Asymmetric Methoxyselenenylations and Cyclizations with 3-Camphorseleno Electrophiles Containing Oxime Substituents at C-2. Formation of an Unusual Oxaselenazole from an Oxime-Substituted Selenenyl Bromide

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Received August 27, 2001

Di[(1*R*)-2-Oximo-*endo*-3-bornyl] diselenide (**4**) and its benzoate derivative **5** were prepared from the corresponding known 2-keto diselenide **1**. Treatment of **4** and **5** with bromine, followed by silver triflate in methanol−dichloromethane, generated the corresponding selenenyl triflates **6b** and **7b**. The latter reagents reacted with a variety of mono-, di-, and trisubstituted alkenes to afford the corresponding 1,2-addition products (β-methoxy selenides) in a highly diastereoselective manner. The free oxime **6b** was particularly effective in such methoxyselenenylations, giving diastereomeric ratios (d.r.s) ranging from 86:14 to >98:2. Even cis-disubstituted alkenes, which typically give poor d.r.s in similar additions with other chiral selenium electrophiles, underwent highly stereoselective additions with this reagent. Reductive deselenizations of the adducts obtained from styrene and *cis*- and *trans*-stilbene provided the corresponding methyl ethers, whose absolute configurations were determined by comparison with authentic samples. As expected, the dominant enantiomers thus obtained from *cis*- and *trans*-stilbene, using either **6b** or **7b**, had opposite configurations. Moreover, each geometrical isomer of stilbene produced methyl ethers with the same configuration when treated with either the oxime **6b** or the benzoate **7b**. Coordination effects between the substituents at the 2-position of the camphor molecule and the positive selenium atoms in the intermediate seleniranium ions are believed to play an important role in determining the stereochemical outcome of methoxyselenenylations. Selenenyl triflate **6b** and selenenyl chloride **7c** were also investigated in the electrophilic cyclizations of several unsaturated alcohols and carboxylic acids. However, diastereoselectivities were typically much lower than in the methoxyselenenylations. When the selenenyl bromide **6a**, derived from the addition of bromine to the corresponding diselenide **4**, was allowed to stand in the absence of an alkene, it underwent intramolecular cyclization with the oxime hydroxyl group, followed by further bromination, to afford the unusual oxaselenazole **11**, whose structure was determined by spectroscopic means as well as by X-ray crystallography.

Introduction

Organoselenium reagents and reactions have become well established in the repertoire of synthetic organic chemists.[1] The additions of electrophilic selenium species of the general structure RSeX (X = a halide or other leaving group) to alkenes are of particular interest and have been widely studied for several decades.[2] Thus, selenenyl chlorides and bromides (X = Cl or Br) undergo anti-addition to variously substituted alkenes in inert solvents via bridged seleniranium ions, with predominantly Markovnikov regiochemistry in the case of unsymmetrical alkenes. When the reaction is performed in a nucleophilic solvent such as water or methanol, incorporation of the solvent into the product occurs in place of the halide, again with anti stereochemistry. Finally, when the alkene moiety is tethered to a nucleophilic substituent, intramolecular attack of the latter upon the intermediate seleniranium ion takes place, leading to the corresponding cyclized product.[2,3] These reactions are illustrated in Scheme 1. The selenium residue can then be removed reductively[4] or oxidatively[5] to afford saturated or unsaturated final products, respectively.

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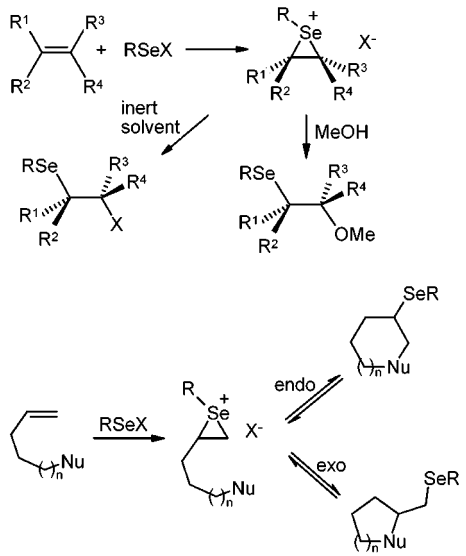
(1) (a) *Organoselenium Chemistry − A Practical Approach*; Back, T. G., Ed.; Oxford University Press: Oxford, 1999. (b) *Topics in Current Chemistry: Organoselenium Chemistry*; Wirth, T., Ed.; Springer-Verlag: Berlin, 2000, Vol. 208.

(2) For reviews of electrophilic selenium reactions, see: (a) Beaulieu, P. L.; Déziel, R. In *Organoselenium Chemistry − A Practical Approach*; Back, T. G., Ed.; Oxford University Press: Oxford, 1999; Chapter 3. (b) Tiecco, M. In *Topics in Current Chemistry: Organoselenium Chemistry*; Wirth, T., Ed.; Springer-Verlag: Berlin, 2000; Vol. 208, pp 7−54. (c) Back T. G. In *Organoselenium Chemistry*; Liotta, D., Ed.; Wiley: New York, 1987; Chapter 1. (d) Back, T. G. In *The Chemistry of Organic Selenium and Tellurium Compounds*; Patai, S., Ed.; Wiley: Chichester, 1987; Vol. 2, Chapter 3. (e) Paulmier, C. *Selenium Reagents and Intermediates in Organic Synthesis*; Pergamon Press: Oxford, 1986; Chapters 7 and 8. (f) Schmid, G. H.; Garratt, D. G. In *The Chemistry of Double-Bonded Functional Groups. Supplement A, Part 2*; Patai, S., Ed.; Wiley: New York, 1977; Chapter 9.

(3) For reviews of cyclizations induced with electrophilic selenium reagents, see: (a) Petragnani, N.; Stefani, H. A.; Valduga, C. J. *Tetrahedron* **2001**, *57*, 1411. (b) Nicolaou, K. C.; Petasis, N. A. *Selenium in Natural Products Synthesis*; CIS: Philadelphia, 1984; Chapter 7. (c) Nicolaou, K. C.; Petasis, N. A.; Claremon, D. A. In *Organoselenium Chemistry*; Liotta, D., Ed.; Wiley: New York, 1987; Chapter 2. Such processes have been termed "cyclofunctionalizations"; see: (d) Clive, D. L. J.; Chittattu, G.; Curtis, N. J.; Kiel, W. A.; Wong, C. K. *J. Chem. Soc., Chem. Commun.* **1977**, 725. (e) Clive, D. L. J.; Russell, C. G.; Chittattu, G.; Singh, A. *Tetrahedron* **1980**, *36*, 1399.

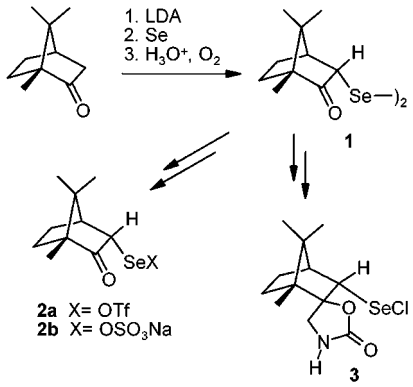
10.1021/jo016061c CCC: $22.00
Published on Web 01/03/2002

Scheme 1



The above processes often result in the creation of new stereocenters, and the task of developing enantioselective variations is of particular current importance.[6] In principle, this can be achieved by employing chiral, optically pure reagents R*SeX, where R* is a chiral auxiliary group. The preparation of the initial adduct is thus achieved diastereoselectively, followed by enantioselective formation of the final deselenized product. Several types of chiral selenium electrophiles have been investigated for this purpose,[7,8] but diastereoselectivity tends to be highly dependent upon the conditions and substitution patterns of the alkene substrates, thereby limiting the scope and general effectiveness of this method.

Scheme 2



We recently investigated a series of 3-camphorseleno derivatives in asymmetric methoxyselenenylations (additions of selenenyl electrophiles R*SeX in the presence of methanol as the external nucleophile) of alkenes and cyclizations of unsaturated alcohols and carboxylic acids.[9] These compounds are easily prepared from the diselenide **1**, which is in turn available in a one-pot step from (1*R*)-(+)-camphor and elemental selenium (Scheme 2).[10] The best results for methoxyselenenylations were obtained with the 2-keto selenenyl triflate derivative **2a**,[9b,9c] whereas cyclizations of unsaturated alcohols or carboxylic acids were most effectively carried out with the selenenyl chloride **3**, containing a spiro-oxazolidinone moiety at C-2.[9a,9c] However, the stereoselectivity in both series of reactions was variable, ranging from diastereomeric ratios (d.r.s) of >95:5 to <60:40. Subsequent to our initial communication,[9a] Tiecco et al.[11] reported similar studies of the selenenyl sulfate analogue **2b** at 0 °C, but generally obtained comparable or poorer diastereoselectivity than that afforded by the triflate **2a** at the lower temperature of −78 °C. We now report the extension of our earlier work to the preparation of the novel 2-oxime-containing diselenides **4** and **5** and the investigation of their corresponding selenenyl derivatives **6** and **7**, respectively, in a series of asymmetric methoxyselenenylations and cyclizations. The selenenyl triflates **6b** and **7b** proved to be remarkably effective in asymmetric methoxyselenenylations, with the free oxime **6b** being particularly advantageous in additions to *cis*-alkenes.[12] On the other hand, cyclizations attempted with reagents **6** or **7** were less successful, giving relatively poor stereoselectivities.

(4) For a review of deselenizations of selenium compounds, see: Back, T. G. In *Organoselenium Chemistry − A Practical Approach*; Back, T. G., Ed.; Oxford University Press: Oxford, 1999; Chapter 9.

(5) Oxidative deselenization most commonly takes place by *syn*-elimination of the corresponding selenoxide; for reviews, see: (a) Back, T. G. In *Organoselenium Chemistry − A Practical Approach*; Back, T. G., Ed.; Oxford University Press: Oxford, 1999; Chapter 2. (b) Nishibayashi, Y.; Uemura, S. In *Topics in Current Chemistry: Organoselenium Chemistry*; Wirth, T., Ed.; Springer-Verlag: Berlin, 2000; Vol. 208, pp 201−233.

(6) For recent reviews, see: (a) Wirth, T. *Tetrahedron* **1999**, *55*, 1. (b) Wirth, T. *Angew. Chem., Int. Ed.* **2000**, *39*, 3741.

