

# Synthesis of the Tricyclic Skeleton of the Cyathin Diterpene Using the Brook Rearrangement-Mediated [3 + 4] Annulation

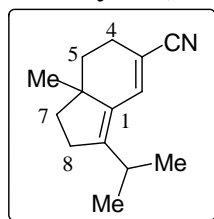
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## Supporting Information

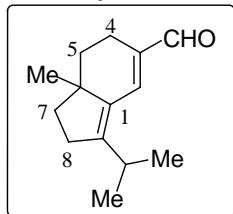
**General:** IR spectra were recorded on a Perkin-Elmer FT1640 spectrometer.  $^1\text{H}$  NMR spectra were taken on Varian UnityPlus 500 (500 MHz) in  $\text{CDCl}_3$  with reference to  $\text{CHCl}_3$  ( $\delta$  7.26) unless otherwise noted.  $^{13}\text{C}$  NMR spectra were measured with Varian UnityPlus 500 (125 MHz) in  $\text{CDCl}_3$  with reference to the  $\text{CDCl}_3$  triplet ( $\delta$  77.2) unless otherwise noted. Resonance patterns were described as s = singlet, d = doublet, t = triplet, sep = septet, m = multiplet, and br = broad. The assignment of  $^1\text{H}$  and  $^{13}\text{C}$  NMR spectra is based on H-H decoupling and HMQC experiments. Low- and high-resolution mass spectra (EI-MS) were obtained with a JEOL JMS-D-300 spectrometer combined with a JEOL JMA-2000 data processing system. For routine chromatography, the following adsorbents were used: Fuji-Davison silica gel BW-200 (150-325 mesh) for column chromatography; Merck precoated silica gel 60 F-254 plates for analytical thin-layer chromatography. All moisture sensitive reactions were performed under a positive pressure of nitrogen. Anhydrous  $\text{MgSO}_4$  was used for drying all organic solvent extracts in workup, and the removal of the solvents was performed with a rotary evaporator. Dry solvents and reagents were obtained by using standard procedures. Melting points (uncorrected) were determined by using a Yanagimoto micro-melting point apparatus. Elemental combustion analysis was performed at the Microanalysis Laboratory of this University.

### 6-Methyl-9-(1-methylethyl)bicyclo[4.3.0]nona-2,9-diene-3-carbonitrile (**11**)



To a solution of **10** (1.84 g, 9.54 mmol) in benzene (4 mL) was added  $\text{Me}_3\text{SiCN}$  (1.65 mL, 12.4 mmol) and  $\text{ZnI}_2$  (75 mg) at room temperature. The solution was stirred at room temperature for 1 h before addition of pyridine (15 mL) and  $\text{POCl}_3$  (2.59 mL, 28.6 mmol). After being stirred at the same temperature for 1 h, the mixture was poured into  $\text{Et}_2\text{O}$ -ice-satd.  $\text{NaHCO}_3$  solution. Phases were separated, and the organic phase was extracted with  $\text{Et}_2\text{O}$ . Combined organic phase was successively washed with  $\text{H}_2\text{O}$  and saturated brine, then dried, and concentrated. The residual oil was subjected to column chromatography (silica gel, 30 g; elution with 2:1 hexane-AcOEt) to give **11** (1.24 g, 65%). colorless needles (hexane),  $R_f$  = 0.41 (hexane:AcOEt = 15:1). mp 60 °C. IR (KBr) 2195  $\text{cm}^{-1}$ .  $^1\text{H}$ -NMR  $\delta$  0.90 (3H, s, Me), 1.00 (3H, d,  $J$  = 6.8 Hz,  $\text{CHMe}$ ), 1.03 (3H, d,  $J$  = 6.8 Hz,  $\text{CHMe}$ ), 1.38 -1.51 (2H, m, H-5 and H-7), 1.76-1.82 (2H, m, H-5 and H-7), 2.27-2.34 (2H, m, H-4 and H-8), 2.39-2.51 (2H, m, H-4 and H-8), 2.81 (1H, sep,  $J$  = 6.8 Hz,  $\text{CHMe}_2$ ), 7.02 (1H, d,  $J$  = 2.4 Hz, H-2).  $^{13}\text{C}$  NMR  $\delta$  21.2, 21.7, and 21.8 ( $\text{CHMe}_2$  and 6-Me), 25.7 and 29.2 (C-5 and C-7), 27.2 ( $\text{CHMe}_2$ ) 34.9 and 38.8 (C-4 and C-8), 107.8 (C-1, C-3, and C-9), 121.1 (CN), 134.9 (C-2), 135.4 and 152.4 (C-1 and C-9). HRMS calcd for  $\text{C}_{14}\text{H}_{19}\text{N}$  201.1517, found 201.1519.

