1,3-Allylic Strain as a Control Element in the Paternò−Büchi Reaction of Chiral Silyl Enol Ethers: Synthesis of Diastereomerically Pure Oxetanes Containing Four Contiguous Stereogenic Centers

Thorsten Bach,* Kai Jödicke, Kristian Kather, and Roland Fröhlich†

Contribution from the Organisch-Chemisches Institut der Westfälischen Wilhelms-Universität Münster, D-48149 Münster, Germany

Received November 4, 1996[⊗]

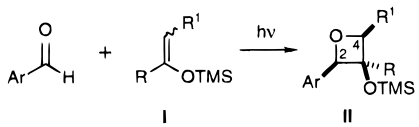
Abstract: The facial diastereoselectivity in the Paternò−Büchi reaction of chiral silyl enol ethers and benzaldehyde was studied. The substituents (R^S, R^L) at the stereogenic carbon atom ($-C^*HR^SR^L$) attached to the β-position of the silyl enol ether were varied in order to evaluate the influence of steric bulk and electronic effects. The combined yields for the two diastereomeric 3-(silyloxy)oxetanes **a** and **b** range between 44% and 76%. In accordance with the 1,3-allylic strain model the facial diastereoselectivity (diastereomeric ratio (dr) = **a**/**b**) was best with large (R^L = *t*-Bu, $SiMe_2Ph$) and polar (R^L = OMe) substituents at the γ-position of the silyl enol ether (dr up to >95/5). Two regioselective ring opening reactions were applied to the product oxetanes **29a**, **50**, and **51**. They furnished diastereomerically pure diols (**52**, **53**) and triols (**31**) in excellent yields.

Introduction

The Paternò−Büchi reaction has long been established as one of the most important and most useful photochemical transformations.[1] Since up to three new stereogenic centers are formed in the course of the reaction, there have been many studies as to both the relative and the absolute configurations of the product oxetanes.[2] The former aspect of relative configuration is related to two basic topics, i.e., the simple diastereoselectivity of C−C bond formation[3] and the stereospecifity of the process with regard to the alkene configuration.[4] The latter aspect of absolute configuration addresses the problem of facial diastereoselectivity if a chiral moiety is attached to either one of the reaction partners or of enantioselectivity if a catalytic approach is pursued.[5] From a synthetic point of view it is desirable to minimize the numbers of stereoisomers in order to retain maximum efficiency. We have recently shown that silyl enol ethers of the general type **I** react well with aromatic aldehydes and yield the diastereomerically pure oxetanes **II** (Scheme 1).[6]

The relative configuration established in this reaction is determined in the intermediate 1,4-biradical ^{3}D.[7] The bulky alkyl groups R and R^1 are oriented *trans* to each other in the relatively long lived triplet species (^{3}D), and the reaction proceeds therefore in a stereoconvergent manner; i.e., it is independent of the initial olefin configuration.[6d] In a second selection step the simple diastereoselectivity between the newly formed stereogenic centers at C-2 and C-3 is determined. The impact of viable intersystem crossing (ISC) geometries[8] can be counterbalanced or overridden by the competition between retrocleavage and ring closure in a short-lived singlet biradical (^{1}D). We have postulated that it is this competition which dictates the simple diastereoselectivity for the silyl enol ether photocycloaddition.[6b] Oxetanes of the general structure **II** represent 1,2,3-trifunctional building blocks which can be used readily in successive ring-opening reactions.[9]

Scheme 1



I II

If one of the two alkene substituents R or R^1 is chiral, the question of facial diastereoselectivity comes into play. In order to achieve a complete face differentiation, the attachment of a stereogenic center to the β-position of the silyl enol ether **III** (R^1 chiral) appeared to be particularly promising to us (Scheme 2). The obvious reason for this notion was the preferred conformation **III′** to be predicted on the grounds of 1,3-allylic

* To whom correspondence should be addressed. New address: Philipps-Universität Marburg, Fachbereich Chemie, D-35032 Marburg, Germany.

† To whom inquiries about the X-ray analysis should be addressed at the Universität Münster.

⊗ Abstract published in *Advance ACS Abstracts,* February 15, 1997.

(1) (a) Paternò, E.; Chieffi, G. *Gazz. Chim. Ital.* **1909**, *39*−1, 341−361. (b) Büchi, G.; Inman, C. G.; Lipinsky, E. S. *J. Am. Chem. Soc.* **1954**, *76*, 4327−4331.

(2) For recent reviews, see: (a) Mattay, J.; Conrads, R.; Hoffmann, R. In *Methoden der Organischen Chemie (Houben-Weyl) 4te Aufl.*; Helmchen, G., Hoffmann, R. W., Mulzer, J., Schaumann, E., Eds.; Thieme: Stuttgart, 1995; Vol. E 21c, pp 3133−3178. (b) Porco, J. A.; Schreiber, S. L. In *Comprehensive Organic Synthesis*; Trost, B., Ed.; Pergamon Press: Oxford, 1991; Vol. 5, pp 151−192. (c) Carless, H. A. J. In *Synthetic Organic Photochemistry*; Horspool, W. M., Ed.; Plenum Press: New York, 1984; pp 425−487. (d) Jones, G. In *Organic Photochemistry*; Padwa, A., Ed.; Dekker: New York, 1981; Vol. 5, pp 1−123.

(3) Bach, T. *Angew. Chem.* **1996**, *108*, 976−977; *Angew. Chem., Int. Ed. Engl.* **1996**, *35*, 884−886 and references cited therein.

(4) Khan, N.; Morris, T. H.; Smith, E. H.; Walsh, R. *J. Chem. Soc., Perkin Trans. 1* **1991**, 865−870 and references cited therein.

(5) Review: Inoue, Y. *Chem. Rev.* **1992**, *92*, 741−770.

(6) (a) Bach, T. *Tetrahedron Lett.* **1991**, *32*, 7037−7038. (b) Bach, T.; Jödicke, K. *Chem. Ber.* **1993**, *126*, 2457−2466. (c) Bach, T. *Tetrahedron Lett.* **1994**, *35*, 5845−5848. (d) Bach, T. *Liebigs Ann. Chem.* **1995**, 855−866.

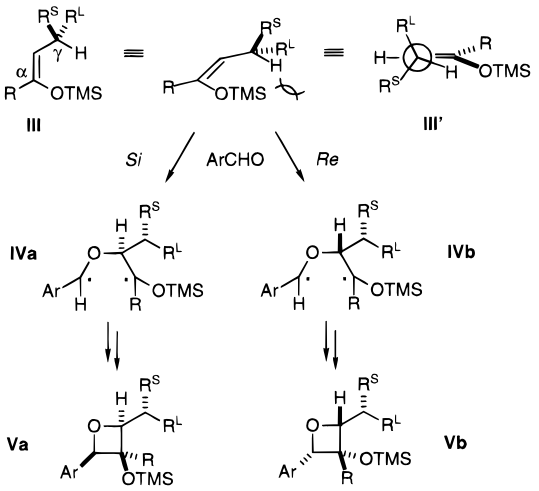
(7) First detection of a preoxetane 1,4-biradical: Freilich, S. C.; Peters, K. S. *J. Am. Chem. Soc.* **1981**, *103*, 6255−6257. Freilich, S. C.; Peters, K. S. *J. Am. Chem. Soc.* **1985**, *107*, 3819−3822.

(8) For a comprehensive review on the various intersystem crossing geometries related to oxetane formation, see: Griesbeck, A. G.; Mauder, H., Stadtmüller, S. *Acc. Chem. Res.* **1994**, *27*, 70−75.

(9) (a) Bach, T. *Tetrahedron Lett.* **1994**, *35*, 1855−1858. (b) Bach, T. *Liebigs Ann. Chem.* **1995**, 1045−1053. (c) Bach, T.; Kather, K. *J. Org. Chem.* **1996**, *61*, 3900−3901. (d) Bach, T.; Lange, C. *Tetrahedron Lett.* **1996**, *37*, 4363−4364.

S0002-7863(96)03827-9 CCC: $14.00

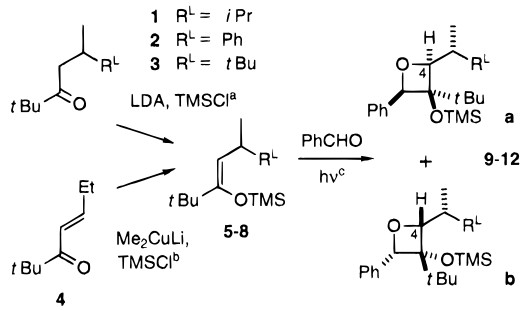
Scheme 2



strain.[10] As depicted in Scheme 2 a conformation **III′** in which the hydrogen atom at the stereogenic center and the α-carbon atom of the silyl enol ether are locked in a synperiplanar fashion is strongly favored. An approach of the photoexcited carbonyl compound should occur from the less shielded face. If the further course of the reaction included the previously encountered selection steps (*vide supra*), the stereogenic center in the γ-position of the silyl enol ether **III** was to control the relative configuration of all stereogenic centers within the oxetane **V**. Contrary to the observations made by Scharf et al. in their work on the auxiliary assisted Paternò−Büchi reaction of chiral phenyl glyoxylates,[11] the retrocleavage was not expected to significantly influence the facial diastereoselectivity. For the remote stereogenic center in the 1,4-biradical **IV**, a conformational preference with regard to the prostereogenic radical centers was not foreseen. An impact on the retrocleavage in either one of the two diastereoisomers **IVa** or **IVb** seemed unlikely. This hypothesis which was borne out experimentally (*vide infra*) simplifies the discussion as only the C−O bond formation step has to be considered to explain the facial diastereoselectivity.

The strategy of acyclic stereoselection has rarely been exploited in Paternò−Büchi reactions.[12] Most studies are concerned with the facial diastereoselectivity in cyclic systems.[13] Furthermore, concave auxiliaries such as 8-phenylmenthol have been established as reliable control elements.[11] Examples of good diastereofacial control based on 1,3-allylic strain was reported by Schreiber and Hoveyda in the context of intramolecular Paternò−Büchi reactions.[14] In this paper we present our results on the successful embodiment of 1,3-allylic strain in the intermolecular photocycloaddition of chiral silyl enol ethers and aldehydes.[15] In addition, two facile ring-opening reactions are described which demonstrate the synthetic versatility of functionalized oxetanes.

Scheme 3[a]



[a] Reagents and conditions: (a) −78 → +25 °C (THF); (b) Me_2CuLi, −78 → 0 °C, TMSCl, NEt_3, 0 °C (THF); (c) 30 °C (PhH).

