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Cationic Cyclization of 2-Alkenyl-1,3-dithiolanes: Diastereoselective Synthesis of *trans*-Decalins

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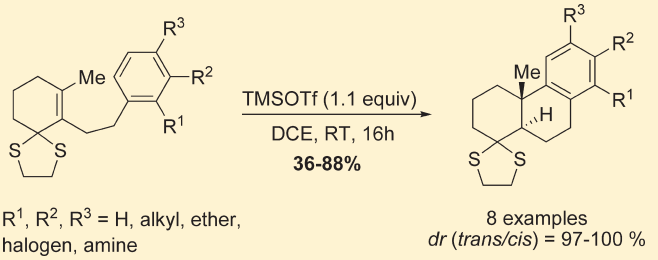
Supporting Information

ABSTRACT: An unprecedented and highly diastereoselective 6-*endo*-*trig* cyclization of 2-alkenyl-1,3-dithiolanes has been developed yielding *trans*-decalins, an important scaffold present in numerous di- and triterpenes. The novelty of this 6-*endo*-*trig* cyclization stands in the stepwise mechanism involving 2-alkenyl-1,3-dithiolane, acting as a novel latent initiator. It is suggested that the thioketal opens temporarily under the influence of TMSOTf, triggering the cationic 6-*endo*-*trig* cyclization, and closes after C−C bond formation and diastereoselective protonation to terminate the process. DFT calculations confirm this mechanistic proposal and provide a rationale for the observed diastereoselectivity. The reaction tolerates a wide range of functionalities and nucleophilic partners within the substrate. We have also shown that the one-pot 6-*endo*-*trig* cyclization followed by *in situ* 1,3-dithiolane deprotection afford directly the corresponding ketone. This improvement allowed the achievement of the shortest total synthesis of triptophenolide and the shortest formal synthesis of triptolide.



INTRODUCTION

The design of new strategies for the stereoselective synthesis of decalin carbocycles continues to be of great interest in organic synthesis due to the crucial importance of this skeleton as part of biologically relevant natural products.[1] For instance, *trans*-decalin is the central structure of many di- and triterpenes such as sesterstatin 6 (**1**),[1a] polygodial[1b] (**2**), and (−)-triptolide[1c] (**3**) that exhibit a wide diversity of biological activities (Figure 1).

To date, numerous reports of methodologies targeting the *trans*-decalin scaffold of di- and triterpenes have been developed,[2] and the bioinspired acid-induced polycationic cyclization of polyprenoides,[3] originally pioneered by van Tamelen, Johnson, and Goldsmith, remains the most widely used methods for the fashioning of polycylic terpenoids.[4] Recently, the radical-mediated polyene cyclization reported by MacMillan has also emerged as a powerful approach for the stereoselective construction of complex steroidal and terpenoidal frameworks exhibiting *trans*-decalinic units.[5] Halonium-induced cyclization of polyolefine has also been demonstrated recently to be a powerful alternative for the construction of functionalized decalins with impressive *trans*-stereoselection.[6] Besides these approaches, a number of elegant stereoselective methods, including substrate controlled hydrogenation of unsaturated bicylic systems, have been developed to access this important class of compounds.[7] As mentioned recently by Loh,[8] the key to a successful highly diastereoselective cationic cyclization delivering *trans*-decalin is to have a good initiator embedded within the substrate such as acetal, epoxide, allylic alcohol, *N*-acetal, 1,3-dicarbonyl,[8] aziridine,[9] or hydroxylactam.[10] Despite the fact that a considerable amount of effort has been directed toward improving the efficacy of these cyclizations, primarily by achieving high diastereoselectivities and enantioselectivities, the discovery of novel reagents and new broadly applicable strategies remains a goal of paramount importance for the stereoselective preparation of decalin carbocycles.

As part of our ongoing program devoted to the total synthesis of triptolide, we have recently communicated our preliminary endeavors on the construction of *trans*-decalin dithiolane **5a** (R_1 = OMe, R_2 = *i*Pr, R_3 = H) by using a novel 6-*endo*-*trig* cyclization of the corresponding 2-alkenyl-1,3-dithiolane **4a** as a highly promising latent initiator upon Lewis acid treatment (Scheme 1).[11]

The critical choice of this novel initiator has been driven by the failure of the parent enone **6** (Scheme 2) to cyclize efficiently and with high diastereoselectivity.[11]Herein we wish to report in full details our findings on the successful development of the first TMSOTf induced 6-*endo*-*trig* cationic cyclization of 2-alkenyl-1,3-dithiolane that displays a broad and significant substrate scope and holds broad promises for applications in natural product syntheses, as well as the exploration of the suggested mechanism by DFT calculations.

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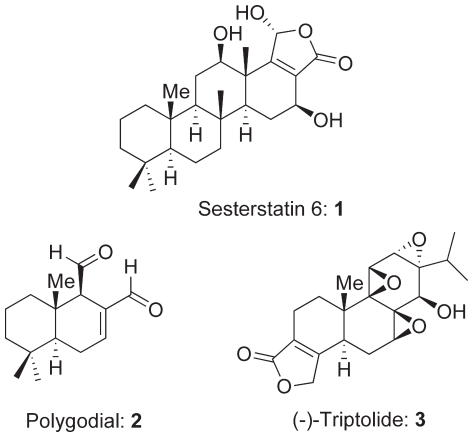
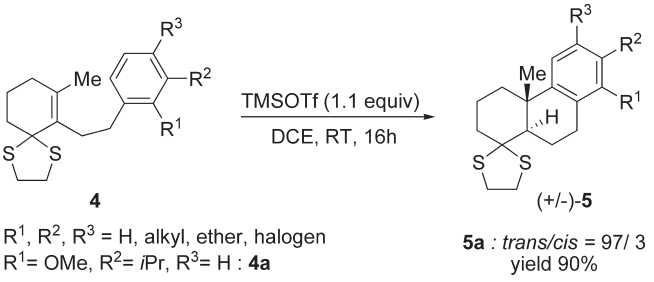


Figure 1. Structure of sesterstatin 6 (**1**), polygodial (**2**), and (−)-triptolide (**3**).

Scheme 1. 6-*endo-trig* Cationic Cyclization of 2-Alkenyl-1, 3-dithiolanes

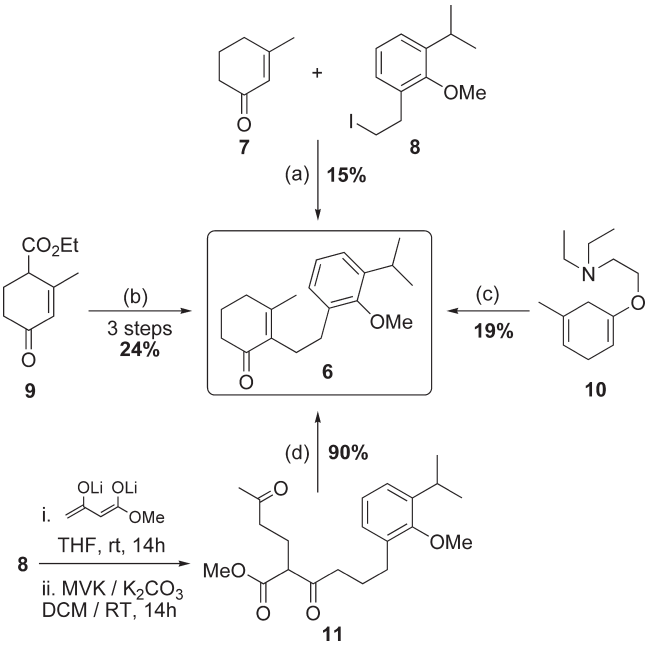


RESULTS AND DISCUSSION

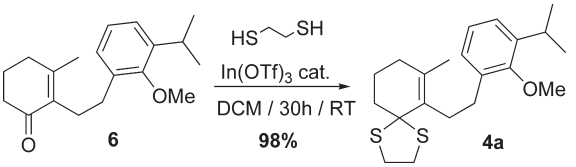
Synthesis of 2-Alkenyl-1,3-dithiolane 4a. Initial efforts focused on establishing optimal conditions for the diastereoselective cyclization of 2-alkenyl-1,3-dithiolane **4a** to *trans*-decalin **5a** (Scheme 1). Prior to embarking on this investigation, we first studied the synthesis of the precursor enone **6** by investigating different routes based either on the electrophilic alkylation of (a) 3-methylcyclohexenone **7**,[12] (b) Hagemann ester **9**,[13] and (c) Enders's diene **10**[14] with the known iodide **8**[15] or on (d) the *de novo* construction of 2-substituted 3-methylcyclohexenone system (Scheme 2).[16] While the approaches a−c afforded the desired enone **6** in one to three steps, however, in low yields, we have finally found a novel practical protocol based on a one-pot four-step domino cascade reaction of triketone **11**[17] (route d) for the preparation of **6** starting from commercially available methyl acetoacetate and iodide **8**. In addition, during our optimization work, a novel three-step synthetic strategy to access iodide **8** in large scale has been developed, allowing its preparation in 84% overall yield (see the Supporting Information) compared to previous syntheses (4 steps in 27% overall yield).[15] This route (d) permitted access to the desired α,β-unsaturated ketone **6** in satisfactory 66% yield over 3 steps (Scheme 2).