### 6-Methyl-9-(1-methylethyl)bicyclo[4.3.0]nona-2,9-diene-3-carbaldehyde (**12**)

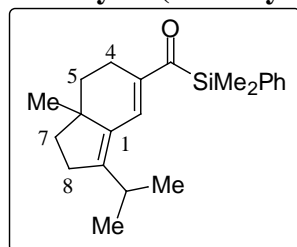


To an ice-cooled solution of **11** (0.42 g, 2.1 mmol) in  $\text{Et}_2\text{O}$  (12 mL) was added DIBAL (0.94 M hexane solution, 2.68 mL, 2.52 mmol). After being stirred at the same temperature for 1 h, the reaction mixture was quenched with addition of MeOH, and filtered through a pad of Celite and concentrated. The residue was dissolved in THF (10 mL) in ice-water bath, and 10% aqueous  $(\text{COOH})_2$  (10 mL) solution was added. The mixture was stirred at the same temperature for 30 min, and poured into  $\text{Et}_2\text{O}$ -water.

Phases were separated, and the aqueous phase was extracted with  $\text{Et}_2\text{O}$ . Combined organic phases were successively washed with water and saturated brine, dried, and concentrated. The residual oil was subjected to column chromatography (silica gel, 15 g; elution with 2:1 hexane-AcOEt) to give **12** (326 mg, 76%). a pale yellow oil,  $R_f$  = 0.41 (hexane:AcOEt = 12:1). IR (film) 2955, 2920, 1675  $\text{cm}^{-1}$ .  $^1\text{H}$ -NMR  $\delta$  0.91 (3H, s,

Me), 1.05 (3H, d,  $J = 6.8$  Hz, CHMe), 1.07 (3H, d,  $J = 6.8$  Hz, CHMe), 1.34 (1H, ddd,  $J = 12.6, 12.6, 5.6$  Hz, H-5), 1.52 (1H, ddd,  $J = 10.6, 10.6, 10.6$  Hz, H-7), 1.79-1.86 (2H, m, H-5 and H-7), 2.20-2.29 (1H, m, H-4), 2.38 (1H, dd,  $J = 17.7, 9.0$  Hz, H-8), 2.49-2.57 (1H, m, H-4), 2.49-2.57 (1H, m, H-8), 2.96 (1H, sep,  $J = 6.8$  Hz, CHMe<sub>2</sub>), 7.16 (1H, d,  $J = 2.1$  Hz, H-2), 9.49 (1H, s, CHO). <sup>13</sup>C NMR  $\delta$  20.2, 21.3, 21.8, 22.0, 27.5, 29.7, 34.8, 39.0, 45.6, 137.7, 137.9, 139.3, 155.0, 194.5. HRMS calcd for C<sub>14</sub>H<sub>20</sub>O 204.1514, found 204.1498.

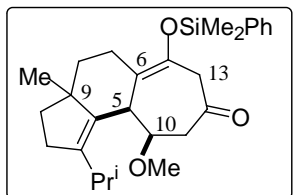
#### 6-Methyl-9-(1-methylethyl)bicyclo[4.3.0]nona-2,9-diene-1-carbonyl(dimethyl)phenylsilane (**13**)



To a cooled (-80 °C) solution of PhMe<sub>2</sub>SiLi (0.62 M in THF, 11.8 mL, 7.32 mmol) in THF (19 mL) was added dropwise **12** (1.00 g, 4.89 mmol). The solution was stirred at the same temperature for 1 h, and then quenched by saturated aqueous NH<sub>4</sub>Cl solution. The mixture was extracted with Et<sub>2</sub>O, and the combined organic phases were washed with saturated brine, dried, and concentrated. The residual oil was subjected to column chromatography (silica gel, 100 g; elution with 20:1 hexane-AcOEt) to give silylcarbinol (**775** mg, 47%).

This material was dissolved in CH<sub>2</sub>Cl<sub>2</sub> (20 mL) and *N*-methylmorpholine-*N*-oxide (399 mg, 3.4 mmol) and TPAP (800 mg, 2.28 mmol). The reaction mixture was stirred at room temperature for 5 min, filtered through a pad of silica gel (45 g) eluting with hexane-AcOEt (24:1), and the solvent was concentrated. The residual oil was subjected to column chromatography (silica gel, 50 g; elution with 25:1 hexane-AcOEt) to give **13** (440 mg, 46%). a pale yellow needles,  $R_f = 0.47$  (hexane:AcOEt = 12:1). <sup>1</sup>H-NMR  $\delta$  1.25 (1H, ddd,  $J = 12.7, 12.7, 5.6$  Hz, H-5), 1.42 (1H, ddd,  $J = 10.5, 10.5, 10.5$  Hz, H-7), 1.70-1.78 (2H, H-5 and H-7), 2.09-2.18 (1H, m, H-4), 2.25 (1H, dd,  $J = 17.8, 8.8$  Hz, H-8), 2.32 (1H, sep,  $J = 6.8$  Hz, CHMe<sub>2</sub>), 2.38-2.47 (1H, m, H-8), 2.46-2.52 (1H, m, H-4), 7.14 (1H, d,  $J = 2.4$  Hz, H-2), 7.36-7.40 (3H, m, Ph), 7.59 (2H, m, Ph). <sup>13</sup>C NMR  $\delta$  -2.6 and -2.7 (SiMe<sub>2</sub>), 20.3 (C-4), 21.2, 21.8, and 22.0 (6-Me, CHMe<sub>2</sub>), 27.2 (CHMe<sub>2</sub>), 29.7 (C-8), 35.1 (C-5), 39.0 (C-7), 45.0 (C-6), 128.3, 129.6, 134.1, 136.4 (C-2), 137.6, 138.1, 142.0, 153.6, 233.8 (C=O). HRMS calcd for C<sub>22</sub>H<sub>30</sub>OSi 338.2066, found 338.2057.

