Synthesis of the Apoptosis Inducing Agent Apoptolidin. Assembly of the C(16)-C(28) Fragment.

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Experimental Section

Materials and Methods. All reactions were carried out under a nitrogen or argon atmosphere using dry glassware which had been flame-dried under a stream of nitrogen, unless otherwise noted. All necessary solvents were purified prior to use. Tetrahydrofuran and ethyl ether were distilled from sodium/benzophenone; dichloromethane was distilled from calcium hydride. Pyridine and triethylamine were distilled from calcium hydride and stored over sodium hydroxide. Toluene was distilled from calcium hydride.

Reactions were monitored by thin-layer chromatography (TLC) using 0.25-mm E. Merck precoated silica gel plates. Visualization was accomplished with UV light and aqueous ceric ammonium molybdate solution or anisaldehyde stain followed by charring on a hot-plate. Flash chromatography was perfomed with the indicated solvents using silica gel 60 (particle size 0.040-0.063 mm). Yields refer to chromatographically and spectroscopically pure compounds unless otherwise stated.

Melting points are uncorrected unless otherwise noted. ^{1}H and ^{13}C NMR spectra were recorded on a Varian-200, 300 and 500 spectrometers at ambient temperature. ^{1}H and ^{13}C NMR data are reported as δ values relative to tetramethylsilane. Infrared spectra were recorded on Mattson Galaxy Series FT-IR 5000 or FT-IR 6021 spectrometers. Optical rotations were measured on a Jasco DIP-181 digital polarimeter at ambient temperature. High-resolution mass spectra were obtained at Texas A&M University Mass Spectrometry Service Center by Dr. Lloyd Sumners on a VG Analytical 70S high resolution, double focusing, sectored (EB) mass spectrometer.

2: Obtained as a light yellow oil: $[\alpha]^{24}_{D}$ +34.1° (c 1.7, $CHCl_3$); IR (CH_2Cl_2) 3436, 1107 cm^{-1}; ^{1}H-NMR (300 MHz, C_6D_6) δ 7.5-7.1 (m, 10H), 4.84 (d, J = 11.7 Hz, 1H), 4.73 (d, J = 11.7 Hz, 1H), 4.56 (m, 1H), 4.46 (s, 2H), 4.40 (m, 2H), 4.31 (s, 2H), 3.97 (m, 1H), 3.77 (dd, J = 11.1, 4.5 Hz, 1H), 3.68 (d, J = 4.2 Hz, 1H), 3.49 (dd, J = 9.9, 5.4 Hz, 1H), 3.42 (dd, J = 9.9, 5.1 Hz, 1H), 3.38 (dd, J = 9.9, 6.0 Hz, 1H), 3.29 (s, 3H), 3.26 (dd, J = 9.9, 6.0 Hz, 1H), 3.12 (s, 3H), 3.11 (s, 3H), 2.26 (m, 1H), 2.13 (ddd, J = 15.0, 7.5, 2.4 Hz, 1H), 1.86 (m, 2H), 1.56 (m, 2H), 1.26 (d, J = 6.3 Hz, 3H), 1.04 (d, J = 6.9 Hz, 3H); ^{13}C-NMR (75 MHz, C_6D_6) δ 140.28, 139.15, 128.97, 128.71, 128.14, 128.06, 102.20, 98.85, 97.93, 81.75, 79.07, 76.89, 75.84, 73.81, 73.26, 73.17, 69.83, 67.89, 59.23, 58.41, 56.40, 40.11, 37.09, 37.01, 36.36, 12.63, 5.68; HRMS(FAB) *m/z* 629.3299 [$(M+Na)^+$, cald for $C_{33}H_{50}O_{10}Na$ 629.3302].

