Some Observations on the Palladium-Catalyzed Triflate–Arene Cyclization of Electron-Rich Biaryl Substrates

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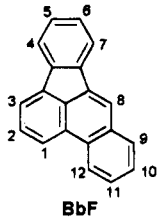
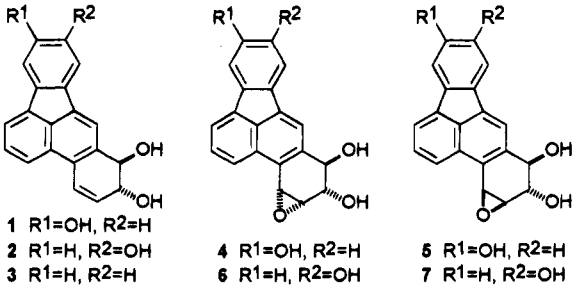
Introduction

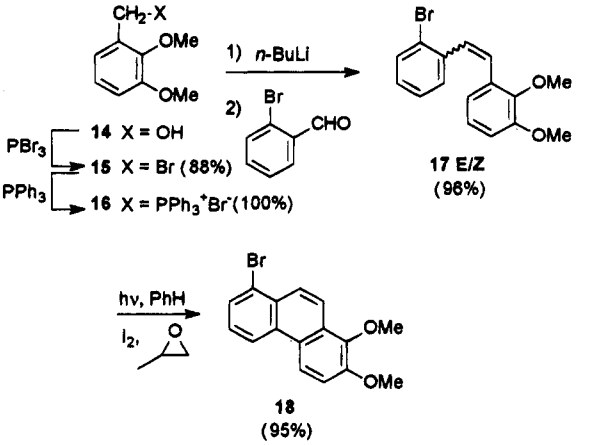
Benzo[*b*]fluoranthene (BbF) is the most carcinogenic of the isomeric benzofluoranthenes.[1] The environmental prevalence of BbF, along with its well-documented carcinogenicity in mice and rats, makes this compound a potential human health hazard.[2] Recently, several reports have been published which present evidence supporting the involvement of multiple sites of activation for BbF.[3] In particular, the involvement of dihydrodiols (**1**–**3**) and phenolic dihydrodiol epoxides (**4**–**7**) as proximate and ultimate carcinogenic metabolites of BbF has been postulated. Unfortunately the lack of general synthetic





methods for the preparation of specifically-substituted derivatives of nonalternant PAH has been a hinderance for the evaluation of such a hypothesis. The development of a palladium-catalyzed triflate–arene cyclization procedure has allowed for the preparation of substituted BbF derivatives in a regiocontrolled manner.[4] To date, all of the derivatives prepared using this method had a single functional group at position 4, 5, 6, or 7. A logical extension of the capabilities of this reaction is toward the preparation of derivatives containing a functionality at other locations within the ring system or derivatives which are simultaneously substituted in different rings. Such compounds could serve as intermediates for the synthesis of BbF derivatives **1**–**7**. In this report, application of the palladium-catalyzed triflate–arene cyclization reaction to the synthesis of polyoxygenated BbF derivatives **8**–**10** is detailed. Of particular interest is the observation that for highly methoxylated substrates the addition of LiCl (thought to be necessary in most cases for palladium-catalyzed reactions involving triflates) may have a deleterious effect on the reaction.

Scheme 1



Results and Discussion

Di- and trimethoxyBbF derivatives **8**–**10** were selected for synthesis on the basis of the likelihood that they could serve as precursors for *trans*-dihydrodiols **1**–**3**. It was envisioned that **8**–**10** should be accessible *via* intramolecular triflate–arene coupling of suitable 8-aryl-1,2-dimethoxyphenanthrene derivatives such as **11**–**13**. One potential complication with this approach is the possibility that isomers may be formed during the cyclization. It has been reported that cyclization of a fluoro-substituted aryl triflate attached to the 1-(or 8)-position of phenanthrene gave a 1:1 mixture of isomers, presumably as a result of a free-radical mechanism operating during the oxidative-addition phase of the reaction.[4b]

