Published in final edited form as:

J Org Chem. 2014 January 3; 79(1): 140–171. doi:10.1021/jo4023765.

Catalytic, Enantioselective, Intramolecular Carbosulfenylation of Olefins. Preparative and Stereochemical Aspects

Scott E. Denmark* and Alex Jaunet

Roger Adams Laboratory, Department of Chemistry, University of Illinois, Urbana, IL 61801

Abstract

The first catalytic, enantioselective, intramolecular carbosulfenylation of isolated alkenes with aromatic nucleophiles is described. The combination of *N*-phenylsulfenylphthalimide, a chiral selenophosphoramidate derived from BINAM, and ethanesulfonic acid as a co-catalytic Brønsted acid induced an efficient and selective cyclofunctionalization of various alkenes (aliphatic and aromatic) tethered to a 3,4-methylenedioxyphenyl ring. Under these conditions, 6-phenylthio-5,6,7,8-tetrahydronaphthalenes are formed diastereospecifically in good yields (50–92%) and high enantioselectivities (71:29 – 97:3 er). *E*-Alkenes reacted much more rapidly and with much higher selectivity than *Z*-alkenes, whereas electron rich alkenes reacted more rapidly but with comparable selectivity to electron-neutral alkenes and electron deficient alkenes. The Brønsted acid played a critical role in effecting reproducible enantioselectivity. A model for the origin of enantioselectivity and the dependence of rate and selectivity on alkene structure is proposed along with a rationale for the site selectivity in reactions with mono-activated arene nucleophiles.

Introduction and Background

1. Sulfenofunctionalization

The reaction of sulfur(II) electrophiles with alkenes¹ to afford sulfenofunctionalized products has been thoroughly studied since the 1960's primarily in the context of investigating the chemistry of thiiranium ions.² These reactive intermediates can be generated by a variety of different sulfenylating reagents such as dimethyl(methylthio)sulfonium tetrafluoroborate,^{2d} methyl(bismethylthio)sulfonium hexachloroantimonate, sulfenyl halides,^{2e,3} sulfenate esters,⁴ sulfenylamides, and disulfides. A wide range of nucleophiles, e.g. enol ethers, silyl ketene acetals, allylsilanes, aromatic rings, organometallic agents (aluminum, zinc), carboxylic acids, alcohols, amines, nitriles and thiols have been employed in sulfenofunctionalization reactions following the general process illustrated in Scheme 1.^{2d} For many such processes, the chlorosulfenylation product is generated first followed by generation of the thiiranium ion with a Lewis acid in the presence of the pronucleophile.

Alternatively, intramolecular captures (sulfenocyclization reactions) can be effected with sulfenylating agents to form carbocycles and heterocycles, Scheme 2. Warren and co-workers⁵ have extensively investigated the preparative and mechanistic features of sulfanyl migration reactions from thiiranium ions generated by neighboring group participation of the sulfur moiety for the synthesis of oxygen- and nitrogen-containing⁶ heterocycles. In

*Address Correspondence to: Professor Scott E. Denmark Department of Chemistry University of Illinois 600 S. Mathews Ave. Urbana, IL 61801 tel: (217) 333-0066 FAX: (217) 333-3984 sdenmark@illinois.edu.

Supporting Information. Optimization experiments, X-ray coordinates for (*S*)-**17a** and *trans*-**34**, and copies of ¹H and ¹³C NMR spectra. This material is available free of charge via the Internet at <http://pubs.acs.org>.

addition, sulfenium initiated cyclizations have also been successful with polyolefins⁷ and electron rich arenes.⁸

1.1. Enantioselective Sulfenofunctionalization—Several examples of nucleophilic opening of chiral thiiranium ions are on record. These species are generated by anchimerically-assisted ionization of enantiomerically enriched hydroxy sulfides formed from asymmetric dihydroxylation of alkenes.⁹ These enantiomerically enriched thiiranium ions have been captured by nitriles, sulfonamides, silyl enol ethers and substituted benzene rings. Intramolecular capture has also been developed.¹⁰ However, only two reports of direct, enantioselective methylsulfenylation reactions have been reported, both employing stoichiometric reagents, Scheme 3.¹¹

1.2. Lewis Base Catalysis of Sulfenofunctionalization—As part of a broadly based program to apply the concept of Lewis base activation of Lewis acids¹² to the reactions of main group elements, we have investigated the chemistry of selenium (II)¹³ and sulfur (II)¹⁴ electrophiles. From extensive preparative and mechanistic studies, we have discovered that the functionalization of isolated alkenes with both *N*-phenylselenosuccinimide and *N*-phenylsulfenophthalimide is susceptible to catalysis by Lewis bases (Scheme 4).

However, whereas the intermediate seleniranium ions are not configurationally stable, the corresponding thiiranium ions are stable^{15a} and can be captured stereospecifically with a variety of heteroatom nucleophiles.^{15b} These insights led to the development of the first, catalytic, enantioselective sulfenofunctionalization of isolated alkenes (Scheme 5).^{14,16,17,18}

In continuation of these studies, we sought to expand the scope of the asymmetric sulfenofunctionalization to include carbocyclizations with aromatic nucleophiles. Although such transformations are known (as mentioned above) no examples of catalytic, enantioselective cyclizations are on record. Thus, we initiated a program to evaluate (1) the diversity of substituent patterns on the alkene tether, (2) the nucleophilicity of the aromatic residue needed for effective cyclization, (3) the reactivity of the thiiranium ions generated under catalytic conditions compared to those generated stoichiometrically and (4) the dependence of enantioselectivity on the alkene structure. The results of these studies along with some unexpected insights into the role of the Brønsted acid coactivator are described herein.¹⁹

Results

1. Synthesis of the Alkene Substrates

As the point of entry, we chose to evaluate electron rich methylenedioxybenzenes to capture the intermediate thiiranium ions given the success of sulfenocarbocyclizations with these species.^{8,20} To study the scope of the carbosulfenylation with variously substituted alkenes required a general and flexible synthesis of geometrically defined olefins. Of the many methods to synthesize trans-disubstituted carbon-carbon double bonds, initial attempts focused on the Schlosser modification of the Wittig olefination reaction.²¹ Thus, 5-(3-oxopropyl)-1,3-benzodioxolane **1**²² was combined with the ethylidenetriphenylphosphorane under standard Wittig-Schlosser olefination conditions to afford the alkene **2** in 60% yield as a 96:4 *E/Z* mixture (Table 1, entry 1). Initial optimization of the carbosulfenocyclization reaction was carried out with this *E/Z* mixture of isomers **2a**. However, the 4% of *Z*-alkene produced when R² = Me and the low yielding reaction when R² = *i*-butyl and Ph (entries 2 and 3) stimulated the search for an alternative preparation of these substrates.²³

The next strategy for the preparation of geometrically defined (3,4-methylenedioxyphenyl) alkenes employed the Warren modification of the Horner-Wittig reaction.²⁴ Thus, addition

of methyl ester **3**²⁵ to a solution of ethyldiphenylphosphine oxide and *n*-BuLi afforded β -keto diphenylphosphine oxide **4** (Scheme 6). Both diastereomeric alcohols *anti*- and *syn*-**5** could be selectively prepared by the reduction of **4** under appropriate reaction conditions.²⁶ Treatment of ketone **4** with LiBH₄ and CeCl₃ afforded a (separable) mixture of β -hydroxy diphenylphosphine oxide diastereoisomers **5** in a 75:25 *anti*/*syn* ratio, whereas reduction of **4** with BH₃•py and TiCl₄ furnished diastereoisomers **5** in a 20:80 *anti*/*syn* ratio. Finally, β -hydroxy phosphine oxides **5** were transformed into the corresponding alkenes **2** in good yields (74–76%, Scheme 1).

To access the trisubstituted alkenes, β -hydroxy phosphine oxide **4** was first alkylated with MeI and KO^{*t*}-Bu and the gem-dimethylated product **6** was subsequently reduced with NaBH₄ to afford β -hydroxy phosphine oxide **7** (Scheme 7). β -hydroxy phosphine oxide **7** was converted into trisubstituted alkene **2c** in good yield (72%), upon treatment with KH.

A third strategy was employed for the synthesis of various (3,4-methylenedioxyphenyl) derived alkenes through a B-alkyl Suzuki-Miyaura cross-coupling reaction.²⁷ In view of the ready availability of styrenes and vinyl iodides, this reaction was envisaged to provide access to aliphatic and aromatic substituted (3,4-methylenedioxyphenyl) derived alkenes (Table 2).

The initial conditions for the cross-coupling reaction between styrene **8a** and (*E*)-(2-iodoethenyl)benzene (**10b**) employed PdCl₂(dppf) (5 mol %), Cs₂CO₃ (2.0 equiv), Ph₃As (10 mol %), and H₂O (15.0 equiv) in DMF/THF for 15 h at room temperature (Table 2, entry 1).²⁸ Three products were isolated from this reaction: cross-coupling product **2b**, alkene hydroboration product **9** and starting alkene **8a** formed from β -elimination of **9** during the cross-coupling). By extending the reaction time to 24 h, no hydroboration product **9** was observed by ¹H NMR spectroscopic analysis and the cross-coupling product **2b** was isolated in 43% yield (Table 1, entry 2). Despite extensive optimization of the reaction conditions (solvent, temperature, base and ligands), none of the modifications completely suppressed of the formation of the β -elimination product **8a**. Decreasing the amount of H₂O increased the amount of **8a** (entry 3), but increasing the amount of both PdCl₂(dppf) and Ph₃As slightly improved the formation of the desired alkene **2b** (entry 4). The absence of the Ph₃PAs, slightly favored the formation of alkene **8a** (entry 5). Removing water slowed the cross-coupling reaction and afforded only alkylborane **9** (entry 6). Changing the base to either CsF or NaOMe also caused the cross-coupling reaction to fail (entries 7 and 8). Modification of the palladium source to Pd(OAc)₂, as reported by Fu,²⁹ did not improve the coupling (entry 9).

Although still far from optimal, the conditions in entry 2 were employed in the cross-coupling of (*E*)-1-iodoheptene (**10n**) to afford the target alkene (*E*)-**2n** in 20% yield. (Table 3, entry 1). Despite the use of different bases to activate the alkyl-9-BBN derivative, it is clear that other activators for the cross-coupling reactions needed to be evaluated. For example, thallium salts (TlOH, Tl₂CO₃, TlOEt) have been used to enhance the rate of Suzuki-Miyaura cross-coupling reactions between vinylboronic acids and vinyl halides^{30,31} as well as between alkylboranes and vinyl halides.³² By employing the conditions recommended by Danishefsky [PdCl₂(dppf) (20 mol %), Ph₃As (20 mol %), TlOEt (3.0 equiv), H₂O (5.0 equiv), THF, rt] (Table 3, entry 2), the cross-coupling product (*E*)-**2n** was formed in a gratifying 71% yield.

Re-optimization of certain experimental variables was next conducted. The first series of experiments evaluated the loading of the palladium catalyst. Lowering the palladium loading to 10 mol % afforded an identical yield of 70 % (entry 3), but with 5 mol %, the yield of (*E*)-**2n** dropped to 58% (entry 4). The amount of TlOEt was next investigated. Two

equivalents of TIOEt afforded a comparable yield of **2c**; however, lowering the amount of the salt to 1.5 equiv afforded (*E*)-**2n** in 66% yield (entries 5 and 6). Moreover, the use of Pd(PPh₃)₄ produced (*E*)-**2n** in only 20% yield (entry 7).

From these optimization studies, the best conditions were identified as PdCl₂(dppf) (10 mol %), Ph₃As (20 mol %), TIOEt (2.0 equiv), H₂O (5.0 equiv), THF, rt, 12 h. However, in several cases the use of TIOEt did not afford superior yields compared with the previous protocol using Cs₂CO₃. Considering the high cost and toxicity of TIOEt, aryl-substituted alkenyl iodides **2e**, **2h**, **2j** and **2s** were cross-coupled using the initial reaction conditions (B: PdCl₂(dppf) (5 mol %), Ph₃As (10 mol %), Cs₂CO₃ (2.0 equiv), H₂O (15.0 equiv), THF/DMF, rt, 12 h). A wide variety of alkyl- and aryl-substituted alkenyl iodides coupled in acceptable yields (60–70%) (Table 4). The electronic character of the aryl substituent of the alkenyl iodides did not affect the yield of reaction, as both electron-deficient and electron-rich aryl residues afforded the transalkenes in acceptable yields (64–70%) (entries 1–6). However, substitution in the 2-position of the benzene ring afforded the alkene **2i** in lower yield (entry 7). In contrast, alkyl substituted alkenyl iodides furnished trans-alkenes **2k–2p** in good yields (entries 9–14). Finally, **10b** and **10n** coupled with (3-methoxyphenyl)- (**8b**) and (4-methoxyphenyl)alkylboranes (**8c**) in good yields (entries 15–18).

2. Optimization of the Sulfenocarbocyclization

2.1. Initial Survey of Cyclization Conditions—A recent disclosure from these laboratories described the development of a catalytic, enantioselective sulfenoetherification of unactivated double bonds using *N*-phenylsulfenylphthalimide **13**, MsOH (to help activate **13**), and a chiral selenophosphoramidate as the Lewis base.¹⁴ In view of these studies and the known configurational stability of the intermediate thiiranium species at –20 °C,¹⁵ the initial conditions for the sulfenocarbocyclization of alkene **2a** employed MsOH (1.0 equiv), **13** (1.0 equiv) and Lewis base (10 mol %) in CH₂Cl₂ at –20 °C. The initial success of these reaction conditions led to the following optimization of the Lewis base structure. However, as will become apparent in subsequent sections, the role of MsOH in these reactions was quite different from the sulfenoetherifications and required a significant amount or reoptimization. Moreover, careful investigation of the uncatalyzed reaction revealed a remarkable autocatalytic process that had heretofore gone unnoticed.

2.2. Survey of Chiral Lewis Bases—With a method for effecting the racemic, intramolecular sulfenocarbocyclization in hand, a number of chiral phosphoramidates were tested to develop an asymmetric variant of the reaction. The initial survey of Lewis bases was carried out with *E/Z* mixtures of the starting material **2a** (Table 5). As was observed in the sulfenoetherification reaction, 1,1'-binaphthalene-2,2'-diamine (BINAM) derived thio- and selenophosphoramidates proved to be efficient and selective chiral Lewis base catalysts.¹⁴ In early studies various modifications of the BINAM backbone and the internal nitrogen substituents were evaluated. Thio- and selenophosphoramidates derived from the parent 2,2'-dimethylamino-1,1'-binaphthyl were the most selective. To evaluate the various Lewis base catalysts the initial reactions conditions MsOH (1.0 equiv), **13** (1.0 equiv) and phosphoramidate (*R*)-**15a** (10 mol %). The trans/cis ratio of the diastereomeric products **14a** was determined by ¹H NMR spectroscopic analysis of the purified material and the enantiomeric composition of the products was determined by chiral stationary phase, supercritical fluid chromatographic (CSP-SFC) analysis (Table 5).

Chiral Lewis base (*R*)-**15a** afforded cyclized products **14a** with high diastereospecificity (trans/cis, 62:38) and reasonable enantioselectivity for the major product, *trans*-**14a** (Table 5 entry 1). However, the minor, *cis*-**14a** was produced in racemic form. The corresponding thiophosphoramidate catalyst (*R*)-**15b** still afforded excellent diastereospecificity (trans/cis,

96:4) but significantly lower enantioselectivity was obtained for *trans*-**14a**. Nevertheless, (*R*)-**15b** delivered the first non-racemic sample of *cis*-**14a** (entry 2). Altering the external nitrogen substituent to a piperidine (catalyst (*R*)-**16a**) afforded excellent diastereospecificity but did not improve the selectivity of *trans*-**14a** and *cis*-**14a** (entry 3). Once again, the corresponding thiophosphoramidate catalyst (*R*)-**16b** provided excellent diastereospecificity however, the enantiomeric composition of *trans*-**14a** was lower compared with that formed from the selenophosphoramidate catalyst (*R*)-**16a** (c.f. entries 3 and 4). On the other hand, the enantiomeric ratio of *cis*-**14a** was slightly improved.

In general, thiophosphoramidate catalysts (i.e. (*R*)-**15b**, (*R*)-**16b**) afforded lower enantioselectivity for *trans*-**14a** than the corresponding selenophosphoramidates (i.e. (*R*)-**15a**, (*R*)-**16**). For these reasons, the thiophosphoramidate catalysts were not further evaluated, and the investigation focused on the substituents on the external nitrogen. Increasing the size of the ring to the azepane catalyst (*R*)-**17a** led to excellent diastereospecificity (*trans*/*cis*, 96:4) and higher enantioselectivity for *trans*-**14a** but to *cis*-**14a** in racemic form (entry 5). A further increase in the size of the ring to produce the azocane catalyst (*R*)-**18a** still achieved excellent diastereospecificity but slightly reduced enantioselectivity in the formation of *trans*-**14a** (entry 6). As was observed with the previous catalysts, *cis*-**14a** was obtained with moderate enantioselectivity.

The next evaluation of external nitrogen substituents focused on the use of acyclic, branched, secondary amines. For example, diisopropylamino substituted selenophosphoramidate (*R*)-**19a** afforded excellent diastereospecificity and reasonable enantioselectivity for *trans*-**14a** (entry 7). As with the cyclic secondary amine-based catalysts, this catalyst produced *cis*-**14a** with poor enantioselection (entry 7). The corresponding thiophosphoramidate catalyst (*R*)-**19b** afforded excellent diastereospecificity but lower enantioselectivity compared to selenophosphoramidate catalysts (*R*)-**19a** for *trans*-**14a**. Evaluation of other catalysts prepared from branched secondary amines allowed the identification of the diisobutyl-derived catalyst (*S*)-**20a**, which afforded excellent diastereospecificity and enantioselectivity for *trans*-**14a** (entry 9). Further extension to the diisoamylamine derived catalyst (*S*)-**21a** afforded results similar to the azepane catalyst (*R*)-**17a** for *trans*-**14a** and a slight improvement for *cis*-**14a** (entry 10).

Continuing the survey of chiral Lewis bases for this cyclization led to the evaluation of selenophosphoramidates derived from linear dialkylamines. Catalyst (*R*)-**22a** and (*S*)-**23a** bearing diethylamino and dibutylamino substituents afforded excellent diastereospecificity and enantioselectivities for *trans*-**14a** but lower enantioselectivities than (*S*)-**19a** bearing a diisobutylamino group. The ethyl(butyl)amino derived catalyst (*S*)-**24a** furnished excellent diastereospecificity and enantiomeric ratio for *trans*-**14a**, as well (entry 13). Finally, phenyl(methyl)amine derived catalyst (*R*)-**25a** afforded moderate and poor enantioselectivity for *trans*- and *cis*-**14a**, respectively (entry 14).

In the final phase of optimization, the loading of catalyst (*S*)-**20a** was evaluated. Lowering the catalyst loading to 5 and 7.5 mol % led to decreases in the enantioselection for *trans*-**14a** (entries 15 and 16), whereas increasing the loading to 15 mol % did not improve the enantioselectivity (entry 17). At this point, the reaction conditions in Table 5, entry 9, were deemed sufficient to explore the generality of this transformation with respect to other substrates.

2.3. Brønsted Acid Effect

2.3.1. An Unexpected Complication: With the various reaction parameters established for the catalytic, asymmetric sulfenocarbocyclization of (*E*)-**2a**, an evaluation of the substrate

scope was next undertaken. Good enantioselectivities were obtained with *E*-aryl-substituted alkenes, on a 0.1 mmol scale (>89:11 *er*, Table 6). Effectively the same enantioselectivity was obtained with electron-rich and electron-neutral aromatic substrates (phenyl (*E*)-**2b**, (entry 1); 4-tolyl (*E*)-**2d**, (entry 2) and 4-methoxyphenyl (*E*)-**2f** (entry 3)). Surprisingly, however, upon scaling the reactions to 1.0 mmol, the enantioselectivity decreased. Clearly, not all the critical reaction parameters had been properly optimized. Because of the early success of the conditions adapted from sulfenoetherification, the amount of the Brønsted acid employed was not evaluated making it the prime suspect for the lack reproducibility.

Several modifications relating to the Brønsted acid were explored. First, the rate of the addition of MsOH was reduced from 6.5 $\mu\text{L}/\text{sec}$ to 0.7 $\mu\text{L}/\text{sec}$, but lower enantiomeric ratios were still observed on a 1.0 mmol scale. Second, a solution of MsOH in CH_2Cl_2 (0.2 M) was prepared and pre-cooled to -70°C before slow addition (0.7 $\mu\text{L}/\text{sec}$) into the reaction mixture. Unfortunately, MsOH (m.p. 19°C) crystallized in the pre-cooled solution. Thus, an alternative, Brønsted acid with similar a pK_a value but a lower melting point was sought. Fortunately, ethanesulfonic acid (EtSO_3H) which possesses a melting point of -18°C and a pK_a value of -1.68 in H_2O ,³³ is commercially available.

2.3.2. Optimization of the Brønsted Acid: Extensive optimization of the loading and delivery (neat vs. solution) of the Brønsted acid co-catalyst revealed that 0.75 equiv of EtSO_3H gave reproducible results and restored the original enantioselectivity for the cyclization. Detailed studies on the protonation state of the catalyst, (*S*)-**20a**, the sulfonylating agent, **13**, the structure and concentration of the catalytically active species revealed the remarkable behavior of EtSO_3H in these reactions and are the subject of a forthcoming manuscript. For the purposes of the preparative component of this study, the use of 0.75 equiv of EtSO_3H delivered neat solved the problem of reproducibility.

2.3.3. Optimization of the Catalyst Loading: Identification of the appropriate conditions for the cyclization reaction led to a re-optimization of the catalyst loading with alkene (*E*)-**2d**. With 0.75 equiv of EtSO_3H and 10 mol % of catalyst (*S*)-**20a**, cyclization afforded excellent enantioselection (Table 7, entry 1), slightly higher than with 1.0 equiv of EtSO_3H . Lowering the loading of (*S*)-**20a** to 5 and 2 mol % afforded enantiomeric ratios of 88:12 and 83:17, respectively (entries 2 and 3). In addition to the erosion of enantioselection, the rate of the reactions with 5 and 2 mol % of Lewis base (*S*)-**20a** were slower affording only 60% and 36% conversion to product *trans*-**14d**. The use of 0.5 equiv of EtSO_3H and 10 mol % of (*S*)-**20a** produced identical enantioselection (entry 4), compared to 0.75 equiv of EtSO_3H , with 80% conversion after 10 h (entry 4). The best conditions for the sulfenocarbocyclization were defined in regard to the enantioselectivity achieved with 10 mol % of (*S*)-**20a** and the better conversion obtained with the use 0.75 equiv of EtSO_3H .

3. Sulfenocarbocyclization with (3,4-Methylenedioxyphenyl) Derived Alkenes

3.1. Alkyl Substituents—At this point, the exploration of the generality of this transformation with other substrates was investigated. Gratifyingly, application of the optimized conditions to a large variety of *E*-alkyl- and aryl-substituted alkenes afforded the cyclized products in moderate to excellent yields (50–92%) with good to excellent enantioselectivities and as single (*trans*) diastereomers. For example, under these conditions *E*-methyl-substituted alkene (*E*)-**2a** formed *trans*-**14a** in excellent yield and enantioselectivity (Table 8, entry 1). In contrast, the corresponding isomer (*Z*)-**2a** led to *cis*-**14a** as a nearly racemic mixture (52:48 *er* (entry 2)) but in excellent yield (91%). *E*-Alkenes **2n–2p** lacking substitution at the allylic position furnished the cyclized products *trans*-**14n** - *trans*-**14p** in moderate yields but very good enantiomeric ratios (entries 3–5). Cyclopropyl substrate (*E*)-**2k** bearing branching at the allylic position led to a good yield

and enantioselectivity (entry 6) whereas common cycloalkyls (5- and 6-membered) gave lower yields and enantioselectivities (entries 7–8). If the alkene contained a *tert*-butyl substituent, no cyclization occurred.³⁴ Cyclization of substrates **2c** and (*E*)-**2j** containing geminally-disubstituted alkenes allowed formation of quaternary carbon centers albeit with moderate enantiomeric ratios but good yields (entries 9 and 10). Interestingly, byproducts **26** and **27** resulting from the proton-initiated cyclization reaction was formed in 2–8% yield with these trisubstituted alkenes (Figure 1).

3.2. Aryl Substituents—The next stage of the investigation focused on the scope of (*E*)-aryl-substituted alkenes that could participate in the cyclization (Table 9). Substrates (*E*)-**2b**, (*E*)-**2d**, and (*E*)-**2f** bearing no substituents or electron-donating substituents afforded cyclization products in good yields and enantioselectivities (entries 1–3). However, substrate (*E*)-**2i** bearing a methyl group in the ortho position reacted slowly, but with good enantioselectivity (entry 4). Interestingly, **28**, the product of proton-initiated isomerization of the double bond was obtained in 4% yield (Figure 1). Substrate (*E*)-**2g** bearing a 2-naphthyl substituent afforded good selectivity but in lower yield (entry 5). Finally, alkenes (*E*)-**2e** and (*E*)-**2h** bearing electron-deficient aromatic groups furnished nearly identical enantioselectivities in very slow reactions (entries 6 and 7).

4. Sulfenocarbocyclization with Methoxyphenyl Derivatives

The final exploration of substrate scope was carried out with less nucleophilic aryl groups. The position of the electron-donating substituent on the aromatic ring had a major impact on the reactivity and site selectivity of the sulfenocarbocyclization. Substrates bearing a methoxy group in the 3-position with respect to the tethered alkene afforded a mixture of cyclized products **29–33**, with both *n*-pentyl ((*E*)-**11n**) and phenyl ((*E*)-**11b**) substituents (Table 10). With (*E*)-**11n**, a 3:1 ratio of **30/31** was produced in good yields and enantioselectivities (entry 1). However, substrate (*E*)-**11b** bearing a phenyl substituent afforded a 1:1 ratio of **31/32**, but good enantioselectivity was still achieved for both constitutional isomers (entry 2). For substrate (*E*)-**12b** with the activating group in the 4-position a good yield of **33** was obtained, albeit with moderate enantioselectivity (entry 3). Interestingly, having the activating group in the 4-position of the phenyl ring did not lead to cyclization with the corresponding *n*-pentyl-substituted alkene (*E*)-**12n**.³⁵

5. Stereochemical Assignment

Most of the sulfenocarbocyclization took place with high enantioselectivity. The relative configuration of tetrahydronaphthalenes was confirmed by correlation of the ¹H NMR chemical shifts of HC(3) with known products *trans*-**2a** and *cis*-**2a**, (Figure 2). All of the *trans*-products displayed diastereotopic methylene protons on C(3) of the tetrahydronaphthalene that split in two distinct chemical shift around 1.80–1.92 ppm and 2.08–2.18 ppm. On the other hand, in *syn*-product, the chemical shift of the methylene protons on C(3) appeared around 2.00 and 2.06 ppm. Furthermore, the absolute configuration of the (–)-*trans*-**14d** was determined to be (1*R*,2*R*) by X-ray crystallographic analysis of the derived sulfone *trans*-**34** (obtained by *m*-CPBA oxidation of the parent sulfide) (Scheme 8).³⁶ The negative Cotton effect in the CD spectra of the products allowed an unambiguous assignment of the absolute configurations of the major enantiomer of the cyclization products by in comparison with *trans*-**14d**.

Discussion

Our primary objective in this work was to develop a catalytic, asymmetric carbosulfenylation of olefins as a method to prepare enantioenriched 1-alkyl or 1-aryl-2-thiophenyl-1,2,3,4-tetrahydronaphthalenes. Moreover, given the striking divergence in

behavior of these cyclizations compared to the sulfenocycloetherifications reported previously,¹⁴ a second goal focused on a more refined understanding of the role of the Brønsted acid in these reactions.

1. Synthesis of the Alkene Substrates

1.1 Suzuki-Miyaura Cross-Coupling Reaction—In a view of the ready availability of (*E*)-2-iodostyrene and other vinyl iodides, a general synthesis of alkyl- and aryl-substituted olefins was undertaken using the B-alkyl Suzuki-Miyaura cross-coupling reaction. Since the first report of cross-coupling between B-alkyl-9-BBN derivatives and aromatic or alkenyl halide in 1989,³⁷ detailed accounts of the reaction conditions of the B-alkyl Suzuki-Miyaura reaction have been reported.³⁸ The most commonly used conditions for the Suzuki-Miyaura reaction between alkylborane derivatives and iodoalkenyl or styrenyl iodides employs PdCl₂(dppf), Ph₃As and Cs₂CO₃, with the borane partner prepared by hydroboration of the corresponding olefin. Initial attempts to effect cross-coupling between *in situ* generated B-alkyl borane **9** and (*E*)-(2-iodoethenyl)benzene (**10**), employed these standard conditions, (PdCl₂(dppf) (2 mol %), AsPh₃ (10 mol %), Cs₂CO₃ (2.0 equiv) and water (15.0 equiv)) and afforded two products, **2b**, and β-hydride elimination product **8a**.³⁹ No further optimization could be achieved by adjusting these reaction parameters. Ultimately, success was achieved by the use of thallium bases as has been described by others previously.⁴⁰ Kishi *et al.* first reported the use of TIOH for the cross-coupling reaction between sp² centers. Subsequently, Roush,^{31a} Chamberlain,^{31b} and Markó⁴⁰ employed various thallium salts (TIOEt, *in situ* generated TIOH, and Tl₂CO₃) to improve the efficiency of Suzuki cross-coupling reactions. Markó commented that a likely reason for the performance of thallium salts is the precipitation of the thallium halide by combination with palladium(II) species (ArylPd(dppf)X). This process would then form a highly reactive, cationic palladium(II) species (ArylPd(dppf)⁺) that would undergo rapid transmetalation with alkenyl-B(catechol)OTl[−] followed by rapid reductive elimination. After screening the conditions described by Danishefsky *et al.* (using TIOEt) it was possible to reduce the amount of PdCl₂(dppf) to 10 mol % and TIOEt to 2.0 equiv without adversely affecting the yield and the reaction time of the cross-coupling. Under these newly developed conditions, a wide range of (*E*)-(2-iodoethenyl)benzenes and vinyl iodides were coupled. Interestingly, the cross-coupling of electron-poor (*E*)-(2-iodoethenyl)benzene derivatives afforded comparable yields using either activator Cs₂CO₃ or TIOEt. This behavior may result from the greater electrophilicity of the palladium(II) species (Pd(dppf)(styrene)⁺) with electron-deficient styrenyl moieties.

2. Sulfenocarbocyclization of 3,4-Methylenedioxyphenyl Derivatives

The sulfenocarbocyclization of *E*-alkenes catalyzed by (*S*)-**20a** afforded the cyclized products in good to excellent yields (Tables 8–10). The exclusive formation of *trans*- and *cis*-1,2-disubstituted-1,2,3,4-tetrahydronaphthalenes from *E*- and *Z*-olefins respectively is in accordance with the anticipated diastereospecificity characteristic of other seleno-¹³ and thiofunctionalizations.¹⁵

2.1. Effect of the Olefin Configuration on Enantioselectivity and Rate—Both the enantioselectivity and the rate of the reaction were highly dependent on the substitution and configuration of the alkene whereas the formation of the catalytically active species is independent of the alkene. To enter the catalytic cycle, sulfenylating agent **13** is activated by protonation with EtSO₃H (Figure 3, step a), whereupon the sulfenyl group is transferred to the Lewis base to generate the catalytically active sulfenylating agent **35** (step b). Approach of **35** onto the alkene leads to the formation of thiiranium ion **i** (step c), which upon subsequent intra- or intermolecular nucleophilic capture (step d) delivers the corresponding enantioenriched thio ether (step e). The dramatic difference in reactivity and selectivity

among the various alkenes (and in particular between *E*- and *Z*-alkenes)⁴¹ must arise from either the rate of formation of the thiiranium ion *i* (step c) or the intramolecular trapping of that ion (step d).

Our interest in a detailed mechanistic understanding of this reaction - especially the structure of the catalytically active species **35** - led to numerous attempts at crystallization of various salts which have been unsuccessful to date. Computational studies to determine the conformation of the putative catalytic species **35** and develop a better understanding of the transition state structure for the formation of thiiranium ion *i* are ongoing. However, a single crystal X-ray diffraction analysis of Lewis base catalyst (*S*)-**17a**⁴² could be obtained from which working models can be proposed to explain the origin of the enantioselectivity with related Lewis base (*S*)-**20a**.

The solid-state structure of (*S*)-**17a** revealed the pseudo-equatorial positions of the N-methyl groups the azepine ring relative to the 1,3,2-diazaphosphaphine ring. Moreover, the plane defined by the C(1)-N-C(6) atoms of the azepine ring is nearly coincident with the P=Se unit (−8.77°) and thus the ring carbons occupy space near the P=Se unit (Figure 4).

The models employed in the discussion below are derived from the crystallographic coordinates of catalyst (*S*)-**17a** with the following modifications: (1) the azepino group of (*S*)-**17a** is replaced with the diisobutylamino group of catalyst (*S*)-**20a**, (2) all of the atoms of the (*S*)-**17a** backbone are fixed and the diisobutylamino group was minimized with molecular mechanics, and (3) an S-phenyl group was attached to the selenium atom and again minimized with molecular mechanics. Model 1 illustrates the destabilizing steric interaction between the S-phenyl group and the diisobutylamino group of the active species **35** causing the phenylsulfenyl group to point toward the binaphthyl subunit (Models-2 and 3). The energy profile for the C–S–Se–P dihedral angle is very flat with two minima at 121° and 83°. For our purposes, this angle is assumed to be close to 120° as seen in [(Me₂N)₃P–Se]₂²⁺[(BiCl₄)₂]_n[−] in which the P–Se–Se–P dihedral angle is 112°. ⁴³

The next step in rationalizing the stereochemical course of the reaction involves the approach of the alkene onto **35**. Several factors influence this approach such that the orbital interactions are maximized and the destabilizing steric interactions are minimized. To maximize orbital overlap between the HOMO of the alkene and the LUMO of the electrophile, the bonding π -electrons of the alkene must approach the sulfur atom in *i* along the trajectory of the S–Se σ^* -orbital.⁴⁴ Two, limiting transition state geometries are considered for the thiiranium ion formation: the spiro and the planar approaches (Figure 5). By analogy with the epoxidation of alkenes with dioxiranes and peracids,⁴⁵ a spiro transition state is favored over the planar transition state due to stabilizing interaction of an sulfur lone pair with π^* -orbital of the alkene in the former.

