

Platinum-Catalysed Aerobic 1,2-Aminooxygenation of Alkenes

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SUPPORTING INFORMATION

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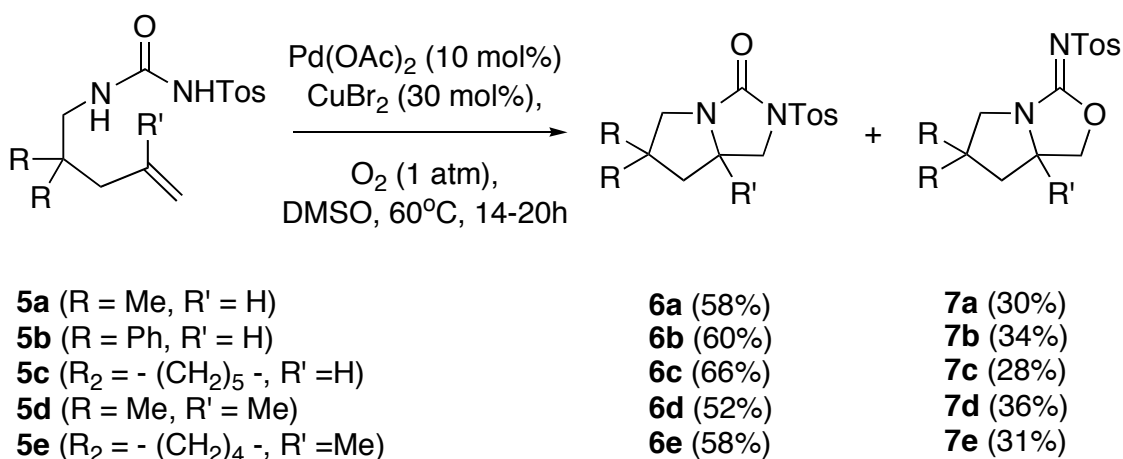
General. All organic reagents were purchased from Acros, if not noted otherwise. All platinum salts were purchased from Strem. Column chromatography was performed with silica gel (Merck, type 60, 0.063-0.2mm). NMR spectra were recorded on Bruker Avance 400 MHz, Bruker DPX 300 MHz and Bruker DRX 500 MHz spectrometers. All chemical shifts in NMR experiments are reported as ppm downfield from TMS. The following calibrations were used: CDCl_3 δ = 7.26 and 77.00 ppm, C_6D_6 δ = 7.16 and 128.0 ppm. MS (ESI-LCMS) experiments were performed using an Agilent 1100 HPLC with a Bruker micro-TOF instrument (ESI). Unless other wise stated, a Supelco C8 (5cm x 4.6mm, 5 μm particles) column was used with an linear elution gradient from 100% H_2O (0.5% HCO_2H) to 100% MeCN in 13min at a flow rate of 0.5mL/min. MS (EI) and HRMS experiments were performed on a Kratos MS 50 within the service centers at the Kekulé-Department, Bonn University. IR Spectra in the range of 4000-400 cm^{-1} were obtained on a Nicolet Magna 550 FT-IR Spectrometer with samples investigated as KBr pellets and the data is reported as cm^{-1} .

General Procedure for the Aminooxygenation of Alkenes:

A solution of the alkene (0.3 mmol, 1.0 eq.), CuBr_2 (0.09 mmol, 0.3 eq.), and PtCl_2 (0.03 mmol, 0.1 eq.) in DMSO (6 mL, 0.05M) was stirred in a Schlenck flask and three consecutive times set under vacuum and refilled with molecular oxygen. It was then sealed, the Schlenck outlet was connected to a gas ballon containing oxygen and the solution was heated in an oil bath to a temperature of 60°C. The reaction was stopped by addition of 2 mL saturated aqueous $\text{Na}_2\text{S}_2\text{O}_3$ solution and stirred for an additional 20 min. Water (5 mL) was added and the mixture was extracted with ethyl acetate (3 x 10 mL). The organic phase was dried over MgSO_4 and the solvent removed under reduced pressure. Purification by column chromatography yielded analytically pure products.

Cyclisation of Five-Membered Ring Precursors

The oxidation was carried out as described above. In contrast to piperidine annelated products **2**, mixtures of ureas **6** and isoureas **7** were obtained in these cases. The selectivity was generally in the range of 2:1. Scheme S-1 details the individual reaction outcome:



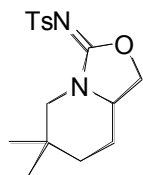
Scheme 2. Platinum-catalysed aerobic diamination and aminooxygenation of alkenes: pyrrolidine annelation. Yields for compounds **6** and **7** refer to isolated material after separation and purification by column chromatography.

Characterisation of Compounds

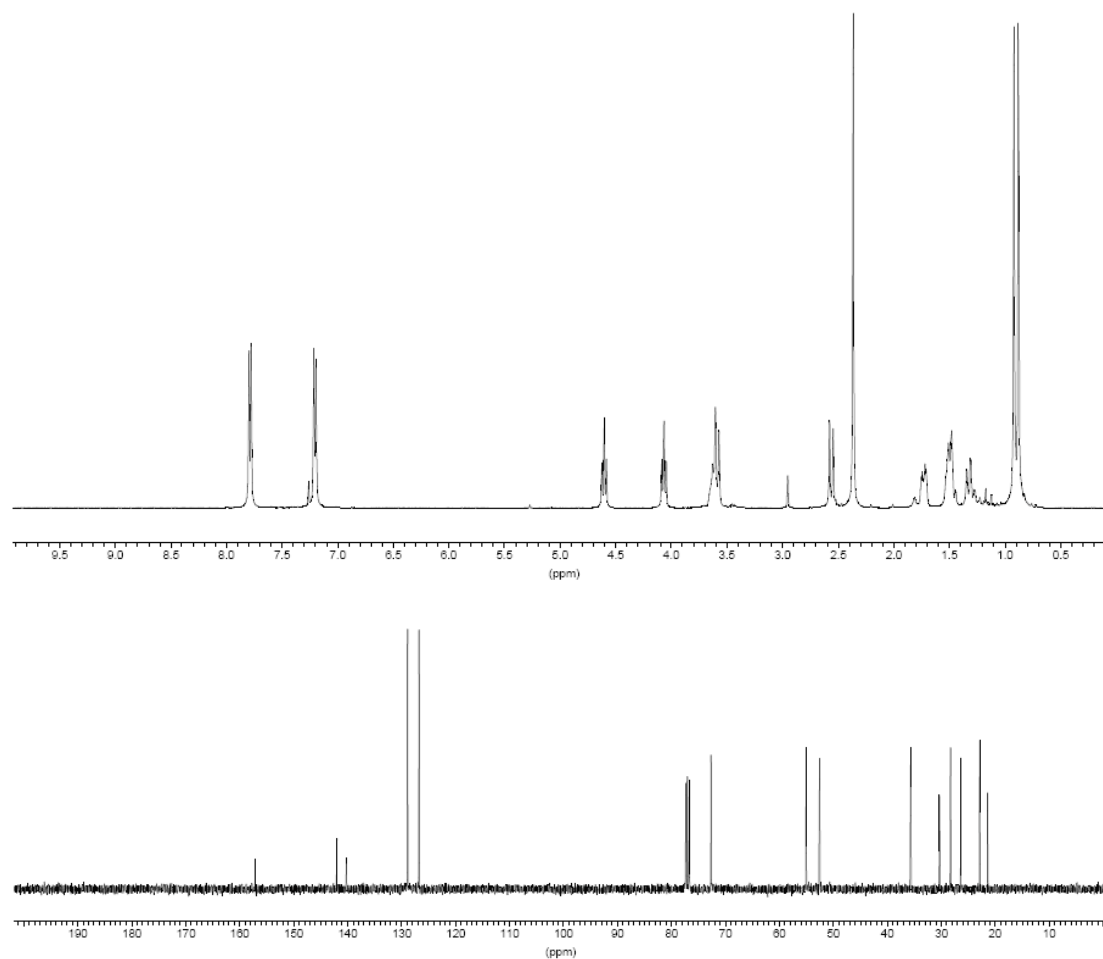
Compounds **1a-h**,¹ **5a-e**,¹ **6a-e**¹ and **7b-d**² represent previously characterised molecules.