The preparation of 8-bromo-1,2-dimethoxyphenanthrene **18** is outlined in Scheme 1. Benzyl alcohol **14** was converted into bromide **15** (PBr_3, pyridine, CH_2Cl_2, 0–20 °C) and then into phosphonium salt **16** (PPh_3, toluene, reflux) in 88% yield for the two steps. Wittig reaction with 2-bromobenzaldehyde afforded bromostilbene **17** in 96% yield as a mixture of *E*- and *Z*-isomers. Photocyclization using conditions developed by Katz *et al.*[5] (I_2, propylene oxide (63 equiv), benzene, 450 W Hg-vapor lamp) afforded the desired bromodimethoxyphenanthrene **18** in 95% yield as the sole product. No demethoxylation or dehydrobromination products were observed.[6]

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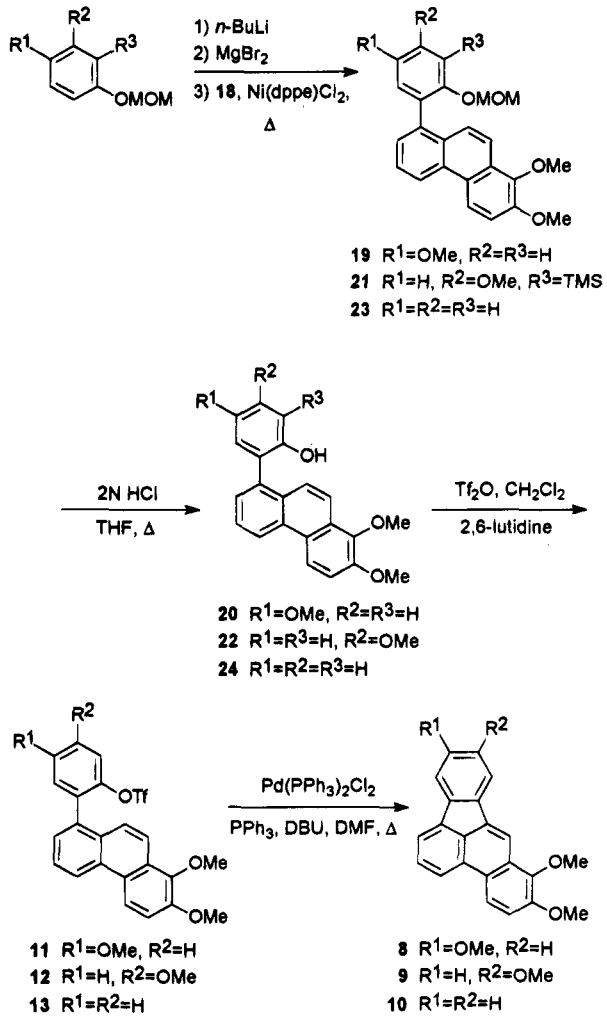
Scheme 2



Coupling of **18** to the previously described [5-methoxy-2-(methoxymethoxy)phenyl]magnesium bromide[4b] occurred in the presence of $Ni(dppe)Cl_2$[7] to give **19** in 90% yield (Scheme 2). Conditions for the acid-catalyzed hydrolysis of the MOM group had to be carefully worked out to avoid demethylation of the methoxy groups. It was found that treatment of **19** with 2 N HCl in THF at 45 °C for 20 h gave the trimethoxyphenol **20** in 80% yield. This was converted to triflate **11** in quantitative yield. Application of the standard conditions for intramolecular triflate–arene coupling of an electron-rich substrate ($Pd(PPh_3)_2Cl_2$, 0.1 equiv; DBU, 1.4 equiv; LiCl, 3 equiv; PPh_3, 4 equiv; DMF; 140 °C) afforded 5,9,10-trimethoxyBbF (**8**) in only 10% yield.

