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Mercury(II)-Mediated Cleavage of Cyclopropylcarbinols by an Intramolecular Sulfinyl Group as a Stereo- and Regioselective Route to Stereotriads and Stereotetrads

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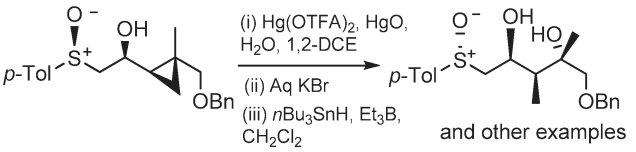

Mercury(II) salt mediated opening of cyclopropylcarbinols by an intramolecular sulfinyl group is disclosed. All four diastereomeric stereotriads have been prepared from *cis*- and *trans*-disubstituted cyclopropanes. The trisubstituted cyclopropanes also react regio- and stereoselectively to afford products possessing quaternary stereogenic centers. The reaction is clean and general.

Introduction

Alternating hydroxy- and methyl-substituted subunits are a characteristic feature of polypropionate derived natural products (Figure 1). The importance[1] of these natural products as antibiotics, antifungals, antitumors, antiparasitics, and immunosuppressants together with their structural and stereochemical complexity has led to the design and development of several unique methodologies to prepare these structures.[2] A common strategy has been the disconnection of the polypropionate chain into smaller subunits containing alternating methyl and hydroxy groups and uniting them by coupling reactions.

In our abiding interest in utilizing the sulfinyl group as an intramolecular nucleophile,[3] we have investigated the oxymercuration−demercuration of cyclopropylcarbinols with the aim of obtaining products possessing such a subunit. Cyclopropanes have been reported to undergo highly regio- and stereoselective intermolecular oxymercuration[4] promoted by mercury(II) salts to furnish 1,3-diols after demercuration, Scheme 1.[5]

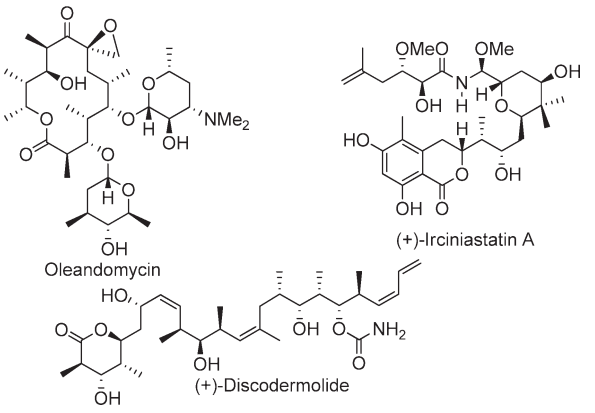

FIGURE 1. Some natural products possessing alternating methyl and hydroxy substituents.

While Collum and co-workers reported on mercuric perchlorate-mediated intramolecular opening of cyclopropanes by carboxylic acid and its derivatives,[6] Cossy and co-workers reported on a stereoselective route to subunits possessing

(1) (a) Omura, S. *Macrolide Antibiotics: Chemistry, biology and practice*, 2nd ed.; Academic Press: San Diego, CA, 2002; p 637. (b) O'Hagan, D. *Nat. Prod. Rep*. **1995**, *12*, 1. (c) Davies-Coleman, M. T.; Garson, M. J. *Nat. Prod. Rep*. **1998**, *15*, 477.

(2) (a) Paterson, I.; Florence, G. J. *Eur. J. Org. Chem*. **2003**, 2193. (b) Koskinen, A. M. P.; Karisalmi, K. *Chem. Soc. Rev*. **2005**, *34*, 677. (c) Faul, M. M.; Huff, B. E. *Chem. Rev*. **2000**, *100*, 2407.

(3) For the oxidative functionalization of disubstituted alkenes see: (a) Raghavan, S.; Rasheed, M. A.; Joseph, S. C.; Rajender, A. *Chem Commun*. **1999**, 1845. (b) Raghavan, S.; Ramakrishna Reddy, S.; Tony, K. A.; Naveen Kumar, Ch.; Varma, A. K.; Nangia, A. *J. Org. Chem*. **2002**, *67*, 5838. (c) Raghavan, S.; Rajender, A.; Joseph, S. C.; Rasheed, M. A.; Ravikumar, K. *Tetrahedron: Asymmetry* **2004**, *15*, 365. For the oxidative functionalization of trisubstituted alkenes see: (d) Raghavan, S.; Sreekanth, T. *Tetrahedron Lett*. **2008**, *49*, 1169.

(4) (a) Collum, D. B.; Still, W. C.; Mohamadi, F. *J. Am. Chem. Soc*. **1986**, *108*, 2094. (b) Barrett, A. G. M.; Tam, W. *J. Org. Chem*. **1997**, *62*, 4653. (c) Kocovsky, P.; Grech, J. M.; Mitchell, W. L. *J. Org. Chem*. **1995**, *60*, 1482. (d) Kocovsky, P.; Grech, J. M.; Mitchell, W. L. *Tetrahedron Lett*. **1996**, *37*, 1125. (e) Kocovsky, P.; Dunn, V.; Grech, J. M.; Srogl, J.; Mitchell, W. L. *Tetrahedron Lett*. **1996**, *37*, 5585.

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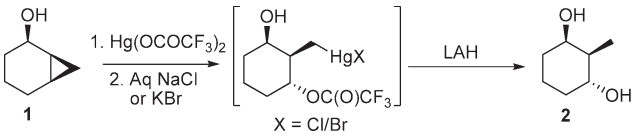
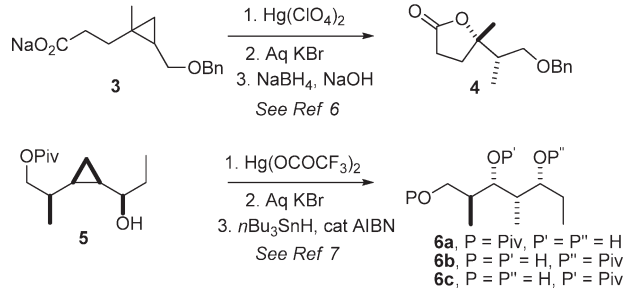
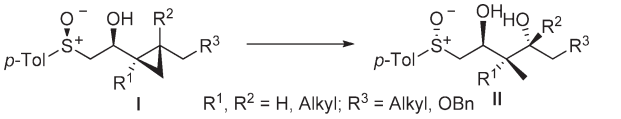
SCHEME 1. Mercuric Trifluoroacetate Promoted Cyclopropane Ring-Opening



SCHEME 2. Intramolecular Opening of the Cyclopropane Ring



SCHEME 3. Preparation of Stereotriads by Cyclopropane Ring-Opening



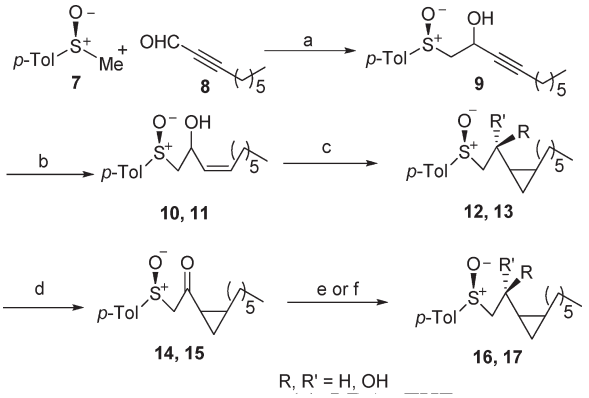
alternating hydroxy and methyl substituents via mercuric trifluoroacetate-promoted opening of cyclopropylcarbinols possessing a remote hydroxy group protected as an ester, Scheme 2.[7] The oxymercuration−demercuration of cyclopropylcarbinols thus compliments epoxide ring-opening with carbon nucleophiles as a strategy for securing the methyl−hydroxyl array.

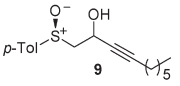
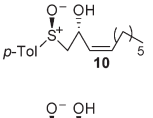
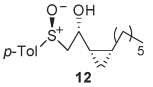
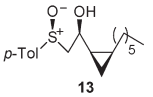
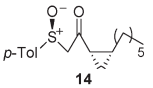
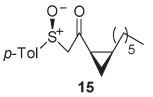
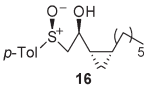
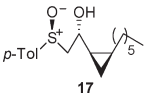
We disclose herein for the first time on the stereospecific opening of cyclopropylcarbinols by an intramolecular sulfinyl group promoted by mercuric trifluoroacetate to furnish stereotriads and stereotetrad, Scheme 3.

