Diastereoselective synthesis of polyfunctional compounds based on the tandem sequence of three Ad_E reactions using cyclic vinyl ethers as first alkene components

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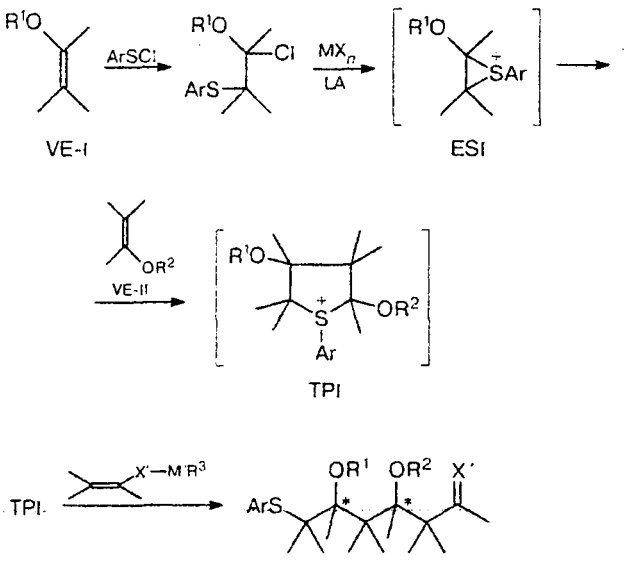
The reaction of the bicyclic thiophanium ions salts, generated by the sequential interaction of *p*-TolSCl with dihydropyran or 1-methoxycycloalkene and then with an acyclic alkyl vinyl ether in the presence of a Lewis acid and with silicon- or tin-capped π-donors, proceeds with high diastereoselectivity at all newly created chiral centers.

Key words: arenesulfenyl chloride, dihydropyran, 1-methoxycycloalkenes, electrophilic addition reaction, episulfonium ion, bicyclic thiophanium ion, silicon- and tin-capped π-donors, stereoselective ring opening.

Creation of new methods for the stereoselective construction of polyfunctional molecules from simple precursors using a one-pot tandem sequence of several reactions represents one of the most vital and at the same time difficult problems of modern organic synthesis.[1] Recently we have developed a novel approach to the solution of this problem based upon the Lewis acid (LA) mediated sequence of three Ad_E reactions of sulfur-containing electrophile with two alkyl vinyl ethers (VE-I and VE-II) and silicon- or tin-containing π-donors, which resulted in the formation of two novel C—C bonds (Scheme 1).[2—4]

At the first step electrophilic addition of the covalent ArSCl to the first alkyl vinyl ether VE-I leads to the formation of a β-arylthio-substituted Cl-adduct, which is further treated with Lewis acid to give an episulfonium ion-like (ESI) intermediate. At the next step an interaction of the latter with the second vinyl ether (VE-II) produces again a stabilized electrophilic intermediate, tentatively identified as cyclic thiophanium ion (TPI) salt.[2] Finally the addition of this intermediate at the double bond of siloxyalkenes or siloxydienes, allylsilanes (allylstannanes), or silyl ketene acetals (C-nucleophilic π-donors) furnishes the chiral polyfunctional molecule, thus enabling the introduction of a wide set of functional groups into the assembled molecular framework.[4] For all that, however, it was found that for the coupling involving the use of acyclic vinyl ethers (*e.g.*, methyl vinyl ether or isobutenyl vinyl ether) as VE-I and VE-II

Scheme 1*



* Here and at Schemes 2—8 the salt-like intermediates formed at the second and third steps are shown only as cationoid complexes (ESI, TPI) without corresponding counterions.

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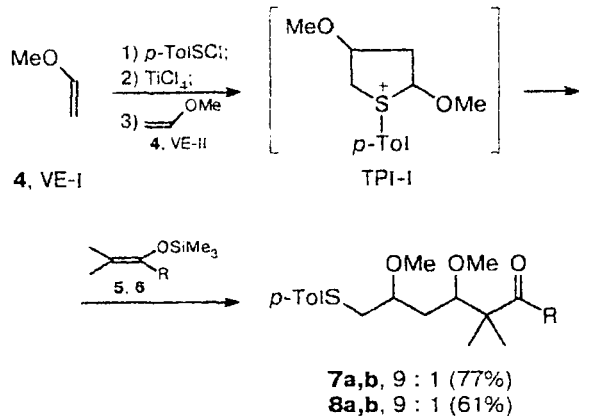
components a rather low diastereoselectivity of formation of two novel chiral centers is typically observed despite numerous variations of the reaction conditions (Lewis acid, temperature, solvent) and the nature of the initial electrophile, ArSCl.[3,4] This non-selectivity affected the synthetic usefulness of the developed method most adversely and therefore our next goal was to investigate more thoroughly the nature of the factors controlling the stereochemistry of the chiral centers formation.

In this communication we present results of the study of the structural factors effects on the stereochemical outcome of the coupling shown in general form in Scheme 1 for the particular case when cyclic vinyl ethers, namely 3,4-dihydro-2*H*-pyran (**1**), 1-methoxycyclohexene (**2a**), 4-*tert*-butyl-1-methoxycyclohexene (**2b**) and 1-methoxycyclopentene (**3**) were employed as the starting vinyl ether units (VE-I).

It was reported earlier[4] that the stereochemical outcome of the studied reaction for the case of coupling of acyclic vinyl ethers might be significantly altered by variations in the structure of the final π-donor interacting with the thiophanium ion intermediate. Thus, for example, the reaction of the intermediate formed upon the coupling of two equivalents of methyl vinyl ether **4** with π-donors not bearing terminal substituents proceeds non-selectively, while the utilization of *gem*-dimethyl-substituted derivatives like **5** or **6** as the π-donors at this stage results in a preferable formation of one of the two possible diastereomers of the adducts **7** or **8** (Scheme 2).

In the presented study it was established that the same effect is also observed for the case of utilization of dihydropyran **1** as the starting alkene component. In fact, the Lewis acid initiated reaction sequence *p*-TolSCl + **1** + **4** + **5** furnishes adduct **9** with a significant predominance of one diastereomer, while previously we observed that the utilization of π-donors not bearing the *gem*-dimethyl fragment in the same sequence gave the

Scheme 2



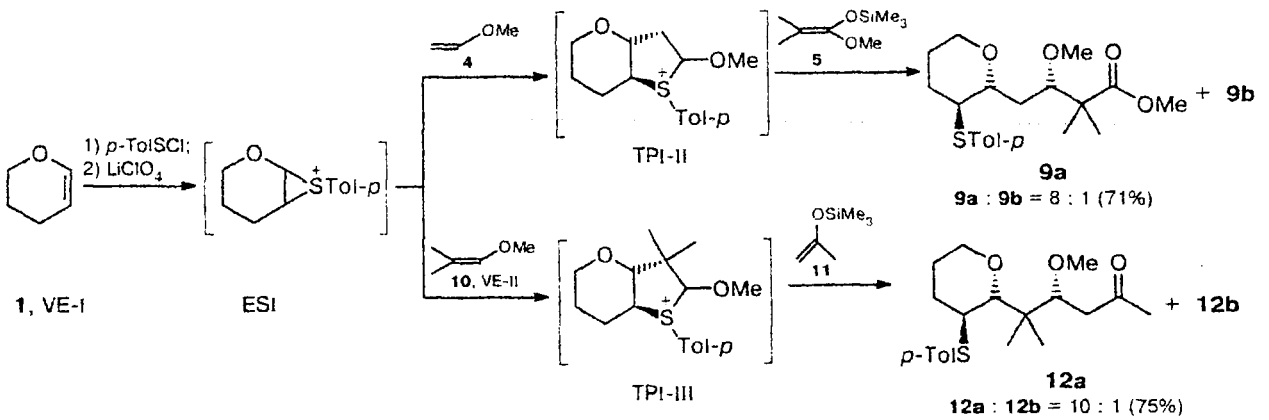
R = OMe (**5**, **7a,b**), H (**6**, **8a,b**)

mixture of diastereomers in a 1.0 : 1.5 ratio.[4] At the same time it was also found that for the pair dihydropyran **1** (VE-I) + methyl isobutenyl ether (**10**) a noticeable diastereoselectivity could be observed even for the sterically unhindered π-donors, such as 2-trimethylsiloxy propene (**11**) (Scheme 3).

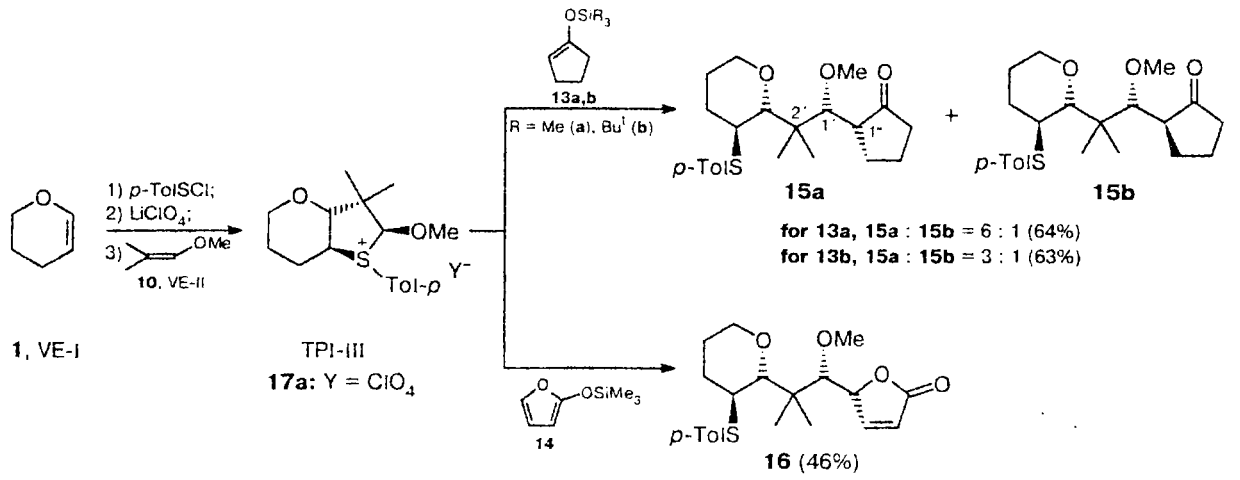
Stereochemistry of the major adduct **12a** (as well as the stereochemistry of adduct **9a**) was ascertained by the comparison of ^{1}H NMR spectral data of these samples with those for the previously prepared authentic analogous adducts.[5]

The disclosed stereoselectivity of the reaction for the pair **1** and **10** prompted us to study the course of the same reaction with sets of other π-donors, especially with the prochiral siloxy derivatives such as 1-trimethylsiloxy- and 1-(*tert*-butyldimethylsiloxy)cyclopentenes (**13a,b**) or α-trimethylsiloxyfuran (**14**) as the final carbon nucleophiles. *p*-Tolylsulfenyl chloride was employed

Scheme 3



Scheme 4



as the initial electrophile and lithium perchlorate served as a Lewis acid. All reactions were carried out as a one-pot sequence of operations. The results are summarized in Scheme 4.

