Copper Phosphoramidite Catalyzed Enantoisoselective Ring-Opening of Oxabicyclic Alkenes: Remarkable Reversal of Stereocontrol

Fabio Bertozzi*a, Mauro Pineschi*b, Franco Macchia*, Leggy A. Arnold*, Adriaan J. Minnard† and Ben L. Feringa*a

a) Department of Organic and Molecular Inorganic Chemistry, University of Groningen, Nijenborgh 4, NL9747 AG Groningen, The Netherlands

b) Dipartimento di Chimica Bioorganica e Biofarmacia, Università di Pisa, Via Bonanno 33, 56126 Pisa, Italy

Supporting Information

General: All reactions were conducted in flame dried glassware with magnetic stirring under an atmosphere of argon. Toluene and diethyl ether were distilled from sodium and stored under argon; CH₂Cl₂ was distilled from P₂O₅. Et₂Zn (1.1 M solution in toluene), Me₂Zn (2.0 M solution in toluene), EtMgBr (3.0 M solution in Et₂O), MeMgBr (3.0 M solution in Et₂O), i-PrMgCl (2.0 M solution in THF) and n-BuMgBr (2.0 M solution in Et₂O) were purchased from Aldrich. Cu(OTf)₂ (Aldrich) and Zn(OTf)₂ (Aldrich) were dried before use.

Analytical TLC were performed on Alugram SIL G/UV254 silica gel sheets (Macherey-Nagel) with detection by 0.5% phosphomolybdic acid solution in 95% EtOH. Silica gel 60 (Macherey-Nagel 230-400 mesh) was used for flash chromatography. Solvents for extraction and chromatography were HPLC grade. Optical rotations were measured on a Perkin-Elmer 241 digital polarimeter with a 1 dm cell. ¹H NMR spectra were recorded on a Varian 200 MHz or 300 MHz and on a Brucker AC-200 (50MHz) spectrometers with complete proton decoupling. Chemical shifts are reported in ppm downfield with the solvent resonance, deuterochloroform: δ 7.24. ¹³C NMR spectra were recorded on a Varian 75 MHz and on a Brucker AC-200 (50MHz) spectrometers with complete proton decoupling. Chemical shifts are reported in ppm downfield with the solvent resonance, deuterochloroform: δ 77.0. Analytical high performance liquid chromatography (HPLC) was performed on a Waters 600E system controller equipped with a Waters 991 photodiode array detector. Enantiomeric excesses were determined by chiral HPLC using Daicel Chiralpak OD or AD columns in comparison with the racemic material. Mass spectra (HRMS) were obtained in an AEI MS-902; infrared spectra (IR) were obtained with a MATTSON 300 FTIR spectrometer.

General procedure for the copper phosphoramidite catalyzed enantoisoselective ring-opening of oxabicyclic alkenes: A solution of Cu(OTf)₂ (10.85 mg, 0.03 mmol) and chiral ligand 1S, 2R-2-Ethyl-1,2-dihydronaphth-1-ol (3a). The reaction was carried out following the general procedure employing chiral ligand 2 or 5 (0.07 mmol) in anhydrous toluene (5 ml) was stirred at r.t. for 40 min. The colorless solution was cooled to 0°C followed by subsequent addition of anhydrous Zn(OTf)₂ (363 mg, 1.0 mmol) and Et₂Zn (1.8 ml); conversion of the starting material (>98%) was reached within 40h. Purification by column chromatography (SiO₂, PrOH 99/1, flow: 1 ml/min, 82.71, H 8.1, found C, 82.65, H 8.4. The oxabenzonorbornadiene substrate (1.0 mmol) in toluene (1 ml). After 5 min., R₂Zn (2.0 mmol) was added and the stirred solution was allowed to warm slowly up to r.t. The mixture was quenched with saturated aqueous NH₄Cl solution (1 ml). Extraction with Et₂O and evaporation of the solution, gave a crude reaction mixture which was subjected to flash chromatography.

