Intramolecular Anodic Olefin Coupling Reactions: The Use of Allylsilane Coupling Partners with Allylic Alkoxy Groups

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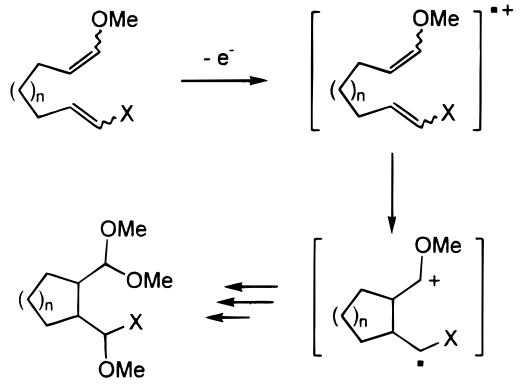
Intramolecular anodic olefin coupling reactions having an alkoxy substituent on the allylic carbon of an allylsilane moiety have been studied. These substrates were examined as part of an effort to determine the compatibility of the anodic olefin coupling reaction with the presence of very acid-sensitive functional groups and the construction of functionalized five-membered rings. In the initial experiment reported, an enol ether moiety was coupled to a trisubstituted allylsilane to afford a five-membered ring product without loss of the allylic alkoxy group. The reaction was stereoselective and could be used to generate a five-membered ring with three contiguous asymmetric centers. The stereochemical outcome of the reaction was best explained by a "pseudoequatorial" alkoxy group in the transition state; an argument that implied the reaction was under kinetic control. This suggestion was tested with the use of two electrolysis substrates that led to identical products through different transition states. The two substrates led to much different product ratios, proving that the reactions were not controlled by thermodynamics but rather governed by kinetic control. This observation was opposite to the conclusion reached with earlier vinylsilane-based substrates. Finally, the reactions were shown to be compatible with the presence of the alkoxy group even when challenged to form a fused bicyclic ring skeleton and a quaternary carbon. As in the initial case, the reaction to form a quaternary carbon was also highly stereoselective.

Introduction

Anodic electrochemistry can provide an excellent means for studying the chemistry of reactive radical cation intermediates.[1] For example, we have been using electrochemistry to generate radical cations from both alkyl and silyl enol ethers.[2−6] These intermediates can be trapped in an intramolecular fashion with simple alkyl olefins, enol ethers, styrenes, allylsilanes, vinylsilanes, and electron-rich aromatic rings. A general reaction scheme for the coupling of two electron-rich olefins is illustrated in Scheme 1. Reactions of this type are of interest because they are oxidative cyclization reactions and, therefore, lead to the formation of new ring skeletons without giving up the functionality used to initiate the reaction. However, while the reactions have proven useful for forming fused and bridged bicyclic rings and generating quaternary carbons in simple model systems, their potential for constructing complex, highly functionalized molecules has not yet been explored.

Scheme 1



With these things in mind, the syntheses of several natural products have been undertaken. One such effort is focusing on the synthesis of crinipellin B (**3**). The crinipellins are a family of tetraquinane natural products that were isolated from the fungus *Crinipellis stipitaria.*[7] They have a unique ring skeleton that has made them a popular synthetic target.[8] At the heart of the angularly

(1) For reviews, see: (a) Yoshida, K. *Electrooxidation in Organic Chemistry: The Role of Cation Radicals as Synthetic Intermediates;* John Wiley and Sons: New York, 1984; pp 136−151. (b) Torii, S. *Electroorganic Synthesis: Methods and Applications: Part I—Oxidations;* VCH: Deerfield Beach, FL, 1985. (c) For intramolecular reactions see: Moeller, K. D. *Top. Curr. Chem.* **1997**, *185*, 50.

(2) For selected examples, see: (a) New, D. G.; Tesfai, Z.; Moeller, K. D. *J. Org. Chem.* **1996**, *61*, 1578. (b) Hudson, C. M.; Moeller, K. D. *J. Am. Chem. Soc.* **1994**, *59*, 2381. (c) Tinao-Wooldridge, L. V.; Moeller, K. D.; Hudson, C. M. *J. Org. Chem.* **1994**, *59*, 2381. (d) Moeller, K. D.; Tinao, L. V. *J. Am. Chem. Soc.* **1992**, *114*, 1033. (e) Hudson, C. M.; Marzabadi, M. R.; Moeller, K. D.; New, D. G. *J. Am. Chem. Soc.* **1991**, *113*, 7372.

(3) For an extensive list of references concerning chemically based oxidative cyclization reactions, see ref 1c and ref 3 therein, as well as: Snider, B. B. *Chem. Rev.* **1996**, *96*, 339.

(4) For more recent oxidative cyclization reactions, see: (a) Jahn, U.; Hartmann, P. *J. Chem. Soc., Chem. Commun.* **1998** 209. (b) Ryter, K.; Livinghouse, T. *J. Am. Chem. Soc.* **1998**, *120*, 2658. (c) Schmittel, M.; Burghart, A.; Malisch, W.; Reising, J.; Söllner, R. *J. Org. Chem.* **1998**, *63*, 396.

(5) Reddy, S. H. K.; Moeller, K. D. *Tetrahedron Lett.* **1998**, *39*, 8027.

(6) Frey, D. A.; Wu, N.; Moeller, K. D. *Tetrahedron Lett.* **1996**, *37*, 8317.

(7) Anke, T.; Heim, J.; Knoch, F.; Mocek, U.; Steffan, B.; Steglich, W. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 109. (b) Kupka, J.; Anke, T.; Oberwinkler, F.; Schramm, G.; Steglich, W. *J. Antibiot.* **1979**, *32*, 130.

(8) For a total synthesis of crinipillen B, see: (a) Piers, E.; Renaud, J. *J. Org. Chem.* **1993**, *25*, 11−13. For prior synthetic efforts, see: (b) Curran, D. P.; Sisko, J. Yeske, P. E.; Liu, H. *Pure Appl. Chem.* **1993**, *65*, 1153. (c) Mehta, G.; Rao, K. S.; Reddy, M. S. *J. Chem. Soc., Perkin Trans. 1* **1991**, 693. (d) Schwartz, C. E.; Curran, D. P. *J. Am. Chem. Soc.* **1990**, *112*, 9272. (e) Mehta, G.; Rao, K. S.; Reddy, M. S. *Tetrahedron Lett.* **1988**, *29*, 5025. (f) Mehta, G.; Rao, K. S. *J. Chem. Soc., Chem. Commun.* **1987**, 1578.

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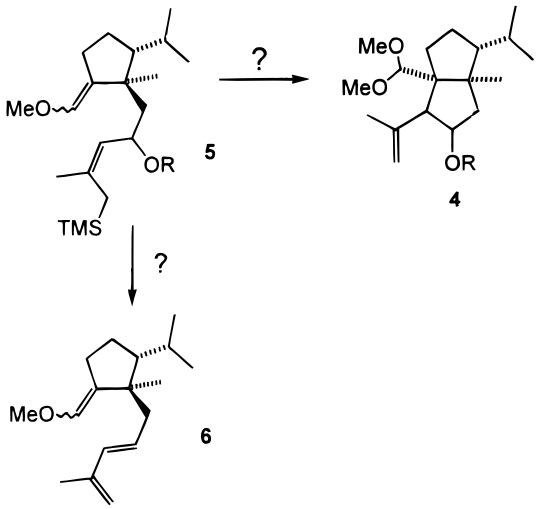
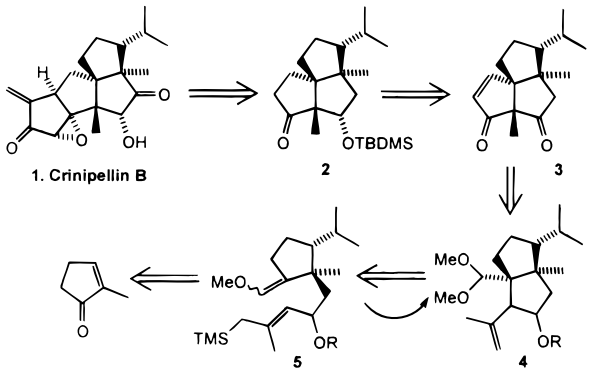


Figure 1.

