Synthesis and Cycloaddition Reactions of 1-(Arylthio)-1,3-dienes. A Combined Experimental and Theoretical Study of Bicyclic Adducts Structures

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A method giving simple access to various 1-(phenylthio)-4-substituted-1,3-dienes (**5**−**10**) is described. The influence of the different functionalizations introduced on the dienic systems has been tested in a set of classical [4 + 2] cycloaddition reactions. Both the *endo*/*exo* and regio selectivities have been investigated. While the *endo* compound is, as expected, the only or major isomer in all cases, the regio competition between sulfur and oxygen is in favor of the oxygen substituent in the case studied here, in contrast to related works. For one type of adduct, X-ray crystallographic analysis and NMR spectroscopy have been used in conjunction with *ab initio* and semiempirical AM1 calculations to determine the structure and conformations of products as well as the energetic pathway from the primary concave *endo* cycloadduct (**28**) to a rearranged bicyclic structure (**39**). The theoretical results fully support the occurrence of a photochemical [1,3] sigmatropic shift of the thiophenyl group.

Introduction

The usefulness of the Diels−Alder reaction due to its exceptional versatility, as well as high regio- and stereoselectivity, has triggered, in the last decade, a wide interest in the synthetic routes to functionalized 1,3-dienes;[1] among these, the conspicuous success encountered by dienes bearing heteroatom substituents is certainly worth emphasizing.[2] Oxygenated dienes, for instance, have found too many applications to be even briefly evocked here, and the most widely used compound of this class, 1-methoxy-3-((trimethylsilyl)oxy)butadiene (Danishefsky diene)[3] provides elegant access to several important natural products.[4] Of a more restricted diffusion, sulfenylbutadienes probably did not receive the attention they deserve albeit they appeared of special interest in several cycloaddition reactions in inter[2,5abf] or intra molecular[5c−e] situations. Such dienes have also proved to behave as useful building blocks in the stereoselective approach of unsaturated pheromones through cross-coupling reactions catalyzed by Ni(II) complexes.[6] Among this class of compounds, and because of their convenient substitution patterns, 1-methoxy-2-(phenylthio)- and 2-methoxy-3-(phenylthio)butadienes have also been considered as key partners in applications to the synthesis of natural products such as carvone[7] or eudesmane sesquiterpenes precursors.[8]

However, access to 1,4-dihetero-substituted dienes is generally known to be complicated by both the nature of substituents and control of the stereochemistry; for instance, the generally proposed route to these structures based upon conrotatory opening of appropriately substituted cyclobutenes[9] fails in the case of 4-methoxy-1-(phenylthio)buta-1,3-diene, leading to a complex mixture of isomers.[10] Thus the problem of an efficient stereocontrolled synthesis of these potent building blocks often constitutes the limiting step to their application.

We have previously shown[11] that γ-(phenylthio)-α,β-unsaturated acetals **4a**,**b**, which derive from corresponding aldehydes (*viz*. crotonaldehyde (**1a**) or senecialdehyde (**1b**), respectively) through their halo acetals **2a**,**b** or **3**, are possible precursors for these dienes since they lead stereoselectively to dienol ethers **5a,b** in strongly basic medium and eventually to dienes **6**−**10** (Scheme 1). This preliminary study[11a] has been extended, and we now report the scope and limitations we have found for the

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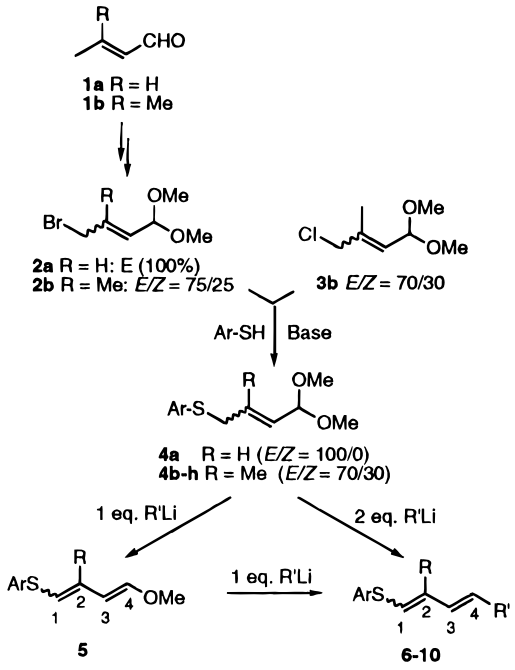
Scheme 1



original synthetic routes and for the cycloaddition reactions applied to the thus prepared dienes. We also present extensive structural studies on several cycloadducts obtained, completed by theoretical calculations on the relative energies of the different conformers of several of them.

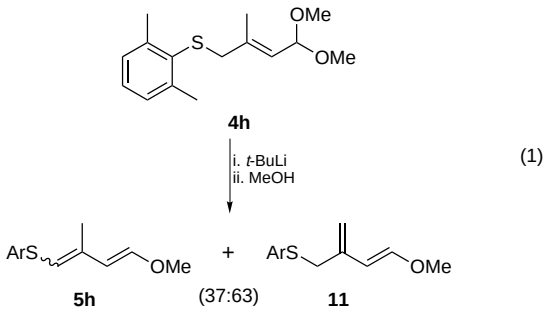
Synthesis of Functionalized Dienol Ethers (5 and 13−18)

As mentioned above, the reaction we have described relies on the δ-elimination of an alkoxy group upon treatment by strong bases (such as alkyllithium compounds or lithium amides) of α,β-unsaturated acetals of type **4**. It provides a gram-scale access to the corresponding dienol ethers **5** (Scheme 1 and Table 1) in high yields. Sodium methoxide is not basic enough to deprotonate thioethers **4a,b**; similarly, the use of catalytic amounts of alkyllithium, which would generate lithium methoxide in the medium, remained uneffective.

The thioether precursors **4** have themselves been obtained through direct addition of thiophenol to bromo acetal **2a**,**b** in ether in the presence of triethylamine (method A), as described previously,[11a] or in a biphasic reaction between commercial aryl thiols in aqueous soda and chloro acetal **3b** in ether (method B).[12] All thioethers **4** were recovered in excellent yield by both methods, if the reaction times were lengthened for bulky thiols. The stereochemical outcome of the reaction is obviously dependent on the starting acetals. Indeed, while linear acetal **2a** was prepared in its pure *E* form and thus gave access to *E* thioether **4a**, branched bromo and chloro acetals **2b** and **3b** were obtained with *E*/*Z* ratios of 75:25 and 70:30, respectively, the same ratios as for thioethers **4a**,**h**.

Addition of commercial *n*-BuLi or *t*-BuLi solutions to **4** in ether or THF led to dienes **5**, whose stereochemistry appears to depend on many parameters such as the substitution pattern in **4** (Table 1, entries 1 and 2 and 3 and 4) or the solvent/temperature effects (entries 1 and 3 and 2 and 4). While yields remain high, raising the temperature depletes the selectivity for both **4a** and **4b**. Also of prime importance is probably the original stereochemistry of thioether **4** itself.[13] Probing the possible influence of the nature of the aryl group born by the sulfur atom has led to the conclusion that this parameter is of moderate importance, and the precise nature and substitution pattern of the aromatic ring has very little effect on the stereoselectivity of the reaction. For instance, comparison of entries 7 and 8 indicates that the electron-withdrawing/donating properties of substituents on the thioaromatic ring poorly affect the configuration of the obtained dienol ethers **5e**,**f**. Thiophenyl itself, in this series, gives the best selectivities obtained (entries 1 and 2) and provides the first stereoselective access to 1-(phenylthio)-4-methoxybutadiene (**5a**).

Also of interest in this context is the reactivity of thioether **4h** prepared from *o*,*o*′-dimethylthiophenol and chloro acetal **3b** following method B (see above). Deprotonation under the usual conditions indeed led to a mixture of expected dienol ether **5h** (*EE*:*ZE* = 73:27) with a new "*exo*" diene **11** of pure *E* configuration (eq 1). The overall yield was good (94%) with a **5h**/**11** ratio of 38:62. Models indicate that the bulk increase due to the two methyl groups on the aromatic ring makes access to the α-position of the sulfur atom difficult. This is probably at the origin of the deprotonation of the vinylic methyl group leading, via a comparable δ-elimination, to diene **11** (kinetic acidity). Generalization of these results to other hetero-substituted acetals is currently being pursued.[14]



(1)

Extensions of this reaction to cyclic acetals has also been considered, in an attempt to stabilize the corresponding intermediate anions. Treatment of methyl acetal **4b** with ethyleneglycol or phenylglycol in the presence of a trace of acid leads to the expected dioxolanes **12a**,**b**[11b,c] (eq 2). When treated as above, these compounds yield, through opening of the dioxolane moieties, the corresponding dienol ethers **13**. In the case of the acetal derived from phenylglycol, this opening is not regioselective and provides a mixture of isomeric alcohols **13b**,**c** (ratios undetermined). The unstability of the dioxolane ring under these basic conditions contrasts with related findings by our group for phosphonate anions[15] but may be considered in relation to results on

(12) Provided by the Rhône-Poulenc Chimie Co.

(13) A sample of pure *E* **4b** has once been isolated by flash chromatography. It led to a 50:50 mixture of *E*,*E* and *Z*,*E* diene **5b** (instead of the 70:30 mixture obtained from a 70:30 *E*/*Z* ratio of **4b**). This can be accounted for if pure *Z* **4b** leads to pure *E*,*E* **5b**. The total amount of the recovered *E*,*E* isomer would then be %*E*,*E*[**5b**] = (%*E*[**4b**] × 0.5) + (%*Z*[**4b**] × 1.0) = 0.65 (experimentaly: 0.7).

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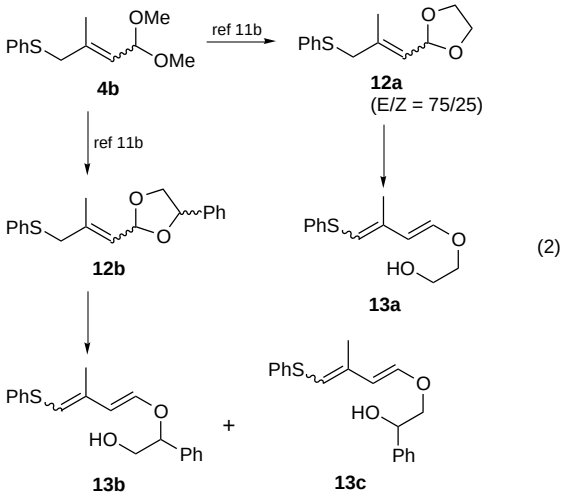
Table 1. Dienol Ethers 5 Prepared by Action of 1 Equivalent *t*-BuLi on Acetals 4 in Ether (Scheme 1)

entry	subst	R	Ar	*T*, °C	solvent	product	EE/ZE[a]	yield, %
1	4a	H	Ph	−78	THF	5a	>95:5	90
2	4b	Me	Ph	−78	THF	5b	85:15	90
3	4a	H	Ph	+34	Et_2O	5a	63:23[b]	95
4	4b	Me	Ph	+34	Et_2O	5b	60:40	96
5	4c	Me	*β*-naphthyl	−78	Et_2O	5c	65:35	91
6	4d	Me	*o*-MeC_6H_4	−78	Et_2O	5d	57:43	97
7	4e	Me	*p*-$MeOC_6H_4$	−78	Et_2O	5e	65:35	89
8	4f	Me	*p*-ClC_6H_4	−78	Et_2O	5f	55:45	98
9	4g	Me	2-Pyr	−78	Et_2O	5g	63:37	93
10	4h	Me	*o,o'*-$Me_2C_6H_3$	−78	Et_2O	5h	73:27	36[c]

[a] Refers to the 1*E*,3*E*/1*Z*,3*E* ratio. [b] Small amounts of other isomers also in the medium. [c] Yield for **5h** only, a 38:62 mixture of **5h** and **11** being recovered in 95% total yield.

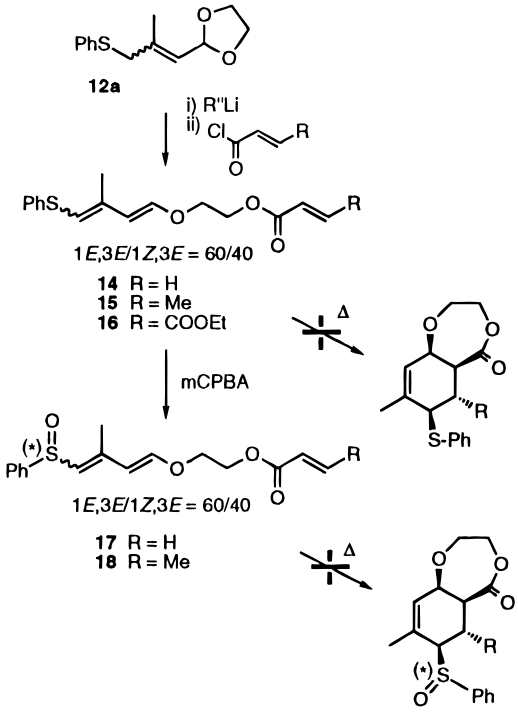
unsaturated dioxolanes[16] or with recent papers about opening of unsaturated dioxane derivatives.[14b,17]



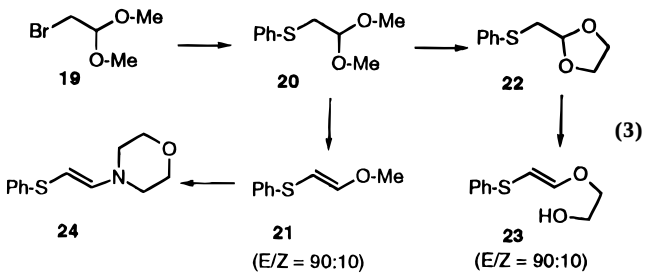
(2)

The intermediate lithium alcoholates derived from the dioxolane ring cleavage can be directly trapped by acid chlorides, yielding the corresponding esters **14**−**16** (Scheme 2). This easy access to trienic structures leads to potential precursors for hetero-bicyclic systems through intramolecular Diels−Alder (IMDA) reactions. A comparable approach has, for instance, been recently adopted by Craig *et al.*[18] to take advantage of an ether tethering during ring closure. Fine tuning of the electronic properties of the dienic part is further possible through the mild MCPBA oxidation of the sulfur atom[19] into the corresponding sulfoxide, thus converting the purely donor diene part into a push-pull type.[11b] This has been achieved on esters **14** and **15** (60 and 44% yields, respectively), and the oxidation does not interfere with the rest of these highly unsaturated molecules. Preliminary IMDA attempts on trienes **14**−**18** have remained, however, unsuccessful to date, under thermal conditions (toluene, 110 °C, 6 days: starting material) as well as in DMSO[20] at room temperature.

Scheme 2



Chain shortening influence on methoxy elimination has also been examined (eq 3); starting from (phenylthio)-acetaldehyde dimethyl acetal (**20**), prepared from commercial bromoacetaldehyde dimethyl acetal (**19**), we observed a comparable *β*-elimination taking place at −70 °C, leading in almost quantitative yield to the corresponding enol ether **21** in a 90:10 *E*/*Z* ratio.[21] Dioxolane **22** similarily led to enol ether **23**, with the same stereochemical outcome.



(3)

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(20) (a) Jung, M. E. *Synlett* **1990**, 186. (b) Jung, M. E.; Gervay, J. *J. Am. Chem. Soc.* **1991**, *113*, 224.

(21) For related exemples see: (a) Nagata, W.; Hayase, Y. *J. Chem. Soc. C* **1969**, 460. (b) Le Gallic, Y. Ph.D. Thesis, Rouen University, France, 1992.

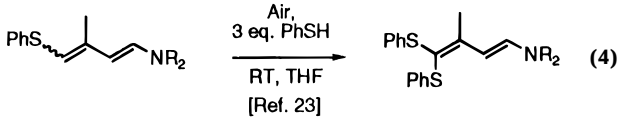
Table 2. 1,3-Dienes 6−10 Prepared by Action of 3 Equivalent of Lithiated Species on Acetals 4 in Ether or THF (Scheme 1)

entry	starting material	product	substituents R	R′	Ar	solvent	*T*, °C	isomer ratios (*EE*:*ZE*[a])	yield, %
1	4a	6a	H	*n*-Bu	Ph	Et_2O	35	60:40	50
2	4b	6b	Me	*n*-Bu	Ph	THF	−60	61:25:10:4[b]	45
3	4b	6b	Me	*n*-Bu	Ph	Et_2O	35	30:40:10:20[b]	60
4	4a	7a	H	*t*-Bu	Ph	THF	−60	64:36	40
5	4b	7b	Me	*t*-Bu	Ph	THF	−60	70:30	60
6	4b	7b	Me	*t*-Bu	Ph	Et_2O	35	57:43	80
7	4a	8a	H	morpholino	Ph	Et_2O	35	53:47	80
8	4b	8b	Me	morpholino	Ph	Et_2O	35	50:50	80
9	4c	8c	Me	morpholino	*β*-naphthyl	Et_2O	35	56:44	80
10	4f	8d	Me	morpholino	*p*-ClC_6H_4	Et_2O	35	50:50	80
11	4b	9	Me	piperidino	Ph	Et_2O	35	55:45	80
12	4b	10	Me	NEt_2	Ph	Et_2O	35	50:50	80

[a] Refers to the 1*E*,3*E*/1*Z*,3*E* ratio. [b] No attribution to the 4 possible stereoisomers.

Synthesis of Functionalized 1,3-Dienes (6−10)

As previously reported,[11a] the use of an excess of lithium reagent in the above-described reactions leads to incorporation of the base itself in the 4-position of the diene structure (Scheme 1 and Table 2). This reaction, to be considered in relation to results for lithio compound addition onto butadiene,[22c] styrene,[22d] or ynol ethers,[22a,b] takes place on enol ethers **5** or directly with 2−3 equiv of base on acetals **4**. It gives access to alkyl dienes (**6**, **7**) or dienamines (**8**−**10**) in decent yields. We wish to underline the handy access this method provides to these latter compounds which are very versatile tools in organic synthesis. We have, for instance, established that dienamines **8b**, **9**, and **10** are direct precursors to the corresponding ketene dithioacetals[23] when exposed to air at room temperature in the presence of 3 equiv of aryl thiols in THF (eq 4).



