Cyclization Pathways of a (*Z*)-Stilbene-Derived Bis(orthoquinone monoketal)

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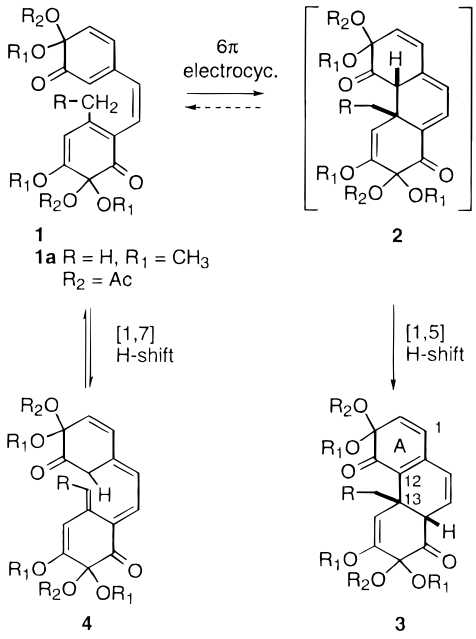
Lead tetraacetate mediated oxidation of a (*Z*)-bisphenolic stilbene derivative affords a bis(orthoquinone monoketal) product. Thermolysis studies of this highly unsaturated dione reveal that sigmatropic hydrogen shifts, followed by either of two distinct solvolytic ring closures, constitute the predominate reaction pathways under heating. No evidence for a desired 6π electron electrocyclization was forthcoming.

Success in approaches to the synthesis of morphinan alkaloids which utilize a biomimetic C(12)−C(13) ring closure (*cf.* **3**, morphine numbering) hinges on controlling the *ortho*−*para* coupling regiochemistry in ring A.[1] A host of direct and indirect solutions to this problem of regiocontrol have been explored, and to date a high-yielding, completely selective strategy remains elusive.[2] An alternative to the typical oxidative phenolic coupling chemistry can be envisioned which completely eliminates the ambiguity in the site of A-ring attachment (Scheme 1). This strategy would rely on a 6π electron electrocyclization of a trienic system specifically spanning the C(12)−C(13) gap to deliver only the correctly substituted phenanthrene skeleton of the morphinan alkaloids (*cf.* **1** → **2**). However, other cyclization pathways are available to this highly functionalized substrate which lead to non-phenanthrene polycycles, as described below.

The desired electrocyclization **1** → **2** would likely face stiff competition from an alternative pericyclic process, the [1,7] sigmatropic shift interconnecting **1** with **4**. The outcome of this competition would determine the feasibility of this approach for morphinan construction. Numerous studies on relatively unfunctionalized trienic systems have documented the kinetic advantages of the [1,7] H-shift over 6π electrocyclization.[3] However, coupling the electrocyclization with an essentially irreversible process, the strain-driven [1,5] sigmatropic H-shift within **2** to provide **3**,[4] may thwart this kinetic preference.[5] Thus, the ready reversibility of the [1,7] shift and the presumed driving force of converting **2** into **3** suggested that this strategy was worthy of experimental inquiry. In a structurally related but much less oxidized system, Fehr et al. provided precedent that the products of 6π electrocyclization (with some subsequent [1,5] H-shift) can predominate over [1,7] H-shift products (ca. 18:1) when both reaction channels are available.[6a] The synthesis of (*Z*)-stilbene **1a**, and characterization of the chemistry emerging from heating or irradiation of this species or its (*E*)-isomer **15**, is described herein. Together, these studies delineate the isomerization chemistry of this highly functionalized polyenyldione.

Scheme 1



1 **1a** R = H, R_1 = CH_3, R_2 = Ac **2** **4** **3**

[⊗] Abstract published in *Advance ACS Abstracts,* July 1, 1997.

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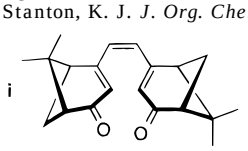
(3) (a) Mella, M.; Freccero, M.; Albini, A. *J. Am. Chem. Soc.* **1996**, *118*, 10311. (b) Baldwin, J. E.; Reddy, V. P. *J. Am. Chem. Soc.* **1987**, *109*, 8051. (c) Curtin, M. L.; Okamura, W. H. *J. Am. Chem. Soc.* **1991**, *113*, 6958. (d) Okamura, W. H.; Elnagar, H. Y.; Ruther, M.; Dobreff, S. *J. Org Chem.* **1993**, *58*, 600 and references cited therein. (e) Bakulev, V. A. *Russ. Chem. Rev.* **1995**, *64*, 99.

(4) Molecular mechanics calculations were performed with Macromodel V4.5 on a Silicon Graphics Indigo2XZ workstation. Structures **2** and **3** (R = H, R_1 = R_2 = CH_3) were subjected to a directed Monte Carlo search of conformational space. The relative strain energies of the "global" minima indicated that **3** is more stable than **2** by 6 kcal/mol. See: Mohamadi, F.; Richards, N. G. J.; Guida, W. C.; Liskamp, R.; Caulfield, C.; Chang, G.; Hendrickson, T.; Still, W. C. *J. Comput. Chem.* **1990**, *11*, 440.

(5) Other examples of thermal 6π electrocyclizations followed by [1,5] sigmatropic H-shifts have been reported; see: Darcy, P. J.; Hart, R. J.; Heller, H. G. *J. Chem. Soc., Perkin Trans. 1* **1978**, 571.

(6) (a) Fehr, C.; Galindo, J.; Guntern, O. *Tetrahedron Lett.* **1990**, *31*, 4021. (b) Paquette et al. have reported that trienedione **i** electrocyclizes and then undergoes H-shift at 110 °C: Paquette, L. A.; Bzowej, E. I.; Branan, B. M.; Stanton, K. J. *J. Org. Chem.* **1995**, *60*, 7277.



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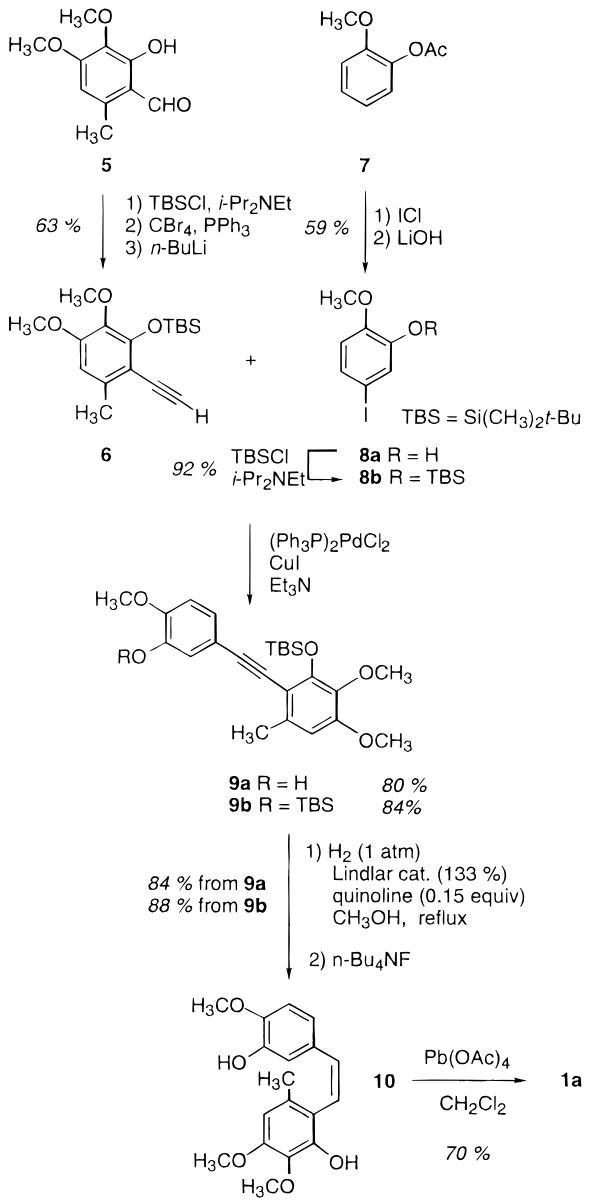
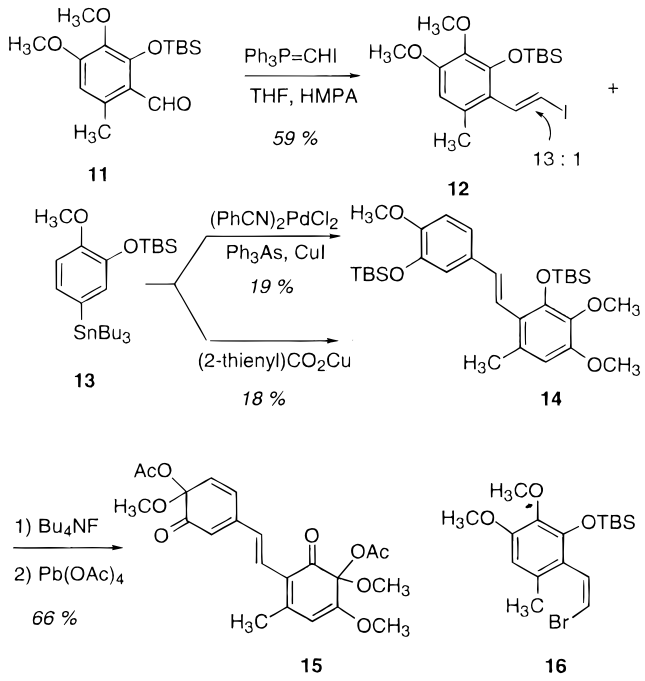
Scheme 2



