(d, J = 8 Hz, 2 H, Ar), 6.52 (br s, 1 H, OH), 4.06 (dd, J = 10 Hz, 1.4 Hz, 1 H, CHO), 3.35 (d, J = 9 Hz, 1 H), 2.5 (td, J = 8 Hz, 2 Hz, 1 H), 2.85 (m, 1 H), 2.52 (dd, J = 10 Hz, 7 Hz, 1 H), 2.44 (s, 3 H, p-Me), 2.25 (m, 1 H), 2.2–1.1 (series of m, 12 H), 0.84 (t, J = 7 Hz, 3 H, Me); ^{13}C NMR δ 142.2 (s, Ar), 136.05 (s, Ar), 129.58 (d, 2 C, Ar), 126.84 (d, 2 C, Ar), 75.06 (d, CO), 67.06 (d, CN), 63.98 (s), 54.21 (t), 53.74 (t), 34.68 (t), 29.47 (t), 27.08 (t), 21.7 (t), 21.33 (q), 20.93 (t), 19.39 (t), 13.81 (q); MS, CI m/z 336 (M + 1). Anal. Calcd for $C_{19}H_{29}NO_2S$: C, 68.02; H, 8.71. Found: C, 68.13; H, 8.60.

11b: an oil, $[\alpha]^{22}_D$ +127° (c 1 in CH_2Cl_2); ^{1}H NMR δ 7.54 (d, J = 8 Hz, 2 H, Ar), 7.29 (d, J = 2 Hz, 2 H, Ar), 5.1 (br s, 1 H, OH), 4.02 (dd, J = 11 Hz, 1.6 Hz, 1 H, CHO), 3.05 (m, 2 H), 2.42 (s, 3 H, p-Me), 2.4–2.2 (m, 2 H), 2.1–1.5 (m, 12 H), 1.27 (m, 1 H), 0.94 (t, J = 7 Hz, 3 H, Me); ^{13}C NMR δ 141.8 (s, Ar), 135.85 (s, Ar), 129.17 (d, 2 C, Ar), 126.86 (d, 2 C, Ar), 74.46 (d, CO), 66.26 (d, CN), 65.24 (2), 53.95 (t), 52.64 (t), 36.29 (t), 25.68 (t), 25.4 (t), 22.72 (t), 21.33 (q), 21.27 (t), 19.94 (t), 14.02 (q); MS, CI m/z 336 (M + 1). Anal. Calcd for $C_{19}H_{29}NO_2S$: C, 68.02; H, 8.71. Found: C, 68.21; H, 8.89.

The following example serves as the general procedure for the dehydrosulfinylation reactions of sulfoxides **10a**, **10b**, **11a**, and **11b**.

(−)-Elaeokanine B [(−)-2]. A solution of 84 mg (0.25 mmol) of alcohol **10a** and 25 mg of triethylamine in 10 mL of toluene was heated under reflux for 2 h. The solution was cooled to 25 °C, solvent was removed under vacuum, and the residue was column chromatographed on silica gel, using a mixture of acetone and methanol as eluant to give 45 mg (92% yield) of (−)-**2** as an oil: $[\alpha]^{22}_D$ −76° (c 0.4 in $CHCl_3$) (lit.[5a] $[\alpha]_D$ −76° in $CHCl_3$); IR (neat) 3300, 1640; ^{1}H NMR δ 5.67 (br s, 1 H, =CH), 4.08 (br s, 1 H, CHO), 2.96 (m, 2 H), 2.85 (m, 1 H), 2.55 (q, J = 9 Hz, 1 H), 2.46 (m, 1 H), 2.22 (m, 2 H), 1.97 (m, 1 H), 1.87 (m, 1 H), 1.73 (m, 1 H), 1.6–1.3 (m, 5 H), 0.92 (t, J = 7 Hz, 3 H, Me); ^{13}C NMR δ 142.38 (s, C=), 118.51 (d, =CH), 72.56 (d, CO), 60.85 (d, CN), 52.91 (t), 46.9 (t), 38.76 (t), 28.38 (t), 25.34 (t), 22.09 (t), 18.85 (t), 13.99 (q); MS, EI m/z 195 (M^+), 194, 178. Anal. Calcd for $C_{12}H_{21}NO$: C, 73.80; H, 10.84; N, 7.17. Found: C, 73.55, H, 11.07; N, 7.01.

(+)-(8a*R*,1′*S*)-1,2,3,5,6,8a-Hexahydro-8-(1-hydroxybutyl)indolizine [(+)-12]: an oil, $[\alpha]^{22}_D$ +22° (c 0.4 in $CHCl_3$); IR (neat) 3250, 1638; ^{1}H NMR δ 5.71 (s, 1 H, =CH), 4.03 (t, J = 7 Hz, 1 H, CHO), 3.05 (m, 1 H), 2.96 (td, J = 9 Hz, 4 Hz, 1 H), 2.86 (m, 1 H), 2.60 (q, J = 8 Hz, 1 H), 2.48 (m, 1 H), 2.4–2.1 (m, 3 H), 1.92 (m, 1 H), 1.86 (m, 1 H), 1.7–1.5 (m, 3 H), 1.45 (m, 1 H), 1.37 (m, 1 H), 0.93 (t, J = 7 Hz, 3 H, Me); ^{13}C NMR δ 141.97 (s, C=), 121.46 (d, =CH), 74.26 (d, CO), 60.88 (d, CN), 52.79 (t), 46.78 (t), 37.45 (t), 28.85 (t), 25.55 (t), 22.11 (t), 19.31 (t), 13.99 (q); MS, EI m/z 195 (M^+), 194, 178. Anal. Calcd for $C_{12}H_{21}NO$: C, 73.80; H, 10.84. Found: C, 73.61; H, 10.99.

The following example serves as the general procedure for the oxidation reactions of alcohols (−)-**2** and (+)-**12** with PCC.

(+)-Elaeokanine A [(+)-1]. To a mixture of 59 mg (0.302 mmol) of alcohol (+)-**12** and 60 mg of 3-Å molecular sieves in 5 mL of CH_2Cl_2 under argon was added 0.13 g (0.6 mmol) of PCC. The mixture was stirred at 25 °C for 2 h, diluted with H_2O, and extracted three times with CH_2Cl_2. The combined CH_2Cl_2 extracts were washed with brine, dried ($MgSO_4$), concentrated, and column chromatographed on silica gel, using hexane and acetone as eluant to give 54 m g (93% yield) of (+)-1 as an oil: $[\alpha]^{22}_D$ +49° (c 0.5 in $CHCl_3$) (lit.[5a] $[\alpha]_D$ +13° in $CHCl_3$); IR (neat) ν 2942, 1650, 1450, 1270, 1195 cm^{-1}; ^{1}H NMR δ 6.87 (s, 1 H, =CH), 3.52 (br s, 1 H, CHN), 3.0–2.8 (m, 3 H), 2.6 (td, J = 9 Hz, 3 Hz, 2 H, CH_2), 2.5–2.3 (m, 4 H), 1.9–1.7 (m, 2 H), 1.64 (q, J = 7 Hz, 2 H), 1.4 (m, 1 H), 0.93 (t, J = 7 Hz, 3 H, Me); ^{13}C NMR δ 199.35 (s, C=O), 139.03 (s, =C)8, 135.99 (d, =CH), 58.65 (d, CN), 53.14 (t), 44.85 (t), 39.1 (t), 29.48 (t), 24.14 (t), 21.76 (t), 17.83 (t), 13.76 (q). Anal. Calcd for $C_{12}H_{19}NO$: C, 74.57; H, 9.91. Found: C, 74.35; H, 10.17.

Acknowledgment. We gratefully acknowledge financial support from the National Institute of General Medical Sciences (Grant GM36336) and the National Science Foundation (Grant CHE-8800654). This project is in part funded by Wesley Foundation, Wichita, KS (Grant 8802041). The Wesley Foundation is an independent, nonprofit organization dedicated to improving the quality of life in Kansas through financial support for health related programs. We are indebted to Mr. Ken Walsh, Coal Research Center, Southern Illinois University of Carbondale, for obtaining mass spectra.