3: Obtained as a colorless oil: $[\alpha]^{22}_{D}$ -1.4° (c 4.2, $CHCl_3$); IR (CH_2Cl_2) 3447, 1711 cm^{-1}; ^{1}H-NMR (300 MHz, C_6D_6) δ 7.4-7.1 (m, 10H), 4.77 (d, J = 11.7 Hz, 1H), 4.59-4.49 (m, 2H) 4.529 (d, J = 11.7 Hz, 1H), 4.527 (d, J = 6.6 Hz, 1H), 4.45 (d, J = 6.6 Hz, 1H), 4.29 (s, 2H), 4.23 (dd, J = 12.6, 3.0 Hz, 1H), 4.00 (s, br, 1H), 3.77 (td, J = 9.0, 3.9 Hz, 1H), 3.68 (td, J = 8.4, 4.8 Hz, 1H), 3.42 (dd, J = 10.2, 5.4 Hz, 1H), 3.338 (dd, J = 12.3, 5.1 Hz, 1H), 3.337 (dd, J = 8.4, 5.4 Hz, 1H), 3.236 (s, 3H), 3.235 (dd, J = 10.5, 3.9 Hz, 1H), 3.12 (s, 3H), 3.07 (s, 3H), 2.07-1.78 (m, 4H), 1.20 (d, J = 6.6 Hz, 3H), 0.97 (s, 9H), 0.82 (d, J = 7.2 Hz, 3H), 0.15 (s, 3H), 0.12 (s, 3H); ^{13}C-NMR (125 MHz, C_6D_6) δ 212.75, 140.78, 139.28, 128.91, 128.83, 128.55, 128.06, 127.92, 127.83, 97.88, 86.01, 78.29, 76.42, 76.25, 73.74, 72.98, 72.50, 72.64, 71.69, 70.62, 59.15, 58.39, 56.38, 47.24, 40.93, 37.44, 36.62, 26.55, 18.67, 11.54, 7.70, -3.86, -4.02; HRMS(FAB) *m/z* 743.4168 [$(M+Na)^+$, cald for $C_{39}H_{64}O_{10}Na$ 743.4167].

4: Obtained as a light yellow oil: $[\alpha]^{20}_{D:}$ -12.3° (c 4.0, $CHCl_3$): IR ($CHCl_3$): 3069, 2975, 1724, 1091 cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 9.83 (s, 1H), 7.29-7.42 (m, 5H), 4.58 (d, J = 1.8 Hz, 2H), 3.90-3.97 (m, 1H), 3.58 (d, J = 4.8 Hz, 2H), 3.45 (s, 3H), 2.69-2.72 (m, 2H); ^{13}C-NMR (75MHz, $CDCl_3$): 199.2, 136.3, 126.8, 126.2, 126.1, 73.7, 71.9, 69.3, 56.1, 44.5, HRMS (FAB), *m/z* 209.1172 [$(M+H)^+$, cald for $C_{12}H_{17}O_3$ 209.1177]

ent-6: Obtained as a colorless oil: $[\alpha]^{20}_{D}$ +20.8° (c 2.6, CH_2Cl_2); IR (CH_2Cl_2) 2955, 1393, 1260 cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$) δ 3.80 (m, 1H), 3.62 (m, 2H), 3.42 (m, 2H), 1.70 (m, 1H), 1.52 (m, 1H), 0.097 (s, 9H), 0.085 (s, 9H), 0.084 (s, 9H); ^{13}C-NMR (75 MHz, $CDCl_3$) δ 70.2, 67.1, 59.0, 36.9, 0.36, -0.48, -0.54.

7: Obtained as a colorless oil: $[\alpha]^{20}_{D}$ -1.4° (c 5.8, $CHCl_3$). IR ($CHCl_3$): 3018, 1629, 1265 cm^{-1}; **¹**H-NMR (300 MHz, $CDCl_3$): δ 7.56 (dd, J = 8.7, 0.3 Hz, 2H), 7.22 (m, 2H), 7.03-7.14 (m, 3H), 6.75 (dd, J = 6.9, 1.2 Hz, 2H), 5.34 (s, 1H), 4.32 (s, 2H), 3.88-3.94 (ddd, J = 9.6, 4.8, 1.2 Hz, 1H), 3.73-3.81 (m, 1H), 3.41-3.50 (m, 2H), 3.24-3.30 (dd, J = 9.6, 4.8 Hz, 1H), 3.18 (s, 3H), 1.57-1.69 (m, 1H). 0.98-1.03 (m, 1H). ^{13}C-NMR (75MHz, $CDCl_3$): δ 160.0, 138.7, 131.9, 128.1, 127.4, 113.3, 101.1, 76.1, 73.1, 73.0, 66.3, 54.4, 28.2. HRMS (FAB), *m/z* 315.1599, [$(M+H)^+$, cald for $C_{19}H_{23}O_4$ 315.1596]

