Supporting Information

Mild and Rapid Method for the Generation of ortho-(Naphtho)quinone Methide Intermediates

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1. General Experimental Procedures

Unless otherwise noted, reactions were carried out under argon atmosphere, in flame dried, three-neck, with magnetic stirring. Organic solutions were concentrated by rotary evaporation at 23–40 °C under 15 Torr. Melting points were taken on a Büchi 510 apparatus and are uncorrected. ^1H and ^{13}C NMR spectra were measured in CDCl_3 or DMSO-d_6 on a 250 or 400 MHz Brüker spectrometer. ^1H chemical shifts are reported in ppm from an internal standard TMS, residual chloroform (7.26 ppm) or DMSO-d_6 (2.50 ppm). ^{13}C NMR chemical shifts are reported in ppm from an internal standard TMS, residual chloroform (77.00 ppm) or DMSO-d_6 (39.43 ppm). High resolution ESI mass spectra were measured on a ThermoFisher Scientific Orbitrap XL system. Low resolution ESI spectra were measured with an Agilent 1100 LC-MS/MS spectrometer. IR spectra were acquired on a Perkin-Elmer 257 or a Perkin-Elmer GX FTIR spectrophotometer as liquids between sodium chloride discs or KBr discs and are reported in wave numbers (cm^{-1}). Elemental analyses were performed on a Carlo Erba 1106 elemental analyser. Analytical thin layer chromatography (TLC) was performed with TLC plates (Merck 70-230 mesh silica gel). Visualization was done under a 254 nm UV light source and generally by immersion in acidic aqueous-ethanolic vanillin solution, or in potassium permanganate (KMnO_4), followed by heating using a heat gun. Purification of reaction products was generally done by dry-column flash chromatography¹ using Merck silica gel 60 and/or flash chromatography² using Carlo Erba Reactifs-SDS silica gel 60.

2. Materials

Solvents, reagents and catalysts were used as received from the manufacturers (Aldrich, Acros, Fluka, and Alfa-Aesar) except for tetrahydrofuran, dichloromethane, ethanol, methanol, ethyl acetate, hexane and toluene that were purified and dried according to recommended procedures.

3. Experimental Procedures

General procedure for the synthesis of nitrate esters **4a,b**, **8**

To a stirred solution of aryl methyl alcohols **3** or **7**³ in THF at 25 °C silver nitrate was added followed by dropwise addition of thionyl chloride and the reaction mixture was left stirring overnight at 25 °C. After TLC analysis had shown complete conversion of the starting materials, water (20 mL) was added and the mixture was extracted with ethyl acetate (3 × 10 mL). The combined organic extracts were dried with sodium sulphate, filtered and the solvent was removed in vacuo. The residue was purified by flash column chromatography with the indicated solvents to give the title products.

2-(*tert*-Butyldimethylsilyloxy)benzyl nitrate (**4a**)

According to the general procedure, {2-[(*tert*-butyldimethylsilyl)oxy]phenyl}-methanol **3a**³ (2.4 g, 10 mmol), silver nitrate (1.7 g, 10 mmol) and thionyl chloride (1.2 g, 10 mmol) were reacted in THF (20 mL) at 25 °C overnight. Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) gave **4a** (1.57 g, 55%) as a colourless oil. $R_f = 0.75$ (20% ethyl acetate in hexane). ¹H NMR (250 MHz, CDCl₃) δ : 7.36-7.33 (d, 1H, $J = 7.5$ Hz), 7.23-7.17 (t, 1H, $J = 7.5$ Hz), 6.97-6.91 (t, 1H, $J = 7.5$ Hz), 6.86-6.83 (d, 1H, $J = 8$ Hz), 4.62 (s, 2H), 1.07 (s, 9H), 0.29 (s, 6H); ¹³C NMR (63 MHz, CDCl₃) δ : ppm 19.21, 26.73, 42.72, 119.58, 122.24, 129.17, 130.71, 131.83, 154.74; IR (NaCl, neat): 3284, 2958, 2860, 1914, 1602, 1492, 1456, 1284, 1258, 1102, 928, 826, 670; HRMS (ESI) Calcd for C₁₄H₂₄NaO₂Si: 275.1438. Found: 275.1428.

{2-[(*tert*-Butyldimethylsilyl)oxy]-1-naphthyl}methyl nitrate (**4b**)

According to the general procedure, {2[(*tert*-butyldimethylsilyl)oxy]naphthalen-1-yl}methanol **3b** (2.9 g, 10 mmol), silver nitrate (1.7 g, 10 mmol) and thionyl chloride (1.2 g, 10 mmol) were reacted in THF (25 mL) at 25 °C overnight. Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) gave **4b** (2.12 g, 63%) as a yellow oil. R_f = 0.70 (20% ethyl acetate in hexane). ^1H NMR (250 MHz, CDCl_3) δ : 8.22-8.11 (q, 1H, J = 8.7 Hz, 9.2 Hz), 7.80-7.67 (m, 2H), 7.55-7.49 (t, 1H, J = 7.9 Hz, 7.0 Hz), 7.40-7.37 (d, 1H, J = 7.3 Hz), 7.14-7.06 (t, 1H, J = 8 Hz), 5.16 (s, 2H), 1.06 (s, 9H), 0.28 (s, 6H); ^{13}C NMR (63 MHz, CDCl_3) δ : ppm 25.37, 29.29, 55.90, 120.18, 122.89, 123.36, 126.42, 126.70, 127.51, 127.98, 129.30; IR (NaCl, neat): 3206, 2958, 2858, 1954, 1626, 1468, 1358, 1248, 1014, 838; HRMS (ESI) Calcd for $\text{C}_{18}\text{H}_{26}\text{NaO}_2\text{Si}$: 325.1594. Found: 325.1589.