Taken together these two factors allow the formulation of six limiting transition structures **TS-A** – **TS-F** to rationalize the enantioselectivity of the reaction. In the case of *Z*-alkenes, models **TS-A** – **TS-C** explain the lower reactivity as well as the poor-enantioselectivity of the thiiranium ion formation (Figure 6). In model **TS-A**, the *Z*-alkene approaches *i* on the *Re-Si* face,⁴⁶ with the alkene substituents facing down (*Re-Si* (d)). This arrangement suffers from destabilizing steric interactions between the binaphthyl moiety of **35** and the substituents on the alkene. It is important to note that same argument can be made if the alkene approaches **35** on the *Si-Re* face with the substituent of the alkene down (*Si-Re* (d), not shown). In models **TS-B** and **TS-C**, the alkene approaches **35** on the *Si-Re* and *Re-Si* faces respectively with the alkene substituents facing up (u). In these transition structures, destabilizing interactions between the S-phenyl group and the R¹/R² substituents of the alkene would reduce the rate of the formation of the thiiranium ion. As none of these

arrangements is devoid of nonbonding interactions, the formation of two thiiranium ion enantiomers *cis-i* and *ent-cis-i* will occur at similar rates which, after cyclization, afford tetralin enantiomers *cis-14* and *ent-cis-14* with equal facility.

In the case of *E*-alkenes, model **TS-D** illustrates the approach of the *Si-Si* face of the alkene to the active species **35** in which destabilizing interactions between the R² substituent of the alkene and the binaphthyl rings of **35** would disfavor this approach (Figure 7). The same argument is also valid when R¹ and R² substituents are interchanged. The two models **TS-E** and **TS-F** depict the approach of the *Re-Re* face of the alkene to **35** in which no repulsive steric interactions occur between the R¹ or R² substituents of the alkene and the binaphthyl rings of **35**. In addition, the approach of the *Re-Re* face of the alkene may prefer **TS-E** because the bulkier substituent (R¹) does not encounter steric repulsions with the *N*-methyl group of the Lewis base. As a consequence reaction via transition states **TS-E** and **TS-F**, a single thiiranium ion *trans-i* is formed which after ring closure, affords tetralin *trans-14*. Comparison of models **TS-E** and **TS-F** with models **TS-B** and **TS-C**, illustrates why the formation of the thiiranium ion is faster for *E*-alkenes than for *Z*-alkenes.

2.2. Reaction of Alkyl-Substituted Alkenes—Unactivated *E*-alkenes bearing linear, β -branched, and alicyclic substituents afforded excellent levels of enantioselectivity and reacted with similar rates. The length of the alkyl chain on the alkene did not influence the rate or enantioselectivity of the reaction, substrates with longer carbon chains ((*E*)-**2n** - (*E*)-**2p**) led to moderate yields, substrate (*E*)-**2a** bearing a methyl group gave excellent yield. The lower enantioselectivity of the sulfenocarbocyclization observed for alkenes bearing branched substituents (*E*)-**2l** and (*E*)-**2m** implies that neither **TS-E** nor **TS-F** can accommodate larger groups on each end of the alkene. The alkene approach via **TS-D** may become competitive, but more likely an alternative transition structure that can accommodate at least one large group leading to the minor enantiomer can be considered. For example, **TS-G** in which the S-Se bond is rotated a different minimum may lead to an increase in the formation of the *ent-trans-14* (Figure 8).

The presence of a chlorine atom on the alkyl chain ((*E*)-**2o**) decreased the rate of the reaction while maintaining high level of enantioselectivity.⁴⁷ The low cyclization rate could be explained by protonation of the chlorine atom or interception of the thiiranium species with the pendant chlorine atom. However, the latter explanation can be ruled out because this would change the relative configuration of the product.⁴⁸ Protonation of the chlorine atom, which was been proposed in an acid-catalyzed Friedel-Crafts alkylation,⁴⁹ would reduce the concentration of Brønsted acid in the solution. Lowering the concentration of the acid would shift the equilibrium protonation of the sulfenylating agent to the left (step a, Figure 3) and lower the overall rate of the reaction.

The electronic properties of the alkenes also influenced the outcome of cyclization. For example, trisubstituted alkenes were more reactive than disubstituted *E*-alkenes, although the enantioselectivities were lower. These results reflect the influence played by the substituent in *cis* position of the alkyl chain, bearing the veratryl ring, on the approach of the alkene to **35**. The greater rate of reaction coupled with the lower enantioselectivity is puzzling. Given the additional steric contributions from a *cis* substituent, these results imply that several competing transition states are lower in energy than those for disubstituted alkenes. This outcome may arise from earlier transition states which result from greater electron density in the trisubstituted alkene. Alternatively, reactions of these substrates may be highly asynchronous or involve discrete carbocations. Although all of the sulfenocarbocyclizations were highly diastereospecific it is conceivable that the reaction of (*E*)-**2j** proceeded through a stepwise process via formation of a tertiary carbocation *ii*.

However, as only one diastereomer was observed, capture of the carbocation must be faster than rotation of bond *a* ($k^1 \gg k^2$) to form *iii* (Scheme 9).

In addition to the Lewis base catalyzed sulfenocarbocyclization reaction of trisubstituted alkenes, the formation of non-sulfur-containing 1,1-disubstituted-1,2,3,4-tetrahydronaphthalenes **26–27** was also observed in certain cases resulting from a proton-initiated intramolecular Friedel-Crafts reaction.

2.3. Reaction of Aryl-Substituted Alkenes—In the case of *E*-alkenes bearing neutral or electron-donating aryl substituents ((*E*)-**2b**, (*E*)-**2d**, (*E*)-**2f**) with Hammett's values $0 > s_p > -0.2$,⁵⁰ very good enantioselectivities were achieved. These selectivities were slightly lower than alkenes bearing linear or β -branched substituents most likely because of different steric demands. Likewise *E*-alkenes bearing electron-donating aryl substituents with Hammett values $s_p < -0.2$ led to a slight decrease of enantioselectivity compared to neutral aryl substituted alkenes. As was observed with trisubstituted alkenes, increasing the electronic density of the double bond led to faster cyclization. Both of these observations are explained by analogy to the behavior of the trisubstituted alkenes above.

Sterically-hindered, aryl-substituted alkenes ((*E*)-**2i** and (*E*)-**2g**) cyclized with lower enantioselectivities. This outcome was attributed to the congestion around **35** that renders the approach of the alkene difficult (models **TS-E** and **TS-F**). The lower reactivity of alkene (*E*)-**2i** allowed for a competing pathway to appear involving migration of the double bond along the alkyl chain into conjugation with the veratryl group. Protonation of the alkene presumably led to formation of a benzylic carbocation *iv* that could undergo a 1,4-hydride shift⁵¹ to produce a more stable benzylic carbocation *v*, potentially through the bridging transition state structure *vi*.⁵² Subsequent deprotonation afforded *E*-alkene **28** that did not cyclize (Scheme 10).

The very slow cyclization (even at room temperature) of *E*-styrenes bearing electron-withdrawing substituents ((*E*)-**2e** and (*E*)-**2h**) could be ascribed to a number of factors. In addition to the electron-deficient nature of the alkene, which would slow the formation of the thiiranium species, the presence of the cyano group in substrate (*E*)-**2e** might serve as a buffer for the Brønsted acid coactivator. Inefficient protonation of the sulfenylating agent **13** (Figure 3, step b) would lead to slow reaction.

Comparison of alkyl-substituted and aryl-substituted alkenes allowed the identification of some trends: (1) increasing the electron density of the alkenes (with electron-rich aryl or trisubstituted alkenes) afforded faster sulfenocarbocyclization but with slightly lower enantioselectivity, (2) small aliphatic rings have identical selectivity as linear alkyl substituted alkenes, (3) increasing the size of the allylic substituent or the steric bulk of aryl substituted alkene decreased both the rate and the enantioselectivity of the reaction, and (4) electron-deficient aryl-substituted alkenes reacted slowly without affecting the enantioselectivity.

2.4. Influence of the Nucleophilic Activator on the Aryl Group—The position of the electron-donating substituent on the nucleophilic aryl group influenced the rate of product formation. Substrate (*E*)-**11n** containing a 3-methoxy-substituted aryl ring attached to an alkyl-substituted alkene, reacted to afford two constitutional isomers **29** and **30** in a 3:1 ratio (Scheme 11). In previous studies, cationic ring closures with *m*-anisole occurred at both C(2) and C(4) positions.⁵³ The enantiomeric ratio obtained for **29** was identical to that obtained for *trans*-**14n**. For the phenyl substituted alkene (*E*)-**11b**, the cyclization led to the formation of constitutional isomers **31** and **32** in a 1:1 ratio.

Interestingly, substrate (*E*)-**12n** containing a 4-methoxy-substituted aryl ring bearing the alkyl-substituted alkene, did not cyclize. This outcome is ascribed to the decreased electron density on the C(3) and C(5) position of the 4-methoxy-substituted aryl group ($\sigma_p = -0.115$). However, phenyl-substituted alkene (*E*)-**12b** afforded 1,2,3,4-tetrahydronaphthalene **33**. The formation of products **31**, **32** and **33** is likely attributed to the presence of the phenyl substituent on the alkene, which through charge stabilization can enhance the electrophilic character of the benzylic carbon of the thiiranium ion.

Cyclizations with the electron-rich veratryl group occurred exclusively at the C(6) position which finds ample precedent in intramolecular cationic cyclization reactions such as *N*-acyliminium ion closures and Friedel-Crafts reactions.⁵⁴ To explain the difference in the site selectivity for the sulfenocarbocyclization reaction between the methylenedioxy and the methoxy activating groups, computational studies were performed using density functional theory (B3LYP/6-31G*) with substrates **36** and **37** to simplify calculations (Figure 9). Computational studies of simplified model **36** showed localization of the HOMO orbital at the C(5) position of the aromatic group and not at the C(3) position. In the case of **37**, similar calculations showed HOMO populations at both C(3) and C(5) positions of the nucleophilic ring. Comparison of the electrostatic (and natural) charges between models **36** and **37** showed in both cases that the C(3) position of the aryl group exhibits higher negative charge than the C(5) position, which if the reaction were purely charge-controlled, would indicate a higher nucleophilic character at C(3) for alkene substrates **36** and **37**. However the experimental results do not align with these charges densities. Calculations of the HOMO orbital occupancies support the experimental data. Thus, the calculations suggest that the sulfenocarbocyclization is under FMO control rather than electrostatic control despite the formation of a charged thiiranium ion intermediate.

Conclusion

In conclusion, the first catalytic, asymmetric carbosulfenylation of olefins has been accomplished by using a cocatalytic system of a Brønsted acid (EtSO₃H) and a chiral Lewis base (*S*)-**20a**. This method enables efficient access to enantioenriched *trans*-tetrahydronaphthalenes with complete diastereospecificity, generally high enantiomeric ratios and a broad substrate scope with *E*-olefins. Olefins bearing α -substituted alkyl groups (cyclic or branched) and electron-poor olefins tend to give lower enantioselectivities due to the higher temperature required. *E*-Olefins reacted slowly and with very poor enantioselectivity. Formation of quaternary centers was achieved in moderate enantioselectivity. Further investigations aimed at expanding the scope of the reaction (different ring sizes and heterocycles) along with mechanistic studies on the origins of the enantioselectivity are in progress. Studies on the role of the Brønsted acid and resting state of the catalyst are the subjects of a forthcoming manuscript.

Experimental Procedures

Preparation of Cyclization Substrates. Phosphine Oxide Route

Preparation of 2-Diphenylphosphinoyl-5(3',4'-methylenedioxyphenyl)pentan-3-one (**4**)—

n-BuLi (2.5 M in hexanes, 32.7 mL, 81.8 mmol) was added dropwise to a stirred solution of diphenylethylphosphine oxide (19.0 g, 82.6 mmol) in THF (300 mL) at 0 °C. After 30 min, the red solution was cooled to –70 °C and a solution of methyl-3-(3',4'-methylenedioxyphenyl)propanoate **3** (8.6 g, 41.3 mmol) in THF (80 mL) was added dropwise over 30 min, with a syringe. After complete addition, the reaction mixture was slowly warmed to room temperature and stirred for 12 h. The reaction was quenched with sat. aq. NH₄Cl (90 mL) and the aqueous phase was extracted with Et₂O (3 × 50 mL). The combined organic layers were washed with brine (120 mL) then dried over MgSO₄, filtered through glass wool and concentrated in vacuo (20 – 23 °C, 10 mmHg). The product was first purified by flash column chromatography on silica gel (SiO₂, 25 g, 30 mm Ø, pentane/EtOAc, 4:1) to afford a mixture of **4** and diphenylethylphosphine oxide (14.76 g). Purification of the mixture via recrystallization from pentane/CH₂Cl₂ (85:15 v/v) (200 mL) gave **4** as white solid 8.5 g for the first crop, and 3.9 g for the second crop (pentane/CH₂Cl₂ (85:15 v/v) (90 mL)) (74%). Data for **4**: mp: 149–151 °C (pentane/CH₂Cl₂ (85:15 v/v)); ¹H NMR: (500 MHz, CDCl₃) 7.82 – 7.74 (m, 4 H, HC(b) and HC(f)), 7.58 – 7.55 (m, 2 H, HC(d)), 7.51 – 7.48 (m, 4 H, HC(c) and HC(e)), 6.67 (d, *J* = 7.5 Hz, 1 H, HC(5')), 6.56 (d, *J* = 1.5 Hz, 1 H, HC(2')), 6.53 (dd, *J* = 7.5, 1.5 Hz, 1 H, HC(6')), 5.91 (s, 2 H, OCH₂O), 3.66 (d, *J* = 14.0, 7.0 Hz, 1 H, HC(2)), 2.84 (t, *J* = 7.5 Hz, 2 H, HC(5)), 2.66 (t, *J* = 7.5 Hz, 2 H, HC(4)), 1.37 (dd, *J* = 16.0, 7.0 Hz, 3 H, HC(1)); ¹³C NMR: (125 MHz, CDCl₃) 206.8 (CO), 147.6 (C(3')), 145.9 (C(4')), 134.8 (C(1')), 132.4 (d, *J* = 2.8, C(d)), 131.6 (d, *J* = 9.3, C(b)), 131.5 (d, *J* = 9.3, C(f)), 131.2 (d, *J* = 98.6, C(a)), 131.0 (d, *J* = 98.6, C(a)), 129.0 (d, *J* = 6.3, C(c)), 128.9 (d, *J* = 6.3, C(e)), 121.4 (C(6')), 109.2 (C(2')), 108.3 (C(5')), 101.0 (OCH₂O), 50.7 (d, *J* = 56.8, C(2)), 45.0 (C(5)), 29.4 (C(4)), 11.5 (C(1)); ³¹P NMR: (202 MHz, CDCl₃) 31.25; IR: (KBr) 2922 (s), 2853 (s), 2850 (s), 1737 (m), 1703 (w), 1498 (s), 1485 (w), 1462 (s), 1403 (m), 1376 (s), 1363 (s), 1346 (m), 1325 (m), 1240 (s), 1185 (s), 1119 (s), 1094 (s), 1035 (s), 996 (m), 928 (s); MS: (ES⁺) 408.1 (20), 407.1 (100); TLC: *R*_f 0.54 (EtOAc/pentane, 4:1) Analysis: C₂₄H₂₃O₄P (406.41) Calcd: C, 70.93; H, 5.70; P, 7.62%. Found: C, 70.65; H, 5.67; P, 7.76%.

Preparation of *anti*-2-Diphenylphosphinoyl-5-(3',4'-methylenedioxyphenyl)pentan-3-ol (*anti*-5**) and *syn*-2-Diphenylphosphinoyl-5-(3',4'-methylenedioxyphenyl)pentan-3-ol (*syn*-**5**)—**

Dried CeCl₃⁵⁵ (788.0 mg, 3.2 mmol) was suspended in THF (30 mL) and stirred for 2 h at room temperature. A solution of ketone **4** (1.0 g, 2.5 mmol) in THF (25 mL) was added and the reaction mixture was stirred for 12 h and then cooled at –70 °C. LiBH₄ (1 M in THF, 7.4 mL) was slowly added and the reaction mixture was vigorously stirred for 3 h at –70 °C. The reaction was quenched by slow addition of sat. NH₄Cl (20 mL) at 0 °C. The aqueous phase was extracted with Et₂O (3 × 20 mL). A diluted solution of HCl (10% in H₂O, 5 mL) was added into the aqueous phase, and extracted again with Et₂O (20 mL). The combined organic layers were washed with brine (60 mL), dried over MgSO₄, filtered through glass wool and then concentrated in vacuo (20 – 23 °C, 10 mmHg). Purification via flash column chromatography (Teledyne Isco Combiflash Rf 75, Silicycle SiO₂, 25 g, 15–40 mm mesh, gradient: 35 to 50% EtOAc in hexane over 70 min, 30 mL/min) to afford *syn*-**5** as pale white oil (230 mg, 23%) that crystallized upon standing, and *anti*-**5** as white solid (690 mg, 69%). Data for *anti*-**5**: mp: 118–122 °C; ¹H NMR: (500 MHz, CDCl₃) 7.82 – 7.73 (m, 4 H, HC(b) and HC(f)), 7.58 – 7.55 (m, 2 H, HC(d)), 7.52 – 7.48 (m, 4 H, HC(c) and HC(e)), 6.95 (d, *J* = 8.0 Hz, 1 H, HC(5')), 6.64 (d, *J* = 1.0 Hz, 1 H, HC(2')), 6.60 (dd, *J* = 8.0, 1.0 Hz, 1 H, HC(6')), 5.91 (s, 2 H, OCH₂O), 4.71 (s, 1 H, OH), 3.88 (q, *J* = 7.5 Hz, 1 H, HC(3)), 2.82 – 2.76 (m, 1 H, HC(5)), 2.74 – 2.69 (m, 1 H, HC(2)), 2.61 – 2.55 (m, 1 H, HC(5)), 1.90 – 1.83

(m, 1 H, HC(4)), 1.77 – 1.70 (m, 1H, HC(4)), 1.04 (d, $J = 17.5, 7.5$ Hz, HC(1)); ^{13}C NMR: (125 MHz, CDCl_3) 147.7 (C(3')), 145.7 (C(4')), 136.1 (C(1')), 132.53 (d, $J = 95.5$ Hz, C(a)), 132.3 (d, $J = 2.6$ Hz, C(d)), 132.2 (d, $J = 2.6$ Hz, C(d)), 132.1 (d, $J = 9.0$ Hz, C(e)), 131.2 (d, $J = 9.0$ Hz, C(c)), 130.5 (d, $J = 95.5$ Hz, C(a)), 129.1 (d, $J = 11.4$ Hz, C(f)), 128.7 (d, $J = 11.4$ Hz, C(b)), 121.4 (C(2')), 109.2 (C(6')), 108.3 (C(5')), 100.9 (OCH₂O), 71.6 (C(3)), 38.4 (d, $J = 68.8$ Hz, C(2)), 37.1 (C(4)), 31.5 (C(5)), 11.9 (C(1)); ^{31}P NMR: (202 MHz, CDCl_3) 41.76; IR:(KBr) 3303 (bs), 2926 (m), 2878 (m), 1503 (s), 1487 (s), 1434 (s), 1313 (w), 1243 (s), 1115 (s), 1035 (s), 994 (w), 928 (m); MS:(EI⁺, 70 eV) 408.1 (15.4), 259.1 (15.7), 230.0 (12.4), 229.0 (11.1), 203.0 (14.9), 202.0 (100.0), 201.0 (72.4), 188.1 (13.5), 135.0 (29.3), 77.1 (33.7), 57.1 (13.9), 51.1 (14.9); HRMS: calcd for $\text{C}_{24}\text{H}_{25}\text{O}_4\text{P}^+$: 408.1491, found: 408.1499; TLC: R_f 0.34 (EtOAc/pentane, 7:3) [KMnO_4]. Data for *syn*-**5**: mp: 56–58 °C; ^1H NMR: (500 MHz, CDCl_3) 7.80 – 7.74 (m, 4 H, HC(b) and HC(f)), 7.55 – 7.46 (m, 6 H, HC(c), HC(d), H(e)) 6.66 (d, $J = 8.0$ Hz, 1 H, HC(5')), 6.62 (d, $J = 1.0$ Hz, 1 H, HC(2')), 6.56 (dd, $J = 8.0, 1.0$ Hz, 1 H, HC(6')), 5.91 (d, $J = 2.5$ Hz, 2 H, OCH₂O), 4.25 (s, 1 H, OH), 4.11 – 4.06 (m, 1 H, HC(3)), 2.69 – 2.63 (m, 1 H, HC(5)), 2.54 – 2.48 (m, 1 H, HC(5)), 2.32 (dq, $J = 7.5, 7.5$ Hz, 1 H, HC(2)), 2.03 – 1.96 (m, 1 H, HC(4)), 1.63 – 1.56 (m, 1 H, HC(4)), 1.21 (dd, $J = 17.0, 7.5$ Hz, 3 H, HC(1)); ^{13}C NMR: (125 MHz, CDCl_3) 147.7 (C(3')), 145.8 (C(4')), 135.6(C(1')), 132.17 (d, $J = 2.8$ Hz, C(d)), 132.0 (d, $J = 2.8$ Hz, C(d)), 131.9 (d, $J = 94.4$ Hz, C(a)), 131.4 (d, $J = 94.4$ Hz, C(a)), 131.0 (d, $J = 11.5$ Hz, C(b)), 130.9 (d, $J = 11.5$ Hz, C(f)), 129.1 (d, $J = 4.1$ Hz, C(c)), 129.0 (d, $J = 4.1$ Hz, C(e)), 121.3 (C(6')), 109.0 (C(2')), 108.3 (C(5')), 100.9 (OCH₂O), 68.5 (C(3)), 36.8 (d, $J = 12.5$ Hz, C(4)), 36.1 (d, $J = 70.1$ Hz, C(2)), 32.1 (C(5)), 5.9 (C(1)); ^{31}P NMR: (202 MHz, CDCl_3) 41.69; IR: (KBr) 3425 (bs), 3059 (m), 2926 (s), 2885 (s), 1712 (s), 1608 (m), 1590 (m), 1503 (s), 1486 (s), 1451 (m), 1434 (m), 1361 (m), 1337 (m), 1234 (s), 1160 (s), 1115 (m), 1035 (m), 924 (s); MS: (EI⁺, 70 eV) 408.2 (16.1), 259.1 (12.3), 231.2 (10.0), 230.1 (13.7), 229.1 (12.2), 203.1 (15.6), 202.0 (100.0), 201.0 (64.0), 191.1 (9.7), 188.1 (20.2), 155.1 (10.8), 135.0 (25.9), 91.1 (11.1), 77.1 (28.6), 71.1 (37.9), 69.1 (12.4), 57.1 (25.7), 55.1 (20.4), 51.0 (12.5); HRMS: calcd for $\text{C}_{24}\text{H}_{25}\text{O}_4\text{P}^+$: 408.14905, found: 408.14850; TLC: R_f 0.42 (EtOAc/pentane, 7:3) [KMnO_4].

Preparation of *syn*-2-Diphenylphosphinoyl-5-(3',4'-methylenedioxyphenyl)pentan-3-ol (*syn*-5**) and *anti*-2-Diphenylphosphinoyl-5-(3',4'-methylenedioxyphenyl)pentan-3-ol (*anti*-**5**)—**

Titanium tetrachloride (0.7 mL, 6.4 mmol) was added to a solution of ketone **4** (2.0 g, 4.92 mmol) in CH_2Cl_2 (30 mL) at -30 °C. The reaction turned immediately red. After 1h, the reaction mixture was cooled to -70 °C and $\text{BH}_3\cdot\text{py}$ (1 M, 8.4 mL, 9.84 mmol) was slowly added and the reaction mixture was stirred for 3 h and then warm up to room temperature. The reaction was quenched with slow addition of dilute HCl (10% in H_2O , 20 mL) at 0 °C. The aqueous phase was extracted with CH_2Cl_2 (3×30 mL), and the combined organic layers were washed with brine (80 mL), dried over MgSO_4 , filtered through glass wool and then concentrated in vacuo ($20 - 23$ °C, 10 mmHg). Purification via flash column chromatography (Teledyne Isco Combiflash Rf 75, Silicycle Silica gel, 25 g, 15–40 mm mesh, gradient: 35 to 50% EtOAc in hexane over 70 min, 30 mL/min) to afford *syn*-**5** as pale white oil (1.4 g, 72%) that crystallized upon standing, and *anti*-**5** as white solid (343 mg, 17%). Characterizations were in accordance with the previously described compounds for *anti*-**5** and *syn*-**5**.

Preparation of 2-Methyl-2-diphenylphosphinoyl-5-(3',4'-methylenedioxyphenyl)pentan-3-one (6**)—**

A solution of $\text{KO}^t\text{-Bu}$ (435 mg, 3.9 mmol) in THF (20 mL) was added at 0 °C via syringe, into a solution of ketone **4** (1.5 g, 3.7 mmol) in THF (50 mL). The homogeneous mixture was then vigorously stirred for 1 hr followed by slow addition of MeI (460.0 mL, 7.4 mmol). After complete addition, the reaction mixture was warmed to room temperature and stirred for 12 h. The reaction was quenched with dilute HCl (10% in H_2O , 20 mL). The aqueous phase was extracted with Et_2O (3×20 mL) and the combined organic layers were washed with brine (60 mL), dried over Na_2SO_4 , filtered through glass wool and then concentrated in vacuo (20 – 23 °C, 10 mmHg). Purification via by flash column chromatography (SiO_2 , 20 g, 25 mm Ø, EtOAc/pentane, 7:3) afforded **6** as white solid (1.36 g, 87%). Recrystallization from hot Et_2O provided 1.31 g of analytically pure **6**. Data for **6**: mp: 108–110 °C (Et_2O); ^1H NMR: (500 MHz, CDCl_3) 7.84 – 7.80 (m, 4 H, HC(b) and HC(f)), 7.58 – 7.54 (m, 2 H, HC(d)), 7.50 – 7.46 (m, 4 H, HC(c) and HC(e)), 6.67 (d, $J = 8.0$ Hz, 1 H, HC(5')), 6.56 (d, $J = 1.5$ Hz, 1 H, HC(2')), 6.54 (dd, $J = 8.0, 1.5$ Hz, 1 H, HC(6')), 5.90 (s, 2 H, OCH_2O), 2.91 (t, $J = 7.5$ Hz, 2 H, HC(5)), 2.62 (t, $J = 7.5$ Hz, 2 H, HC(4)), 1.45 (d, $J = 15.0$ Hz, 6 H, HC(1)); ^{13}C NMR: (125 MHz, CDCl_3) 210.3 (CO), 147.6 (C(3')), 145.9 (C(4')), 135.0 (C(1')), 132.4 (d, $J = 15.0$ Hz, C(b,f)), 132.3 (d, $J = 2.8$ Hz, C(d)), 130.7 (d, $J = 95.5$ Hz, C(a)), 128.7 (d, $J = 14.6$ Hz, C(c,e)), 121.5 (C(2')), 109.3 (C(6')), 108.3 (C(5')), 100.9 (OCH_2O), 53.2 (d, $J = 57.5$ Hz, C(2)), 42.9 (C(5)), 29.82 (C(4)), 21.4 (C(1)); ^{31}P NMR: (202 MHz, CDCl_3) 34.61; IR: (KBr) 3060 (w), 2970 (w), 2922 (w), 1699 (s), 1606 (w), 1592 (w), 1505 (m), 1490 (m), 1482 (m), 1439 (s), 1417 (m), 1370 (m), 1297 (w), 1241 (s), 1177 (s), 1116 (s), 1099 (s), 1039 (s), 996 (m), 928 (s); MS: (TOF ES^+) 422.1 (25.0), 421.1 (16.1, $\text{M}+\text{H}^+$); HRMS: calcd for $\text{C}_{25}\text{H}_{26}\text{O}_4\text{P}^+$: 421.1569, found: 421.1574; TLC: R_f 0.49 (pentane/EtOAc, 3:7); Analysis: $\text{C}_{25}\text{H}_{25}\text{O}_4\text{P}$ (420.44) Calcd: C, 71.42; H, 5.99; P, 7.37%. Found: C, 71.29; H, 6.02; P, 7.49%.

Preparation of 2-Methyl-2-diphenylphosphinoyl-5-(3',4'-methylenedioxyphenyl)pentan-3-ol (**7**)—

Sodium borohydride (675 mg, 17.8 mmol) was added portion wise to a solution of ketone **6** (2.50 g, 5.95 mmol) in $\text{CH}_2\text{Cl}_2/\text{MeOH}$ (1:1 v/v, 100 mL) at room temperature, and stirred for 4 h. The reaction was quenched with sat. aq. NH_4Cl (30 mL) at 0 °C. The aqueous phase was extracted with Et_2O (3×55 mL), and the combined organic layers were successively washed with brine (100 mL), dried over MgSO_4 , filtered through glass wool and then concentrated in vacuo (20 – 23 °C, 10 mmHg). The product **7** was obtained as a white solid (2.51 g, 99%). The crude material was used without further purification. Recrystallization of an aliquot (400 mg) from CH_2Cl_2 20%/Et $_2\text{O}$ 80% (v/v) (5 mL) gave an analytical sample of **7** (380 mg). Data for **7**: mp: 123–125 °C ($\text{CH}_2\text{Cl}_2/\text{Et}_2\text{O}$); ^1H NMR: (500 MHz, CDCl_3) 8.03 – 8.00 (m, 2 H, HC(d)), 7.97 – 7.94 (m, 2 H, HC(e)), 7.60 – 7.50 (m, 6 H, HC(d), HC(c) and HC(f)), 6.70 (d, $J = 8.0$ Hz, 1 H, HC(5')), 6.66 (d, $J = 1.0$ Hz, 1 H, HC(2')), 6.62 (dd, $J = 8.0, 1.0$ Hz, 1 H, HC(6')), 5.92 (s, 2 H, OCH_2O), 5.46 (s, 1 H, OH), 3.86 (dt, $J = 11.0, 1.5$ Hz, 1 H, HC(3)), 2.88 (ddd, $J = 14.0, 10.5, 4.5$ Hz, 1 H, HC(5)), 2.48 (ddd, $J = 14.0, 9.5, 6.5$ Hz, 1 H, HC(5)), 1.72 – 1.64 (m, 1 H, HC(4)), 1.58 – 1.52 (m, 1 H, HC(4)), 1.26 (d, $J = 16.0$ Hz, 3 H, HC(1)), 1.08 (d, $J = 17.0$ Hz, 3 H, HC(1)); ^{13}C NMR: (125 MHz, CDCl_3) 147.6 (C(3')), 145.7 (C(4')), 136.5 (C(1')), 132.4 (d, $J = 8.1$ Hz, C(c)), 132.3 (d, $J = 8.1$ Hz, C(e)), 132.2 (d,

$J = 2.6$ Hz, C(d)), 131.1 (d, $J = 2.5$ Hz, C(d)), 130.4 (d, $J = 89.1$ Hz, C(a)), 128.8 (d, $J = 10.8$ Hz, C(b)), 128.7 (d, $J = 10.8$ Hz, C(f)), 121.4 (C(6')), 109.2 (C(2')), 108.3 (C(5')), 100.9 (OCH₂O), 73.8 (C(3)), 40.5 (d, $J = 68.7$ Hz, C(2)), 32.5 (C(4,5)), 21.4 (C(1)), 16.3 (C(1)); ³¹P NMR: (202 MHz, CDCl₃) 44.8; IR: (KBr) 3306 (bm), 3056 (w), 2966 (m), 2927 (m), 2879 (m), 1609 (w), 1592 (w), 1501 (m), 1488 (s), 1437 (s), 1241 (s), 1168 (s), 1146 (s), 1110 (s), 1093 (s), 1037 (m), 998 (w), 929 (s); MS: (TOF ES⁺) 457.1 (4.0), 425.2 (3.5), 424.2 (23.2), 423.2 (100, M+2H⁺), 403.1 (3.5); HRMS: calcd for C₂₅H₂₈O₄P⁺: 423.1725, found: 423.1715; TLC: R_f 0.47 (EtOAc/pentane, 7:3) [KMnO₄].

General Procedure 1—An oven-dried, 50 mL, two-necked, round-bottomed flask was charged with KH (1.5 equiv) in a glove box and capped with a septum and a stopper. Outside of the glove box, a solution of the requisite b-hydroxy diphenylphosphine oxide (1.0 eq) in DMF (30 mL) at room temperature, then the reaction mixture was heated at 50 °C. After 30 min, the homogeneous orange solution was allowed to cool to room temperature, and the reaction was quenched with H₂O (50 mL). The aqueous phase was extracted with pentane (3 × 20 mL). HCl (1M, 30 mL) was added to the aqueous solution. The aqueous phase was extracted with pentane (2 × 15 mL). The combined organic layers were washed with brine (60 mL), dried over MgSO₄, filtered through glass wool and then concentrated in vacuo (20 – 23 °C, 10 mmHg). The product olefins were purified by flash column chromatography on silica gel (SiO₂, 15 g, 20 mm Ø, pentane/Et₂O, 98:2) followed by distillation.