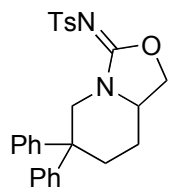
- ¹ J. Streuff, C. H. Hövelmann, M. Nieger and K. Muñiz, *J. Am. Chem. Soc.* 2005, **127**, 14586; K. Muñiz, C. H. Hövelmann and J. Streuff, *J. Am. Chem. Soc.* 2008, **130**, 763.
² B. M. Cochran and F. E. Michael, *Org. Lett.* 2008, **10**, 5039

Characterisation of New Compounds

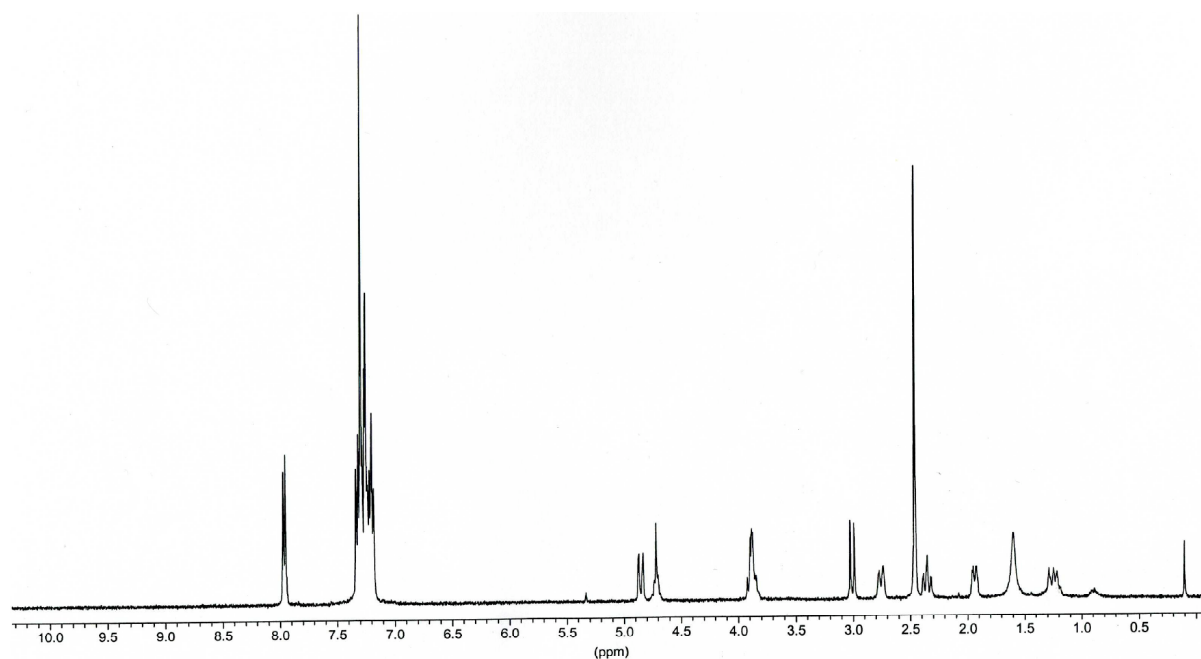


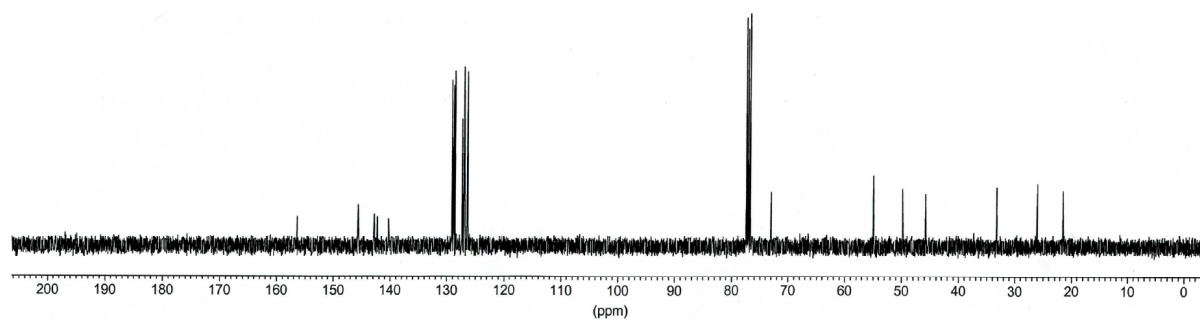
White solid. ^1H NMR (400 MHz, CDCl_3) δ 0.88 (3H, s), 0.92 (3H, s), 1.30-1.34 (1H, m), 1.48-1.53 (2H, m), 1.71-1.75 (1H, m), 2.36 (3H, s), 2.56 (1H, d, $J = 13.2$ Hz), 3.57-3.65 (2H, m), 4.04-4.09 (1H, m), 4.58-4.62 (1H, m), 7.20 (2H, d, $J = 7.3$ Hz), 7.79 (2H, d, $J = 7.3$ Hz). ^{13}C NMR (100 MHz, CDCl_3) δ 21.35, 22.84, 26.37, 28.29, 30.30, 35.64, 52.50, 55.01, 72.63, 126.73, 128.85, 140.19, 141.95, 157.11. IR (cm^{-1}): 2953, 1610, 1482, 1450, 1276, 1151, 1114, 1078, 957, 884, 838, 732, 704. MS (ESI-LCMS): m/z (%): 323 $[\text{M}+\text{H}]^+$ (100). HRMS calcd. for $\text{C}_{16}\text{H}_{22}\text{Li}_1\text{N}_2\text{O}_3\text{S}_1$: 329.1506, found: 329.1511.