{5-(Benzyloxy)-2-[(*tert*-butyldimethylsilyl)oxy]}benzyl nitrate (**8**)

According to the general procedure, {5-(benzyloxy)-2-[(*tert*-butyldimethylsilyl)oxy]phenyl}methanol **7³** (3.5 g, 10 mmol), silver nitrate (1.7 g, 10 mmol) and thionyl chloride (1.2 g, 10 mmol) were reacted in THF (30 mL) at 25 °C overnight. Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) afforded **8** (1.18 g, 55% yield as a brown oil. R_f = 0.69 (20% ethyl acetate in hexane). ^1H NMR (250 MHz, CDCl_3) δ : 7.44-7.32 (m, 5H) 7.01-7.00 (d, 1H, J = 2.9 Hz) 6.84-6.79 (dd, 1H, J = 5.8 Hz, 3 Hz) 6.75-6.72 (d, 1H, J = 8.8 Hz) 5.01 (s, 2H) 4.58 (s, 2H) 1.03 (s, 9H) 0.24 (s, 6H); ^{13}C NMR (63 MHz, CDCl_3) δ : ppm 19.17, 26.69, 42.74, 71.56, 117.05, 117.72, 120.27, 128.87, 129.49, 129.60, 138.01, 148.59, 153.93; IR (NaCl, neat): 3222, 2956, 1874, 1500, 1466, 1278, 1228, 1026, 922, 840, 696; HRMS (ESI) Calcd for $\text{C}_{20}\text{H}_{28}\text{NaO}_3\text{Si}$: 367.1700. Found: 367.1691.

General procedure for the Michael addition reaction

The nitrate esters **4a** or **4b** were dissolved in THF, the reaction mixture was cooled to -78 °C, the appropriate nucleophile (RH, entry 1-11, Table 1, entry 1-2, Table 2) was added followed by TBAF (1M in THF) and the reaction was stirred at -78 °C for 2

min and then room temperature for 10 min. After TLC analysis had shown complete conversion of the starting materials, water (10 mL) was added, the mixture was extracted with EtOAc (3×10 mL), the combined organic extracts were dried with sodium sulphate, filtered and the solvent was removed in vacuo. Flash column chromatography using the stated solvent mixtures yielded the corresponding products **5a-m** and **10a,b** (yields are given in Table 1 and 2).

2-(Pyrrolidin-1-ylmethyl)phenol (**5a**)

According to the general procedure, the nitrate ester **4a** (200 mg, 0.7 mmol) and pyrrolidine (55 mg, 0.77 mmol) were reacted with TBAF (0.7 mL, 0.7 mmol) in THF (8 mL) at -78 °C. Subsequent workup and flash column chromatography (10% ethyl acetate in hexane) afforded **5a** as a pale yellow oil (100 mg, 80%). $R_f = 0.53$ (40% ethyl acetate in hexane) identical in all respects to an authentic sample.⁴

2-[(Benzylamino)methyl]phenol (**5b**) and

2,2'-[(Benzylazanediyl)bis(methylene)]diphenol (**5c**)

According to the general procedure, the nitrate ester **4a** (200 mg, 0.7 mmol) and benzylamine (83 mg, 0.77 mmol) were reacted with TBAF (0.7 mL, 0.7 mmol) in THF (8 mL) at -78 °C. Subsequent workup and flash column chromatography (10% ethyl acetate in hexane) afforded **5b** as colourless oil (20 mg, 13% yield $R_f = 0.45$ (40% ethyl acetate in hexane) identical in all respects to an authentic sample.⁵

The second product obtained flash column chromatography was recrystallized from hexane to afford **5c** as colourless microcrystals (45 mg, 20%). $R_f = 0.62$ (40% ethyl acetate in hexane), m.p. 129 - 131 °C. ^1H NMR (250 MHz, CDCl_3) δ : 10.07 (s, 2H), 7.26-7.35 (m, 5H), 7.18-7.16 (d, 2H, $J = 6.6\text{ Hz}$), 7.11-7.05 (t, 2H, $J = 7.6\text{ Hz}$), 6.79-

6.74 (t, 4H, $J = 7.9$ Hz, 5.6 Hz), 3.58 (s, 6H); ^{13}C NMR (63 MHz, DMSO- d_6) δ : ppm 53.16, 57.19, 115.33, 118.94, 123.18, 127.25, 128.35, 129.14, 129.89, 137.46, 156.39; IR (KBr, neat): 3234, 2240, 1702, 1460, 1274, 1252, 1098, 922, 762; HRMS (ESI) Calcd for $\text{C}_{21}\text{H}_{22}\text{NO}_2$: 320.1645. Found: 320.1647.