Preparation of (*E*)-5-(3',4'-Methylenedioxyphenyl)pent-2-ene ((*E*)-2a)—

Following General Procedure 1, an oven-dried 50 mL, KH (160 mg, 3.97 mmol) and alcohol *anti*-5 (1.08 mg, 2.6 mmol) were reacted to give (*E*)-2a (372 mg, 74%) as colorless liquid after purification by distillation. Data for (*E*)-2a: bp: 45 °C @ 3.2×10^{-5} mmHg; ¹H NMR: (500 MHz, CDCl₃) 6.75 (d, $J = 8.0$ Hz, 1 H, HC(5')), 6.70 (d, $J = 1.0$ Hz, 1 H, HC(2')), 6.65 (dd, $J = 8.0, 1.0$ Hz, 1 H, HC(6')), 5.94 (s, 2 H, OCH₂O), 5.49 – 5.47 (m, 2 H, HC(2) and HC(3)), 2.61 (t, $J = 7.5$ Hz, 2 H, HC(5)), 2.30 – 2.26 (m, 2 H, HC(4)), 1.67 (d, $J = 3.5$ Hz, 3 H, HC(1)); ¹³C NMR: (125 MHz, CDCl₃) 147.6 (C(3')), 145.7 (C(4')), 136.3 (C(1')), 130.6 (C(3)), 125.7 (C(2)), 121.3 (C(6')), 109.2 (C(2')), 108.3 (C(5')), 100.9 (OCH₂O), 36.0 (C(5)), 35.0 (C(4)), 18.1 (C(1)); IR: (neat) 3017 (m), 2912 (s), 2857 (s), 2766 (w), 1608 (w), 1503 (w), 1486 (s), 1441 (s), 1358 (m), 1243 (s), 1035 (s), 966 (s), 938 (s), 855 (m), 806 (s); MS: (EI⁺, 70 eV) 191.1 (3.0), 190.1 (22.2), 136.1 (8.3), 135.0 (100.0), 105.0 (4.2), 79.1 (3.5), 77.1 (11.4), 55.1 (2.4), 51.0 (6.4); HRMS: calcd for C₁₂H₁₄O₂⁺: 190.0988, found: 190.0994; TLC: R_f 0.71 (pentane) [KMnO₄]; Analysis: C₁₂H₁₄O₂ (190.24) Calcd: C, 75.76; H, 7.42%. Found: C, 76.15; H, 7.58%.

Preparation of (*Z*)-5-(3',4'-Methylenedioxyphenyl)pent-2-ene ((*Z*)-2a)—

Following General Procedure 1, KH (134 mg, 3.35 mmol) and alcohol *syn*-5 (913 mg, 2.23 mmol) were reacted to give (*Z*)-2a (2 mg, 76%) as colorless liquid after purification by distillation. Data for (*Z*)-2a: bp: 40 °C @ 3.2×10^{-5} mmHg; ¹H NMR: (500 MHz, CDCl₃) 6.75 (d, $J = 8.0$ Hz, 1 H, HC(5')), 6.72 (d, $J = 1.0$ Hz, 1 H, HC(2')), 6.67 (dd, $J = 8.0, 1.0$ Hz,

1 H, HC(6')), 5.94 (s, 2 H, OCH₂O), 5.53 – 5.41 (m, 2 H, HC(2) and HC(3)), 2.61 (t, $J = 7.5$ Hz, 2 H, HC(5)), 2.34 (dt, $J = 7.5, 7.5$ Hz, 2 H, HC(4)), 1.60 (d, $J = 6.5$ Hz, 3 H, HC(1)); ¹³C NMR: (125 MHz, CDCl₃) 147.7 (C(3')), 145.7 (C(4')), 136.3 (C(1')), 129.7 (C(3)), 124.8 (C(2)), 121.4 (C(6')), 109.1 (C(2')), 108.3 (C(5')), 100.9 (OCH₂O), 35.7 (C(5)), 29.3 (C(4)), 13.0 (C(1)); IR: (neat) 3010 (s), 2926 (s), 2773 (m), 1608 (w), 1503 (s), 1486 (s), 1441 (s), 1358 (m), 1247 (s), 1039 (s), 935 (s), 858 (m), 810 (s); MS: (EI⁺, 70 eV) 191.1 (2.0), 190.1 (14.9), 136.1 (8.2), 135.1 (100.0), 105.0 (4.8), 79.1 (3.7), 78.1 (2.4), 77.1 (14.9), 63.1 (2.3), 51.0 (8.6); HRMS: calcd for C₁₂H₁₄O₂⁺: 190.0994, found: 190.0997; TLC: R_f 0.71 (pentane) [KMnO₄]; Analysis: C₁₂H₁₄O₂ (190.24) Calcd: C, 75.76; H, 7.42%. Found: C, 75.73; H, 7.39%.

Preparation of 2-Methyl-5(3',4'-methylenedioxyphenyl)pent-2-ene (2c)—

Following General Procedure 1, an oven-dried 50 mL, KH (108 mg, 2.7 mmol) and alcohol **7** (760 mg, 1.8 mmol) were reacted to give **2c** (293 mg, 72%) as colorless liquid after purification by distillation. Data for **2c**: bp: 50 °C @ 3.2×10^{-5} mmHg; ¹H NMR: (500 MHz, CDCl₃) 6.75 (d, $J = 8.0$ Hz, 1 H, HC(5')), 6.72 (d, $J = 1.0$ Hz, 1 H, HC(2')), 6.66 (dd, $J = 8.0, 1.0$ Hz, 1 H, HC(6')), 5.94 (s, 2 H, OCH₂O), 5.18 (tq, $J = 7.0, 1.5$ Hz, 1 H, HC(3)), 2.57 (t, $J = 8.0$ Hz, 2 H, HC(5)), 2.27 (dt, $J = 7.5, 7.5$ Hz, 2 H, HC(4)), 1.72 (s, 3 H, HC(1a)), 1.60 (s, 3 H, HC(1b)); ¹³C NMR: (125 MHz, CDCl₃) 147.6 (C(3')), 145.7 (C(4')), 136.5 (C(1')), 132.4 (C(2)), 123.8 (C(3)), 121.3 (C(6')), 109.1 (C(2')), 108.3 (C(5')), 100.9 (OCH₂O), 36.1 (C(5)), 30.6 (C(4)), 25.9 (C(1a)), 17.9 (C(1b)); IR: (neat) 2961 (s), 2912 (s), 2773 (w), 1608 (w), 1503 (s), 1486 (s), 1441 (s), 1379 (m), 1247 (s), 1188 (w), 1094 (w), 1042 (s), 938 (s), 855 (m), 806 (s); MS: (EI⁺, 70 eV) 205.2 (2.6), 204.2 (17.4), 204.1 (17.4), 136.1 (9.1), 135.1 (100.0), 105.0 (3.7), 79.1 (2.8), 77.1 (11.1), 51.0 (5.7); HRMS: calcd for C₁₃H₁₆O₂⁺: 204.1150, found: 204.1155; TLC: R_f 0.35 (pentane) [KMnO₄]; Analysis: C₁₃H₁₆O₂ (204.26) Calcd: C, 76.44; H, 7.90%. Found: C, 76.41; H, 7.65%.

Preparation of Cyclization Substrates. Suzuki Coupling Route

Preparation of Cyclization Substrates (Please refer to footnote 56 for the safe handling and disposal of thallium and arsenic containing compounds).⁵⁶

General Procedure 3—To an oven-dried, 20 mL, two-necked, round-bottomed flask charged with the requisite alkene (1.0 equiv) was added dropwise a solution of 9-BBN (solution in THF, 1.5 equiv) at room temperature with stirring. In a separate flask, the requisite vinyl iodide (1.2 equiv) was added at room temperature to a mixture of PdCl₂(dppf) (0.1 equiv), AsPh₃ (0.2 equiv) and THF. After 2 h, TIOEt (2.0 equiv) and H₂O (5.0 equiv) were sequentially added dropwise to the alkylborane solution. Immediately, the solution turned grey. The reaction mixture was allowed to stir for 2 min, then the alkylborane solution was transferred via cannula into the orange suspension of the vinyl iodide, Pd(dppf)Cl₂ and AsPh₃ at room temperature whereupon the reaction mixture turned pale green.^{56a} The flask containing the borane solution was rinsed with THF (2 mL), and was transferred via cannula into the reaction solution. The reaction flask was wrapped in aluminium foil to exclude light. After being stirred for 12 h, the contents of the flask were poured into H₂O (30 mL).^{56b} The aqueous phase was extracted with Et₂O (3 × 15 mL). Then, the combined organic extracts were stirred with H₂O₂ (30% aq., 4.0 equiv) at room temperature for 20 min whereupon the mixture turned a cloudy yellow. Sat. aq. Na₂SO₃ solution (10 mL) was added dropwise to quench any remaining H₂O₂ (a slight warming of the solution was noted), prompting the mixture to become clear and orange. Starch-iodide

paper was used to confirm that no H₂O₂ remained. The organic phase was successively washed with H₂O (20 mL), brine (60 mL) then dried over MgSO₄, filtered through glass wool^{56c} and concentrated in vacuo (20 – 23 °C, 10 mmHg). The crude products were purified by flash column chromatography on silica gel^{56d} followed by distillation or recrystallization as necessary.

General Procedure 4—To an oven-dried, 20 mL, two-necked, round-bottomed flask charged with the requisite alkene (1.0 eq) was added dropwise a solution of 9-BBN (solution in THF, 1.5 equiv) at room temperature with stirring. In a separate flask, the requisite vinyl iodide (1.2 equiv) was added at room temperature to a mixture PdCl₂(dppf) (0.05 equiv), AsPh₃ (0.1 equiv), Cs₂CO₃ (2.0 equiv) and DMF. After 2 h, H₂O (15.0 equiv) and alkylborane solution were sequentially added dropwise to the Pd(dppf)Cl₂ solution. After stirring for 24 h at room temperature, the contents of the flask were poured into H₂O (50 mL). The aqueous phase was extracted with Et₂O (3 × 15 mL). Then, the combined organic layers were stirred with H₂O₂ (30% aq.) at room temperature for 20 min, to oxidize AsPh₃ residues. The organic phase were successively washed with H₂O (20 mL), brine (60 mL), then dried over MgSO₄, filtered through glass wool and concentrated in vacuo (20 – 23 °C, 10 mmHg). The crude products were purified by flash column chromatography on silica gel.

Preparation of (*E*)-4-(3',4'-Methylenedioxyphenyl)-1-phenylbut-1-ene ((*E*)-2b)—

Following General Procedure 3, olefin **8a** (149 mg, 1.0 mmol), 9-BBN (0.345 M in THF, 4.4 mL, 1.5 mmol), TIOEt (142 mL, 2.0 mmol), H₂O (91 mL, 5.0 mmol) were reacted with PdCl₂(dppf) (73.5 mg, 0.1 mmol), AsPh₃ (61.2 mg, 0.4 mmol), (*E*)-(2-iodovinyl)benzene **10b** (277.6 mg, 1.2 mmol) and THF (4 mL). The product was purified by flash column chromatography (SiO₂, 30 g, 40 mm Ø, hexane/Et₂O, 98:2) to afford 183 mg of (*E*)-**2b** as orange oil. Purification by distillation afforded 179 mg (71%) of analytically pure (*E*)-**2b** as slightly orange oil. Data for (*E*)-**2b**: bp: 120 °C @ 3.0×10⁻⁵ mmHg; ¹H NMR: (500 MHz, CDCl₃) 7.36 – 7.29 (m, 4 H, HC(b) and HC(c)), 7.22 (dt, *J* = 7.0, 1.5 Hz, 1 H, HC(d)), 6.76 (d, *J* = 8.0 Hz, 1 H, HC(5')), 6.74 (d, *J* = 1.0 Hz, 1 H, HC(2')), 6.68 (dd, *J* = 8.0, 1.0 Hz, 1 H, HC(6')), 6.42 (d, *J* = 16.0 Hz, 1 H, HC(1)), 6.26 (dt, *J* = 16.0, 6.5 Hz, 1 H, HC(2)), 5.94 (s, 2 H, OCH₂O), 2.73 (t, *J* = 7.5 Hz, 2 H, HC(4)), 2.50 (dtd, *J* = 7.5, 7.5, 1.0 Hz, 2 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 147.8 (C(3')), 145.9 (C(4')), 137.9 (C(a)), 135.8 (C(1')), 130.7 (C(d)), 130.1 (C(1)), 128.7 (C(c)), 127.2 (C(2)), 126.2 (C(b)), 121.4 (C(6')), 109.1 (C(2')), 108.4 (C(5')), 100.9 (OCH₂O), 35.9 (C(4)), 35.3 (C(3)); IR: (neat) 3060 (w), 3024 (m), 2931 (m), 2902 (m), 2845 (m), 1607 (w), 1596 (w), 1499 (s), 1487 (s), 1447 (s), 1366 (m), 1242 (s), 1200 (s), 1117 (m), 1101 (m), 1036 (s), 962 (s), 923 (s), 868 (s), 804 (s), 757 (s), 737 (s), 687 (s); MS: (EI⁺, 70 eV) 252.1 (45.0), 136.1 (11.5), 135.1 (100.0), 117.1 (9.0), 115.1 (8.8); HRMS: calcd for C₁₇H₁₆O₂⁺: 252.1150, found: 252.1142; TLC: *R*_f 0.49 (hexane/Et₂O, 96:4) [KMnO₄].

Preparation of (*E*)-4-(3',4'-Methylenedioxyphenyl)-1-(4-methylphenyl)but-1-ene ((*E*)-2d)—

Following General Procedure 3, olefin **8a** (149 mg, 1.0 mmol), 9-BBN (0.345 M in THF, 4.4 mL, 1.5 mmol), TIOEt (142 mL, 2.0 mmol), H₂O (91 mL, 5.0 mmol) were reacted with PdCl₂(dppf) (73.5 mg, 0.10 mmol), AsPh₃ (61.6 mg, 0.20 mmol), (*E*)-1-(2-iodovinyl)-4-methylbenzene **10d** (292 mg, 1.2 mmol) and THF (4 mL). Purification by flash column chromatography (SiO₂, 24 g, 40 mm Ø, hexanes/Et₂O, 96:4) afforded (*E*)-**2d** (166 mg, 62%) as white solid. Recrystallization from hot hexane provided 160 mg (60%) of analytically pure (*E*)-**2d**. Data for (*E*)-**2d**: mp: 67–68 °C (hexane); ¹H NMR: (500 MHz, CDCl₃) 7.27 (d, *J* = 8.0 Hz, 2 H, HC(b)), 7.14 (d, *J* = 8.0 Hz, 2 H, HC(c)), 6.77 (d, *J* = 8.0 Hz, 1 H, HC(5')), 6.75 (d, *J* = 1.0 Hz, 1 H, HC(2')), 6.70 (dd, *J* = 8.0, 1.0 Hz, 1 H, HC(6')), 6.41 (d, *J* = 16.0 Hz, 1 H, HC(1)), 6.22 (dt, *J* = 15.5, 6.5 Hz, 1 H, HC(2)), 5.96 (s, 2 H, OCH₂O), 2.74 (t, *J* = 8.0 Hz, 2 H, HC(4)), 2.51 (dt, *J* = 7.5, 7.5 Hz, 2H, HC(3)), 2.36 (s, 3 H, HC(1)); ¹³C NMR: (125 MHz, CDCl₃) 147.8 (C(3')), 145.9 (C(4')), 136.9 (C(d)), 135.9 (C(a)), 135.1 (C(1')), 130.5 (C(2)), 129.4 (C(b)), 129.0 (C(1)), 126.1 (C(c)), 121.4 (C(6')), 109.2 (C(2')), 108.4 (C(5')), 101.0 (OCH₂O), 35.9 (C(4)), 35.4 (C(3)), 21.4 (C(e)); IR: (KBr) 3022 (w), 2929 (m), 2897 (m), 2852 (w), 2783 (w), 1607 (w), 1498 (s), 1486 (s), 1442 (s), 1355 (m), 1243 (s), 1189 (s), 1122 (m), 1100 (s), 1037 (s), 970 (s), 936 (s), 924 (s), 859 (s), 810 (s), 800 (s), 768 (s); MS: (TOF ES⁺) 364.4 (50.0), 341.3 (72.0), 282.3 (100.0), 267.1 (65.0), 175.1 (80.0), 145.1 (91.5); HRMS: calcd for C₁₈H₁₉O₂⁺: 267.1385, found: 267.1382; TLC: *R_f* 0.51 (hexane/Et₂O, 96:4) [KMnO₄]; Analysis: C₁₈H₁₈O₂ (266.33) Calcd: C, 81.17; H, 6.81%. Found: C, 81.42; H, 6.68%.

Preparation of (*E*)-4-(3',4'-Methylenedioxyphenyl)-1-(4-cyanophenyl)but-1-ene ((*E*)-**2e**)—

Following General Procedure 4, olefin **8a** (222.0 mg, 1.5 mmol) in THF (2 mL), 9-BBN (0.577 M in THF, 3.9 mL, 2.25 mmol) and H₂O (0.41 mL, 22.5 mmol) were reacted with PdCl₂(dppf) (54.8 mg, 74.9 mmol), AsPh₃ (45.8 mg, 149.8 mmol), Cs₂CO₃ (976.4 mg, 3.0 mmol), (*E*)-4-(2-iodovinyl)benzonitrile **10e** (458.6 mg, 1.8 mmol) and DMF (4 mL). Purification by flash column chromatography (SiO₂, 27 g, 30 mm Ø, hexanes/Et₂O, 80:20) afforded (*E*)-**2e** (262 mg, 63%) as white solid, along with starting material **8a** (26 mg 12%). Recrystallization of (*E*)-**2e** from hot hexane provided 253 mg (16%) of analytically pure (*E*)-**2e**. Data for (*E*)-**2e**: mp: 105–106 °C (hexane); ¹H NMR: (500 MHz, CDCl₃) 7.58 (d, *J* = 8.0 Hz, 2 H, HC(c)), 7.41 (d, *J* = 8.0 Hz, 2H, HC(b)), 6.74 (d, *J* = 7.5 Hz, 1 H, HC(5')), 6.72 (s, 1H, HC(2')), 6.70 (d, *J* = 7.5, 1.0 Hz, 1 H, HC(6')), 6.45 – 6.36 (m, 2 H, HC(1) and HC(2)), 5.95 (s, 2 H, OCH₂O), 2.75 (t, *J* = 7.5 Hz, 2 H, HC(4)), 2.51 (dt, *J* = 7.0, 7.0 Hz, 2 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 147.9 (C(3')), 146.0 (C(4')), 142.4 (C(a)), 135.3 (C(1)), 134.3 (C(1')), 132.6 (C(c)), 129.4 (C(2)), 126.7 (C(b)), 121.4 (C(6')), 119.3 (CN), 110.4 (C(d)), 109.1 (C(2')), 108.4 (C(5')), 101.0 (OCH₂O), 35.4 (C(4)), 35.3 (C(3)); IR: (KBr) 3026 (w), 2990 (w), 2909 (w), 2880 (w), 2775 (w), 2223 (m), 1645 (w), 1645 (w), 1603 (s), 1500 (s), 1486 (s), 1452 (m), 1440 (s), 1411 (m), 1351 (m), 1251 (s), 1229 (s), 1185 (m), 1100 (m), 1029 (s), 974 (s), 956 (s), 920 (s), 873 (s), 859 (s), 802 (s); MS: (TOF

ES⁺) 324.0 (20.0), 323.0 (100.0), 278.1 (10.0); HRMS: calcd for C₁₈H₁₆O₂⁺: 278.1181, found: 278.1174; TLC: *R*_f 0.37 (hexane/Et₂O, 80:20) [KMnO₄]; Analysis: C₁₈H₁₅NO₂ (277.32) Calcd: C, 77.96; H, 5.45; N, 5.05%. Found: C, 77.88; H, 5.51; N, 4.98%.

Preparation of (*E*)-4-(3',4'-Methylenedioxyphenyl)-1-(4-Methoxyphenyl)but-1-ene ((*E*)-2f)—

Following General Procedure 4, olefin **8a** (222.0 mg, 1.5 mmol) in THF (2 mL), 9-BBN (0.577 M in THF, 3.9 mL, 2.25 mmol) and H₂O (0.41 mL, 22.5 mmol) were reacted with PdCl₂(dppf) (54.8 mg, 74.9 mmol), AsPh₃ (45.8 mg, 149.8 mmol), Cs₂CO₃ (976.4 mg, 3.0 mmol), (*E*)-1-(2-iodovinyl)-4-methoxybenzene **10f** (458.6 mg, 1.8 mmol) and DMF (4 mL). Purification by flash column chromatography (SiO₂, 35 g, 30 mm Ø, hexanes/Et₂O, 95:5) afforded (*E*)-**2e** (180 mg, 43%) as white solid, along with starting material **8a** (22 mg, 10%). Recrystallization of (*E*)-**2e** from hot hexane provided 170 mg (40%) of (*E*)-**2e**. Data for (*E*)-**2f**: mp: 92–93 °C (hexane); ¹H NMR: (500 MHz, CDCl₃) 7.30 (d, *J* = 9.0 Hz, 2 H, HC(b)), 6.87 (d, *J* = 8.0 Hz, 2 H, HC(c)), 6.77 (d, *J* = 8.0 Hz, 1 H, HC(5')), 6.75 (d, *J* = 1.0 Hz, 1 H, HC(2')), 6.69 (dd, *J* = 8.0, 1.0 Hz, 1 H, HC(6')), 6.39 (d, *J* = 16.0 Hz, 1 H, HC(1)), 6.12 (dt, *J* = 16.0, 7.0 Hz, 1 H, HC(2)), 5.95 (s, 2 H, OCH₂O), 3.83 (s, 3 H, OCH₃), 2.73 (t, *J* = 7.5 Hz, 2 H, HC(4)), 2.51 (dt, *J* = 7.5, 7.5 Hz, 2 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 159.0 (C(d)), 147.8 (C(3')), 145.8 (C(4')), 136.0 (C(1')), 130.8 (C(a)), 130.0 (C(1)), 127.9 (C(2)), 127.3 (C(b)), 121.4 (C(6')), 114.15 (C(c)), 109.1 (C(2')), 108.4 (C(5')), 101.0 (OCH₂O), 55.5 (OCH₃), 36.1 (C(4)), 35.4 (C(3)); IR: (KBr) 3014 (m), 2961 (m), 2937 (w), 2913 (w), 2840 (m), 1597 (s), 1569 (s), 1506 (s), 1464 (s), 1410 (s), 1415 (s), 1369 (w), 1300 (s), 1247 (s), 1177 (s), 1112 (s), 1025 (s), 982 (s), 958 (s), 817 (s), 800 (s), 750 (s); MS: (EI⁺, 70 eV) 282.1 (16.9), 267.1 (5.4), 266.1 (27.0), 265.1 (6.2), 235.1 (6.2), 151.0 (6.0), 148.0 (11.2), 147.1 (100.0), 135.0 (23.8), 121.0 (7.8), 115.0 (6.6); HRMS: calcd for C₁₈H₁₈O₃⁺: 282.12560, found: 282.12578; TLC: *R*_f 0.29 (hexane/Et₂O, 95:5) [KMnO₄]; Analysis: C₁₈H₁₈O₃ (282.12) Calcd: C, 76.57; H, 6.43%. Found: C, 76.67; H, 6.51%.

Following General Procedure 3, olefin **8a** (149 mg, 2.0 mmol), 9-BBN (0.345 M in THF, 4.4 mL, 1.5 mmol), TIOEt (142 mL, 2.0 mmol), H₂O (91 mL, 5.0 mmol) were reacted with PdCl₂(dppf) (73.5 mg, 0.1 mmol), Ph₃As (61.6 mg, 0.2 mmol) and (*E*)-1-(2-iodovinyl)-4-methoxybenzene **10f** (313.8 mg, 1.2 mmol). Purification by flash column chromatography (SiO₂, 25 g, 40 mm Ø, hexanes/Et₂O, 95:5) afforded (*E*)-**2f** (160 mg, 64%) as pale yellow solid. Recrystallization from hot hexane provided 172 mg (61%) of analytically pure (*E*)-**2f**. Spectroscopic data matched those of the product from the previous procedure.

Preparation of (*E*)-4-(3',4'-Methylenedioxyphenyl)-1-(2-naphthalenyl)but-1-ene ((*E*)-2g)—

Following General Procedure 3, olefin **8a** (149 mg, 1.0 mmol), 9-BBN (0.345 M in THF, 4.4 mL, 1.5 mmol), TIOEt (142.4 mL, 2.0 mmol), H₂O (91.0 mL, 5.0 mmol) were reacted with PdCl₂(dppf) (73.5 mg, 0.1 mmol), AsPh₃ (61.6 mg, 0.2 mmol), (*E*)-2-(2-

iodovinyl)naphthalene **10g** (313.8 mg, 1.2 mmol) and THF (4 mL). Purification by flash column chromatography (SiO₂, 26 g, 40 mm Ø, hexanes/Et₂O, 96:4) afforded (*E*)-**2g** (217 mg, 72%) as pale green solid. Recrystallization from hot hexane provided 212 mg (70%) of analytically pure (*E*)-**2g**. Data for (*E*)-**2g**: mp: 96–98 °C (hexane); ¹H NMR: (500 MHz, CDCl₃) 7.83 – 7.79 (m, 3 H, HC(c) and H(f) and H(g)), 7.70 (s, 1 H, HC(j)), 7.60 (dd, *J* = 8.5, 1.0 Hz, 1 H, HC(h)), 7.50 – 7.43 (m, 2 H, HC(b), HC(e)), 6.79 (d, *J* = 8.0 Hz, 1 H, HC(5')), 6.78 (d, *J* = 1.0 Hz, 1 H, HC(2')), 6.72 (dd, *J* = 8.0, 1.0 Hz, 1 H, HC(6')), 6.61 (d, *J* = 16.0 Hz, 1 H, HC(1)), 6.40 (dt, *J* = 16.0, 7.0 Hz, 1 H, HC(2)), 5.97 (s, 2 H, OCH₂O), 2.79 (t, *J* = 8.0 Hz, 2 H, HC(4)), 2.51 (dt, *J* = 8.0, 8.0 Hz, 2 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 147.8 (C(3')), 145.9 (C(4')), 135.8 (C(1')), 135.4 (C(i)), 133.9 (C(a)), 133.0 (C(d)), 130.8 (C(2)), 130.5 (C(1)), 128.3 (C(c)), 128.1 (C(g)), 127.9 (C(f)), 126.4 (C(e)), 125.8 (C(j)), 125.7 (C(b)), 123.8 (C(h)), 121.5 (C(6')), 109.1 (C(2')), 108.4 (C(5')), 101.0 (OCH₂O), 35.9 (C(4)), 35.5 (C(3)); IR: (KBr) 3051 (m), 3018 (w), 2994 (w), 2917 (m), 2856 (m), 2795 (w), 1624 (w), 1605 (w), 1496 (s), 1486 (s), 1440 (s), 1359 (s), 1247 (s), 1187 (s), 1122 (s), 1098 (s), 1041 (s), 960 (s), 924 (s), 867 (s), 814 (s), 780 (s), 766 (s), 738 (s); MS: (EI⁺, 70 eV) 381.3 (6.1), 365.3 (7.1), 340.2 (15.1), 326.2 (17.3), 325.2 (71.8), 303.2 (7.2), 302.2 (24.8), 287.2 (6.3), 279.2 (7.5), 266.1 (15.6), 239.1 (9.7), 231.1 (14.6), 191.1 (17.3), 168.1 (5.9), 167.1 (58.8), 166.1 (5.9), 165.1 (13.2), 152.1 (9.2), 147.1 (7.4), 141.0 (6.0), 136.0 (10.7), 135.0 (100.0), 127.1 (7.5), 121.1 (6.4), 105.1 (8.8); HRMS: calcd for C₂₁H₁₈O₂⁺: 302.1307, found: 302.1304; TLC: *R*_f 0.42 (hexane/Et₂O, 96:4) [KMnO₄]; Analysis: C₂₁H₁₈O₂ (302.37) Calcd: C, 83.42; H, 6.00%. Found: C, 83.52; H, 6.24%.

Preparation of (*E*)-4-(3',4'-Methylenedioxyphenyl)-1-(4-trifluorophenyl)but-1-ene ((*E*)-2h**)—**

Following General Procedure 4, olefin **8a** (250 mg, 1.7 mmol) in THF (2 mL), 9-BBN (0.577 M in THF, 4.4 mL, 2.5 mmol) and H₂O (455 mL, 25.2 mmol) were reacted with PdCl₂(dppf) (61.7 mg, 84.4 mmol), AsPh₃ (51.7 mg, 168.7 mmol), Cs₂CO₃ (1.1 g, 3.4 mmol) and (*E*)-1-(2-iodovinyl)-4-(trifluoromethyl)benzene **10h** (603.5 mg, 2.0 mmol) and DMF (4 mL). Purification by flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexanes/Et₂O, 95:5) afforded (*E*)-**2h** (357 mg, 66%) as pale yellow solid along with **8a** (25 mg, 10%). Recrystallization of (*E*)-**2h** from hot hexane provided 346 mg (64%) of analytically pure (*E*)-**2h**. Data for (*E*)-**2h**: mp: 53–54 °C (hexane); ¹H NMR: (500 MHz, CDCl₃) 7.56 (d, *J* = 8.0 Hz, 2 H, HC(b)), 7.43 (d, *J* = 8.0, 2 H, HC(c)), 6.77 (d, *J* = 8.0 Hz, 1 H, HC(5')), 6.74 (d, *J* = 1.0 Hz, 1 H, HC(2')), 6.69 (dd, *J* = 8.0, 1.0 Hz, 1 H, HC(6')), 6.46 (d, *J* = 16.0 Hz, 1 H, HC(1)), 6.39 (dt, *J* = 15.5, 8.0 Hz, 1 H, HC(2)), 5.96 (s, 2 H, OCH₂O), 2.75 (t, *J* = 8.0 Hz, 2 H, HC(4)), 2.54 (dt, *J* = 7.5, 7.5 Hz, 2 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 147.9 (C(3')), 146.0 (C(4')), 141.4 (C(a)), 135.5 (C(1')), 132.9 (C(2)), 129.5 (C(1)), 129.0 (q, *J* = 32.6 Hz, C(d)), 126.31 (C(b)), 125.7 (q, *J* = 3.8 Hz, C(c)), 124.4 (d, *J* = 250.0 Hz, CF₃), 121.4 (C(6')), 109.1 (C(2')), 108.4 (C(5')), 101.0 (OCH₂O), 35.6 (C(4)), 35.3 (C(3)); ¹⁹F NMR: (376 MHz, CDCl₃) – 62.8; IR: (KBr) 3010 (w), 2929 (w), 2876 (m), 2779 (w), 1652 (m), 1614 (s), 1500 (s), 1488 (s), 1438 (s), 1413 (s), 1320 (s), 1329 (s), 1168 (s), 1124 (s), 1108 (s), 1063 (s), 1041 (s), 1015 (s), 972 (s), 954 (s), 936 (s), 922 (s), 861 (s), 806 (s); MS: (EI⁺, 70 eV) 320.1 (32.4), 227.0 (5.9), 191.1 (5.8), 165.0 (6.9), 159.0 (5.8), 152.0 (24.6), 149.0 (12.6), 147.0 (5.0), 137.0 (5.6), 136.0 (61.6), 135.0 (100.0), 131.0 (5.4), 116.0 (7.8), 115.0 (12.1), 105.0 (20.6), 91.0 (7.8), 79.1 (9.1), 78.1 (6.2), 77.1 (51.4); HRMS: calcd for C₁₈H₁₅F₃O₂⁺: 320.1024, found: 320.1021; TLC: *R*_f 0.53 (hexane/Et₂O, 95:5) [KMnO₄];

Analysis: C₁₈H₁₅F₃O₂ (320.31) Calcd: C, 67.50; H, 4.72; F, 17.79%. Found: C, 67.59; H, 4.65; F, 17.23%.

Preparation of (*E*)-4-(3',4'-Methylenedioxyphenyl)-1-(2-methylphenyl)but-1-ene ((*E*)-2i)—

Following General Procedure 4, olefin **8a** (222 mg, 1.5 mmol) in THF (2 mL), 9-BBN (0.577 M in THF, 3.9 mL, 1.5 mmol) and H₂O (405 mL, 22.5 mmol) were reacted with PdCl₂(dppf) (54.8 mg, 74.9 mmol), AsPh₃ (45.9 mg, 149.8 mmol), Cs₂CO₃ (976.4 g, 3.0 mmol), (*E*)-1-(2-iodovinyl)-2-methylbenzene **10i** (603.5 mg, 2.0 mmol) and DMF (4 mL). Purification by flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexanes/Et₂O, 98:2) afforded (*E*)-**2i** (194 mg, 49%) as pale yellow solid along with **8a** (19 mg, 9%).

Recrystallization of (*E*)-**2i** from hot hexane provided 346 mg (47%) of analytically pure (*E*)-**2i**. Data for (*E*)-**2i**: mp: 38–40 °C (hexane); ¹H NMR: (500 MHz, CDCl₃) 7.41 (d, *J* = 8.0 Hz, 2 H, HC(b)), 7.18–7.14 (m, 3 H, HC(c), HC(d), HC(e)), 6.77 (d, *J* = 8.0 Hz, 1 H, HC(5')), 6.75 (d, *J* = 1.0 Hz, 1 H, HC(2')), 6.70 (dd, *J* = 8.0, 1.0 Hz, 1 H, HC(6')), 6.60 (d, *J* = 15.5 Hz, 1 H, HC(1)), 6.11 (dt, *J* = 15.5, 7.0 Hz, 1 H, HC(2)), 5.95 (s, 2 H, OCH₂O), 2.75 (t, *J* = 8.0 Hz, 2 H, HC(4)), 2.54 (dt, *J* = 7.0, 7.0 Hz, 2 H, HC(3)), 2.33 (s, 3 H, HC(1)); ¹³C NMR: (125 MHz, CDCl₃) 147.9 (C(3')), 146.8 (C(4')), 137.2 (C(a)), 135.9 (C(f)), 135.2 (C(1')), 131.4 (C(2)), 130.4 (C(d)), 128.9 (C(1)), 127.1 (C(c)), 126.3 (C(e)), 125.9 (C(b)), 121.5 (C(6')), 109.2 (C(2')), 108.4 (C(5')), 101.0 (OCH₂O), 36.0 (C(4)), 35.5 (C(3)), 19.9 (C(g)); IR: (KBr) 3017 (w), 2922 (m), 2891 (m), 2776 (w), 1607 (w), 1502 (s), 1487 (s), 1441 (s), 1362 (w), 1242 (s), 1186 (m), 1096 (w), 1037 (s), 964 (m), 936 (m), 925 (m), 807 (m), 745 (s); MS: (EI⁺, 70 eV) 267.1 (2.7), 266.1 (13.7), 136.0 (8.2), 135.0 (100.0), 131.1 (12.8), 116.0 (4.2), 115.0 (4.6), 105.0 (2.7), 91.0 (4.1), 77.0 (8.5), 51.0 (3.9); HRMS: calcd for C₁₈H₁₈O₂⁺: 266.13068, found: 266.12971; TLC: *R*_f 0.52 (hexane/Et₂O, 96:4) [KMnO₄]; Analysis: C₁₈H₁₈O₂ (266.33) Calcd: C, 81.17; H, 6.81%. Found: C, 80.90; H, 6.73%.