Results and Discussion

Preparation of Cyclopropylcarbinols. The *cis*-disubstituted cyclopropanes **12** and **13** were prepared starting from alkynyl aldehyde[8] **8**, Table 1. Reaction of **8** with the lithio anion of (*S*)-methyl *p*-tolyl sulfoxide[9] afforded roughly an equimolar inseparable mixture of propargylic alcohols **9**. Chemoselective partial reduction of the alkyne with nickel boride[10] furnished a separable mixture of *cis*-allylic alcohols **10** and **11**. Hydroxy group directed cyclopropanation

TABLE 1. Stereoselective Preparation of *cis*-Cyclopropylcarbinols[b]



Entry	Substrate	Reagents and conditions	Product	Yield (%)
1	**7**	a	 **9**	90
2	**9**	b	 **10** + **11**	89[a]
3	**10**	c	 **12**	90
4	**11**	c	 **13**	89
5	**12**	d	 **14**	89
6	**13**	d	 **15**	91
7	**14**	e	 **16**	90
8	**15**	f	 **17**	86

[a]The allylic alcohols **10** and **11** were isolated in roughly equimolar amounts by column chromatography. [b]Reagents and conditions: (a) LDA, THF, −40 °C, 30 min, cool to −78 °C, add **8**. (b) $Ni(OAc)_2 \cdot 6H_2O$, $NaBH_4$, $H_2NCH_2CH_2NH_2$, EtOH, rt. (c) CH_2I_2, Et_2Zn, CH_2Cl_2, 1,2-DME, 0 °C to rt. (d) DMP, CH_2Cl_2, 0 °C. (e) Dibal-H, $ZnCl_2$, THF, −78 °C. (f) Dibal-H, THF, −78 °C.

(5) For some applications of the ring-opening of cyclopropanes with mercury(II) salts, see: (a) Landais, Y.; Parra-Rapado, L. *Tetrahedron Lett.* **1996**, *37*, 1209. (b) Kocovsky, P.; Srogl, J.; Pour, M.; Gogoll, A. *J. Am. Chem. Soc.* **1994**, *116*, 186. (c) Kocovsky, P.; Srogl, J. *J. Org. Chem.* **1992**, *57*, 4565. (d) Kocovsky, P.; Dunn, V.; Gogoll, A.; Langer, V. *J. Org. Chem.* **1999**, *64*, 101. (e) Misslitz, U.; Primke, H.; de Meijere, A. *Chem. Ber.* **1989**, *122*, 537. (f) Lautens, M.; Tam, W.; Blackwell, J. *J. Am. Chem. Soc.* **1997**, *119*, 623. (g) Lautens, M.; Blackwell, J. *Synthesis* **1998**, 537. (h) Cossy, J.; Blanchard, N.; Defosseux, M.; Meyer, C. *Angew. Chem., Int. Ed.* **2002**, *41*, 2144. (i) Defosseux, M.; Blanchard, N.; Meyer, C.; Cossy, J. *J. Org. Chem.* **2004**, *69*, 4626.

(6) Collum, D. B.; Mohamadi, F.; Hallock, J. S. *J. Am. Chem. Soc.* **1983**, *105*, 6882.

(7) (a) Defosseux, M.; Blanchard, N.; Meyer, C.; Cossy, J. *Tetrahedron* **2005**, *61*, 7632. (b) Cossy, J.; Blanchard, N.; Meyer, C. *Org. Lett.* **2001**, *3*, 2567. (c) Cossy, J.; Blanchard, N.; Hamel, C.; Meyer, C. *J. Org. Chem.* **1999**, *64*, 2608. (d) Cossy, J.; Blanchard, N.; Meyer, C. *Synthesis* **1999**, 1063. (e) Cossy, J.; Blanchard, N.; Meyer, C. *Eur. J. Org. Chem.* **2001**, 2841. (f) Cossy, J.; Blanchard, N.; Meyer, C. *Tetrahedron Lett.* **1999**, *40*, 8361. (g) For an account concerning the ring-opening of cyclopropylcarbinols with mercury(II) salts, see: Meyer, C.; Blanchard, N.; Defosseux, M.; Cossy, J. *Acc. Chem. Res.* **2003**, *36*, 766.

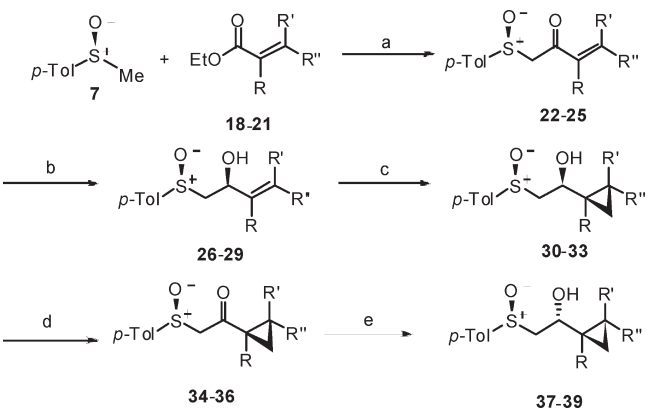
following the Furukawa protocol[11] yielded cyclopropylcarbinols **12** and **13**, respectively. Epimeric alcohol **16** was obtained by diastereoselective reduction of ketone **14**, obtained by oxidation of **12** with Dess−Martin periodinane,[12] using Dibal-H in the presence of anhydrous zinc chloride.[13] Likewise oxidation of alcohol **13** to ketone **15** followed by diastereoselective reduction exploiting the chirality of the sulfinyl group furnished alcohol **17**, Table 1. The diastereomeric carbinols were prepared to investigate the influence of the configuration of hydroxy and sulfinyl groups on the outcome of the reaction.

The *trans*-disubstituted cyclopropylcarbinols were prepared by the reaction[14] of the lithio anion of **7** with unsaturated esters **18**−**21** to furnish *β*-keto sulfoxides **22**−**25**, respectively. Diastereoselective reduction with Dibal-H in the presence of anhydrous zinc chloride yielded *β*-hydroxy sulfoxides **26**−**29**, respectively. Hydroxy group directed cyclopropanation afforded cyclopropanes **30**−**33**, Table 2. Epimeric alcohols **37**−**39** were prepared from **30**, **32**, and **33**, respectively, by an oxidation−reduction sequence.

The racemic alcohols **46** and **47** were prepared as depicted in Scheme 4. Aldehyde **40**, readily obtained by conjugate addition of thiophenol to methacolein,[15] was subjected to the Corey−Fuchs reaction.[16] Thus aldehyde **40** was reacted with carbon tetrabromide to yield the intermediate dibromoalkene that on treatment with *n*-BuLi and quenching with an excess of acetaldehyde afforded an equimolar inseparable mixture of propargylic alcohols **41**. Selective hydrogenation of the alkyne with nickel boride yielded allylic alcohols[17] **42** and **43** as separable isomers. Oxidation of sulfides individually afforded the corresponding sulfoxides as inseparable diastereomers, and further cyclopropanation yielded compounds **46** and **47**.

Oxymercuration−Demercuration of Cyclopropane Derivatives. Treatment of cyclopropane **12** with 2 equiv of mercuric trifluoroacetate in the presence of 0.5 equiv of mercuric oxide,[18] 1.3 equiv of water in 1,2-dichloroethane as the solvent in the dark overnight, afforded organomercurial **48** after treatment with aq potassium bromide. Demercuration of **48** with lithium borohydride[19] yielded 1,3-diol **49** as the

TABLE 2. Stereoselective Preparation of *trans*-Disubstituted and Trisubstituted Cyclopropylcarbinols[a]



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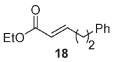
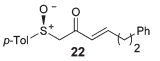
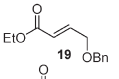
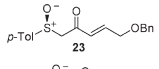
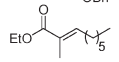
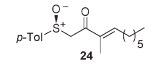
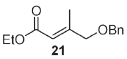
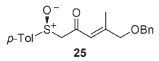
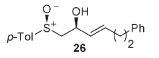
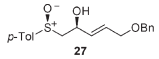
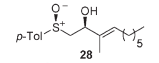
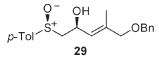
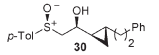
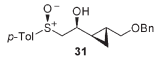
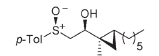
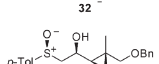
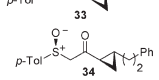
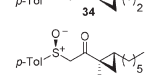
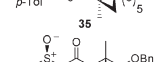
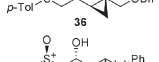
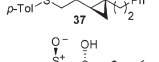
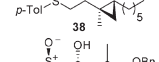
1	 **18**	a	 **22**	64
2	 **19**	a	 **23**	60
3	 **20**	a	 **24**	65
4	 **21**	a	 **25**	58
5	**22**	b	 **26**	89
6	**23**	b	 **27**	91
7	**24**	b	 **28**	93
8	**25**	b	 **29**	86
9	**26**	c	 **30**	92
10	**27**	c	 **31**	90
11	**28**	c	 **32**	93
12	**29**	c	 **33**	86
13	**30**	d	 **34**	90
14	**32**	d	 **35**	92
15	**33**	d	 **36**	90
16	**34**	e	 **37**	89
17	**35**	e	 **38**	92
18	**36**	e	 **39**	88

[a]Reagents and conditions: (a) LDA, THF, −40 to 0 °C. (b) Dibal-H, $ZnCl_2$, THF, −78 °C. (c) CH_2I_2, Et_2Zn, CH_2Cl_2, 1,2-DME, 0 °C to rt. (d) DMP, CH_2Cl_2, 0 °C. (e) Dibal-H, THF, −78 °C.