(7) For a review of asymmetric oxyselenenylations, see: (a) Fujita, K. In *Reviews on Heteroatom Chemistry*; Oae, S., Ed.; MYU: Tokyo, 1997; Vol. 16, pp 101−117. For some specific examples, see: (b) Fujita, K.; Murata, K.; Iwaoka, M.; Tomoda, S. *Tetrahedron* **1997**, *53*, 2029. (c) Fujita, K.; Murata, K.; Iwaoka, M.; Tomoda, S. *Tetrahedron Lett.* **1995**, *36*, 5219. (d) Fujita, K.; Iwaoka, M.; Tomoda, S. *Chem. Lett.* **1994**, 923. (e) Fujita, K.; Iwaoka, M.; Tomoda, S. *Chem. Lett.* **1992**, 1123. (f) Tomoda, S.; Fujita, K.; Iwaoka, M. *J. Chem. Soc., Chem. Commun.* **1990**, 129. (g) Tomoda, S.; Iwaoka, M. *Chem. Lett.* **1988**, 1895. (h) Déziel, R.; Malenfant, E.; Thibault, C.; Fréchette, S.; Gravel, M. *Tetrahedron Lett.* **1997**, *38*, 4753. (i) Déziel, R.; Goulet, S.; Grenier, L.; Bordeleau, J.; Bernier, J. *J. Org. Chem.* **1993**, *58*, 3619. (j) Fukuzawa, S.; Takahashi, K.; Kato, H.; Yamazaki, H. *J. Org. Chem.* **1997**, *62*, 7711. (k) Fukuzawa, S.; Kasugahara, Y.; Uemura, S. *Tetrahedron Lett.* **1994**, *35*, 9403. (l) Wirth, T.; Fragale, G.; Spichty, M. *J. Am. Chem. Soc.* **1998**, *120*, 3376. (m) Wirth, T.; Häuptli, S.; Leuenberger, M. *Tetrahedron: Asymmetry* **1998**, *9*, 547. (n) Wirth, T.; Fragale, G. *Synthesis* **1998**, 162. (o) Wirth, T.; Fragale, G. *Chem. Eur. J.* **1997**, *3*, 1894. (p) Wirth, T.; *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 1726. (q) Fragale, G.; Neuburger, M.; Wirth, T. *J. Chem. Soc., Chem. Commun.* **1998**, 1867. (r) Santi, C.; Fragale, G.; Wirth, T. *Tetrahedron: Asymmetry* **1998**, *9*, 3625. (s) Wirth, T.; Kulicke, K. J.; Fragale, G. *J. Org. Chem.* **1996**, *61*, 2686. (t) Tiecco, M.; Testaferri, L.; Santi, C.; Tomassini, C.; Marini, F.; Bagnoli, L.; Temperini, A. *Tetrahedron: Asymmetry* **2000**, *11*, 4645. (u) Tiecco, M.; Testaferri, L.; Bagnoli, L.; Marini, F.; Temperini, A.; Tomassini, C.; Santi, C. *Tetrahedron Lett.* **2000**, *41*, 3241. (v) Uchiyama, M.; Satoh, S.; Ohta, A. *Tetrahedron Lett.* **2001**, *42*, 1559.

(8) For examples, see: refs 7b, 7h, 7n, 7p, 7q, and 7u and (a) Nishibayashi, Y.; Srivastava, S. K.; Takada, H.; Fukuzawa, S.; Uemura, S. *J. Chem. Soc., Chem. Commun.* **1995**, 2321. (b) Takada, H.; Nishibayashi, Y.; Uemura, S. *J. Chem. Soc., Perkin Trans. 1* **1999**, 1511. (c) Fujita, K.; Murata, K.; Iwaoka, M.; Tomoda, S. *J. Chem. Soc., Chem. Commun.* **1995**, 1641. (d) Déziel, R.; Malenfant, E. *J. Org. Chem.* **1995**, *60*, 4660. (e) Déziel, R.; Malenfant, E.; Thibault, C. *Tetrahedron Lett.* **1998**, *39*, 5493. (f) Uchiyama, M.; Oka, M.; Harai, S.; Ohta, A. *Tetrahedron Lett.* **2001**, *42*, 1931.

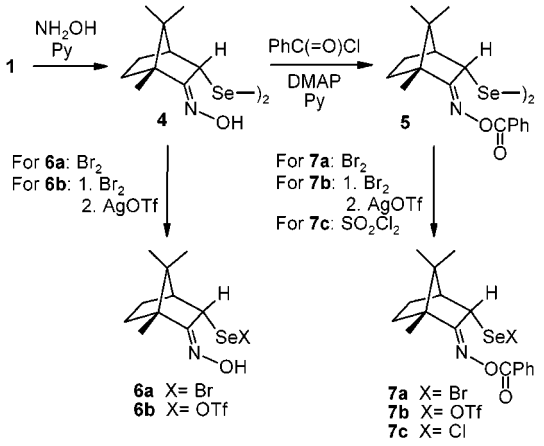
(9) (a) Back, T. G.; Dyck, B. P. *J. Chem. Soc., Chem. Commun.* **1996**, 2567. (b) Back, T. G.; Nan, S. *J. Chem. Soc., Perkin Trans. 1* **1998**, 3123. (c) Back, T. G.; Dyck, B. P.; Nan, S. *Tetrahedron* **1999**, *55*, 3191.

(10) Back, T. G.; Dyck, B. P.; Parvez, M. *J. Org. Chem.* **1995**, *60*, 703.

(11) (a) Tiecco, M.; Testaferri, L.; Santi, C.; Marini, F.; Bagnoli, L.; Temperini, A. *Tetrahedron Lett.* **1998**, *39*, 2809. (b) Tiecco, M.; Testaferri, L.; Marini, F.; Santi, C.; Bagnoli, L.; Temperini, A. *Tetrahedron: Asymmetry* **1999**, *10*, 747. For related hydroxyselenenylations, see: (c) Tiecco, M.; Testaferri, L.; Santi, C.; Marini, F.; Bagnoli, L.; Temperini, A.; Tomassini, C. *Eur. J. Org. Chem.* **1998**, 2275.

(12) Preliminary communication: Back, T. G.; Moussa, Z. *Org. Lett.* **2000**, *2*, 3007.

Scheme 3



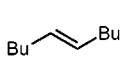
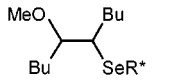
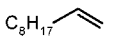
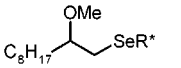
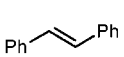
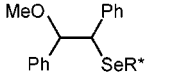
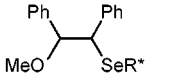
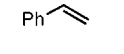
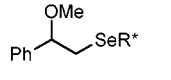
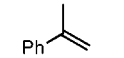
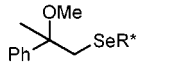
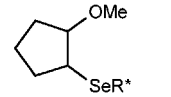
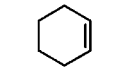
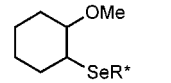
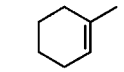
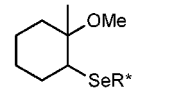
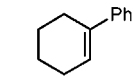
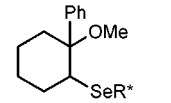
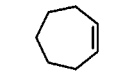
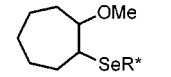
Results and Discussion

The preparation of diselenides **4** and **5** from **1** was straightforward and is shown in Scheme 3. Bromination of each diselenide produced selenenyl bromides **6a** and **7a** in situ, which were treated with silver triflate to generate the corresponding selenenyl triflates **6b** and **7b**, respectively. Alternatively, treatment of **5** with sulfuryl chloride generated the selenenyl chloride **7c**, whereas the similar chlorination of **4**, which contains a free hydroxyl group, produced a complex mixture of products instead of the corresponding selenenyl chloride. We assumed that the free hydroxyl group of selenenyl derivatives (*Z*)-**6a** and (*Z*)-**6b** would be capable of coordinating with the positive selenium atom in the transition states leading to the corresponding seleniranium ion intermediates formed in electrophilic additions or cyclizations. Improvements in the diastereoselectivity of similar processes were previously noted when coordinating substituents were present in other chiral auxiliary groups.[13] The corresponding benzoates **7** were included for comparison with the free oximes **6**. An X-ray crystal structure of diselenide **5** (see Supporting Information) confirmed the *Z*-configuration of the oxime moiety. We infer a similar *Z*-geometry for its precursor **4** and for the corresponding selenenyl derivatives **6** and **7**. Moreover, the relatively short interatomic distances of 2.95 and 2.97 Å between the oxime oxygen and selenium atoms are noteworthy in **5**, suggesting that the oxime benzoate moiety might also be capable of coordinating with the selenium atom in seleniranium ions derived from reagents **7** and various alkenes.[14]

The methoxyselenenylation of a series of alkenes with **6b** and **7b** in dichloromethane−methanol is summarized in Table 1. Attempted use of the selenenyl bromides **6a** and **7a**, or the chloride **7c**, gave inferior results. All reactions were performed at −78 °C, where d.r.s were greater than those at higher temperatures. In general, the mixtures of unseparated diastereomers were isolated and measurement of their d.r.s was attempted by ^{1}H NMR integration. In cases where this was precluded by incomplete resolution of the proton signals of the respective diastereomers, ^{77}Se NMR integration was used instead.[15]

Table 1 shows that both the oxime **6b** and its *O*-benzoate derivative **7b** are highly effective in methoxyselenenylations, with both compounds affording compa-

Table 1. Methoxyselenenylations of Alkenes with 6b and 7b[a]

entry	substrate	product	isolated yield (%) (d.r.)[b] with **6b**	with **7b**
1			73 (92:8)[c]	60 (94:6)[c]
2			50 (94:6)[c]	[d]
3			68 (>98:2)[c,e]	70 (90:10)[f]
4			78 (90:10)[c]	30 (77:23)[f]
5			52 (94:6)[c]	[d]
6			[d]	92 (82:18)[f]
7			89 (87:13)[c]	65 (75:25)[f]
8			56 (88:12)[f]	50 (62:38)[f]
9			81 (>98:2)[c,e]	71 (>95:5)[c,e]
10			72 (90:10)[c]	80 (95:5)[c]
11			73 (86:14)[c]	70 (73:27)[f]

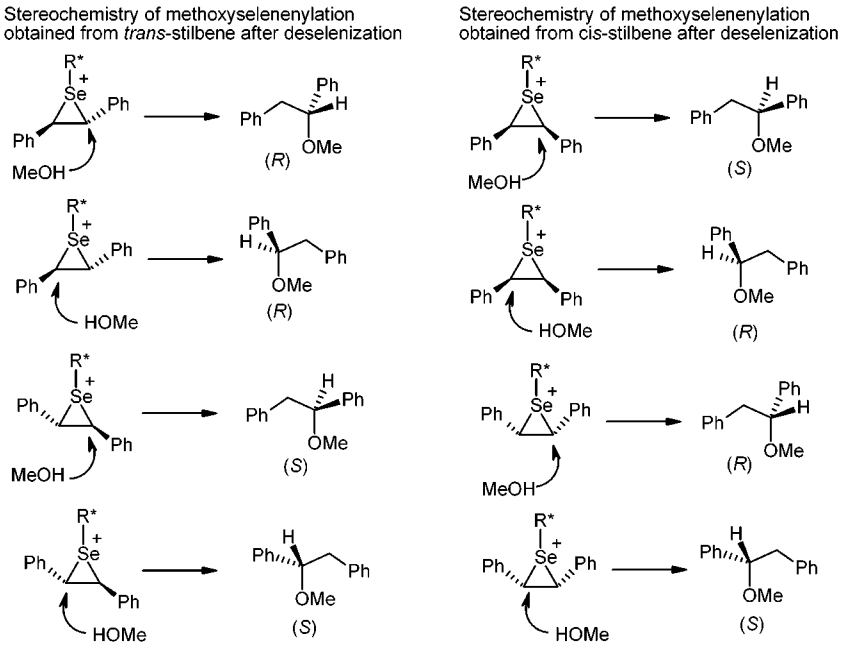
[a] All reactions were performed in dichloromethane/methanol at −78 °C. [b] d.r. = diastereomeric ratio. [c] Measured by ^{77}Se NMR integration. [d] Products could not be separated from impurities that precluded an unambiguous determination of yield and d.r. [e] Minor distereomer was not detected; ratio is based on the estimated minimum detection threshold. [f] Measured by ^{1}H NMR integration.

(13) Specific examples are found in refs 7 and 8. For a theoretical analysis, see: (a) Wang, X.; Houk, K. N.; Spichty, M.; Wirth, T. *J. Am. Chem. Soc.* **1999**, *121*, 8567. (b) Spichty, M.; Fragale, G.; Wirth, T. *J. Am. Chem. Soc.* **2000**, *122*, 10914.

(14) The ^{77}Se NMR spectra of diselenides **4** and **5** are quite similar to those of the original 2-keto derivative **1** (**4**: δ 377.3; **5**: δ 375.3; and **1**: δ 375.2 ppm relative to dimethyl selenide), indicating that any O−Se coordination is very weak in the diselenides **4** and **5**. However, it is reasonable to expect that such coordination would be considerably enhanced as the selenium atom assumes a positive charge during the formation of seleniranium ions from the corresponding selenenyl triflates. For an NMR study of intramolecular nonbonded O−Se interactions, see: Komatsu, H.; Iwaoka, M.; Tomoda, S. *J. Chem. Soc., Chem. Commun.* **1999**, 205.