Registry No. (±)-1, 33023-01-7; (−)-1, 125636-82-0; (−)-**2**, 33023-02-8; **4**, 123642-79-5; **5**, 872-32-2; **6**, 125475-12-9; **7** (isomer 1), 125475-13-0; **7** (isomer 2), 125517-31-9; **8** (isomer 1), 125517-32-0; **8** (isomer 2), 125517-33-1; **9a**, 89772-92-9; **9b**, 18881-13-5; **10a**, 125475-14-1; **10b**, 125517-34-2; **11a**, 125517-35-3; **11b**, 125517-36-4; **12**, 125517-30-8; $I(CH_2)_3I$, 627-31-6.

Supplementary Material Available: Positional and equivalent isotropic thermal parameters for non-H atoms (Table 1), bond distances and bond angles (Tables 2 and 3), calculated hydrogen atom coordinates and temperature factors (Table 4), U values (Table 5), torsion angles (Table 6), and intermolecular distances involving the non-hydrogen atoms (Table 7) for sulfoxide **10a** (7 pages). Ordering information is given on any current masthead page.

Three-Different-Component [1 + 2 + n]-Annulation Reactions: Ionic and Radical Cyclizations

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One-carbon-atom Michael donors are used to initiate convergent and flexible [1 + 2 + 3]-hexannulations and [1 + 2 + 2]-pentannulations in which the initial nucleophilic carbon atom terminates the reaction sequence in an ionic fashion as an electrophilic center or in a carbon-centered radical fashion as a nucleophilic center. This protocol is used to prepare regiospecifically substituted bicyclic ketones and lactones and a cis-bicyclic tetrahydrofuran.

Current general practice is to construct carbocycles often by linking together *two* units, as for example in [2 + 4]-Diels–Alder cycloadditions[1] and Robinson annulations[2] and in [2 + 3]-dipolar cycloadditions.[3] Forming carbocyclic systems by sequential joining of *three* smaller carbon units, for example, a one-carbon unit, an α-enone, and an allylic

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(1) (a) Onischchenko, A. S. *Diene Synthesis*; Israel Programme for Scientific Translations: Jerusalem, 1964. (b) Wasserman, A. *Diels–Alder Reactions*; Elsevier: New York, 1965. (c) Wollweber, H. *Diels–Alder Reaktion*; Georg Thieme Verlag: Stuttgart, 1972. (d) Taber, D. F. *Intramolecular Diels–Alder and Alder Ene Reactions*; Springer-Verlag: New York, 1983.

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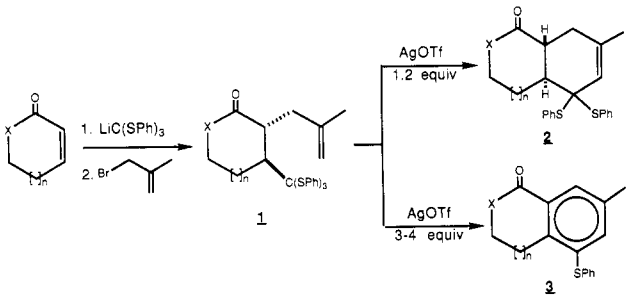
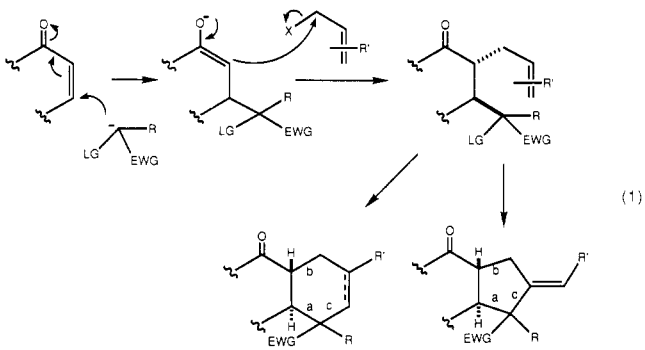
Scheme I



	X	n	1	2	3
a,	CH_2	0	82%	-	60%
b,	CH_2	1	92%	56%	71%
c,	O	1	54%	94%	73%

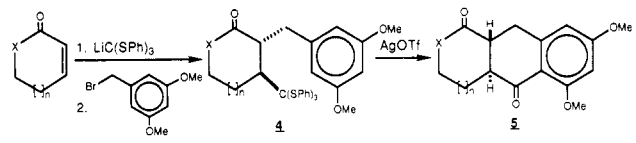
halide, offers the advantages of increased availability of cheap starting materials and increased flexibility in preparing synthetic targets of diverse structural and functional types.

We have recently developed a simple experimental protocol for one-pot multicomponent [2 + 2 + 2]-hexannulations.[4] We report here generalization of this synthetic method to include sequential, three-different-component, [1 + 2 + 3]-hexannulation and [1 + 2 + 2]-pentannulation reactions, as illustrated in general by eq 1 in



which three new carbon–carbon bonds (a, b, c) are formed in tandem fashion. Our first concern was selecting appropriate one-carbon systems which are able to act initially as Michael donors and ultimately as electrophilic centers. Another concern in designing these experiments was whether the intermediate enolate ion in eq 1 could be C-alkylated under sufficiently mild reaction conditions to avoid both undesirable retro-Michael addition[5] and irreversible 1,3-intramolecular nucleophilic substitution (S_Ni) of the leaving group LG (i.e. cyclopropane formation).[6]

Scheme II



	X	n	4	5
a,	CH_2	0	50%	51%
b,	CH2	1	75%	80%
c,	O	1	85%	52%

Final ring closure via cationic intermediates formed by loss of a phenylthiolate leaving group was examined first. Tris(phenylthio)methyllithium, a thioester acyl anion equivalent which was known to undergo conjugate additions to α-enones,[7] added in a Michael fashion to cyclopentenone, cyclohexenone, and 2-pentenolide to give an intermediate enolate ion which was methallylated satisfactorily between −30 °C to room temperature in THF solvent containing a polar cosolvent such as HMPA or *N*-methylpyrrolidinone (Scheme I). 2-Methyl-2-cyclohexenone and 2-cycloheptenone did not undergo this vicinal difunctionalization satisfactorily.

Of several Lewis acids tried (e.g. cuprous triflate,[8a] mercuric triflate,[8b] silver triflate[8c]) as well as thiophilic dimethyl(methylthio)sulfonium tetrafluoroborate (DMTSF),[9] silver triflate was the most effective in promoting cyclization. By changing the amount of Lewis acid used in THF as solvent, silver triflate in small excess converted vicinally disubstituted products **1** into [1 + 2 + 3]-hexannulated products **2** in 51–52% overall yields, whereas silver triflate in large excess led to [A + B + C]-benzannulated[4b] products **3** in 39–65% overall yields. Formation of aromatic products **3** involved an (air) oxidation step. Regiospecifically tetrasubstituted benzene **3b** was formed also on *gram scale* in a *one-pot* procedure, without isolation of the corresponding 2,3-disubstituted cyclohexanone **1b**, in 56% overall yield [vs 65% (92 × 71) for the two-step protocol]; because these overall yields are not vastly different, the one-pot procedure may be preferred for practical reasons since it involves only one chromatographic purification (i.e. of product **3b**). The expected[10] trans stereochemistry of the vicinal substituents in disubstituted cycles **1** and of the ring junction in bicyclic lactone **2c** was established by 400-MHz ^1H NMR decoupling experiments which revealed a vicinal tertiary H–H coupling constant of 9–14 Hz. It was not possible to determine the corresponding coupling constant for octalone **2b** because the tertiary hydrogens did not stand out in the ^1H NMR spectrum; therefore, the trans ring junction depicted for octalone **2b** is based on analogy with that of the corresponding bicyclic lactone **2c**.