2-[[4-Methoxyphenyl]amino]methyl}phenol (5d**)**

2, 2'-[[4-Methoxyphenyl]azanediyl]bis(methylene)}diphenol (5e**)**

According to the general procedure, the nitrate ester **4a** (200 mg, 0.7 mmol) and *p*-anisidine (95 mg, 0.77 mmol) were reacted with TBAF (0.7 mL, 0.7 mmol) in THF (8 mL) at -78°C . Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) yielded **5d** as an off white solid which was recrystallized from hexane to afford **5d** as off white microcrystals (50 mg, 30% yield). $R_f = 0.52$ (40% ethyl acetate in hexane), m.p. $129\text{--}131^\circ\text{C}$, identical in all respects to an authentic sample.⁶

The second product obtained from flash column chromatography was recrystallized from toluene-hexane to afford **5e** as colourless microcrystals (46 mg, 20% yield). $R_f = 0.44$ (40% ethyl acetate in hexane), m.p. $163\text{--}165^\circ\text{C}$. ^1H NMR (250 MHz, DMSO- d_6) δ : 9.59 (s, 2H), 7.06–6.98 (q, 4H, $J = 7.6$ Hz, 6.4 Hz), 6.82–6.79 (d, 2H, $J = 7.7$ Hz), 6.72–6.70 (d, 4H, $J = 6.6$ Hz), 6.57–6.53 (d, 2H, $J = 8.9$ Hz), 4.44 (s, 4H), 3.60 (s, 3H); ^{13}C NMR (63 MHz, CDCl_3) δ : ppm 56.28, 58.19, 115.26, 115.72, 116.92, 118.83, 120.73, 124.97, 129.54, 130.13, 131.30, 142.61, 156.99, 157.67; IR (KBr, neat): 3308, 2986, 1588, 1512, 1462, 1378, 1246, 1188, 1038, 928, 832, 760; HRMS (ESI) Calcd for $\text{C}_{21}\text{H}_{22}\text{NO}_3$: 336.1594. Found: 336.1591.

2-(Azidomethyl)phenol (5f**)**

According to the general procedure, the nitrate ester **4a** (200 mg, 0.7 mmol), sodium azide (55 mg, 0.84 mmol) and 18-crown-6 (5 mg) were reacted with TBAF (0.7 mL, 0.7 mmol) in THF (8 mL) at -78 °C. Subsequent workup and flash column chromatography (10% ethyl acetate in hexane) yielded **5f** as pale yellow oil (66 mg, 63%). $R_f = 0.53$ (40% ethyl acetate in hexane) identical in all respects to an authentic sample.⁷

2-(Methoxymethyl)phenol (**5g**)

According to the general procedure, the nitrate ester **4a** (200 mg, 0.7 mmol) was reacted with TBAF (0.7 mL, 0.7 mmol) in MeOH (8 mL) instead of THF at -78 °C. Methanol was then evaporated under reduced pressure, subsequent workup and flash column chromatography (5% ethyl acetate in hexane) yielded **5g** as colourless oil (45 mg, 94%). $R_f = 0.52$ (40% ethyl acetate in hexane) identical in all respects to an authentic sample.⁸

2-(*iso*-Propoxymethyl)phenol (**5h**)

According to the general procedure, the nitrate ester **4a** (200 mg, 0.7 mmol) was reacted with TBAF (0.7 mL, 0.7 mmol) in *i*-PrOH (8 mL) at -78 °C. The solvent was then evaporated under reduced pressure, subsequent workup and flash column chromatography (5% ethyl acetate in hexane) yielded **5h** as a colourless oil (76 mg, 65%). $R_f = 0.58$ (40% ethyl acetate in hexane). ^1H NMR (250 MHz, DMSO- d_6) δ : 9.36 (s, 1H), 7.23-7.20 (d, 1H, $J = 7.4$ Hz), 7.08-7.03 (t, 1H, $J = 8.4$ Hz), 6.79-6.73 (t, 2H, $J = 7.6$ Hz, 8 Hz), 4.41 (s, 2H), 3.70-3.56 (m, 1H), 1.14-1.12 (d, 6H); ^{13}C NMR (63 MHz, CDCl_3) δ : ppm 22.77, 70.72, 72.79, 117.46, 120.64, 123.49, 128.67, 130.16, 157.41; IR (NaCl, neat) 3258, 2974, 1898, 1590, 1490, 1458, 1382, 1242,

1122, 1034, 754; Elemental Analysis: Found: C, 72.22; H, 8.47. $C_{10}H_{14}O_2$ requires C, 72.26; H, 8.49.

2-(Phenoxymethyl)phenol (**5i**)

According to the general procedure, the nitrate ester **4a** (200 mg, 0.7 mmol) and phenol (132 mg, 1.4 mmol) were reacted with TBAF (0.7 mL, 0.7 mmol) in THF (8 mL) at $-78\text{ }^{\circ}\text{C}$. Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) yielded **5i** as a colourless oil (73 mg, 52%). $R_f = 0.57$ (40% ethyl acetate in hexane) identical in all respects to an authentic sample.⁹

Diethyl 2-(2-hydroxybenzyl)malonate (**5j**)