(15) The chemical shifts of ^{77}Se NMR signals cover a broad range (>2000 ppm) and are highly sensitive to even minor structural changes. Consequently, they tend to be well separated even in closely related compounds such as diastereomers. For a review, see: Luthra, N. P.; Odom, J. D. In *The Chemistry of Organic Selenium and Tellurium Compounds*; Patai, S., Rappoport, Z., Eds.; Wiley: Chichester, 1986; Vol. 1, Chapter 6.

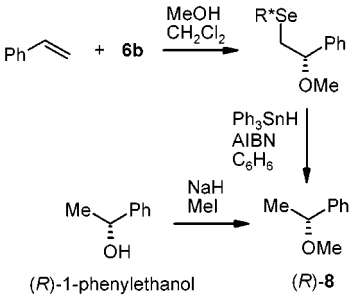
Scheme 4

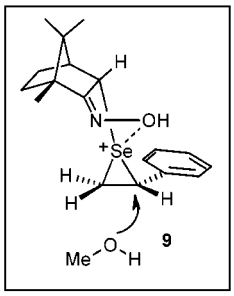


rable or superior d.r.s compared to that of the previously investigated[9b,c] 2-keto derivative **2a**. The reaction was successful with monosubstituted, gem-, cis-, and trans-disubstituted, and trisubstituted alkenes. The regiochemistry favors the Markovnikov isomers, where the selenium residue is incorporated at the less substituted position of the alkene. This is consistent with achiral precedents,[2] as well as those with other camphorseleno species.[9c,11a] The results obtained with the free oxime **6b** in the case of cis-disubstituted substrates (entries 4, 7, 8, and 11) are particularly noteworthy, as asymmetric methoxyselenenylations with other chiral selenium electrophiles, including the benzoate **7b**, typically give significantly lower d.r.s with *cis*-alkenes than with their trans isomers. It has been pointed out[7a,g] that the mechanism for diastereoselection is different for *cis*- and *trans*-alkenes. In the case of *trans*-alkenes (as well as mono-, *gem*-di-, and trisubstituted ones), diastereoselectivity is determined by the facial selectivity of the reagent toward the alkene during the formation of the seleniranium ion. On the other hand, the overall stereochemistry for additions to *cis*-alkenes is established in the second step, where the two diastereomers are produced by backside attack of the nucleophile at the two respective carbon atoms of the seleniranium ion. This is illustrated in Scheme 4, where the resulting absolute configurations are shown for the deselenized products of methoxyselenenylations of *cis*- and *trans*-stilbene proceeding via electrophilic addition to either face of the alkene, followed by ring-opening by attack of methanol at either of the respective carbon atoms of the intermediate seleniranium ions. For reasons not yet clearly understood, the free oxime reagent **6b** appears to be particularly effective in guiding the approach of the nucleophile preferentially toward one of the carbon atoms of the seleniranium ion.

We also wished to determine the absolute configurations of the new stereocenters formed in representative products in Table 1 after reductive deselenization. We chose the adducts obtained from styrene and *cis*- and *trans*-stilbene for this purpose, since the corresponding deselenized products are relatively nonvolatile and easy to isolate, and authentic samples of known absolute

Scheme 5

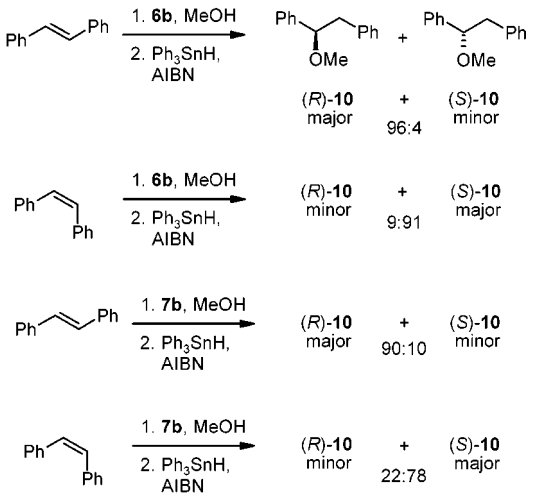




configuration are available for comparison. Thus, the adduct obtained from selenenyl triflate **6b** and styrene was subjected to deselenization with triphenyltin hydride[16] and the product **8** was compared to an authentic sample of (*R*)-**8** obtained from the treatment of commercially available (*R*)-1-phenylethanol with sodium hydride and iodomethane (Scheme 5). GC analysis of the deselenized product **8** with a chiral Cyclodex B column indicated that the enantiomeric ratio (e.r.) was 98:2 in favor of the (*R*)-enantiomer. This ratio confirms the similarly high d.r. of the initial adduct (94:6), as measured by NMR integration (Table 1, entry 5). Furthermore, it is consistent with the formation of the seleniranium ion stereoisomer **9** (Scheme 5), where coordination

(16) Clive, D. L. J.; Chittattu, G. J.; Farina, V.; Kiel, W. A.; Menchen, S. M.; Russell, C. G.; Singh, A.; Wong, C. K.; Curtis, N. J. *J. Am. Chem. Soc.* **1980**, *102*, 4438.

Scheme 6

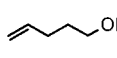
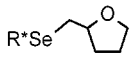
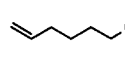
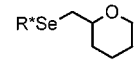
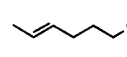
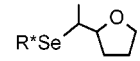
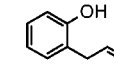
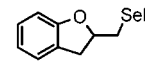
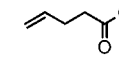
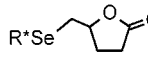


of the oxime hydroxyl group with the selenium atom occurs and the bulky styrene phenyl substituent occupies the least congested quadrant around the styrene double bond.

Similarly, deselenization of the adducts obtained from trans- and *cis*-stilbene and each of the selenenyl triflates **6b** and **7b** (Table 1, entries 3 and 4) afforded α-methoxybibenzyl (**10**) with the e.r.s indicated in Scheme 6. A scalemic mixture of (*R*)- and (*S*)-**10** was independently obtained in the ratio of 37:63 by a literature method[17,18] and was compared with the four deselenized products in Scheme 6 by GC analysis on a chiral column. Thus, it was determined that the product obtained from either the free oxime **6b** or the benzoate **7b** and *trans*-stilbene contained (*R*)-**10** as the major enantiomer. As expected, the reaction of *cis*-stilbene with either **6b** or **7b** favored the opposite (*S*)-configuration. In each case, the e.r.s of the deselenized products (Scheme 6) showed close correlation with the d.r.s of the corresponding methoxyselenenylation products (Table 1).

We also investigated the cyclizations of several unsaturated alcohols with selenenyl reagents **6** and **7**. Although similar cyclization reactions had been previously carried out most effectively with the selenenyl chloride **3** (as opposed to the corresponding triflate) in the 2-spirooxazolidinone series of chiral auxiliaries,[9a,9c] we were unable to generate the corresponding selenenyl chloride cleanly by chlorination of the diselenide **4** (vide supra), containing the free oxime hydroxyl group. Instead, the triflate **6b** was generated in the usual manner and employed in a variety of cyclizations, the results of which are shown in Table 2. On the other hand, the selenenyl chloride **7c** was easily formed from diselenide **5** (oxime benzoate substituent) and cyclizations performed with **7c**

Table 2. Cyclizations with 6b and 7c[a]

entry	substrate	product	isolated yield (%) (d.r.)[b] with **6b**	with **7c**
1			55 (60:40)[c]	63 (67:33)[d]
2			54 (57:43)[c]	61 (60:40)[d]
3			[e]	99 (71:29)[d]
4			74 (53:47)[c]	72 (66:34)[d]
5			84 (58:42)[c]	64 (56:44)[c]

[a] All reactions were performed in dichloromethane/methanol at −78 °C. [b] d.r. = diastereomeric ratio. [c] Measured by ^{77}Se NMR integration. [d] Measured by ^{1}H NMR integration. [e] The products could not be separated from impurities that precluded an unambiguous determination of yield and d.r.

are also shown in Table 2. The selenenyl bromides **6a** and **7a** were less successful at effecting cyclizations and gave either no cyclized products or poor yields, while the selenenyl triflate **7b** gave complex mixtures that were difficult to separate. The cyclizations performed with **6b** and **7c** proceeded by 5-exo- and 6-exo-tet closures of the corresponding seleniranium ions, as established by NMR analysis. This is consistent both with Baldwin's Rules[19] and related precedents.[9c,20] In contrast to the highly diastereoselective methoxyselenenylations with **6b** and **7b** listed in Table 1, and to the earlier cyclization results obtained with spiro-oxazolidinone **3**,[9a,9c] the present cyclizations with **6b** and **7c** proved to be disappointing, affording generally low d.r.s. Similar cyclizations of 4-pentenoic acid with **6b** or **7c** also provided the corresponding lactones with poor diastereoselectivity (Table 2). The unexpected difference between the remarkably high d.r.s observed in the methoxyselenenylations shown in Table 1 and the low ones measured in the related cyclizations in Table 2 indicates that subtle factors that are not yet fully understood play a determining role in these processes.

An unexpected product was formed when the selenenyl bromide **6a** was prepared in situ in the usual way from equimolar amounts of diselenide **4** and bromine in the absence of both silver triflate and an unsaturated substrate. The resulting bright red product could be isolated via careful and rapid flash chromatography and was stable for several weeks in the refrigerator at −5 °C. Spectroscopic and elemental analyses suggested the unusual structure **11**, which was confirmed by X-ray crystallography.[21] Very few cyclic structures containing the N−O−Se moiety have been reported to date, but include some oxaselenaazapentalenes[22] and, very recently, an oxaselenazolidine.[23]

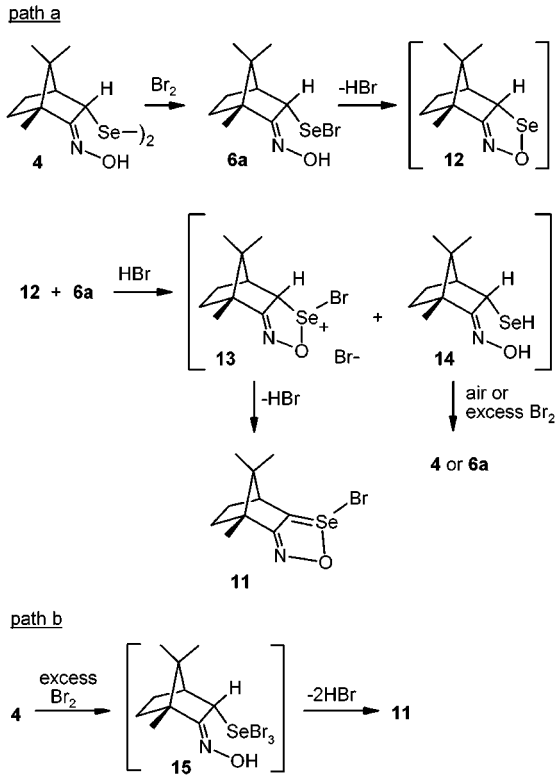
(17) 1,2-Diphenylethanol was partially resolved by the method of: Gerrard, W.; Kenyon, J. *J. Chem. Soc.* **1928**, 2564. The product was then treated with sodium hydride and methyl iodide to afford the corresponding authentic scalemic methyl ether **10**, obtained in an enantiomeric ratio of 63:37, as measured by chiral GC analysis.