(8) See the Supporting Information for the preparation. No efforts were made to prepare single diastereomers since the product distribution from diastereomeric *β*-hydroxy sulfoxides was to be investigated.

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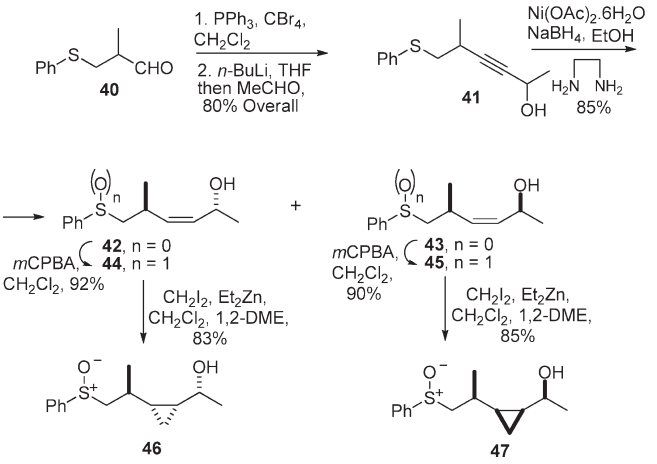
(17) The structure could not be assigned to cyclopropanes **46** and **47** at this stage. It could be assigned only based on the NOE analysis of the acetonide derived from **59**.

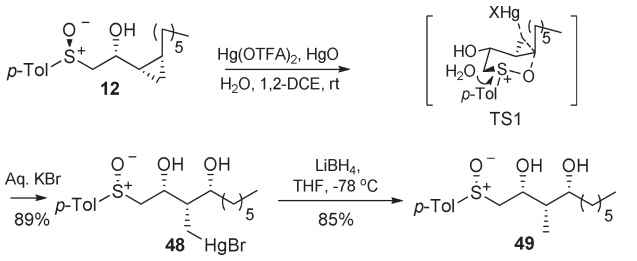
(18) Mercuric oxide sequesters the liberated trifluoroacetic acid thus preventing the reaction mixture from becoming acidic. For the use of HgO see: Giese, B.; Hueck, K. *Tetrahedron Lett.* **1980**, *21*, 1829.

(19) Takacs, J. M.; Helle, M. A.; Takusagawa, F. *Tetrahedron Lett.* **1989**, *30*, 7321.

SCHEME 4. Synthesis of Racemic Cyclopropylcarbinols 46 and 47



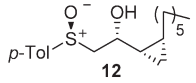
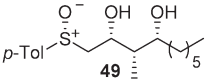
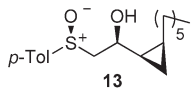
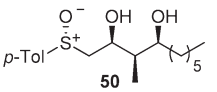
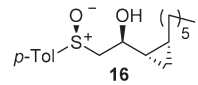
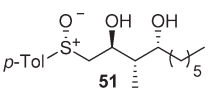
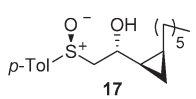
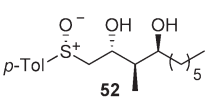
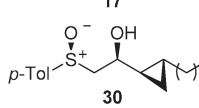
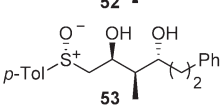
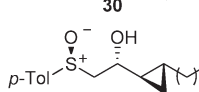
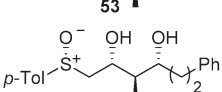
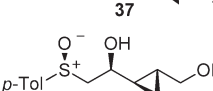
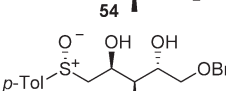
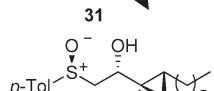
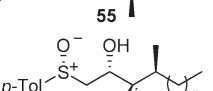
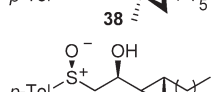
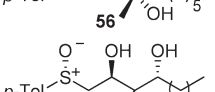
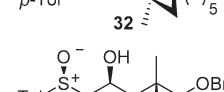
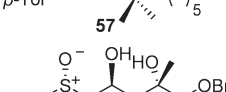
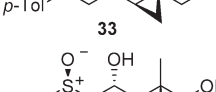
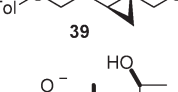
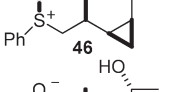
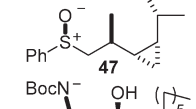
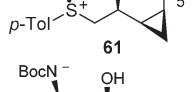
SCHEME 5. Stereo- and Regioselective Preparation of a *Syn*−*Syn* Stereotriad



sole product. Compound **48** is obtained stereoselectively via intramolecular 6-*endo* opening of the cyclopropane ring by the sulfinyl group,[20] TS1, Scheme 5. While compound **48** was characterized, the organomercuric bromides resulting from other cyclopropylcarbinols were not characterized and were directly subjected to demercuration with *n*-tributyltin hydride[21] in the presence of catalytic amounts of triethylborane in an oxygen atmosphere.[22] The sulfinyl group reduction to the corresponding sulfide, observed as a minor side reaction while using lithium borohydride as the reducing agent, was avoided by using *n*-tributyltin hydride. The results of oxymercuration−demercuration are collected in Table 3.

Cyclopropane **13**, wherein the sulfinyl oxygen and the hydroxy groups are relatively *syn*-disposed, furnished *syn* 1,3-diol **50** under the standard conditions. Diastereomers **12** and **13** are expected to react at different rates; however, in practice both of them were consumed after overnight stirring. Cyclopropane **16** afforded the *anti*−*syn* stereotriad **51** while **17** furnished diol **52**. These results clearly point to the absence of any influence of sulfur chirality on the regio- and stereoselectivity of diol formation and that it is controlled only by the relative configuration of the stereogenic centers

TABLE 3. Mercuric Trifluoroacetate Promoted Sulfinyl Group Opening of Cyclopropylcarbinol[a]

Entry	Substrate	Product	Yield (%)
1			85
2			84
3			82
4			75
5			78
6			73
7			76
8			72
9			74
10			76
11		b	
12			83
13		b	
14		b	
15		b	

[a]Reagents and conditions: (i) All reactions were carried out on 0.25 mmol scale in the presence of 2 equiv of $Hg(OTFA)_2$, 0.5 equiv of HgO, 1.3 equiv of water in 1,2-dichloroethane as solvent in the dark at rt for 16 h; (ii) Aq KBr; (iii) $n$$Bu_3SnH$, Et_3B, CH_2Cl_2. [b]Recovered unreacted starting material.

of the cyclopropane ring. This in practical terms avoids the necessity of working with diastereomerically pure sulfoxides and preparing the cyclopropylcarbinols only via the route

(20) The inversion of sulfur configuration is expected based on precedented electrophile promoted nucleophilic sulfinyl group heterofunctionalization of alkenes, see ref 3.

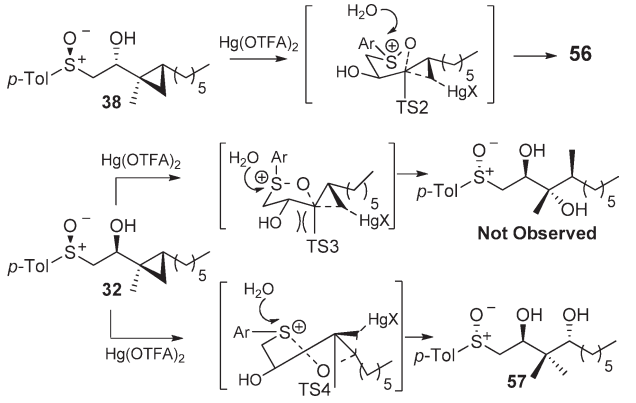
(21) (a) Whitesides, G. M.; San Fillipo, J., Jr. *J. Am. Chem. Soc.* **1970**, *92*, 6611. (b) Kang, S. H.; Lee, J. H.; Lee, S. B. *Tetrahedron Lett.* **1988**, *39*, 59 and references cited therein. (c) Evans, D. A.; Bender, S. L.; Morris, J. *J. Am. Chem. Soc.* **1988**, *110*, 2506.