Trapping the intermediate enolate ion generated via Michael addition of tris(phenylthio)methyllithium to cyclohexenone with the silicon-substituted allylic iodide

(2) (a) House, H. O. *Modern Synthetic Reactions*, 2nd ed.; Benjamin: New York, 1972; Chapters 9, 10. (b) Jung, M. E. *Tetrahedron* **1976**, *32*, 3. (c) Gawley, R. E. *Synthesis* **1976**, 777.

(3) (a) Oppolzer, W. *Tetrahedron* **1985**, *41*, 17. (b) Trost, B. M.; Mignani, S. M.; Nanninga, T. N. *J. Am. Chem. Soc.* **1988**, *110*, 1602 and references therein.

(4) (a) Posner, G. H.; Lu, S.-B.; Asirvatham, E.; Silversmith, E. F.; Shulman, E. M. *J. Am. Chem. Soc.* **1986**, *108*, 511. (b) Posner, G. H. *Chem. Rev.* **1986**, *86*, 831. (c) Posner, G. H.; Asirvatham, E.; Webb, K.; Jew, S.-s. *Tetrahedron Lett.* **1987**, *28*, 5071. (d) Posner, G. H.; Webb, K. S.; Asirvatham, E.; Jew, S.-s.; Degl'Innocenti, A. *J. Am. Chem. Soc.* **1988**, *110*, 4754. (e) Posner, G. H.; Shulman-Roskes, E. M. *J. Org. Chem.* **1989**, *54*, 3514.

(5) (a) Seuron, N.; Seyden-Penne, J. *Tetrahedron* **1984**, *40*, 635. (b) Zervos, M.; Wartski, L.; Seyden-Penne, J. *Ibid.* **1986**, *42*, 4963.

(6) (a) Ramig, K.; Bhupathy, M.; Cohen, T. *J. Am. Chem. Soc.* **1988**, *110*, 2678. (b) Loupy, A.; Lefour, J.-M.; Deschamps, B.; Seyden-Penne, J. *Nouv. J. Chim.* **1980**, *4*, 121 and unpublished results of T. Strzalko and J. Seyden-Penne using 2-cyclopentenone plus lithiophenylchloroacetonitrile to give at least 30% of a bicyclic phenylcyanocyclopropane product.

(7) (a) Cf.: Myers, M. R.; Cohen, T. *J. Org. Chem.* **1989**, *54*, 1290 and references therein. See also: (b) Rahman, A.; Manas, B.; Smith, R. A. *J. Chem. Soc., Chem. Commun.* **1975**, 216. (c) Damon, R. E.; Schlessinger, R. H. *Tetrahedron Lett.* **1976**, 1561.

(8) (a) Miyachi, N.; Kanda, F.; Shibasaki, M. *J. Org. Chem.* **1989**, *54*, 3512 and references therein. (b) Yamada, T.; Suzuki, H.; Mukaiyama, T. *Chem. Lett.* **1987**, 293. (c) For an application and a leading reference, see: Fujii, N.; et al. *J. Chem. Soc.* **1989**, 283. See also Williams, R. M.; Armstrong, R. W.; Dung, J.-S. *J. Am. Chem. Soc.* **1985**, *107*, 3253.

(9) (a) Trost, B. M.; Sato, T. *J. Am. Chem. Soc.* **1985**, *107*, 719. (b) Trost, B. M.; Shibata, T. *Ibid.* **1982**, *104*, 3225. (c) Trost, B. M.; Murayama, E. *Ibid.* **1981**, *103*, 6529. (d) Amat, M.; Linares, A.; Salas, M.-L.; Alvarez, M.; Bosch, J. *J. Chem. Soc., Chem. Commun.* **1988**, 420.

(10) Cf.: Chapdelaine, M. J.; Hulce, M. *Org. React.*, in press. See also: Stork, G.; Rychnovsky, S. D. *Pure Appl. Chem.* **1987**, *59*, 345. Hanessian, S.; Murray, P. J. *J. Org. Chem.* **1987**, *52*, 1170.

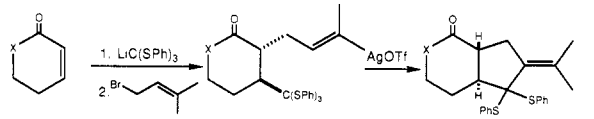
shown in eq 2 followed by silver ion promoted cyclization of the intermediate allylic silane gave an exocyclic double bond isomer of hexannulated product **2b** (i.e. **2d**) in 32% overall yield. Thus, by suitable choice of the third component in these [A + B + C]-annulations, either endocyclic olefin **2b** or its exocyclic isomer **2d** can be prepared. Although tandem vicinal difunctionalization of acyclic ethyl vinyl ketone with tris(phenylthio)methyllithium and then with methallyl bromide proceeded smoothly, subsequent six-membered ring closure was not successful with various Lewis acid catalysts; a ketene dithioacetal was the major product formed via β-elimination of benzenethiol.

(2)

2d

Michael addition of [tris(phenylthio)methyl]lithium to cyclopentenone, to cyclohexenone, and to 2-pentenolide followed by C-benzylation of the intermediate enolate ions produced 2,3-disubstituted cyclohexanones **4**. Excess silver triflate in methylene chloride caused overall intramolecular Friedel–Crafts acylation[11] to form the new central cyclohexanone ring in linear tricycles **5** via a convergent [1 + 2 + 3]-hexannulation process in which the one-atom carbonyl unit was used initially as an acyl anion nucleophilic equivalent[12] and subsequently as an acyl electrophile (Scheme II). Attempts to perform Scheme II via a one-pot protocol were not promising.

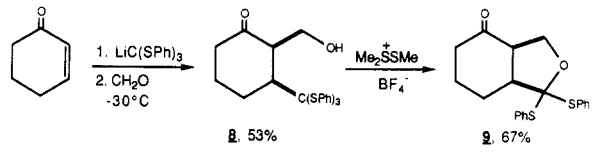
[1 + 2 + 2]-Pentannulation was accomplished in a similar fashion via 2-dimethallylated cyclohexanone and pentanolide intermediates **6** (eq 3). Lewis acid promoted cyclization led effectively and simply to three-different-component construction of regiospecifically polyfunctionalized cyclopentane derivatives **7** in overall 48–53% yields.



(3)

		6	**7**
a,	X = CH_2	80%	60%
b,	X = O	58%	92%

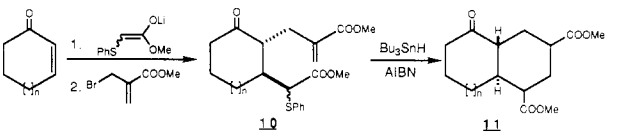
[1 + 2 + 2]-Heteroannulation to form a tetrahydrofuran ring system was achieved using formaldehyde as the third component,[7c] as shown in eq 4. When the aldol condensation producing β-hydroxy ketone 8 was performed above −30 °C, cyclopropane formation[6] became a problem. Effective isolation of β-hydroxy ketone 8 depended on the way the reaction mixture was quenched: HCl/diethyl ether[13] proved to be much more satisfactory than the usual aqueous ammonium chloride. Only crystalline cis-disubstituted cyclohexanone 8, with a vicinal tertiary H–H coupling constant of 2.8 Hz, was isolated.[14] This surprising but unambiguous stereochemical outcome stands in contrast to that reported in a similar system.[7c] Optimal cyclization conditions were found not to involve Lewis acids but rather to involve DMTSF to form cis-3,4-disubstituted tetrahydrofuran **9** in overall 36% yield.[15] Although tandem vicinal difunctionalization of acyclic ethyl vinyl ketone as in eq 4 proceeded smoothly, subsequent attempts to form a tetrahydrofuran were not promising. It is noteworthy that annulated products **9** (as well as **2**, **3**, and **7**) contain geminal phenylthio groups which offer a variety of possibilities for subsequent manipulation (e.g., hydrolysis into a ketone).