It was found that the utilization of 1-trimethylsiloxycyclopentene **13a** as a final nucleophile resulted in a highly selective formation of the adduct **15**. In fact, ^{1}H NMR data for the reaction mixture revealed that out of

Table 1. Main X-ray diffraction characteristics of compounds **15a,b** and **17b**

Parameter	**15a**	**15b**	**17b**
Molecular formula	$C_{22}H_{32}O_3S$	$C_{22}H_{32}O_3S$	$C_{18}H_{27}Cl_2F_6O_2SSb$
Molecular weight	376.54	376.54	614.11
Diffractometer	Siemens CCP	Siemens P3	Syntex $P2_1$
Radiation (λ/Å)	Mo-Kα (0.71072)	Mo-Kα (0.71072)	Mo-Kα (0.71072)
T/°C	28	28	−80
a/Å	14.5830(4)	9.439(4)	10.627(2)
b/Å	17.9171(6)	11.245(4)	16.604(3)
c/Å	8.0985(3)	11.765(3)	14.594(3)
α/deg		103.12(3)	
β/deg	96.235(1)	105.52(3)	106.42(2)
γ/deg		110.36(3)	
V/Å^3	2103.50(12)	1054.8(6)	2470.1(8)
Z	4	2	4
Space group	$P2_1/c$	$P\bar{1}$	$P2_1/n$
F(000)	816	408	1224
μ/mm^{-1}	0.172	0.171	14.75
d_{calc}/g cm^{-1}	1.189	1.186	1.651
Scan mode	$2\theta/\omega$	$\theta/2\theta$	$\theta/2\theta$
θ_{max}/deg	50	50	50
Total number of reflections	10083	3967	4892
Number of independent reflections	3652	3717	4366
R_1 on reflections with $I > 2\sigma(I)$	0.0601 (on 2214 reflections)	0.0580 (on 2049 reflections)	0.0417 (on 3520 reflections)
wR_2 on all reflections	0.1687 (on 3650 reflections)	0.2415 (on 3675 reflections)	0.1120 (on 4303 reflections)
GOF	0.948	1.051	1.018
Number of refined parameters	271	236	307

eight possible diastereomers only two are formed in a ratio 6 : 1 (total yield 64%). Both isomers, **15a** and **15b**, were isolated as individual compounds. Their relative configuration was established by single crystal X-ray analysis as (1′*R**,1″*R**,2*R**,3*S**)-2-[1″-methoxy-2′-methyl-1′-(2″-oxocyclopentyl)prop-2′-yl]-3-(*p*-tolylthio)tetrahydropyran for the major **15a** and as the (1′*R**,1″*S**,2*R**,3*S**)-epimer for the minor **15b** isomers respectively (see Tables 1 and 2; Figs. 1 and 2, Scheme 4). Thus these products differ only by the configuration of the chiral center at the cyclopentane ring and hence in the reaction sequence leading to the preparation of adducts **15a,b** three out of four chiral centers are formed diastereospecifically. A plausible mechanism of this sequence will be considered below.

It is noteworthy that the replacement of the trimethylsilyl group in **13a** by a more bulky *tert*-butyldimethylsilyl group in **13b** noticeably reduced diastereoselectivity and the adduct **15** was formed as a mixture of the same diastereomers but in a ratio **15a** : **15b** = 3 : 1. The formation of a single diastereomer **16** was observed for the sequence which employed cyclic ketene acetal **14** as a carbon nucleophile. However, a rather modest yield of the isolated product did not allow us to draw a reliable conclusion about the extent of diastereoselectivity of this coupling. The shown configuration of **16** was assigned by analogy.

In order to discuss the stereochemical peculiarities of the described reaction sequence it was mandatory to elucidate the nature of intermediates formed at its key steps. The first of these, episulfonium salt ("episulfonium ion," ESI), had been extensively studied earlier.[6] In particular, numerous data for various Ad_E reactions which are known to proceed *via* formation of these intermediates, revealed that practically in all cases the ESI ring opening occurs as an S_N2-like process. As a result, an exclusive formation of *trans*-addition products is observed irrespective of the nature of the alkene precursor.[6—9] Obviously the same holds true for the reactions leading to the formation of the adducts shown in Schemes 3 and 4 (see stereochemistry of the vicinal substituents in the tetrahydropyran fragment of the adducts **9**, **12**, **15**, and **16**).

A suggestion about the formation of the cyclic thiophanium salt TPI as the second intermediate shown in Schemes 1 and 2, which had been advanced earlier, was confirmed recently by isolation of the similar salt for the case of the coupling of two acyclic vinyl ethers **4** and **10**.[10] In the present study, we have found that similar procedure is also applicable for the isolation of the bicyclic thiophanium salt TPI-III, a plausible intermediate in the reactions with participation of dihydropyran as VE-1 (see Scheme 4). In fact, a sequential coupling of *p*-TolSCl with ethers **1** and **10** carried out in the presence of $AgSbF_6$ in nitromethane solution at −20 °C followed by treatment of the reaction complex with hexane enabled us to prepare TPI-III as hexafluoroantimonate **17b** (solvate with CH_2Cl_2, 1 : 1) in 56% yield as colorless hygroscopic crystals (m.p. 79—82 °C, decomp.) (Scheme 5). The salt thus obtained reacted readily with allyltributyltin **18b** to give the corresponding adduct in 76% yield as a mixture of diastereomers (**19a,b**) (**19a** : **19b** = 4 : 1). This result was fully corroborated by the data on diastereomer ratio for the product prepared by the treatment of generated *in situ* salt **17a** with allyltrimethylsilane **18a**. The structure of the main isomer of adduct **19a** was confirmed by comparison with the earlier prepared sample, which was characterized by X-ray analysis data.[5]

The crystal structure of salt **17b** as (1*R**,2*R**,3a*R**,-7a*S**)-2-methoxy-3,3-dimethyl-1-(*p*-tolyl)tetrahydropyrano-[2,3-*b*]thiophanium hexafluoroantimonate was determined by single crystal X-ray analysis (see Scheme 5, Fig. 3).

The bond lengths and bond angles (Table 3) in compound **17b** have the expected values for that class of substances.[11] The sulfur atom (Fig. 3) is characterized

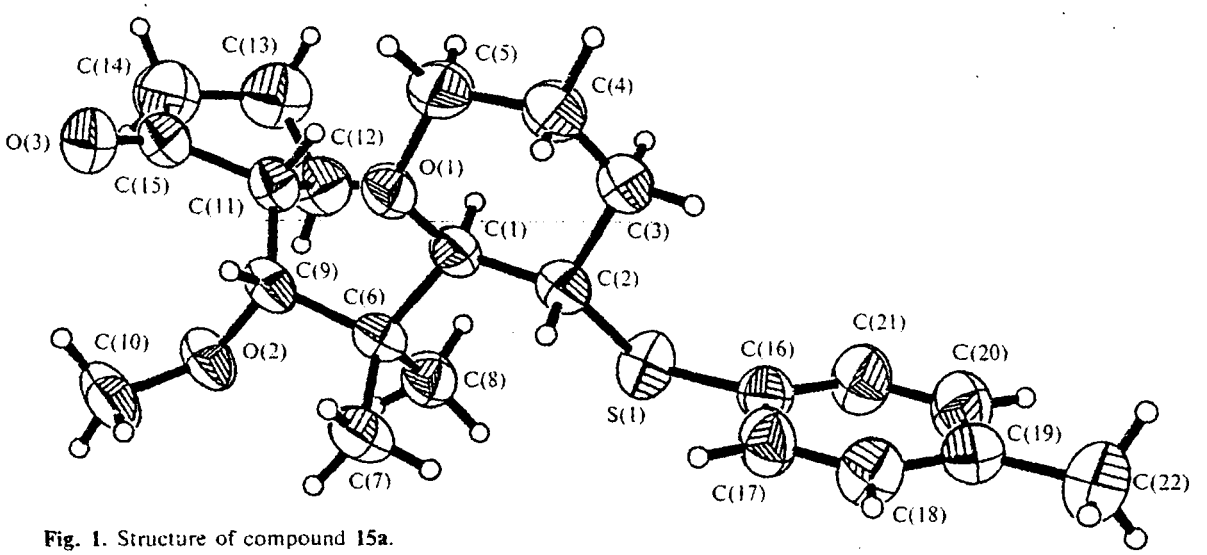
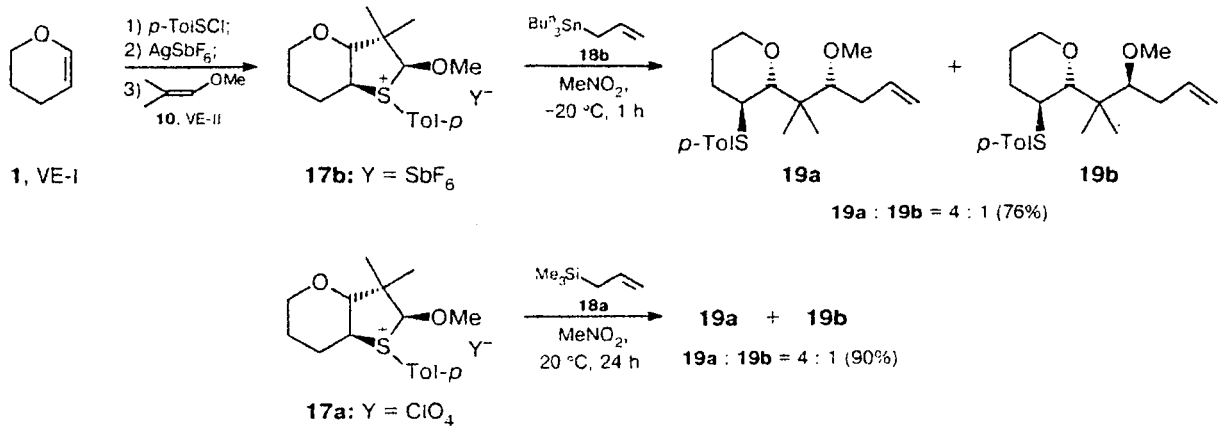


Fig. 1. Structure of compound **15a**.