The reaction was carried out following the general procedure employing chiral ligand 2 (37.73 mg, 0.07 mmol), substrate 1 (144 mg, 1.0 mmol) and Et₂Zn (1.8 ml); conversion of the starting material (>98%) was reached within 40h. Purification by column chromatography (SiO₂, 15% AcOEt in hexanes) gave 3a (153 mg, 88%) as a white solid. M.p. = 34°-35°C (uncrist.); Rf = 0.27 on silica gel (hexanes/AcOEt 85/15); [α]D19 = -289.4° (c = 1.26, CHCl₃); IR (nujol) 3415, 3025, 2950, 1594, 1384, 1196, 792 cm⁻¹; ¹H NMR spectra were recorded on a Varian 200 MHz and on a Brucker AC-200 (50MHz) spectrometers with complete proton decoupling. Chemical shifts are reported in ppm downfield with the solvent resonance, deuterochloroform: δ 7.32. ¹³C NMR spectra were recorded on a Varian 75 MHz and on a Brucker AC-200 (50MHz) spectrometers with complete proton decoupling. Chemical shifts are reported in ppm downfield with the solvent resonance, deuterochloroform: δ 77.0. Analytical high performance liquid chromatography (HPLC) was performed on a Waters 600E system controller equipped with a Waters 991 photodiode array detector. Enantiomeric excesses were determined by chiral HPLC using Daicel Chiralpak OD or AD columns in comparison with the racemic material. Mass spectra (HRMS) were obtained in an AEI MS-902; infrared spectra (IR) were obtained with a MATTSON 300 FTIR spectrometer.

(-)-(1S, 2R)-2-Ethyl-1,2-dihydronaphth-1-ol (3a).

Employing chiral ligand 5 (42.10 mg, 0.07 mmol), substrate 1 (144 mg, 1.0 mmol) and Et₂Zn (1.8 ml), a conversion of the starting material (>98%) was reached within 14h. Purification by column chromatography (SiO₂, 15% AcOEt in hexanes) gave 3a (160 mg, 92%). The ee of 94% was determined by HPLC on chiral stationary phase (DAICEl CHIRALPAK OD).


S-1
The reaction was carried out following the general procedure employing chiral ligand 2 (37.73 mg, 0.07 mmol), substrate 1 (144 mg, 1.0 mmol) and Me₂Zn (1.0 ml); conversion of the starting material (35%) was reached within 160 h. Purification by column chromatography (SiO₂, 15% AcOEt in hexanes) gave 3b (27 mg, 17%) as a white solid. M.p. = 63°-64° (uncrist.); Rf = 0.23 on silica gel (hexanes/AcOEt 85/15); [α]D₂₀ = -116.8° (c = 0.61, CHCl₃); IR (nujol) 3328, 3038, 1492, 1311, 1195, 788 cm⁻¹; ¹H NMR (300 MHz, CDCl₃) δ 7.38 (1H, d, J = 6.2 Hz), 7.29-7.19 (2H, m), 7.09 (1H, d, J = 6.2 Hz), 6.43 (1H, d, J = 9.5 Hz), 5.91 (1H, dd, J = 9.5, 4.4 Hz), 4.44 (1H, d, J = 5.8 Hz), 2.68-2.56 (1H, m), 1.74 (1H, d, J = 5.8 Hz, OH), 1.05 (3H, d, J = 6.9 Hz); ¹³C NMR (75 MHz, CDCl₃): δ 135.7, 132.3, 128.3, 127.6, 127.2, 126.4, 125.8, 74.1, 37.4, 16.9; EI⁺-MS m/z (relative intensity): 160 (72), 145 (82), 142 (20), 131 (100), 117 (27), 115 (36); Anal. Calcd. for C₁₁H₁₂O: C, 82.46, H, 7.55; found C, 82.49, H, 7.51. The ee of 88% was determined by HPLC on chiral stationary phase (DAICEL CHIRALPAK AD, heptane/i-PrOH 99/1, flow: 1 ml/min, λ = 254), retention times were 33.5 min (major) and 35.8 min.

