Chiral organometallic reagents. Part XXV.[1] The stereochemistry of the ring opening of cyclopropylallyllithium compounds

Reinhard W. Hoffmann * and Ralf Koberstein

Fachbereich Chemie, Philipps-Universität Marburg, Hans-Meerwein-Strasse, D-35032 Marburg, Germany

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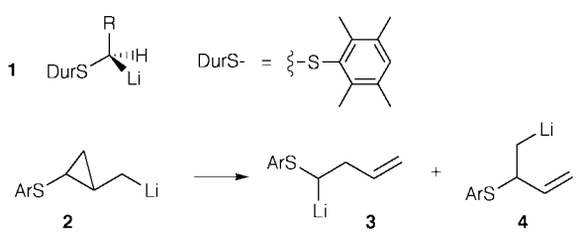
The ring opening of the cyclopropylallyllithium compounds **19** and **34** to give the α-durylhomoallyllithium compounds **20** has been shown to proceed at −107 °C with ≥90% of stereochemical purity. The resulting α-durylthioalkyllithium compounds are configurationally stable at that temperature. They racemize at −78 °C with a half life of 90 min.

Introduction

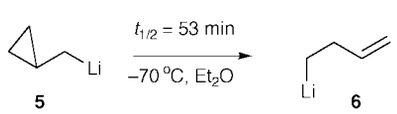
The stereochemistry of carbon–lithium bond forming reactions might be as multifaceted as the stereochemistry of the reactions of the resulting organolithium compounds. Most of our knowledge in this area relates to overall transformations, formation of an organolithium compound followed by trapping with an electrophile. Any uncertainty regarding the stereochemistry of one of these steps leads to an uncertainty in the other step. The present state of knowledge derives from studies of organolithium compounds which are configurationally stable, such as α-oxygenated or α-amino-substituted cases,[2] or cyclopropyllithium compounds.[3] It has thus been established that the tin/lithium exchange reaction and the halogen/lithium exchange reactions proceed with retention of configuration at the lithium-bearing carbon atom.[4–6] We added to the list of stereochemically defined organolithium compounds the α-durylthioalkyllithium species **1**[7] which are configurationally

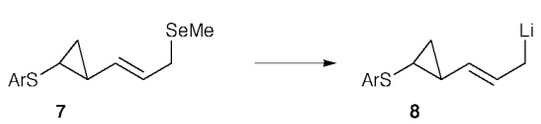


stable on a macroscopic timescale at or below −100 °C in THF solution. With the aid of **1** we have been able to show that the formation of a carbon–lithium bond in the carbolithiation of vinyl sulfides proceeds in a non-stereospecific manner.[8,9] In the present paper we report that the formation of a carbon–lithium bond by ring opening of a cyclopropylmethyllithium compound occurs with predominant retention of configuration at the new lithium-bearing stereocenter.[10] This reaction may be seen as the electrophilic cleavage of a carbon–carbon bond by a lithium cation or, to place it in a more familiar context, as the reverse of the carbolithiation of a carbon–carbon double bond.

In order to investigate the stereochemistry of the transformation of the cyclopropylcarbinyllithium compound **2** into the homoallyllithium compound **3** two obvious constraints have to be fulfilled. The regioselectivity of the ring opening of **2** has to be such that the lithium compound **3** and not its regioisomer **4** is formed. Since on ring opening of cyclopropylmethylmetal compounds the more stabilized anion should be formed,[11,12] we presumed that the anion stabilizing arylthio-substituent[13] should guarantee the formation of the desired regioisomer **3**. The other prerequisite is that the ring opening reaction should proceed at a temperature as low as −100 °C, in order to preserve the configuration of the organolithium compound **3** formed. The ring opening of the simple cyclopropylmethyllithium compound **5** has been found by Lansbury *et al.*,[14] *cf.* also ref. 11, to occur at −70 °C in ether with a half life of 53 min. Lansbury *et al.* reported that the rate of this process is highest in lithium ion coordinating solvents. We therefore believe that the rate determining step is the detachment of the lithium cation in **5** from carbon.

This suggests that the reaction could be realized at lower temperatures, if the lithium cation is less tightly bound at the migration origin than in **5**. This led us to study the ring opening

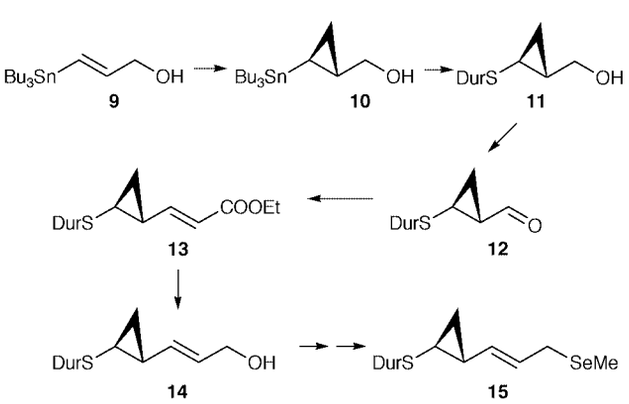




of the allyllithium compound **8**. We wanted to generate the latter from the selenoether **7** by a selenium/lithium exchange reaction,[15] which may be effected at very low temperatures.[16]

Synthesis of starting materials

The starting material **15** was synthesized in the following manner.



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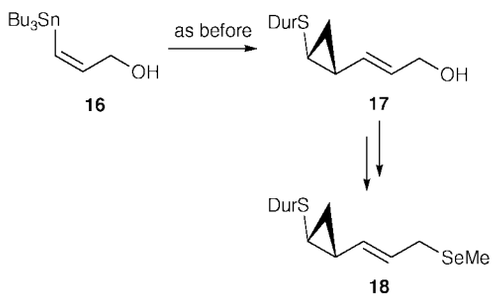
(*E*)-(Tributylstannyl)allyl alcohol **9**[17] was subjected to Charette's asymmetric cyclopropanation[18] which furnished the alcohol **10** with 90% ee (determined by NMR analyses of the Mosher ester). Tin/lithium exchange on **10** by butyllithium was followed by treatment with diduryl disulfide to generate the thioether **11** (51%). Standard steps (Swern oxidation, Horner olefination and DIBAL-H reduction) furnished the allylic alcohol **14**, which was converted *via* the tosylate to the selenoether **15**.

The corresponding *cis*-substituted cyclopropane derivative **17** of 90% ee was prepared by a similar reaction sequence starting from the *Z*-stannylated allyl alcohol **16**.[19] At the stage



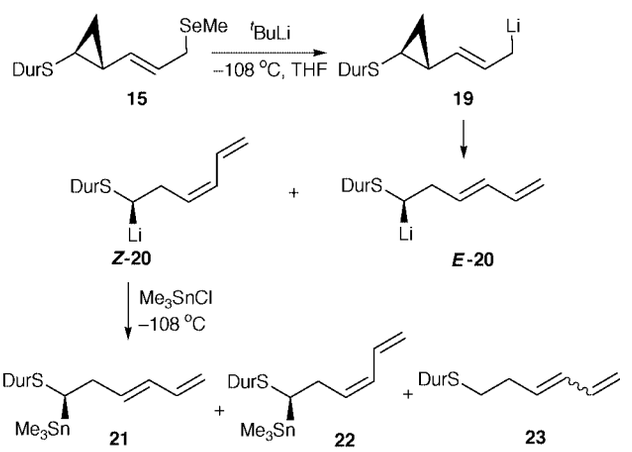
16 **17** **18**

of **17**, X-ray crystal structure analysis secured the absolute and relative configurations of the intermediate *en route* to the cyclopropane **18**.