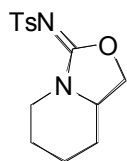




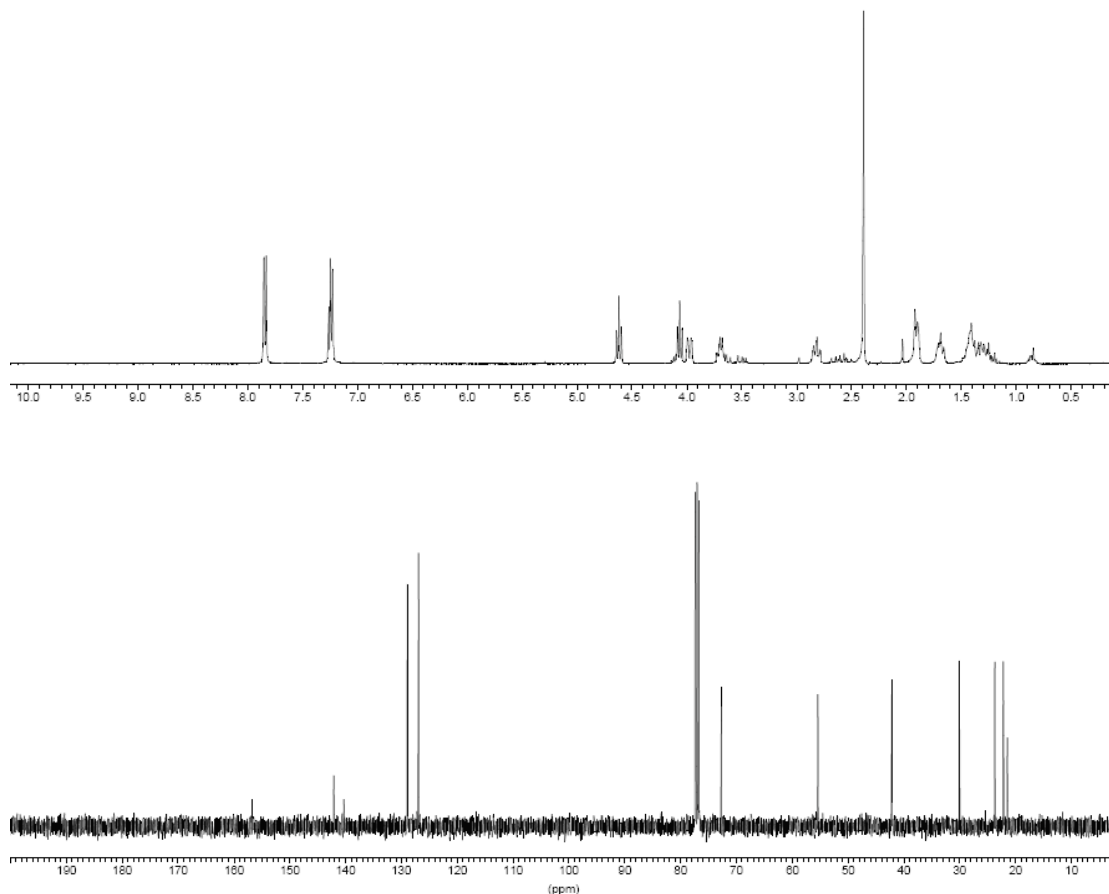
White solid. ^1H NMR (400 MHz, CDCl_3) δ 1.22-1.29 (1H, m), 1.93-1.96 (1H, m), 2.32-2.39 (1H, m), 2.46 (3H, s), 2.73-2.77 (1H, m), 3.01 (1H, d, $J = 14.0$ Hz), 3.85-3.92 (2H, m), 4.72 (1H, t, $J = 7.3$ Hz), 4.83-4.87 (1H, m), 7.18-7.34 (12h, m), 7.96 (2H, d, $J = 8.2$ Hz). ^{13}C NMR (100 MHz, CDCl_3) δ 21.49, 26.00, 33.23, 45.82, 49.76, 54.95, 72.95, 126.38, 126.88, 127.29, 128.56, 128.75, 129.07, 140.26, 142.26, 142.81, 145.65, 156.36. IR (cm^{-1}): 3058, 2953, 1614, 1483, 1450, 1300, 1265, 1156, 1116, 1081, 963, 887, 855, 823, 734, 701, 659. MS (ESI-LCMS): m/z (%): 447 $[\text{M}+\text{H}]^+$ (100). HRMS calcd. For $\text{C}_{26}\text{H}_{26}\text{Li}_1\text{N}_2\text{O}_3\text{S}_1$: 453.1819, found: 453.1853.

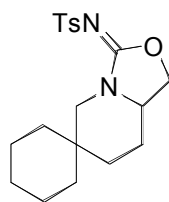




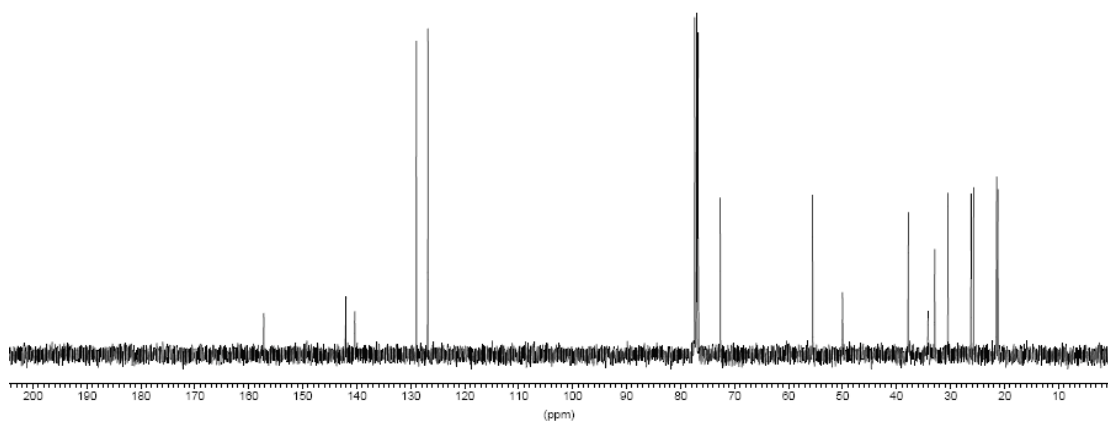
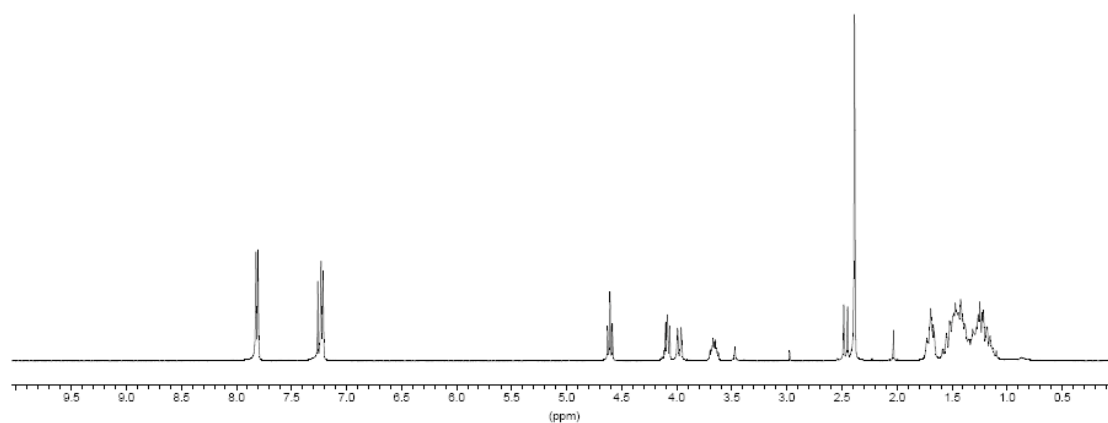


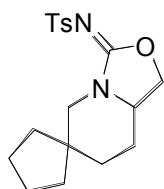
White solid. ^1H NMR (400 MHz, CDCl_3) δ 1.25-1.45 (3H, m), 1.68 (1H, t, $J = 9.4$ Hz), 1.91 (2H, d, $J = 9.6$ Hz), 2.39 (3H, s), 2.78-2.85 (1H, m), 3.64-3.73 (1H, m), 3.94-4.00 (1H, m), 4.06 (1H, t, $J = 8.5$ Hz), 4.62 (1H, t, $J = 8.5$ Hz), 7.23 (2H, d, $J = 8.0$ Hz), 7.84 (2H, d, $J = 8.0$ Hz). ^{13}C NMR (100 MHz, CDCl_3) δ 21.44, 22.15, 23.72, 30.04, 42.15, 55.40, 72.69, 126.91, 128.94, 140.24, 142.07, 156.68. IR (cm^{-1}): 2948, 1613, 1481, 1452, 1299, 1265, 1155, 1112, 1080, 893, 855, 812, 734, 702, 664. MS (ESI-LCMS): m/z (%): 295 $[\text{M}+\text{H}]^+$ (100). HRMS calcd. For $\text{C}_{14}\text{H}_{18}\text{Li}_1\text{N}_2\text{O}_3\text{S}_1$: 301.1193, found: 301.1170.