The preparation of bis(orthoquinone monoketal) **1a** relies on the $Pb(OAc)_4$-mediated oxidation of the appropriate precursor bis(phenol) **10** (Scheme 2). The (*Z*)-stilbene derivative **10** was assembled from the known salicylaldehyde derivative **5**[7] and guaiacol acetate (**7**) utilizing precedented chemistry. Lindlar semi-hydrogenation of either the sterically hindered alkynyl phenol **9a** or its silyl ether derivative **9b** proved problematic and required extensive optimization. Eventually adherence to the carefully defined conditions indicated permitted reproducibly high yields of the isomerically pure (*Z*)-alkene **10** to be obtained from either substrate. Bis(phenol) **10** was exposed to several established phenolic oxidants (e.g., $Pb(OAc)_4$, $Tl(NO_3)_3$, $PhI(OAc)_2$, $PhI(OTFA)_2$), but only Wessely conditions ($Pb(OAc)_4$ in CH_2Cl_2)[8] furnished the desired bis(orthoquinone monoketal) **1a** (1:1 mixture of diastereomers) in good yield and free of difficultly removable impurities. Similar oxidation of

Scheme 3



10 in CH_3OH provided **1a** with no evidence for dimethoxy ketal-containing products, but in an inferior yield compared with using CH_2Cl_2 as solvent. The bright orange bis(orthoquinone monoketal) **1a** was subject to decomposition both upon standing under ambient conditions and upon contact with unpassivated silica gel. Consequently, purification of this and all subsequent orthoquinone monoketal species was best accomplished by rapid chromatography on silica gel deactivated by 10−20% H_2O.

The corresponding (*E*)-alkenyl isomer **15** was unexpectedly available also, as a consequence of a normally (*Z*) selective Wittig alkenylation reaction[9] proceeding with high (*E*) selectivity on the congested aldehyde **11**, Scheme 3. Coupling of the stannylated A-ring precursor **13** with the hindered iodide **12** under either Farina/Liebeskind's $Ph_3As/Pd(0)$-based protocol[10a] or Liebeskind's copper salt alternative[10b] afforded only modest yields of the (*E*)-stilbene derivative **14**. In these transformations, the sensitive aryl tin coupling partner was rapidly consumed in processes which did not lead to stilbene product. The related (*Z*)-alkenyl bromide **16** did not couple with **13** under either set of conditions. Oxidation of the (*E*)-bis(phenol) derived by desilylation of **14** occurred without event under Wessely conditions to furnish the corresponding (*E*)-bis(orthoquinone monoketal) **15** in good yield as an inseparable mixture of stereoisomers.

Warming a dilute (ca. 1 mM) solution of (*Z*)-alkenyl bis(orthoquinone monoketal) **1a** in benzene at reflux effected clean conversion of the starting material into a mixture of three rearrangement products in approximately equal proportions (Scheme 4). Chromatographic purification on deactivated silica gel afforded a less polar off-white solid and a more polar yellow-orange solid. The first-eluting solid appeared by ^1H NMR to be a 1:1 mixture of compounds with similar structures. Further

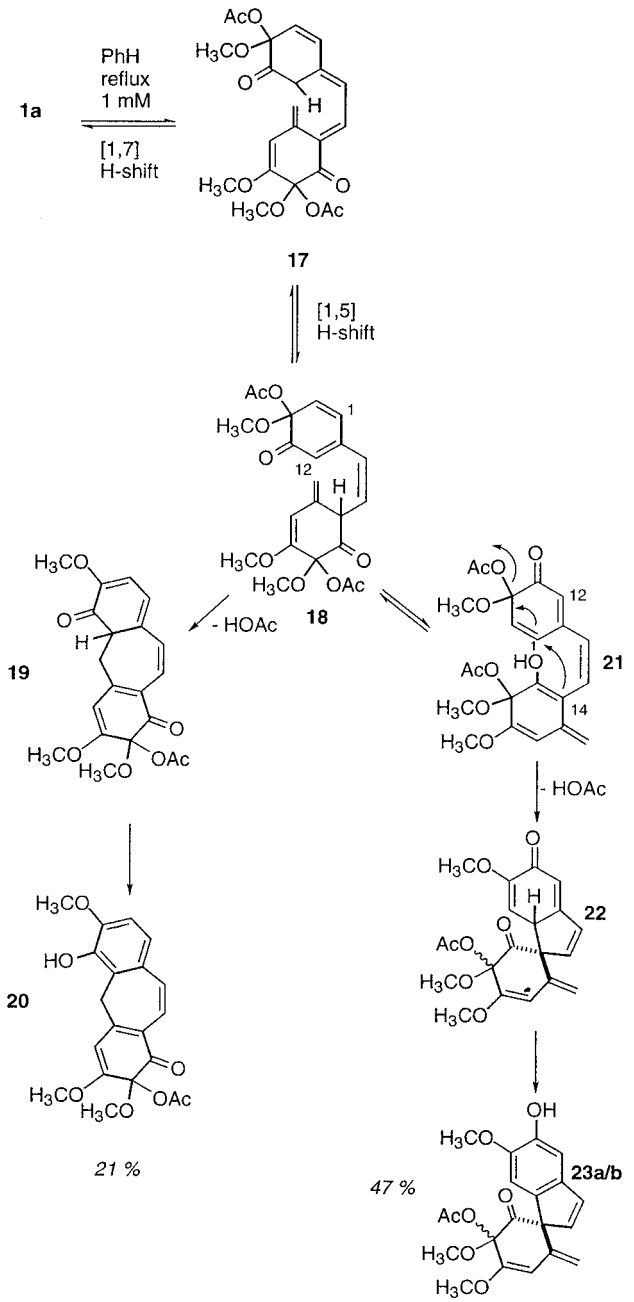
(7) Ishii, H.; Ishikawa, T.; Wada, H.; Miyazaki, H.; Kaneko, Y.; Harayama, T. *Chem. Pharm. Bull.* **1992**, *40*, 2614.

(8) (a) Wessely, F.; Swoboda, J.; Guth, V. Monatsh. **1964**, *95*, 649 and references cited therein. (b) Bubb, W. A.; Sternhell, S. *Tetrahedron Lett.* **1970**, 4499.

(9) Stork, G.; Zhao, K. *Tetrahedron Lett.* **1989**, *30*, 2173.

(10) Farina, V.; Kapadia, S.; Krishnan, R.; Wang, C.; Liebeskind, L. S. *J. Org. Chem.* **1994**, *59*, 5905. (b) Allred, G. D.; Liebeskind, L. S. *J. Am. Chem. Soc.* **1996**, *118*, 2748.

Scheme 4



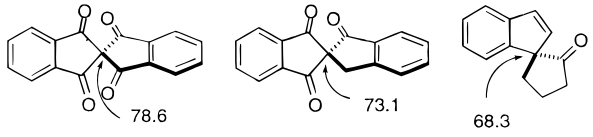
purification of this mixture by HPLC led to fractions enriched in each compound (ca. 80% pure). The spectral data from these enriched mixtures could be interpreted. In addition, partial decomposition of this mixture upon HPLC afforded a new, more polar homogeneous yellow oil.