Scheme 2



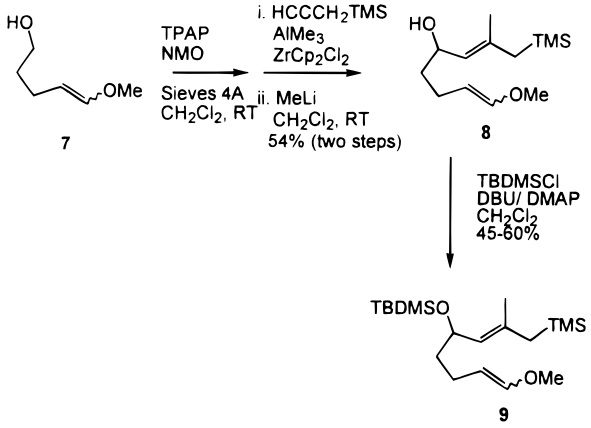
fused portion of this skeleton are three contiguous quaternary centers. It is tempting to suggest the use of an intramolecular anodic olefin coupling reaction for constructing the central carbon in this sequence. For example, in the retrosynthetic analysis for crinipellin B outlined in Scheme 2, a sequential anodic olefin coupling reaction−intramolecular aldol condensation strategy would be used to assemble the angularly fused portion of the ring skeleton. The olefin coupling reaction would be initiated by the oxidation of an enol ether and terminated with an allylsilane group (**5** to **4**). While such a proposed cyclization appears reasonable, it requires the presence of an oxygen on the allylic carbon of the allylsilane. Would the fact that electrolysis reactions can be done under neutral conditions allow an anodic olefin coupling reaction to tolerate the presence of such a group or would the electrolysis reaction simply lead to elimination of the alkoxy group and formation of a diene side product (Figure 1)?

To address this question, we began a study to examine the compatibility of intramolecular anodic olefin coupling reactions with the presence of an allylic alkoxy group.[9]

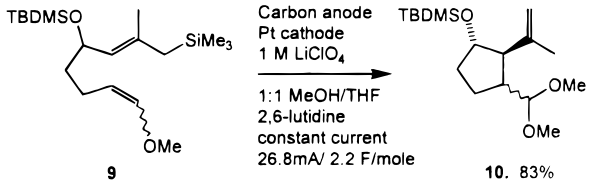
Initial Studies

To begin this work, substrate **9** was synthesized by adding the vinyl anion generated from propargyltrimethylsilane[10] to the aldehyde derived from **7** (Scheme 3). The alcohol was then protected as the *tert*-butyldimethylsilyl ether. The yield of this protection step was low due to the competitive elimination of the allylic alkoxy group. When *tert*-butyldimethylsilyl triflate was used as the reagent for the protection, only the corresponding diene product was obtained.

Scheme 3



Scheme 4



The oxidation of substrate **9** (Scheme 4) at a reticulated vitreous carbon anode[11] using constant current electrolysis conditions, a platinum cathode, a lithium perchlorate in 1:1 methanol/THF electrolyte solution, and 2,6-lutidine as a proton scavenger led to the formation of an 83% isolated yield of cyclized product.[12] No evidence for a product resulting from elimination of the allylic alkoxy group was obtained. Interestingly, the cyclization reaction generated only two of the four possible diastereomeric products. Evidence that the two diastereomers were isomeric at the carbon bearing the acetal was gained by hydrolysis of the acetals and epimerization of the resulting aldehydes with DBU to afford a single product. This suggestion was confirmed by 2D-NMR.

Because of the ease with which **10a** and **10b** could be characterized by NMR, and the difficulty encountered with their separation, the products obtained from the oxidation of **9** were characterized as a mixture. To this end, the complete connectivity for both **10a** and **10b** was assigned with the use of a COSY experiment. The stereochemistry for each isomer was then determined with the use of a NOESY experiment. The spectra obtained from these experiments are included in the Supporting Information.

The key NOE cross-peaks used to assign the stereochemistry of **10a** and **10b** are highlighted in Figure 2. For the major isomer, **10a**, the large volume integrals for the interactions between H_1 and H_7 and H_1 and the allylic methyl provided evidence that methine proton H_1

(9) For a preliminary account of this work, see: Frey D. A.; Marx, J. A.; Moeller, K. D. *Electrochim. Acta* **1997**, *42*, 1967.

(10) Negishi, E. *Pure Appl. Chem.* **1981**, 53.

(11) Reticulated virteous carbon anodes were purchased from The Electrosynthesis Co., Inc., 72 Ward Road, Lancaster, NY 14086-9779.

(12) The initial electrolysis conditions employed were identical to those used in previous cyclizations utilizing allylsilane terminating groups.[2b,e]

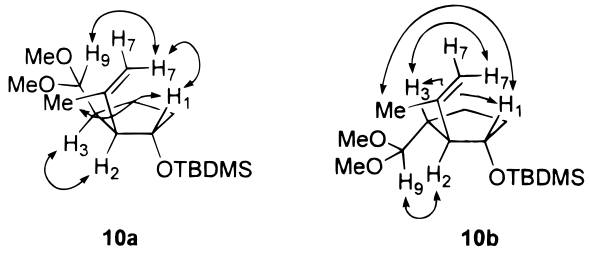


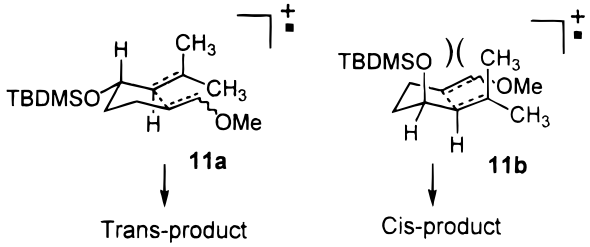
Figure 2. Key NOE interactions for **10a** and **10b**.

and the vinyl substituent were on the same face of the molecule. This indicated that the relationship between the ether and the vinyl substituent was trans. The presence of a cross-peak between H_7 and H_9, the lack of a signal between H_2 and H_9, the absence of a signal between H_3 and H_7, and the fact that the volume integral for the trans-relationship between H_1 and H_2 was small relative to the larger volume integral for the cross-peak between H_2 and H_3 all indicated that the relationship between the vinyl substituent and the dimethoxymethyl group was cis.

This assignment was also supported by the relatively small volume integral for the cross-peak between H_2 and H_3 in the minor isomer **10b**. This observation suggested that in the minor isomer a trans relationship existed between the vinyl group and the dimethoxymethyl substituent, a conclusion that was supported by large volume integrals for the cross-peak between H_2 and H_9 and between H_3 and H_7. In both cases, the ring methine proton was on the same face as the neighboring substituent, indicating that the subtituents were trans to each other. For **10b**, the relationship between the alkoxy substituent and the vinyl group was again trans. Evidence for this was based upon the presence of a cross-peak between H_1 and the allylic methyl group and a cross-peak between H_1 and H_3, indicating that these two methine protons were on the same side of the molecule. All of these interactions combined to make it clear that **10b** had all trans stereochemistry and that **10a** and **10b** differed only at the center bearing the dimethoxy acetal substituent.