(18) It has been previously established that the (*S*)-enantiomer of 1,2-diphenylethanol is dextrorotatory; see: Berti, G.; Bottari, F.; Ferrarini, P, L.; Macchia, B.; *J. Org. Chem*. **1965**, 30, 4091. Since the scalemic mixture of authentic 1,2-diphenylethanol that we obtained was also dextrorotatory, the major enantiomer in this mixture must also have the (*S*)-configuration; therefore, we assume that so does the major isomer in the corresponding authentic scalemic mixture of methyl ethers **10**. The major (*S*)-enantiomer in the scalemic mixture of **10** had the shorter retention time, and a baseline separation of the two enantiomers was possible with a chiral Cyclodex B GC column.

(19) Baldwin, J. E. *J. Chem. Soc., Chem. Commun.* **1976**, 734.

(20) In some other cyclizations of seleniranium ions, different exo vs endo product distributions were observed under kinetic and thermodynamic conditions; see ref 9c and Gruttadauria, M.; Meo, P. L.; Noto, R. *Tetrahedron* **2001**, *57*, 1819.

Scheme 7



A possible explanation for the formation of **11** is that cyclization of **6a** gradually takes place to produce **12**, which then undergoes bromination by the original selenenyl bromide (or by bromine if it is present in excess), followed by deprotonation of **13** (Scheme 7, path a). The byproduct selenol **14** regenerates the original diselenide **4** upon exposure to air or is recycled to the selenenyl bromide in the presence of excess bromine, thereby permitting the formation of additional **11**. Thus, as expected, the yield of **11** improved from 52 to 76% when 3 mol of bromine per mole of diselenide was employed instead of only 1 mol. Alternatively, we considered that the selenenyl tribromide **15** may be formed when the diselenide **4** is treated with excess bromine (Scheme 7, path b), followed by displacement of bromide ion from the selenium atom by the oxime hydroxyl group and elimination of HBr to afford **11**. When product **11** was reduced by sodium borohydride, followed by aerial oxidation, it regenerated diselenide **4**, along with unseparated byproducts tentatively identified as the C-3 epimers of **4**.

In an attempt to obtain additional insight into the formation of **11**, we studied the bromination of diselenides **4** and **5** by ^{1}H NMR spectroscopy. When the oxime benzoate **5** in $CDCl_3$ was treated with an equimolar amount of bromine in carbon tetrachloride, it cleanly produced a single new product, in which a downfield shift

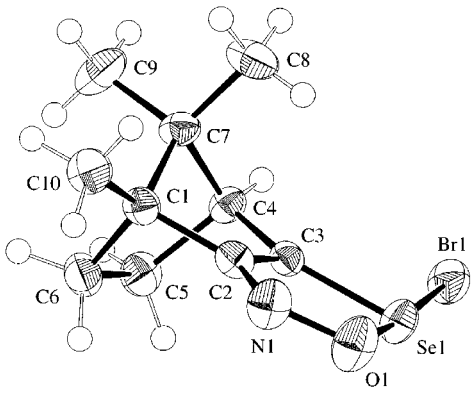


Figure 1. ORTEP diagram of **11**

of the C-3 proton from δ 4.65 to 5.34 (d, J = 3.8 Hz) was consistent with the expected formation of the corresponding selenenyl bromide **7a**. No further change was observed even after 6 h, or when an excess of bromine was added. Thus, the further conversion of **7a** to the corresponding selenium tribromide apparently does not take place under these conditions. This in turn suggests that path b is less likely than path a in Scheme 7, assuming that the selenium tribromide **15** is formed with similar difficulty from diselenide **4** via the further bromination of selenenyl bromide **6a**. When an equimolar amount of bromine was added to the free oxime **4**, its signals disappeared immediately and a new signal was observed at δ 5.25 (dd, J = 4.1, 1.0 Hz) and similarly attributed to the C-3 proton of the selenenyl bromide **6a**. After several hours at room temperature, NMR analysis of the mixture revealed that new signals from **11** had appeared at the expense of the peak at δ 5.25 from **6a**, along with unidentified minor products that were presumably formed from selenol **14**. Unfortunately, intermediates **12** and **13** could not be identified when the reaction was monitored either at room temperature or at −40 °C. Treatment of **4** with 3 or more molar equiv of bromine at room temperature resulted in the clean formation of **11**. These results are consistent with path a in Scheme 7, in which rapid conversion of the diselenide **4** to the selenenyl bromide **6a** is followed by the slower transformation of **6a** to heterocycle **11**.

The X-ray structure of **11** is shown in Figure 1 as an ORTEP diagram. The relatively short bond lengths of 1.790 and 1.313 Å confirm the double-bond character of the C−Se and C−N bonds, respectively. The O and Se atoms are clearly joined by a covalent bond with a bond length of 1.981 Å. The molecules occur as pairs in the unit cell, where the respective O−Se−Br moieties are associated and aligned head-to-tail (see Supporting Information). The O−Se−Br bond angle of 175.94° indicates a nearly linear geometry.

The facile cyclization of the electrophilic selenenyl bromide moiety of **6a** with the adjacent oxime function to afford **12** (and ultimately **11**, as shown in Scheme 7) suggests that more reactive electrophilic selenium analogues of **6a** should undergo similar cyclizations even more readily. Thus, it is possible that methoxyselenylations and other electrophilic reactions carried out with the selenenyl triflate **6b** proceed via initial cyclization to **12**, which then functions as the true electrophilic reagent in subsequent interactions with alkenes. This in turn could account for the differences in diastereoselectivity observed between selenenyl triflate **6b**, containing

(21) For a review of structural organoselenium and tellurium chemistry, see: Hargittai, I.; Roszondai, B. In *The Chemistry of Organic Selenium and Tellurium Compounds*; Patai, S., Rappoport, Z., Eds.; Wiley: Chichester, 1986; Vol. 1, Chapter 3.

(22) (a) Allen, C.; Boeyens, J. C. A.; Briggs, A. G.; Denner, L.; Markwell, A. J.; Reid, D. H.; Rose, B. G. *J. Chem. Soc., Chem. Commun.* **1987**, 967. (b) Dingwall, J. G.; Dunn, A. R.; Reid, D. H.; Wade, K. O. *J. Chem. Soc., Perkin Trans. 1* **1972**, 1360. (c) Llaguno, E.; Paul, I. C. *J. Chem. Soc., Perkin Trans. 2* **1972**, 2001.

(23) Kano, N.; Nakanishi, N.; Daicho, Y.; Kawashima, T. *Chem. Lett.* **2001**, 610.

a free oxime substituent, and its benzoate **7b**. Unfortunately, attempts to isolate **12** have not yet been successful.

In conclusion, it was demonstrated that the presence of an oxime or oxime benzoate substituent at C-2 of the camphor moiety of the corresponding selenenyl triflates **6b** and **7b** dramatically improves the diastereoselectivity of methoxyselenenylations, relative to the 2-keto analogue **2a**. The efficacy of the free oxime **6b** in the methoxyselenenylations of *cis*-alkenes is particularly noteworthy as these substrates tend to provide low d.r.s with other chiral selenium electrophiles. This may be the result of cyclization of selenenyl triflate **6b** to **12** prior to electrophilic addition to the alkene. The isolation of the oxaselenazole **11** from the selenenyl bromide **6a** supports this hypothesis. It was also found that neither **6b**, **7b**, nor **7c** serves as an effective reagent for the asymmetric cyclizations of unsaturated alcohols and carboxylic acids, for which the previously reported spiro-oxazolidinone **3** is recommended.

Experimental Section

^{1}H and ^{13}C NMR spectra were recorded in deuteriochloroform and are reported relative to residual chloroform or TMS as the internal standard. ^{77}Se NMR spectra are reported relative to dimethyl selenide (δ 0.0 ppm). Mass spectra were obtained by EI at 70 eV. Chromatography refers to flash chromatography on silica gel (230−400 mesh), unless otherwise noted.

Di[(1*R*)-2-oximo-*endo*-3-bornyl] Diselenide (4). Diselenide **1**[10] (5.00 g, 10.9 mmol) and hydroxylamine hydrochloride (6.00 g, 86.3 mmol) were refluxed in 200 mL of pyridine for 16 h. The mixture was poured into 400 mL of ether, washed five times with 5% HCl, water, and NaCl solution, dried (Na_2SO_4), and concentrated in vacuo. The product was chromatographed (20% ethyl acetate−hexanes) to afford 5.20 g (98%) of a mixture of geometrical isomers of the diselenide **4** in the ratio of 83:17 (NMR integration). Further chromatography (7% ethyl acetate−hexanes) afforded (3.90 g, 73%) of the *Z,Z* isomer **4** as a yellow solid foam: IR (film) 3237, 1667 cm^{-1}; ^{1}H NMR (200 MHz) δ 8.90 (br s, 2 H), 4.59 (dd, J = 4.4, 1.6 Hz, 2 H), 2.25 (m, 2 H), 2.04−1.44 (m, 8 H), 1.01 (s, 12 H), 0.86 (s, 6 H); ^{13}C NMR (50 MHz) δ 167.2, 52.9, 49.7 48.0, 43.7, 32.0, 23.8, 19.4, 19.2, 11.8; ^{77}Se NMR δ 377.3; MS (*m*/*z*, %) 492 (<1, M$^+$), 474 (6), 228 (19), 41 (100); HRMS calcd for $C_{20}H_{32}N_2O_2Se_2$ 492.0794, found 492.0812.

Di[(1*R*)-2-*O*-benzoyl Oximo-*endo*-3-bornyl] Diselenide (5). Benzoyl chloride (4.37 mL, 37.7 mmol), DMAP (229 mg, 1.87 mmol), and the 83:17 mixture of geometrical isomers of diselenide **4** (4.62 g, 9.42 mmol) were stirred for 9 h at room temperature in 200 mL of pyridine. The mixture was poured into 400 mL of ether, washed five times with 5% HCl, water, and NaCl, dried (Na_2SO_4), and concentrated in vacuo. The residue was chromatographed (elution with 10% ethyl acetate−hexanes) to afford 5.80 g (88%) of **5** as a similar 83:17 mixture of geometrical isomers. Recrystallization from chloroform−hexanes afforded yellow crystals of the pure *Z,Z* diselenide: mp 165−167 °C; IR (film) 1747, 1647 cm^{-1}; ^{1}H NMR (200 MHz) δ 8.26−8.19 (m, 4 H), 7.65−7.55 (m, 2 H), 7.50−7.40 (m, 4 H), 4.65 (d, J = 4.3 Hz, 2 H), 2.24−2.13 (m, 2 H), 2.14−2.01 (m, 2 H), 1.89−1.58 (m, 6 H), 1.18 (s, 6 H), 1.05 (s, 6 H), 0.90 (s, 6 H); ^{13}C NMR (50 MHz) δ 175.0, 163.7, 133.2, 130.0, 128.9, 128.4, 54.4, 49.5, 48.3, 43.7, 31.5, 23.8, 19.6, 19.2, 11.7; ^{77}Se NMR δ 375.3; MS (*m*/*z*, %) 456 (11), 229 (80), 93 (100). Anal. Calcd for $C_{34}H_{40}N_2O_4Se_2$: C, 58.45; H, 5.77; N, 4.01. Found: C, 58.23; H, 5.84; N, 4.00. X-ray crystallographic data for **5** is shown in Supporting Information.