Preparation of (*E*)-5-(3',4'-Methylenedioxyphenyl)-2-phenylpent-2-ene ((*E*)-2j)—

Following General Procedure 4, olefin **8a** (500 mg, 3.4 mmol) in THF (2 mL), 9-BBN (0.577 M in THF, 8.8 mL, 5.1 mmol) and H₂O (911 mL, 50.6 mmol) were reacted with PdCl₂(dppf) (123.5 mg, 168.7 mmol), AsPh₃ (103.3 mg, 337.5 mmol), Cs₂CO₃ (2.2 g, 6.7 mmol), (*E*)-(1-iodoprop-1-en-2-yl)benzene **10j** (988.4 mg, 4.0 mmol) and DMF (8 mL). Purification by flash column chromatography (SiO₂, 30 g, 50 mm Ø, hexane/Et₂O, 98:2) afforded 733 mg of (*E*)-**2j** as pale yellow oil along with **8a** (45 mg, 9%). The product was purified by distillation to afford (*E*)-**2j** (719 mg, 80%) as colorless oil. Data for (*E*)-**2j**: bp: 125 °C @ 2.7×10⁻⁵ mmHg; ¹H NMR: (500 MHz, CDCl₃) 7.37 (d, *J* = 8.0 Hz, 2 H, HC(b)), 7.32 (d, *J* = 8.0, 2 H, HC(c)), 7.23 (dt, *J* = 7.0, 1.0 Hz, 1 H, HC(d)), 6.75 (d, *J* = 8.0 Hz, 1 H, HC(5')), 6.74 (d, *J* = 1.5 Hz, 1 H, HC(2')), 6.68 (dd, *J* = 8.0, 1.5 Hz, 1 H, HC(6')), 5.94 (s, 2 H, OCH₂O), 5.80 (dt, *J* = 7.0, 1.5 Hz, 1 H, HC(3)), 2.70 (t, *J* = 8.0 Hz, 2 H, HC(5)), 2.49 (dt, *J* = 7.5, 7.5 Hz, 2 H, HC(4)), 2.00 (s, 3 H, HC(1)); ¹³C NMR: (125 MHz, CDCl₃) 147.8

(C(3')), 145.8 (C(4')), 144.1 (C(a)), 136.1 (C(1')), 135.7 (C(2)), 128.4 (C(c)), 127.5 (C(3)), 126.8 (C(d)), 125.9 (C(b)), 121.4 (C(6')), 109.2 (C(2')), 108.3 (C(5')), 101.0 (OCH₂O), 35.8 (C(5)), 31.2 (C(4)), 16.1 (C(1)); IR: (neat) 3056 (w), 3030 (w), 2918 (m), 2889 (m), 1600 (w), 1501 (s), 1487 (s), 1440 (s), 1359 (w), 1242 (s), 1189 (m), 1097 (w), 1038 (s), 935 (s), 854 (m), 807 (m), 755 (s), 694 (s); MS: (TOF ES⁺) 323.0 (96.2), 265.1 (100.0), 145.1 (63.2); HRMS: calcd for C₁₈H₁₉O₂⁺: 267.1385, found: 267.1393; TLC: *R_f* 0.49 (hexane/Et₂O, 96:4) [KMnO₄]; Analysis: C₁₈H₁₈O₂ (266.33) Calcd: C, 81.17; H, 6.81%. Found: C, 81.01; H, 6.75%.

Preparation of (*E*)-4-(3',4'-Methylenedioxyphenyl)-1-cyclopropylbut-2-ene ((*E*)-2k)—

Following General Procedure 3, olefin **8a** (296 mg, 2.0 mmol), 9-BBN (0.321 M in THF, 9.4 mL, 3.0 mmol), TIOEt (283.3 mL, 4.0 mmol), H₂O (180.0 mL, 10.0 mmol) were reacted with PdCl₂(dppf) (146.4 mg, 0.2 mmol), AsPh₃ (122.5 mg, 0.4 mmol), (*E*)-(2-iodovinyl)cyclopropyl **10k** (465.6 mg, 2.4 mmol) and THF (9 mL). Purification by flash column chromatography (SiO₂, 25 g, 40 mm Ø, hexanes/diethyl ether, 98:2) afforded (*E*)-**2k** (370 mg, 85%) as colorless oil. Distillation provided 355 mg (82%) of analytically pure (*E*)-**2k**. Data for (*E*)-**2k**: bp: 65 °C @ 3×10⁻⁵ mmHg; ¹H NMR: (500 MHz, CDCl₃) 6.75 (d, *J* = 8.0 Hz, 1 H, HC(5')), 6.70 (d, *J* = 1.0 Hz, 1 H, HC(2')), 6.65 (dd, *J* = 8.0, 1.0 Hz, 1 H, HC(6')), 5.94 (s, 2 H, OCH₂O), 5.56 (dt, *J* = 15.0, 6.5 Hz, 1 H, HC(2)), 5.03 (dd, *J* = 15.0, 8.5 Hz, 1 H, HC(1)), 2.61 (t, *J* = 8.0 Hz, 2 H, HC(4)), 2.27 (dt, *J* = 7.5, 7.5 Hz, 2 H, HC(3)), 1.40 – 1.33 (m, 1 H, HC(a)), 0.70 – 0.67 (m, 2 H, HC(b *trans*)), 0.35 – 0.32 (m, 2 H, HC(b *cis*)); ¹³C NMR: (125 MHz, CDCl₃) 147.6 (C(3')), 145.7 (C(4')), 136.3 (C(1')), 134.7 (C(1)), 127.3 (C(2)), 121.3 (C(6')), 109.1 (C(2')), 108.3 (C(5')), 100.9 (OCH₂O), 36.1 (C(4)), 34.9 (C(3)), 13.7 (C(a)), 6.5 (C(b)); IR: (neat) 3078 (w), 3009 (w), 2925 (m), 2772 (w), 1609 (w), 1503 (s), 1487 (s), 1441 (s), 1364 (m), 1242 (s), 1186 (s), 1097 (m), 1037 (s), 962 (s), 935 (s), 855 (s), 808 (s); MS: (EI⁺) 216.1 (17.8), 136.0 (9.1), 135.0 (24.1), 81.1 (7.7), 77.1 (14.4), 51.0 (7.6); HRMS: calcd for C₁₄H₁₆O₂⁺: 216.1150, found: 216.1152; TLC: *R_f* 0.63 (hexane/Et₂O, 96:4) [KMnO₄].

Preparation of (*E*)-4-(3',4'-Methylenedioxyphenyl)-1-cyclopentylbut-2-ene ((*E*)-2l)—

Following General Procedure 3, olefin **8a** (296 mg, 2.0 mmol), 9-BBN (0.321 M in THF, 9.4 mL, 3.0 mmol), TIOEt (283.3 mL, 4.0 mmol), H₂O (180.0 mL, 10.0 mmol) were reacted with PdCl₂(dppf) (146.4 mg, 0.2 mmol), AsPh₃ (122.5 mg, 0.4 mmol), (*E*)-(2-iodovinyl)cyclopentane **10l** (532.9 mg, 2.4 mmol) and THF (9 mL). Purification by flash column chromatography (SiO₂, 30 g, 40 mm Ø, hexanes/diethyl ether, 98:2) afforded 310 mg (63%) of (*E*)-**2l** as colorless oil. Distillation provided 303 mg (62%) of analytically pure (*E*)-**2l**. Data for (*E*)-**2l**: bp: 50 °C @ 2.4×10⁻⁵ mmHg; ¹H NMR: (500 MHz, CDCl₃) 6.75 (d, *J* = 8.0 Hz, 1 H, HC(5')), 6.70 (d, *J* = 1.5 Hz, 1 H, HC(2')), 6.64 (dd, *J* = 8.0, 1.5 Hz, 1 H,

HC(6')), 5.94 (s, 2 H, OCH₂O), 5.44 – 5.42 (m, 2 H, HC(1) and HC(2)), 2.61 (t, $J = 7.5$ Hz, 2 H, HC(4)), 2.43 – 2.36 (m, 1 H, HC(a)), 2.29 – 2.25 (m, 2 H, HC(3)), 1.79 – 1.73 (m, 2 H, HC(b)), 1.69 – 1.61 (m, 2H, HC(c)), 1.60 – 1.51 (m, 2 H, HC(c)), 1.30 – 1.23 (m, 2H, HC(b)); ¹³C NMR: (125 MHz, CDCl₃) 147.6 (C(3')), 145.7 (C(4')), 136.3 (C(1')), 136.1 (C(1)), 127.4 (C(2)), 121.4 (C(6')), 109.2 (C(2')), 108.2 (C(5')), 100.9 (OCH₂O), 43.5 (C(a)), 36.2 (C(4)), 35.0 (C(3)), 33.4 (C(b)), 25.3 (C(c)); IR: (neat) 2949 (m), 2866 (m), 1609 (w), 1503 (s), 1488 (s), 1441 (s), 1362 (m), 1242 (s), 1186 (m), 1121 (m), 1097 (m), 1039 (s), 966 (m), 938 (s), 856 (m), 805 (s); MS: (TOF ES⁺) 339.2 (14.9), 322.0 (100.0), 243.1 (28.6), 187.1 (18.7), 161.1 (15.1), 135.0 (28.6); HRMS: calcd for C₁₆H₂₁O₂⁺: 245.1542, found: 245.1544; TLC: R_f 0.67 (hexane/Et₂O, 96:4) [KMnO₄]; Analysis: C₁₆H₂₀O₂ (244.33) Calcd: C, 78.65; H, 8.25%. Found: C, 78.91; H, 8.16%.

Preparation of (*E*)-4-(3',4'-Methylenedioxyphenyl)-1-cyclohexylbut-2-ene ((*E*)-2m)—

Following General Procedure 3, olefin **8a** (296 mg, 2.00 mmol), 9-BBN (0.345 M in THF, 8.7 mL, 3.00 mmol), TIOEt (283.3 mL, 4.0 mmol), H₂O (180.0 mL, 10.0 mmol) were reacted with PdCl₂(dppf) (146.3 mg, 0.2 mmol), AsPh₃ (122.5 mg, 0.4 mmol), (*E*)-(2-iodovinyl)cyclohexane **10m** (567 mg, 2.40 mmol) and THF (9 mL). Purification by flash column chromatography (SiO₂, 25 g, 40 mm Ø, hexanes/diethyl ether, 98:2) afforded 300 mg (58%) of (*E*)-**2m** as colorless oil. Distillation provided 289 mg (56%) of analytically pure (*E*)-**2m**. Data for (*E*)-**2m**: bp: 70 °C @ 2.4×10⁻⁵ mmHg; ¹H NMR: (500 MHz, CDCl₃) 6.74 (d, $J = 8.0$ Hz, 1 H, HC(5')), 6.70 (d, $J = 1.5$ Hz, 1 H, HC(2')), 6.64 (dd, $J = 7.5, 1.5$ Hz, 1 H, HC(6')), 5.94 (s, 2 H, OCH₂O), 5.42 – 5.40 (m, 2 H, HC(1) and HC(2)), 2.60 (t, $J = 7.5$ Hz, 2 H, HC(4)), 2.28 – 2.25 (m, 1H, HC(a)), 1.95 – 1.89 (m, 2 H, HC(3)), 1.75 – 1.65 (m, 5 H, HC(b) and HC(c) and HC(d)), 1.32 – 1.21 (m, 2 H, HC(c)), 1.21 – 1.14 (m, 2 H, HC(d)), 1.10 – 1.03 (m, 2 H, HC(b)); ¹³C NMR: (125 MHz, CDCl₃) 147.6 (C(3')), 145.7 (C(4')), 137.5 (C(1')), 136.4 (C(1)), 126.8 (C(2)), 121.4 (C(6')), 109.2 (C(2')), 108.2 (C(5')), 100.9 (OCH₂O), 40.9 (C(a)), 36.0 (C(4)), 35.1 (C(3)), 33.4 (C(b)), 26.5 (C(d)), 26.4 (C(c)); IR: (neat) 2921 (m), 2850 (m), 1503 (m), 1488 (s), 1442 (m), 1360 (w), 1242 (s), 1186 (m), 1096 (w), 1039 (s), 967 (m), 938 (m), 855 (w), 805 (m); MS: (TOF ES⁺) 338.3 (28.9), 300.2 (27.8), 275.2 (22.2), 271.2 (55.1), 259.2 (77.2), 257.2 (56.4), 175.1 (19.4), 161.1 (28.1), 135.0 (100.0); HRMS: calcd for C₁₇H₂₂O₂⁺: 259.1698, found: 259.1706; TLC: R_f 0.67 (hexane/Et₂O, 96:4) [KMnO₄]; Analysis: C₁₇H₂₂O₂ (258.36) Calcd: C, 79.03; H, 8.58%. Found: C, 79.24; H, 8.46%.

Preparation of (*E*)-1-(3',4'-Methylenedioxyphenyl)non-3-ene ((*E*)-2n)—

Following General Procedure 3, olefin **8a** (296 mg, 2.0 mmol), 9-BBN (0.312 M in THF, 9.4 mL, 3.0 mmol), TIOEt (283.3 mL, 4.00 mmol), H₂O (180.0 mL, 10.0 mmol) were reacted with PdCl₂(dppf) (146.4 mg, 0.2 mmol), AsPh₃ (122.5 mg, 0.4 mmol), (*E*)-1-iodoheptene **10n** (537.8 mg, 2.4 mmol) and THF (9 mL). Purification by flash column chromatography (SiO₂, 32 g, 40 mm Ø, hexanes/diethyl ether, 97:3) afforded (*E*)-**2n** (360

mg, 73%) as colorless oil. Distillation provided 345 mg (68%) of analytically pure (*E*)-**2n**. Data for (*E*)-**2n**: bp: 75 °C @ 3×10^{-5} mmHg; ^1H NMR: (500 MHz, CDCl_3) 6.75 (d, $J = 8.0$ Hz, 1 H, HC(5')), 6.70 (d, $J = 1.5$ Hz, 1 H, HC(2')), 6.65 (dd, $J = 8.0, 1.5$ Hz, 1 H, HC(6')), 5.94 (s, 2 H, OCH_2O), 5.46 – 5.44 (m, 2 H, HC(3) and HC(4)), 2.62 (t, $J = 8.0$ Hz, 2 H, HC(1)), 2.28 (dt, $J = 7.0, 7.0$ Hz, 2 H, HC(2)), 2.00 (dt, $J = 7.0, 7.0$ Hz, 2 H, HC(5)), 1.36 – 1.26 (m, 6 H, HC(6) and HC(7) and HC(8)), 1.92 (t, $J = 7.5$ Hz, 3 H, HC(9)); ^{13}C NMR: (125 MHz, CDCl_3); 147.7 (C(3')), 145.7 (C(4')), 136.3 (C(1')), 131.5 (C(3)), 129.4 (C(4)), 121.4 (C(6')), 109.2 (C(2')), 108.3 (C(5')), 100.9 (OCH_2O), 36.1 (C(1)), 35.0 (C(2)), 32.8 (C(5)), 31.6 (C(7)), 29.5 (C(6)), 22.8 (C(8)), 14.3 (C(9)); IR: (neat) 2957 (m), 2922 (m), 2862 (m), 1609(w), 1503 (s), 1488 (s), 1443 (s), 1359 (m), 1243 (s), 1185 (m), 1095 (m), 1040 (s), 966 (m), 938 (s), 856 (m), 804 (s); MS: (TOF ES^+) 343.3 (58.7), 341.2 (100.0), 245.3 (50.1), 231.1 (28.2), 135.0 (53.0); HRMS: calcd for $\text{C}_{16}\text{H}_{23}\text{O}_2^+$: 247.1698, found: 247.1697; TLC: R_f 0.69 (hexane/ Et_2O , 96:4) [KMnO_4]; Analysis: $\text{C}_{16}\text{H}_{22}\text{O}_2$ (246.35) Calcd: C, 78.01; H, 9.00%. Found: C, 78.31; H, 8.98%.

Preparation of (*E*)-7-(3',4'-Methylenedioxyphenyl)-1-chlorohept-4-ene ((*E*)-**2o**)

Following General Procedure 3, olefin **8a** (296 mg, 2.0 mmol), 9-BBN (0.321 M in THF, 9.4 mL, 3.0 mmol), TIOEt (283.3 mL, 4.0 mmol), H_2O (180.0 mL, 10.0 mmol) were reacted with $\text{PdCl}_2(\text{dppf})$ (146.4 mg, 0.2 mmol), Ph_3As (122.5 mg, 0.4 mmol), (*E*)-5-chloro-1-iodopent-1-ene **10o** (553.1 mg, 2.4 mmol) and THF (9 mL). Purification by flash column chromatography (SiO_2 , 30 g, 40 mm Ø, hexanes/diethyl ether, 98:2) afforded (*E*)-**2o** (378 mg, 75%) as colorless oil. Distillation provided 368 mg (73%) of analytically pure (*E*)-**2o**. Data for (*E*)-**2o**: bp: 65 °C @ 3.0×10^{-5} mmHg; ^1H NMR: (500 MHz, CDCl_3) 6.73 (d, $J = 8.0$ Hz, 1 H, HC(5')), 6.67 (d, $J = 1.0$ Hz, 1 H, HC(2')), 6.62 (dd, $J = 8.0, 1.0$ Hz, 1 H, HC(6')), 5.92 (s, 2 H, OCH_2O), 5.48 (dt, $J = 14.0, 6.5$ Hz, 1 H, HC(3)), 5.36 (dt, $J = 14.0, 6.5$ Hz, 1 H, HC(4)), 3.48 (t, $J = 6.5$ Hz, 2 H, HC(7)), 2.59 (t, $J = 8.0$ Hz, 2 H, HC(1)), 2.27 (dt, $J = 7.5, 7.5$ Hz, 2 H, HC(2)), 2.13 (dt, $J = 7.0, 7.0$ Hz, 2 H, HC(5)), 1.80 (dq, $J = 7.0, 7.0$ Hz, 2 H, HC(6)); ^{13}C NMR: (125 MHz, CDCl_3) 147.7 (C(3')), 145.8 (C(4')), 136.0 (C(1')), 131.1 (C(3)), 129.2 (C(4)), 121.4 (C(6')), 109.1 (C(2')), 108.3 (C(5')), 101.0 (OCH_2O), 44.6 (C(7)), 35.9 (C(1)), 34.9 (C(2)), 32.4 (C(6)), 29.8 (C(5)); IR: (neat) 2857 (w), 2930 (m), 2849 (w), 2780 (w), 1607 (w), 1503 (s), 1488 (s), 1441 (s), 1357 (w), 1243 (s), 1187 (m), 1097 (w), 1039 ((s), 969 (m), 937 (s), 858 (s), 808 (s), 723 (m); MS: (TOF ES^+) 359.1 (55.7), 338.3 (38.9), 309.1 (55.7), 267.1 (39.4), 251.1 (59.4), 239.0 (21.4), 219.0 (100.0), 217.2 (26.3), 149.0 (21.3), 135.0 (30.3); HRMS: calcd for $\text{C}_{14}\text{H}_{16}\text{ClO}_2^+$: 251.0839, found: 251.0846; TLC: R_f 0.50 (hexane/ Et_2O , 96:4) [KMnO_4]; Analysis: $\text{C}_{14}\text{H}_{17}\text{ClO}_2$ (252.74) Calcd: C, 66.53; H, 6.78%. Found: C, 66.45; H, 7.07%.

Preparation of (*E*)-1-(3',4'-Methylenedioxyphenyl)-6-methylhept-3-ene ((*E*)-**2p**)

Following General Procedure 3, olefin **8a** (296 mg, 2.00 mmol), 9-BBN (0.321 M in THF, 9.4 mL, 3.0 mmol), TIOEt (283.3 mL, 4.0 mmol), H_2O (180.0 mL, 10.0 mmol) were reacted

with $\text{PdCl}_2(\text{dppf})$ (146.3 mg, 0.2 mmol), Ph_3As (122.5 mg, 0.4 mmol), (*E*)-1-iodo-4-methyl-1-pentene **10p** (504.1 mg, 2.4 mmol) and THF (9 mL). Purification by flash column chromatography (SiO_2 , 28 g, 40 mm Ø, hexanes/diethyl ether, 98:2) afforded (*E*)-**2p** (333 mg, 71%) as colorless oil. Distillation provided 321 mg (69%) of analytically pure (*E*)-**2p**. Data for (*E*)-**2p**: bp: 40 °C @ 3.0×10^{-5} mmHg; ^1H NMR: (500 MHz, CDCl_3) 6.75 (d, $J = 8.0$ Hz, 1 H, HC(5')), 6.70 (d, $J = 1.0$ Hz, 1 H, HC(2')), 6.65 (dd, $J = 8.0, 1.0$ Hz, 1 H, HC(6')), 5.94 (s, 2 H, OCH_2O), 5.44 – 5.42 (m, 2 H, HC(3) and HC(4)), 2.16 (t, $J = 8.0$ Hz, 2 H, HC(1)), 2.31 – 2.28 (m, 2 H, HC(2)), 1.90 – 1.87 (m, 2 H, HC(5)), 1.64 – 1.55 (m, 1 H, HC(6)), 0.88 (dd, $J = 6.5, 1.5$ Hz, 6 H, HC(7)); ^{13}C NMR: (125 MHz, CDCl_3) 147.6 (C(3')), 145.7 (C(4')), 136.3 (C(1')), 130.5 (C(3)), 130.1 (C(4)), 121.4 (C(6')), 109.2 (C(2')), 108.2 (C(5')), 100.9 (OCH_2O), 42.2 (C(5)), 36.2 (C(1)), 35.0 (C(2)), 28.68 (C(6)), 22.5 (C(7)); IR: (neat) 2949 (s), 2929 (m), 2901 (m), 2872 (m), 1608 (w), 1502 (s), 1488 (s), 1442 (s), 1365 (w), 1243 (s), 1187 (m), 1096 (s), 1039 (s), 966 (m), 940 (s); MS: (EI^+ , 70 eV) 233.1 (2.8), 232 (15.4), 136.0 (8.9), 135.0 (100.0), 105.0 (2.5), 77.0 (6.2); HRMS: calcd for $\text{C}_{15}\text{H}_{20}\text{O}_2^+$: 232.1463, found: 232.1468; TLC: R_f 0.67 (hexane/ Et_2O , 96:4) [KMnO_4].

Preparation of (*E*)-4-(3'-Methoxyphenyl)-1-phenylbut-1-ene ((*E*)-11b)—

Following General Procedure 4, 3-methoxystyrene **8b** (500.0 mg, 3.7 mmol) in THF (4 mL), 9-BBN (0.577 M in THF, 9.7 mL, 5.6 mmol) and H_2O (1.0 mL, 55.9 mmol) were reacted with $\text{PdCl}_2(\text{dppf})$ (136.3 mg, 0.19 mmol), Ph_3As (114.1 mg, 0.37 mmol), Cs_2CO_3 (2.4 g, 7.45 mmol), (*E*)-(2-iodovinyl)benzene **10b** (1.03 mg, 4.47 mmol) and DMF (6 mL). Purification by flash column chromatography (SiO_2 , 32 g, 40 mm Ø, hexanes/diethyl ether, 98:2) afforded (*E*)-**11b** (621 mg, 70%) as colorless oil along with starting material **8b** (70 mg, 14%). Distillation of (*E*)-**11b** provided 607 mg (68%) of analytically pure (*E*)-**11b**. Data for (*E*)-**11b**: bp: 100 °C @ 2.4×10^{-5} mmHg; ^1H NMR: (500 MHz, CDCl_3) 7.37 – 7.21 (m, 6 H, HC(b) and HC(c) and HC(d) and HC(5')), 6.85 (d, $J = 8.0$, 1 H, HC(6')), 76.81 – 6.77 (m, 2 H, HC(2'), HC(4')), 6.45 (d, $J = 16.0$ Hz, 1 H, HC(1)), 6.29 (dd, $J = 16.0, 7.0$ Hz, 1 H, HC(2)), 3.83 (s, 3 H, OCH_3), 2.80 (t, $J = 8.0$ Hz, 2 H, HC(4)), 2.56 (dt, $J = 8.0, 8.0$ Hz, 2H, HC(3)); ^{13}C NMR: (125 MHz, CDCl_3) 160.1 (C(3')), 143.7 (C(a)), 138.11 (C(1')), 130.8 (C(2)), 130.3 (C(1)), 129.6 (C(5')), 128.7 (C(c)), 127.2 (C(d)), 126.3 (C(b)), 121.2 (C(6')), 114.6 (C(3')), 55.4 (OCH_3), 36.2 (C(4)), 34.9 (C(3)); IR: (neat) 3022 (m), 2935 (m), 2832 (m), 1596 (s), 1581 (s), 1488 (s), 1452 (s), 1435 (s), 1259 (s), 1150 (s), 1043 (s), 963 (s), 910 (m), 872 (s), 777 (s), 735 (s), 691 (s); MS: (TOF ES^+) 341.2 (42.5), 323.0 (65.1), 282.3 (28.3), 278.1 (32.1), 239.1 (39.6), 237.1 (90.6), 161.1 (100.0), 131.1 (17.8), 121.1 (13.5); HRMS: calcd for $\text{C}_{17}\text{H}_{19}\text{O}^+$: 239.1436, found: 239.1438; TLC: R_f 0.47 (hexane/ Et_2O , 96:4) [KMnO_4]; Analysis: $\text{C}_{17}\text{H}_{18}\text{O}$ (238.32) Calcd: C, 85.67; H, 7.61%. Found: C, 85.49; H, 7.39%.

Preparation of (*E*)-1-(3'-Methoxyphenyl)non-3-ene ((*E*)-11n)—

Following General Procedure 3, 3-methoxystyrene **8b** (268.8 mg, 2.0 mmol), 9-BBN (0.321 M in THF, 9.4 mL, 3.0 mmol), TIOEt (283.3 mL, 4.0 mmol), H_2O (180.0 mL, 10.0 mmol)

were reacted with PdCl₂(dppf) (146.4 mg, 0.2 mmol), Ph₃As (122.5 mg, 0.4 mmol), (*E*)-1-iodoheptene **10n** (538 mg, 2.4 mmol) and THF (9 mL). Purification by flash column chromatography (SiO₂, 30 g, 40 mm Ø, hexanes/diethyl ether, 97:3) afforded (*E*)-**11n** (365 mg (77%)) as colorless oil. Distillation provided 357 mg (75%) of analytically pure (*E*)-**11n**. Data for (*E*)-**11n**: bp: 60 °C @ 2.6×10⁻⁵ mmHg; ¹H NMR: (500 MHz, CDCl₃) 7.21 (ddd, *J* = 7.5, 7.5, 1.0 Hz, 1H, HC(5')), 6.81 – 6.74 (m, 3 H, HC(2') and HC(4') and HC(6')), 5.47 – 5.45 (m, 2 H, HC(3) and HC(4)), 3.82 (s, 3 H, OCH₃), 2.67 (t, *J* = 7.5 Hz, 2 H, HC(1)), 2.34 – 2.30 (m, 2 H, HC(2)), 2.01 – 1.97 (m, 2 H, HC(5)), 1.38 – 1.24 (m, 6 H, HC(6) and HC(7) and HC(8)), 0.90 (t, *J* = 7.0 Hz, 3 H, HC(9)); ¹³C NMR: (125 MHz, CDCl₃) 159.9 (C(3')), 144.0 (C(1')), 131.4 (C(4')), 129.4 (C(3')), 129.3 (C(5')), 121.1 (C(6')), 114.6 (C(2')), 111.3 (C(4')), 55.3 (OCH₃), 36.4 (C(1)), 34.3 (C(2)), 32.6 (C(5)), 31.5 (C(7)), 29.4 (C(6)), 22.6 (C(8)), 14.1 (C(9)); IR: (neat) 2957 (m), 2924 (s), 2853 (m), 1602 (s), 1585 (s), 1488 (s), 1467 (m), 1454 (s), 1435 (m), 1259 (s), 1164 (m), 1151 (s), 1045 (s), 968 (s), 869 (s), 775 (s), 694 (s); MS: (TOF ES⁺) 231.2 (5.5), 122.0 (8.8), 121.0 (100.0), 91.0 (3.2), 78.1 (4.6), 77.1 (3.9); HRMS: calcd for C₁₆H₂₄O⁺: 232.1827, found: 232.1821; TLC: *R*_f 0.67 (hexane/Et₂O, 96:4) [KMnO₄].

Preparation of (*E*)-4-(4'-Methoxyphenyl)-1-phenylbut-1-ene ((*E*)-**12b**)—

Following General Procedure 4, 4-methoxystyrene **8c** (500.0 mg, 3.72 mmol) in THF (4 mL), 9-BBN (0.577 M in THF, 9.7 mL, 5.6 mmol) and H₂O (1.0 mL, 55.9 mmol) were reacted with PdCl₂(dppf) (136.3 mg, 0.19 mmol), Ph₃As (114.1 mg, 0.37 mmol), Cs₂CO₃ (2.42 g, 7.45 mmol) and (*E*)-(2-iodovinyl)benzene **10b** (1.03 mg, 4.47 mmol) and DMF (6 mL). Purification by flash column chromatography (SiO₂, 32 g, 40 mm Ø, hexanes/Et₂O, 97:3) afforded (*E*)-**12b** (506 mg, 57%) as white solid along with starting material **8c** (60 mg, 12%). Recrystallization from hot hexane provided 480 mg (54%) of analytically pure (*E*)-**12b**. Data for (*E*)-**12b**: mp: 75–77 °C (hexane); ¹H NMR: (500 MHz, CDCl₃) 7.37 (d, *J* = 7.5 Hz, 2 H, HC(b)), 7.33 (t, *J* = 8.0, 2 H, HC(c)), 7.23 (d, *J* = 7.5 Hz, 1 H, HC(d)), 7.17 (d, *J* = 8.5 Hz, 1 H, HC(2')), 6.89 (d, *J* = 8.5 Hz, 1 H, HC(3')), 6.45 (d, *J* = 15.5 Hz, 1 H, HC(1)), 6.29 (dt, *J* = 15.5, 7.0 Hz, 1H, HC(2)), 3.83 (s, 3 H, OCH₃), 2.79 (t, *J* = 8.0 Hz, 2 H, HC(4)), 2.54 (dt, *J* = 8.0, 8.0 Hz, 2 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 158.1 (C(4')), 138.0 (C(a)), 134.1 (C(1')), 130.5 (C(2)), 130.3 (C(1)), 129.6 (C(2')), 128.7 (C(c)), 127.2 (C(d)), 126.2 (C(b)), 114. (C(3')), 55.5 (OCH₃), 35.4 (C(4)), 35.2 (C(3)); IR: (KBr) 3030 (w), 3009 (w), 2935 (m), 2909 (w), 2836 (w), 1650 (w), 1609 (m), 1598 (w), 1507 (w), 1507 (s), 1465 (m), 1445 (m), 1441 (m), 1299 (m), 1237 (s), 1179 (s), 1151 (s), 1033(s), 985 (s), 977 (s), 828 (s), 809 (s), 740 (s); MS: (EI⁺, 70 eV) 238.2 (7.6), 136.1 (9.0), 135.1 (100.0), 122.1 (8.2), 121.1 (95.5), 77.1 (8.8); HRMS: calcd for C₁₇H₁₈O⁺: 238.1358, found: 238.1354; TLC: *R*_f 0.47 (hexane/Et₂O, 96:4) [KMnO₄]; Analysis: C₁₇H₁₈O (238.32) Calcd: C, 85.67; H, 7.61%. Found: C, 85.77; H, 7.66%.