(4)

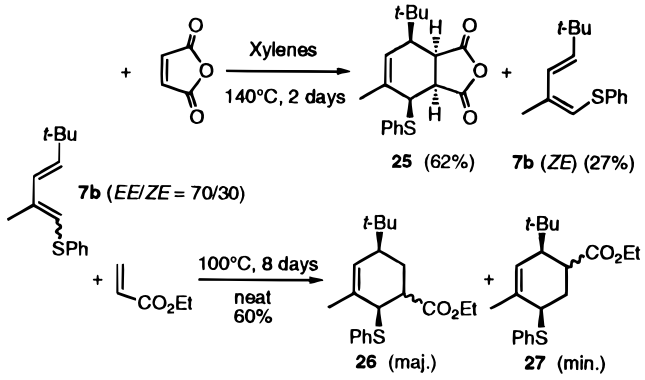
In regard to the control this method affords on the configurations of the two double bonds, the situation is quite contrasted: while the 3,4 one is in most cases recovered in its pure *E* form, the 1,2 bond stereoselectivity in favor of the *E* isomer varies between 0 (entries 8, 10, 12) and 40% (entry 5).

Similarly, the addition reaction of morpholine lithium amide on shorter chain homologue **21** leads stereoselectively and in high yields to the known[24] *trans*-1-(phenylthio)-2-morpholinoethylene (**24**) (eq 3).

Cycloaddition Reactions

The 1-(arylsulfenyl)-substituted compounds prepared above may be classified into three categories: (i) 4-alkyl-, (ii) 4-alkoxy-, and (iii) 4-amino-1,3-dienes. We have studied a few [4 + 2] Diels−Alder cycloaddition reactions involving a selected item among each of these classes (**5b**, **7b**, **8b**). For the sake of simplicity, results presented in this paper have been restricted to isoprenyl type compounds (R = Me, Scheme 1). These dienes have been opposed to either symmetrical (maleic anhydride or methyl/phenylmaleimides) or unsymmetrical (ethyl acrylate) dienophiles in an attempt to evaluate the regio and *endo*/*exo* selectivities this type of diene can afford.

Scheme 3



We have first considered the case of 1-(phenylthio)-2,5,5-trimethylhexa-1,3-diene (**7b**), taken as a representative of the 4-alkyl dienes class. The bicyclic adduct **25** was obtained after 2 days with maleic anhydride at reflux of xylenes (Scheme 3). Only the *E*,*E* isomer of **7b** is reactive here as proved by the recovery of over 90% of the *Z*,*E* isomer.[25] After control of the crude medium, solid adduct **25** was isolated and characterized as the pure *endo* isomer, both by NMR and X-ray crystallography analysis (Figure 1), in excellent agreement with many related examples.[26] A conformational study of **25** is proposed below.

By contrast, results obtained with ethyl acrylate have turned out to be of little interest. A mixture of the four possible regio/*endo*−*exo* isomers **26** and **27** (Scheme 3) is indeed recovered in unattractive ratios,[27] indicating that the regiocontrol exerted by the *tert*-butyl and phenylthio groups on the acrylate approach are not too different, a surprising result in comparison to related

(22) (a) Montijn, P. P.; Harryvan, E.; Brandsma, L. *Recl. Trav. Chim. Pays-Bas* **1964**, *83*, 1211. (b) Kooyman, J. G. A.; Hendriks, H. P. G.; Montijn, P. P.; Brandsma, L.; Arens, J. F. *Ibid.* **1968**, *87*, 69. (c) Glaze, W. H.; Jones, P. C. *Chem. Commun.* **1969**, 1434. (d) Wei, X.; Taylor, J. K. *J. Chem. Soc., Chem. Commun.* **1996**, 187.

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(24) Duhamel, L.; Chauvin, J.; Messier, A. *J. Chem. Res., Synop.* **1982** (S), 48.

(25) Stereochemistry of diene **7b** is not thermally altered, as checked by warming it alone.

(26) See for instance: (a) Danishefsky, S.; Yan, C. F.; Mc Curry, P. M. *J. Org. Chem.* **1977**, *42*, 1819. (b) Overman, L. E.; Petty, C. B.; Ban, T.; Huang, G. T. *J. Am. Chem. Soc.* **1983**, *105*, 6335. (c) Blatcher, P.; Warren, S. *J. Chem. Soc., Perkin Trans. 1* **1985**, 1055. (d) Tripathy, R.; Franck, R. W.; Onan, K. D. *J. Am. Chem. Soc.* **1988**, *110*, 3257. (e) Branchadell, V.; Sodupe, M.; Ortuno, R. M.; Oliva, A.; Gomez-Pardo, A.; Guingant, A.; D'Angelo, J. *J. Org. Chem.* **1991**, *56*, 4135.

(27) As checked by ^{1}H NMR spectroscopy; selectivities have not been determined.

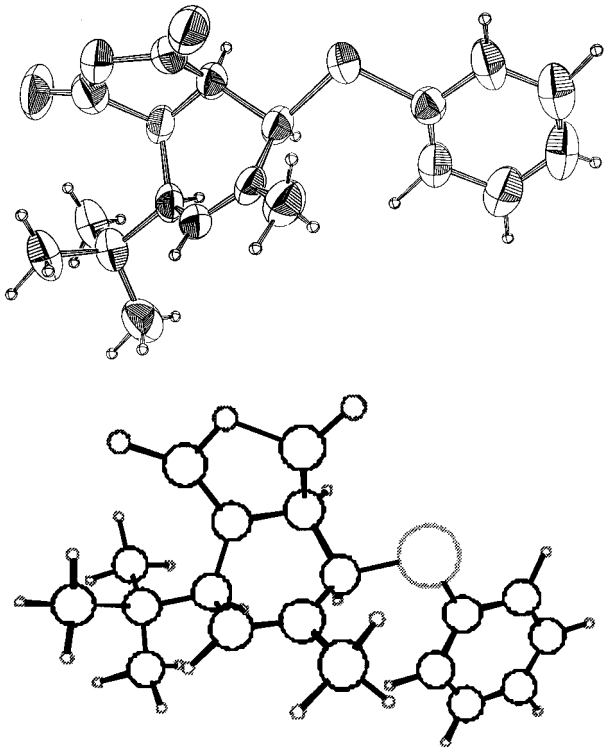


Figure 1. Structures of adduct **25** from (A, top) X-ray crystallographic analysis and (B, bottom) AM1 computations.

examples in the literature.[2] As expected, **26** appears to be the main product. The mediocre *endo*/*exo* selectivity provided by ethyl acrylate has been well-known for many years.[28] These four isomers have not been separated.

We next studied 4-methoxy-2-methyl-1-(phenylthio)-buta-1,3-diene (**5b**), which was interacted with the same categories of dienophiles. We have retained in this case *N*-phenyl- and *N*-methylmaleimides instead of maleic anhydride since yields proved low with this latter compound, probably because of the sensitivity of the enol ether function in **5b** to hydrolysis in the presence of acid traces. Warming an ether solution of *N*-phenylmaleimide up to reflux with the crude diene mixture **5b**, in the presence of catalytic amounts of hydroquinone, leads to almost total consumption of the 1*E*,3*E* diene in 2 days and progressive precipitation of a white solid (Scheme 4). At this stage the 1*Z*,3*E* isomer sits in the medium; however, pushing the warming further leads to its slow cycloaddition and gives access to both adducts **28** and **29**. If needed, these may be readily separated by flash chromatography. The discussion will be limited here to the syn adducts **28**. Analysis of the crude mixture led us to the conclusion that there is also only one stereoisomer in this case,[29] and both NMR and X-ray crystallographic analysis after purification indicated this compound to be the *endo* isomer (Figure 2). In solution, **28** undergoes a photoinduced thioallylic rearrangement (leading to **39**, *vide infra*).

When refluxed in neat ethyl acrylate, **5b** leads after 3 days to the expected adduct as a mixture of the isomers **30**−**32** (Scheme 4); these have been assayed in the crude medium prior to being separated and fully characterized. The main products (87%) are the *endo*/*exo* stereoisomers **30** and **31** (75:25) of the same regioisomer, as demonstrated by $^1H/^1H$ and $^1H/^{13}C$ NMR correlation experiments. The 13% remaining consisted of the *endo*/*exo* mixture of the other regioisomer **32**. It thus appears that the approach of ethyl acrylate is mainly guided by the oxygen donor effect rather than that of the sulfur.

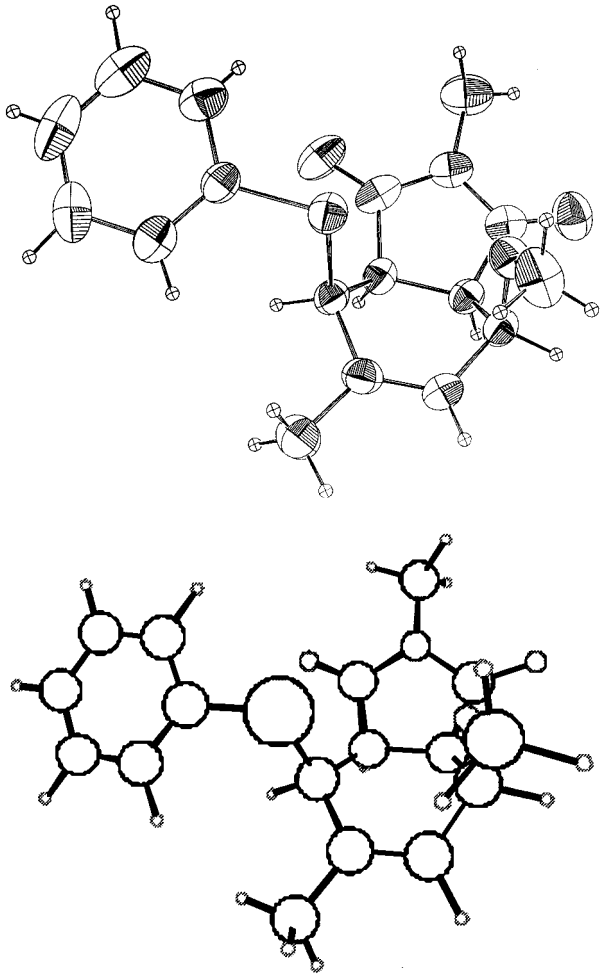
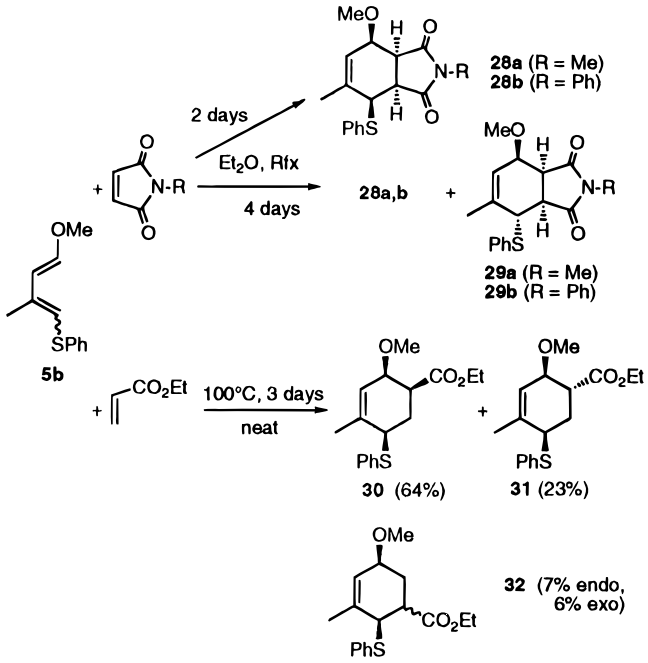


Figure 2. Structure of adduct **28a** from (A, top) X-ray crystallographic analysis and (B, bottom) AM1 computations.

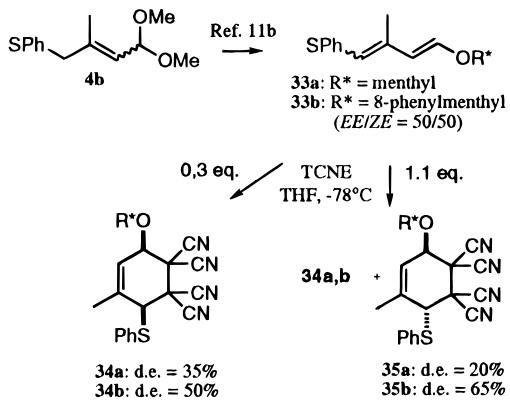
Scheme 4



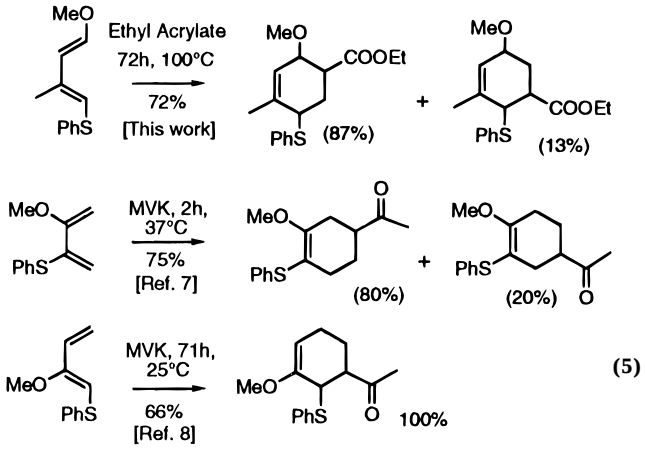
(28) Mellor, J. M.; Webb, C. F. *J. Chem. Soc., Perkin Trans. 2* **1974**, 17.

(29) Adduct **29** is also obtained as a single (*endo*) isomer.

Scheme 5



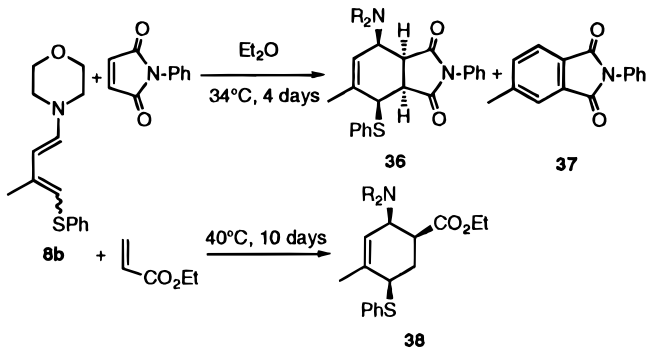
Competition between O and S regiodirectivities has been examined for 1,2- and 2,3-disubstituted butadienes in the literature.[5a,7,8] In both cases, it has been clearly established that sulfur is the directing element, and Trost even indicates that it takes the replacement of the phenyl by a strongly π-deficient aromatic system (such as 2-pyrimidyl) on the sulfur atom to reverse the regioselectivity in favor of the oxygen in 2,3-disubstituted dienes.[7] The relative α positions (1,2 or 2,3, eq 5) of S and O in these latter examples, by contrast to the δ (1,4) pattern in our case, is however to be kept in mind in relation to the competition between FMO[30] and dipole−dipole interactions supposed to be at the origin of the regioselectivity in such cases.[7]



(5)

The corresponding dienol ethers bearing a chiral moiety are also within reach since **4b**, in the presence of secondary alcohols and a trace of acid, undergoes a coupled trans-acetalization−conjugate elimination reaction, directly giving access to dienol ethers.[11b,c] Those derived from L-(−)-menthol (**33a**) and (−)-8-phenylmenthol (**33b**) have been studied in this reaction (Scheme 5). These very sensitive compounds, difficult to purify, can efficiently add tetracyanoethylene (TCNE) at low temperature in THF. After a few minutes, a mixture of adducts **34** and **35**, resulting from the rapid addition of both **33** 1*E*,3*E* and 1*Z*,3*E* isomers, is recovered. These cycloadducts were not separated since TLC analysis showed the four epimers of both **34** and **35** to be very intricate. However ^{1}H NMR spectra of the raw material directly provides the diastereoselectivity figures indicated on Scheme 5. Identity of the diastereoisomers derived

Scheme 6



from the single *EE* diene has indeed been established in a second experiment using 0.3 equiv of TCNE. These conditions lead to the kinetic selective addition of the *EE* diene,[31] confirmed by the selective disparition of the NMR signals corresponding to the *E*,*E* isomer. The simultaneous apparition of the peaks of only two adducts permits their attribution to **34a**/**35a** and **34b**/**35b**, respectively, in the original experiment. While modest, these excess values are comparable to those reported for cycloaddition reactions involving dienes bearing comparable chiral auxiliaries.[32] The sense of the induction for the two newly created asymmetric centers of these adducts has not been determined.

Finally, we decided to study 2-methyl-4-morpholino-1-(phenylthio)buta-1,3-diene (**8b**) in the same reactions (Scheme 6). *N*-Phenylmaleimide leads, after 4 days at reflux of ether, to the expected addition product **36** in a low 23% yield. The major contaminant is the corresponding aromatization product **37**.[33] **36** has been determined to be the *endo* form derived from the *EE* diene **8b**; however, no conformational conclusion could be drawn from a complementary NOE study.

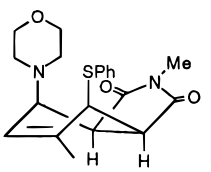
As above, the regioselectivity provided by **8b** has been examined opposing this diene to ethyl acrylate (Scheme 6). The reaction is slow, and after 10 days at 40 °C, the expected adduct **38** is recovered in low yield as a mixture with the starting *EE* and *ZE* dienamines. NMR spectroscopy performed on both the crude and chromatographied adduct **38** indicates its structure to be the one represented on Scheme 6. This *endo* adduct thus presents a regioselectivity totally controlled by the nitrogen atom, as clearly established by a COSY experiment. This result is in fine agreement with the only other report we are aware of in the literature probing the competition between regiodirectivities imposed by nitrogen and sulfur through a 2,4-thiosubstituted dienamine[34] and with results by Overman and colleagues about carbamate-

(30) Kahn, S. D.; Pau, C. F.; Overman, L. E.; Herhe, W. J. *J. Am. Chem. Soc.* **1986**, *108*, 7381.

(31) Rücker, C.; Lang, D.; Sauer, J.; Friege, H.; Sustmann, R. *Chem. Ber.* **1980**, 113, 1663.