Scheme 5



by trigonal-pyramidal configuration with deflection of the S(1) atom by 0.80 Å from the plane of the atoms C(1), C(4), and C(11). The five-membered sulfur-containing cycle has the half chair conformation with deflection of the S(1) and C(3) atoms by 0.41 and 0.72 Å, respectively, from the plane of the atoms C(1), C(2), and C(4) (plane *A*). Endocyclic angle C(1)—S(1)—C(4) is of 92.5(2)°. The angle between plane *A* and the plane of the toluene ring is equal to 86°. The six-membered oxygen-containing cycle has the chair conformation with deflection of the O(1) and C(5) atoms from the mean-square plane C(3)C(4)C(6)C(7) by 0.67 and 0.70 Å, respectively. The six-membered and five-membered cycles are *trans*-fused with dihedral angle H(3a)—C(3)—C(4)—H(4a) of 167°.

It should be noticed that bond lengths S(1)—C(1) (1.957(4) Å) and S(1)—C(4) (1.817(4) Å) differ significantly. The standard length $C(sp^3)$—S is of 1.823 Å.[11] One of the possible reasons for the observed lengthening of the S(1)—C(1) bond (by 0.14 Å) can be the interaction of its antibonding orbital (σ^*) with the unshared electron pair (n) of the O(2) atom ($n—\sigma^*$ interaction).[12] In fact, one of the torsion angles n_O-O(2)—C(1)—S(1) (163°) is close to the optimal value (180°) for the overlapping of these orbitals. It is known that the electron displacement toward the antibonding orbital of the bond weakens this bond. The weakening of the S—C(OMe) bond caused by this effect might be considered as the most likely reason for the observed high

Table 2. Most important bond lengths (*d*) and bond angles (ω) in structures **15a,b**

Bond	*d*/Å	
	15a	**15b**
S(1)—C(16)	1.775(3)	1.773(3)
S(1)—C(2)	1.832(3)	1.838(3)
O(1)—C(5)	1.425(3)	1.434(3)
O(1)—C(1)	1.441(3)	1.437(3)
O(2)—C(10)	1.428(4)	1.418(4)
O(2)—C(9)	1.434(3)	1.436(3)
O(3)—C(15)	1.197(4)	1.209(4)
C(1)—C(2)	1.537(4)	1.546(4)
Angle	**ω/deg**	
	15a	**15b**
C(16)—S(1)—C(2)	102.57(12)	102.42(14)
C(5)—O(1)—C(1)	113.9(2)	113.4(2)
C(10)—O(2)—C(9)	115.4(2)	116.7(3)
O(1)—C(1)—C(2)	106.6(2)	107.4(2)
O(1)—C(1)—C(6)	106.7(2)	106.4(2)
C(3)—C(2)—C(1)	109.3(2)	109.7(2)
C(3)—C(2)—S(1)	110.5(2)	110.7(2)
C(1)—C(2)—S(1)	112.4(2)	111.2(2)
O(1)—C(5)—C(4)	110.8(2)	110.(2)
O(2)—C(9)—C(11)	107.4(2)	107.9(2)
O(2)—C(9)—C(6)	109.1(2)	109.4(2)
O(3)—C(15)—C(14)	125.8(3)	124.5(4)
O(3)—C(15)—C(11)	126.1(3)	125.4(4)
C(21)—C(16)—S(1)	119.1(2)	119.9(3)
C(17)—C(16)—S(1)	122.6(2)	121.8(2)

Table 3. Most important bond lengths (*d*) and bond angles (ω) in structure **17b**

Bond	*d*/Å	Angle	ω/deg
S(1)—C(1)	1.957(4)	C(3)—O(1)—C(7)	110.2(3)
S(1)—C(4)	1.817(4)	C(1)—O(2)—C(8)	113.5(4)
S(1)—C(11)	1.769(4)	O(2)—C(1)—C(2)	112.6(3)
O(1)—C(3)	1.412(4)	O(2)—C(1)—S(1)	109.8(3)
O(1)—C(7)	1.437(5)	C(2)—C(1)—S(1)	104.5(3)
O(2)—C(1)	1.359(5)	O(1)—C(3)—C(2)	112.2(3)
O(2)—C(8)	1.442(6)	O(1)—C(3)—C(4)	108.7(3)
		C(5)—C(4)—S(1)	119.6(3)
Angle	**ω/deg**	C(3)—C(4)—S(1)	104.7(3)
C(11)—S(1)—C(4)	109.1(2)	O(1)—C(7)—C(6)	111.7(4)
C(11)—S(1)—C(1)	106.3(2)	C(16)—C(11)—S(1)	125.1(3)
C(4)—S(1)—C(1)	92.5(2)	C(12)—C(11)—S(1)	115.2(3)

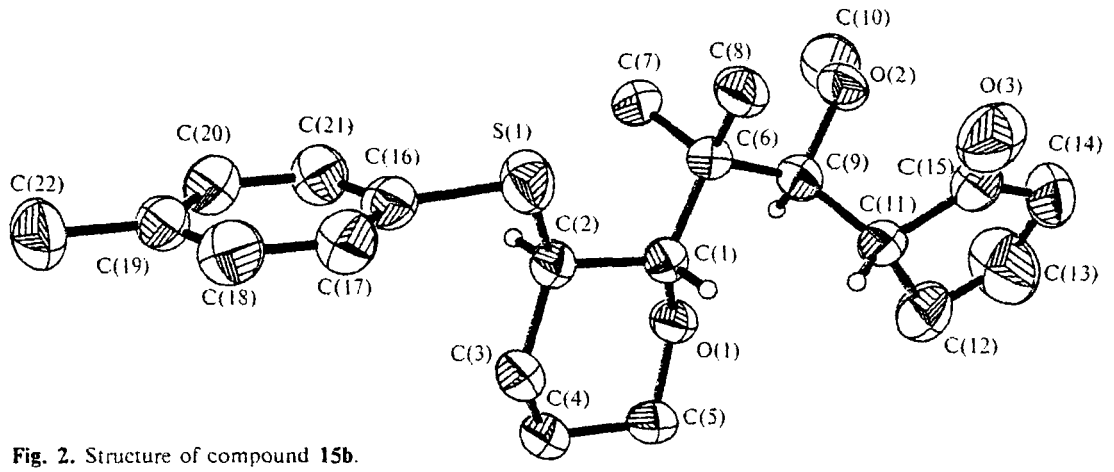


Fig. 2. Structure of compound **15b**.

reactivity of the above mentioned thiophanium salts as compared to that, for example, of the *S*-aryl-2,4-diarylthiophanium salts with the S—C(Ar) bond length close to a standard value of 1.82 Å.[13]* In addition to the significant lengthening of the S—C(1) bond a noticeable shortening of the O(2)—C(8) bond (1.359(5) Å) is also observed as compared to the standard O—C(sp^3) bond length (1.43 Å).[11] This effect can be attributed to the significant contribution of double bonding. Taking into account that all intermolecular as well as intramolecular contacts correspond to the normal van der Waals interactions, the observed S—C(1) bond lengthening can not be explained solely by the steric effects.

^{1}H and ^{13}C NMR spectral data, including 2D homonuclear COSY, NOESY, or ROESY spectra as well as heteronuclear ^{1}H—^{13}C HMQC spectra, clearly indicated that the structure of the main diastereomer in CD_3NO_2 or CD_2Cl_2 solutions at −20 °C is identical to the crystal structure of this salt (see Scheme 5).** It seems logical to suggest the same structure for the main diastereomer of TPI-III formed *in situ* as perchlorate **17a**, as is shown in Scheme 4. If one assumes that the latter is also the most reactive diastereomer, then comparison of the structures of intermediates **17a,b** with those of the main diastereomers of adducts **9a**, **12a**, **15a,b**, **16**, and **19a** derived thereof leads to a paradoxical conclusion, that the ring opening reaction of the bicyclic intermediates shown above in Schemes 3—5 under the action of C-nucleophiles must proceed predominately, or even exclusively, with the retention of configuration at the reacting center. Obviously, these data can not be explained in terms of S_N2 mechanism, which quite adequately describes the steric course of the reactions, involving the formation of the bridged episulfonium-like intermediates and proceeding with the inversion of configuration at the reacting cationoid center (see data on stereochemistry of such reactions cited above). It should be also noted that although an assumption about formation of the ion-like cyclic thiophanium intermediate followed by its S_N2-like ring opening upon action of nucleophiles can be found in some recent publica-