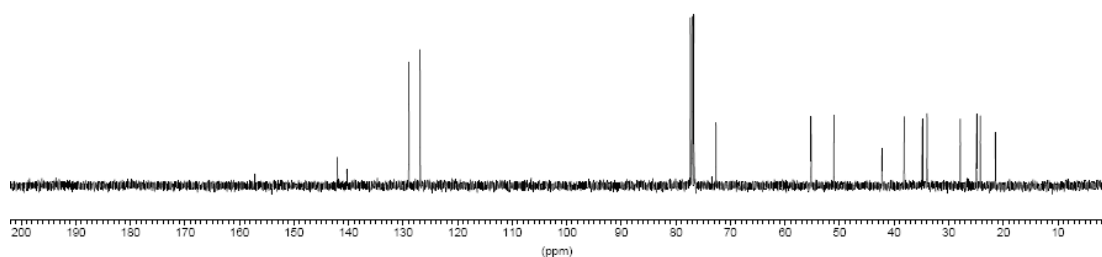
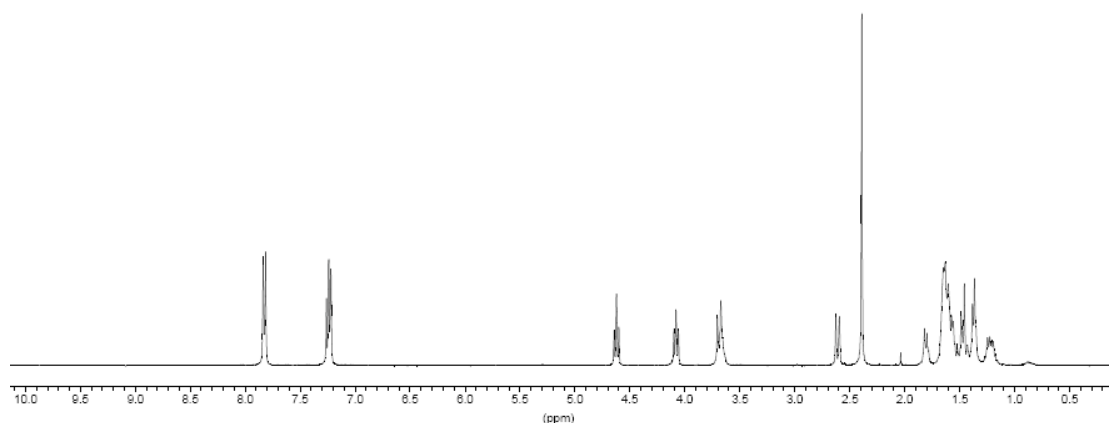


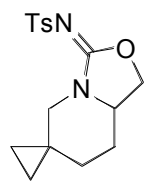
White solid. ^1H NMR (400 MHz, CDCl_3) δ 1.15-1.55 (12H, m), 1.66-1.72 (2H, m), 2.38 (3H, s), 2.46 (1H, d, $J = 13.5$ Hz), 3.62-3.70 (1H, m), 3.98 (1H, d, $J = 13.5$ Hz), 4.08 (1H, dd, $J_1 = 7.0$ Hz, $J_2 = 8.8$ Hz), 4.60 (1H, t, $J = 8.5$ Hz), 7.22 (2H, d, $J = 8.2$ Hz), 7.81 (2H, d, $J = 8.2$ Hz). ^{13}C NMR (100 MHz, CDCl_3) δ 21.22, 21.41, 21.43, 25.69, 26.21, 30.46, 32.91, 34.13, 37.75, 49.95, 55.51, 72.63, 126.80, 128.89, 140.32, 141.97, 157.19. IR (cm^{-1}): 2929, 1611, 1451, 1300, 1265, 1155, 891, 735, 704. MS (ESI-LCMS): m/z (%): 363 $[\text{M}+\text{H}]^+$ (100). HRMS calcd. For $\text{C}_{19}\text{H}_{26}\text{Li}_1\text{N}_2\text{O}_3\text{S}_1$: 369.1819, found: 369.1812.