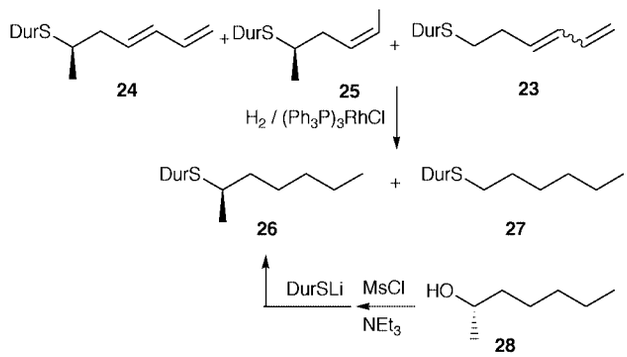
The retro-carbolithiation reaction

In order to test the feasibility of the approach a cold (−108 °C) solution of **15** in THF was added in a two-compartment reaction vessel[20] to a cold (−108 °C) solution of 1.6 equivalents of *tert*-butyllithium in THF. After stirring for 30 min a precooled (−108 °C) solution of 2.6 equivalents of trimethyltin chloride was added. The reaction mixture was quenched after 100 min at −108 °C to give a 60:9:31 mixture of compounds **21**, **22** and **23**. Repeated flash chromatography provided a mixture of **21** and **22** (28%) which showed a strong positive optical rotation of $[a]_D^{20} = +109$.

Since no starting material **15** was recovered, we conclude that



transmetallation of **15** to give the lithium compound **19** is rapid at −108 °C. As none of the trapping products had an intact cyclopropane ring, the ring opening of the lithium compound **19** to the lithium compound **20** must also be fast ($t_{\frac{1}{2}} \leq 5$ min) at −108 °C. The fact that the products **21** and **22** display substantial optical activity provides evidence that racemization of **20** must be slow at −108 °C. The protonation product **23** was one of the major products obtained. This indicates that stannylation of **20** might be a comparatively slow reaction and may not have gone to completion during 100 min at −108 °C. Methyl iodide is likely to be a more reactive reagent. Therefore transmetallation of the selenoether **15** with *tert*-butyllithium was followed by addition of a precooled solution of methyl iodide (10 equivalents). Quenching after 1 h at −108 °C led to a 83:12:5 mixture of the thioethers **24**, **25**, and **23** in *ca.* 90% yield. The mixture showed an optical rotation of $[a]_D^{24} = +47.5$. The *E*/*Z*-ratio of the methylated compounds **24** and **25** = 87:13 is identical to the *E*/*Z*-ratio of **21**/**22**. This ratio likely reflects the ratio of *E*- and *Z*-**20** in solution.



Determination of the absolute configuration of either the tin compounds **21**/**22** or the thioethers **24**/**25** would allow an assignment of the overall stereochemical course of the ring opening of the lithium compounds **19**. To this end the mixture of **24**, **25**, and **23** obtained was hydrogenated to provide a 95:5 mixture of the durylthioalkanes **26** and **27** having a rotation of $[a]_D^{20} = +7.3$ (benzene). Dextrorotatory $[a]_D^{20} = +9.2$ (benzene) **26** of known absolute configuration was prepared from (*S*)-(+)-heptanol of 97% ee. This indicates that the optical purity of **26** obtained from the lithium compounds **20** is 83% (corrected for the presence of 5% of **27**). Since the starting material **15** of known absolute configuration had 90% ee the overall process proceeds with ≥90% retention of configuration. These results also leave no doubt that both thioethers **24** and **25** as well as the lithium compounds *Z*-**20** and *E*-**20** have pairwise the same absolute configuration.

A more detailed discussion on the nature of the partial racemization required knowledge of the configurational stability of the organolithium compounds **20** under the reaction conditions. For this more detailed study we chose to trap the organolithium compounds **20** with menthyldimethyltin bromide **29**, a reagent recently used by Hammerschmidt *et al.*[5] in a similar context. Trapping of *E*/*Z*-**20** with **29** should lead to four diastereomeric tin compounds **30**–**33** that could be distinguished by ^{119}Sn NMR spectroscopy. This allows for a reliable determination of the enantiomeric purities of both *E*- and *Z*-**20** in parallel.

The lithium compounds *E*/*Z*-**20** were generated as above at −108 °C and were trapped after 30 min by a precooled solution of (−)-menthyldimethyltin bromide **29**. This led to a 80:11:9 mixture of adducts characterized by ^{119}Sn NMR signals at $\delta = -2.0$, −2.3, and −1.6 ppm. Trapping of the lithium compounds *E*/*Z*-**20** with the enantiomeric (+)-menthyldimethyltin bromide (*ent*-**29**) led to a 10:83:7 mixture of adducts having ^{119}Sn NMR signals at $\delta = -2.0$, −2.3, and −1.7 ppm. These pieces of information were combined to make the assignments shown below. The assignments are based on the assumption that *E*-**20** derived from **15** has the configuration shown and that trapping both with methyl iodide (to give **24**) and with **29** (to give **30** + **31**) proceeds with retention of configuration.

Using ^{119}Sn NMR spectroscopy to monitor the products obtained on quenching of the reaction with menthyldimethyltin bromide **29** a series of reactions was carried out, the results of which are given in Table 1.

Experiment 4—trapping with the enantiomeric tin reagent *ent*-**29**—has been carried out to demonstrate that the diastereomer ratio of the trapping products **30**–**33** is not controlled by

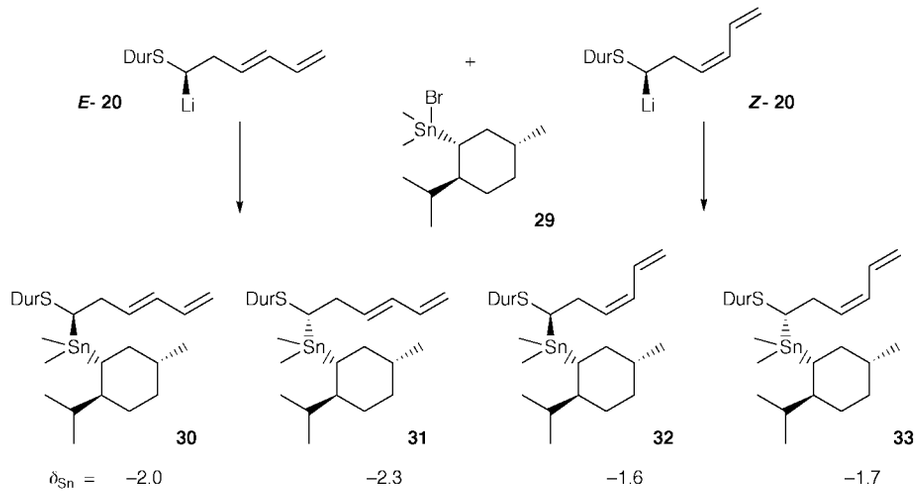


Table 1 Stereochemical course of the generation and trapping of 1-durylthio-3,5-hexadienyllithium compounds

Entry	Starting material[a]	Temp./°C	Time/min	Trapping reagent	**30**:**31**:**32**:**33** or enantiomers	**30**:**31**	Yield (%) of **30**–**33**
1	**15**	−107	10	**29**	82:8:10:—	91:9	
2	**15**	−108	30	**29**	80:11:9:—	88:12	67
3	**15**	−107	60	**29**	79:10:10:—	89:11	
4	**15**	−108	30	*ent*-**29**	10:83:—:7	11:89	
5	**18**	−108	20	**29**	9:87:—:4	10:90	
6	**18**	−108	60	**29**	9:87:—:4	10:90	52
7	**15**	−90	30	**29**	79:12:9:—	87:13	
8	**15**	−78	30	**29**	74.0:16.6:9.4:—	82:18	
9	**15**	−78	45	**29**	68.9:18.2:13.0:—	79:21	
10	**15**	−78	75	**29**	65.3:22.7:12.1:—	74:26	
11	**15**	−78	105	**29**	59.5:26.4:14.1:—	69:31	69
12	**15**	−78	240	**29**	50.8:38.6:10.6:—	57:43	
13	**15**	−78	30	*ent*-**29**	17.4:72.1:—:10.6	20:80	
14	**15**	−78	75	*ent*-**29**	24.4:64.5:3.0:8.2	27:73	79
15	**15**	−78	105	*ent*-**29**	28.8:59.6:4.1:7.5	33:67	
16	**21** + **22**[b]	−107	60	**29**	76:11:13:—	87:13	50

[a] Ee of **15** = 90%, of **18** = 90%, of **21**, **22** ≤ **22** ≤ 90%. [b] The tin/lithium exchange was effected with MeLi.