(32) (a) Dauben, W. G.; Bunce R. A. *Tetrahedron Lett.* **1982**, *23*, 4975. (b) Thiem, R.; Rotscheidt, K.; Breitmaier, E. *Synthesis* **1989**, 836. (c) Arnold, T.; Reissig, H. U. *Synlett* **1990**, 514.

(33) The unusually large amount of aromatic material **37** recovered could however be due to an easy double 1,2-diaxial anti elimination made possible by a convex structure of the following type:



(34) Murase, M.; Hosaka, T.; Yoshida, N.; Tobinaga, S. *Chem. Pharm. Bull.* **1992**, *40*, 1343.

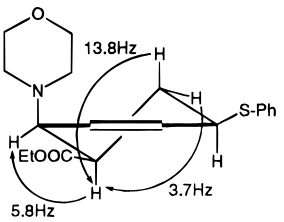


Figure 3. Conformation and ^{1}H coupling constants of adduct **38**.

substituted dienamines.[26b] From a conformational point of view, ^{1}H coupling constants of **38** are clearly in favor of a half-chair structure in which the morpholino group occupies an axial position (Figure 3). This conformer minimizes the number of axial substituents over the other possible half-chair. The obtention of a single *endo* isomer is somewhat unexpected in regard to related results dealing with cycloaddition reactions of (1*E*,3*E*)-1-(dimethylamino)buta-1,3-diene for which a 61:39 *endo* selectivity in the reaction with methyl acrylate is reported.[35] There is however a significant difference of chemical reactivity between these dienes: while the reaction described by Sustmann and colleagues is almost quantitative at room temperature, the one presented here shows very little progress after the same amount of time in refluxing ether. The deactivating effect of the sulfur group[26e] is at work here again.

Discussion and Structure Determinations

Conformations of bicyclic structures such as those obtained above represent an interesting problem which, to our knowledge, has never been the subject of a general study.[36] The control of the overall shape of taylor-made molecules has become lately a real challenge to organic chemists since this parameter is the key assett in supramolecular chemistry. It has, for instance, been shown[37] that advantage may be taken from the conformational rigidity imposed by a chiral tricyclic system to induce asymmetry through an efficient Diels−retro Diels sequence of reactions. We have thus tried to determine the exact conformation of these adducts from available experimental data on the one hand and quantum mechanical calculations on the other.

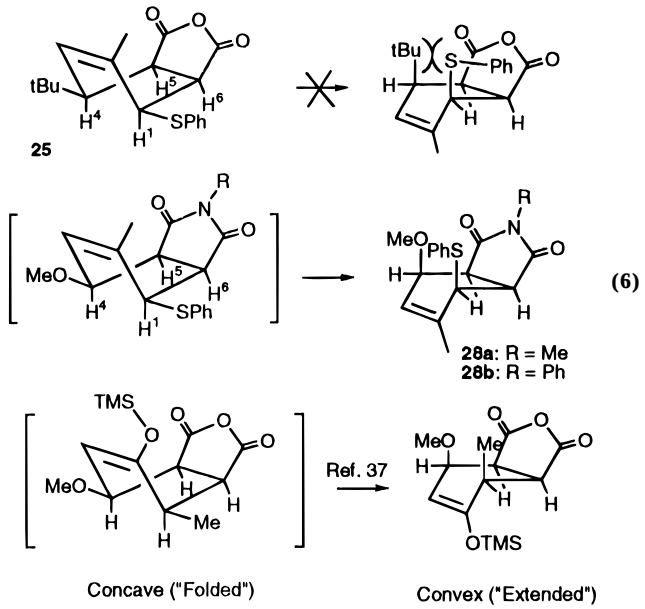
Let us first consider adduct **25**. Single-crystal X-ray diffraction (Figure 1A) indicates this *endo* isomer to be, in the solid state, in a boat-shaped concave conformation ("folded" after Danishefsky's naming for related bicyclic compounds[38]) with both *tert*-butyl and phenylthio appendages in expected equatorial positions. The clear out-of-the-plane distorsion induced on the anhydride moiety can be attributed to the steric strain exerted by the *tert*-butyl group on the five-membered ring. The conformational data deduced from the X-ray analysis give reasonable account for both the measured proton−proton coupling constants and a strong 1−4 NOE effect (10% difference), indicating a close similarity between solution

Table 3. Experimental and Theoretical Values of H−H Dihedral Angles and Coupling Constants (Hz) for 25

	Φ (J_{calc})[a]		
H−H	crystal	AM1	J_{exp}
1−6	−43 (5.8)	−53 (4.0)	4.2
3−4	−134 (6.6)	−116 (3.2)	5.0
4−5	39 (6.5)	72 (1.4)	7.3
5−6	11 (10.2)	3 (10.5)	9.2

[a] J in C_6D_6 and Φ calculated according to the following modified Karplus equation:[49] $^3J_{H-H} = 10.81 \cos^2 \Phi - 0.96 \cos \Phi + 0.70$.

and crystal conformations. Such a concave shape is to be considered as the frozen picture of the *endo* transition state; its good stability[39] may appear surprising since, for cyclohexene itself, the boat conformers are expected to lie between 5.5 and 6.5 kcal/mol higher in energy than their half-chair counterparts.[40] However, the rigidity induced by the 5-membered-ring anhydride or imide functions renders the compounds studied here more comparable to cyclohexadienic structures than to regular [4.3.0] bicyclic ones. A boat conformation is therefore not unlikely.[40e] The AM1 computations carried out on **25** led to conformational parameters presented together with related experimental data in Table 3 and Figure 1B. This theoretical study confirms the absence of any stable half-chair conformer for this compound and leads to a boat-shaped bicyclic structure. However, the distorsion undergone by the anhydride ring is underestimated by ~20°, a difference partly responsible for the discrepancies between vicinal coupling constants calculated from the torsion angles taken in the crystal and in the theoretical structure with respect to those measured from NMR data. Crystal packing effects could, in addition to the possible defects of the AM1 method, contribute to disagreements between some results of Table 3.



When the conformation of **28a** is considered, the single-crystal X-ray analysis shows this *endo* adduct to still be

(35) Sustmann, R.; Rogge, M.; Nüchter, U.; Bandmann, H. *Chem. Ber.* **1991**, *125*, 1647.

(36) See however the excellent conformational analysis by Bucourt, R. in *Topics in Stereochemistry*, Vol. 8; J. Wiley & Sons: New York, 1974.

(37) (a) Bloch, R.; Seck, M. *Tetrahedron* **1989**, *45*, 3731. (b) Beckmann, M.; Hildebrandt, H.; Winterfeldt, E. *Tetrahedron: Asymm.* **1990**, *1*, 335. (c) Bloch, R.; Bortolussi, M.; Girard, C.; Seck, M. *Tetrahedron* **1992**, *48*, 453. (d) Winterfeldt, E.; Wray, V. *Chem. Ber.* **1992**, *125*, 2159.

(38) Danishefsky, S.; Yan, C. F.; Singh, R. K.; Gammill, R. B.; McCurry, P. M.; Fritsch, N.; Clardy, J. *J. Am. Chem. Soc.* **1979**, *101*, 7001.

(39) Warming up **25** to reflux of xylenes only leads to a slow degradation/aromatization of this structure.

(40) This problem is still at the heart of active debates: (a) Rivera-Gaines, V. E.; Leibowitz, S. J.; Laane, J. *J. Am. Chem. Soc.* **1991**, *113*, 9735. (b) Anet, F. A. L.; Freedberg, D. I.; Storer, J. W.; Houk, K. N. *J. Am. Chem. Soc.* **1992**, *114*, 10969. (c) Anet, F. A. L. In *The Conformational Analysis of Cyclohexenes, Cyclohexadienes, and Related Hydroaromatic Compounds*; Rabideau, P. W., Ed.; VCH: New York, 1989. (d) Laane, J.; Choo, J. *J. Am. Chem. Soc.* **1994**, *116*, 3889. (e) Sieburth S. Mc. N. *J. Chem. Soc., Chem. Commun.* **1994**, 1663.

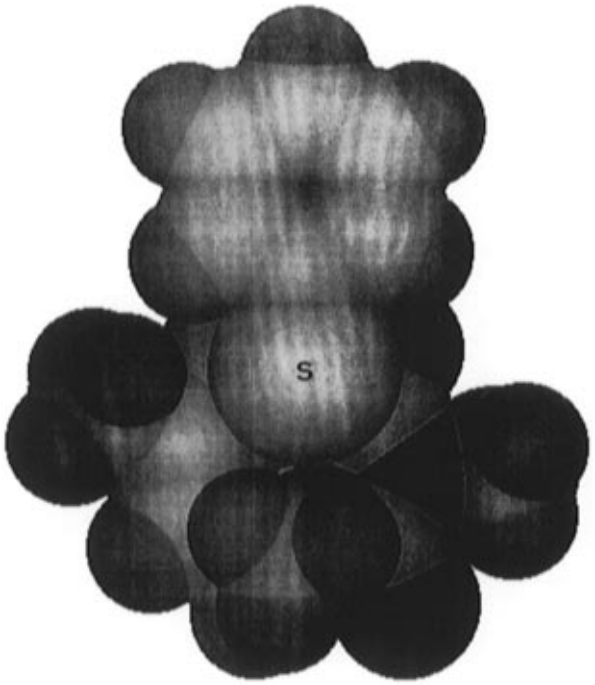
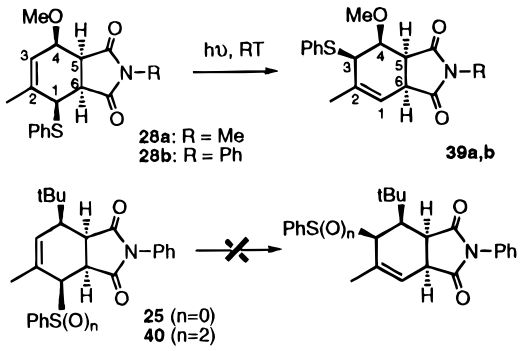


Figure 4. Top view of a compact model of **28a**.

in the boat form but of the convex type this time, surprisingly placing both methoxy and phenylthio substituents in axial positions (Figure 2A). Such a situation, while avoiding the allylic $A^{1,2}$ strain[40c] between the phenylthio and vinylic methyl groups induced by the concave boat conformation, is at the origin of an extremly short oxygen−sulfur distance (~3.0 Å) in this compound, a trend clearly showing up on the compact model representation of Figure 4. Thus, decreasing the bulkiness of the substituent in the 4-position (such as when going from *t*-Bu in **25** to MeO in **28**) makes its passage to an axial position spontaneous and leads to cyclohexenic adduct **28** conformationally comparable to the one described previously by Danishefsky's group[38] (eq 6). These authors also proposed a rearrangement from an eventual primary concave boat into a more stable convex conformer. A major difference between their case and ours is the fact that the bulky substituent sits at the vinylic position (TMSO in Danishefsky's example) while it occupies the allylic position in our case. Since release of the $A^{1,2}$ strain requires the relative motion of the allylic group, a concave−convex folding is conceivable in their case or for adducts **28** but just impossible for **25** which is locked in its concave shape by the cumbersome *tert*-butyl. An AM1-optimized structure for the corresponding diaxial compound is 50 kcal/mol higher in energy than that of diconvex **25**.

Despite their apparent intramolecular strain, both **28a,b** are perfectly stable in the solid state and may be kept for months in the refrigerator without any decomposition. On the other hand their solutions undergo a relatively slow sigmatropic 1,3-shift at room temperature, easily followed by NMR. It leads quantitatively and stereospecifically to the transposition products **39a,b** (eq 7), as determined through a COSY−NOESY−COLOC set of NMR experiments.

The NMR spectra of the starting adduct and rearranged material are very different, and several protons undergo a dramatic chemical shift during this process (see experimental data). Especially worthy of note is the



(7)

shielding observed for the ortho protons born by the thiophenyl group; they go, in C_6D_6, from an unusual 7.89 in **28a** and **28b** to 7.38 and 7.22 ppm in **39a** and **39b**, respectively, probably because of the proximity of these aromatic protons to one of the imide carbonyl groups in the convex forms of **28**.[41] The rearrangement takes place in all solvents tested ($CDCl_3$, C_6D_6, CD_2Cl_2, CD_3OD, d_5-pyridine)[42] for both adducts **28a,b** at different rates with the exception of d_{10}-diethyl ether in which **28** is nearly insoluble. While the migration is a little faster when the temperature is raised, this thiophenyl migration proceeds much faster upon strong irradiation in methylene chloride (Figure 5). It remains limited (<20%) during the synthesis of **28** because this compound precipitates out of the ether solution. The driving force for such an isomerization is at least 2-fold: (i) releasing the strong 1,4-diaxial interaction in **28** by going to the flatter system **39**; (ii) placing the double bond in the thermodynamically favored $\alpha-\beta$ position (instead of $\beta-\gamma$) with respect to the cis hydrindane type junction.[36] This kind of thioallylic rearrangement is well-known; its mechanism has been the subject of many discussions[44] and may even depend on reaction conditions.[45] The rearrangement takes place here under very mild conditions, and its dramatic acceleration under illumination (Figure 5) is definitely in favor of a photoinduced radical mechanism.[46] It also nicely fits the theoretical results for the excited state of **28** which are presented below. Interesting in this regard is the excellent stability of adduct **25** in the solid state as well as in solution (CH_2Cl_2) in the dark or after a 17-h-long intense irradiation in a quartz vessel (eq 7). This difference of behavior shows the homolytic cleavage of the C−S bond to be much easier when the thiophenyl group is in an axial position (i.e., in the convex situation) than when it occupies an equatorial position (which is the case for the concave compounds). This hypothesis is supported by the stability of the corresponding sulfone (**40**) under the same conditions (eq 7), while the easy

(41) See ref 37d for a comparable observation.

(42) Since the isomerization takes place in all solvents, we did not think it essential to explicitely take into account the solvent effect in our computations.[43]

(43) (a) Cramer, C. J.; Truhlar, D. G. *J. Comput. Chem.* **1992**, *13*, 1089. (b) Karelson, M.; Tamm, T.; Zerner, M. C. *J. Phys. Chem.* **1993**, *97*, 11901.

(44) (a) Brownbridge, P.; Warren, S. *J. Chem. Soc., Perkin Trans. 1* **1976**, 2125. (b) Reference 26c and references cited therein. (c) Kwark, H. *Phosphorus Sulfur* **1983**, *15*, 293. (d) Bernard, A. M.; Piras, P. P. *J. Chem. Soc., Chem. Commun.* **1994**, 257.

(45) Apparao, S.; Rahman, A.; Ila, H.; Junjappa, H. *Tetrahedron Lett.* **1982**, *23*, 971.

(46) In agreement with a personal suggestion by Dr. S. Warren but in contradiction with Kwart, H.; Johnson, N. *J. Am. Chem. Soc.* **1970**, *92*, 6064 and ref 44c. See also in relation recent evidences about photochemical [1,3]-stannyl migration of 3-aryl-substituted allyltins: Takuwa, A.; Kanaue, T.; Nishigaichi, Y.; Iwamoto, H. *Tetrahedron Lett.* **1995**, *36*, 575.

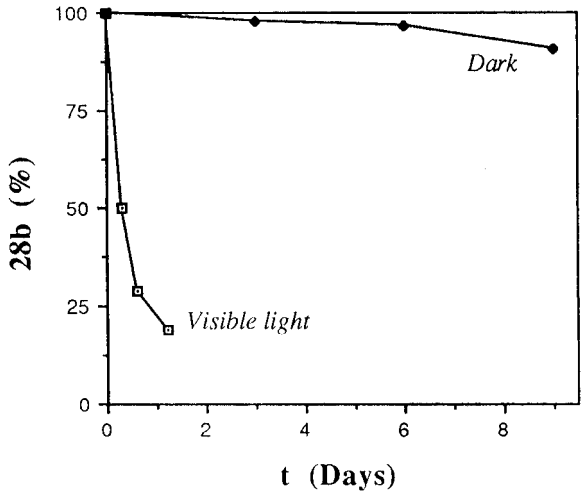
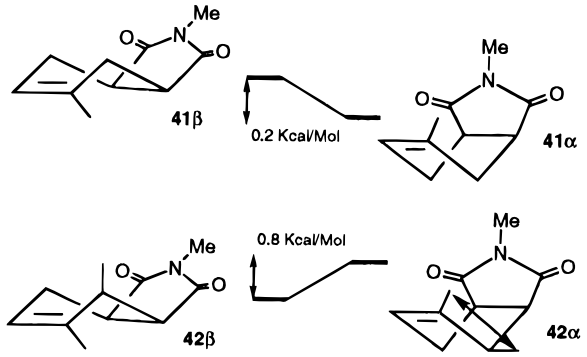


Figure 5. 28b → 39b rearrangement in CH_2Cl_2, in the dark and under visible light irradiation.

Scheme 7



rearrangement of allylic sulfones is well documented.[47] The possible role of the *tert*-butyl steric hindrance in both **25** and **40** is however to be kept in mind.

A better understanding of the driving forces at the origin of this cascade of transformations (**28a**[concave] → **28a**[convex] → **39a**) and of their thermodynamic consistency required further calculations. In a first step, complete optimizations of the concave and convex "naked" bicyclic skeletons of **28**, *viz.* imide **41** and its 1-methyl-substituted equivalent **42**, have been performed (Scheme 7). It indicates in the case of **41** an energetic preference for the original concave structure of 0.2 kcal/mol at the AM1 level. This negligible difference prompted us to check this preference at the *ab initio* DFT level. The most stable conformation of **41** is still found to be a concave boat but by 1.2 kcal/mol this time. By contrast, the substituted structure **42** is more stable under its convex form β by 0.8 kcal/mol (AM1), probably because such a conformation releases the allylic strain between methyl groups, as mentioned above (Scheme 7). These results thus indicate that the steric constraints induced by the substitution patterns of the adducts studied here (and particularly the vinylic methyl group) are at the origin of the general preference for a convex boat, a concave one being encountered in the single case of *tert*-butyl-substituted **25**.