#### [**3** + **4**] annulation of **13** with lithium enolate of 4-methoxy-3-buten-2-one

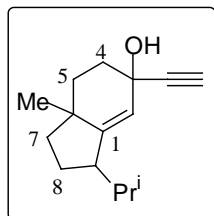


To a stirred and cooled (-80 °C) solution of lithium diisopropylamide (LDA) prepared from diisopropylamine (216  $\mu$ L, 156 mg, 1.54 mmol) and *n*-BuLi (1.47 M in hexane, 1.05 mL, 1.54 mmol) in THF (1 mL) was added dropwise a solution of 4-methoxy-3-buten-2-one (130  $\mu$ L, 128 mg, 1.28 mmol) in THF (1 mL). After stirring at -80 °C for 30 min, the solution was added dropwise via a cannula to a cooled (-80 °C) solution of **13** (440 mg, 1.30 mmol) in THF (3.8 mL). The reaction mixture was

allowed to warm to room temperature over 1 h, and then quenched by addition of AcOH (88  $\mu$ L) in THF (1 mL). The mixture was concentrated, and the residue was subjected to column chromatography (silica gel, 80 g; elution with 12:1 hexane-AcOEt) to give **14** (265 mg, 47%) as a 1:1 mixture of diastereomers along with **13** (62 mg, 14%). The mixture could be separated by subjecting MPLC (elution with 12:1 hexane-AcOEt) to give **14a** (less polar) and **14b** (more polar). **14a**: a colorless oil,  $R_f = 0.36$  (hexane:AcOEt=12:1). IR (film) 1710 cm<sup>-1</sup>. <sup>1</sup>H-NMR  $\delta$  0.47 (3H, s, SiMe), 0.48 (3H, s, SiMe), 0.94 (3H, d,  $J = 6.8$  Hz, CHMe), 0.94 (3H, d,  $J = 6.8$  Hz, CHMe), 1.06 (3H, s, 9-CH<sub>3</sub>), 1.01 (1H, dm, H-1 or H-2), 1.38 (1H, (1H. ddd.  $J = 11.1, 11.1, 11.1$  Hz, H-8), 1.64 (1H, ddd,  $J = 12.4, 3.6, 3.6$  Hz, H-1 or H-2), 1.72 (1H, dd,  $J = 11.1, 3.6$  Hz, H-8), 2.05-2.16 (2H, m, H-7 and H-1 or H-2), 2.24-2.32 (1H, m, H-7), 2.48 (1H, sep,  $J = 6.8$  Hz, CHMe<sub>2</sub>), 2.68 (1H, dd,  $J = 10.8, 6.6$  Hz, H-11), 2.74 (1H, dd,  $J = 10.8, 6.6$  Hz, H-11), 2.76 (1H, d,  $J = 19.0$  Hz, H-13), 3.18 (1H, s, H-5), 3.19 (3H, s, OCH<sub>3</sub>), 3.47 (1H, dd,  $J = 19.0, 3.4$  Hz, H-13), 3.55 (1H, ddd,  $J = 6.6, 6.6, 2.8$  Hz, H-10), 7.36-7.43 (3H, m, ArH), 7.59-7.61 (2H, m, ArH). <sup>13</sup>C NMR  $\delta$  -0.86 and -0.66 (SiMe<sub>2</sub>), 21.2, 21.7, and 21.8 (9-Me and CHMe<sub>2</sub>), 23.0 (C-1 or C-2), 26.9 (CHMe<sub>2</sub>), 27.1 (C-7), 38.9 (C-1 or C-2), 40.5 (C-5), 41.9 (C-8), 45.9 (C-9), 47.2 (C-11), 50.2 (C-13), 57.6 (OCH<sub>3</sub>), 86.0 (C-10), 119.9 (C-6), 128.2, 130.1, 133.6, 137.2, 137.8, 138.9, 142.4 (C-14), 207.0 (C-12). HRMS calcd for C<sub>27</sub>H<sub>38</sub>O<sub>3</sub>Si 438.2590, found 438.2574. **14b**: a colorless oil,  $R_f = 0.36$  (hexane:AcOEt = 12:1). IR (film) 1710 cm<sup>-1</sup>. <sup>1</sup>H-NMR  $\delta$  0.48 (6H, s, SiMe<sub>2</sub>), 0.71 (3H, s, CH<sub>3</sub>), 0.90 (3H, d,  $J = 6.8$  Hz, CHMe), 1.00 (3H, d,  $J = 6.8$  Hz, CHMe), 1.38 (1H, br ddd,  $J = 10.9, 10.9, 10.9$  Hz, H-8), 1.51 (1H, ddd,  $J = 12.1, 6.2, 1.7$  Hz, H-1 or H-2), 1.54-1.64 (2H, m, H-8 and H-1 or H-2), 2.07 (1H, ddd,  $J = 15.4, 8.5, 1.5$  Hz, H-7), 2.25-2.32 (1H, m, H-7), 2.35-2.48 (2H, m, H-1 or H-2), 2.52 (1H, sep,  $J =$