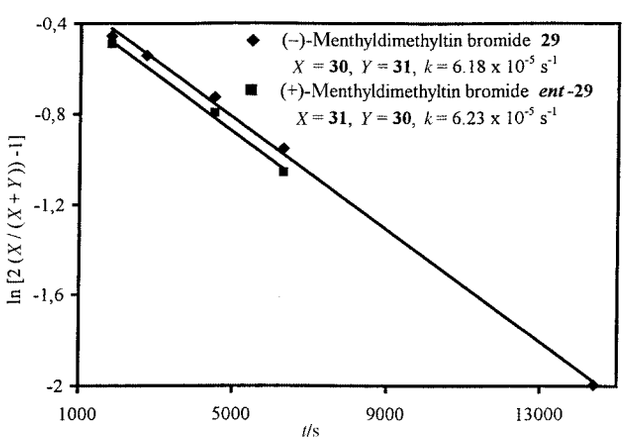


Fig. 1 Racemization of *E*-**20** at −78 °C in THF, determined after reaction with either **29** or *ent*-**29**.

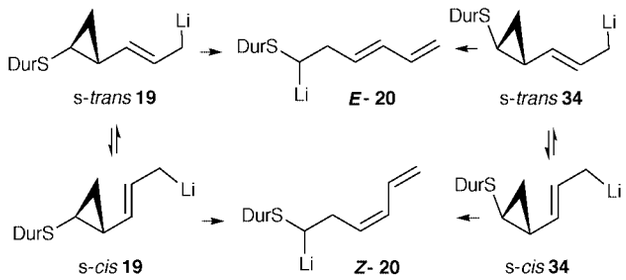
kinetic resolution of rapidly equilibrating organolithium compounds **20** by a chiral trapping agent **29**. If this were the case, trapping with *ent*-**29** should have given a diastereomer distribution matching that in entry 2 (although giving products of the enantiomeric series).

The constant diastereomer ratio obtained in experiments 1–3 or 7 shows that there is no appreciable racemization of the organolithium compound **20** occurring at the reaction temperature of −107 °C or for that matter at −90 °C. Racemization occurs, however, with a half life of 90 min at −78 °C as derived from experiments 8–12 and 13–15. Fig. 1 shows that the two racemization experiments followed first order reaction kinetics with $k = 6.18 \pm 0.15 \times 10^{-5}$ s^{-1} and $k = 6.23 \pm 0.46 \times 10^{-5}$ s^{-1} respectively at −78 °C, corresponding to a $\Delta G^{\ddagger}_{195} = 15.0$ kcal mol^{-1}.

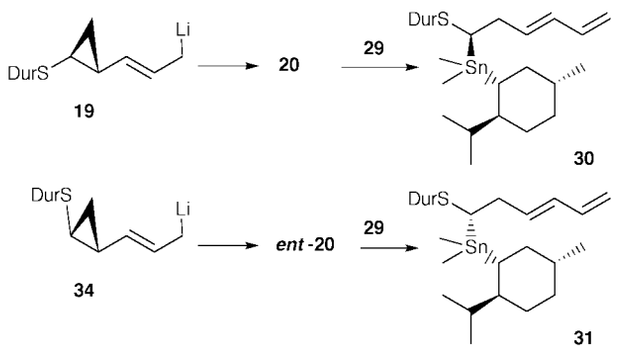
A comparison of experiments 3 and 6 involving diastereomeric starting materials shows that the ratio of (**30** + **31**):(**32** + **33**), reflecting the ratio of *E*-**20** to *Z*-**20**, is different. This indicates that this ratio is kinetically controlled and does not arise from a rapid equilibration of *E*- and *Z*-**20** *via* rapid reclosure to the cyclopropylallyllithium compound **19**.[21]

Discussion

The ring opening of the cyclopropylallyllithium compound **19** proceeds readily and cleanly at −108 °C to give the *E*- or *Z*-α-durylthioalkyllithium compounds *E*-**20** and *Z*-**20** in a ratio of 9:1. At −78 °C the selectivity of the ring opening is slightly lower. The transition states leading to *E*- and *Z*-**20** respectively differ in the conformation of the cyclopropyl–C_α bond. The tendency to react *via* a transition state with an s-*cis* arrangement around this bond should be smaller when starting from the *cis*-durylthiocyclopropane system **18**, due to the more sterically hindered nature of the s-*cis* conformer of the lithium compound **34**. In fact, the *E*/*Z*-selectivity in the formation of **20** is increased to 25:1 when starting from the lithium compound **34**.



The *cis*-α-durylthioallyllithium compound **34** is also of interest with respect to the overall stereochemistry of the reaction sequence:



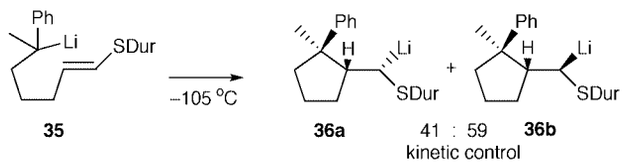
The ring opening of **19** and trapping of **20** by the tin compound **29** are presumed to give **30** with overall retention of configuration, as determined for the trapping with methyl iodide to give **24** (*vide infra*). Since the lithium compound **19** has two stereogenic centers, it was not clear whether the overall retention might be germane to the *trans*-diastereomer. It was therefore of interest to see whether the *cis*-diastereomer would follow the same stereochemical path. We have found that ring opening of the two cyclopropylallyllithium compounds **19** and **34**—with opposite configuration at the sulfur-bearing carbon atom—led to the predominant formation of different products **30** and **31** respectively. One may therefore conclude that the stereochemical course of the ring opening is not stereoconvergent, but rather distinct and specific for each diastereomer.

But which is the stereochemical course of the retro-carbolithiation reaction? The overall transformation of the lithium compound **19** to the methylated compound **24** (+ **25**) takes place with retention of configuration. It is generally accepted,[22] for an exception see ref. 23, that methylation of "low reactive" sp^3-hybridized alkyllithium compounds proceeds with retention of configuration. But we have as yet no definitive proof that this also holds for the methylation of the lithium compounds **20** to **24** and **25**. Trapping of such organolithium compounds with trialkyltin halides is also accepted[22] to proceed with retention of configuration. Likewise the lithio-destannylation to give organolithium compounds should proceed with retention of configuration.[6] At least, we can try to show that the organolithium compound **20** is not exceptional in this respect.

Treatment of the trimethyltin compounds **21** + **22** with methyllithium at −107 °C was followed by quenching with the menthyldimethyltin bromide **29**. The results of this experiment (*cf.* entry 16 in the table) show that trimethylstannylation of **20** to give **21** and **22** and destannylation of that latter mixture proceed with overall retention of configuration, likely with retention in each of the two steps. Thus we have no result which should make us suspicious that trapping of the organolithium compounds **20** would not occur with retention of configuration.

Hence, the simplest explanation is to conclude that the ring openings of the cyclopropylallyllithium compound **19** to give **20** and of **34** to give *ent*-**20** both proceed with retention of configuration at the carbon atom to which the lithium attaches itself. This finding is not obvious, because transformation of **19** into **20** can be viewed as an electrophilic ring opening of a cyclopropane system, *i.e.* a S_E2_{ret} process.[24] There is a precedent for electrophilic ring opening of cyclopropanes both with retention and with inversion of configuration.[25]

The extent of retention of configuration in the ring opening of the cyclopropylallyllithium compounds **19** to **20** at −107 °C is high (*ca.* 90%). It remains open whether the 10% racemization observed is real or has to be ascribed to uncertainties in the procedures to determine the enantiomeric purity of the starting materials and the products. Even if partial racemization is real, the stereochemical fidelity of the conversion of **19** to **20** is higher than that found in the carbolithiation of the vinyl sulfides **35** to the lithium compounds **36**.[9]



It should be noted that the epimerization barrier of **36** ($\Delta G^{\ddagger}_{183}$ = 13.3 kcal mol^{-1}) is found to be lower than the racemization barrier of **20** determined here ($\Delta G^{\ddagger}_{195}$ = 15.0 kcal mol^{-1}). Since the rate limiting step of the racemization of α-durylthioalkyllithium compounds is a rotational barrier[7,26] the more facile epimerization of the organolithium compounds **36** could be ascribed to a ground state destabilization due to a higher degree of substitution at the β-carbon in **36** as compared to **20**.