The calculated characteristics for the most stable form of the two boat conformers of **28a** are reported in Table 4 and Figure 2 together with the relevant experimental data. The AM1 energies of the two optimized conformers differ by 0.9 kcal/mol, the concave → convex flip taking place through an "early" transition state associated with a 4.6 kcal/mol activation energy barrier (Figure 6). The change of sign of the torsion angles characterizing the convex/concave switch indeed takes place after the passage through the transition state, as illustrated on Figure 6 with dihedral angle ϕ(3,4,5,6) as a function of the ϕ-(7,1,6,5) angle (reaction coordinate). It is clear from Figure 7 that this transition state is of the half-chair type with the thiophenyl group in a pseudoaxial position. These results also indicate that the theoretical convex arrangement fits both the crystal and NMR data (Table 4). It is worth underlining that the coupling constants measured for **28a** in d_{10} ether are identical to those in other deuterated solvents, indicating that the absence of rearrangement in ether (Figure 7) is not due to a peculiar conformation imposed by this solvent but only to the poor solubility of **28**.

We then considered the [1,3] shift undergone by **28** in the next step (**28** → **39**). The crucial role apparently

Table 4. Experimental and Theoretical Values of H−H Dihedral Angles and Coupling Constants (Hz) for 28b

	Φ (J_{calc})[a]			
		AM1		
H−H	crystal	**28b**β (convex)	**28b**α (concave)	J_{exp}
1−6	−35 (7.2)	−36 (7.0)	58 (3.2)	8.1
3−4	21 (9.2)	25 (8.7)	106 (1.8)	5.6
4−5	41 (6.1)	32 (7.7)	−60 (5.6)	5.2
5−6	−4 (10.5)	2 (10.5)	−10 (10.2)	10.3

[a] J in C_6D_6 and Φ calculated according to the following modified Karplus equation:[49] $^3J_{H-H} = 10.81 \cos^2 \Phi - 0.96 \cos \Phi + 0.70$.

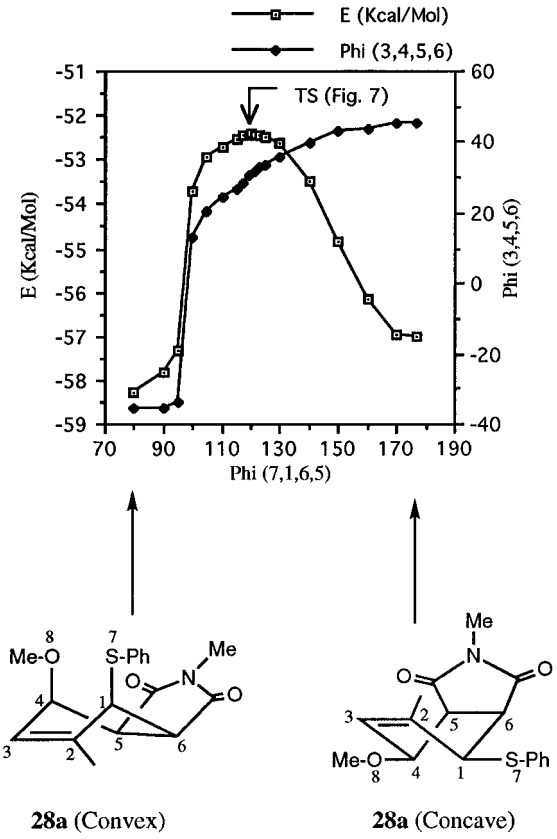


Figure 6. AM1 energy and puckering angle variations occurring during the **28a** concave−convex conformational change.

(47) See for instance: (a) Liu, P.; Whitham, G. H. *J. Chem. Soc., Chem. Commun.* **1983**, 1102. (b) Padwa, A.; Bullock, W. H.; Dyszlewski, A. D. *Tetrahedron Lett.* **1987**, *28*, 3193; *J. Org. Chem.* **1990**, *55*, 955. (c) Jones-Hertzog, D. K.; Jorgensen, W. L. *J. Am. Chem. Soc.* **1995**, *117*, 9077.

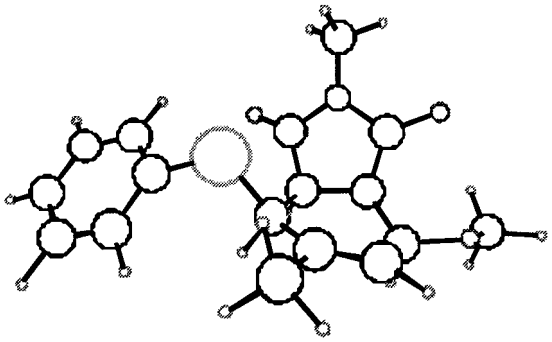


Figure 7. Theoretical structure of the transition state for the **28a** concave−convex conformational change.

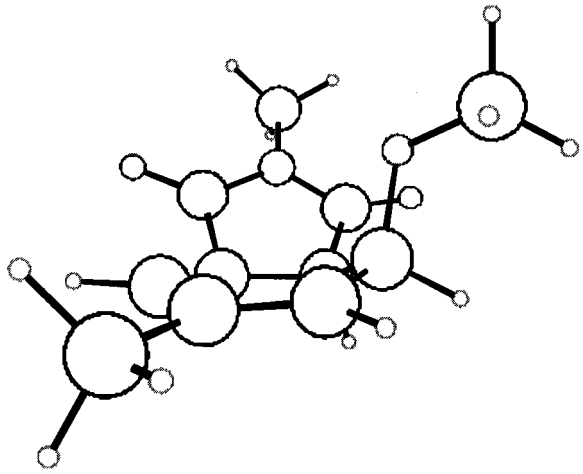


Figure 8. Theoretical structure of the bicyclic allylic radical intermediate calculated for the **28a** → **39a** rearrangement.

played by the molecular excited state of **28** in this rearrangement prompted us to undertake two other sets of calculations. The first one concerns an optimization of the first singlet and triplet excited states of convex **28a**. The second set deals with the separate study of the two radicals formed after a homolytic cleavage of the C−S bond, leading to PhS• on the one hand and the corresponding allylic radical on the other. The calculated structures for these species indicate (i) a simultaneous shortening of the Ph−S bond from 1.70 to 1.60 Å (1.62 Å in PhS•) and minor lengthening of the C_1−S bond (from 1.80 to 1.82 Å) and (ii) a concomitant variation of the two bonds of the ring involved in the rearrangement (1−2 and 2−3), going from 1.49 and 1.34 Å to 1.38 and 1.39 Å, respectively, leading to an almost perfect delocalization of the planar allylic part of the bicyclic radical (Figure 8). The energetic path corresponding to the details of this photochemical rearrangement is illustrated in Figure 9. It clearly shows that the C−S bond breaking can easily take place through the lowest allowed singlet excited state and does not call for any participation of its spin forbidden triplet equivalent. The energy barrier to this first excited singlet is about 55 kcal/mol, a value in reach of a 520 nm irradiation, i.e., in the visible region as expected. Finally, the half-chair conformers of **39a** lie at least 2 kcal/mol lower than the starting material (**28a**). This energetic situation, in addition to the favorable topology of the convex conformer (see Figure 4), probably explains the extreme ease and efficiency of this reaction.

The stereochemistry of **39** was however still to be determined. The Woodward−Hoffman rules predict a four-electron [1,3] shift such as the one described here to occur in a supra−supra mode[48] leading to a *cis* relationship between the MeO and PhS groups in **39a**. However, the likely radical mechanism we are dealing with here precludes the application of rules restricted to concerted mechanisms. We thus had to undertake a complete optimization for the two possible conformers (with the PhS group in a pseudoaxial or equatorial position) of the two possible (*cis* and *trans*) isomers. The following nomenclature has been adopted: the *cis* isomer of **39a**, corresponding to a "supra" migration of the PhS group, is labeled **39a**(s), and its conformers, in which the thiophenyl group adopts an axial or an equatorial position, are named **39a**(s-ax) and **39a**(s-eq), respectively. Similarly, the two conformers of the *trans* isomer, corresponding to an antara migration, are called **39a**-(a-ax) and **39a**(a-eq). Results of these optimization steps are gathered in Table 5. Unfortunately, these data do not permit an unambiguous determination of the structure of **39a**, and the complementary COSY and NOESY experiments performed at room temperature in this case, while confirming the presence of a single isomer, are helpless in choosing between a dynamic mixture of **39a**(s-ax) + **39a**(s-eq) and **39a**(a-ax). Obvious steric considerations (Figure 4) however support a straightforward supra migration of the thiophenyl group, and we assume the rearranged product to be, in solution, under the form of a balanced mixture of the **39a**(s-ax) and **39a**(s-eq) conformers shown in Figure 10. This hypothesis fully accounts for the spectroscopic data presented here.

We think the above agreements between the conformations given by the quantum mechanical calculations and those obtained from the experimental techniques constitute a fair body of evidence which improves the level of confidence in the conformational analysis of such flexible *cis*-fused bicyclic systems. The hazards of deducing conformations of bicyclic structures on the single basis of NMR coupling constants has been previously underlined by Danishefsky *et al.*[38] This combined experimental and theoretical approach indicates that relatively safe milestones along nonobservable pathways are possible as well as characterization of isolated adducts and intermediates such as those studied here.

Experimental Section

Experimental Indications. ^{1}H and ^{13}C NMR spectra were taken in perdeuteriobenzene or deuteriochloroform with Brücker WP-80, AM-200, 300-FT, 360-FT, or 400 FT NMR spectrometers. Mass spectra and high-resolution mass spectra (HRMS) were recorded with a JEOL JMS AX-500 spectrometer. The silica gel used for flash chromatography was from the SDS Co. (230−400 mesh). All reagents were of reagent grade and were used as such or distilled prior to use. Analytical TLC plates for adducts were conveniently revealed with an acidic aqueous solution of $PdCl_2$.

X-ray Analysis.[49,53] **(a) Adduct 25.** $SO_3C_{19}H_{22}$: M_r = 330.5, triclinic, *P*-1, a = 6.713(7), b = 10.177(4), and c = 12.822-(1) Å, α = 85.99(6), β = 80.00(7), and γ = 88.23(6)°, V = 860-(1) Å^3, Z = 2, D_x = 1.276 mg m^{-3}, λ(Mo K$_\alpha$) = 0.70926 Å, μ = 1.91 cm^{-1}, F(000) = 352, T = 293 K, final R = 0.092 for 1537 observations.

(48) Gilchrist, T. L.; Storr, R. C. *Organic Reactions and Orbital Symmetry*; Cambridge University Press: London, 1972; p 240.

(49) (a) Fair, C. K. *MolEN: an Interactive Intelligent System for Crystal Structure Analysis*; Enraf-Nonius: Delft, The Netherlands, 1990. (b) *International Tables for X-Ray Crystallography*, Vol. IV; Kynoch Press: Birmingham, U.K., 1974. (c) Johnson, C. K. ORTEP, Report ORNL-3794, Oakridge National Laboratory, Tennessee, 1965.

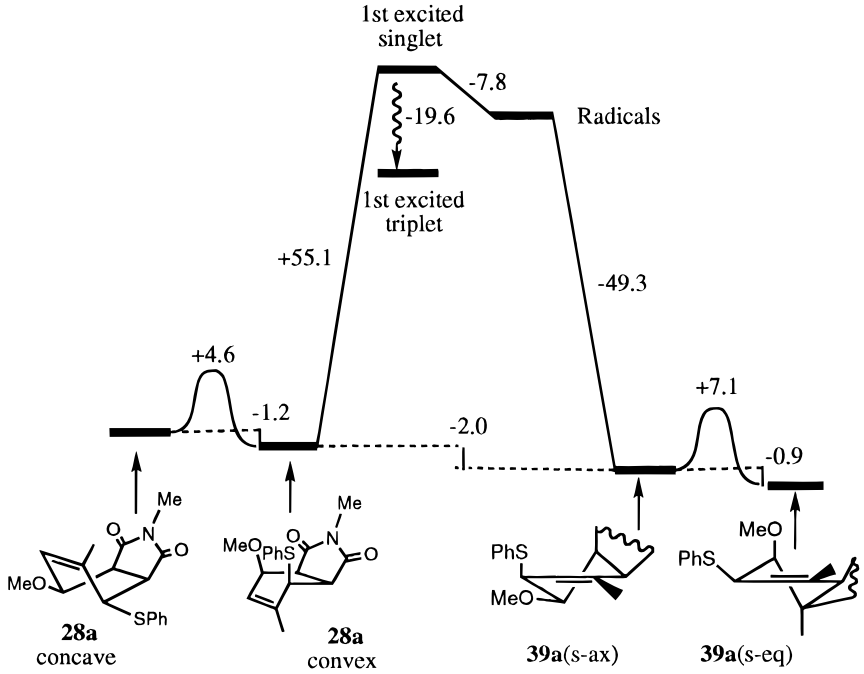


Figure 9. Calculated photochemical energetic path between **28a** and **39a** (values in kcal/mol).

Table 5. Main Torsion Angles, Vicinal H−H Coupling Constants (Hz), and Relative Energies of the Four Different Isomers/Conformers of 39a

	Φ (J_{calc})[a]				
	39a supra		**39a** antara		
H−H	s-ax	s-eq	a-ax	a-eq	J_{exp}[b]
1−6	−44 (5.6)	−78 (1.0)	−68 (1.9)	−37 (6.8)	2.9
3−4	61 (2.8)	−66 (2.1)	68 (1.9)	−178 (12.5)	2.7
4−5	−47 (5.1)	38 (6.7)	38 (6.7)	−44 (5.6)	4.3
5−6	5 (10.5)	−4 (10.5)	−12 (10.1)	−1 (10.5)	8.8
Δ*E* (kcal/mol)	+3.3	+2.4	0.0	+4.4	

[a] *J* calculated according to the following modified Karplus equation:[49] $^3J_{H-H} = 10.81 \cos^2 \Phi - 0.96 \cos \Phi + 0.70$. [b] In C_6D_6.

The sample (0.10 × 0.25 × 0.45 mm) was studied on a CAD4 Enraf-Nonius automatic diffractometer with graphite-monochromatized Mo K_α radiation. The cell parameters were obtained by fitting a set of 25 high-θ reflections. The data collection ($2\theta_{max} = 50°$; scan $\omega/2\theta = 1$; $t_{max} = 60$ s; range *hkl* *h* 0.7 *k* −12.12 *l* −15.15; intensity control without appreciable decay (0.1%) gives 3289 reflections from which 1537 were independent ($R_{int} = 0.025$) with $I > 4\sigma(I)$.

After Lorenz and polarization corrections the structure was solved with direct methods which reveal all the non-hydrogen atoms of the molecule. After isotropic ($R = 0.137$) and then anisotropic ($R = 0.097$) refinement, the hydrogen atoms were found with a Fourier difference. The whole structure was refined by the full-matrix least-squares technique (use of *F* magnitude; *x*, *y*, *z*, $\beta_{i,j}$ for S, O, N, and C atoms and *x*, *y*, *z* for H atoms; 275 variables and 1537 observations; $w = 1/\sigma(F_o)^2 = [\sigma^2(I) + (0.04F_o^2)^2]^{-1/2}$) with the resulting $R = 0.095$, $R_w = 0.092$, and $S_w = 1.37$ (residual $\Delta\rho \leq 0.22$ e Å^{-3}). All X-ray data calculations have been performed on a Digital Micro Vax 3100 computer.

(b) Adduct 28a. $SO_3NC_{17}H_{19}$: $M_r = 317.41$, orthorombic, $Pna2_1$, $a = 16.085(3)$, $b = 13.100(4)$, and $c = 7.489(3)$ Å, $V = 1578.0$ (8) Å^3, $Z = 4$, $D_x = 1.336$ mg m^{-3}, λ(Mo K_α) = 0.70926 Å, $\mu = 2.07$ cm^{-1}, $F(000) = 672$, $T = 294$K, final $R = 0.025$ for 1123 observations.

The sample (0.30 × 0.45 × 0.55 mm) was studied on a CAD4 Enraf-Nonius automatic diffractometer with graphite-monochromatized Mo K_α radiation. The cell parameters were obtained by fitting a set of 25 high-θ reflections. The data collection ($2\theta_{max} = 50°$; scan $\omega/2\theta = 1$; $t_{max} = 60$ s; range *hkl* *h* 0.6 *k* 0.15 *l* 0.19; intensity control without appreciable decay (0.1%) gave 1472 reflexions from which 1123 with $I > 2\sigma(I)$.

After Lorenz and polarization corrections the structure was solved with direct methods which reveal all the non-hydrogen atoms of the molecule. After isotropic ($R = 0.076$) and then anisotropic ($R = 0.051$) refinement, the hydrogen atoms are found with a Fourier difference (between 0.3 and 0.19 e Å^{-3}). The whole structure was refined by the full-matrix least-squares technique (use of *F* magnitude; *x*, *y*, *z*, $\beta_{i,j}$ for S, O, N, and C atoms and *x*, *y*, *z* for H atoms; 256 variables and 1123 observations; $w = 1/\sigma(F_o)^2 = [\sigma^2(I) + (0.04F_o^2)^2]^{-1/2}$) with the resulting $R = 0.027$, $R_w = 0.025$, and $S_w = 0.72$ (residual $\Delta\rho \leq 0.12$ e Å^{-3}).

Computational Procedures and Inputs. The computations have been carried out using a semiempirical quantum mechanical method (AM1 with the Dewar original parametrization[51]) for the two following reasons. (i) Among the very different conformers/fragments that we had to consider, only two compounds have been subjected to crystallographic X-ray analysis and one of them (the *tert*-butyl derivative **25**) is not involved in the conformational rearrangement/isomerization mechanism. Therefore, overall optimizations were necessary, especially in the case of the transition state and radical intermediates. (ii) The number of optimizations to be carried out on systems involving 30−40 atoms prohibited a systematic *ab initio* study. However, to establish the validity of our semiempirical results, the complete geometrical optimization of the concave and convex conformations of the smallest compound (**41**) has been repeated using density functional theory as implemented in Gaussian 92/DFT.[52] For this computation, we retained the 6-31G** basis set and the Becke's three parameters of the exchange functional with the Perdew correlation functional (B3P86).

General Methods for Preparation of Thioethers 4. Method A. To a solution of **3** in triethylamine (1.8 M) was

(50) Obtained by averaging eqs 5 and 8 in Haasnoot, C. A. G.; De Leeuw, F. A. A. M.; Altona, C. *Tetrahedron* **1980**, *36*, 2783. The electronegativities of substituents have been neglected for eq 8 since the strain induced by bicyclic structures could not be taken into account while probably of prime importance in this system. The equation retained here gives fair account for threshold values.