Table 1. Facial Diastereoselectivity in the Photocycloaddition of Chiral, γ-Alkyl-Substituted Silyl Enol Ethers

alkene	R^G	product	yield[a] (%)	dr[b] (**a**/**b**)	regioselectivity[c]
5	Et	**9**	61	61/39	87/13
6	*i*-Pr	**10**	57	70/30	82/18
7	Ph	**11**	76	71/29	80/20
8	*t*-Bu	**12**	58	95/5	75/25

[a] Total yield of the two diastereoisomers **a** and **b**. [b] Diastereomeric ratio determined by ^{1}H NMR analysis of the crude product mixture. [c] Ratio of regioisomers (3- vs 2-(silyloxy)oxetane) determined by GLC analysis of the crude product mixture.

Results and Discussion

Influence of Steric Bulk. The first series of silyl enol ethers we synthesized and tested in the Paternò−Büchi reaction carried a *tert*-butyl substituent in the α-position (R = *t*-Bu) and a methyl group at the stereogenic center in the γ-position (R^S = Me). The additional γ-substituent R^L was varied in size. In general, the ketones **1**−**3**[16] are readily transferred to the corresponding silyl enol ethers **6**−**8** by kinetically controlled deprotonation and subsequent quench with chlorotrimethylsilane (TMSCl) at −78 °C (Scheme 3).[17] As the ketones are generated by conjugate cuprate addition to 2,2-dimethyl-4-hexen-3-one, the enolate can also be directly trapped with TMSCl.[18] In the case of compound **8** the yield improved considerably by employing the latter protocol. For the preparation of silyl enol ether **5** the conjugate addition/enolate quench was applied to ketone **4**.[19] By irradiation of the olefinic substrates **5**−**8** in the presence of benzaldehyde, we obtained preliminary information as to the steric influence of the γ-substituent R^L.

From the data recorded in Table 1 it can be seen that only two stereoisomeric oxetanes **a** and **b** were isolated. The relative configuration within the four-membered ring is identical in either isomer, but the isomers differ in the stereochemical relation between the exocyclic stereogenic center and the carbon atom C-4. Their ratio which can be determined by both ^{1}H NMR and GLC reflects the extent of facial diastereoselection exerted by the stereogenic center in the silyl enol ether. The higher the steric demand of the substituent R^L the better is the diastereomeric ratio (dr). On the basis of the preferred conformation **III′** depicted in Scheme 2, the results can be

(10) Review: Hoffmann, R. W. *Chem. Rev.* **1989**, *89*, 1841−1860.

(11) (a) Buschmann, H.; Scharf, H.-D.; Hoffmann, N.; Plath, M. W.; Runsink, J. *J. Am. Chem. Soc.* **1989**, *111*, 5367−5373. (b) Buschmann, H.; Scharf, H.-D.; Hoffmann, N.; Esser, P. *Angew. Chem.* **1991**, *103*, 480−518; *Angew. Chem., Int. Ed. Engl.* **1991**, *30*, 477−515 and references cited therein.

(12) (a) Jarosz, S.; Zamojski, A. *Tetrahedron* **1982**, *38*, 1453−1456. (b) Schreiber, S. L. *Science* **1985**, *227*, 857−863. (c) Zagar, C.; Scharf, H.-D. *Chem. Ber.* **1991**, *124*, 967−969. (d) Bach, T.; Jödicke, K.; Wibbeling, B. *Tetrahedron* **1996**, *52*, 10861−10878.

(13) (a) Morton, D. R.; Morge, R. A. *J. Org. Chem.* **1978**, *43*, 2093−2101. (b) Araki, Y.; Senna, K.; Matsuura, K.; Ishido, Y. *Carbohydr. Res.* **1978**, *60*, 389−395. (c) Vasudevan, S.; Brock, C. P.; Watt, D. S.; Morita, H. *J. Org. Chem.* **1994**, *59*, 4677−4679.

(14) Hoveyda, A. H. Ph.D. Thesis, Yale University, 1986, cited in ref 2b.

(15) Preliminary communication: Bach, T., Jödicke, K.; Kather, K.; Hecht, J. *Angew. Chem.* **1995**, *107*, 2455−2457; *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 2271−2273.

(16) (a) **1**: Azzena, U.; Luisi, P. L.; Suter, U. W. *Helv. Chim. Acta* **1981**, *64*, 2821−2829. (b) **2**: Malmberg, H.; Nilson, M.; Ullenius, C. *Acta. Chem. Scand., Ser. B* **1981**, *B35*, 625−629. (c) **3**: House, H. O:; Weeks, P. D. *J. Am. Chem. Soc.* **1975**, *97*, 2770−2777.

(17) Heathcock, C. H. In *Modern Synthetic Methods*; Scheffold, R., Ed.; Verlag Helvetica Chimica Acta: Basel, 1992; Vol. 6, pp 1-102.

(18) Stork, G.; Hudrlik, P. F. *J. Am. Chem. Soc.* **1968**, *90*, 4462−4464.

(19) Ketone **4**: Oare, D. A.; Henderson, M. A.; Sanner, M. A.; Heathcock, C. H. *J. Org. Chem.* **1990**, *55*, 132−157.

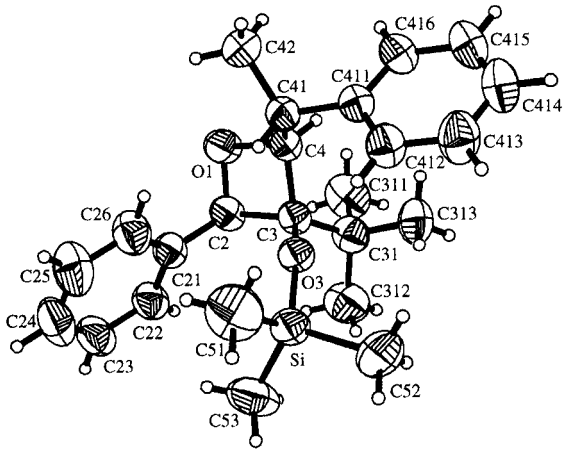


Figure 1. Structure of oxetane **11a** in the crystal.

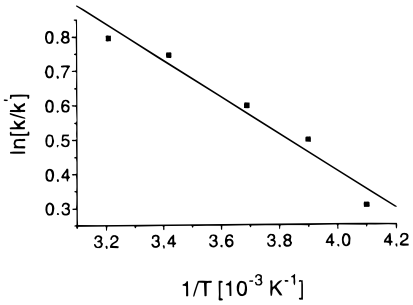


Figure 2. Eyring plot relating the facial diastereoselectivity observed in the photocycloaddition of silyl enol ether **7** and benzaldehyde to 1/*T*.

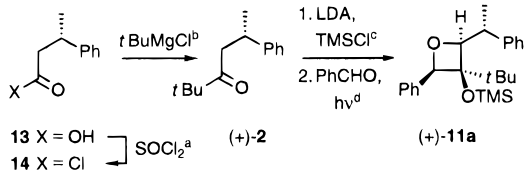
readily understood. It is the difference in bulk between R^L and R^S = Me which favors the *Si*-attack. With the extremely bulky *tert*-butyl group (R^L = *t*-Bu) a clear-cut preference (dr = >95/5) was noted. The total yields for both diastereomers **a** and **b** range between 57% and 72%. The decrease in yield as compared with related 3-(silyloxy)oxetanes[6d] is partially connected to an increasing amount of regioisomer (2-(silyloxy)-oxetane) formed by attack of the photoexcited aldehyde at the α-position of the silyl enol ether. The regioselectivity as defined in Table 1 was determined by GLC integration. For this purpose the peak assignment was based on GLC−MS data recorded under otherwise identical conditions. In the MS the main fragmentation pathway is the retro-[2 + 2]-cycloaddition which occurs in either direction, i.e., between O/C-2 and C-3/C-4 as well as between O/C-4 and C-2/C-3. A distinction between the regioisomers by this method is therefore facile and unambiguous.

The structure elucidation was carried out by single-crystal X-ray analysis. Figure 1 represents the structure of the major diastereoisomer **11a** in the crystal. It is remarkable that even in the oxetane the proton at the exocyclic stereogenic center and the carbon atom C-3 which carries the silyloxy group adopt an eclipsed orientation. From Figure 1 one can easily envisage the approach of benzaldehyde to the less shielded *Si*-face of the silyl enol ether **7** to yield the major product **11a**. The conformational preference is governed by 1,3-allylic strain as still evident in the product.

The decisive facial diastereoselection occurs in the C−O-bond-forming step, i.e. the attack of the photocexcited carbonyl triplet at the β-carbon of the olefin (cf. Scheme 2). In the loose early transition state of such a reaction the entropy levels should be narrowly spaced.[20] As a consequence the selectivity is

(20) Skell, P. S.; Cholod, M. S. *J. Am. Chem. Soc.* **1969**, *91*, 7131−7137.

Scheme 4[a]



[a] Reagents and conditions: (a) neat, 80 °C; (b) CuCl, −78 °C (Et_2O); (c) −78 → +25 °C (THF); (d) 30 °C (PhH).

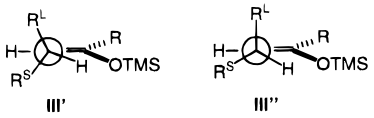


Figure 3. Possible conformations which explain the facial differentiation in the Paternò−Büchi reaction of the silyl enol ethers **5**−**8**.

expected to be predominantly influenced by the activation entropy difference $\Delta\Delta S^{\neq}$. In the case of oxetane **11** we were able to show that there is indeed a linear dependence of ln(*k*/*k*′) and 1/*T* in the (experimentally) limited temperature range from −30 to +40 °C (Eyring plot in Figure 2) where *k*/*k*′ represents the facial diastereoselection as determined by the diastereomeric ratio (dr). The calculated values for $\Delta\Delta H^{\ddagger}$ and $\Delta\Delta S^{\ddagger}$ are 4.5 kJ mol^{-1} and 21.3 J mol^{-1} K^{-1}, respectively. These figures clearly indicate an entropically determined diastereoselection. In the temperature range we studied there is no apparent change in the mechanism. The competition beween retrocleavage and ring closure in a 1,4-biradical which is known to be enthalpy determined[11a] does not influence the facial diastereoselectivity even at comparably high temperature. Preparatively, the increase of the diastereomeric ratio from 58/42 at −30 °C to 70/30 at +40 °C is significant and provides a handle for improving the selectivity of the photocycloaddition.

Since we intended to prove that the oxetane formation proceeds without racemization, the silyl enol ether **7** was also prepared in enantiomerically pure form. For this purpose the readily available carboxylic acid **13**[21] was converted into the ketone (+)-**2** via the corresponding acyl chloride **14** (Scheme 4). Silyl enol ether formation and subsequent Paternò−Büchi reaction proceeded uneventfully and provided the oxetane (+)-**11a** whose enantiomeric purity was determined to be >95% enantiomeric excess (ee) by shift experiments with tris[3-[(heptafluoropropyl)hydroxymethylene]-D-camphorato]europium ($Eu(hfc)_3$). With respect to the ee determination the *tert*-butyl substituent at the C-3 position of the oxetane was deliberately chosen. Its ^1H NMR signal was most sensitive toward the shift reagent.