Experimental

All temperatures quoted are not corrected. Temperatures around −100 °C were determined with a GTH 215 precision digital thermometer by Fa. Greisinger, Regenstauf, Germany. ^{1}H NMR, ^{13}C NMR: Bruker ARX-200, AC-300, ARX-400, AMX-500. Boiling range of petroleum ether: 40–60 °C. Flash chromatography: Silica gel Si60 (40–63 μm; E. Merck AG, Darmstadt).

1. (1*S*,2*R*)-1-(Tributylstannyl)-2-(hydroxymethyl)cyclopropane (10)

Molecular sieve (4 Å, 0.6 g) was added to a solution of (*E*)-1-(tributylstannyl)prop-1-en-3-ol (5.21 g, 15.0 mmol) in dichloromethane (75 mL). (4*R*,5*R*)-2-Butyl-4,5-bis(*N*,*N*-dimethylcarbamoyl)-1,3,2-dioxaborolane[18] (4.61 g, 17.1 mmol) was added and the mixture was cooled to −18 °C. In a separate vessel diiodomethane (12.1 mL, 150 mmol) was added to a solution of diethylzinc (7.70 mL, 75.1 mmol) in 1,2-dimethoxyethane (7.8 mL, 75 mmol) and dichloromethane (75 mL) at −18 °C. The second solution was added over 70 min into the first solution. After 45 min the mixture was cooled to −78 °C, stirred for 12 h and quenched by addition of saturated aqueous NH_4Cl solution (100 mL). After reaching room temperature the phases were separated and the aqueous phase was extracted with *tert*-butyl methyl ether (3 × 70 mL). The combined organic phases were dried (Na_2SO_4) and concentrated. Flash chromatography of the residue with *tert*-butyl methyl ether–pentane = 1 : 10 furnished 4.91 g (91%) of the product **10** as a colorless liquid. $[a]_D^{20}$ = +14.6, $[a]_{546}^{20}$ = 17.4, $[a]_{436}^{20}$ = +29.5 (c = 1.65, $CHCl_3$). ^{1}H NMR (300 MHz, CD_3OD): δ = −0.26 (ddd, J = 10.1, 7.0, 6.2 Hz, 1 H), 0.48–0.66 (m, 2 H), 0.85–0.92 (m, 6 H), 0.96 (t, J = 7.4 Hz, 9 H), 1.00–1.12 (m, 1 H), 1.31–1.45 (m, 6 H), 1.52–1.64 (m, 6 H), 3.30 (dd, J = 11.2 and 7.2 Hz, 1 H), 3.58 (dd, J = 11.2 and 5.7 Hz, 1 H), 4.92 (s, 1 H). The ^{1}H NMR spectra recorded in $CDCl_3$ corresponded to the data given in

ref. 19. ^{13}C NMR (75 MHz, CD_3OD): $\delta = -1.4$, 8.5 ($J_{C,Sn} = 19$ Hz), 9.8 ($J_{C,Sn} = 337/321$ Hz), 14.4, 19.0 ($J_{C,Sn} = 16$ Hz), 28.7 ($J_{C,Sn} = 51$ Hz), 30.6 ($J_{C,Sn} = 20$ Hz), 69.6 ($J_{C,Sn} = 12$ Hz).

To the alcohol **10** (29 mg, 80 μmol) and 4-(dimethylamino)pyridine (8.0 mg, 65 μmol) was added a solution of (*S*)-(+)-α-methoxy-α-(trifluoromethyl)phenylacetyl chloride (30 μL, 160 μmol) in pyridine (1.5 mL). After stirring for 12 h chloroform (3.0 mL) was added. The solution was washed with water (1.0 mL) and brine (1.0 mL) and concentrated. ^{1}H NMR (500 MHz, C_6D_6) showed two methoxy signals at $\delta = 3.53$ and 3.49 in a 95 : 5 ratio.

2. (1*S*,2*R*)-2-(Hydroxymethyl)-1-(2,3,5,6-tetramethylphenylthio)-cyclopropane (11)

n-Butyllithium in hexane (1.55 M, 17.7 mL, 27.4 mmol) was added dropwise into a solution of the alcohol **10** (4.77 g, 13.2 mmol) in THF (50 mL) at 0 °C. After stirring for 15 min a solution of bis(2,3,5,6-tetramethylphenyl) disulfide (7.50 g, 22.7 mmol) in THF (50 mL) was added over 15 min. After stirring for 3 h at 0 °C a mixture of saturated aqueous $NaHCO_3$ solution (35 mL) and saturated aqueous NH_4Cl solution (35 mL) was added. The phases were separated and the aqueous phase was extracted with *tert*-butyl methyl ether (3 × 60 mL). The combined organic phases were dried (Na_2SO_4) and concentrated. Flash chromatography of the residue with *tert*-butyl methyl ether–pentane = 1 : 5 furnished 1.60 g (51%) of the alcohol **11** as a colorless solid. Mp 70–71 °C. $[a]_D^{20} = +9.6$, $[a]_{546}^{20} = +11.4$, $[a]_{436}^{20} = +19.2$ ($c = 0.92$, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 0.73$ (ddd, $J = 7.9$, 5.5, and 5.5 Hz, 1 H), 0.79–0.88 (m, 1 H), 1.24–1.37 (m, 1 H), 1.45 (broad s, 1 H), 1.97 (ddd, $J = 8.0$, 4.1, and 4.1 Hz, 1 H), 2.24 (s, 6 H), 2.48 (s, 6 H), 3.32 (dd, $J = 11.3$ and 7.2 Hz, 1 H), 3.46 (dd, $J = 11.3$ and 6.4 Hz, 1 H), 6.94 (s, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 13.3$, 18.6, 20.8, 21.4, 24.7, 65.4, 131.9, 134.2, 134.6, 138.1. $C_{14}H_{20}OS$ (236.38): Calcd. C, 71.14; H, 8.53. Found C, 70.82; H, 8.50%.

3. (1*R*,2*S*)-2-(2,3,5,6-Tetramethylphenylthio)cyclopropanemethanal (12)

Dimethyl sulfoxide (2.06 mL, 29.0 mmol) was added dropwise at −60 °C into a solution of oxalyl chloride (1.20 mL, 13.8 mmol) in dichloromethane (30 mL). After 2 min a solution of the alcohol **11** (2.74 g, 11.6 mmol) in dichloromethane (10 mL) was slowly added. The resulting suspension was stirred for 15 min during which the temperature rose to −40 °C. Triethylamine (8.60 mL, 61.7 mmol) was added and the temperature was allowed to reach −20 °C over 70 min. A mixture of saturated aqueous $NaHCO_3$ solution (25 mL) and saturated aqueous NH_4Cl solution (25 mL) was added. The phases were separated and the aqueous phase was extracted with dichloromethane (3 × 50 mL). The combined organic phases were washed with brine (50 mL), dried (Na_2SO_4) and concentrated. Flash chromatography of the residue with *tert*-butyl methyl ether–pentane = 1 : 30 + 0.3% triethylamine furnished 2.16 g (79%) of the product **12** as a colorless solid. Mp 66–67 °C. $[a]_D^{21} = +124.2$, $[a]_{546}^{21} = +151.9$, $[a]_{436}^{21} = +298.4$ ($c = 0.98$, benzene). ^{1}H NMR (300 MHz, C_6D_6): $\delta = 0.87$ (ddd, $J = 8.5$, 5.8, and 4.9 Hz, 1 H), 1.11 (ddd, $J = 8.4$, 5.1, and 5.1 Hz, 1 H), 1.83 (dddd, $J = 8.6$, 5.0, 3.7, and 3.7 Hz, 1 H), 2.07 (s, 6 H), 2.43 (s, 6 H), 2.50 (ddd, $J = 8.4$, 5.8, and 3.5 Hz, 1 H), 6.82 (s, 1 H), 8.76 (d, $J = 3.8$ Hz, 1 H). ^{13}C NMR (125 MHz, C_6D_6): $\delta = 17.1$, 18.7, 20.8, 26.6, 32.6, 132.7, 133.3, 134.5, 138.5, 197.5. $C_{14}H_{18}OS$ (234.36): Calcd. C, 71.75; H, 7.74. Found C, 71.61; H, 7.46%.