8: Obtained as a colorless oil: IR ($CHCl_3$): 3462, 1615, 1091 cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$) δ 7.20-7.34 (m, 7H), 6.85(d, J = 9.9 Hz , 2H), 4.53 (s, 2H), 4.41 (s, 2H), 4.00 (m, 1H), 3.78 (s, 3H), 3.60 (m, 2H), 3.40 (m, 2H), 1.75 (q, J = 12.0, 5.7 Hz, 2H). ^{13}C-NMR (75MHz, $CDCl_3$): δ 159.2, 138.6, 130.7, 129.1, 128.2, 127.5, 113.7, 74.8, 72.9, 72.4, 68.4, 67.2, 54.5, 33.6; HRMS (FAB), *m/z* 316.1686, [$(M+H)^+$, cald for $C_{19}H_{24}O_4$ 316.1675]

10: Obtained as a colorless oil: $[\alpha]^{20}_D$ –8.1° (c 3.2, CH_2Cl_2); IR (CH_2Cl_2) 1624, 1250 cm^{-1}; ^{1}H-NMR (300 MHz, C_6D_6) δ 7.61 (d, J = 8.4 Hz, 2H), 6.80 (d, J = 8.4 Hz, 2H), 5.38 (s, 1H), 3.97 (ddd, J = 11.4, 5.1, 1.2 Hz, 1H), 3.79 (app dquin, J = 5.4, 2.4 Hz, 1H), 3.51 (dt, J = 11.7, 2.4 Hz, 1H), 3.40 (dd, J = 9.9, 5.7 Hz, 1H), 3.25 (s, 3H), 3.21 (dd, J = 10.2, 4.8 Hz, 1H), 3.14 (s, 3H), 1.69 (ddd, J = 24.4, 12.9, 5.1 Hz, 1H), 1.06 (ddd, J = 13.0, 3.6, 1.5 Hz, 1H); ^{13}C-NMR (75 MHz, C_6D_6) δ 160.3, 132.2, 128.0, 113.7, 101.4, 76.4, 75.9, 66.6, 59.1, 54.7, 28.4; HRMS (EI) *m/z* 238.1216 [M^+, cald for $C_{13}H_{18}O_4$ 238.1205]

11: Obtained as a colorless oil: $[\alpha]^{20}_D$ +1.0° (c 3.8, CH_2Cl_2); IR (CH_2Cl_2) 3498, 1609, 1035 cm^{-1}; ^{1}H-NMR (300 MHz, C_6D_6) δ 7.16 (d, J = 8.7 Hz, 2H), 6.76 (d, J = 8.7 Hz, 2H), 4.25 (s, 2H), 3.99 (m, 1H), 3.50 (s, 3H), 3.29 (s, 3H), 3.15 (d, J = 5.4 Hz, 2H), 3.03 (s, 3H), 2.63 (d, J = 3.0 Hz, 1H, OH), 1.72 (q, J = 6.0 Hz, 2H); ^{13}C-NMR (75 MHz, C_6D_6) δ 159.7, 131.0, 129.4, 114.1, 77.2, 72.9, 68.9, 67.7, 58.6, 54.7, 33.9; HRMS(EI) *m/z* 240.1367 [M^+, cald for $C_{13}H_{20}O_4$ 240.1362].