Methoxyselenenylation of *trans*-5-Decene with 6b (Typical Procedure, Table 1, Entry 1). A 1.0 M solution of bromine (0.18 mmol) in tetrachloromethane was added dropwise to a stirred solution of diselenide **4** (89 mg, 0.18 mmol) in 5 mL of dry dichloromethane at −40 °C under argon. After 15 min, a 0.70 M solution of silver triflate (0.53 mmol) in methanol was added, which resulted in an immediate discharge of the orange selenenyl bromide color and produced a light brown heterogeneous mixture. After another 15 min, the mixture was cooled to −78 °C, and *trans*-5-decene (0.18 mL, 0.94 mmol) was added; stirring was continued for 1 h. The reaction was quenched with aqueous $NaHCO_3$ solution and concentrated in vacuo. The residue was chromatographed (elution with 10% ethyl acetate−hexanes) to afford 111 mg (73% based on **4**) of the addition product as a pale yellow oil: IR (neat) 3375, 1649, 1376, 1091, 938 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 3.78 (d, J = 4.3 Hz, 1 H), 3.57−3.46 (m, 1 H), 3.40 (s, 3 H), 3.38−3.32 (m, 1 H), 2.08−2.00 (m, 1 H), 1.91−1.52 (m, 6 H), 1.45−1.20 (m, 10 H), 0.98 (s, 6 H), 0.96−0.85 (m, 6 H), 0.81 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 168.2, 85.4, 58.1, 52.5, 50.2, 48.4, 47.6, 39.6, 31.8, 31.7, 31.3, 30.5, 28.3, 24.1, 22.9, 22.7, 19.1, 18.9, 14.1, 11.8; ^{77}Se NMR major diastereomer: δ 292.7, minor diastereomer: δ 394.0, integrating in the ratio of 92:8; MS (*m*/*z*, %) 417 (3, M$^+$), 399 (8), 228 (10), 148 (54), 106 (67), 69 (100), 41 (80); HRMS calcd for $C_{21}H_{39}NO_2Se$ 417.2146, found 417.2124.

Methoxyselenenylations with **7b** were performed by the same procedure, using diselenide **5** instead of **4**. The other reactions listed in Table 1 were performed similarly, and the properties of the resulting products are as follows.

Methoxyselenenylation of *trans*-5-Decene with 7b (Table 1, Entry 1): IR (neat) 1746, 1649 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.37−8.28 (m, 2 H), 7.62−7.39 (m, 3 H), 4.64 (d, J = 4.2 Hz, 1 H), 3.37 (s, 3 H), 3.27−3.16 (m, 1 H), 3.09−2.98 (m, 1 H), 2.44−2.25 (m, 1 H), 2.06−1.97 (m, 1 H), 1.89−1.20 (m, 15 H), 1.18 (s, 3 H), 1.09 (s, 3 H), 0.97−0.86 (m, 9 H); ^{13}C NMR (50 MHz) major diastereomer: δ 176.2, 164.0, 132.8, 130.2, 129.4, 128.1, 85.8, 58.4, 53.8, 48.3, 44.9, 39.7, 32.1, 31.5, 31.2, 30.6, 28.6, 23.5, 22.9, 22.8, 22.6, 20.0, 19.1, 14.1, 13.9, 11.8; ^{77}Se NMR major diastereomer: δ 251.8, minor diastereomer: δ 279.7, integrating in the ratio of 94:6; MS (*m*/*z*, %) 521 (<1), 69 (100); HRMS calcd for $C_{28}H_{43}NO_3Se$ 521.2408, found 521.2423.

Methoxyselenenylation of 1-Decene with 6b (Table 1, Entry 2): IR (neat) 3281, 1644 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.18 (br s, 1 H), 3.93 (d, J = 4.6 Hz, 1 H), 3.53 (m, 3 H), 3.38 (s, 3 H), 2.01 (m, 1 H), 1.89−1.43 (m, 8 H), 1.39−1.21 (m, 10 H), 0.99 (s, 3 H), 0.97 (s, 3 H), 0.90 (crude t, 3 H), 0.83 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 168.3, 77.6, 58.7, 52.5, 50.6, 48.4, 41.9, 39.1, 32.4, 31.9, 29.7, 29.6, 29.5, 29.3, 27.6, 24.2, 22.6, 19.1, 19.0, 14.1, 11.8; ^{77}Se NMR major diastereomer: δ 275.3, minor diastereomer: δ 184.6, integrating in the ratio of 94:6 (two minor impurities, <5%) were also detected at δ 367.6 and 193.5;[24] MS (*m*/*z*, %) 417 (1, M$^+$), 148 (68), 106 (94), 83 (81), 69 (100); HRMS calcd for $C_{21}H_{39}NO_2Se$ 417.2146, found 417.2159.

Methoxyselenenylation of *trans*-Stilbene with 6b (Table 1, Entry 3): IR (neat) 3281, 1601 cm^{-1}; ^{1}H NMR (200 MHz) δ 9.00 (br s, 1 H), 7.53−7.14 (m, 10 H), 4.73 (s, 2 H), 3.09 (s, 3 H), 2.78 (d, J = 3.8 Hz, 1 H), 1.65−1.3 (m, 5 H), 0.96 (s, 3 H), 0.81 (s, 3 H), 0.47 (s, 3 H); ^{13}C NMR (50 MHz) δ 168.0, 141.2, 140.1, 128.5, 128.3, 128.1, 127.7, 126.7, 87.9, 56.9, 52.4, 50.1, 49.9, 48.1, 40.9, 31.8, 23.6, 18.8, 18.7, 11.8; ^{77}Se NMR δ 347.2; MS (*m*/*z*, %) 457 (<1, M$^+$), 179 (73), 121 (100); HRMS calcd for $C_{25}H_{31}NO_2Se$ 457.1520, found 457.1537. The minor diastereomer was not detected, and the ratio in Table 1 is based on the estimated minimum detection threshold.

Methoxyselenenylation of *trans*-Stilbene with 7b (Table 1, Entry 3): IR (neat) 1744, 1647 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.35−8.27 (m, 2 H), 7.74−7.51 (m, 3 H), 7.31−7.12 (m, 10 H), 4.61 (d, J = 8.6 Hz, 1 H), 4.08

(24) While it is not possible to determine with certainty which, if any, of the three minor ^{77}Se NMR peaks stem from the minor diastereomer of the methoxyselenenylation reaction and which are from trace impurities, the ratio of 94:6 is based on the integration of the signal from the major diastereomer at δ 275.3 and the strongest of the three weaker signals at δ 184.6. Thus, this ratio is the minimum possible value for the diastereomeric ratio.

(d, J = 8.6 Hz, 1 H), 3.12 (d, J = 3.6 Hz, 1 H), 3.09 (s, 3 H), 2.08−1.86 (m, 1 H), 1.77−1.20 (m, 4 H), 1.05 (s, 3 H), 0.93 (s, 3 H), 0.55 (s, 3 H), minor diastereomer: δ 8.26−8.19 (m, 2 H), 4.54 (d, J = 7.2 Hz, 1 H), 4.18 (d, J = 7.2 Hz, 1 H), 0.62 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 176.7, 164.0, 140.3, 139.3, 133.0, 130.1, 129.6, 129.2, 128.3, 128.2, 128.0, 127.8, 127.4, 127.1, 87.5, 57.1, 53.8, 50.1, 48.7, 48.2, 41.4, 31.4, 23.7, 19.6, 18.8, 11.6; ^{77}Se NMR major diastereomer: δ 355.8. Signals from the minor diastereomer could not be clearly discerned in either the ^{13}C or ^{77}Se NMR spectra. The average integration of three separate sets of ^{1}H NMR signals gave the ratio of 90:10. Attempted EI mass spectrometry resulted in extensive fragmentation. The product was subjected to deselenization (vide infra), and the deselenized product was characterized further.

Methoxyselenenylation of *cis*-Stilbene with 6b (Table 1, Entry 4): IR (neat) 3415, 1636 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 7.24−7.07 (m, 10 H), 4.73 (d, J = 9.2 Hz, 1 H), 4.58 (d, J = 9.2 Hz, 1 H), 3.34 (d, J = 5.0 Hz, 1 H), 3.28 (s, 3 H), 1.79−1.51 (m, 5 H), 0.93 (s, 3 H), 0.87 (s, 3 H), 0.51 (s, 3 H), minor diastereomer: δ 4.76 (d, J = 9.0 Hz, 1 H), 4.57 (d, J = 9.0 Hz, 1 H), 3.26 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 168.4, 139.8, 130.0, 129.6, 127.9 (2 signals), 127.6, 127.2, 126.9, 88.2, 57.0, 52.5, 52.1, 50.0, 48.1, 38.9, 32.1, 24.1, 18.9, 18.6, 11.7; ^{77}Se NMR major diastereomer: δ 366.6, minor diastereomer: δ 454.9, integrating in the ratio of 90:10; MS (m/z, %) 457 (<1, M$^+$), 439 (1), 409 (2), 121 (100). The product was subjected to deselenization (vide infra), and the deselenized product was characterized further.

Methoxyselenenylation of *cis*-Stilbene with 7b (Table 1, Entry 4): IR (neat) 1744, 1649 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.41−8.33 (m, 2 H), 7.78−7.46 (m, 3 H), 7.23−6.96 (m, 9 H), 6.93−6.78 (m, 1 H), 4.52 (d, J = 9.4 Hz, 1 H), 4.34 (d, J = 9.4 Hz, 1 H), 3.75 (d, J = 3.9 Hz, 1 H), 3.23 (s, 3 H), 2.05−1.82 (m, 1 H), 1.80−1.47 (m, 4 H), 1.11 (s, 3 H), 0.92 (s, 3 H), 0.62 (s, 3 H), minor diastereomer: δ 8.32−8.26 (m, 2 H), 4.26 (d, J = 8.7 Hz, 1 H), 3.85 (d, J = 3.9 Hz, 1 H), 0.97 (s, 3 H); integration of the signals at δ 3.75 and 3.85 gave the ratio of 77:23; ^{13}C NMR (50 MHz) major diastereomer: δ 177.7, 164.4, 139.3, 139.0, 132.9, 132.8, 130.2, 129.1, 128.5, 128.2, 127.9, 127.2, 88.5, 56.9, 54.1, 51.9, 49.4, 48.2, 41.0, 31.7, 23.9, 19.3, 18.7, 11.7, minor diastereomer: δ 176.8, 164.0, 138.9, 133.1, 129.0, 127.8, 127.7, 88.7, 57.2, 53.9, 51.5, 48.6, 48.4, 40.2, 23.6, 19.8. Attempted EI mass spectrometry resulted in extensive fragmentation. The product was subjected to deselenization (vide infra), and the deselenized product was characterized further.

Methoxyselenenylation of Styrene with 6b (Table 1, Entry 5): IR (neat) 3293, 1668 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 7.41−7.28 (m, 5 H), 4.46 (dd, J = 8.4, 4.6 Hz, 1 H), 3.81 (d, 4.3 Hz, 1 H), 3.27 (s, 3 H), 3.21 (dd, J = 12.1, 8.4 Hz, 1 H), 3.01 (dd, J = 12.3, 4.8 Hz, 1 H), 2.00−1.92 (m, 1 H), 1.9−1.47 (m, 5 H), 0.98 (s, 3 H), 0.95 (s, 3 H), 0.75 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 168.0, 141.5, 128.4, 127.8, 126.5, 84.5, 56.9, 52.4, 50.0, 48.3, 39.5, 32.8, 31.9, 23.9, 19.1, 18.9, 11.8; ^{77}Se NMR major diastereomer: δ 212.1, minor diastereomer: δ 206.3, integrating in the ratio of 94:6; MS (m/z, %) 381 (<1, M$^+$), 363 (1, M$^+$ − H_2O), 121 (100); HRMS calcd for $C_{19}H_{27}NO_2Se$ 381.1207, found 381.1203.