4. Ethyl (2*E*,1′*R*,2′*S*)-3-[2′-(2,3,5,6-tetramethylphenylthio)-cyclopropyl]propenoate (13)

Diethyl ethoxycarbonylmethylphosphonate (4.80 mL, 24.2 mmol) was added dropwise into a suspension of sodium hydride (80% in white oil, 703 mg, 23.4 mmol) in THF (30 mL). After stirring for 1 h a solution of the aldehyde **12** (3.80 g, 16.2 mmol) in THF (20 mL) was added at 0 °C. After stirring for 1 h additional phosphonate anion from phosphonate (0.90 mL) and sodium hydride (132 mg) in THF (6 mL) was added. The mixture was quenched after 10 min by addition of a mixture of saturated aqueous $NaHCO_3$ solution (20 mL) and saturated aqueous NH_4Cl solution (20 mL). The phases were separated and the aqueous phase was extracted with *tert*-butyl methyl ether (3 × 30 mL). The organic phases were dried (Na_2SO_4) and concentrated. Flash chromatography of the residue with *tert*-butyl methyl ether–pentane = 1 : 30, 0.3% triethylamine furnished 4.59 g (93%) of the ester **13** as a colorless solid. Mp 75–76 °C. $[a]_D^{20} = +90.6$, $[a]_{546}^{20} = +110.8$, $[a]_{436}^{20} = +217.4$ ($c = 0.94$, benzene). ^{1}H NMR (300 MHz, C_6D_6): $\delta = 0.60$ (ddd, $J = 8.1$, 5.3, and 5.3 Hz, 1 H), 0.89 (ddd, $J = 8.7$, 5.3, and 5.3 Hz, 1 H), 1.00 (t, $J = 7.1$ Hz, 3 H), 1.61 (dddd, $J = 9.8$, 8.8, 5.3, and 3.7 Hz, 1 H), 1.98 (ddd, $J = 8.2$, 5.3, and 3.6 Hz, 1 H), 2.09 (s, 6 H), 2.46 (s, 6 H), 4.04 (q, $J = 7.1$ Hz, 2 H), 5.84 (d, $J = 15.4$ Hz, 1 H), 6.43 (dd, $J = 15.4$ and 9.9 Hz, 1 H), 6.83 (s, 1H). ^{13}C NMR (50 MHz, C_6D_6): $\delta = 14.3$, 17.9, 18.9, 20.9, 25.7, 26.6, 59.9, 120.0, 132.5, 133.9, 134.3, 138.4, 150.0, 165.9. $C_{18}H_{24}O_2S$ (304.45): Calcd. C, 71.01; H, 7.95. Found C, 70.90; H, 7.97%.

5. (2*E*,1′*R*,2′*S*)-3-[2′-(2,3,5,6-Tetramethylphenylthio)cyclopropyl]prop-2-en-1-ol (14)

A solution of diisobutylaluminium hydride (1.0 M, 16.7 mL, 16.7 mmol) in petroleum ether was added dropwise at −78 °C into a solution of the ester **13** (2.43 g, 7.98 mmol) in dichloromethane (40 mL). After stirring for 75 min a mixture of saturated aqueous $NaHCO_3$ solution (25 mL) and saturated aqueous NH_4Cl solution (25 mL) was added. After reaching room temperature hydrochloric acid (1 M, 50 mL) was added and the phases were separated. The aqueous phase was extracted with *tert*-butyl methyl ether (6 × 50 mL). The combined organic phases were dried (Na_2SO_4) and concentrated. Flash chromatography of the residue with *tert*-butyl methyl ether–pentane = 1 : 4, 0.3% triethylamine furnished 1.92 g (92%) of the allyl alcohol **14** as a colorless solid. Mp 91–92 °C. $[a]_D^{28} = +37.6$, $[a]_{546}^{28} = +44.8$, $[a]_{436}^{28} = +78.6$ ($c = 1.01$, benzene). ^{1}H NMR (300 MHz, C_6D_6): $\delta = 0.69$ (ddd, $J = 7.9$, 5.4, and 5.4 Hz, 1 H), 0.95 (ddd, $J = 8.8$, 5.0, and 5.0 Hz, 1 H), 1.01 (broad s, 1 H), 1.62–1.72 (m, 1 H), 2.02 (ddd, $J = 7.9$, 4.8, and 3.7 Hz, 1 H), 2.12 (s, 6 H), 2.56 (s, 6 H), 3.75 (dd, $J = 5.6$ and 1.2 Hz, 2 H), 4.99 (ddt, $J = 15.3$, 8.4, and 1.4 Hz, 1 H), 5.42 (dt, $J = 15.3$ and 5.6 Hz, 1 H), 6.85 (s, 1 H). ^{13}C NMR (75 MHz, C_6D_6): $\delta = 16.7$, 18.9, 20.8, 25.08, 25.14, 63.0, 129.1, 132.3, 132.4, 134.2, 134.7, 138.4. $C_{16}H_{22}OS$ (262.42): Calcd. C, 73.23; H, 8.45. Found C, 72.94; H, 8.34%.

6. (2*E*,1′*R*,2′*S*)-3-[2′-(2,3,5,6-Tetramethylphenylthio)cyclopropyl]-1-(methylseleno)prop-2-ene (15)

n-Butyllithium in hexane (1.60 M, 3.40 mL, 5.44 mmol) was added dropwise into a solution of the alcohol **14** (1.37 g, 5.24 mmol) in THF (15 mL) at −78 °C. After stirring for 10 min a solution of toluene-*p*-sulfonyl chloride (1.15 g, 6.03 mmol) in THF (10 mL) was added and the mixture was allowed to reach −45 °C over 60 min. A second solution was prepared by addition of *n*-butyllithium (1.60 M in hexane, 3.90 mL, 6.24 mmol) to a solution of methylselenol (753 mg, 7.93 mmol) in THF (12 mL) at −78 °C. This solution was allowed to reach room temperature and was added *via* cannula over 1 min into the first solution at −45 °C. The mixture was allowed to reach −15 °C over 90 min. A mixture of saturated aqueous $NaHCO_3$ solution (20 mL) and aqueous saturated NH_4Cl solution (20 mL) was added and the phases were separated. The aqueous phase was extracted with *tert*-butyl methyl ether (3 × 40 mL). The combined organic phases were dried (Na_2SO_4) and concentrated. Flash chromatography of the residue with pentane (0.3% triethylamine) furnished 1.22 g (69%) of the selenoether

15 as a colorless solid. Mp 56–57 °C. $[\alpha]_D^{26} = +49.8$, $[\alpha]_{546}^{26} = +60.2$, $[\alpha]_{436}^{26} = +112.2$ ($c = 0.54$, benzene). ^{1}H NMR (400 MHz, C_6D_6): $\delta = 0.64$ (ddd, $J = 7.9$, 5.4, and 5.4 Hz, 1 H), 0.95 (ddd, $J = 8.8$, 5.0, and 5.0 Hz, 1 H), 1.57–1.65 (m, 1 H) overlaid by 1.60 (s, $J_{H,Se} = 10.9$ Hz, 3 H), 1.98 (ddd, $J = 7.8$, 4.9, and 3.9 Hz, 1 H), 2.12 (s, 6 H), 2.55 (s, 6 H), 2.75 (dd, $J = 7.7$ and 1.0 Hz, $J_{H,Se} = 14.3$ Hz, 2 H), 4.59 (dd, $J = 15.0$ and 8.5 Hz, 1 H), 5.34 (dt, $J = 15.0$ and 7.7 Hz, 1 H), 6.85 (s, 1 H). ^{13}C NMR (75 MHz, C_6D_6): $\delta = 3.0$, 17.0, 18.9, 20.9, 25.0, 25.3, 26.1, 126.4, 132.2, 133.1, 134.2, 134.8, 138.3. $C_{17}H_{24}SSe$ (339.40): Calcd. C, 60.16; H, 7.13. Found C, 60.17; H, 7.20%.