(4)

8, 53% **9**, 67%

Scheme III



10 **11**

a,	n = 0	90%	85%
b,	n = 1	81%	80%

A phenylthio substituent offered also the possibility of generating a carbon-centered free radical that might undergo final ring closure. α-Phenylthio ester enolate conjugate addition[16] followed by C-allylation as in Scheme III gave vicinally disubstituted products **10** as a mixture of diastereomers. Under typical radical-generating conditions (Bu_3SnH, AIBN), the α-phenylthio ester group was converted into a stabilized carbon-centered radical which underwent intramolecular addition to the electrophilic β-carbon atom of the pendant acrylate unit[17] to form new 6-membered carbocycles **11** as a mixture of two diastereomers via a [1 + 2 + 3]-hexannulation strategy overall in 65–77% yields. These high-yielding annulation reactions represent noteworthy examples of the usefulness of radicals in organic synthesis, and they stand in contrast to failed attempts to initiate cyclization of vicinally disubstituted products **10** by selectively deprotonating the α-phenylthio ester group (i.e. ionic Michael addition). Thus, depending on the reaction conditions chosen, *the phenylthio substituent can be induced to undergo either productive homolytic ($Bu_3SnH/AIBN$) or heterolytic (Ag^+) cleavage.*

In conclusion, versatile one-carbon Michael donors and suitable reaction conditions have been found for three-different-component [1 + 2 + *n*]-annulation reactions leading to various fused bicyclic ketones and lactones and a tetrahydrofuran. Thus a novel, flexible, and simple approach to annulation producing regiospecifically and,

(11) For a closely related cyclization, see: Cossy, J.; Henin, F.; Leblanc, C. *Tetrahedron Lett.* **1987**, *28*, 1417.

(12) For reviews, see: (a) Seebach, D. *Angew. Chem., Int. Ed. Engl.* **1969**, *8*, 639. (b) Lever, O. W., Jr. *Tetrahedron* **1976**, *32*, 1943. (c) Gröbel, B.-T.; Seebach, D. *Synthesis* **1977**, 357. (d) *Umpoled Synthons*; Hase, T. A., Ed.; Wiley-Interscience: New York, 1987.

(13) Vidal, J.; Hurt, F. *J. Org. Chem.* **1988**, *53*, 611.

(14) Cf.: Linderman, R. J.; Godfrey, A. *J. Am. Chem. Soc.* **1988**, *110*, 6249.

(15) (a) Semmelhack, M. F.; Keller, L.; Sato, T.; Spiess, E. J.; Wulff, W. *J. Org. Chem.* **1985**, *50*, 5566. (b) Mukaiyama, T.; Hayashi, M.; Ichikawa, J. *Chem. Lett.* **1986**, 1157.

(16) See: Takasu, M.; Wakabayashi, H.; Furuta, K.; Yamamoto, H. *Tetrahedron Lett.* **1988**, *29*, 6943.

(17) For analogies, see: (a) Hanessian, S.; Dhans, D. S.; Beaulieu, P. L. *Can. J. Chem.* **1987**, *65*, 1859. (b) Harrison, T.; Pattenden, G.; Myers, P. L. *Tetrahedron Lett.* **1988**, *29*, 3869. (c) Ihara, M.; Yasui, K.; Taniguchi, N.; Fukumoto, K.; Kametani, T. *Ibid.* **1988**, *29*, 4963. (d) Rao, Y. K.; Nagarajan, M. *Ibid.* **1988**, *29*, 107. (e) Subba Rao, G. S. R. *Ibid.* **1989**, *30*, 225. (f) Araki, Y.; Endo, T.; Arai, Y.; Tanji, M.; Ishido, Y. *Ibid.* **1989**, *30*, 2829. (g) Yeung, B.-W. A.; Contelles, J. L. M.; Fraser-Reid, B. *J. Chem. Soc., Chem. Commun.* **1989**, 1160. (h) Hart, D. J.; Huang, H.-C.; Krishnamarthy, R.; Schwartz, T. *J. Am. Chem. Soc.* **1989**, *111*, 750. (i) Porter, N. A.; Lacher, B.; Chang, V. H.; Magnin, D. R. *Ibid.* **1989**, *111*, 8309. (j) Ramig, K.; Bhupathy, M.; Cohen, T. *J. Org. Chem.* **1989**, *154*, 4404. (k) Smith, T. A. K.; Whitham, G. H. *J. Chem. Soc., Perkin Trans. 1* **1989**, 313. (l) Harrison, T.; Myers, P. L.; Pattenden, G. *Tetrahedron* **1989**, *45*, 5247.

in some cases, stereospecifically functionalized 5- and 6-membered carbocycles and a 5-membered heterocycle has been developed in which the one-carbon unit is a multicoupling reagent[18] acting initially as a nucleophilic Michael donor and finally as an electrophilic ionic center (d^1/a^1)[18] or finally as a nucleophilic radical center (d^1/d^1).[18] Applications of this convergent methodology to efficient synthesis of more complex molecules is anticipated.

Experimental Section

Reactions were run in oven-dried glassware under argon. Melting points are uncorrected. ^1H NMR spectra were recorded at 400 MHz. The following solvents were distilled from sodium/benzophenone before use: diethyl ether and tetrahydrofuran. Dichloromethane and hexamethylphosphoramide were distilled from calcium hydride under argon. All other reagents and solvents were used as received. Flash chromatography was carried out using Merck Kieselgel 60 (230 mesh) silica gel. The purity of the title compounds was judged to be > 95% by chromatographic (TLC) and 400-MHz ^1H NMR spectral determinations.

Typical Procedure for Tandem Vicinal Difunctionalization. Michael Addition Followed by α-Functionalization. Cyclization Precursor *trans*-2-(2-Methyl-2-propenyl)-3-[tris(phenylthio)methyl]cyclohexan-1-one (1b). A dry one-neck 25-mL flask under argon was charged with 187.5 mg (0.55 mmol) of tris(phenylthio)methane and 2 mL of dry THF. The reaction flask was cooled to −78 °C and after 10 min 348 μL (0.55 mmol) of 1.58 M *n*-butyllithium in hexane was added. After 10 min 48.4 μL (0.5 mmol) of distilled 2-cyclohexenone (Aldrich) in 500 μL of THF was added dropwise over a period of 5 min into the pale yellow [tris(phenylthio)methyl]lithium kept at −78 °C. After 10 min 1.25 mL of HMPA (Aldrich) *or* *N*-methylpyrrolidinone was added. The reaction flask was transferred to a cold bath at −30 °C. After 5 min 110 mg (0.80 mmol) of 1-bromo-2-methyl-2-propene (prepared from the alcohol) in 500 μL of THF was added. The reaction flask was stirred at −30 °C for 1 h and at 25 °C overnight. Aqueous NH_4Cl was added to the reaction mixture. The organic layer was separated, and the aqueous layer was extracted with diethyl ether (2 × 10 mL). Combined organic layers were washed several times with distilled water (5 × 50 mL) to remove the cosolvent. The organic layer was washed with brine and dried over $MgSO_4$. Filtration and solvent evaporation gave 360 mg of crude product, which was purified by flash chromatography (eluting solvent, ether/hexane = 1:9) to give 227 mg (92%) of compound **1b**: IR ($CHCl_3$) 1704 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.77 (s, 3 H), 2.05–2.65 (9 H), 3.51 (dd, J = 10.8, 6.0 Hz, 1 H), 4.58 (s, 1 H), 4.68 (s, 1 H), 7.10–7.60 (15 H, Ar); HRMS calc for $C_{23}H_{25}OS_2$ (M − C_6H_5S) 381.1347, found 381.1326.