Methoxyselenenylation of α-Methylstyrene with 7b (Table 1, Entry 6): IR (neat) 1744, 1647 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.38−8.23 (m, 2 H), 7.69−7.42 (m, 3 H), 7.39−7.18 (m, 5 H), 3.54 (d, J = 3.6 Hz, 1 H), 3.10 (s, 3 H), 3.00 (d, J = 12.3 Hz, 1 H), 2.80 (d, J = 12.5 Hz, 1 H), 2.16−1.98 (m, 1 H), 1.9−1.7 (m, 3 H), 1.66 (s, 3 H), 1.63−1.45 (m, 1 H), 1.11 (s, 3 H), 0.98 (s, 3 H), 0.71 (s, 3 H), minor diastereomer: δ 4.05 (d, J = 4.1 Hz, 1 H), 3.08 (s, 3 H), 2.92 (d, J = 7.0 Hz, 1 H), 1.14 (s, 3 H), 1.02 (s, 3 H), 0.81 (s, 3 H); integration of the signals at δ 3.54 and 4.05 provided the ratio of 82:18; ^{13}C NMR (50 MHz) major diastereomer: δ 176.6, 164.0, 143.3, 133.0, 130.0, 128.2, 128.1, 127.4, 127.3, 126.4, 79.5, 53.9, 53.8, 51.0, 48.3, 39.6, 38.5, 31.4, 23.5, 22.3, 19.7, 19.0, 11.7, minor diastereomer: δ 143.7, 126.2, 79.2, 50.8, 48.6, 40.2, 38.8, 22.8; MS (m/z, %) 377 (1), 135 (76), 105 (100); HRMS calcd for $C_{27}H_{33}NO_3Se$ 499.1626, found 499.1645.

Methoxyselenenylation of Cyclopentene with 6b (Table 1, Entry 7): IR (neat) 3308, 1652 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 7.86 (br s, 1 H), 4.04 (dd, J = 4.4, 1.4 Hz, 1 H), 3.81−3.73 (m, 1 H), 3.69−3.58 (m, 1 H), 3.32 (s, 3 H), 2.19 (m, 1 H), 2.09−1.47 (m, 10 H), 1.01 (s, 3 H), 0.98 (s, 3 H), 0.86 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 167.7, 90.0, 56.7, 52.4, 50.1, 48.3, 43.0, 39.0, 31.9, 31.6, 30.9, 24.0, 23.0, 19.2, 18.9, 11.8, minor diastereomer: δ 167.6, 88.7, 49.8, 48.2, 43.1, 38.9, 32.5, 31.7, 31.1, 29.6, 23.9, 22.9, 19.3; ^{77}Se NMR major diastereomer: δ 293.3, minor diastereomer: δ 297.9, integrating in the ratio of 87:13; MS (m/z, %) 345 (1, M$^+$), 313 (2), 148 (39), 106 (100); HRMS calcd for $C_{16}H_{27}NO_2Se$ 345.1207, found 345.1218.

Methoxyselenenylation of Cyclopentene with 7b (Table 1, Entry 7): IR (neat) 1744, 1647 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.33−8.17 (m, 2 H), 7.64−7.41 (m, 3 H), 4.44 (dd, J = 4.4, 1.5 Hz, 1 H), 3.86−3.78 (m, 1 H), 3.23 (s, superimposed on m at δ 3.28−3.18, total 4 H), 2.37−1.45 (m, 11 H), 1.19 (s, 3 H), 1.09 (s,3 H), 0.95 (s, 3 H), minor diastereomer: δ 4.32 (dd, J = 4.3, 1.7 Hz, 1 H), 3.31 (s, 3 H), 1.06 (s, 3 H); integration of signals at δ 4.44 and 4.32 gave a ratio of 75:25; ^{13}C NMR (50 MHz) major diastereomer: δ 176.2, 163.9, 132.9, 130.0, 129.4, 128.2, 89.3, 56.7, 53.8, 48.6, 48.5, 42.3, 39.8, 31.4 (two signals), 30.3, 23.6, 22.8, 19.8, 19.1, 11.7, minor diastereomer: δ 176.9, 164.1, 129.6, 89.7, 56.8, 53.9, 49.5, 43.4, 40.4, 31.5, 30.8, 24.0, 22.6, 19.5; MS (m/z, %) 449 (<1, M$^+$), 328 (3), 227 (11), 148 (45), 132 (40), 97 (100); HRMS calcd for $C_{23}H_{31}NO_3Se$ − $PhCO_2$ 328.1180, found 328.1189.

Methoxyselenenylation of Cyclohexene with 6b (Table 1, Entry 8): IR (neat) 3342, 1661 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 4.24 (dd, J = 4.3, 1.7 Hz, 1 H), 3.40 (s, 3 H), 3.34−3.13 (m, 2 H), 2.26−2.09 (m, 2 H), 2.08−1.99 (m, 1 H), 1.93−1.16 (m, 10 H), 0.99 (s, 3 H), 0.96 (s, 3 H), 0.82 (s, 3 H), minor diastereomer: δ 4.18 (dd, J = 4.1, 1.5 Hz, 1 H), 3.39 (s, 3 H), 1.05 (s, 3 H), 0.92 (s, 3 H); integration of peaks at δ 4.24 and 4.18 gave a ratio of 88:12; ^{13}C NMR (50 MHz) major diastereomer: δ 168.6, 85.15, 56.7, 52.4, 50.3, 48.3, 44.7, 39.7, 32.0, 31.6, 30.6, 26.1, 24.1, 23.6, 19.1, 19.0, 11.7; ^{77}Se NMR major diastereomer δ 303.9; MS (m/z, %) 359 (1, M$^+$), 341 (4), 81 (100); HRMS calcd for $C_{17}H_{29}NO_2Se$ 359.1364, found 359.1371.

Methoxyselenenylation of Cyclohexene with 7b (Table 1, Entry 8): IR (neat) 1745, 1647 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.38−8.29 (m, 2 H), 7.67−7.40 (m, 3 H), 4.63 (dd, J = 4.3, 1.2 Hz, 1 H), 3.34 (s, 3 H), 3.30−3.13 (m, 1 H), 2.88−2.76 (m, 1 H), 2.33−1.98 (m, 4 H), 1.90−1.24 (m, 9 H), 1.18 (s, 3 H), 1.08 (s, 3 H), 0.94 (s, 3 H), minor diastereomer: δ 8.21−8.12 (m, 2 H), 7.63−7.51 (m, 3 H), 4.48 (dd, J = 4.6, 1.7 Hz, 1 H), 3.36 (s, 3 H), 1.03 (s, 3 H), 0.94 (s, 3 H); integration of signals at δ 4.63 and 4.48 gave a ratio of 62:38; ^{13}C NMR (50 MHz) major diastereomer: δ 176.7, 164.1, 132.8, 130.1, 129.5, 128.2, 85.4, 56.4, 48.7, 48.4, 43.1, 39.9, 31.5 (two signals), 31.4, 30.5, 25.9, 24.1, 23.6, 19.9, 19.0, 11.7, minor diastereomer: δ 178.6, 164.3, 85.8, 56.5, 54.1, 31.4, 30.7, 25.6, 23.4, 19.4, 19.1; MS (m/z, %) 105 (99), 81 (100), 77 (95); HRMS calcd for $C_{24}H_{33}NO_3Se$ 463.1626, found 463.1621.

Methoxyselenenylation of 1-Methyl-1-cyclohexene with 6b (Table 1, Entry 9): IR (neat) 3326, 1639 cm^{-1}; ^{1}H NMR (200 MHz) δ 8.08 (br s, 1 H), 3.94 (dd, J = 4.1, 1.5 Hz, 1 H), 3.38 (dd, J = 8.6, 3.9 Hz, 1 H), 3.24 (s, 3 H), 2.22−2.08 (m, 1 H), 2.06−1.98 (m, 1 H), 1.95−1.20 (m, 11 H), 1.32 (s, 3 H), 0.99 (s, 6 H), 0.85 (s, 3 H); ^{13}C NMR (50 MHz) δ 167.9, 77.2, 52.5, 50.2, 48.8, 48.4, 48.2, 39.6, 34.7, 31.8, 30.6, 24.7, 24.1, 22.3, 21.1, 19.3, 19.0, 11.7; ^{77}Se NMR δ 258.7; MS (m/z, %) 373 (<1, M$^+$) 355 (1), 95 (93), 41 (100); HRMS calcd for $C_{18}H_{31}NO_2Se$ 373.1520, found 373.1512. The minor diastereomer was not detected, and the ratio in Table 1 is based on the estimated minimum detection threshold.

Methoxyselenenylation of 1-Methyl-1-cyclohexene with 7b (Table 1, Entry 9): IR (neat) 1746, 1649 cm^{-1}; ^{1}H NMR (200 MHz) δ 8.40−8.25 (m, 2 H), 7.67−7.37 (m, 3 H), 4.52 (d, J = 4.3 Hz, 1 H), 3.14 (s, 3 H), 3.02 (dd, J = 9.1, 3.8 Hz, 1 H), 2.35−2.19 (m, 1 H), 2.18−1.15 (m, 12 H), 1.29 (s, 3 H), 1.16 (s, 3 H), 1.07 (s, 3 H), 0.91 (s, 3 H); ^{13}C NMR (50 MHz) δ 176.5, 164.1, 132.8, 130.1, 129.5, 128.2, 77.7, 53.8, 48.4 (two signals),

48.3, 48.2, 40.7, 34.5, 31.4, 30.4, 25.1, 23.8, 22.2, 20.2, 20.0, 19.0, 11.7; ^{77}Se NMR δ 274.8; MS (*m*/*z*, %) 355 (5, M^+ − PhCOOH), 127 (80), 105 (99), 95 (100); HRMS calcd for $C_{25}H_{35}NO_3Se$ − PhCOOH 355.1414, found 355.1445. The minor diastereomer was not detected, and the ratio in Table 1 is based on the estimated minimum detection threshold.

Methoxyselenenylation of 1-Phenyl-1-cyclohexene with 6b (Table 1, Entry 10): IR (neat) 3405, 1639 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.15 (br s, 1 H), 7.53−7.2 (m, 5 H), 3.73 (br s, 1 H), 2.97 (s, 3 H), 2.62−2.53 (m, 1 H), 2.51−2.3 (m, 1 H), 2.16−1.98 (m, 2 H), 1.73−1.18 (m, 11 H), 0.85 (s, 3 H), 0.76 (s, 3 H), 0.43 (s, 3 H); ^{13}C NMR (50 MHz,) major diastereomer: δ 168.8, 143.9, 127.7, 127.0, 81.0, 52.7, 52.2, 50.4, 50.1, 47.9, 41.5, 31.9, 29.7, 25.7, 23.8, 22.6, 20.9, 18.7, 18.6, 11.7; ^{77}Se NMR major diastereomer: δ 298.7, minor diastereomer: δ 390.5, integrating in the ratio of 90:10; MS (*m*/*z*, %) 435 (1, M^+), 417 (6), 91 (100); HRMS calcd for $C_{23}H_{33}NO_2Se$ 435.1677, found 435.1696.

Methoxyselenenylation of 1-Phenyl-1-cyclohexene with 7b (Table 1, Entry 10): IR (neat) 1746, 1648 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.42−8.32 (m, 2 H), 7.74−7.53 (m, 3 H), 7.50−7.35 (m, 2 H), 7.22−7.09 (m, 3 H), 3.04 (m, 1 H), 3.00 (s, 3 H), 2.71−2.46 (m, 2 H), 2.42−2.34 (m, 1 H), 2.18−1.89 (m, 4 H), 1.79−1.33 (m, 7 H), 1.03 (s, 3 H), 0.96 (s, 3 H), 0.46 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 175.9, 163.8, 143.7, 133.0, 130.2, 129.4, 128.1, 127.8, 127.4, 127.3, 80.8, 53.6, 50.5, 48.9, 47.8, 47.7, 39.3, 31.3, 30.2, 25.3, 23.4, 22.3, 20.9, 20.0, 18.8, 11.6; ^{77}Se NMR major diastereomer: δ 295.9, minor diastereomer: δ 287.8, integrating in the ratio of 95:5; other minor signals in the ^{77}Se NMR spectrum were observed at 387.9 and 19.2 ppm and were attributed to impurities present in amounts of ca. 7 and <1%, respectively;[25] MS (*m*/*z*, %) 539 (<1, M^+), 417 (3, M^+ − PhCOOH), 105 (100); HRMS calcd for $C_{30}H_{37}NO_3Se$ − PhCOOH 417.1571, found 417.1565.