It is interesting to note that the oxidation of the alcohol precursor to **9** (**8**) did not lead to a similar cyclization reaction. Instead, a complex mixture of products was formed. Clearly, the presence of the free hydroxyl group interfered with the cyclization. This was surprising since all of the previous intramolecular anodic olefin coupling reactions utilized methanol as either the solvent or a cosolvent. Why was the presence of alcohol in these reactions not a problem? One potential explanation for this apparent contradiction is that the cyclization reactions happen in the double layer surrounding the electrode surface.[13] The double layer is highly ordered and serves to lower the effective concentration of solvent near the electrode surface. This protects the reactive intermediates generated at the electrode surface from solvent trapping and provides greater time for intramolecular reactions.[14] For intramolecular anodic olefin coupling reactions, the initially generated radical cation would be protected from methanol trapping providing greater time for the desired cyclization to occur. However, in the case of **8** the alcohol group was covalently attached to the substrate, dragged into the double layer, and available for side reactions involving the radical cation intermediates generated at the electrode surface. The net result was that the desired carbon−carbon bond-forming reaction did not proceed.

Scheme 5



Previous cyclic voltammetry studies involving intramolecular anodic olefin coupling substrates lend support to this argument. These studies showed that the potential measured for a olefin coupling substrate was dependent on the length of the chain between the two olefins being coupled;[2d] the faster the cyclization reaction, the lower the potential that was measured. This observation was consistent with either a concerted reaction where the cyclization occurred as the initial electron was being removed or a stepwise reaction where the cyclization was fast enough to drain the initially formed radical cation away from the electrode surface. In either case, the cyclic voltammetry evidence suggested that the cyclization reaction occurred at or near the electrode surface and, hence, in the double layer.

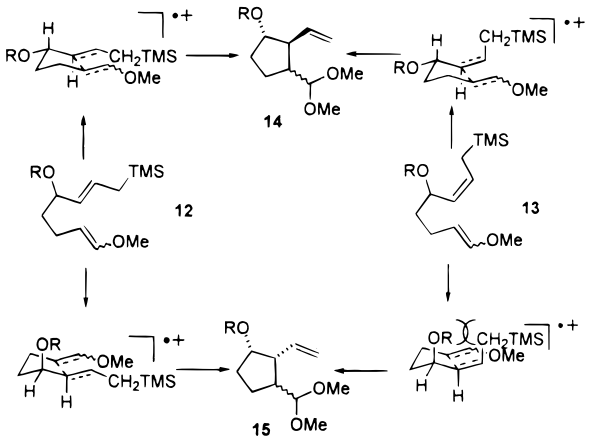
Probing the Question of Stereochemistry—A Closer Look

Although the formation of products with control over relative stereochemistry was not important for the crinipellin synthesis (in the synthesis, the angularly fused tricyclic ring skeleton will be used to control the relative stereochemistry of the centers), the possibility that anodic olefin coupling reactions could be used to stereoselectively generate cyclic systems with contiguous asymmetric centers was very intriguing. The formation of products with a trans relationship between the ether and vinyl substituents was attributed to the presence of an $A^{1,3}$-interaction in the transition state (**11b**) leading to the cis product (Scheme 5). This explanation assumed that the reactions were under kinetic control and that the product outcome was governed by the difference in transition-state energies. While this argument seemed reasonable, previous cyclization reactions utilizing enol ether and vinylsilane coupling partners were best explained by suggesting that the reactions were reversible and under thermodynamic control.[2b] One could invoke a similar argument here and justify the formation of products with a trans relationship between the alkoxy group and the vinyl substituent based upon thermodynamic grounds. This explanation was not favored because of the major product having the vinyl group and dimethoxymethyl substituent cis to each other, but it could not be ruled out.

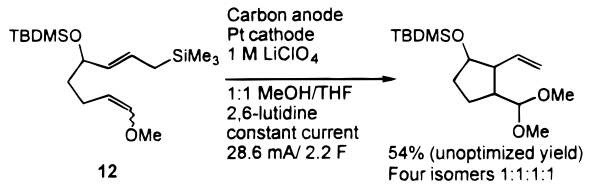
(13) For discussions of the double layer, see ref 1a p 13 and: Fry, A. J. *Synthetic Organic Electrochemistry*, 2nd ed.; John Wiley and Sons: New York; 1989; p 37.

(14) For the discussion of a related example involving the dimerization of acrylonitrile, see: *Organic Electrochemistry: An Introduction and a Guide*, 2nd ed.; Baizer, M. M., Lund, H., Eds.; Marcel Dekker: New York, 1983; p 394.

Scheme 6



Scheme 7



For this reason, the disubstituted allylsilane substrates **12** and **13** were examined (Scheme 6). For the *trans*-allylsilane substrate **12**, neither the transition state leading to the trans product **14** nor the transition state leading to the cis product **15** would have an $A^{1,3}$-interaction. If the $A^{1,3}$-interaction did control the reaction, then the selectivity observed in the initial cyclization reaction would be lost. For the *cis*-allylsilane substrate **13**, the transition state leading to the cis product would again be higher in energy due to the presence of the $A^{1,3}$-interaction. If the reaction were under kinetic control and governed by the $A^{1,3}$-interaction, then this reaction would be selective like the initial cyclization. However, if the reactions were governed by thermodynamics, then both the *trans*-allylsilane substrate **12** and the *cis*-allylsilane substrate **13** would afford the same stereochemical results since both substrates lead to the same products.

The trans-disubstituted allylsilane substrate **12** was synthesized by substituting Dibal-H for the trimethylaluminum reagent used in Scheme 3. All other aspects of the synthesis were identical. Although the yield of the overall process was very low (ca. 3% over the three steps), enough of substrate **12** was obtained for exploring the electrolysis reaction. The synthesis was not attempted a second time because of the lack of selectivity observed in the cyclization (Scheme 7). To this end, substrate **12** was oxidized at a reticulated vitreous carbon anode using the conditions described above for the oxidation of **9**. In this case, a 54% unoptimized yield of the cyclized products was obtained. No significant degree of selectivity was observed, and the reaction led to a complex mixture of diastereomeric products. The proton NMR of the mixture was consistent with the presence of all four possible diastereomers. The oxidation of **12** was not optimized.

The cis-disubstitued allylsilane was synthesized as illustrated in Scheme 8. In this case, the substrate was made from a propargyl anion addition to the aldehyde derived from **7**, a selective hydrogenation of the acetylene, and then protection of the resulting alcohol. The *cis*-

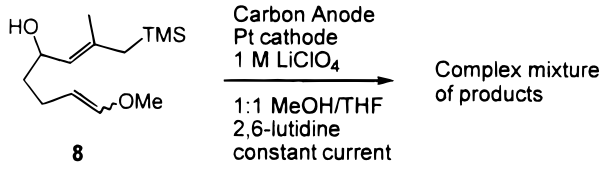


Figure 3.