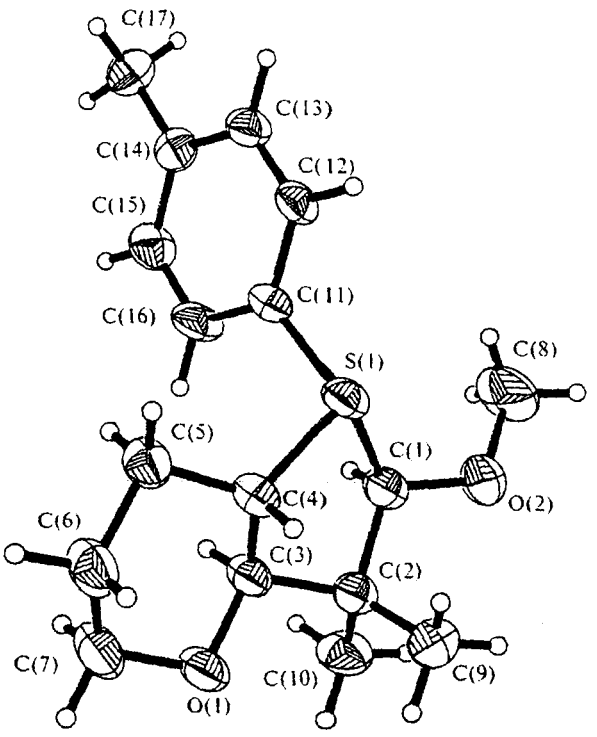
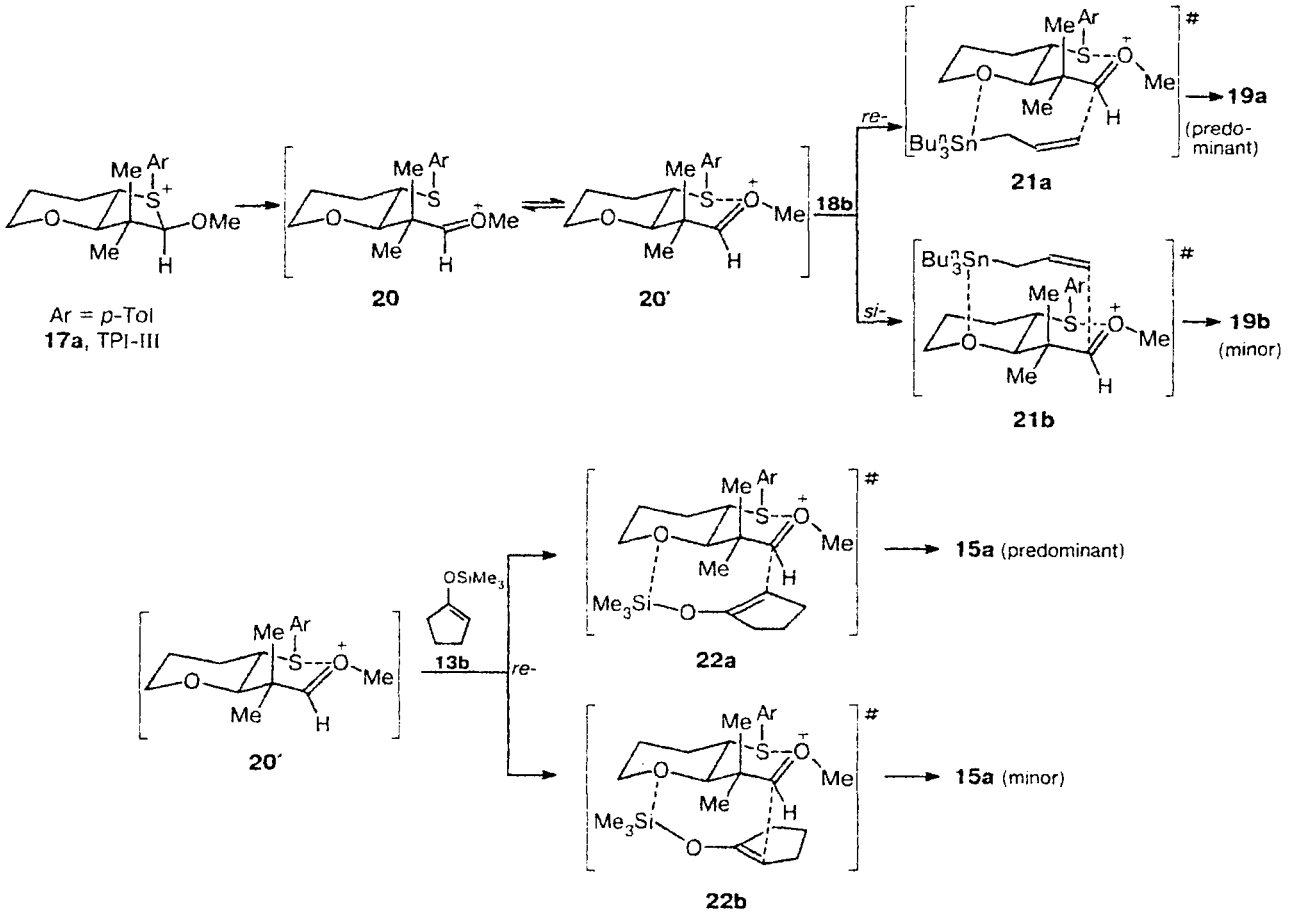


Fig. 3. Structure of thiophanium salt **17b** (the SbF_6^- ion and solvate CH_2Cl_2 molecule are not shown).

* Thiophanium ring opening for the salts of this structure to give the respective δ-acetoxyalkyl aryl sulfides occurs only upon reflux of the mixture of AcOH—AcONa for 5 h.[13]

** Spectra recorded at −20 ° C revealed also the presence of three sets of signals with low intensities indicating the presence of three other diastereomers (at C(2) and S centers). Temperature increase up to +30 °C results in the averaging of signals in the ^{1}H and ^{13}C spectra. Quantitative analysis of observed equilibrium processes will be given in the forthcoming communications.

Scheme 6



tions,[14,15] in none of the reported cases were these intermediates characterized and hence the suggested mechanistic interpretation seems to be rather arbitrary.

We have shown earlier that the monocyclic thiophanium salt opening upon treatment with π-donors occurs as a rule nonstereoselectively. These data forced us to suggest the S_N1 mechanism for this reaction, which envisages the transformation of the cyclic intermediate into the open oxocarbenium ion.[10] It seems reasonable to assume that the ring opening reactions of the bicyclic intermediates **17a,b** described above should follow the same pattern, *i.e.*, *via* formation of oxocarbenium ion (**20**) (Scheme 6). However, for the latter case this interpretation should also take into account the observed high diastereoselectivity of the formation of novel chiral centers in the resulting adducts (see, for example, Scheme 4, formation of **15a,b**). In connection with the problem under consideration it is noteworthy that the problem of stereocontrol for closely related reactions, such as Lewis acid catalyzed aldol-like reactions for α, β-, or γ-chirally substituted carbonyl compounds or acetals with π-donor nucleophiles, is widely discussed in the literature.[16–18] For the reactions with acetals both the S_N1 and S_N2 mechanisms are considered to be viable and traditionally both schemes have been used for interpretation of the stereochemical regularities observed (see, for example, data in the monograph[18]). However, recent and more thorough investigations[19–21] carried out for a wide set of the substrates and under different reaction conditions have shown that for the majority of the studied cases the observed reaction pattern is best accounted for by the S_N1 mechanism, which supposes the intermediate formation of an oxocarbenium-like intermediate. Within the frame of this mechanism the explanation of the stereoselectivity at the newly created chiral centers is based on the comparison of steric and/or polar interactions of unbound substituents in the transition states, corresponding to the alternative modes of π-donor approach to the carbenium center[19–21] (see also the review[22]).

It seems obvious that since the realization of the S_N1 mechanism could be considered as experimentally established in our case, the explanation of the observed peculiarities of the steric course requires the consideration of such interactions in the structure of the oxocarbenium intermediate **20**. One may assume that

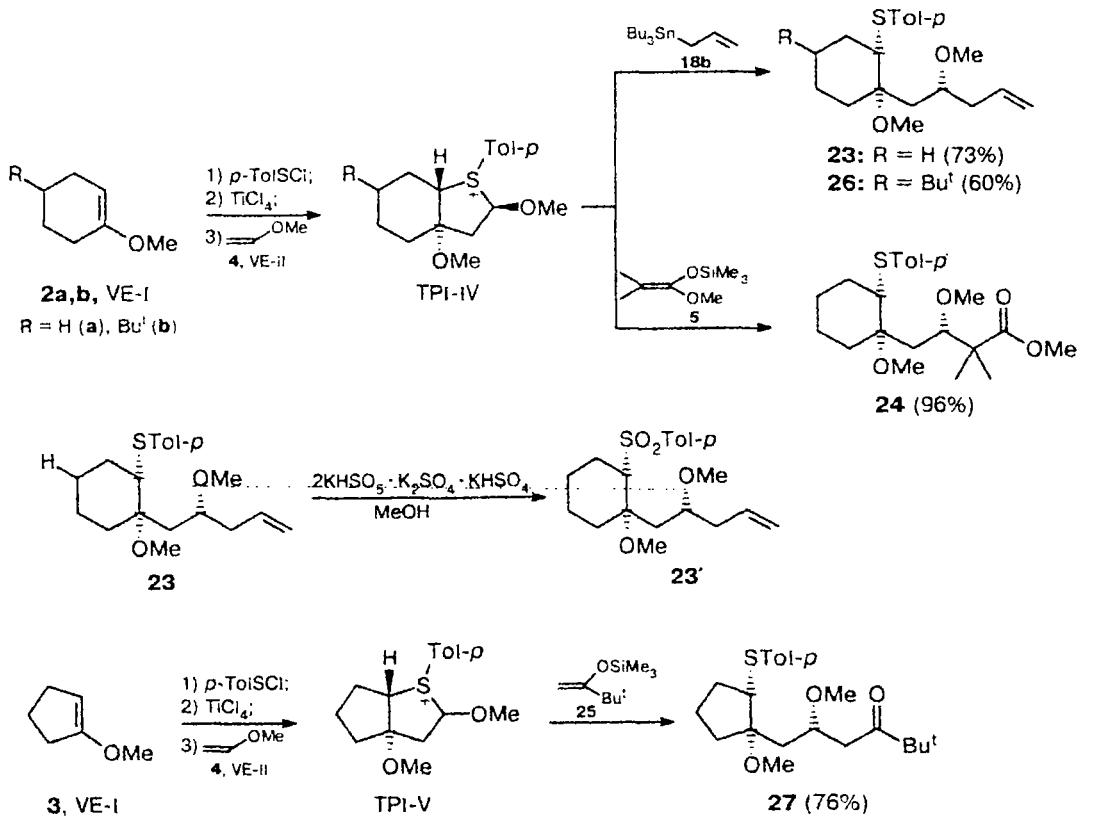
the discrimination of the C-nucleophile approach to the reacting center of this intermediate is determined by a combined action of two factors: (1) an intramolecular electrostatic interaction of the oxonium center with the unshared electron pair of the sulfur atom (secures the preference of the folded conformation of type **20'**) and (2) donor-acceptor interaction between the silicon (or tin) atom of the reagent as a Lewis acid and the unshared electron pair of the oxygen atom of the dihydropyran fragment, which can promote a coordination of reactants in the transition state as is shown in the structures **21a,b** (see Scheme 6).