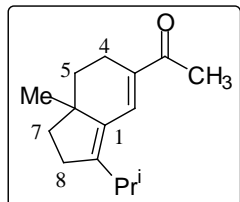
6.8 Hz,  $\text{CHMe}_2$ ), 2.68 (1H, dd,  $J = 10.5, 7.1$  Hz, H-11), 2.73 (1H, dd,  $J = 10.5, 7.1$  Hz, H-11), 2.75 (1H, d,  $J = 19.5$  Hz, H-13), 3.20 (3H, s,  $\text{OCH}_3$ ), 3.26 (1H, s, H-5), 3.42 (1H, ddd,  $J = 19.5, 3.0, 3.0$  Hz, H-13), 3.81 (1H, ddd,  $J = 7.1, 7.1, 2.6$  Hz, H-10), 7.35-7.42 (3H, m, ArH), 7.60-7.62 (2H, m, ArH).  $^{13}\text{C}$  NMR  $\delta$  -0.68 and -0.4 ( $\text{SiMe}_2$ ), 21.1, 21.4, and 21.9 (9-Me,  $\text{CHMe}_2$ ), 23.4 (C-1 or C-2), 27.3 (C-7), 27.3 ( $\text{CHMe}_2$ ), 32.7 (C-1 or C-2), 39.1 (C-8), 39.5 (C-5), 45.9 (C-9), 46.9 (C-11), 50.3 (C-13), 57.8 ( $\text{OCH}_3$ ), 84.8 (C-10), 117.8 (C-6), 128.2, 130.2, 133.5, 137.4, 137.7, 138.8, 140.7 (C-14), 208.2 (C-12). HRMS calcd for  $\text{C}_{27}\text{H}_{38}\text{O}_3\text{Si}$  438.2590, found 438.2582.

### 1-Ethynyl-6-methyl-9-(1-methylethyl)bicyclo[4.3.0]non-1-en-3-ol (15)



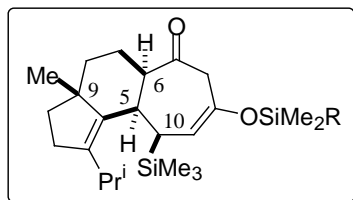
To an ice-cooled solution of ethynylmagnesium bromide (0.5 M in THF, 8.7 mL, 4.3 mmol) in THF (2 mL) was added **11** (695 mg, 3.60 mmol) in THF (1 mL). The mixture was stirred at room temperature for 20 h before quenching saturated aqueous  $\text{NaHCO}_3$  solution (30 mL). The mixture was extracted with  $\text{Et}_2\text{O}$ . Combined organic phases were washed with saturated brine, dried, concentrated. The residual oil was distilled (150-200 °C/4 mmHg, bulb-to-bulb) to give **15** (625 mg, 79%) which solidified after standing. a colorless needles,  $R_f = 0.34$  (hexane:AcOEt = 5:1). IR (KBr) 3290, 2955, 2100  $\text{cm}^{-1}$ .  $^1\text{H}$ -NMR  $\delta$  0.73 and 0.96 (3H, d,  $J = 6.8$  Hz,  $\text{CHMe}_2$ ), 1.05 (3H, s, 6-Me), 1.16 (1H, br ddd,  $J = 11.2, 11.2, 11.2$  Hz, H-7), 1.49-1.61 (2H, m, H-7 and H-4 or H-5), 1.67 (1H, ddd,  $J = 13.7, 13.7, 3.0$  Hz, H-8), 1.74-1.85 (2H, m, H-8 and H-4 or H-5), 1.97-2.06 (2H, m,  $\text{CHMe}_2$  or H-4 or H-5), 2.07 (1H, s,  $\text{HC}\equiv\text{C}$ ), 2.16 (1H, dm,  $J = 14.7$  Hz, H-4 or H-5), 2.50 (1H, s, OH), 2.51-2.60 (1H, m, H-9), 5.23 (1H, br dd,  $J = 1.8, 1.8$  Hz, H-2).  $^{13}\text{C}$  NMR  $\delta$  15.8 ( $\text{CHMe}$ ), 22.2 ( $\text{CHMe}_2$  and C-4 or C-5), 24.7 (6-Me), 29.1 ( $\text{CHMe}_2$ ), 35.6 (C-8 and C-4 or C-5), 35.8 ( $\text{HC}\equiv\text{C}$ ), 37.6 ( ), 40.1 (C-4, C-5), 42.4 (C-6), 44.9 (C-9), 68.3 (C-3), 71.8, 87.9 ( $\text{HC}\equiv\text{C}$ ), 119.8 (C-2), 123, 6, 134.1, 152.2, 154.2.  $\text{C}_{15}\text{H}_{22}\text{O}$  218.34. Anal. calcd for  $\text{C}_{15}\text{H}_{22}\text{O}$  : C: 82.52; H: 10.16 ; found: C, 82.70; H, 10.25.