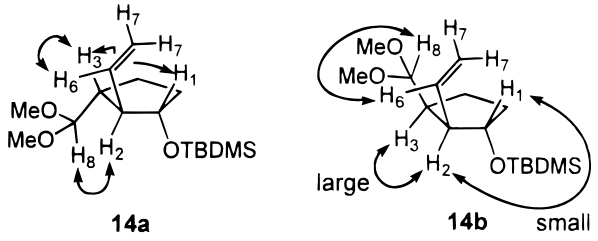
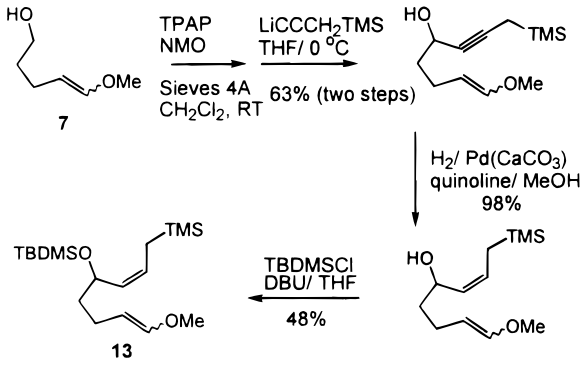
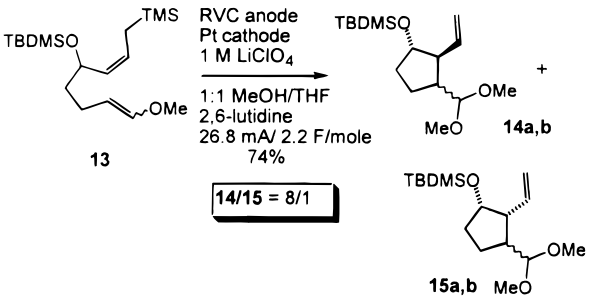


Figure 4. Key NOE interactions for **14a** and **14b**.

Scheme 8



Scheme 9



allylsilane substrate **13** was again oxidized using the conditions described above for **9** (Scheme 9). In this case, four diastereomeric products were obtained in a 74% overall yield. The two major products **14a** and **14b** were formed in a 2:1 ratio. The ratio of the two major products (**14a** plus **14b**) to the two minor products (**15a** plus **15b**) was 8:1. The product ratios were determined by integration of the acetal methine region of the proton NMR spectrum obtained for the crude reaction mixture. As with **10a** and **10b**, the ease with which the products could be characterized by 2D-NMR and the difficulty associated with separating the isomers led to characterization of **14a** and **14b** as the mixture. This was again accomplished using a combination of COSY data to assign the connectivity of the molecules and NOESY data to assess the spatial arrangements of the substituents about the ring (Figure 4).

As illustrated, the trans relationship between the alkoxy and vinyl substituents in **14a** was made by first establishing the relationship between H_3 and H_2 and then

by showing that H_1 was on the same face of the ring as H_3. The trans relationship between H_2 and H_3 was established by the interaction between H_3 and the vinyl proton H_6, the interaction between H_2 and H_8, and the small size of the interaction between H_2 and H_3 relative to the same interaction in isomer **14b**, which was approximately twice as large. All of these items pointed to H_2 and H_3 being on opposite faces of the ring and, hence, the vinyl and dimethoxymethyl groups having a trans relationship. The NOESY cross-peak between H_1 and H_3 then established H_1 as being on the same face of the molecule as H_3 and therefore trans to H_2. Isomer **14a** was the all-trans compound.

The stereochemistry of the second major product **14b** was determined in a similar fashion. In this case, a cross-peak between H_6 and H_8 and a large cross-peak for the interaction between H_2 and H_3 (relative to that observed for **14a**) were both indicative of a cis relationship between the vinyl group and the dimethoxymethyl substituent. The trans relationship between H_1 and H_2 was established by comparing the small volume integral for this interaction with the larger volume integral for the known cis interaction between H_2 and H_3. These volume integrals suggested that H_1 was further away from H_2 than is H_3, a situation that was consistent with a trans relationship between the alkoxy and vinyl subsituents and not consistent with a cyclized product having all three groups cis.

The two minor products from the cyclization reaction could not be separated from the major isomers and therefore could not be unambiguously assigned. The NMR resonances for these two minor products were buried beneath the resonances for the major products. However, the resonances that could be observed were consistent with what would be expected for the remaining two possible diastereomers from the cyclization reaction having a cis relationship between the alkoxy and vinyl substituents.

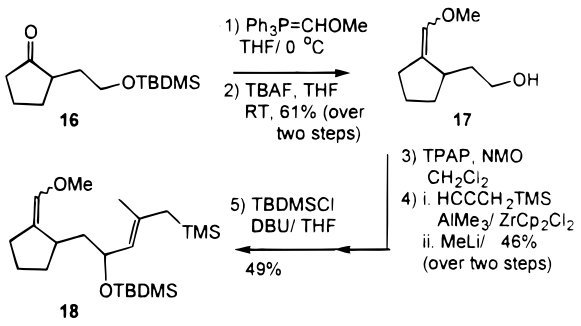
Despite our inability to assign the two minor products, it was clear that the use of a cis-disubstituted allylsilane substrate did reintroduce the stereoselectivity into the reaction. Both major products were trans with respect to the alkoxy and vinyl substituents, and the yield of the reaction was good. No such propensity for forming trans products was observed when the trans-disubstituted allylsilane substrate was oxidized. Therefore, it was concluded that the stereochemical outcome of the cyclization reaction was dependent on the stereochemistry of the starting allylsilane and that reactions using allylsilane terminating groups were under "kinetic control".

Our current working hypothesis for the intramolecular anodic olefin coupling reaction is that they cyclize to generate a radical at the terminating end of the reaction.[2b] Kinetic vs thermodynamic control is then determined by the rate at which the molecule undergoes the second oxidation reaction. In the case of the vinylsilane groups, the cyclizations lead to an α-silyl radical that is not prone to rapid oxidation. However, in the case of an allylsilane terminating group the cyclizations lead to β-silyl radicals that are much more likely to oxidize quickly. Hence, kinetic control of the reactions was observed.

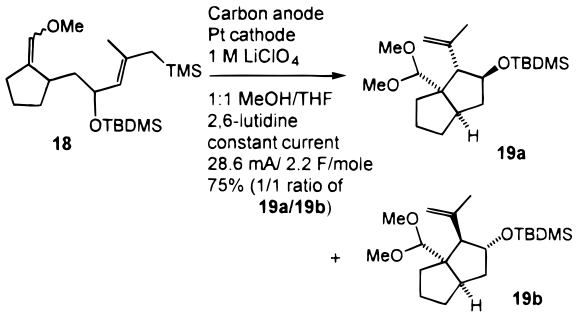
A Bicyclic Substrate and the Formation of a Quaternary Carbon

While the above studies demonstrated that intramolecular anodic olefin coupling reactions leading to the formation of five-membered rings could tolerate the presence of an allylic alkoxy substituent, it was not clear what would happen with a substrate that led to a less efficient cyclization. For example, what would happen in the cyclization proposed for the crinipellin synthesis when the reaction was challenged with the formation of a quaternary carbon? Would such a steric barrier reduce the rate of cyclization to a point where elimination of the allylic alkoxy group began to compete with the desired reaction? This was certainly a possibility. Related but much slower six-membered ring cyclization reactions[15] did lead to a small amount of an elimination product.[16]

Scheme 10



Scheme 11



To determine the feasibility of the cyclization proposed for the crinipillen synthesis, substrate **18** was synthesized (Scheme 10). The synthesis started from the known cyclopentanone derivative **16**[17] and directly paralleled the earlier construction of substrate **9**. Once again, the final protection step of the synthesis was complicated by elimination of the allylic alkoxy group and formation of the corresponding diene. While the elimination reaction did lower the yield of the silation step, it did not interfere with the electrolysis reaction. When **18** was oxidized using the same conditions described earlier, a 75% isolated yield of two cyclized products was obtained (Scheme 11). No evidence for the elimination reaction was present in the ^{1}H NMR spectrum of the crude reaction mixture. Both of the cyclized products possesed a cis-fused ring juncture and a trans relationship between the alkoxy and vinyl substituents. As in the earlier studies, the stereochemistry of the cyclized products was assigned with the use of a 2D-NOESY experiment. The assignment of chemical shifts for the individual resonances was again made using a 2D-COSY experiment. The key NOESY cross-peaks used to make the assignments are highlighted in Figure 5.