The consideration of the molecular models reveals that the transition state **21a**, formed as a result of the *re*-attack of the nucleophile "from below" the plane of intermediate **20'**, is sterically more preferable, and hence the predominant formation of diastereomer **19a** should be observed, when allylsilane **18a** or stannane **18b** serves as a nucleophile. To all appearances, the preference of such an approach increases for the sterically demanding C-nucleophiles, such as **13a,b** and **14**, since in these cases we did not observe appreciable formation of the diastereomers at the reacting center of the thiophanium ion. Since the latter nucleophiles contain an additional stereogenic center, for these reactions one should have anticipated the possibility of formation of the two transition states (**22a,b**) corresponding to the alternative orientations of reactants upon the approach of the reagent "from below." Preferential formation of the diastereomers **15a**, **16** in these reactions can be considered as evidence that the orientation shown in the transition state structure **22a** is more favorable. This interpretation is also consistent with the fact that introduction of a more bulky substituent at the silicon atom (replacement of **13a** by **13b**) noticeably decreases the reaction diastereoselectivity at the center considered (see Scheme 4).

1-Methoxycycloalkenes had not been used earlier in the reaction of multicomponent coupling. We have established that derivatives such as 1-methoxycyclohexene (**2a**), 4-*tert*-butyl-1-methoxycyclohexene (**2b**), and 1-methoxycyclopentene (**3**) can be used in the role of VE-I component, and for these cases the diastereoselectivity of the described reaction is even more expressed than that reported for dihydropyran.

The course of the reaction for the case of 1-methoxycyclohexene (**2a**) was studied in some detail. It was found that the adduct of alkene **2a** with *p*-toluenesulfenyl chloride prepared *in situ* is converted upon sequential treatment with $TiCl_4$ and vinyl ether **4** into the stable (in the solution) reaction complex TPI-IV, which readily reacts with allylstannane **18b** or silyl ketene acetal **5** thus

Scheme 7



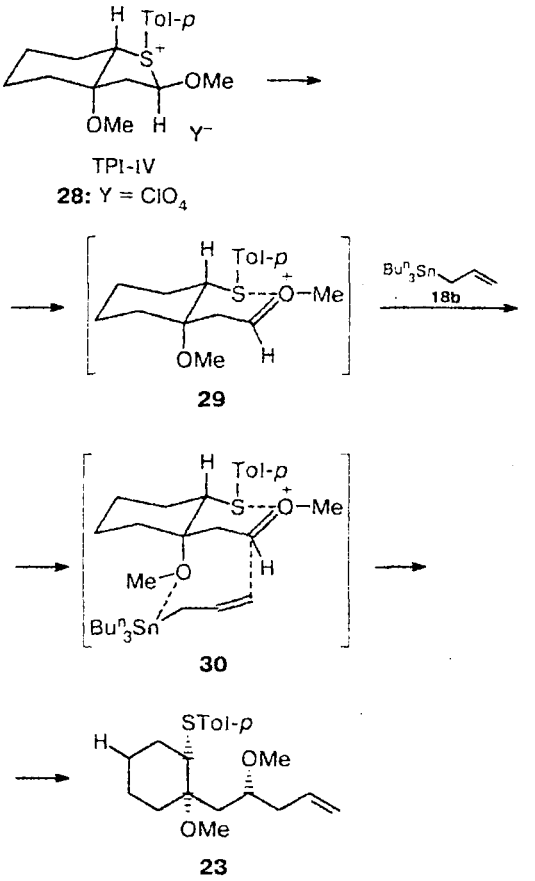
giving the adducts **23** and **24**, isolated as the only reaction products in the form of individual isomers in 73 and 96% yields, respectively (Scheme 7).*

In order to establish the structure of the product **23** the latter was transformed to sulfone **23'** (upon oxidation with oxone®).[23] The relative configuration of this sulfone was determined as (1*S**,2*S**,2'*R**)-1-methoxy-1-(2'-methoxypent-4'-enyl)-2-(4-tolylsulfonyl)cyclohexane.[24] The structure of adduct **24** is accepted by analogy.

The described coupling was also carried out for 4-*tert*-butyl-1-methoxycyclohexene (**2b**) and 1-methoxycyclopentene (**3**) under similar conditions using at the final stage allylstannane **18b** or trimethylsilyl enol ether of pinacolone (**25**), respectively. For both reactions the formation of only one of the possible diastereomers was observed. The structures of adducts **26** and **27** given in Scheme 7 was also accepted by analogy.

For the pair of ethers **2a** and **4** an attempt was undertaken to isolate the thiophanium intermediate TPI-IV as hexafluoroantimonate (by analogy with the salt **18b**). Unfortunately, this effort failed since a decomposition of the reaction mixture was observed under conditions of the coupling **2a** + *p*-toluenesulfenyl chloride + **4** in the presence of $AgSbF_6$. However, this reaction proceeded smoothly in the presence of $LiClO_4$, and the corresponding perchlorate **28** was isolated in individual form as a noncrystallized oil. Upon treatment of this complex with stannane **18b** the same adduct **23** was obtained in 65% yield. The structure of **28** shown in Scheme 7 was established from ^1H and ^{13}C NMR spectral data, including 2D homonuclear COSY, NOESY, or ROESY spectra as well as heteronuclear $^1H-^{13}C$ HMQC spectra. Obviously the formation of the *trans*-fused bicyclic system of intermediate **28** (and correspondingly, *trans*-orientation of the arylthio group and the side chain in product **23**) fully corroborates the above mentioned peculiarities of the steric course of the reaction, proceeding *via* ESI-intermediates formation. The comparison of the configuration of the CHOMe fragments in **28** and **23** reveals that the opening of the thiophanium system of intermediate **28** also proceeds with the retention of configuration at the reaction center, as was noted above for the reactions of salt **17** (see Scheme 5). Hence one may safely claim that the given reaction also proceeds in accordance with the mechanism involving an intermediate generation of oxocarbenium ion (**29**) followed by an interaction of the latter with allylstannane *via* the formation of the transition state of type **30** (Scheme 8). The observed unambiguity of nucleophile attack from the *re*-side of the oxocarbenium ion is possibly due to the coordination of the Lewis center of the nucleophile with the unshared electron pair of the MeO group fixed in axial position of structure **30**. As a result of this effect a very high diastereoselectivity of the coupling is achieved even though the sterically unhindered ether **4** is used as VE-II.

Scheme 8



Obviously, in the absence of direct evidence of the assumed stereochemistry of adducts **24**, **26**, and **27** it is premature to discuss the reaction mechanism in detail, but the identity of the reaction conditions as well as the fact of formation of these adducts as individual diastereomers enabled us to conclude that for these cases the mechanism shown in Scheme 8 could be considered as a plausible suggestion.

Results of the present research not only broaden the scope of the preparative applicability of the described multicomponent coupling for the assembly of polyfunctional compounds from simple precursors with the help of the controlled sequence of three kinetically independent Ad_E reactions, but attest also to the promise and some particular opportunities of this method for the diastereoselective synthesis of compounds containing a number (up to four!) of newly created chiral centers.

It is evident that the quantum-chemical calculations of the transition state structure could be used in order to confirm the correctness of the mechanistic schemes

* In these, as well as in other transformations described below, TLC and NMR data did not reveal the presence of other diastereomers. Hence one may conclude that their possible content does not exceed 5%.

proposed in the present paper and our studies in this direction are now in progress.

Experimental

^1H and ^{13}C NMR spectra were recorded on Bruker WP-200-SY (200 and 50.3 MHz for ^1H and ^{13}C, respectively), Bruker WM-250 (250 and 62.9 MHz for ^1H and ^{13}C, respectively), and Varian Nova 300 (300 and 75.4 MHz for ^1H and ^{13}C, respectively) spectrometers. Assignments of the signals in the ^{13}C NMR spectra for the majority of the products is confirmed by application of the DEPT technique (with proton noise suppression and with an opposite phase for the signals of C atoms containing an even or odd number of protons). Mass spectra (EI, 70 eV) were recorded on a Varian MAT CH-6 instrument with direct input of the sample into the ion source. GC-MS analyses were made on a Hewlett Packard 5790 GS instrument with chromatographic input of the sample into the ion source (EI, 70 eV); the column was a 30 m × 0.25 mm ID J&W Scientific, Inc., DB5 coated capillary. High-resolution mass spectra (HRMS) were performed by the Mass Spectroscopy Service Laboratory of the Chemistry Department, University of Minnesota, on a Finnigan MAT 95 instrument (EI, 70 eV). Elemental analyses were performed by the Microanalysis laboratory of the N. D. Zelinsky Institute of Organic Chemistry of the RAS (Moscow) and Atlantic Microlab, Inc. (Norcross, Georgia). X-ray analysis conditions are listed in Table 1.

All reactions were carried out under dry argon or nitrogen in electrical oven-predried or flame-predried chemical glassware with the use of the dried up and freshly distilled solvents. Analytical TLC was performed on Merck precoated 0.2 mm aluminum plates of silica gel 60 F_{254}. Preparative isolation of the products was carried out by column chromatography with a 200 mm × 20 mm Armsorb SI-10 (40—100 μm) silica gel layer.

4-Toluenesulfenyl chloride was obtained *via* chlorination of di(4-tolyl) disulfide with SO_2Cl_2 in CCl_4 at −10 °C.[25] Methyl vinyl ether (**4**) was synthesized from butyl vinyl ether and MeOH in the presence of $Hg(OAc)_2$.[26] 1-Methoxy-2-methylprop-1-ene (**10**) was obtained by pyrolysis of the dimethyl acetal of isobutyraldehyde in the presence of TsOH.[27] 1-Methoxycycloalkenes were synthesized following the known procedure[28] from the corresponding cycloalkanones without isolation of acetals. Trimethylsilyl enol ethers were synthesized *via* treatment of the corresponding ketones with Me_3SiCl in the presence of NaI.[29]

Procedures used for the preparation of **methyl esters of 3,5-dimethoxy-2,2-dimethyl-6-(4-tolylthio)hexanoic acid (7a,b)** and **3,5-dimethoxy-2,2-dimethyl-6-(4-tolylthio)hexanals (8a,b)** with all spectral and analytical data for these adducts are described in the previous paper.[4]

***trans*-2-(2′-Methoxy-3′-methoxycarbonyl-3′-methylbutyl)-3-(4-tolylthio)tetrahydropyrans (9a,b).** To a stirred solution of 4-TolSCl (0.159 g, 1 mmol) in $MeNO_2$ (20 mL) at −20 °C were added sequentially 0.084 g (1 mmol) of 3,4-dihydro-2*H*-pyran **1**, a solution of vinyl ether **4** (0.07 g, 1.2 mmol) in $MeNO_2$ (2 mL), and a solution of anhydrous $LiClO_4$ (0.426 g, 4 mmol) in 3 mL of $MeNO_2$. After complete formation of TPI (15 min, TLC control) 0.209 g (1.2 mmol) of methyl trimethylsilyl dimethylketene acetal **5** was added, the temperature was allowed to rise to ambient, and the reaction mixture was stirred for 24 h at this temperature. The reaction mixture was quenched with saturated aqueous $NaHCO_3$ solution (20 mL) and extracted with diethyl ether (2×20 mL). After separation by column chromatography on SiO_2 (hexane—AcOEt, 30 : 1) products **9a,b** were obtained.