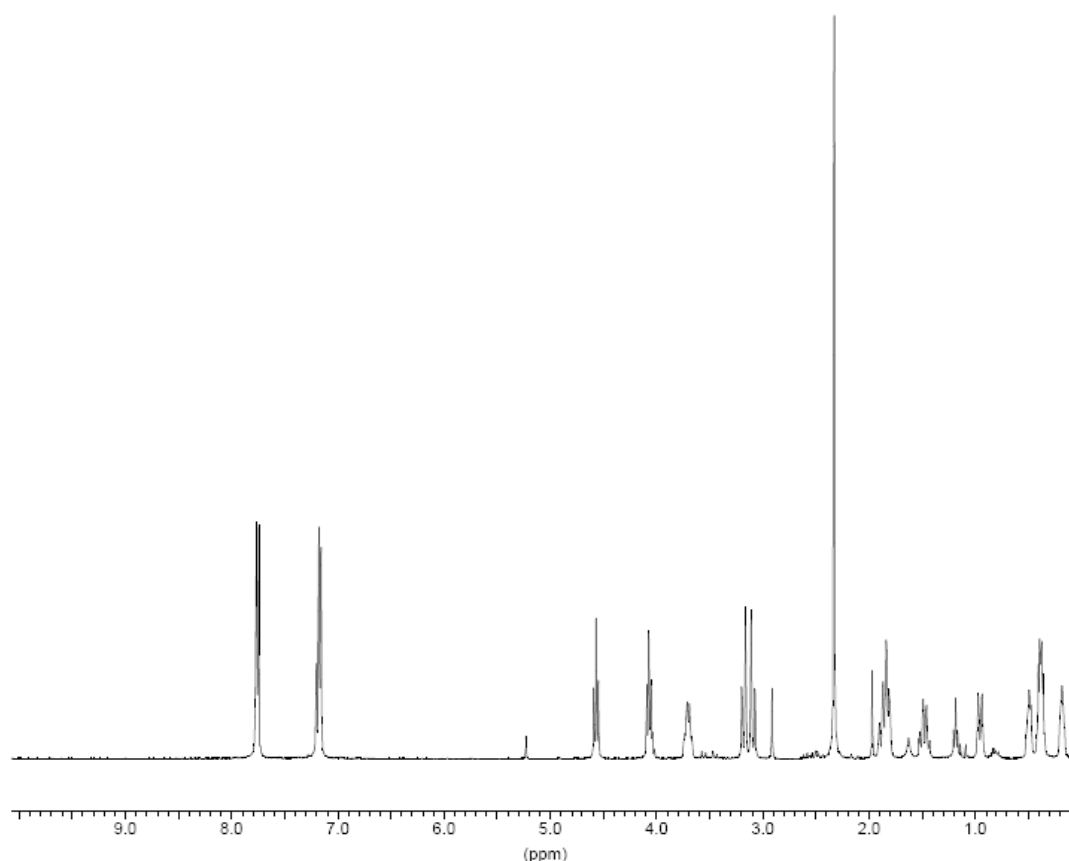


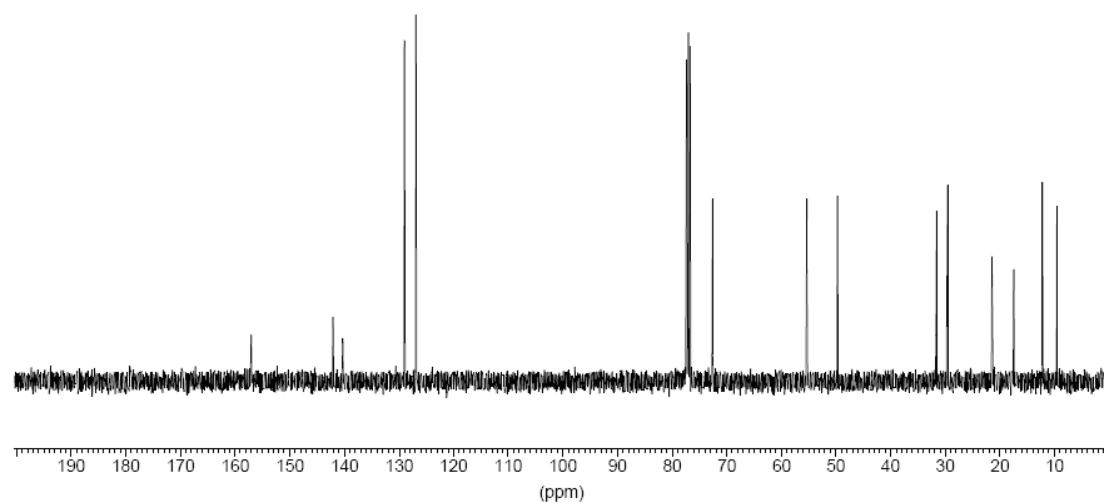
White solid. ^1H NMR (400 MHz, CDCl_3) δ 1.19-1.25 (1H, m), 1.37-1.82 (2H, m), 1.43-1.52 (2H, m), 1.56-1.65 (6H, m), 1.80-1.82 (1H, m), 2.39 (3H, s), 2.61 (1H, d, $J = 12.8$ Hz), 3.67-3.71 (2H, m), 4.08 (1H, t, $J = 8.8$ Hz), 4.63 (1H, t, $J = 8.8$ Hz), 7.23 (2H, d, $J = 8.0$ Hz), 7.82 (2H, d, $J = 8.0$ Hz). ^{13}C NMR (100 MHz, CDCl_3) δ 21.44, 24.17, 24.84, 27.80, 33.94, 34.83, 38.13, 42.21, 51.01, 55.15, 72.65, 126.86, 128.92, 140.31, 142.00, 157.11. IR (cm^{-1}): 2948, 2860, 1611, 1482, 1447, 1299, 1278, 1155, 1117, 1082, 967, 908, 815, 733, 703, 659. MS (ESI-LCMS): m/z (%): 349 $[\text{M}+\text{H}]^+$ (100). HRMS calcd. For $\text{C}_{18}\text{H}_{24}\text{Na}_1\text{N}_2\text{O}_3\text{S}_1$: 371.1400, found: 371.1382.

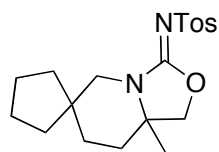




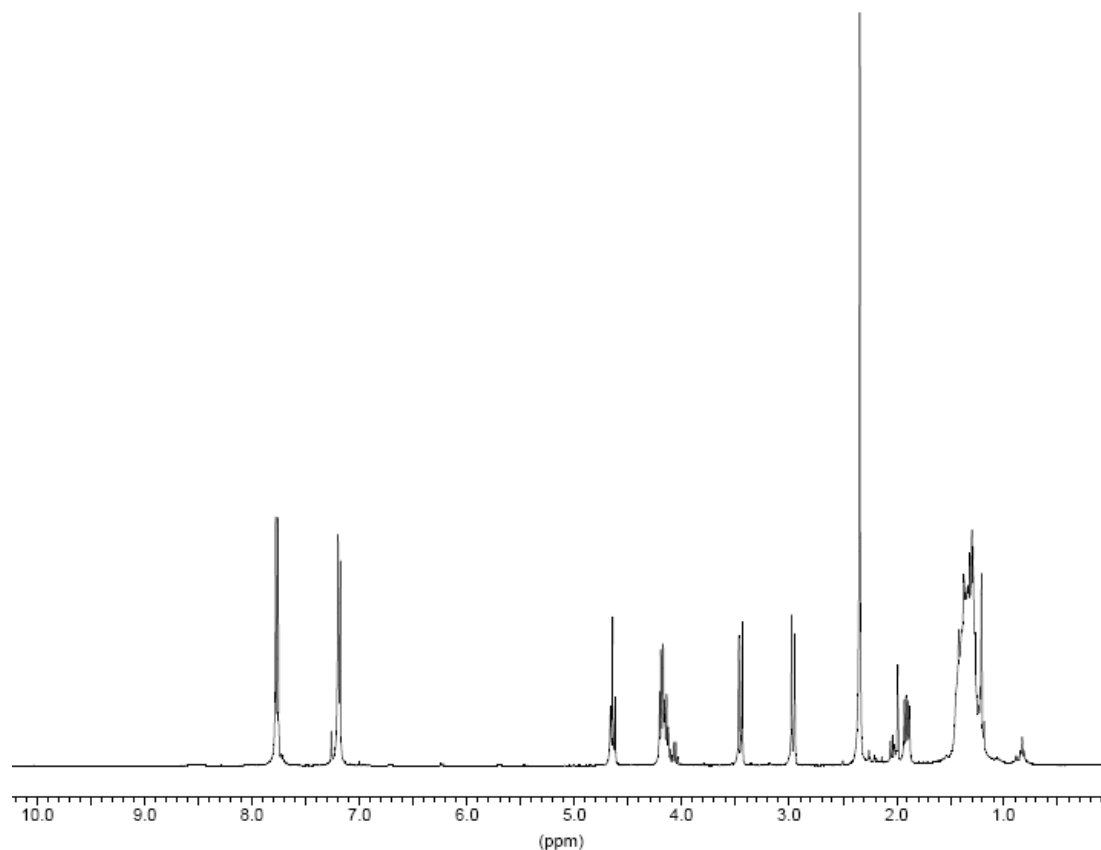
White solid. ^1H NMR (400 MHz, CDCl_3) δ 0.21-0.26 (1H, m), 0.42-0.47 (2H, m), 0.54-0.56 (1H, m), 1.01 (1H, d, $J = 14.0$ Hz), 1.49-1.59 (1H, m), 1.86-1.96 (2H, m), 2.38 (3H, s), 3.15 (1H, d, $J = 13.4$ Hz), 3.24 (1H, d, $J = 13.4$ Hz), 3.72-3.80 (1H, m), 4.11-4.15 (1H, m), 4.63 (1H, t, $J = 8.6$ Hz), 7.23 (2H, d, $J = 8.0$ Hz), 7.81 (2H, d, $J = 8.0$ Hz). ^{13}C NMR (100 MHz, CDCl_3) δ 9.56, 12.12, 17.41, 21.43, 29.55, 31.58, 49.68, 55.28, 72.58, 126.86, 128.92, 140.21, 142.04, 156.95. IR (cm^{-1}): 3056, 2926, 1612, 1481, 1447, 1299, 1265, 1154, 1119, 1081, 888, 815, 735, 704, 670. MS (ESI-LCMS): m/z (%): 321 $[\text{M}+\text{H}]^+$ (100). HRMS calcd. For $\text{C}_{16}\text{H}_{20}\text{Li}_1\text{N}_2\text{O}_3\text{S}_1$: 327.1349, found: 327.1326.

