Sequenced Reactions with Samarium(II) Iodide. Tandem Nucleophilic Acyl Substitution/Ketyl−Olefin Coupling Reactions

Gary A. Molander* and Christina R. Harris

Contribution from the Department of Chemistry and Biochemistry, University of Colorado, Boulder, Colorado 80309-0215

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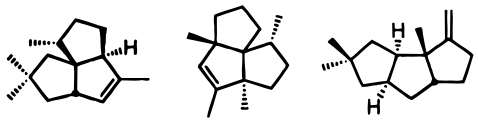
Abstract: Samarium(II) iodide has been employed to promote a tandem intramolecular nucleophilic acyl substitution/intramolecular ketyl−olefin coupling cyclization sequence, generating bicyclic, tricyclic, and spirocyclic ring systems in excellent yield and with high diastereoselectivity. This versatile reaction sequence allows entry to several different naturally occurring tricyclic systems containing the angular and linear triquinane framework.

Introduction

Applications of samarium(II) iodide (SmI_2) to organic chemistry have matured significantly since the first reported uses of this reductant in organic chemistry in the early 1980s.[1] The reducing ability and therefore the chemoselectivity of this reagent are largely solvent dependent and therefore adjustable. This characteristic, combined with the high diastereoselectivities associated with many SmI_2-promoted reactions, makes it a singularly effective reductant for promoting both individual and sequential organic reactions.[1,2]

Previous research from this laboratory has demonstrated that SmI_2 promotes a variety of individual reduction reactions and reductive coupling processes. Among them, nucleophilic acyl substitution reactions of haloalkyl carboxylic acid derivatives[3] and ketyl−olefin coupling reactions with both activated and unactivated systems have been demonstrated.[2b,c,4] Efforts directed toward sequencing reactions with SmI_2 have also proven successful.[1a] For example, a tandem nucleophilic acyl substitution/Barbier-type coupling sequence leading to bicyclic and tricyclic ring systems has been reported.[2a] As part of an ongoing effort aimed at utilizing SmI_2 in sequential reactions, this powerful ring-building strategy has been extended to include a tandem nucleophilic acyl substitution/ketyl−olefin coupling sequence. This concise transformation of simple acyclic substrates to more complex carbocycles provides a unique entry to a variety of bicyclic, tricyclic, and spirocyclic ring systems. Included is an approach to both the angular and linear triquinane ring systems found in the sesterterpenes pentalenene (**1**), isocomene (**2**), and hirsutene (**3**).



1 **2** **3**

Figure 1. Ring systems accessible through SmI_2-induced sequential reactions.

Results and Discussion

At the outset, studies on the development of this sequential process concentrated primarily on esters and lactones containing both a tethered halide and a pendant olefin. A representative example is shown in Scheme 1. The mechanism for this sequential process likely involves initial generation of an organosamarium species with subsequent nucleophilic acyl substitution on the lactone carbonyl.[3] Presumably, attack on the lactone results in the formation of a tetrahedral intermediate that collapses to liberate the ketone, which is poised for an ensuing 5-exo radical cyclization reaction through its ketyl. The resultant carbon-centered radical is rapidly reduced to an organosamarium, generating the desired bicyclic product after an aqueous workup. The major diastereomers in the exo cyclizations are those with the developing radical center trans to the alkoxy group. The formation of this isomer avoids unfavorable stereoelectronic interactions in the radical cyclization.[4]

Initially, a series of olefinic esters was prepared to demonstrate the scope and limitations of this sequential process. Optimum reaction conditions for these substrates involved the slow, dropwise addition of the substrate to a solution of 4.4 equiv of SmI_2 in THF containing 5 equiv of hexamethylphos-

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(1) (a) Molander, G. A.; Harris, C. R. *Chem. Rev.* **1996**, *96*, 307. (b) Molander, G. A. In *Organic Reactions*; Paquette, L. A., Ed.; Wiley: New York, 1994; Vol. 46, p 211. (c) Molander, G. A. *Chem. Rev.* **1992**, *92*, 29. (d) Molander G. A. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon: Oxford, U.K., 1991; Vol. 1, Chapter 1.9. (e) Soderquist, J. A. *Aldrichim. Acta* **1991**, *24*, 15. (f) Kagan, H. B. *New J. Chem.* **1990**, *14*, 453. (g) Molander, G. A. In *Chemistry of the Metal-Carbon Bond*: Hartley, F. R., Patai, S., Eds.; Wiley: New York, 1989; Vol. 5, p 319. (h) Kagan, H. B.; Sasaki, M.; Collin, J. *Pure Appl. Chem.* **1988**, *60*, 1725.

(2) (a) Molander, G. A.; Harris, C. R. *J. Am. Chem. Soc.* **1995**, *117*, 3705. (b) Molander, G. A.; McKie, J. A. *J. Org. Chem.* **1992**, *57*, 3132. (c) Molander, G. A.; Harring, L. S. *J. Org. Chem.* **1990**, *55*, 6171. (d) Molander, G. A.; Kenny, C. *J. Org. Chem.* **1991**, *56*, 1439. (e) Takai, K.; Nitta, K.; Fuimara, O.; Utimoto, K. *J. Org. Chem.* **1989**, *54*, 4732. (f) Curran, D. P.; Fevig, T. L.; Totleben, M. J. *Synlett.* **1990**, 773. (g) Curran, D. P.; Wolin, R. L. *Synlett* **1991**, 317. (h) Enholm, E. J.; Jiang, S.; Abboud, K. *J. Org. Chem.* **1993**, *58*, 4061. (i) Yu, Y.; Lin, R.; Zhang, Y. *Tetrahedron Lett.* **1993**, *34*, 4547. (j) Batey, R. A.; Motherwell, W. B. *Tetrahedron Lett.* **1991**, *32*, 6649. (k) Enholm, E. J.; Trivellas, A. *Tetrahedron Lett.* **1994**, *35*, 1627. (l) Sasaki, M.; Collin, J.; Kagan, H. B. *Tetrahedron Lett.* **1988**, *29*, 6105. (m) Lannoye, G.; Cook, J. M. *J. Org. Chem.* **1988**, *29*, 171. (n) Lannoye, G.; Sambasivarao, K.; Wehrli, S.; Cook, J. M. *J. Org. Chem.* **1988**, *53*, 2327. (o) Murakami, M.; Kawano, T.; Ito, H.; Ito, Y. *J. Org. Chem.* **1993**, *58*, 1458.

(3) (a) Molander, G. A.; McKie, J. A. *J. Org. Chem.* **1993**, *58*, 7216. (b) Molander, G. A.; Shakya, S. R. *J. Org. Chem.* **1994**, *59*, 3445.

(4) Molander, G. A.; Kenny, C. *J. Am. Chem. Soc.* **1989**, *111*, 8236.

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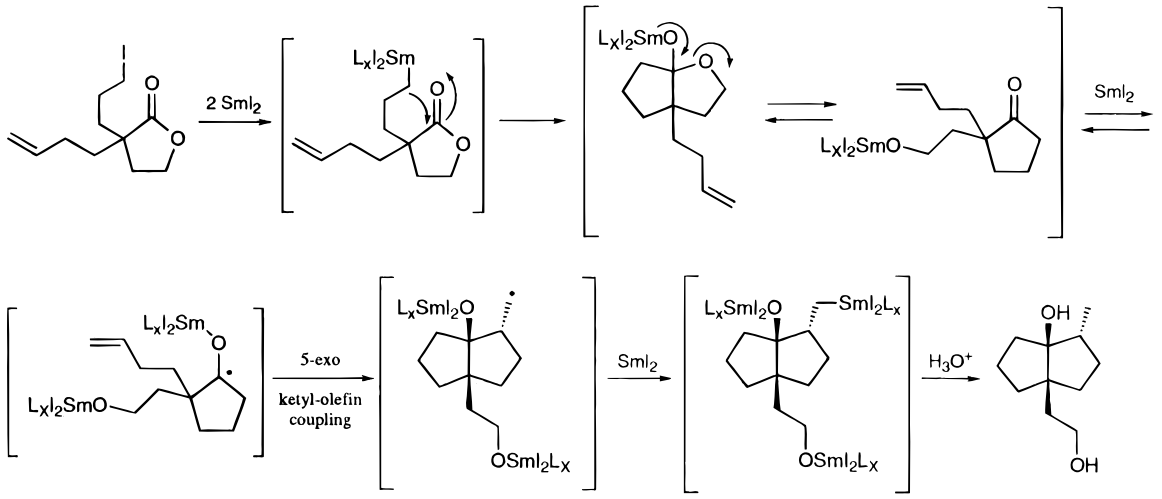
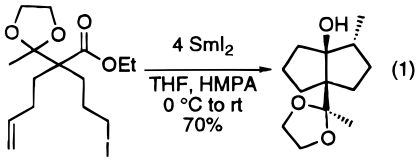
Scheme 1



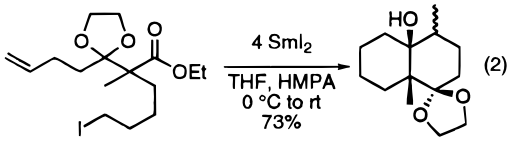
phoramide (HMPA)[5] at 0 °C. The standard reaction conditions did not involve the intentional addition of a proton source to quench the final organosamarium intermediate. In general, these reactions were complete after 30−45 min. Hence, the sequential cyclization of the ethyl acetoacetate derived acetal **4** (eq 1)



4 **5**

provided the desired bicyclic alcohol, **5**, in 70% yield as a single diastereomer. Substrate **4** was prepared by successive alkylation of ethyl acetoacetate with 4-bromo-1-butene and 1-chloro-3-iodopropane, protection of the ketone as the ketal, and finally reaction with NaI.

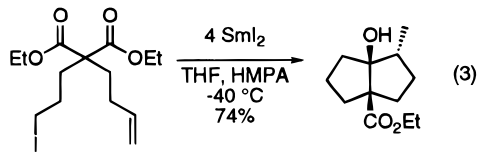
Subjecting the ethyl acetoacetate derived acetal **6** to the standard reaction conditions provided a demonstration of the ability to generate bicyclic products resulting from two sequential six-membered-ring-forming reactions (eq 2). The desired



6 **7**
2 : 1 ds

bicyclio[3.3.0]decan-1-ol **7** was obtained in 73% yield as a 2:1 mixture of diastereomers epimeric at C-2. Substrate **6** was prepared in a manner similar to that of **4** by successive alkylation of ethyl 2-methylacetoacetate with 1-chloro-4-iodobutane and then allyl bromide, acetal formation, and finally a Finkelstein reaction with NaI to provide **6**.

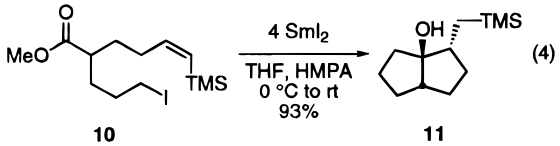
The hydroxy ester **9** in eq 3 was generated as a single diastereomer in high yield when the SmI_2-promoted sequential reaction with **8** was initiated and quenched at −40 °C.



8 **9**

Performing the reaction under standard reaction conditions resulted in a substantial decrease in the yield of the desired product. The lower yields can be ascribed to a retro-aldol reaction which results in decomposition of the desired bicyclic β-hydroxy ester at higher reaction temperatures or with prolonged stirring.[2a,4,6] The diester substrate **8** was prepared in two steps by sequential alkylation of diethyl malonate with 4-bromo-1-butene and then 1,3-diiodopropane.

Substrates with activating groups on the alkene were anticipated to provide higher yields of the tandem cyclization product than substrates incorporating unactivated alkenes. The sequential cyclization depicted in eq 4 supports this supposition. The



10 **11**

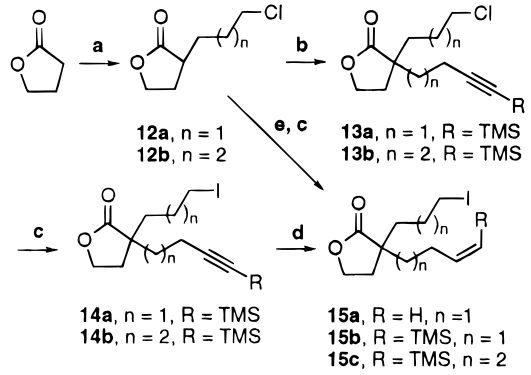
desired bicyclic alcohol **11** was obtained in excellent yield as a single diastereomer under the standard reaction conditions. The substrate in eq 4 was prepared by alkylation of methyl 5-chlorovalerate with 4-iodo-1-(trimethylsilyl)-4-butyne, subsequent Finkelstein reaction with NaI, and finally hydroboration/protonation of the resultant iodoalkyne.

In the second phase of our investigations, efforts were directed at the sequential cyclization process using lactone precursors. The preparation of these substrates is outlined in Scheme 2. Most of these substrates were prepared from the γ-lactone by alkylation with either 1-chloro-3-iodopropane or 1-chloro-4-iodobutane, followed by alkylation with either 4-bromo-1-butene or an appropriate trimethylsilyl-substituted alkynyl halide.

(5) (a) During the course of our investigations, a report appeared wherein 1,1,3,3-tetramethylguanidine (TMG) was found to be superior to additives such as HMPA in its ability to facilitate aryl radical cyclizations by acting as a strong ligand donor. Cabri, W.; Candiani, I.; Colombo, M.; Franzoi, L.; Bedeschi, A. *Tetrahedron Lett.* **1995**, *36*, 949. In our hands, TMG proved to be capable of promoting the present cyclizations, albeit providing markedly decreased yields of the desired bicyclic products along with a considerable amount of reduced ketone and a smaller amount of reduced halide component. Consequently, all sequential cyclization reactions were performed using 5 equiv of HMPA (relative to SmI_2) as the cosolvent. Inanaga, J.; Ujikawa, O.; Yamaguchi, M. *Tetrahedron Lett.* **1991**, *32*, 1737. (b) Hou, Z.; Wakatsuki, Y. *J. Chem. Soc., Chem. Commun.* **1994**, 1205.

(6) (a) Molander, G. A.; Etter, J. B.; Zinke, P. W. *J. Am. Chem. Soc.* **1987**, *109*, 453. (b) Heathcock, C. H. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon: Oxford, U.K., 1991; Vol. 2, Chapter 1.6.5.

Scheme 2



(a) LDA, THF, HMPA, $ICH_2(CH_2)_nCH_2Cl$

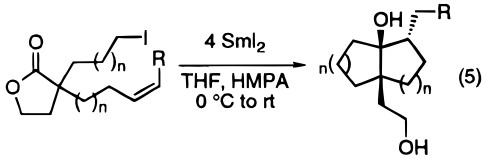
(b) LDA, THF, HMPA, $ICH_2(CH_2)_nC{\equiv}CSiMe_3$

(c) NaI, acetone, Δ_x (d) dicyclohexylborane; AcOH, Δ_x

(e) LDA, THF, HMPA, 4-bromo-1-butene (R = H)

Finally, a Finkelstein reaction with NaI and subsequent hydroboration of the resultant alkyne provided the requisite substrates **15**−**c** for the cyclization studies.

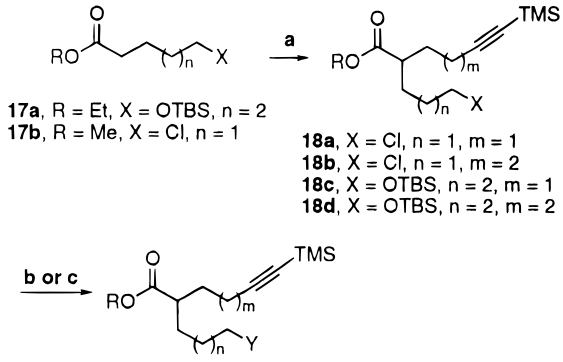
As indicated in eq 5, the yields in the SmI_2 promoted sequential process were markedly increased when the lactone substrate contained an activated olefin (compare **15a** with **15b**).