12: Obtained as a light yellow oil: $[\alpha]^{20}_D$ +31.8° (c 2.7, $CHCl_3$); IR (CH_2Cl_2) 1720, 1103 cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$) δ 9.75 (t, J = 2.0, 1H), 7.31 (m, 5H), 4.62 (q, J = 13.5 Hz, 2H), 4.08 (app quin, J = 5.4 Hz, 1H), 3.48 (m, 2H), 3.35 (s, 3H), 2.67 (m, 2H); ^{13}C-NMR (75 MHz, $CDCl_3$) δ 200.7, 138.1, 128.4, 127.8, 127.7, 74.1, 73.2, 72.1, 59.2, 46.3; HRMS(FAB) *m/z* 209.1170 [$(M+H)^+$, cald for $C_{12}H_{17}O_3$ 209.1178].

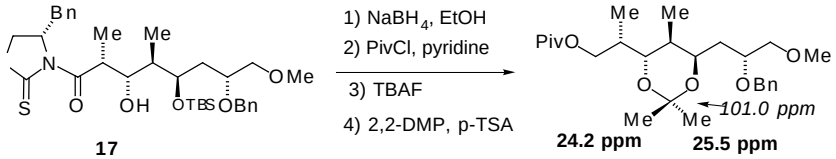
14: Obtained as a colorless oil: $[\alpha]^{20}_D$ +76.0° (c 2.0, $CHCl_3$); IR (CH_2Cl_2) 3510, 1700, 1601, 1188 cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$) δ 7.33-7.20 (m, 10H), 4.91 (ddd, J = 13.2, 6.6, 3.0 Hz, 1H), 4.70 (d, J = 11.7 Hz, 1H), 4.63 (qd, J = 6.9, 3.6 Hz, 1H), 4.57 (d, J = 11.7 Hz, 1H), 4.31-4.20 (m, 3H), 3.85 (m, 1H), 3.52 (dd, J = 10.2, 5.1 Hz, 1H), 3.46 (dd, J = 10.2, 5.1 Hz, 1H), 3.36 (s, 3H), 3.23 (dd, J = 13.2, 3.6 Hz, 1H), 2.74 (dd, J = 13.2, 10.2 Hz, 1H), 1.77 (ddd, J = 14.4, 9.3, 3.9 Hz, 1H), 1.68 (ddd, J = 14.4, 7.8, 2.7 Hz, 1H), 1.29 (d, J = 6.9 Hz, 3H); ^{13}C-NMR (75 MHz, $CDCl_3$) δ 185.1, 177.6, 138.5, 135.1, 129.4, 128.9, 128.4, 127.8, 127.6, 127.4, 75.5, 75.0, 72.3, 70.1, 68.7, 60.1, 59.2, 42.8, 37.5, 36.6, 11.1; HRMS(FAB) *m/z* 480.1844 [$(M+Na)^+$, cald for $C_{25}H_{31}O_5NSNa$ 480.1821].

15: Obtained as a colorless oil: $[\alpha]^{22}_D$ +20.9° (c 2.3, $CHCl_3$); ^{1}H-NMR (300 MHz, C_6D_6) δ 4.11 (dd, J = 11.1, 6.3 Hz, 1H), 3.91-4.00 (m, 2H), 3.76 (dt, J = 9.6, 6.0 Hz, 1H), 3.30 (dd, J = 9.6, 6.0 Hz, 1H), 3.16 (dd, J = 10.5, 4.2 Hz, 1H), 3.14 (s, 3H), 1.75 (m, 1H), 1.46 (m, 1H), 1.32 (s, 3H), 1.31 (s, 3H), 1.16 (s, 9H), 0.96(d, J=6.6 Hz, 3H); ^{13}C-NMR (75MHz, C_6D_6) δ 177.6, 100.4, 75.5, 67.1, 66.6, 66.0, 58.8, 38.8, 37.6, 32.4, 27.3, 24.7, 24.6, 12.2 .HRMS (FAB), *m/z* 325.1990 [$(M+Na)^+$, cald for 325.1991]