Finally 1,3-dithiolane **4a** was synthesized by protecting the ketone using 1,2-ethanedithiol in the presence of a catalytic amount of indium(III) trifluoromethanesulfonate in excellent isolated 98% yield (Scheme 3).[18]

Scheme 2. Synthesis of the C2-Alkylated 3-Methylcylohexenone 6



Scheme 3. Synthesis of 2-Alkenyl 1,3-Dithiolane 4a



Investigation of the 6-*endo-trig* Cyclization. Initial cyclization experiments of **4a** were performed with Brönsted acid such as TfOH in dichloromethane (DCM) as solvent and at room temperature for 16 h (Table 1). Even though a large excess of TfOH was used (15 equiv), the conversion of **4a** was marginal (only 5%), and the cyclized product **5a** was not obtained (Table 1, entry 1). The challenge of developing a diastereoselective cyclization of 2-alkenyl-1,3-dithiolanes appears to be associated with the low reactivity and eventually the low nucleophilicity of the nonconjugated olefin of the substrate **4a**. As a consequence, we decided to evaluate the reactivity of hard Lewis acids such as $Sc(OTf)_3$, $BF_3 \cdot Et_2O$, $TiCl_4$, $SnCl_4$, $ZrCl_4$, and $AlCl_3$ (Table 1, entries 2−7). Notably, the use of these reagents, except for $Sc(OTf)_3$ and $ZrCl_4$ (entries 2 and 6), established the feasibility of the cyclization for **4a**, since the *trans*-decalin **5a** was obtained diastereoselectively (dr *trans*:*cis* = 100:0)[11,19] in the range of 27−44% yield (entries 3−5 and 7). It is worth mentioning that in these conditions the conversion of **4a** was always high and between 88% and 100%; however, all of the reactions suffered from competitive background pathways such as the irreversible rupture of the 1,3-dithiolane moiety before cyclization, leading back to enone **6** (30−40%). These results suggested that the C−C bond-forming reaction might eventually be triggered by the initial rupture of one C−S bond of the 1,3-dithiolane **4a**, under the influence of the Lewis

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Table 1. Lewis Acid Screening for the 6-*endo-trig* Cationic Cyclization of 4a

entry	Lewis acid[a]	conversion (%)[b]	yield (%)[c]
1	TfOH	5	
2	$Sc(OTf)_3$	36	
3	$BF_3 \cdot Et_2O$	88	44
4	$TiCl_4$	91	27
5	$SnCl_4$	100	31
6	$ZrCl_4$	100	2
7	$AlCl_3$	98	29
8	$Yb(OTf)_3$	42	
9	$FeCl_3$	100	
10	$In(OTf)_3$	99	10
11	$TMSNTf_2$	100	52
12	TMSOTf	100	64
13	TMSOTf[d]	100	64
14	TMSOTf[e]	42	26

[a] 15 equiv of acid was used, in DCM at rt and for 16 h. [b] Conversion quantified by HPLC analysis. [c] Yield determined by HPLC. [d] 1.1 equiv of TMSOTf was used. [e] 0.5 equiv of TMSOTf was used.

acid, generating a vinyl sulfonium cation that would induce the cyclization event. After the *trans*-decalin formation, it is then postulated that the 1,3-dithiolane is regenerated *in situ* affording the desired product **5a**.[11,20] It was then thought that the use of softer Lewis acid would avoid the competitive complete deprotection of the carbonyl group of **4a** while generating the reactive vinyl sulfonium ion needed for the efficient cationic 6-*endo-trig* cyclization. Unfortunately, the use of $Yb(OTf)_3$, $FeCl_3$, and $In(OTf)_3$ in the same conditions was unsuccessful in fulfilling our expectations, because of either low conversion of **4a** (entry 8) and/or mainly degradation of the starting material (entries 8 and 10). We decided next to evaluate the reactivity of silicon-based electrophilic reagents such as $TMSNTf_2$[21] and TMSOTf that could activate sulfur atoms.[20] Gratifyingly, exposure of a dichloromethane solution of **4a** with 15 equiv of $TMSNTf_2$ or TMSOTf resulted in the formation of **5a** with substantially improved chemical yields, 52% and 64%, respectively (entries 11 and 12), compared to $BF_3 \cdot Et_2O$ (44%), and without alteration of the diastereoselectivity (100% *trans*). While TMSOTf catalyzed or uncatalyzed C−C bond-forming reactions are usually used to activate oxygen atoms (acetal, epoxide, or carbonyl group)[22] or nitrogen (trichloroacetimidate),[23] the observed 6-*endo-trig* cyclization differs significantly since the reaction involves C−S bond activation leading to a transformation with no literature precedent.

Encouraged by this promising result, and with the best identified Lewis acid, that is, TMSOTf, we next turned our attention on the optimization of the reaction conditions by (i) diminishing the Lewis acid quantity, (ii) identifying the optimal temperature for the transformation, and (iii) finding the suitable solvent for the reaction. It appeared that the 6-*endo-trig* cyclization of **4a** can also be promoted efficiently, without altering the diastereoselectivity, when 1.1 equiv of TMSOTf is used (0.03 M, DCM, rt, 16 h) (64% of **5a**, entry 13). Conversely, we noticed that in the presence of a catalytic amount of TMSOTf (0.5 equiv), under otherwise identical conditions, **5a** is obtained in lower isolated yield (26%) as a result of limited conversion of **4a**, even after prolonged reaction time. This result suggests the irreversible transformation of TMSOTf during the reaction precluding any possible recycling of the reagent, eventually due

Table 2. Influence of Solvent Nature on the 6-*endo-trig* Cyclization of 4a

entry	solvent[a]	conversion (%)[a]	yield (%)[b]	dr **5a**: *trans*/*cis*(%)[c]
1	DCM	100	64	100
2	Et_2O	6		
3	1,4-dioxane			
4	$MeNO_2$	94	75	100
5	DCE	100	88	97/3

[a] Conversion quantified by HPLC analysis. [b] Yield evaluated by HPLC. [c] dr was determined by HPLC analysis.

to the complexation of TMSOTf with the thioketal moiety and/or to the formation of TfOH. We also noticed that the efficiency of the cyclization for **4a** was temperature-dependent, and lower temperatures, such as −78 and −20 °C, either inhibited the reaction or delivered **5a** in diminished yield for the same reaction time and concentration of substrate, respectively (see the Supporting Information). Additionally, it was found through a screening of solvents that Et_2O and 1,4-dioxane were not valuable solvents for the reaction (Table 2, entries 2 and 3), whereas nitromethane and 1,2-dichloroethane (DCE) afforded **5a** with improved yields compared to DCM (entries 1, 4, and 5), with DCE being the most effective solvent in terms of chemical isolated yield of **5a**. It is noteworthy to mention that in all solvents the reactions were highly diastereoselective, providing *trans*-**5a** exclusively, except when DCE was used, when a 97/3 *trans*/*cis* ratio was obtained (Table 2, entry 5).

A mechanism that can account for the observed *trans*-stereochemistry preference is proposed in Scheme 4. It is assumed that the TMSOTf-induced thioketal **4a** opening leads first to the reactive vinyl thionium ion **13**.[20] The resulting highly electrophilic intermediate is subsequently attacked by the aromatic ring, affording intermediate **16**, after deprotonation−rearomatization. Protonation of the latter furnishes the *trans*-decalin junction of **17**. Finally, 1,3-dithiolane reinstallation affords the final product **5a**.

Investigation of the Mechanism by DFT Calculations. In order to investigate the energetic feasibility of this mechanistic proposal and to rationalize the origin of the observed diastereoselectivity, we have performed density functional calculations on the cyclization of 2-alkenyl-1,3-dithiolane **4a** to decalin **5a** (see Experimental Section for computational details). The first step, the formation of the Si−S bond with a subsequent ring opening of the dithiolane moiety to afford intermediate **13**/**14**, has been found to be endothermic by ca. 9 kcal/mol. However, this value is rather uncertain since it involves the transformation of two neutral species into two charged ones. In this case the solvation effects are rather large and lead thus to large uncertainties. The calculations here are used merely to show that this step is feasible. The following C−C bond-formation step has also been found to be endothermic by 24.8 kcal/mol. However, the subsequent deprotonation-rearomatization step, mediated by the triflate ion (**15** → **16**), is exothermic by 26.3 kcal/mol. So the sum of the two steps is about thermoneutral. It is likely that they occur concertedly, which avoids the large endothermicity of the former step. Here, it should be noted that after the ring opening of the dithiolane the 2-((trimethylsilyl)thio)ethyl chain can freely rotate and thus cannot be considered as shielding one of the two faces, neither for the nucleophilic attack by the aromatic ring nor for the protonation step. The latter is the only step determining the diasteroselectivity of the process. We have hence located the transition states for the protonation on the two faces of **16**. It turns out that the barriers are quite similar (6.5 and 7.2 kcal/mol for the formation

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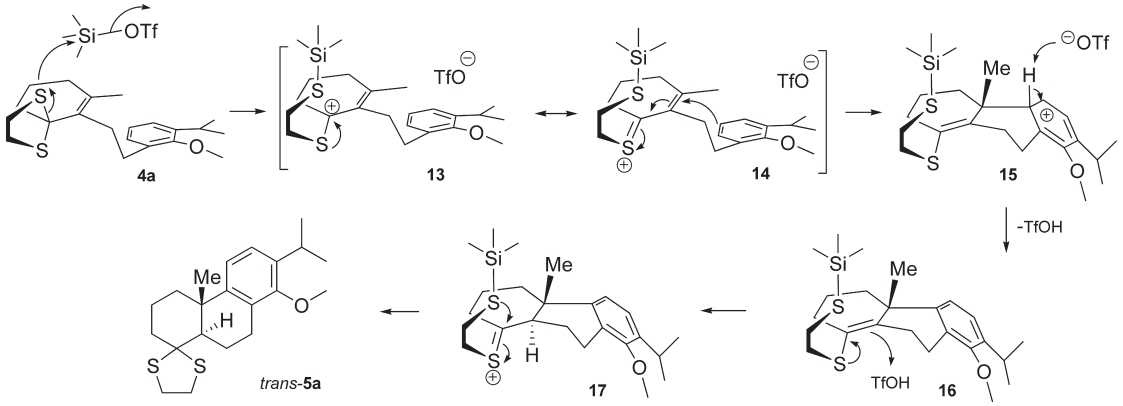
Scheme 4. Suggested Mechanism for the 6-*endo-trig* Cyclization for 4a