The yellow-orange solid displayed spectral data consistent with the structural assignment **20**. In particular, interpretation of IR and mass spectral data indicated that one orthoquinone monoketal moiety in **1a** suffered loss of acetic acid with concomitant aromatization while the remaining oxidized ring survived intact. ^{1}H and ^{13}C NMR spectra revealed the key resonances of the central cycloheptatriene ring and furthermore allowed assignment of the regiochemistry of the A-ring by observation of an *ortho* hydrogen−hydrogen coupling. A plausible mechanism of formation of **20** from **1a** is detailed in Scheme 4. The conversion of the allylic methyl in **1a** into the exomethylene of **17** implicates the [1,7] H-shift discussed earlier. A subsequent [1,5] H-shift within **17** delivers a reactive species **18** poised for intramolecular cyclization. Solvolysis of the dienol ether−dienyl acetate unit of **18**, followed by aromatization of the A-ring, completes the synthesis of **20**. Apparently, the lability of pentaene **18** and the opportunity to aromatize **19** conspire to provide a low-energy pathway which consumes intermediate **18**.

Unraveling the structures of the compounds constituting the less polar off-white mixture proved more challenging than that of **20** but eventual recourse to HMQC/HMBC NMR techniques allowed complete assignment of proton and carbon resonances (see Supporting Information) and led to the structural proposals **23a/b**. As with **20**, initial analysis of the MS and IR data confirmed that (1) a molecule of acetic acid had been lost, (2) one of the original carbonyls was now a phenolic hydroxyl, and (3) the remaining carbonyl was no longer adjacent to an alkene. The ^{1}H and ^{13}C spectra of each compound in the mixture provided similar evidence for (1) an exo methylene, (2) one methoxy−acetoxy ketal unit, and (3) a disubstituted alkene whose $^{3}J_{H-H}$ value (5.5 Hz in both compounds) was suggestive of a cyclopentene ring. HMQC/HMBC spectra of the less polar of the two compounds provided unambiguous support for the proposed structures **23a/b** (key $^{3}J_{C-H}$ are given in the Supporting Information). The spiro carbons' ^{13}C resonances (72.4 and 69.4 for the two compounds) were unexpectedly far downfield, but nevertheless consistent with cognate model compounds of known structure.[11] Two uncoupled aromatic proton resonances on the A-ring permit assignment of regiochemistry as shown.

A mechanistic pathway which connects **1a** to these diastereomeric indene derivatives **23a/b** is proposed in Scheme 4. The key intermediate **18** is a likely branch point from which chemistry leading to **23a/b** diverges from that leading to **20**. Thus, the most direct route which links **18** to **23a/b** would involve enolization to provide the nucleophilic entity which traps an electrophilic A-ring species generated by acetate solvolysis, **18 → 21 → 22.** Aromatization of **22** then completes the conversion to **23 a/b**. An alternative scheme for forming enol **21** from ketone **18** which relies on sigmatropic H-shifts also can be envisioned.[12] It is noteworthy that the dienolic nucleophile of **21** apparently favors addition (from C(14)) to C(1) (morphinan numbering) of the ambident electrophile generated by A-ring acetate solvolysis, while the dienolic nucleophile of **18** prefers addition to C(12) of that same electrophilic species. A rationale for this dichotomy is at present obscure.

(11) P. Maslak, unpublished results, Penn State University.



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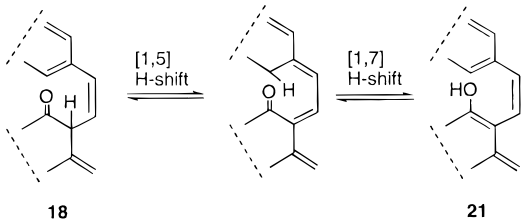
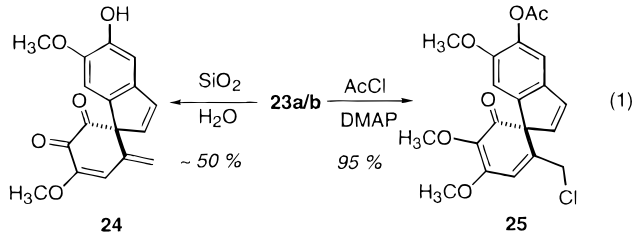


Partial hydrolysis of the mixture **23a/b** accompanied HPLC purification, eq 1. A more polar yellow oil was isolated and assigned the structure **24** on the basis of analysis of spectral data. This unstable dienedione decomposes to unidentified material upon standing at ambient conditions for a few hours. Further evidence for the lability of the dienyl ketal moiety of **23a/b** can be gleaned from the results of attempted acylation, eq 1. When a 1:1 mixture of **23a/23b** was subjected to AcCl/DMAP, a new dienyl chloride species **25** was formed to the exclusion of any direct ketal-containing acetylated products. Apparently, the DMAP·HCl formed as an acylation byproduct is a potent enough acid to promote ketal solvolysis with Sn2′ capture of chloride.

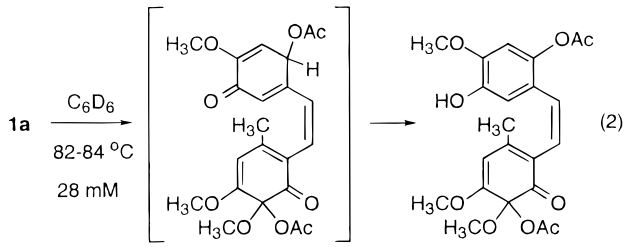


24 **25** (1)

The thermal rearrangement pathway taken by **1a** appears to be sensitive to concentration. Heating a 28 mM solution of **1a** in C_6D_6 in 10 °C increments with ^1H NMR monitoring revealed that the signals for the bis(orthoquinone monoketal) had disappeared after 9 h at 82−84 °C, but the rearrangement/solvolysis products **20/23a/b** comprised only about 20% of the product mixture. The major component (ca. 80%) of the species present was isolated following chromatography and assigned structure **27** on the basis of analysis of spectral data, eq 2. The tetrasubstituted A-ring of **27** might plausibly result from initial 1,3-acetate shift within **1a** to furnish transient dienone **26**, followed by aromatization. In an independent experiment, a 1 mM solution of **1a** in C_6D_6 was charged with 3 equiv of acetic acid and warmed at reflux for 2.5 h. At that time, starting bis(orthoquinone monoketal) **1a** was consumed, and a mixture containing approximately 15% of **27** and 85% of the solvolysis products **20/23a/b** was present. No **27** was seen in the original 1 mM thermolysis without added acid. It is possible, then, that the concentration of acetic acid plays a role in determining the facility of the 1,3-acetate shift.[13] The higher concentration run (28 mM) produces a proportionately higher concentration of acetic acid as a byproduct from **20/23a/b** formation, and this acid might then catalyze the conversion of **1a** into **27**. As a final control experiment, heating the (*E*)-alkenyl bis(orthoquinone monoketal) isomer **15** (ca. 23 mM solution in C_6D_6) led to formation of a similar 1,3-acetate shift product at 90 °C.

The possibility of photochemically redirecting the pericyclic chemistry of **1a** toward electrocyclization was explored in a few scouting experiments. Irradiation of a C_6D_6 solution of **1a** with 350 nm light furnished the (*E*)-alkene isomer **15** cleanly. Similarly, **15** survived 350 nm irradiation unchanged. In no case was even a trace amount of cyclization products detected.

The goal of preparing oxidized phenanthrene systems related to the morphinan skeleton by electrocyclization



26 **27**

has not been realized. Competitive sigmatropic hydrogen shifts intervene, and these isomerizations are rendered irreversible by facile acetate solvolyses which afford a suite of unusual tricyclic dienone derivatives. One diastereomeric set of tricyclic products featuring a spiroindene framework is quite sensitive to a second acetate solvolysis, leading to ketonic or dienyl chloride products depending on conditions.

Experimental Section

THF, DME, and diethyl ether (Et_2O) were dried by distillation from sodium/benzophenone under Ar. Benzene and CH_2Cl_2 were dried by distillation from CaH_2 under Ar. Liquid (flash)[14] chromatography was carried out using 32−63 μm silica gel and the indicated solvent system. Hexane and Et_2O used in flash chromatography were distilled from CaH_2 prior to use. All moisture and air sensitive reactions were carried out in predried glassware under an inert atmosphere of Ar. All melting points are uncorrected. Chemical ionization mass spectra (CIMS) were obtained with isobutane as the reagent gas. Combustion analyses were performed by Midwest Microlabs, Indianapolis, IN. ^1H and ^{13}C NMR spectra are provided in the Supporting Information to establish purity for those compounds which were not subject to combustion analyses.