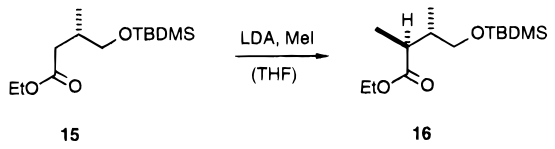
Polar Groups in the γ-Position. On the basis of stereoelectronic considerations and in agreement with the Curtin-Hammett principle,[22] one may also trace back the facial diastereoselection in the cases described above to the conformation **III**″ depicted in Figure 3.[23] It differs only slightly from the conformation **III**′ discussed earlier and should be readily accessible. The large substituent R^L is positioned orthogonal to the double bond plane, increasing the HOMO energy of the nucleophilic π-system by σπ-interaction. In the transition state the antiperiplanar orientation of its σ-bond to the developing σ*-orbital leads to a considerable stabilization.[23b] The attack of the carbonyl triplet and the C−O bond formation occur from

(21) Mukaiyama, T.; Iwasawa, N. *Chem. Lett.* **1981**, 913−916.

(22) Eliel, E. L.; Wilen, S. H. *Stereochemistry of Organic Compounds*; Wiley: New York, 1994; pp 651−654.

(23) (a) McGarvey, G. J.; Williams, J. M. *J. Am. Chem. Soc.* **1985**, *107*, 1435−1437. (b) Houk, K. N.; Paddon-Row, M. N.; Rondan, N. G.; Wu, Y.-D.; Brown, F. K.; Spellmayer, D. C.; Metz, J. T.; Li, Y.; Lonchrich, R. J. *Science* **1986**, 231, 1108−1117 and references cited therein.

Scheme 5

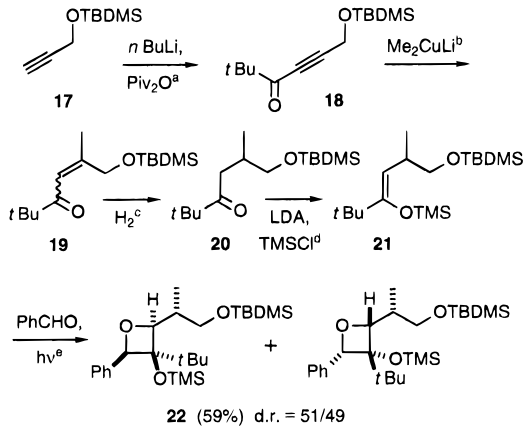


the face opposite R^L. Whereas conformation **III′** accounts well for a face differentiation on steric grounds according to the 1,3-allylic strain model, conformation **III″** takes the stereoelectronic aspects into consideration.

Precedence for the addition of an electrophilic radical to a prostereogenic double bond carrying a chiral substituent can be found in the work of Curran et al. who employed enol ethers derived from chiral alcohols.[24] We are, however, not aware of studies in which the β-substituent of a heteroatom-substituted alkene is chiral. The reverse case, i.e., a nucleophilic radical attack to an acceptor substituted alkene with a chiral β-substituent, is amply documented.[25] For comparison, reports about electrophilic reactions may be consulted, i.e., on the alkylation of chiral enolates. The facial diastereoselectivities observed in these reactions parallel our results for simple alkyl substituents R^L.[26] It is interesting to note that polar substituents have a strong impact on the facial diastereoselectivity. An example is shown in Scheme 5.[23a] Enolate alkylation of ester **15** results in preferential formation of diastereoisomer **16** (dr = 90/10). The success of the $TBDMSOCH_2$ group was correlated with its donor character which makes it act as R^L in a conformation similar to **III″**.

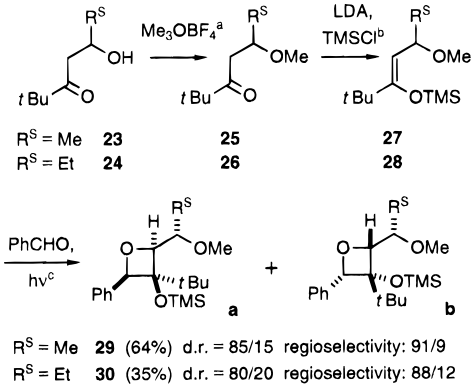
As the *A* values of Me and $ROCH_2$ are roughly the same,[27] their difference in size can be considered marginal. A silyl enol ether which bears a chiral substituent $-CHMeCH_2OR$ in the β-position was selected to distinguish between stereoelectronic (conformation **III″**) and sheer steric (conformation **III′**) effects. For its synthesis, the conjugate addition of known α-alkoxy-anions[28] to 2,2-dimethyl-4-hexen-3-one proved to be not suited. A different route was chosen. The TBDMS-protected propargylic alcohol **17**[29] served as the starting material which was acylated according to a known procedure.[30] Conjugate addition to the alkyne **18** delivered ketone **19** as a mixture of diastereoisomers (dr = 60/40) (Scheme 6). Hydrogenation of this intermediate to its saturated analogue **20** and subsequent enolate silylation furnished the desired silyl enol ether **21**. Upon irradiation in the presence of benzaldehyde a facile photocycloaddition occurred. Disappointingly, the two oxetanes **22** were formed in a ratio of roughly 1:1 (regioselectivity 88/12). In contrast to the above mentioned enolate alkylations, the stereoelectronic donor capacity of the $ROCH_2$ substituent does not significantly influence the facial diastereoselectivity in Paternò−Büchi reactions of chiral silyl enol ethers. Consequently, our picture of a conformation **III′** which is attacked preferentially from the less shielded face in an early transition state describes best these and the other results so far obtained.

Scheme 6[a]



[a] Reagents and conditions: (a) *n*-BuLi, −30 → 0 °C, Piv_2O, −50 → +25 °C (THF). (b) −78 °C (Et_2O); (c) $Pd(OH)_2$, 25 °C (MeOH); (d) −78 → +25 °C (THF); (e) 30 °C (PhH).

Scheme 7[a]



[a] Reagents and conditions: (a) 1,8-bis(dimethylamino)naphthalene, 25 °C (CH_2Cl_2); (b) −78 → +25 °C (THF); (c) 30 °C (PhH).

Next we turned our attention to the possible installation of an alkoxy group at the stereogenic center. Attempts to disilylate the hydroxy ketone **23**[31] were not successful although there was precedence for a similar reaction conducted with a β-hydroxy ester.[32] Elimination products were observed presumably because the intermediate β-silyloxy ketone enolate is silylated slowly and the E_1cB process is favored. The same problem was anticipated with other hydroxy-protected derivatives of compound **23**. As it turned out, the methoxy (R^L = OMe)[33] substituent resists an elimination successsfully and we obtained the silyl enol ether **27** conveniently in two steps from 2,2-dimethyl-5-hydroxy-3-heptanone (**23**) via ketone **25** (Scheme 7**)**. The photocycloaddition of **27** to benzaldehyde proceeded with good facial diastereoselectivity (dr = 85/15), and the major diastereoisomer **29a** was isolated in 54% yield. Its relative configuration was determined by X-ray crystallography after desilylation (K_2CO_3 in MeOH) to the corresponding oxetanol.[15] If the size of the alkyl substituent (R^S) in the γ-position is increased, the selectivity decreases. With ethyl compound **28** which was obtained from ketone **24**[34] in analogy to the silyl enol ether **27** the diastereomeric ratio of oxetane **30** dropped slightly to 80/20. The yield is significantly lower, a fact which can be attributed to the deterioration of the regioselectivity and to a higher tendency for hydrogen abstraction reactions in **28**.

(24) Curran, D. P.; Geib, S. J.; Kuo, L. H: *Tetrahedron Lett.* **1994**, *35*, 6235−6238. We thank a reviewer for providing us with this reference.
(25) Reviews: (a) Smadja, W. *Synlett* **1994**, 1−26. (b) Curran, D. P.; Porter, N. A.; Giese, B. *Stereochemistry of Radical Reactions*; VCH: Weinheim, 1996.
(26) (a) Fleming, I.; Lewis, J. J. *J. Chem. Soc., Chem. Commun.* **1985**, 149−151. (b) Yamamoto, Y.; Maruyama, K. *Ibid.* **1984**, 904−905.
(27) Hirsch, J. A. *Top. Stereochem.* **1967**, *1*, 199−222.
(28) Corey, E. J.; Eckrich, T. M. *Tetrahedron Lett.* **1983**, *24*, 3165−3168.
(29) Bundy, G. L.; Lin, C. H.; Sih, J. C. *Tetrahedron* **1981**, *37*, 4419−4430.
(30) Chopra, A. K.; Moss, G. P.; Weedon, B. C. L. *J. Chem. Soc., Perkin Trans. 1* **1988**, 1371−1382.
(31) Bienvenue, A. *J. Am. Chem. Soc.* **1973**, *95*, 7345−7353.
(32) Shirai, F.; Nakai, T. *Tetrahedron Lett.* **1988**, *29*, 6461−6464.
(33) Methylation: Diem, M. J.; Burow, O. F.; Fry, J. L. *J. Org. Chem.* **1977**, *42*, 1801−1802.
(34) Singh, B. M.; Aguliar, F. J.; Brunet, E. *Tetrahedron* **1994**, *50*, 8169−8184.

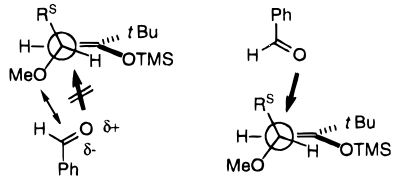
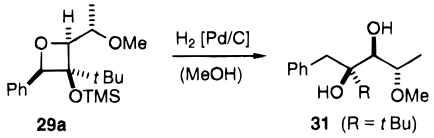


Figure 4. Electrostatic repulsion as possible reason for the observed facial diastereoselection in the Paternò−Büchi reaction of γ-methoxy-substituted silyl enol ethers.