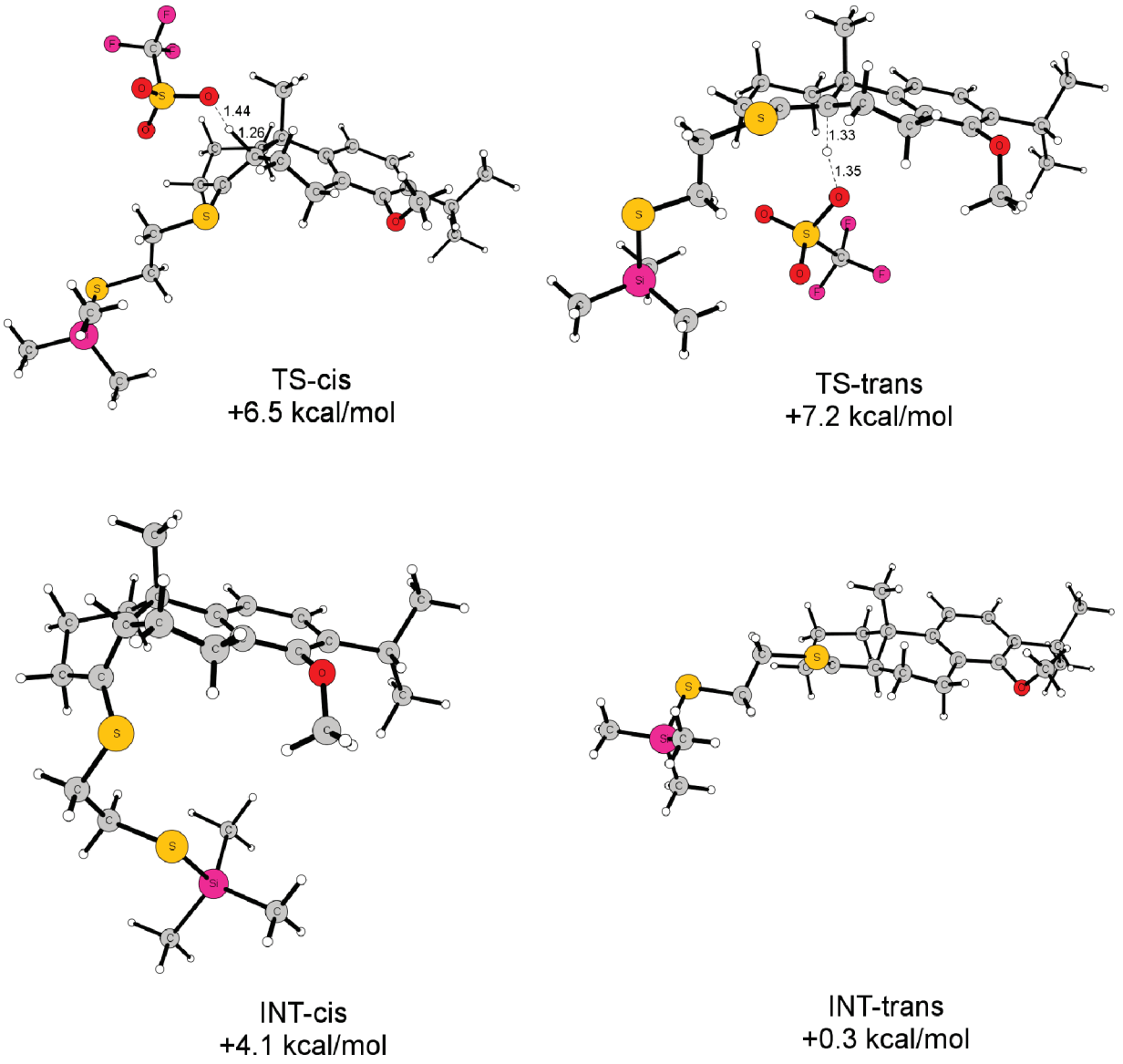


Figure 2. Optimized transition states and products of the protonation step. Energies are relative to **16**.

of the *cis* and the *trans* isomer, respectively, see Figure 2 for optimized structures). However, the energies of the resulting intermediates differ quite substantially, *trans*-**17** being 3.8 kcal/mol lower than *cis*-**17**. The energy difference stems mainly from the unfavorable ring

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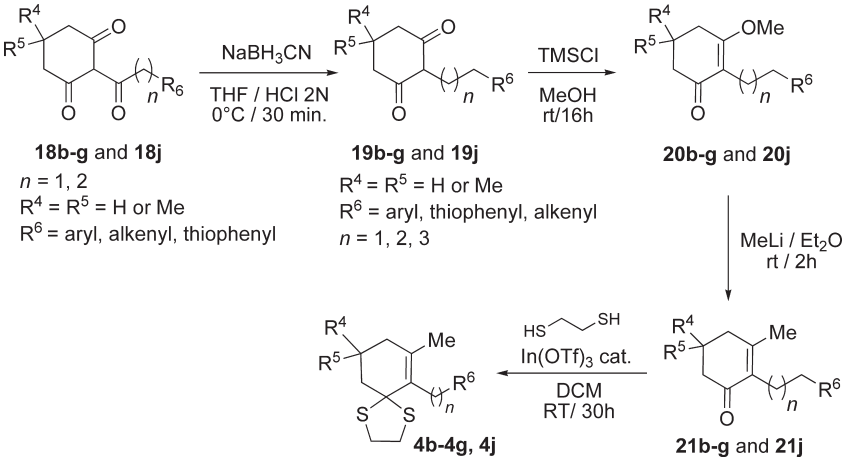
Scheme 5. Three-Step Synthesis of 2-Alkenyl-1,3-dithiolanes 4b−4g and 4j

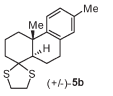
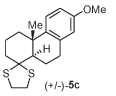
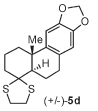
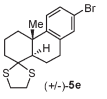
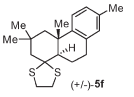
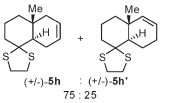
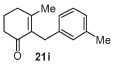
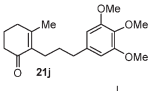
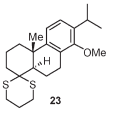


junction of *cis*-**17** and is very similar to the experimental value for *trans*/*cis* isomerism measured for decalin.[24] Since this step is endothermic and hence reversible, these energies show that the selectivity is thermodynamically controlled. The calculated *trans*/*cis* energy difference is in good agreement with the observed diastereomeric ratio of 97:3. Finally, we have calculated that the whole process, i.e., the conversion of substrate **4a** to product *trans*-**5a**, is exothermic by 5.9 kcal/mol. Here, it should be mentioned that an alternative mechanism involving activation of the olefin by the trimethylsilyl group has also been considered. However, one key intermediate for this pathway was found to be very high in energy when compared to intermediate **13** (more than 40 kcal/mol), which is enough to rule out this mechanism (see Supporting Information for details).

Application of the 6-*endo*-*trig* Cyclization to Various Dithiolanes. Having rationalized the stereochemical outcome of the 6-*endo*-*trig* cyclization for **4a**, we evaluated next the substrate scope of our newly developed 6-*endo*-*trig* cationic cyclization reaction in the optimized conditions. To reach that goal, a panel of 2-alkenyl-1,3-dithiolanes **4b**−**4g** and **4j** bearing electron-rich and electron-deficient arenes, a thiophenyl moiety, and a terminal olefin were synthesized in a three-step protocol starting from the corresponding 2-acyl 1,3-cyclohexanediones **18b**−**18g** and **18j** (Scheme 5) (see the Supporting Information).[25] Compounds **4h** and **4i** have been prepared by a different protocol based on a recently published one-pot four-step domino reaction for the construction of the C2-substituted-3-methylcyclohex-2-enone moiety (compounds **21h** and **21i**)[17] followed by construction of the 1,3-dithiolane moiety. Further dithiolane protection of the enone upon treatment with 1,2-ethanedithiol, as described in Scheme 5, afforded the desired 2-alkenyl-1,3-dithiolanes. Additionally, in order to determine whether the ring size of the thioketal initiator would influence the efficiency of the reaction and/or the diastereoselectivity, we prepared substrate **22** and envisioned to study its reactivity in the same conditions as substrates **4a**−**4j** (Figure 3). Attempts to prepare also 2-alkenyl-1,3-dioxolanes analogues from the corresponding enones (**21**), in order to study eventually the influence of the ketals functionality in the reactivity, failed, and their generation still remains an unsolved problem.

Finally, with **4b**−**4j** and **19** in hand we were able to perform our cyclization study. The results confirmed that the

Table 3. Scope and Limitations for the 6-*endo*-*trig* Cationic Cyclization

entry	1,3-dithiolane	product	isolated yield (%)
1	**4b**	 (+/-)-**5b**	83
2	**4c**	 (+/-)-**5c**	82
3	**4d**	 (+/-)-**5d**	68[a]
4	**4e**	 (+/-)-**5e**	41
5	**4f**	 (+/-)-**5f**	36[b]
6	**4g**	 (+/-)-**5g**	59
7	**4h**	 (+/-)-**5h** : (+/-)-**5h'** 75 : 25	44
8	**4i**	 **21i**	14[c]
9	**4j**	 **21j**	18[d]
10	**22**	 **23**	23[e]

[a] 15% of **4d** recovered. [b] Isolated as an inseparable mixture with 58% of **4f**. [c] 67% of **4i** was recovered. [d] 47% of **4j** recovered. [e] Isolated as an inseparable mixture with 23% of **22** along with 42% of **6**.

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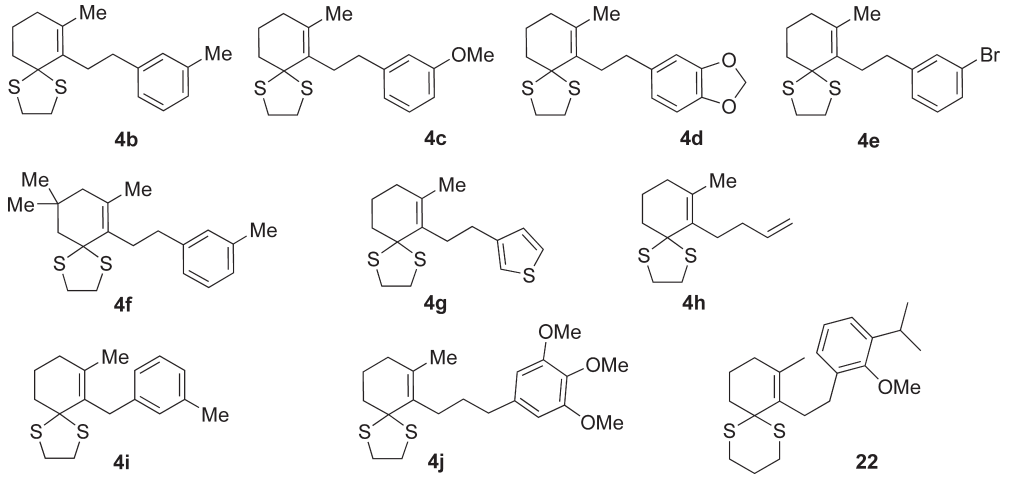
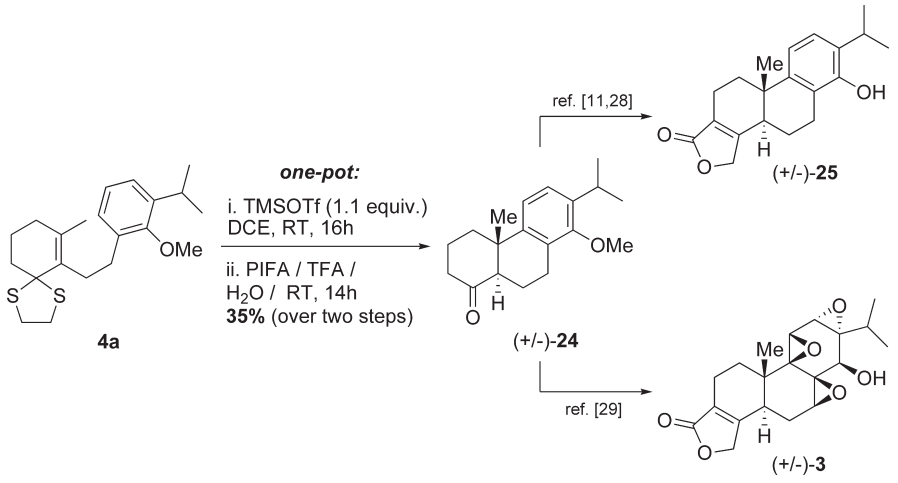


Figure 3. 2-Alkenyl-1,3-dithiolanes **4b**−**4j** and 1,3-dithiane **22** investigated in this study.