### 3-Acetyl-6-methyl-9-(1-methylethyl)bicyclo[4.3.0]nona-2,9-diene (16)



Ethynylalcohol **15** (1.00 g, 4.60 mmol) was dissolved in  $\text{HCOOH}$  (10 mL) and refluxed for 15 min. The mixture was poured into saturated aqueous  $\text{NaHCO}_3$ , and extracted with pentane. Combined organic phases were successively washed with saturated aqueous  $\text{NaHCO}_3$  and saturated brine, dried, and concentrated. The residual oil was subjected to column chromatography (silica gel, 80 g; elution with 8:1 hexane-AcOEt) to give **16** (419 mg, 42%). a colorless plate,  $R_f = 0.47$  (hexane:AcOEt = 5:1). mp 42-43 °C (hexane). IR (KBr) 1700, 1625  $\text{cm}^{-1}$ .  $^1\text{H}$  NMR  $\delta$  0.89 (3H, s, Me), 1.04 and 1.07 (each 3H, d,  $J = 6.8$  Hz,  $\text{CHMe}_2$ ), 1.32 (1H, dd,  $J = 12.6, 12.6, 5.6$  Hz, H-5), 1.48 (1H, ddd,  $J = 12.0, 9.2, 9.2$  Hz, H-8), 1.79 (1H, dd,  $J = 12.0, 7.1$  Hz, H-8), 1.82 (1H, ddd,  $J = 12.6, 5.8, 1.5$  Hz, H-5), 2.21-2.32 (1H, m, H-4), 2.35 (3H, s,  $\text{MeCO}$ ), 2.35 (1H, dd,  $J = 16.9, 9.6$  Hz, H-7), 2.47-2.56 (1H, m, H-7), 2.58 (1H, dd,  $J = 18.6, 5.6$  Hz, H-4), 2.94 (1H, sep,  $J = 6.8$  Hz,  $\text{CHMe}_2$ ), 7.29 (1H, br d,  $J = 2.4$  Hz, H-2).  $^{13}\text{C}$  NMR  $\delta$  21.3, 21.8, 21.9, and 22.1 (6-Me, C-4,  $\text{CHMe}_2$ ), 25.7 ( $\text{MeCO}$ ), 27.2 ( $\text{CHMe}_2$ ), 29.6 (C-7), 35.3 (C-5), 39.0 (C-8), 44.7 (C-6), 130.3 (C-2), 136.4, 137.6, and 152.7 (C-1, C-3, and C-9), 199.7 (C=O). Anal. calcd for  $\text{C}_{15}\text{H}_{22}\text{O}$  C: 82.52; H: 10.16. found: C, 82.63; H, 10.27.