(-)-(1S,2R)-2-Isopropyl-1,2-dihydronaphth-1-ol (3c).

The reaction was carried out at –15°C, following the general procedure, employing chiral ligand 2 (37.73 mg, 0.07 mmol), substrate 1 (144 mg, 1.0 mmol) and i-Pr₂Zn (2.0 ml); conversion of the starting material (>98%) was reached within 26 h. Purification by column chromatography (SiO₂, 10% AcOEt in hexanes) gave 3c (103 mg, 55%) as an oil; Rf = 0.28 on silica gel (hexanes/AcOEt 85/15); [α]D₂₀ = -208.2° (c = 0.50, CHCl₃); IR (neat) 3391, 3034, 2960, 2928, 2874, 1635, 1458, 1384, 1368, 1265, 1033, 827 cm⁻¹; ¹H NMR (300 MHz, CDCl₃) δ 7.34 (1H, d, J = 6.9 Hz), 7.31-7.18 (2H, m), 7.11 (1H, d, J = 7.7 Hz), 6.55 (1H, d, J = 9.5 Hz), 5.97 (1H, dd, J = 9.5, 4.8 Hz), 4.65 (1H, dd, J = 6.6, 4.4 Hz), 2.46-2.38 (1H, m), 1.74 (1H, dq, J = 13.5, 6.6 Hz), 1.63 (1H, d, J = 6.6 Hz, OH), 0.88 (3H, d, J = 6.6 Hz), 0.80 (3H, d, J = 6.9 Hz); ¹³C NMR (50 MHz, CDCl₃): δ 136.4, 128.8, 128.4, 127.7, 126.8, 126.7, 126.5, 70.8, 41.9, 29.8, 20.7, 19.3; HRMS calcd. for C₁₃H₁₆O (M)⁺ 189.128, found 189.127. The ee of 91% was determined by HPLC on chiral stationary phase (DAICEL CHIRALPAK OD, heptane/i-PrOH 99/1, flow: 1 ml/min, λ = 254), retention times were 26.1 min (major) and 35.8 min.

(-)-(1S,2R)-2-α-Butyl-1,2-dihydronaphth-1-ol (3d).

The reaction was carried out following the general procedure employing chiral ligand 5 (42.10 mg, 0.07 mmol), substrate 1 (144 mg, 1.0 mmol) and n-But₂Zn (2.0 ml); conversion of the starting material (>98%) was reached within 68 h. Purification by column chromatography (SiO₂, 10% AcOEt in hexanes) gave 3d (192 mg, 95%) as a white solid. M.p. = 66°-67°C; Rf = 0.31 on silica gel (hexanes/AcOEt 85/15); [α]D₂₀ = -233.03° (c = 0.94, CHCl₃); IR (nujol) 3228, 3043, 2930, 1927, 1610, 1548, 1260, 1025, 792 cm⁻¹; ¹H NMR (300 MHz, CDCl₃) δ 7.30 (1H, d, J = 6.6 Hz), 7.26-7.14 (2H, m), 7.05 (1H, d, J = 6.6 Hz), 6.44 (1H, d, J = 9.5 Hz), 5.98 (1H, dd, J = 9.5, 4.8 Hz), 4.66 (1H, dd, J = 6.6, 4.4 Hz), 2.55-2.46 (1H, m), 1.76 (1H, OH), 1.42-1.18 (6H, m), 0.83 (3H, t, J = 7.0 Hz); ¹³C NMR (75 MHz, CDCl₃): δ 135.6, 132.3, 131.0, 128.4, 127.8, 127.5, 126.4, 125.8, 72.3, 42.4, 31.3, 29.2, 22.8, 13.9; EI⁺-MS m/z (relative intensity): 202 (35), 173 (33), 145 (100), 141 (23), 127 (24), 117 (25); Anal. Calcd. for C₁₄H₁₈O: C, 83.12, H, 8.97; found C, 83.09, H, 8.93. The ee of 92% was determined by HPLC on chiral stationary phase (DAICEL CHIRALPAK OD, heptane/i-PrOH 99/1, flow: 1 ml/min, λ = 254), retention times were 24.2 min (major) and 30.7 min.