(15) For comparisons of intramolecular anodic olefin coupling reactions leading to five- and six-membered rings, see refs 2c and 2e.
(16) Unpublished results with Mr. Nicholas Wu.
(17) Molander, G. A.; Harris, C. R. *J. Org. Chem.* **1998**, *63*, 812.

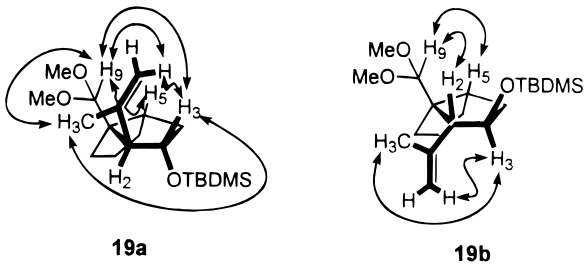


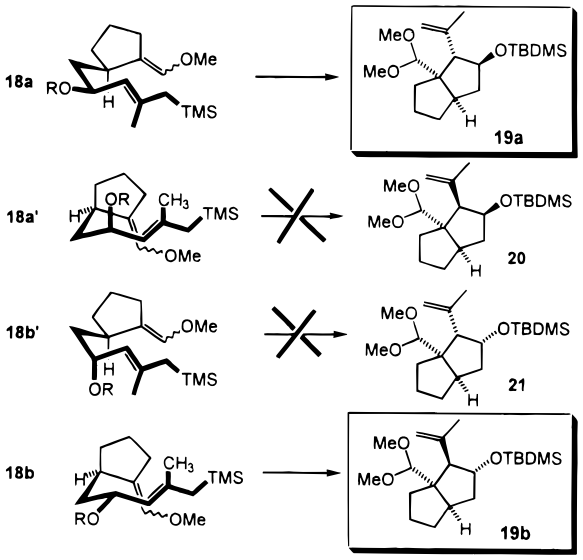
Figure 5. Key NOE interactions for **19a** and **19b**.

The assigment for compound **19a** was based on establishing that the methine proton α to the alkoxy group (H_3), the vinyl substituent, and the dimethoxymethyl substituent were all on the same face of the molecule. This relationship was established by the presence of cross-peaks between H_3 and one of the vinyl protons, H_3 and the allylic methyl group, H_3 and the dimethoxy acetal proton (H_9), H_9 and one of the vinyl protons, and H_9 and the allylic methyl group. A cross-peak between the acetal proton H_9 and the bridgehead proton H_5 established the cis stereochemistry of the ring juncture. In this isomer, no cross-peak appeared for an interaction between the allylic methine H_2 and the acetal methine proton H_9.

For isomer **19b**, the presence of a cross-peak between the allylic proton (H_2) and the acetal methine (H_9) was used to establish the trans relationship between the dimethoxymethyl and vinyl substituents. Cross-peaks between both the methine proton α to the alkoxy group (H_3) and the allylic methyl group and H_3 and one of the vinyl protons established the relationship between the alkoxy group and the vinyl substituent as trans. The cis stereochemistry of the ring juncture was again established using a cross-peak between the acetal methine proton and the bridgehead proton H_5.

The exclusive formation of products **19a** and **19b** indicated that the cyclization reaction was very stereoselective. This conclusion was based on the fact that the starting material (**18**) used for the cyclization was a mixture of diastereomers. In addition to the two enol ether isomers, the substrate was a mixture with respect to the stereochemistry of alkoxy group relative to that of the carbon α to the enol ether. Ignoring the enol ether stereoisomers, it would appear that each of the starting material diastereomers led to the formation of a single cyclized product. Consider the transition state representations shown in Scheme 12. Structures **18a** and **18a′** represent the two possible "chairlike" transition states for one diastereomer (again ignoring the enol ether isomers), and **18b** and **18b′** represent the two possible "chairlike" transition states for the second starting material diastereomer. For the first diastereomer, transition state **18a** would be expected to be of lower energy than **18a′** because of both the $A^{1,3}$-interaction between the alkoxy group and the allylic methyl and the 1,3-diaxial interaction between the alkoxy group and the ring in **18a′**. In practice, the reaction gave rise to **19a** and none of the isomeric product **20**, an observation that was consistent with this transition state analysis. For the second diastereomer, transition state **18b** would be expected to be of lower energy than **18b′** because of the psuedoaxial alkoxy group and corresponding $A^{1,3}$-interaction in **18b′**. In this case, the formation of **19b** and none of the isomeric **21** again supported the notion that the position of the alkoxy group in the transition state dictated product stereochemistry.

Scheme 12



Conclusions

Intramolecular anodic olefin coupling reactions leading to the formation of five-membered rings have proven compatible with the presence of an allylic alkoxy group. No elimination of the alkoxy group was observed. The cyclization reactions utilizing either a trisubstituted or cis-disubstituted allylsilane-terminating olefin were stereoselective. The stereochemistry of the five-membered ring products could be explained with the use of a pseudochair transition state with the allylic alkoxy group occupying a psuedoequatiorial position. These conclusions remained consistent when the cyclization reaction was used to generate a fused bicyclic ring skeleton and a quaternary carbon.

A cyclization reaction utilizing a trans-disubstituted allylsilane as the trapping olefin led to a mixture of diastereomeric products. No stereoselectivity was observed for this reaction, indicating that the stereochemistry of the products was dependent on the stereochemistry of the initial terminating olefin. This conclusion was indicative of a cyclization reaction that was under kinetic control.

What is clear from these studies is that the intramolecular anodic olefin coupling reaction proposed for the synthesis of the crinipellin ring skeleton is feasible. Work aimed at exploring the application of this reaction to such a total synthesis effort is underway.

Experimental Section[18]

5-Methoxy-(*E,Z*)-4-penten-1-ol (7). To a stirred suspension of 13.71 g (40.0 mmol) of methoxymethyltriphenylphosphonium chloride in 40 mL of tetrahydrofuran at 0 °C was added dropwise 30.8 mL (40.0 mmol) of 1.3 M *sec*-butyllithium in cyclohexane. The dark red mixture was allowed to warm to room temperature over 1 h. In another flask, a stirred solution of 1.72 g (20.0 mmol) 4-hydroxybutyric acid γ-lactone in 20 mL of ether at −20 °C was treated dropwise with 11.0 mL of 1.0 M diisobutylaluminum hydride in hexanes. The reaction

(18) For general experimental details, see: Wong, P. L.; Moeller, K. D. *J. Am. Chem. Soc.* **1993**, *115*, 11434.

mixture was allowed to warm to room temperature. After 2 h, the reaction was cooled to 0 °C and quenched with 20 mL of methanol. The white slurry was diluted with 100 mL of pentane, filtered through a plug of silica gel, and eluted with 1% triethylamine in pentane. The filtered solution was dried over $MgSO_4$, filtered, and concentrated in vacuo. The concentrated crude lactol was diluted with 10 mL of tetrahydrofuran and then slowly cannulated into the stirring 0 °C methoxymethyltriphenylphosphoranylidene solution generated above. The reaction mixture was allowed to warm to room temperature. After 24 h, the reaction mixture was diluted with of ether and quenched with brine. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using 20% ether/pentane solution containing 1% triethylamine. Elution with 20% ether/pentane solution containing 1% triethylamine afforded 1.13 g (48.7% based on the lactone) of the alcohol enol ether (**7**). The spectral data for the mixture of olefin isomers were as follows: ^{1}H NMR ($CDCl_3$/300 MHz) δ 6.28 (d, J = 12.6 Hz, 0.9 H), 5.91 (d, J = 6.7 Hz, 0.1 H), 4.69 (dt, J_d = 12.6 Hz, J_t = 7.4 Hz, 0.9 H), 4.32 (q, J_q = 6.7 Hz, 0.1 H), 3.61 (t, J = 6.5 Hz, 2 H), 3.55 and 3.47 (2s, 3 H), 1.98 (q, J = 7.3 Hz, 2 H), 1.58 (m, 2H); ^{13}C NMR ($CDCl_3$/75 MHz) δ 147.4, 102.3, 62.2, 55.9, 33.5, 24.0; IR (neat/NaCl) 3248, 1675, 1670 cm^{-1}; HRMS (EI) *m*/*z* calcd for $C_6H_{12}O_2$ 116.0837 (M^+), found 116.0839.