16: Obtained as a light yellow oil: $[\alpha]^{20}_D$ +79.3° (c 2.9, $CHCl_3$); IR ($CHCl_3$) 1722, 1096 cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$) δ 9.76 (d, J = 0.9 Hz, 1H), 7.33-7.25 (m, 5H), 4.72 (d, J = 11.7 Hz, 1H), 4.50 (d, J=11.7 Hz, 1H), 4.29 (ddd, J = 8.1, 4.5, 3.3 Hz, 1H), 3.67 (m, 1H), 3.46 (d, J = 1.5 Hz, 1H), 3.44 (d, J = 2.1 Hz, 1H), 3.35 (s, 3H), 2.39 (qdd, J = 6.9, 3.3, 0.9 Hz, 1H), 1.72 (ddd, J = 14.1, 8.7, 4.5 Hz, 1H), 1.52 (ddd, J = 14.1, 8.1, 3.6 Hz, 1H), 1.02 (d, J = 6.9 Hz, 3H), 0.84 (s, 9H), 0.03 (s, 3H), 0.01 (s, 3H); ^{13}C-NMR (75 MHz, $CDCl_3$) δ 205.3, 138.6, 128.3, 127.5, 127.4, 75.2, 75.0, 71.4, 69.7, 59.2, 52.1, 37.4, 25.7, 18.0, 7.9, -4.3, -4.4; HRMS (FAB) *m/z* 381.2443 $[(M + H)^+$, cald for $C_{21}H_{37}O_4Si$, 381.2461].

17: Obtained as a yellow oil: $[\alpha]^{20}_D$ +104.5° (c 20.1, CH_2Cl_2); IR (CH_2Cl_2) 3455, 1711, 1192 cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$) δ 7.2-7.3 (m, 10H), 5.01 (m, 1H), 4.82 (dq, J = 6.9, 2.4 Hz, 1H), 4.76 (d, J = 11.7 Hz, 1H), 4.51 (d, J = 11.7 Hz, 1H), 4.24-4.32 (m, 3H), 4.15 (dt, J = 8.1, 3.0 Hz, 1H), 3.97 (s, br, 1H), 3.69 (m, 1H), 3.53 (dd, J = 10.2, 3.9 Hz, 1H), 3.49 (dd, J = 10.2, 5.4 Hz, 1H), 3.37 (s, 3H), 3.29 (dd, J = 13.6, 3.3 Hz, 1H), 2.72 (dd, J = 13.4, 10.0 Hz, 1H), 1.82-2.02 (m, 2H), 1.73, (ddd, J = 14.3, 8.4, 3.3 Hz, 1H), 1.16 (d, J = 6.9 Hz, 3H), 0.89 (d, J = 6.9 Hz, 3H), 0.87 (s, 9H), 0.10 (s, 3H), 0.04 (s, 3H); ^{13}C-NMR (75 MHz, $CDCl_3$) δ 185.31, 177.03, 138.97, 135.44, 129.40, 128.92, 128.28, 127.35, 127.28, 127.24, 75.66, 75.25, 73.65, 72.30, 71.23, 70.29, 59.98, 59.13, 41.11, 40.59, 37.78, 35.35, 25.90, 17.99, 12.47, 8.66, -4.18, -4.74; HRMS(FAB) *m/z*, 630.3278 $[(M + H)^+$, cald for $C_{34}H_{52}O_6SiSN$, 630.3285].