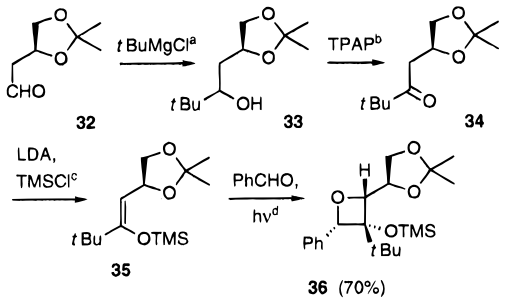
To explain the face selectivity in the photocycloaddition of silyl enol ether **27**, we again rely on the initially mentioned 1,3-allylic strain model (Scheme 2). Electrophilic addition reactions to chiral allylic ethers are well precedented,[35] and several rationalizations have been proposed which try to account for the partially contradictory results.[36] For cases in which a (*Z*)-substituent on the double bond severely increases the 1,3-allylic strain, it is generally accepted that a conformation such as **III′** is strongly favored by 12−15 kJ mol^{-1}.[10] There is no reason to believe that this preference will dramatically change by going from the ground state to the transition state. Still, small variations in the dihedral angle (±30°) of the bond connecting the stereogenic carbon atom and the double bond are possible. In our example an approach of the electrophilic triplet has taken place from the face shielded by the methyl group (R^S = Me) and opposite the methoxy substituent (R^L = OMe). On stereoelectronic and electrostatic[37] grounds such a trajectory appears not particularly appealing at first sight. We have earlier seen (*vide supra*), however, that stereoelectronic considerations do not apply to the photocycloaddition. It remains to clarify why the attack occurs opposite the methoxy group in conformation **III′**, i.e., why the electrophile avoids the nucleophilic substituent. In our opinion the clue to this apparent paradox lies in the electronic situation of the reactive nπ*-excited carbonyl group which embraces both an electrophilic carbonyl oxygen and a *nucleophilic* carbon atom. As depicted in Figure 4 the C−O bond formation will occur perpendicularly to the double bond plane or slightly twisted. During the approach to the double bond the electron rich carbonyl carbon atom will turn away from the olefinic π-system. It will therefore get into close proximity to the γ-substituents and it will avoid for electrostatic reasons the nucleophilic methoxy group. The attack from the opposite face is favored. By increasing the steric bulk of the alkyl substituent situated at this face (R^S = Et), the selectivity decreases.

Oxetanes such as **29a** contain four contiguous stereogenic centers which can be employed for the construction of interesting cyclic and acyclic molecules. The relative configuration established at C-3, C-4, and the exocyclic stereogenic center for instance correlates to the stereochemical arrangement found in branched sugars.[38] Simple hydrogenolysis of the 2-aryl-oxetanes yields open chain products which may be manipulated further. An example is shown in Scheme 8. We currently investigate additional consecutive reactions and their use for the synthesis of biologically relevant products (*vide infra*).

Scheme 8



Scheme 9[a]



[a] Reagents and conditions: (a) −78 → +25 °C (THF); (b) NMO, molecular sieves 4 Å, 25 °C (CH_2Cl_2); (c) −78 → +25 °C (THF); (d) 30 °C (PhH).

For the synthesis of enantiomerically pure compounds (*S*)-malic acid serves as a readily available starting material. Aldehyde **32**,[39] for example, can be converted to the silyl enol ether **35** in three steps (Scheme 9). The *t*-BuMgCl addition proceeded well and gave alcohol **33**. Oxidation of the alcohol **33** with NMO/TPAP (cat.)[40] and subsequent enolate silylation gave the desired alkene **35**. The choice of the diol protective group has not yet been optimized. Attempts to use a carboxylic acid or its derivatives as electrophile to directly obtain ketone **34** remained unsuccessful. The photocycloaddition of silyl enol ether **35** proceeded smoothly (regioselectivity >95/5) and furnished diastereomerically pure oxetane **36** which was isolated in 70% yield. The facial diastereoselectivity (dr = 90/10) is good, which again reveals that the steric influence of the CH_2OR substituent is comparable to the one of a methyl group (cf. **21**) at the stereogenic center.

Further Variations in the α- and γ-Positions of the Silyl Enol Ether. The α-substituent R on the silyl enol ether has been held constant in all previous experiments in order to allow an undisturbed evaluation of the facial diastereoselection. A variation of this group is possible, of course, and we have studied two cases in more detail. A protected ketone and a carboxylic acid moiety were introduced into the α-position. Starting from the known ketone **37**,[41] an aldol reaction lead to alcohol **38** (Scheme 10). Methylation[33] furnished the corresponding methyl ether **39** which was subsequently converted to the silyl enol ether **40** according to the standard protocol. The photocyclo-addition proceeded smoothly (regioselectivity >95/5), and the oxetane **41** was isolated in diastereomerically pure form after chromatography. The diastereomeric ratio (dr = 79/21) in the crude product mixture was slightly lower than in the comparable *tert*-butyl case (cf. oxetane **29**).

For the installation of a protected carboxylic acid in the α-position the synthesis commenced with the nitrile **42**.[42]

(35) Only some selected references are provided. (a) Diels−Alder reaction: McDougal, P. G.; Rico, J. G.; VanDerveer, D. *J. Org. Chem.* **1986**, *51*, 4494−4497. Kozikowski, A. P.; Jung, S. H.; Springer, J. P. *J. Chem. Soc., Chem. Commun.* **1988**, 167−169. See also ref 23. (b) Dihydroxylation: Cha, J. K.; Christ, W. J.; Kishi, Y. *Tetrahedron* **1984**, *40*, 2247−2255. (c) 1,3-Dipolar cycloaddition: Houk, K. N., Moses, S. R.; Wu, Y.-D.; Rondan, N. G., Jäger, V., Schohe, R.; Fronczek, F. R. *J. Am. Chem. Soc.* **1984**, *106*, 3880−3882. Kozikowski, A. P.; Ghosh, A. K. *J. Org. Chem.* **1984**, *49*, 2762−2772. (d) Mukaiyama aldol reaction: See ref 32.

(36) (a) Tripathy, R.; Franck, R. W.; Onan, K. D. *J. Am. Chem. Soc.* **1988**, *110*, 3257−3262. (b) Adam, W.; Gläser, J.; Peters, K.; Prein, M. *Ibid.* **1995**, *117*, 9189−9193

(37) Kahn, S. D.; Pau, C. F.; Chamberlin, A. R.; Hehre, W. J. *J. Am. Chem. Soc.* **1987**, *109*, 650−663.

(38) Yoshimura, J. *Adv. Carbohydr. Chem. Biochem.* **1984**, *42*, 69−134.

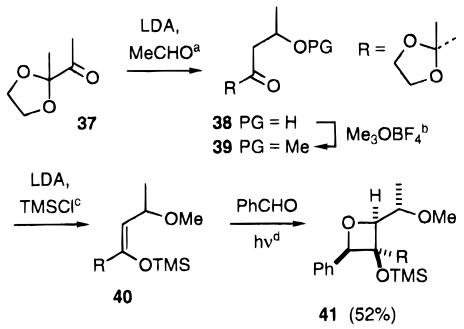
(39) Saito, S.; Hasegawa, T.; Inabe, M.; Nishida, R. *Chem. Lett.* **1984**, 1389−1392.

(40) Ley, S. V.; Norman, J.; Griffith, W. P.; Marsden, S. P. *Synthesis* **1994**, 639−666.

(41) Böeseken, J.; Tellegen, F. *Recl. Trav. Chim. Pays-Bas* **1938**, *57*, 133−143.

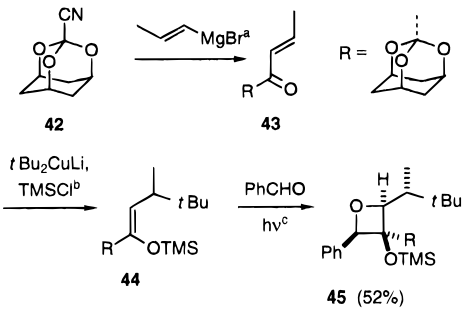
(42) Stetter, H.; Hunds, A. *Liebigs Ann. Chem.* **1984**, 1577−1590.

Scheme 10[a]



[a] Reagents and conditions: (a) −78 °C (THF); (b) 1,8-bis(dimethylamino)naphthalene, 25 °C (CH_2Cl_2); (c) −78 → +25 °C (THF); (d) 30 °C (PhH).

Scheme 11[a]



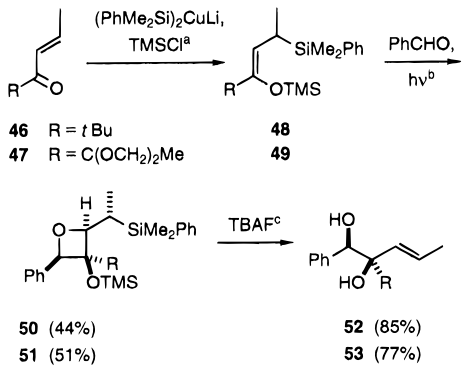
[a] Reagents and conditions: (a) −25 → −15 °C (THF); (b) *t*-Bu_2CuLi, −78 → 0 °C, TMSCl, NEt_3, 0 → 25 °C (THF); (c) 30 °C (PhH).

Addition of 1-propenylmagnesium bromide gave the α,*β*-unsaturated ketone **43** which was transformed to the silyl enol ether **44** by the one-pot sequence conjugate addition/silylation (Scheme 11). The oxetane formation was initiated by irradiation of the olefin **44** in the presence of benzaldehyde. Only a single diastereoisomer **45** was detected (dr = >95/5) which was accompanied by regioisomeric impurities (regioselectivity 85/15). After hydrolysis of the excess silyl enol ether, the pure oxetane **45** was obtained in 52% yield.

Despite the success encountered in terms of facial diastereoselection, it must be noted that the regioselectivity highly depends on the bulkiness of the α-substituent. Attempted photocycloaddtion reactions with an *i*-Pr-substituted silyl enol ether exhibited a strong deterioration in this type of selectivity (regioselectivity 70/30). As can be seen from the above-mentioned examples, there are nonetheless several protected functional groups which can be introduced and used successfully. In an earlier study we have already shown that other aromatic aldehydes may be employed in the photocycloaddition to silyl enol ethers.[6d] Aliphatic aldehydes, however, appear unsuited for this particular reaction. Attempts to react acetaldehyde and related carbonyl compounds in a fashion analogous to that described for benzaldehyde remained unsuccessful and gave only low yields of the corresponding oxetane (<5%). It can be assumed that the singlet state is not quenched efficiently because the concentration of the alkene is comparably low. In the triplet manifold the well-documented reactions of aliphatic aldehydes[2d] (Norrish type cleavage, hydrogen abstraction) take over and inhibit oxetane formation.

With respect to a projected ring opening between O and C-4 in the photocycloaddition product, we prepared a couple of silyl enol ethers which bear a silicon substituent in the γ-position. The idea was to facilitate a fragmentation of the product oxetane in order to generate diastereomerically pure 3-butene-1,2-diols. The corresponding starting materials were prepared by conjugate addition of $(PhMe_2Si)_2CuLi$[43] to the α,*β*-unsaturated ketones **46**[31] and **47**[44] and *in situ* quench of the intermediate enolates (Scheme 12). As expected from the steric requirements of the silyl group, the facial diastereoselectivity in the subsequent Paternò−Büchi reaction was excellent. By this means the diastereomerically pure oxetanes **50** (dr = 95/5, regioselectivity 70/30) and **51** (dr = 83/17, regioselectivity 80/20) can be readily generated. Treatment with tetrabutylammonium fluoride (TBAF) promoted a smooth ring opening to the desired diols **52** and **53** which are valuable intermediates for further functionalization. The (*E*)-configuration of the double bond suggests an antiperiplanar stereospecific E2 type elimination. The two-step sequence photocycloaddition/fragmentation allows the formal allyl transfer of a bulky allylic α-alkoxy anion to a carbonyl group with good stereocontrol. It is complementary to known allyl transfer reactions which enable stereoselective access to less crowded 1,2-diols.[45] Since the photocycloaddition proceeds racemization-free, enantiomerically pure material should be readily accessible from enantiomerically pure chiral silyl enol ethers.[46]

Scheme 12[a]



[a] Reagents and conditions: (a) $(PhMe_2Si)_2CuLi$, −23 → 0 °C, TMSCl, NEt_3, 0 → 25 °C (THF); (b) 30 °C (PhH); (c) 25 °C (THF).