5-Hydroxy-1-methoxy-7-methyl-8-(trimethylsilyl)-1(*E*,*Z*),6(*E*)-octadiene (8). To a stirred suspension of 1.71 g (7.14 mmol) of zirconocene dichloride in 10 mL of methylene chloride was added 7.1 mL (14.3 mmol) of 2.0 M trimethylaluminum in toluene followed by 1.60 g (14.3 mmol) of propargyl trimethylsilane at room temperature. After 16 h, the reaction mixture was cooled to −78 °C, and 4.3 mL (10.7 mmol) of a 2.5M *n*-butyllithium solution in hexanes was added dropwise. In a second flask, 0.81 g (7.1 mmol) of 5-methoxy-(*E*,*Z*)-4-penten-1-ol (**6**) was diluted with 10 mL of methylene chloride treated with 3.50 g of crushed 4A molecular sieves, 1.25 g (10.7 mmol) of 4-methylmorpholine *N*-oxide, and 0.125 g (0.357 mmol) of tetrapropylammonium perruthenate at 0 °C and allowed to warm to room temperature. After 30 min, the black reaction mixture was filtered through a plug of silica gel with a 1% triethylamine/ether solution and concentrated in vacuo. The crude aldehyde was diluted with 10 mL of methylene chloride, slowly cannulated into the stirring −78 °C vinyl anion solution prepared above, and allowed to warm to room temperature. After 18 h, the reaction mixture was cooled to 0 °C, quenched slowly with Rochelle's solution, and diluted with ether. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using 5% ether/hexane solution containing 1% triethylamine. Elution with 5% ether/hexane solution containing 1% triethylamine afforded 0.933 g (54%) of desired product **8**. The spectral data for the product were as follows: ^{1}H NMR ($CDCl_3$/300 MHz) δ 6.27 (d, J = 12.6 Hz, 1 H), 4.97 (d, J = 8.8 Hz, 1 H), 4.72 (dt, J_d = 12.6 Hz, J_t = 7.2 Hz, 1 H), 4.34 (q, 1 H), 3.48 (s, 3 H), 1.95 (m, 2 H), 1.65 (s, 3 H), 1.60−1.40 (m, 4 H); 1.22 (m, 1 H), 0.04 (s, 9 H); ^{13}C NMR 147.2, 137.3, 125.9, 102.6, 68.3, 55.9, 38.8, 30.2, 23.9, 19.2; IR (neat/NaCl) 3410, 3060, 3045, 1673, 1655 cm^{-1}; HRMS (IE) *m*/*z* (rel intensity) calcd for $C_{13}H_{26}O_2Si$ (M^+) 242.1702, found 242.1699.

5-(*tert*-Butyldimethlsilyloxy)-1-methoxy-7-methyl-8-(trimethylsilyl)-1(*E*,*Z*),6(*E*)-octadiene (9). To a stirred solution of 0.248 g (1.02 mmol) of 5-hydroxy-1-methoxy-7-methyl-8-(trimethylsilyl)-1(*E*,*Z*),6(*E*)-octadiene (**7**) in 5 mL of tetrahydrofuran was added 0.013 g (0.102 mmol) of 4-(dimethylamino)pyridine, 0.18 mL (1.2 mmol) of 1,8-diazobicyclo-[5.4.0]undec-7-ene, and a solution of 0.170 g (1.13 mmol) of *tert*-butyldimethlsilyl chloride in 3 mL of tetrahydrofuran. After 14 h, the reaction was diluted with ether and brine. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using a 1% triethylamine/pentane solution. Elution with a 1% triethylamine/pentane mobile phase afforded 0.167 g (46%) of the protected product **9**. The spectral data for the mixture of olefin isomers were as follows: ^{1}H NMR ($CDCl_3$/300 MHz) δ 6.27 (d, J = 12.6 Hz, 0.6 H), 5.86 (d, J = 6.2 Hz, 0.4 H), 4.93 (d, J = 8.7 Hz, 1 H), 4.74 (dt, J_d = 12.6 Hz, J_t = 7.3 Hz, 0.6 H), 4.32 (m, 1.4 H), 3.54 and 3.47 (2s, 3 H), 1.95 (m, 2 H), 1.61 (s, 3 H), 1.47 (m, 2 H); 0.87 (s, 9 H) 0.04 (m, 9 H); ^{13}C NMR ($CDCl_3$/75 MHz) δ 147.4, 146.5, 133.2, 127.9, 106.9, 103.2, 70.1, 69.8, 59.6, 56.1, 40.6, 39.5, 30.1, 29.8, 26.1, 26.0, 24.2, 24.0, 20.5, 19.4, 18.5; IR (neat/NaCl) 3070, 3030, 1660 cm^{-1}; HRMS (EI) calcd for $C_{19}H_{40}O_2Si_2$ (M^+) 356.2566, found 356.2553.

1-(*tert*-Butyldimethlsilyloxy)-3-dimethoxymethyl-2-(1-methyl-1-ethenyl)cyclopentane (10a and 10b). To 0.169 g (0.47 mmol) of 5-(*tert*-butyldimethlsilyloxy)-1-methoxy-7-methyl-8-(trimethylsilyl)-1(*E*,*Z*),6(*E*)-octadiene (**9**) in 7.5 mL of tetrahydrofuran and 7.5 mL of methanol were added 0.33 mL (2.8 mmol) of 2,6-lutidine and 1.59 g (15.0 mmol) of lithium perchlorate. The electrodes were inserted into the flask using a two-hole septum equipped with a nitrogen inlet. A reticulated vitreous carbon anode and a platinum wire cathode were used. The reaction mixture was stirred until all of the electrolyte was dissolved in solution and then degassed by sonication for 10 min. The reaction mixture was cooled to 0 °C, and current was passed at a constant rate of 26.8 mA and until 100.4 C (2.2 F/mol) of electricity had been passed. The reaction mixture was diluted with brine and ether. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using a 1% triethylamine/pentane solution. Elution with a 1% triethylamine/pentane solution afforded 0.111 g (84%) of desired products **10a** and **10b**. The spectral data for the 60:40 ratio of trans-trans and trans-cis isomers of the cyclized products were as follows: ^{1}H NMR ($CDCl_3$/300 MHz) δ 4.85 (s, 0.6 H), 4.76 (s, 0.4 H), 4.72 (s, 0.4 H), 4.59 (s, 0.6 H), 4.17 (m, 1 H), 4.13 (m, 0.6 H), 3.90 (q, J = 6.0 Hz, 0.4 H), 3.35, 3.32, 3.27, 3.26 (4s, 6 H), 2.60 (p, J = 8.5 Hz, 0.6 H), 2.41 (dd, J_d = 4.1, 8.3 Hz, 0.6 H), 2.25 (m, 0.4 H), 2.16 (p, J = 8.2 Hz, 0.4 H), 2.04 (q, J = 3.5 Hz, 0.4 H), 1.80 (m, 1 H), 1.74 and 1.71 (2s, 3 H), 1.65 (m, 0.8), 1.50 (m, 1.6 H), 0.85 (s, 9 H), 0.04 (s, 6 H); ^{13}C NMR ($CDCl_3$/75 MHz) δ 145.9, 144.8, 111.5, 108.1, 78.2, 78.1, 78.0, 77.9, 76.4, 58.1, 56.6, 54.1, 53.8, 53.5, 52.3, 43.5, 43.4, 42.8, 42.7, 34.5, 34.4, 34.0, 25.9, 25.8, 25.7, 25.0, 24.6, 23.7, 23.6, 20.9, 18.1; IR (neat/NaCl) 3080, 1647 cm^{-1}; HRMS (EI) calcd for $C_{17}H_{31}O_2Si$ ($M^+ - OCH_3$) 283.2093, found 283.2095. COSY and NOESY data for these products are included in the Supporting Information.