### [3 + 4] annulation of **16** with acryloylsilanes (**17a,b**)

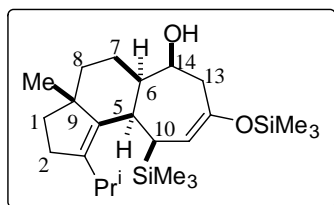


This procedure is representative of reactions of **16** with **17a**. To a stirred and cooled (-80 °C) solution of LDA from diisopropylamine (86  $\mu\text{L}$ , 62 mg, 0.62 mmol) and  $n\text{-BuLi}$  (1.61 M in hexane, 0.385 mL, 0.62 mmol) in THF (0.5 mL) was added dropwise a solution of **16** (122 mg, 0.56 mmol) in THF (1 mL). After stirring at -80 °C for 30 min, the solution was added dropwise via a cannula to a cooled (-80 °C) solution of **17a** (223 mg, 1.21 mmol) in THF (5.8 mL). The reaction mixture was allowed to warm to 0 °C, and then quenched by addition of saturated aqueous  $\text{NH}_4\text{Cl}$  solution (50 mL). The mixture was extracted with  $\text{Et}_2\text{O}$ . Combined organic phases were washed with saturated brine, dried, and concentrated. The residual oil was subjected to column chromatography (silica gel, 30 g; elution with 20:1 hexane-AcOEt) to give **20a** (155 mg, 60%). a pale yellow oil,  $R_f = 0.39$  (hexane:AcOEt = 11:1). IR (film) 1700, 1645, 1250  $\text{cm}^{-1}$ .  $^1\text{H}$  NMR  $\delta$  -0.03 (9H, s,  $\text{SiMe}_3$ ), 0.11 and 0.15

(each, 3H, SiMe<sub>3</sub>), 0.90 and 0.96 (each 3H, d,  $J$  = 6.8 Hz, CHMe<sub>2</sub>), 0.91 (9H, s, *t*-Bu), 1.16-1.25 (1H, m, H-1), 1.18 (3H, s, 9-Me), 1.54-1.64 (4H, m, H-1, H-7, and H-8), 1.92 (1H, ddd,  $J$  = 8.1, 6.8, 0.7 Hz, H-10), 2.17 (1H, ddd,  $J$  = 16.0, 9.4, 6.4 Hz, H-2), 2.25 (1H, ddd,  $J$  = 16.0, 9.2, 6.0 Hz, H-2), 2.45 (1H, ddd,  $J$  = 13.2, 6.8, 4.3 Hz, H-6), 2.53 (1H, dddd,  $J$  = 13.2, 13.2, 13.2, 4.1 Hz, H-7), 2.74 (1H, sep,  $J$  = 6.8 Hz, CHMe<sub>2</sub>), 2.98 (1H, d,  $J$  = 19.7 Hz, H-13), 3.30 (1H, dm,  $J$  = 19.7 Hz, H-13), 3.43 (1H, ddm,  $J$  = 6.8, 6.8 Hz, H-5), 4.91 (1H, dd,  $J$  = 8.1, 2.1 Hz, H-11). <sup>13</sup>C NMR  $\delta$  -4.47 and -3.61 (SiMe<sub>2</sub>), -1.08 (SiMe<sub>3</sub>), 18.1 (C-Bu<sup>t</sup>), 20.4 and 22.1 (CHMe<sub>2</sub>), 22.7 (C-7), 25.1 (9-Me), 25.8 (Bu<sup>t</sup>), 27.0 (CHMe<sub>2</sub>), 27.5 (C-2), 28.0 (C-10), 38.7 (C-8), 40.3 (C-1), 46.7 (C-9), 49.2 (C-13), 58.7 (C-6), 108.5 (C-11), 138.6 and 142.9 (C-3 and C-4), 148.5 (C-12), 214.7 (C-14). HRMS calcd for C<sub>27</sub>H<sub>48</sub>O<sub>2</sub>Si<sub>2</sub> 460.3190, found 460.3180.

**20b**: colorless needles,  $R_f$  = 0.33 (hexane:Et<sub>2</sub>O = 17:1), mp 103 °C. IR (KBr) 1700, 1630 cm<sup>-1</sup>. <sup>1</sup>H-NMR  $\delta$  -0.02 (9H, s, SiMe<sub>3</sub>), 0.19 (9H, s, OSiMe<sub>3</sub>), 0.90 (3H, d,  $J$  = 6.8 Hz, CHMe), 0.95 (3H, d,  $J$  = 6.8 Hz, CHMe), 1.19 (3H, s, 9-CH<sub>3</sub>), 1.17-1.22 (1H, m, H-8), 1.54-1.65 (4H, m, H-1, H-7, and H-8), 1.93 (1H, dd,  $J$  = 8.1, 6.6 Hz, H-10), 2.18 (1H, ddd,  $J$  = 16.0, 9.4, 6.4 Hz, H-2), 2.26 (1H, ddd,  $J$  = 16.0, 9.4, 6.0 Hz, H-2), 2.45 (1H, ddd,  $J$  = 13.3, 7.3, 4.7 Hz, H-6), 2.55 (1H, dddd,  $J$  = 13.3, 13.3, 13.3, 4.3 Hz, H-7), 2.75 (1H, sep,  $J$  = 6.8 Hz, CHMe), 3.00 (1H, d,  $J$  = 19.7 Hz, H-13), 3.31 (1H, d,  $J$  = 19.7 Hz, H-13), 3.44 (1H, dd,  $J$  = 7.3, 6.6 Hz, H-5), 4.94 (1H, dd,  $J$  = 8.1, 2.1 Hz, H-11). <sup>13</sup>C NMR  $\delta$  -1.1 (SiMe<sub>3</sub>), 0.7 (OSiMe<sub>3</sub>), 20.4 and 22.1 (CHMe<sub>2</sub>), 22.8 (C-7), 25.2 (9-Me), 27.0 (CHMe<sub>2</sub>), 27.5 (C-10), 28.1 (C-2), 38.8 (C-5), 40.3 (C-1 and C-8), 46.8 (C-9), 49.2 (C-13), 58.7 (C-6), 108.7 (C-11), 138.6 and 142.9 (C-3 and C-4), 148.5 (C-12), 214.5 (C-14). HRMS calcd for C<sub>24</sub>H<sub>42</sub>O<sub>2</sub>Si<sub>2</sub> 418.2723, found 418.2729.