The low yield for this cyclization was disappointing. One source of trouble was thought to be the highly electron-rich nature of the substrate. It was previously shown in our laboratory and elsewhere[4,8] that such substrates could be induced to react in higher yield by increasing the catalyst concentration and raising the temperature. The catalyst concentration was increased to 0.3 equiv and the temperature was raised to 155 °C, but only a modest gain in yield to 34% was realized (Table 1). In one run LiCl was omitted and a substantial increase in yield to 55% was observed. This result is unexpected since it has been generally accepted that LiCl is an essential additive for palladium-catalyzed coupling reactions of aryl and vinyl triflates. The original reports of such coupling reactions used $Pd(PPh_3)_4$ as the catalyst. In solution this dissociates to the coordinatively unsaturated species $Pd(PPh_3)_2$ and 2 equiv of PPh_3. Following oxidative addition of the aryl triflate, chloride ion is needed to displace OTf from the metal to allow for continuation of the catalytic cycle.[9] In the present reaction, the catalyst employed, $Pd(PPh_3)_2Cl_2$, dissociates in solution into $Pd(PPh_3)_2$ and $2Cl^-$. Thus, chloride ion for displacing triflate from the metal is already present in solution. The addition of LiCl to the reaction increases the concentration of Cl^- in solution and generally increases the rate of reaction. Triflate **11** has a high concentration of methoxy groups, two of which are *ortho*. It is known that at high temperature LiCl in DMF can demethylate aryl methoxy ethers, particularly if the methoxy group has an *ortho* substituent. Indeed, selective demethylation of a more crowded methyl ether in the presence of a less crowded ether using this reagent has been reported.[10] It is likely that under the reaction conditions LiCl is partially demethylating triflate **11**, either prior to or following its cyclization, and the resulting phenolic compound is unstable and undergoes further degradation to unrecognizable byproducts. It should be noted that recovered starting material was not observed during the course of this reaction. When LiCl is omitted from the reaction mixture the concentration of chloride ions resulting from dissociation of the catalyst is sufficient to allow the cyclization to proceed in acceptable yield and within a reasonable time period.

Table 1. Reaction conditions for the cyclization of 11, 12, and 13[a]

substrate	$Pd(PPh_3)_2Cl_2$ (equiv)	temp (°C)	LiCl (equiv)	product (% yield)
11	0.1	140	3	**8** (10)
11	0.3	155	3	**8** (34)
11	0.3	155	0	**8** (55)
12	0.3	155	0	**9** (83)
13	0.3	155	0	**10** (73)

[a] All reactions were performed in DMF with 1.4 equiv of DBU and 1.2 equiv of PPh_3.

One other aspect of the cyclization of **11** to **8** is that isomer formation was not observed. This stands in contrast to the cyclization of 1-[5-fluoro-2-(trifluoromethanesulfonyloxy)phenyl]phenanthrene which gave a mixture of 5- and 7-fluoroBbF upon intramolecular palladium-catalyzed cyclization. Isomer formation was rationalized in that case by a free-radical mechanism for the oxidative addition to palladium. A stable radical could abstract a proton from the 10-phenanthryl position to give a new radical which could undergo oxidative addition to palladium and cyclize in either of two directions.[4b] A similar isomerization was reported for a Pschorr ring closure of a fluoro-substituted phenyl ring to the 10-position of pyrene (analogous to a 10-phenanthryl position) to give a mixture of indeno[1,2,3-*cd*]pyrene derivatives.[11] The Pschorr ring closure is known to proceed through a free-radical mechanism.[12] Isomer

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formation was not observed during Pschorr ring closure of methoxy-substituted 1-phenylpyrenes.[13] These results suggest that fluoro-substituted aryl radicals may be particularly stable and have half-lives that are long enough to allow for proton abstraction from strategically-located 10-phenanthryl positions. Apparently, a methoxy group does not have the same stabilizing influence on phenyl radicals and oxidative addition to palladium occurs faster than proton abstraction.

The synthesis of 6,9,10-trimethoxyBbF (**9**) and 9,10-dimethoxyBbF (**10**) is shown in Scheme 2. Coupling of **18** with [4-methoxy-2-(methoxymethoxy)-3-(trimethylsilyl)phenyl]magnesium bromide or [2-(methoxymethoxy)-phenyl]magnesium bromide[4b] occurred to give **21** and **23** in 88% and 91% yield, respectively. The TMS group serves as a positional protecting group to allow for selective lithiation (and subsequent transmetallation with $MgBr_2$) at the 6-position. Acid-catalyzed hydrolysis of the MOM protecting group occurred in 77 and 98% yield, and the resulting phenols **22** and **24** were converted to their respective triflates **12** and **13** in 86 and 93% yield. Treatment with $Pd(PPh_3)_2Cl_2$ in the presence of DBU, PPh_3, and DMF but without the addition of LiCl allowed the preparation of **9** and **10** in 83 and 73% yield, respectively. The conversion of **8**, **9**, and **10** to *trans*-dihydrodiols **1**, **2**, and **3** has been reported previously.[3c]