(22) Miura, K.; Ichinose, Y.; Nozaki, K.; Fugami, K.; Oshima, K.; Utimoto, K. *Bull. Chem. Soc. Jpn.* **1989**, *62*, 143.

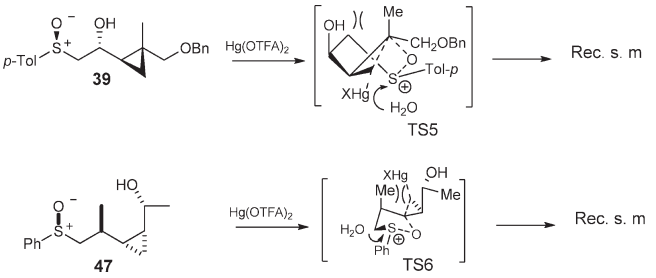
indicated earlier, using unsaturated carbonyl compounds and optically pure methyl *p*-tolyl sulfoxide. Many a route can be envisioned for the preparation of chiral allylic alcohols[23] and chiral cyclopropanes.[24] The *trans*-cyclopropane **30** cleanly afforded the *syn*−*anti* stereotriad **53**. In a similar fashion, cyclopropane **37** afforded the *anti*−*anti* stereotriad **54**. On the basis of the kinetic preference for 5- versus 6-membered ring formation in neighboring group assisted reactions[25] it was interesting to observe exclusive 6-*endo* opening of cyclopropylcarbinols. This can be rationalized by the deactivating inductive effect of the hydroxy group, which would destabilize a partial positive charge at the adjacent carbon. Given this backdrop, it is noteworthy that cyclopropane **31** underwent ring-opening and also regioselectively to furnish **55** as the only product. Thus beginning with *cis*- and *trans*-cyclopropylcarbinols all four stereotriads can be synthesized. Cyclopropane **38** afforded exclusively 1,2-diol **56** constituting adjacent tertiary and quaternary stereogenic centers. This result is significant since asymmetric dihydroxylation of trisubstituted alkenes has been reported to afford 1,2-diols with poor enantioselectivity[26] and diastereoselectivity.[27] Cyclopropane **32** furnished 1,3-diol **57** regio- and stereoselectively. The 2,2-dimethyl-1,3-diol motif of **57** is commonly observed in many natural products, Figure 1. The formation of **56** can be rationalized by Markonikov's rule, the methyl group at C3 in the putative transition state TS2 probably stabilizes the developing partial positive charge. The formation of **57** can be explained by the presence of A1,2 steric interactions between the hydroxy and cyclopropyl ring in transition state TS3 during 5-*exo* opening, which is avoided in a twist chair conformation in transition state TS4 during 6-*endo* opening, Scheme 6.

Cyclopropane **33** cleanly afforded **58**, the product of 6-*endo* opening expected due to the inductive stabilizing effect of the methyl group. Entries 7 and 10 are to the best of our knowledge the only examples of successful oxymercuration of cyclopropanes flanked by hydroxy substituents on both carbon atoms.[4b] Cyclopropane **39** returned only unreacted starting material even after prolonged reaction periods. This may be explained due to the unfavorable A1,3 steric interactions between OH- and Me-groups in transition state TS5, Scheme 7. The cyclopropanes **46** and **47** flanked by stereogenic centers on both sides were next subjected to the

SCHEME 6. Probable Transition States for the Formation of 56 and 57



SCHEME 7. Rationalization of Unreactivity of 39 and 47



oxymercuration−demercuration sequence. Compound **46** reacted without incident to furnish *anti*−*syn*−*syn* stereotetrad **59** via 5-*exo* opening. On the other hand **47** returned only unreacted starting material.[28] The recalcitrant behavior of **47** probably may be rationalized by the presence of unfavorable A1,3 steric interactions between the Me- and OH-substituents in the 5-*exo* opening transition state TS6, Scheme 7.

The intramolecular opening of the cyclopropane ring by a sulfilimine group was next explored as a possible stereoselective route to 1,3-amino alcohols. The sulfilimines **61** and **63** were prepared by treatment of sulfides, obtained by the reduction[29] of sulfoxides **13** and **30**, respectively, with Na*N*ClBoc[30] in acetonitrile. Oxymercuration−demercuration under standard conditions returned only unreacted starting materials after prolonged reaction periods. The reason for the sulfilimines failing to open the cyclopropyl ring is probably due to the unfavorable steric interactions between the nitrogen substituent and the cyclopropane ring in the transition state for ring-opening. See the Supporting Information for the preparation of sulfilimines.

On the basis of the mechanism, an inversion of configuration is expected at sulfur and at the electrophilic carbon. The structure of diol **53**, obtained from **30**, was proven by X-ray crystallography. The structure of the other products was assigned based on analogy and further confirmed by ^{1}H NMR-NOE analysis of the acetonides derived from the diols.

(23) For the preparation of allylic alcohols by asymmetric vinylation of aldehydes see: (a) Salvi, L.; Jeon, S.-J.; Fisher, E. L.; Carroll, P. J.; Walsh, P. J. *J. Am. Chem. Soc.* **2007**, *129*, 16119. (b) Lurain, A. E.; Carroll, P. J.; Walsh, P. J. *J. Org. Chem.* **2005**, *70*, 1262. (c) Oppolzer, W.; Radinov, R. N. *J. Am. Chem. Soc.* **1993**, *115*, 1593. (d) Wipf, P.; Ribe, S. *J. Org. Chem.* **1998**, *63*, 6454. (e) Srebnik, M. *Tetrahedron Lett.* **1991**, *32*, 2449. (f) Hart, D. W.; Schwartz, J. *J. Am. Chem. Soc.* **1974**, *96*, 8115.

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(28) The *trans*-cyclopropanes corresponding to **46** and **47** are expected to react without any incident to furnish *anti*−*anti*−*syn* and *syn*−*anti*−*syn* stereotetrads. Unlike *cis*-allylic alcohols **42** and **43** that could be separated, the corresponding *trans*-allylic alcohols, obtained by reduction of **41** with Red-Al, could not be separated. Therefore further sulfoxide preparation and cyclopropanation was not attempted.

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Conclusion

The following conclusions can be drawn: (a) The reaction is general in nature and proceeds with equal facility on di- and trisubstituted cyclopropylcarbinols. (b) The reaction proceeds highly regioselectively and the outcome can be rationalized by the destabilizing inductive effect of the hydroxy/stabilizing inductive effect of the methyl groups. (c) The reaction proceeds with clean inversion of configuration at the electrophilic carbon and sulfur atoms. (d) The reaction can be considered to be complementary to other routes to stereotriads/stereotetrads such as the two-step epoxidation followed by dimethyl cuprate opening of allylic alcohols, hydroboration, and hydrosilylation reactions. (e) The methodology has predictive value for use in total synthesis. (f) The products in addition to possessing alternating hydroxy and methyl groups also possess the sulfinyl group that provides a versatile handle for further carbon−carbon and carbon−heteroatom bond formations. The sulfinyl group may be exploited for further carbon−carbon bond forming reactions like alkylation,[31] Pummerer followed by ene reaction,[32] and as chiral ligands.[33] Also the rich chemistry of α-chloro sulfides[34] can be taken advantage of by reduction of sulfoxides to sulfides.

In summary, we have disclosed for the first time a highly regio- and stereoselective synthesis of diastereomeric stereotriads and tetrads by oxymercuration−demercuration of cyclopropylcarbinols employing an intramolecular sulfinyl group as the nucleophile. The reaction proceeds with equal facility on di- and trisubstituted alkenes to furnish products possessing tertiary and quaternary stereogenic centers. It is noteworthy that the sulfinyl group is tolerated under the Furukawa's cyclopropanation conditions. However, there are some limitations: the reaction did not proceed using sulfilimines as intramolecular nucleophiles. The application of the methodology in the synthesis of polypropionate containing natural products is currently underway and shall be disclosed in due course.