Scheme 6. One-Pot 6-*endo-trig* Cyclization/1,3-Dithiolane Deprotection of 4a



intramolecular 6-*endo-trig* reaction proceeded well when 1,3-dithiolanes **4b**, **4c**, and **4d** bearing electron-donating substituents on the aromatic part were used (Table 3, entries 1−3). Good yields of the expected *trans*-decalins **5b**, **5c**, and **5d**, respectively, were obtained in 68−83% (entries 1−3). In these cases, the *cis*-decalin isomers were not detected by ^{1}H NMR spectroscopy or HPLC analysis of the crude reaction mixture. Subjecting electron-deficient arene **4e** to the same reaction conditions yielded *trans*-decalin **5e** (41%) in 41% yield along with 41% of the starting reactant (entry 4). The low reactivity observed for **4e** might be ascribed to the lower nucleophilicity of the bromoarene moiety, limiting the consumption of the substrate. We further examined whether substituents on the thioketal cyclohexenyl part would affect both the reactivity and the stereoselectivity. *gem*-Dimethyl dithiolane **4f** was submitted to cyclization conditions; however, the reaction afforded **5f** with a moderate yield of 36%, as an inseparable mixture with 58% of the starting material **4j** (entry 5). Conversely, the 1,3-dithiolane **4g**, featuring a thiophenyl group, provided regioselectively and exclusively as a single diastereoisomer the *trans*-decalin **5g** in good isolated yield (59%) (entry 6).

The cyclization event involved highly regioselectively the substitution at the C2 position of the thiophenyl surrogate without affecting the C3 position. Pleasingly, the cyclization also underwent in a stereoselective manner when the olefinic substrate **4h** was treated in the same conditions providing ready access to the *trans*-decalins regioisomers **5h** and **5h′** in a 3:1 ratio and in an acceptable yield (44%, entry 7). Attempts to promote 5-*endo-trig* and 7-*endo-trig* cyclization for 2-alkenyl-1,3-dithiolanes **4i** and **4j**, respectively, were unsuccessful, presumably due to high energy transition state (entries 8 and 9). It is not surprising that the 5-*endo-trig* cyclization was not observed since this pathway is generally disfavored by Baldwin rules and difficult to achieve due to severe spatial distortion and bond angles requirements.[26] However, even though the 7-*endo-trig* cyclization pathway was favored, the reaction was not promoted under our room temperature conditions and may necessitate higher energy activation to increase the rate of the reaction. In both cases, starting materials were recovered along with 15−20% of the corresponding enones **21i** and **21j**, respectively. Finally, we also found that 1,3-dithiane **22** was significantly less reactive in the 6-*endo-trig* cyclization compared to 1,3-dithiolane analogue **4b**. It clearly appeared that an increase of the thioketal ring size was accompanied by a decreased reactivity of **22** and yield (23%) of the corresponding cyclized decalin product **23** (*trans*:*cis* = 100:0), leading mainly to 1,3-dithiane side reaction deprotection (42%)

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(entry 10). This result demonstrates the crucial importance of the 1,3-dithiolane functionality combined with the unique activation mode of TMSOTf in the 6-*endo-trig* cationic cyclization. Overall, this study illustrates that the TMSOTf-induced 6-*endo-trig* cyclization of 2-alkenyl-1,3-dithiolane is sensitive to steric hindrance and in some extent to the nucleophilicity of the arene or the alkenyl group. It is important to mention that this method appears to be quite general and permits the access to a variety of *trans*-decalin moiety with a high to exclusive *trans* diastereoselectivity. Additionally the failure of 1,3-dithiane **22** to promote efficiently 6-*endo-trig* cyclizations demonstrates the unique reactivity of 2-alkenyl-1,3-dithiolanes over 2-alkenyl-1,3-dithianes.

Finally, to further illustrate the synthetic utility of our developed methodology, we achieved successfully the shortest total synthesis of (±)-triptophenolide **25** and the shortest formal total synthesis of (±)-triptolide **3** starting from the common intermediate **4a** (Scheme 6). Indeed, in this context, we have further discovered that the one-pot 6-*endo-trig* cyclization followed by *in situ* 1,3-dithiolane deprotection afforded directly ketone (±)-**24** in satisfactory isolated yield of 35% over two steps. This synthetic improvement, compared to our previous synthesis,[11] made it possible to reach, after further functional group transformation of (±)-**24**,[27] (±)-triptophenolide **25**[28] in only 8 steps starting from the known iodide **8**, for which we have considerably improved the preparation (see Supporting Information). To the best of our knowledge, this synthesis represents the shortest synthesis reported to date of (±)-**25**, but also the shortest formal total synthesis of (±)-triptolide **3**.[29] It is anticipated that this powerful cationic 6-*endo-trig* cyclization of 2-alkenyl-1,3-dithiolanes and its one-pot cyclization/deprotection version could be strategically used for the fashioning of many other natural products featuring *trans*-decalin scaffold.

CONCLUSION

In summary, we have developed a novel and efficient cationic 6-*endo-trig* cyclization of 2-alkenyl-1,3-dithiolanes for the stereoselective preparation of *trans*-decalins, the most prevalent structural unit contained within natural products. Key for the success of this highly diastereoselective 6-*endo-trig* cyclization is the use of TMSOTf, which was found to be unique in inducing good reactivity and diastereoselectivity. The unprecedented cyclization of these latent initiators, 2-alkenyl-1,3-dithiolanes, appeared to be quite general and tolerated arenes, thiophene, and alkene as internal nucleophiles. DFT calculations have been performed in order to explore the energetics of the postulated mechanism and to investigate the origin of the diastereoselectivity. It turns out that the selectivity is introduced at the reversible protonation step and that it is thermodynamically controlled, i.e., the transition states leading to the two diastereomers are quite similar, but the resulting intermediates differ significantly, due to the newly formed ring junction. This approach opens new opportunities for the invention of related intra- and intermolecular asymmetric processes. This work is under progress in our laboratory.

EXPERIMENTAL SECTION

General Experimental Methods. All reactions were carried out in flame-dried glassware under an argon atmosphere with dry solvents, under anhydrous conditions unless otherwise indicated. Solvents for reactions were dried using a dry solvent station. All reactions were controlled by analytical thin-layer chromatography using precoated silica gel plates with F254 indicator. Visualization was accomplished by UV light (254 nm), cerium sulfate, or vanillin stains. Yields refer to chromatographically and spectroscopically pure compounds, unless otherwise indicated. Purifications by column chromatography were carried out using silica gel Si 60 (0.040−0.063). Yields determined by liquid chromatography were done with a 300SB-C18 column, using a mixture of acetonitrile and water as eluent. ^{1}H NMR and ^{13}C NMR were recorded on at 400 and 100 MHz, respectively. Chemical shift values (δ) are reported in ppm (residual chloroform δ = 7.26 ppm for ^{1}H; residual chloroform δ = 77.16 ppm for ^{13}C). The proton spectra are reported as follows δ (multiplicity, coupling constant J, number of protons). Multiplicities are indicated by s (singlet), d (doublet), t (triplet), q (quartet), quint. (quintuplet), hept (heptuplet), m (multiplet). High resolution mass spectra were recorded with a mass apparatus equipped with a positive ESI source. Melting points were recorded using the capillary method.

3-Isopropyl-2-methoxybenzaldehyde. Potassium carbonate (17.12 g, 123.9 mmol, 1.5 equiv) and methyl iodide (7.8 mL, 123.9 mmol, 1.5 equiv) were added to a solution of 2-hydroxy-3-isopropylbenzaldehyde (13.56 g, 82.6 mmol, 1.0 equiv) in dry DMF (80 mL). Then, the mixture was stirred for 14 h. After addition of saturated NH_4Cl (100 mL) and water (500 mL), the aqueous phase was extracted with Et_2O (3 × 100 mL). The combined organic extracts were dried with Na_2SO_4 and filtered, and the solvent was removed under reduce pressure. The residue was purified by flash column chromatography on SiO_2 (cyclohexane/EtOAc 95:5) to give **5** as a pale yellow oil (14.72 g, 100%); R_f = 0.68 (cyclohexane/EtOAc 80:20); ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.38 (s, 1H), 7.68 (dd, J_1 = 3.0 Hz, J_2 = 6.0 Hz, 1H), 7.52 (dd, J_1 = 3.0 Hz, J_2 = 6.0 Hz, 1H), 7.19 (t, J = 6.0 Hz, 1H), 3.90 (s, 3H), 3.33 (m, J = 6.0 Hz, 1H), 1.22 ppm (dd, J_1 = 6.0 Hz, J_2 = 9.0 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ190.4, 160.7, 143.1, 133.4, 129.3, 126.7, 124.9, 64.8, 26.0, 23.7 ppm; IR (neat) ν 2965, 2870, 1690, 1587, 1473, 1458, 1429, 1388, 1256, 1241, 1211, 1093, 1050, 1004, 854, 798, 768, 743 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{11}H_{14}O_2$ $[M + H]^+$ 179.1072, found 179.1069.

1-Isopropyl-2-methoxy-3-vinylbenzene. To a solution of PPh_3MeI (18.3 g, 44.1 mmol, 1.4 equiv) in dry THF (130 mL) under argon was added NaHMDS (25.2 mL, 50.4 mmol). After 3 h of stirring at room temperature, a solution of **5** (5.61 g, 31.5 mmol, 1.0 equiv) in dry THF (130 mL) was added at −78 °C. Then, the mixture was stirred overnight at room temperature. After addition of water (200 mL), the aqueous phase was extracted with Et_2O (4 × 100 mL). The combined organic extracts were dried with Na_2SO_4 and filtered, and the solvent was removed under reduce pressure. The residue was purified by flash column chromatography on SiO_2 (cyclohexane/EtOAc 95:5) to give **6** as a colorless liquid (5.22 g, 94%); R_f = 0.78 (cyclohexane/EtOAc 90:10); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35 (d, J = 6.0 Hz, 1H), 7.18 (d, J = 6.0 Hz, 1H), 7.06 (t, J = 6.0 Hz, 1H), 6.98 (dd, J_1 = 12.0 Hz, J_2 = 18.0 Hz, 1H), 5.78 (d, 1H), 5.28 (d, 1H), 3.74 (s, 3H), 3.29 (m, J = 6.0 Hz, 1H), 1.23 ppm (d, J = 6.0 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.1, 142.1, 132.2, 131.1, 126.3, 124.5, 124.0, 114.8, 62.0, 26.4, 23.9 ppm; IR (neat) ν 2964, 2870, 1628, 1459, 1429, 1410, 1336, 1253, 1206, 1170, 1099, 1053, 1011, 911, 815, 800, 764 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{12}H_{16}O$ $[M + H]^+$ 177.1279, found 177.1276.