Experimental Section

Ether and THF were freshly distilled from sodium and benzophenone prior to use. Methylene chloride, toluene, pyridine, 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU), and DMF were distilled from CaH_2 prior to use. Trifluoromethanesulfonic anhydride (Tf_2O) was freshly distilled from P_2O_5. [1,2-Bis(diphenylphosphino)ethane]nickel(II) chloride [Ni(dppe)Cl_2] was dried under reduced pressure at 60 °C before use. Bis(triphenylphosphine)palladium(II) chloride [$Pd(PPh_3)_2Cl_2$] was used as received from Aldrich Chemical Co., Milwaukee, WI. ^{1}H-NMR (200 MHz) and ^{13}C-NMR (50 MHz) spectra were recorded in $CDCl_3$ unless otherwise noted. Results from attached proton test (APT) experiments are reported as (u) for quaternary and CH_2 carbons and (d) for CH and CH_3 carbons. Combustion analyses were performed by Atlantic Microlabs, Inc., Norcross, GA. High resolution mass spectrometric analysis was performed by the Washington University Resource for Biomedical and Bio-organic Mass Spectrometry, St. Louis, MO. Flash Chromatography was performed using 230–400 mesh silica gel from ICN as described previously.[14]

2,3-Dimethoxybenzyl Bromide (15). A solution of 2,3-dimethoxybenzyl alcohol (7.7 g, 45.8 mmol) in CH_2Cl_2 (50 mL) and pyridine (3.0 g, 37.9 mmol) was cooled to 0 °C under N_2 and treated dropwise with a solution of PBr_3 (10.0 g, 36.9 mmol) in CH_2Cl_2 (80 mL). The reaction mixture was allowed to warm to rt and was stirred for 6 h. The solution was then diluted with CH_2Cl_2, washed with brine, and dried over Na_2SO_4. Solvents were removed under reduced pressure, and the residue was passed through a short silica gel column eluting with 50% CH_2Cl_2/hexane to afford 9.33 g (88%) of **15** as a colorless oil: ^{1}H-NMR δ 7.09–6.86 (m, 3), 4.57 (s, 2), 3.97 (s, 3), 3.87 (s, 3); ^{13}C-NMR δ 153.3 (u), 147.9 (u), 132.4 (u), 124.6 (d), 123.0 (d), 113.5 (d), 61.3 (d), 56.3 (d), 28.6 (u).

8-Bromo-1,2-dimethoxyphenanthrene (18). A solution of **15** (14.0 g, 60.0 mmol) and PPh_3 (16.0 g, 61.0 mmol) in toluene (250 mL) was heated at reflux for 12 h. The solution was cooled to rt, and the white phosphonium salt, **16**, was isolated by filtration (29.8 g, 100%). This was used without further purification for the next step. A suspension of **16** (5.11 g, 10.37 mmol) in THF/ether (150 mL, v/v = 1:2) was cooled to −30 °C under Ar and treated dropwise with *n*-BuLi (6.5 mL, 1.6 M in hexane). After stirring for 30 min the ylide was treated with 2-bromobenzaldehyde (2.1 g, 11.4 mmol). The reaction mixture was allowed to warm to rt and was stirred overnight. The solution was concentrated and purified by flash chromatography, eluting with 50% ether/hexane to give 3.2 g (96%) of **17** as a colorless oil (a mixture of *E*- and *Z*-isomers). Nitrogen was bubbled through a solution of **17** (686 mg, 2.15 mmol) and I_2 (546 mg, 2.15 mmol) in benzene (900 mL) for 15 min. Propylene oxide (25 mL, 358 mmol) was added, and the solution was irradiated for 16 h by a 400 W medium-pressure Hg vapor lamp through a Pyrex filter. The solution was washed with 5% $Na_2S_2O_3$, and the organic layer was passed through a short plug of silica gel, eluting with 10% EtOAc/hexane. Upon evaporation of the solvent, **18** was obtained as an off-white solid: 645 mg, 95% yield; mp 138–140 °C (EtOAc/hexane); ^{1}H-NMR δ 8.54 (d, 1, J = 8.4), 8.36 (d, 1, J = 9.2), 8.19 (s, 2), 7.82 (d, 1, J = 7.6), 7.43 (dd, 1, J = 8.1, 7.7), 7.37 (d, 1, J = 9.1), 4.03 (s, 6); ^{13}C-NMR δ 150.7 (u), 144.2 (u), 132.6 (u), 130.5 (d), 130.1 (u), 127.9 (u), 127.5 (d), 126.2 (d), 125.5 (u), 124.3 (u), 122.5 (d), 122.4 (d), 119.7 (d), 114.4 (d), 61.9 (d), 56.9 (d). Anal. Calcd for $C_{16}H_{13}BrO_2$: C, 60.59; H, 4.13 Found: C, 60.40; H, 4.11.