2-Methoxy-5-iodophenol (8a). This procedure was adapted from the method of Bushby.[15] A stirring solution of guaiacol (10.0 g, 80.6 mmol) and pyridine (15.0 mL, 186 mmol) in 200 mL of CH_2Cl_2 was cooled in an ice bath and treated with acetyl chloride (6.4 mL, 90 mmol). After 5 min, TLC (1:1 Et_2O/hexane) indicated consumption of guaiacol, and the reaction solution was poured into ice cold 1 M H_3PO_4. The organic phase was extracted with 50 mL of CH_2Cl_2, and the combined organic layers were washed with brine, dried with Na_2SO_4, filtered, and concentrated in vacuo to afford a light yellow oil. This oil in 200 mL of CH_2Cl_2 was cooled in an ice bath, and with vigorous stirring a solution of ICl (15.5 g, 96 mmol) in 100 mL of CH_2Cl_2 was added dropwise over 2 h. TLC analysis (PhH) indicated consumption of acetate, and the reaction solution was poured into an ice cold saturated $Na_2S_2O_3$ solution. The aqueous layer was extracted with 50 mL of CH_2Cl_2, and the combined organic phases were washed with brine, dried with Na_2SO_4, filtered, and concentrated to yield 20.5 g of a light yellow solid. This solid was dissolved in 60 mL of CH_3OH, 60 mL of THF, and 20 mL of H_2O, and $LiOH·H_2O$ (11.8 g, 280 mmol) was added in one portion. After vigorous stirring at rt for 3.5 h, TLC (1:1 Et_2O/hexane) indicated consumption of the starting iodoacetate. The reaction solution was poured into ice cold 1 M HCl, and this mixture was extracted with 3 × 100 mL of Et_2O. The combined ethereal layers were washed with brine, dried with Na_2SO_4, filtered, and concentrated in vacuo to furnish an off-white solid. Crystallization from 50 mL of hexane and 3 mL of Et_2O (concentrated by boiling to ~20 mL, then cooled to rt) yielded 11.8 g (59% from guaiacol) of iodophenol **8a** as chunky off-white crystals upon filtration. An analytical sample could be prepared by vapor diffusion crystallization from THF/hexane,

(13) Acetic acid and *p*-nitrobenzoic acid catalysis of 1,3 acetate shifts have been reported: (a) Braude, E. A.; Turner, D. W.; Waight, E. S. *J. Chem. Soc.* **1958**, 2396. (b) Pocker, Y. *J. Chem. Soc.* **1958**, 4318.

(14) Still, W. C. Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

(15) Boden, N.; Bushby, R. J.; Cammidge, A. N. *J. Am. Chem. Soc.* **1995**, *117*, 924.

mp 87−88 °C: IR (CCl_4) 3351 cm^{-1}; ^1H NMR ($CDCl_3$, 200 MHz) 7.22 (d, J = 2.1 Hz, 1H), 7.14 (dd, J = 8.4, 2.1 Hz, 1H), 6.57 (d, J = 8.4 Hz, 1H), 5.62 (s, 1H), 3.84 (s, 3H); ^{13}C NMR ($CDCl_3$, 50 MHz) 146.6, 146.5, 129.0, 123.4, 112.5, 82.9, 55.9; CIMS *m/z* (relative intensity) 250 (M^+, 100). Anal. Calcd for $C_7H_7IO_2$: C, 33.63; H, 2.82; I, 50.75. Found: C, 33.51; H, 2.76; I, 50.97.

3-(*tert*-Butyldimethylsiloxy)-4-methoxyiodobenzene (8b). A stirring solution of phenol **8a** (2.01 g, 8.0 mmol) and *tert*-butyldimethylsilyl chloride (1.46 gm, 9.6 mmol) in 10 mL of DMF was treated with diisopropylethylamine (1.94 mL, 11.6 mmol). After 30 min at rt, TLC (3:1 hexane/Et_2O) indicated complete consumption of starting alcohol. The reaction solution was poured into ice cold 1 M H_3PO_4, and this mixture was extracted with 2 × 25 mL of Et_2O. The combined ethereal layers were washed with brine, dried with Na_2SO_4, filtered, and concentrated in vacuo. The oily residue so obtained was purified by flash chromatography on SiO_2 with 19:1 hexane/Et_2O as eluent to furnish 2.65 g of the silyl ether **8b** as a colorless oil (91%). An analytical sample could be prepared by crystallization from hexane at −10 °C, mp 36 °C: ^1H NMR ($CDCl_3$, 360 MHz), 7.20 (dd, J = 8.4, 2.2 Hz, 1 H), 7.14 (d, J = 2.2 Hz, 1H), 6.58 (d, J = 8.5 Hz, 1 H), 3.77 (s, 3H), 0.98 (s, 9H), 0.15 (s, 6H); ^{13}C NMR ($CDCl_3$, 90 MHz) 151.3, 146.1, 130.6, 129.8, 114.0, 82.1, 55.5, 25.7, 18.4, −2.6; CIMS *m/z* (relative intensity) 365 (M^+, 18); HRMS calcd for $C_{13}H_{21}IO_2Si$ 364.0357, found 364.0327.

2-(*tert*-Butyldimethylsiloxy)-3,4-dimethoxy-6-methylbenzaldehyde (11). A stirring solution of phenol **5**[7] (4.87 g, 24.8 mmol) and *tert*-butyldimethylsilyl chloride (4.88 gm, 32.3 mmol) in 20 mL of DMF was treated with diisopropylethylamine (6.47 mL, 32.7 mmol). After 15 min, TLC (3:1 hexane/Et_2O) indicated complete consumption of starting alcohol. The reaction solution was poured into ice cold 1 M H_3PO_4, and this mixture was extracted with 2 × 50 mL of Et_2O. The combined ethereal layers were washed with brine, dried with Na_2SO_4, filtered, and concentrated in vacuo. The residue was purified by flash chromatography on SiO_2 with 4:1 hexane/Et_2O as eluent to furnish 7.04 g (92%) of silyl ether **11** as a white solid. An analytical sample could be prepared by recrystallization from hexane at −10 °C, mp 62−64 °C: IR (CCl_4) 1683 cm^{-1}; ^1H NMR ($CDCl_3$, 360 MHz) 10.47 (s, 1H), 6.40 (s, 1H), 3.92 (s, 3H), 3.75 (s, 3H), 2.56 (s, 3H), 1.01 (s, 9H), 0.22 (s, 6H); ^{13}C NMR ($CDCl_3$, 90 MHz) 191.2, 157.3, 154.2, 138.0, 137.7, 120.7, 108.5, 60.5, 55.9, 25.9, 21.9, 18.8, −2.8; CIMS *m/z* (relative intensity) 311 (M^+, 100). Anal. Calcd for $C_{16}H_{26}O_4Si$: C, 61.90; H, 8.44. Found: C, 62.20; H, 8.62.

1,1-Dibromo-2-[2-(*tert*-butyldimethylsiloxy)-3,4-dimethoxy-6-methylphenylethene. As per the method of Corey and Fuchs,[16] CBr_4 (3.32 g, 10 mmol) in 15 mL of CH_2Cl_2 was added dropwise to a stirring, ice-cooled solution of PPh_3 (5.25 g, 20 mmol) in 40 mL of CH_2Cl_2. Aldehyde **11** (1.55 g, 5 mmol) in 10 mL of CH_2Cl_2 was added to this homogeneous orange ylide solution, and the mixture was allowed to warm to rt over 2 h, at which time TLC (9:1 hexane/Et_2O) indicated complete consumption of aldehyde. The reaction solution was poured into 200 mL of vigorously stirring hexane, and this mixture was filtered through SiO_2 to remove a beige solid. The filtrate was concentrated in vacuo, and the residue obtained was purified by flash chromatography on SiO_2 with 50:1 hexane/Et_2O → 25:1 hexane/Et_2O as eluent to furnish 1.88 g (81%) of dibromide product as a colorless viscous oil. An analytical sample could be prepared by crystallization from hexane at −10 °C, mp 67−69 °C: ^1H NMR ($CDCl_3$, 360 MHz) 7.26 (s, 1H under $CHCl_3$ signal), 6.41 (s, 1H), 3.85 (s, 3H), 3.71 (s, 3H), 2.22 (s, 3H), 1.02 (s, 9H), 0.18 (s, 6H); ^{13}C NMR ($CDCl_3$, 90 MHz) 153.1, 146.5, 138.0, 135.3, 131.6, 121.9, 106.7, 93.8, 60.4, 55.7, 25.9, 20.1, 18.6, −2.8; CIMS *m/z* (relative intensity) 467 (MH^+, 100); HRMS calcd for $C_{17}H_{26}Br_2O_3Si$ 464.0019, found 464.0010.