1-(2-Iodoethyl)-3-isopropyl-2-methoxybenzene (8). To a solution of $ZrCp_2Cl_2$ (1.86 g, 6.24 mmol, 1.1 equiv) in dry THF (15 mL) under argon at 0 °C was added drop by drop DIBAL-H (6.24 mL, 6.24 mmol, 1.1 equiv), and the mixture stirred for 30 min. Then, a solution of **6** (1.0 g, 5.67 mmol, 1.0 equiv) in dry THF (6 mL) was added at 0 °C, and the mixture was stirred for 1 h at room temperature. After cooling at −78 °C, a solution of iodine (1.87 g, 7.36 mmol, 1.3 equiv) in dry THF (10 mL) was added, and the mixture was allowed to stir at room temperature overnight. Then, HCl 2 N (30 mL) was slowly added, and the aqueous phase was extracted with Et_2O (3 × 50 mL). The combined organic extracts were washed with saturated $Na_2S_2O_3$ (20 mL), saturated $NaHCO_3$ (20 mL), and brine (20 mL), dried with Na_2SO_4, and filtered, and the solvent was

removed under reduce pressure. The residue was purified by flash column chromatography on SiO_2 (cyclohexane/EtOAc 95:5) to give **8** as an orange oil (1.53 g, 89%). Analyses were identical to the ones described in literature.[15b]

General Procedure for the Synthesis of Cyclic Enol Ether. Sodium cyanoborohydride (1.5 equiv) was added to a solution of the triketone **18b**−**g** or **18j** (1.5 equiv) in tetrahydrofuran (25 mL) and HCl 2 N (20 mL) at 0 °C. The reaction mixture was stirred 30 min at 0−5 °C. Then, after addition of ethyl acetate (40 mL) and water (10 mL), the aqueous phase was extracted by ethyl acetate (3 × 20 mL). The combined organic extracts were washed with brine, dried over sodium sulfate, and evaporated. The residue was purified by flash chromatography on a silica gel column (eluent: cyclohexane/ethyl acetate) to give the diketone product **19b**−**g** and **19j**, which appeared to be very unstable. So, it was immediately put in reaction without further analysis. Trimethylsilyl chloride (1.6 equiv) was added to a solution of the diketone **19b**−**g** or **19j** (1.0 equiv) in methanol (3 mL), and the reaction mixture was stirred overnight. Then, after addition of triethylamine (150 μL) and evaporation of methanol, the residue was taken up into water (20 mL) and extracted by ethyl acetate (3 × 20 mL). The combined organic extracts were washed with brine, dried over sodium sulfate, and evaporated. The residue was purified by flash chromatography on a silica gel column (eluent: cyclohexane/ethyl acetate) to give the enol ether **20b**−**g** and **20j**.

3-Methoxy-2-[2-(3-methylphenyl)ethyl]cyclohex-2-en-1-one (***20b***). Obtained as a yellow oil (1.58 g, 41% over two steps) from starting triketone **18b** (3.88 g, 15.89 mmol). R_f = 0.57 (cyclohexane/EtOAc 40:60); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.13 (t, J = 7.6 Hz, 1H), 6.97 (m, 3H), 6.67 (s, 3H), 2.55 (m, 4H), 2.49 (t, J = 6.0 Hz, 2H), 2.34 (t, J = 6.0 Hz, 2H), 2.33 (s, 3H), 1.94 ppm (quint., J = 6.0 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.1, 172.1, 142.9, 137.4, 129.5, 127.9, 126.2, 125.7, 119.1, 55.1, 36.5, 34.7, 24.8, 24.2, 21.4, 20.9 ppm; IR (neat) ν 2944, 1643, 1610, 1458, 1367, 1237, 1159, 1078, 1044, 785, 702 cm^{-1}; HRMS (m/z) calcd for $C_{16}H_{20}O_2$ $[M + H]^+$ 245.1542, found 245.1545.

3-Methoxy-2-[2-(3-methoxyphenyl)ethyl]cyclohex-2-en-1-one (***20c***). Obtained as a yellow oil (869 mg, 24% over two steps) from starting triketone **18c** (3.63 g, 13.96 mmol). R_f = 0.52 (cyclohexane/EtOAc 40:60); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.14 (t, J = 7.6 Hz, 1H), 6.79 (td, J_1 = 1.6 Hz, J_2 = 7.6 Hz, 1H), 6.76 (t, J = 0.8 Hz, 1H), 6.68 (qd, J_1 = 0.8 Hz, J_2 = 8.0 Hz, 1H), 3.79 (s, 3H), 3.67 (s, 3H), 2.54 (m, 4H), 2.49 (t, J = 6.0 Hz, 2H), 2.32 (t, J = 6.0 Hz, 2H), 1.93 ppm (quint., J = 6.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.1, 172.2, 159.5, 144.6, 128.9, 121.2, 119.0, 114.2, 111.1, 55.2, 55.1, 36.5, 34.9, 24.8, 24.0, 21.0 ppm; IR (neat) ν 2944, 1643, 1608, 1488, 1369, 1254, 1239, 1161, 1079, 1041, 783, 698 cm^{-1}; HRMS (m/z) calcd for $C_{16}H_{20}O_3$ $[M + Na]^+$ 283.1310, found 283.1314.

2-[2-(1,3-Benzodioxol-5-yl)ethyl]-3-methoxycyclohex-2-en-1-one (***20d***). Obtained as a white solid (727 mg, 48% over two steps) from starting triketone **18d** (1.52 g, 5.54 mmol). R_f = 0.58 (cyclohexane/EtOAc 30:70); mp 107−110 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.63 (m, 3H), 5.89 (s, 2H), 3.71 (s, 3H), 2.50 (m, 6H), 2.31 (t, J = 6.0 Hz, 2H), 1.93 ppm (quint., J = 6.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.2, 172.2, 147.3, 145.4, 136.9, 121.3, 119.0, 109.2, 107.9, 100.6, 55.1, 36.5, 34.6, 24.0, 24.4, 21.0 ppm; IR (neat) ν 2944, 1642, 1609, 1489, 1369, 1242, 1161, 1081, 1038, 927, 810 cm^{-1}; HRMS (m/z) calcd for $C_{16}H_{18}O_4$ $[M + Na]^+$ 297.1103, found, 297.1099.

2-[2-(3-Bromophenyl)ethyl]-3-methoxycyclohex-2-en-1-one (***20e***). Obtained as a white solid (1.44 g, 41% over two steps) from starting triketone **18e** (3.52 g, 11.39 mmol). R_f = 0.39 (cyclohexane/EtOAc 40:60); mp 87−88 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 (d, J = 1.6 Hz, 1H), 7.25 (m, 1H), 7.10 (m, 32), 3.64 (s, 3H), 2.52 (m, 4H), 2.48 (t, J = 6.0 Hz, 2H), 2.31 (t, J = 6.0 Hz, 2H), 1.93 ppm (quint., J = 6.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.1, 172.4, 145.3, 131.8, 129.5, 128.6, 127.5, 121.9, 118.4, 55.1, 36.5, 34.4, 24.8, 23.8, 20.9 ppm; IR (neat) ν 2945, 1644, 1612, 1369, 1239, 1160, 1094, 1075, 1043, 780 cm^{-1}; HRMS (m/z) calcd for $C_{15}H_{17}BrO_2$ $[M + K]^+$ 347.0049, found 347.0044.

3-Methoxy-5,5-dimethyl-2-[2-(3-methylphenyl)ethyl]cyclohex-2-en-1-one (***20f***). Obtained as a colorless oil (2.28 g, 42% over two steps) from starting triketone **18f** (5.45 g, 20.00 mmol). R_f = 0.48 (cyclohexane/EtOAc 70:30); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.12 (t, J = 7.2 Hz, 1H), 7.00 (m, 2H), 6.95 (d, J = 7.2 Hz, 1H), 3.65 (s, 3H), 2.53 (m, 4H), 2.35 (s, 3H), 2.32 (s, 3H), 2.22 (s, 2H), 1.06 ppm (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.0, 170.2, 142.9, 137.5, 129.6, 127.9, 126.3, 125.8, 117.9, 55.1, 50.5, 38.9, 34.7, 32.0, 28.7, 24.0, 21.5 ppm; IR (neat) ν 2954, 1646, 1615, 1458, 1368, 1297, 1235, 1147, 1072, 774, 700 cm^{-1}; HRMS (m/z) calcd for $C_{18}H_{24}O_2$ $[M + H]^+$: 273.1855, found 273.1851.

3-Methoxy-2-[2-(3-thienyl)ethyl]cyclohex-2-en-1-one (***20g***). Obtained as a white solid (1.21 g, 41% over two steps) from starting triketone **18g** (2.98 g, 12.61 mmol). R_f = 0.41 (cyclohexane/EtOAc 40:60); mp 111−114 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.18 (dd, J_1 = 3.2 Hz, J_2 = 4.8 Hz, 1H), 6.95 (dd, J_1 = 1.2 Hz, J_2 = 4.8 Hz, 1H), 6.91 (dd, J_1 = 1.2 Hz, J_2 = 3.2 Hz, 1H), 3.69 (s, 3H), 2.56 (m, 4H), 2.50 (t, J = 6.0 Hz, 2H), 2.31 (t, J = 5.6 Hz, 2H), 1.93 ppm (quint., J = 6.0 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.1, 172.3, 143.2, 128.7, 124.5, 119.9, 118.9, 55.1, 36.5, 29.1, 24.8, 23.1, 20.9 ppm; IR (neat) ν 2945, 1641, 1608, 1368, 1239, 1160, 1138, 1081, 1044, 778 cm^{-1}; HRMS (m/z) calcd for $C_{13}H_{16}O_2S$ $[M + Na]^+$ 259.0767, found 259.0763.

2-{3-[4-(1-Hydroxyethyl)-3,5-dimethoxyphenyl]propyl}-3-methoxycyclohex-2-en-1-one (***20j***). Obtained as a yellow oil (763 mg, 38% over two steps) from starting triketone **18j** (2.00 g, 5.97 mmol). R_f = 0.26 (cyclohexane/EtOAc 40:60); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.41 (s, 2H), 3.83 (s, 6H), 3.80 (s, 3H), 3.78 (s, 3H), 2.52 (m, 4H), 2.30 (m, 4H), 1.92 (quint., J = 6.4 Hz, 2H), 1.58 ppm (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.4, 172.0, 153.0, 138.9, 135.9, 119.6, 105.3, 60.9, 56.1, 55.2, 36.5, 36.5, 30.2, 24.9, 22.1, 21.0 ppm; IR (neat) ν 2941, 1642, 1609, 1588, 1507, 1456, 1420, 1369, 1237, 1124, 1011 cm^{-1}; HRMS (m/z) calcd for $C_{19}H_{26}O_5$ $[M + H]^+$ 335.1858, found 335.1861.