***trans*-2-(2-Methyl-2-propenyl)-3-[tris(phenylthio)methyl]cyclopentan-1-one (1a)**: 198 mg (82%); mp 78–80 °C; IR ($CHCl_3$) 1733 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.64 (s, 3 H), 1.95 (m, 1 H), 2.20 (d, J = 6.8 Hz, 2 H), 2.25 (m, 1 H), 2.50 (m, 2 H), 2.70 (m, 1 H), 3.05 (m, 1 H), 4.42 (s, 1 H), 4.66 (s, 1 H), 7.25–7.65 (15 H, Ar); HRMS calc for $C_{22}H_{23}OS_2$ (M − C_6H_5S) 367.1190, found 367.1190.

***trans*-3-(2-Methyl-2-propenyl)-4-[tris(phenylthio)methyl]-3,4,5,6-tetrahydropyran-2-one (1c)**: 270 mg (55%); mp 140–141 °C; IR ($CHCl_3$) 1725 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.83 (s, 3 H), 2.00–2.35 (m, 4 H), 2.71 (dt, J = 9.2, 1.6 Hz, 1 H), 3.67 (dt, J = 9.2, 1.6 Hz, 1 H), 4.09 (t, J = 12.0 Hz, 1 H), 4.23 (m, 1 H), 4.63 (s, 1 H), 4.81 (s, 1 H), 7.20–7.70 (15 H, Ar); HRMS calc for $C_{22}H_{23}O_2S_2$ (M − C_6H_5S) 383.1139, found 383.1139.

General Procedure for [1 + 2 + 3]-Hexannulation: 4-Methyl-6,6-bis(phenylthio)-3,6,9,10-tetrahydroisochroman-1-one (2c). Compound **1c** (68 mg, 0.138 mmol) was dissolved in 3 mL of THF in a flask and cooled to 0 °C in an ice bath. After 10 min 42.6 mg (0.165 mmol) of silver triflate (Aldrich) was added in one portion. Immediate formation of a cloudy yellow precipitate was observed. After 10 min, the ice bath was removed and the reaction was quenched with water. The reaction mixture was warmed to room temperature and diluted with ether. The organic layer was separated, and the aqueous layer was extracted with ether (2 × 10 mL). Combined organic layers were dried over $MgSO_4$. Filtration and solvent evaporation gave a yellow oil which was purified by flash chromatography (eluting solvent, ethyl acetate/hexane = 1:9) to give 50 mg (94%) of compound **2c**: IR (neat) 1742 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.38 (s, 3 H), 1.95–2.75 (5 H), 3.75 (m, 1 H), 4.40 (m, 2 H), 5.75 (s, 1 H), 7.00–7.75 (10 H, Ar); HRMS calc for $C_{22}H_{22}O_2S_2$ (M^+) 382.1061, found 382.1068.

Irradiation of the allylic protons (δ 3.68 and 2.65) caused the signal for the proton adjacent to the lactone carbonyl group (δ 2.2) to become a doublet with J = 13.6 Hz.

***trans*-3,4,4a,5,8,8a-Hexahydro-7-methyl-5,5-bis(phenylthio)naphthalen-1(2*H*)-one (2b)**: mp 155–156 °C; IR ($CHCl_3$) 1695 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.36 (s, 3 H), 1.60–2.50 (8 H), 3.04 (m, 1 H), 3.61 (broad d, J = 8.0 Hz, 1 H), 5.64 (s, 1 H), 7.20–7.75 (10 H, Ar). Irradiation of the allylic multiplet at δ 3.5 caused the multiplet at δ 2.25 (tertiary H adjacent to the carbonyl group) to collapse into a doublet with J = 14 Hz. Anal. Calc for $C_{23}H_{24}OS_2$: C, 72.63; H, 6.32; S, 16.84. Found: C, 72.61; H, 6.39; S, 16.77.

7-Methylene-5,5-bis(phenylthio)-3,4,4a,5,6,7,8,8a-octahydronaphthalen-1(2*H*)-one (2d): 14 mg (70%); mp 100–102 °C, IR ($CHCl_3$) 1690 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.60–2.50 (10 H), 2.93 (m, 1 H), 3.04 (m, 1 H), 4.26 (d, J = 1.9 Hz, 1 H), 4.78 (d, J = 1.9 Hz, 1 H), 7.26–7.80 (10 H, Ar); HRMS calc for $C_{23}H_{24}OS_2$ (M^+) 380.1269, found 380.1274.

General Procedure for [A + B + C]-Benzannulation: 6-Methyl-4-(phenylthio)-2,3-dihydroinden-1-one (3a). Ketone **1a** (56 mg, 0.117 mmol) was placed in a flask and dissolved in 3 mL of THF. The reaction flask was cooled to 0 °C in an ice bath. After 10 min, 33.3 mg (0.129 mmol) of silver triflate was added in one portion. Immediate formation of a cloudy yellow precipitate indicated the completion of the cyclization process. The ice bath was removed and, after 10 min, 67 mg (2.20 equivalents) of silver triflate was added in one portion. The reaction mixture turned dark gray. This slurry was stirred at room temperature for 10 min and diluted with ether. The organic layer was filtered, and the residue was washed several times with ether. Combined ether layers were washed with water and brine and dried over $MgSO_4$. Filtration and solvent evaporation gave a dark brown oil, which was purified by flash chromatography (eluting solvent, ether/hexane = 1:9) to give 18 mg (60%) of compound **3a**: IR ($CHCl_3$) 1709 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.35 (s, 3 H), 2.67 (t, J = 6.0 Hz, 2 H), 2.96 (t, J = 6.0 Hz, 2 H), 7.27–7.32 (5 H, C_6H_5S), 7.33 (s, 1 H), 7.48 (s, 1 H); HRMS calc for $C_{16}H_{14}OS$ (M^+) 254.0765, found 254.0770.

7-Methyl-5-(phenylthio)-3,4-dihydronaphthalen-1(2*H*)-one (3b): 27 mg (71%); IR ($CHCl_3$) 1681 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.08 (q, J = 6.4 Hz, 2 H), 2.30 (s, 3 H), 2.62 (t, J = 6.4 Hz, 2 H), 2.96 (t, J = 6.4 Hz, 2 H), 7.15–7.30 (5 H, C_6H_5S), 7.36 (s, 1 H), 7.85 (s, 1 H); HRMS calc for $C_{17}H_{16}OS$ (M^+) 268.0922, found 268.0921.

4-Methyl-6-(phenylthio)-7,8-dihydroisochroman-1-one [3c (*n* = 1)]: 24 mg (73%); IR ($CHCl_3$) 1719 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.35 (s, 3 H), 3.03 (t, J = 6.0 Hz, 2 H), 4.46 (t, J = 6.0 Hz, 2 H), 7.15–7.30 (5 H, C_6H_5S), 7.43 (s, 1 H), 7.91 (s, 1 H); HRMS calc for $C_{16}H_{14}O_2S$ (M^+) 270.0715, found 270.0717.

One-Pot Procedure for [A + B + C]-Benzannulation. Conjugate addition of [tris(phenylthio)methyl]lithium [prepared from 3.746 g of tris(phenylthio)methane and 6.96 mL of 1.58 M *n*-butyllithium] to 2-cyclohexenone (968 μL, 110 mmol) was carried out at −78 °C (10 min) in THF. *N*-Methylpyrolidinone (40 mL, 25% by v/v) was added, and the reaction flask was warmed to −30 °C. After 5 min, 1-bromo-2-methyl-2-propene (2.02 g, 15 mmol) in 15 mL of THF was added. The reaction mixture was stirred at −30 °C for 1 h and at room temperature overnight. The next day, the reaction flask was placed in a 0 °C ice bath, and 3.08 g (12 mmol) of silver triflate was added in one portion. Immediate formation of a yellow precipitate indicated that the cyclization process was complete. The reaction flask was warmed to room temperature, and excess silver triflate (6.2 g) was added. The black slurry was stirred for an additional 10 min, and the organic layer was filtered off. The organic layer was washed with water (2 × 30 mL) and brine and dried over $MgSO_4$. Filtration and solvent evaporation gave a yellow oil, which was purified by

(18) (a) Seebach, D. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 239. (b) Seebach, D.; Knochel, P. *Helv. Chim. Acta* **1984**, *67*, 261.

flash chromatography (eluting solvent, ether/hexanes = 5:95) to obtain 1.50 g (56%) of compound **3b**.