1,2-Dimethoxy-8-[5-methoxy-2-(methoxymethoxy)phenyl]-phenanthrene (19). A solution of 4-(methoxymethoxy)anisole (3.19 g, 18.2 mmol) in ether (100 mL) was treated under N_2 with *n*-BuLi (12 mL, 19.3 mmol, 1.6 M in hexane). The reaction mixture was stirred at rt for 4 h, after which a solution of freshly prepared $MgBr_2$ (20 mmol) [from Mg (480 mg, 20 mmol) and 1,2-dibromoethane (3.74 g, 20 mmol)] in ether (75 mL) was added. A separate flask was charged with **18** (2.9 g, 9.1 mmol), Ni(dppe)Cl_2 (240 mg, 0.46 mmol), and ether (30 mL) and was cooled to −78 °C under N_2. The Grignard reagent was added to this solution *via* cannula and the solution was allowed to warm to rt and then heated at reflux for 15 h. The reaction mixture was cooled to rt and filtered through a short silica gel column, eluting with 50% CH_2Cl_2 in hexane. The eluate was concentrated and further purified by flash chromatography, eluting with 10% EtOAc/hexane to afford **19** as a white solid: 3.34 g (90% yield); ^{1}H-NMR δ 8.64 (d, 1, J = 8.4), 8.48 (d, 1, J = 9.1), 8.02 (d, 1, J = 9.5), 7.72–7.48 (m, 3), 7.38 (d, 1, J = 9.2), 7.24 (d, 1, J = 8.9), 7.01–6.91 (m, 2), 4.88 (s, 2), 4.04 (s, 3), 4.01 (s, 3), 3.82 (s, 3), 3.18 (s, 3); ^{13}C-NMR δ 155.1 (u), 150.3 (u), 149.4 (u), 144.2 (u), 138.0 (u), 132.9 (u), 130.8 (u), 130.0 (u), 128.0 (d), 127.7 (u), 126.5 (d), 126.1 (d), 122.5 (d), 120.5 (d), 119.7 (d), 117.9 (d), 117.7 (d), 114.6 (d), 113.9 (d), 96.8 (u), 96.2 (u), 61.8 (d), 57.0 (d), 56.4 (d), 56.2 (d).

1,2-Dimethoxy-8-[4-methoxy-2-(methoxymethoxy)-3-(trimethylsilyl)phenyl]phenanthrene (21). **21** was prepared as described above for **19** (reflux for 12 h) to give 2.10 g (88% yield) of **21** as an oil: ^{1}H-NMR δ 8.63 (d, 1, J = 8.1), 8.48 (d, 1, J = 9.2), 8.07 (d, 1, J = 9.5), 7.75 (d, 1, J = 9.5), 7.73–7.55 (m, 2), 7.38 (d, 1, J = 8.8), 7.34 (d, 1, J = 7.7), 6.80 (d, 1, J = 8.4), 4.48 (AB quartet, 2, J = 5.1, $\Delta\nu$ = 11.1), 4.06 (s, 3), 4.05 (s, 3), 3.89 (s, 3), 2.56 (s, 3), 0.45 (s, 9); ^{13}C-NMR δ 165.8 (u), 160.5 (u), 150.3 (u), 144.3 (u), 138.8 (u), 134.9 (d), 131.0 (u), 130.3 (u), 129.0 (d), 127.7 (u), 127.5 (u), 126.5 (d), 126.2 (d), 126.1 (u), 122.1 (d), 121.4 (u), 120.6 (d), 119.7 (d), 114.0 (d), 106.7 (d), 99.9 (u), 61.8 (d), 57.2 (d), 57.0 (d), 55.8 (d), 2.0 (d).