(*Z*)-1-Bromo-2-[2-(*tert*-butyldimethylsiloxy)-3,4-dimethoxy-6-methylphenylethene (16).[17] A stirring rt solution of the dibromide from above (1.00 g, 2.1 mmol) and $Pd(PPh_3)_4$ (121 mg, 0.105 mmol) in 20 mL of benzene was treated with *n*-Bu_3SnH (706 uL, 2.63 mmol). TLC analysis (2:1 hexane/CH_2Cl_2 on SiO_2 plates impregnated with $AgNO_3$ (dipped in 10% $AgNO_3/CH_3CN$ solution)) revealed that some dibromide remained after 18 h. Additional aliquots of *n*-Bu_3SnH were added at 18 h (250 uL, 0.93 mmol) and 24 h (100 uL, 0.37 mmol), and TLC analysis indicated almost complete consumption of starting dibromide after 29 h. The reaction mixture was poured into saturated $NaHCO_3$ solution and extracted with 2 × 25 mL of hexane. The combined organic phases were washed with brine, dried with Na_2SO_4, filtered, and concentrated in vacuo. The residue was purified by flash chromatography with 99:1 hexane/Et_2O → 50:1 hexane/Et_2O as eluent to furnish 852 mg of (*Z*)-bromide **16** (93%) as a viscous, colorless oil. An analytical sample could be prepared by crystallization from hexane at −10 °C, mp 52−53 °C: ^1H NMR ($CDCl_3$, 200 MHz) 7.02 (d, J = 7.5 Hz, 1H), 6.51 (d, J = 7.3 Hz, 1H), 6.43 (s, 1H), 3.85 (s, 3H), 3.73 (s, 3H), 2.22 (s, 3H), 0.98 (s, 9H), 0.16 (s, 6H); ^{13}C NMR ($CDCl_3$, 90 MHz) 152.7, 146.7, 137.8, 131.6, 131.1, 121.0, 111.5, 106.6, 60.4, 55.7, 26.0, 20.2, 18.6, −3.1; CIMS *m/z* (relative intensity) 387 MH^+, 50). Anal. Calcd for $C_{17}H_{27}BrO_3Si$: C, 52.71; H, 7.03; Br, 20.63. Found: C, 53.11; H, 7.17; Br, 20.28.

1-(*tert*-Butyldimethylsiloxy)-2,3-dimethoxy-6-ethynyl-5-methylbenzene (6). As per the method of Corey and Fuchs,[16] a stirring, −78 °C solution of the dibromide from above (803 mg, 1.72 mmol) in 10 mL of THF was treated with a 2.5 M *n*-BuLi solution in hexane (1.70 mL, 4.25 mmol) to furnish a yellow solution. TLC (3:1 hexane/CH_2Cl_2 on $AgNO_3$-impregnated SiO_2 plates) indicated complete consumption of starting dibromide after 10 min. The reaction solution was poured into ice cold 1 M H_3PO_4, and this mixture was extracted with 2 × 10 mL of Et_2O. The combined organic phases were washed with brine, dried over Na_2SO_4, filtered, and concentrated in vacuo. The residue was purified by flash chromatography on SiO_2 with 9:1 hexane/Et_2O as eluent to afford 503 mg of alkyne **6** (96%) as a colorless oil. An analytical sample could be prepared by crystallization from hexane at −10 °C, mp 50−51 °C: IR (CCl_4) 3311, 2104 cm^{-1}; ^1H NMR ($CDCl_3$, 360 MHz) 6.41 (s, 1H), 3.85 (s, 3H), 3.71 (s, 3H), 3.34 (s, 1H), 1.04 (s, 9H), 0.23 (s, 6H); ^{13}C NMR ($CDCl_3$, 90 MHz) 153.7, 151.2, 137.9, 137.5, 108.6, 106.5, 84.1, 80.1, 60.3, 55.8, 25.9, 21.0, 18.6, −3.1; CIMS *m/z* (relative intensity) 307 (MH^+, 75). Anal. Calcd for $C_{17}H_{26}O_3Si$: C, 66.62; H, 8.55. Found: C, 67.06; H, 8.64.

(*E*)-1-Iodo-2-(2-*tert*-butyldimethylsiloxy)-3,4-dimethoxy-6-methylphenylethene (12). As per the method of Stork,[9] a 1 M solution of TMS_2NNa in THF (2.50 mL, 2.50 mmol) was added dropwise to a stirring, rt suspension of $Ph_3PCH_2I_2$ (1.33 gm, 2.5 mmol) in 5 mL of THF. This homogeneous orange solution was cooled in a dry ice−acetone bath, and 0.75 mL of HMPA followed by aldehyde **11** (620 mg, 2.00 mmol) in 7 mL of THF was added, resulting in a cloudy yellow solution. After 30 min, TLC analysis (3:1 hexane/Et_2O) indicated complete consumption of aldehyde. The reaction solution was poured into 100 mL of vigorously stirring hexane, and the mixture was filtered through SiO_2. Concentration of the filtrate and purification of the resulting yellow oil via flash chromatography on SiO_2 with 19:1 hexane/Et_2O as eluent furnished 512 mg of iodide **12** (59%, 13:1 *E*/*Z*) as a colorless oil. An analytical sample of the *E* isomer could be prepared by crystallization from hexane at −10 °C, mp 63−64 °C: ^1H NMR ($CDCl_3$, 360 MHz) 7.40 (d, J = 15.0 Hz, 1H), 6.48 (d, J = 15.0 Hz, 1H), 6.38 (s, 1H), 3.84 (s, 3H), 3.72 (s, 3H), 2.27 (s, 3H), 1.00 (s, 9H), 0.17 (s, 6H); ^{13}C NMR ($CDCl_3$, 90 MHz) 152.5, 147.1, 140.2, 138.2, 131.3, 123.4, 107.3, 80.5, 60.4, 55.8, 26.0, 21.3, 18.6, −4.0; CIMS *m/z* (relative intensity) 435 (MH^+, 55). Anal. Calcd for $C_{17}H_{27}IO_3Si$: C, 47.01; H, 6.27; I, 29.21. Found: C, 47.16; H, 6.38; I, 29.00.

1-(*tert*-Butyldimethylsiloxy)-2,3-dimethoxy-6-[(3-hydroxy-4-methoxyphenyl)ethynyl]-5-methylbenzene (9a). A stirring solution of alkyne **6** (1.68 g, 5.49 mmol), phenolic iodide **8a** (1.51 g, 6.04 mmol,), $(Ph_3P)_2PdCl_2$ (115 mg, 0.16 mmol), and CuI (61 mg, 0.32 mmol) in 15 mL of triethylamine

(16) Corey, E. J.; Fuchs, P. L. *Tetrahedron Lett.* **1972**, 3769.
(17) Uenishi, J.; Kawahama, R.; Shiga, Y.; Yonemitsu, U.; Tsuji, J. *Tetrahedron Lett.* **1996**, *37*, 6759.

was purged with Ar and maintained at rt with TLC monitoring. After 1 h, TLC (1:1 hexane/Et_2O) indicated that iodide **8a** was consumed while alkyne **6** remained. An additional portion of iodide (100 mg, 0.4 mmol) was added. After 30 min, TLC indicated that alkyne was consumed. The reaction solution was poured into ice cold 1 M H_3PO_4 and extracted with 2 × 50 mL of Et_2O. The combined organic phases were washed with brine, dried with Na_2SO_4, filtered, and concentrated in vacuo to give an orange oil. This oil was purified by flash chromatography with 1:4 Et_2O/hexane as eluent to furnish 1.89 g of alkyne **9a** (80%) as a white fine powder. An analytical sample could be prepared by vapor diffusion crystallization from THF/hexane, mp 134−135 °C: IR (CCl_4) 3556, 2240 cm^{-1}; ^1H NMR ($CDCl_3$, 360 MHz) 7.08 (d, J = 1.9 Hz, 1H), 7.04 (dd, J = 8.3, 2.0 Hz, 1H), 6.81 (d, J = 8.4 Hz, 1H), 6.44 (s, 1H), 5.58 (s, 1H), 3.91 (s, 3H), 3.86 (s, 3H), 3.73 (s, 3H), 2.43 (s, 3H), 1.06 (s, 9H), 0.25 (s, 6H); ^{13}C NMR ($CDCl_3$, 90 MHz) 153.3, 150.1, 146.6, 145.3, 138.0, 137.0, 123.8, 117.3, 110.5, 109.8, 106.6, 96.0, 84.7, 60.4, 55.9, 55.8, 26.0, 21.2, 18.7, −3.1; CIMS *m/z* (relative intensity) 429 (MH^+, 100). Anal. Calcd for $C_{24}H_{32}O_5Si$: C, 67.26; H, 7.53. Found: C, 67.19; H, 7.62.