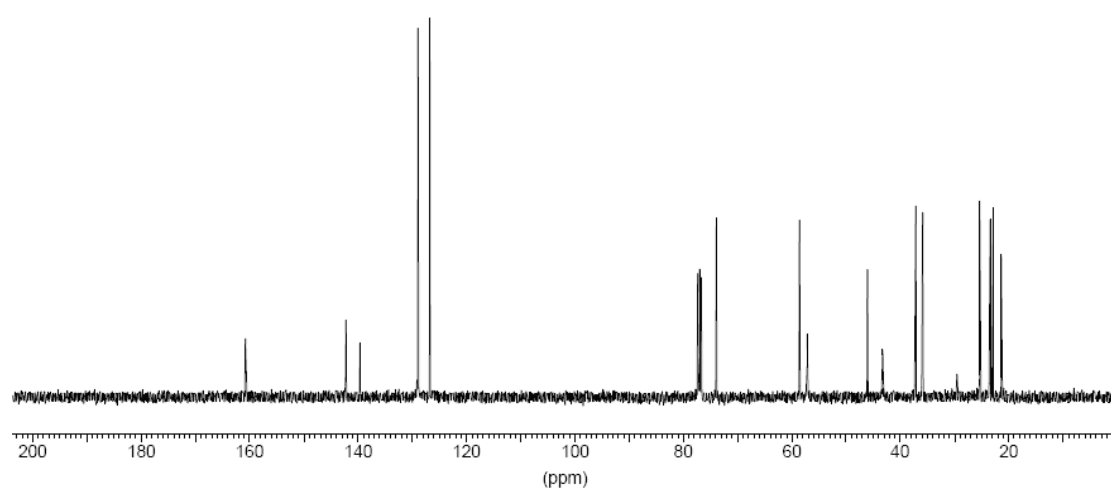


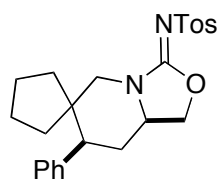




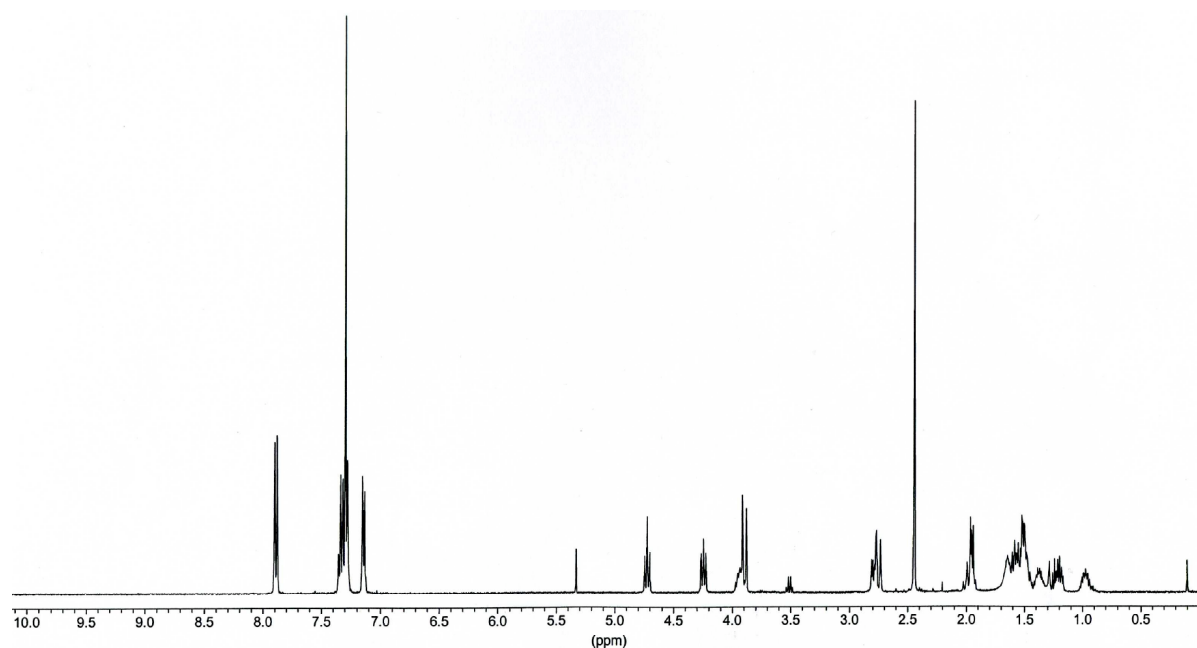
White solid. ^1H NMR (400 MHz, CDCl_3) δ 1.07-1.17 (2H, m), 1.34 (3H, s), 1.36-1.45 (8H, m), 1.59-1.71 (2H, m), 2.38 (3H, s), 2.84 (1H, d, $J = 12.3$ Hz), 3.79 (1H, d, $J = 12.3$ Hz), 4.29 (2H, q, $J = 5.0$ Hz), 7.22 (2H, d, $J = 8.2$ Hz), 7.81 (2H, d, $J = 8.2$ Hz). ^{13}C NMR (100 MHz, CDCl_3) δ 21.44, 22.90, 23.74, 25.30, 26.83, 36.49, 37.46, 45.83, 50.18, 56.40, 66.18, 81.06, 126.91, 128.90, 139.75, 142.23, 161.45. IR (cm^{-1}): 2954, 2863, 1595, 1434, 1300, 1265, 1156, 1080, 855, 734, 703, 667. MS (ESI-LCMS): m/z (%): 363 $[\text{M}+\text{H}]^+$ (100). HRMS calcd. For $\text{C}_{19}\text{H}_{26}\text{Li}_1\text{N}_2\text{O}_3\text{S}_1$: 369.1819, found: 369.1763.