(-)-(1S, 2R)-2-Ethyl-6,7-difluoro-1,2-dihydronaphth-1-ol (11).

The reaction was carried out following the general procedure employing chiral ligand 2 (37.73 mg, 0.07 mmol), 6,7-difluoro-1,4-epoxy-1,4-dihydronaphthalene (6) (180 mg, 1.0 mmol) and Et₂Zn (1.82 ml); conversion of the starting material (75%) was reached within 70h. Purification by column chromatography (SiO₂, 10% AcOEt in hexanes) gave 11 (122 mg, 58%) as a white solid. M.p. = 54° - 55°C (uncrist.); Rᵣ = 0.31 on silica gel (hexanes/AcOEt 85/15); [α]D₂₀ = -125.7° (c = 1.19, CHCl₃); IR (nujol) 3274, 3061, 2965, 1633, 1599, 1498, 1311, 1263, 1082, 782 cm⁻¹; ¹H NMR (300 MHz, CDCl₃) δ 7.19 (1H, dd, J = 10.6, 8.1 Hz), 6.88 (1H, dd, J = 10.6, 7.7 Hz), 6.37 (1H, d, J = 9.5 Hz), 5.99 (1H, dd, J = 9.5, 4.4 Hz), 4.46 (1H, t, J = 7.7 Hz); ¹³C NMR (75 MHz, CDCl₃): δ 132.8, 131.3, 124.6, 118.4, 116.6, 116.4, 115.1, 114.8, 71.2, 43.6, 24.2, 11.2; HRMS calcd. for C₁₂H₁₂FO₂ (M)+ 210.085, found 210.084. The ee of 80% was determined by HPLC on chiral stationary phase (DAICEL CHIRALPAK AD, heptane/i-PrOH 99/1, flow: 1 ml/min, λ = 254), retention times were 8.8 min (major) and 10.5 min.

(-)-(1S, 2R)-2-Ethyl-6,7-dimethoxy-1,2-dihydronaphth-1-ol (12).

The reaction was carried out following the general procedure employing chiral ligand 2 (37.73 mg, 0.07 mmol), 6,7-dimethoxy-1,4-epoxy-1,4-dihydronaphthalene (7) (204 mg, 1.0 mmol) and Et₂Zn (1.82 ml); conversion of the starting material (100%) was reached within 70h. Purification by column chromatography (SiO₂, 1% Et₃N, 15% AcOEt in hexanes) gave 12 (152 mg, 65%) as a solid. M.p. = 105-108°C (uncrist.). IR (neat) 3489, 3032, 2960, 2931, 1604, 1510, 1460, 1273, 1222, 1022, 860 cm⁻¹; ¹H NMR (300 MHz, CDCl₃) δ 6.89 (1H, s), 6.62 (1H, s), 6.38 (1H, d, J = 9.8 Hz), 5.90 (1H, dd, J = 9.8, 4.9 Hz), 4.45 (1H, t, J = 4.4 Hz), 3.89 (3H, s), 3.87 (3H, s), 2.51-2.36 (1H, m), 1.66 (1H, OH), 1.51-1.17 (2H, m), 0.94 (3H, t, J = 7.3 Hz); ¹³C NMR (75 MHz, CDCl₃): δ 148.8, 148.3, 128.7, 128.4, 125.5, 125.4, 111.5, 110.0, 72.2, 56.1, 44.3, 24.7, 11.6; HRMS calcd. for C₁₄H₁₈O₃ (M)+ 234.125, found 234.126.