1,2-Dimethoxy-8-[2-(methoxymethoxy)phenyl]phenanthrene (23). **23** was prepared as described above for **19** (18 h reflux) to give 1.06 g (91% yield) of **23** as a white solid: mp 123–125 °C (EtOAc/hexane); ^{1}H-NMR δ 8.65 (d, 1, J = 8.4), 8.47 (d, 1, J = 9.2), 8.04 (d, 1, J = 9.4), 7.75–7.32 (m, 7), 7.20 (m, 1), 5.03 (AB quartet, 2, J = 6.9, $\Delta\nu$ = 9.3), 4.04 (s, 3), 4.03 (s, 3), 3.25 (s, 3); ^{13}C-NMR δ 150.0 (u), 144.9 (u), 138.9 (u), 132.8 (u), 127.1 (d), 126.1 (u), 125.4 (u), 124.7 (u), 124.2 (d), 122.7 (d), 122.3 (u), 121.2 (d), 120.8 (d), 117.1 (d), 117.0 (d), 115.0 (d), 114.3 (d), 110.3 (d), 108.6 (d), 89.8 (u), 56.4 (d), 51.6 (d), 51.1 (d). Anal. Calcd for $C_{24}H_{22}O_4$: C, 76.99; H, 5.92. Found: C, 76.81; H, 5.90.

1,2-Dimethoxy-8-[5-methoxy-2-(trifluoromethanesulfonyloxy)phenyl]phenanthrene (11). A solution of **19** (760 mg, 1.88 mmol) in THF (50 mL) was treated with 2 N HCl (25 mL) and stirred under N_2 at 45 °C for 20 h. The solution was cooled to rt, extracted with ether, dried over Na_2SO_4, and evaporated. Flash chromatography eluting with 15% EtOAc/hexane afforded 585 mg (80% yield) of phenol **20** as a white solid: mp 147–149 °C (EtOAc/hexane); ^{1}H-NMR δ 8.66 (d, 1, J = 8.2), 8.44 (d, 1, J = 9.2), 8.05 (d, 1, J = 9.4), 7.73–7.51 (m, 3), 7.38 (d, 1, J = 9.2),

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7.05–6.92 (m, 2), 6.86 (d, 1, J = 2.6), 4.63 (s, 1), 4.04 (s, 3), 3.99 (s, 3), 3.80 (s, 3); ^{13}C-NMR δ 153.9 (u), 150.5 (u), 147.7 (u), 144.3 (u), 135.3 (u), 131.5 (u), 129.8 (u), 128.6 (d), 127.8 (u), 127.8 (u), 127.1 (d), 125.9 (u), 124.9 (d), 123.4 (d), 121.8 (d), 119.7 (d), 116.9 (d), 116.6 (d), 115.7 (d), 114.2 (d), 61.8 (d), 56.9 (d), 56.3 (d). Anal. Calcd for $C_{23}H_{20}O_4$: C, 76.65; H, 5.59. Found: C, 76.69; H, 5.57. The phenol (500 mg, 1.28 mmol) was dissolved in CH_2Cl_2 (20 mL) and 2,6-lutidine (192 mg, 1.80 mmol) and cooled to −10 °C under N_2. Triflic anhydride (451 mg, 1.6 mmol) was added, and the solution was allowed to warm to 0 °C and stirred for 1 h. The solution was treated with H_2O (15 mL) and allowed to warm to rt. The CH_2Cl_2 layer was separated, and the aqueous layer was extracted with CH_2Cl_2. The combined organic layers were dried over Na_2SO_4 and evaporated. Flash chromatography (10% EtOAc in hexane) afforded a quantitative yield of triflate **11** as an oil: ^{1}H-NMR δ 8.71 (d, 1, J = 8.5), 8.47 (d, 1, J = 9.2), 8.09 (d, 1, J = 9.5), 7.70 (dd, 1, J = 8.3, 7.2), 7.57–7.50 (m, 2), 7.44–7.36 (m, 2), 7.08–7.02 (m, 2), 4.03 (s, 6), 3.84 (s, 3); ^{13}C-NMR δ 159.3 (u), 150.5 (u), 144.3 (u), 141.5 (u), 136.2 (u), 134.2 (u), 131.2 (u), 129.6 (u), 128.6 (d), 127.7 (u), 126.3 (d), 125.9 (u), 124.8 (d), 123.7 (d), 123.3 (d), 121.4 (d), 119.7 (d), 118.7 (u) (quartet, J_{CF_3} = 318.9), 118.3 (d), 115.2 (d), 114.3 (d), 61.8 (d), 56.9 (d), 56.3 (d).