***trans*-2-[(3,5-Dimethoxyphenyl)methyl]-3-[tris(phenylthio)methyl]cyclopentan-1-one (4a)**: 102 mg (50%); mp 139–140 °C; IR ($CHCl_3$) 1732, 1606, 1595 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.50 (m, 1 H), 1.83 (m, 1 H), 2.24 (m, 1 H), 2.34 (m, 1 H), 2.76 (dd, J = 13.6, 6.4 Hz, 1 H), 2.84 (m, J = 5.2 Hz, 1 H), 3.11 (dd, J = 13.6, 4.8 Hz, 1 H), 3.23 (q, J = 4.8 Hz, 1 H), 3.69 (s, 6 H), 6.11 (d, J = 2.0 Hz, 2 H), 6.24 (t, J = 2.0 Hz, 1 H), 7.25–7.60 (15 H, Ar); HRMS calc for $C_{27}H_{26}O_3S_2$ (M – C_6H_5S) 462.1323, found 462.1332.

***trans*-2-[(3,5-Dimethoxyphenyl)methyl]-3-[tris(phenylthio)methyl]cyclohexan-1-one (4b)**: 440 mg (75%); IR ($CHCl_3$) 1703, 1606, 1596 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.60 (m, 1 H), 2.05 (m, 3 H), 2.35 (m, 2 H), 2.80 (m, 3 H), 3.62 (t, J = 8.0 Hz, 1 H), 3.73 (s, 6 H), 6.23 (d, J = 2.0 Hz, 2 H), 6.28 (t, J = 2.0 Hz, 1 H), 7.30–7.55 (15 H, Ar); HRMS calc for $C_{28}H_{28}O_3S_2$ (M – C_6H_5S) 476.1480, found 476.1484.

***trans*-3-[(3,5-Dimethoxyphenyl)methyl]-4-[tris(phenylthio)methyl]-3,4,5,6-tetrahydropyran-2-one (4c)**: 183 mg (85%); mp 176–178 °C; IR ($CHCl_3$) 1730, 1606, 1596, 1471 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.85 (m, 1 H), 2.00 (m, 1 H), 2.88–2.98 (m, 2 H), 3.05 (dd, J = 13.6, 6.0 Hz, 1 H), 3.27 (t, J = 12.4 Hz, 1 H), 3.72 (s, 6 H), 3.84 (dt, J = 6.4, 3.2 Hz, 1 H), 3.96 (td, J = 11.2, 3.6 Hz, 1 H), 6.21 (d, J = 2.4 Hz, 2 H), 6.31 (t, J = 2.4 Hz, 1 H), 7.30–7.70 (15 H, Ar); HRMS calc for $C_{27}H_{26}O_4S_2$ (M – C_6H_5S) 478.1273, found 478.1264.

5,6-(3′,5′-Dimethoxybenzo)perhydroindene-1,4-dione (5a). Silver triflate (80 mg, 0.30 mmol) was added in one portion into a CH_2Cl_2 solution of 35 mg (0.06 mmol) of compound **4** (X = CH_2, n = 0), at room temperature. The reaction mixture was stirred for 4 h at room temperature. Methylene chloride was filtered, and the residue was washed with CH_2Cl_2 (2 × 10 mL). Combined CH_2Cl_2 layers were washed with water and dried over $MgSO_4$. Filtration and solvent evaporation gave 17 mg of a dark brown solid, which was purified by flash chromatography (eluting solvent, ethyl acetate/hexane = 1:1) to give 8.1 mg (51%) of compound **5a**: IR ($CHCl_3$) 1741, 1661, 1600, 1573, 1456, 1163 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.10 (dd, J = 18.0, 8.8 Hz, 1 H), 2.2–2.4 (m, 2 H), 2.51 (m, 1 H), 2.80 (m, 1 H), 3.03 (dd, J = 16.0, 5.6 Hz, 1 H), 3.14 (dd, J = 16.0, 5.2 Hz, 1 H), 3.27 (dt, J = 8.0, 4.0 Hz, 1 H), 3.84 (s, 3 H), 3.86 (s, 3 H), 6.33 (s, 2 H); HRMS calc for $C_{15}H_{16}O_4$ (M^+) 260.1049, found 260.1052.

6,8-Dimethoxy-2,3,4,4a,10,10a-hexahydroanthracene-1,5-dione (5b). Isomer A: 12 mg (57%); mp 164–166 °C; IR ($CHCl_3$) 1711, 1668, 1600, 1573 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.72 (m, 2 H), 2.22 (m, 1 H), 2.38 (m, 1 H), 2.48 (m, 2 H), 2.56 (m, 1 H), 2.74 (dt, J = 12.4, 4.0 Hz, 1 H), 3.03 (dd, J = 17.2, 12.4 Hz, 1 H), 3.14 (dd, J = 17.2, 4.0 Hz, 1 H), 3.84 (s, 3 H), 3.88 (s, 3 H), 6.35 (m, 2 H); HRMS calc for $C_{16}H_{18}O_4$ (M^+) 274.1205, found 274.1211. Isomer B: 5 mg (23%); IR ($CHCl_3$) 1711, 1662, 1600, 1574 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.90 (m, 3 H), 2.38 (m, 2 H), 2.62 (m, 2 H), 2.88 (dd, J = 16.0, 4.0 Hz, 1 H), 3.12 (m, 2 H), 3.40 (d, J = 16.0, 4.0 Hz, 1 H), 3.86 (s, 6 H), 6.31 (d, J = 2.0 Hz, 1 H), 6.40 (d, J = 2.0 Hz, 1 H); HRMS calc for $C_{16}H_{18}O_4$ (M^+) 274.1205, found 274.1208.

6,7-(3′,5′-Dimethoxybenzo)perhydroisochroman-1,5-dione (5c): mp 219–220 °C; IR ($CHCl_3$) 1739, 1675, 1600, 1573, 1456 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.26–2.48 (m, 2 H), 2.70 (m, 1 H), 2.85 (dt, J = 12.0, 4.0 Hz, 1 H), 3.16 (m, 1 H), 3.44 (dd, J = 16.8, 4.0 Hz, 1 H), 3.87 (s, 3 H), 3.90 (s, 3 H), 4.41 (dt, J = 6.4, 0.8 Hz, 2 H), 6.39 (b d, J = 6.0 Hz, 2 H). Anal. Calc for $C_{15}H_{16}O_5$: C, 65.21; H, 5.79. Found: C, 65.11; H, 5.84. Isomer B: IR ($CHCl_3$) 1730, 1662, 1601, 1574, 1456 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.25 (m, 1 H), 2.50 (m, 1 H), 3.09 (m, 2 H), 3.24 (m, 1 H), 3.42 (dd, J = 15.6, 4.8 Hz, 1 H), 3.86 (s, 3 H), 3.87 (s, 3 H), 4.35 (m, 2 H), 6.35 (d, J = 2.0 Hz, 1 H), 6.39 (d, J = 2.0 Hz, 1 H); HRMS calc for $C_{15}H_{16}O_5$ (M^+) 276.0998, found 276.1000.