5-(*tert*-Butyldimethlsilyloxy)-1-methoxy-8-(trimethylsilyl)-1(*E*,*Z*),6(*E*)-octadiene (12). To a stirred suspension of 2.78 g (11.6 mmol) of zirconocene dichloride in 20 mL of methylene chloride was added 23.2 mL (23.2 mmol) of 1.0 M diisobutylaluminum hydride in hexanes followed by 2.60 g (11.6 mmol) of propargyl trimethylsilane at room temperature. After 16 h, the reaction mixture was cooled to −78 °C, and 12.4 mL (17.4 mmol) of 1.4 M methyllithium in hexanes was added dropwise. In another flask, 1.35 g (11.6 mmol) of 5-methoxy-(*E*,*Z*)-4-pentene-1-ol (**7**) was diluted with 20 mL of methylene chloride treated with 5.80 g of crushed 4A molecular sieves, and 2.05 g (17.3 mmol) of 4-methylmorpholine *N*-oxide and 0.204 g (0.58 mmol) of tetrapropylammonium were perruthenate added at 0 °C. The mixture was allowed to warm to room temperature. After 30 min, the black reaction mixture was filtered through a plug of silica gel with a 1% triethylamine/ether solution and concentrated in vacuo. The crude aldehyde was diluted with 10 mL of methylene chloride and slowly cannulated into the stirring −78 °C vinyl anion solution prepared above and allowed to warm to room temperature. After 18 h, the reaction mixture was cooled to 0 °C, quenched slowly with Rochelle's solution, and diluted with ether. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using 5% ether/hexane

solution containing 1% triethylamine. Elution with 5% ether/hexane solution containing 1% triethylamine afforded a mixture of products that was carried on through a protection step. To a stirred mixture of approximately 0.273 g (1.20 mmol) of 5-hydroxy-1-methoxy-8-(trimethylsilyl)-1(*E,Z*),6(*E*)-octadiene in 5 mL of tetrahydrofuran was added 0.014 g (0.12 mmol) of 4-(dimethylamino)pyridine, 0.18 mL (1.2 mmol) of 1,8-diazobicyclo[5.4.0]undec-7-ene, and a solution of 0.180 g (1.20 mmol) of *tert*-butyldimethlsilyl chloride in 3 mL of tetrahydrofuran. After 14 h, the reaction was diluted with ether and brine. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using a 1% triethylamine/pentane solution. Elution with a 1% triethylamine/pentane solution afforded 0.127 g (3.1%) of the protected product **12** over the two steps. The spectral data for the mixture of enol ether isomers are included in the Supporting Information.

The Cyclization of the *trans*-Allylsilane Substrate 12: 1-(*tert*-Butyldimethlsilyloxy)-3-dimethoxymethyl-2-(1-ethenyl)cyclopentane. To 0.052 g (0.15 mmol) of 5-(*tert*-butyldimethlsilyloxy)-1-methoxy-8-(trimethylsilyl)-1(*E,Z*),6(*E*)-octadiene (**12**) in 2.5 mL of tetrahydrofuran and 2.5 mL of methanol were added 0.11 mL (0.91 mmol) of 2,6-lutidine and 0.531 g (5.00 mmol) of lithium perchlorate. The electrodes were inserted into the flask using a two-hole septum equipped with a nitrogen inlet. A reticulated vitreous carbon anode and a platinum wire cathode were used. The reaction mixture was stirred until all of the electrolyte was dissolved in solution and then degassed by sonication for 10 min. The reaction mixture was cooled to 0 °C, and current was passed at a constant rate of 26.8 mA and until 32.2 C (2.2 F/mol) of electricity had been passed. The reaction mixture was diluted with brine and ether. The layers were separated and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using a 1% triethylamine/pentane solution. Elution with a 1% triethylamine/pentane solution afforded 0.024 g (54%) of the cyclized product. The spectral data for the mixture of enol ether isomers are included in the Supporting Information.

5-Hydroxy-1-methoxy-8-(trimethylsilyl)-1(*E,Z*)-en-6-octyne. To a solution of 1.00 g (8.92 mmol) of propargyl trimethylsilane in 10 mL of tetrahydrofuran was added 6.86 mL of 1.3 M *sec*-butyllithium in cyclohexane dropwise at 0 °C. In another flask, 0.517 g (4.46 mmol) of 5-methoxy-(*E,Z*)-4-penten-1-ol (**7**) was diluted with 10 mL of methylene chloride treated with 2.50 g of crushed 4A molecular sieves, 0.78 g (6.7 mmol) of 4-methylmorpholine *N*-oxide, and 0.078 g (0.22 mmol) of tetrapropylammonium perruthenate at 0 °C and allowed to warm to room temperature. After 30 min, the black reaction mixture was filtered through a plug of silica gel with a 1% triethylamine/ether solution and concentrated in vacuo. The crude aldehyde was diluted with 10 mL of methylene chloride, slowly cannulated into the stirring 0 °C propargyl anion solution prepared above, and allowed to warm to room temperature. After 18 h, the reaction mixture was cooled to 0 °C, quenched slowly with Rochelle's solution, and diluted with ether. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using 25% ether/hexane solution containing 1% triethylamine. Elution with 5% ether/hexane solution containing 1% triethylamine afforded 0.635 g (63%) of product. The spectral data for the mixture of enol ether isomers are included in the Supporting Information.

5-Hydroxy-1-methoxy-8-(trimethylsilyl)-1(*E,Z*),6(*Z*)-octadiene. To 0.176 g (0.78 mmol) of 5-hydroxy-1-methoxy-8-(trimethylsilyl)-1(*E,Z*)-en-6-octyne in 10 mL of methanol was added 0.018 mL (0.16 mmol) of quinoline and 0.165 g (0.008 mmol) of 5% palladium on calcium carbonate. The reaction flask was equipped with a hydrogen balloon, and the mixture was stirred under a hydrogen atmosphere for 48 h. The reaction mixture was filtered through a plug of Celite. The filtrate was concentrated in vacuo and chromatographed through silica gel that was slurry-packed using 25% ether/hexane solution containing 1% triethylamine. Elution with 5% ether/hexane solution containing 1% triethylamine afforded 0.1754 g (98%) of the cis olefin. The spectral data for the mixture of enol ether isomers are included in the Supporting Information.

5-(*tert*-Butyldimethlsilyloxy)-1-methoxy-8-(trimethylsilyl)-1(*E,Z*),6(*Z*)-octadiene (13). To a stirred solution of 0.175 g (0.77 mmol) of 5-hydroxy-1-methoxy-8-(trimethylsilyl)-1(*E,Z*),6(*Z*)-octadiene in 2 mL of tetrahydrofuran was added 0.009 g (0.08 mmol) of 4-(dimethylamino)pyridine, 0.13 mL (0.85 mmol) of 1,8-diazobicyclo[5.4.0]undec-7-ene, and a solution of 0.138 g (0.92 mmol) of *tert*-butyldimethlsilyl chloride in 3 mL of tetrahydrofuran. After 14 h, the reaction was diluted with ether and brine. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using 1% triethylamine/pentane solution. Elution with 1% triethylamine/pentane solution afforded 0.127 g (48%) of the protected product **13**. The spectral data for the mixture of enol ether isomers are included in the Supporting Information.