Experimental Section

Compound 9: To a solution of diisopropylamine (1.47 mL, 10.6 mmol) in dry THF (20 mL) at 0 °C under nitrogen atmosphere was added *n*-BuLi (3.85 mL, 2.5 M in hexanes, 9.64 mmol) dropwise with stirring for 15 min. The mixture was then cooled to −40 °C and a solution of sulfoxide **7** (1.36 g, 8.84 mmol) in dry THF (8 mL) was added dropwise with stirring for 30 min. The reaction mixture was then cooled to −78 °C and a solution of the crude aldehyde obtained above (1.2 g, 8.84 mmol) in dry THF (16 mL) was added dropwise. After 30 min at −78 °C the reaction was quenched by the addition of an aqueous saturated ammonium chloride solution. The reaction mixture was diluted with ether (20 mL) and the layers were separated. The organic layer was washed with water and brine, dried over Na_2SO_4, and evaporated to afford the crude product, which was purified by column chromatography (30% EtOAc/hexanes, v/v) to afford a ∼1:1 mixture of diastereomers in 90% combined yield (2.32 g, 7.96 mmol). Pale yellow liquid; R_f 0.25 (30% EtOAc/hexanes, v/v); IR (neat) 3416, 2958, 2925, 2855, 1638, 1459, 1386, 1083, 1028, 752 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.55 (d, J = 7.8 Hz, 2H), 7.53 (d, J = 7.8 Hz, 2H), 7.31 (d, J = 7.8 Hz, 4H), 4.83−4.75 (m, 2H), 3.27 (dd, J = 12.7, 6.8 Hz, 1H), 3.07 (dd, J = 12.7, 8.8 Hz, 1H), 2.98−2.90 (m, 2H), 2.42 (s, 6H), 2.21−2.12 (m, 4H), 1.5−1.20 (m, 16H), 0.92−0.83 (m, 6H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 141.7, 141.6, 139.5, 139.1, 124.1, 123.9, 87.3, 86.7, 78.5, 78.4, 64.4, 63.9, 58.2, 56.9, 31.1, 28.3, 28.2, 22.3, 21.2, 18.5, 13.8; MS (ESI) 315 $[M + Na]^+$; HRMS (ESI) m/z $[M + Na]^+$ calcd for $C_{17}H_{24}O_2NaS$ 315.1552, found 315.1546.

General Procedure for the Reduction of Propargylic Alcohols to Allylic Alcohols. To a suspension of $Ni(OAc)_2 \cdot 4H_2O$ (1 equiv) in ethanol (0.11 M) was added sodium borohydride (1 equiv) portionwise at rt. The mixture was maintained under hydrogen atmosphere and stirred at rt for 1 h. Ethylenediamine (4 equiv) was added, followed by a solution of propargylic alcohol (1 equiv) in ethanol (0.5 M). After completion of the reaction, the reaction mixture was filtered and the solids washed with ethanol twice. The combined filtrates were evaporated. The crude residue was diluted with ethyl acetate washed successively with aq 1 N HCl, aq saturated sodium bicarbonate, water, and brine, dried over Na_2SO_4, and concentrated to furnish the crude product.

The crude compound obtained from **9** following the general procedure detailed above was purified by column chromatography (22% EtOAc/hexanes, v/v) to afford the allylic alcohols **10** and **11** in an equimolar ratio in 89% combined yield.

Compound 10: colorless liquid; R_f 0.25 (35% EtOAc/hexanes, v/v); $[\alpha]^{25}_D$ −63 (*c* 1, $CHCl_3$); IR (neat) 3356, 2955, 2925, 2855, 1459, 1397, 1083, 1030, 809 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.52 (d, J = 8.1 Hz, 2H), 7.34 (d, J = 8.1 Hz, 2H), 5.45−5.29 (m, 2H), 5.01−4.90 (m, 1H), 3.10 (dd, J = 13.6, 10.0 Hz, 1H), 2.50 (dd, J = 13.6, 1.7 Hz, 1H), 2.44 (s, 3H), 1.91−1.56 (m, 2H), 1.46−1.05 (m, 8H), 0.89 (t, J = 7.3 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 140.9, 139.6, 132.1, 129.7, 129.6, 123.6, 62.9, 62.2, 31.4, 29.1, 28.7, 27.4, 22.3, 21.1, 13.8; MS (ESI) 295 $[M + H]^+$; HRMS (ESI) m/z $[M + Na]^+$ calcd for $C_{17}H_{26}O_2NaS$ 317.1565, found 317.1551.

Compound 11: colorless liquid; R_f 0.25 (40% EtOAc/hexanes, v/v); $[\alpha]^{25}_D$ −18.2 (*c* 1, $CHCl_3$); IR (neat) 3356, 2955, 2925, 2855, 1459, 1397, 1083, 1030, 809 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ 7.52 (d, J = 8.3 Hz, 2H), 7.30 (d, J = 8.3 Hz, 2H), 5.56−5.30 (m, 2H), 4.97 (dt, J = 8.3, 3.8 Hz, 1H), 3.05 (dd, J = 12.8, 8.3 Hz, 1H), 2.65 (dd, J = 12.8, 3.8 Hz, 1H), 2.42 (s, 3H), 2.14−1.92 (m, 2H), 1.45−1.15 (m, 8H), 0.89 (t, J = 6.8 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 141.5, 140.1, 132.9, 129.7, 129.6, 124.0, 63.8, 63.7, 31.3, 29.1, 28.6, 27.4, 22.3, 21.1, 13.8; MS (ESI) 295 $[M + H]^+$.

General Procedure for Cyclopropanation with Furukawa's Protocol. A mixture of dichloromethane (0.15 M) and 1,2-dimethoxyethane (3 equiv) was cooled to −10 °C with an ice-salt bath. Diethyl zinc (1 M/hexane, 3 equiv) was added followed by diiodomethane (6 equiv) over a period of 10 min while the temperature was maintained below −5 °C. After the addition was complete, the resulting clear solution was stirred for 45 min at 0 °C. A solution of allylic alcohol (1 equiv) in dichloromethane (0.25 M) was added via canula under argon atmosphere over a 5−10 min period while maintaining the temperature below −5 °C. The cooling bath was removed and the reaction mixture was allowed to warm to room temperature and stirred for 12−18 h at that temperature. The reaction was quenched with aq saturated ammonium chloride and aq 10% hydrochloric acid. The two layers were separated and the aq layer was extracted with dichloromethane twice. The combined organic phases were washed successively with aq saturated sodium sulphite, aq saturated sodium bicarbonate, and brine. The organic layer was dried over Na_2SO_4, filtered, and concentrated to furnish the crude product.

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Compound 12: The crude compound was purified by column chromatography (35% EtOAc/hexanes, v/v) to afford the cyclopropylcarbinol **12** (277 mg, 0.90 mmol) as a single diastereomer in 90% yield. Colorless liquid; R_f 0.25 (40% EtOAc/hexanes, v/v); $[\alpha]^{25}_D$ −90 (*c* 1, $CHCl_3$); IR (neat) 3370, 2955, 2924, 2854, 1459, 1399, 1299, 1027, 810, 504 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.46 (d, J = 8.3 Hz, 2H), 7.26 (d, J = 8.3 Hz, 2H), 3.69−3.58 (m, 1H), 3.10 (dd, J = 12.8, 9.8 Hz, 1H), 2.67 (dd, J = 12.8, 1.5 Hz, 1H), 2.37 (s, 3H), 1.32−1.06 (m, 10H), 0.84 (t, J = 6.8 Hz, 3H), 0.76−0.58 (m, 3H), 0.15−0.06 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 141.1, 139.5, 129.7, 123.7, 67.3, 62.1, 31.5, 29.9 28.8, 28.1, 22.4, 21.6, 21.1, 15.7, 13.8, 10.1; MS (ESI) 309 $[M + H]^+$; HRMS (ESI) m/z $[M + Na]^+$ calcd for $C_{18}H_{28}O_2NaS$ 331.1720, found 331.1707.

General Procedure for the Oxidation of Cyclopropylcarbinols to Cyclopropylketones. Dess−Martin periodinane (1.3 equiv) was added to the solution of cyclopropyl carbinol (1 equiv) in dichloromethane (0.2 M) at 0 °C and the reaction mixture was stirred for 30 min at the same temperature. The reaction mixture was diluted with dichloromethane, the precipitated solid was filtered, and the filtrate was washed with aq saturated sodium bicarbonate, water, and brine, dried over Na_2SO_4, and concentrated to furnish the crude product.