Summary

In summary, our studies have revealed that chiral silyl enol ethers of the general formula **III** (Scheme 2) are suitable alkene components in stereoselective Paternò−Büchi reactions. The yields of the major product oxetanes range between 44% and 76%. In order to ensure good facial diastereoselectivity (dr = ≥85/15), the substituent R^L in the γ-position should be bulky (R^L = $SiMe_2Ph$, *t*-Bu) or polar (R^L = OR). In a single step three new stereogenic centers are established in a predictable manner. The formation of 1 out of 16 possible isomeric oxetanes is strongly favored. The reaction proceeds racemization-free, and as a consequence, enantiomerically pure oxetanes are equally well accessible. Ring-opening reactions which occur selectively at the bond either between O and C-2 or between O and C-4 have been developed and applied to selected oxetanes. With these methods the stereochemical information generated in the photochemical step can be transformed to acyclic target molecules.

(43) (a) Ager, D. J.; Fleming, I.; Patel, S. K. *J. Chem. Soc., Perkin Trans. 1* **1981**, 2520−2526. (b) Fleming, I.; Newton, T. W. *Ibid.* **1984**, 1805−1809.

(44) **47** was prepared in full analogy to **46** from the corresponding hydroxy ketone **38**.

(45) Hoffmann, R. W.; Metternich, R. *Liebigs Ann. Chem.* **1985**, 2390−2402.

(46) Matsumoto, Y.; Hayashi, T., Ito, Y. *Tetrahedron* **1994**, *50*, 335−346.

Experimental Section

General Procedures. See ref 6d.

2,2,5-Trimethyl-3-[(trimethylsilyl)oxy]-3-heptene (5). Typical Procedure A. To a stirred suspension of 2 mmol (179 mg) of CuCN in 5 mL of THF was added dropwise at 0 °C a solution of 3 mmol of MeLi (2 mL of a 1.5 M solution) in ether. After 30 min the mixture was cooled to −78 °C and a solution of 1 mmol of α,β-unsaturated ketone **4**[19] (140 mg) in 5 mL of THF was added dropwise. The reaction mixture was stirred for 30 min, warmed to 0 °C, and stirred for an additional 30 min. At this temperature 1 mmol of triethylamine (101 mg, 139 μL) and 2 mmol of TMSCl (217 mg, 254 μL) were added successively by syringe. After stirring for another 5 min, the mixture was warmed to ambient temperature. It was quenched with an aqueous saturated NH_4Cl solution, and the product was extracted into ether. The combined organic layers were washed with brine and dried over $MgSO_4$. After filtration the solvents were removed *in vacuo*. The residue proved to be sufficiently pure (GLC) for further transformations. Yield: 206 mg (90%). R_f = 0.72 (90/10). ^{1}H NMR ($CDCl_3$): 0.22 (s, 9 H), 0.85 (t, ^3J = 7.4 Hz, 3 H), 0.91 (d, ^3J = 6.7 Hz, 3 H), 1.04 (s, 9 H), 1.15−1.35 (m, 2 H), 2.20−2.35 (m, 1 H), 4.29 (d, ^3J = 9.3 Hz, 1 H). ^{13}C NMR ($CDCl_3$): 1.0 (q) 11.7 (q), 20.6 (q), 28.7 (q), 30.7 (t), 32,7 (d), 36.1 (s), 110.5 (d), 157.0 (s). Anal. Calcd for $C_{13}H_{28}OSi$ (228.4): C, 68.35; H, 12.35. Found: C, 68.20; H, 12.44.

2,2,5,6-Tetramethyl-3-[(trimethylsilyl)oxy]-3-heptene (6). Typical Procedure B. To a stirred solution of 10 mmol of LDA prepared from 10.5 mmol of diisopropylamine (1.06 g, 1.47 mL) and 10 mmol of *n*-BuLi (4 mL of a 2.5 M solution in *n*-hexane) at 0 °C in 20 mL of THF was slowly added at −78 °C ketone **1**[16a] (10 mmol, 1.70 g). After 20 min 11 mmol of TMSCl was added (1.20 g, 1.40 mL) within 10 min. After another 30 min, the mixture was warmed to room temperature and the solvent was removed *in vacuo*. The residue was filtered, and the solid in the filter was washed thoroughly with pentane. The solvent was removed, and the procedure (filtration, washing, solvent removal) was repeated until a clear solution resulted. Purification by flash chromatography (CH/EA = 99/1) yielded 1.29 g (53%) of the desired product. R_f = 0.70 (95/5). ^{1}H NMR ($CDCl_3$): 0.22 (s, 9 H), 0.84 (d, ^3J = 6.7 Hz, 3 H), 0.85 (d, ^3J = 6.7 Hz, 3 H), 0.88 (d, ^3J = 6.7 Hz, 3 H), 1.04 (s, 9 H), 1.44 (virt oct, $^3J \approx$ 6.7 Hz, 1 H), 2.16 (virt dquint, ^3J = 9.8 Hz, $^3J \approx$ 6.7 Hz, 1 H), 4.35 (d, ^3J = 9.8 Hz, 1H). Anal. Calcd for $C_{14}H_{30}OSi$ (242.5): C, 69.35; H, 12.47. Found: C, 69.46; H, 12.29. For further analytical data see the Supporting Information.

3-(1,1-Dimethylethyl)-4-(1-methylpropyl)-2-phenyl-3-[(trimethylsilyl)oxy]oxetane (9) Typical Procedure C. A quartz tube was charged with 3.5 mmol of silyl enol ether **5** (799 mg) dissolved in 6 mL of benzene. The sample was irradiated at 300 nm (RPR 3000 Å) in a merry-go-round unit. Benzaldehyde (1 mmol, 106 mg, 102 μL) was added slowly as a solution in 1 mL of benzene via syringe (within 2 h). Upon complete addition the reaction was monitored by TLC and GLC. After the aldehyde was fully consumed the irradiation was stopped. The solvent was evaporated *in vacuo*, and the residue was analyzed by ^{1}H NMR spectroscopy and by GLC−MS to determine the diastereo- and regioselectivity (dr = 60/40; regioselectivity 87/13). Silyl enol ether was recovered from the crude product mixture by distillation in a Kugelrohr apparatus. Further purification was carried out by flash chromatography (CH/EA = 99/1). The diastereoisomers were not fully separable. Total yield: 222 mg (61%). R_f = 0.44 (90/10). Anal. Calcd for $C_{20}H_{34}O_2Si$ (334.6): C, 71.80; H 10.24. Found: C, 71.66; H, 10.13. Major isomer (2*RS*,3*RS*,4*SR*,1′*RS*)-**9a**. ^{1}H NMR ($CDCl_3$): −0.31 (s, 9 H), 0.76 (d, ^3J = 6.4 Hz, 3 H), 0.92 (t, ^3J = 7.1 Hz, 3 H), 1.08 (s, 9 H), 1.30−2.10 (m, 3 H), 4.21 (d, ^3J = 10.5 Hz, 1 H), 5.62 (s, 1 H), 7.20−7.50 (m, 5 H). ^{13}C NMR ($CDCl_3$): 2.3 (q), 10.7 (q), 13.1 (q), 24.4 (q), 24.5 (t), 28.8 (s), 36.2 (d), 86.1 (d), 87.5 (s), 89.3 (d), 127.6 (d), 128.0 (d), 128.2 (d), 139.9 (s). Minor isomer (2*SR*,3*SR*,4*RS*,1′*RS*)-**9b**. ^{1}H NMR ($CDCl_3$): −0.30 (s, 9 H), 0.77 (d, ^3J = 6.6 Hz, 3 H), 0.94 (t, ^3J = 7.4 Hz, 3 H), 1.07 (s, 9 H), 1.30−2.10 (m, 3 H), 4.27 (d, ^3J = 10.5 Hz, 1 H), 5.63 (s), 7.20−7.50 (m, 5 H).

3-(1,1-Dimethylethyl)-4-(1,2-dimethylpropyl)-2-phenyl-3-[(trimethylsilyl)oxy]oxetane (10). As described in typical procedure C the oxetane formation was carried out on a 1 mmol scale starting with silyl enol ether **6** (855 mg). The crude product (dr = 70/30; regioselectivity 82/18) was purified by flash chromatography (CH/EA = 99/1). Total yield: 195 mg (57%). Major isomer (2*RS*,3*RS*,4*SR*,1′*RS*)-**10a**. R_f = 0.32 (95/5). ^{1}H NMR ($CDCl_3$): −0.30 (s, 9 H), 0.77 (d, ^3J = 6.8 Hz, 3 H), 0.95 (d, ^3J = 7.2 Hz, 3 H), 0.97 (d, ^3J = 7.2 Hz, 3 H), 1.09 (s, 9 H), 1.68 (dsept, ^3J = 7.2 Hz, ^3J = 1.9 Hz, 1 H,), 2.14 (ddq, ^3J = 10.9 Hz, ^3J = 6.8 Hz, ^3J = 1.9 Hz, 1 H), 4.45 (d, ^3J = 10.9 Hz, 1 H), 5.62 (s, 1 H), 7.25−7.40 (m, 5 H). Anal. Calcd for $C_{21}H_{36}O_2Si$ (348.6): C, 72.36; H, 10.41. Found: C, 72.10; H, 10.16. For further analytical data see the Supporting Information. Minor isomer (2*SR*,3*SR*,4*RS*,1′*RS*)-**10b**. R_f = 0.36 (95/5). ^{1}H NMR ($CDCl_3$): −0.30 (s, 9 H), 0.64 (d, ^3J = 6.9 Hz, 3 H), 0.83 (d, ^3J = 6.9 Hz, 3 H), 1.03 (d, ^3J = 7.2 Hz, 3 H), 1.08 (s, 9 H), 2.09 (ddq, ^3J = 10.7 Hz, ^3J = 6.9 Hz, ^3J = 2.9 Hz, 1 H), 2.39 (dsept, ^3J = 6.9 Hz, ^3J = 2.9 Hz, 1 H), 4.40 (d, ^3J = 10.7 Hz, 1 H), 5.63 (s, 1 H), 7.25−7.38 (m, 5 H).