The lower yields generally observed in reactions of lactone substrates with unactivated alkenes can be attributed in part to an intramolecular hemiacetal−hydroxy ketone equilibrium (Scheme 1) that undoubtedly hinders the desired ketyl−olefin coupling reaction. Replacement of the unactivated olefin with the more activating trimethylsilyl-substituted alkene (**15b**, eq 5, R = TMS) lowers the π^* orbital energy (LUMO) of the alkene and establishes more effective overlap with the ketyl radical anion SOMO.[7] Any ketyl generated through the pertinent equilibria would thus be more efficiently trapped by the alkene, facilitating the cyclization. For the inherently slower 6-oxo ketyl−olefin cyclizations (**15c**, eq 5, R = TMS) the hemiacetal−hydroxy ketone equilibrium remains a problem even with the activated olefinic substrate. Treatment of **15c** (eq 5) under either the standard sequential cyclization reaction conditions or more vigorous conditions (SmI_2/THF/HMPA heated at reflux) provides only a complex mixture of products with no apparent formation of the desired product. Ester substrates which do not have this intramolecular hemiacetal−hydroxy ketone equilibrium manifold available to them provide consistently higher yields of the desired bicyclic products than do lactones under the standard reaction conditions (eqs 1−4).

Having examined sequential reactions utilizing alkenes as the ketyl acceptors in the final stage of the process, it seemed appropriate to explore the use of alkynes as radical acceptors as well. Both inter- and intramolecular ketyl−alkyne coupling

Scheme 3

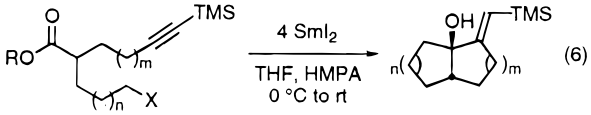


(a) LDA, THF, HMPA, $ICH_2(CH_2)_mC{\equiv}C(TMS)$

(b) (for X = Cl), NaI, acetone, Δ_x

(c) (for X = OTBS), AcOH, THF, H_2O (3:1:1); then CBr_4, PPh_3, Et_2O

reactions mediated by SmI_2 have been reported.[4,8] These studies have established that successful ketyl−alkyne coupling requires the use of an activating group on the terminus of the alkyne to facilitate the coupling. Hence, the ester substrates (**19a**−**d**) in eq 6 were prepared as outlined in Scheme 3 and subjected to



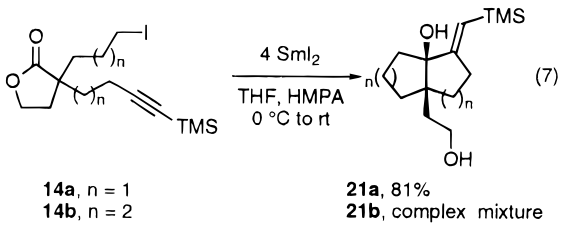
the standard sequential cyclization reaction conditions. The tandem cyclization reactions culminating in a 5-exo ketyl−alkyne coupling (eq 6, substrates **19a,c**) each provided the desired bicyclic alcohols (**20a,c**) as single diastereomers in excellent yield. In contrast, those sequential cyclization reactions terminating in a 6-exo mode (eq 6, substrates **19b,d**) provided bicyclic products (**20b,d**) which were isolated as mixtures of diastereomers about the olefin.

The ketyl−alkyne coupling sequence also worked well with lactone substrates terminating in a 5-exo mode, providing a single diastereomer (**21a**) in excellent yield (eq 7).[9] However, a ketyl-alkyne coupling sequence terminating in a 6-exo fashion (**21b**) provided only complex mixtures of intractable products (**14b**, eq 7).

(7) Fleming, I. *Frontier Orbitals and Organic Chemical Reactions*; Wiley-Interscience: New York, 1976.

(8) (a) Inanaga, J.; Katsuki, J.; Ujikawa, O.; Yamaguchi, M. *Tetrahedron Lett*. **1991**, *32*, 4921. (b) Shim, S. C.; Hwang, J.-T.; Kang, H.-Y.; Chang, M. H. *Tetrahedron Lett*. **1990**, *31*, 4765.

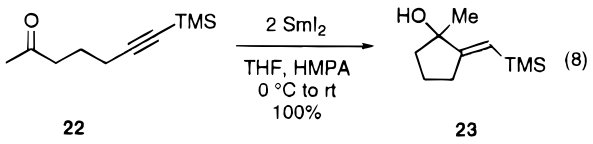
(9) A report recently appeared demonstrating the silicon-directed stereoselective syn addition of hydroxy groups to olefinic alkenylsilanes in the presence of acid. Interestingly, the desired product in this cyclization series was quantitatively transformed to the (trimethylsilyl)methyltetrahydropyran in the NMR tube, as shown by ^1H NMR in $CDCl_3$ (proton NMR spectrum of the (trimethylsilyl)methyltetrahydropyran-derived product ^1H NMR (400 MHz, $CDCl_3$) δ 3.70 (dd, J = 6.75, 11.99 Hz, 1H), 3.58 (dt, J = 4.16, 12.27 Hz, 1H), 2.58 (2, 1H), 1.86 (m, 2H), 1.75−1.51 (m, 7H), 1.43 (m, 2H), 1.29 (dd, J = 4.10, 12.93 Hz, 1H), 1.13 (d, J = 14.84 Hz, 1H), 0.58 (d, J = 14.83 Hz, 1H), 0.00 (s, 9H)). However, performing the ^1H NMR measurement in benzene-d_6 provided a spectrum of the desired bicyclic diol. Miura, K.; Okajima, S.; Hondo, T.; Hosomi, A. *Tetrahedron Lett*. **1995**, *36*, 1483.



14a, n = 1
14b, n = 2

21a, 81%
21b, complex mixture

Confirmation of the stereochemistry about the alkenylsilane was undertaken by examining the stereochemistry of the cyclization product **23** derived from 7-(trimethylsilyl)-6-heptyn-2-one (**22**, eq 8).[8b] Substrate **22** was prepared by alkylation of



22 **23**

methyl acetoacetate with 4-iodo-1-(trimethylsilyl)but-1-yne, followed by subsequent LiCl-assisted decarboxylation to afford the desired ketone **22**. After the SmI_2-promoted cyclization, NOE difference experiments performed on **23** demonstrated that the olefinic proton and methyl group were in close proximity (Figure 2). Hence, irradiation of the singlet methyl group (δ 1.28) provided a 1.6% observed enhancement in the olefinic proton with no concomitant enhancement at the singlet TMS signal (δ 0.08). Irradiation of the olefinic proton (δ 5.56) provided a 1.4% observed enhancement at the singlet methyl group, further demonstrating that the methyl group and the olefinic proton were sterically quite close. These analyses confirm the stereochemistry of the product as depicted.

Further efforts were directed at determining the mechanism of the ketyl−alkyne coupling. Presumably, the initial coupling occurs through the ketyl of the intermediate ketone. However, as depicted in Scheme 4, the resulting trimethylsilyl-substituted alkenyl radical either could be quenched by hydrogen atom abstraction from THF solvent or perhaps could be reduced further to the alkenyl anion. A series of experiments were performed to provide more insight into the mechanistic details of this process.

Thus, treatment of **19a** (eq 6) under the standard sequential cyclization reaction conditions but in the presence of 2.5 equiv of D_2O provided the desired bicyclic alcohol with approximately 45% deuterium incorporation on the alkene as determined by ^{1}H NMR. The presence of deuterium in the final products suggests the intermediacy of an alkenyl anion. Inanaga and co-workers reported similar results during an intermolecular carbonyl−alkyne reductive coupling reaction using aryl-substituted alkynes.[8a] In their study, a nearly 1:1 mixture of deuterated to protonated coupling product was observed when CD_3OD was employed as a trapping agent. The remaining protonated material in their study was postulated to be derived from hydrogen atom abstraction from another source, presumably THF solvent. Hence, in an effort to determine if hydrogen atom abstraction from THF solvent was indeed an operative reaction manifold in our reaction sequence, the sequential cyclization process was performed on **19a** using THF-d_8 as the solvent under otherwise standard reaction conditions; *i.e.*, no intentional addition of a proton source. Isolation (81% yield) and analysis of the resultant sequential cyclization product **20a** revealed *no deuterium incorporation*, as determined by both ^{2}H NMR and by integration of the olefinic proton in question in the ^{1}H NMR spectrum. Thus, it appears unlikely that the nondeuterated material results from hydrogen atom abstraction from THF solvent, although the source of the proton (or

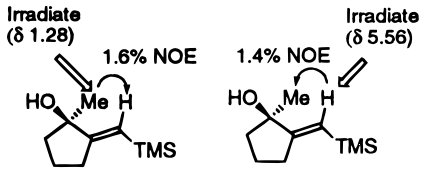
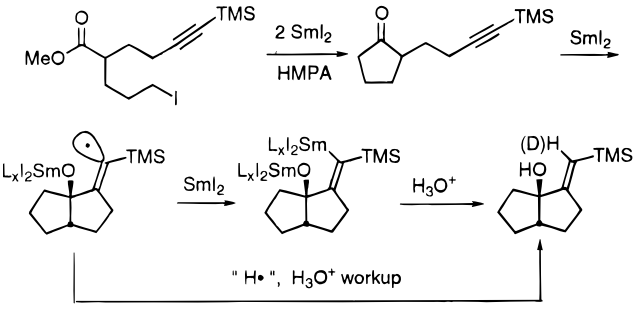
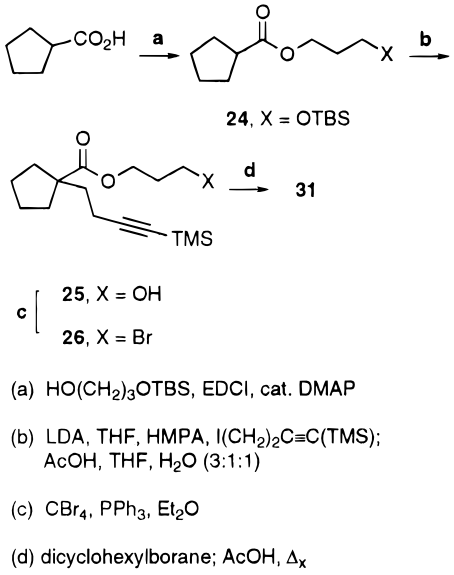


Figure 2. Observed NOE's from ketyl−alkyne cuyclization reaction.

Scheme 4



Scheme 5



(a) $HO(CH_2)_3OTBS$, EDCI, cat. DMAP

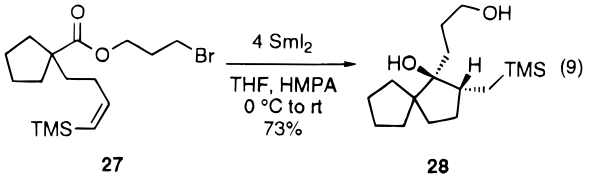
(b) LDA, THF, HMPA, $I(CH_2)_2C{\equiv}C(TMS)$; AcOH, THF, H_2O (3:1:1)

(c) CBr_4, PPh_3, Et_2O

(d) dicyclohexylborane; AcOH, Δ_x

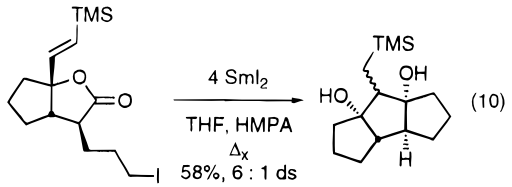
hydrogen atom) still remains unclear. One additional experiment was performed to determine if liberated alkoxide resulting from seminal attack of the organosamarium reagent on the ester functionality could serve as a potential hydrogen atom source (perhaps by coordination to Sm(II) or Sm(III)). Thus, when the ethyl-d_5 ester of **19a** was prepared and subjected to the standard reaction conditions, no deuterium incorporation was observed in the final product **20a** (as determined by integration of the appropriate signal in the ^{1}H NMR), ruling out alkoxide as a significant source of hydrogen atoms in this reaction sequence. Further attempts to trap the alleged alkenyl anion with electrophiles other than D_2O met with failure, perhaps attesting to the short-lived nature of the alkenyl anion that is apparently generated. For example, performing the reaction in the presence of acetone provided no product derived from attack of the alkenyl anion on the carbonyl carbon of acetone.

The SmI_2-promoted sequential process can be utilized to gain access to ring systems other than fused bicycles. For example, spirocycles can be generated as well. Thus, sequential cyclization of the cyclopentanecarboxylate ester **27** provided the desired spirocyclic diol **28** in good yield as a single diastereomer (eq 9). The substrate cyclopentanecarboxylate was readily prepared in four steps from cyclopentanecarboxylic acid, as depicted in Scheme 5.



27 **28**

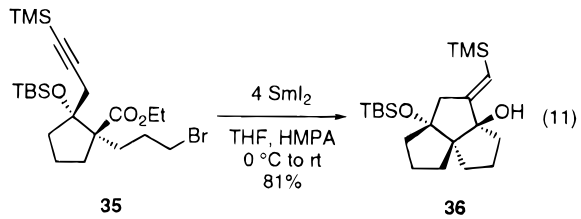
To demonstrate further the wide applicability of this sequential process, the method was applied to the synthesis of linear and angular triquinane frameworks. Sequential cyclization of the fused bicyclic lactone **31** provided the desired linear triquinane framework **32** in good yield as a 6:1 mixture of diastereomers epimeric at C-2 (eq 10). Amazingly, the derived



31 **32**

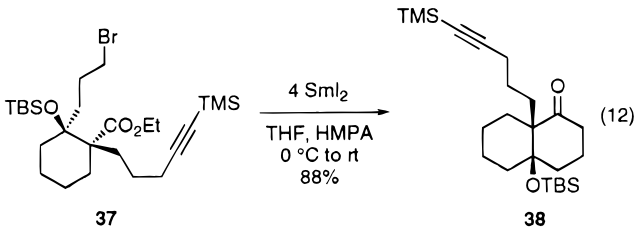
product is formed even though it requires the formation of a highly strained *trans:anti:cis* linear triquinane framework.[10] Evidence for the stereochemical assignment made for this cyclization product **32** is based in part on observation of the IR spectra of both the major and minor diastereomeric products isolated. Molecular models indicate that both diastereomers (epimers at C-2) should exhibit considerable intramolecular hydrogen bonding. Observation of the hydroxyl stretching vibrations as seen in the IR spectrum of each diastereomer in nonpolar CCl_4 solvent performed at high dilution (0.04 M) revealed a sharp "free hydroxyl" stretch (3617.7 and 3614.8 cm^{-1}), intermolecular hydrogen bonding (3592.9/3550.1 cm^{-1}), and a broad shallow band at 3395.1/3404.4 cm^{-1} resulting from intramolecular hydrogen bonding for both the major and minor diastereomers, respectively. Molecular models of the potential products resulting from reversible ketyl−olefin coupling (and/or epimerization of the position α to the cyclopentanone intermediate) to provide a *cis:anti:cis* or *cis:syn:cis* framework do not have the potential for intramolecular hydrogen bonding, thus supporting the stereochemical assignments and indicating that the ketyl−olefin coupling process is irreversible. It deserves note that formation of the desired product occurred in good yield only when the substrate lactone was added slowly dropwise to a SmI_2/THF/HMPA mixture heated at reflux. Nevertheless, the product formed is clearly the kinetic product of the reaction. Substrate **31** was prepared from the known ethyl 2-oxocyclopentane acetate as described previously (Scheme 6).[2a]

Efforts directed toward the preparation of the angular triquinane framework were also successful. Sequential cyclization of the cyclopentanoid substrate **35** (eq 11), prepared from



35 **36**

ethyl 2-oxocyclopentanecarboxylate in four steps as described previously (Scheme 7),[2a] provided a single tricyclic product in excellent yield. Unfortunately, attempts to extend this approach to the one-carbon homologated substrate **37** were unsuccessful (eq 12). The major product isolated under various reaction

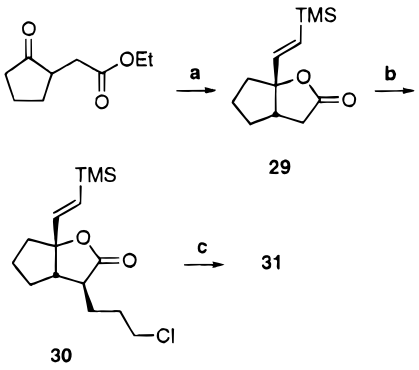


37 **38**

conditions was the bicyclic alkynyl ketone **38**. Attempted ketyl cyclizations on isolated **38** were also unproductive. Thus, when **38** was reacted with 2 equiv of SmI_2 in THF/HMPA for 18 h in the presence or absence of *t*-BuOH, the alcohol resulting from reduction of the ketone was produced in yields of 48−60%, and 40−50% of the starting material remained. No cyclized material was detected.