Preparation of (*E*)-1-(4'-Methoxyphenyl)non-3-ene ((*E*)-**12n**)—

Following General Procedure 3, olefin **45** (276 mg, 2.0 mmol), 9-BBN (0.345 M in THF, 8.7 mL, 3.0 mmol), TIOEt (283.3 µL, 4.0 mmol), H₂O (180.0 µL, 10.0 mmol) were reacted with PdCl₂(dppf) (146.3 mg, 0.2 mmol), Ph₃As (122.5 mg, 0.4 mmol), (*E*)-1-iodoheptene

10n (537.8 mg, 2.4 mmol) and THF (9 mL). Purification by flash column chromatography (SiO₂, 28 g, 40 mm Ø, hexanes/diethyl ether, 98:2) afforded (*E*)-**12n** (331 mg, 70%) as colorless oil. Data for (*E*)-**12n**: ¹H NMR: (500 MHz, CDCl₃) 7.10 (d, *J* = 8.5 Hz, 2 H, HC(3')), 6.83 (d, *J* = 8.5 Hz, 2 H, HC(2')), 5.47 – 5.37 (m, 2 H, HC(3) and HC(4)), 3.79 (s, 3 H, OCH₃), 2.61 (t, *J* = 8.0 Hz, 2 H, HC(1)), 2.31 – 2.22 (m, 2 H, HC(2)), 2.00 – 1.92 (m, 2 H, HC(5)), 1.38 – 1.19 (m, 6 H, HC(6) and HC(7) and HC(8)), 0.89 (t, *J* = 7.0 Hz, 3 H, HC(9)); ¹³C NMR: (125 MHz, CDCl₃) 157.6 (C(4')), 134.3 (C(1')), 131.1 (C(3)), 129.3 (C(2')), 129.3 (C(4)), 113.6 (C(3')), 55.22 (OCH₃), 35.2 (C(1)), 34.7 (C(2)), 32.5 (C(5)), 31.4 (C(7)), 29.2 (C(6)), 22.6 (C(8)), 14.1 (C(9)); IR: (neat) 2954 (s), 2919 (s), 2850 (m), 1611 (w), 1510 (s), 1462 (w), 1438 (w), 1299 (w), 1243 (s), 1174 (m), 1039 (m), 966 (w), 820 (w); MS: (EI⁺, 70 eV) 233.2 (3.5), 232.2 (24.5), 122.1 (12.7), 121.0 (100.0), 91.1 (14.1), 86.0 (3.0), 84.9 (4.6), 84.0 (5.1), 82.9 (7.1), 78.0 (12.8), 77.0 (12.9); HRMS: calcd for C₁₆H₂₄O⁺: 232.1827, found: 232.1826; TLC: *R*_f 0.68 (hexane/Et₂O, 96:4) [KMnO₄]

Preparation of (*S*)-4-(Diisobutylamino)-3,5-dimethyl-4,5-dihydro-3*H*-dinaphtho[2,1-*d*:1',2'-*f*][1,3,2]diazaphosphepine-4-selenide ((*S*)-20a**)—**

To a flame-dried, 100 mL Schlenk flask equipped with a magnetic stir bar and septum were added *N,N'*-dimethyl-1,1'-binaphthalene-2,2'-diamine (**37**) (2.00 g, 6.40 mmol) and Et₃N (2.23 mL, 16.0 mmol, 2.50 equiv) and THF (64.0 mL) were added via syringe. The homogeneous mixture was cooled to 0 °C. PCl₃ (1.68 mL, 19.2 mmol, 3.00 equiv) was added dropwise via syringe whereupon a colorless precipitate formed immediately. The reaction mixture was stirred at 0 °C for 1.5 h, then was allowed to warm to room temperature and was stirred for another 3 h. The volatiles were removed under high vacuum (room temperature, 0.5 mmHg) and Et₂O (20.0 mL) was added via syringe, then the mixture was stirred for 5 min. The supernatant was cannula filtered into a tared, flame-dried, argon filled, 200 mL Schlenk flask equipped with a rubber septum. The remaining precipitate in the reaction flask was washed with Et₂O (20 mL) and was filtered into the receiver Schlenk flask. The volatiles were removed under high vacuum (room temperature, 0.5 mmHg) to afford a light yellow solid. The solid was redissolved with Et₂O (20 mL) and the volatiles were again removed under high vacuum (room temperature, 1.0 mmHg) to afford a white solid. The solid was then dried for 3 h at reduced pressure (45 °C, 0.50 mmHg) to give a white foam (2.34 g). CH₂Cl₂ (60.0 mL) was added via syringe and the mixture was cooled to 0 °C. Et₃N (0.74 mL, 5.30 mmol, 1.2 equiv) and diisobutylamine (1.23 mL, 7.10 mmol, 1.1 equiv) were added via syringe and the reaction mixture was allowed to warm to room temperature and then stirred for 14 h. Powdered selenium (1.46 g, 18.6 mmol, 2.9 equiv) was added and the mixture was stirred for 50 h, then filtered through a pad of Celite (12 g, 70 mm Ø). The pad was washed with EtOAc (100 mL) and the filtrate was concentrated in vacuo (40 °C, 10 mmHg) Purification via flash column chromatography (SiO₂, 55 g, 50 mm Ø, hexane/Et₂O 4:1) afforded (*S*)-**20a** (2.55 g, 73%) as slightly orange solid.

Recrystallization from hot pentane provided (2.35 g, 67%). Data for (*S*)-**20a**: mp: 118–120 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.98 (d, *J* = 9.0 Hz, 1 H, HC(4)), 7.92 (d, *J* = 9.0 Hz, 1 H, HC(4')), 7.90 (d, *J* = 8.5 Hz, 1 H, HC(6)), 7.86 (d, *J* = 8.0 Hz, 1 H, HC(6')), 7.67 (d, *J* = 9.0 Hz, 1 H, HC(3')), 7.66 (dd, *J* = 9.0, 1.0 Hz, 1 H, HC(3)), 7.43 (dt, *J* = 7.5, 1.0 Hz, 1 H, HC(7)), 7.36 (t, *J* = 7.5 Hz, 1 H, HC(7')), 7.28 (d, *J* = 8.0 Hz, 1 H, HC(8)), 7.24 (dt, *J* = 8.5, 1.0 Hz, 1 H, HC(9)), 7.12 (dt, *J* = 8.0, 1.0 Hz, 1 H, HC(8')), 7.04 (d, *J* = 9.0 Hz,

1 H, HC(9')), 3.21 (d, $J = 13.5$ Hz, 3 H, HC(11')), 3.18 – 3.11 (m, 2 H, HC(12)), 2.96 (d, $J = 13.5$ Hz, 3 H, H₃C(11)), 2.81 (dt, $J = 14.0, 6.0$ Hz, 2 H, HC(12')), 1.96 – 1.87 (m, 2 H, HC(13, 13')), 0.86 (d, $J = 6.5$ Hz, 6 H, HC(14')), 0.84 (d, $J = 6.5$ Hz, 6 H, HC(14)); ¹³C NMR: (125 MHz, CDCl₃) 143.4 (d, $J = 5.0$ Hz, C(2')), 142.3 (C(2)), 132.7 (C(10)), 132.5 (C(10')), 131.5 (C(5')), 131.3 (C(5)), 129.5 (C(4)), 128.7 (C(4')), 128.3 (C(9)), 128.2 (C(6')), 128.0 (C(6)), 127.5 (C(1,1')), 127.3 (C(9')), 126.3 (C(8)), 125.9 (C(8')), 125.5 (C(7')), 124.9 (C(7')), 124.6 (C(3')), 122.6 (C(3)), 55.1 (C(12, 12')), 39.3 (d, $J = 11.3$ Hz, C(11')), 36.1 (d, $J = 5.0$ Hz, C(11)), 27.2 (C(13, 13')), 21.0 (C(14')), 20.9 (C(14')); ³¹P NMR: (202 MHz, CDCl₃) 95.39; IR: (KBr) 3052 (w), 2954 (s), 2864 (s), 2801 (w), 1618 (w), 1590 (m), 1503 (s), 1465 (s), 1386 (m), 1365 (m), 1327 (s), 1271 (s), 1261 (s), 1157 (m), 1115 (s), 1087 (s), 1007 (s), 955 (m), 935 (s), 876 (m), 810 (s), 747 (s); MS: (EI⁺, 70 eV) 422.1 (5.6), 421.1 (18.7), 419.1 (9.5), 342.1 (23.5), 341.1 (100.0), 312.1 (6.4), 282.2 (5.2), 281.1 (18.4), 215.1 (6.3), 128.1 (15.5), 57.1 (7.6); HRMS: calcd for C₃₀H₃₆N₃PSe⁺: 549.1812, found: 549.1809; TLC: R_f 0.61 (hexanes/Et₂O, 4:1) [CAM]; Opt Rot.: $[\alpha]_D^{24} +187.5$ (c = 1.67, EtOH); SFC: (*S*)-**37**, t_R 12.8 min (99.8%); (*R*)-**37**, t_R 15.6 min (0.8%) (Chiralpak OJ, 5% MeOH in CO₂, 2 mL/min, 220 nm, 40 °C);⁵⁷ Analysis: C₃₀H₃₆N₃PSe (549.56) Calcd: C, 65.68; H, 6.61%; N, 7.66; P, 5.65; Se, 14.39%. Found: C, 65.75; H, 6.69%; N, 7.42; P, 5.52; Se, 14.46%.

Sulfenocarbocyclizations with (*S*)-**20a**

General Procedure 8—An oven-dried, 10-mL, two-necked, round-bottomed flask under nitrogen was charged with *N*-phenylthiophthalimide **13** (256 mg, 1.00 mmol, 1.0 equiv), **20a** (54.9 mg, 0.10 mmol, 0.1 eq), olefin (1.00 mmol) in CH₂Cl₂. The flask was placed into isopropyl alcohol bath and cooled at the requisite temperature via cryocool. A solution of EtSO₃H (1 M in CH₂Cl₂) was added over 20 sec and the mixture was allowed to stir for the specified time. The reaction was quenched while cold by addition of Et₃N (1.6 mL). The resultant mixture was poured into H₂O (20 mL) and the aqueous phase was extracted with Et₂O (3 × 10 mL). The combined organic layers were washed with brine (50 mL), dried over MgSO₄, filtered through glass wool and then concentrated in vacuo (20 – 23 °C, 10 mmHg). The thio ether products were purified by flash column chromatography followed by distillation or recrystallization.

Preparation of (*5R,6R*)-5-Methyl-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*dj*]-1,3-dioxole (*trans*-**14a**)—

Following General Procedure 8, (*E*)-**2a** (190 mg, 1.0 mmol), **13** (256 mg, 1.0 mmol), (*S*)-**20a** (54.8 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at –20 °C for 72 h. Purification by flash column chromatography (SiO₂, 32 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded *trans*-**14a** (277 mg, 93%) as a white solid. Recrystallization from hot pentane provided 273 mg (92%) of analytically pure *trans*-**14a**. Data for *trans*-**14a**: mp: 46–48 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.46 (dd, $J = 8.0, 1.0$ Hz, 2 H, HC(13)), 7.34 (t, $J = 8.0$ Hz, 2 H, HC(14)), 7.27 (tt, $J = 8.5, 1.5$ Hz, 1 H, HC(15)), 6.64 (s, 1 H, HC(6)), 6.58 (s, 1 H, HC(9)), 5.91 (s, 2 H, OCH₂O), 3.43 – 3.40 (m, 1 H, HC(2)), 2.97 – 2.91 (m, 2 H, HC(1) and HC(4)), 2.66 (ddd, $J = 16.5, 5.5, 5.5$ Hz, 1 H, HC(4)), 2.23 – 2.16 (m, 1 H, HC(3)), 1.91 – 1.85 (m, 1 H, HC(3)), 1.42 (d, $J = 7.0$ Hz, 3 H, HC(11)); ¹³C NMR: (125 MHz, CDCl₃) 146.0 (C(7)), 145.9 (C(8)), 135.4 (C(12)), 132.6 (C(5)), 131.9 (C(13)), 129.0 (C(14)), 128.2 (C(10)),

126.9 (C(15)), 108.8 (C(9)), 108.6 (C(6)), 100.7 (OCH₂O), 49.9 (C(2)), 38.3 (C(1)), 26.6 (C(4)), 24.8 (C(3)), 24.1 (C(11)); IR: (KBr) 3052 (w), 2961 (m), 2926 (m), 2885 (m), 2766 (w), 1580 (m), 1500 (s), 1479 (s), 1438 (m), 1379 (m), 1233 (s), 1184 (m), 1087 (w), 1035 (s), 938 (s), 858 (m), 740 (s); MS: (EI⁺, 70 eV) 299.1 (14.2), 298.1 (69.8), 190.1 (13.2), 189.1 (100.0), 188.1 (75.1), 174.0 (18.0), 173.0 (43.8), 162.1 (26.5), 159.1 (34.4), 131.1 (22.0), 116.1 (12.2), 115.0 (26.2), 103.1 (7.3), 91.1 (10.9), 85.0 (31.7), 83.0 (48.7), 65.1 (8.1); HRMS: calcd for C₁₈H₁₈O₂S⁺: 298.1028, found: 298.1032; TLC: *R_f* 0.44 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot.: [α]_D²⁵ -18.7 (c = 0.53, EtOH); SFC: (5*S*,6*S*)-**14a**, *t_R* 11.7 min (3%); (5*R*,6*R*)-**14a**, *t_R* 15.2 min (97%) (Chiralpak OJ, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₁₈H₁₈O₂S (298.40) Calcd: C, 72.45; H, 6.08%. Found: C, 72.59; H, 5.90%

Preparation of *trans*-5-Methyl-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*dj*-1,3-dioxole (*cis*-14a)—

Following General Procedure 8, (*Z*)-**2a** (190 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.8 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at 0 °C for 72 h. Purification by flash column chromatography (SiO₂, 32 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded of *cis*-**14a** (275 mg, 92%) as a white solid. Recrystallization from hot pentane provided 271 mg (91%) of analytically pure *cis*-**14a**. Data for *cis*-**14a**: mp: 76–78 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.46 (dd, *J* = 7.5 Hz, 2 H, HC(13)), 7.33 (t, *J* = 7.5 Hz, 2 H, HC(14)), 7.26 (t, *J* = 7.6 Hz, 1 H, HC(15)), 6.58 (s, 1 H, HC(6)), 6.56 (s, 1 H, HC(9)), 5.90 (s, 2 H, OCH₂O), 3.69 – 3.65 (m, 1 H, HC(2)), 3.10 – 3.04 (m, 1 H, HC(1)), 2.89 (ddd, *J* = 17.0, 5.5, 5.5 Hz, 1 H, HC(4)), 2.80 (ddd, *J* = 17.0, 8.5, 8.5 Hz, 1 H, HC(4)), 2.05 – 2.00 (m, 2 H, HC(3)), 1.33 (d, *J* = 7.0 Hz, 3 H, HC(11)); ¹³C NMR: (125 MHz, CDCl₃) 146.1 (C(7)), 145.9 (C(8)), 135.5 (C(12)), 134.6 (C(5)), 131.5 (C(13)), 129.1 (C(14)), 127.8 (C(10)), 126.8 (C(15)), 108.5 (C(9)), 108.5 (C(6)), 100.8 (OCH₂O), 48.9 (C(2)), 36.9 (C(1)), 29.3 (C(4)), 24.9 (C(3)), 18.9 (C(11)); IR: (KBr) 2961 (m), 2898 (m), 1580 (w), 1500 (s), 1479 (s), 1434 (w), 1375 (w), 1247 (s), 1219 (s), 1087 (w), 1039 (s), 941 (m), 928 (m), 893 (w), 862 (m), 737 (m), 688 (m); MS: (EI⁺, 70 eV) 299.1 (14.4), 298.1 (68.5), 231.2 (35.6), 189.1 (100.0), 188.1 (24.8), 174.1 (11.2), 173.1 (26.7), 162.1 (34.9), 159.1 (37.9), 135.1 (20.7), 131.1 (31.6), 128.1 (10.8), 116.1 (15.2), 115.1 (30.0), 107.1 (12.6), 103.1 (12.1), 91.1 (27.6), 78.1 (12.6), 77.1 (18.8), 65.1 (14.6), 57.1 (23.6), 55.1 (12.0), 51.1 (11.6); HRMS: calcd for C₁₈H₁₈O₂S⁺: 298.1028, found: 298.1034; TLC: *R_f* 0.42 (hexanes/Et₂O, 96:4) [KMnO₄]; SFC: *cis*-**14a**, *t_{R1}* 12.6 min (52%); *cis*-**14a**, *t_{R2}* 14.1 min (48%) (Chiralpak OJ, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₁₈H₁₈O₂S (298.40); Calcd: C, 72.45; H, 6.08%. Found: C, 72.43; H, 6.03%.

Preparation of ((5*R*,6*R*)-5-Phenyl-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*dj*-1,3-dioxole (*trans*-14b)—

Following General Procedure 8, (*E*)-**2b** (252.3 mg, 1.0 mmol), **13** (256 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at –20 °C for 48 h. Purification by flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded *trans*-**14b** (328 mg, 91%) as a pale yellow solid. Recrystallization from hot pentane provided 324 mg (90%) of analytically pure *trans*-**14b**. Data for *trans*-**14b**: mp: 54–56 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.42 (d, *J* = 7.5 Hz, 2 H, HC(16)), 7.34 – 7.22 (m, 6 H, HC(13) and HC(14) and HC(17) and HC(18)), 7.07 (d, *J* = 7.5 Hz, 2 H, HC(12)), 6.66 (s, 1 H, HC(6)), 6.32 (s, 1 H, C(9)), 5.90 (d, *J* = 2.5 Hz, 2 H, OCH₂O), 4.13 (d, *J* = 5.0 Hz, 1 H, HC(1)), 3.68 – 3.65 (m, 1 H, HC(2)), 3.00 (ddd, *J* = 16.0, 8.0, 5.5 Hz, 1 H, HC(4)), 2.81 (ddd, *J* = 17.0, 6.0, 6.0 Hz, 1 H, HC(4)), 2.20 – 2.14 (m, 1 H, HC(3)), 2.19 – 2.12 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 146.4 (C(7)), 146.2 (C(8)), 145.5 (C(11)), 135.1 (C(15)), 132.4 (C(16)), 129.5 (C(5)), 129.4 (C(10)), 129.1 (C(12)), 129.0 (C(13)), 128.5 (C(17)), 127.2 (C(18)), 126.7 (C(14)), 110.4 (C(9)), 108.3 (C(6)), 100.8 (OCH₂O), 51.5 (C(2)), 50.4 (C(1)), 26.8 (C(4)), 24.9 (C(3)); IR: (KBr) 3052 (w), 3017 (w), 2919 (m), 2885 (m), 1580 (w), 1500 (m), 1479 (s), 1448 (m), 1434 (m), 1382 (w), 1236 (s), 1170 (w), 1039 (s), 938 (m), 869 (m), 740 (m), 699 (m); MS: (EI⁺, 70 eV) 361.1 (18.7), 360.0 (71.7), 252.1 (16.6), 251.1 (91.6), 250.0 (100.0), 224.0 (20.2), 223.0 (29.6), 205.1 (19.0), 194.0 (15.6), 193.1 (10.4), 191.1 (19.0), 189.0 (13.2), 178.0 (13.9), 173.0 (13.6), 166.1 (17.0), 165.0 (35.2), 160.0 (9.5), 159.0 (15.7), 152.0 (8.4), 143.0 (7.3), 135.0 (18.3), 115.0 (28.6), 109.0 (11.8); HRMS: calcd for C₂₃H₂₀O₂S⁺: 360.1164, found: 360.1178; TLC: *R*_f 0.40 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot.: [α]_D²²⁵ –33.0 (c = 0.65, EtOH); SFC: (*5R,6R*)-**14b**, *t*_R 14.0 min (94%); (*5S,6S*)-**14b**, *t*_R 17.2 min (6%) (Chiralpak OJ, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C).

Preparation of (6*R*)-5,5-Dimethyl-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole ((*R*)-14c**) and 5,5-Dimethyl-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (**26**)—**

Following General Procedure 8, a 10-mL Schlenk flask was charged with **4c** (204.3 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.5 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.5 mL, 0.5 mmol) at –20 °C for 24 h. Purification by flash column chromatography (SiO₂, 32 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded (*R*)-**14c** (284 mg, 91%) as a white solid along with of **26** (20 mg, 10%) as colorless oil. Distillation provided 281 mg (90%) of analytically pure (*R*)-**14c**. Data for (*R*)-**14c**: bp: 130 °C @ 2.2×10^{–5} mmHg; ¹H NMR: (500 MHz, CDCl₃) 7.47 (t, *J* = 8.0, 1.5 Hz, 2 H, HC(14)), 7.33 (t, *J* = 7.5 Hz, 2 H, HC(15)), 7.25 (t, *J* = 7.0 Hz, 1 H, HC(16)), 6.85 (s, 1 H, HC(6)), 6.51 (s, 1 H, C(9)), 5.91 (s, 2 H, OCH₂O), 3.43 (dd, *J* = 10.5, 3.0 Hz, 1 H, HC(2)), 2.86 (ddd, *J* = 16.5, 5.5, 5.0 Hz, 1 H, HC(4)), 2.71 (ddd *J* = 16.0, 10.0, 1.0 Hz, 1 H, HC(4)), 2.21 – 2.15 (m, 1 H, HC(3)), 2.06 – 1.98 (m, 1 H, HC(3)), 1.56 (s, 3 H, HC(12)), 1.40 (m, 3 H, HC(11)); ¹³C NMR: (125 MHz, CDCl₃) 146.3 (C(7)), 145.7 (C(8)), 138.1 (C(12)), 136.6

(C(5)), 131.6 (C(14)), 129.1 (C(15)), 128.0 (C(10)), 126.7 (C(16)), 108.3 (C(9)), 106.6 (C(6)), 100.8 (OCH₂O), 57.8 (C(2)), 38.9 (C(1)), 30.8 (C(11)), 29.5 (C(4)), 27.7 (C(12)), 26.6 (C(3)); IR: (neat) 3066 (m), 2961 (s), 2891 (s), 2766 (m), 1625 (w), 1580 (s), 1503 (s), 1434 (s), 1368 (s), 1333 (s), 1302 (s), 1240 (s), 1191 (s), 1160 (s), 1115 (s), 1087 (s), 1049 (s), 1021 (s), 938 (s), 914 (s), 893 (s); MS: (EI⁺, 70 eV) 313.0 (10.0), 312.0 (46.5), 204.1 (13.6), 203.1 (100.0), 202.1 (13.7), 188.0 (21.3), 187.0 (29.6), 176.0 (20.6), 173.0 (23.1), 161.0 (10.4), 145.1 (10.2), 131.0 (10.4), 129.0 (9.5), 128.0 (8.3), 115.0 (11.2), 103.0 (6.5), 77.1 (6.6); HRMS: calcd for C₁₉H₂₀O₂S⁺: 312.1184, found: 312.1190; TLC: *R_f* 0.42 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : [α]_D²⁵ –10.72 (c = 0.63, EtOH); SFC: (5*S*)-**14c**, *t_R* 14.7 min (20%); (6*R*)-**14c**, *t_R* 16.5 min (80%) (Chiralpak AD, 1–5% MeOH over 40 min in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₁₉H₂₀O₂S (312.12) Calcd: C, 73.04; H, 6.45%. Found: C, 73.24; H, 6.57%. Data for **26**: ⁵⁸H NMR: (500 MHz, CDCl₃) 6.83 (s, 1 H, HC(6)), 6.53 (s, 1 H, C(9)), 5.90 (s, 2 H, OCH₂O), 2.69 (t, *J* = 6.5 Hz, 2 H, HC(4)), 1.82 – 1.77 (m, 2 H, HC(3)), 1.66 – 1.64 (m, 2 H, HC(2)), 1.27 (s, 6 H, HC(11) and HC(12)); ¹³C NMR: (125 MHz, CDCl₃) 145.9 (C(7)), 145.2 (C(8)), 139.0 (C(5)), 129.3 (C(10)), 108.6 (C(9)), 106.6 (C(6)), 100.6 (OCH₂O), 39.4 (C(2)), 34.1 (C(1)), 32.1 (C(11) and C(12)), 31.0 (C(4)), 20.0 (C(3)); IR: (neat) 2947 (s), 2926 (s), 2766 (w), 1621 (w), 1500 (s), 1483 (s), 1371 (s), 1333 (w), 1233 (s), 1191 (m), 1108 (m), 1039 (s), 1011 (w), 931 (m), 865 (m), 844 (m), 740 (w); MS: (EI⁺, 70 eV) 204.1 (29.0), 190.1 (12.5), 189.1 (100.0), 160.1 (29.6), 176.0 (20.6), 173.0 (23.1), 160.1 (5.7), 159.1 (23.2), 131.1 (15.0), 115.0 (9.3), 91.1 (6.8), 84.0 (6.8); HRMS: calcd for C₁₃H₁₆O₂⁺: 204.1150, found: 204.1154; TLC: *R_f* 0.52 (hexanes/Et₂O, 96:4) [KMnO₄].

Preparation of ((5*R*,6*R*)-5-(4-Methylphenyl)-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14d**))—**

Following General Procedure 8, a 10-mL (*E*)-**2d** (266.3 mg, 1.0 mmol), **13** (256 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol, 0.1 equiv) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at –20 °C for 48 h. Purification by flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexane/Et₂O, 96:4) afford *trans*-**14d** (327 mg, 87%) as a white solid. Recrystallization from hot pentane provided 322 mg (86%) of analytically pure *trans*-**14d**. Data for *trans*-**14d**: mp: 72–74 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.43 (d, *J* = 7.0 Hz, 2 H, HC(17)), 7.32 (t, *J* = 7.5 Hz, 2 H, HC(18)), 7.27 (t, *J* = 7.5 Hz, 1 H, HC(19)), 7.11 (d, *J* = 7.5 Hz, 2 H, HC(13)), 6.96 (d, *J* = 7.5 Hz, 2 H, HC(12)), 6.65 (s, 1 H, HC(6)), 6.33 (s, 1 H, C(9)), 5.89 (s, 2 H, OCH₂O), 4.09 (d, *J* = 4.5 Hz, 1 H, HC(1)), 3.67 – 3.64 (m, 1 H, HC(2)), 2.99 (ddd, *J* = 16.0, 8.0, 5.5 Hz, 1 H, HC(4)), 2.80 (ddd, 1H, *J* = 16.0, 6.0, 6.0 Hz, 1 H, HC(4)), 2.35 (s, 3 H, HC(15)), 2.20 – 2.14 (m, 1 H, HC(3)), 1.87 – 1.81 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 146.4 (C(7)), 146.1 (C(8)), 142.5 (C(14)), 136.2 (C(11)), 135.1 (C(16)), 132.3 (C(17)), 129.8 (C(5)), 129.4 (C(10)), 129.2 (C(13)), 129.0 (C(18)), 128.9 (C(12)), 127.0 (C(19)), 110.3 (C(9)), 108.2 (C(6)), 100.8 (OCH₂O), 51.4 (C(2)), 50.0 (C(1)), 26.8 (C(4)), 24.9 (C(3)), 21.2 (C(15)); IR: (KBr) 3003 (w), 2919 (m), 2885 (m), 1580 (w), 1500 (s), 1479 (s), 1434 (m), 1382 (w), 1236 (s), 1174 (w), 1035 (s), 938 (m), 869 (w), 806 (w), 740 (m), 692 (m); MS: (EI⁺, 70 eV) 375.1 (21.2), 374.1 (75.9), 326.2 (26.2), 266.1 (19.0), 265.1 (100.0), 264.1 (90.0), 249.0 (9.3), 237.0 (9.8), 224.0 (9.8), 223.0 (58.2), 191.1 (10.8), 189.0 (11.0), 179.0

(9.8), 178.0 (10.7), 173.0 (17.7), 165.0 (21.8), 159.0 (96.4), 159.0 (15.7), 143.0 (11.4), 135.0 (14.0), 115.0 (23.2), 109.0 (10.9), 105.1 (66.4); HRMS: calcd for $C_{24}H_{22}O_2S^+$: 374.1341, found: 374.1336; TLC: R_f 0.35 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : $[\alpha]_D^{25}$ -28.4 (c = 0.59, EtOH); SFC: (5*S*,6*S*)-**14d**, t_R 12.7 min (6%); (5*R*,6*R*)-**14d**, t_R 14.1 min (94%) (Chiralpak AD, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: $C_{24}H_{22}O_2S$ (374.50) Calcd: C, 76.97; H, 5.92%. Found: C, 76.79; H, 6.03%.

Preparation of ((5*R*,6*R*)-5-(4-Cyanophenyl)-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14e**))—**

Following General Procedure 8, (*E*)-**2e** (277.3 mg, 1.0 mmol, 1.0 equiv), **13** (256 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at room temperature for 96 h. Purification by flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexane/Et₂O, 80:20) afford *trans*-**14e** (324 mg, 84%) as a white solid. Recrystallization from hot pentane provided 320 mg (83%) of analytically pure *trans*-**14e**. Data for *trans*-**14e**: mp: 64–66 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.55 (d, J = 8.0 Hz, 2 H, HC(13)), 7.37 – 7.35 (m, 2 H, HC(17) and HC(23)), 7.41 – 7.25 (m, 3 H, HC(18) and HC(19) and HC(20)), 7.13 (d, J = 8.0 Hz, 2 H, HC(12)), 6.63 (s, 1 H, HC(6)), 6.17 (s, 1 H, C(9)), 5.88 (s, 2 H, OCH₂O), 4.11 (d, J = 5.5 Hz, 1 H, HC(1)), 3.52 – 3.49 (m, 1 H, HC(2)), 2.97 (ddd, J = 17.0, 14.0, 6.0 Hz, 1 H, HC(4)), 2.79 (ddd, 1H, J = 17.0, 6.5, 6.5 Hz, 1 H, HC(4)), 2.13 – 2.07 (m, 1 H, HC(3)), 1.88 – 1.82 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 151.0 (C(7)), 146.9 (C(8)), 146.5 (C(16)), 134.5 (C(17,21)), 132.9 (C(13)), 132.4 (C(12)), 129.7 (C(10)), 129.3 (C(18,20)), 128.4 (C(5)), 127.7 (C(19)), 119.1 (C(15)), 110.7 (C(14)), 110.0 (C(9)), 108.6 (C(6)), 101.1 (OCH₂O), 51.8 (C(2)), 50.9 (C(1)), 27.3 (C(4)), 25.8 (C(3)); IR: (KBr) 3059 (w), 2968 (w), 2926 (w), 2885 (w), 2216 (m), 1604 (w), 1580 (w), 1500 (s), 1476 (s), 1434 (m), 1382 (m), 1236 (s), 1035 (s), 938 (m), 820 (m), 740 (m); MS: (EI⁺, 70 eV) 385.2 (22.9), 381.3 (18.4), 340.3 (17.6), 326.2 (24.7), 325.2 (100), 276.2 (30.4), 275.1 (33.4), 269.2 (14.2), 239.2 (14.6), 231.2 (34.4), 191.2 (48.8), 190.1 (16.6), 175.1 (12.8), 160.1 (14.1), 141.1 (12.4), 135.1 (29.8), 121.0 (12.8), 115.1 (22.3), 107.1 (18.8), 91.1 (22.0), 77.1 (19.2), 69.1 (14.0), 57.1 (48.1), 55.1 (22.0); HRMS: calcd for $C_{24}H_{19}NO_2S^+$: 385.1137, found: 385.1129; TLC: R_f 0.38 (hexanes/Et₂O, 80:20) [KMnO₄]; Opt Rot. : $[\alpha]_D^{25}$ -19.9 (c = 0.58, EtOH); SFC: (5*S*,6*S*)-**14e**, t_R 23.9 min (89%); (5*R*,6*R*)-**14e**, t_R 27.6 min (11%) (Chiralpak OD, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: $C_{24}H_{19}NO_2S$ (385.48) Calcd: C, 74.78; H, 4.97%; N, 3.63%. Found: C, 74.50; H, 4.69%; N, 3.60%.

Preparation of ((5*R*,6*R*)-5-(4-Methoxyphenyl)-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14f**))—**

Following General Procedure 8, a 10-mL Schlenk flask was charged with (*E*)-**2f** (282.3 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at –20 °C for 24 h. Purification by flash column chromatography (SiO₂, 32 g, 30 mm Ø, hexane/Et₂O, 90:10) afforded *trans*-**14f** (340 mg, 87%) as a white solid. Recrystallization from hot pentane provided 336 mg (86%) of analytically pure *trans*-**14f**. Data for *trans*-**14f**: mp: 104–106 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.42 – 7.41 (m, 2 H, HC(17) and HC(21)), 7.33 – 7.28 (m, 2 H, HC(18) and HC(20)), 7.26 (tt, *J* = 7.0, 2.0 Hz, 1 H, HC(19)), 6.97 (d, *J* = 7.5 Hz, 2 H, HC(13)), 6.84 (d, *J* = 7.5 Hz, 2 H, HC(12)), 6.64 (s, 1 H, HC(6)), 6.32 (s, 1 H, C(9)), 5.86 (s, 2 H, OCH₂O), 4.06 (d, *J* = 5.0 Hz, 1 H, HC(1)), 3.81 (s, 3 H, HC(15)), 3.63 – 3.60 (m, 1 H, HC(2)), 2.98 (ddd, *J* = 16.0, 9.0, 6.0 Hz, 1 H, HC(4)), 2.79 (ddd, *J* = 17.0, 5.5, 5.5 Hz, 1 H, HC(4)), 2.19 – 2.13 (m, 1 H, HC(3)), 1.88 – 1.81 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 158.4 (C(14)), 146.4 (C(7)), 146.2 (C(8)), 137.7 (C(11)), 135.3 (C(16)), 132.4 (C(17,20)), 130.1 (C(13)), 129.4 (C(10)), 129.1 (C(18,20)), 127.2 (C(19)), 113.9 (C(12)), 110.4 (C(9)), 108.3 (C(6)), 100.9 (OCH₂O), 55.5 (C(15)), 51.7 (C(2)), 49.7 (C(1)), 27.0 (C(4)), 25.0 (C(3)); IR: (KBr) 2919 (m), 2829 (m), 1608 (m), 1580 (m), 1507 (s), 1479 (s), 1434 (m), 1389 (w), 1299 (w), 1240 (s), 1039 (m), 941 (w), 869 (w), 817 (m), 740 (m); MS: (EI⁺, 70 eV) 390.2 (17.0), 381.5 (16.5), 340.3 (20.3), 326.2 (26.2), 325.2 (100.0), 295.4 (12.0), 281.2 (23.0), 280.2 (20.2), 269.3 (15.0), 231.2 (43.9), 223.1 (16.0), 191.2 (58.7), 175.2 (14.2), 159.1 (14.1), 149.2 (16.1), 143.1 (11.5), 141.1 (20.0), 135.1 (40.6), 133.1 (12.1), 128.1 (14.8), 127.1 (13.6), 121.1 (32.2), 115.1 (28.0), 57.0 (60.0); HRMS: calcd for C₂₄H₂₂O₃S⁺: 390.1290, found: 390.1297; TLC: *R*_f 0.36 (hexanes/Et₂O, 90:10) [KMnO₄]; Opt Rot. : [α]_D²⁵ –25.9 (c = 0.54, EtOH); SFC: (*5R,6R*)-**14f**, *t*_R 23.7 min (92%); (*5S,6S*)-**14f**, *t*_R 42.7 min (8%) (Chiralpak OJ, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₂₄H₂₂O₃S (390.13) Calcd: C, 73.82; H, 5.68%. Found: C, 73.89; H, 5.60%.