7. (2*Z*)-3-(Tributylstannyl)prop-2-en-1-ol (16)

A solution of methyllithium (1.60 M in diethyl ether, 7.3 mL, 11.7 mmol) was added dropwise into a solution of 3-iodoprop-2-en-1-ol[27] (*E*/*Z* = 18 : 82, 2.06 g, 11.2 mmol) in diethyl ether (20 mL) at −40 °C. After stirring for 15 min at −78 °C the mixture is transferred *via* cannula into a solution of *tert*-butyllithium (1.50 M in pentane, 16.0 mL, 24.0 mmol) in petroleum ether (15 mL). After stirring for 1 h at −78 °C tributyltin chloride (8.00 mL, 29.5 mmol) was added dropwise over 10 min. After stirring for a further 75 min a mixture of saturated aqueous $NaHCO_3$ solution (25 mL) and saturated aqueous NH_4Cl solution (25 mL) was added. After reaching room temperature the phases were separated and the aqueous phase was extracted with *tert*-butyl methyl ether (3 × 50 mL). The combined organic phases were dried (Na_2SO_4) and concentrated. Flash chromatography of the residue with *tert*-butyl methyl ether–petroleum ether = 1 : 14 furnished 2.27 g (71%) of the product which was obtained with an *E*/*Z*-ratio of <1 : >99. The ^{1}H NMR and ^{13}C NMR spectra corresponded to those given in ref 17.

8. (1*R*,2*R*)-1-(Tributylstannyl)-2-(hydroxymethyl)cyclopropane

The alcohol **16** (3.84 g, 11.1 mmol) was cyclopropanated as described under 1. to give 2.50 g (62%) of the product with an enantiomeric excess of 89%. $[\alpha]_D^{22} = -8.9$, $[\alpha]_{546}^{22} = -10.8$, $[\alpha]_{436}^{22} = -18.8$ ($c = 1.11$, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = -0.03$ (ddd, $J = 9.3$, 9.3, and 7.5 Hz, 1 H), 0.18 (ddd, $J = 7.4$, 4.2, and 4.2 Hz, 1 H), 0.71–0.95 (m, 7 H), overlaid with 0.88 (t, $J = 7.3$ Hz, 9 H), 1.23–1.57 (m, 14 H), 3.23 (ddd, $J = 10.8$, 7.7, and 5.0 Hz, 1 H), 3.55 (ddd, $J = 10.8$, 6.1, and 6.1 Hz, 1 H), the data correspond to those given in ref. 28.^{13}C NMR (75 MHz, $CDCl_3$): $\delta = -1.3$, 7.2, 9.8 ($J_{C,Sn} = 335/320$ Hz), 13.6, 17.5, 27.3 ($J_{C,Sn} = 55$ Hz), 29.1 ($J_{C,Sn} = 20$ Hz), 68.5.

9. (1*R*,2*R*)-2-(Hydroxymethyl)-1-(2,3,5,6-tetramethylphenylthio)cyclopropane

The tin compound obtained under 8. (4.50 g, 12.5 mmol) was converted into the title compound as described under 2.: 1.93 g (65%) as a colorless solid. Mp 76 °C. $[\alpha]_D^{20} = -65.6$, $[\alpha]_{546}^{20} = -78.4$, $[\alpha]_{436}^{20} = -138.3$ ($c = 1.49$, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 0.43$ (ddd, $J = 5.2$, 5.2, and 5.2 Hz, 1 H), 0.99 (ddd, $J = 8.5$, 8.0, and 5.3 Hz, 1 H), 1.19 (broad s, 1 H), 1.30–1.44 (m, 1 H), 2.24 (s, 6 H), 2.40 (ddd, $J = 7.6$, 7.6, and 5.1 Hz, 1 H), 2.49 (s, 6 H), 3.64 (dd, $J = 11.7$ and 9.1 Hz, 1 H), 3.82–3.94 (m, 1 H), 6.94 (s, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 12.3$, 18.5, 20.8, 22.01, 22.05, 63.5, 131.8, 134.4, 134.6, 137.6. $C_{14}H_{20}OS$ (236.38): Calcd. C, 71.14; H, 8.53. Found C, 70.92; H, 8.30%.

10. (1*R*,2*R*)-2-(2,3,5,6-Tetramethylphenylthio)cyclopropanemethanal

The alcohol obtained under 9. (1.74 g, 7.34 mmol) was converted to the aldehyde as described under 3. to give 1.34 g (78%) of the product as a colorless solid. Mp 53–54 °C. $[\alpha]_D^{20} = -32.1$, $[\alpha]_{546}^{20} = -38.8$, $[\alpha]_{436}^{20} = -75.8$ ($c = 1.21$, benzene). ^{1}H NMR (300 MHz, C_6D_6): $\delta = 0.66$ (ddd, $J = 8.1$, 8.1, and 5.6 Hz, 1 H), 1.02 (ddd, $J = 5.9$, 5.9 and 5.9 Hz, 1 H), 1.47 (dddd, $J = 8.0$, 8.0, 6.0, and 6.0 Hz, 1 H), 2.07 (s, 6 H), 2.11 (ddd, $J = 7.8$, 7.8, and 6.3 Hz, 1 H), 2.41 (s, 6 H), 6.82 (s, 1 H), 9.37 (d, $J = 6.2$ Hz, 1 H). ^{13}C NMR (75 MHz, C_6D_6): $\delta = 14.3$, 18.6, 20.7, 26.2, 29.8, 132.6, 134.1, 134.6, 138.2, 199.0. $C_{14}H_{18}OS$ (234.36): Calcd. C, 71.75; H, 7.74. Found C, 71.62; H, 7.99%.

11. Ethyl (2*E*,1′*R*,2′*R*)-3-[2′-(2,3,5,6-tetramethylphenylthio)-cyclopropyl]propenoate

The aldehyde obtained under 10. (1.32 g, 5.63 mmol) was converted into the α,β-unsaturated ester as described under 4. to give 1.45 g (84%) of the product as a colorless solid. Mp 48–49 °C. $[\alpha]_D^{20} = +26.7$, $[\alpha]_{546}^{20} = +31.6$, $[\alpha]_{436}^{20} = +54.3$ ($c = 1.12$, benzene). ^{1}H NMR (300 MHz, C_6D_6): $\delta = 0.61$ (ddd, $J = 5.7$, 5.7, and 5.7 Hz, 1 H), 0.81 (ddd, $J = 8.2$, 8.2, and 5.3 Hz, 1 H), 1.05 (t, $J = 7.1$ Hz, 3 H), 1.29 (dddd, $J = 10.0$, 7.9, 7.9, and 5.9 Hz, 1 H), 2.10 (s, 6 H), 2.22 (ddd, $J = 7.7$, 7.7, and 5.9 Hz, 1 H), 2.54 (s, 6 H), 4.09 (q, $J = 7.1$ Hz, 2 H), 5.94 (d, $J = 15.5$ Hz, 1 H), 6.81 (s, 1 H), 7.21 (dd, $J = 15.5$ and 10.1 Hz, 1 H). ^{13}C NMR (75 MHz, C_6D_6): $\delta = 14.4$, 16.9, 18.8, 20.8, 22.9, 26.7, 59.9, 121.5, 132.2, 134.3, 134.5, 138.2, 149.6, 165.7. $C_{18}H_{24}O_2S$ (304.45): Calcd. C, 71.01; H, 7.95. Found C, 70.87; H, 7.86%.