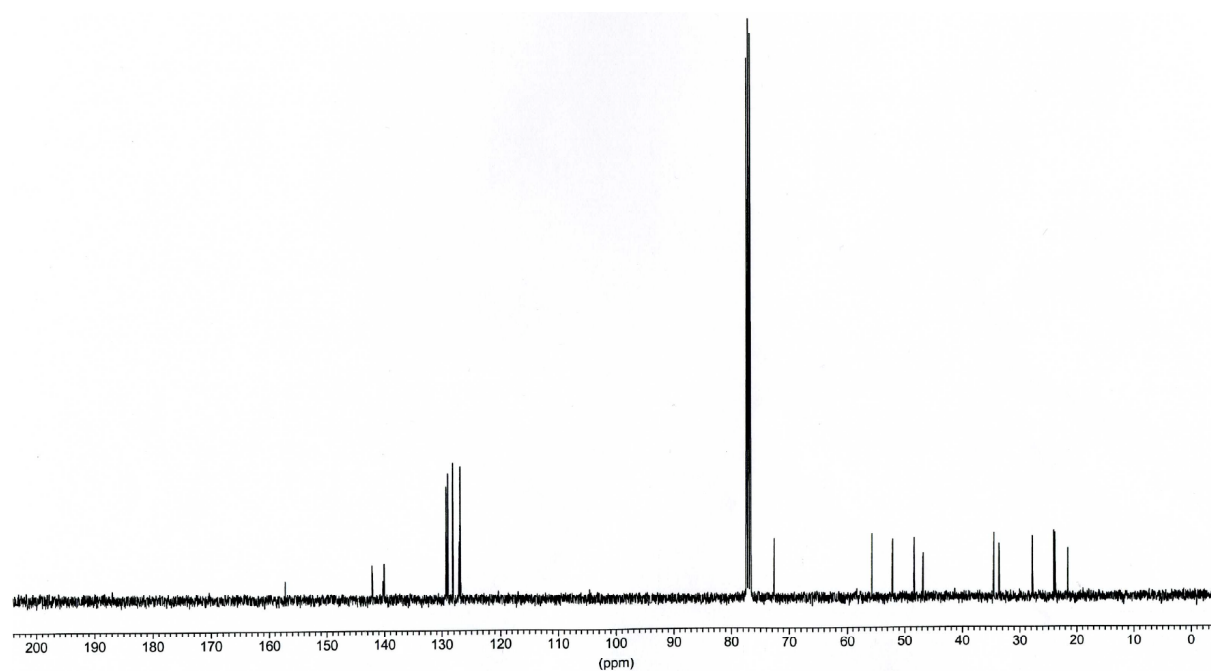






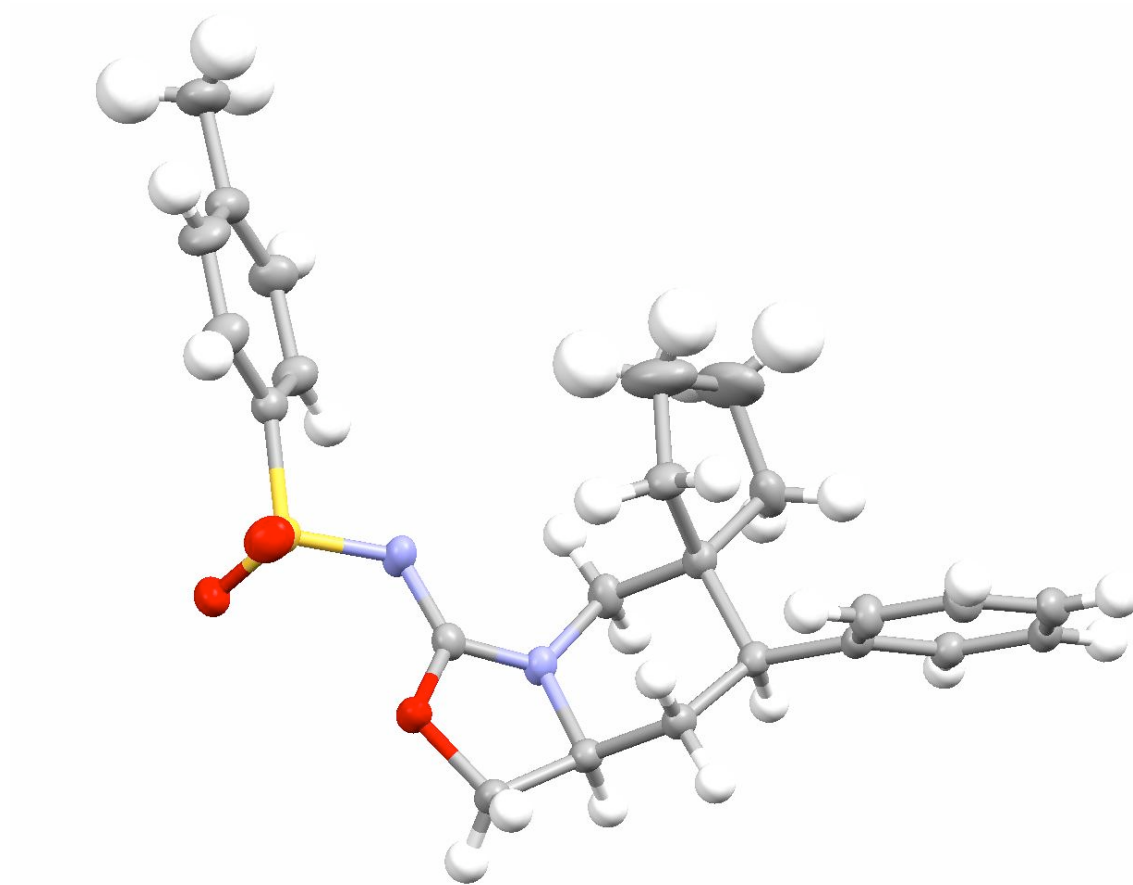
White solid. ^1H NMR (400 MHz, CDCl_3) δ 0.90-1.03 (m, 1H), 1.32-1.41 (m, 1H), 1.44-1.70 (m, 6H), 1.91-2.03 (m, 2H), 2.75 (d, $J = 13.1$ Hz, 1H), 2.79 (dd, $J = 4.7, 10.6$ Hz, 1H), 3.90 (d, $J = 13.1$ Hz, 1H), 3.88-3.97 (m, 1H), 4.24 (dd, $J = 7.4, 8.7$ Hz, 1H), 4.72 (dd, $J = 8.7, 8.8$ Hz, 1H), 7.14 (d, $J = 8.3$ Hz, 2H), 7.25-7.36 (m, 5H), 7.89 (d, $J = 8.3$ Hz, 2H). ^{13}C NMR (100 MHz, CDCl_3) δ 21.9, 23.72, 23.96, 27.72, 33.57, 34.48, 46.78, 52.08, 55.65, 72.58, 126.91, 127.04, 128.10, 128.99, 129.31, 10.05, 142.11, 157.19. IR (cm^{-1}): 2955, 2868, 1610, 1483, 1459, 1299, 1282, 1156, 1076, 841, 733, 705, 659. MS (ESI-LCMS): m/z (%): 425 $[\text{M}]^+$ (100). HRMS: calc. for $\text{C}_{24}\text{H}_{28}\text{LiN}_2\text{O}_3\text{S}$: 431.2000, found: 431.1980





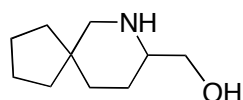
X-Ray Crystallography for Compound 2h.