According to the general procedure, the nitrate ester **4a** (200 mg, 0.7 mmol) and diethyl malonate (124 mg, 0.77 mmol) [it was reacted first with sodium hydride (20 mg) in THF (8 mL) to generate the carbanion] were reacted with TBAF (0.7 mL, 0.7 mmol) at $-78\text{ }^{\circ}\text{C}$. Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) yielded **5j** as a colourless oil (112 mg, 60%). $R_f = 0.47$ (40% ethyl acetate in hexane). ^1H NMR (250 MHz, $\text{DMSO}-d_6$) δ : 9.51 (s, 1H), 7.05-6.97 (q, 2H, $J = 7.4\text{ Hz}$), 6.78-6.75 (d, 1H, $J = 7.9\text{ Hz}$), 6.70-6.64 (t, 1H, $J = 7.4\text{ Hz}$), 4.09-4.01 (q, 4H), 3.82-3.75 (t, 1H), 3.01-2.98 (d, 2H), 1.12-1.06 (m, 6H); ^{13}C NMR (63 MHz, CDCl_3) δ : ppm 14.87, 30.32, 53.69, 62.84, 117.68, 121.51, 125.11, 129.36, 132.00, 155.42, 170.90; IR (NaCl, neat): 3228, 1952, 1732, 1458, 1372, 1232, 1154, 1102, 1032, 860, 754; HRMS (ESI) Calcd for $C_{14}H_{18}NaO_5$: 289.1046. Found: 280.1046.

2-[(Phenylthio)methyl]phenol (**5k**)

According to the general procedure, the nitrate ester **4a** (200 mg, 0.7 mmol) and thiophenol (93 mg, 0.84 mmol) were reacted with TBAF (0.7 mL, 0.7 mmol) in THF (8 mL) at -78 °C. Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) yielded **5k** as colourless oil (103 mg, 68%). $R_f = 0.67$ (40% ethyl acetate in hexane) identical in all respects to an authentic sample.¹⁰

Methyl 2-[(2-hydroxybenzyl)thio]acetate (**5l**)

According to the general procedure, the nitrate ester **4a** (200 mg, 0.7 mmol) and methyl thioglycolate (82 mg, 0.77 mmol) were reacted with TBAF (0.7 mL, 0.7 mmol) in THF (8 mL) at -78 °C. Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) yielded **5l** as a colourless oil (84 mg, 56% yield). $R_f = 0.43$ (40% ethyl acetate in hexane). ^1H NMR (250 MHz, DMSO- d_6) δ : 9.54 (s, 1H), 7.14-7.11 (d, 1H, $J = 7.4$ Hz), 7.07-7.04 (d, 1H, $J = 7.5$ Hz), 6.81-6.78 (d, 1H, $J = 7.7$ Hz), 6.76-6.70 (t, 1H, $J = 7.4$ Hz), 3.72 (s, 2H), 3.62 (s, 3H), 3.26 (s, 2H); ^{13}C NMR (63 MHz, CDCl_3) δ : ppm 32.77, 32.96, 53.74, 117.91, 121.53, 123.28, 130.19, 131.77, 155.88, 172.66; IR (NaCl, neat): 3322, 1954, 1954, 1726, 1712, 1634, 1456, 1300, 1170, 1006, 850, 756; HRMS (ESI): Calcd for $\text{C}_{10}\text{H}_{12}\text{NaO}_3\text{S}$: 235.0399. Found: 235.0395.

2-[(Butylthio)methyl]phenol(**5m**)

According to the general procedure, the nitrate ester **4a** (200 mg, 0.7 mmol) and methyl 1-buthylmercaptan (70 mg, 0.77 mmol) were reacted with TBAF (0.7 mL, 0.7 mmol) in THF (8 mL) at -78 °C. Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) yielded **5m** as a colourless oil (91 mg, 66%). $R_f = 0.56$ (40% ethyl acetate in hexane) identical in all respects to an authentic sample.¹¹

1-[(Phenylthio)methyl]naphthalen-2-ol (10a)

According to the general procedure, the nitrate ester **4b** (200 mg, 0.59 mmol) and thiophenol (72 mg, 0.65 mmol) were reacted with TBAF (0.59 mL, 0.59 mmol) in THF (8 mL) at -78 °C. Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) yielded a brown solid which was recrystallized from ethanol to afford **10a** as colourless microcrystals (120 mg, 75%). R_f = 0.52 (40% ethyl acetate in hexane) m.p. 123-125 °C identical in all respects to an authentic sample.¹²

1-[[4-(4-Methoxyphenyl)amino]methyl]naphthalen-2-ol (10b)

According to the general procedure, the nitrate ester **4b** (200 mg, 0.59 mmol) and *p*-anisidine (81 mg, 0.65 mmol) were reacted with TBAF (0.59 mL, 0.59 mmol) in THF (8 mL) at -78 °C. Subsequent workup and flash column chromatography (10% ethyl acetate in hexane) yielded a yellow solid which was recrystallized from chloroform-hexane to afford **10b** colourless microcrystals (126 mg, 75%). R_f = 0.55 (40% ethyl acetate in hexane), m.p. 125-127 °C identical in all respects to an authentic sample.¹³

General procedure for hetero Diels-Alder reaction of the nitrate ester (4a)

The nitrate ester **4a** was dissolved in toluene (20 mL) and the reaction mixture was cooled to -78 °C. Ethyl vinyl ether or ethyl vinyl sulfide was added followed by dropwise addition of TBAF (1M in THF) for a period of about 4 h. After TLC analysis had shown complete conversion of the starting material the precipitated solid was filtered off, washed with hexane and recrystallized from acetone to give the

trimer of *o*-quinone methide as colourless needles m.p. 188-190 °C [lit.¹⁴ m.p. = 190-192 °C]. The filtrate was evaporated under reduced pressure and the residue was purified using preparative TLC (5% ethyl acetate in hexane) to yield the corresponding products **6a,b**.