Methoxyselenenylation of Cycloheptene with 6b (Table 1, Entry 11): IR (neat) 3302, 1657 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 7.88 (br s, 1 H), 4.19 (dd, J = 4.3, 1.5 Hz, 1 H), 3.63−3.42 (m, 2 H), 3.36 (s, 3 H), 2.19−1.23 (m, 15 H), 1.00 (s, 3H), 0.98 (s, 3H), 0.85 (s, 3H), minor diastereomer: δ 4.06 (dd, J = 4.1, 1.4 Hz, 1 H), 3.35 (s, 3 H), 1.04 (s, 3 H), 0.91 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 168.0, 87.9, 56.7, 52.4, 50.2, 48.3, 46.9, 39.7, 32.0, 31.1, 30.3, 28.7, 26.8, 24.0, 22.0, 19.1, 19.0, 11.7, minor diastereomer: δ 170.7, 88.3, 54.5, 53.4, 50.0, 47.9, 41.0, 33.3, 21.5, 11.1; ^{77}Se NMR major diastereomer: δ 328.9, minor diastereomer: δ 301.0, integrating in the ratio of 86:14; MS (*m*/*z*, %) 373 (3, M^+), 148 (78), 106 (100); HRMS calcd for $C_{18}H_{31}NO_2Se$ 373.1520, found 373.1538.

Methoxyselenenylation of Cycloheptene with 7b (Table 1, Entry 11): IR (neat) 1745, 1650 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.39−8.07 (m, 2 H), 7.69−7.38 (m, 3 H), 4.48 (dd, J = 4.5, 1.4 Hz, 1 H), 3.60−3.37 (m, 1 H), 3.28 (s, 3 H), 3.22−3.06 (m, 1 H), 2.40−1.30 (m, 15 H), 1.18 (s, 3 H), 1.08 (s, 3 H), 0.95 (s, 3 H), minor diastereomer: δ 3.33 (s, 3 H), 1.27 (s, 3 H), 1.05 (s, 3 H); integration of signals at δ 3.28 and 3.33 gave a ratio of 73:27; ^{13}C NMR (50 MHz) major diastereomer: δ 176.6, 164.1, 132.9, 130.1, 130.0, 128.3, 87.4, 56.4, 53.9, 48.7, 48.5, 45.6, 40.1, 31.5, 30.9, 29.8, 28.6, 26.5, 23.7, 21.9, 19.9, 19.1, 11.8, minor diastereomer: δ 177.6, 129.7, 129.5, 87.8, 56.7, 54.0, 49.5, 46.7, 40.4, 31.6, 30.8, 30.2, 29.7, 26.1, 23.9, 22.3, 19.6; MS (*m*/*z*, %) 477 (<1, M^+), 356 (2), 146 (29), 127 (61), 95 (100); HRMS calcd for $C_{25}H_{35}NO_3Se$ − $PhCO_2$ 356.1493, found 356.1512.

Deselenization of the Adduct from Styrene and 6b. A mixture of triphenyltin hydride (517 mg, 1.47 mmol) and AIBN (26.9 mg) was added to a solution of the methoxyselenenylation product obtained from styrene with **6b** (Table 1, entry 5) (277 mg, 0.73 mmol) in 5 mL of refluxing toluene. After 2 h, additional triphenyltin hydride (260 mg, 0.74 mmol) and AIBN (13.5 mg) were added, and heating was continued for 1 h. The reaction mixture was then concentrated in vacuo, and the residue was purified by chromatography (elution with 5% ethyl acetate−hexanes) to afford 38 mg (38%) of **8** containing traces of tin-containing impurities. This was subjected to GC analysis using a chiral 30 m × 0.32 mm Cyclodex B column, which provided a nearly baseline separation of the two enantiomers of **8**, obtained in the ratio of 98:2. This mixture was compared to authentic (*R*)-**8** prepared by the treatment of authentic, commercial (*R*)-1-phenylethanol with sodium hydride and methyl iodide in THF solvent for 3 h. The resulting authentic (*R*)-**8** was identical by chiral GC to the major diastereomer of **8** obtained in the above deselenization. The identity of the product was confirmed by NMR and GC-MS analysis.

Deselenization of Adducts from *cis*- and *trans*-Stilbene and 6b or 7b. The mixtures of diastereomers obtained from the methoxyselenenylation of *cis*- and *trans*-stilbene with **6b** and **7b** (Scheme 6 and Table 1, entries 3 and 4) were deselenized as in the preceding procedure. The resulting products **10** were compared with an authentic mixture of (*R*)- and (*S*)-**10**, obtained in the ratio of 37:63 by a literature method.[17,18] GC analysis on a chiral Cyclodex B column thus permitted identification of the major and minor enantiomers of **10** obtained by deselenization, as well as their ratio. The identity of each enantiomer in the deselenized product mixtures was further confirmed by adding the deselenized product to a racemic mixture of authentic **10** and observing whether the peak with the shorter or longer retention time (corresponding to *S*- and *R*-enantiomers, respectively) was enhanced. The results are summarized in Scheme 6. The identity of the deselenized products was further confirmed by IR, NMR, MS, and HRMS analysis.

Cyclization of 4-Penten-1-ol with 6b (Typical Procedure, Table 2, Entry 1). A 1.0 M solution of bromine (0.20 mmol) in tetrachloromethane was added dropwise to a stirred solution of diselenide **4** (100 mg, 0.20 mmol) in 5 mL of dry dichloromethane at −40 °C under argon. After 15 min, a 0.70 M methanol solution of silver triflate (0.63 mmol) was added to the reaction mixture. After another 15 min, the mixture was cooled to −78 °C, and 4-penten-1-ol (0.083 mL, 0.80 mmol) was added; stirring was continued for 1 h. The mixture was then concentrated in vacuo, triturated with a minimum amount of chloroform, and filtered through a plug of silica gel. Reconcentration of the filtrate and chromatography (elution with 10% ethyl acetate−hexanes) afforded 73.4 mg (55%) of the cyclization product as a colorless oil: IR (neat) 3297, 1456 cm^{-1}; ^{1}H NMR (200 MHz), coinciding signals from both diastereomers: δ 4.22−4.03 (m, 1 H), 3.98 (d, J = 5.0 Hz, 1 H), 3.92−3.69 (m, 2 H), 3.10−2.74 (m, 2 H), 2.12−2.01 (m, 1 H), 1.98−1.50 (m, 8 H), 0.99 (s, 3 H), 0.97 (s, 3 H), 0.82 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 167.9, 79.3, 68.2, 52.4, 50.0, 48.3, 39.5, 31.9, 31.7, 30.5, 25.9, 23.9, 19.1, 18.9, 11.8, minor diastereomer: δ 167.9, 78.9, 68.2, 49.8, 39.2, 31.6, 26.0; ^{77}Se NMR major diastereomer: δ 192.6, minor diastereomer: δ 187.3, integrating in the ratio of 60:40; MS (*m*/*z*, %) 314 (1, M^+ − OH), 313 (1, M^+ − H_2O), 41 (100); HRMS calcd for $C_{15}H_{25}NO_2Se$ − OH 314.1023, found 314.1027.

Cyclization of 4-Penten-1-ol with 7c (Typical Procedure, Table 2, Entry 1). Sulfuryl chloride (6.4 μL, 0.08 mmol) was added to an ice-cooled solution of diselenide **5** (44.0 mg, 0.063 mmol) in 1.5 mL of dry dichloromethane. The resulting orange solution was stirred at 0 °C for 15 min and then cooled to −78 °C, at which time 25.5 μL of 4-penten-1-ol (0.25 mmol) was added and stirring was continued for 45 min. The mixture was then warmed to room temperature and concentrated in vacuo. The crude product was taken up in a minimum amount of chlorofrom and filtered through a plug of silica gel. The filtrate was reconcentrated under reduced pressure and chromatographed (elution with 15% ethyl acetate−hexanes) to afford 34.7 mg (63% based on **5**) of the corresponding cyclic ether as a colorless oil; IR (neat) 1743, 1649 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.31−8.19 (m, 2 H), 7.65−7.39 (m, 3 H), 4.32 (dd, J = 4.4, 1.4 Hz, 1 H), 4.13−3.94 (m, 1 H), 3.91−3.64 (m, 2 H), 2.81−2.63 (m, 2 H), 2.25−1.48 (m, 9 H), 1.17 (s, 3 H), 1.07 (s, 3 H), 0.92 (s, 3 H), minor diastere-

(25) We tentatively assign the peak at δ 287.8 to the minor diastereomer because of its similar chemical shift to that of the major diastereomer at δ 295.9. The other signals that were detected at δ 387.9 and 19.2 are therefore assigned to minor impurities.

omer: δ 4.40 (dd, J = 4.4, 1.4 Hz, 1 H); integration of signals at δ 4.32 and 4.40 gave a ratio of 67:33; ^{13}C NMR (50 MHz) major diastereomer: δ 176.5, 164.1, 132.9, 130.0, 129.5, 128.2, 78.8, 68.2, 54.0, 49.0, 48.5, 40.2, 31.6, 31.5, 30.1, 25.9, 23.7, 19.6, 19.1, 11.7, minor diastereomer: δ 176.3, 164.0, 129.4, 78.9, 68.3, 48.7, 39.6, 31.7, 31.6, 29.7, 25.9, 23.6, 19.7; MS (*m*/*z*, %) 313 (1, M^+ − PhCOOH), 77 (100); HRMS calcd for $C_{22}H_{29}NO_3Se$ − PhCOOH 313.0945, found 313.0933.

The other reactions listed in Table 2 were performed similarly to the above two procedures, and the properties of the resulting products are as follows.

Cyclization of 5-Hexen-1-ol with 6b (Table 2, Entry 2): IR (neat) 3297 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: 8.90 (broad s, 1 H), 4.05−3.86 (m, 2 H), 3.57−3.25 (m, 2 H), 3.01−2.74 (m, 2 H), 2.10−1.98 (m, 1 H), 1.87−1.23 (m, 10 H), 0.98 (s, 3 H), 0.95 (s, 3 H), 0.81 (s, 3 H), minor diastereomer: δ 8.98 (broad s, 1 H); ^{13}C NMR (50 MHz) major diastereomer: δ 167.7, 77.9, 68.6, 52.4, 49.8, 48.3, 39.2, 31.9, 31.3, 31.2, 25.8, 23.9, 23.4, 19.2, 19.0, 11.8, minor diastereomer: δ 167.9, 78.3, 50.0, 39.6, 32.0, 23.9, 19.1; ^{77}Se NMR major diastereomer: δ 190.6, minor diastereomer: δ 196.6, integrating in the ratio of 57:43; MS (*m*/*z*, %) 345 (4, M^+), 148 (87), 106 (100), 99 (86), 67 (97), 43 (98); HRMS calcd for $C_{16}H_{27}NO_2Se$ 345.1207, found 345.1216.

Cyclization of 5-Hexen-1-ol with 7c (Table 2, Entry 2): IR (neat) 1749 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.30−8.20 (m, 2 H), 7.65−7.41 (m, 3 H), 4.37 (dd, J = 4.6, 1.5 Hz, 1 H), 4.02−3.87 (m, 1 H), 3.50−3.27 (m, 2 H), 2.81−2.50 (m, 2 H), 2.23−2.00 (m, 2 H), 1.90−1.23 (m, 9 H), 1.17 (s, 3 H), 1.07 (s, 3 H), 0.92 (s, 3 H), minor diastereomer: δ 4.30 (dd, J = 4.6, 1.5 Hz, 1 H); integration of signals at δ 4.37 and 4.30 gave a ratio of 60:40; ^{13}C NMR (50 MHz) major diastereomer: δ 176.3, 164.1, 132.9, 130.0, 129.4, 128.2, 78.0, 68.5, 53.9, 48.7, 48.5, 39.8, 31.9, 31.5, 30.2, 25.7, 23.6, 23.3, 19.7, 19.1, 11.7, minor diastereomer: δ 176.7, 164.1, 130.0, 129.5, 77.9, 49.1, 40.2, 31.8, 30.7, 23.8, 19.6; MS (*m*/*z*, %) 328 (2, M^+ − PhCOO), 105 (80), 77 (100); HRMS calcd for $C_{23}H_{31}NO_3Se$ − PhCOO 328.1180, found 328.1196.

