett.* **2001**, *42*, 6547−6551.

[10] [10a] P. W. Rabideau, Z. Marcinow, *Org. React.* **1992**, *42*, 1−334. [10b] D. F. Taber, R. S. Bhamidipati, L. Yet, *J. Org. Chem.* **1995**, *60*, 5537−5539. [10c] P. W. Rabideau, *Tetrahedron* **1989**, *45*, 1579−1603. [10d] C. Eaborn, R. A. Jackson, R. Pearce, *J. Chem. Soc., Perkin Trans. 1* **1975**, 470−474. [10e] R. A. Benkeser, C. A. Tincher, *J. Organomet. Chem.* **1968**, *13*, 139−143. [10f] D. J. Coughlin, R. G. Salomon, *J. Org. Chem.* **1979**, *44*, 3784−3790.

[11] C. W. Roberson, K. A. Woerpel, *Org. Lett.* **2000**, *2*, 621−623.

[12] C. Eaborn, R. A. Jackson, R. Pearce, *J. Chem. Soc., Perkin Trans. 1* **1974**, 2055−2061.

[13] [13a] M. Bordeau, C. Biran, P. Pons, M.-P. Léger-Lambert, J. Dunoguès, *J. Org. Chem.* **1992**, *57*, 4705−4711. [13b] D. Deffieux, M. Bordeau, C. Biran, J. Dunoguès, *Organometallics* **1994**, *13*, 2415−2422.

[14] For a recent report on the use of a tubular flow cell with a sacrificial aluminum anode, see: P. Clavel, M.-P. Léger-Lambert, C. Biran, F. Serein-Spirau, M. Bordeau, N. Roques, H. Marzouk, *Synthesis* **1999**, 829−834.

[15] [15a] J. J. Partridge, N. K. Chadha, M. R. Uskokovic, *J. Am. Chem. Soc.* **1973**, *95*, 7171−7172. [15b] N. N. Joshi, C. Pyun, V. K. Mahindroo, H. C. Brown, *J. Org. Chem.* **1992**, *57*, 504−511. [15c] A. Pelter, K. Smith, H. C. Brown, *Borane Reagents*, Academic Press, New York, **1988**, p. 497.

[16] For related studies in the racemic series, see: L. A. Paquette, J. H. Barrett, *Org. Synth.* **1965**, *49*, 62−65.

[17] [17a] Z. X. Wang, Y. Tu, M. Frohn, J. R. Zhang, Y. Shi, *J. Am. Chem. Soc.* **1997**, *119*, 11224−11235. [17b] Z. X. Wang, Y. Tu, M. Frohn, J. R. Zhang, Y. Shi, *J. Org. Chem.* **1997**, *62*, 2328−2329.

[18] D. Yang, M. K. Wong, Y. C. Yip, *J. Org. Chem.* **1995**, *60*, 3887−3889.

[19] The ^{1}H NMR spectrum of **10** showed only one signal for the methyl groups and also only one for the protons 2-H and 2′-H (Scheme 4). Moreover, the protons of the CH_2 group are magnetically very different, with $\Delta\delta = 0.46$ ppm and $\Delta\nu/J = 6$. This is in good agreement with the *meso* configuration proposed in Scheme 4. The relative configuration has not been firmly established but was assumed to be that resulting from an epoxidation occurring *anti* relative to the allylic methyl group.

[20] P. K. Jadhav, H. C. Brown, *J. Org. Chem.* **1981**, *46*, 2988−2990.

[21] This configuration is in good agreement with a borane approaching *anti* relative to the allylic methyl group. The absolute configuration of **11** was not determined.

[22] [22a] H. C. Kolb, M. S. van Nieuwenhze, K. B. Sharpless, *Chem. Rev.* **1994**, *94*, 2483−2547. [22b] H. C. Kolb, P. G. Andersson, K. B. Sharpless, *J. Am. Chem. Soc.* **1994**, *116*, 1278−1291.

[23] I. Fleming, J. Dunoguès, R. Smithers, *Org. React.* **1989**, *37*, 57−575. The relative configurations of diols **12f** and **12g** were established unambiguously from ^{1}H NMR studies on their corresponding lactones **26a** and **26c**.

[24] S. L. Schreiber, T. S. Schreiber, D. B. Smith, *J. Am. Chem. Soc.* **1987**, *109*, 1525−1529.

[25] E. J. Corey, M. C. Noe, *J. Am. Chem. Soc.* **1994**, *118*, 11038−11053.

[26] [26a] G. Li, H. T. Chang, K. B. Sharpless, *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 451−454. [26b] J. Rudolph, P. C. Sennhenn, C. P. Vlaar, K. B. Sharpless, *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 2810−2812. [26c] G. Li, H. H. Angert, K. B. Sharpless, *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 2813−2817. [26d] B. Tao, G. Schlingloff, K. B. Sharpless, *Tetrahedron Lett.* **1998**, *39*, 2507−2510. [26e] M. Bruncko, G. Schlingloff, K. B. Sharpless, *Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 1483−1486.

[27] [27a] Hydrolysis of the osmium glycolate intermediate in AD reactions has been reported to be the rate-determining step for di-, tri- and tetrasubstituted olefins. The same probably holds for hydrolysis of osmium azaglycolate in AA reactions. Slow turnover rates in AA reactions have also been attributed to the slow hydrolysis of the osmium(VI) bis(azaglycolate) generated in the Sharpless second catalytic cycle.[26b][27b]For a discussion, see also: E. J. Corey, M. C. Noe, *J. Am. Chem. Soc.* **1996**, *118*, 319−329.

[28] H. Han, C. W. Cho, K. D. Janda, *Chem. Eur. J.* **1999**, *5*, 1565−1569.

[29] G. L. Larson, "The Chemistry of α-silyl carbonyl compounds" in *Advances in Silicon Chemistry*, JAI Press, Inc., **1996**, vol. 3, pp. 105−271.

[30] H. Franzyk, F. R. Stermitz, *J. Nat. Prod.* **1999**, *62*, 1646−1654.

[31] D. H. R. Barton, S. W. McCombie, *J. Chem. Soc., Perkin Trans. 1* **1975**, 1574−1585.

[32] W. Hartwig, *Tetrahedron* **1983**, *39*, 2609−2645 and references cited therein.

[33] F. Villar, O. Equey, P. Renaud, *Org. Lett.* **2000**, *2*, 1061−1064.

[34] For a study on the ozonolysis of allylsilanes as a route to α-silyl aldehydes, see: D. Enders, B. B. Lohray, *Angew. Chem. Int. Ed. Engl.* **1987**, *26*, 351−352.

[35] [35a] V. Bhushan, B. B. Lohray, D. Enders, *Tetrahedron Lett.* **1993**, *34*, 5067−5070. [35b] F. Le Bideau, F. Gilloir, Y. Nilsson, C. Aubert, M. Malacria, *Tetrahedron* **1996**, *52*, 7487−7510.

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