(-)-(1S, 2R)-2-Ethyl-5,8-dimethyl-1,2-dihydronaphth-1-ol (13).

The reaction was carried out following the general procedure employing chiral ligand 2 (37.73 mg, 0.07 mmol), 5,8-dimethyl-1,4-epoxy-1,4-dihydronaphthalene (8) (172 mg, 1.0 mmol) and Et₂Zn (1.82 ml); conversion of the starting material (>98%) was reached within 16h. Purification by column chromatography (SiO₂, 10% AcOEt in hexanes) gave 13 (182 mg, 90%) as an oil; Rᵣ = 0.29 on silica gel (hexanes/AcOEt 85/15); [α]D₂₀ = -256.16° (c = 2.66, CHCl₃); IR (neat) 3489, 3032, 2960, 2931, 1604, 1510, 1460, 1273, 1222, 1022, 860 cm⁻¹; ¹H NMR (300 MHz, CDCl₃) δ 6.97 (2H, ABdd, J = 7.7 Hz), 6.69 (1H, d, J = 9.8 Hz), 6.08 (1H, dd, J = 9.8, 5.9 Hz), 4.75 (1H, br. singl.), 2.56-2.48 (1H, m), 2.37 (3H, s), 2.31 (3H, s), 1.76 (1H, OH), 1.29-1.19 (2H, m), 0.93 (3H, t, J = 7.3 Hz); ¹³C NMR (75 MHz, CDCl₃): δ 134.2, 132.7, 131.4, 130.1, 130.0, 129.9, 129.4, 122.7, 67.8, 43.7, 24.8, 18.9, 18.2, 12.1; HRMS calcd. for C₁₄H₂₀O (M)+ 234.125, found 234.126.

(-)-(1S, 2R)-2-Ethyl-5,8-dimethoxy-1,2-dihydronaphth-1-ol (14).

The reaction was carried out following the general procedure employing chiral ligand 2 (37.73 mg, 0.07 mmol), 5,8-dimethoxy-1,4-epoxy-1,4-dihydronaphthalene (9) (204 mg, 1.0 mmol) and EtZn (1.82 ml); conversion of the starting material (>98%) was reached within 48h.

Purification by column chromatography (SiO2, 15% AcOEt in hexanes) gave 14 (192 mg, 82%) as an oil; Rf = 0.14 on silica gel (hexanes/AcOEt 85/15); [α]D20 = -192.47° (c = 3.82, CHCl3); IR (neat) 3431, 3045, 2960, 2837, 1599, 1487, 1450, 1381, 1263, 1087, 787 cm⁻¹; 1H NMR (300 MHz, CDCl3) δ 6.84 (1H, d, J = 9.9 Hz), 6.74 (2H, ABdd, J = 9.2 Hz), 6.06 (1H, dd, J = 9.9, 5.5 Hz), 4.96 (1H, br. singl.), 3.81 (3H, s), 3.78 (3H, s), 2.56-2.46 (1H, m), 2.12 (1H, OH), 1.28 (2H, dq, J = 13.2, 7.3 Hz), 0.92 (3H, t, J = 7.3 Hz); 13C NMR (75 MHz, CDCl3): δ 151.3, 149.4, 130.3, 123.9, 122.1, 119.1, 110.9, 110.1, 64.9, 56.1, 55.9, 43.0, 25.3, 11.8; HRMS calcd. for C14H18O3 (M+) 234.125, found 234.126. The ee of 97% was determined by HPLC on chiral stationary phase (DAICEL CHIRALPAK OD, heptane/i-PrOH 90/10, flow: 1 ml/min, λ = 254), retention times were 10.6 min and 22.3 min (major).

(-)-(1S,2R)-2-Ethyl-1,4-dimethyl-1,2-dihydronaphth-1-ol (15).