General Procedure for the Synthesis of 3-Methylcyclohex-2-enones. Methyllithium 1.6 M in diethyl ether (1.25 equiv) was added slowly to a solution of the enol ether **20b**−**g** or **20j** (1.0 equiv) in diethyl ether (2 mL) at 0 °C. The reaction mixture was stirred 2 h at room temperature. Then, after addition of water (10 mL), the aqueous phase was extracted by ethyl acetate (3 × 10 mL). The combined organic extracts were washed with brine, dried over sodium sulfate, and evaporated. The residue was purified by flash chromatography on a silica gel column (eluent: cyclohexane/ethyl acetate) to give the 3-methylcyclohexenone **21b**−**g** and **21j**.

3-Methyl-2-[2-(3-methylphenyl)ethyl]cyclohex-2-en-1-one (***21b***). Obtained as a yellow oil (464 mg, 71%) from enol ether **20b** (700 mg, 2.87 mmol). R_f = 0.47 (cyclohexane/EtOAc 60:40). ^{1}H NMR and IR analysis are identical to the ones reported in literature.[30] ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.7, 156.0, 142.3, 137.8, 134.9, 129.5, 128.2, 126.5, 125.7, 38.0, 35.1, 32.9, 27.7, 22.4, 21.4, 21.17 ppm; HRMS (m/z) calcd for $C_{16}H_{20}O$ $[M + H]^+$ 229.1592, found 229.1596.

2-[2-(3-Methoxyphenyl)ethyl]3-methylcyclohex-2-en-1-one (***21c***). Obtained as a colorless oil (645 mg, 82%) from enol ether **20c** (839 mg, 3.22 mmol). R_f = 0.72 (cyclohexane/EtOAc 60:40); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.15 (t, J = 7.2 Hz, 1H), 6.99 (m, 3H), 2.57 (s, 3H), 2.58 (s, 4H), 2.37 (t, J = 6.4 Hz, 2H), 2.28 (t, J = 6.0 Hz, 2H), 1.90 (quint., J = 6.0 Hz, 2H), 1.77 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.7, 156.6, 156.1, 144.0, 134.8, 129.2, 121.1, 114.3, 111.3, 55.2, 38.0, 35.3, 32.9, 27.6, 22.4, 21.1 ppm; IR (neat) ν 2936, 1659, 1601, 1584, 1489, 1454, 1379, 1256, 1152, 1038, 781, 698 cm^{-1}; HRMS (m/z) calcd for $C_{16}H_{20}O_2$ $[M + H]^+$ 245.1542, found 245.1539.

2-[2-(1,3-Benzodioxol-5-yl)ethyl]-3-methylcyclohex-2-en-1-one (***21d***). Obtained as a colorless solid (398 mg, 60%) from enol ether **20d** (700 mg, 2.55 mmol). R_f = 0.79 (cyclohexane/EtOAc 40:60); mp 85−86 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.68 (m, 2H), 6.60 (dd, J_1 = 1.6 Hz, J_2 = 7.6 Hz, 1H), 5.90 (s, 2H), 2.52 (s, 4H), 2.36 (t, J = 6.4 Hz, 2H),

2.29 (t, J = 6.0 Hz, 2H), 1.89 (quint., J = 6.0 Hz, 2H), 1.78 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.7, 156.1, 147.5, 145.6, 136.2, 134.7, 121.4, 109.2, 108.1, 100.8, 38.0, 34.9, 32.9, 27.9, 22.4, 21.2 ppm; IR (neat) ν 2928, 1657, 1502, 1489, 1442, 1379, 1243, 1185, 1037, 928, 808 cm^{-1}; HRMS (m/z) calcd for $C_{16}H_{18}O_3$ $[M + H]^+$ 259.1334, found 259.1329.

2-[2-(3-Bromophenyl)ethyl]-3-methylcyclohex-2-en-1-one (***21e***). Obtained as a colorless solid (905 mg, 71%) from enol ether **20e** (1.35 g, 4.37 mmol). R_f = 0.59 (cyclohexane/EtOAc 80:20); mp 51−53 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.28 (m, 2H), 7.11 (m, 2H), 2.52 (m, 4H), 2.37 (t, J = 6.4 Hz, 2H), 2.29 (t, J = 6.0 Hz, 2H), 1.90 (quint., J = 6.0 Hz, 2H), 1.75 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.6, 156.4, 144.6, 134.4, 131.8, 129.8, 128.9, 127.4, 122.2, 38.0, 34.8, 32.9, 27.4, 22.3, 21.2 ppm; IR (neat) ν 2930, 1659, 1627, 1567, 1473, 1426, 1378, 1179, 1071, 779, 694 cm^{-1}; HRMS (m/z) calcd for $C_{15}H_{17}BrO$ $[M + H]^+$ 293.0541, found 293.0543.

3,5,5-Trimethyl-2-[2-(3-methylphenyl)ethyl]cyclohex-2-en-1-one (***21f***). Obtained as a yellow oil (474 mg, 56%) from enol ether **20f** (898 mg, 3.30 mmol). R_f = 0.55 (cyclohexane/EtOAc 90:10); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.13 (t, J = 7.2 Hz, 1H), 7.02 (m, 3H), 2.58 (s, 4H), 2.32 (s, 3H), 2.25 (s, 2H), 2.18 (s, 2H), 1.75 (s, 3H), 1.01 ppm (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.9, 153.4, 142.3, 137.8, 133.7, 129.6, 128.2, 126.6, 125.7, 51.5, 47.2, 35.2, 37.8, 28.4, 27.6, 21.5, 21.3 ppm; IR (neat) ν 2955, 1662, 1632, 1610, 1451, 1378, 1367, 1317, 1192, 1148, 1105, 778, 700 cm^{-1}; HRMS (m/z) calcd for $C_{18}H_{24}O$ $[M + Na]^+$ 279.1725, found 279.1720.

3-Methyl-2-[2-(3-thienyl)ethyl]cyclohex-2-en-1-one (***21g***). Obtained as an orange oil (775 mg, 71%) from enol ether **20g** (1.18 g, 4.98 mmol). R_f = 0.72 (cyclohexane/EtOAc 60:40); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20 (dd, J_1 = 2.8 Hz, J_2 = 4.8 Hz, 1H), 6.93 (dd, J_1 = 1.6 Hz, J_2 = 4.8 Hz, 1H), 6.90 (dd, J_1 = 1.2 Hz, J_2 = 2.8 Hz, 1H), 2.55 (m, 4H), 2.37 (t, J = 6.0 Hz, 2H), 2.29 (t, J = 6.0 Hz, 2H), 1.89 (quint., J = 6.0 Hz, 2H), 1.77 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.7, 156.2, 142.6, 134.7, 128.6, 125.0, 120.3, 38.0, 32.9, 29.4, 26.7, 22.4, 21.1 ppm; IR (neat) ν 2927, 1659, 2626, 1453, 1428, 1379, 1326, 1179, 1136, 1078, 776 cm^{-1}; HRMS (m/z) calcd for $C_{13}H_{16}OS$ $[M + H]^+$ 221.1000, found 221.0995.

3-Methyl-2-[3-(3,4,5-trimethoxyphenyl)propyl]cyclohex-2-en-1-one (***21j***). Obtained as a pale yellow oil (427 mg, 61%) from enol ether **20j** (730 mg, 2.19 mmol). R_f = 0.66 (cyclohexane/EtOAc 60:40); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.40 (s, 2H), 3.84 (s, 6H), 3.80 (s, 3H), 2.55 (t, J = 7.6 Hz, 2H), 2.31 (m, 6H), 1.87 (m, 5H), 1.58 ppm (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.9, 155.4, 153.1, 138.3, 136.0, 135.6, 105.3, 60.9, 56.1, 38.0, 36.5, 32.9, 30.6, 25.2, 22.4, 21.3 ppm; IR (neat) ν 2936, 1660, 1588, 1508, 1455, 1420, 1379, 1329, 1238, 1181, 1126, 1011 cm^{-1}; HRMS (m/z) calcd for $C_{19}H_{26}O_4$ $[M + H]^+$ 319.1909; found, 319.1912.

General Procedure for the Synthesis of 2-Alkenyl-1,3-dithiolanes. 1,2-Ethanedithiol (5.76 mmol, 1.1 equiv) and $In(OTf)_3$ (0.524 mmol, 0.1 equiv) were added successively to a solution of the corresponding α,β-unsaturated ketone **21b**−**21j** (5.24 mmol, 1.0 equiv) in DCM (25 mL), and the reaction mixture was stirred for 24 h. Then, additional 1,2-ethanedithiol (5.76 mmol, 1.1 equiv) and $In(OTf)_3$ (0.524 mmol, 0.1 equiv) were added. After 6 h of stirring, dilution with DCM (20 mL) and quenching with water (40 mL), the aqueous phase was extracted by DCM (2 × 20 mL). The combined organic extracts were washed with brine, dried over sodium sulfate, and evaporated. The residue was purified by flash chromatography on a silica gel column (eluent: cyclohexane/EtOAc 95:5) to give the 1,3-dithiolane derivative **4b**-**4j**.

7-Methyl-6-[2-(3-methylphenyl)ethyl]-1,4-dithiaspiro[4.5]dec-6-ene (***4b***). Obtained as a colorless solid (272 mg, 91%). R_f = 0.87 (cyclohexane/EtOAc 70:30); mp 56−57 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17 (t, J = 8.0 Hz, 1H), 7.07 (m, 2H), 7.00 (d, J = 7.2 Hz, 1H), 3.30 (m, 4H), 2.85 (m, 2H), 2.53 (m, 2H), 2.35 (s, 3H), 2.23 (m, 2H), 2.00 (t, J = 6.4 Hz, 2H), 1.79 (m, 2H), 1.77 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 143.3, 137.9, 134.44, 130.9, 129.1, 128.3, 126.5, 125.3, 72.2, 44.4, 40.3, 36.9, 33.5, 31.8, 22.5, 21.5, 20.9 ppm; IR (neat) ν 2957, 2925, 2862, 1483, 1451, 1436, 1329, 1261, 1230, 1165, 1037, 917, 821, 736, 662 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{18}H_{24}S_2$ $[M + H]^+$ 305.1398, found 305.1396.