Efforts directed at extending this protocol to incorporate heterosubstituents α to the ester were only modestly rewarded. Successful 5-exo ketyl−olefin cyclization in preference to reductive elimination of an α-hetero substituent has been

Scheme 6

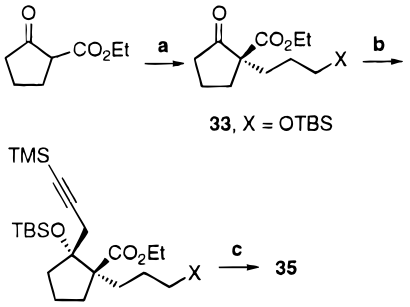


(a) *trans*-BrCH=CHSiMe$_3$, Mg, THF

(b) LDA, THF, HMPA, I(CH$_2$)$_3$Cl

(c) NaI, acetone, Δ_x

Scheme 7



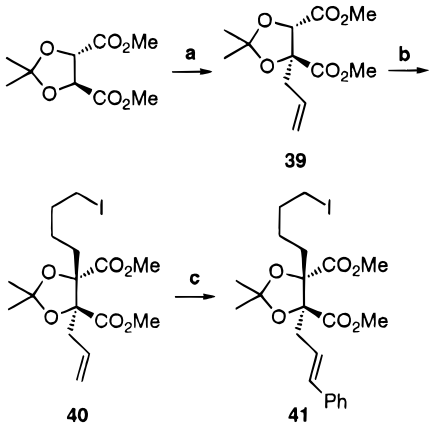
(a) NaH, Br(CH$_2$)$_3$OTBS, DMF

(b) BrCH$_2$C≡CSiMe$_3$, Zn, DMF; then, TBSOTf 2, 6-lutidine, CH$_2$Cl$_2$

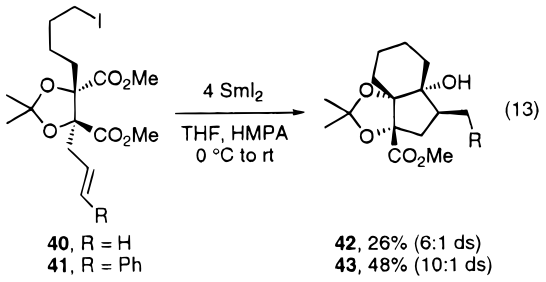
(c) AcOH:THF:H$_2$O; then, CBr$_4$, PPh$_3$, Et$_2$O

(10) Fevig, T. L.; Elliot, R. L.; Curran, D. P. *J. Am. Chem. Soc.* **1988**, *110*, 5064.

Scheme 8



reported.[11] However, in systems with slower cyclization rates (e.g., 6-exo cyclizations), α-hetero substituent extrusion effectively competes with the ketyl−olefin reductive coupling to provide only low yields of the desired products. In the present study, sequential cyclization of the dimethyl tartrate derived substrate **40** (eq 13) provided the desired tricyclic product **42**



in 26% yield as a 6:1 mixture of diastereomers epimeric at C-3 under the standard reaction conditions. Attempts to enrich the ketyl−olefin reaction manifold were partially successful when the olefin was activated with a phenyl group. Hence, subjecting the activated olefinic substrate **41** to standard reaction conditions provided the desired tricyclic product **43** (eq 13) in markedly increased yield (48%) as a 10:1 mixture of diastereomers epimeric at C-3. The substrates in these cyclization events were readily prepared from the dimethyl tartrate derived acetonide by successive alkylation with allyl bromide and 1,4-diiodobutane followed by ozonolysis and subsequent Wittig olefination (Scheme 8).[12]

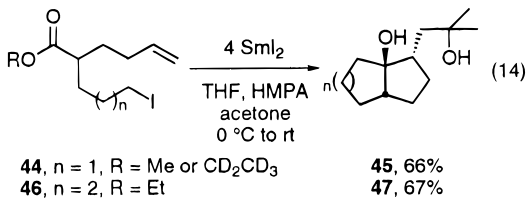
Finally, we had hoped to trap the organosamarium species generated after the ketyl−olefin cyclization with an electrophile in order to extend the sequence of carbon−carbon bond-forming reactions to three separate events. In our hands this could be accomplished only when the electrophile was present during the entire reaction sequence. As stated previously, under the standard reaction conditions, in no instance was a proton source (*t*-BuOH, MeOH, *etc*.) added deliberately until after the complete consumption of the starting material. Apparently, either the initially generated carbon-centered radical species or the further reduced carbon-centered anion generated in the ketyl−olefin cyclization is quenched prematurely by either an unidentified hydrogen atom source or protic acid source, respectively. Performing the reaction by adding a proton source (D_2O) concurrently with the substrate (**44**) provided near-quantitative deuterium incorporation (81% yield of the bicyclic product) at the C-2 methyl, indicating that an organosamarium is indeed formed and that H atom abstraction from another source (*i.e*., THF solvent) is not a significant reaction manifold.

One potential protic acid source is the cyclopentanone or cyclohexanone intermediate formed after initial nucleophilic acyl substitution (Scheme 1). However, these intermediates were excluded as a source of adventitious protons by performing the cyclization sequence on 2-(3-butenyl)cyclopentanone exhaustively deuterated at the positions α to the carbonyl. Thus, performing the cyclization sequence on this deuterated substrate provided no deuterium incorporation at the C-2 methyl group, thus indicating that enolization of the intermediate cycloalkanone is not a significant source of acidic protons in this sequence.

Another potential source of hydrogen atoms could be the resultant ethoxide (or methoxide) or alkoxide coordinated with Sm(II)/Sm(III), generated after the initial nucleophilic acyl substitution. However, the sequential process carried out on the deuterated ethyl ester (CD_3CD_2O) of **44** provided no deuterium incorporation at the C-2 methyl, thus appearing to rule out the resultant alkoxide as a potential hydrogen source.

Finally, Ashby and Welder[13] have reported significant ^1H incorporation in reductions performed with $LiAlD_4$. In that communication, it was determined that the reaction vessel (*i.e*., Pyrex) could serve as a significant source of ^1H incorporation in reductions performed with LAD. Consequently, one cannot rule out the possibility of the reaction vessel as a source of protic acid.

In any event, with the requirement that the final, intermolecular trapping could be accomplished only when the electrophile was present during the entire reaction sequence, successful electrophiles were limited primarily to ketones that are not competitively reduced to the alcohol under the reaction conditions. Thus, when acetone was present during the entire reaction sequence, bicyclic trapped materials were isolated in good yields as single diastereomers (eq 14).



The SmI_2-promoted intramolecular nucleophilic acyl substitution/ketyl−olefin cyclization sequence has been utilized to convert a variety of suitable substrates to bicyclic, tricyclic, and spirocyclic alcohols efficiently, in high yield and with excellent diastereoselectivity. Substrates for these sequential processes are readily prepared by classical alkylation chemistry in a relatively few steps. The overall transformation represents an effective means by which simple starting materials can be converted to relatively complex products in a one-pot process.

Experimental Section

Reagents. Tetrahydrofuran (THF) was distilled immediately prior to use from benzophenone ketyl under Ar. Samarium metal was purchased from Cerac Inc., Milwaukee, WI, and was weighed and stored

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(12) (a) Naef, R.; Seebach, D. *Angew. Chem., Int. Ed. Engl*. **1981**, *20*, 1030. (b) Ladner, W. *Angew. Chem., Int. Ed. Engl*. **1982**, *21*, 449. (c) Tokunaga, Y.; Nagano, H.; Shiota, M. *J. Chem. Soc., Perkin Trans. 1* **1986**, 581.

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under an inert atmosphere. CH_2I_2 was purchased from Aldrich Chemicals and was distilled prior to use and stored under argon over copper turnings. HMPA was purchased from either Aldrich or Sigma Chemicals and was distilled from either Na(0) or CaH_2 at 0.04 mmHg and stored over 4 Å molecular sieves under Ar. Standard benchtop techniques were employed for the handling of air-sensitive reagents,[14] and all reactions were carried out under argon.

Ethyl 2-acetyl-2-(3-chloropropyl)-5-hexenoate was prepared according to the general procedure outlined for the preparation of **8** by alkylation of ethyl 2-(3-butenyl)-acetoacetate[15] with 1,3-dichloropropane to afford the title compound in 81% yield after flash chromatography with 4% EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.74 (m, 1H), 4.98 (m, 2H), 4.18 (q, J = 7.08 Hz, 2H), 3.50 (dt, J = 6.10, 2.20 Hz, 2H), 2.12 (s, 3H), 2.03−1.78 (m, 6H), 1.56 (m, 2H), 1.24 (t, J = 7.08 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.99, 137.25, 115.25, 62.62, 61.41, 44.79, 30.52, 28.56, 28.00, 27.18, 26.60 (2), 14.05.

Ethyl 2-Acetyl-2-(3-chloropropyl)-5-hexenoate, Ethylene Glycol Acetal. A solution of ethyl 2-acetyl-2-(3-chloropropyl)-5-hexenoate (3.05 g, 10.0 mmol) and ethylene glycol (1.24 g, 20.0 mmol) in 25 mL of benzene with catalytic *p*-toluenesulfonic acid was heated at reflux for 18 h with azeotropic removal of water. After this period, the reaction mixture was cooled to room temperature and the residual solvent was removed *in vacuo*. The resultant reaction mixture was subjected to flash chromatography with 10% EtOAc/hexanes to afford the title compound in 82% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.79 (m, 1H), 4.97 (m, 2H), 4.15 (q, J = 7.14 Hz, 2H), 3.92 (s, 4H), 3.53 (t, J = 5.92 Hz, 2H), 2.10 (m, 1H), 1.96−1.67 (m, 7H), 1.34 (s, 3H), 1.25 (t, J = 7.16 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.54, 138.78, 114.34, 118.86, 64.79, 64.69, 60.62, 56.97, 45.88, 30.18, 29.00, 28.26, 28.13, 21.28, 14.14.

Ethyl 2-acetyl-2-(3-iodopropyl)-5-hexenoate, ethylene glycol acetal (4), was prepared from ethyl 2-acetyl-2-(3-chloropropyl)-5-hexenoate, ethylene glycol acetal, according to the general procedure outlined for the preparation of **15a** to afford **4** in 96% yield after flash chromatography with 8% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.79 (m, 1H), 4.97 (m, 2H), 4.15 (q, J = 7.19 Hz, 2H), 3.92 (s, 4H), 3.17 (t, J = 6.47 Hz, 2H), 2.11 (m, 1H), 1.99−1.70 (m, 7H), 1.33 (s, 3H), 1.25 (t, J = 7.13 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.53, 138.76, 114.38, 111.82, 64.82, 64.70, 60.66, 56.92, 31.84, 30.24, 29.01, 28.84, 21.31, 14.17, 7.75.

(1*R,2*S**,5*S*)-5-Acetyl-2-methylbicyclo[3.3.0]octan-1-ol, ethylene glycol acetal (5),** was prepared from **4** according to the general procedure outlined for the preparation of **16a** to afford **5** as a single diastereomer in 70% yield after flash chromatography with 10% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.97 (m, 4H), 2.80 (s, 1H), 2.17 (m, 1H), 1.81 (m, 2H), 1.70−1.51 (m, 5H), 1.41 (s, 3H), 1.27 (m, 2H), 1.05 (m, 1H), 0.95 (d, J = 6.74 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 114.67, 92.53, 64.46, 64.20, 60.64, 46.58, 39.22, 36.33, 34.35, 29.29, 25.06, 20.59, 13.28; IR (CCl_4) 3553.7 cm^{-1}; HRMS calcd for $C_{13}H_{22}O_3$ 226.1569, found 226.1560; LRMS (EI$^+$) *m*/*z* 226 (65), 211 (100), 193 (31), 184 (25), 164 (55). Anal. Calcd for $C_{13}H_{22}O_3$: C, 68.99; H, 9.80. Found: C, 68.75; H, 9.84.

Ethyl 2-acetyl-2-(4-chlorobutyl)-2-methylhexanoate was prepared according to the general procedure outlined for the preparation of **8** by alkylation of ethyl 2-methylacetoacetate with 1-chloro-4-iodobutane to afford the title compound in 71% yield after flash chromatography with 3% EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.18 (q, J = 7.10 Hz, 2H), 3.51 (t, J = 6.59 Hz, 2H), 2.13 (s, 3H), 1.79 (m, 4H), 1.32 (s, 3H), 1.25 (t, J = 7.10 Hz, 3H), 1.24 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 205.46, 172.83, 61.37, 59.48, 44.47, 33.49, 26.10, 21.51, 18.83, 14.08, 6.24.

Ethyl 2-(4-Chlorobutyl)-2-methyl-3-oxo-6-heptenoate. Ethyl 2-acetyl-2-(4-chlorobutyl)-2-methylhexanoate (3.87 g, 14.2 mmol) was added dropwise to a −78 °C solution of LDA (15.6 mmol). After the addition of the substrate was complete, the reaction mixture was maintained at −78 °C for 20−30 min before a solution of allyl bromide (1.90 g, 15.6 mmol) in 3 mL of HMPA was added *via* cannula. After the addition of the electrophile was complete, the reaction mixture was maintained at −78 °C for 30 min and then warmed to room temperature. TLC analysis at this time indicated the complete consumption of the starting material. The reaction was quenched by the addition of saturated aqueous NH_4Cl. An aqueous workup followed by flash chromatography with 3% EtOAc/hexanes provided the title compound (0.88 g, 3.20 mmol) in 23% yield: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.75 (m, 1H), 4.98 (m, 2H), 4.16 (q, J = 7.08 Hz, 2H), 3.51 (t, J = 6.35 Hz, 2H), 2.50 (dt, J = 7.08, 3.18 Hz, 2H), 2.30 (m, 2H), 1.75 (m, 4H), 1.32 (s, 3H), 1.24 (t, J = 7.08 Hz, 3H), 1.23 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 206.74, 172.87, 136.95, 115.37, 61.32, 59.29, 44.47, 37.59, 33.87, 32.67, 27.87, 21.50, 18.81, 14.05.