The reaction was carried out following the general procedure employing chiral ligand 2 (37.73 mg, 0.07 mmol), 1,4-dimethyl-1,4-epoxy-1,4-dihydronaphthalene (10) (172 mg, 1.0 mmol) and EtZn (1.82 ml); conversion of the starting material (>98%) was reached within 40h.

Purification by column chromatography (SiO2, 10% AcOEt in hexanes) gave 15 (172 mg, 85%) as an oil; Rf = 0.4 on silica gel (hexanes/AcOEt 85/15); [α]D20 = -31.03° (c = 2.03, CHCl3); IR (neat) 3402, 3067, 3032, 2966, 2879, 1633, 1452, 1381, 1234, 1130, 1076, 783 cm⁻¹; 1H NMR (300 MHz, CDCl3) δ 7.62-7.54 (1H, m), 7.29-7.18 (3H, m), 5.72 (1H, br. singl.), 2.29-2.20 (1H, m), 2.07 (3H, s), 1.87-1.75 (2H, m), 1.82 (1H, OH), 1.34-1.19 (1H, m), 1.27 (3H, s), 0.98 (3H, t, J = 7.3 Hz); 13C NMR (75 MHz, CDCl3): δ 143.7, 133.9, 131.4, 127.8, 127.6, 127.2, 123.2, 123.1, 74.7, 48.5, 22.4, 21.0, 19.1, 12.1; HRMS calcd. for C14H18O (M+) 202.1358 found 202.1364. The ee of 92% was determined by HPLC on chiral stationary phase (DAICEL CHIRALPAK AD, heptane/i-PrOH 99/1, flow: 1 ml/min, λ = 254), retention times were 15.8 min (major) and 26.4 min.

(-)-(1S,2R)-2-Ethyl-4-methyl-1,2-dihydronaphth-1-ol (17).

The reaction was carried out following the general procedure employing chiral ligand 2 (37.73 mg, 0.07 mmol), (±)-1-methyl-1,4-epoxy-1,4-dihydronaphthalene (16) (158 mg, 1.0 mmol) and EtZn (0.68 ml, 0.75 eq); conversion of the starting material (56%) was reached within 60h.

Purification by column chromatography (SiO2, 5% AcOEt in hexanes) gave 16 (52 mg, 33%) and 17 (74 mg, 39%) as a solid; M.p. = 48-50°C (uncrist.). 1H NMR (200 MHz, CDCl3) δ 7.41-7.20 (m, 4H), 5.80 (d, 1H, J = 6.13 Hz), 4.49 (dd, 1H, J = 7.08 and 6.13 Hz), 2.50-2.35 (m, 1H), 2.09 (s, 3H), 1.59-1.21 (m, 2H), 0.95 (s, 3H, J = 7.37 Hz); 13C NMR (50 MHz, CDCl3): δ 136.6, 134.0, 130.7, 127.3, 123.3, 72.5, 43.9, 24.6, 19.1, 11.5; Anal. Calcd. for C13H16O: C, 82.94, H, 8.57, found C, 82.88, H, 8.65. The ee of 92% (16) and 86% (17) were determined by HPLC on chiral stationary phase (DAICEL CHIRALPAK OD-H, heptane/i-PrOH 99/1, flow: 0.5 ml/min, λ = 254), retention times for compound 16 were 17.5 min (major) and 19.1 min; retention times for compound 17 were 22.4 min (major) and 24.7 min.