(51) (a) Dewar, M. J. S.; Zoebisch, E. G.; Healy, E. F.; Stewart, J. P. J. *J. Am. Chem. Soc.* **1985**, *107*, 3902. (b) Dewar, M. J. S.; Yuan, Y. C. *Inorg. Chem.* **1990**, *29*, 3881.

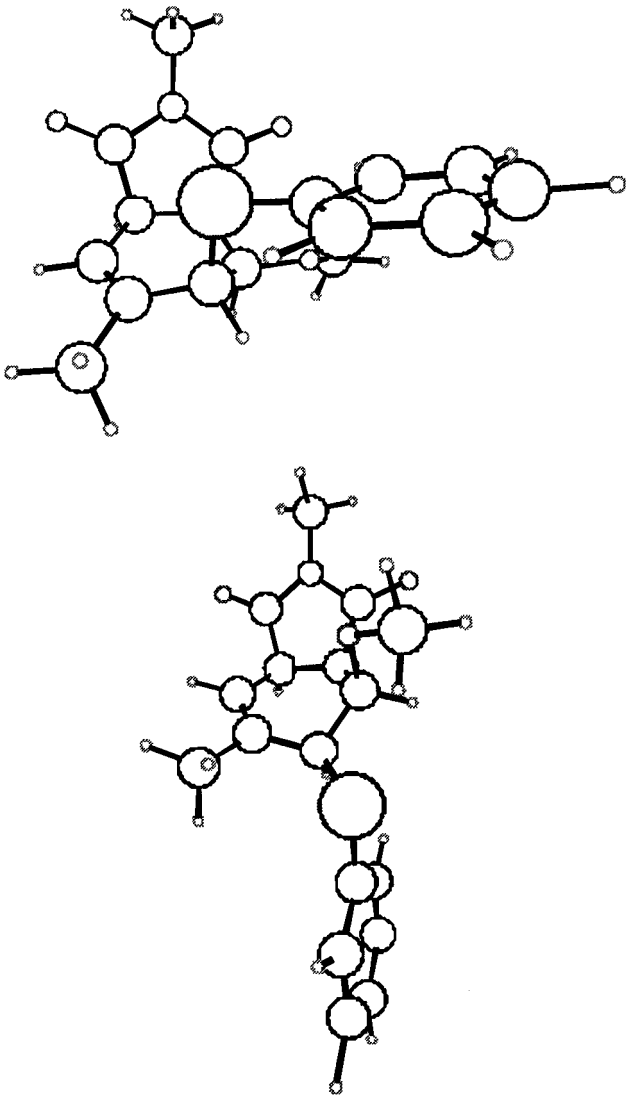


Figure 10. Theoretical structures of **39a**(s-ax) (top) and **39a**(s-eq) (bottom).

added dropwise, at 20 °C, a solution of aryl thiol in ether (9.5 M). The mixture was stirred until disappearance of **3** (GC); the precipitate was then filtered out and washed with ether. After evaporation of the solvent, the crude thioether **4** was recovered in 67−97% yield as a 7:3 mixture of *E* and *Z* isomers.

Method B. To a mixture of aryl thiol in concentrated aqueous soda (1.8 M) was added a solution of **3** in ether (1.0 M). The mixture was stirred until disappearance of **3** (GC); then the aqueous phase was extracted two times by ether then dried. After evaporation, the crude product was recovered in 78−91% yield as a 7:3 mixture of *E* and *Z* isomers.

1,1-Dimethoxy-3-methyl-4-(2-naphthylthio)but-2-enes (4c). Using method A with **3** (2.8 g, 17 mmol) and naphthane-2-thiol (2.9 g, 18 mmol), **4c** was recovered (4.1 g, 84%) after 6 days: pale yellow solid, mp 133−135 °C (Et_2O); IR (neat) 1671 cm^{-1}; mass spectrum (EI) *m*/*z* 288 ($M^{+\bullet}$, 31), 256 ($M^{+\bullet} - CH_3OH$, 14), 225 (10), 199 (38), 128 (100), 115 (52); ^1H NMR 200 MHz (C_6D_6) δ (ppm) *E* isomer, 1.78 (3H, d, ^4J = 1.2 Hz), 3.00 (6H, s), 3.32 (2H, s), 4.96 (1H, d, J = 5.8 Hz), 5.52 (1H, dq, ^3J = 5.8 Hz, ^4J = 1.2 Hz), 7.15−7.95 (7H, m); *Z* isomer, 1.78 (3H, m), 3.07 (6H, s), 3.61 (2H, s), 4.91 (1H, d, J = 6.0 Hz), 5.52 (1H, m), 7.15−7.95 (7H, m).

1,1-Dimethoxy-3-methyl-4-((2-methylphenyl)thio)but-2-enes (4d). Using method B with **3** (3.2 g, 19 mmol) and 2-methylthiophenol (2.5 g, 20 mmol), **4d** was recovered (4.4 g, 89%) after 5 days: IR (neat) 1672 cm^{-1}; mass spectrum (EI) *m*/*z* 252 ($M^{+\bullet}$, 25), 220 ($M^+ - CH_3OH$, 18), 189 (9), 163 (45), 128 (85), 75 (100); ^1H NMR 200 MHz (C_6D_6) δ (ppm) *E* isomer, 1.73 (3H, m), 2.30 (3H, s), 3.04 (6H, s), 3.17 (2H, s), 4.96 (1H, d, J = 5.8 Hz), 5.46 (1H, m), 6.85−7.83 (4H, m); *Z* isomer, 1.73 (3H, m), 2.35 (3H, s), 3.09 (6H, s), 3.44 (2H, s), 4.85 (1H, d, J = 5.9 Hz), 5.46 (1H, m), 6.85−7.83 (4H, m).

1,1-Dimethoxy-3-methyl-4-((4-methoxyphenyl)thio)-but-2-ene (4e). Using method B with **3** (2.0 g, 12 mmol) and 4-methoxythiophenol (1.5 g, 12 mmol), **4e** was recovered (2.8 g, 89%) after 4 days: IR (neat) 1670 cm^{-1}; mass spectrum (EI) *m*/*z* 268 ($M^{+\bullet}$, 23), 237 (60), 205 (7), 179 (43), 139 (100); ^1H NMR 200 MHz (C_6D_6) δ (ppm) *E* isomer, 1.75 (3H, m), 3.03 (6H, s), 3.16 (2H, s), 3.20 (2H, s), 4.94 (1H, d, J = 5.8 Hz), 5.31 (1H, dq, ^3J = 5.8 Hz, ^4J = 1.0 Hz), 6.60 (1H, d, J = 8.8 Hz), 7.26 (2H, d, J = 8.8 Hz); *Z* isomer, 1.75 (3H, m), 3.05 (6H, s), 3.21 (3H, s), 3.42 (2H, s), 4.63 (1H, d, J = 6.0 Hz), 5.42 (1H, d, ^3J = 6.0 Hz,), 6.55 (1H, d, J = 8.8 Hz), 7.40 (2H, d, J = 8.8 Hz); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) *E* isomer, 15.8, 45.4, 51.5, 54.7, 100.1, 114.7, 126.4, 134.4 (2C), 126.4, 137.0, 159.6; *Z* isomer, 22.4, 38.8, 51.7, 54.7, 99.8, 114.9 126.8, 133.1, 126.4, 137.2, 159.6.

1,1-Dimethoxy-3-methyl-4-((4-chlorophenyl)thio)but-2-ene (4f). Using method B with **3** (2.8 g, 17 mmol) and 4-chlorothiophenol (2.6 g, 18 mmol), **4f** was recovered (4.1 g, 85%) after 8 h: IR (neat) 1672 cm^{-1}; mass spectrum (EI) *m*/*z* 272−274 ($M^{+\bullet}$, 17−6), 240−242 ($M^{+\bullet} - CH_3OH$, 42−20), 226−228 (27−10), 128 (67), 75 (100); ^1H NMR 200 MHz (C_6D_6) δ (ppm) *E* isomer, 1.65 (3H, d, ^4J = 1.2 Hz), 3.01 (6H, s), 3.07 (2H, s), 4.89 (1H, d, J = 5.8 Hz), 5.33 (1H, dq, ^3J = 5.8 Hz, ^4J = 1.2 Hz), 6.93 (4H, m); *Z* isomer, 1.66 (3H, d, ^4J = 1.3 Hz), 3.05 (6H, s), 3.34 (2H, s), 4.73 (1H, d, J = 5.9 Hz), 5.40 (1H, dq, ^3J = 5.9 Hz, ^4J = 1.3 Hz), 6.93 (4H, m).

1,1-Dimethoxy-3-methyl-4-(2-pyridinethio)but-2-ene (4g). Using method A with **3** (2.8 g, 17 mmol) and 2-pyridinethiol (2.0 g, 18 mmol), **4g** was recovered (3.9 g, 96%) after 15 days: IR (neat) 1670 cm^{-1}; mass spectrum (EI) *m*/*z* 239 ($M^{+\bullet}$, 6), 208 (100), 164 (41), 111 (21); ^1H NMR 200 MHz (C_6D_6) δ (ppm) *E* isomer, 1.77 (3H, d, ^4J = 1.2 Hz), 3.10 (6H, s), 3.89 (2H, s), 5.01 (1H, d, J = 5.8 Hz), 5.80 (1H, dq, ^3J = 5.8 Hz, ^4J = 1.2 Hz), 6.34−6.38 (1H, m), 6.70−6.87 (2H, m), 8.14−8.25 (1H, m); *Z* isomer, 1.75 (3H, d, ^4J = 1.2 Hz), 3.20 (6H, s), 4.17 (2H, d, ^4J = 0.5 Hz), 5.35 (1H, d, J = 6.0 Hz), 5.53 (1H, dq, ^3J = 6.0 Hz, ^4J = 1.2 Hz), 6.34−6.38 (1H, m), 6.70−6.87 (2H, m), 8.14−8.25 (1H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) *E* isomer, 16.2, 38.1, 51.5, 100.2, 119.4, 122.4, 126.2, 135.7, 137.4, 149.6, 158.9; *Z* isomer, 22.5, 31.4, 51.9, 101.4,120.8, 122.2, 127.1, 137.0, 137.4, 149.4, 159.2.

1,1-Dimethoxy-3-methyl-4-((2,6-dimethylphenyl)thio)-but-2-enes (4h). Using method B with **3** (1.4 g, 8.5 mmol) and 2,6-dimethylthiophenol (1.2 g, 8.9 mmol), **4h** was recovered (1.9 g, 84%) after 8 days: IR (neat) 1672 cm^{-1}; mass spectrum (EI) *m*/*z* 266 ($M^{+\bullet}$, 25), 234 ($M^{+\bullet} - CH_3OH$, 39), 128 (100); ^1H NMR 200 MHz (C_6D_6) δ (ppm) *E* isomer, 1.75 (3H, d, ^4J = 1.2 Hz), 2.45 (6H, s), 2.99 (2H, s), 3.02 (6H, s), 4.91 (1H, d, J = 5.9 Hz), 5.16 (1H, dq, ^3J = 5.9 Hz, ^4J = 1.2 Hz), 6.90 (3H, m); *Z* isomer, 1.73 (3H, d, ^4J = 1.4 Hz), 2.52 (6H, s), 3.03 (6H, s), 3.23 (2H, s), 4.50 (1H, d, J = 5.5 Hz), 5.33 (1H, dq, ^3J = 5.5 Hz, ^4J = 1.4 Hz), 6.90 (3H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) *E* isomer, 16.2, 22.1, 44.3, 51.4, 100.0, 125.9, 128.4, 133.6, 137.2, 143.4; *Z* isomer, 22.1, 22.7, 37.0, 51.6, 99.9, 126.6, 128.5, 134.1, 137.7, 143.8.

1,1-Dimethoxy-2-(phenylthio)ethane (20). Using method A with 1,1-dimethoxy-2-chloroethane (2.5 g, 20 mmol) and thiophenol (6.1 mL, 60 mmol), **20** was recovered (1.6 g, 40% conversion) after 5 days: IR (neat) 1578 cm^{-1}; ^1H NMR 200 MHz (C_6D_6) δ (ppm) 3.01 (2H, d, J = 5.7 Hz), 3.05 (6H, s), 4.46 (1H, t, J = 5.7 Hz), 6.85−7.40 (5H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 36.5, 53.0, 103.4, 126.1, 129.1, 129.3, 137.3.

(52) GAUSSIAN 92, Revision B: Frisch, M. B.; Trucks, G. W.; Head-Gordon, M.; Gill, P. M. W.; Wong, M. W.; Foresman, J. B.; Johnson, B. G.; Schlegel, H. B.; Robb, M.A.; Replogle, E. S.; Gonperts, R.; Andres, J. L.; Raghavachari, K.; Binkley, J. S.; Gonzalez, C.; Martin, R. L.; Fox, D. J.; Defrees, D. J.; Baker, J.; Stewart, J.J. P.; Pople, J. A., Gaussian, Inc., Pittsburgh, PA, 1992.

(53) The authors have deposited atomic coordinates for structures **25** and **28** the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK.

2-((Phenylthio)methyl)-1,3-dioxolane (22). Using method A with 2-(chloromethyl)-1,3-dioxolane (3.8 g, 31 mmol) and thiophenol (6.1 mL, 60 mmol), **22** was recovered (2.6 g, 43% conversion) after 7 days: IR (neat) 1582 cm^{-1}; mass spectrum (EI) *m/z* 196 ($M^{+\bullet}$, 32), 135 (21), 123 (11), 73 (100); ^1H NMR 200 MHz (C_6D_6) δ (ppm) 3.01 (2H, d, J = 4.1 Hz), 3.25−3.55 (4H, m), 5.01 (1H, t, J = 4.1 Hz), 6.85−7.40 (5H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 38.0, 65.2, 103.3, 126.0, 129.1, 129.3, 137.5.

2-(2′-Methyl-3′-(phenylthio)prop-2′-enyl)-1,3-dioxolane (12a). To a solution of **4b** (0.3 g, 1.3 mmol) and glycol (0.1 mL, 1.8 mmol) in ether (4 mL) were added a little *p*-TSA and methyl orthoformate (0.04 mL, 0.4 mmol). After 4 h at room temperature, saturated $NaHCO_3$ (10 mL) was added. The organic layer was separated, dried ($MgSO_4$), and evaporated. The crude product was purified by chromatography on silica gel using 3/7 ether/petroleum ether as eluent to give **12a** (200 mg, 68%) as a 75:25 mixture of *E* and *Z* isomers, respectively: IR (neat) 1675 cm^{-1}; mass spectrum (EI) *m/z* 236 ($M^{+\bullet}$, 6), 175 (23), 126 (29), 73 (100); exact mass calcd for $C_{13}H_{16}O_2S$ *m/z* 236.0871, found 236.0858; ^1H NMR 200 MHz (C_6D_6) δ (ppm) *E* isomer, 1.71 (3H, s), 3.17 (2H, s), 3.28−3.35 (2H, m), 3.46−3.53 (2H, m), 5.38 (1H, d, J = 6.6 Hz), 5.51 (1H, d, J = 6.6 Hz), 6.86−7.34 (5H, m); *Z* isomer, 1.68 (3H, s), 3.47 (2H, s), 3.28−3.35 (2H, m), 3.46−3.53 (2H, m), 5.30 (1H, d, J = 6.7 Hz), 5.51 (1H, d, J = 6.6 Hz), 6.86−7.34 (5H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) *E* isomer, 15.8, 43.3, 64.7, 100.3, 126.4, 129.0, 130.5, 136.7, 138.5; *Z* isomer, 22.7, 36.3, 64.7, 100.0, 126.4, 129.0, 130.5, 136.7, 138.5.

2-(2′-Methyl-3′-(phenylthio)prop-2′-enyl)-4-phenyl-1,3-dioxolane (12b). To a solution of **4b** (0.5 g, 2.1 mmol) and phenylglycol (0.29 g, 2.1 mmol) in ether (5 mL) were added a little TsOH and methyl orthobenzoate (0.02 mL, 0.1 mmol). After 4 h at room temperature, saturated $NaHCO_3$ (10 mL) was added. The organic layer was separated, dried ($MgSO_4$), and evaporated. The crude product was purified by chromatography on silica gel using 15/84/1 ether/petroleum ether/triethylamine as eluent to give **12b** (430mg, 66%) as a complex mixture of isomers: IR (neat) 1680 cm^{-1}; mass spectrum (EI) *m/z* 312 ($M^{+\bullet}$, 12), 202 (55), 55 (100); exact mass calcd for $C_{19}H_{20}O_2S$ *m/z* 312.1184, found 312.1207; ^1H NMR 200 MHz (C_6D_6) δ (ppm) 1.70−1.80 (3H, m), 3.03−3.22 (2H, m), 3.33−4.07 (2H, m), 4.60−4.96 (1H, m), 5.40−5.85 (2H, m), 6.85−7.35 (10H, m).

General Enol (21, 23) and Dienol (5, 13) Ethers Preparation. To a solution of the corresponding thioether (**4**, **20**, **22**) in ether (0.1 M) was added dropwise, at −70 °C, exactly 1 equiv of *t*-BuLi in pentane. The mixture was stirred for 5 min at −70 °C and then warmed up to 20 °C for 30 min. The reaction was then quenched by addition of absolute methanol (1 mL) followed by concentrated $NaHCO_3$ (10 mL). The medium is extracted two times with 10 mL of ether and then dried (K_2CO_3) and evaporated to yield the enol (**21**, **23**) or dienol (**5**, **13**) ethers in 89−98% yield. Data for compounds **5a,b** have already been reported.[11a,c]

(1*E*, 3*E*)- and (1*Z*, 3*E*)-4-Methoxy-2-methyl-1-(2-naphthylthio)buta-1,3-diene (5c). Following the above procedure, this compound was obtained as a 65:35 mixture of *E,E* and *Z,E* isomers (91%): mass spectrum (CI, CH_4) *m/z* 257 (M + H^+, 100), 285 (M + $C_2H_5^+$, 6); ^1H NMR 200 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 1.90 (3H, d, ^4J = 0.9 Hz), 3.14 (3H, s), 5.62 (1H, d, J = 13.2 Hz), 6.10 (1H, s), 6.50 (1H, d, J = 13.2 Hz), 7.10−7.80 (7H, m); 1*Z*,3*E* isomer, 1.69 (3H, d, ^4J = 1.1 Hz), 3.15 (3H, s), 5.80 (1H, s), 6.48 (1H, d, J = 13.6 Hz), 6.71 (1H, d, J = 13.6 Hz), 7.10−7.80 (7H, m).