Ethyl 2-(4-chlorobutyl)-2-methyl-3-oxo-6-heptenoate, ethylene glycol acetal, was prepared from ethyl 2-(4-chlorobutyl)-2-methyl-3-oxo-6-heptenoate according to the general procedure outlined for the preparation of **4** to afford the title compound in 72% yield after flash chromatography with 5% EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.77 (m, 1H), 4.75 (m, 2H), 4.14 (m, 2H), 3.99 (m, 4H), 3.51 (t, J = 6.59 Hz, 2H), 1.89 (m, 4H), 1.27 (m, 3H), 1.43 (m, 3H), 1.25 (t, J = 6.59 Hz, 3H), 1.49 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.48, 138.47, 114.40, 113.92, 66.95, 66.88, 60.65, 56.09, 44.78, 34.98, 33.23, 33.15, 27.54, 22.31, 17.43, 14.17.

Ethyl 2-(4-iodobutyl)-2-methyl-3-oxo-6-heptenoate, ethylene glycol acetal (6), was prepared from ethyl 2-(4-chlorobutyl)-2-methyl-3-oxo-6-heptenoate, ethylene glycol acetal, according to the general procedure outlined for the preparation of **15a** to afford **6** in 75% yield after flash chromatography with 5% EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.77 (m, 1H), 4.96 (m, 2H), 4.14 (m, 2H), 4.00 (m, 4H), 3.16 (t, J = 7.08 Hz, 2H), 1.93 (m, 4H), 1.78 (m, 3H), 1.40 (m, 3H), 1.26 (t, J = 7.08 Hz, 3H), 1.18 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.38, 138.46, 114.39, 113.90, 66.94, 66.87, 60.67, 56.04, 34.97, 34.06, 32.88, 27.53, 25.92, 17.45, 14.22, 6.64.

(1*R,2*R**/*S**,6*S**)-2,6-Dimethyl-5-oxabicyclo[4.4.0]decan-1-ol, ethylene glycol acetal (7),** was prepared from **6** according to the general procedure outlined for the preparation of **16a** to afford **7** as a 2:1 mixture of diastereomers epimeric at C-2 in 73% combined yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.91 (m, 4H), 3.26 (s, 1H), 2.08 (m, 1H), 1.94−1.61 (m, 3H), 1.56−1.43 (m, 7H), 1.34−1.21 (m, 2H), 1.00 (s, 3H), 0.87 (d, J = 7.74 Hz, 1.5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 114.54, 113.61, 75.47, 75.22, 65.21, 64.27, 64.19, 64.00, 46.25, 45.56, 37.04, 31.27, 31.16, 30.75, 30.06, 29.86, 29.81, 27.39, 27.17, 26.43, 22.35, 22.27, 21.31, 20.80, 20.28, 14.93, 14.81, 12.37; IR (CCl_4) 3541.0 cm^{-1}; HRMS calcd for $C_{14}H_{24}O_3$ 240.1725, found 240.1733; LRMS (EI$^+$) *m*/*z* 240 (12), 222 (16), 178 (21), 169 (18), 155 (17), 136 (34), 123 (98), 99 (100), 86 (26), 55 (22), 41 (36), 27 (19). Anal. Calcd for $C_{14}H_{24}O_3$: C, 69.96; H, 10.06. Found: C, 69.78; H, 10.24.

Diethyl 2-(3-butenyl)malonate was prepared by alkylation of diethyl malonate with 4-bromo-1-butene according to the general procedure outlined for the preparation of **8** to afford the title compound in 56% yield after flash chromatography with 3% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.75 (m, 1H), 5.01 (m, 2H), 4.18 (q, J = 7.12 Hz, 4H), 3.33 (t, J = 7.14 Hz, 1H), 2.08 (m, 2H), 1.98 (m, 2H), 1.25 (t, J = 7.14 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.41 (2), 136.88, 115.93, 61.30 (2), 51.19, 31.28, 27.82, 14.06 (2).

Diethyl 2-(3-Butenyl)-2-(3-iodopropyl)malonate (8). General Procedure for the Alkylation of *β*-Dicarbonyl Substrates. 8 was prepared from diethyl 2-(3-butenyl)malonate by alkylation with 1,3-diiodopropane according to the following general procedure. Diethyl 2-(3-butenyl)malonate (5.06 g, 22.4 mmol) in 10 mL of dry DMF was added dropwise via cannula to a stirred slurry of NaH (1.09 g of a 60% dispersion in mineral oil, 26.88 mmol) at 0 °C. After the addition of the substrate was complete and the H_2 evolution had ceased, the reaction mixture was warmed to room temperature and stirred for 2 h. After this period of time, the reaction mixture was cooled to 0 °C, 1,3-diiodopropane (9.94 g, 33.6 mmol) was added (neat), and the reaction mixture was then warmed to room temperature and stirred for 2 h. The reaction mixture was then heated at 50 °C for 12 h before being quenched at room temperature by the careful addition of saturated aqueous $NaHCO_3$ and subjected to an aqueous workup. Flash chromatography with 2% EtOAc/hexanes afforded **8** in 28% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.76 (m, 1H), 4.99 (m, 2H), 4.17 (q, J = 7.14 Hz, 4H), 3.15 (t, J = 6.73 Hz, 2H), 2.00−1.94 (m, 6H), 1.72 (m, 2H),

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1.24 (t, J = 7.18 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 171.22 (2), 137.38, 115.14, 61.26 (2), 56.67, 33.35, 31.79, 28.31 (2), 14.08 (2), 5.82.

(1*R,4*R**,5*S**)-Ethyl 5-hydroxy-4-methylbicyclo[3.0.0]octanecarboxylate (9)** was prepared from **8** according to the general procedure outlined for the preparation of **16a**, except that the substrate **8** was added as a 0.05 M solution in THF to a stirred solution of SmI_2/HMPA at −40 °C over a period of approximately 2 h. After this period of time, TLC and GC analysis indicated that the starting material was completely consumed, with concomitant formation of a single diastereomer. The reaction mixture was quenched at −40 °C and subjected to an aqueous workup. Flash chromatography with 12% EtOAc/hexanes afforded **9** as a clear, colorless oil in 74% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.13 (q, J = 7.13 Hz, 2H), 2.57 (s, 1H), 2.47 (m, 1H), 2.21 (m, 1H), 1.98 (m, 1H), 1.73 (m, 2H), 1.66−1.48 (m, 4H), 1.39 (m, 1H), 1.26 (t, J = 7.13 Hz, 3H), 1.17 (m, 1H), 0.98 (d, J = 6.75 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 176.94, 93.82, 61.69, 60.68, 45.23, 37.97, 35.47, 35.35, 30.49, 24.78, 14.18, 13.20; IR (neat) 3500.3, 1704.3, 1454.6 cm^{-1}; HRMS calcd for $C_{12}H_{20}O_3$ 212.1412, found 212.1418; LRMS (EI$^+$) *m*/*z* 212 (31), 166 (98), 156 (99), 149 (36), 138 (84), 121 (82), 110 (96), 97 (41), 79 (28), 67 (30), 55 (33), 41 (64), 29 (48). Anal. Calcd for $C_{12}H_{20}O_3$: C, 67.89; H, 9.50. Found: C, 67.82; H, 9.69.

Methyl (5*Z*)-2-(3-iodopropyl)-6-(trimethylsilyl)-5-hexenoate (10) was prepared according to the general procedure outlined for the preparation of **15b** by hydroboration of **19a** to afford **10** in 81% yield after flash chromatography with 3−4% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.21 (m, 1H), 5.49 (d, J = 13.98 Hz, 1H), 3.66 (s, 3H), 3.15 (t, J = 6.86 Hz, 2H), 2.38 (m, 1H), 2.09 (m, 2H), 1.81−1.50 (m, 6H), 0.08 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.91, 147.34, 130.07, 51.56, 44.24, 33.14, 32.31, 31.19, 31.14, 5.97, 0.13 (3).

(1*R,2*S**,5*S**)-2-((Trimethylsilyl)methyl)cyclo[3.3.0]octan-1-ol (11)** was prepared from **10** according to the general procedure outlined for the preparation of **16a** to afford **11** as a single diastereomer in 93% yield after flash chromatography with 7% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.08 (m, 2H), 1.81 (m, 2H), 1.71 (m, 1H), 1.62 (m, 2H), 1.46 (t, J = 7.23 Hz, 2H), 1.28 (s, 1H), 1.12 (m, 3H), 0.76 (dd, J = 3.12, 14.38 Hz, 1H), 0.39 (dd, J = 11.43, 14.42 Hz, 1H), −0.01 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 93.91, 50.54, 47.28, 36.54, 35.16, 32.18, 30.00, 25.60, 15.93, −0.84 (3); IR (CCl_4) 3373.3 cm^{-1}; HRMS calcd for $C_{12}H_{24}OSi$ 212.1596, found 212.1605; LRMS (EI$^+$) *m*/*z* 212 (20), 197 (100), 183 (41), 169 (92), 75 (98). Anal. Calcd for $C_{12}H_{24}OSi$: C, 67.86; H, 11.39. Found: C, 67.58; H, 11.69.

Dihydro-3-(chloropropyl)furan-2(3*H*)-one (12a). General Procedure for the Alkylation of Esters and Lactones.[16] A 1.0 M solution of γ-butyrolactone (1.72 g, 20.0 mmol) in THF was added dropwise *via* cannula over 1.0−1.5 h to a stirred solution of 22.0 mmol of LDA at −78 °C. After the addition of the substrate was complete, the reaction mixture was stirred an additional 20−30 min at −78 °C. After this period of stirring, 1-chloro-3-iodopropane (4.90 g, 24.0 mmol) in 4.2 mL of HMPA was added slowly dropwise. After the addition of the halide was complete, the reaction mixture was warmed to −30 °C with continued stirring at reduced temperature overnight. After this period, TLC/GC analysis revealed the near-complete consumption of the starting material. The reaction mixture was quenched with saturated aqueous NH_4Cl. Aqueous workup followed by flash chromatography (15% EtOAc/hexanes) afforded 2.30 g (14.2 mmol) of **12a** as a clear yellow oil in 71% yield after Kugelrohr distillation (ot 100−110 °C, 0.05 mmHg): ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.34 (m, 1H), 4.18 (m, 1H), 3.55 (t, J = 6.30 Hz, 2H), 2.53 (m, 1H), 2.40 (m, 1H), 2.03−1.79 (m, 4H), 1.63 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 178.92, 66.40, 44.40, 38.55, 30.10, 28.66, 27.70.

Dihydro-3-(3-butenyl)-3-(3-chloropropyl)furan-2(3*H*)-one was prepared according to the general alkylation procedure described for **12a** by alkylation of **12a** with 4-bromo-1-butene. The crude product was subjected to flash chromatography with 10% EtOAc/hexanes to afford the desired olefinic lactone as a clear yellow liquid in 70% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.77 (m, 1H), 5.01 (m, 2H), 4.25 (t, J = 7.32 Hz, 2H), 3.53 (t, J = 5.56 Hz, 2H), 2.21−2.10 (m, 3H), 2.04 (m, 1H), 1.86 (m, 1H), 1.78−1.53 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 178.29, 137.32, 115.38, 65.09, 45.31, 44.90, 34.83, 33.12, 32.41, 28.47, 27.41.

Dihydro-3-(3-chloropropyl)-3-(4-(trimethylsilyl)-3-butynyl)furan-2(3*H*)one (13a) was prepared according to the general procedure for the preparation of **12a** by alkylation of **12a** with 4-iodo-1-trimethylsilyl-1-butyne[17] to afford **13a** in 45% yield as a clear yellow oil after flash chromatography with 12% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.26 (ddd, J = 2.91, 6.49, 9.63 Hz, 2H), 3.52 (t, J = 5.68 Hz, 2H), 2.25 (m, 3H), 2.13 (m, 3H), 1.86 (m, 3H), 1.72 (m, 3H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 178.26, 105.58, 85.64, 65.07, 45.22, 44.74, 34.03, 32.67, 32.34, 27.31, 15.26, −0.03 (3).

Dihydro-3-(5-(trimethylsilyl)-4-pentynyl)furan-2(3*H*)-one was prepared from γ-butyrolactone by alkylation with 1-iodo-5-(trimethylsilyl)-4-pentyne[15] according to the general procedure outlined for the preparation of **12a** to afford the title compound in 45% yield after flash chromatography with 10% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.33 (dt, J = 2.89, 8.81 Hz, 1H), 4.17 (dt, J = 6.75, 9.37 Hz, 1H), 2.54 (m, 1H), 2.40 (m, 1H), 2.26 (t, J = 7.16 Hz, 2H), 1.95 (m, 2H), 1.67−1.51 (m, 3H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 179.12, 106.41, 85.17, 66.43, 38.86, 29.56, 28.73, 26.33, 19.70, 0.10 (3).

Dihydro-3-(4-chlorobutyl)-3-(5-(trimethylsilyl)-4-pentynyl)furan-2(3*H*)-one (13b) was prepared from dihydro-3-(5-(trimethylsilyl)-4-pentynyl)furan-2(3*H*)-one by alkylation with 1-chloro-4-iodobutane to afford **13b** in 65% yield after flash chromatography with 8% EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.24 (t, J = 7.33 Hz, 2H), 3.53 (t, J = 6.35 Hz, 2H), 2.22 (t, J = 6.84 Hz, 2H), 2.15 (dt, J = 7.08, 1.47 Hz, 2H), 1.79−1.40 (m, 10H), 0.13 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 180.77, 106.34, 85.26, 65.12, 45.64, 44.54, 34.92, 34.90, 32.59, 32.32, 23.48, 21.52, 20.08, 0.11 (3).

Dihydro-3-(3-iodopropyl)-3-(4-(trimethylsilyl)-3-butynyl)furan-2(3*H*)-one (14a) was prepared from **13a** according to the general procedure outlined for the preparation of **15a** to afford **14a** in 90% yield after flash chromatography with 12% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.26 (m, 2H), 3.15 (t, J = 6.30 Hz, 2H), 2.29 (m, 3H), 2.13 (m, 1H), 1.78 (m, 6H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 179.92, 105.56, 85.64, 45.14, 36.20, 34.08, 32.32, 28.08, 15.26, 5.85, −0.02 (3).

Dihydro-3-(4-iodobutyl)-3-(5-(trimethylsilyl)-4-pentynyl)furan-2(3*H*)-one (14b) was prepared from **13b** according to the general procedure outlined for the preparation of **15a** to afford **14b** in 90% yield after flash chromatography with 8% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.24 (t, J = 7.44 Hz, 2H), 3.17 (t, J = 6.85 Hz, 2H), 2.22 (t, J = 6.78 Hz, 2H), 2.14 (dt, J = 7.02, 2.44 Hz, 2H), 1.81 (m, 2H), 1.72−1.49 (m, 7H), 1.34 (m, 1H), 0.13 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 180.72, 106.33, 85.26, 65.11, 45.59, 34.90, 34.47, 33.34, 32.34, 25.09, 23.48, 20.07, 6.22, 0.12 (3).