General procedure for the synthesis of racemic $S,N_2$ anti-adducts: To a stirring suspension of CuCN (9.0 mg, 0.1 mmol) in anhydrous Et$_2$O (0.5 mL), at -40°C, was added dropwise the Grignard reagent (2.5 eq). The heterogeneous mixture was allowed to stir for 30 min at the same temperature and was then cooled down to -65°C. A solution of the oxabicyclic compound (0.5 mmol) in Et$_2$O (0.5 ml) was slowly added and the resulting mixture was allowed to warm up to r.t. The reaction was followed with analytical TLC and quenched, after complete conversion of the starting material, with saturated aqueous NH$_4$Cl. Extraction with Et$_2$O and evaporation of the dried (MgSO$_4$) organic phase gave almost exclusively the corresponding racemic $S,N_2$ anti-adducts for all the oxabenzonorbornadiene substrates.

Synthesis of the sultam-ester (1S, 2R)

In a dry, three necked round-bottomed flask, at r.t., to a solution of (1S, 2R)-2-ethyl-1,2-dihydronaphth-1-ol (3a) (87 mg, 0.5 mmol) in dry CH$_2$Cl$_2$ (6 ml) was added, under vigorous stirring, the chiral auxiliary$^8$ (540 mg, 1.25 mmol). After 5 min, was added dicyclohexylcarbodiimide (DCC, 257 mg, 1.25 mmol) and subsequently 4-dimethylamminopyridine (DMAP, 15 mg, 0.125 mmol). The mixture was left at reflux until complete conversion of the alcohol (checked by analytical TLC hex/AcOEt 85/15); the insoluble was filtered off by a short column of silica gel (CH$_2$Cl$_2$ as eluent). Purification by column chromatography (SiO$_2$, 15% AcOEt in hexanes) gave the title compound (256 mg, 87%) as a white solid. After recrystalization from methanol a suitable crystal for X-ray analysis was obtained. $[$α$]_{D}^{20} = -203.63^\circ$ (c = 1.24, CHCl$_3$); IR (nujol) 3095, 3072, 2960, 2731, 1745, 1718, 1703, 1680, 1585, 1552, 1375, 1255, 1145, 1120, 1087, 794 cm$^{-1}$; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 7.85 (1H, s), 7.46 (1H, s), 7.35-7.10 (4H, m), 6.54 (1H, d, $J = 9.89$ Hz), 6.03 (1H, dd, $J = 9.89, 5.13$ Hz), 5.99 (1H, d, $J = 2.93$ Hz), 3.97-3.90 (1H, m), 3.39 (2H, ABdd, $J = 13.92$), 2.66-2.57 (1H, m), 2.54-2.42 (1H, m), 2.20-2.08 (1H, m), 1.98-1.84 (3H, m), 1.52-1.28 (4H, m), 1.24 (3H, s), 0.97 (3H, s), 0.94 (3H, t, $J = 7.32$ Hz); $^{13}$C NMR (75 MHz,CDCl$_3$) $\delta$ 165.2, 162.9, 136.5, 134.6, 133.6, 131.4, 131.0, 129.9, 129.7, 129.3, 128.9, 127.4, 126.4, 125.8, 74.9, 65.6, 52.9, 48.3, 47.7, 44.7, 40.8, 37.5, 33.0, 26.4, 20.8, 20.1, 11.4; TOF-MS m/z (relative intensity): 610 (63), 605 (25). Crystal data (C$_{30}$H$_{31}$Cl$_2$NO$_5$S), Mr=588.53, orthorhombic, colorless, platelet, $P2_1 2_1 2_1$, $a=10.4788(4)$, $b=24.743(1)$, $c=11.0878(5)$ Å, $V=2874.8(2)$ Å$^3$, $Z=4$, $D=1.360$ gcm$^{-3}$, $F(000)=1232$, $\mu=3.39$ cm$^{-1}$, $\lambda$(MoK$_\alpha$)=0.71073 Å, $T=100$ K, GooF=1.045, $wR(F^2)=0.0741$ for 7631 reflections and 476 parameters and $R(F)=0.0294$ for 7283 reflections obeying $F > 4.0 \sigma(F)$ criterion of observability.

$^8$ Harada, N.; Koumura, N.; Robillard, M. Enantiomer 1997, 2, 303