(1*E*, 3*E*)- and (1*Z*, 3*E*)-4-Methoxy-2-methyl-1-((2-methylphenyl)thio)buta-1,3-diene (5d). Following the above procedure, this compound was obtained as a 57:43 mixture of *E,E* and *Z,E* isomers (97%): IR (neat) 1630 cm^{-1}; mass spectrum (EI) *m/z* 220 ($M^{+\bullet}$, 100), 205 (8), 189 (42), 161 (9); ^1H NMR 200 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 1.86 (3H, d, ^4J = 1.0 Hz), 2.32 (3H, s), 3.12 (3H, s), 5.57 (1H, d, J = 12.7 Hz), 5.91 (1H, s), 6.48 (1H, d, J = 12.7 Hz), 6.90−7.40 (4H, m); 1*Z*,3*E* isomer, 1.67 (3H, d, ^4J = 1.2 Hz), 2.33 (3H, s), 3.13 (3H, s), 5.71 (1H, s), 6.42 (1H, d, J = 12.9 Hz), 6.68 (1H, d, J = 12.9 Hz), 6.90−7.40 (4H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 20.3 (2C), 56.0, 108.9, 117.4, 125.9, 126.8, 128.1, 130.4, 128.0, 136.9, 137.8, 151.3; *1Z,3E* isomer, 14.5, 20.3, 55.6, 103.6, 114.9, 126.1, 126.8, 128.3, 130.4, 128.0, 136.8, 137.7, 148.8.

(1*E*, 3*E*)- and (1*Z*, 3*E*)-4-Methoxy-2-methyl-1-((4-methoxyphenyl)thio)buta-1,3-diene (5e). Following the above procedure, this compound was obtained as a 65:35 mixture of *E,E* and *Z,E* isomers (89%): IR (neat) 1630 cm^{-1}; mass spectrum (IE) *m/z* 236 ($M^{+\bullet}$, 57), 205 (29), 139 (100), 113 (28), 84 (62); ^1H NMR 200 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 1.87 (3H, s), 3.17 (3H, s), 3.25 (3H, s), 5.58 (1H, d, 12.8 Hz), 6.00 (1H, s), 6.48 (1H, d, J = 12.8 Hz), 6.65 (2H, d, J = 8.8 Hz), 7.29 (2H, d, J = 8.8 Hz); 1*Z*,3*E* isomer, 1.67 (3H, s), 3.12 (3H, s), 3.25 (3H, s), 5.80 (1H, s), 6.40 (1H, d, 12.9 Hz), 6.58 (1H, d, J = 12.9 Hz), 6.63 (2H, d, J = 8.8 Hz), 7.33 (2H, d, J = 8.8 Hz).

(1*E*, 3*E*)- and (1*Z*, 3*E*)-4-Methoxy-2-methyl-1-((4-chlorophenyl)thio)buta-1,3-diene (5f). Following the above procedure, this compound was obtained as a 55:45 mixture of *E,E* and *Z,E* isomers (98%): IR (neat) 1692 cm^{-1}; mass spectrum (EI) 242−240 ($M^{+\bullet}$, 13−31), 209 (24), 144 (26), 113 (100); ^1H NMR 200 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 1.79 (3H, d, ^4J = 0.8 Hz), 3.12 (3H, s), 5.55 (1H, d, J = 12.7 Hz), 5.81 (1H, s), 6.47 (1H, d, J = 12.7 Hz), 6.90−7.00 (4H, m); 1*Z*,3*E* isomer, 1.64 (3H, d, ^4J = 1.2 Hz), 3.12 (3H, s), 5.61 (1H, s), 6.31 (1H, d, J = 12.9 Hz), 6.65 (1H, d, J = 12.9 Hz), 6.90−7.00 (4H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 20.2, 56.1, 100.0, 114.0, 129.2, 129.3, 131.6, 136.3, 138.5, 151.7; 1*Z*,3*E* isomer, 14.5, 55.7, 103.4, 116.5, 129.2, 129.3, 131.6, 136.3, 138.5, 149.3.

(1*E*, 3*E*)- and (1*Z*, 3*E*)-4-Methoxy-2-methyl-1-(2-pyridinylthio)buta-1,3-diene (5g). Following the above procedure, this compound was obtained as a 63:37 mixture of *E,E* and *Z,E* isomers (93%): IR (neat) 1628 cm^{-1}; mass spectrum (EI) *m/z* 207 ($M^{+\bullet}$, 100), 192 (93), 174 (41), 111 (60); ^1H NMR 200 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 1.72 (3H, d, ^4J = 1.7 Hz), 3.12 (3H, s), 6.25 (1H, d, J = 12.7 Hz), 6.41 (1H, m), 6.59 (1H, s), 6.67 (1H, d, J = 12.7 Hz), 6.80−6.90 (2H, m), 8.27 (1H, m); 1*Z*,3*E* isomer, 1.81 (3H, d, ^4J = 0.8 Hz), 3.10 (3H, s), 5.69 (1H, d, J = 12.8 Hz), 6.41 (1H, m), 6.49 (1H, d, J = 12.8 Hz), 6.80−6.90 (2H, m), 6.96 (1H, s), 8.27 (1H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 20.4, 55.7, 104.0, 112.5, 119.5, 121.5, 134.9, 135.3, 136.0, 151.0; 1*Z*,3*E* isomer, 15.1, 55.8, 109.0, 114.7, 119.6, 121.8, 134.9, 135.3, 136.0, 149.8.

(1*E*, 3*E*)- and (1*Z*, 3*E*)-4-Methoxy-2-methyl-1-((2,6-dimethylphenyl)thio)buta-1,3-diene (5h) and (*E*)-3-[((2,6-Dimethylphenyl)thio)methyl]-1-methoxybuta-1,3-diene (11). Following the above procedure, this compound was obtained as a 28:10:62 mixture of 1*E*,3*E*, 1*Z*,3*E* (**5h**), and *exo* isomers (**11**) in an overall 95% yield: IR (neat) 1668, 1640 cm^{-1}; mass spectrum (EI) *m/z* 234 ($M^{+\bullet}$, 100), 219 (13), 203 (25), 187 (46); ^1H NMR 200 MHz (C_6D_6) δ (ppm) **5h** 1*E*,3*E* isomer, 1.85 (3H, d, ^4J = 1.0 Hz), 2.45 (6H, s), 3.11 (3H, s), 5.40 (1H, d, J = 12.6 Hz), 5.45 (1H, s), 6.42 (1H, d, J = 12.6 Hz), 6.90−7.00 (3H, m); *1Z,3E* isomer, 1.56 (3H, d, ^4J = 1.1 Hz), 2.45 (6H, s), 3.11 (3H, s), 5.30 (1H, s), 6.36 (1H, d, J = 12.9 Hz), 6.63 (1H, d, J = 12.6 Hz), 6.90−7.00 (3H, m); an NOE experiment showed that irradiation at δ 1.56 resulted in enhancements at δ 5.30 and 6.63; **11**, 2.49 (6H, s), 3.11 (3H, s), 3.20 (2H, s), 4.47 (1H, d, J = 1.0 Hz), 4.66 (1H, d, J = 1.0 Hz), 5.45 (1H, d, J = 12.7 Hz), 6.77 (1H, d, J = 12.7 Hz), 6.90−7.00 (3H, m).

2-Methoxy-1-(phenylthio)ethylene (21). Following the above procedure, this compound was obtained as a 90:10 mixture of *E* and *Z* isomers (90%): ^1H NMR 400 MHz (C_6D_6) δ (ppm) *E* isomer, 2.98 (3H, s), 5.21 (1H, d, J = 12.3 Hz), 6.77 (1H, d, J = 12.3 Hz), 6.90−7.40 (5H, m); *Z* isomer, 3.03 (3H, s), 5.04 (1H, d, J = 5.1 Hz), 5.81 (1H, d, J = 5.1 Hz), 6.90−7.40 (5H, m).

(1*E*,3*E*)- and (1*Z*,3*E*)-4-(2-Hydroxyethoxy)-2-methyl-1-(phenylthio)buta-1,3-diene (13a). Following the above procedure, this compound was obtained as a 60:40 mixture of *E,E* and *Z,E* isomers (95%): IR (neat) 3430, 1635 cm^{-1}; mass spectrum (EI) *m/z* 236 ($M^{+\bullet}$, 31), 143 (45), 110 (62), 73 (100); exact mass calcd for $C_{13}H_{16}O_2S$ *m/z* 236.0871, found 236.0876; ^1H NMR 400 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 1.30 (1H, m),

1.86 (3H, d, ^4J = 1.0 Hz), 3.31 (4H, m), 5.65 (1H, d, J = 12.6 Hz), 6.01 (1H, s), 6.38 (1H, d, J = 12.6 Hz), 6.85−7.35 (5H, m); 1*Z*,3*E* isomer, 1.30 (1H, m), 1.67 (3H, d, ^4J = 1.1 Hz), 3.31 (4H, m), 5.80 (1H, s), 6.46 (1H, d, J = 12.8 Hz), 6.57 (1H, d, J = 12.8 Hz), 6.85−7.35 (5H, m).

(1*E*, 3*E*)- and (1*Z*, 3*E*)-4-(2-Hydroxy-1-(or 2-)phenylethoxy)-2-methyl-1-(phenylthio)buta-1,3-diene (13b,c). Following the above procedure, this compound was obtained as a complex mixture of isomers (89%): IR (neat) 3416, 1630 cm^{-1}; mass spectrum (EI) *m*/*z* 312 ($M^{+\bullet}$, 20), 281 (5), 250 (11), 206 (45), 193 (41), 175 (40), 107 (100); ^{1}H NMR 200 MHz (C_6D_6) δ (ppm) 1.76 and 1.88 (3H, 2s), 3.50−3.85 (2H, m), 4.60−4.85 (1H, m), 5.55−6.80 (3H, m), 6.90−7.60 (10H, m).

1-(2-Naphthylthio)-2-methyl-4-morpholinobuta-1,3-diene (8c). Following the procedure reported previously for compounds **6**, **7**, and **8a**,[11a,c] **8c** was obtained as a 56:44 mixture of *E*,*E* and *Z*,*E* isomers (80%): IR (neat) 2852, 1620, 1500, 1446 cm^{-1}; mass spectrum (EI) *m*/*z* 311 ($M^{+\bullet}$, 46), 282 (84), 225 (84), 160 (100), 115 (47), 107 (67); exact mass calcd for $C_{19}H_{21}NOS$ *m*/*z* 311.1344, found 311.1345; ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 1*E*,3*E* isomer, 2.05 (3H, s), 3.02 (4H, m), 3.73 (4H, m), 5.77 (1H, s), 5.90 (1H, d, J = 13.6 Hz), 6.35 (1H, d, J = 13.7 Hz), 7.15−7.85 (7H, m); 1*Z*,3*E* isomer, δ (ppm) 2.05 (3H, s), 3.02 (4H, m), 3.73 (4H, m), 5.48 (1H, d, J = 13.6 Hz), 6.01 (1H, s), 6.28 (1H, d, J = 13.6 Hz), 7.15−7.85 (7H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 20.3, 48.2, 65.7, 99.1, 109.2, 124.6, 125.0, 125.9, 126.3, 126.8, 127.6, 128.3, 131.6, 134.1, 137.0, 141.3, 141.5; 1*Z*,3*E* isomer, 20.3, 48.4, 65.7, 104.4, 111.8, 124.6, 125.0, 125.4, 126.3, 126.6, 127.3, 128.3, 131.6, 134.1, 137.0, 139.6, 141.3.

1-((4-Chlorophenyl)thio)-2-methyl-4-morpholinobuta-1,3-diene (8d). Following the above procedure, this compound was obtained as a 50:50 mixture of *E*,*E* and *Z*,*E* isomers (80%): IR (neat) 2852, 1622, 812 cm^{-1}; mass spectrum (EI) *m*/*z* 297 ($M^{+\bullet}$, 45), 295 ($M^{+\bullet}$, 46), 211 (24), 209 (59), 152 (27), 75 (100); exact mass calcd for $C_{15}H_{18}ClNOS$ *m*/*z* 297.0786 and 295.0792, found 297.0768 and 295.0797; ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 1*E*,3*E* isomer, 1.95 (3H, s), 2.95 (4H, m), 3.70 (4H, m), 5.55 (1H, s), 5.75 (1H, d, J = 14.0 Hz), 6.80 (1H, d, J = 14.0 Hz), 7.10−7.35 (4H, m); (1*Z*,3*E*) isomer, δ (ppm) 1.92 (3H, s), 2.95 (4H, m), 3.70 (4H, m), 5.30 (1H, d, J = 14.0 Hz), 5.77 (1H, s), 6.20 (1H, d, J = 14.0 Hz), 7.10−7.35 (4H, m).

(1*E*,3*E*)- and (1*Z*,3*E*)-2-Methyl-1-(phenylthio)-4-piperidinobuta-1,3-diene (9). The experimental procedure was similar to that previously described for **8b** (ref 11a) but starting this time from **4b**; it yielded crude **9** in 82% [(1*E*,3*E*)/(1*Z*,3*E*) = 55:45]: IR (neat) 1615 cm^{-1}; mass spectrum (CI, CH_4) *m*/*z* 260 (M + H^+, 100); ^{1}H NMR 400 MHz ($CDCl_3$) δ (ppm) 1*E*,3*E* isomer, 1.57 (6H, m), 1.99 (3H, s), 3.00 (4H, m), 5.55 (1H, s), 5.76 (1H, d, J = 13.9 Hz), 6.37 (1H, d, J = 13.9 Hz), 7.1−7.3 (5H, m); 1*Z*,3*E* isomer, 1.57 (6H, m), 1.99 (3H, s), 3.00 (4H, m), 5.36 (1H, d, J = 13.9 Hz), 5.81 (1H, s), 6.29 (1H, d, J = 13.9 Hz), 7.1−7.3 (5H, m); ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 1*E*,3*E* isomer, 20.6, 25.3, 49.5, 97.2, 107.3, 124.9, 127.0, 128.6, 138.6, 141.8, 142.1; 1*Z*,3*E* isomer, 14.5, 24.2, 49.5, 102.6, 109.8, 126.9, 127.0, 128.5, 138.1, 140.4, 143.1.

(1*E*,3*E*)- and (1*Z*,3*E*)-4-(Diethylamino)-2-methyl-1-(phenylthio)buta-1,3-diene (10). Following the above procedure, this compound was obtained in 78% [(1*E*,3*E*)/(1*Z*,3*E*) = 50:50] yield: IR (neat) 1620 cm^{-1}; mass spectrum (CI, CH_4) *m*/*z* 248 (M + H^+, 100); ^{1}H NMR 400 MHz ($CDCl_3$) δ (ppm) 1*E*,3*E* isomer, 1.12 (6H, m), 2.01 (3H, s), 3.12 (4H, q, J = 7.2 Hz), 5.47 (1H, s), 5.61 (1H, d, J = 13.8 Hz), 6.46 (1H, d, J = 13.8 Hz), 7.1−7.3 (5H, m); 1*Z*,3*E* isomer, 1.12 (6H, m), 2.01 (3H, s), 3.12 (4H, q, J = 7.2 Hz), 5.23 (1H, d, J = 13.9 Hz), 5.73 (1H, s), 6.40 (1H, d, J = 13.9 Hz), 7.1−7.3 (5H, m); ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 1*E*,3*E* isomer, 13.0, 20.5, 45.2, 94.9, 104.5, 124.5, 126.7, 128.5, 138.9, 139.8, 142.7; 1*Z*,3*E* isomer, 13.0, 14.4, 45.2, 99.6, 106.6, 124.5, 126.4, 128.9, 138.1, 139.4, 144.7. Anal Calcd for $C_{15}H_{21}NS$: C, 72.82; H, 8.55; N, 5.66. Found: C, 72.59; H, 8.58; N, 5.45.

2-Morpholino-1-(phenylthio)ethylene (24). Following the above procedure, this compound was obtained in 82% in its pure *E* form: yellow solid, mp = 67−68 °C; IR (neat) 2852, 1950, 1598 cm^{-1}; mass spectrum (EI) *m*/*z* 221 ($M^{+\bullet}$, 100), 188 (29), 162 (29), 130 (76), 86 (27); exact mass calcd for $C_{12}H_{15}NOS$ *m*/*z* 221.0875, found 221.0860; ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 3.05 (4H, m), 3.72 (4H, m), 4.90 (1H, d, J = 13.0Hz), 6.51 (1H, d, J = 13.0 Hz), 7.25 (5H, s); ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 48.1, 65.8, 83.8, 124.3, 125.1, 128.3, 140.6, 150.3.

(3-Methyl-4-(phenylsulfinyl)buta-1,3-dienyl)-2-oxoethyl Acrylate (17). The experimental procedure is identical to that described above for **13a** except that the reaction was quenched with neat acryloyl chloride (1 equiv) for 15 min at −60 °C; the medium was then warmed up to room temperature. Usual workup yields crude **14** [(1*E*,3*E*)/(1*Z*,3*E*) = 60:40] which was not purified at this stage but used as such or directly oxidized into the more stable corresponding sulfoxide **17**, according to the following procedure.

To a CH_2Cl_2 solution of **14** (0.2 M) was added at 0 °C under argon neat MCPBA (1.05 equiv). After 5 min the reaction was quenched with sodium thiosulfate (3 equiv) and $NaHCO_3$ (4 equiv). The solution was filtered and then evaporated, and the crude oil obtained was directly chromatographed on silica gel using ether/petroleum ether/triethylamine (15/84/1) as eluent to yield **17** (60% overall): mass spectrum (CI, iBuH) *m*/*z* 307 (M + H^+, 80), 363 (M + $C_4H_9^+$, 7); ^{1}H NMR 360 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 1.40 (3H, s), 3.42 (2H, m), 4.05 (2H, m), 5.25 (2H, m), 5.60−6.60 (4H, m), 7.05 (3H, m), 7.65 (2H, m); 1*Z*,3*E* isomer, 1.82 (3H, s), 3.42 (2H, m), 4.05 (2H, m), 5.25 (2H, m), 5.60−6.60 (4H, m), 7.05 (3H, m), 7.65 (2H, m).