Compound 14: The crude compound obtained following the procedure detailed above was purified by column chromatography (30% EtOAc/hexanes, v/v) to afford the ketone **14** (0.44 mmol) in 89% yield. Viscous liquid; R_f 0.25 (30% EtOAc/hexanes, v/v); $[\alpha]^{25}_D$ −13 (*c* 1, $CHCl_3$); IR (neat) 2976, 2930, 2107, 1727, 1546, 1373, 1282, 1188, 1026, 804 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.54 (d, J = 8.1 Hz, 2H), 7.31 (d, J = 8.1 Hz, 2H), 3.96 (d, J = 13.6 Hz, 1H), 3.91 (d, J = 13.6 Hz, 1H), 2.41 (s, 3H), 2.15−2.05 (m, 1H), 1.55−1.44 (m, 1H), 1.43−1.34 (m, 2H), 1.33−1.14 (m, 8H), 1.12−0.97 (m, 2H), 0.86 (t, J = 7.2 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 200.0, 141.9, 139.6, 129.9, 124.1, 69.6, 39.6, 29.7, 28.8, 27.9, 27.4, 26.0, 22.4, 21.3, 16.4, 13.9; MS (ESI) 307 $[M + H]^+$; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{18}H_{27}O_2S$ 307.1734, found 307.1731.

Compound 16: A solution of the mixture of the keto sulfoxide **14** (132 mg, 0.43 mmol) and anhydrous $ZnCl_2$ (70 mg, 0.52 mmol) in dry THF (4 mL) was stirred at rt for 30 min. The mixture was cooled to −78 °C and DIBAL-H (0.46 mL, 1.4M/toluene) was added dropwise. After 1 h at −78 °C the reaction was quenched by the addition of methanol (1 mL). The reaction mixture was allowed to warm to rt. The volatiles were evaporated under reduced pressure to afford the crude product. Water and EtOAc were added at this stage and the solution was adjusted to pH 2 by the addition of 5% aq H_2SO_4 solution. The aqueous phase was extracted with ethylacetate. The combined organic layers were washed successively with water and brine, dried over Na_2SO_4, and concentrated to furnish the crude product. The crude compound was purified by column chromatography (35% EtOAc/hexanes, v/v) to afford the cyclopropylcarbinol **16** (122 mg, 0.39 mmol) as a single diastereomer in 90% yield. Yellow liquid; R_f 0.25 (40% EtOAc/hexanes, v/v); $[\alpha]^{25}_D$ −40.5 (*c* 1, $CHCl_3$); IR (neat) 3370, 2955, 2924, 2854, 1459, 1399, 1299, 1027, 810, 504 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.53 (d, J = 8.1 Hz, 2H), 7.32 (d, J = 8.1 Hz, 2H), 3.82 (td, J = 8.8, 2.8 Hz, 1H), 3.06 (dd, J = 13.1, 8.8 Hz, 1H), 2.88 (dd, J = 13.1, 2.8 Hz, 1H), 2.43 (s, 3H), 1.71−1.57 (m, 1H), 1.55−1.39 (m, 2H), 1.39−1.14 (m, 7H), 1.05−0.83 (m, 5H), 0.72−0.63 (m, 1H), −0.01−0.07 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 141.6, 140.5 129.9, 123.8, 69.5, 63.3, 31.9, 29.7, 29.1, 28.4, 22.5, 22.1, 21.3, 16.8, 13.9, 9.2; MS (ESI) 309 $[M + H]^+$.

Compound 17: To a solution of ketone **15** (138 mg, 0.45 mmol) in anhydrous THF (4.5 mL) cooled at −78 °C was added a solution of DIBAL-H (0.48 mL, 1.4 M/toluene). After 1 h at −78 °C, the reaction was quenched by the addition of methanol. The volatiles were evaporated under reduced pressure to afford the crude product, water and EtOAc were added at this stage, then the solution was adjusted to pH 2 by the addition of 5% aq H_2SO_4 solution. The aqueous phase was extracted with ethyl acetate. The combined organic layers were washed successively with water and brine, dried over Na_2SO_4, and concentrated to furnish the crude product. The crude compound was purified by column chromatography (35% EtOAc/hexanes, v/v) to afford the cyclopropylcarbinol **17** (120 mg, 0.39 mmol) as a single diastereomer in 86% yield. Colorless liquid; R_f 0.25 (40% EtOAc/hexanes, v/v); $[\alpha]^{25}_D$ −79.5 (*c* 1, $CHCl_3$); IR (neat) 3370, 2955, 2924, 2854, 1459, 1399, 1299, 1027, 810, 504 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.51 (d, J = 8.1 Hz, 2H), 7.33 (d, J = 8.1 Hz, 2H), 3.74 (td, J = 9.8, 1.7 Hz, 1H), 3.12 (dd, J = 13.4, 9.8 Hz, 1H), 2.84 (dd, J = 13.4, 1.7 Hz, 1H), 2.42 (s, 3H), 1.62−1.47 (m, 1H), 1.46−0.93 (m, 11H), 0.87 (t, J = 7.0 Hz, 3H), 0.67−0.56 (m, 1H), −0.22−0.31 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 141.3, 139.9, 129.9, 123.9, 67.4, 63.1, 31.7, 29.8, 29.1, 28.4, 22.6, 22.0, 21.3, 17.1, 14.0, 9.1; MS (ESI) 309 $[M + H]^+$.

General Procedure for Preparation of β-Keto Sulfoxides. A solution of *n*-BuLi (1.6 M/hexanes 1.05 equiv) was added to a solution of diisopropylamine (1.1 equiv) in dry THF (0.33 M) at 0 °C. After 15 min the resulting lithium diisopropylamide solution was cooled to −40 °C and the solution of (*S*)-methyl *p*-tolylsulfoxide (1 equiv) in dry THF (0.88 M) was added dropwise and stirred at the same temperature for 30 min. The temperature was allowed to rise to 0 °C and the solution of the ester (0.5 equiv) in THF (0.88 M) was added dropwise. The reaction was stirred further for a period of 1 h at 0 °C. The reaction was quenched by the addition of an aq saturated NH_4Cl solution and then the solution adjusted to pH 2 by the addition of aq 5% H_2SO_4 solution. The two layers were separated and the aqueous phase extracted with ethyl acetate. The combined organic layers were washed successively with water and brine, dried over Na_2SO_4, and concentrated to furnish the crude product.

Compound 22: The crude compound obtained following the general procedure was purified by column chromatography (30% EtOAc/hexanes, v/v) to afford the β-keto sulfoxide **22** (6.4 mmol) in 64% yield. Viscous liquid; R_f 0.25 (45% EtOAc/hexanes, v/v); $[\alpha]^{25}_D$ −75.2 (*c* 1, $CHCl_3$); IR (neat) 2925, 2856, 1669, 1622, 1496, 1453, 1327, 1130, 1044, 809 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.50 (d, J = 8.3 Hz, 2H), 7.30 (d, J = 8.3 Hz, 2H), 7.28−7.10 (m, 5H), 6.86 (td, J = 15.9, 6.8 Hz, 1H), 6.12 (d, J = 15.9 Hz, 1H), 3.99 (d, J = 13.6 Hz, 1H), 3.81 (d, J = 13.6 Hz, 1H), 2.77 (t, J = 6.8 Hz, 2H), 2.55 (q, J = 6.8 Hz, 2H), 2.44 (s, 3H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 190.1, 149.7, 141.3, 139.8, 139.3, 130.0, 129.4, 127.9, 127.7, 125.6, 123.6, 65.6, 33.6, 33.4, 20.8; MS (ESI) 335 $[M + Na]^+$; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{18}H_{21}O_2S$ 313.1270, found 313.1262.

Compound 26: The crude compound, obtained following the procedure detailed for the preparation of **16** from **14**, was purified by column chromatography (50% EtOAc/hexanes, v/v) to afford the hydroxy sulfoxide **26** (1.79 mmol) as a single diastereomer in 89% yield. Colorless liquid; R_f 0.27 (50% EtOAc/hexanes, v/v); $[\alpha]^{25}_D$ −87.4 (*c* 1, $CHCl_3$); IR (neat) 3349, 2923, 2855, 1494, 1453, 1304, 1085, 1030, 972, 810, 700 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.53 (d, J = 8.3 Hz, 2H), 7.33 (d, J = 8.3 Hz, 2H), 7.28−7.09 (m, 5H), 5.82 (dt, J = 15.1, 6.7 Hz, 1H), 5.47 (dd, J = 15.1, 6.0 Hz, 1H), 4.76−4.67 (m, 1H), 2.96 (dd, J = 12.8, 9.1 Hz, 1H), 2.72 (dd, J = 12.8, 3.1 Hz, 1H), 2.69 (t, J = 8.3 Hz, 2H), 2.43 (s, 3H), 2.35 (q, J = 7.5 Hz, 2H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 141.4, 141.2, 140.1, 131.9, 130.6, 129.7, 128.1, 127.9, 125.5, 123.9, 68.4, 63.4, 35.0, 33.5, 21.1; MS (ESI) 315 $[M + H]^+$; HRMS (ESI) m/z $[M + Na]^+$ calcd for $C_{19}H_{22}O_2NaS$ 337.1234, found 337.1238.