2-Ethoxychroman (6a)

According to the general procedure, the benzyl nitrate **4a** (200 mg, 0.7 mmol) and ethyl vinyl ether (5 g, 70 mmol) were reacted with TBAF (0.7 mL, 0.7 mmol) in toluene (20 mL) at -78 °C. Subsequent workup and purification yielded **6a** as colourless oil (20 mg, 16%). R_f = 0.68 (40% ethyl acetate in hexane) identical in all respects to an authentic sample.¹⁵

2-(Ethylthio)chroman (6b)

According to the general procedure, the benzyl nitrate **4a** (200 mg, 0.7 mmol) and ethyl vinyl sulfide (6.2 g, 70 mmol) were reacted with TBAF (0.7 mL, 0.7 mmol) in toluene (20 mL) at -78 °C. Subsequent workup and purification yielded **6b** as pale yellow oil (28 mg, 23%). R_f = 0.60 (40% ethyl acetate in hexane) identical in all respects to an authentic sample.¹⁵

General procedure for the Diels-Alder reaction of the nitrate esters **4b**, **8**

The nitrate ester **4b** or **8** was dissolved in the designated solvent, the reaction mixture was cooled to -78 °C and the appropriate dienophile was added followed by dropwise addition of TBAF (1M in THF) for a period of about 4 h. After TLC analysis had shown complete conversion of the starting materials, water (10 mL) was added, the mixture was extracted with EtOAc (3 × 10 mL), the combined extracts were dried

with sodium sulphate, filtered and the solvent was removed in vacuo. Flash column chromatography using the stated solvent mixtures yielded the corresponding products **9a**, **b**, **11** and **12** (yields are given in Scheme 3 and 4).

6-(Benzyloxy)-2-ethoxychroman (**9a**)

According to the general procedure, the nitrate ester **8** (200 mg, 0.5 mmol) and ethyl vinyl ether (3.69 g, 50 mmol) were reacted with TBAF (0.24 mL, 0.5 mmol) in toluene (20 mL) at -78 °C. Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) yielded **9a** as a colourless oil (168 mg, 84%). $R_f = 0.55$ (20% ethyl acetate in hexane) identical in all respects to an authentic sample.³

6-(Benzyloxy)-2-(ethylthio)chroman (**9b**)

According to the general procedure, the nitrate ester **8** (200 mg, 0.5 mmol) and ethyl vinyl sulfide (4.5 g, 50 mmol) were reacted with TBAF (0.24 mL, 0.5 mmol) in Toluene (20 mL) at -78 °C. Subsequent workup and flash column chromatography (2% ethyl Acetate in hexane) yielded **9b** as a colourless oil (158 mg, 74%). $R_f = 0.53$ (20% ethyl acetate in hexane) identical in all respects to an authentic sample.³

1,2-Dihydro-2'H-spiro(benzo[f]chromene-3,1'-naphthalen)-2'-one (**11**)

According to the general procedure, the nitrate ester **4b** (200 mg, 0.59 mmol) was reacted with TBAF (0.59 mL, 0.59 mmol) in THF (10 mL) at -78 °C. Subsequent workup and flash column chromatography (5% ethyl Acetate in hexane) yielded a

yellow viscous oil that crystallized on standing to give **11** (75 mg, 40%). $R_f = 0.65$ (20% ethyl acetate in hexane). m.p. 143-145 °C identical in all respects to an authentic sample.¹⁶

3-Ethoxy-2,3-dihydro-1H-benzo[f]chromene (12)

According to the general procedure, the nitrate ester **4b** (200 mg, 0.59 mmol) and ethyl vinyl ether (216 mg, 2.9 mmol) were reacted with TBAF (0.59 mL, 0.59 mmol) in THF (8 mL) at -78 °C. Subsequent workup and flash column chromatography (5% ethyl acetate in hexane) yielded **12** as colourless oil (32 mg, 23% yield. $R_f = 0.51$ (20% ethyl acetate in hexane) identical in all respects to an authentic sample.¹⁷

1-{2-[(*tert*-Butyldimethylsilyl)oxy]benzyl}pyrrolidine (13)

The nitrate ester **4a** (200 mg, 0.7 mmol) and pyrrolidine (60 mg, 0.84 mmol) were dissolved in THF (10 mL) at -78 °C and stirred for 6 h from -78 °C to 0 °C then at rt for 1 h as there was no major change in starting material it was refluxed for 24 h. After TLC analysis had shown complete conversion of the starting material water (10 mL) was added, the mixture was extracted with EtOAc (3 × 10 mL), the combined extracts were dried with sodium sulphate, filtered and the solvent was removed in vacuo. Flash column chromatography (50% ethyl acetate in hexane) yielded **13** as colourless oil (94 mg, 45%). $R_f = 0.26$ (10% ethyl acetate in hexane). ^1H NMR (250 MHz, CDCl_3) δ : 7.38-7.35 (d, 1H, $J = 7.4$ Hz), 7.14-7.08 (t, 1H, $J = 7.8$ Hz), 6.96-6.90 (t, 1H, $J = 7.2$ Hz), 6.81-6.78 (d, 1H, $J = 7.9$ Hz), 3.65 (s, 2H), 2.55 (s, 4H), 1.77 (s, 4H) 1.03 (s, 9H), 0.23 (s, 6H); ^{13}C NMR (63 MHz, CDCl_3) δ : ppm 18.45, 23.61, 26.01, 54.20, 118.74, 121.05, 127.55, 129.99, 130.64, 153.69; IR (NaCl, neat): 2929, 1591, 1471, 1409, 1255, 1102, 913, 835, 751; HRMS (ESI) Calcd for $\text{C}_{17}\text{H}_{30}\text{ONSi}$: 292.2091. Found: 292.2078.