Cyclization of (*E*)-4-Hexen-1-ol with 7c (Table 2, Entry 3): IR (neat) 1741 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.28−8.14 (m, 2 H), 7.62−7.38 (m, 3 H), 5.48−5.36 (m, 1 H), 4.35 (dd, J = 4.3, 1.2 Hz, 1 H), 4.00−3.58 (m, 2 H), 3.49−3.30 (m, 1 H), 2.28−1.50 (m, 9 H), 1.32 (t, J = 6.3 Hz, 3 H), 1.16 (s, 3 H), 1.05 (s, 3 H), 0.91 (s, 3 H), minor diastereomer: δ 4.45 (dd, J = 4.3, 1.2 Hz, 1 H), 3.25−3.08 (m, 1 H), 2.71−2.50 (m, 1 H); ^{13}C NMR (50 MHz), integration of signals at δ 4.35 and 4.45 gave a ratio of 71:29, major diastereomer: δ 176.0, 163.9, 133.1, 129.9, 129.2, 128.3, 79.2, 67.9, 53.7, 49.2, 48.6, 43.5, 39.7, 32.4, 31.3, 27.8, 23.7, 20.9, 19.8, 19.0, 11.7, minor diastereomer: δ 176.8, 132.9, 130.0, 129.4, 128.2, 83.5, 68.3, 53.9, 48.7, 48.4, 39.8, 31.4, 28.9, 26.1, 23.6, 18.3, 17.9; MS (*m*/*z*, %) 328 (3, M^+ − PhCOO), 99 (81), 77 (100); HRMS calcd for $C_{23}H_{31}NO_3Se$ − PhCOO 328.1180, found 328.1190.

Cyclization of 2-Allylphenol with 6b (Table 2, Entry 4): IR (neat) 3350 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 9.17 (broad s, 1 H), 7.22−7.04 (m, 2 H), 6.84 (t, J = 7.3 Hz, 1 H), 6.76 (d, J = 8.0 Hz, 1 H), 5.18−4.94 (m, 1 H), 3.99 (d, J = 4.3 Hz, 1 H), 3.47−3.22 (m, 2 H), 3.21−2.95 (m, 2 H), 2.17−2.08 (m, 1 H), 1.90−1.25 (m, 4 H), 1.01 (s, 3 H), 0.97 (s, 3 H), 0.85 (s, 3 H), minor diastereomer: δ 9.22 (broad s, 1 H), 4.11 (d, J = 4.3 Hz, 1 H), 2.03−1.94 (m, 1 H), 1.02 (s, 3 H), 0.93 (s, 3 H), 0.91 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 167.8, 159.2, 127.9, 126.4, 124.9, 120.4, 109.4, 83.1, 52.4, 50.1, 48.4, 39.8, 35.7, 31.9, 30.4, 24.0, 19.1, 19.0, 11.8, minor diastereomer: δ 159.2, 127.9, 126.5, 109.3, 82.7, 49.7, 48.4, 39.4, 36.0, 30.3, 23.8, 19.1; ^{77}Se NMR major diastereomer: δ 194.0, minor diastereomer: δ 183.8, integrating in the ratio of 53:47; MS (*m*/*z*, %) 379 (1, M^+), 131 (100); HRMS calcd for $C_{19}H_{25}NO_2Se$ 379.1051, found 379.1061.

Cyclization of 2-Allylphenol with 7c (Table 2, Entry 4): IR (neat) 1716 cm^{-1}; ^{1}H NMR (200 MHz) major diastereomer: δ 8.38−8.22 (m, 2 H), 7.66−7.39 (m, 3 H), 7.21−7.03 (m, 2 H), 6.95−6.76 (m, 2 H), 4.58−4.36 (m, 2 H), 3.49−2.79 (m, 4 H), 2.20−1.46 (m, 5 H), 1.14 (s, 3 H), 1.03 (s, 3 H), 0.88 (s, 3 H), minor diastereomer: δ 1.11 (s, 3 H), 0.99 (s, 3 H), 0.87 (s, 3 H), integration of signals at δ 1.03 and 0.99 gave a ratio of 66:34; ^{13}C NMR (50 MHz) major diastereomer: δ 176.5, 164.9, 154.4, 133.4, 131.6, 130.1, 128.8, 128.5, 123.7, 120.2, 115.7, 61.9, 54.0, 48.6, 48.4, 40.1, 39.5, 31.5, 32.0, 23.6, 19.6, 19.1, 11.6, minor diastereomer: δ 176.5, 154.5, 131.5, 130.2, 128.3, 61.7, 48.5, 48.2, 40.4, 39.7; MS (*m*/*z*, %) 362 (1), 361 (<1), 131 (100); HRMS calcd for $C_{26}H_{29}NO_3Se$ − PhCOOH 361.0945, found 361.0966.

Cyclization of 4-Pentenoic Acid with 6b (Table 2, Entry 5): IR (neat) 3417, 1772, 1640, cm^{-1}; ^{1}H NMR (200 MHz) both diastereomers: δ 4.92−4.65 (m, 1 H), 3.99−3.86 (m, 1 H), 3.30−3.11 (m, 1 H), 3.09−2.90 (m, 1 H), 2.71−2.32 (m, 4 H), 2.13−1.90 (m, 1 H), 1.82−1.66 (m, 3 H), 1.62−1.49 (m, 1 H), 0.99 (s, 3 H), 0.97 (s, 3 H), 0.83 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 176.8, 167.9, 79.8, 52.4, 49.8, 48.5, 40.3, 31.9, 29.8, 28.8, 27.6, 23.9, 19.0, 18.9, 11.7, minor diastereomer: δ 176.6, 167.7, 80.5, 50.0, 40.1, 28.8, 28.0; ^{77}Se NMR major diastereomer: δ 175.8, minor diastereomer: δ 190.2, integrating in the ratio of 58:42; MS (*m*/*z*, %) 345 (1, M^+), 327 (3, $M^+ - H_2O$), 41 (100); HRMS calcd for $C_{15}H_{23}NO_3Se$ 345.0843, found 345.0866.

Cyclization of 4-Pentenoic Acid with 7c (Table 2, entry 5): IR (neat) 1774, 1744, 1649 cm^{-1}; ^{1}H NMR (200 MHz) both diastereomers: δ 8.20 (d, J = 7.9 Hz, 2 H), 7.65−7.41 (m, 3 H), 4.79−4.59 (m, 1 H), 4.36 (d, J = 4.1 Hz, 1 H), 2.96−2.72 (m, 2 H), 2.62−2.45 (m, 2 H), 2.41−2.22 (m, 1 H), 2.14−2.07 (m, 1 H), 2.04−1.59 (m, 5 H), 1.18 (s, 3 H), 1.06 (s, 3 H), 0.94 (s, 3 H); ^{13}C NMR (50 MHz) major diastereomer: δ 176.2, 176.0, 164.0, 133.1, 129.9, 129.3, 128.4, 79.5, 54.0, 48.6, 40.6 (two signals), 31.5, 28.9, 28.6, 27.7, 23.6, 19.6, 19.1, 11.7, minor diastereomer: δ 79.7, 54.0, 48.7, 40.6, 27.7; ^{77}Se NMR major diastereomer: δ 188.7, minor diastereomer: δ 192.6, integrating in the ratio of 56:44; MS, (*m*/*z*, %) 327 (11, M^+ − PhCOOH), 105 (100), 77 (86); HRMS calcd for $C_{22}H_{27}NO_4Se$ − PhCOOH 327.0738, found 327.0731.

Intramolecular Cyclization of Selenenyl Bromide 6a. Diselenide **4** (40 mg, 0.081 mmol) was dissolved in 2.0 mL of dichloromethane. A 1 M tetrachloromethane solution of bromine (0.24 mmol) was added dropwise at −40 °C under argon with stirring. The red solution was cooled to −78 °C, and stirring was continued for 30 min. The reaction mixture was allowed to warm to −40 °C over 30 min, filtered through Celite, and concentrated in vacuo. Rapid chromatography (elution with 10% ethyl acetate−hexanes) afforded 40 mg (76%) of the cyclized product **11** as a red oil, which solidified upon standing. Recrystallization from ethanol or chloroform−hexanes afforded red crystals: mp 92−96 °C; IR (neat) 1445, 1376, 1031 cm^{-1}; ^{1}H NMR (200 MHz): δ 3.96 (d, J = 4.8 Hz, 1 H), 2.40−2.09 (m, 2 H), 1.55 (s, 3 H), 1.53−1.20 (m, 2 H), 1.10 (s, 3 H), 0.82 (s, 3 H); ^{13}C NMR δ 205.3, 176.3, 62.3, 60.2, 54.4, 31.9, 25.2, 20.1, 18.8, 10.8;^{77}Se NMR δ 1422.5; λ_{max} (acetonitrile) 234 nm (ϵ 24,400), 313 nm (ϵ 3,240), 368 nm (ϵ 1260); MS (*m*/*z*, %) 244 (M^+ − Br), 228 (9), 144 (100), 117 (95), 91 (87); HRMS calcd for $C_{10}H_{14}BrNOSe$ − Br 244.0241, found 244.0227. Anal. Calcd for $C_{10}H_{14}BrNOSe$: C, 37.18; H, 4.37; N, 4.34; Br, 24.73. Found: C, 38.44; H, 4.40; N, 4.13; Br, 26.37.[26] X-ray crystallographic data for **11** is shown in Figure 1 and Supporting Information.

When the reaction was repeated with equimolar amounts of bromine and diselenide **4**, the yield of **11** was 52% and diselenide **4** was recovered in 15% yield.

Reduction of 11. Sodium borohydride (87 mg, 2.3 mmol) was added in portions to an ice-cooled solution of **11** (77 mg, 0.24 mmol) in 3.2 mL of ethanol. The red color was discharged immediately to give a colorless heterogeneous mixture. Once the addition was complete, the ice bath was removed and the reaction was stirred at room temperature for 1 h. The reaction was quenched with aqueous NH_4Cl and left exposed to air. the mixture was then extracted with several portions of ether and dichloromethane, dried (Na_2SO_4), and concentrated in vacuo. The crude product was chromatographed on silica gel

(26) Gradual decomposition of the analytical sample precluded us from obtaining an elemental analysis in closer agreement with the calculated values.

(elution with 20% ethyl acetate−hexanes) to afford 44.7 mg (76%) of a yellow foam that contained diselenide **4** as a major constituent (TLC, ^{1}H NMR, and ^{13}C NMR). Other constituents were tentatively identified as 3-epimers of **4**.

Acknowledgment. We thank the Natural Sciences and Engineering Research Council of Canada (NSERC) for financial support. We thank Dr. R. Yamdagni, Ms. Q. Wu, and Ms. D. Fox for assistance in obtaining NMR and mass spectra and elemental analyses. The Br analysis of **11** was provided by Canadian Microanalytical Service, Ltd.

Supporting Information Available: ^{1}H, ^{13}C, and ^{77}Se NMR spectra of **4**, **5**, and **11** and of the products shown in Tables 1 and 2, as well as X-ray data for compounds **5** and **11** This material is available free of charge via the Internet at http://pubs.acs.org.

JO016061C