1-(*tert*-Butyldimethlsilyloxy)-3-dimethoxymethyl-2-(1-ethenyl)cyclopentane (14a and 14b). To 0.100 g (0.29 mmol) of 5-(*tert*-butyldimethylsilyloxy)-1-methoxy-8-(trimethylsilyl)-1(*E,Z*),6(*Z*)-octadiene (**13**) in 2.5 mL of tetrahydrofuran and 2.5 mL of methanol were added 0.20 mL (1.7 mmol) of 2,6-lutidine and 0.531 g (5.0 mmol) of lithium perchlorate. The electrodes were inserted into the flask using a two-hole septum equipped with a nitrogen inlet. A reticulated vitreous carbon anode and a platinum wire cathode were used. The reaction mixture was stirred until the entire electrolyte was dissolved in solution and then degassed by sonication for 10 min. The reaction mixture was cooled to 0 °C, and current was passed at a constant rate of 26.8 mA and until 62.0 C (2.2 F/mol) of electricity had been passed. The reaction mixture was diluted with brine and ether. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using a 1% triethylamine/pentane solution. Elution with a 1% triethylamine/pentane solution afforded 0.0643 g (74%) of the cyclized products. Four isomeric products were observed in the proton NMR of the material. This spectrum is included in the Supporting Information. The two major products (**14a** and **14b**) were generated in a 2:1 ratio. In addition, two minor isomers were obtained. The ratio of the two major isomers to the two minor isomer was 8:1. The ratio of products were determined by integration of the acetal region of the spectrum. The spectral data for the mixture isomers are included in the Supporting Information.

1-(Methoxy-(*E,Z*)-methylidene)-2-(2′-hydroxyethyl)cyclopentane (17). To a stirred suspension of 1.309 g (3.82 mmol) of methoxymethyltriphenylphosphonium chloride in 5.0 mL of tetrahydrofuran at 0 °C was added 7.6 mL (3.8 mmol) of 0.5 M potassium hexamethyldisilane in toluene dropwise. After 1 h, the dark red mixture was treated with a solution of 0.466 g (1.91 mmol) of 2-(2′-*tert*-butyldimethylslilyloxyethy)-cyclopentanone (**16**) in 5 mL of tetrahydrofuran. After 48 h, the reaction was diluted with ether and brine. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$ and concentrated in vacuo. The crude product was diluted with 10 mL of tetrahydrofuran and treated with 0.75 mL (0.75 mmol) of 1 M tetrabutylammonium fluoride. After 18 h, the reaction was diluted with ether and brine. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using 5% ether/hexane solution containing 1% triethylamine to afford 0.191 g (1.22 mmol) 64% of the desired product. The spectral data for products are included in the Supporting Information.

1-(Methoxy-(*E,Z*)-methylidene)-2-(2′-hydroxy-4-methyl-5-trimethylsilane-3-pentene)cyclopentane. To a stirred suspension of 1.067 g (4.46 mmol) of zirconocene dichloride in 5 mL of methylene chloride was added 4.50 mL (8.9 mmol) of 2.0 M trimethylaluminum in toluene followed by 1.00 g (8.92 mmol) of propargyl trimethylsilane at room temperature. After 16 h, the reaction mixture was cooled to −78 °C, and 4.3 mL (6.4 mmol) of 1.4 M methyllithium in diethyl ether was added dropwise. In another flask, 0.696 g (4.46 mmol) of 1-(methoxy-(*E,Z*)-methylidene)-2-(2′-hydroxyethyl)cyclopentane (**17**) was diluted with 5 mL of methylene chloride, treated with 2.50 g of crushed 4A molecular sieves, 0.783 g (6.69 mmol) of 4-methylmorpholine *N*-oxide, and 0.078 g (0.22 mmol) of tetrapropylammonium perruthenate at 0 °C, and allowed to warm to room temperature. After 30 min, the black reaction mixture was filtered through a plug of silica gel with a 1% triethylamine/ether solution and concentrated in vacuo. The crude aldehyde was diluted with 10 mL of methylene chloride, slowly cannulated into the stirring −78 °C vinyl anion solution prepared above, and allowed to warm to room temperature. After 20 h, the reaction mixture was cooled to 0 °C, quenched slowly with Rochelle's solution, and diluted with ether. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using 5% ether/hexane solution containing 1% triethylamine. Elution with 5% ether/hexane solution containing 1% triethylamine afforded 0.579 g (2.05 mmol) 46% of desired alcohol product. The spectral data for the mixture of diastereomers are included in the Supporting Information.

1-(Methoxy-(*E,Z*)-methylidene)-2-(2′-*tert*-butyldimethylsilyloxy-4-methyl-5-trimethylsilane-3-pentene)cyclopentane (18). To a stirred solution of 0.104 g (0.367 mmol) of 1-(methoxy-(*E,Z*)-methylidene)-2-(2′-hydroxy-4-methyl-5-trimethylsilane-3-pentene)cyclopentane in 2 mL of tetrahydrofuran was added 0.13 mL (0.85 mmol) of 1,8-diazo-bicyclo-[5.4.0]undec-7-ene followed by a solution of 0.138 g (0.92 mmol) of *tert*-butyldimethlsilyl chloride in 3 mL of tetrahydrofuran. After 14 h, the reaction was diluted with ether and brine. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using a 1% triethylamine/pentane solution. Elution with a 1% triethylamine/pentane solution afforded 0.127 g (49%) of the protected product **18**. The spectral data for the mixture of diastereomers are included in the Supporting Information.

3-(*tert*-Butyldimethlsilyloxy)-1-dimethoxymethyl-2-(1-methyl-1-ethenyl)bicyclo[3.3]octane (19a and 19b). To 0.217 g (0.618 mmol) of 1-(methoxy-(*E,Z*)-methylidene)-2-(2′-*tert*-butyldimethylsilyloxy-4-methyl-5-trimethylsilane-3-pentene)cyclopentane (**18**) in 5.0 mL of tetrahydrofuran and 5.0 mL of methanol were added 0.43 mL (3.7 mmol) of 2,6-lutidine and 1.063 g (10.0 mmol) of lithium perchlorate. The electrodes were inserted into the flask using a two-hole septum equipped with a nitrogen inlet. A reticulated vitreous carbon anode and a platinum wire cathode were used. The reaction mixture was stirred until all of the electrolyte was dissolved in solution and then degassed by sonication for 10 min. The reaction mixture was cooled to 0 °C, and current was passed at a constant rate of 26.8 mA and until 131.1 C (2.2 F) of electricity had been passed. The reaction mixture was diluted with brine and ether. The layers were separated, and the aqueous layer was extracted with ether. The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo, and chromatographed through silica gel that was slurry-packed using a 1% triethylamine/pentane solution. Elution with a 1% triethylamine/pentane solution afforded 0.163 g (75%) of desired product. The two isomers were separated and characterized. The COSY and NOESY data for **19a** and **19b** are included in the Supporting Information as are the full characterization data.

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Supporting Information Available: The COSY and NOESY spectral data are included for the cyclized products (**10**, **14**, and **19**) along with tables highlighting the key NOESY interactions. In addition, the raw proton and carbon NMR data are included for all new compounds, as well as the full characterization data for compounds **12**−**19**. This material is available free of charge via the Internet at http://pubs.acs.org.

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