Diastereomer 9a. R_f 0.40 (hexane—AcOEt, 30 : 1), yield 0.231 g (63%). Found (%): C, 65.50; H, 8.31; S, 9.20. $C_{20}H_{30}O_4S$. Calculated (%): C, 65.54; H, 8.25; S, 8.75. ^1H NMR ($CDCl_3$), δ: 1.11 (s, 3 H, Me); 1.17 (s, 3 H, Me); 1.37—1.76 (m, 4 H, 2 CH_2 ring); 2.05—2.27 (m, 2 H, CH_2 chain); 2.32 (s, 3 H, MePh); 2.81 (dt, 1 H, CHS, J_1 = 4.0 Hz, J_2 = 10.6 Hz); 3.11—3.40 (m, 2 H, CH_aOCH ring); 3.34 (s, 3 H, MeO); 3.57 (t, 1 H, CHOMe, J = 5.1 Hz); 3.69 (s, 3 H, MeOC=O); 3.96 (m, 1 H, CH_eO ring); 7.10 and 7.30 (both d, 4 H arom, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$), δ: 20.52, 20.78, and 20.95 (3 Me); 26.94 and 31.93 (2 CH_2 ring); 35.75 (CH_2 chain); 48.11 (CHS); 50.24 (MeOC=O); 51.69 (C); 58.79 (MeO); 67.87 (CH_2O); 81.05 and 84.04 (CHOMe, CHO ring); 129.66 (2 CH arom); 130.29 (C arom); 133.18 (2 CH arom); 137.42 (C arom); 177.40 (C=O). MS, *m/z* (I_{rel} (%)): 366 $[M]^+$ (8), 334 (20), 275 (7), 265 (10), 233 (11), 211 (100), 189 (73), 161 (62), 150 (75), 123 (55).

Diastereomer 9b. R_f 0.35 (hexane—AcOEt, 30 : 1), yield 0.029 g (8%). ^1H NMR ($CDCl_3$), δ: 1.07 (s, 3 H, Me); 1.16 (s, 3 H, Me); 1.35—1.75 (m, 4 H, 2 CH_2 ring); 2.02—2.32 (m, 2 H, CH_2 chain); 2.32 (s, 3 H, MePh); 2.74 (m, 1 H, CHS); 3.22—3.40 (m, 2 H, CH_aOCH ring); 3.41 (s, 3 H, MeO); 3.55 (m, 1 H, CHOMe); 3.67 (s, 3 H, MeOC=O); 3.90 (m, 1 H, CHO ring); 7.10 and 7.33 (both d, 4 H arom, J = 8.0 Hz). MS, *m/z* (I_{rel} (%)): 366 $[M]^+$ (7), 334 (23), 275 (5), 265 (9), 233 (11), 211 (100), 189 (75), 161 (70), 150 (78), 123 (62).

Compounds **12a,b**, **15a,b**, **16**, and **19a,b** were prepared similarly.

***trans*-2-(3′-Methoxy-2′-methyl-5′-oxohex-2′-yl)-3-(4-tolylthio)tetrahydropyrans (12a,b). Diastereomer 12a.** R_f 0.38 (hexane—AcOEt, 8 : 1), yield 0.238 g (68%). M.p. 43—45 °C. Found (%): C, 68.72; H, 8.74; S, 8.60. $C_{20}H_{30}O_3S$. Calculated (%): C, 68.53; H, 8.63; S, 9.15. ^1H NMR ($CDCl_3$), δ: 1.08 (s, 3 H, Me); 1.15 (s, 3 H, Me); 1.45—1.70 and 1.85—2.00 (both m, 4 H, 2 CH_2 ring); 2.22 (s, 3 H, MeC=O); 2.33 (s, 3 H, MePh); 2.59 (m, 2 H, CH_2C=O); 3.06 (d, 1 H, CHO ring, J = 8.0 Hz); 3.15—3.37 (m, 2 H, CHS, CH_aO ring); 3.39 (s, 3 H, MeO); 3.88 (m, 1 H, CH_eO ring); 3.93 (dd, 1 H, CHOMe, J_1 = 4.8 Hz, J_2 = 6.3 Hz); 7.13 and 7.35 (both d, 4 H arom, J = 7.5 Hz). ^{13}C NMR ($CDCl_3$), δ: 19.97, 20.03, and 21.18 (3 Me); 24.54 and 30.37 (2 CH_2 ring); 30.83 (MeC=O); 43.49 (C); 45.58 (CH_2C=O); 46.60 (CHS); 60.01 (MeO); 67.12 (CH_2O); 81.94 and 85.15 (CHOMe, CHO ring); 129.89 (2 CH arom); 130.73 (C arom); 133.44 (2 CH arom); 137.59 (C arom); 200.96 (C=O). MS, *m/z* (I_{rel} (%)): 350 $[M]^+$ (11), 207 (65), 189 (43), 161 (24), 149 (19), 125 (13), 123 (14), 101 (23), 82 (20), 44 (100).

Diastereomer 12b. R_f 0.33 (hexane—AcOEt, 8 : 1), yield 0.025 g (7%). ^1H NMR ($CDCl_3$), δ: 0.90 (s, 3 H, Me); 1.08 (s, 3 H, Me); 1.50—1.80 and 1.85—1.98 (both m, 4 H, 2 CH_2 ring); 2.22 (s, 3 H, MeC=O); 2.34 (s, 3 H, MePh); 2.58 (dd, 1 H, CH_AC=O, J_1 = 4.0 Hz, J_2 = 16.0 Hz); 2.60 (dd, 1 H, CH_BC=O, J_1 = 7.2 Hz, J_2 = 16.0 Hz); 3.18—3.28 and 3.36—3.48 (both m, 3 H, CH_aOCH ring, CHS); 3.36 (s, 3 H, MeO); 3.94 (m, 1 H, CH_eO ring); 4.06 (dd, 1 H, CHOMe, J_1 = 4.0 Hz, J_2 = 7.2 Hz); 7.12 and 7.32 (both d, 4 H arom, J = 7.5 Hz). MS, *m/z* (I_{rel} (%)): 350 $[M]^+$ (14), 207 (100), 189 (71), 161 (70), 137 (17), 135 (21), 123 (28), 105 (12), 91 (14), 83 (38).

(1′*R,1″*R**,2*R**,3*S**)-2-[1′-Methoxy-2′-methyl-1′-(2″-oxocyclopentyl)prop-2′-yl]-3-(*p*-tolylthio)tetrahydropyran (15a).** R_f 0.37 (hexane—AcOEt, 10 : 1), yield 0.207 g (55%).

M.p. 82—84 °C. Found (%): C, 70.15; H, 8.58; S, 8.60. $C_{22}H_{32}O_3S$. Calculated (%): C, 70.17; H, 8.56; S, 8.52. ^{1}H NMR ($CDCl_3$), δ: 1.06 (s, 3 H, Me); 1.17 (s, 3 H, Me); 1.45—2.00 (m, 8H, 4 CH_2 rings); 2.00—2.40 (m, 3 H, $CH_2C(=O)CH$); 2.33 (s, 3 H, MePh); 3.04 (d, 1 H, CHO ring, J = 8.2 Hz); 3.15—3.33 (m, 2 H, CHS, CH_aO ring); 3.25 (s, 3 H, MeO); 3.92 (m, 1 H, CH_eO ring); 4.07 (s, 1 H, CHOMe); 7.12 and 7.38 (both d, 4 H arom, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$), δ: 20.98, 21.08, and 21.24 (3 Me); 24.35, 24.51, 30.19, and 37.90 (4 CH_2 rings); 40.37 (CH_2C=O); 43.58 (C); 46.31 and 50.16 (CHS, CHC=O); 60.32 (MeO); 67.20 (CH_2O); 82.87 and 85.83 (CHOMe, CHO ring); 129.63 (2 CH arom); 130.53 (C arom); 133.24 (2 CH arom); 137.28 (C arom); 221.65 (C=O). HRMS: found: m/z 376.2070; calculated for $C_{22}H_{32}O_3S$: $[M]^+$ = 376.2072.

(1′*R,1″*S**,2*R**,3*S**)-Epimer 15b.** R_f 0.30 (hexane—AcOEt, 10 : 1), yield 0.034 g (9%). M.p. 87—89 °C. Found (%): C, 70.21; H, 8.61; S, 8.62. $C_{22}H_{32}O_3S$. Calculated (%): C, 70.17; H, 8.56; S, 8.52. ^{1}H NMR ($CDCl_3$), δ: 1.13 (s, 3 H, Me); 1.17 (s, 3 H, Me); 1.45—2.00 (m, 8 H, 4 CH_2 rings); 2.05—2.41 (m, 3 H, $CH_2C(=O)CH$); 2.32 (s, 3 H, MePh); 3.12 (d, 1 H, CHO ring, J = 8.1 Hz); 3.15—3.37 (m, 2 H, CHS, CH_aO ring); 3.38 (s, 3 H, MeO); 3.56 (d, 1 H, CHOMe, J = 2.5 Hz); 3.89 (m, 1 H, CH_eO ring); 7.10 and 7.33 (both d, 4 H arom, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$), δ: 19.92, 19.98, and 21.03 (3 Me); 23.92, 29.57, 29.63, and 31.15 (4 CH_2 rings); 39.13 (CH_2C=O); 44.43 (C); 46.36 and 49.26 (CHS, CHC=O); 60.56 (MeO); 66.66 (CH_2O); 84.85 and 87.77 (CHOMe, CHO ring); 129.63 (2 CH arom); 130.54 (C arom); 133.11 (2 CH arom); 137.28 (C arom); 217.55 (C=O). HRMS: found: m/z 376.2074; calculated for $C_{22}H_{32}O_3S$: $[M]^+$ = 376.2072.