Preparation of ((5*R*,6*R*)-5-(2-Naphthyl)-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14g**))—**

Following General Procedure 8, (*E*)-**2g** (302 mg, 1.0 mmol, 1.0 equiv), **13** (256 mg, 1.0 mmol, 1.0 equiv), (*S*)-**20a** (55 mg, 0.1 mmol, 0.1 equiv) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at –20 °C for 48 h. Purification by flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded *trans*-**14g** (254 mg, 62%) as a white solid along with unreacted (*E*)-**2g** (109 mg, 36%). Recrystallization from hot pentane provided 250 mg (61%) of analytically pure *trans*-**14g**. Data for *trans*-**14g**: mp: 92–94 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.83 –

7.77 (m, 2 H, H(C-aryl)), 7.50 – 7.42 (m, 5 H, HC(22) and HC(26) and H(C-aryl)), 7.32 – 7.20 (m, 5 H, HC(23) and HC(24) and HC(25) and H(C-aryl)), 6.69 (s, 1 H, HC(6)), 6.33 (s, 1 H, C(9)), 5.89 (s, 2 H, OCH₂O), 4.27 (d, $J = 5.5$ Hz, 1 H, HC(1)), 3.78 – 3.73 (m, 1 H, HC(2)), 3.03 (ddd, $J = 18.0, 8.0, 6.5$ Hz, 1 H, HC(4)), 2.86 (ddd, $J = 17.0, 6.0, 5.5$ Hz, 1 H, HC(4)), 2.25 – 2.18 (m, 1 H, HC(3)), 1.91 – 1.85 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 146.6 (C(7)), 146.3 (C(8)), 142.9 (C(11)), 135.1 (C(21)), 133.5 (C-aryl), 132.6 (C(22,26)), 132.5 (C-aryl), 129.7 (C(5)), 129.5 (C(10)), 129.1 (C(23,25)), 128.4 (C(aryl)), 128.3 (C(aryl)), 128.0 (C(aryl)), 127.8 (C(aryl)), 127.3 (C(aryl)), 127.0 (C(24)), 126.3 (C(aryl)), 125.9 (C(aryl)), 110.5 (C(9)), 108.4 (C(6)), 101.0 (OCH₂O), 51.5 (C(2)), 50.8 (C(1)), 27.2 (C(4)), 25.5 (C(3)); IR: (KBr) 3045 (w), 2968 (w), 2919 (m), 2885 (m), 1597 (w), 1580 (w), 1500 (s), 1479 (s), 1438 (m), 1382 (w), 1236 (s), 1170 (w), 1115 (m), 1035 (s), 938 (m), 855 (w), 817 (m), 796 (w), 744 (s), 692 (m); MS: (EI⁺, 70 eV) 446.2 (66.5), 325.2 (58.7), 310.4 (12.6), 295.3 (34.6), 279.3 (30.9), 259.3 (18.2), 247.2 (17.8), 239.2 (54.4), 231.2 (100.0), 227.2 (21.0), 215.2 (17.1), 205.2 (15.7), 191.2 (93.0), 175.2 (28.9), 159.1 (24.4), 149.1 (27.1), 143.1 (25.5), 141.1 (33.5), 133.1 (21.2), 128.1 (25.7), 121.1 (32.4), 115.1 (38.3), 109.1 (30.5), 107.1 (44.4), 105.1 (46.2); HRMS: calcd for C₂₇H₂₂O₂S⁺: 410.1341, found: 410.1343; TLC: R_f 0.36 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : $[\alpha]_D^{25} -19.2$ (c = 0.54, EtOH); SFC: (5*S*,6*S*)-**14g**, t_R 23.4 min (11%); (5*R*,6*R*)-**14g**, t_R 23.5 min (89%) (Chiralpak OD, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₂₇H₂₂O₂S (410.13) Calcd: C, 78.99; H, 5.40%. Found: C, 78.98; H, 5.48%.

Preparation of ((5*R*,6*R*)-5-(4-Trifluoromethylphenyl)-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14h**))—**

Following General Procedure 8, (*E*)-**2h** (320.3 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at 22 °C for 72 h. Purification by flash column chromatography (SiO₂, 30 g, 32 mm Ø, hexane/Et₂O, 96:4) afford *trans*-**14h** (368 mg, 86%) as a white solid. Recrystallization from hot pentane provided 364 mg (85%) of analytically pure *trans*-**14h**. Data for *trans*-**14h**: mp: 98–100 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.54 (d, $J = 8.0$ Hz, 2 H, HC(13)), 7.39 (t, $J = 7.0$ Hz, 2 H, HC(17)), 7.31 (t, $J = 6.5$ Hz, 2 H, HC(18)), 7.23 (t, $J = 7.5$ Hz, 1 H, HC(19)), 7.16 (d, $J = 8.0$ Hz, 2 H, HC(12)), 6.66 (s, 1 H, HC(6)), 6.23 (s, 1 H, C(9)), 5.90 (s, 2 H, OCH₂O), 4.16 (d, $J = 5.5$ Hz, 1 H, HC(1)), 3.60 – 3.57 (m, 1 H, HC(2)), 3.00 (ddd, $J = 16.5, 8.0, 6.0$ Hz, 1 H, HC(4)), 2.82 (ddd, 1H, $J = 17.0, 6.0, 6.0$ Hz, 1 H, HC(4)), 2.18 – 2.11 (m, 1 H, HC(3)), 1.90 – 1.84 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 149.5 (C(11)), 146.7 (C(7)), 146.3 (C(8)), 134.6 (C(16)), 132.6 (C(18)), 129.6 (C(10)), 129.5 (C(12)), 129.1 (C(17)), 129.0 (q, $J = 32.0$ Hz, C(14)), 128.8 (C(5)), 127.5 (C(19)), 125.4 (q, $J = 3.9$ Hz, C(13)), 124.3 (q, $J = 272.0$ Hz, C(15)), 110.1 (C(9)), 108.4 (C(6)), 101.0 (OCH₂O), 51.6 (C(2)), 50.6 (C(1)), 27.1 (C(4)), 25.5 (C(3)); IR: (KBr) 2927 (w), 2891 (w), 1608 (w), 1580 (w), 1503 (s), 1479 (s), 1437 (m), 1381 (w), 1301 (w), 1238 (s), 1171 (m), 1032 (s), 937 (m), 906 (w), 818 (m); MS: (EI⁺, 70 eV) 429.2 (22.9), 428.2 (84.1), 325.2 (17.9), 319.1 (17.2), 318.1 (100.0), 291.1 (9.2), 289.2 (9.5), 260.1 (9.2), 233.1 (12.0), 223.1 (47.5), 191.1 (10.3), 189.1 (11.4), 165.0 (20.0), 161.1 (11.6), 160.1 (36.1), 159.1 (30.9), 115.1 (16.3); HRMS: calcd for C₂₄H₁₉F₃O₂S⁺: 428.1058, found: 428.1050; TLC: R_f 0.29 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : $[\alpha]_D^{25} -18.5$ (c = 0.55, EtOH); SFC: (5*R*,6*R*)-**14h**, t_R 6.4 min (92%); (5*S*,6*S*)-**14h**, t_R 9.8 min (8%) (Chiralpak OJ,

5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₂₄H₂₂F₃O₂S (428.11) Calcd: C, 67.28; H, 4.47%. Found: C, 67.92; H, 4.35%.

Preparation of ((5*R*,6*R*)-5-(2-Methylphenyl)-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14i**) and (*E*)-1-(3',4'-Methylenedioxyphenyl)-4-(2-methylphenyl)but-1-ene (**28**)—**

Following General Procedure 8, (*E*)-**2i** (266.3 mg, 1.00 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at –20 °C for 86 h. Purification by flash column chromatography (SiO₂, 95 g, 40 mm Ø, hexane/Et₂O, 96:4) afforded *trans*-**14i** (323 mg, 86%) as a white solid. Recrystallization of *trans*-**14i** from hot pentane provided 308 mg (82%) of analytically pure *trans*-**14i**. Isomerized starting material **28** was isolated from earlier unoptimized experiments. Data for *trans*-**14i**: mp: 56–58 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.45 – 7.43 (m, 2 H, HC(19) and HC(23)), 7.32 – 7.25 (m, 3 H, HC(20) and HC(21) and HC(22)), 7.18 (d, *J* = 6.5 Hz, 1 H, HC(14)), 7.12 (d, *J* = 7.5 Hz, 1.5 H, HC(15)), 7.08 (dt, *J* = 7.5, 1.5 Hz, 1 H, HC(16)), 6.76 (d, *J* = 7.5 Hz, 1 H, HC(17)), 6.66 (s, 1 H, HC(6)), 6.28 (s, 1 H, C(9)), 5.90 (s, 2 H, OCH₂O), 4.36 (d, *J* = 4.5 Hz, 1 H, HC(1)), 3.58 – 3.55 (m, 1 H, HC(2)), 3.06 (ddd, *J* = 16.5, 11.5, 5.5 Hz, 1 H, HC(4)), 2.80 (ddd, *J* = 16.5, 5.5, 5.5 Hz, 1 H, HC(4)), 2.31 (s, 3 H, HC(13)), 2.18 – 2.11 (m, 1 H, HC(3)), 1.87 – 1.80 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 146.4 (C(7)), 146.3 (C(8)), 143.6 (C(14)), 136.2 (C(18)), 135.1 (C(12)), 133.2 (C(19,23)), 130.5 (C(14)), 130.0 (C(5)), 129.6 (C(17)), 129.5 (C(10)), 129.0 (C(20, 22)), 127.4 (C(21)), 126.5 (C(15)), 126.0 (C(16)), 110.1 (C(9)), 108.2 (C(6)), 100.8 (OCH₂O), 50.4 (C(2)), 46.6 (C(1)), 26.5 (C(4)), 24.5 (C(3)), 19.6 (C(13)); IR: (KBr) 3059 (m), 3015 (m), 2924 (s), 2770 (w), 1583 (m), 1504 (s), 1485 (s), 1454 (s), 1385 (s), 1348 (m), 1305 (w), 1283 (w), 1236 (s), 1176 (m), 1088 (w), 1038 (s), 941 (s), 907 (m), 868 (m), 823 (m), 741 (s); MS: (EI⁺, 70 eV) 374.1 (32.2), 325.2 (25.5), 265.1 (41.9), 264.1 (33.9), 239.1 (14.8), 223.1 (28.9), 220.2 (28.9), 206.2 (21.1), 205.2 (71.9), 192.1 (15.5), 191.1 (100.0), 175.1 (16.6), 165.1 (17.3), 149.0 (43.8), 145.1 (16.6), 135.1 (86.3), 131.1 (16.1), 129.1 (17.1), 128.1 (15.4), 121.1 (27.4), 115.1 (28.3), 111.1 (13.1), 109.1 (12.2), 107.1 (36.4), 105.1 (44.9); HRMS: calcd for C₂₄H₂₂O₂S⁺: 374.1341, found: 374.1334; TLC: *R*_f 0.37 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : [α]_D²⁵ –40.1 (c = 0.43, EtOH); SFC: (5*S*,6*S*)-**14i**, *t*_R 10.2 min (8%); (5*R*,6*R*)-**14i**, *t*_R 11.5 min (92%) (Chiralpak AD, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₂₄H₂₂O₂S (374.13) Calcd: C, 76.97; H, 5.92%. Found: C, 77.26; H, 5.77%. Data for **28**: ¹H NMR: (500 MHz, CDCl₃) 7.17 – 7.08 (m, 4 H, HC(b) and HC(c) and HC(d) and HC(e)), 6.70 (d, *J* = 7.0 Hz, 1 H, HC(5')), 6.62 (s, 1 H, HC(2')), 6.59 (d, *J* = 7.0 Hz, 1 H, C(6')), 6.44 (d, *J* = 11.5 Hz, 1 H, HC(1)), 5.90 (s, 2 H, OCH₂O), 5.72 (dt, *J* = 11.5, 7.0 Hz, 1 H, HC(2)), 2.63 (t, *J* = 8.0 Hz, 2 H, HC(4)), 2.48 (dt, *J* = 7.0, 7.0 Hz, 2 H, HC(3)), 2.21 (s, 3 H, HC(g)); ¹³C NMR: (125 MHz, CDCl₃) 147.6 (C(3')), 145.7 (C(4')), 136.7 (C(a)), 136.4 (C(f)), 135.7 (C(1')), 131.6 (C(2)), 129.9 (C(aryl)), 129.1 (C(1)), 128.8 (C(aryl)), 127.0 (C(aryl)), 125.4 (C(b)), 121.3 (C(6')), 109.1 (C(2')), 108.2 (C(5')), 100.9 (OCH₂O), 35.8 (C(3)), 30.5 (C(4)), 20.0 (C(g)); IR: (KBr) 3017 (w), 2919 (m), 1601(w), 1500 (m), 1486 (s), 1441 (m), 1361 (w), 1243 (s), 1184 (w), 1094 (s), 1039 (w), 962 (w), 935 (m), 858 (w), 806 (w), 744 (m); MS: (EI⁺, 70 eV) 266.1 (22.9), 149.0 (5.6), 136.0 (9.0), 135.0 (100.0), 131.1 (10.3), 120.9 (5.8), 118.9 (6.8), 115.0 (5.2); HRMS: calcd for C₁₈H₁₈O₂⁺: 266.1307, found: 266.1315; TLC: *R*_f 0.60 (hexanes/Et₂O, 96:4) [KMnO₄].

Preparation of ((5*R*,6*R*)-5-Methyl-5-phenyl-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14j) and 5-Methyl-5-phenyl-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (27)—

Following General Procedure 8, a 10-mL Schlenk flask was charged with (*E*)-**2j** (266 mg, 1.0 mmol, 1.0 equiv), **13** (256 mg, 1.0 mmol, 1.0 equiv), (*S*)-**20** (55 mg, 0.1 mmol, 0.1 equiv) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at –20 °C for 48 h. Purification by flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded *trans*-**14j** (318 mg, 85%) as a white solid along with **27** (5 mg, 2%) as colorless oil. Recrystallization from hot pentane provided 310 mg of analytically pure *trans*-**14j**. Data for *trans*-**14j**: mp: 90–92 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.33 – 7.19 (m, 10 H, HC(13) and HC(14), and HC(15) and HC(17) and HC(18) and HC(19)), 6.59 (s, 1 H, HC(6)), 6.34 (s, 1 H, C(9)), 5.89 (s, 2 H, OCH₂O), 3.68 (dd, *J* = 9.0, 4.5 Hz, 1 H, HC(2)), 2.97 (ddd, *J* = 17.0, 5.5, 5.5 Hz, 1 H, HC(4)), 2.86 (ddd, *J* = 16.0, 8.0, 8.0 Hz, 1 H, HC(4)), 2.13 – 2.07 (m, 2 H, HC(3)), 1.84 (s, 3 H, HC(11)); ¹³C NMR: (125 MHz, CDCl₃) 148.6 (C(12)), 146.1 (C(7)), 146.0 (C(8)), 137.4 (C(5)), 136.2 (C(16)), 132.2 (C(17)), 128.9 (C(14)), 128.7 (C(10)), 128.0 (C(13) and C(18)), 126.8 (C(15)), 126.3 (C(19)), 109.2 (C(9)), 107.9 (C(6)), 100.8 (OCH₂O), 60.2 (C(2)), 47.7 (C(1)), 29.3 (C(4)), 26.8 (C(3)), 25.7 (C(11)); IR: (KBr) 3045 (w), 2968 (m), 2933 (m), 2885 (m), 1580 (w), 1500 (m), 1483 (s), 1438 (m), 1368 (m), 1330 (w), 1229 (s), 1115 (w), 1035 (s), 935 (m), 858 (m), 752 (m), 737 (m), 699 (s); MS: (EI⁺, 70 eV) 375.1 (16.9), 374.1 (55.4), 266.1 (23.0), 265.1 (100.0), 264.1 (16.3), 249.1 (12.5), 237.1 (14.0), 224.0 (10.7), 223.0 (70.1), 205.1 (12.0), 1919.1 (17.7), 189.0 (12.5), 187.0 (11.0), 178.0 (12.7), 173.0 (107), 165.0 (24.9), 135.0 (13.0), 129.0 (10.5), 120.9 (19.6), 118.9 (22.1), 115.0 (15.7), 110.0 (12.4), 109.0 (13.8), 105.0 (32.6), 101.0 (9.5); HRMS: calcd for C₂₄H₂₂O₂S⁺: 374.1341, found: 374.1343; TLC: *R*_f 0.37 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : [α]_D²⁵ +72.9 (c = 0.48, EtOH); SFC: (*5R,6R*)-**14j**, *t*_R 15.5 min (71%); (*5S,6S*)-**14j**, *t*_R 21.5 min (29%) (Chiralpak OD, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₂₄H₂₂O₂S (374.13) Calcd: C, 76.97; H, 5.92%. Found: C, 76.91; H, 5.85%. Data for **27**: ¹H NMR: (500 MHz, CDCl₃) 7.27 (t, *J* = 7.5 Hz, 2 H, HC(14)), 7.17 (t, *J* = 7.5 Hz, 1 H, HC(15)), 7.16 (d, *J* = 7.5 Hz, 2 H, HC(13)), 6.60 (s, 1 H, HC(6)), 6.46 (s, 1 H, C(9)), 5.89 (d, *J* = 10.0 Hz, 2 H, OCH₂O), 2.77 (t, *J* = 6.5 Hz, 2 H, HC(4)), 2.02 (ddd, *J* = 13.5, 8.5, 3.0 Hz, 1 H, HC(2)), 1.86 (ddd, *J* = 12.5, 9.0, 3.0 Hz, 1 H, HC(2)), 1.79 – 1.72 (m, 1 H, HC(3)), 1.70 (s, 3 H, HC(11)), 1.68 – 1.62 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 151.6 (C(12)), 145.9 (C(7)), 145.7 (C(8)), 137.4 (C(5)), 130.4 (C(10)), 127.9 (C(14)), 127.5 (C(13)), 125.6 (C(15)), 108.9 (C(9)), 108.3 (C(6)), 100.7 (OCH₂O), 43.1 (C(1)), 41.6 (C(2)), 30.6 (C(4)), 30.1 (C(3)), 15.8 (C(11)); IR: (neat) 2926 (m), 1500 (m), 1479 (s), 1441 (w), 1372 (w), 1226 (s), 1163 (w), 1039 (m), 931 (w), 827 (w), 754 (w), 695 (w); MS: (EI⁺, 70 eV) 267.1 (10.8), 266.1 (56.8), 252.0 (17.8), 251.1 (100.0), 189.0 (16.9), 115.1 (7.4), 91.1 (22.7), 86.0 (15.3), 84.0 (24.0); HRMS: calcd for C₁₈H₁₈O₂⁺: 266.1307, found: 266.1303; TLC: *R*_f 0.58 (hexanes/Et₂O, 96:4) [KMnO₄].

Preparation of ((5*R*,6*R*)-5-Cyclopropyl-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14k)—

Following General Procedure 8, (*E*)-**2k** (216.3 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at –20 °C for 72 h. Purification by flash column chromatography (SiO₂, 30 g, 25 mm Ø, hexane/Et₂O, 96:4) to afford *trans*-**14k** (292 mg, 90%) as colorless oil. Recrystallization from hot pentane provided 285 mg (88%) of analytically pure *trans*-**14k**. Data for *trans*-**14k**: mp: 25 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.43 (dd, *J* = 7.5, 1.0, 2 H, HC(15)), 7.32 (t, *J* = 7.5 Hz, 2 H, HC(16)), 7.25 (tt, *J* = 7.5, 1.0 Hz, 1 H, HC(17)), 6.68 (s, 1 H, HC(6)), 6.61 (s, 1 H, C(9)), 5.92 (s, 2 H, OCH₂O), 3.85 (q, *J* = 2.0 Hz, 1 H, HC(2)), 3.04 (ddd, *J* = 17.5, 12.0, 6.0 Hz, 1 H HC(4)), 2.68 (ddd, *J* = 17.0, 6.0, 1.5 Hz, 1 H, HC(4)), 2.34 – 2.27 (m, 1 H, HC(3)), 2.03 (d, *J* = 9.0 Hz, 1 H, HC(1)), 2.02 – 1.97 (m, 1 H, HC(3)), 0.99 – 0.92 (m, 1 H, HC(11)), 0.65 – 0.60 (m, 1 H, HC(12)), 0.56 – 0.50 (m, 1 H, HC(13)), 0.48 – 0.44 (m, 1 H, HC(12)), 0.29 – 0.22 (m, 1 H, HC(13)); ¹³C NMR: (125 MHz, CDCl₃) 146.4 (C(7)), 145.7 (C(8)), 135.6 (C(14)), 131.7 (C(15)), 139.5 (C(5)), 129.0 (C(16)), 128.1 (C(10)), 126.8 (C(17)), 109.4 (C(9)), 108.7 (C(6)), 100.8 (OCH₂O), 48.3 (C(1,2)), 25.2 (C(4)), 23.2 (C(3)), 19.9 (C(11)), 6.2 (C(12)), 4.0 (C(13)); IR: (neat) 3066 (s), 2996 (s), 2919 (s), 2766 (s), 1580 (s), 1503 (s), 1379 (s), 1344 (s), 1271 (s), 1229 (s), 1181 (s), 1125 (m), 1046 (s), 1021 (s), 983 (s), 938 (s), 737 (s); MS: (EI⁺, 70 eV) 324.9 (12.2), 324.0 (54.6), 215.0 (30.2), 214.0 (36.0), 185.0 (13.3), 175.0 (12.7), 174.0 (100.0), 173.0 (39.3), 161.0 (13.1), 160.1 (9.6), 143.0 (9.2), 128.0 (11.1), 116.0 (11.7), 115.0 (33.2), 85.9 (28.5), 83.9 (44.0); HRMS: calcd for C₂₀H₂₀O₂S⁺: 324.1184, found: 324.1181; TLC: *R*_f 0.29 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : [α]_D²⁵ –23.9 (c = 0.53, EtOH); SFC: (*5S,6S*)-**14k**, *t*_R 9.6 min (5%); (*5R,6R*)-**14k**, *t*_R 11.3 min (95%) (Chiralpak OD, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C).

Preparation of ((5*R*,6*R*)-5-Cyclopentyl-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14l**))—**

Following General Procedure 8, (*E*)-**2l** (244.4 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at 0 °C for 72 h. Purification by flash column chromatography (SiO₂, 30 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded *trans*-**14l** (183 mg, 52%) as a white solid along with unreacted (*E*)-**2l** (37 mg, 15%). Recrystallization from hot pentane provided 180 mg (50%) of analytically pure *trans*-**14l**. Data for *trans*-**14l**: mp: 102–104 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.39 (d, *J* = 7.0 Hz, 2 H, HC(17)), 7.29 (t, *J* = 7.0 Hz, 2 H, HC(18)), 7.22 (tt, *J* = 7.0, 1.5 Hz, 1 H, HC(19)), 6.58 (s, 1 H, HC(6)), 6.55 (s, 1 H, C(9)), 5.89 (dd, *J* = 4.5, 1.5 Hz, 2 H, OCH₂O), 3.82 – 3.80 (m, 1 H, HC(2)), 2.97 (ddd, *J* = 18.0, 11.0, 7.5 Hz, 1 H, HC(4)), 2.70 (ddd, *J* = 18.0, 7.0, 2.0 Hz, 1 H, HC(4)), 2.56 (d, *J* = 9.0 Hz, 1 H, HC(1)), 2.26 – 2.19 (m, 1 H, HC(3)), 1.91 – 1.76 (m, 3 H, HC(3) and HC(11) and HC(13)), 1.68 – 1.62 (m, 3 H, HC(13) and HC(14) and HC(15)), 1.58 – 1.51 (m, 1 H,

HC(12)), 1.48 – 1.37 (m, 1 H, HC(14)), 1.31 – 1.17 (m, 3 H, HC(12), and HC(15)), ^{13}C NMR: (125 MHz, CDCl_3) 146.2 (C(7)), 145.1 (C(8)), 136.0 (C(16)), 131.7 (C(17)), 131.1 (C(5)), 129.0 (C(18)), 128.2 (C(10)), 126.8 (C(19)), 110.4 (C(9)), 108.8 (C(6)), 100.7 (OCH₂O), 49.6 (C(1)), 47.7 (C(11)), 46.9 (C(2)), 32.9 (C(15)), 30.9 (C(12)), 25.0 (C(13)), 24.9 (C(14)), 24.4 (C(4)), 22.6 (C(3)); IR:(KBr) 2926 (m), 2864 (m), 1500 (s), 1479 (s), 1455 (m), 1434 (w), 1375 (w), 1347 (w), 1229 (s), 1181 (m), 1118 (w), 1035 (s), 935 (m), 851 (w); MS: (EI^+ , 70 eV) 325.1 (10.1), 352.1 (36.8), 284.0 (6.7), 283.0 (43.2), 243.1 (7.9), 242.1 (8.4), 175.0 (20.5), 174.0 (100.0), 173.0 (63.3), 161.0 (16.0), 145.1 (6.7), 144.0 (10.0), 143.0 (8.6), 135.0 (8.3), 119.9 (5.6), 117.0 (9.5), 116.0 (16.0), 115.0 (35.3), 110.0 (12.9), 109.0 (9.4), 103.0 (5.0); HRMS: calcd for $\text{C}_{22}\text{H}_{24}\text{O}_2\text{S}^+$: 352.1497, found: 352.1491; TLC: R_f 0.52 (hexanes/Et O, 96:4) [KMnO_4]; Opt Rot. : $[\alpha]_{\text{D}}^{25} +11.8$ (c = 0.19, EtOH); SFC: (5S, 6S)-**14l**, t_R 9.6 min (18%); (5R,6R)-**14l**, t_R 11.3 min (82%) (Chiralpak OD, 5% MeOH in CO_2 , 2.0 mL/min, 220 nm, 40 °C); Analysis: $\text{C}_{22}\text{H}_{24}\text{O}_2\text{S}$ (352.49) Calcd: C, 74.59; H, 6.86%. Found: C, 74.72; H, 6.50%.

Preparation of ((5R,6R)-5-Cyclohexyl-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-d]-1,3-dioxole (*trans*-14m**))—**

Following General Procedure 8, (*E*)-**2m** (258.4 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH_2Cl_2 (4.25 mL) were reacted with a solution of EtSO_3H (1 M in CH_2Cl_2 , 0.75 mL, 0.75 mmol) at 0 °C for 72 h. Purification by flash column chromatography (SiO_2 , 40 g, 50 mm Ø, hexane/ Et_2O , 96:4) afforded *trans*-**14m** (264 mg, 72%) as a white solid along with unreacted (*E*)-**2m** (41 mg, 16%). Recrystallization from hot pentane provided 257 mg of analytically pure *trans*-**14m**. Data for *trans*-**14m**: mp: 90–92 °C (pentane); ^1H NMR: (500 MHz, CDCl_3) 7.43 (dd, J = 8.0, 1.5 Hz, 2 H, HC(18)), 7.32 (t, J = 8.0 Hz, 2 H, HC(19)), 7.22 (dt, 1H, J = 7.0, 1.0 Hz, 1 H, HC(20)), 6.59 (s, 1 H, HC(6)), 6.55 (s, 1 H, C(9)), 5.92 (dd, J = 7.0, 1.5 Hz, 2 H, OCH₂O), 3.82 (dt, J = 7.0, 4.0 Hz, 1 H, HC(2)), 2.91 (ddd, J = 17.0, 10.0, 7.0 Hz, 1 H, HC(4)), 2.70 (ddd, 1H, J = 17.0, 10.0, 4.0 Hz, 1 H, HC(4)), 2.59 (dd, J = 4.0, 2.0 Hz, 1 H, HC(1)), 2.20 – 2.13 (m, 1 H, HC(3)), 1.89 – 1.84 (m, 1 H, HC(3)), 1.79 – 1.71 (m, 3 H, HC(14) and HC(15) and HC(16)), 1.67 – 1.63 (m, 1 H, HC(12)), 1.62 – 1.59 (m, 1 H, HC(13)), 1.59 – 1.43 (m, 1 H, HC(11)), 1.22 – 1.12 (m, 3 H, HC(13), and HC(14) and HC(15)), 1.08 – 1.00 (m, 2H, HC(12) and HC(16)); ^{13}C NMR: (125 MHz, CDCl_3) 146.1 (C(7)), 145.2 (C(8)), 136.0 (C(17)), 131.9 (C(18)), 130.1 (C(5)), 129.2 (C(10)), 129.0 (C(19)), 126.9 (C(20)), 110.6 (C(9)), 108.5 (C(6)), 100.7 (OCH₂O), 49.7 (C(1)), 45.5 (C(2)), 44.3 (C(11)), 32.2 (C(12)), 31.1 (C(16)), 27.0 (C(13)), 26.9 (C(15)), 26.6 (C(14)), 2.55 (C(4)), 24.3 (C(3)); IR: (KBr) 2919 (s), 2843 (m), 1580 (w), 1500 (m), 1479 (s), 1444 (m), 1375 (w), 1347 (w), 1236 (s), 1036 (s), 935 (m), 865 (m), 737 (m), 688 (m); MS: (EI^+ , 70 eV) 366.1 (31.9), 284.1 (10.2), 283.1 (51.0), 191.1 (8.5), 175.1 (18.5), 174.1 (100.0), 173.0 (53.4), 161.0 (9.8), 144.0 (10.2), 135.0 (10.6), 116.0 (16.2), 115.0 (28.6); HRMS: calcd for $\text{C}_{23}\text{H}_{26}\text{O}_2\text{S}^+$: 366.1654, found: 366.1659; TLC: R_f 0.52 (hexanes/ Et_2O , 96:4) [KMnO_4]; Opt Rot. : $[\alpha]_{\text{D}}^{25} -1.29$ (c = 0.21, EtOH); SFC: (5S, 6S)-**14m**, t_R 11.0 min (15%); (5R,6R)-**14m**, t_R 12.8 min (85%) (Chiralpak OD, 5% MeOH in CO_2 , 2.0 mL/min, 220 nm, 40 °C); Analysis: $\text{C}_{23}\text{H}_{26}\text{O}_2\text{S}$ (366.53) Calcd: C, 75.37; H, 7.15%. Found: C, 75.40; H, 7.11%.

Preparation of ((5*R*,6*R*)-5-Pentyl-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14*n*)—

Following General Procedure 8, (*E*)-**2n** (246.3 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at –20 °C for 72 h. Purification by flash column chromatography (SiO₂, 32 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded of *trans*-**14n** (266 mg, 76%) as colorless oil. Distillation provided 259 mg of analytically pure *trans*-**14n**. Data for *trans*-**14n**: bp: 140 °C @ 5.5×10^{–5} mmHg; ¹H NMR: (500 MHz, CDCl₃) 7.45 (dd, *J* = 7.5, 1.0 Hz, 2 H, HC(17)), 7.33 (t, *J* = 7.5 Hz, 2 H, HC(18)), 7.26 (tt, *J* = 7.0, 1.0 Hz, 1 H, HC(19)), 6.58 (s, 2 H, HC(6) and HC(9)), 5.91 (s, 2 H, OCH₂O), 3.673 – 3.65 (m, 1 H, HC(2)), 2.97 (ddd, *J* = 17.0, 10.5, 6.0 Hz, 1 H, HC(4)), 2.80 (dt, *J* = 8.0, 4.5 Hz, 1 H, HC(1)), 2.64 (ddd, *J* = 17.0, 6.0, 3.5 Hz, 1 H, HC(4)), 2.15 (dddd, *J* = 11.0, 6.5, 3.5 Hz, 1 H, HC(3)), 1.91 – 1.85 (m, 1 H, HC(3)), 1.72 – 1.59 (m, 2 H, HC(11)), 1.41 – 1.22 (m, 6 H, HC(12) and HC(13) and HC(14)), 0.90 (t, *J* = 7.0 Hz, 3 H, HC(15)); ¹³C NMR: (125 MHz, CDCl₃) 146.0 (C(7)), 145.8 (C(8)), 135.6 (C(16)), 132.0 (C(17)), 131.8 (C(5)), 129.0 (C(18)), 128.3 (C(10)), 126.9 (C(19)), 109.3 (C(6)), 108.6 (C(9)), 100.7 (OCH₂O), 46.6 (C(2)), 43.6 (C(1)), 38.1 (C(11)), 32.0 (C(13)), 27.1 (C(12)), 25.6 (C(4)), 23.4 (C(3)), 22.7 (C(14)), 14.2 (C(15)); IR: (neat) 3052 (m), 2926 (s), 2857 (m), 2766 (m), 2666 (w), 2613 (w), 1621 (w), 1583 (s), 1503 (s), 1483 (s), 1469 (s), 1451 (s), 1441 (s), 1379 (s), 1233 (s), 1118 (s), 1087 (s), 1035 (s), 938 (s), 903 (s), 858 (m); MS: (EI⁺, 70 eV) 299.1 (14.2), 298.1 (69.8), 190.1 (13.2), 189.1 (100.0), 188.1 (75.1), 174.0 (18.0), 173.0 (43.8), 162.1 (26.5), 159.1 (34.4), 131.1 (22.0), 116.1 (12.2), 115.0 (26.2), 103.1 (7.3), 91.1 (10.9), 85.0 (31.7), 83.0 (48.7), 65.1 (8.1); HRMS: calcd for C₂₂H₂₆O₂S⁺: 354.1650, found: 354.1654; TLC: *R*_f 0.52 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : [α]_D²⁵ + 12.8 (c = 0.76, EtOH); SFC: (5*S*, 6*S*)-**14n**, *t*_R 9.2 min (4%); (5*R*,6*R*)-**14n**, *t*_R 10.3 min (96%) (Chiralpak OD, 4% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C).