6-[2-(3-Methoxyphenyl)ethyl]-7-methyl-1,4-dithiaspiro[4.5]dec-6-ene (***4c***). Obtained as a colorless oil (307 mg, 68%). R_f = 0.71 (cyclohexane/EtOAc 70:30); The product appeared to be very unstable neat and in solution. Only ^{1}H NMR could be done and HRMS analysis if injected rapidly in the apparatus. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.16 (t, J = 8.8 Hz, 1H), 6.72 (dd, J_1 = 2.8 Hz, J_2 = 8.8 Hz, 2H), 6.57 (d, J = 3.2 Hz, 1H), 3.78 (s, 3H), 3.22 (m, 2H), 3.12 (m, 2H), 2.82 (m, 4H), 2.23 (m, 2H), 2.04 (m, 2H), 1.91 (m, 2H), 1.39 ppm (s, 3H); HRMS (ESI, m/z) calcd for $C_{18}H_{24}OS_2$ $[M + H]^+$ 321.1347, found 321.1351.

5-[2-(7-Methyl-1,4-dithiaspiro[4.5]dec-6-en-6-yl)ethyl]-1,3-benzodioxole (***4d***). Obtained as a colorless oil (175 mg, 80%). R_f = 0.77 (cyclohexane/EtOAc 90:10); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.69 (m, 3H), 5.91 (s, 2H), 3.29 (m, 4H), 2.78 (m, 2H), 2.47 (m, 2H), 2.21 (m, 2H), 1.98 (t, J = 6.0 Hz, 2H), 1.76 (m, 2H), 1.74 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.5, 145.5, 137.3, 134.5, 130.7, 120.9, 108.8, 108.2, 100.8, 72.2, 44.4, 40.3, 36.7, 33.9, 31.8, 22.5, 20.9 ppm; IR (neat) ν 2954, 2922, 2861, 1483, 1451, 1437, 1314, 1258, 1045, 919, 815, 734, 660 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{18}H_{22}O_2S_2$ $[M + H]^+$ 335.1139, found 335.1134.

6-[2-(3-Bromophenyl)ethyl]-7-methyl-1,4-dithiaspiro[4.5]dec-6-ene (***4e***). Obtained as a colorless oil (308 mg, 89%). R_f = 0.82 (cyclohexane/EtOAc 70:30); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 (t, J = 1.6 Hz, 1H), 7.30 (dt, J_1 = 1.6 Hz, J_2 = 7.6 Hz, 1H), 7.13 (m, 2H), 3.31 (m, 4H), 2.84 (m, 2H), 2.50 (m, 2H), 2.22 (m, 2H), 1.99 (t, J = 6.2 Hz, 2H), 1.78 (m, 2H), 1.74 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.7, 134.8, 131.3, 130.4, 129.9, 128.8, 127.0, 122.4, 72.1, 44.4, 40.3, 36.6, 33.3, 31.8, 22.5, 20.9 ppm; IR (neat) ν 2957, 2925, 2863, 1496, 1434, 1335, 1248, 1231, 1159, 1032, 920, 821, 736, 658 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{17}H_{21}BrS_2$ $[M + H]^+$ 369.0346, found 369.0341.

7,9,9-Trimethyl-6-[2-(3-methylphenyl)ethyl]-1,4-dithiaspiro[4.5]dec-6-ene (***4f***). Obtained as a colorless oil (48 mg, 15%). R_f = 0.71-(cyclohexane/EtOAc 90:10); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17 (t, J = 8.0 Hz, 1H), 7.06 (m, 2H), 7.00 (d, J = 7.6 Hz, 1H), 3.32 (m, 4H), 2.87 (m, 2H), 2.54 (m, 2H), 2.35 (s, 3H), 2.29 (s, 2H), 1.88 (s, 2H), 1.78 (s, 3H), 1.01 ppm (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 143.4, 137.9, 132.5, 130.7, 129.0, 128.34, 126.5, 125.2, 71.1, 57.0, 46.5, 40.7, 36.9, 33.4, 31.0, 28.9, 21.5, 21.4 ppm; IR (neat) ν 2957, 2925, 2863, 1496, 1434, 1335, 1248, 1231, 1159, 1032, 920, 821, 736, 658 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{20}H_{28}S_2$ $[M + H]^+$ 333.1711, found 333.1714.

7-Methyl-6-[2-(3-thienyl)ethyl]-1,4-dithiaspiro[4.5]dec-6-ene (***4g***). Obtained as a colorless oil (158 mg, 59%). R_f = 0.92 (cyclohexane/EtOAc 60:40). Due to its important unstability, **17f** was engaged directly into the 6-*endo-trig* cyclization, without further analysis.

6-But-3-en-1-yl-7-methyl-1,4-dithiaspiro[4.5]dec-6-ene (***4h***). Obtained as a colorless oil (316 mg, 63%). R_f = 0.93 (cyclohexane/EtOAc 80:20); ^{1}H NMR (400 MHz, $CDCl_3$) δ5.84 (m, 1H), 5.02 (dd, J_1 = 2.0 Hz, J_2 = 17.2 Hz, 1H), 4.92 (dd, J_1 = 2.0 Hz, J_2 = 10.0 Hz, 1H), 3.26 (m, 4H), 2.31 (s, 4H), 2.18 (m, 2H), 1.95 (t, J = 6.4 Hz, 2H), 1.73 (m, 2H), 1.67 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ139.3, 134.2, 130.7, 113.8, 72.0, 44.4, 40.2, 35.0, 31.8, 30.4, 22.5, 20.8 ppm; IR (neat) ν 2968, 2925, 1513, 1433, 1346, 1251, 1178, 1158, 1032, 920, 845, 732, 667 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{13}H_{20}S_2$ $[M + H]^+$ 241.1085, found 241.1081.

7-Methyl-6-(3-methylbenzyl)-1,4-dithiaspiro[4.5]dec-6-ene (***4i***). Obtained as a colorless oil (205 mg, 76%). R_f = 0.85 (cyclohexane/EtOAc 90:10); ^{1}H NMR (400 MHz, $CDCl_3$) δ7.15 (t, J = 7.2 Hz, 1H), 6.95 (m, 3H), 3.72 (s, 2H), 3.28 (s, 4H), 2.34 (s, 3H), 2.30 (m, 2H), 2.07 (t, J = 6.4 Hz, 2H), 1.84 (m, 2H), 1.50 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ141.7, 137.6, 137.0, 128.8, 128.7, 128.0, 126.2, 124.8, 72.3, 44.2, 40.1, 36.4, 31.9, 22.4, 21.7, 21.6 ppm; IR (neat) ν 2953, 2920, 2861, 1483, 1455, 1389, 1316, 1257, 1045, 919, 815, 731 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{17}H_{22}S_2$ $[M + H]^+$ 291.1241, found 291.1237.

*7-Methyl-6-[3-(3,4,5-trimethoxyphenyl)propyl]-1,4-dithiaspiro[4.5]dec-6-ene (**4j**).* Obtained as a colorless oil (57 mg, 48%). R_f = 0.33 (cyclohexane/EtOAc 90:10); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.44 (s, 2H), 3.84 (s, 6H), 3.81 (s, 3H), 3.14 (m, 4H), 2.57 (t, J = 7.6 Hz, 2H), 2.15 (m, 4H), 1.85 (m, 4H), 1.71 (m, 2H), 1.62 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.4, 136.0, 133.8, 131.3, 105.6, 72.1, 60.6, 56.1, 44.3, 40.1, 36.8, 32.0, 31.7, 30.7, 22.5, 20.8 ppm; IR (neat) ν 2954, 2916, 2855, 1483, 1446, 1410, 1303, 1227, 1041, 912, 826, 740, 652 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{21}H_{30}O_3S_2$ $[M + H]^+$ 395.1715, found 395.1713.

*2-Isopropyl-6-[2-(8-methyl-1,5-dithiaspiro[5.5]undec-7-en-7-yl)-ethyl]phenyl Methyl Ether (**22**).* 1,3-Propanedithiol (30 μL, 0.384 mmol, 1.1 equiv), and $In(OTf)_3$ (20.0 mg, 0.0349 mmol, 0.1 equiv) were added successively to a solution of the corresponding α,β-unsaturated ketone **6** (100 mg, 0.349 mmol, 1.0 equiv) in DCM (2 mL), and the reaction mixture was stirred for 24 h. Then, additional 1,3-propanedithiol (30 μL, 0.384 mmol, 1.1 equiv) and $In(OTf)_3$ (20.0 mg, 0.0349 mmol, 0.1 equiv) were added. After 6 h of stirring and dilution with DCM (10 mL) and water (20 mL), the aqueous phase was extracted by DCM (2 × 10 mL). The combined organic extracts were washed with brine, dried over sodium sulfate, and evaporated. The residue was purified by flash chromatography on a silica gel column (eluent: cyclohexane/EtOAc 95:5) to give **22** as a colorless oil (79 mg, 60%). R_f = 0.70 (cyclohexane/EtOAc 95:5); ^{1}H NMR (400 MHz, $CDCl_3$) δ7.21 (dd, J_1 = 2.0 Hz, J_2 = 7.2 Hz, 1H), 7.11 (dd, J_1 = 2.0 Hz, J_2 = 7.2 Hz, 1H), 7.05 (t, J = 7.2 Hz, 1H), 3.80 (s, 3H), 3.31 (hept., J = 6.8 Hz, 1H), 3.04 (td, J_1 = 2.8 Hz, J_2 = 12.4 Hz, 2H), 2.85 (m, 2H), 2.61 (m, 5H), 2.42 (m, 2H), 2.05 (t, J = 6.4 Hz, 3H), 1.81 (s, 3H), 1.75 (m, 2H), 1.23 ppm (d, J = 6.8 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ155.6, 141.8, 136.6, 135.8, 131.4, 127.6, 124.4, 62.1, 56.6, 36.6, 32.5, 31.4, 31.3, 26.9, 26.4, 25.1, 24.2, 20.7, 19.9 ppm; IR (neat) ν 2958, 2934, 2863, 1498, 1462, 1403, 1327, 1277, 1032, 916, 804, 732, 651 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{22}H_{32}OS_2$ $[M + NH_4]^+$ 394.2245, found 394.2242.

General Procedure for the Synthesis of *trans*-Decalins. Fresh TMSOTf (0.243 mmol, 1.1 equiv) was added to a solution of 1,3-dithiolane **4b**−**j** or 1,3-dithiane **22** (0.221 mmol, 1.0 equiv) in 1,2-dichloroethane (7 mL), and the reaction mixture was stirred 16 h at room temperature. Then, after addition of water (20 mL), the aqueous phase was extracted by DCM (3 × 10 mL). The combined organic extracts were washed with brine, dried over sodium sulfate, and evaporated. The residue was purified by flash chromatography on a silica gel column (eluent: cyclohexane/EtOAc 95:5) to give the *trans*-decalins (±)-**5b-j** and **23**.