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¹H NMR of compound 4a

NAME GVAS2
EXPNO 69
PROCNO 1
Date_ 20100513
Time_ 20.34
INSTRUM spect
PROBHD 5 mm Multinucl
PULPROG zg
TD 32768
SOLVENT CDCl3
NS 1
DS 0
SWH 3676.471 Hz
FIDRES 0.112197 Hz
AQ 4.4564981 sec
RG 16
DW 136.000 usec
DE 6.00 usec
TE 298.0 K
D1 5.00000000 sec
TD0 1

===== CHANNEL f1 =====
NUC1 1H
P1 9.00 usec
PL1 4.00 dB
PL1W 7.67000008 W
SFO1 250.1315259 MHz
SI 32768
SF 250.1300221 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

¹³C NMR of compound **4a**

```
NAME          GVAS2
EXPNO          70
PROCNO         1
Date_         20100513
Time          21.44
INSTRUM        spect
PROBHD         5 mm Multinucl
PULPROG        zgdc
TD            22010
SOLVENT        CDCl3
NS             3000
DS             4
SWH            15723.271 Hz
FIDRES         0.714369 Hz
AQ            0.6999680 sec
RG             362
DW            31.800 usec
DE             6.00 usec
TE            298.0 K
D1            0.50000000 sec
D11           0.03000000 sec
TD0            1

===== CHANNEL f1 =====
NUC1           13C
P1            2.32 usec
PL1           -2.00 dB
PL1W          54.14257431 W
SF01          62.9031528 MHz

===== CHANNEL f2 =====
CPDPRG2       waltz16
NUC2           1H
PCPD2         135.00 usec
PL2           120.00 dB
PL12          22.00 dB
PL2W          0.00000000 W
PL12W         0.12156131 W
SFO2          250.1311770 MHz
SI            32768
SF            62.8951841 MHz
WDW            EM
SSB            0
LB             3.00 Hz
GB             0
PC             0.80
```


F: FTMS + p ESI Full ms [85.00-1000.00]

¹H NMR of compound **4b**

^{13}C NMR of compound **4b**

NAME	GVAS2	
EXPNO	372	
PROCNO	1	
Date_	20110727	
Time	8.59	
INSTRUM	spect	
PROBHD	5 mm	Multinucl
PULPROG	zgdc	
TD	22010	
SOLVENT	CDCl3	
NS	45000	
DS	4	
SWH	15723.271	Hz
FDIRES	0.714369	Hz
AQ	0.6999680	sec
RG	1024	
DW	31.800	usec
DE	6.00	usec
TE	295.1	K
D1	0.50000000	
D11	0.03000000	sec
TD0	1	

```
===== CHANNEL f1 =====
NUC1                13C
P1                  2.32 usec
PL1                 -2.00 dB
PL1W                54.14257431 W
SFO1                62.9031528 MHz
```

```

===== CHANNEL f2 =====
CPDPRG2      waltz16
NUC2         1H
PCPD2        135.00 usec
PL2          120.00 dB
PL12         22.00 dB
PL2W         0.00000000 W
PL12W        0.12156131 W
SFO2         250.1311770 MHz
SI           32768
SF           62.8952645 MHz
WDW          EM
SSB          0
LB           3.00 Hz
GB           0
PC           0.80

```

GVAS-44_110726101010 #8 RT: 0.29 AV: 1 NL: 8.45E4

F: FTMS + p ESI Full ms [85.00-1500.00]

325.1589

 $C_{18}H_{26}O_2NaSi = 325.1594$

-1.7015 ppm

¹H NMR of compound 8

NAME GVAS2
EXPNO 261
PROCNO 1
Date_ 20110208
Time 20.21
INSTRUM spect
PROBHD 5 mm Multinucl
PULPROG zg
TD 32768
SOLVENT CDCl3
NS 8
DS 0
SWH 3676.471 Hz
FIDRES 0.112197 Hz
AQ 4.4564981 sec
RG 512
DW 136.000 usec
DE 6.00 usec
TE 298.0 K
D1 5.00000000 sec
TD0 1

===== CHANNEL f1 =====
NUC1 1H
P1 9.00 usec
PL1 4.00 dB
PL1W 7.67000008 W
SFO1 250.1315259 MHz
SI 32768
SF 250.1300013 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

¹³C NMR of compound 8

NAME GVAS2
EXPNO 262
PROCNO 1
Date_ 20110209
Time 5.14
INSTRUM spect
PROBHD 5 mm Multinucl
PULPROG zgdc
TD 22010
SOLVENT CDCl3
NS 25000
DS 4
SWH 15723.271 Hz
FIDRES 0.714369 Hz
AQ 0.6999680 sec
RG 1024
DW 31.800 usec
DE 6.00 usec
TE 298.0 K
D1 0.50000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
NUC1 13C
P1 2.32 usec
PL1 -2.00 dB
PL1W 54.14257431 W
SFO1 62.9031528 MHz