Dihydro-3-(3-butenyl)-3-(3-iodopropyl)furan-2(3*H*)-one (15a). Sodium iodide (3.0 g, 20.0 mmol) was added to a stirred solution of dihydro-3-(3-butenyl)-3-(3-chloropropyl)furan-2(3*H*)-one (0.43 g, 2.0 mmol) in 10 mL of acetone. The resultant solution was heated at reflux for 12 h. After this period, the reaction mixture was cooled to room temperature and the solvent was removed *in vacuo*. The resultant reaction mixture was diluted in ether, washed with saturated aqueous sodium thiosulfate and brine, and then dried over $MgSO_4$. The crude product was purified by flash chromatography (10% EtOAc/hexanes) to afford **15a** as a clear yellow oil (0.59 g, 1.90 mmol) in 95% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.75 (m, 1H), 5.01 (m, 2H), 4.25 (t, J = 7.26 Hz, 2H), 3.16 (t, J = 4.35 Hz, 2H), 2.15 (m, 3H), 2.05−1.63 (m, 7H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 180.49, 137.30, 115.40, 65.09, 45.25, 36.66, 34.88, 32.41, 28.48, 28.20, 6.08.

Dihydro-3-(3-iodopropyl)-((3*Z*)-4-(trimethylsilyl)-3-butenyl)furan-2(3*H*)-one (15b). General Procedure for the Preparation of (*Z*)-

(16) Hermann, J. L.; Schlessinger, R. H. *J. Chem. Soc., Chem. Commun.* **1973**, 711.

(17) 4-Iodo-1-(trimethylsilyl)-1-butyne, 3-bromo-1-(trimethylsilyl)-1-propyne, and 5-iodo-1-(trimethylsilyl)-1-pentyne were prepared from 3-butyn-1-ol, propargyl alcohol, and 4-pentyn-1-ol, respectively, according to the following general procedures: (a) Overman, L. E.; Brown, M. J.; McCann S. F. In *Organic Synthesis*; White, J. D., Ed.; Wiley: New York, 1989; Collect. Vol. 68, p 182. (b) Miller, B. *Synth. Commun.* **1972**, *2*, 267.

Olefins from (Trimethylsilyl)alkynes.[18] Substrate **14a** (1.13 g, 3.0 mmol) in 5 mL of dry THF was added dropwise to a slurry of dicyclohexylborane (3.3 mmol, 0.05 M in THF) at 0 °C. The resultant reaction mixture was stirred for 2 h at 0 °C and then 1.5 h at room temperature. During this time the initial white precipitate disappeared and the reaction mixture became clear and colorless. After this period of time, the reaction mixture was diluted with 0.76 mL of glacial acetic acid and heated at 55−60 °C for several hours. The reaction mixture was quenched by the *careful* addition of saturated aqueous $NaHCO_3$. After an aqueous workup, the crude product was dissolved in 10 mL of THF and cooled to 0 °C, whereupon a solution of 0.70 mL of 3 N NaOAc and 0.45 mL of 30% H_2O_2 was added slowly dropwise. The reaction mixture was stirred at 0 °C for 1 h and at room temperature for 1.5 h. The reaction mixture was quenched by the addition of H_2O and subjected to an aqueous workup. Flash chromatography with 10% EtOAc/hexanes afforded **15d** as a clear yellow oil (0.88 g, 2.31 mmol) in 77% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.19 (m, 1H), 5.51 (d, J = 13.94 Hz, 1H), 4.25 (t, J = 7.56 Hz, 2H), 3.16 (t, J = 6.16 Hz, 2H), 2.22−2.06 (m, 4H), 1.91−1.53 (m, 6H), 0.10 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 180.30, 146.65, 130.46, 65.05, 45.30, 36.62, 35.58, 32.38, 28.20 (2), 5.96, −0.14 (3).

Dihydro-3-(4-iodobutyl)-3-((4*Z*)-5-(trimethylsilyl)-4-pentenyl)furan-2(3*H*)-one (15c) was prepared from **14b** according to the general procedure outlined for the preparation of **15b** to afford **15c** in 81% yield after flash chromatography with 8% EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.23 (m, 1H), 5.49 (d, J = 13.92 Hz, 1H), 4.23 (t, J = 7.08 Hz, 2H), 3.17 (t, J = 6.83 Hz, 2H), 2.12 (m, 4H), 1.80 (m, 2H), 1.62−1.44 (m, 6H), 1.33 (m, 2H), 0.09 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 180.94, 147.78, 130.02, 65.13, 45.77, 35.59, 34.76, 33.39, 33.36, 32.19, 25.15, 25.15, 24.30, 6.32, 0.23 (3).

(1*R,2*S**,5*R**)-5-(2-Hydroxyethyl)-2-methylbicyclo[3.3.0]octan-1-ol (16a). General Procedure for the SmI_2-Induced Nucleophilic Acyl Substitution/Ketyl−Olefin Coupling Reactions.** Diiodomethane (0.937 g, 3.50 mmol) was added to a vigorously stirred solution of Sm (0.58 g, 3.89 mmol) in 25 mL of dry THF. The resultant blue-green reaction mixture was stirred for 2.5 h at room temperature, and then HMPA (3.0 mL) was added. The resultant deep purple solution was stirred for 15 min at room temperature. The reaction mixture was cooled to 0 °C, and substrate **15a** (0.216 g, 0.70 mmol) was added slowly dropwise over 2 h as a 0.05 M solution in THF. After the substrate addition was complete, the reaction mixture was warmed to room temperature and stirred an additional 30−45 min. TLC and GC analysis at this time revealed the complete consumption of starting material and the formation of a single diastereomeric product. The reaction was quenched with saturated aqueous $NaHCO_3$. Aqueous workup followed by flash chromatography (25% EtOAc/hexanes) afforded **16a** as a clear colorless oil (0.080 g, 0.43 mmol) in 61% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.76 (t, J = 7.33 Hz, 2H), 2.35 (s, 2H), 1.80 (m, 2H), 1.69 (t, J = 6.33 Hz, 2H), 1.66−1.45 (m, 6H), 1.37 (m, 2H), 1.10 (m, 1H), 0.97 (d, J = 6.72 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 91.14, 59.85, 53.14, 44.70, 41.04, 39.47, 36.59, 36.41, 30.05, 23.79, 13.59; IR (CCl_4) 3635.3, 3466.0, 1032.6 cm^{-1}; HRMS calcd for $C_{11}H_{20}O_2$ 184.1463, found 184.1470; LRMS (EI$^+$) *m/z* 184 (18), 141 (100), 128 (99), 109 (31), 97 (96), 81 (41), 67 (35), 55 (49), 41 (96). Anal. Calcd for $C_{11}H_{20}O_2$: C, 71.70; H, 10.94. Found: C, 71.57; H, 10.89.

(1*R,2*S**,5*R**)-5-(2-Hydroxyethyl)-2-((trimethylsilyl)methyl)bicyclo[3.3.0]-octan-1-ol (16b)** was prepared from **15b** according to the general procedure outlined for the preparation of **16a** to afford **16b** as a single diastereomer in 92% yield after flash chromatography with 25% EtOAc/hexanes: mp 89.0−90.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.75 (t, J = 6.43 Hz, 2H), 2.34 (s, 2H), 1.82−1.54 (m, 8H), 1.50−1.33 (m, 4H), 1.02 (m, 1H), 0.78 (dd, J = 3.07, 14.36 Hz, 1H), 0.41 (dd, J = 11.38, 14.37 Hz, 1H), −0.01 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 92.01, 59.77, 52.27, 46.34, 41.08, 39.53, 36.91, 36.41, 29.92, 23.61, 16.16, −0.81 (3); IR (CCl_4) 3252.5 cm^{-1}; HRMS calcd for $C_{14}H_{28}O_2Si$ 256.1859, found 256.1848; LRMS (EI$^+$) *m/z* 256 (31), 238 (28), 223 (98), 211 (70), 193 (42), 169 (38), 128 (100), 73 (97). Anal. Calcd for $C_{14}H_{28}O_2Si$: C, 65.57; H, 11.00. Found: C, 65.23; H, 11.26.

(18) (a) Hoshi, M.; Masada, Y.; Arase, A. *Chem. Lett.* **1991**, 251. (b) Zweifel, G.; Polston, N. L. *J. Am. Chem. Soc.* **1970**, *92*, 4068.

Ethyl 6-((*tert*-Butyldimethylsilyl)oxy)hexanoate (17a). General Procedure for the Preparation of *tert*-Butyldimethylsilyl Ethers.[19] Imidazole (17.0 g, 250.0 mmol) and *tert*-butyldimethylsilyl chloride (18.1 g, 120.0 mmol) were added successively to a stirred solution of ethyl 6-hydroxyhexanoate in 30 mL of DMF. The resultant reaction mixture became slightly warm and was heated at 40−50 °C for 12 h. The reaction was quenched by the addition of water and subjected to an aqueous workup, extracting with pentane. Flash chromatography with 5% EtOAc/hexanes afforded **17a** (26.29 g, 96.0 mmol) in 96% yield: ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.10 (q, J = 7.08 Hz, 2H), 3.58 (t, J = 6.35 Hz, 2H), 2.28 (t, J = 7.33 Hz, 2H), 1.62 (m, 2H), 1.51 (m, 2H), 1.35 (m, 2H), 1.23 (t, J = 7.08 Hz, 3H), 0.87 (s, 9H), 0.02 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 173.76, 62.96, 60.15, 34.36, 32.46, 25.94 (3), 25.42, 24.80, 18.33, 14.23, −5.20 (2).

Ethyl 2-(4-hydroxybutyl)-7-(trimethylsilyl)-6-heptynoate was prepared from **17a** according to the general procedure for the preparation of **12a** by alkylation of **17a** with 5-iodo-1-(trimethylsilyl)-1-pentyne[15] to afford the alkylated *tert*-butyldimethylsilyl ether of **17a** (46% yield), which was chromatographed through a short plug of silica gel to remove the residual HMPA and then subjected to the following reaction conditions. Removal of the primary *tert*-butyldimethylsilyl protecting group was accomplished by stirring the protected alcohol in a 3:1:1 mixture of THF/AcOH/H_2O at room temperature overnight. After this period of time, the reaction mixture was diluted in 20 mL of brine and subjected to an aqueous workup, extracting with ethyl acetate. Flash chromatography with 35% EtOAc/hexanes afforded the title compound in 39% overall yield from **17a**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.12 (q, J = 7.32 Hz, 2H), 3.62 (q, J = 6.34 Hz, 2H), 2.33 (m, 1H), 2.20 (t, J = 7.08 Hz, 2H), 1.68−1.41 (m, 9H), 1.38−1.30 (m, 2H), 1.24 (t, J = 7.32 Hz, 3H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.05, 106.86, 84.84, 62.72, 60.19, 45.14, 32.60, 32.00, 31.41, 26.34, 23.56, 19.74, 14.35, 0.15 (3).

Ethyl 2-(4-((*tert*-butyldimethylsilyl)oxy)butyl)-6-(trimethylsilyl)-5-hexynoate (18c) was prepared according to the general procedure for the preparation of **12a** by alkylation of **17a** with 4-iodo-1-(trimethylsilyl)-1-butyne[15] to afford **18c** in 20% yield after flash chromatography with 3% EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.10 (m, 2H), 3.58 (m, 2H), 2.28 (t, J = 7.57 Hz, 2H), 2.21 (m, 1H), 1.62 (m, 2H), 1.49 (m, 4H), 1.35 (m, 2H), 1.23 (t, J = 7.57 Hz, 3H), 0.86 (s, 9H), 0.12 (s, 6H), 0.02 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.76, 106.35, 85.25, 62.70, 62.89, 60.19, 44.50, 34.38, 32.64, 25.44 (3), 24.82, 23.52, 18.34, 14.30, 0.10 (2), −5.30 (3).

Methyl 2-(3-chloropropyl)-6-(trimethylsilyl)-5-hexynoate was prepared according to the general procedure for the preparation of **12a** by alkylation of methyl 5-chlorovalerate with 4-iodo-1-(trimethylsilyl)-1-butyne[15] to afford the title compound in 45% yield after flash chromatography with 8% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.67 (s, 3H), 3.51 (t, J = 6.30 Hz, 2H), 2.52 (m, 1H), 2.23 (m, 2H), 1.87 (m, 1H), 1.79−1.62 (m, 5H), 0.12 (s, 9H).

Methyl 2-(3-iodopropyl)-6-(trimethylsilyl)-5-hexynoate (19a) was prepared from methyl 2-(3-chloropropyl)-6-(trimethylsilyl)-5-hexynoate according to the general procedure outlined for the preparation of **15a** to afford **19a** in 88% yield after flash chromatography with 4% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.67 (s, 3H), 3.15 (t, J = 6.76 Hz, 2H), 2.51 (m, 1H), 2.21 (m, 2H), 1.89−1.53 (m, 6H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.55, 105.89, 85.36, 51.67, 43.31, 32.67, 30.98, 30.76, 17.95, 5.80, 0.10 (3).

Methyl 2-(3-chloropropyl)-7-(trimethylsilyl)-6-heptynoate was prepared according to the general procedure outlined for the preparation of **12a** by alkylation of methyl 5-chlorovalerate with 5-iodo-1-(trimethylsilyl)-1-hexyne[15] to afford the title compound in 61% yield after flash chromatography with 3−4% EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.66 (s, 3H), 3.51 (t, J = 5.86 Hz, 2H), 2.38 (m, 1H), 2.21 (t, J = 7.08 Hz, 2H), 1.77−1.57 (m, 6H), 1.48 (m, 2H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.99, 106.62, 84.97, 51.56, 44.59, 44.31, 31.27, 30.28, 29.40, 26.19, 19.66, 0.12 (3).

Methyl 2-(3-iodopropyl)-7-(trimethylsilyl)-6-heptynoate (19b) was prepared from methyl 2-(3-chloropropyl)-7-(trimethylsilyl)-6-heptynoate according to the general procedure outlined for the preparation of **15a** to afford **19b** in 84% yield after flash chromatography with 4%

(19) Corey, E. J.; Venkateswarlu, A. *J. Am. Chem. Soc.* **1972**, *94*, 6190.

EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.66 (s, 3H), 3.15 (t, J = 6.84 Hz, 2H), 2.88 (m, 1H), 2.21 (t, J = 7.08 Hz, 2H), 1.81−1.45 (m, 8H), 0.13 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.96, 106.62, 84.99, 51.59, 44.05, 32.98, 31.26, 31.14, 26.21, 19.67, 5.96, 0.14 (3).

Ethyl 2-(4-bromobutyl)-6-(trimethylsilyl)-5-hexynoate (19c) was prepared from **18c** according to the general procedure for the preparation of **19d** by protecting group removal under acidic conditions (AcOH/THF/H_2O (3:1:1)) followed by bromination with CBr_4/PPh_3 to afford **19c** in 40% yield from **18c**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.12 (q, J = 7.06 Hz, 2H), 3.37 (m, 2H), 2.47 (m, 1H), 2.29 (t, J = 7.39 Hz, 1H), 2.22 (q, J = 7.23 Hz, 1H), 1.84 (m, 3H), 1.63 (m, 2H), 1.45 (m, 3H), 1.24 (m, 3H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.36, 106.12, 85.13, 60.32, 40.20, 33.37, 32.46, 31.03, 30.83, 25.75, 17.94, 14.29, 0.08 (3).