1,2-Dimethoxy-8-[4-methoxy-2-(trifluoromethanesulfonyloxy)phenyl]phenanthrene (12). **12** was prepared as described above for **11**, employing 2 N HCl in THF at 65 °C for 24 h for the hydrolysis step to give 1.16 g (77% yield) of phenol **22**. Triflate **12** was prepared in 86% yield (1.27 g) as an oil: ^{1}H-NMR δ 8.68 (d, 1, J = 8.2), 8.47 (d, 1, J = 9.2), 8.03 (d, 1, J = 9.5), 7.68 (dd, 1, J = 8.3, 7.3), 7.72–7.30 (m, 4), 7.10–7.00 (m, 2), 4.04 (s, 3), 4.01 (s, 3), 3.93 (s, 3); ^{13}C-NMR δ 160.7 (u), 150.4 (u), 148.3 (u), 144.3 (u), 134.0 (d), 131.1 (u), 130.0 (u), 129.0 (d), 127.7 (u), 126.9 (u), 126.3 (d), 126.0 (u), 124.9 (d), 123.4 (d), 121.2 (d), 119.7 (d), 119.68 (u), 118.7 (u) (quartet, J_{CF_3} = 318.8), 114.5 (d), 114.2 (d), 108.3 (d), 61.8 (d), 57.0 (d), 56.4 (d).

1,2-Dimethoxy-8-[2-(trifluoromethanesulfonyloxy)phenyl]phenanthrene (13). **13** was prepared as described above for **11**, employing 2 N HCl in THF at 60 °C for 12 h for the hydrolysis step to give 940 mg (98% yield) of phenol **24**. Triflate **13** was prepared in 93% yield (1.20 g) as an oil: ^{1}H-NMR δ 8.73 (d, 1, J = 8.4), 8.45 (d, 1, J = 9.2), 8.18 (d, 1, J = 9.5), 7.74 (dd, 1, J = 8.2, 7.3), 7.64–7.50 (m, 6), 7.35 (d, 1, J = 9.2), 4.08 (s, 3), 4.01 (s, 3); ^{13}C-NMR δ 150.6 (u), 148.1 (u), 144.4 (u), 135.1 (u), 134.2 (u), 133.8 (d), 131.3 (u), 130.2 (d), 129.8 (u), 128.9 (d), 128.8 (d), 127.8 (u), 126.4 (d), 126.0 (u), 124.8 (d), 123.8 (d), 122.3 (d), 121.5 (d), 119.8 (d), 118.9 (u) (quartet, J_{CF_3} = 318.6), 114.3 (d), 61.7 (d), 56.8 (d).