===== CHANNEL f2 =====
CPDPRG2 waltz16
NUC2 1H
PCPD2 135.00 usec
PL2 120.00 dB
PL12 22.00 dB
PL2W 0.00000000 W
PL12W 0.12156131 W
SFO2 250.1311770 MHz
SI 32768
SF 62.8951794 MHz
WDW EM
SSB 0
LB 3.00 Hz
GB 0
PC 0.80

GVAS-68_110726101010 #6 RT: 0.18 AV: 1 NL: 1.29E6

F: FTMS + p ESI Full ms [85.00-1500.00]

¹H NMR of compound **5c**

¹³C NMR of compound **5c**

```
NAME          GVAS2
EXPNO          368
PROCNO          1
Date_          20110726
Time           14.07
INSTRUM        spect
PROBHD         5 mm Multinucl
PULPROG        zgdc
TD             22010
SOLVENT        DMSO
NS             6000
DS             4
SWH            15723.271 Hz
FIDRES         0.714369 Hz
AQ             0.6999680 sec
RG             1024
DW             31.800 usec
DE             6.00 usec
TE             295.1 K
D1             0.50000000 sec
D11            0.03000000 sec
TD0            1
```

```
===== CHANNEL f1 =====
NUC1            13C
P1              2.32 usec
PL1            -2.00 dB
PL1W           54.14257431 W
SFO1           62.9031528 MHz
```

```
===== CHANNEL f2 =====
CPDPRG2        waltz16
NUC2            1H
PCPD2          135.00 usec
PL2            120.00 dB
PL12           22.00 dB
PL2W           0.00000000 W
PL12W          0.12156131 W
SFO2           250.1311770 MHz
SI             32768
SF             62.8952645 MHz
WDW            EM
SSB            0
LB             3.00 Hz
GB             0
PC             0.80
```

RT: 0.00 - 11.50

250711-GVAS-26-A #357 RT: 4.96 AV: 1 NL: 2.90E6

F: FTMS + p ESI Full ms [150.00-1000.00]

¹H NMR of compound **5e**

NAME nmr
EXPNO 363
PROCNO 1
Date_ 20110725
Time 14.18
INSTRUM spect
PROBHD 5 mm Multinucl
PULPROG zg
TD 32768
SOLVENT DMSO
NS 8
DS 0
SWH 3676.471 Hz
FIDRES 0.112197 Hz
AQ 4.4564981 sec
RG 1024
DW 136.000 usec
DE 6.00 usec
TE 295.4 K
D1 5.00000000 sec
TD0 1

===== CHANNEL f1 =====
NUC1 1H
P1 9.00 usec
PL1 4.00 dB
PL1W 7.67000008 W
SFO1 250.1315259 MHz
SI 32768
SF 250.1299972 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

¹³C NMR of compound **5e**

NAME GVAS2
EXPNO 61
PROCNO 1
Date_ 20100430
Time 0.41
INSTRUM spect
PROBHD 5 mm Multinucl
PULPROG zgpg30
TD 22010
SOLVENT CDCl3
NS 6000
DS 4
SWH 15723.271 Hz
FIDRES 0.714369 Hz
AQ 0.6999680 sec
RG 256
DW 31.800 usec
DE 6.00 usec
TE 298.0 K
D1 0.50000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
NUC1 13C
P1 2.32 usec
PL1 -2.00 dB
PL1W 54.14257431 W
SFO1 62.9031528 MHz

===== CHANNEL f2 =====
CPDPRG2 waltz16
NUC2 1H
PCPD2 135.00 usec
PL2 120.00 dB
PL12 22.00 dB
PL2W 0.00000000 W
PL12W 0.12156131 W
SFO2 250.1311770 MHz
SI 32768
SF 62.8951779 MHz
WDW EM
SSB 0
LB 3.00 Hz
GB 0
PC 0.80

RT: 0.00 - 11.49

250711-GVAS-27-B #359 RT: 5.14 AV: 1 NL: 2.50E6

F: FTMS + p ESI Full ms [150.00-1000.00]

¹H NMR of compound **5h**

¹³C NMR of compound **5h**

NAME GVAS2
EXPNO 74
PROCNO 1
Date_ 20100518
Time 21.39
INSTRUM spect
PROBHD 5 mm Multinucl
PULPROG zgdc
TD 22010
SOLVENT CDCl3
NS 5000
DS 4
SWH 15723.271 Hz
FIDRES 0.714369 Hz
AQ 0.6999680 sec
RG 512
DW 31.800 usec
DE 6.00 usec
TE 295.0 K
D1 0.50000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
NUC1 13C
P1 2.32 usec
PL1 -2.00 dB
PL1W 54.14257431 W
SFO1 62.9031528 MHz

===== CHANNEL f2 =====
CPDPRG2 waltz16
NUC2 1H
PCPD2 135.00 usec
PL2 120.00 dB
PL12 22.00 dB
PL2W 0.00000000 W
PL12W 0.12156131 W
SFO2 250.1311770 MHz
SI 32768
SF 62.8951800 MHz
WDW EM
SSB 0
LB 3.00 Hz
GB 0
PC 0.80