1-(*tert*-Butyldimethylsiloxy)-6-[3-(*tert*-butyldimethysiloxy)-4-(methoxyphenyl)ethynyl]-2,3-dimethoxy-6-methylbenzene (9b). In a manner analogous to the synthesis of **9a**, alkyne **6** (503 mg, 1.64 mmol), iodide **8b** (657 mg, 1.8 mmol), $(Ph_3P)_2PdCl_2$ (35 mg, 0.05 mmol), and CuI (19 mg, 0.1 mmol) were combined in 5 mL of triethylamine. Workup as described for **9a** (no additional iodide was required) yielded 648 mg (84%) of alkyne **9b** as a white solid following flash chromatography on SiO_2 with 4:1 hexane/Et_2O as eluent. An analytical sample could be prepared by recrystallization from hexane at −10 °C, mp 130 °C: ^1H NMR ($CDCl_3$, 360 MHz) 7.09 (dd, J = 8.3, 2.0 Hz, 1H), 7.01 (d, J = 2.0 Hz, 1H), 6.79 (d, J = 8.4 Hz, 1H), 6.44 (s, 1H), 3.86 (s, 3H), 3.82 (s, 3H), 3.73 (s, 3H), 2.43 (s, 3H), 1.06 (s, 9H), 1.01 (s, 9H), 0.25 (s, 6H), 0.17 (s, 6H); ^{13}C NMR ($CDCl_3$, 360 MHz) 153.2, 150.6, 149.3, 144.7, 137.7, 136.9, 125.4, 123.7, 116.7, 111.9, 109.4, 106.6, 96.3, 84.4, 60.4, 55.8, 55.5, 26.0, 25.7, 21.2, 18.7, 18.4, −2.6, −3.1; CIMS *m/z* (relative intensity) 543 (MH^+, 100). Anal. Calcd for $C_{30}H_{46}O_5Si_2$: C, 66.36; H, 8.56. Found: C, 65.94; H, 8.68.

(*Z*)-1-(3,4-Dimethoxy-2-hydroxy-5-methylphenyl)-2-(3-hydroxy-4-methoxyphenyl)ethene (10). From Bis(silyl ether) 9b. A stirring solution of alkyne **9b** (377 mg, 0.69 mmol) and quinoline (1.56 mL of a 0.071 M quinoline/CH_3OH solution, 0.11 mmol) in 50 mL of CH_3OH was charged with Lindlar's catalyst (471 mg), purged with Ar and then H_2, and brought to reflux under a balloon filled with H_2. After 1.5 h, TLC analysis (9:1 hexane/Et_2O) indicated complete consumption of starting material. The reaction solution was cooled to rt, purged with Ar, filtered through Celite, and concentrated in vacuo. The residue was taken up in 30 mL of THF and cooled in an ice bath, and n-Bu_4NF (1.72 mL of a 1 M THF solution, 1.72 mmol) was added with stirring. After 5 min, TLC (1:1 hexane/Et_2O) indicated consumption of bis-silyl ether. The reaction solution was poured into ice cold 1M H_3PO_4 and extracted with 2 × 20 mL of Et_2O. The combined organic phases were washed with brine, dried with Na_2SO_4, filtered, and concentrated in vacuo. The residue was purified by flash chromatography on SiO_2 with 2:1 hexane/Et_2O → 1:1 hexane/Et_2O to furnish 191 mg (88% from alkyne **9b**) of the bis(phenol) **10** as a white solid. An analytical sample could be prepared by vapor diffusion crystallization with THF/hexane, mp 136−138 °C: IR (CCl_4) 3557, 3525 cm^{-1}; ^1H NMR ($CDCl_3$, 360 MHz) 6.73 (s, 1H), 6.66 (d, J = 1.1 Hz, 1H), 6.61 (d, J = 12.0 Hz, 1H), 6.32 (d, J = 13.5 Hz, 1H), 5.69 (s, 1H), 5.43 (s, 1H), 3.86 (s, 3H), 3.85 (s, 3H), 3.83 (s, 3H), 2.10 (s, 3H); ^{13}C NMR ($CDCl_3$, 90 MHz) 151.3, 146.4, 145.9, 145.1, 133.8, 132.0, 131.9, 131.0, 122.3, 120.7, 117.2, 114.2, 110.2, 105.6, 61.0, 55.8, 55.7, 20.0; CIMS *m/z* (relative intensity) 317 (MH^+, 100). Anal. Calcd for $C_{18}H_{20}O_5$: C, 68.34; H, 6.37. Found: C, 68.38; H, 6.49.

From Monophenol 9a. In a manner analogous to that described above, alkyne **9a** (730 mg, 1.70 mmol), 950 mg of Lindlar's catalyst, and quinoline (3.59 mL of a 0.071 M solution in CH_3OH, 0.25 mmol) were stirred at reflux in 50 mL of CH_3OH under a balloon of hydrogen. Workup as described above, followed by desilylation with a 1 M n-Bu_4NF solution (2.0 mL, 2.0 mmol), furnished 450 mg (84%) of bis(phenol) **10** as a white solid following chromatography.

(*Z*)-1-[6-Acetoxy-5,6-dimethoxy-3-methyl-1-oxocyclohexa-2,4-dien-2-yl]-2-[6-acetoxy-6-methoxy-1-oxocyclohexa-2,4-dien-3-yl]ethene (1a). A solution of bis(phenol) **10** (190 mg, 0.60 mmol) in 5 mL of CH_2Cl_2 was added dropwise to a stirring, −78 °C solution/suspension of $Pb(OAc)_4$ (586 mg, 1.32 mmol) in 25 mL of CH_2Cl_2. An immediate bright yellow-orange solution resulted. After 30 min, TLC indicated complete consumption of **10**. The reaction solution was poured into 20 mL of ice cold H_2O containing 1 mL of a saturated $NaHCO_3$ solution, and the layers were separated. The aqueous phase was extracted with CH_2Cl_2, and the combined organic layers were washed with brine, dried with Na_2SO_4, filtered, and concentrated in vacuo. The residue was purified by flash chromatography on SiO_2 deactivated with 15% by wt H_2O using 2:1 Et_2O/hexane → 3:1 Et_2O/hexane as eluent to yield 182 mg (1:1 mixture of diastereomers A and B, 70%) of bis(quinone monoketal) **1a** as an orange foam. Chromatography of SiO_2 without H_2O deactivation led to significant decomposition: IR (CCl_4) 1743, 1673 cm^{-1}; ^1H NMR (C_6D_6, 360 MHz), 6.73 (dd, J = 10.1, 1.5 Hz, 1H A), 6.65 (dd, J = 10.1, 1.6 Hz, 1H B), 6.50 (d, J = 11.9 Hz, 1H A), 6.45 (d, J = 11.8 Hz, 1H B), 6.11 (dd, J = 10.0, 0.5 Hz, 1H A), 6.07 (dd, J = 10.6, 0.5 Hz, 1H B), 6.03 (s, 1H A), 6.02 (s, 1H B), 5.95 (d, J = 11.9 Hz, 1H A), 5.91 (d, J = 11.9 Hz, 1H B), 4.89 (s, 1H A), 4.85 (s, 1H B), 3.44 (s, 2 × 3H A and B), 3.37 (s, 3H A), 3.33 (s, 3H B), 2.99 (s, 3H A), 2.97 (s, 3H B), 1.86 (d, J = 1.1 Hz, 3H A), 1.80 (d, J = 1.1 Hz, 3H B), 1.71 (s, 3H A), 1.70 (s, 3H B), 1.60 (s, 3H A), 1.59 (s, 3H B); ^{13}C NMR (C_6D_6, 90 MHz) 191.1, 191.0, 188.4, 188.3, 169.5, 169.3, 169.0, 168.9, 161.5, 161.3, 152.4, 152.1, 149.0, 148.9, 134.7, 134.5, 131.4, 131.3, 126.9, 126.7, 124.8, 124.6, 124.4, 100.4, 100.3, 93.7, 93.6, 93.3, 93.2, 55.4, 55.3, 51.8, 50.8, 22.4, 20.2, 20.1, 20.0; FABMS *m/z* (relative intensity) 432 (M^+, 6); HRMS calcd for $C_{22}H_{24}O_9$ 432.1420, found 432.1429.