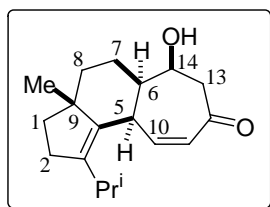
## 21



To an ice-cooled solution of **20b** (670 mg, 1.60 mmol) in Et<sub>2</sub>O (14 mL) was added DIBAL (0.95 M in hexane, 2.02 mL, 1.92 mmol). After being stirred at the same temperature for 10 min, the reaction mixture was quenched with addition of MeOH, and filtered through a pad of Celite and concentrated. The residual oil was subjected to column chromatography (silica gel, 40 g; elution with 2:1 hexane-Et<sub>2</sub>O) to give **21** (488 mg, 72%). a colorless oil,  $R_f$  = 0.54 (hexane:Et<sub>2</sub>O = 1:1).

IR (film) 3395 cm<sup>-1</sup>. <sup>1</sup>H-NMR (substantial peak broadening was observed):  $\delta$  0.03 (9H, s, SiMe<sub>3</sub>), 0.17 (9H, s, OSiMe<sub>3</sub>), 0.93 (3H, d,  $J$  = 6.8 Hz, CHMe), 0.96 (3H, d,  $J$  = 6.8 Hz, CHMe), 1.11 (3H, s, 9-CH<sub>3</sub>), 1.12-1.20 (1H, br m), 1.47-1.62 (3H, br m), 1.75 (1H, br s), 2.14 (1H, dm,  $J$  = 15.8 Hz, H-2), 2.24 (1H, ddd,  $J$  = 15.8, 8.6, 6.4 Hz, H-2), 2.45 (1H, dd,  $J$  = 18.2, 6.2 Hz, H-13), 2.60 (1H, dm,  $J$  = 18.2 Hz, H-13), 2.71-2.79 (1H, br s, CHMe<sub>2</sub>), 3.32-3.27 (1H, br s, H-5), 3.95-4.08 (1H, br s, H-14), 4.92-4.96 (1H, br s, H-11). <sup>13</sup>C NMR  $\delta$  0.68, 20.9, 22.0, 24.2, 25.4, 26.9, 27.3, 41.4, 47.2, 48.5, 70.3 (C-14), 100.9 (C-11), 113.0, 135.3, 141.3 (C-12). HRMS calcd for C<sub>24</sub>H<sub>44</sub>O<sub>2</sub>Si<sub>2</sub> 420.7760, found 420.2871.

## 22

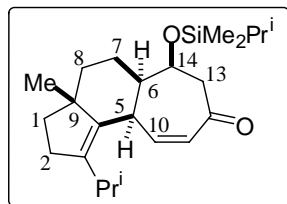


To an ice-cooled solution of **21** (329 mg, 0.782 mmol) in THF (8.3 mL) was added NBS (145.7 mg, 0.821 mmol). The reaction mixture was stirred at the same temperature for 10 min before addition of TBAF (1.0 M in THF, 782  $\mu$ L, 0.782 mmol). After being stirred at the same temperature for 5 min, the mixture was poured into saturated aqueous NaHCO<sub>3</sub> solution. Phases were separated, and the aqueous phase was extracted with Et<sub>2</sub>O. Combined organic phases were successively washed with