Compound 41: A two-necked round-bottomed flask, equipped with a magnetic stir bar, rubber septum, an additional

funnel fitted with a rubber septum, and an argon inlet, is charged with carbon tetrabromide (8 g, 24 mmol) and then dry dichloromethane (30 mL) is added. The solution is cooled in an ice bath and a solution of triphenylphosphine (12.6 g, 48 mmol) in dry dichloromethane (30 mL) is then added dropwise via the additional funnel over 20 min. The reaction mixture is stirred at 0 °C for 10 min, and then the solution of the aldehyde (2.16 g, 12 mmol) in dichloromethane (20 mL) is added over 5 min via cannula. The solution is stirred at 0 °C for 1 h, and then water is added. The water layer is separated, then extracted 3 times with CH_2Cl_2 (30 mL). The combined organic layers were washed with brine, dried over Na_2SO_4, filtered, and concentrated. The residue was diluted with diethyl ether (50 mL), cooled to 0 °C, and filtered. This was repeated 4 times. The ether layers were concentrated and the residue was purified by small flash column chromatography. The product was directly used in the next step. Yield 95% (11.4 mmol). To a solution of the above dibromo compound in tetrahydrofuran (95 mL) cooled at −78 °C was added *n*-butyllithium (10.1 mL, 2.5 M, 25 mmol). The reaction mixture was stirred at the same temperature for 30 min, then a solution of acetaldehyde (14 mmol) in tetrahydrofuran (15 mL) was added dropwise with cannula. After 30 min the reaction was quenched by adding aq saturated ammonium chloride. The aq layer was separated and reextracted with ether. The combined organic layers were washed successively with water and brine, dried over Na_2SO_4, and evaporated. The crude product was purified by column chromatography with 15% EtOAc/hexanes (v/v) to afford the sulfide **41** as an inseperable mixture (9.69 mmol) in 80% yield. Orange liquid; R_f 0.25 (20% EtOAc/hexanes, v/v); IR (neat) 3418, 2975, 2926, 1634, 1582, 1442, 1326, 1074, 1023, 740 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.27 (d, J = 7.4 Hz, 2H), 7.18 (t, J = 7.5 Hz, 2H), 7.10 (t, J = 7.0 Hz, 1H), 4.45−4.31 (m, 1H), 3.01 (dd, J = 13.0, 6.6 Hz, 1H), 2.79 (dd, J = 13.0, 7.3 Hz, 1H), 2.68−2.39 (m, 1H), 1.30 (d, J = 6.6 Hz, 3H), 1.16 (d, J = 6.8 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 135.9, 129.5, 128.7, 126.1, 86.5, 83.6, 58.0, 40.4, 26.1, 24.3, 19.9; MS (ESI) 221 $[M + H]^+$; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{13}H_{17}OS$ 221.0994, found 221.1000.

Compounds 42 and 43: The crude compound obtained by reduction of **41**, following the procedure mentioned earlier for the synthesis of **10** and **11** from **9**, was purified by column chromatography (12% EtOAc/hexanes, v/v) to afford the allylic alcohols roughly as a 1:1 mixture of diasteriomers in 85% combined yield. Compound **42**: pale yellow liquid; R_f 0.22 (20% EtOAc/hexanes, v/v); IR (neat) 3376, 2965, 2924, 1582, 1478, 1442, 1371, 1059, 1027, 740 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.36−7.22 (m, 4H), 7.22−7.11 (m, 1H), 5.44 (dd, J = 10.9, 8.8 Hz, 1H), 5.25 (dd, J = 9.8, 8.8 Hz, 1H), 4.54−4.42 (m, 1H), 2.95−2.72 (m, 3H), 1.24 (d, J = 6.2 Hz, 3H), 1.13 (d, J = 6.4 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 136.5, 134.4, 133.8, 128.8, 128.7, 125.7, 63.9, 40.6, 32.0, 23.6, 20.7; MS (ESI) 261 $[M + O + H]^+$. Compound **43**: pale yellow liquid; R_f 0.20 (20% EtOAc/hexanes, v/v); IR (neat) 3376, 2965, 2924, 1582, 1478, 1442, 1371, 1059, 1027, 740 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.38−7.22 (m, 4H), 7.22−7.13 (m, 1H), 5.46 (dd, J = 10.5, 9.0 Hz, 1H), 5.16 (dd, J = 10.5, 9.6 Hz, 1H), 4.50−4.37 (m, 1H), 2.95 (dd, J = 12.0, 3.7 Hz, 1H), 2.87−2.75 (m, 1H), 2.71 (dd, J = 12.0, 8.3 Hz, 1H), 1.19 (d, J = 6.0 Hz, 3H), 1.08 (d, J = 6.0 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 136.2, 134.5, 134.4, 129.1, 128.9, 126.1, 63.3, 40.6, 32.4, 22.9, 21.0; MS (ESI) 261 $[M + O + H]^+$; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{13}H_{19}O_2S$ 239.1110, found 239.1105.

Compound 44: To a solution of the sulfide **42** (1.48 g, 6 mmol) in dichloromethane (30 mL) cooled at −40 °C was added *m*-CPBA (6 mmol) and the progress of the reaction was followed by TLC. After 1 h the reaction mixture was diluted with dichloromethane, washed successively with aq saturated $NaHSO_3$, aq saturated $NaHCO_3$, water, and brine, dried over anhydrous Na_2SO_4, and evaporated. The crude product was purified by column chromatography with (50% EtOAc/hexanes, v/v) to afford an equimolar inseparable mixture of diastereomeric sulfoxides **44** (5.60 mmol) in 92% yield. Viscous liquid; R_f 0.25 (60% EtOAc/hexanes, v/v); IR (neat) 3394, 2965, 2925, 1723, 1447, 1294, 1086, 1020, 750, 694 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.64−7.56 (m, 4H), 7.55−7.43 (m, 6H), 5.68 (dd, J = 10.5, 9.4 Hz, 1H), 5.37 (dd, J = 10.5, 9.4 Hz, 1H), 5.27 (t, J = 10.7 Hz, 1H), 5.12 (t, J = 10.7 Hz, 1H), 4.72−4.58 (m, 2H), 3.48−3.22 (m, 2H), 2.91 (dd, J = 12.4, 4.1 Hz, 1H), 2.85 (dd, J = 13.2, 6.9 Hz, 1H), 2.62 (dd, J = 13.2, 6.2 Hz, 1H), 2.46 (dd, J = 12.4, 11.7 Hz, 1H), 1.26 (d, J = 6.2 Hz, 3H), 1.23 (d, J = 6.2 Hz, 3H), 1.18 (d, J = 6.8 Hz, 3H), 1.09 (d, J = 6.8 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 143.6, 143.3, 135.5, 134.3, 133.3, 133.0, 131.5, 131.2, 129.4, 129.3, 124.0, 123.9, 64.1, 63.8, 63.1, 62.4, 28.3, 27.8, 23.2, 22.6, 21.2, 20.8; MS (ESI) 239 $[M + H]^+$; HRMS (ESI) m/z $[M + Na]^+$ calcd for $C_{13}H_{18}O_2NaS$ 261.0929, found 261.0925.

Compound 48: To a solution of cyclopropylcarbinol (0.25 mmol) in 1,2-dichloroethane (2 mL, 0.13 M) and water (0.33 mmol) was added mercuric trifluoroacetate (0.5 mmol) and HgO (0.13 mmol). The reaction was stirred in the dark at rt for 16 h under nitrogen atmosphere. The reaction was quenched by the addition of aq KBr and extracted with dichloromethane. The organic layer was washed with water and brine, dried over Na_2SO_4, and evaporated to furnish the crude organomercuric bromide, which was purified by column chromatography to afford the compound **48** (133 mg, 0.22 mmol) as a single diastereomer in 89% yield. Amorphous solid; mp 155−156 °C; R_f 0.25 (40% EtOAc/hexanes, v/v); $[\alpha]^{25}_D$ +37 (c 1, $CHCl_3$); IR (neat) 3446, 2929, 2855, 1636, 1512, 1249, 1089, 1035, 835 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.59 (d, J = 8.3 Hz, 2H), 7.36 (d, J = 8.3 Hz, 2H), 4.70−4.58 (m, 1H), 4.07−3.94 (m, 1H), 3.32 (dd, J = 12.8, 9.8 Hz, 1H), 2.81 (dd, J = 12.8, 1.8 Hz, 1H), 2.44 (s, 3H), 2.15−2.06 (m, 1H), 1.66−1.44 (m, 2H), 1.43−1.17 (m, 10H), 0.88 (t, J = 6.8 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 142.5, 138.6, 130.3, 124.5, 74.2, 71.7, 60.9, 46.2, 34.8, 31.7, 29.5, 29.1, 25.9, 22.5, 21.4, 14.0; MS (ESI) 606 $[M]^+$; HRMS (ESI) m/z $[M + Na]^+$ calcd for $C_{18}H_{29}O_3NaSHgBr$ 629.1045, found 629.1049.