Preparation of ((5*R*,6*R*)-5-(3-Chloropropyl)-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14*o*)—

Following General Procedure 8, (*E*)-**2o** (253.7 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at room temperature for 6 d. Purification by flash column chromatography (SiO₂, 32 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded *trans*-**14o** (235 mg, 65%) as colorless oil. Distillation provided 227 mg of analytically pure *trans*-**14o**. Data for *trans*-**14o**: bp: 135 °C @ 3.2×10^{–5} mmHg; ¹H NMR: (500 MHz, CDCl₃) 7.45 (t, *J* = 7.5 Hz, 2 H, HC(15)), 7.34 (t, *J* = 7.5 Hz, 2 H, HC(16)), 7.28 (t, *J* = 7.0 Hz, 1 H, HC(17)), 6.58 (s, 2 H, HC(6) and C(9)), 5.92 (d, *J* = 2.5 Hz, 2 H, OCH₂O), 3.59 – 3.56 (m, 1 H, HC(2)), 3.55 – 3.45 (m, 2 H, HC(13)), 2.95 (ddd, *J* = 16.5, 10.5, 5.0 Hz, 1 H, HC(4)), 2.85 – 2.82 (m,

1 H, HC (1)), 2.65 (ddd, $J = 10.5, 5.5, 5.5$ Hz, 1 H, HC(4)), 2.16 (dddd, $J = 13.5, 10.0, 5.5, 3.0$ Hz, 1 H, HC(3)), 1.92 – 1.76 (m, 5 H, HC(3) and HC(11) and HC(12)); ^{13}C NMR: (125 MHz, CDCl_3) 146.2 (C(7)), 146.0 (C(8)), 135.1 (C(14)), 132.6 (C(16)), 130.8 (C(5)), 129.1 (C(15)), 128.6 (C(10)), 127.2 (C(17)), 109.1 (C(9)), 108.7 (C(6)), 100.8 (OCH₂O), 46.9 (C(2)), 45.0 (C(13)), 42.9 (C(1)), 34.8 (C(11)), 30.2 (C(12)), 25.9 (C(4)), 24.0 (C(3)); IR: (neat) 3044 (m), 2911 (s), 2761 (m), 1581 (s), 1501 (s), 1484 (s), 1466 (s), 1431 (s), 1378 (s), 1290 (s), 1237 (s), 1030 (s), 933 (s), 902 (s), 858 (s), 823 (s); MS: (EI^+ , 70 eV) 360.1 (63.8), 283.2 (13.6), 253.1 (30.6), 252.1 (28.7), 251.1 (92.5), 250.1 (47.2), 188.1 (19.0), 187.2 (13.8), 175.1 (18.4), 174.1 (89.9), 173.1 (100.0), 161.1 (24.9), 145.1 (17.7), 144.1 (14.8), 131.0 (18.2), 129.1 (13.0), 128.1 (13.1), 117.1 (13.1), 116.1 (23.1), 115.1 (58.9), 109.0 (13.0), 103.1 (14.6), 91.1 (10.9), 77.1 (12.8), 65.1 (11.0); HRMS: calcd for $\text{C}_{20}\text{H}_{21}\text{ClO}_2\text{S}^+$: 360.0951, found: 360.0941; TLC: R_f 0.21 (hexanes/Et₂O, 96:4) [KMnO_4]; Opt Rot. : $[\alpha]_D^{25} +16.03$ ($c = 0.51$, EtOH); SFC: (5*S*,6*S*)-**14o**, t_R 12.1 min (6%); (5*R*,6*R*)-**14o**, t_R 14.6 min (94%) (Chiralpak OD, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: $\text{C}_{20}\text{H}_{21}\text{ClO}_2\text{S}$ (360.90) Calcd: C, 66.56; H, 5.87%. Found: C, 66.61; H, 5.90%.

Preparation of ((5*R*,6*R*)-5-(2-Methylpropyl)-6-(phenylthio)-5,6,7,8-tetrahydronaphtho[2,3-*d*]-1,3-dioxole (*trans*-14p**))—**

Following General Procedure 8, a 10-mL Schlenk flask was charged with (*E*)-**2p** (232.3 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH_2Cl_2 (4.25 mL) were reacted with a solution of EtSO_3H (1 M in CH_2Cl_2 , 0.75 mL, 0.75 mmol) at -20°C for 72 h. Purification by flash column chromatography (SiO_2 , 32 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded *trans*-**14p** (269 mg, 79%) as colorless oil. Distillation provided 262 mg (77%) of analytically pure *trans*-**14p**. Data for *trans*-**14p**: bp: $>135^\circ\text{C}$ @ 1.5×10^{-5} mmHg; ^1H NMR: (500 MHz, CDCl_3) 7.43 (dd, $J = 8.0, 1.5$, 2 H, HC(16)), 7.34 (t, $J = 7.0$ Hz, 2 H, HC(17)), 7.24 (tt, $J = 7.0, 1.5$ Hz, 1 H, HC(18)), 6.56 (s, 1 H, HC(6)), 6.51 (s, 1 H, C(9)), 5.88 (s, 2 H, OCH₂O), 3.64 – 3.62 (m, 1 H, HC(2)), 3.00 (ddd, $J = 17.5, 9.5, 6.5$ Hz, 1 H, HC(4)), 2.84 (dd, $J = 9.0, 4.5$ Hz, 1 H, HC(1)), 2.61 (ddd, $J = 17.0, 6.0, 1.5$ Hz, 1 H, HC(4)), 2.14 – 2.07 (m, 1 H, HC(3)), 1.90 – 1.86 (m, 1 H, HC(3)), 1.71 – 1.63 (m, 1 H, HC(12)), 1.52 (ddd, $J = 14.0, 9.5, 5.0$ Hz, 1 H, HC(11)), 1.37 (ddd, $J = 14.0, 9.0, 5.0$ Hz, 1 H, HC(11)), 0.90 (d, $J = 6.5$ Hz, 3 H, HC(14)); ^{13}C NMR: (125 MHz, CDCl_3) 146.0 (C(7)), 145.9 (C(8)), 135.5 (C(15)), 132.3 (C(16)), 132.1 (C(5)), 129.0 (C(17)), 128.0 (C(10)), 127.1 (C(18)), 109.4 (C(9)), 108.7 (C(6)), 100.7 (OCH₂O), 48.4 (C(11)), 46.6 (C(2)), 41.2 (C(1)), 25.7 (C(12)), 24.9 (C(4)), 23.6 (C(14)), 22.3 (C(3)), 22.0 (C(13)); IR: (neat) 2917 (s), 2850 (s), 1580 (w), 1503 (s), 1483 (s), 1451 (s), 1377 (s), 1240 (s), 1216 (s), 1181 (m), 1122 (w), 1043 (s), 945 (m), 858 (m), 692 (s); MS: (EI^+ , 70 eV) 341.1 (20.6), 340.2 (83.8), 283.1 (19.1), 231.2 (63.9), 230.2 (48.2), 187.1 (12.3), 175.1 (44.3), 174.1 (100.0), 173.1 (75.0), 161.1 (50.0), 159.1 (12.6), 145.1 (15.4), 144.1 (13.8), 135.1 (13.0), 131.0 (19.2), 128.1 (10.2), 117.1 (13.5), 116.1 (23.8), 115.1 (49.3), 109.0 (13.7), 103.1 (14.4), 91.1 (12.9), 77.1 (11.6), 65.1 (10.5), 57.1 (11.2); HRMS: calcd for $\text{C}_{21}\text{H}_{24}\text{O}_2\text{S}^+$: 340.1497, found: 340.1493; TLC: R_f 0.47 (hexanes/Et₂O, 96:4) [KMnO_4]; Opt Rot. : $[\alpha]_D^{25} +17.16$ ($c = 0.61$, EtOH); SFC: (5*R*,6*S*)-**14p**, t_R 6.4 min (96%); (5*S*,6*S*)-**14p**, t_R 6.9 min (4%) (Chiralpak OD, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: $\text{C}_{21}\text{H}_{24}\text{O}_2\text{S}$ (340.48) Calcd: C, 74.08; H, 7.10%. Found: C, 74.33; H, 7.31%.

Preparation of (1*R*,2*R*)-6-Methoxy-1-pentyl-2-(phenylthio)-1,2,3,4-tetrahydronaphthalene (29**) and (1*R*,2*R*)-8-Methoxy-1-pentyl-2-(phenylthio)-1,2,3,4-tetrahydronaphthalene (**30**)—**

Following General Procedure 8, (*E*)-**11n** (232.3 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at –20 °C for 72 h. Purification by flash column chromatography (SiO₂, 32 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded **29** (210 mg, 62%) as colorless oil along with **30** (73 mg, 21%) as a white solid. Distillation provided 204 mg (60%) of analytically pure **29**. Recrystallization of **30** from hot pentane provided 68 mg (20%) of analytically pure **30**. Data for **29**: bp: 140 °C @ 1.5×10^{–5} mmHg; ¹H NMR: (500 MHz, CDCl₃) 7.46 (dd, *J* = 7.5, 1.5 Hz, 2 H, HC(17)), 7.33 (tt, *J* = 7.5, 1.5 Hz, 2 H, HC(18)), 7.27 (tt, *J* = 7.0, 1.0 Hz, 1 H, HC(19)), 7.04 (d, *J* = 8.5 Hz, 1 H, HC(9)), 6.76 (dd, *J* = 8.5, 2.5 Hz, 1 H, HC(8)), 6.66 (d, *J* = 2.5 Hz, 1 H, HC(6)), 3.81 (s, 3 H, OCH₃), 3.71 – 3.69 (m, 1 H, HC(2)), 3.06 (ddd, *J* = 17.0, 11.0, 5.5 Hz, 1 H, HC(4)), 2.89 – 2.86 (m, 1 H, HC(1)), 2.72 (ddd, *J* = 17.5, 6.0, 4.0 Hz, 1H, HC(4)), 2.19 (dddd, *J* = 14.0, 9.0, 6.0, 3.0 Hz, 1 H, HC(3)), 1.94 – 1.88 (m, 1 H, HC(3)), 1.74 – 1.62 (m, 2 H, HC(11)), 1.42 – 1.24 (m, 6 H, H(12) and HC(13), and HC(14)), 0.90 (t, *J* = 7.0 Hz, 3 H, HC(15)); ¹³C NMR: (125 MHz, CDCl₃) 157.7 (C(7)), 136.5 (C(5)), 135.6 (C(16)), 132.0 (C(17)), 131.1 (C(10)), 130.7 (C(9)), 129.0 (C(18)), 126.9 (C(19)), 113.2 (C(6)), 112.4 (C(8)), 55.2 (OCH₃), 46.8 (C(2)), 42.7 (C(1)), 38.0 (C(11)), 32.00 (C(13)), 27.0 (C(12)), 25.8 (C(4)), 23.4 (C(3)), 22.7 (C(14)), 14.2 (C(15)); IR: (neat) 3052 (s), 2919 (s), 2843 (s), 1608 (s), 1580 (s), 1500 (s), 1455 (s), 1434 (s), 1375 (m), 1320 (m), 1254 (s), 1233 (s), 1157 (m), 1125 (s), 1087 (m), 1039 (s), 896 (m), 844 (m), 813 (m), 740 (s); MS: (EI⁺, 70 eV) 340.1 (20.5), 269.2 (23.0), 231.1 (100.0), 191.2 (47.8), 161.1 (24.5), 160.1 (36.1), 159.1 (30.2), 147.1 (31.4), 135.1 (48.5), 121.1 (24.7), 115.1 (19.2), 107.1 (26.8), 91.1 (25.00), 77.1 (19.5), 57.1 (37.7), 55.1 (22.8); HRMS: calcd for C₂₂H₂₈OS⁺: 340.1861, found: 340.1856; TLC: *R*_f 0.38 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : [α]_D²⁵ +14.5 (c = 0.54, EtOH); SFC: (1*R*,2*R*)-**29** *t*_R 8.8 min (96%); (1*S*,2*S*)-**29**, *t*_R 13.7 min (4%) (Chiralpak OJ, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₂₂H₂₈OS (340.19) Calcd: C, 77.60; H, 8.29%. Found: C, 77.89; H, 8.42%. Data for **30**: mp: 72–74 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.45 (dd, *J* = 7.5 Hz, 2 H, HC(17)), 7.32 (t, *J* = 7.5 Hz, 2 H, HC(18)), 7.25 (t, *J* = 7.0, 1.0 Hz, 1 H, HC(19)), 7.13 (t, *J* = 8.0 Hz, 1 H, HC(7)), 6.74 (d, *J* = 8.5, 1 H, HC(6)), 6.71 (d, *J* = 8.5 Hz, 1 H, HC(8)), 3.82 (s, 3 H, OCH₃), 3.79 (s, 1 H, HC(2)), 3.22 (d, *J* = 6.0 Hz, 1 H, HC(1)), 3.10 (ddd, *J* = 17.5, 11.5, 6.0 Hz, 1 H, HC(4)), 2.72 (dd, *J* = 17.5, 4.5 Hz, 1 H, HC(4)), 2.20 – 2.13 (m, 1 H, HC(3)), 1.90 – 1.87 (m, 1 H, HC(3)), 1.79 – 1.68 (m, 1 H, HC(11)), 1.50 – 1.23 (m, 7 H, HC(11) and (HC(12) and HC(13), and HC(14)), 0.91 (t, *J* = 7.0 Hz, 3 H, HC(15)); ¹³C NMR: (125 MHz, CDCl₃) 157.6 (C(9)), 136.4 (C(16)), 136.1 (C(5)), 131.8 (C(17)), 128.9 (C(18)), 128.1 (C(10)), 126.70 (C(19)), 126.4 (C(7)), 121.66 (C(6)), 107.7 (C(8)), 55.3 (OCH₃), 45.6 (C(2)), 37.6 (C(1)), 35.6 (C(11)), 31.7 (C(13)), 27.6 (C(12)), 24.9 (C(4)), 22.7 (C(14)), 22.0 (C(3)), 14.2 (C(15)); IR: (KBr) 2940 (m), 2912 (s), 2843 (m), 1580 (s), 1465 (s), 1451 (s), 1438 (m), 1337 (m), 1250 (s), 1084 (s), 1066 (s), 765 (m), 737 (m); MS: (EI⁺, 70 eV) 341.1 (12.6), 340.2 (47.4), 269.1 (34.7), 231.2 (42.7), 230.2 (11.9), 174.1 (13.9), 161.1 (50.4), 160.1 (31.8), 159.1 (69.0), 148.0 (12.1), 147.1 (100.0), 145.1 (13.3), 144.0 (17.2), 135.1 (11.6), 129.1 (14.2), 128.1 (14.9), 127.0 (10.3), 121.1 (10.3), 115.1 (24.0), 109.0 (10.8), 91.1 (14.7), 85.9 (52.3), 84.0 (79.4), 58.1 (9.6); HRMS: calcd for C₂₂H₂₈OS⁺: 340.1861, found: 340.1865; TLC: *R*_f 0.54 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : [α]_D²⁵ +13.6 (c = 0.61, EtOH); SFC: (1*R*,2*R*)-**30**, *t*_R 5.8 min (91%); (1*S*,2*S*)-**30**, *t*_R 8.9

min (9%) (Chiralpak OJ, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₂₂H₂₈OS (340.19) Calcd: C, 77.60; H, 8.29%. Found: C, 77.43; H, 8.22%.

Preparation of (1*R*,2*R*)-6-Methoxy-1-phenyl-2-(phenylthio)-1,2,3,4-tetrahydronaphthalene (31) and (1*R*,2*R*)-8-Methoxy-1-phenyl-2-(phenylthio)-1,2,3,4-tetrahydronaphthalene (32)—

Following General Procedure 8, (*E*)-**11b** (238.3 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at –20 °C for 72 h. Purification by flash column chromatography (SiO₂, 32 g, 30 mm Ø, hexane/Et₂O, 96:4) afforded **31** (160 mg, 46%) as colorless oil along with **32** (161 mg, 46%) as a white solid. Distillation provided 156 mg (45%) of analytically pure **31**. Recrystallization of **32** from hot pentane provided 156 mg (45%) of analytically pure **32**. Data for **31**: bp: 135 °C @ 1.6×10^{–5} mmHg; ¹H NMR: (500 MHz, CDCl₃) 7.49 (dd, *J* = 8.5, 1.5 Hz, 2 H, HC(16)), 7.35 (t, *J* = 9.0 Hz, 2 H HC(17)), 7.30 – 7.22 (m, 4 H, HC(7) and HC(13) and HC(18)), 7.18 (tt, *J* = 7.0, 1.0 Hz, 1 H, HC(14)), 6.99 (d, *J* = 7.0 Hz, 2 H, HC(12)), 6.88 (d, *J* = 7.5 Hz, 1 H, HC(6)), 6.70 (d, *J* = 8.0 Hz, 1 H, HC(8)), 4.55 (s, 1 H, HC(1)), 3.81 – 3.79 (m, 1 H, HC(2)), 3.57 (s, 3 H, OCH₃), 3.19 (ddd, *J* = 17.5, 12.5, 6.0 Hz, 1 H, HC(4)), 2.85 (ddd, *J* = 17.0, 5.5, 2.0 Hz, 1H, HC(4)), 2.11 – 2.03 (m, 1 H, HC(3)), 1.83 – 1.77 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 158.1 (C(9)), 146.0 (C(11)), 137.7 (C(10)), 135.8 (C(15)), 132.1 (C(16)), 129.2 (C(12)), 128.3 (C(17)), 128.2 (C(13)), 127.4 (C(7)), 127.1 (C(18)), 126.2 (C(14)), 125.7 (C(5)), 121.3 (C(6)), 108.3 (C(7)), 55.7 (OCH₃), 50.8 (C(2)), 44.0 (C(1)), 25.1 (C(4)), 21.6 (C(3)); IR: (neat) 3052 (w), 3017 (w), 2926 (m), 2829 (w), 1583 (s), 1465 (s), 1434 (m), 1337 (w), 1254 (s), 1222 (w), 1091 (s), 1066 (m), 1021 (w), 955 (w), 817 (w), 768 (m), 737 (s), 699 (s); MS: (EI⁺, 70 eV) 346.0 (12.4), 346.0 (43.1), 238.0 (18.9), 237.1 (98.4), 236.0 (29.3), 179.0 (12.1), 178.0 (13.6), 165.0 (13.7), 159.0 (27.4), 145.0 (21.7), 144.0 (11.0); 129.0 (11.8), 121 (16.5), 115.0 (19.4), 109.0 (10.8), 91.0 (100.0), 65.1 (10.3); HRMS: calcd for C₂₃H₂₂OS⁺: 346.1391, found: 346.1384; TLC: *R*_f 0.38 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : [α]_D²⁵ –84.3 (c = 0.55, EtOH); SFC: (1*R*,2*R*)-**31**, *t*_R 12.3 min (90%); (1*S*,2*S*)-**31**, *t*_R 13.8 min (10%) (Chiralpak OD, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C). Data for **32** : mp: 77–79 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.41 (d, *J* = 7.5 Hz, 2 H, HC(16)), 7.32 – 7.19 (m, 6 H, HC(13) and HC(14) and HC(17) and HC(18)), 7.03 (d, *J* = 7.5 Hz, 1 H, HC(12)), 6.76 (d, *J* = 8.5 Hz, 1 H, HC(9)), 6.71 (d, *J* = 2.5 Hz, 1 H, HC(6)), 6.66 (dd, *J* = 8.5, 2.5 Hz, 1 H, HC(8)), 4.16 (d, *J* = 5.5 Hz, 1 H, HC(1)), 3.77 (s, 3 H, OCH₃), 3.67 (ddd, *J* = 8.5, 5.5, 3.0 Hz, 1 H, HC(2)), 3.05 (ddd, *J* = 16.5, 8.5, 5.5 Hz, 1 H, HC(4)), 2.86 (ddd, *J* = 17.0, 6.0, 6.0 Hz, 1 H, HC(4)), 2.21 – 2.15 (m, 1 H, HC(3)), 1.89 – 1.83 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 158.2 (C(7)), 145.9 (C(11)), 137.5 (C(10)), 135.2 (C(15)), 132.5 (C(16)), 132.1 (C(9)), 129.2 (C(5,12)), 129.1 (C(17)), 128.5 (C(13)), 127.2 (C(18)), 125.7 (C(14)), 113.1 (C(6)), 113.0 (C(8)), 55.4 (OCH₃), 51.8 (C(2)), 49.9 (C(1)), 27.3 (C(4)), 25.3 (C(3)); IR: (KBr) 3052 (m), 3017 (m), 2926 (s), 2829 (m), 1608 (s), 1583 (s), 1503 (s), 1451 (s), 1434 (s), 1323 (s), 1250 (s), 1236 (s), 1219 (s), 1153 (s), 1122 (s), 1108 (m), 1087 (m), 1035 (s), 928 (m), 893 (m), 858 (m), 820 (m), 792 (s), 696 (s); MS: (EI⁺, 70 eV) 246.3 (15.0), 243.5 (14.5), 237.2 (26.8), 231.12 (100.0), 191.2 (86.0), 175.2 (17.7), 159.1 (17.2), 149.1 (42.0), 145.1 (14.8), 135.1 (99.9), 129.1 (13.3), 121.0 (43.0), 115.1 (19.3), 111.1 (12.4), 107.1 (53.5), 105.1 (22.2), 95.1 (20.9), 91.1 (37.8), 81.1 (16.2), 77.1 (23.8), 69.1 (20.8), 67.1 (14.7), 65.1 (11.7), 57.1 (65.4), 55.1 (38.4); HRMS: calcd for C₂₃H₂₂OS⁺: 346.1391, found: 346.1383; TLC: *R*_f 0.32 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : [α]_D²⁵ –55.0 (c = 0.48,

EtOH); SFC: (1*R*,2*R*)-**32**, t_R 13.6 min (94%); (1*S*,2*S*)-**32**, t_R 16.1 min (6%) (Chiralpak OD, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₂₃H₂₂OS (346.14) Calcd: C, 79.73; H, 6.40%. Found: C, 80.01; H, 6.03%.

Preparation of (1*R*,2*R*)-7-Methoxy-1-phenyl-2-(phenylthio)-1,2,3,4-tetrahydronaphthalene (33**)—**

Following General Procedure 8, (*E*)-**12b** (238.3 mg, 1.0 mmol), **13** (256.0 mg, 1.0 mmol), (*S*)-**20a** (54.9 mg, 0.1 mmol) and CH₂Cl₂ (4.25 mL) were reacted with a solution of EtSO₃H in CH₂Cl₂ (1 M in CH₂Cl₂, 0.75 mL, 0.75 mmol) at 0 °C for 36 h. Purification by flash column chromatography (SiO₂, 26 g, 30 mm Ø, hexane/Et₂O, 96:4) to afforded **33** (298 mg, 86%) as a white solid. Recrystallization from hot pentane provided 294 mg (85%) of analytically pure **33**. Data for **33**: mp: 92–94 °C (pentane); ¹H NMR: (500 MHz, CDCl₃) 7.43 (dd, J = 8.0, 2.0 Hz, 2 H, HC(16)), 7.34 – 7.21 (m, 6 H, HC(13) and HC(14) and HC(17) and HC(18)), 7.11 (d, J = 8.5 Hz, 1 H, HC(6)), 7.05 (d, J = 6.5 Hz, 2 H, HC(12)), 6.78 (dt, J = 8.5, 2.5 Hz, 1 H, HC(7)), 6.39 (d, J = 2.0 Hz, 1 H, HC(9)), 4.18 (d, J = 5.0 Hz, 1 H, HC(1)), 3.68 (s, 3 H, OCH₃), 3.70 – 3.66 (m, 1 H, HC(2)), 3.06 – 3.00 (m, 1 H, HC(4)), 2.84 (ddd, J = 17.0, 6.0, 6.0 Hz, 1 H, HC(4)), 2.23 – 2.16 (m, 1 H, HC(3)), 1.90 – 1.86 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 158.0 (C(8)), 145.5 (C(11)), 138.0 (C(15)), 135.2 (C(5)), 132.5 (C(16)), 129.9 (C(6)), 129.2 (C(17)), 129.1 (C(12)), 128.6 (C(10)), 128.5 (C(13)), 127.2 (C(18)), 126.7 (C(14)), 115.5 (C(9)), 113.2 (C(7)), 55.4 (OCH₃), 51.6 (C(2)), 50.8 (C(1)), 26.1 (C(4)), 25.4 (C(3)); IR: (KBr) 3045(w), 3017 (w), 2926 (m), 2829 (w), 1608 (m), 1580 (m), 1500 (s), 1451 (m), 1434 (m), 1268 (s), 1250 (s), 1157 (s), 1111 (w), 1035 (m), 876 (w), 813 (m), 740 (s), 696 (s); MS: (EI⁺, 70 eV) 347.0 (14.2), 346.0 (55.5), 238.1 (13.1), 237.1 (78.2), 236.1 (93.2), 235.0 (10.6), 210.0 (11.1), 209.0 (18.1), 179.0 (16.7), 178.0 (15.7), 165.0 (15.3), 159.0 (24.9), 145.0 (28.8), 129.0 (10.2), 121.0 (16.7), 115.0 (15.4), 109.0 (9.3), 91.0 (100.0), 77.0 (9.0), 65.1 (9.7); HRMS: calcd for C₂₃H₂₂OS⁺: 346.1391, found: 346.1386; TLC: R_f 0.33 (hexanes/Et₂O, 96:4) [KMnO₄]; Opt Rot. : [α]_D²⁵ -29.3 (c = 0.53, EtOH); SFC: (1*R*,2*R*)-**33**, t_R 12.0 min (84%); (1*S*,2*S*)-**33**, t_R 15.7 min (16%) (Chiralpak OD, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₂₃H₂₂OS (346.14) Calcd: C, 79.73; H, 6.40%. Found: C, 79.66; H, 6.28%.

Preparation of ((5*R*,6*R*)-5-(4-Methylphenyl)-6-(phenylsulfonyl)-5,6,7,8-tetrahydronaphtho[2,3-*d'*]-1,3-dioxole (*trans*-34**)—**

To a solution of *trans*-**14d** (128.0 mg, 0.34 mmol) in CH₂Cl₂ (6 mL) was added *m*-CPBA (177 mg, 1.02 mmol) at room temperature. After being stirred for 2 h, the contents of the flask were poured in H₂O (30 mL). The aqueous phase was extracted with CH₂Cl₂ (3 × 10

mL). The combined organic layers were successively washed with sat. aq. Na₂SO₃ (10 mL), brine (40 mL) then dried over MgSO₄ and filtered through glass wool and then concentrated in vacuo (20 – 23 °C, 10 mmHg). Purification by flash column chromatography (SiO₂, 15 g, 25 mm Ø, hexane/Et₂O, 1:1) afforded *trans*-**34** (135 mg, 98%) as white solid. Recrystallization from pentane/CH₂Cl₂ (60:10) (v/v) (14 mL) provided 130 mg (94%) of analytically pure *trans*-**34**. Data for *trans*-**34**: mp: 138–140 °C (pentane/CH₂Cl₂); ¹H NMR: (500 MHz, CDCl₃) 7.82 (d, *J* = 7.5 Hz, 2 H, HC(17)), 7.62 (t, *J* = 7.5 Hz, 1 H, HC(19)), 7.49 (t, *J* = 8.0, 2 H, HC(18)), 6.98 (d, *J* = 8.0 Hz, 2 H, HC(13)), 6.77 (d, *J* = 8.0 Hz, 2 H, HC(12)), 6.58 (s, 1 H, HC(6)), 6.31 (s, 1 H, HC(9)), 5.87 (d, *J* = 2.5 Hz, 2 H, OCH₂O), 4.54 (d, *J* = 4.5 Hz, 1 H, HC(1)), 3.57 – 3.54 (m, 1 H, HC(2)), 3.03 (ddd, *J* = 16.0, 8.0, 5.5, 1 H, HC(4)), 2.81 (ddd, *J* = 17.0, 6.0, 6.0 Hz, 1 H, HC(4)), 2.28 (s, 3 H, HC(14)), 2.29 – 2.23 (m, 1 H, HC(3)), 2.19 – 2.12 (m, 1 H, HC(3)); ¹³C NMR: (125 MHz, CDCl₃) 146.4 (C(7,8)), 141.6 (C(11)), 138.7 (C(16)), 136.5 (C(14)), 133.5 (C(19)), 129.4 (C(13)), 129.1 (C(10,18)), 128.9 (C(5)), 128.7 (C(17)), 128.5 (C(12)), 109.8 (C(9)), 108.0 (C(6)), 100.9 (OCH₂O), 67.1 (C(2)), 43.6 (C(1)), 26.7 (C(4)), 21.1 (C(15)), 20.5 (C(3)); IR: (KBr) 3445 (bm), 2968 (m), 2912 (m), 2878 (m), 1698 (s), 1573 (w), 1503 (m), 1483 (s), 1444 (m), 1302 (s), 1261 (s), 1240 (s), 1143 (s), 1084 (m), 1035 (m), 938 (w), 848 (w), 810 (w), 747 (s). MS: (EI⁺, 70 eV) 325.5 (21.7), 265.1 (21.1), 264.1 (1000), 231.1 (37.6), 191.1 (60.5), 158.0 (21.0), 156.0 (63.3), 141.0 (21.6), 139.0 (64.1), 135.1 (37.3), 115.0 (19.7), 11.0 (35.6), 107.0 (24.4), 105.1 (30.6); HRMS: calcd C₂₄H₂₃O₄S⁺: 407.1317, found: 407.1316; TLC: *R*_f 0.37 (hexanes/Et₂O, 50:50) [KMnO₄]; Opt Rot.: [α]_D²⁵ –30.3 (*c* = 0.52, EtOH); SFC: (1*R*,2*R*)-**34**, *t*_R 14.0 min (92%); (1*S*,2*S*)-**34**, *t*_R 17.7 min (8%) (Chiralpak OJ, 5% MeOH in CO₂, 2.0 mL/min, 220 nm, 40 °C); Analysis: C₂₄H₂₂O₄S (406.12) Calcd: C, 70.91; H, 5.46%. Found: C, 70.85; H, 5.38%.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Mr. W.-T. Timothy Chang, and Mr. Larry M. Wolf are thanked for providing helpful preparative and computational advice. Mr. David J.-P. Kornfilt is thanked for providing the X-ray crystal structure of (5*S*)-**17a** and Mr. Hyung-Min Chi is thanked for additional technical assistance. We are grateful to the National Institutes of Health for generous financial support (R01 GM85235).

References

- (1). de la Mare, PBD.; Bolton, R. Electrophilic Additions to Unsaturated Systems. 2nd Ed.. de la Mare, PBD.; Bolton, R., editors. Vol. Vol. 9. Elsevier; Amsterdam: 1982. p. 198-246.
- (2). (a) Schmid GH. Supplement A: The chemistry of double-bonded functional groups (Part 1). 1989; Volume 2:679–731.(b) Schmid, GH.; Garratt, DG. The chemistry of double-bonded functional groups Part 2. John Wiley & Sons; London: 1977. p. 725-912.(c) Lucchini V, Modena G, Pasquato L. Gazz. Chim. Ital. 1997; 127(4):177–188.(d) Rayner, CM. Organosulfur Chemistry: Synthetic Aspects. Page, P., editor. Academic Press; London: 1995. p. 89-131.(e) Modena G, Pasquato L, Lucchini V. Phosphorus, Sulfur Silicon Relat. Elem. 1994; 95–6(1–4):265–282.(f) Capozzi, G.; Modena, G.; Pasquato, L. The Chemistry of Sulphenic Acids and Their Derivatives. Patai, S., editor. John Wiley & Sons Ltd; West Sussex: 1990. p. 403-516.(g) Harring SR, Edstrom ED, Livinghouse T. Adv. Heterocyclic Nat. Prod. Synth. 1992; 2:299–376.(h) Capozzi, G.; Modena, G. Organic Sulfur Chemistry: Theoretical and Experimental Advances. Bernardi, F.; Csizmadia, IG.; Mangini, A., editors. Vol. Vol. 19. Elsevier; Amsterdam: 1985. p. 246-298.(i) Mueller WH. Angew. Chem. Int. Ed. 1969; 8:482–492.
- (3). (a) Drabowicz, J.; Lyzwa, P.; Mikolajczyk, M. The Chemistry of Sulphenic Acids and Their Derivatives. Patai, S., editor. John Wiley & Sons Ltd; West Sussex: 1990. p. 187-220.(b)

Drabowicz, J.; Kielbasinski, P.; Mikolajczyk, M. The Chemistry of Sulphenic Acids and Their Derivatives. Patai, S., editor. John Wiley & Sons Ltd; West Sussex: 1990. p. 221-292.