¹H NMR of compound 5j

¹³C NMR of compound **5j**

NAME GVAS2
EXPNO 87
PROCNO 1
Date_ 20100602
Time 23.16
INSTRUM spect
PROBHD 5 mm Multinucl
PULPROG zgdc
TD 22010
SOLVENT CDCl3
NS 3500
DS 4
SWH 15723.271 Hz
FIDRES 0.714369 Hz
AQ 0.6999680 sec
RG 362
DW 31.800 usec
DE 6.00 usec
TE 294.8 K
D1 0.50000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
NUC1 13C
P1 2.32 usec
PL1 -2.00 dB
PL1W 54.14257431 W
SFO1 62.9031528 MHz

===== CHANNEL f2 =====
CPDPRG2 waltz16
NUC2 1H
PCPD2 135.00 usec
PL2 120.00 dB
PL12 22.00 dB
PL2W 0.00000000 W
PL12W 0.12156131 W
SFO2 250.1311770 MHz
SI 32768
SF 62.8951805 MHz
WDW EM
SSB 0
LB 3.00 Hz
GB 0
PC 0.80

RT: 0.00 - 11.51

250711-GVAS-35 #449 RT: 6.37 AV: 1 NL: 4.09E6

F: FTMS + p ESI Full ms [150.00-1000.00]

¹H NMR of compound **5l**

¹³C NMR of compound **51**

NAME GVAS2
EXPNO 100
PROCNO 1
Date_ 20100605
Time 22.28
INSTRUM spect
PROBHD 5 mm Multinucl
PULPROG zgdc
TD 22010
SOLVENT CDCl3
NS 4500
DS 4
SWH 15723.271 Hz
FIDRES 0.714369 Hz
AQ 0.6999680 sec
RG 574.7
DW 31.800 usec
DE 6.00 usec
TE 294.5 K
D1 0.50000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
NUC1 13C
P1 2.32 usec
PL1 -2.00 dB
PL1W 54.14257431 W
SFO1 62.9031528 MHz

===== CHANNEL f2 =====
CPDPRG2 waltz16
NUC2 1H
PCPD2 135.00 usec
PL2 120.00 dB
PL12 22.00 dB
PL2W 0.00000000 W
PL12W 0.12156131 W
SFO2 250.1311770 MHz
SI 32768
SF 62.8951830 MHz
WDW EM
SSB 0
LB 3.00 Hz
GB 0
PC 0.80

GVAS-36_110726101010 #3 RT: 0.09 AV: 1 NL: 5.15E5

F: FTMS + p ESI Full ms [85.00-1500.00]

¹H NMR of compound 13

GVAS23@250 H-1

7.386
7.357
7.149
7.143
7.113
7.088
7.082
6.961
6.931
6.903
6.819
6.787

```
NAME      GVAS2
EXPNO     417
PROCNO    1
Date_     20111124
Time      23.11
INSTRUM   spect
PROBHD    5 mm Multinucl
PULPROG   zg
TD        32768
SOLVENT   CDCl3
NS         8
DS         0
SWH       3676.471 Hz
FIDRES    0.112197 Hz
AQ        4.4564981 sec
RG         32
DW        136.000 usec
DE         6.00 usec
TE        294.6 K
D1        5.00000000 sec
TD0        1

----- CHANNEL f1 -----
NUC1       1H
P1         9.00 usec
PL1        4.00 dB
PL1W       7.67000008 W
SFO1       250.1315259 MHz
SI         32768
SF         250.1300014 MHz
WDW        EM
SSB        0
LB         1.00 Hz
GB         0
PC         1.40
```

— 3.660

— 2.551

— 1.777

— 1.037

— 0.236

7.5

7.0

6.5

6.0

5.5

5.0

4.5

4.0

3.5

3.0

2.5

2.0

1.5

1.0

0.5

0.0

ppm

0.97

1.01

1.00

1.02

2.00

4.07

4.02

9.09

6.02

¹³C NMR of compound 13

GVAS23@250 C-13

— 153.690

— 130.649
— 129.999
— 127.550

— 121.057
— 118.746

```
NAME          GVAS2
EXPNO         418
PROCNO        1
Date_         20111124
Time          23.14
INSTRUM       spect
PROBHD        5 mm Multinucl
PULPROG       zgpg
TD            22010
SOLVENT       CDCl3
NS            50
DS            4
SWH           15723.271 Hz
FIDRES        0.714369 Hz
AQ            0.6999680 sec
RG            1024
DW            31.800 usec
DE            6.00 usec
TE            294.5 K
D1            0.5000000 sec
D11           0.0300000 sec
TD0           1
```

```
----- CHANNEL f1 -----
NUC1          13C
P1            2.32 usec
PL1           -2.00 dB
PL1W          54.14257431 W
SFO1          62.9031528 MHz
```

```
----- CHANNEL f2 -----
CPDPRG2       waltz16
NUC2          1H
PCPD2         135.00 usec
PL2           120.00 dB
PL12          22.00 dB
PL2W          0.0000000 W
PL12W         0.12156131 W
SFO2          250.1311770 MHz
SI            32768
SF            62.8952320 MHz
WDW           EM
SSB           0
LB            3.00 Hz
GB            0
PC            0.80
```

— 54.203

— 26.017
— 23.617

— 18.450

NB-GVAS-23(WILLIAMS)_111107142658 #12 RT: 0.19 AV: 1 NL: 1.57E7
 F: FTMS + p ESI Full ms [85.00-2000.00]

HRMS of compound 13