[3-(*tert*-Butyldimethylsiloxy)-4-methoxyphenyl]tri-*n*-butylstannane (13). Aryl iodide **8b** (2.61 g, 7.2 mmol) in 15 mL of THF was added dropwise to a rt suspension of Mg° (190 mg, 7.9 g-atom) in *n*-Bu_3SnCl (2.1 mL, 7.9 mmol) with vigorous stirring. The solution began refluxing and was maintained at this temperature by gentle warming. After 5 h, most of the Mg was consumed and the mixture was cooled to rt, poured into ice cold 1 M H_3PO_4, and extracted with 2 × 50 mL of hexane. The combined organic phases were washed with brine, dried with Na_2SO_4, filtered, and concentrated in vacuo to afford 4.24 g of a colorless mobile oil. ^1H NMR analysis revealed a 3:1 mixture of arylstannane to starting iodide. A portion of this mixture (3.66 g) was purified by flash chromatography on SiO_2 deactivated with 25 wt % H_2O, using 98:1:1 hexane/benzene/triethylamine as eluent, to furnish 1.02 g (27%) of stannane **13** as a colorless, mobile oil. The remainder of the recovered material consisted of a mixture of stannane **13**, iodide **8b**, and destannylated TBDS·guaiacol. **13**: ^1H NMR ($CDCl_3$, 360 MHz) 6.97 (dd, J = 7.7, 1.2 Hz, 1H), 6.92 (d, J = 1.2 Hz, 1H), 6.85 (d, J = 7.8 Hz, 1H), 3.79 (s, 3H), 1.5 (m, 6H), 1.3 (m, 6H), 1.0 (m, 6H), 0.99 (s, 9H), 0.88 (t, J = 7.3 Hz, 9H), 0.15 (s, 6H); ^{13}C NMR ($CDCl_3$, 90 MHz) 151.0, 144.9, 132.4, 129.8, 128.7, 107.9, 55.4, 29.1, 27.4, 25.8, 18.5, 13.6, 9.6, −2.7; CIMS *m/z* (relative intensity) 529 (MH^+, 19); HRMS calcd for $C_{25}H_{48}SiSnO_2$ 528.2459, found 528.2462.

(*E*)-1-(6-Acetoxy-5,6-dimethoxy-3-methyl-1-oxocyclohexa-2,4-dien-2-yl)-2-(6-acetoxy-6-methoxy-1-oxocyclohexa-2,4-dien-3-yl)ethene (15). Method A. As per the method of Liebeskind,[10b] iodide **12** (247 mg, 0.57 mmol) and stannane **13** (300 mg, 0.57 mmol) in 3 mL of *N*-methylpyrrolidone were cooled to 0 °C and treated with copper 2-thienecarboxylate (163 mg, 0.85 mmol) with vigorous stirring. TLC analysis (4:1 hexane/Et_2O) indicated consumption of stannane after 15 min, but iodide **12** remained. After 5 h, TLC revealed a new compound along with iodide **12**. The reaction solution was poured into 50 mL of Et_2O, filtered through a plug of SiO_2, concentrated, and purified by flash chromatography on SiO_2 with 50:1 hexane/Et_2O → 25:1 hexane/Et_2O as eluent to furnish

54 mg (18%) of (*E*)-biaryl alkene **14** as a colorless oil which crystallized upon standing: ^{1}H NMR ($CDCl_3$, 200 MHz) 7.0 (m, 2H), 6.92 (d, J = 17.4 Hz, 1H), 6.82 (d, J = 8.4 Hz, 1H), 6.68 (d, J = 18.0 Hz, 1H), 6.44 (s, 1H), 3.86 (s, 3H), 3.83 (s, 3H), 3.75 (s, 3H), 2.39 (s, 3H), 1.02 (s, 9H), 0.96 (s, 9H), 0.18 (s, 6H), 0.13, (s, 6H).

Method B. As per the method of Farina,[10a] stannane **13** (321 mg, 0.61 mmol), iodide **12** (265 mg, 0.61 mmol), $(PhCN)_2PdCl_2$ (8 mg, 0.03 mmol), CuI (6 mg, 0.03 mmol), and Ph_3As (37 mg, 0.12 mmol) in 4 mL of DMF were warmed to 58 °C with vigorous stirring. After 1 h, TLC indicated consumption of stannane, and the solution was worked up as described in method A to afford 63 mg (19%) of (*E*)-alkene **14**.

The combined silyl ether samples from three coupling runs (135 mg, 0.24 mmol) in 5 mL of THF were treated with a 1 M solution of n-Bu_4NF in THF (600 uL, 0.6 mmol) at 0 °C with stirring. TLC analysis (1:1 Et_2O/hexane) indicated complete consumption of starting material after 5 min. The reaction mixture was poured into ice cold 1 M H_3PO_4 and extracted with 2 × 10 mL of Et_2O. The combined ethereal layers were washed with brine, dried with Na_2SO_4, filtered, and concentrated in vacuo. The residue was purified by flash chromatography on SiO_2 with 1:1 hexane/Et_2O as eluent to yield 66 mg (88%) of bis(phenol) as a white solid: ^{1}H NMR ($CDCl_3$, 200 MHz) 7.24 (d, J = 14.8 Hz, 1H), 7.18 (d, J = 3.1 Hz, 1H), 6.99 (d, J = 15.5 Hz, 1H), 6.97 (dd, J = 9.0, 3.0 Hz, 1H), 6.82 (d, J = 8.8 Hz, 1H), 6.37 (s, 1H), 6.27 (s, 1H), 5.52 (s, 1H), 3.92 (s, 6H), 3.87 (s, 3H), 2.38 (s, 3H).

This bis(phenol) (64 mg, 0.20 mmol) in 2 mL of CH_2Cl_2 was added dropwise to a stirring solution/suspension of $Pb(OAc)_4$ (194 mg, 0.44 mmol) in 3 mL of $CHCl_2$ at −78 °C. An immediate bright orange solution with a white precipitate resulted. After 5 min at −78 °C, TLC (1:1 hexane/Et_2O) indicated that starting bis(phenol) was consumed. The reaction solution was poured into ice cold water containing 1 mL of saturated $NaHCO_3$ solution, and the layers were separated. The aqueous phase was extracted with 2 × 10 mL of Et_2O, and the combined organic layers were washed with brine, dried over Na_2SO_4, filtered, and concentrated in vacuo. The reside was purified by flash chromatography on SiO_2 using Et_2O as eluent to furnish 65 mg (75%, 1:1 mixture of diastereomers A and B) of **15** as an orange solid: IR (CCl_4) 1746, 1670 cm^{-1}; ^{1}H NMR (C_6D_6, 360 MHz) 7.30 (d, J = 16.2 Hz, 1H A), 7.28 (d, J = 16.3 Hz, 1H B), 6.84 (d, J = 16.5 Hz, 1H A), 6.83 (d, J = 16.2 Hz, 1H B), 6.44 (dd, J = 10.3, 1.4 Hz, 1H A), 6.42 (dd, J = 10.2, 1.4 Hz, 1H B), 6.14 (m, 2H A and B), 4.83 (s, 1H A and B), 3.42 (s, 3H A and B), 3.39 (s, 3H A), 3.38 (s, 3H B), 3.10 (s, 3H A and B), 1.77 (s, 3H A), 1.76 (s, 3H B), 1.664 (s, 3H A), 1.660 (s, 3H B), 1.55 (s, 3H A and B); ^{13}C NMR (C_6D_6, 90 MHz) 191.0, 189.9, 188.9, 169.2, 168.9, 162.05, 162.02, 155.3, 153.3, 147.7, 147.6, 135.4, 135.3, 130.3, 130.2, 128.65, 128.60, 124.3, 124.2, 124.1, 122.8, 122.6, 122.5, 101.56, 101.55, 94.4, 94.3, 93.6, 55.6, 52.15, 52.13, 51.0, 21.8, 21.7, 20.2, 20.1; FABMS *m*/*z* (relative intensity) 432 (10), 373 (82); HRFABMS calcd for $C_{22}H_{24}O_9$ 432.1420, found 432.1436.

Irradiation of (*Z*)-Bis(orthoquinone monoketal) 1a. (*Z*)-Bis(orthoquinone monoketal) **1a** (9 mg, 0.02 mmol) in 1.5 mL of C_6D_6 was deoxygenated by three freeze−thaw cycles in a resealable NMR tube and placed in a Rayonet photoreactor equipped with 350 nm bulbs. After 2 h, ^{1}H NMR analysis indicated an approximately 3:1 mixture of (*E*)-alkene **15** and (*Z*) starting material **1a**. No evidence for other compounds could be discerned.

Irradiation of (*E*)-Bis(orthoquinone monoketal) 15. (*E*)-Bis(orthoquinone monoketal) **15** (12 mg, 0.028 mmol) in 1.5 mL of C_6D_6 was deoxygenated by three freeze−thaw cycles in a resealable NMR tube and placed in a Rayonet photoreactor equipped with 300 nm bulbs. After a 6 h irradiation, ^{1}H NMR analysis indicated that no new compounds were evident.