2-((3-Methyl-4-(phenylsulfinyl)buta-1,3-dienyl)oxy)-ethyl Crotonate (18). A similar procedure using crotonoyl chloride led to **15** [(1*E*,3*E*)/(1*Z*,3*E*) = 60:40]. As above, this compound may be used as such or directly oxidized into its more stable sulfoxide **18** (44% overall): IR (neat) 1716, 1632, 1626 cm^{-1}; mass spectrum (CI, NH_3) *m*/*z* 321 (M + H^+, 100), 338 (M + NH_4^+, 26); ^{1}H NMR 360 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 1.33 (3H, m), 1.84 (3H, s), 3.34 (2H, t, J = 5.3 Hz), 4.10 (2H, t, J = 5.3 Hz), 5.17 (1H, d, J = 13.3 Hz), 5.80 (1H, m), 6.00 (1H, s), 6.39 (1H, d, J = 13.3 Hz), 7.00 (1H, m), 7.12 (3H, m), 7.73 (2H, m); 1*Z*,3*E* isomer, 1.32 (3H, m), 1.39 (3H, s), 3.34 (2H, t, J = 5.3 Hz), 4.10 (2H, t, J = 5.3 Hz), 5.80 (1H, m), 5.82 (1H, s), 6.48 (1H, d, J = 13.3 Hz), 6.59 (1H, d, J = 13.3 Hz), 7.00 (1H, m), 7.12 (3H, m), 7.73 (2H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 14.2, 17.5, 62.1, 68.0, 108.4, 122.4, 124.3, 129.1, 129.9, 133.0, 143.6, 145.3, 147.4, 152.0, 165.7; 1*Z*,3*E* isomer, 17.5, 19.8, 62.1, 68.0, 103.3, 122.4, 124.3, 129.1, 129.9, 131.7, 142.9, 145.3, 147.4, 152.7, 165.7.

Ethyl 2-((3-Methyl-4-(phenylthio)buta-1,3-dienyl)oxy)-ethyl Fumarate (16). A similar procedure using crotonoyl chloride leads to **16** [(1*E*,3*E*)/(1*Z*,3*E*) = 60:40] in 70% yield. This compound has been used as such without any further purification: mass spectrum (CI, iBuH) *m*/*z* 363 (M + H^+, 100), 380 (M + NH_4^+, 15), 419 (M + $C_4H_9^+$, 35); ^{1}H NMR 200 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 0.87 (3H, t, J = 7.1 Hz), 1.83 (3H, d, ^4J = 0.8 Hz), 3.39 (2H, t, J = 4.8 Hz), 3.93 (4H, m), 5.62 (1H, d, J = 12.7 Hz), 6.00 (1H, s), 6.35 (1H, d, J = 12.7 Hz), 6.85−7.07 (4H, m), 7.28 (2H, m); 1*Z*,3*E* isomer, 0.87 (3H, t, J = 7.1 Hz), 1.67 (3H, d, ^4J = 1.1 Hz), 3.39 (2H, t, J = 4.8 Hz), 3.93 (4H, m), 5.79 (1H, s), 6.37 (1H, d, J = 12.9 Hz), 6.56 (1H, d, J = 12.9 Hz), 6.85−7.07 (4H, m), 7.28 (2H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 13.9, 20.2, 61.0, 63.4, 67.5, 105.0, 115.8, 125.9, 128.2, 129.2, 132.9, 133.7, 137.2, 147.4, 164.4; 1*Z*,3*E* isomer, 13.9, 14.5, 61.0, 63.2, 66.9, 110.5, 118.5, 125.9, 128.2, 129.2, 132.9, 133.7, 137.2, 149.9, 164.4.

6-(1,1-Dimethylethyl)-4-methyl-3-(phenylthio)cyclohex-4-ene-1,2-dicarboxylic Anhydride (25). To a solution of **7b** (0.9 g, 3.9 mmol) in mixed xylenes (15 mL) were added maleic anhydride (0.7 g, 7.6 mmol) and a little hydroquinone. The mixture was stirred for 2 days at 140 °C. The solvent was then evaporated and the crude material crystallized from ethyl acetate/petroleum ether to yield **25** (680 mg, 62%). The 1*Z*,3*E* unreacted isomer of **7b** was recovered (180 mg) by flash chromatography using ethyl acetate/petroleum ether (15/85) as eluent: mp 156−158 °C; IR (neat) 1774 cm^{-1}; mass spectrum (EI) *m*/*z* 330 ($M^{+\bullet}$, 15), 279 (3), 241 (8), 110 (67), 57 (100); exact mass calcd for $C_{19}H_{22}O_3S$ *m*/*z* 330.1290, found 330.1297; ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 0.96 (9H, s), 1.48

(1H, m), 1.88 (3H, m), 2.62 (1H, dd, J = 9.2 Hz, J = 7.3 Hz), 2.90 (1H, dd, J = 9.2 Hz, J = 4.2 Hz), 3.34 (1H, m), 5.54 (1H, m), 6.45−7.00 (3H, m), 7.20−7.23 (2H, m); NOE experiments showed that irradiation at δ 3.34 ppm resulted in enhancements at 1.48, 2.62, and 2.90 ppm; ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 21.5, 28.2, 31.9, 43.5, 47.2, 47.3, 49.6, 124.6, 126.6, 129.4, 138.0, 140.4, 170.7, 171.7. Anal Calcd for $C_{19}H_{22}O_3S$: C, 69.09; H, 6.67. Found: C, 69.19; H, 6.83.

Ethyl 5-(1,1-Dimethylethyl)-3-methyl-2-(phenylthio)-cyclohex-3-enoate (26) and Ethyl 6-(1,1-Dimethylethyl)-4-methyl-3-(phenylthio)cyclohex-4-enoate (27). A solution of **7b** (0.9 g, 3.9 mmol) in neat ethyl acrylate (10 mL) with a little hydroquinone was stirred for 8 days at 100 °C. After evaporation of the dienophile, the crude material was purified by flash chromatography using ethyl acetate/petroleum ether (2.5/97.5) as eluent to give unreacted **7b** (300 mg, (1*E*,3*E*)/(1*Z*,3*E*) = 30/70) and a mixture of **26** and **27** (520 mg, 60%): IR (neat mixture) 1732, 1582 cm^{-1}; mass spectrum (EI) m/z 332 ($M^{+\bullet}$, 32), 223 (59), 57 (100). NMR data follows.

Major isomer of **26**: ^{1}H NMR 360 MHz ($CDCl_3$) δ (ppm) 0.86 (9H, s), 1.23 (3H, t, J = 7.2 Hz), 2.24 (1H, ddd, J = 14.4 Hz, J = 5.8 Hz, J = 3.6 Hz), 2.33 (1H, m), 2.35 (1H, m), 2.72 (1H, m), 3.59 (1H, t, J = 5.8 Hz), 4.07 (2H, m), 5.68 (1H, m), 7.18−7.41 (5H, m); ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 13.6, 22.5, 28.9, 31.7, 34.3, 41.1, 46.9, 49.0, 60.1, 126.5, 126.6, 129.0, 130.1, 135.6, 174.5.

Minor isomer of **26**: ^{1}H NMR 360 MHz ($CDCl_3$) δ (ppm) 0.86 (9H, s), 1.23 (3H, t, J = 7.2 Hz), 2.00 (2H, m), 2.50 (1H, d, J = 10.8 Hz), 2.98 (1H, dt, J = 10.8 Hz, J = 2.9 Hz), 3.54 (1H, s), 4.07 (2H, m), 5.55 (1H, s), 7.18−7.41 (5H, m); ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 13.8, 22.1, 27.3, 32.5, 33.2, 36.8, 46.3, 48.3, 60.1, 126.5, 127.2, 129.0, 130.1, 136.0, 177.2.

Major isomer of **27**: ^{1}H NMR 360 MHz ($CDCl_3$) δ (ppm) 0.86 (9H, s), 0.89 (3H, m), 1.90 (6H, m), 2.83 (1H, ddd, J = 10.8 Hz, J = 6.7 Hz, J = 2.7 Hz), 3.42 (1H, dq, J = 14.4 Hz, J = 10.8 Hz) 3.88 (1H, s),3.90 (1H, m), 5.52 (1H, s), 7.18−7.41 (5H, m); ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 13.4, 20.7, 21.8, 26.9, 32.5, 45.2, 45.7, 52.3, 59.7, 126.5, 126.8, 129.0, 130.1, 133.5, 136.6, 172.3.

Minor isomer of **27**: ^{1}H NMR 360 MHz ($CDCl_3$) δ (ppm) 0.87 (9H, s), 1.20 (3H, t, J = 7.1 Hz), 1.91 (3H, s), 1.95 (1H, m), 1.98 (2H, m), 2.91 (1H, s), 4.02 (1H, s), 4.10 (2H, dq, J = 7.1 Hz, J_{app} = 3.0 Hz), 5.55 (1H, s), 7.18−7.41 (5H, m); ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 14.1, 20.8, 22.9, 27.1, 32.6, 42.5, 44.2, 48.6, 60.4, 126.4, 127.6, 129.0, 130.1, 131.8, 136.5, 173.4.

***N*-Methyl- and *N*-Phenyl-6-methoxy-4-methyl-3-(phenylthio)cyclohex-4-ene-1,2-dicarboxamides (28, 29).** To a solution of **5b** (0.4 g, 2.0 mmol) in ether (10 mL) were added *N*-phenylmaleimide (1.0 g, 6.0 mmol) and a little hydroquinone. The mixture was stirred for 3 days at 40 °C. The solvent was then evaporated, and the crude material was purified by flash column chromatography on silica gel using ethyl acetate/petroleum ether (80:20) as eluent to give **28b** (315 mg, 70%) and a mixture of **39b** and **29b**.

The same procedure using *N*-methylmaleimide leads to **28a** (37%) and to a mixture of **29a** and **39a**.

Spectral data for **28b**: colorless solid, mp = 169−170 °C; IR (neat) 1778, 1708, 1656 cm^{-1}; mass spectrum (EI) m/z 379 ($M^{+\bullet}$, 56), 269 (23), 173 (64), 144 (48), 123 (99), 108 (100); ^{1}H NMR 200 MHz (C_6D_6) δ (ppm) 1.63 (3H, s), 2.56 (1H, dd, J = 10.4 Hz, J = 5.0 Hz), 2.88 (1H, dd, J = 10.4 Hz, J = 8.0 Hz), 3.04 (3H, s), 3.65 (1H, d, J = 8.0 Hz), 4.02 (1H, dd, J = 5.0 Hz, J = 4.7 Hz), 5.33 (1H, d, J = 4.7 Hz), 6.94−7.15 (6H, m), 7.61 (2H, d, J = 7.7 Hz), 7.85 (2H, d, J = 7.2 Hz); a NOE experiment showed that irradiation at δ 4.02 ppm resulted in enhancements at 2.56 and 3.04 ppm and that irradiation at δ 2.88 ppm resulted in enhancements at 3.65 and 2.56 ppm; ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 21.7, 43.4, 45.7, 50.1, 55.6, 69.7, 122.7, 127.1, 127.4, 128.1, 129.0, 129.1, 132.5, 133.2, 140.2, 144.5, 174.3, 175.4. Anal Calcd for $C_{22}H_{21}NO_3S$: C, 69.63; H, 5.58; N, 3.69. Found: C, 69.64; H, 5.87; N, 3.61.

Spectral data for **29b**: ^{1}H NMR 200 MHz (C_6D_6) δ (ppm) 1.64 (3H, m), 2.96 (1H, dd, J = 8.5 Hz, J = 2.1 Hz), 3.14 (1H, dd, J = 8.5 Hz, J = 8.5 Hz), 4.36 (1H, m), 4.48 (1H, d, J = 2.1 Hz), 5.66 (1H, m), 6.88−7.45 (10H); a NOE experiment showed that irradiation at δ 3.14 ppm resulted in enhancements at 4.36 ppm, that irradiation at δ 4.36 ppm resulted in enhancements at 3.14 ppm, that irradiation at δ 2.96 ppm resulted in enhancements at 4.48 ppm, and that irradiation at δ 4.48 ppm resulted in enhancements at 2.96 ppm.

Spectral data for **28a**: colorless solid, mp = 151−152 °C; IR (neat) 1776, 1698 cm^{-1}; mass spectrum (EI) m/z 317 ($M^{+\bullet}$, 30), 123 (100); ^{1}H NMR 200 MHz (C_6D_6) δ (ppm) 1.60 (3H, d, ^4J = 1.5Hz), 2.36 (1H, dd, J = 10.4 Hz, J = 5.5 Hz), 2.70 (1H, dd, J = 10.4 Hz, J = 8.0 Hz), 2.76 (3H, s), 3.02 (3H, s), 3.58 (1H, d, J = 8.0 Hz), 3.97 (1H, dd, J = 5.5 Hz, J = 5.0 Hz), 5.28 (1H, d, J = 5.0 Hz), 6.92−7.15 (3H, m), 7.89 (2H, d, J = 7.0 Hz); a NOE experiment showed that irradiation at δ 3.97 ppm resulted in enhancements at 2.36, 3.03, and 5.28 ppm; ^{1}H NMR 200 MHz (Pyr-d_5) δ (ppm) 2.03 (3H, s), 3.12 (3H, s), 3.35 (3H, s), 3.49 (1H, dd, J = 5.0 Hz, J = 9.7 Hz), 3.97 (1H, dd, J = 8.3 Hz, J = 10.2 Hz), 4.28 (1H, d, J = 8.1 Hz), 4.56 (1H, dd, J = 5.2 Hz, J = 5.6 Hz), 5.98 (1H, d, J = 5.7 Hz), 7.45 (3H, m), 8.10 (2H, d, J = 7.1 Hz); a set of NOE experiments showed that irradiation at δ 4.56 ppm resulted in enhancements at δ 3.49 and 5.98 ppm and that irradiation at δ 4.28 ppm resulted in enhancements at δ 3.97 ppm; ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 21.7, 24.6, 43.5, 45.7, 49.8, 55.3, 69.5, 122.6, 127.3, 129.1, 132.4, 140.4, 144.3, 175.2, 176.1. Anal Calcd for $C_{17}H_{19}NO_3S$: C, 64.33; H, 6.03; N, 4.41. Found: C, 64.14; H, 6.17; N, 4.33.

Ethyl 6-Methoxy-4-methyl-3-(phenylthio)cyclohex-4-enoates (30, 31) and Ethyl 5-Methoxy-3-methyl-2-(phenylthio)cyclohex-3-enoates (32). To a solution of diene **5b** (0.4 g, 2.0 mmol) in neat ethyl acrylate (10 mL) was added a little hydroquinone. The mixture was stirred for 3 days at 100 °C; then the dienophile was evaporated and the crude material purified by flash chromatography using ethyl acetate/petroleum ether (5/95) as eluent to give a mixture of **30**, **31**, and **32a,b** (300 mg total, 72%): IR (neat mixture): 1732, 1582 cm^{-1}; mass spectrum (EI) m/z 306 ($M^{+\bullet}$, 16), 274 (22), 197 (51), 123 (100), 109 (25). Anal. Calcd for $C_{17}H_{22}O_3S$: C, 66.67; H, 7.19. Found: C, 66.54; H, 7.07.

Spectral data for **30** (64%): ^{1}H NMR 360 MHz ($CDCl_3$) δ (ppm) 0.95 (3H, t, J = 7.1 Hz), 1.86 (3H, s), 2.22 (1H, ddd, J = 13.5 Hz, J = 3.2 Hz, J = 3.2 Hz), 2.39 (1H, dddd, J = 13.5 Hz, J = 6.3 Hz, J = 3.2 Hz, ^4J = 1.0 Hz), 2.64 (1H, ddd, J = 13.5 Hz, J = 13.5 Hz, J = 11.2 Hz), 3.07 (3H, s), 3.20 (1H, m), 3.98 (3H, m), 5.59 (1H, m), 6.95 (3H, m), 7.34 (2H, m); ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 14.3, 22.5, 27.9, 45.5, 43.3, 56.2, 60.1, 72.7, 124.3, 127.0, 129.0, 132.2, 135.1, 140.6, 171.5.

Spectral data for **31** (23%): ^{1}H NMR 360 MHz ($CDCl_3$) δ (ppm) 0.89 (3H, t, J = 7.0 Hz), 1.78 (3H, t, J = 1.4 Hz), 1.95 (1H, m), 2.12 (1H, m), 3.24 (3H, s), 3.20 (1H, m), 3.41 (1H, m), 3.98 (2H, m), 4.33 (1H, d, J = 9.4 Hz), 5.54 (1H, s), 6.95 (3H, m), 7.34 (2H, m); ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 14.1, 22.0, 32.0, 41.6, 49.3, 55.7, 60.4, 77.3, 126.3, 127.2, 129.2, 131.1, 135.4, 140.6, 174.6.

Spectral data for **32a** (7%): ^{1}H NMR 360 MHz ($CDCl_3$) δ (ppm) 0.76 (3H, t, J = 7.1 Hz), 1.75 (3H, t, J = 1.6 Hz), 2.16 (1H, ddd, J = 13.1 Hz, J = 13.1 Hz, J = 10.2 Hz), 2.10 (1H, m), 2.57 (1H, ddd, J = 13.1 Hz, J = 4.1 Hz, J = 2.5 Hz), 3.09 (3H, s), 3.45 (1H, dq, J = 11.6 Hz, J = 7.1 Hz), 3.58 (1H, m), 3.83 (1H, m), 3.90 (1H, dq, J = 11.6 Hz, J = 7.1 Hz), 5.50 (1H, s), 6.93 (3H, m), 7.45 (2H, m); ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 13.9, 21.5, 26.0, 44.5, 52.8, 54.9, 60.2, 75.6, 127.0, 128.9, 129.2, 132.2, 136.0, 137.2, 171.1.

Spectral data for **32b** (6%): ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 14.3, 22.3, 26.2, 40.9, 49.8, 56.8, 60.2, 72.9 124.1, 127.2, 129.3, 131.5, 132.4, 137.0, 172.4.