Ethyl 2-(4-Bromobutyl)-7-(trimethylsilyl)-6-heptynoate (19d). General Procedure for the Preparation of Bromides from Alcohols. CBr_4 (3.3 g, 9.88 mmol) and PPh_3 (2.70 g, 10.27 mmol) were added successively to a solution of ethyl 2-(4-hydroxybutyl)-7-(trimethylsilyl)-6-heptynoate (1.18 g, 3.95 mmol) dissolved in 20 mL of Et_2O. The resultant reaction mixture was stirred at room temperature for 18 h. After this period of time, the reaction mixture was dilluted in pentane and filtered through a plug of Celite to remove most of the phosphorus salts. Flash chromatography of the resultant concentrated reaction mixture with 5% EtOAc/hexanes afforded **19d** (1.18 g, 3.27 mmol) in 83% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.13 (q, J = 7.14 Hz, 2H), 3.73 (t, J = 6.72 Hz, 2H), 2.33 (m, 1H), 2.21 (t, J = 7.08 Hz, 2H), 1.84 (m, 2H), 1.80−1.39 (m, 8H), 1.24 (t, J = 7.08 Hz, 3H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.81, 106.77, 84.87, 60.23, 44.96, 33.45, 32.58, 31.38, 31.45, 26.27, 25.94, 19.71, 14.34, 0.14 (3).

(1*R,5*S**)-2-((*E*)-(Trimethylsilyl)methylene)bicyclo[3.3.0]octan-1-ol (20a)** was prepared from **19a** according to the general procedure outlined for the preparation of **16a** to afford **20a** as a single diastereomer in 85% yield after flash chromatography with 8% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.57 (m, 1H), 2.44 (m, 2H), 2.19 (m, 1H), 2.03 (m, 1H), 1.91 (m, 1H), 1.78−1.61 (m, 4H), 1.39−1.24 (m, 3H), 0.08 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.78, 117.96, 91.22, 51.04, 40.91, 32.07, 31.36, 29.28, 25.26, −0.36 (3); IR (CCl_4) 3354.2, 1631.6, 914.6 cm^{-1}; HRMS calcd for $C_{12}H_{22}OSi$ 210.1440, found 210.1444; LRMS (EI$^+$) *m/z* 210 (8), 195 (48), 177 (54), 165 (38), 75 (100). Anal. Calcd for $C_{12}H_{22}OSi$: C, 68.51; H, 10.54. Found: C, 68.09; H, 10.29.

(1*R,6*R**)-2-((Trimethylsilyl)methylene)bicyclo[4.3.0]nonan-1-ol (20b)** was prepared from **19b** according to the general procedure outlined for the preparation of **16a** to afford **20b** as a 4:1 mixture of *E* and *Z* isomers in 61% combined yield after flash chromatography with 7% EtOAc/hexanes: mp 94−95 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.62 (s, 1H), 2.56 (m, 1H), 2.06 (m, 3H), 1.82 (m, 3H), 1.69 (m, 2H), 1.37 (m, 2H), 1.26 (s, 1H), 1.19 (m, 2H), 0.09 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.97, 118.85, 84.69, 51.23, 36.40, 32.20, 31.25, 30.44, 26.95, 21.02, 0.28 (3); IR (CCl_4) 3597.7, 1609.2, 1248.0, 866.5 cm^{-1}; HRMS calcd for $C_{13}H_{23}OSi$ (M − H)$^+$ 223.1518, found 223.1521; LRMS (EI$^+$) *m/z* 206 (23), 191 (72), 151 (18), 134 (27), 119 (42), 106 (40), 91 (38), 75 (98), 59 (42). Anal. Calcd for $C_{13}H_{25}OSi$: C, 69.58; H, 10.78. Found: C, 70.11; H, 10.72.

(1*R,6*S**)-9-((*E*)-Trimethylsilyl)methylene)bicyclo[4.3.0]nonan-1-ol (20c)** was prepared from **19c** according to the general procedure outlined for the preparation of **16a** to afford **20c** as a single diastereomer in 77% yield after flash chromatography with 8% EtOAc/hexanes: mp 57−58 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.48 (t, J = 2.47 Hz, 1H), 2.43 (m, 2H), 1.81 (m, 2H), 1.67 (m, 2H), 1.47 (m, 4H), 1.30 (s, 1H), 1.29 (m, 3H), 0.08 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.53, 117.48, 80.09, 45.35, 33.77, 28.26, 26.52, 25.50, 22.97, 22.59, −0.51 (3); IR (CCl_4) 3604.1, 3468.7, 1960.7, 1627.2, 844.3 cm^{-1}; HRMS calcd for $C_{13}H_{24}OSi$ 224.1596, found 224.1588; LRMS (EI$^+$) *m/z* 224 (11), 209 (61), 191 (100), 165 (89), 75 (98). Anal. Calcd for $C_{13}H_{24}OSi$: C, 69.58; H, 10.78. Found: C, 70.04; H, 10.93.

(1*R,6*R**)-2-((Trimethylsilyl)methylene)bicyclo[4.4.0]decan-1-ol (20d)** was prepared from **19d** according to the general procedure outlined for the preparation of **16a** to afford **20d** as a 1:1 mixture of *E* and *Z* isomers in 80% yield after flash chromatography with 5% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.53 (s, 0.5H), 5.28 (s, 0.5H), 2.49 (m, 1H), 2.34 (m, 1H), 2.13 (dt, J = 13.31, 9.24 Hz, 1H), 1.93 (m, 1H), 1.69−1.22 (m, 12H), 0.08 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.17, 118.59, 75.47, 73.19, 46.08, 44.75, 35.31, 32.32, 31.41, 29.08, 28.93, 28.71, 27.78, 27.56, 26.00, 22.12, 0.30, 0.28; IR (CCl_4) 3445.7, 1611.1, 907.3 cm^{-1}; HMRS calcd for $C_{14}H_{26}OSi$ 238.1753, found 238.1754; LRMS (EI$^+$) *m/z* 223 (28), 205 (100), 179 (53), 119 (90), 75 (99). Anal. Calcd for $C_{14}H_{26}OSi$: C, 70.52; H, 10.99. Found: C, 70.82; H, 10.74.

(1*R,5*R**)-5-(2-Hydroxyethyl)-2-((*E*)-(trimethylsilyl)methylene)-bicyclo[3.3.0]octan-1-ol (21a)** was prepared from **14a** according to the general procedure outlined for the preparation of **16a** to afford **21a** as a single diastereomer in 81% yield after flash chromatography with 23% EtOAc/hexanes: mp 70−71 °C; ^{1}H NMR (400 MHz, C_6D_6) δ 5.81 (m, 1H), 3.38 (m, 2H), 2.28 (m, 2H), 1.94 (m, 1H), 1.74 (m, 4H), 1.47 (m, 6H), 1.21 (m, 1H), 0.15 (s, 9H); ^{13}C NMR (100 MHz, C_6D_6) δ 168.17, 117.48, 90.54, 59.40, 53.52, 41.28, 38.42, 37.91, 34.17, 29.32, 22.77, −0.13 (3); IR (CCl_4) 3630.8, 3600.0, 1438.5, 3292.3, 1623.1 cm^{-1}; HRMS calcd for $C_{14}H_{26}O_2Si$ 254.1702, found 254.1694; LRMS (EI$^+$) *m/z* 221 (32), 192 (31), 165 (27), 120 (96), 105 (23), 91 (29), 75 (100). Anal. Calcd for $C_{14}H_{26}O_2Si$: C, 66.09; H, 10.30. Found: C, 65.84; H, 10.53.

Methyl 2-acetyl-6-(trimethylsilyl)-5-hexynoate was prepared from methyl acetoacetate according to the general procedure outlined for the preparation of **8** to afford the title compound in 56% yield after flash chromatography with 8% EtOAc/hexanes and Kugelrohr distillation (ot 100−110 °C at 20 mmHg): ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.73 (s, 3H), 2.26 (s, 3H), 2.13−1.99 (m, 5H), 0.13 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 202.68, 169.76, 105.05, 86.34, 57.68, 52.51, 29.57, 26.51, 17.76, 0.04 (3).

7-(Trimethylsilyl)-6-heptyn-2-one (22) was prepared according to the general procedure.[20] A solution of methyl 2-acetyl-6-(trimethylsilyl)-5-hexynoate (0.152 g, 0.63 mmol), LiCl (0.085 g, 2.0 mmol), and H_2O (0.03 g, 2.0 mmol) in 5 mL of HMPA was heated at 140 °C for 6 h with vigorous stirring. TLC analysis of the reaction mixture after this period of time showed complete consumption of starting material with the formation of a single product. The reaction mixture was cooled to room temperature and quenched with water. An aqueous workup followed by flash chromatography with 7% EtOAc/hexanes provided **22** (74.7 mg, 0.41 mmol) as a clear colorless oil in 65% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.55 (t, J = 7.26 Hz, 2H), 2.24 (t, J = 6.90 Hz, 2H), 2.14 (s, 3H), 1.75 (pent, J = 7.06 Hz, 2H), 0.13 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 208.38, 106.31, 85.41, 42.16, 30.09, 22.39, 19.16, 0.14 (3).

1-Methyl-2-((*E*)-(trimethylsilyl)methylene)cyclopentan-1-ol (23) was prepared according to the following general procedure. Substrate **22** (13.8 mg, 0.076 mmol) was added dropwise as a 0.05 M solution in THF to a stirred solution of SmI_2 (prepared from Sm (0.02 g, 0.21 mmol) and CH_2I_2 (0.051 g, 0.19 mmol) in 3 mL of dry THF) and HMPA (0.20 mL) at 0 °C. After addition of the substrate was complete, the reaction mixture was warmed to room temperature. TLC/GC analysis at this time showed complete consumption of the starting material for formation of a single product. The reaction mixture was quenched with saturated aqueous $NaHCO_3$ and subjected to an aqueous workup. Flash chromatography with 8% EtOAc/hexanes and Kugelrohr distillation (ot 100−110 °C at 15 mmHg) provided **23** in near-quantitative yield: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.56 (t, J = 2.44 Hz, 1H), 2.51 (m, 1H), 2.34 (m, 1H), 1.82−1.54 (m, 4H), 1.40 (s, 1H), 1.28 (s, 3H), 0.08 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.26, 117.65, 79.42, 41.02, 30.89, 27.08, 21.53, −0.59 (3); IR (neat) 3353.8, 1633.6, 837.6 cm^{-1}; HRMS calcd for $C_{10}H_{20}OSi$ 184.1283, found 184.1278; LRMS (EI$^+$) *m/z* 169 (19), 151 (58), 123 (8), 111 (14), 94 (21), 75 (100), 61 (12), 43 (32), 28 (16).

3-((*tert*-Butyldimethylsilyl)oxy)propyl cyclopentanecarboxylate (24) was prepared from cyclopentanecarboxylic acid and the *tert*-butyldimethylsilyl ether of 1,3-propanediol[21] according to the following general procedure. 1-(3-(Dimethylamino)propyl)-3-ethylcarbodiimide methiodide (EDCI; 5.77 g, 19.4 mmol) and a catalytic amount of DMAP were added to a stirred solution of cyclopentanecarboxylic acid (1.71 g, 15.0 mmol) dissolved in 10 mL of CH_2Cl_2 and stirred at room

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temperature for 12 h. After this period of time the reaction mixture was quenched with water and subjected to an aqueous workup to afford **24** in 84% yield after flash chromatography with 5% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.13 (q, J = 7.12 Hz, 2H), 3.56 (m, 2H), 2.51 (m, 1H), 2.40 (m, 1H), 2.24 (m, 1H), 1.92 (m, 4H), 1.63−1.38 (m, 3H), 1.23 (t, J = 7.11 Hz, 3H), 0.86 (s, 9H), 0.01 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 215.02, 171.12, 63.02, 61.31, 60.18, 37.91, 32.78, 30.17, 28.19, 25.89 (3), 19.53, 18.25, 14.05, −5.39 (2).

3-Hydroxypropyl 1-(4-(trimethylsilyl)-3-butynyl)cyclopentanecarboxylate (25) was prepared by alkylation of **24** with 4-iodo-1-(trimethylsilyl)-1-butyne[15] according to the general alkylation procedure described for the preparation of **12a** and subsequent deprotection of the primary *tert*-butyldimethylsilyl ether under acidic conditions (AcOH/THF/H_2O, 3:1:1) to afford **25** in 45% yield (two steps) after flash chromatography with 20% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.23 (t, J = 6.07 Hz, 2H), 3.67 (m, 2H), 2.13 (m, 2H), 2.05 (m, 2H), 1.85 (m, 5H), 1.62 (m, 4H), 1.49 (m, 2H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.59, 106.86, 84.48, 61.31, 59.18, 53.78, 37.91, 35.92 (2), 31.82, 24.88 (2), 16.80, 0.09 (3).

3-Bromopropyl 1-(4-(trimethylsilyl)-3-butynyl)cyclopentanecarboxylate (26) was prepared from **25** according to the general bromination procedure described for the preparation of **19d** to afford **26** in 65% yield after flash chromatography with 5% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.18 (t, J = 6.01 Hz, 2H), 3.44 (t, J = 6.53 Hz, 2H), 2.20−2.04 (m, 6H), 1.87 (m, 2H), 1.62 (m, 4H), 1.49 (m, 2H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.87, 106.77, 84.49, 62.20, 53.78, 37.91 (2), 31.62, 29.35, 24.87 (2), 18.83, 0.09 (3).

3-Bromopropyl 1-((3*Z*)-4-(trimethylsilyl)-3-butenyl)cyclopentanecarboxylate (27) was prepared by hydroboration of **26** according to the general procedure outlined for the preparation of **15b** to afford **27** in 77% yield after flash chromatography with 5% EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.20 (dt, J = 7.08, 14.16 Hz, 1H), 5.45 (dd, J = 1.22, 13.9 Hz, 1H), 4.18 (t, J = 6.10 Hz, 2H), 3.44 (t, J = 6.59 Hz, 2H), 2.09 (m, 6H), 1.65 (m, 6H), 1.49 (m, 2H), 0.07 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.32, 147.95, 129.35, 62.09, 54.09, 39.03, 36.05 (2), 30.20, 29.38, 24.91, 24.84 (2), 0.81 (3).

(1*R,2*R**)-1-(3-Hydroxypropyl)-2-((trimethylsilyl)methyl)spiro[4.4]nonan-1-ol (28)** was prepared from **27** according to the general procedure outlined for the preparation of **16a** to afford **28** in 73% yield after flash chromatography with 25% EtOAc/hexanes: mp 88−89 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.64 (m, 2H), 1.97 (m, 2H), 1.75−1.43 (m, 14H), 1.34 (m, 2H), 1.16 (m, 1H), 0.71 (d, J = 14.08 Hz, 1H), 0.38 (m, 1H), −0.01 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 85.64, 63.79, 57.28, 45.08, 36.83, 34.35, 33.74, 29.27, 28.68, 27.04, 25.25, 23.66, 20.25, −0.82 (3); IR (CCl_4) 3637.7, 3625.8, 3318.4 cm^{-1}; HRMS calcd for $C_{16}H_{32}O_2Si$ 284.2172, found 284.2166 LRMS (EI$^+$) *m/z* 284 (42), 253 (34), 209 (48), 188 (100), 175 (23), 167(16), 156 (15), 144 (13), 111 (17), 73 (99). Anal. Calcd for $C_{16}H_{32}O_2Si$: C, 67.54; H, 11.34. Found: C, 67.58; H, 11.76.