3-(1,1-Dimethylethyl)-2-phenyl-4-(1-phenylethyl)-3-[(trimethylsilyl)oxy]oxetane (11). As described in typical procedure C the oxetane formation was carried out on a 1 mmol-scale starting with silyl enol ether **7**[47] (967 mg). The crude product (dr = 71/29; regioselectivity 80/20) was purified by flash chromatography (CH/EA = 99/1). Total yield: 289 mg (76%). Major isomer (2*RS*,3*RS*,4*SR*,1′*RS*)-**11a**. R_f = 0.25 (95/5). ^{1}H NMR ($CDCl_3$): −0.27 (s, 9 H,), 0.71 (s, 9 H), 1.45 (d, ^3J = 6.9 Hz, 3 H), 3.50 (dq, ^3J = 10.2 Hz, ^3J = 6.9 Hz, 1 H), 4.77 (d, ^3J = 10.2 Hz, 1 H), 5.65 (s, 1 H), 7.13−7.48 (m, 5 H). Anal. Calcd for $C_{24}H_{34}O_2Si$ (382.6): C, 75.34; H, 8.96. Found: C, 75.45; H, 8.85. For further analytical data see the Supporting Information. Enantiomerically pure oxetane (+)-**11a** was prepared from silyl enol ether (+)-**7** in the same fashion. $[\alpha]^{20}_D$ = +76.7 (*c* = 1.2, acetone). Minor isomer (2*SR*,3*SR*,4*RS*,1′*RS*)-**11b**. R_f = 0.17 (95/5). ^{1}H NMR ($CDCl_3$): −0.21 (s, 9H), 1.14 (s, 9 H), 1.15 (d, ^3J = 6.7 Hz, 3 H), 3.37 (dq, ^3J = 10.6 Hz, ^3J = 6.7 Hz, 1 H), 4.74 (d, ^3J = 10.6 Hz, 1 H), 5.61 (s, 1 H), 7.13−7.48 (m, 5 H). Anal. Calcd for $C_{24}H_{34}O_2Si$ (382.6): C, 75.34; H, 8.96. Found: C, 75.38; H, 8.95. For further analytical data see the Supporting Information. Enantiomerically pure oxetane (+)-**11b** was prepared from silyl enol ether (+)-**7** in the same fashion. $[\alpha]^{20}_D$ = +155.7 (*c* = 1.0, acetone). The temperature dependent measurements of the diastereomeric ratio **11a**/**11b** were carried out in an immersion apparatus as previously described.[6b]

X-ray crystal structure analysis of **11a**: formula $C_{24}H_{34}O_2Si$, M = 382.60, 0.7 × 0.4 × 0.35 mm, a = 15.977(3) Å, b = 17.205(3)Å, c = 8.575(2) Å, β = 101.06(3)°, V = 2313.4(8) Å^3, ρ_{calc} = 1.099 g cm^{-3}, μ = 9.96 cm^{-1}, no absorption correction, Z = 4, monoclinic, space group $P2_1/c$ (no. 14), λ = 1.541 78 Å, T = 293 K, $\omega/2\theta$ scans, 5205 reflections collected (±*h*, -*k*, +*l*), [(sin θ)/λ]$_{max}$ = 0.62 Å^{-1}, 4867 independent and 4021 observed reflections [$I \le 2\sigma(I)$], 252 refined parameters, R = 0.046, wR^2 = 0.127, maximum residual electron density 0.21 (-0.29) e Å^{-3}, hydrogens calculated and riding.

3-(1,1-Dimethylethyl)-2-phenyl-4-(1,2,2-trimethylpropyl)-3-[(trimethylsilyl)oxy]oxetane (12a). As described in typical procedure C the oxetane formation was carried out on a 1 mmol scale starting with silyl enol ether **8**[47] (900 mg). The crude product (dr = >95/5; regioselectivity 75/25) was purified by flash chromatography (CH/EA = 99/1). Yield: 248 mg (58%). R_f = 0.25 (95/5). ^{1}H NMR ($CDCl_3$): −0.22 (s, 9 H), 0.94 (s, 9 H), 1.10 (s, 9 H), 1.17 (d, ^3J = 7.2 Hz, 3 H), 1.50 (dq, ^3J = 7.2 Hz, ^3J = 0.8 Hz, 1 H), 5.18 (d, ^3J = 0.8 Hz, 1 H), 5.79 (s, 1 H), 7.21−7.44 (m, 5 H). Anal. Calcd for $C_{22}H_{38}O_2Si$ (362.6): C, 72.87; H, 10.56. Found: C, 72.85; H, 10.28. For further analytical data see the Supporting Information.

2,2-Dimethyl-5-methoxy-3-hexanone (25). Typical procedure D. To a solution of 70 mmol of hydroxyketone **23**[31] (10.1 g) in 100 mL of CH_2Cl_2 were added 100 mmol of trimethyloxonium tetrafluoroborate (14.8 g) and 120 mmol of 1,8-bis(dimethylamino)naphthalene (25.7 g). The suspension was stirred at room temperature for 20 d and was subsequently quenched with ice-cold water. The product was thoroughly extracted into ether (6 × 50 mL). The combined organic layers were washed with an aqueous saturated $NaHCO_3$ solution and with brine and dried over $MgSO_4$. After filtration the solvents were removed *in vacuo*. The residue was filtered through a plug of silica (ether as eluent) and subsequently distilled *in vacuo*. Yield: 6.42 g (58%). Bp: 100−110 °C (20 mbar). ^{1}H NMR ($CDCl_3$): 1.08 (s, 9 H), 1.13 (d, ^3J

(47) For preparation see the Supporting Information.

= 6.2 Hz, 3 H), 2.43 (dd, ^2J = 16.9 Hz, ^3J = 6.2 Hz, 1 H), 2.84 (dd, ^2J = 16.9 Hz, ^3J = 6.2 Hz, 1 H), 3.33 (s, 3 H), 3.83 (virt sex, $^3J \approx$ 6.2 Hz, 1 H). Anal. Calcd for $C_9H_{18}O_2$ (158.2): C, 68.31; H, 11.47. Found: C, 68.49; H, 11.46. For further analytical data see the Supporting Information.

2,2-Dimethyl-5-methoxy-3-[(trimethylsilyl)oxy]-3-hexene (27). As described in typical procedure B the silyl enol ether formation was carried out on a 35 mmol scale starting with ketone **25** (5.54 g). The crude product proved to be sufficiently pure (GLC) for further transformations. Yield: 7.70 g (95%). Bp: 150 °C (2 mbar). R_f = 0.53 (90/10). ^{1}H NMR ($CDCl_3$): 0.24 (s, 9 H), 1.06 (s, 9 H), 1.19 (d, ^3J = 6.5 Hz, 3 H), 3.22 (s, 3 H), 4.07 (dq, ^3J = 9.0 Hz, ^3J = 6.5 Hz, 1 H), 4.50 (d, ^3J = 9.0 Hz, 1 H). Anal. Calcd for $C_{12}H_{26}O_2Si$ (230.4): C, 62.55; H, 11.37. Found: C, 62.44; H, 11.26. For further analytical data see the Supporting Information.

3-(1,1-Dimethylethyl)-4-(1-methoxyethyl)-2-phenyl-3-[(trimethylsilyl)oxy]oxetane (29). As described in typical procedure C the oxetane formation was carried out on a 1 mmol-scale starting with silyl enol ether **27** (806 mg). The crude product (dr = 85/15; regioselectivity 91/9) was purified by flash chromatography (CH/EA = 99/1). Total yield: 209 mg (62%). Major isomer (2*RS*,3*RS*,4*SR*,1′*SR*)-**29a**. Mp: 96 °C. R_f = 0.21 (95/5). ^{1}H NMR ($CDCl_3$): −0.26 (s, 9 H), 1.08 (s, 9 H), 1.31 (d, ^3J = 6.2 Hz, 3 H), 3.33 (s, 3 H), 3.80 (dq, ^3J = 8.9 Hz, ^3J = 6.2 Hz, 1 H), 4.37 (d, ^3J = 8.9 Hz, 1 H), 5.64 (s, 1 H), 7.26−7.36 (m, 5 H). ^{13}C NMR ($CDCl_3$): 2.5 (q), 14.0 (q), 25.4 (q), 36.0 (s), 55.5 (q), 74.5 (d) 85.9 (d), 86.5 (d), 88.1 (s), 127.6 (d), 127.7 (d), 128.1 (d), 139.4 (s). Anal. Calcd for $C_{19}H_{32}O_3Si$ (336.5): C, 67.81; H, 9.58. Found: C, 67.85; H, 9.33. Minor isomer (2*SR*,3*SR*,4*RS*,1′*SR*)-**29b**. R_f = 0.11 (90/10). ^{1}H NMR ($CDCl_3$): −0.30 (s, 9 H), 1.07 (d, ^3J = 6.2 Hz, 3 H), 1.07 (s, 9 H), 3.59 (s, 3 H), 3.81 (dq, ^3J = 9.3 Hz, ^3J = 6.2 Hz, 1 H), 4.48 (d, ^3J = 9.3 Hz, 1 H), 5.71 (s, 1 H), 7.25−7.46 (m, 5 H). Anal. Calcd. for $C_{19}H_{32}O_3Si$ (336.5): C, 67.81; H, 9.58. Found: C, 67.97; H, 9.43. For further analytical data see the Supporting Information.

2,2-Dimethyl-5-methoxy-3-(phenylmethyl)-3,4-hexanediol (31). Oxetane **29a** (2.5 mmol, 840 mg) was dissolved in 20 mL of methanol, and 0.5 mmol of the catalyst Pd/C [10% w/w] (265 mg) was added to the solution. The hydrogenolysis was carried out in a conventional hydrogenation apparatus at ambient temperature and atmospheric pressure. The progression of the reaction was indicated by the volume of consumed hydrogen and was further monitored by TLC. Upon complete transformation (72 h) the mixture was filtered and the solvent removed *in vacuo*. The residue was purified by chromatography (FC, CH/EA = 95/5). Yield: 565 mg (85%). Mp: 112 °C. R_f = 0.45 (75/25). ^{1}H NMR ($CDCl_3$): 0.99 (d, ^3J = 5.9 Hz, 3 H), 1.08 (s, 9 H), 1.67 (d, ^3J = 6.2 Hz, 1 H), 2.80 (s, 3 H), 2.94 (dq, ^3J = 9.0 Hz, ^3J = 5.9 Hz, 1 H), 2.95 (d, ^2J = 13.8 Hz, 1 H), 3.03 (d, ^2J = 13.8 Hz, 1 H), 3.60 (dd, ^3J = 9.0 Hz, ^3J = 6.2 Hz, 1 H), 4.48 (s, 1 H), 7.17−7.47 (m, 5 H). ^{13}C NMR ($CDCl_3$): 15.6 (q), 26.2 (q), 36.5 (t), 39.5 (s), 54.7 (q), 75.2 (d), 78.4 (d), 79.8 (s), 125.9 (d), 127.6 (d), 131.5 (d), 139.7 (s). Anal. Calcd for $C_{16}H_{25}O_3$ (266.4): C, 72.14; H, 9.46. Found: C, 71.94, H 9.62.