The main X-ray characteristics for compounds **15a,b** are seen in Table 1; the important bond lengths and bond angles in Table 2.

***trans*-2-[1′-Methoxy-2′-methyl-1′-(2″,5″-dihydro-5″-oxofur-2″-yl)prop-2′-yl]-3-(4-tolylthio)tetrahydropyran (16).** R_f 0.31 (hexane—AcOEt, 20 : 1), yield 0.173 g (46%). Found (%): C, 67.05; H, 7.41; S, 8.62. $C_{21}H_{28}O_4S$. Calculated (%): C, 66.99; H, 7.50; S, 8.52. ^{1}H NMR ($CDCl_3$), δ: 1.15 (s, 3 H, Me); 1.27 (s, 3 H, Me); 1.45—1.70 and 1.80—1.95 (both m, 4 H, 2 CH_2 ring); 2.32 (s, 3 H, MePh); 3.09—3.39 (m, 3 H, CH_aOCH ring, CHS); 3.31 (s, 3 H, MeO); 3.43 (d, 1 H, CHOMe, J = 2.0 Hz); 3.89 (m, 1 H, CH_eO ring); 5.16 (m, 1 H, CHO ring); 6.12 (dd, 1 H, CH=, J_1 = 2.2 Hz, J_2 = 5.6 Hz); 7.10 and 7.30 (both d, 4 H arom, J = 8.0 Hz); 7.48 (dd, 1 H, CHC=O, J_1 = 1.6 Hz, J_2 = 5.6 Hz). MS, m/z: 376 $[M]^+$.

***trans*-2-(3′-Methoxy-2′-methylhex-5′-en-2′-yl)-3-(4-tolylthio)tetrahydropyrans (19a,b).** R_f 0.30 (hexane—AcOEt, 30 : 1), yield 0.3 g (90%), ratio **19a : 19b** = 4 : 1. **Diastereomer 19a.** ^{1}H NMR ($CDCl_3$), δ: 1.09 (s, 3 H, Me); 1.13 (s, 3 H, Me); 1.54—1.66 and 1.96 (both m, 4 H, 2 CH_2 ring); 2.12—2.31 (m, 2 H, CH_2CH); 2.34 (s, 3 H, MePh); 3.12 (d, 1 H, CHO ring, J = 8.4 Hz); 3.17—3.52 (3 m, 3 H, CHS, CH_aO and CHOMe); 3.43 (s, 3 H, MeO); 3.92 (m, 1 H, CH_eO ring); 5.10 (m, 2 H, CH_2=); 5.97 (ddt, 1 H, CH=, J_1 = 6.9 Hz, J_2 = 10.2 Hz, J_3 = 17.2 Hz); 7.12 and 7.33 (both d, 4 H arom, J = 8.0 Hz). MS, m/z: 334 $[M]^+$.

Diastereomer 19b. ^{1}H NMR ($CDCl_3$), δ: 0.93 (s, 3 H, Me); 1.08 (s, 3 H, Me); 1.54—1.66 and 1.96 (both m, 4 H, 2 CH_2 ring); 2.12—2.31 (m, 2 H, CH_2CH); 2.34 (s, 3 H, MePh); 3.17—3.52 (m, 4 H, CHS, CH_aOCH and CHOMe); 3.41 (s, 3 H, MeO); 3.54 (m, 1 H, CH_eO ring); 5.08 (m, 2 H, CH_2=); 5.96 (m, 1 H, CH=); 7.12 and 7.33 (both d, 4 H arom, J = 8.0 Hz).

(1*R,2*R**,3a*R**,7a*S**)-2-Methoxy-3,3-dimethyl-1-(4-tolyl)tetrahydropyrano[2,3-*b*]thiophanium hexafluoroantimonate (17b).** To a stirred solution of 4-TolSCl (0.159 g, 1 mmol) in CH_2Cl_2 (20 mL) at −20 °C were added sequentially 0.084 g (1 mmol) of 3,4-dihydro-2*H*-pyran **1**, 0.103 g (1.2 mmol) of methyl isobutenyl ether **10**, and a solution of 0.344 g (1 mmol) $AgSbF_6$ in 2 mL of CH_2Cl_2. During addition of the salt a white precipitate of AgCl was formed. The temperature was raised to 0 °C, and after stirring for 30 min at that temperature the reaction mixture was filtered through a glass filter, poured into precooled (to −20 °C) hexane (40 mL), and left in the refrigerator overnight. An oily precipitate was formed on the walls and bottom of the flask. The bulk of the solution was decanted and the residue was washed with cold hexane (2×5 mL) and evacuated with slight heating (up to 30—35 °C). The solid thus isolated was crystallized from chloroform. The yield of the solvate of salt **17b**·CH_2Cl_2 was 0.344 g (56%). M.p. 79—82 °C (decomp.; $CHCl_3$). ^{1}H NMR (CD_2Cl_2, −20 °C), δ: 1.05 and 1.32 (both s, 6 H, 2 Me); 1.65—2.00 (m, 4 H, CH_2CH_2 ring); 2.42 (s, 3 H, MePh); 3.49 (s, 3 H, MeO); 3.54 (m, 1H, CH_aO); 3.67 (d, 1 H, CHO); 3.79 (m, 1 H, CHS); 4.04 (m, 1 H, CH_eO); 5.84 (s, 1 H, CHOMe); 7.51 and 7.64 (both d, 4 H arom, J = 8.3 Hz).

The main X-ray characteristics for thiophanium salt **17b** are seen in Table 1; the important bond lengths and bond angles in Table 3.

Interaction of 2-methoxy-3,3-dimethyl-1-(4-tolyl)tetrahydropyrano[2,3-*b*]thiophanium hexafluoroantimonate (17b) with allyltributyltin (18b). To a stirred solution of the solvate of thiophanium salt **17b**·CH_2Cl_2 (0.265 g, 0.43 mmol) in $MeNO_2$ (10 mL) at −20 °C allyltin **18b** (0.199 g, 0.6 mmol) was added and the reaction mixture was stirred at that temperature for 1 h. TLC control showed the full conversion of salt **17b** into the reaction products. Standard workup and preparative isolation gave a mixture of diastereomers **19a,b** in a ratio 4 : 1, yield 0.109 g (76%).

(1*S,2*S**,2′*R**)-1-Methoxy-1-(2′-methoxypent-4′-enyl)-2-(4-tolylthio)cyclohexane (23).** To a stirred solution of 4-TolSCl (0.159 g, 1 mmol) in CH_2Cl_2 (20 mL) at −78 °C were added sequentially 1-methoxycyclohexene **2a** (0.112 g, 1 mmol), a solution of vinyl ether **4** (0.07 g, 1.2 mmol) in CH_2Cl_2 (2 mL), and a solution of $TiCl_2$ (0.228 g, 1.2 mmol) in CH_2Cl_2 (2 mL). After 30 min Bu_3SnCH_2CH=CH_2 (**18b**) (0.397 g, 1.2 mmol) was added. The reaction mixture was stirred at that temperature for 5 h with control of TPI conversion into the reaction products by TLC. After usual workup and preparative isolation the product **23** was obtained. R_f 0.30 (hexane—AcOEt, 8 : 1), yield 0.244 g (73%). Found (%): C, 71.90; H, 9.09; S, 10.01. $C_{20}H_{30}O_2S$. Calculated (%): C, 71.81; H, 9.04; S, 9.59. ^{1}H NMR ($CDCl_3$), δ: 1.45—1.55 and 1.69—1.78 (both m, 8 H, 4 CH_2 ring); 1.80 (dd, 1 H, CH_A, J_1 = 2.4 Hz, J_2 = 15.3 Hz); 2.14 (dd, 1 H, CH_B, J_1 = 8.7 Hz, J_2 = 15.3 Hz); 2.28 (s, 3 H, MePh); 2.34 (m, 2 H, CH_2H=); 3.20 (s, 3 H, MeO); 3.27—3.35 (m, 1 H, CHS); 3.29 (s, 3 H, MeO); 3.42 (m, 1 H, CHOMe); 5.08 (m, 2 H, CH_2=); 5.81 (ddt, 1 H, CH=, J_1 = 7.2 Hz, J_2 = 10.1 Hz, J_3 = 17.2 Hz); 7.06 and 7.31 (both d, 4 H arom, J = 8.2 Hz). ^{13}C NMR ($CDCl_3$), δ: 20.86 (MePh); 21.58, 24.13, 29.36, and 31.47 (4 CH_2 ring); 37.55 and 38.19 (2 CH_2 chain); 48.43 (CHS); 55.65 and 56.16 (2 MeO); 77.02 and 77.27 (CHOMe, COMe); 117.25 (CH_2=); 129.30 (2 CH arom); 132.03 (2 CH arom); 132.86 and 136.08 (2 C arom); 134.39 (CH=). MS, m/z: 334 $[M]^+$.

The compounds **24**, **26**, and **27** were obtained similarly.

***Z*-1-Methoxy-1-(2′-methoxy-3′-methylbutyl)-2-(4-tolylthio)cyclohexane (24).** R_f 0.40 (hexane—AcOEt, 20 : 1), yield 0.379 g (96%). Found (%): C, 66.79; H, 8.69; S, 7.99. $C_{22}H_{34}O_4S$. Calculated (%): C, 66.97;

H, 8.69; S, 8.13. ^{1}H NMR ($CDCl_3$), δ: 1.15 (s, 3 H, Me); 1.24 (s, 3 H, Me); 1.40–1.93 (m, 8H, 4 CH_2 ring); 1.61 (dd, 1 H, CH_A, J_1 = 1.3 Hz, J_2 = 15.2 Hz); 2.11 (dd, 1 H, CH_B, J_1 = 10.1 Hz, J_2 = 15.2 Hz); 2.30 (s, 3 H, MePh); 3.24 (s, 3 H, MeO); 3.26–3.30 (m, 1 H, CHS); 3.39 (s, 3 H, MeO); 3.67 (s, 3 H, MeOCO); 3.68 (dd, 1 H, CHOMe, J_1 = 1.3 Hz, J_2 = 10.1 Hz); 7.06 and 7.34 (both d, 4 H arom, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$), δ: 20.60, 20.94, and 21.66 (3 Me); 21.83, 23.51, 29.20, and 31.77 (4 CH_2 ring); 34.89 (CH_2); 47.50 (C); 48.45 (CHS); 51.61 (MeOC=O); 56.51 and 60.13 (2 MeO); 77.35 and 83.30 (CHOMe, COMe); 129.41 (2 CH arom); 132.49 (2 CH arom); 132.86 and 136.45 (2 C arom); 177.35 (C=O). MS, m/z: 394 $[M]^+$.