(1*R,5*R**)-1-((*E*)-2-(Trimethylsilyl)ethenyl)-2-oxabicyclo[3.3.0]octan-3-one (29)** was prepared according to the following general procedure.[22] A solution of *trans*-(2-bromovinyl)trimethylsilane (2.15 g, 12.0 mmol) in 10 mL of dry THF was added slowly to a slurry of magnetically stirred Mg turnings (0.35 g, 14.4 mmol) in 5 mL of dry THF. After the addition was complete, the reaction mixture was heated at reflux for 1 h and then cooled to −78 °C, whereupon the Grignard reagent was treated with ethyl 2-oxocyclopentaneacetate[2a] (1.70 g, 10.0 mmol) in 10 mL of THF (added *via* cannula to the −78 °C cooled solution). The resultant solution was stirred at −78 °C for 30 min and then warmed to room temperature. TLC analysis at this time showed complete consumption of the starting material. The reaction mixture was quenched by the careful addition of saturated aqueous NH_4Cl. An aqueous workup followed by flash chromatography with 12% EtOAc/hexanes afforded **29** in 45% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.02 (d, J = 18.79 Hz, 1H), 5.96 (d, J = 18.80 Hz, 1H), 2.76 (dd, J = 18.11, 9.55 Hz, 1H), 2.58 (m, 1H), 2.27 (dd, J = 18.11, 1.86 Hz, 1H), 2.02 (m, 2H), 1.75 (m, 2H), 1.54 (m, 2H), 0.04 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.34, 145.38, 128.35, 97.29, 43.71, 38.80, 35.91, 33.96, 24.50, −1.41 (3).

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(1*R,4*R**,5*R**)-4-(3-Chloropropyl)-1-((*E*)-2-(trimethylsilyl)ethenyl)-2-oxabicyclo[3.3.0]octan-3-one (30)** was prepared from **29** according to the general alkylation procedure outlined for the preparation of **12a** to afford **30** in 40% yield after flash chromatography with 4% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.06 (d, J = 18.81 Hz, 1H), 4.93 (d, J = 18.82 Hz, 1H), 3.51 (m, 2H), 2.33 (m, 2H), 1.99 (m, 2H), 1.83 (m, 3H), 1.72 (m, 3H), 1.56 (m, 2H), 0.05 (s, 9H).

(1*R,4*R**,5*R**)-4-(3-Iodopropyl)-1-((*E*)-2-(trimethylsilyl)ethenyl)-2-oxabicyclo[3.3.0]octan-3-one (31)** was prepared from **30** according to the general procedure outlined for the preparation of **15a** to afford **31** in 95% yield after flash chromatography with 2−3% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.05 (d, J = 18.82 Hz, 1H), 5.94 (d, J = 18.82 Hz, 1H), 3.14 (m, 2H), 2.23 (m, 2H), 2.04−1.80 (m, 3H), 1.78−1.74 (m, 4H), 1.72−1.53 (m, 2H), 0.05 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 179.03, 146.66, 128.08, 95.70, 49.97, 48.08, 39.24, 34.56, 33.29, 31.01, 24.58, 5.66, −1.37 (3).

(1*R,2*RS**,3*S**,7*S**,8*S**)-2-((Trimethylsilyl)methyl)tricyclo[6.3.0^{3,7}]-undecan-1,3-diol (32)** was prepared from **31** according to the general procedure outlined for the preparation of **16a**, except the substrate was added as a 0.05 M solution in THF over a period of approximately 2.5 h to SmI_2/HMPA heated at reflux, which afforded **32** as a 6:1 mixture of diastereomers epimeric at C-2 in 58% combined yield. Major diastereomer, high R_f: mp 91−92 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.55 (s, 1H), 2.14 (m, 1H), 1.99 (m, 2H), 1.87−1.75 (m, 3H), 1.63−1.49 (m, 6H), 1.44−1.30 (m, 4H), 0.70 (m, 2H), 0.02 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 99.39, 94.48, 59.47, 51.37, 49.49, 39.61, 32.52, 30.29, 26.95, 26.13, 22.82, 10.12, −0.74 (3); IR (CCl_4) 3620.6, 3556.2, 1249.1, 875.1 cm^{-1}; HRMS calcd for $C_{15}H_{28}O_2Si$ 268.1859, found 268.1859; LRMS (EI$^+$) *m/z* 268 (2), 250 (19), 235 (100), 222 (52), 156 (100), 73 (85). Anal. Calcd for $C_{15}H_{28}O_2Si$: C, 67.71; H, 10.51. Found: C, 66.76; H, 10.21. Minor diastereomer, low R_f: mp 93−94 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.90 (s, 1H), 2.17−1.93 (m, 3H), 1.88−1.65 (m, 5H), 1.62−1.33 (m, 6H), 1.23 (m, 2H), 0.54 (dd, J = 4.46, 15.21 Hz, 1H), 0.19 (dd, J = 8.16, 15.21 Hz, 1H), 0.02 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 102.35, 97.76, 56.63, 52.75, 51.87, 37.25, 30.62, 29.58, 27.50, 26.59, 22.48, 13.86, −0.99 (3); IR (CCl_4) 3614.8, 3553.8, 3404.5, 1549.8, 1249.7, 1004.1, 810.0 cm^{-1}; HRMS calcd for $C_{15}H_{27}O_2Si$ (M − H)$^+$ 267.1781, found 267.1732; LRMS (EI$^+$) *m/z* 250 (31), 235 (98), 222 (95), 207 (43), 156 (100), 73 (92).

Ethyl 1-(3-((*tert*-butyldimethylsilyl)oxy)propyl)-2-oxocyclopentanecarboxylate (33) was prepared according to the general procedure outlined for the preparation of **8** by alkylation of ethyl 2-oxocyclopentanecarboxylate with the *tert*-butyldimethylsilyl-protected ether of 3-bromo-1-propanol to afford **33** in 64% yield after flash chromatography with 3% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.13 (q, J = 7.12 Hz, 2H), 3.56 (m, 2H), 2.51 (m, 1H), 2.40 (m, 1H), 2.24 (m, 1H), 1.92 (m, 4H), 1.63−1.38 (m, 3H), 1.23 (t, J = 7.11 Hz, 3H), 0.86 (s, 9H), 0.01 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 215.02, 171.12, 63.02, 61.31, 60.18, 37.91, 32.78, 30.17, 28.19, 25.89 (3), 19.53, 18.26, 14.05, −5.39 (2); IR (neat) 1753.4, 1724.2 cm^{-1}.

(1*R,2*R**)-Ethyl 1-(3-((*tert*-butyldimethylsilyl)oxy)propyl)-2-hydroxy-2-(3-(trimethylsilyl)-2-propynyl)cyclopentanecarboxylate** was prepared according to the following general procedure.[23] Unactivated zinc metal (0.26 g, 4.0 mmol) was added to a vigorously stirred mixture of **33** (0.89 g, 2.78 mmol) and 3-bromo-1-(trimethylsilyl)-1-propyne[15] (0.76 g, 4.0 mmol) in 5 mL of DMF at room temperature. Following the addition of the zinc metal, the reaction mixture became very warm after approximately 15−20 min. The reaction mixture was stirred at room temperature for 2 h after the exotherm had subsided. TLC analysis at this time showed complete consumption of the starting material. The reaction mixture was quenched by the careful addition of saturated aqueous NH_4Cl. An aqueous workup followed by flash chromatography with 5% EtOAc/hexanes provided the title compound (0.84 g, 1.90 mmol) in 70% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.11 (m, 2H), 3.56 (m, 2H), 2.49 (d, J = 16.9 Hz, 1H), 2.38 (d, J = 16.9 Hz, 1H), 2.23 (s, 1H), 2.20 (m, 1H), 1.95 (m, 2H), 1.87−1.68 (m, 3H), 1.49 (m, 2H), 1.25 (t, J = 7.12 Hz, 2H), 1.23 (m, 3H), 0.86 (s, 9H), 0.14 (s, 9H), 0.02 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.18, 102.88, 88.03, 81.70, 63.44, 60.57, 59.87, 36.50, 30.93, 29.64, 28.96, 28.23, 25.89 (3), 18.73, 18.27, 14.15, −0.05 (3), −5.35 (2); IR (neat) 3530.1, 1723.5, 841.8 cm^{-1}.

(23) Shono, T.; Ishifune, M.; Kashimura, S. *Chem. Lett*. **1990**, 449.

(1*R,2*R**)-Ethyl 1-(3-((*tert*-butyldimethylsilyl)oxy)propyl)-2-((*tert*-butyldimethylsilyl)oxy)-2-(3-(trimethylsilyl)-2-propynyl)cyclopentanecarboxylate (34)** was prepared according to the following general procedure.[24] 2,6-Lutidine (0.33 g, 3.1 mmol) and *tert*-butyldimethylsilyl triflate (0.66 g, 2.5 mmol) were added successively to a stirred mixture of (1*R**,2*R**)-ethyl 1-(3-((*tert*-butyldimethylsilyl)oxy)propyl)-2-hydroxy-2-(3-(trimethylsilyl)-2-propynyl)cyclopentanecarboxylate (0.55 g, 1.25 mmol) in 2 mL of CH_2Cl_2 at 0 °C. The reaction mixture was stirred for 1 h at 0 °C and then 12 h at room temperature. TLC analysis after this period showed complete consumption of starting material and formation of a single product. The reaction mixture was quenched by the careful addition of a 1% HCl solution. An aqueous workup followed by flash chromatography with 1−2% EtOAc/hexanes afforded **34** in 92% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.08 (q, J = 7.13 Hz, 2H), 3.54 (m, 2H), 2.52 (d, J = 17.1 Hz, 1H), 2.35 (d, J = 17.1 Hz, 1H), 2.17 (m, 1H), 2.06 (m, 2H), 1.79 (m, 1H), 1.66 (m, 4H), 1.46 (m, 2H), 1.23 (t, J = 7.08 Hz, 3H), 0.88 (s, 9H), 0.86 (s, 9H), 0.18 (s, 6H), 0.12 (s, 9H), 0.01 (s, 6H).

(1*R,2*R**)-Ethyl 1-(3-bromopropyl)-2-((*tert*-butyldimethylsilyl)oxy)-2-(3-(trimethylsilyl)-2-propynyl)cyclopentanecarboxylate (35)** was prepared from **34** according to the general procedure outlined for the preparation of **19d** by removal of the primary *tert*-butyldimethylsilyl protecting group under acidic conditions (AcOH/THF/H_2O, 3:1:1) followed by bromination with CBr_4/PPh_3 to afford **35** in 77% yield (two steps) after flash chromatography with 4% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.10 (m, 2H), 3.36 (m, 2H), 2.54 (d, J = 17.2 Hz, 1H), 2.35 (d, J = 17.1 Hz, 1H), 2.21 (m, 2H), 2.04 (m, 1H), 1.83−1.59 (m, 7H), 1.25 (t, J = 7.15 Hz, 3H), 0.90 (s, 9H), 0.19 (s, 6H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.03, 104.14, 87.47, 85.36, 61.72, 60.55, 36.68, 34.25, 31.86, 31.10, 29.74, 29.17, 25.98, 19.48 (3), 18.68, 14.15, −0.06 (3), −2.31, −2.42; IR (neat) 2178.0, 1722.9, 1462,9, 1249.3, 840.1 cm^{-1}.

(1*R,4*S**,8*S**)-4-((*tert*-Butyldimethylsilyl)oxy)-2-((*E*)-trimethylsilyl)-methylene)tricyclo[6.3.0^{4,8}]undecan-1-ol (36)** was prepared according to the general procedure outlined for the preparation of **16a** to afford **36** in 81% yield after flash chromatography with 5% EtOAc/hexanes: mp 107−108 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.53 (m, 1H), 2.61 (d, J = 15.27 Hz, 1H), 2.42 (dd, J = 15.27, 2.47 Hz, 1H), 2.33 (m, 1H), 1.82 (m, 4H), 1.67−1.44 (m, 7H), 1.26 (m, 1H), 0.87 (s, 9H), 0.08 (s, 9H), 0.08 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.22, 116.10, 89.32, 87.07, 64.94, 45.72, 43.53, 42.96, 35.11, 33.94, 25.82 (3), 34.18, 23.89, 18.12, −0.12 (3), −2.45, −2.52; IR (CCl_4) 3600.1, 1633.5, 1471.4, 1248.9, 1082.4, 850.1, 836.6 cm^{-1}; HRMS calcd for $C_{21}H_{40}O_3Si_2$ 380.2567, found 380.2563; LRMS (EI$^+$) *m/z* 380 (12), 323 (51), 224 (23), 147 (21), 73 (60). Anal. Calcd for $C_{21}H_{40}O_2Si_2$: C, 66.25; H, 10.59. Found: C, 66.58; H, 10.65.

Ethyl 2-oxo-1-(5-(trimethylsilyl)-4-pentynyl)cyclohexanecarboxylate was prepared from ethyl 2-oxocyclohexanecarboxylate according to the general procedure outlined for the preparation of **8** to afford the title compound in 44% yield after flash chromatography with 7−8% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.18 (q, J = 7.12 Hz, 2H), 2.48 (m, 1H), 2.43 (m, 2H), 1.19 (t, J = 7.24 Hz, 2H), 1.96 (m, 1H), 1.91 (m, 1H), 1.76−1.53 (m, 4H), 1.48−1.39 (m, 3H), 1.24 (t, J = 7.13 Hz, 3H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 207.83, 171.87, 106.83, 84.75, 61.19, 60.64, 41.03, 35.94 33.87, 27.57, 23.67, 22.48, 20.23, 14.16, 0.12 (3).

(1*R,2*R**)-Ethyl 2-((*tert*-Butyldimethylsilyl)oxy-2-(3-((*tert*-butyldimethylsilyl)oxy)propyl)-1-(5-(trimethylsilyl)-4-pentynyl)cyclohexanecarboxylate.** The *tert*-butyldimethylsilyl ether of 3-bromo-1-propanol (3.47 g, 13.7 mmol) in 10 mL of dry THF was added to a slurry of Mg metal (0.50 g, 20.6 mmol) with vigorous stirring. After the addition of the bromide was complete, the reaction mixture was heated at reflux for 1 h. After this period, the dark gray solution was cooled to −78 °C and a solution of ethyl 2-oxo-1-(5-(trimethylsilyl)-4-pentynyl)cyclohexanecarboxylate (1.69 g, 5.48 mmol) in 5−10 mL of dry THF was added dropwise *via* cannula. After the addition of the substrate was complete, the reaction mixture was warmed to room temperature and then heated at reflux for 12 h. After this period of time, TLC analysis of the crude reaction mixture showed complete consumption of the starting material. The reaction mixture was quenched with saturated aqueous NH_4Cl and filtered through a plug of Celite to remove the metal salts. An aqueous workup followed by flash chromatography with 6% EtOAc/hexanes afforded the desired alcohol as a 55:1 mixture of diastereomers (capillary GC) in 65% yield. The alcohol was then subjected to the general reaction conditions described for the preparation of **34** to afford the title compound in 94% yield after flash chromatography with 1−2% EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.20 (m, 1H), 4.09 (m, 1H), 3.58 (t, J = 6.35 Hz, 2H), 2.24 (m, 3H), 1.91−1.70 (m, 5H), 1.63−1.47 (m, 5H), 1.28 (t, J = 7.08 Hz, 3H), 1.35−1.22 (m, 5H), 0.94 (s, 9H), 0.92 (s, 9H), 0.19 (s, 9H), 0.18 (s, 6H), 0.06 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 175.68, 107.27, 84.48, 78.68, 63.58, 60.07, 55.17, 33.04, 32.84, 28.94, 28.02 (3), 26.92 (3), 26.02, 25.93, 25.65, 23.94, 23.06, 22.65, 20.69, 20.43, 18.83, 18.29, 14.40, 0.16 (3), −1.11 (2).