12. (2*E*,1′*R*,2′*R*)-3-[2′-(2,3,5,6-Tetramethylphenylthio)cyclopropyl]prop-2-en-1-ol (17)

The ester obtained under 11. (1.39 g, 4.55 mmol) was reduced as described under 5. to give 865 mg (72%) of the allyl alcohol **17** as a colorless solid. Mp 116–117 °C. $[\alpha]_D^{20} = -82.8$, $[\alpha]_{546}^{20} = -100.2$, $[\alpha]_{436}^{20} = -185.1$ ($c = 1.20$, benzene). ^{1}H NMR (300 MHz, C_6D_6): $\delta = 0.61$ (ddd, $J = 5.6$, 5.6, and 5.6 Hz, 1 H), 0.84 (ddd, $J = 8.2$, 8.2, and 5.1 Hz, 1 H + OH), 1.43 (dddd, $J = 8.2$, 8.2, 8.2, and 6.2 Hz, 1 H), 2.12 (s, 6 H), 2.19 (ddd, $J = 7.8$, 7.8, and 5.4 Hz, 1 Hz), 2.55 (s, 6 H), 3.92 (broad s, 2 H), 5.62 (dt, $J = 15.4$ and 5.5 Hz, 1 H), 5.74 (dd, $J = 15.4$ and 8.6 Hz, 1 H), 6.84 (s, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 15.9$, 18.6, 20.8, 22.0, 24.4, 63.5, 129.8, 131.5, 132.5, 134.0, 134.7, 137.9. $C_{16}H_{22}OS$ (262.42): Calcd. C, 73.23; H, 8.45. Found C, 73.10; H, 8.30%. The absolute and relative configuration of this compound has been secured by an X-ray crystal structure analysis. Crystallographic details have been deposited at the Cambridge Crystallographic Data Centre (CCDC), deposition number 188/225. See http://www.rsc.org/suppdata/p2/a9/a908668d/ for crystallographic files in .cif format.

13. (2*E*,1′*R*,2′*R*)-3-[2′-(2,3,5,6-Tetramethylphenylthio)cyclopropyl]-1-(methylseleno)prop-2-ene (18)

The allyl alcohol **17** (655 mg, 2.50 mmol) was converted into the selenoether **18** as described under 6. to give 631 mg (74%) as a colorless solid. Mp 68–69 °C. $[\alpha]_D^{22} = -115.2$, $[\alpha]_{546}^{22} = -139.3$, $[\alpha]_{436}^{22} = -260.0$ ($c = 2.54$, benzene). ^{1}H NMR (400 MHz, C_6D_6): $\delta = 0.54$ (ddd, $J = 6.0$, 5.3, and 5.3 Hz, 1 H), 0.81 (ddd, $J = 8.2$, 8.2, and 5.2 Hz, 1 H), 1.46 (dddd, $J = 8.1$, 8.1, 8.1, and 6.2 Hz, 1 H), 1.78 (s, $J_{H,Se} = 10.7$ Hz, 3 H), 2.14 (ddd, $J = 7.9$, 7.9, and 5.4 Hz, 1 H), overlaid by 2.12 (s, 6 H), 2.55 (s, 6 H), 2.99 (d, $J = 6.8$ Hz, $J_{H,Se} = 14.0$ Hz, 2 H), 5.52 (dd, $J = 15.1$ and 7.9 Hz, 1 H), 5.62 (dt, $J = 15.1$ and 7.1 Hz, 1 H), 6.85 (s, 1 H). ^{13}C NMR (75 MHz, C_6D_6): $\delta = 3.3$, 16.0, 18.9, 20.9, 22.4, 25.0, 26.5, 128.1, 131.7, 132.1, 134.2, 135.2, 138.3. $C_{17}H_{24}SSe$ (339.40): Calcd. C, 60.16; H, 7.13. Found C, 60.07; H, 6.94%.

14. Trapping of the organolithium compounds 20 with menthyldimethyltin bromide (29)

Cf. Table 1: into a two-compartment reaction vessel[20] was added a solution of *tert*-butyllithium (1.60 M in pentane, 0.15 mL, 0.24 mmol), into the lower compartment. A solution of the selenoether (**15** or **18**) (0.10 M, 2.00 mL, 0.20 mmol) in THF was placed in the top compartment. After the temperature given in the table had been reached the solution of the top

compartment was allowed to flow into the lower compartment. After stirring for the time indicated in the table a precooled solution (top compartment) of menthyldimethyltin bromide (**29**) (0.40 M in THF, 1.50 mL, 0.60 mmol) was added to the reaction mixture. After stirring for 75 min a mixture of saturated aqueous $NaHCO_3$ solution (5 mL) and saturated aqueous NH_4Cl solution (5 mL) was added and the mixture was allowed to reach room temperature. The phases were separated and the aqueous phase was extracted with *tert*-butyl methyl ether (3 × 10 mL). The combined organic phases were dried (Na_2SO_4) and concentrated. The crude product was directly subjected to NMR-spectroscopic analysis.

The crude product was purified by flash chromatography with pentane to give a mixture of the products **30**–**33**. After trapping with (−)-**29** the following characteristic NMR data could be recorded: **30**: ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 0.20$ (s, $J_{H,Sn} = 49.4/47.5$ Hz, 3 H), 4.96 (d, $J = 10.5$ Hz, 1 H), 5.07 (d, $J = 16.9$ Hz, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 115.4$, 131.5. ^{119}Sn NMR (187 MHz, $CDCl_3$) $\delta = -2.0$. **32**: ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 0.22$ (s, $J_{H,Sn} = 49.5/47.5$ Hz, 3 H), 5.01 (d, $J = 10.3$ Hz, 1 H), 5.13 (d, $J = 16.1$ Hz, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 117.3$, 129.9. ^{119}Sn NMR (187 MHz, $CDCl_3$): $\delta = -1.6$.

From the reaction of (+)-**29** the following spectroscopic data could be recorded: **31**: ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 0.21$ (s, $J_{H,Sn} = 49.5/47.5$ Hz, 3 H), 4.96 (d, $J = 9.9$ Hz, 1 H), 5.06 (d, $J = 16.9$ Hz, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 115.3$, 131.5. ^{119}Sn NMR (187 MHz, $CDCl_3$): $\delta = -2.3$. **33**: ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 0.22$ (s, 3 H), 5.01 (d, $J = 10.9$ Hz, 1 H), 5.12 (d, $J = 15.9$ Hz, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 117.2$, 129.9. ^{119}Sn NMR (187 MHz, $CDCl_3$): $\delta = -1.7$.

$C_{28}H_{46}SSn$ (533.45): Calcd. C, 63.04; H, 8.69. Found for mixture of **30**–**33**: C, 62.91; H, 8.91%.

15. Trapping of the organolithium compound 20 with trimethyltin chloride

A solution of *tert*-butyllithium (1.60 M in pentane, 0.49 mL, 0.78 mmol) was placed in the lower compartment of a two-compartment reaction vessel.[20] A solution of the selenoether **15** (0.10 M, 5.00 mL, 0.50 mmol in THF) was placed in the top compartment. After the temperature had reached −108 °C the solution was allowed to flow into the lower compartment. After 30 min a precooled solution of trimethyltin chloride (263 mg, 1.32 mmol) in THF (5.0 mL) was added and the mixture was stirred for 100 min. After workup as described under 14. the crude product was purified by flash chromatography with pentane to give 148 mg of a mixture of **21**, **22** and **23**, the composition of which was evaluated by ^{1}H and ^{119}Sn NMR. Repeated flash chromatography gave 57 mg (28%) of an 85 : 15 mixture of **21** and **22** as a colorless oil. ^{1}H NMR (300 MHz, C_6D_6): **21**: $\delta = 0.31$ (s, $J_{H,Sn} = 52.9$ Hz, 9 H), 2.14 (s, 6 H), 2.43–2.66 (m, 2 H), overlaid with 2.61 (s, 6 H), 2.72 (dd, $J = 7.4$ and 5.1 Hz, 1 H), 4.93 (d, $J = 9.9$ Hz, 1 H), 5.03 (d, $J = 17.3$ Hz, 1 H), 5.66 (ddd, $J = 14.8$, 7.4, and 7.4 Hz, 1 H), 5.98 (dd, $J = 14.7$ and 10.3 Hz, 1 H), 6.23 (ddd, $J = 16.9$, 10.3, and 9.9 Hz, 1 H), 6.88 (s, 1 H). ^{13}C NMR (75 MHz, C_6D_6): $\delta = -9.3$ ($J_{C,Sn} = 333/317$ Hz), 18.8, 20.9, 32.8, 37.1, 115.6, 132.1, 132.8, 134.18, 134.22, 136.0, 137.3, 138.7. ^{119}Sn NMR (187 MHz, $CDCl_3$): $\delta = 8.8$.