(1*E*,3*E*)- and (1*Z*,3*E*)-4-[L-(−)-Menthyloxy]-2-methyl-1-(phenylthio)buta-1,3-dienes (33a). To a solution of **4b** (0.1 g, 0.4 mmol) and L-(−)-menthol (0.2 g, 1.3 mmol) in ether (5 mL) were added 2,2-dimethoxypropane (0.1 mmol) and a little *p*-TSA. The mixture was stirred for 2 h at 40°C. After the solution was cooled to room temperature, anhydrous K_2CO_3 (1.0 g) was added and the medium was washed with saturated $NaHCO_3$ (10 mL), dried ($MgSO_4$), filtered, and concentrated to give the crude product **33a**. The compound was obtained as a 50:50 mixture of the *E*,*E* and *Z*,*E* isomers. Chromatography on silica gel using ether/petroleum ether/triethylamine (10/89/1) as eluent may be performed yielding **33a** (26 mg, 20%): mass spectrum (CI, NH_3) m/z 331 ($M + H^+$, 100); exact

mass calcd for $C_{21}H_{30}OS$ *m*/*z* 330.2017, found 330.2019; ^{1}H NMR 200 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 0.60−2.40 (18H, m), 1.96 (3H, s), 2.90−3.50 (1H, m), 5.98 (1H, d, J = 12.0 Hz), 6.00 (1H, s), 6.43 (1H, d, J = 12.0 Hz), 6.88−7.35 (5H, m); 1*Z*,3*E* isomer, 0.60−2.40 (18H, m), 1.76 (3H, s), 2.90−3.50 (1H, m), 5.82 (1H, s), 6.60 (1H, d, J = 12.8 Hz), 6.81 (1H, d, J = 12.8 Hz).

(1*E*,3*E*)- and (1*Z*,3*E*)-4-[((−)-8-Phenylmenthyl)oxy]-2-methyl-1-(phenylthio)buta-1,3-dienes (33b). The same procedure as above was applied to a solution of **4b** (0.1 g, 0.4 mmol) and (−)-8-phenylmenthol (0.29 g, 1.2 mmol) to yield crude **33b**. This compound was obtained as a 50:50 mixture of *E*,*E* and *Z*,*E* isomers: mass spectrum (CI, CH_4) *m*/*z* 407 ($M + H^+$, 7), 215 (100); exact mass calcd for $C_{27}H_{34}OS$ *m*/*z* 406.2330, found 406.2337; ^{1}H NMR 200 MHz (C_6D_6) δ (ppm) 1*E*,3*E* isomer, 0.45−1.90 (15H, m), 1.94 (3H, s), 3.20−3.50 (1H, m), 5.86 (1H, d, J = 12.0 Hz), 6.01 (1H, s), 6.23 (1H, d, J = 12.0 Hz), 6.85−7.35 (10H, m); 1*Z*,3*E* isomer, 0.45−1.90 (15H, m), 1.77 (3H, s), 3.20−3.50 (1H, m), 5.82 (1H, s), 6.38 (1H, d, J = 12.5 Hz), 6.67 (1H, d, J = 12.5 Hz), 6.85−7.35 (10H, m).

4-(Menthyloxy)-2-methyl-1-(phenylthio)-5,5,6,6-tetracyanocyclohex-2-ene (34a, 35a). A crude **33a** ether solution was cooled to −78 °C. Tetracyanoethylene was then added slowly (3 equiv, 0.25 M in THF); after 5 min at −78 °C, the mixture was warmed up to 20 °C and concentrated, and the crude material was purified by flash column chromatography using methylene chloride/petroleum ether (35/65) as eluent to give **34a** and **35a** (65%): IR (neat) 2280, 1662 cm^{-1}; mass spectrum (EI) *m*/*z* 458 (M^+, 20), 330 (21), 192 (100); exact mass calcd for $C_{27}H_{30}N_4OS$ *m*/*z* 458.2140, found 458.2176. **34a** major: ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 0.75 (1H, m), 0.75−0.92 (8H, m), 0.98 (3H, d, J = 6.6 Hz), 1.20 (1H, m), 1.30−1.45 (3H, m), 1.53 (3H, s), 1.70 (1H, m), 2.73 (1H, hd, J = 6.0 Hz, J = 2.6 Hz), 3.40 (1H, td, J = 10.2 Hz, J = 4.3 Hz), 3.81 (1H, s), 4.45 (1H, m), 5.19 (1H, m), 6.92 (3H, m), 7.23 (2H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 16.0, 20.2−22.3 (3C), 22.7, 25.1, 31.1, 34.1, 41.2, 42.8, 45.0, 48.7, 56.3, 73.2, 82.8, 109.1, 110.1, 111.7, 111.8, 124.0, 129.8, 130.0, 133.5, 133.8. **34a** minor: ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 0.75−0.92 (9H, m), 0.66 (3H, d, J = 6.9 Hz), 1.00 (1H, m), 1.05 (1H, m), 1.30−1.45 (2H, m), 1.60 (3H, s), 1.70 (1H, m), 2.73 (1H, hd, J = 6.0 Hz, J = 2.6 Hz), 3.40 (1H, td, J = 10.3 Hz, J = 4.3 Hz), 3.81 (1H, s), 4.45 (1H, m), 5.22 (1H, m), 6.92 (3H, m), 7.23 (2H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 15.5, 20.2−22.3 (3C), 23.0, 25.2, 31.6, 34.0, 39.6, 42.8, 45.0, 47.8, 56.5, 71.7, 79.8, 109.1, 110.1, 111.7, 111.8, 121.7, 129.8, 130.0, 133.5, 133.8. **35a** major: ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 0.75−0.92 (9H, m), 0.68 (3H, d, J = 7.0 Hz), 1.00 (1H, m), 1.15 (1H, m), 1.30−1.45 (2H, m), 1.57 (3H, d, ^4J = 1.1 Hz), 2.00 (1H, m), 2.16 (1H, hd, J = 7.0 Hz, J = 2.3 Hz), 2.96 (1H, td, J = 10.2 Hz, J = 4.3 Hz), 4.18 (1H, s), 4.65 (1H, m), 5.22 (1H, m), 6.92 (3H, m), 7.23 (2H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 16.2, 21.0−22.2 (3C), 23.2, 25.4, 31.5, 33.4 39.6, 46.9, 47.9, 48.1, 56.2, 72.1, 79.4, 109.2, 110.1, 111.1, 111.6, 123.7, 130.1, 130.2, 131.5, 133.7, 134.0. **35a** minor: ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 0.75 (1H, m), 0.75−0.92 (8H, m), 0.95 (3H, d, J = 7.0 Hz), 1.20 (1H, m), 1.30−1.45 (3H, m), 1.50 (3H, d, ^4J = 1.0 Hz), 1.70 (1H, m), 2.53 (1H, hd, J = 7.0 Hz, J = 2.0 Hz), 3.42 (1H, td, J = 10.2 Hz, J = 4.3 Hz), 4.18 (1H, s), 4.74 (1H, m), 5.22 (1H, m), 6.92 (3H, m), 7.23 (2H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 16.3, 21.0−22.2 (3C), 22.8, 25.3, 31.0, 34.1 41.2, 46.9, 48.1 48.7, 56.0, 73.9, 83.0, 109.2, 110.1, 111.1, 111.6, 126.0 130.1, 130.2, 131.5, 133.7, 134.0.

4-((8-Phenylmenthyl)oxy)-2-methyl-1-(phenylthio)-5,5,6,6-tetracyanocyclohex-2-ene (34b, 35b). The same procedure as above was applied to a solution of crude diene **33b**, leading to a mixture of **34b** and **35b** (65%): IR (neat) 2280, 1662 cm^{-1}; mass spectrum (EI) *m*/*z* 534 ($M^{+\bullet}$, 1), 406 (4), 119 (100). **34a** major: ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 0.75 (3H, d, J = 6.0 Hz), 0.80−1.20 (5H, m), 1.05 (1H, m), 1.32 (3H, s), 1.40 (3H, s), 1.55 (3H, s), 1.58 (1H, m) 1.95 (1H, m), 3.09 (1H, dt, J = 10.0 Hz, J = 4.0 Hz), 4.17 (1H, m), 4.66 (1H, m), 4.82 (1H, m), 6.90 (3H, m), 7.20 (5H, m), 7.40 (2H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 21.4, 21.5, 27.5, 31.1−31.3 (3C), 34.1, 39.3, 40.6, 46.5, 48.0, 51.5, 56.0, 77.7, 79.3, 109.2, 109.7, 110.8, 111.2, 123.3, 125.4, 126.0, 128.0, 129.7, 129.9, 133.6, 132.5, 133.2. **34a** minor: ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 0.75 (3H, d, J = 6.0 Hz), 0.80−1.20 (5H, m), 1.05 (1H, m), 1.32 (3H, s), 1.40 (3H, s), 1.50 (3H, s), 1.58 (1H, m), 1.95 (1H, m), 3.09 (1H, dt, J = 10.0 Hz, J = 4.0 Hz), 4.17 (1H, m), 4.88 (1H, m), 5.18 (1H, m), 6.90 (3H, m), 7.20 (5H, m), 7.40 (2H, m). **35a** major: ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 0.76 (3H, d, J = 6.0 Hz), 0.90−1.20 (5H, m), 1.10 (1H, m), 1.37 (3H, s), 1.42 (3H, s), 1.58 (3H, s), 1.60 (1H, m) 1.95 (1H, m), 3.10 (1H, dt, J = 10.5 Hz, J = 4.9 Hz), 3.73 (1H, m), 4.95 (1H, m), 4.76 (1H, m), 6.90 (3H, m), 7.20 (5H, m) 7.40 (2H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 21.9, 22.0, 27.9, 30.9−31.1 (3C), 34.4, 39.8, 40.5, 40.8, 41.2, 51.8, 56.5, 71.3, 80.0, 109.1, 110.3, 111.4, 112.2, 122.1, 125.7, 126.5, 128.4, 129.7, 130.0, 132.5, 133.8, 133.9. **35a** minor: ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 0.76 (3H, d, J = 6.0 Hz), 0.90−1.20 (5H, m), 1.10 (1H, m), 1.37 (3H, s), 1.42 (3H, s), 1.53 (3H, s), 1.60 (1H, m), 1.95 (1H, m), 3.10 (1H, dt, J = 10.5 Hz, J = 4.9 Hz), 3.73 (1H, m), 4.72 (1H, m), 5.12 (1H, m), 6.90 (3H, m), 7.20 (5H, m), 7.40 (2H, m).

***N*-Phenyl-4-methyl-6-morpholino-3-(phenylthio)cyclohex-4-ene-1,2-dicarboxamide (36).** To a solution of diene **8b** (0.4 g, 1.5 mmol) in ether (10 mL) were added *N*-phenylmaleimide (0.5 g, 2.9 mmol) and a little hydroquinone. The mixture was stirred for 4 days at 40 °C. The solvent was then evaporated, and the crude material was purified by flash column chromatography using ethyl acetate/petroleum ether (3/7) as eluent to give **36** (155 mg, 23%): IR (neat) 1776, 1702 cm^{-1}; mass spectrum (CI, CH_4) *m*/*z* 435 ($M + H^+$, 60), 324 (100); ^{1}H NMR 200 MHz ($CDCl_3$) δ (ppm) 1.79 (3H, t, J = 1.5 Hz), 2.68 (4H, m), 3.39 (1H, dd, J = 8.3 Hz, J = 1.5 Hz), 3.58 (1H, dd, J = 8.3 Hz, J = 8.3 Hz), 3.65 (1H, m), 3.72 (4H, t, J = 4.6 Hz), 4.30 (1H, d, J = 1.5 Hz), 5.82 (1H, s), 7.06−7.50 (10H, m); a NOE experiment showed that irradiation at δ 4.30 ppm resulted in enhancements at δ 3.39; ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 22.4, 41.1, 45.1, 47.1, 52.2, 60.2, 66.7, 126.1, 126.2, 127.6, 128.4, 128.8, 129.2, 131.5, 133.6, 135.7, 174.4, 176.2. Anal. Calcd for $C_{25}H_{26}N_2O_3S$: C, 68.97; H, 5.99; N, 6.45. Found: C, 68.94; H, 5.77; N, 6.61.

Ethyl 4-Methyl-6-morpholino-3-(phenylthio)cyclohex-4-enoate (38). To a solution of diene **8b** (0.4 g, 1.5 mmol) in Et_2O (10 mL) were added ethyl acrylate (1 mL) and a little hydroquinone. The mixture was stirred for 10 days at 40 °C. The solvent was then evaporated and the crude material purified by flash column chromatography using ethyl acetate/petroleum ether (15/85) as eluent to give **38** (120 mg, 21%): IR (neat) 1732, 1672 cm^{-1}; mass spectrum (EI) *m*/*z* 361 (M^+, 13), 261 (100), 251 (32), 225 (33), 175 (59); exact mass calcd for $C_{20}H_{27}NO_3S$ *m*/*z* 361.1712, found 361.1705; ^{1}H NMR 360 MHz ($CDCl_3$) δ (ppm) 1.21 (3H, t, J = 7.23 Hz), 2.02 (3H, s), 2.06 (1H, m), 2.20 (1H, ddd, J = 9.3 Hz, J = 3.7 Hz, J = 3.7 Hz), 2.35 (2H, m), 2.61 (1H, ddd, J = 13.8 Hz, J = 5.8 Hz, J = 3.7 Hz), 3.31 (1H, m), 3.44 (3H, m), 4.10 (2H, m), 5.67 (1H, m), 7.24 (5H, m), 7.43 (2H, m); ^{13}C NMR 50 MHz ($CDCl_3$) δ (ppm) 14.5, 22.8, 29.6, 52.7, 59.7, 59.9, 67.7, 123.7, 127.8, 129.0, 133.8, 134.3, 138.9, 172.3.

***N*-Methyl- and *N*-Phenyl-3-methoxy-5-methyl-4-(phenylthio)cyclohex-5-ene-1,2-dicarboxamides (39).** These compounds were obtained directly, keeping a solution (see solvents in text) of **28** at room temperature and daylight in an NMR tube for 15−60 days. A quicker procedure is as follows: **28a** (10 mg, 0.03 mmol) was disolved in methylene chloride (1.6 mL) and irradiated for 48 h under a 500 W halogen lamp in an air-cooled quartz (UV type) cuvette. After evaporation of the solvent, **39a** (10 mg, 0.03 mmol) was recovered.

Spectral data for **39a**: ^{1}H NMR 300 MHz (C_6D_6) δ (ppm) 1.82 (3H, dd, J = 1.6 Hz, J = 3.2 Hz), 2.77 (3H, s), 2.80 (3H, s), 3.39 (1H, dd, J = 5.2 Hz, J = 7.8 Hz), 3.53 (1H, d, J = 3.2 Hz), 4.08 (1H, t, J = 3.2 Hz), 6.01 (1H, m), 7.04 (3H, m), 7.35 (2H, m); ^{1}H NMR 300 MHz (Pyr-d_5) δ (ppm) 1.93 (3H, d, J = 1.8 Hz), 2.95 (3H, s), 3.11 (3H, s), 3.54 (1H, m), 3.83 (1H, dd, J = 4.3 Hz, J = 9.0 Hz), 4.00 (1H, d, J = 2.7 Hz), 4.19 (1H, dd, J = 2.8 Hz, J = 4.3 Hz), 6.10 (1H, m), 7.29 (3H, m), 7.61 (2H, d, J = 8.9 Hz); ^{13}C NMR 75 MHz (Pyr-d_5) δ (ppm) 22.1, 24.5, 39.8, 40.8, 47.9, 57.8, 77.7, 119.5, 128.0, 129.7, 132.1, 134.8, 177.0, 177.4. The COSY, NOESY, and COLOC sets of experi-

ments performed on that compound show the expected correlations between nuclei.

Spectral data for **39b**: mass spectrum (EI) *m/z* 379 ($M^{+\bullet}$, 64), 347 (5), 269 (50), 186 (8), 123 (100), 91 (44); IR: 2932, 1708, 1080 cm^{-1}; ^1H NMR 200 MHz (C_6D_6) δ (ppm) 1.76 (3H, m), 2.70 (1H, m), 2.76 (3H, s), 3.45 (1H, dd, J = 9.0 Hz, J = 4.4 Hz), 3.50 (1H, d, J = 2.8 Hz), 4.06 (1H, dd, J = 4.4 Hz, J = 2.8 Hz), 5.96 (1H, m), 6.92−7.47 (10H); a set of NOE experiments showed that irradiation at δ 4.06 ppm resulted in enhancements at 3.45 and 3.50 ppm; ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 22.2, 39.5, 40.6, 49.0, 57.7, 78.2, 119.4, 126.9, 128.2, 128.3, 129.0, 129.5, 131.8, 132.6, 133.3, 135.1, 175.0, 175.7.

6-(1,1-Dimethylethyl)-4-methyl-3-(phenylsulfonyl)cyclohex-4-ene-1,2-dicarboxylic Anhydride (40). To a solution of adduct **25** (85 mg, 0.26 mmol) in CH_2Cl_2 (2 mL) at 0 °C was added a solution of 65% MCPBA (140 mg, 1.25 mmol) in the same solvent (3 mL). After 1 h, the medium was allowed to warm up to room temperature overnight and washed with sodium thiosulfate and $NaHCO_3$ saturated solutions (2 × 2 mL). The organic phase was then dried ($MgSO_4$) and evaporated, yielding sulfone **40** (72 mg, 76%): yellow solid, mp 158−160 °C; IR (neat) 2966, 1784, 1149 cm^{-1}; ^1H NMR 200 MHz ($CDCl_3$) δ (ppm) 1.05 (9H, s), 1.60 (1H, m), 2.18 (3H, s), 3.52 (1H, dd, J = 8.0 Hz, J = 8.0 Hz), 3.73 (1H, m), 3.85 (1H, dd, J = 4.0 Hz, J = 8.0 Hz), 5.80 (1H, m), 7.65 (3H, m), 8.05 (2H, m); ^{13}C NMR 50 MHz (C_6D_6) δ (ppm) 20.4, 28.0, 32.0, 43.5, 45.6, 47.9, 63.5, 127.5, 128.6, 129.4, 134.2, 139.0, 170.4, 178.6.

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Supporting Information Available: NMR spectra (72 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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