1,2-Dihydroxy-5,5-dimethyl-1,2-*O*-isopropylidene-4-hexanone (34). To a solution of 5.9 mmol of alcohol **33**[47] (1.19 g) in 50 mL of CH_2Cl_2 were added 12 mmol of *N*-methylmorpholine *N*-oxide (1.40 g) and 4 g of powdered molecular sieves 4 Å. The suspension was stirred at room temperature for 10 min. Then 0.6 mmol of tetrapropylammonium perruthenate (211 mg) was added, and stirring was continued for 6 h. The crude product mixture was filtered through a plug of silica (ethyl acetate as eluent), and the solvents were removed *in vacuo*. The residue proved to be sufficiently pure (GLC) for further transformations. Yield: 967 mg (82%). $[\alpha]^{20}_D$ = +7.9 (c = 0.3, CH_2Cl_2). R_f = 0.18 (90/10). ^{1}H NMR ($CDCl_3$): 1.16 (s, 9 H), 1.30 (s, 3 H), 1.36 (s, 3 H), 2.67 (dd, ^2J = 17.4 Hz, ^3J = 7.3 Hz, 1 H), 3.12 (dd, ^2J = 17.4 Hz, ^3J = 5.7 Hz, 1 H), 3.51 (dd, ^2J = 8.1 Hz, ^3J = 6.9 Hz, 1 H), 4.15 (dd, ^2J = 8.1 Hz, ^3J = 5.9 Hz, 1 H), 4.42 (virt tt, $^3J \approx$ 7.3 Hz, $^3J \approx$ 5.8 Hz, 1 H). Anal. Calcd for $C_{11}H_{20}O_3$ (200.3): C, 65.96; H, 10.07. Found: C, 65.55; H, 10.67. For further analytical data see the Supporting Information.

4-(2,2-Dimethyl-1,3-dioxolan-4-yl)-3-(2,2-dimethylethyl)-2-phenyl-3-[(trimethylsilyl)oxy]oxetane (36). As described in typical procedure C the oxetane formation was carried out on a 0.38 mmol scale starting with silyl enol ether **35**[47] (205 mg). The crude product (dr = 90/10; regioselectivity >95/5) was purified by flash chromatography (CH/EA = 99/1). Yield: 100 mg (70%). $[\alpha]^{20}_D$ = +32.2 (c = 0.8, CH_2Cl_2). R_f = 0.36 (90/10). ^{1}H NMR ($CDCl_3$): −0.24 (s, 9 H), 1.10 (s, 9 H), 1.33 (s, 3 H), 1.40 (s, 3 H), 4.05 (dd, ^2J = 8.4 Hz, ^3J = 5.0 Hz, 1 H), 4.27 (dd, ^2J = 8.4 Hz, ^3J = 6.3 Hz, 1 H), 4.37 (ddd, ^3J = 8.8 Hz, ^3J = 6.3 Hz, ^3J = 5.0 Hz, 1 H), 4.53 (d, ^3J = 8.8 Hz, 1 H), 5.64 (s, 1 H), 7.23−7.39 (m, 5 H). ^{13}C NMR ($CDCl_3$): 2.6 (q), 25.4 (q), 25.7 (q), 27.2 (q), 36.6 (s), 67.1 (t), 74.6 (d), 86.7 (d), 86.9 (d), 87.3 (s), 110.2 (s), 127.3 (d), 128.0 (d), 128.8 (d), 140.8 (s). Anal. Calcd for $C_{21}H_{34}O_4Si$ (378.6): C, 66.63; H, 9.05. Found: C, 66.94; H, 9.18.

3-(2-Methyl-1,3-dioxolan-2-yl)-4-(1-methoxyethyl)-2-phenyl-3-[(trimethylsilyl)oxy]oxetane (41). As described in typical procedure C the oxetane formation was carried out on a 0.86 mmol scale starting with silyl enol ether **40**[47] (785 mg). The crude product (dr = 79/21; regioselectivity >95/5) was purified by flash chromatography (CH/EA = 95/5). Total yield: 235 mg (75%). Major isomer (2*RS*,3*RS*,4*SR*,1′*SR*)-**41**. Mp: 80 °C. R_f = 0.20 (90/10). ^{1}H NMR ($CDCl_3$): −0.29 (s, 9 H), 1.27 (d, ^3J = 6.4 Hz), 1.32 (s, 3 H), 3.36 (s, 3 H), 3.86 (dq, ^3J = 8.8 Hz, ^3J = 6.4 Hz, 1 H), 4.00−4.25 (m, 4H), 4.43 (d, ^3J = 8.8 Hz, 1 H), 5.68 (s, 1 H), 7.28−7.40 (m, 5 H). NOE experiment ($CDCl_3$): H (4.43), $H_{(5.68)}$ [0.51%]; H (1.32), $H_{(4.43)}$ [1.7%]. ^{13}C NMR ($CDCl_3$): 1.8 (q), 14.3 (q), 19.6 (q), 56.1 (q), 65.1 (t), 74.3 (d), 84.6 (d), 85.2 (s), 86.3 (d), 109.7 (s), 126.1 (d), 126.5 (d), 127.0 (d), 136.4 (s). Anal. Calcd for $C_{19}H_{30}O_5Si$ (366.5): C, 62.26; H, 8.25. Found: C, 62.56; H, 8.22. Minor isomer (2*SR*,3*SR*,4*RS*,1′*SR*)-**41**. R_f = 0.05 (90/10). ^{1}H NMR ($CDCl_3$): −0.31 (s, 9 H), 1.11 (d, ^3J = 6.3 Hz), 1.27 (s, 3 H), 3.56 (s, 3 H), 3.86 (dq, ^3J = 9.0 Hz, ^3J = 6.3 Hz, 1 H), 4.01−4.19 (m, 4H), 4.58 (d, ^3J = 9.0 Hz, 1 H), 5.73 (s, 1 H), 7.27−7.45 (m, 5 H). NOE experiment ($CDCl_3$): H (5.73), $H_{(4.58)}$ [0.42%]; H (1.27), $H_{(5.73)}$ [0.56%], $H_{(4.58)}$ [1.15%]. For further analytical data see the Supporting Information.

1-(2,4,10-Trioxaadamant-3-yl)-2-buten-1-one (43). To a stirred solution of 1.0 mmol of nitrile **42**[42] (167 mg) in 10 mL of THF was slowly added at −78 °C (within 25 min) 1 mmol of MeCHCHMgBr (0.6 mL of a 1.7 M solution in THF). The solution was warmed to −10 °C and stirred at this temperature for another 1.5 h. The mixture was quenched with a cold aqueous HCl solution (1 N), and the product was extracted into CH_2Cl_2. The combined organic layers were dried over $MgSO_4$. After filtration the solvents were removed *in vacuo*. The residue was purified by flash chromatography (CH/EA = 60/40). Yield: 149 mg (71%). Mp: 80 °C. R_f = 0.26 (40/60). ^{1}H NMR ($CDCl_3$): 1.79 (d, ^2J = 12.7 Hz, 3 H), 1.93 (dd, ^3J = 7.0 Hz, ^4J = 1.7 Hz, 3 H), 2.75 (d, ^2J = 12.7 Hz, 3 H), 4.54 (s, 3 H), 6.61 (dq, ^3J = 15.6 Hz, ^4J = 1.7 Hz, 1 H), 7.18 (dq, ^3J = 15.6 Hz, ^3J = 7.0 Hz, 1 H). Anal. Calcd for $C_{11}H_{14}O_4$ (210.2): C, 62.85; H, 6.71. Found: C, 62.58; H, 6.73. For further analytical data see the Supporting Information.

1-(2,4,10-Trioxaadamant-3-yl)-3,4,4-trimethyl-1-[(trimethylsilyl)-oxy]-1-pentene (44). As described in typical procedure A the silyl enol ether formation was carried out on a 3 mmol scale starting with ketone **43** (631 mg) and employing 9 mmol of *t*-BuLi (6 mL of a 1.5 M solution in pentane). The crude product was purified by flash chromatography (CH/EA = 75/25). Yield: 864 mg (85%). Mp: 57 °C. R_f = 0.66 (40/60). ^{1}H NMR ($CDCl_3$): 0.21 (s, 9 H), 0.85 (s, 9 H), 0.90 (d, ^3J = 6.9 Hz, 3 H), 1.68 (d, ^2J = 12.5 Hz, 3 H), 2.25 (dq, ^3J = 10.2 Hz, ^3J = 6.9 Hz, 1 H), 2.64 (d, ^2J = 12.5 Hz, 3 H), 4.43 (s, 3 H), 5.12 (d, ^3J = 10.2 Hz, 1 H). Anal. Calcd for $C_{18}H_{32}O_4Si$ (339.5): C, 63.68; H, 9.50. Found: C, 63.54; H, 9.57. For further analytical data see the Supporting Information.

2-Phenyl-4-(1,2,2-trimethylpropyl)-3-(2,4,10-trioxaadamant-3-yl)-3-[(trimethylsilyl)oxy]oxetane (45). As described in typical procedure C the oxetane formation was carried out on a 0.65 mmol scale starting with silyl enol ether **44** (766 mg). The crude product (dr = >95/5; regioselectivity 85/15) was dissolved in 80 mL of ether, and upon addition of 50 mL of 2 N HCl, the mixture was stirred for 21 d. After neutralization with an aqueous saturated $NaHCO_3$ solution, the product was extracted into ether. The combined organic layers were washed with brine and dried over $MgSO_4$. After filtration the solvents were removed *in vacuo*. The residue was purified by flash chromatography (CH/EA = 90/10). Yield: 151 mg (52%). Mp: 141 °C. R_f = 0.43 (75/25). ^{1}H NMR ($CDCl_3$): 0.05 (s, 9 H), 1.20 (s, 9 H), 1.40 (d, ^3J =

7.4 Hz, 3 H), 2.14 (dq, ^3J = 7.4 Hz, ^3J = 3.1 Hz, 1 H), 2.02 (d, ^2J = 12.5 Hz, 3 H), 2.94 (d, 3 H, ^2J = 12.5 Hz), 4.75 (s, 3 H), 5.57 (d, ^3J = 3.1 Hz, 1 H), 6.22 (s, 1 H), 7.48−7.71 (m, 5 H). ^{13}C NMR ($CDCl_3$): 2.2 (q), 10.4 (q), 27.8 (q), 28.7 (s), 33.1 (t), 42.4 (d), 68.0 (d), 82.7 (d), 84.1 (d), 85.4 (s), 109.0 (s), 127.1 (d), 127.3 (d), 128.0 (d), 138.7 (s). Anal. Calcd for $C_{25}H_{38}O_5Si$ (446.7): C, 67.23; H, 8.57. Found: C, 67.32; H, 8.45.