22: The following signals could be recorded: ^{1}H NMR (300 MHz, C_6D_6): $\delta = 5.5$–5.6 (m, 1 H), 6.40 (ddd, $J = 16.8$, 10.6 and 10.6 Hz, 1 H). ^{13}C NMR (75 MHz, C_6D_6): $\delta = -9.4$, 32.7, 117.6. ^{119}Sn NMR (187 MHz, $CDCl_3$) $\delta = 9.7$.

$C_{19}H_{30}SSn$ (409.22): Calcd. C, 55.77; H, 7.39. Found C, 56.00, H, 7.37%.

16. Generation of the lithium compounds 20 by destannylation of the trimethyltin compounds 21 and 22

An 85 : 15 mixture of the compounds **21** and **22** (43 mg, 0.11 mmol) in THF (2.0 mL) was allowed to react with a solution of methyllithium (1.60 M in diethyl ether, 0.20 mL, 0.32 mmol) as described under 14. After reaction with **29** and workup as described under 14. a mixture of the compounds **30**, **31**, and **32** was obtained. For the details see Table 1.

17. Trapping of the organolithium compound 20 with methyl iodide

A solution of *tert*-butyllithium (1.50 M in pentane, 0.50 mL, 0.75 mmol) was placed in the lower compartment of a two-compartment reaction vessel.[20] A solution of the selenoether **15** (0.1 M in THF, 5.00 mL, 0.50 mmol) was placed in the top compartment. After the temperature had reached −107 °C the solution was allowed to flow into the lower compartment. After stirring for 30 min a precooled solution of methyl iodide (710 mg, 5.00 mmol) in THF (4.0 mL, stirred for 60 min over molecular sieves 4 Å) was added and the mixture was allowed to react for 55 min. After room temperature had been reached the mixture was worked up as described under 14. Flash chromatography with pentane furnished 120 mg of a mixture of **24**, **25**, and **23**, the ratio of which was determined from the ^{1}H NMR spectrum.

24: ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 1.17$ (d, $J = 6.6$ Hz, 3 H), 2.20–2.42 (m, 2 H), overlaid with 2.25 (s, 6 H), 2.51 (s, 6 H), 2.94 (ddq, $J = 7.7$, 6.6, and 5.5 Hz, 1 H), 5.01 (d, $J = 10.2$ Hz, 1 H), 5.12 (d, $J = 16.9$ Hz, 1 H), 5.71 (ddd, $J = 15.1$, 7.4, and 7.4 Hz, 1 H), 6.08 (dd, $J = 15.1$ and 10.3 Hz, 1 H), 6.32 (ddd, $J = 16.9$, 10.3, and 10.3 Hz, 1 H), 6.95 (s, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 18.7$, 20.3, 20.9, 40.0, 44.0, 115.5, 131.79, 131.81, 133.2, 133.5, 134.1, 137.0, 138.9.

The following signals of **25** could be recorded: ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 1.19$ (d, $J = 7.0$ Hz, 3 H), 5.46–5.58 (m, 1 H), 6.52 (dddd, $J = 16.7$, 11.0, 10.0, and 1.1 Hz, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 20.2$, 44.2, 117.6. $C_{17}H_{24}S$ (260.44): Calcd. C, 78.40; H, 9.29. Found for **24** + **25** + **23**: C, 78.57; H, 9.42%.

18. (*R*)-(+)-2-(2,3,5,6-Tetramethylphenylthio)heptane (26) from 24 and 25

A mixture of **24** and **25** (87 : 13, 100 mg, 384 μmol) containing additional **23** (5 mg, 20 μmol) obtained under 17. was dissolved in anhydrous benzene (2.0 mL). Tris(triphenylphosphine)-rhodium(I) chloride (37 mg, 40 μmol) was added and the solution was degassed and then stirred under 1.1 bar of hydrogen for 12 h. The solution was concentrated and the residue was purified by flash chromatography with pentane to give 94 mg of a 95 : 5 (by GC) mixture of **26** and **27**. $[\alpha]_D^{20} = +7.3$ ($c = 1.32$, benzene).

26: ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 0.92$ (t, $J = 6.9$ Hz, 3 H), 1.15 (d, $J = 6.7$ Hz, 3 H), 1.24–1.68 (m, 8 H), 2.27 (s, 6 H), 2.53 (s, 6 H), 2.90 (ddq, $J = 6.5$, 6.5, and 6.5 Hz, 1 H), 6.96 (s, 1 H). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 14.0$, 18.7, 20.8, 20.9, 22.6, 26.7, 31.8, 37.0, 44.4, 131.6, 133.86, 133.95, 139.0.

27, the following signals could be recorded: ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 2.59$ (t, $J = 7.3$ Hz, 2 H). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 28.7$, 29.7, 31.5, 36.2. $C_{17}H_{28}S$ (264.47): Calcd. C, 77.20; H, 10.67. Found for **26** + **27**: C, 77.22; H, 10.82%.

From (*S*)-(+)-heptan-2-ol (**28**): Triethylamine (78 μl, 0.56 mmol) and methanesulfonyl chloride (39 μl, 0.50 mmol) were added at −20 °C into a solution of (*S*)-(+)-heptan-2-ol (**28**) (Aldrich, 97% ee, $[\alpha]_D^{24} = +10.5$ ($c = 1.53$, $CHCl_3$)) in dichloromethane (2.0 mL). After stirring for 5 min the mixture was allowed to reach room temperature. After 30 min saturated aqueous $NaHCO_3$ solution (5.0 mL) was added, the phases were separated and the aqueous phase was extracted with dichloromethane (3 × 5.0 mL). The combined organic phases were dried (Na_2SO_4) and concentrated. The residue was taken up in THF (2.0 mL) = solution (1). Methyllithium (1.60 M in diethyl ether, 0.40 mL, 0.64 mmol) was added at −50 °C into a solution of 2,3,5,6-tetramethylbenzenethiol (128 mg, 0.77 mmol) in THF (1.5 mL) = solution (2). After stirring solution

(2) for 5 min solution (1) was added at −50 °C. The mixture was allowed to reach room temperature. After 3 d saturated aqueous K_2CO_3 solution (4.0 mL) and pentane (10 mL) were added. The phases were separated and the aqueous phase was extracted with pentane (2 × 10 mL). The combined organic phases were dried (Na_2SO_4) and concentrated. Flash chromatography with pentane resulted in a mixture of bis(2,3,5,6-tetramethylphenyl) disulfide (45 mg) and the desired product **26** (84 mg). To remove the disulfide the mixture was taken up in THF (5.0 mL) and the solution was added at 0 °C to a suspension of lithium aluminium hydride (17 mg, 0.45 mmol) in THF (5.0 mL). After stirring for 4 h acetic anhydride (0.30 mL, 3.2 mmol) were added. The mixture was allowed to reach room temperature. After 2 h a mixture of saturated aqueous $NaHCO_3$ solution (5 mL) and saturated aqueous NH_4Cl solution (5 mL) was added. The phases were separated and the aqueous phase was extracted with pentane (2 × 10 mL). The combined organic extracts were dried (Na_2SO_4) and concentrated. Flash chromatography of the residue with pentane furnished the desired thioether **26** (64 mg, 62%) as a colorless liquid. $[a]_D^{25} = +9.2$, $[a]_{546}^{25} = +11.3$, $[a]_{436}^{25} = +19.7$ ($c = 0.94$, benzene).

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