***Z,Z*-4-*tert*-Butyl-1-methoxy-1-(2′-methoxypent-4′-enyl)-2-(4-tolylthio)cyclohexane (26).** R_f 0.33 (hexane–AcOEt, 8 : 1), yield 0.234 g (60%). ^{1}H NMR ($CDCl_3$), δ: 0.82 (s, 9H, 3 Me); 1.18–2.10 (m, 7 H, 3 CH_2 ring, CH ring); 1.90 (dd, 1 H, CH_A, J_1 = 2.7 Hz, J_2 = 15.1 Hz); 2.22 (dd, 1 H, CH_B, J_1 = 8.8 Hz, J_2 = 15.1 Hz); 2.31 (s, 3 H, MePh); 2.36 (m, 2 H, CHC_2H=); 3.20 (s, 3 H, MeO); 3.22–3.30 (m, 1 H, CHS); 3.29 (s, 3 H, MeO); 3.42 (m, 1 H, CHOMe); 5.08 (m, 2 H, CH_2=); 5.82 (ddt, 1 H, CH=, J_1 = 7.1 Hz, J_2 = 10.5 Hz, J_3 = 17.6 Hz); 7.06 and 7.31 (both d, 4 H arom, J = 8.3 Hz). ^{13}C NMR ($CDCl_3$), δ: 20.98 (MePh); 27.49 (3 Me); 22.00, 27.56, 31.95, and 32.08 (3 CH_2 and CH ring); 38.29 and 38.46 (2 CH_2 chain); 48.51 and 48.94 (CHS, C); 55.63 and 57.71 (2 MeO); 76.87 and 77.60 (CHOMe, COMe); 117.41 (CH_2=); 129.39 (2 CH arom); 131.10 (2 CH arom); 133.62 and 135.85 (2 C arom); 134.60 (CH=). MS, m/z (I_{rel} (%)): 390 $[M]^+$ (6), 375 (1), 349 (5), 317 (4), 301 (2), 291 (23), 259 (10), 235 (17), 217 (3), 203 (100).

***Z*-1-(5′,5′-Dimethyl-2′-methoxy-4′-oxohexyl)-1-methoxy-2-(4-tolylthio)cyclopentane (27).** R_f 0.34 (hexane–AcOEt, 15 : 1), yield 0.288 g (76%). ^{1}H NMR ($CDCl_3$), δ: 1.13 (s, 9 H, 3 Me); 1.50–2.20 (m, 6H, 3 CH_2 ring); 1.82 (dd, 1 H, CH_A, J_1 = 3.4 Hz, J_2 = 14.6 Hz); 1.95 (dd, 1 H, CH_B, J_1 = 8.1 Hz, J_2 = 14.6 Hz); 2.30 (s, 3 H, MePh); 2.60 (dd, 1 H, CH_AC=O, J_1 = 6.9 Hz, J_2 = 17.3 Hz); 2.86 (dd, 1 H, CH_BC=O, J_1 = 5.4 Hz, J_2 = 17.3 Hz); 3.25 (s, 3 H, MeO); 3.26 (s, 3 H, MeO); 3.45 (t, 1 H, CHS, J = 8.5 Hz); 3.91 (m, 1 H, CHOMe); 7.07 and 7.31 (both d, 4 H arom, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$), δ: 20.89 (MePh); 26.11 (3 Me); 21.05, 31.64, and 32.83 (3 CH_2 ring); 38.40 and 41.81 (2 CH_2 chain); 44.29 (C); 50.39 (CHS); 56.52 and 57.08 (2 MeO); 74.61 and 85.98 (CHOMe, COMe); 129.35 (2 CH arom); 130.90 (2 CH arom); 133.47 and 135.75 (2 C arom); 214.47 (C=O). MS, m/z (I_{rel} (%)): 378 $[M]^+$ (13), 363 (4), 346 (3), 331 (7), 314 (12), 279 (13), 261 (9), 246 (22), 223 (100), 189 (94).

1,8-Dimethoxy-7-(4-tolyl)-7-thioniabicyclo[4.3.0]nonane perchlorate (28). To a stirred solution of 4-TolSCl (0.159 g, 1 mmol) in CH_2Cl_2 (10 mL) at −20 °C were added sequentially 0.112 g (1 mmol) of 1-methoxycyclohexene **2a**, a solution of methyl vinyl ether **4** (0.07 g, 1.2 mmol) in CH_2Cl_2 (2 mL), and a solution of anhydrous $LiClO_4$ (0.1 g, 1 mmol) in 2 mL of $MeNO_2$. During addition of the salt solution a white precipitate of LiCl was formed. After stirring for 30 min at a temperature of −20 °C the reaction mixture was filtered through a glass filter and poured into a precooled to −20 °C mixture of hexane (20 mL) and absolute ether (4 mL). After 15 min the formed oily precipitate was separated from the solution by decantation; the residue was washed with cold ether (2 mL) and then evacuated with a bath temperature of 0 °C. The salt was obtained in the form of a pale-yellow foamy mass, which on standing as well as on crystallizing rapidly turned dark with transformation into a tar-like product. Yield of salt **28** 0.236 g (60%). ^{1}H NMR (CD_2Cl_2, 20 °C), δ: 1.20–2.30 (6 m, 8 H, 4 CH_2); 2.30 (dd, 1 H, $H(9)_a$, J_1 = 8.9 Hz, J_2 = 14.8 Hz); 2.39 (s, 3 H, MePh); 3.05 (s, 3 H, MeOCH); 3.15 (dd, 1 H, $H(9)_e$, J_1 = 5.3 Hz, J_2 = 14.8 Hz); 3.20 (s, 3 H, MeOC); 3.88 (dd, 1 H, CHS, J_1 = 4.2 Hz, J_2 = 12.4 Hz); 6.12 (dd, 1 H, CHOMe, J_1 = 5.3 Hz, J_2 = 8.9 Hz); 7.42 and 7.68 (both d, 4 H arom, J = 8.3 Hz). ^{13}C NMR (CD_2Cl_2, 20 °C), δ: 19.42 (C(3)H_2); 21.62 (MePh); 24.16 (C(5)H_2); 25.10 (C(4)H_2); 28.46 (C(2)H_2); 41.43 (C(9)H_2); 49.37 (MeOC); 61.99 (MeOCH); 68.71 (CHS); 81.57 (COMe); 109.10 (CHOMe); 115.80 (CS arom); 131.66 (2 CH arom); 133.43 (2 CH arom); 146.36 (CMe arom).*

Interaction of 1,8-dimethoxy-7-(4-tolyl)-7-thioniabicyclo-[4.3.0]nonane perchlorate (28) with allyltributyltin (18b). To a stirred solution of thiophanium salt **28** (0.196 g, 0.5 mmol) in CH_2Cl_2 (10 mL) at 0 °C allyltin **18b** (0.199 g, 0.6 mmol) was added; the reaction mixture was stirred at that temperature for 2 h. The TLC control showed the full conversion of the salt **28** into the reaction product. Usual workup and preparative isolation gave compound **23**, yield 0.110 g (66%).

(1*S,2*S**,2′*R**)-1-Methoxy-1-(2′-methoxypent-4′-enyl)-2-(4-tolylsulfonyl)cyclohexane (23a)** (for the X-ray data for sulfone **23a**, see Ref. 24). To a solution of 0.167 g (0.5 mmol) of sulfide **23** in 4 mL MeOH under stirring was added a solution of 1.85 g (3 mmol) of oxone in 8 mL of water. The reaction mixture was stirred at ambient temperature for 24 h, then water (20 mL) was added, and the reaction mixture was extracted with chloroform (3×10 mL). The organic layers were washed with water, dried with $MgSO_4$, and evaporated in vacuum; the solid residue of sulfone **23a** was crystallized from a mixture of hexane–diethyl ether. Yield 0.257 g (70%). M.p. 85–87 °C. ^{1}H NMR ($CDCl_3$), δ: 1.10–2.04 (4 m, 10 H, 4 CH_2 ring, CH_2 chain); 2.37 (m, 2 H, CH_2CH=); 2.42 (s, 3 H, MePh); 2.83 (dd, 1 H, $CHSO_2$, J_1 = 10.0 Hz, J_2 = 14.4 Hz); 3.11 (s, 3 H, MeO); 3.31 (s, 3 H, MeO); 3.59 (dd, 1 H, CHOMe, J_1 = 5.1 Hz, J_2 = 11.2 Hz); 5.16 (m, 2 H, CH_2=); 5.86 (m, 1 H, CH=); 7.30 and 7.80 (both d, 4 H arom, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$), δ: 21.69 (MePh); 20.99, 24.58, 24.64, and 31.59 (4 CH_2 ring); 37.50 and 38.20 (2 CH_2 chain); 48.30 ($CHSO_2$); 56.10 and 69.31 (2 MeO); 77.82 (CHOMe, COMe); 117.63 (CH_2=); 128.85 (2 CH arom); 129.15 (2 CH arom); 134.42 (CH=); 138.80 and 143.20 (2 C arom).

X-ray diffraction experiment and structure refinement. The structures were solved by direct methods and refined by anisotropic-isotropic full-matrix approximation on F^2. The positions of hydrogen atoms were calculated and refined as riding atoms. In structure **17b** the analysis of the residual electron density peaks in the area of SbF_6 as well as in the area of the solvate molecule of CH_2Cl_2 showed that the F and Cl atoms are statistically disordered in two positions (F(1), F(3), F(5), F(6) and F(1′), F(3′), F(5′), F(6′); Cl(1), Cl(2) and Cl(1′), Cl(2′), in SbF_6 and CH_2Cl_2, respectively). The refinement of two sets of F and Cl positions showed that they have population densities of 0.55 and 0.45.

All calculations were performed using the SHELXTL PLUS (Version 5.0)[30] suite of programs using personal computers. Total tables of the geometric parameters and coordinates of atoms in structures **15a,b** and **17b** were sent to the Cambridge Structural Data Bank.

* In the ^{1}H and ^{13}C NMR spectra for salt **28** the signals of the inverted at the sulfur atom isomer are also present (up to 20%).

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