water and saturated brine, dried, and concentrated. The residual oil was subjected to column chromatography (silica gel, 25 g; elution with 1:2 hexane-Et<sub>2</sub>O) to give **22** (169 mg, 79%). a yellow oil,  $R_f$  = 0.25 (hexane:Et<sub>2</sub>O = 1:2). IR (film) 3430, 1650 cm<sup>-1</sup>. <sup>1</sup>H-NMR  $\delta$  0.93 (3H, d,  $J$  = 6.8 Hz, CHMe), 0.97 (3H, d,  $J$  = 6.8 Hz, CHMe), 1.02 (3H, s, 9-CH<sub>3</sub>), 1.29 (1H, ddd,  $J$  = 13.2, 13.2, 3.7 Hz, H-8), 1.46-1.59 (2H, m, H-1 and H-7), 1.64-1.73 (2H, m, H-1 and H-7), 1.77 (1H, ddd,  $J$  = 13.2, 3.2, 3.2 Hz, H-8), 1.80-1.86 (1H, m, H-6), 2.20 (1H, dd,  $J$  = 15.8, 8.8 Hz, H-2), 2.33 (1H, ddd,  $J$  = 15.8, 8.8, 2.1 Hz, H-2), 2.63 (1H, sep,  $J$  = 6.8 Hz, CHMe<sub>2</sub>), 2.83 (1H, dd,  $J$  = 16.8, 1.5 Hz, H-13), 2.96 (1H, dd,  $J$  = 16.8, 8.6 Hz, H-13), 3.87 (1H, ddd,  $J$  = 8.6, 8.6, 1.5 Hz, H-14), 3.92 (1H, m, H-5), 5.89 (1H, dd,  $J$  = 12.2, 2.6 Hz, H-11), 6.21 (1H, dd,  $J$  = 12.2, 3.9 Hz, H-10). <sup>13</sup>C NMR  $\delta$  21.6 (CHMe<sub>2</sub>), 24.1 (CHMe<sub>2</sub>), 25.0 (C-7), 26.5 (CHMe<sub>2</sub>), 27.9 (C-2), 36.8 (C-5), 40.5 (C-

1), 40.9 (C-8), 46.4 (C-6), 47.1 (C-9), 49.9 (C-13), 70.9 (C-14), 130.8 (C-11), 138.4 and 141.7 (C-3 and C-4), 150.6 (C-10), 201.5 (C-12). HRMS calcd for  $C_{18}H_{26}O_2$  274.1933, found 274.1946.

## 23



To an ice-cooled solution of **22** (62 mg, 0.226 mmol) in  $CH_2Cl_2$  (1 mL) was added imidazole (77 mg, 1.13 mmol) and *i*-PrMe<sub>2</sub>SiCl (39  $\mu$ L, 0.248 mmol). The solution was stirred at the same temperature for 10 min, and poured into saturated aqueous  $NaHCO_3$  solution. Phases were separated, the aqueous phase was extracted with  $Et_2O$ . Combined organic phases were successively washed with water and saturated brine, dried, and concentrated. The residual oil was subjected to column chromatography (silica gel, 7 g; elution with 8:1 hexane- $Et_2O$ ) to give **23** (78 mg, 92%). a pale yellow oil,  $R_f$  = 0.33 (hexane: $Et_2O$  = 8:1). IR (film) 1660  $cm^{-1}$ .  $^1H$ -NMR  $\delta$  0.05 and 0.06 (each 3H, s, SiMe), 0.79 (1H, sep,  $J$  = 7.3 Hz, SiHMe<sub>2</sub>), 0.92-0.98 (12H, m, CHMe<sub>2</sub>, SiCHMe<sub>2</sub>), 1.01 (3H, s, 9-Me), 1.29 (1H, ddd,  $J$  = 12.8, 12.8, 3.7 Hz, H-8), 1.46-1.53 (2H, m, H-1 and H-7), 1.59 (1H, dddd,  $J$  = 13.3, 12.8, 12.8, 3.2 Hz, H-7), 1.71 (1H, ddd,  $J$  = 10.7, 7.7, 1.5 Hz, H-1), 1.79 (1H, ddd,  $J$  = 12.8, 3.2, 3.2 Hz, H-8), 1.79-1.86 (1H, m, H-6), 2.21 (1H, ddd,  $J$  = 15.8, 9.4, 1.3 Hz, H-2), 2.34 (1H, ddd,  $J$  = 15.8, 8.5, 1.7 Hz, H-2), 2.65 (1H, sep,  $J$  = 6.8 Hz, CHMe<sub>2</sub>), 2.79 (1H, dd,  $J$  = 16.6, 2.6 Hz, H-13), 2.85 (1H, dd,  $J$  = 16.6, 6.8 Hz, H-13), 3.90 (1H, ddd,  $J$  = 6.8, 6.6, 2.6 Hz, H-14), 3.95 (1H, ddd,  $J$  = 5.1, 3.0, 2.7 Hz, H-5), 5.88 (1H, dd,  $J$  = 12.5, 2.7 Hz, H-11), 6.10 (1H, dd,  $J$  = 12.5, 3.0 Hz, H-10).  $^{13}C$  NMR  $\delta$  -3.8 and -3.5 (SiMe<sub>2</sub>), 14.9, 17.0, 21.5, 21.6, 24.3 (C-7), 26.6 (CHMe<sub>2</sub>), 28.0 (C-2), 37.5 (C-5), 40.5 (C-1), 41.4 (C-8), 47.0 (C-6), 47.5 (C-9), 49.4 (C-13), 71.1 (C-14), 130.5 (C-11), 139.2 and 140.8 (C-3 and C-4), 149.7 (C-10), 201.4 (C-12). HRMS calcd for  $C_{23}H_{38}O_2Si$  374.2641, found 374.2662.