5,9,10-Trimethoxybenzo[*b*]fluoranthene (8). A solution of **11** (150 mg, 0.31 mmol), bis(triphenylphosphine)palladium(II) chloride (60 mg, 0.09 mmol), triphenylphosphine (94 mg, 0.36 mmol), DBU (0.054 mL, 0.43 mmol), and DMF (2 mL) was heated at reflux under N_2 for 8 h. The solution was cooled to rt, H_2O (5 mL) was added, and the solution was extracted with EtOAc. The EtOAc extract was dried over Na_2SO_4, concentrated *in vacuo*, and purified by flash chromatography on silica gel, eluting with 10% EtOAc in hexane to afford 56 mg (55% yield) of **8** as an ivory solid: mp 174–176 °C; ^{1}H-NMR δ 8.46 (s, H_8), 8.31–8.27 (m, $H_{1,12}$), 7.93 (d, H_7, $J_{6,7}$ = 8.3), 7.87 (d, H_3, $J_{2,3}$ = 6.7), 7.68 (dd, H_2, $J_{1,2}$ = 8.1, $J_{2,3}$ = 7.1), 7.43 (d, H_4, $J_{4,6}$ = 2.4), 7.29 (d, H_{11}, $J_{11,12}$ = 9.0), 6.94 (dd, H_6, $J_{6,7}$ = 8.4, $J_{4,6}$ = 2.4), 4.10 (s, 3), 4.03 (s, 3), 3.94 (s, 3); ^{13}C-NMR δ 160.9 (u), 150.8 (u), 145.8 (u), 143.1 (u), 137.3 (u), 135.8 (u), 132.5 (u), 132.2 (u), 130.1 (u), 128.6 (d), 128.1 (u), 125.6 (u), 123.4 (d), 122.0 (d), 119.7 (d), 119.2 (d), 114.1 (d), 113.5 (d,2C), 107.7 (d), 61.9 (d), 56.9 (d), 56.1 (d). Anal. Calcd for $C_{23}H_{18}O_3$: C, 80.68; H, 5.30. Found: C, 80.53; H, 5.28.

6,9,10-Trimethoxybenzo[*b*]fluoranthene (9). **9** was prepared as described above for **8** (7 h reflux) to give 340 mg (83% yield) of **9** as a yellow solid; mp 165–167 °C; ^{1}H-NMR δ 8.56 (s, H_8), 8.24 (d, H_{12}, $J_{11,12}$ = 9.1), 8.18 (d, H_1, $J_{1,2}$ = 8.1), 7.78–7.63 (m, $H_{2,3,4}$), 7.59 (d, H_7, $J_{5,7}$ = 2.4), 7.26 (d, H_{11}, $J_{11,12}$ = 8.9), 6.94 (dd, H_5, $J_{4,5}$ = 8.3, $J_{5,7}$ = 2.4), 4.11 (s, 3), 4.00 (s, 3), 3.95 (s, 3); ^{13}C-NMR δ 160.4 (u), 150.6 (u), 145.9 (u), 141.0 (u), 137.6 (u), 135.9 (u), 134.4 (u), 132.0 (u), 129.7 (u), 128.9 (d), 128.0 (u), 126.2 (u), 122.5 (d), 120.7 (d), 119.7 (d), 118.3 (d), 115.4 (d), 114.6 (d), 114.0 (d), 108.0 (d), 62.0 (d), 56.8 (d), 56.1 (d). Anal. Calcd for $C_{23}H_{18}O_3$: C, 80.68; H, 5.30. Found: C, 80.77; H, 5.28.

9,10-Dimethoxybenzo[*b*]fluoranthene (10). **10** was prepared as described above for **8** (8 h reflux) to give 335 mg (73% yield) of **10** as a yellow solid: mp 153–155 °C; ^{1}H-NMR δ 8.62 (s, H_8), 8.28 (d, H_1, $J_{1,2}$ = 8.1), 8.26 (d, H_{12}, $J_{11,12}$ = 9.0), 8.10–8.00 (m, 1), 7.92–7.89 (m, 2), 7.69 (dd, H_2, $J_{1,2}$ = 8.1, $J_{2,3}$ = 7.3), 7.46–7.41 (m, 2), 7.27 (d, H_{11}, $J_{11,12}$ = 8.9), 4.13 (s, 3), 4.01 (s, 3); ^{13}C-NMR δ 145.3 (u), 140.5 (u), 135.9 (u), 133.8 (u), 132.1 (u), 130.5 (u), 126.4 (u), 124.5 (u), 123.3 (d), 123.2 (d), 122.8 (u), 122.5 (d), 120.7 (u), 117.2 (d), 116.41 (d), 116.38 (d), 114.3 (d), 113.9 (d), 110.1 (d), 108.6 (d), 56.5 (d), 51.4 (d); mass spectrum (EI), m/e (rel intensity) 312 (100, M^+), 297 (25), 254 (24); HRMS calcd for $C_{22}H_{16}O_2$ 312.115 03, obsd 312.115 03.

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Supporting Information Available: ^{1}H-NMR spectra for compounds **10**, **11**, **13**, **15**, and **21** and ^{13}C-NMR spectra for compounds **12**, **13**, **15**, **19**, and **21** (10 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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