Stereochemical proof of 17



17 **17a**

17a: Obtained as a colorless oil: $[\alpha]^{22}_D$ +35.5° (c 2.9, $CHCl_3$); IR (CH_2Cl_2) 1722, 1268, 736 cm^{-1}; ^{1}H-NMR (300 MHz, C_6D_6) δ 7.4-7.1 (m, 5H), 4.77 (d, J = 11.7 Hz, 1H), 4.51 (d, J = 11.7 Hz, 1H), 4.22 (ddd, J = 10.8, 4.8, 2.4 Hz, 1H), 4.12 (dd, J = 10.8, 8.1 Hz, 1H), 4.01 (dd, J = 10.8, 6.0 Hz, 1H), 3.86 (m, 1H), 3.38 (d, J = 10.5 Hz, 1H), 3.37 (dd, J = 9.9, 5.4 Hz, 1H), 3.29 (dd, J = 9.9, 4.5 Hz, 1H), 3.11 (s, 3H), 1.80-1.50 (m, 4H), 1.32 (s, 3H), 1.29 (s, 3H), 1.17 (s, 9H), 0.85 (d, J = 6.9 Hz, 3H), 0.69 (d, J = 6.9 Hz, 3H); ^{13}C-NMR (75 MHz, C_6D_6) δ 177.79, 140.22, 128.88, 128.07, 127.90, 100.99, 76.65, 76.04, 74.23, 72.97, 66.74, 66.37, 59.27, 39.18, 37.30, 36.12, 34.93, 27.76, 25.55, 24.19, 12.60, 11.14; HRMS(FAB) *m/z* 473.2860 $[(M+Na)^+$, cald for $C_{26}H_{42}O_6Na$, 473.2879].

18: $[\alpha]^{22}_D$ +9.4° (c 2.4, $CHCl_3$); IR ($CHCl_3$) 1665, 1127 cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$) δ 7.2-7.4 (m, 5H), 4.64 (d, J = 12.3Hz, 1H), 4.52 (d, J = 12.3 Hz, 1H), 4.10 (dd, J = 8.1, 2.7 Hz, 1H), 3.97 (m, 1H), 3.60 (s, 3H), 3.51 (m, 1H), 3.42(d, J = 4.5 Hz, 2H), 3.34 (s, 3H), 3.12 (s, 3H), 2.88 (m. 1H); ^{13}C-NMR

(75MHz, $CDCl_3$) δ 176.3, 138.8, 128.2, 127.6, 127.3, 75.8. 75.1, 73.7, 71.5, 70.2, 60.6, 59.1, 43.2, 38.6, 38.1, 26.0, 18.2, 10.1, 9.6, 7.1, 5.5, -3.0, -3.7.

19: $[\alpha]^{21}_D$ -16.9° (c 3.08, $CHCl_3$); IR (CH_2Cl_2) 1690, 1265, 1066 cm^{-1}; ^{1}H-NMR (300 MHz, C_6D_6) δ 7.4-7.1 (m, 5H), 5.80 (s, 1H), 4.72 (d, J= 11.7 Hz, 1H), 4.61 (d, J = 11.7 Hz, 1H), 4.52 (s, 2H), 4.35 (td, J = 5.4, 2.1 Hz, 1H), 4.25 (dd, J = 8.1, 2.4 Hz, 1H), 3.76 (quin, J = 4.8 Hz, 1H), 3.48 (dd, J = 9.9, 5.4 Hz, 1H), 3.36 (dd, J = 9.9, 4.8 Hz, 1H), 3.19 (s, 3H), 3.16 (s, 3H), 2.33 (m, 1H), 2.09 (dd, J = 14.1, 7.5 Hz, 1H), 2.00 (dt, J = 14.4, 5.1 Hz, 1H), 1.88 (m, 1H), 1.12 (t, J = 7.8 Hz, 9H), 1.06 (s, 9H), 0.98 (d, J = 6.9 Hz, 3H), 0.96 (d, J = 6.9 Hz, 3H), 0.84 (m, 6H), 0.32 (s, 9H), 0.27 (s, 3H), 0.24 (s, 3H); ^{13}C-NMR (75 MHz, C_6D_6) δ 140.20, 138.67, 128.80, 128.07, 127.82, 126.61, 96.75, 76.99, 76.12, 74.39, 72.26, 71.76, 59.26, 56.03, 43.79, 40.48, 39.87, 26.87, 19.11, 11.22, 10.74, 8.07, 6.55, 1.49, -2.33, -2.92.