Thermolysis of (*Z*)-Bis(orthoquinone monoketal) 1a in Benzene, 0.94 mM Concentration. (*Z*)-Bis(orthoquinone monoketal) **1a** (82 mg, 0.19 mmol) in 200 mL of benzene was heated to reflux and held there for 4.5 h. At that time, TLC analysis (3:1 Et_2O/hexane) indicated that starting bis(orthoquinone) **1a** was consumed, and two new less polar compounds were evident. The solution was cooled to rt, concentrated in vacuo, and purified by flash chromatography on SiO_2 deactivated with 20 wt % H_2O, using 2:1 hexane/Et_2O → 1:1 hexane/Et_2O as eluent, to afford 33 mg (47%) of the less polar off-white compounds **23a**/**b** as an inseparable mixture followed by 15 mg (21%) of the more polar species **20** as a yellow/orange solid.

20: IR (CCl_4) 3551, 1747, 1678 cm^{-1}; ^{1}H NMR ($CDCl_3$, 360 MHz) 6.98 (d, J = 11.5 Hz, 1H), 6.91 (d, J = 11.8 Hz, 1H), 6.80 (d, J = 8.4 Hz, 1H), 6.77 (d, J = 8.4 Hz, 1H), 5.70 (s, 1H), 5.54 (s, 1H), 3.90 (s, 3H), 3.79 (s, 3H), 3.60 (d, J = 12.5 Hz, 1H), 3.41 (s, 3H), 3.32 (d, J = 12.5 Hz, 1H), 2.14 (s, 3H); ^{13}C NMR ($CDCl_3$, 90 MHz) 188.5, 169.3, 160.9, 147.6, 147.0, 141.8, 132.1, 131.3, 123.0, 122.6, 120.4, 119.1, 108.8, 100.9, 93.6, 56.3, 56.2, 52.4, 33.1, 20.4; FABMS *m*/*z* (relative intensity) 372 (45), 313 (80); HRFABMS calcd for $C_{20}H_{20}O_7$ 372.1209, found 372.1205.

HPLC purification (1:1 Et_2O/hexane as solvent) of the mixture **23a/b** led to enriched fractions of **23a** and **23b** consisting of ca. 80% of the title compound and 20% of a mixture of its diastereomer and unidentified material.

23a: IR (CCl_4) 3351, 1737 cm^{-1}; ^{1}H NMR ($CDCl_3$, 360 MHz) 6.96 (s, 1H), 6.81 (s, 1H), 6.64 (d, J = 5.4 Hz, 1H), 6.51 (d, J = 5.5 Hz, 1H), 5.91 (s, 1H), 5.69 (s, 1H), 4.76 (s, 1H), 4.25 (s, 1H), 3.90 (s, 3H), 3.78 (s, 3H), 3.33 (s, 3H), 2.14 (s, 3H); ^{13}C NMR ($CDCl_3$, 90 MH_3) 194.4, 169.1, 151.6, 145.8, 145.5, 139.3, 137.9, 136.2, 135.9, 131.4, 110.1, 108.7, 108.2, 105.4, 96.2, 72.4, 56.4, 55.9 53.0 20.4; CIMS *m*/*z* (relative intensity) 372 (M^+, 65); HRMS calcd for $C_{20}H_{20}O_7$ 372.1209, found 372.1206.

23b: IR (CCl_4) 3553, 1748, 1730 cm^{-1}; ^{1}H NMR ($CDCl_3$, 360 MHz) 7.05 (s, 1H), 6.87 (s, 1H), 6.85 (d, J = 5.5 Hz, 1H), 6.41 (d, J = 5.5 Hz, 1H), 5.97 (s, 1H), 5.60 (s, 1H), 4.80 (s, 1H), 4.73 (s, 1H) 3.84 (s, 3H) 3.81 (s, 3H), 3.26 (s, 3H), 2.13 (s, 3H); ^{13}C NMR ($CDCl_3$, 90 MHz) 194.5, 169.4, 151.6, 145.7, 144.8, 139.5, 138.6, 138.0, 137.0, 133.5, 110.7, 108.2, 106.9, 105.5, 95.4, 69.5, 56.4, 55.9, 53.0, 20.5; CIMS *m*/*z* (relative intensity) 372 (60); HRMS calcd for $C_{20}H_{20}O_7$ 372.1209, found 372.1229.

Further elution afforded the ketal hydrolysis product **24**: IR (CCl_4) 3551, 1697 cm^{-1}; ^{1}H NMR ($CDCl_3$, 360 MHz) 6.97 (s, 1H), 6.82 (d, J = 5.6 Hz, 1H), 6.81 (s, 1H), 6.41 (d, J = 5.5 Hz, 1H), 5.71 (s, 1H), 5.15 (s, 1H), 5.04 (s, 1H), 3.90 (s, 3H), 3.88 (s, 3H); ^{13}C NMR ($CDCl_3$, 90 MH_3) 190.6, 177.1, 153.0, 146.4, 145.5, 137.3, 134.4, 134.3, 133.6, 122.1, 116.2, 109.1, 107.3, 74.4, 56.3, 55.9; CIMS *m*/*z* (relative intensity) 298 (16); HRCIMS calcd for $C_{17}H_{14}O_5$ 298.0841, found 298.1063.

Acetylation of 23a/b. A stirring solution of **23a/b** (ca. 1:1 mixture) (8 mg, 21 μmol) in 1 mL of CH_2Cl_2 at rt was treated sequentially with DMAP (10 mg, 82 μmol) and AcCl (3 μL, 42 μmol). After 22 h at rt, TLC analysis (4:1 hexane/Et_2O) indicated that **23a/b** was consumed. The solution was poured into ice cold 1 M H_3PO_4, and the layers were separated. The aqueous phase was extracted wtih 10 mL of CH_2Cl_2, and the combined organic layers were washed with brine, dried over Na_2SO_4, filtered, and concentrated in vacuo. The residue was purified by flash chromatography on SiO_2 with 4:1 hexane/Et_2O as eluent to furnish 8 mg (95%) of dienone **25** as a yellow solid: IR (CCl_4) 1776, 1660 cm^{-1}; ^{1}H NMR ($CDCl_3$, 360 MHz) 7.07 (s, 1H), 7.02 (d, J = 5.4 Hz, 1H), 6.71 (t, J = 1.3 Hz, 1H), 6.69 (s, 1H), 6.13 (d, J = 5.4 Hz, 1H), 4.17 (s, 3H), 3.77 (s, 3H), 3.73 (s, 3H), 3.62 (dd, J = 14.3, 1.4 Hz, 1H), 3.56 (dd, J = 14.3, 1.4 Hz, 1H), 2.31 (s, 3H); ^{13}C NMR ($CDCl_3$, 90 MHz) 190.7, 168.8, 158.3, 143.0, 142.2, 140.3, 137.9, 136.6, 135.9, 135.0, 120.7, 116.7, 107.2, 71.3, 60.3, 58.8, 56.3, 42.0, 20.7; CIMS *m*/*z* (relative intensity) 391 (MH^+, 65); HRMS calcd for $C_{20}H_{19}C1O_6$ 390.0870, found 390.0881.

Thermolysis of (*Z*)-Bis(orthoquinone monoketal) 1a in Benzene, 27.8 mM Concentration. (*Z*)-Bis(orthoquinone monoketal) **1a** (18 mg, 0.041 mmol) in 1.5 mL C_6D_6 was frozen and evacuated in a resealable NMR tube. This tube was placed in a 82−84 °C oil bath with ^{1}H NMR monitoring. After 9.5 h, ^{1}H NMR analysis indicated that starting material **1a** was consumed. One major new compound **27** was evident, along with small amounts (∼7% each of **20** and **23a/b**). Flash chromatography on SiO_2 with 1:1 hexane/Et_2O → 1:2 hexane/Et_2O as eluent yielded 2 mg (11%) of quinone monoketal **27** as a yellow/orange solid: IR (CCl_4) 3561, 1767, 1747, 1671

cm^{-1}; ^1H NMR ($CDCl_3$, 360 MHz) 6.92 (s, 1H), 6.54 (d, J = 12.1 Hz, 1H), 6.52 (s, 1H), 6.14 (d, J = 11.9 Hz, 1H), 6.11 (d, J = 1.1 Hz, 1H), 5.96 (s, 1H), 5.19 (s, 1H), 3.84 (s, 3H), 3.74 (s, 3H), 3.47 (s, 3H), 2.31 (s, 3H), 2.18 (s, 3H), 1.81 (s, 3H); FABMS *m/z* (relative intensity) 432 (M^+, 60); HRFABMS calcd for $C_{22}H_{24}O_9$ 432.1420, found 432.1429.

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Supporting Information Available: ^1H and ^{13}C NMR spectra for **1a**, **8b**, **13**, **15**, **20**, **23a/b**, **24**, **25**, and **27** and HMQC/HMBC spectra with interpretation for **23a** (15 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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