- (4). Hogg, DR. The Chemistry of Sulphenic Acids and Their Derivatives. Patai, S., editor. John Wiley & Sons Ltd; West Sussex: 1990. p. 361-402.
- (5). Fox DJ, House D, Warren S. *Angew. Chem., Int. Ed.* 2002; 41:2462–2482.
- (6). Coldham I, Warren S. J. *Chem. Soc. Perkin Trans.* 1993; 1:1637.
- (7). (a) Moore JT, Soldi C, Fettinger JC, Shaw JT. *Chem. Sci.* 2013:292–296. [PubMed: 23565327] (b) Edstrom ED, Livinghouse T. *J. Org. Chem.* 1987; 52:949–951. (c) Masaki Y, Hashimoto K, Sakuma K, Kaji K. *Tetrahedron Lett.* 1982:1481–1484.
- (8). Edstrom ED, Livinghouse T. *J. Am. Chem. Soc.* 1986; 108:1344–1346.
- (9). (a) T. Toshimitsu A, Hirose C, Tamao K. *Synlett.* 1996:465–467. (b) Toshimitsu A, Abe H, Hirose C, Tamao K. *J. Chem. Soc., Perkin Trans.* 1994; 1:3465–3471. (c) Toshimitsu A, Hirose C, Tamao K. *Tetrahedron.* 1994; 50:8997–9008. (d) Toshimitsu A, Hirose C, Tanimoto S. *Chem. Lett.* 1992:239–242. (e) Toshimitsu A, Abe H, Hirose C, Tanimoto S. *J. Chem. Soc., Chem. Commun.* 1992:284–285. (f) Toshimitsu A, Hirose C, Tanimoto S. *Tetrahedron Lett.* 1991; 32:4317–4320.
- (10). Branchaud BP, Blanchette HS. *Tetrahedron Lett.* 2002; 43:351–353.
- (11). (a) Archer NJ, Rayner CM, Bell D, Miller D. *Synlett.* 1994:617–619. (b) Pasquato L, Modena G. *Chem. Commun.* 1999:1469–1470.
- (12). Denmark SE, Beutner GL. *Angew. Chem., Int. Ed.* 2008; 47:1560–1638.
- (13). (a) Denmark SE, Kalyani D, Collins WR. *J. Am. Chem. Soc.* 2010; 132:15752–15765. [PubMed: 20961070] (b) Denmark SE, Collins WR. *Org. Lett.* 2007; 9:3801–3804. [PubMed: 17705396]
- (14). Denmark SE, Kornfilt DJP, Vogler T. *J. Am. Chem. Soc.* 2011; 133:15308–15311. [PubMed: 21859086]
- (15). (a) Denmark SE, Collins WR, Cullen MD. *J. Am. Chem. Soc.* 2009; 131:3490–3491. [PubMed: 19227982] (b) Denmark SE, Vogler T. *Chem. Eur. J.* 2009; 15:11737–11745. [PubMed: 19760721]
- (16). Enantioselective sulfenylation of activated alkenes derived from aldehydes, ketones and amides has also been reported recently. Aldehydes: Zhao GL, Rios R, Vesely J, Eriksson L, Córdova A. *Angew. Chem., Int. Ed.* 2008; 47:8468–8472. Marigo M, Wabnitz TC, Fielenbach D, Jorgensen KA. *Angew. Chem., Int. Ed.* 2005; 44:794–797. Ketones: Lin A, Fang L, Zhu X, Zhu C, Cheng Y. *Adv. Synth. Catal.* 2011; 353:545. Polaske NW, Dukey R, Nichol GS, Olenyuk B. *Tetrahedron: Asymmetry.* 2009; 20:2742. [PubMed: 20161615] . Fang L, Lin A, Hu H, Zhu C. *Chem. Eur. J.* 2009; 15:7039. [PubMed: 19533696] . Sobhani S, Fielenbach D, Marigo M, Wabnitz TC, Jorgensen KJ. *Chem. Eur. J.* 2005; 11:5689. [PubMed: 16035005] . Indolones: Han Z, Chen W, Dong S, Yang C, Liu H, Pan Y, Yan L, Jiang Z. *Org. Lett.* 2012; 14:4670–4673. [PubMed: 22920600] . Li X, Liu C, Xue X-S, Cheng J-P. *Org. Lett.* 2012; 14:4374–4377. [PubMed: 22901058] . Wang C, Yang X, Loh CCJ, Raabe G, Enders D. *Chem. Eur. J.* 2012; 18:11531–11535. [PubMed: 22836361] . Cai Y, Li J, Chen W, Xie M, Liu X, Lin L, Feng X. *Org. Lett.* 2012; 14:2726–2729. [PubMed: 22587589]
- (17). For a recent report of catalytic, enantioselective oxysulfenylation of unactivated alkenes under chiral Brønsted acid catalysis see: Guan H, Wang H, Huang D, Shi Y. *Tetrahedron.* 2012; 68:2728–2735.
- (18). For a recent report of catalytic desymmetrization of meso thiiranium ions see: Jacobsen, Lin S, E. N. *Nature: Chemistry.* 2012; 4:817–824.
- (19). For a preliminary communication of these studies see: Denmark SE, Jaunet A. *J. Am. Chem. Soc.* 2013; 135:6914–6922.
- (20). The methylenedioxy substituent is less donating than a single 4-methoxy group and roughly equivalent to 3,4-dimethoxy substituents. McDaniel DH, Brown HC. *J. Org. Chem.* 1968; 23:420–427. Hammett LP. *Physical Organic Chemistry.* 1940:188. McGraw-Hill New York
- (21). (a) Schlosser M, Christmann KF. *Liebigs Ann Chim.* 1967; 708:1–35. (b) Schlosser M, Christmann KF. *Angew. Chem., Int. Ed.* 1966; 5:126.
- (22). Schobert R, Siegfried S, Gordon GJ. *J. Chem. Soc., Perkin Trans.* 2001; 1:2393–2397.

- (23). The *E/Z* ratio varied from 96/4 to 64/36. The SFC analysis of the cyclized products was also complicated by overlap of the *trans* and *cis* diastereomers. The yield obtained for *i*-Bu and phenyl were 38% (>99:1 *E/Z*) and 42% (>99:1), respectively.
- (24). (a) Buss AD, Warren S. J. Chem. Soc., Perkin Trans. 1985; 1:2307–2325. (b) Buss AD, Cruse WB, Kennard O, Warren S. J. Chem. Soc., Perkin Trans. 1984; 1:243–247.
- (25). Brown TH, Blakemore RC, Durant GJ, Emmet JC, Ganellin CR, Parsons ME, Rawlings DA, Walker TF. Eur. J. Med. Chem. 1988; 23:53–62.
- (26). (a) Bartoli G, Bosco M, Dalpozzo R, Marcantoni E, Sambri L. Chem. Eur. J. 1997; 3:1941–1950. (b) Bartoli G, Bosco M, Sambri L, Marcantoni E. Tetrahedron Lett. 1996; 37:7421–7424.
- (27). Johnson CR, Braun MP. J. Am. Chem. Soc. 1993; 115:11014–11015.
- (28). Kim G, Jung S-D, Kim W-J. Org. Lett. 2001; 3:2985–2987. [PubMed: 11554824]
- (29). Netherton MR, Dai C, Neuschütz K, Fu GC. J. Am. Chem. Soc. 2001; 123:10099–10100. [PubMed: 11592890]
- (30). For Suzuki-Miyaura cross-coupling reaction between vinylboronic acids and vinyl halides with TIOH see: Roush WR, Sciotti RJ. J. Am. Chem. Soc. 1998; 120:7411–7419. Roush WR, Brown BB. J. Am. Chem. Soc. 1993; 115:2268–2278. Uenishi J-I, Beau J-M, Armstrong RW, Kishi Y. J. Am. Chem. Soc. 1987; 109:4756–4758.
- (31). For Suzuki-Miyaura cross-coupling reaction between vinylboronic acids and vinyl halides with TIOEt see: Frank SA, Chen H, Kunz RK, Schnaderbeck MJ, Roush WR. Org. Lett. 2000; 2:2691–2694. [PubMed: 10990429]. Humphrey JM, Aggen JB, Chamberlain AR. J. Am. Chem. Soc. 1996; 118:11759–11770.
- (32). (a) Chemler SR, Danishefsky SJ. Org. Lett. 2000; 2:2695–2698. [PubMed: 10990430] (b) Roush WR, Moriarty KJ, Brown BB. Tetrahedron Lett. 1990; 45:6509–6512. (c) Sato M, Miyaura N, Suzuki A. Chem. Lett. 1989:1405–1408.
- (33). MeSO₃H, pK_a (water) –1.91; EtSO₃H, pK_a (water) –1.68. Tully PS. Kroschwitz. Sulfonic Acids. Kirk-Othmer Encyclopedia of Chemical Technology (4th Ed.). 1997; Vol. 23:194–21. Wiley New York
- (34). The reactions were run at room temperature in presence of tetrahydrothiophene (1.0 eq), MsOH (1.0 equiv), **13** (1.0 equiv) and (*E*)-1-(3',4'-methylenedioxyphenyl)-5,5-dimethylhex-3-ene for 24 h. ¹H NMR spectroscopic analysis of the reaction mixture did not show the characteristic proton in α-position of the thiophenyl group, around 3.40 – 3.80 ppm.
- (35). The reactions were run at room temperature in presence of tetrahydrothiophene (1.0 equiv), MsOH (1.0 equiv), **13** (1.0 equiv) and (*E*)-1-(4'-Methoxyphenyl)non-3-ene for 24h. ¹H NMR spectroscopic analysis of the reaction mixture did not show the characteristic proton in α-position of the thiophenyl group, around 3.40 – 3.80 ppm.
- (36). The crystallographic coordinates of *trans*-**34** have been deposited with the Cambridge Crystallographic Data Centre; deposition no. 913987. These data can be obtained free of charge via from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: (+44) 1223-336-033; via www.ccdc.cam.ac.uk/conts/retrieving.html or deposit@ccdc.cam.ac.uk.
- (37). Miyaura N, Ishiyama M, Suzuki A. Tetrahedron Lett. 1986; 27:6369–6372.
- (38). (a) Suzuki A, Yamamoto Y. Chem. Lett. 2011; 40:894–901. (b) Doucet H. Eur. J. Org. Chem. 2008:2013–2030. (c) Miyaura N. Top. Curr. Chem. 2002; 219:11–59. (d) Chemler SR, Trauner D, Danishefsky SJ. Angew. Chem. Int. Ed. 2001; 40:4544–4568.
- (39). The complete hydroboration of alkene **8** was observed by ¹H NMR spectroscopic analysis of the reaction mixture.
- (40). Markó IE, Murphy F, Dolan S. Tetrahedron Lett. 1996; 37:2507–2510.
- (41). Reaction of (*Z*)-**2a** under standard conditions at –20 °C for 6 days provided 60% conversion.
- (42). The crystallographic coordinates of (*S*)-**17a** have been deposited with the Cambridge Crystallographic Data Centre; Deposition No. 917496. These data can be obtained free of charge via the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, U.K.; fax: (+44) 1223-336-033; via www.ccdc.cam.ac.uk/conts/retrieving.html or deposit@ccdc.cam.ac.uk
- (43). Willey GR, Barras JR, Rud MD, Drew MGB. J. Chem. Soc. Dalton Trans. 1994:3025–3029.

- (44). For a discussion of the phenylsulfonium ion transfer between alkenes see: Solling TI, Radom L. Chem. Eur. J. 2001; 7:1516–1524. [PubMed: 11330907] . Solling TI, Wild SB, Radom L. Chem. Eur. J. 2000; 6:590–591.. Modena G, Pasquato L, Lucchini V. Chem. Eur. J. 2000; 6:589–590. [PubMed: 10807169] . Fachini M, Lucchini V, Modena G, Pasi M, Pasquato L. J. Am. Chem. Soc. 1999; 121:3944–3950.. Solling YI, Wild SB, Radom L. Chem. Eur. J. 1999; 5:509–514.
- (45). (a) Houk KN, Liu J, Demello NC, Condroski KD. J. Am. Chem. Soc. 1997; 119:10147–10152. (b) Bach RD, Andres JL, Owensby AL, Schlegel HB, McDouall RD. J. Am. Chem. Soc. 1992; 114:7207–7217.
- (46). According the Cahn-Ingold-Prelog priority rules, at C(a) the priority order is going down from the double bond to R¹ and the hydrogen. At C(b), the priority is going down from the double bond to R² and the hydrogen.
- (47). Only starting material was recovered when the cyclization was run at –20 °C for 24 h.
- (48). Nucleophilic attack on carbon C(1) of the thiiranium ion by the chlorine atom would lead to intermediate **viii** with inversion of configuration. Nucleophilic capture of the chloronium ion by the veratryl group with inversion of configuration would afford *cis*-**14o** which was not observed. For chlorine assisted opening of epoxides see: Petersen PE, Indelicato JM, Bonazza BR. Tetrahedron Lett. 1971; 12:13–16..

- (49). Fu X, He W, Lei Q, Luo B. Synth. Commun. 1991; 21:1273–1279.
- (50). Hansch C, Leo A, Taft RW. Chem. Rev. 1991; 91:165–195.
- (51). (a) Chou DTH, Huang X, Batchelor RJ, Einstein FWB, Bennet A. J. Org. Chem. 1998; 63:575–581. [PubMed: 11672047] (b) Essig MG, Stevenson TT, Shefizageh F. J. Org. Chem. 1984; 49:3652–3656. (c) Warnhoff EW. Chem. Comm. 1976:571–518. (d) Gwynn D, Skillern L. Chem. Comm. 1968:490–491.
- (52). Vr ek IV, Vre k V, Siehl H-U. J. Phys. Chem. A. 2002; 106:1604–1611.
- (53). (a) Goncalves S, Nicolas M, Maillos P, Baati R. Tetrahedron. 2011; 67:8373–8382. (b) Nagumo S, Miura T, Mizukami M, Miyoshi I, Imai M, Kawahara N, Akita H. Tetrahedron. 2009; 65:9884–9896. (c) Sperry JB, Wright DL. Tetrahedron Lett. 2005; 46:411–414. (d) Youn SW, Pastine SJ, Sames D. Org. Lett. 2004; 6:581–584. [PubMed: 14961628] (e) Tedesco R, Youngman MK, Wilson SC, Katzenellenbogen JA. Bioorg. Med. Chem. Lett. 2001; 11:1281–1284. [PubMed: 11392537] (f) Elings JA, Downing RS, Sheldon RA. Eur. J. Org. Chem. 1999:837–846. (g) Taylor SK, Dickinson MG, May SA, Pickering DA, Sadek PC. Synthesis. 1998:1133–1136. (h) Parlow JJ. Tetrahedron. 1994; 50:3297–3314. (i) Rao GSRS, Devi LU, Sheriff UJ. J. Chem. Soc. Perkin Trans. 1991; 1:964–965. (j) Ghosh S, Banik BK, Ghatak UR. J. Chem. Soc. Perkin Trans. 1991; 1:3189–3193. (k) Banik BK, Ghosh S, Ghatak UR. Tetrahedron. 1988; 44:6947–6955. (l) Amupitan JA, Huq E, Mellor M, Scovell EG, Sutherland JK. J. Chem. Soc. Perkin Trans. 1983; 1:751–753. (m) Murphy WS, Wattanasin S. J. Chem. Soc. Perkin Trans. 1980; 1:1567–1577. (n) Johnson WS, Banerjee DK, Schneider WP, Gutsche D, Shelberg WE, Chinn L. J. Am. Chem. Soc. 1952; 74:2832–2849.
- (54). (a) Goncalves S, Santoro S, Nicolas M, Wagner A, Maillos P, Himo F, Baati R. J. Org. Chem. 2011; 76:3274–3285. [PubMed: 21446693] (b) Nicolaou KC, Reingruber R, Sarlah D, Bräse S. J. Am. Chem. Soc. 2009; 131:2086–2087. [PubMed: 19173649] (c) Bailey PD, Morgan KM, Smith

DI, Vernon JM. Tetrahedron. 2003; 59:3369–3378.(d) Appelbe Z, Casey M, Keaveney CM, Kelly CJ. Synlett. 2002:1404–1408.(e) Itoh T, Chika J-I, Takagi Y, Nishiyama S. J. Org. Chem. 1993; 58:5717–5723.(f) Hanessian S, Léger R. Synlett. 1992:402–404.(g) Pelter A, Ward RS, Pritchard MC. J. Chem. Soc., Perkin Trans. 1988; 1:1615–1623.(h) Beugelmans R, Chastanet J, Ginsburg H, Quintero-Cortes L, Roussi G. J. Org. Chem. 1985; 50:4933–4938.(i) Murphy WS, Wattanasin S. J. Chem. Soc., Perkin Trans. 1982; 1:271–276.(j) Schwartz MA, Rose BF, Vishnuvajjala B. J. Am. Chem. Soc. 1973; 95:612–613.(k) Orcutt RM, Bogert MT. J. Am. Chem. Soc. 1936; 58:2055–2056.

- (55). Takeda N, Imamoto T. Org. Synth. 1999; 76:228–233.
- (56). **Note:** The thallium salts and arsenic-based compounds in this procedure are *extremely* toxic and, as such, special attention should be paid to the safe handling and disposal of these materials. Throughout the described procedure, detailed guidelines are included at each stage regarding the cleaning of thallium/arsenic-contaminated apparatus and the disposal of thallium/arsenic-contaminated residues. Prior to starting this procedure it is recommended to have in place the following items: one large, sealable plastic tub (for disposal of contaminated gloves, tissues, disposable syringes, MgSO_4 etc.), one pair of neoprene gloves to wear over normal laboratory gloves as a precautionary measure during the work up, conc. H_2SO_4 (a squeeze bottle of conc. H_2SO_4 is most convenient), household bleach, and three glass bottles for collecting aqueous (4 L bottle), conc. H_2SO_4 (1 L bottle), and bleach (4 L bottle) waste streams respectively. (a) The stirrer bar was removed from the 20-mL flask containing the alkylborane and TIOEt and was submerged overnight in conc. H_2SO_4 in a 20 mL scintillation vial to dissolve any thallium residues – it was then rinsed with H_2O (into the aqueous waste bottle) and the contaminated H_2SO_4 was transferred to the H_2SO_4 waste bottle, with the 20 mL scintillation vial disposed of in the sealed plastic tub. The brown glass bottle, septum, and plastic syringe were also transferred to the sealed plastic tub to eventually dispose of as thallium-contaminated debris, and the cannula was rinsed through sequentially with conc. H_2SO_4 (into the waste H_2SO_4 glass bottle), H_2O (into the aqueous waste glass bottle), then acetone. (b) In subsequent, large scale runs, this extraction was complicated by much insoluble material. Instead, the dark green suspension was filtered under house vacuum into a 1-L, round-bottomed flask through a pad of Celite (5 g) in a 4 cm diameter, 40 mL, medium porosity sintered funnel to remove the green residue, resulting in a clear, orange filtrate. The Celite pad was then rinsed through with Et_2O (2×20 mL). The reaction flask was set aside in the fumehood for later cleaning, and the green residue and Celite were transferred to the plastic tub for disposal, thus freeing up the sintered funnel for re-use later in the work up. (c) Occasionally, a yellow solid formed from the treatment with brine (possibly thallium chloride salts) that were removed by filtration through glass wool as indicated. This solid was dissolved in conc. H_2SO_4 and transferred to the designated H_2SO_4 waste bottle, followed by a sequential H_2O and acetone rinse into the designated aqueous waste bottle; the flask could then be re-used later in the work up. The yellow residue and Celite were transferred to the plastic tub for disposal, thus freeing up the sintered funnel for one final use. The stirrer bar was cleaned as described for the previous stirrer bar. The separatory funnel was rinsed sequentially with conc. H_2SO_4 (into the waste H_2SO_4 glass bottle) and H_2O (into the aqueous waste glass bottle), then filled with bleach and left to stand overnight – the bleach was then transferred to the designated bleach waste bottle. (d) The silica gel used for the column was collected in a double-skinned ziplock, plastic bag and disposed of as thallium and arsenic-contaminated silica gel waste.
- (57). The CSP-SFC analysis was performed on the diamine (*S*)-**53** because the racemic catalyst **20a** was not available. The enantiomeric purity of the catalyst is assumed to be no lower than that of the diamine.
- (58). Orcutt RM, Bogert MT. J. Am. Chem. Soc. 1936; 58:2055–2056.

Scheme 1.

Scheme 2.

Scheme 3.

Scheme 4.

Scheme 5.

Scheme 6.

Scheme 7.

Scheme 8.

Scheme 9.

Scheme 10.

Scheme 11.

Figure 1.
Products of unexpected side reactions.

Figure 2.
Configurations of *trans*-**2a** and *cis*-**2a**.

Figure 3.
Proposed catalytic cycle for sulfenofunctionalization.

Figure 4.

X-ray crystallographic structure of (*S*)-**17a** and proposed models for the geometry of the catalytically active species *i*.

Figure 5.
The spiro and planar transition states for the thiiranium ion formation.

Figure 6.
Proposed rationale for the unselective formation of thiiranium ions from Z-alkenes.

Figure 7.
Proposed rationale for the selective formation of thiiranium ions from *E*-alkenes.

Figure 8.
Proposed rationale for thiiranium ion formation from branched *E*-alkenes.

Figure 9. Electrostatic charge (natural charge values) and local energies of HOMO orbitals for models **36** and **37**.

Table 1

Wittig-Schlosser Olefination.

entry	R ¹	product	R ²	<i>E/Z</i> ^a	yield, % ^b
1	Et	2a	Me	96:4	60
2	PhCH ₂	2b	Ph	>99:1	42

^a *E/Z* selectivity was determined by ¹H NMR spectroscopic analysis of the purified product.

^b yield of isolated, purified products.

Table 2

Optimization of Suzuki Cross-Coupling Reaction.

entry	Pd source (mol %)	ligand (mol %)	base (equiv)	H ₂ O, equiv	solvent	time, h	Temp, °C	8	ratio, % ^a	9	2b
1	PdCl ₂ (dppf) (5)	Ph ₃ As (10)	Cs ₂ CO ₃ (2.0)	15.0	DMF/THF	15	22	25	25	-	50
2	PdCl ₂ (dppf) (5)	Ph ₃ As (10)	Cs ₂ CO ₃ (2.0)	15.0	DMF/THF	24	22	35	-	-	65 ^b
3	PdCl ₂ (dppf) (5)	Ph ₃ As (10)	Cs ₂ CO ₃ (2.0)	10.0	DMF/THF	24	22	88	-	-	12
4	PdCl ₂ (dppf) (15)	Ph ₃ As (30)	Cs ₂ CO ₃ (2.0)	10.0	DMF/THF	24	22	30	-	-	70
5	PdCl ₂ (dppf) (5)	-	Cs ₂ CO ₃ 2.0	15.0	DMF/THF	24	22	55	-	-	45
6	PdCl ₂ (dppf) (5)	Ph ₃ As (10)	Cs ₂ CO ₃ (2.0)	-	DMF/THF	24	22	-	100	-	-
7	PdCl ₂ (dppf) (3)	-	NaOMe 2.0	-	THF	12	66	-	100	-	-
8	PdCl ₂ (dppf) (50)	-	CsF (4.0)	49.0	CH ₃ CN	24	82	-	100	-	-
9	Pd(OAc) ₂ (4)	Cy ₃ P (8)	K ₃ PO ₄ (2.0)	0.8	THF	12	22	50	50	-	-

^a ratio determined by ¹H NMR spectroscopic analysis.^b (E)-2b was isolated in 43% yield.

Table 3

The Effect of Thallium Ethoxide in the Suzuki-Miyaura Cross-Coupling of **9**.^a

entry	Pd source (mol %)	AsPh ₃ , mol %	TlOEt, equiv	H ₂ O, equiv	(E)-2n, yield, % ^b
1	PdCl ₂ (dppf) (5)	10	— ^c	15	20 ^d
2	PdCl ₂ (dppf) (20)	20	3.0	5.0	71
3	PdCl ₂ (dppf) (10)	20	3.0	5.0	70
4	PdCl ₂ (dppf) (5)	20	3.0	5.0	58
5	PdCl ₂ (dppf) (10)	20	2.0	5.0	70
6	PdCl ₂ (dppf) (10)	20	1.5	5.0	66
7	Pd(PPh ₃) ₄ (10)	-	2.0	825.0	20

^a Reaction carried out in THF at 22 °C for 12 h.^b Yield of isolated, purified product.^c Cs₂CO₃ (2.0 equiv) was used instead of TlOH.^d Starting alkene **8a** was recovered (37%).

Table 4

Substrate Scope of the B-Alkyl Suzuki-Miyaura Cross-Coupling Reaction.^a

entry	conditions	R ¹	R ²	R ³	R ⁴	iodide	product	yield, % ^b
1	A	-OCH ₂ O-		C ₆ H ₅	H	10b	(<i>E</i>)- 2b	71
2	A	-OCH ₂ O-		4-CH ₃ C ₆ H ₄	H	10d	(<i>E</i>)- 2d	60
3	B	-OCH ₂ O-		4-NC-C ₆ H ₄	H	10e	(<i>E</i>)- 2e	61
4	A	-OCH ₂ O-		4-CH ₃ OC ₆ H ₄	H	10f	(<i>E</i>)- 2f	61
5	A	-OCH ₂ O-		2-naphthyl	H	10g	(<i>E</i>)- 2g	70
6	B	-OCH ₂ O-		4-CF ₃ C ₆ H ₄	H	10h	(<i>E</i>)- 2h	64
7	A	-OCH ₂ O-		2-CH ₃ C ₆ H ₄	H	10i	(<i>E</i>)- 2i	47
8	B	-OCH ₂ O-		C ₆ H ₅	CH ₃	10j	(<i>E</i>)- 2j	80
9	A	-OCH ₂ O-		cyclopropyl	H	10k	(<i>E</i>)- 2k	82
10	A	-OCH ₂ O-		cyclopentyl	H	10l	(<i>E</i>)- 2l	62
11	A	-OCH ₂ O-		cyclohexyl	H	10m	(<i>E</i>)- 2m	56
12	A	-OCH ₂ O-		<i>n</i> -C ₅ H ₁₁	H	10n	(<i>E</i>)- 2n	70
13	A	-OCH ₂ O-		Cl(CH ₂) ₃	H	10o	(<i>E</i>)- 2o	73
14	A	-OCH ₂ O-		(CH ₃) ₂ CHCH ₂	H	10p	(<i>E</i>)- 2p	69
15	A	CH ₃ O	H	C ₆ H ₅	H	10b	(<i>E</i>)- 11b	68
16	A	CH ₃ O	H	<i>n</i> -C ₅ H ₁₁	H	10n	(<i>E</i>)- 11n	75
17	B	H	CH ₃ O	C ₆ H ₅	H	10b	(<i>E</i>)- 12b	54
18	B	H	CH ₃ O	<i>n</i> -C ₅ H ₁₁	H	10n	(<i>E</i>)- 12b	70

^a Conditions A: PdCl₂(dppf) (10 mol %), AsPh₃ (20 mol %), TIOEt (2.0 equiv), H₂O (5.0 equiv), THF, 22 °C, 12 h. Conditions B: PdCl₂(dppf) (5 mol %), AsPh₃ (10 mol %), Cs₂CO₃ (2.0 equiv) H₂O (15.0 equiv), THF/DMF, 22 °C, 24 h.

^b Yield of analytically pure products.

Table 5

Survey of Chiral Lewis Bases to Sulfenocarbocyclization of **2a**.^a

Entry	<i>E/Z</i> ^b	cat	mol %	Y	X	<i>trans/cis</i> ^c	er, ^d <i>trans</i>	er, ^d <i>cis</i>
1	62:38	(<i>R</i>)- 15a	10	Se		62:38	19:81	49:51
2	96:4	(<i>R</i>)- 15b	10	S		96:4	44:56	36:64
3	62:38	(<i>R</i>)- 16a	10	Se		62:38	33:67	44:56
4	96:4	(<i>R</i>)- 16b	10	S		96:4	49:51	40:60
5	96:4	(<i>R</i>)- 17a	10	Se		96:4	11:89	49:51

Entry	<i>E/Z</i> ^b	cat	mol %	Y	X	<i>trans/cis</i> ^c	er, ^d <i>trans</i>	er, ^d <i>cis</i>
6	94:6	(<i>S</i>)- 18a	10	Se		94:6	86:14	60:40
7	94:6	(<i>S</i>)- 19a	10	Se	N(<i>i</i> -Pr) ₂	94:6	82:18	53:47
8	96:4	(<i>R</i>)- 19b	10	S	N(<i>i</i> -Pr) ₂	96:4	24:76	40:60
9	96:4	(<i>S</i>)- 20a	10	Se	N(<i>i</i> -Bu) ₂	96:4	95:5	52:48
10	95:5	(<i>S</i>)- 21a	10	Se	N(<i>i</i> -amyl) ₂	95:5	88:12	64:36
11	62:38	(<i>R</i>)- 22a	10	Se	N(Et) ₂	62:38	15:85	47:53
12	95:5	(<i>S</i>)- 23a	10	Se	N(<i>n</i> -Bu) ₂	95:5	92:8	66:34
13	96:4	(<i>S</i>)- 24a	10	Se	N(<i>n</i> -Bu)Et	96:4	94:6	58:42
14	62:38	(<i>R</i>)- 25a	10	Se	N(Me)Ph	62:38	31:69	52:48
15	100:0	(<i>S</i>)- 20a	5	Se	N(<i>i</i> -Bu) ₂	100:0	86:14	-
16	100:0	(<i>S</i>)- 20a	7.5	Se	N(<i>i</i> -Bu) ₂	100:0	94:6	-
17	100:0	(<i>S</i>)- 20a	15	Se	N(<i>i</i> -Bu) ₂	100:0	95:5	-

^aReaction conditions: **2a** (0.12 mmol), **13** (0.12 mmol), MsOH (0.12 mmol), CH₂Cl₂ (0.2 M), −20 °C. All reactions were completed in 24 h.

^b*E/Z* ratio of the starting material was determined by ¹H NMR spectroscopic analysis.

^cthe *E/Z* ratio and *trans/cis* ratio of the cyclization products was determined by ¹H NMR spectroscopic analysis.

^dthe enantiomeric ratio was determined by CSP-SFC analysis.

Table 6

Initial Survey of Reaction Scope.^a

entry	aryl	substrate	er ^b on 0.1mmol scale	er ^b on 1.0 mmol scale
1	C ₆ H ₅	2b	92:8	87:13
2	4-CH ₃ C ₆ H ₄	2d	93:7	89:11
3	4-CH ₃ OC ₆ H ₄	2f	89:11	87:13

^a All reactions were complete within 24 h. Conversion was determined by ¹H NMR spectroscopic analysis.

^b The enantiomeric ratio was determined by CSP-SFC analysis.

Table 7

Effect of Catalyst Loading on the Enantioselectivity.^a

entry	EtSO_3H , equiv	<i>(S)</i> - 20a , equiv	conv, % ^b	er ^c
1	0.75	0.10	82	93:7
2	0.75	0.05	60	88:12
3	0.75	0.02	36	83:17
4	0.5	0.10	80	93:7

^a Reaction conditions: *(E)*-**2d** (0.5 mmol), **13** (0.5 mmol), CH_2Cl_2 (0.2 M) at -20°C .^b Conversion was determined by ^1H NMR spectroscopic analysis of the crude product.^c The enantiomeric ratio was determined by CSP-SFC analysis.

Table 8

Cychzation with Alkyl-substituted Alkenes.

entry	substrate	R ₁	R ₂	product	time, d	temp, °C	yield, % ^a	er ^{b,c}
1	(<i>E</i>)- 2a	H	CH ₃	<i>trans</i> - 14a	3	−20	92	97:3
2	(<i>Z</i>)- 2a	CH ₃	H	<i>cis</i> - 14a	1	0	91	52:48
3	(<i>E</i>)- 2n	H	<i>n</i> -C ₅ H ₁₁	<i>trans</i> - 14n	3	−20	73	96:4
4	(<i>E</i>)- 2o	H	(CH ₂) ₃ Cl	<i>trans</i> - 14o	6	20	63	93:7
5	(<i>E</i>)- 2p	H	<i>i</i> -Bu	<i>trans</i> - 14p	3	−20	77	96:4
6	(<i>E</i>)- 2k	H	cyclopropyl	<i>trans</i> - 14k	3	−20	88	95:5
7	(<i>E</i>)- 2l	H	cyclopentyl	<i>trans</i> - 14l	3	0	50 ^d	82:18
8	(<i>E</i>)- 2m	H	cyclohexyl	<i>trans</i> - 14m	3	0	70 ^e	85:15
9	2c	CH ₃	CH ₃	14c	1	−20	90 ^f	80:20
10	(<i>E</i>)- 2j	CH ₃	C ₆ H ₅	<i>trans</i> - 14j	2	−20	82 ^g	71:29

^aYields of analytically pure products.^bThe enantiomeric ratio was determined by CSP-SFC analysis.^cThe absolute configurations of the products were assigned by comparison of their CD spectra with *trans*-**14d**.^dUnreacted starting material was recovered (15%).^eUnreacted starting material was recovered (16%).^fAn 8% yield of **26** was isolated.^gA 2% yield of **27** was isolated.

Table 9

Cychzation of Aryl-Substituted Alkenes.

entry	substrate	Aryl	product	time, d	temp, °C	yield, % ^a	er ^{b,c}
1	(<i>E</i>)- 2b	Ph	<i>trans</i> - 14b	2	−20	90	94:6
2	(<i>E</i>)- 2d	4-CH ₃ C ₆ H ₄	<i>trans</i> - 14d	2	−20	86	94:6
3	(<i>E</i>)- 2f	4-CH ₃ OC ₆ H ₄	<i>trans</i> - 14f	1	−20	86	92:8
4	(<i>E</i>)- 2i	2-CH ₃ C ₆ H ₄	<i>trans</i> - 14i	3.5	−20	82 ^d	92:8
5	(<i>E</i>)- 2g	2-naphthyl	<i>trans</i> - 14g	2	−20	61 ^e	89:11
6	(<i>E</i>)- 2e	4-NC-C ₆ H ₄	<i>trans</i> - 14e	6	20	83	89:11
7	(<i>E</i>)- 2h	4-CF ₃ C ₆ H ₄	<i>trans</i> - 14h	3	20	85	92:8

^aYields of analytically pure products.^bThe enantiomeric ratio was determined by CSP-SFC analysis.^cThe absolute configurations of the products were assigned by comparison of their CD spectra with *trans*-**14d**.^dA 4% yield of **28** was isolated from earlier, unoptimized experiments.^eUnreacted starting material was recovered (36%).

Table 10

Cyclization with Monomethoxyphenyl-Substituted Substrates.

entry	substrate	time, d	temp, °C	products	isomeric ratio	yield, % ^a	er ^{b,c}
1		3	-20		29:30	60	96:4
2		3	-20		31:32	45	94:6
3		1.5	0		-	85	84:16

^aYields of analytically pure products.^bThe enantiomeric ratio was determined by CSP-SFC analysis.^cThe absolute configurations of the products were assigned by comparison of their CD spectra with *trans*-**14d**.