*(±)-4a′,7′-Dimethyl-3′,4′,4a′,9′,10′,10a′-hexahydro-2′H-spiro[1,3-dithiolane-2,1′-phenanthrene] ((±)-**5b**).* Obtained as a colorless oil (201 mg, 83%). R_f = 0.83 (cyclohexane/EtOAc 80:20); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.15 (d, J = 8.0 Hz, 1H), 6.96 (d, J = 8.0 Hz, 1H), 6.91 (s, 1H), 3.07 (m, 6H), 2.91 (m, 2H), 2.26 (m, 7H), 2.07 (dd, J_1 = 2.0 Hz, J_2 = 12.0 Hz, 1H), 1.89 (q, J = 12.4 Hz, 2H), 1.27 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.4, 135.2, 135.0, 129.8, 126.7, 124.5, 73.0, 51.5, 46.8, 40.7, 39.4, 38.4, 38.0, 30.2, 25.0, 22.0, 21.5, 20.9 ppm; IR (neat) ν 2918, 2859, 1497, 1450, 1433, 1375, 1276, 1066, 813, 778, 733, 565 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{18}H_{24}S_2$ $[M + H]^+$ 305.1398, found 305.1394.

*(±)-7′-Methoxy-4a′-methyl-3′,4′,4a′,9′,10′,10a′-hexahydro-2′H-spiro[1,3-dithiolane-2,1′-phenanthrene] ((±)-**5c**).* Obtained as a colorless oil (182 mg, 82%). R_f = 0.88 (cyclohexane/EtOAc 90:10); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.15 (d, J = 8.8 Hz, 1H), 6.70 (dd, J_1 = 2.8 Hz, J_2 = 8.8 Hz, 1H), 6.59 (d, J = 2.4 Hz, 1H), 3.77 (s, 3H), 3.11 (m, 5H), 2.91 (m, 2H), 2.24 (m, 4H), 2.05 (dd, J_1 = 1.6 Hz, J_2 = 12.0 Hz, 1H), 1.88 (m, 3H), 1.24 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.3, 140.8, 136.7, 125.7, 113.4, 112.1, 72.9, 55.2, 51.6, 46.8, 40.7, 39.1, 38.5, 38.2, 30.6, 25.0, 22.0, 21.5 ppm; IR (neat) ν 2927, 2833, 1607, 1498, 1464, 1435, 1279, 1257, 1241, 1153, 1038, 852 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{18}H_{24}OS_2$ $[M + H]^+$ 321.1347, found 321.1348.

*(±)-11b′-Methyl-2′,3′,4a′,5′,6′,11b′-hexahydro-1′H-spiro[1,3-dithiolane-2,4′-phenanthro[2,3-d][1,3]dioxole] ((±)-**5d**).* Obtained as a colorless oil (99 mg, 68%). R_f = 0.86 (cyclohexane/EtOAc 90:10); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.74 (s, 1H), 6.50 (s, 1H), 5.87 (s, 2H), 3.10 (m, 5H), 2.83 (m, 2H), 2.27 (m, 2H), 2.14 (d, J = 11.2 Hz, 1H), 2.02 (dd, J_1 = 2.0 Hz, J_2 = 11.6 Hz, 1H), 1.87 (m, 3H), 1.62 (m, 1H), 1.23 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.9, 145.4, 141.4, 128.4, 108.6, 104.7, 100.7, 72.9, 51.6, 46.7, 40.7, 39.7, 38.4, 38.3, 30.5, 24.8, 22.0, 21.5 ppm; IR (neat) ν 2925, 1501, 1481, 1435, 1374, 1237, 1201, 1098, 1038, 936, 909, 876, 854, 844 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{18}H_{22}O_2S_2$ $[M + H]^+$ 335.1139, found 335.1134.

*(±)-7′-Bromo-4a′-methyl-3′,4′,4a′,9′,10′,10a′-hexahydro-2′H-spiro[1,3-dithiolane-2,1′-phenanthrene] ((±)-**5e**).* Obtained in 41% yield (106 mg) after a slow atmospheric pressure column chromatography on silica. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.09 (m, 3H), 3.21 (m, 4H), 3.10 (m, 1H), 2.84 (m, 2H), 2.50 (m, 1H), 2.22 (m, 3H), 1.87 (m, 4H), 1.23 ppm (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 147.4, 137.9, 131.9, 128.9, 126.6, 119.4, 72.8, 51.2, 46.7, 40.8, 39.6, 38.5, 37.9, 30.1, 24.9, 21.9, 21.2 ppm; HRMS (ESI, m/z) calcd for $C_{17}H_{21}BrS_2$ $[M + H]^+$ 369.0346, found 369.0344.

*(±)-3,3′,4a′,7′-Tetramethyl-3′,4′,4a′,9′,10′,10a′-hexahydro-2′H-spiro[1,3-dithiolane-2,1′-phenanthrene] ((±)-**5f**).* Obtained in 43.3 mg (94%) as an inseparable mixture with 2-alkenyl-1,3-dithiolane **4f** in a 1:1.6 ratio. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17 (d, J = 8.0 Hz, 2H), 7.06 (m, 3H), 7.00 (m, 2H), 3.22 (m, 7H), 3.09 (m, 2H), 2.87 (m, 4H), 2.53 (m, 3H), 2.34 (m, 5H), 2.29 (s, 2H), 2.28 (s, 1H), 1.85 (s, 2H), 1.78 (s, 3H), 1.44 (d, J = 2.0 Hz, 1H), 1.38 (s, 3H), 1.33 (s, 3H), 1.01 (s, 6H), 0.99 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.0, 134.9, 134.3, 129.9, 126.6, 124.8, 72.0, 57.3, 51.5, 51.1, 41.8, 39.4, 37.9, 36.5, 32.8, 30.3, 29.1, 26.6, 21.3, 20.9 ppm.

*9a′-Methyl-5′,5a′,7′,8′,9′,9a′-hexahydro-4′H-spiro[1,3-dithiolane-2,6′-naphtho[1,2-b]thiophene] ((±)-**5g**).* Obtained as a pale yellow solid (93 mg, 59%). R_f = 0.92 (cyclohexane/EtOAc 60:40); mp 97−98 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.08 (d, J = 5.2 Hz, 1H), 6.68 (d, J = 5.2 Hz, 1H), 3.29 (m, 2H), 3.10 (m, 2H), 2.81 (m, 1H), 2.61 (m, 1H), 2.22 (m, 3H), 2.04 (m, 1H), 1.79 (m, 3H), 1.61 (m, 2H), 1.59 ppm (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 134.8, 127.4, 127.3, 122.2, 74.0, 52.5, 39.7, 39.2, 38.4, 37.0, 32.5, 25.5, 22.2 ppm; IR (neat) ν 2925, 2859, 1458, 1378, 1327, 1276, 1231, 1042, 913, 867, 848 cm^{-1}; HRMS (ESI, m/z) calcd for $C_{15}H_{20}S_3$ $[M + H]^+$ 297.0805, found 297.0800.

*4a′-Methyl-3′,4′,4a′,7′,8′,8a′-hexahydro-2′H-spiro[1,3-dithiolane-2,1′-naphthalene] ((±)-**5h**) and 4a′-Methyl-3′,4′,4a′,5′,8′,8a′-hexahydro-2′H-spiro[1,3-dithiolane-2,1′-naphthalene] ((±)-**5h′**).* Obtained in 125 mg (44%) in a 3:1 ratio (±)-**5h**:(±)-**5 h′**. ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.66 (m, 0.75H), 5.48 (m, 0.75H), 5.42 (m, 0.25H), 5.33 (td, J_1 = 2.0 Hz, J_2 = 9.6 Hz, 0.25H), 3.06 (m, 4H), 2.12 (m, 2H), 1.86 (m, 3H), 1.70 (m, 2H), 1.46 (m, 3H), 1.16 (m, 2H), 1.03 (s, 0.8H), 0.95 ppm (s, 2.4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.5, 126.6, 124.2, 123.9, 72.4, 52.0, 49.3, 47.5, 47.3, 44.5, 41.0, 40.9, 40.6, 40.2, 38.8, 38.4, 38.0, 37.5, 34.7, 30.4, 27.0, 25.9, 21.6, 20.9, 18.9 ppm; HRMS (ESI, m/z) calcd for $C_{13}H_{20}S_2$ $[M + H]^+$ 241.1085, found 241.1080.

*7′-Isopropyl-4a′-methyl-3′,4′,4a′,9′,10′,10a′-hexahydro-2′H-spiro[1,3-dithiane-2,1′-phenanthren]-8′-yl Methyl Ether ((±)-**23**.* Obtained in 37 mg (47%) as an inseparable mixture with 2-alkenyl-1,3-dithiane **22** in a 1:1 ratio. R_f = 0.70 (cyclohexane/EtOAc 95:5); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.98 (m, 5H), 3.92 (s, 3H), 3.80 (s, 3H), 3.17 (m, 3H), 3.03 (m, 4H), 2.61 (m, 12H), 2.42 (m, 2H), 1.96 (m, 6H), 1.82 (s, 3H), 1.37 (s, 3H), 1.23 (d, J = 7.2 Hz, 6H), 1.20 ppm (d, J = 7.2 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.1, 148.1, 138.4, 128.5, 123.9, 120.2, 60.6, 52.0, 39.1, 38.9, 38.6, 27.1, 26.9, 26.8, 26.2, 25.9, 25.6, 24.9, 24.1, 24.0, 20.4, 19.9 ppm.

Computational Details. All calculations were performed using the B3LYP functional[31] as implemented in the Gaussian03 software package.[32] Geometries were optimized with the 6-311+G(d) basis set for S and Si and the 6-31G(d,p) basis set for the other atoms, and

characterized with frequency calculations. Final energies were obtained with the larger 6-311+G(2d,2p) basis set on all atoms and corrected for zero-point effects obtained from the frequency calculations. The effect of solvation in DCE was calculated using the conductor-like polarizable continuum model (CPCM)[33] with UAKS radii.

■ ASSOCIATED CONTENT

Supporting Information. ^{1}H NMR and ^{13}C NMR spectra of all compounds, crystallographic data of ketone **6** in CIF format, and potential energy surface. This material is available free of charge via the Internet at http://pubs.acs.org.

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(19) The *trans* diastereoselectivity of (±)-**5a** was determined after deprotection of the dithiolane moiety using PIFA leading to the corresponding ketone *trans*-decalin **24** with a satisfactory yield of 84%. The *trans* stereochemistry was determined by NMR analysis and corroborated unambiguously by X-ray crystallography analysis. Supplementary crystallographic data could be obtained from the Cambridge Crystallographic Data Center *via* www.ccdc.cam.ac.uk/data_request/cif with the deposition number CCDC 753095.

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