***trans*-2-(3,3-Dimethylallyl)-3-[tris(phenylthio)methyl]cyclohexan-1-one (6a).** The cyclization precursor was prepared from 48.4 μL (0.5 mmol) of 2-cyclohexenone, 0.55 mmol of [tris(phenylthio)methyl]lithium, 1.25 mL of *N*-methylpyrrolidinone (30 vol %), and 120 mg (0.80 mmol) of 3,3-dimethylallyl bromide (Aldrich). The crude product (360 mg) was purified by flash chromatography (eluting solvent, ether/hexane = 1:9) to give 203 mg (80%) of compound **6a** as white solid: mp 110–111 °C; IR ($CHCl_3$) 1699, 1472, 1438 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.49 (s, 3 H), 1.65 (s, 3 H), 1.70–2.45 (8 H), 2.60 (m, 1 H), 3.35 (m, 1 H), 5.00 (m, 1 H), 7.20–7.65 (15 H, Ar). Anal. Calc for $C_{30}H_{32}OS_3$: C, 71.40; H, 6.35; S, 19.05. Found: C, 71.39; H, 6.58; S, 19.01.

***trans*-3-(3,3-Dimethylallyl)-4-[tris(phenylthio)methyl]-3,4,5,6-tetrahydropyran-2-one (6b)**: 292 mg (58%); mp 157–159 °C; IR ($CHCl_3$) 1733 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.46 (s, 3 H), 1.69 (s, 3 H), 1.90–2.50 (4 H), 2.62 (dt, J = 7.6, 2.4 Hz, 1 H), 3.56 (dt, J = 7.6, 2.4 Hz, 1 H), 4.05 (m, 1 H), 4.18 (m, 1 H), 5.15 (t, J = 7.6 Hz, 1 H), 7.20–7.70 (15 H, Ar). Anal. Calc for $C_{29}H_{30}O_2S_3$: C, 68.77; H, 5.92; S, 18.97. Found: C, 68.84; H, 5.99; S, 19.00.

2-(1-Methylethylidene)-1,1-bis(phenylthio)octahydroinden-4-one (7a). In a 10-mL flask was dissolved 32 mg (0.063 mmol) of compound **6** (X = CH_2) in 1.5 mL of THF, and the mixture was cooled to 0 °C in an ice bath. Silver triflate (20 mg, 0.076 mmol) was added in one portion. Immediate formation of a pale yellow precipitate was observed. The reaction was quenched by adding water after 5 min at 0 °C. The reaction flask was warmed to room temperature and diluted with ether. The ether layer was separated, and the aqueous layer was extracted with ether (2 × 10 mL). Combined ether layers were dried over $MgSO_4$. Filtration and solvent evaporation gave 33 mg of a yellow oil, which was purified by flash chromatography (eluting solvent, ether/hexane = 1:9) to give 15 mg (60%) of compound **7a**: IR ($CHCl_3$) 1705 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.26 (s, 3 H), 1.32 (s, 3 H), 2.05–2.60 (8 H), 2.80 (m, 1 H), 3.03 (m, 1 H), 3.65 (t, J = 8.0 Hz, 1 H), 7.05–7.75 (10 H, Ar); HRMS calc for $C_{24}H_{26}OS_2$ (M^+) 394.1426, found 394.1432.

Compound 7b: 38 mg (92%); IR ($CHCl_3$) 1746 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.31 (s, 6 H), 2.45–2.96 (5 H), 3.86 (t, J = 8.0 Hz, 1 H), 4.42 (m, 2 H), 7.05–7.45 (10 H, Ar); HRMS calc for $C_{23}H_{24}O_2S_2$ (M^+) 396.1218, found 396.1225. Irradiation of one of the allylic multiplets at δ 3.86 caused the multiplet at δ 2.5 (H adjacent to the carbonyl group) to collapse into a doublet of doublets with J = 9.6 and 14 Hz; further decoupling showed that the vicinal coupling of the ring junction hydrogens was 9.6 Hz.

***cis*-2-(Hydroxymethyl)-3-[tris(phenylthio)methyl]cyclohexanone (8).** Tris(phenylthio)methane (1.2672 g, 3.65 mmol) was dissolved in 20 mL of anhydrous THF, cooled to −78 °C, and stirred under argon. Next, 2.30 mL (3.65 mmol) of *n*-BuLi (1.6 M in hexane) was added dropwise to the −78 °C solution. The light yellow solution was stirred under argon for 30 min. Next 326.4 mg (3.40 mmol) of 2-cyclohexenone in 3 mL of anhydrous THF was added and allowed to stir at −78 °C for 15 min, after which time 5 mL of THF and 1 mL of HMPA was added to the cyclohexenone flask, cooled to −78 °C and cannulated into the 23-mL solution. Stirring was continued at −78 °C for an additional 15 min, and the flask warmed to −30 °C. Next, 1 g of paraformaldehyde was cracked and bubbled into the −30 °C solution. Stirring was continued for an additional 20 min at −30 °C followed by quenching with a solution of HCl/Et_2O [450 μL of 12 M HCl (aq) (5.4 mmol) in 4.75 mL of Et_2O] adding 5 mL of water, and separating the THF layer. The aqueous layer was washed with 1 × 25 mL of Et_2O, and the organic layer was evaporated to dryness. The residue was suspended in 200 mL of Et_2O, washed with 2 × 25 mL of water, and dried over anhydrous $MgSO_4$, and the solvent was removed to afford 1.6431 g of a crude oil which was purified via short-path chromatography [silica gel, 60 g, eluting solvent 30% EtOAc/hexane] to yield β-hydroxy ketone **8** (841 mg, (53%) as white crystals): IR ($CHCl_3$, cm^{-1}) 3011, 1972, 1954, 1886, 1805, 1699, 1581, 1472, 1438, 1239, 1221, 1213, 1044, 1025, 777, 754, 735, 704; ^1H NMR ($CDCl_3$) δ 1.62–2.49 (m, 6 H), 2.55–2.61 (m, 1 H), 3.39–3.44 (m, 1 H), 3.62–3.73 (m, 2 H), 7.28–7.39 (m, 9 H), 7.58 (dd, J = 1.6, 8.0 Hz, 6 H). Proton decoupled spectra ^1H NMR ($CDCl_3$): When the proton signals at 3.65 ppm were irradiated, the proton multiplet at 3.39 ppm collapsed into a doublet with J = 2.8 Hz. ^{13}C NMR (100 MHz) ($CDCl_3$): δ 20.70, 25.83, 38.65, 47.31, 54.74, 64.86, 81.78, 128.56, 129.33, 131.71, 136.22, 213.60. An analytical sample was recrystallized from ethyl acetate: mp 147.5–148.5 °C. Anal. Calc for $C_{26}H_{26}O_2S_3$: C, 66.92; H, 5.61; S, 20.61. Found: C, 66.85; H, 5.81; S, 21.05.

Cyclization to Tetrahydrofuran 9. To 154.3 mg (0.33 mmol) of β-hydroxy ketone **8** in 5 mL of anhydrous THF, stirring under argon at 0 °C, was added 60.2 mg (0.307 mmol) of dimethyl(methylthio)sulfonium tetrafluoroborate [recrystallized from

CH_3NO_2/Et_2O (1:1) before use] as a solid to the 0 °C solution. The reaction was allowed to stir at 0 °C for 2 h and quenched with 0.5 mL of saturated ammonium chloride and 1 mL of water. The THF was separated, and the aqueous layer was washed with 2 × 15 mL of Et_2O. The organic layers were combined and evaporated to dryness. The organic residue was suspended in 75 mL of Et_2O and washed with 2 × 15 mL of water and 1 × 15 mL of brine and dried over anhydrous $MgSO_4$, and solvent removal afforded 142.1 mg of an oil that was separated via a 2000-μm preparative TLC plate with the eluting solvent being 20% EtOAc/hexane to yield the desired tetrahydrofuran **9** (79.2 mg, 67.2%) as a colorless oil: IR ($CHCl_3$, cm^{-1}) 3009, 1716, 1475, 1378, 1210, 1010, 728, 692; ^1H NMR ($CDCl_3$) δ 1.50–2.38 (m, 7 H), 3.27–3.36 (m, 1 H), 3.75–3.99 (m, 2 H), 7.27–7.72 (m, 10 H); MS (calc for $C_{20}H_{20}O_2S_2$) 356, M^+ is not readily detected, 247 (55.4, M – PhS), 218 (26.5), 137 (72.1, M – $(PhS)_2$), 110 (100), 81 (69.2), 53 (61.3).