Compound 49: To the solution of the organomercuric bromide **48** (130 mg, 0.22 mmol) in THF (2.2 mL) cooled at −78 °C was added lithium borohydride (0.14 mL, 2 M in THF, 0.28 mmol) dropwise when mercury began to precipitate almost immediately. The reaction mixture was stirred at −78 °C for 1 h. The reaction mixture was quenched with aq saturated NH_4Cl solution and extracted with ethyl acetate. The combined extracts were washed with brine, dried over Na_2SO_4, and concentrated to furnish the crude product. The crude compound was purified by column chromatography (40% EtOAc/hexanes, v/v) to afford the diol **49** (68 mg, 0.21 mmol) as a single diastereomer in 85% yield. Viscous liquid; R_f 0.25 (45% EtOAc/hexanes, v/v); $[\alpha]^{25}_D$ +39 (c 1, $CHCl_3$); IR (neat) 3446, 2929, 2855, 1636, 1512, 1249, 1089, 1035, 835 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ 7.52 (d, J = 8.3 Hz, 2H), 7.32 (d, J = 8.3 Hz, 2H), 4.44 (dt, J = 9.8, 2.6 Hz, 1H), 3.91−3.77 (m, 1H), 3.04 (dd, J = 12.9, 9.1 Hz, 1H), 2.70 (dd, J = 12.9, 2.3 Hz, 1H), 2.43 (s, 3H), 1.92−1.73 (m, 2H), 1.62−1.13 (m, 9H), 0.91 (d, J = 7.6 Hz, 3H), 0.89 (t, J = 8.3 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 142.1, 140.2, 130.2, 123.9, 75.5, 73.2, 60.7, 41.6, 34.9, 31.8, 29.3, 26.0, 22.6, 21.4, 14.1, 5.4; MS (ESI) 327 $[M + H]^+$; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{18}H_{31}O_3S$ 327.2006, found 327.1993.

General Procedure for Oxymercuration−Demercuration of Cyclopropylcarbinols. To a solution of cyclopropylcarbinol (0.25 mmol) in 1,2-dichloroethane (2 mL, 0.13 M) and water (0.33 mmol) was added mercuric trifluoroacetate (0.5 mmol) and HgO (0.13 mmol). The reaction was stirred in the dark at rt for 16 h under nitrogen atmosphere. The reaction was quenched

by the adittion of aq KBr and extracted with dichloromethane. The organic layer was washed with water and brine, dried over Na_2SO_4, and evaporated to furnish the crude organomercuric bromide, which was subjected to demercuration. To the solution of the organomercuric bromide in THF (2.5 mL, 0.1 M) at rt was added triethylborane (5 mol %) and oxygen through a syringe. Tributyltin hydride (0.5 mmol) was added dropwise when mercury began to precipitate almost immediately. The reaction mixture was stirred at rt for 3 h. The reaction mixture was treated with aq saturated KF solution and stirred for 30 min. It was diluted with ethyl acetate and filtered. The residue was washed twice with ethyl acetate. The combined filtrates were dried over Na_2SO_4 and concentrated to furnish the crude product.

Compound 50. The crude compound was purified by column chromatography (40% EtOAc/hexanes, v/v) to afford the diol **50** (68 mg, 0.21 mmol) as a single diastereomer in 84% yield. Viscous liquid; R_f 0.25 (50% EtOAc/hexanes, v/v); $[\alpha]^{25}_D$ +83.2 (*c* 1, $CHCl_3$); IR (neat) 3446, 2929, 2855, 1636, 1512, 1249, 1089, 1035, 835 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.52 (d, J = 8.3 Hz, 2H), 7.33 (d, J = 8.3 Hz, 2H), 4.69−4.58 (br s, 1H, −OH), 4.45−4.36 (m, 1H), 3.93−3.82 (m, 1H), 3.09 (dd, J = 12.8, 10.6 Hz, 1H), 2.59 (dd, J = 12.8, 1.5 Hz, 1H), 2.44 (s, 3H), 1.53−1.14 (m, 11H), 0.90 (d, J = 6.8 Hz, 3H), 0.87 (t, J = 6.8 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 141.5, 139.8, 130.0, 123.9, 75.7, 70.4, 61.9, 41.2, 35.1, 31.7, 29.2, 25.9, 22.5, 21.4, 14.0, 5.4; MS (ESI) 327 $[M + H]^+$.

Compound 59: The crude compound was purified by column chromatography (50% EtOAc/hexanes, v/v) to afford the diol **59** (224 mg, 0.83 mmol) as a mixture of diastereomers differing at sulfur in 83% yield. Viscous liquid; R_f 0.25 (60% EtOAc/hexanes, v/v); IR (neat) 3383, 2924, 2854, 1729, 1374, 1087, 1020, 800, 751, 692 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.69−7.58 (m, 4H), 7.57−7.44 (m, 6H), 4.24−4.13 (m, 2H), 3.75 (dd, J = 10.2, 2.4 Hz, 1H), 3.69 (dd, J = 10.2, 2.4 Hz, 1H), 3.31 (dd, J = 13.2, 3.2 Hz, 1H), 3.17 (dd, J = 13.2, 4.7 Hz, 1H), 2.69 (dd, J = 13.2, 6.9 Hz, 1H), 2.57 (dd, J = 13.2, 9.2 Hz, 1H), 2.25−2.10 (m, 1H), 2.09−1.96 (m, 1H), 1.93−1.81 (m, 1H), 1.72−1.55 (m, 1H), 1.20 (d, J = 6.6 Hz, 6H), 1.13 (d, J = 6.9 Hz, 3H), 1.09 (d, J = 6.9 Hz, 3H), 0.80 (d, J = 6.9 Hz, 3H), 0.76 (d, J = 6.9 Hz, 3H); MS (ESI) 271 $[M + H]^+$; HRMS (ESI) m/z $[M + H]^+$ calcd for $C_{14}H_{23}O_3S$ 271.1372, found 271.1367. The sulfoxides were oxidized to a single sulfone as detailed hereunder and characterized. To a solution of the inseparable mixture of sulfoxide diols **59** (40 mg, 0.15 mmol) in dichloromethane (1.5 mL) cooled at 0 °C was added *m*-CPBA (34.4 mg, 0.20 mmol) with stirring at rt for 30 min. The reaction mixture was diluted with dichloromethane, washed successively with aq saturated $NaHSO_3$, aq saturated $NaHCO_3$, water, and brine, dried over anhydrous Na_2SO_4, and evaporated. The crude product was purified by column chromatography (35% EtOAc/hexanes, v/v) to afford a single sulfone (39 mg, 0.14 mmol) in 93% yield. Viscous liquid; R_f 0.25 (40% EtOAc/hexanes, v/v); IR (neat) 3383, 2924, 2854, 1729, 1374, 1087, 1020, 800, 751, 692 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.93 (d, J = 7.3 Hz, 2H), 7.70−7.61 (m, 1H), 7.61−7.53 (m, 2H), 4.09−4.00 (m, 1H), 3.61 (dd, J = 14.1, 3.0 Hz, 1H), 3.52 (dd, J = 9.6, 1.8 Hz, 1H), 2.93 (dd, J = 14.1, 7.9 Hz, 1H), 2.35−2.20 (m, 1H), 1.68−1.55 (m, 1H), 1.20 (d, J = 6.2 Hz, 3H), 1.09 (d, J = 6.8 Hz, 3H), 0.88 (d, J = 7.2 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 140.1, 133.6, 129.3, 127.8, 79.6, 72.8, 59.5, 38.8, 32.6, 29.7, 21.7, 16.9; MS (ESI) 309 $[M+Na]^+$; HRMS (ESI) m/z $[M+Na]^+$ calcd for $C_{14}H_{22}O_4NaS$ 309.1122, found 309.1136.

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Supporting Information Available: Experimental procedure for the preparation of **8**, **13**, **15**, **18**, **20**, **21**, **23**, **24**, **25**, **27**−**39**, **45**−**47**, **51**−**58**, and **60**−**78**, an ORTEP of **53**, and copies of spectra. This material is available free of charge via the Internet at http://pubs.acs.org.