(1*R,2*R**)-Ethyl 2-(3-bromopropyl)-2-((*tert*-butyldimethylsilyl)-oxy)-1-(5-(trimethylsilyl)-4-pentynyl)cyclohexanecarboxylate (37)** was prepared from (1*R**,2*R**)-ethyl 2-((*tert*-butyldimethylsilyl)oxy)-2-(3-((*tert*-butyldimethylsilyl)oxy)propyl)-1-(5-(trimethylsilyl)-4-pentynyl)cyclohexanecarboxylate according to the general procedure for the preparation of **35** to afford **37** in 52% yield (two steps) after flash chromatography with 1−2% EtOAc/hexanes: ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.18 (m, 1H), 4.06 (m, 1H), 3.33 (m, 2H), 2.18 (m, 2H), 1.97−1.71 (m, 8H), 1.57−1.37 (m, 4H), 1.24 (t, J = 7.08 Hz, 2H), 1.22−1.11 (m, 5H), 0.90 (s, 9H), 0.12 (s, 6H), 0.12 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.59, 107.12, 84.56, 78.50, 60.25, 55.01, 35.59, 34.21, 33.43, 28.84, 27.93, 27.21, 25.98 (3), 23.84, 23.03, 20.64, 20.32, 18.82, 14.41, 0.14 (3), −1.04, −1.08.

(1*R,6*R**)-6-((*tert*-Butyldimethylsilyl)oxy)-1-(5-(trimethylsilyl)-4-pentynyl)bicyclo[4.4.0]decan-2-one (38)** was prepared according to the general procedure outlined for the preparation of **16a** to afford the title compound in 88% yield after flash chromatography with 4% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.37 (m, 1H), 2.23−1.25 (m, 4H), 2.04−1.93 (m, 2H), 1.85 (m, 1H), 1.66 (m, 3H), 1.46−1.34 (m, 7H), 1.25 (m, 2H), 0.91 (s, 9H), 0.13 (s, 9H), 0.11 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 213.52, 107.10, 84.82, 78.76, 58.92, 37.67, 36.07, 34.87, 26.77, 26.24 (3), 22.29, 22.21, 21.00, 20.43, 20.30, 18.84, 0.16 (3), −1.35, −2.00; HRMS calcd for $C_{24}H_{44}O_2Si_2$ 420.2880, found 420.2865; LRMS (EI$^+$) *m/z* 420 (2), 363 (99), 289 (9), 273 (11), 251 (26), 197 (12), 171 (11), 147 (12), 73 (100).

(1*R,2*R**)-Dimethyl 2,3-*O*-isopropylidene-2-(2-propenyl)tartrate (39)** was prepared from (−)-dimethyl 2,3-*O*-isopropylidene-L-tartrate by alkylation with allyl bromide according to the general procedure outlined for the preparation of **12a** to afford **39** in 18% yield after flash chromatography with 7% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.74 (m, 1H), 5.08 (m, 2H), 4.98 (s, 1H), 3.79 (s, 3H), 3.78 (s, 3H), 2.56 (dd, J = 13.97, 7.34 Hz, 1H), 2.43 (dd, J = 13.93, 6.87 Hz, 1H), 1.60 (s, 3H), 1.41 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.89, 168.68, 131.19, 119.40, 112.63, 85.37, 79.41, 52.75, 52.57, 38.82, 27.45, 25.83.

(1*R,2*R**)-Dimethyl 3-(4-iodobutyl)-2,3-*O*-isopropylidene-2-(2-propenyl)tartrate (40)** was prepared from **39** by alkylation with 1,4-diiodobutane according to the general procedure outlined for the preparation of **12a** to afford **40** as a single diastereomer in 35% yield after flash chromatography with 6% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.70 (m, 1H), 5.09 (m, 2H), 3.82 (s, 3H), 3.76 (s, 3H), 3.11 (t, J = 6.98 Hz, 2H), 2.65 (dd, J = 8.09, 13.48 Hz, 1H), 2.42 (dd, J = 5.98, 13.48 Hz, 1H), 2.00 (m, 1H), 1.79 (pent, J = 7.08 Hz, 2H), 1.65−1.54 (m, 2H), 1.58 (s, 3H), 1.55 (s, 3H), 1.21 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.58, 170.12, 131.37, 119.64, 112.56, 89.85, 89.51, 52.64, 52.42, 40.01, 34.45, 33.29, 29.03, 28.95, 25.16, 5.77.

(1*R,2*R**)-Dimethyl 3-(4-Iodobutyl)-2,3-*O*-isopropylidene-2-((*E*)-3-phenyl-2-propenyl)tartrate (41).** Ozone was bubbled through a −78 °C cooled solution of **40** (0.685 g, 1.56 mmol) in 5 mL of 5:1 CH_2Cl_2/MeOH solvent with catalytic $NaHCO_3$ until a blue color persisted. Then, argon was bubbled through the blue reaction mixture until the blue color was no longer apparent and DMS (1 mL) was added. The reaction mixture was warmed to room temperature and stirred overnight. After this period of time, the reaction mixture was filtered through a plug of Celite and concentrated *in vacuo* to afford the crude aldehyde. The crude aldehyde was dissolved in 5 mL of dry THF and treated with the Wittig reagent derived from benzyltriphenylphosphonium

(24) Corey, E. J.; Cho, H.; Rücker, C.; Hua, D. H. *Tetrahedron Lett.* **1981**, *22*, 3455.

chloride (1.52 g, 4.0 mmol) and *n*-butyllithium (4.1 mmol) at −78 °C. After the addition of the substrate was completed, the reaction mixture was warmed to room temperature. TLC at this period showed complete consumption of starting material. The reaction was quenched by the addition of saturated aqueous NH_4Cl. An aqueous workup followed by flash chromatography with 5% EtOAc/hexanes afforded the desired compound **41** as a 4:1 mixture of diastereomeric products (*E* major) in 64% yield (two steps): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.23 (m, 5H), 6.41 (d, J = 15.86 Hz, 1H), 6.09 (m, 1H), 3.84 (s, 3H), 3.75 (s, 3H), 3.12 (t, J = 6.97 Hz, 2H), 2.80 (dd, J = 8.59, 13.70 Hz, 1H), 2.60 (dd, J = 5.74, 13.70 Hz, 1H), 2.20 (m, 1H), 1.80 (m, 2H), 1.64 (s, 3H), 1.63 (m, 2H), 1.58 (s, 3H), 1.21 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.64, 170.17, 136.90, 134.70, 128.39 (2), 127.44, 126.30 (2), 122.68, 112.65, 90.01, 89.54, 52.73, 52.54, 39.39, 34.51, 33.30, 29.08, 29.05, 25.19, 5.83.

(1*R,3*R**,4*S**,9*R**)-Methyl 4-hydroxy-3,11,11-trimethyl-10,12-dioxatricyclo[7.3.0^{4,9}]decanoate (42)** was prepared from **40** according to the general procedure outlined for the preparation of **16a** to afford **42** as a 6:1 mixture of diastereomers in 26% yield after flash chromatography with 7% EtOAc/hexanes (major diastereomer): ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.78 (s, 3H), 2.31 (d, J = 2.59 Hz, 1H), 2.10 (m, 2H), 2.02 (m, 1H), 1.78 (m, 2H), 1.70 (m, 1H), 1.52 (m, 2H), 1.51 (s, 3H), 1.46 (s, 3H), 1.33−1.20 (m, 2H), 1.07 (m, 1H), 0.94 (d, J = 6.22 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.58, 111.40, 93.19, 90.72, 79.15, 52.56, 40.58, 39.89, 31.37, 28.53, 28.00, 27.20, 22.49, 19.29, 11.44; IR (CCl_4) 3565.1, 1734.3, 1452.1, 1371.8 cm^{-1}; HRMS calcd for $C_{15}H_{23}O_5$ (M − H) 283.1164, found 283.1545; LRMS (EI$^+$) *m/z* 283 (6), 269 (96), 209 (68), 181 (39), 149 (100), 121 (46), 95 (26), 59 (36), 41 (79). Anal. Calcd for $C_{15}H_{24}O_5$: C, 63.36; H, 8.51. Found: C, 63.74; H, 8.97.

(1*R,3*R**,4*S**,9*R**)-Methyl 3-benzyl-4-hydroxy-11,11-dimethyl-10,12-dioxatricyclo[7.3.0^{4,9}]decanoate (43)** was prepared from **41** (*E* isomer) according to the general procedure outlined for the preparation of **16a** to afford **43** as a 10:1 mixture of diastereomers in 48% combined yield after flash chromatography with 6−7% EtOAc/hexanes, mp 81−82 °C (major diastereomer): ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.34−7.20 (m, 5H), 2.84 (s, 3H), 3.03 (d, J = 10.99 Hz, 2H), 2.49 (d, J = 2.44 Hz, 1H), 2.32 (m, 3H), 2.11 (m, 1H), 1.84 (m, 2H), 1.73 (m, 1H), 1.66−1.53 (m, 4H), 1.55 (s, 3H), 1.45 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.50, 141.25, 128.63 (2), 128.43 (2), 125.88, 111.52, 93.26, 90.37, 79.26, 52.69, 48.10, 38.54, 34.05, 31.25, 28.58, 28.11, 27.98, 22.49, 19.40; IR (CCl_4) 3569.4, 3064.5, 3027.9, 1732.8, 1584.9, 1444.2 cm^{-1}; HRMS calcd for $C_{21}H_{28}O_5$ 360.1937, found 360.1935; LRMS (EI$^+$) *m/z* 345 (100), 285 (68), 257 (46), 253 (13), 225 (64), 197 (21), 117 (19), 105 (16), 91 (98), 55 (24), 41 (34). Anal. Calcd for $C_{21}H_{28}O_5$: C, 69.98; H, 7.83. Found: C, 69.68; H, 8.13.

Methyl 2-(3-iodopropyl)-5-hexenoate (44) was prepared from methyl 5-chlorovalerate (Aldrich) by alkylation with 4-bromo-1-butene according to the general procedure for preparation of **12a**. The crude chloride obtained was chromatographed through a short plug of silica to remove the HMPA and then subjected immediately to a Finkelstein reaction with NaI to afford the title compound in 45% yield (two steps) after flash chromatography with 2% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.73 (m, 1H), 4.98 (m, 2H), 3.66 (s, 3H), 3.15 (t, J = 6.66 Hz, 2H), 2.37 (m, 1H), 2.02 (m, 2H), 1.83−1.51 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.06, 137.59, 115.28, 51.52, 43.92, 33.00, 31.44 (2), 31.15, 6.00.

(1*R,2*R**,5*R**)-2-(2-Hydroxy-2-methylpropyl)bicyclo[3.3.0]octan-1-ol (45)** was prepared from **44** according to the general procedure outlined for the preparation of **47** to afford **45** as a single diastereomer in 66% yield after flash chromatography with 22−23% EtOAc/hexanes and Kugelrohr distillation (ot 80−90 °C at 0.05 mmHg): ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.21 (bs, 1H), 2.41 (bs, 1H), 2.15 (m, 1H), 2.08 (m, 2H), 1.87 (m, 1H), 1.69−1.55 (m, 4H), 1.45 (m, 2H), 1.32−1.17 (m, 3H), 1.26 (s, 6H), 1.02 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 91.64, 70.97, 50.99, 46.19, 42.92, 36.95, 35.04, 32.46, 32.10, 30.02, 28.11, 25.42; IR (neat) 3316.4 cm^{-1}; LRMS (EI$^+$) *m/z* 180 (31), 165 (17), 125 (42), 107 (46), 97 (49), 84 (100), 67 (29), 59 (72), 43 (86). Anal. Calcd for $C_{12}H_{22}O_2$: C, 72.68; H, 11.18. Found: C, 72.68; H, 11.24.

Ethyl 2-(3-butenyl)-6-((*tert*-butyldimethylsilyl)oxy)hexanoate was prepared by alkylation of **17a** with 4-bromo-1-butene according to the general procedure outlined for the preparation of **12a** to afford the title compound in 42% yield after flash chromatography with 2% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.74 (m, 1H), 4.96 (m, 2H), 4.11 (q, J = 7.14 Hz, 2H), 3.56 (t, J = 6.51 Hz, 2H), 2.32 (m, 1H), 2.02 (m, 2H), 1.72−1.41 (m, 5H), 1.29 (m, 3H), 1.23 (t, J = 7.10 Hz, 3H), 0.86 (s, 9H), 0.01 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.21, 137.96, 114.98, 62.94, 60.03, 45.04, 32.70, 32.25, 31.57, 25.94 (3), 23.67, 18.33, 14.32, −5.20 (2).

Ethyl 2-(3-butenyl)-6-hydroxyhexanoate was prepared from ethyl 2-(3-butenyl)-6-((*tert*-butyldimethylsilyl)oxy)hexanoate by treatment with a 3:1:1 mixture of THF/AcOH/H_2O at room temperature overnight, to afford the title compound in 94% crude yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.75 (m, 1H), 4.98 (m, 2H), 4.12 (q, J = 7.12 Hz, 2H), 3.62 (q, J = 6.40 Hz, 2H), 2.35 (m, 1H), 2.01 (m, 2H), 1.76−1.60 (m, 2H), 1.58−1.42 (m, 5H), 1.32 (m, 2H), 1.24 (t, J = 7.12 Hz, 3H).

Ethyl 2-(4-chlorobutyl)-5-hexenoate was prepared from ethyl 2-(3-butenyl)-6-hydroxyhexanoate according to the general procedure outlined for the preparation of **19d** replacing CCl_4 for CBr_4 to afford the title compound in 82% yield after flash chromatography with 2% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.72 (m, 1H), 4.97 (m, 2H), 4.13 (q, J = 7.12 Hz, 2H), 3.50 (t, J = 6.66 Hz, 2H), 2.34 (m, 1H), 2.02 (m, 2H), 1.74 (m, 2H), 1.51 (m, 2H), 1.43−1.38 (m, 4H), 1.24 (t, J = 7.15 Hz, 3H).

Ethyl 2-(4-iodobutyl)-5-hexenoate (46) was prepared from ethyl 2-(4-chlorobutyl)-5-hexenoate according to the general procedure outlined for the preparation of **15a** to afford **46** in 96% yield after flash chromatography with 2% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.75 (m, 1H), 4.97 (m, 2H), 4.13 (q, J = 7.16 Hz, 2H), 3.15 (t, J = 6.97 Hz, 2H), 2.34 (m, 1H), 2.01 (m, 2H), 1.80 (m, 2H), 1.70 (m, 1H), 1.60 (m, 1H), 1.55−1.35 (m, 4H), 1.25 (t, J = 7.16 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.90, 137.80, 115.12, 60.19, 44.78, 33.22, 31.53, 31.49, 31.18, 28.22, 14.35, 6.51.

(1*R,6*R**,9*R**)-9-(2-Hydroxy-2-methylpropyl)bicyclo[4.3.0]nonan-1-ol (47)** was prepared from **46** according to the general procedure outlined for the preparation of **15b**. However, an electrophile, acetone (2.0 equiv), was added dropwise in THF with the substrate **46**. The product, **47**, was obtained as a single diastereomer in 67% yield after flash chromatography with 20% EtOAc/hexanes: ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.91 (s, 2H), 2.10 (m, 2H), 1.96 (m, 2H), 1.81 (m, 2H), 1.73−1.35 (m, 6H), 1.34−1.13 (m, 4H), 1.23 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 77.51, 70.96, 46.46, 44.87, 42.20, 31.92, 28.34, 28.19, 27.68, 24.17, 23.27, 20.94, 20.22; IR (neat) 3320.2 cm^{-1}; LRMS (EI) *m/z* 194 (34), 139 (23), 121 (54), 98 (100), 83 (33), 59 (57), 41 (67). Anal. Calcd for $C_{13}H_{24}O_2$: C, 73.55; H, 11.39. Found: C, 73.27; H, 11.30.

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