Methyl *trans*-α-Methylene-5-oxo-2-[(methoxycarbonyl)(phenylthio)methyl]cyclopentanepropanoate (10a). Lithium diisopropylamide (0.55 mmol) was prepared in 1 mL of THF at 0 °C (10 min) from 80.6 μL (0.575 mmol) of freshly distilled diisopropylamine and 364 μL (0.55 mmol) of 1.51 M *n*-BuLi and cooled to −78 °C. After 10 min 85.6 μL (0.55 mmol) of methyl α-(phenylthio)acetate (Fluka) in 1 mL of THF was added dropwise over a period of 5 min. The pale yellow reaction mixture was stirred at −78 °C for 40 min. Freshly distilled 2-cyclopentenone (41.8 μL, 0.50 mmol) in 1 mL of THF was added dropwise over a period of 10 min. After 15 min 500 μL of HMPA was added, and the reaction flask was transferred to a cold bath at −30 °C. After 5 min, 84.1 μL (0.70 mmol) of methyl 2-(bromomethyl)acrylate in 1 mL of THF was added over a period of 5 min. The reaction flask was stirred at −30 °C for 1 h and slowly warmed to room temperature overnight. Aqueous NH_4Cl was added to the reaction mixture, which was extracted with ether (2 × 10 mL). The combined ether layers were washed several times with water (5 × 10 mL) and dried over $MgSO_4$. Filtration and solvent evaporation gave 300 mg of a yellow oil, which was purified by flash chromatography (eluting solvent, ethyl acetate/hexane = 1:9) to give 164 mg (90%) of compound **10a** as a mixture of isomers in 2.5:1 ratio by NMR: IR (neat) 1736, 1629, 1582, 1481, 1438, 1270, 1197, 1159, 746 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.10–2.29 (2 H), 2.34–2.54 (4 H), 2.61 (m, 2 H), 3.66 (s, 3 H), 3.68 (s, 3 H, major), 3.69 (s, 3 H, major), 3.73 (s, 3 H), 3.92 (d, J = 7.04 Hz, 1 H), 3.99 (d, J = 4.96 Hz, 1 H, major) 5.6 (s, 1 H, both isomers), 6.17 (s, 1 H, major), 6.22 (s, 1 H), 7.25–7.50 (5 H, Ar); HRMS calc for $C_{19}H_{22}O_5S$ (M^+) 362.1189, found 362.1193.

Methyl *trans*-α-Methylene-6-oxo-2-[(methoxycarbonyl)(phenylthio)methyl]cyclohexanepropanoate (10b). This compound was prepared from 2 mmol of 2-cyclohexenone, 2.20 mmol of the ester enolate (2.20 mmol of *n*-BuLi and methyl α-(phenylthio)acetate), 2 mL of HMPA (20 vol %), and 2.30 mmol of methyl 2-(bromomethyl)acrylate. The crude product (920 mg) was purified by flash chromatography (eluting solvent, ethyl acetate/hexane = 2:8) to give 614 mg (81%) of compound **10b** as a mixture of two diastereomers in 3:1 ratio by NMR: IR ($CHCl_3$) 2950, 1731, 1714, 1437, 1210, 1157, 758 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.50–1.70 (2 H), 1.80–2.50 (6 H), 2.70–3.20 (2 H), 3.48 (s, 3 H), 3.52 (s, 3 H), 3.62 (s, 3 H, major), 3.66 (s, 3 H, major) 3.70 (s, 3 H), 3.71 (s, 3 H), 3.62–3.70 (m, 1 H), 5.51 (s, 1 H), 5.56 (s, 1 H, major), 5.61 (s, 1 H), 6.12 (s, 1 H), 6.15 (s, 1 H, major), 6.20 (s, 1 H), 7.20–7.60 (5 H, Ar); HRMS calc for $C_{20}H_{24}O_5S$ (M^+) 376.1345, found 376.1350.

Radical Cyclization: Dimethyl *trans*-Octahydro-1-oxoindene-4,6-dicarboxylates (11a). Freshly distilled tributyltin hydride (39.2 μL, 0.145 mmol) was added to a refluxing toluene (600 μL) solution of 44 mg (0.12 mmol) of compound **10** (n = 0) and 2 mg (0.012 mmol) of AIBN. The reaction mixture was refluxed at 110 °C for 30 min, cooled to room temperature, and quenched with water. The reaction mixture was extracted with ether and dried over anhydrous $MgSO_4$. Filtration and solvent evaporation gave 90.0 mg of a pale yellow oil, which was purified by flash chromatography (eluting solvent, ethyl acetate/hexane = 2:8). Diastereomer I (12.5 mg, 41%): IR ($CHCl_3$) 3024, 2954, 1732, 1455, 1437 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.50–1.70 (3 H), 1.90 (m, 1 H), 2.05–2.24 (3 H), 2.25–2.42 (3 H), 2.62 (dt, J = 11.5, 3.5 Hz, 1 H), 2.94 (m, 1 H), 3.68 (s, 3 H), 3.71 (s, 3 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 25.65, 27.45, 29.13, 29.99, 31.29, 41.31, 41.40, 44.66, 49.57, 51.84, 52.48, 174.43, 174.59; HRMS calc for $C_{13}H_{18}O_5$ (M^+) 254.1154, found 254.1156. Diastereomer II (13.5 mg, 44%): IR ($CHCl_3$) 3024, 2954, 2931, 1734, 1450, 1436, 1245 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.60–1.74 (2 H), 2.02–2.30 (3 H), 2.34–2.46 (4 H), 2.68 (m, 1 H), 2.76 (m, 1 H), 2.91 (dt, J = 5.3, 2.1 Hz, 1 H), 3.68 (s, 3 H), 3.71 (s, 3 H); HRMS calc for $C_{13}H_{18}O_5$ (M^+) 254.1154, found 254.1151.

Dimethyl *trans*-Decahydro-5-oxonaphthalene-1,3-dicarboxylates (11b). Radical cyclization was carried out in refluxing benzene for 15 min using 250 mg (0.66 mmol) of compound **10** (n = 1), 215 μL (0.79 mmol) of Bu_3SnH, and 11 mg (0.066 mmol) of AIBN. The crude product (480 mg) was purified by flash chromatography (eluting solvent, ethyl acetate/hexane = 2:8) to give 100 mg (56.5%) of diastereomer I: IR ($CHCl_3$) 3022, 2952, 2868, 1731, 1450, 1435, 1224, 1197, 1166 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.42 (m, 1 H), 1.53–1.86 (5 H), 2.07 (m, 1 H), 2.40 (m, 2 H), 2.58 (m, 2 H), 2.74 (m, 2 H), 3.15 (dt, J = 11.9, 3.4 Hz, 1 H), 3.63 (s, 3 H), 3.65 (s, 3 H); HRMS calc for $C_{14}H_{20}O_5$ (M^+) 268.1311, found 268.1317. Diastereomer II (42 mg, 24%): IR ($CHCl_3$) 3022, 2953, 1735, 1436, 1255, 1235, 1197, 1168, 1036 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.38–1.54 (2 H), 1.62–1.74 (3 H), 1.85 (m, 1 H), 2.04–2.18 (3 H), 2.24–2.45 (5 H), 3.68 (s, 3 H), 3.70 (s, 3 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 25.65, 27.45, 29.13, 29.99, 31.29, 41.31, 41.40, 44.66, 49.57, 51.84, 52.48, 174.43, 174.59; HRMS calc for $C_{14}H_{20}O_5$ (M^+) 268.1311, found 268.1317.

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Supplementary Material Available: ^1H NMR (400 MHz) spectra for title compounds (29 pages). Ordering information is given on any current masthead page.