2,2-Dimethyl-5-(dimethylphenylsilyl)-3-[(trimethylsilyl)oxy]-3-hexene (48). Typical Procedure E. To a stirred suspension of 18.75 mmol (1.68 g) of CuCN in 15 mL of THF was added dropwise at 0 °C a solution of 37.5 mmol of $PhMe_2SiLi$ (62.5 mL of a 0.6 M solution) in THF. After 30 min the mixture was cooled to −23 °C and a solution of 15 mmol of α,β-unsaturated ketone **46**[31] (1.90 g) in 75 mL of THF was added dropwise (within 30 min). The reaction mixture was stirred for 1 h and warmed slowly to 0 °C. At this temperature 90 mmol of triethylamine (9.11 mg, 12.5 mL) and 90 mmol of TMSCl (9.78 g, 11.4 mL) were added successively by syringe. The mixture was warmed to ambient temperature and stirred for 18 h. It was diluted with pentane and quenched with an aqueous saturated $NaHCO_3$ solution. After 10 min of rapid stirring an aqueous layer was formed on the bottom of the flask from which the organic layer was decanted and filtered through a plug of silica. From the aqueous layer the product was extracted into pentane. The extracts were also filtered through a plug of silica. The organic layers were combined, and the solvents were removed *in vacuo*. The crude product was purified by flash chromatography (CH/EA/NEt_3 = 1000/3/1). Yield: 3.22 g (64%). R_f = 0.63 (95/5). ^{1}H NMR ($CDCl_3$): δ 0.21 (s, 9 H), 0.24 (s, 3 H), 0.25 (s, 3 H), 0.93 (d, ^3J = 7.4 Hz, 3 H), 1.02 (s, 9 H), 1.93 (dq, ^3J = 11.0 Hz, ^3J = 7.4 Hz, 1 H), 4.27 (d, ^3J = 11.0 Hz, 1 H), 7.30−7.60 (m, 5 H). Anal. Calcd for $C_{19}H_{34}OSi_2$ (334.6): C, 68.19; H, 10.24. Found: C, 68.17; H, 10.37. For further analytical data see the Supporting Information.

3-(Dimethylphenylsilyl)-1-(2-methyl-1,3-dioxolan-2-yl)-1-[(trimethylsilyl)oxy]-1-butene (49). As described in typical procedure E the silyl enol ether formation was carried out on a 2.7 mmol scale starting with ketone **47**[44] (427 mg). The crude product was purified by flash chromatography (CH/EA/NEt_3 = 1000/20/1). Yield: 850 mg (86%). R_f = 0.35 (95/5). ^{1}H NMR (acetone-d_6): δ 0.19 (s, 9 H), 0.25 (s, 3 H), 0.26 (s, 3 H), 0.97 (d, ^3J = 7.4 Hz, 3 H), 1.39 (s, 3 H), 2.05 (dq, ^3J = 11.1 Hz, ^3J = 7.4 Hz, 1 H), 3.78−3.91 (m, 4 H), 4.83 (d, ^3J = 11.1 Hz, 1 H), 7.32−7.36 (m, 3 H), 7.49−7.55 (m, 2 H). Anal. Calcd for $C_{19}H_{32}O_3Si_2$ (364.6): C, 62.59; H, 8.85. Found: C, 62.51; H, 8.83. For further analytical data see the Supporting Information.

3-(2,2-Dimethylethyl)-4-[1-(dimethylphenylsilyl)ethyl]-2-phenyl-3-[(trimethylsilyl)oxy]oxetane (50). As described in typical procedure C the oxetane formation was carried out on a 1.5 mmol scale starting with silyl enol ether **48** (2.26 g). The crude product (dr = 95/5; regioselectivity 70/30) was purified by flash chromatography (CH/EA = 99/1). Yield: 291 mg (44%). R_f = 0.43 (95/5). ^{1}H NMR ($CDCl_3$): δ −0.25 (s, 9 H), 0.36 (s, 3 H), 0.38 (s, 3 H), 0.97 (s, 9 H), 1.20 (d, ^3J = 7.6 Hz, 3 H), 1.55 (dq, ^3J = 7.6 Hz, ^3J = 5.9 Hz, 1 H), 4.86 (d, ^3J = 5.9 Hz, 1 H,), 5.62 (s, 1 H), 7.21−7.59 (m, 10 H). ^{13}C NMR ($CDCl_3$): δ −4.6 (q), −3.0 (q), 2.9 (q), 10.3 (q), 21.6 (d), 25.9 (q), 36.9 (s), 84.9 (d), 85.8 (d), 90.0 (s), 127.7 (d), 127.8 (d), 128.0 (d), 128.4 (d), 128.9 (d), 134.0 (d), 138.6 (s), 139.6 (s). Anal. Calcd for $C_{26}H_{40}O_2Si_2$ (440.8): C, 70.85; H, 9.15. Found: C, 71.02; H, 9.23.

4-[1-(Dimethylphenylsilyl)ethyl]-3-(2-methyl-1,3-dioxolan-2-yl)-2-phenyl-3-[(trimethylsilyl)oxy]oxetane (51). As described in typical procedure C the oxetane formation was carried out on a 63 μmol scale starting with silyl enol ether **49** (70 mg). The crude product (dr = 83/17; regioselectivity 80/20) was purified by flash chromatography (CH/EA = 98/2). The diastereoisomers were not fully separable. Total yield: 18 mg (61%). Anal. Calcd for $C_{26}H_{38}O_4Si_2$ (470.8): C, 66.34; H, 8.14. Found: C, 66.40; H, 7.95. Major isomer (2*RS*,3*SR*,4*RS*,1′*SR*)-**51**. R_f = 0.23 (90/10). ^{1}H NMR ($CDCl_3$): δ −0.27 (s, 9 H), 0.34 (s, 3 H), 0.37 (s, 3 H), 1.13 (s, 3 H), 1.29 (d, ^3J = 7.5 Hz, 3 H), 1.48 (dq, ^3J = 7.5 Hz, ^3J = 4.3 Hz, 1 H), 3.82−4.04 (m, 4 H), 4.89 (d, ^3J = 4.3 Hz, 1 H), 5.68 (s, 1 H), 7.25−7.37 (m, 6 H), 7.43 (dd, ^3J = 7.6 Hz, ^4J = 1.4 Hz, 2 H), 7.53−7.60 (m, 2 H). For further analytical data see the Supporting Information. Minor isomer (2*SR*,3*RS*,4*SR*,1′*SR*)-**51** R_f = 0.26 (90/10). ^{1}H NMR ($CDCl_3$): δ −0.31 (s, 9 H), 0.40 (s, 3 H), 0.44 (s, 3 H), 0.75 (d, ^3J = 7.4 Hz, 3 H), 1.23 (s, 3 H), 1.89 (dq, ^3J = 11.4 Hz, ^3J = 7.4 Hz, 1 H), 4.02 - 4.15 (m, 4 H), 4.63 (d, ^3J = 11.4 Hz, 1 H), 5.61 (s, 1 H), 7.21−7.29 (m, 4 H), 7.31−7.37 (m, 4 H), 7.57−7.61 (m, 2 H). For further analytical data see the Supporting Information.

2,2-Dimethyl-3-(hydroxyphenylmethyl)-4-hexen-3-ol (52). Typical procedure F. To a stirred solution of 0.2 mmol of oxetane **50** (88 mg) in 1 mL of THF was added dropwise via syringe a solution of 0.44 mmol of TBAF (0.44 mL of a 1 M solution) in THF. After stirring for 3 h the mixture was diluted with water and saturated with solid NaCl. The product was extracted into CH_2Cl_2. The combined organic layers were dried over $MgSO_4$. After filtration the solvents were removed *in vacuo*. The residue was purified by flash chromatography (CH/EA = 98/2). Yield: 40 mg (85%). Mp: 87−88 °C. R_f = 0.13 (95/5). ^{1}H NMR ($CDCl_3$): δ 0.92 (s, 9 H), 1.66 (dd, ^3J = 6.5 Hz, ^4J = 1.7 Hz, 3 H), 4.82 (s, 1 H), 5.34 (dq, ^3J = 15.7 Hz, ^3J = 6.5 Hz, 1 H), 5.93 (dq, ^3J = 15.7 Hz, ^4J = 1.7 Hz, 1 H), 7.19−7.31 (m, 5 H). ^{13}C NMR ($CDCl_3$): δ 17.7 (q), 26.4 (q), 37.6 (s), 77.4 (d), 79.8 (s), 125.8 (d), 127.7 (d), 128.0 (d), 128.5 (d), 131.2 (d), 141.4 (s). Anal. Calcd for $C_{15}H_{22}O_2$ (234.3): C, 76.88; H, 9.46. Found: C, 76.93; H, 9.45.

2-(2-Methyl-1,3-dioxolan-2-yl)-1-phenyl-3-penten-1,2-diol (53). As described in typical procedure F the diol formation was carried out on a 250 μmol scale starting with oxetane **51** (118 mg). The crude product was purified by flash chromatography (CH/EA = 85/15). Yield: 51 mg (77%). Mp: 89−90 °C. R_f = 0.18 (70/30). ^{1}H NMR ($CDCl_3$): δ 1.43 (s, 3 H), 1.68 (dd, ^3J = 6.4 Hz, ^4J = 1.7 Hz, 3 H), 1.79 (s, 1 H), 3.79 (s, b, 1 H), 3.98−4.14 (m, 4 H), 5.00 (s, 1 H), 5.40 (dq, ^3J = 15.7 Hz, ^3J = 6.4 Hz, 1 H), 5.95 (dq, ^3J = 15.7 Hz, ^4J = 1.7 Hz, 1 H), 7.23−7.35 (m, 5 H). Anal. Calcd for $C_{15}H_{20}O_4$ (264.3): C, 68.16; H, 7.63. Found: C, 68.18; H, 7.85. For further analytical data see the Supporting Information.

Acknowledgment. This work was generously supported by the *Deutsche Forschungsgemeinschaft* (Grant Ba 1372/1-2), by the *Fonds der Chemischen Industrie*, and by the *Gesellschaft zur Förderung der Westfälischen Wilhelms-Universität*. We thank *Dr. B. Riedl (Bayer AG, Wuppertal)* for a gift of chemicals and *Prof. Dr. D. Hoppe* for his continuing support. This paper is dedicated to Professor Waldemar Adam on the occasion of his 60th birthday.

Supporting Information Available: Details of the X-ray crystal structure analysis of **11a**, experimental procedures for the preparation of compounds **(+)-2**, **7**, **8**, **18**−**22**, **26**, **28**, **30**, **33**, **35**, and **38**−**40**, and additional spectroscopic information (NMR assignments, IR, MS) for all new compounds (33 pages). See any current masthead page for ordering and Internet access instructions.

JA963827V