21: Obtained as a colorless oil: ^{1}H-NMR (300 MHz, C_6D_6) δ 7.44-7.16 (m, 10H), 4.81 (t, J = 6.0 Hz, 1H), 4.75 (d, J = 11.7 Hz, 1H), 4.61 (d, J = 11.7 Hz, 1H), 4.36 (d, J = 6.9 Hz, 1H), 4.33 (s, 2H), 4.28 (d, J = 6.9 Hz, 1H), 4.22 (ddd, J = 10.8, 3.6, 2.1 Hz, 1H), 4.11 (dd, J = 6.9, 2.1 Hz, 1H), 3.95 (d, J = 9.9 Hz, 1H), 3.80 (dq, J = 7.2, 4.5 Hz, 1H), 3.67 (dtd, J = 10.8, 4.5, 2.1 Hz, 1H), 3.57 (s, 2H), 3.55 (dd, J = 6.9, 3.0 Hz, 1H), 3.49 (dd, J = 9.9, 5.4 Hz, 1H), 3.41 (d, J = 4.5 Hz, 1H), 3.39 (dd, J = 10.8, 4.5 Hz, 1H), 3.51 (s, 3H), 3.15 (s, 3H), 3.12 (s, 3H), 2.25 (q, J = 6.9 Hz, 1H), 2.13-1.96 (m, 3H), 1.85 (dqd, J = 9.9, 6.9, 1.2 Hz, 1H), 1.64 (ddd, J = 14.4, 10.8, 2.1 Hz, 1H), 1.46 (s, 3H), 1.23 (s, 3H), 1.05 (s, 9H), 1.03 (d, J = 6.9 Hz, 3H), 0.96 (d, J = 6.9 Hz, 3H), 0.32 (s, 3H), 0.26 (s, 3H); ^{13}C-NMR (75 MHz, C_6D_6) δ 140.27, 139.46, 128.93, 128.82, 128.07, 127.77, 101.44, 98.20, 80.72, 80.23, 77.56, 77.16, 76.91, 76.05, 73.76, 73.65, 72.13, 69.43, 68.27, 59.25, 58.54, 55.88, 41.73, 39.24, 35.36, 33.41, 26.71, 25.06, 24.45, 18.96, 9.48, 6.08, -3.57, -4.01.

22: Obtained as a colorless oil: $[\alpha]^{24}_D$ -40.0° (c 0.5, $CHCl_3$); IR (CH_2Cl_2) 1739, 1107 cm^{-1}; ^{1}H-NMR (500 MHz, C_6D_6) δ 7.41-7.10 (m, 10H), 5.85 (ddd, J = 9.0, 3.5, 2.0 Hz, 1H), 4.70 (d, J = 6.9 Hz, 1H), 4.65 (d, J = 12.0 Hz, 1H), 4.54 (d, J = 12.0 Hz, 1H), 4.53 (d, J = 6.9 Hz, 1H), 4.45 (dd, J = 7.5, 5.0 Hz, 1H), 4.32 (s, 2H), 4.14 (d, J = 9.0, 1.0 Hz, 1H), 3.90 (dd, J = 10.0, 1.5 Hz, 1H), 3.79 (dd, J = 9.5, 2.5 Hz, 1H), 3.67 (quin, J = 5.1 Hz, 1H), 3.51-3.31 (m, 6H), 3.35 (s, 3H), 3.17 (s, 3H), 3.14 (s, 3H), 2.11-1.84 (m, 6H), 1.80 (s, 3H), 1.53 (s, 3H), 1.50 (s, 3H), 1.05 (d, J = 6.5 Hz, 3H), 1.00 (s, 9H), 0.92 (d, J = 7.0 Hz, 3H), 0.18 (s, 3H), 0.13 (s, 3H); ^{13}C-NMR (75 MHz, C_6D_6) δ 170.06, 140.10, 139.42, 128.93, 128.82, 128.07, 127.87, 99.79, 98.86, 79.85, 77.75, 77.05, 75.47, 75.21, 73.78, 73.49, 73.08, 72.15, 70.86, 69.42, 59.24, 58.39, 56.27, 40.66, 39.36, 35.72, 30.61, 30.57, 26.64, 21.25, 20.69, 18.92, 8.14, 5.60, -2.97, -3.90.