Identification code: CCDC-737012



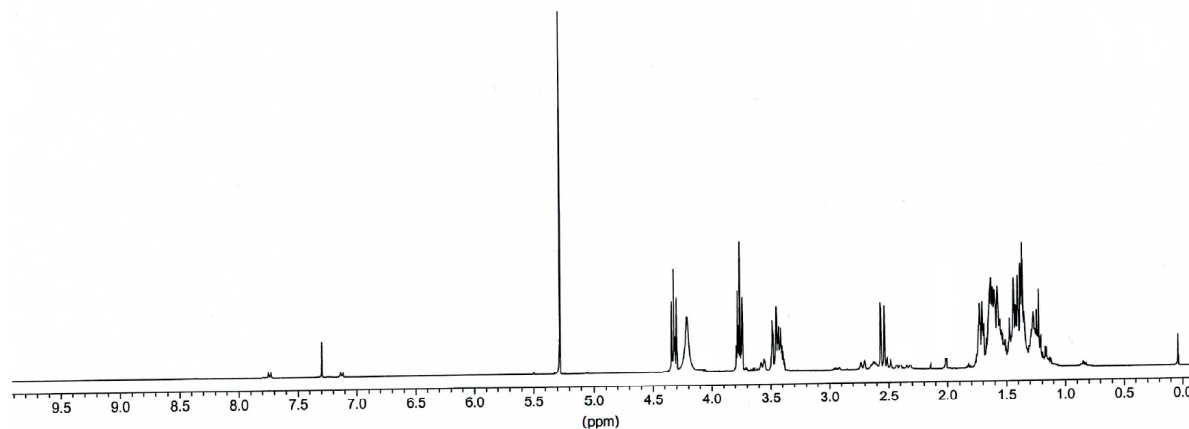
Single crystals of **2h** were recrystallised from methanol at room temperature.

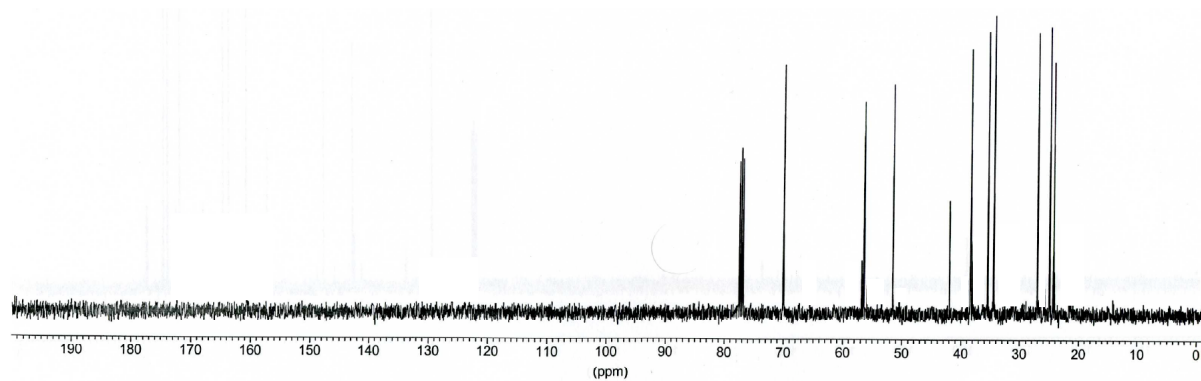
Crystal data. C₂₄H₂₈N₂O₃S, *M* = 424.54, triclinic, *a* = 6.3940(2), *b* = 12.6597(7), *c* = 14.1192(7) Å, α = 76.514(2)°, β = 77.422(3)°, γ = 88.597(3)°, *U* = 1084.29(9) Å³, *T* = 173 K, space group P -1, *Z* = 2, 10439 reflections measured, 4960 unique, *R*1 = 0.0538 [*I* > 2σ(*I*)], *wR*2 = 0.1718 (all data).

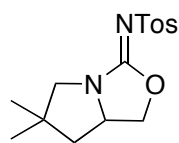


A solution of compound **2e** is dissolved in concentrated HCL (5 mL) and heated to 120°C for a period of 4h. The brownish solution is cooled to room temperature and extracted three times with 15mL of ethyl acetate. The remaining aqueous phase is then brought to pH 14 by slow addition of sodium hydroxide pellets. At this stage it is extracted with dichloromethane. The organic phase is dried over magnesium sulfate, filtered and evaporated under reduced pressure to give the title compound.

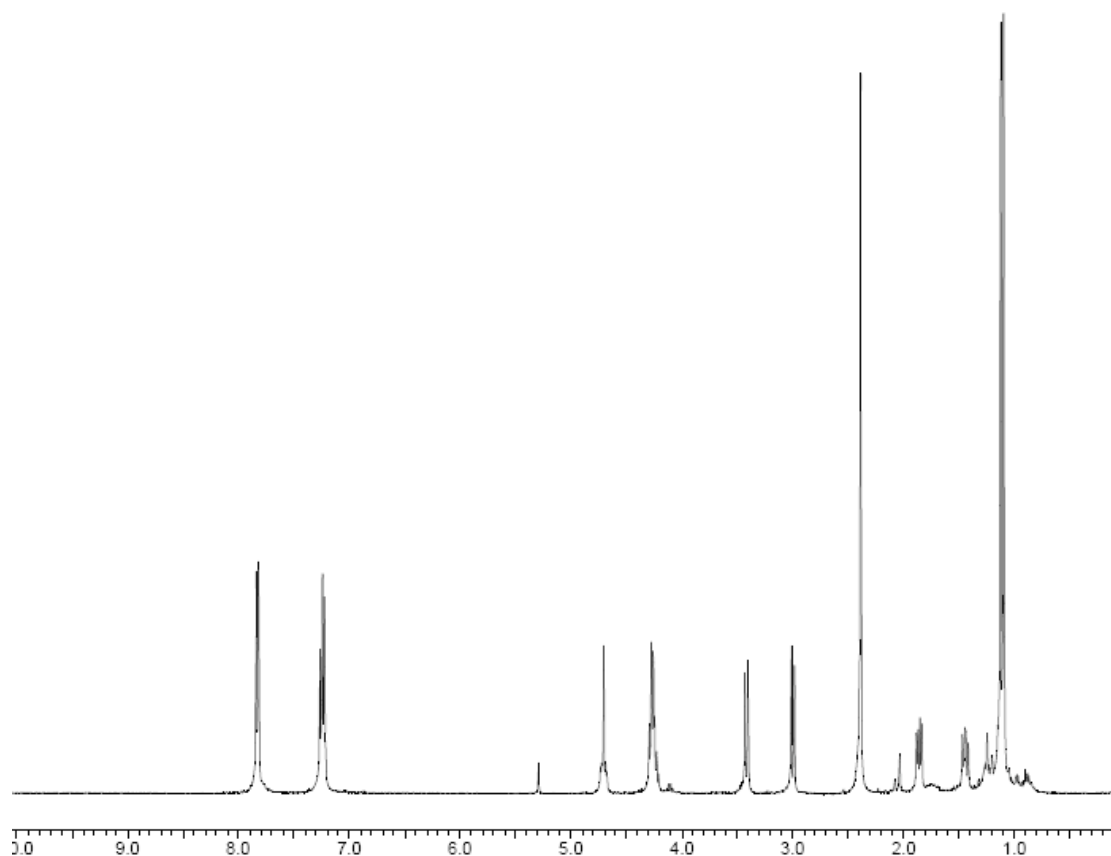
Colourless oil. ¹H NMR (400 MHz, CDCl₃) δ 1.23-1.79 (m, 12H), 2.55 (dd, *J* = 1.4, 12.5 Hz, 1H), 3.45-3.50 (m, 2H), 3.73-3.79 (m, 1H), 4.20 (brs, 1H), 4.29-4.34 (m, 1H). ¹³C NMR (100 MHz, CDCl₃) δ 24.34, 24.99, 27.06, 34.48, 35.43, 38.38, 42.50, 51.51, 56.45, 69.95. IR (cm⁻¹): 3341, 2929, 2855, 1672, 1427, 1279, 1131, 1045, 962, 733. MS *m/z* (Relative Intensity) = 170 (100), 168 (8), 166 (17), 152 (8). HRMS: calc. for C₁₀H₁₉LiNO: 176.1627, found: 176.1646.

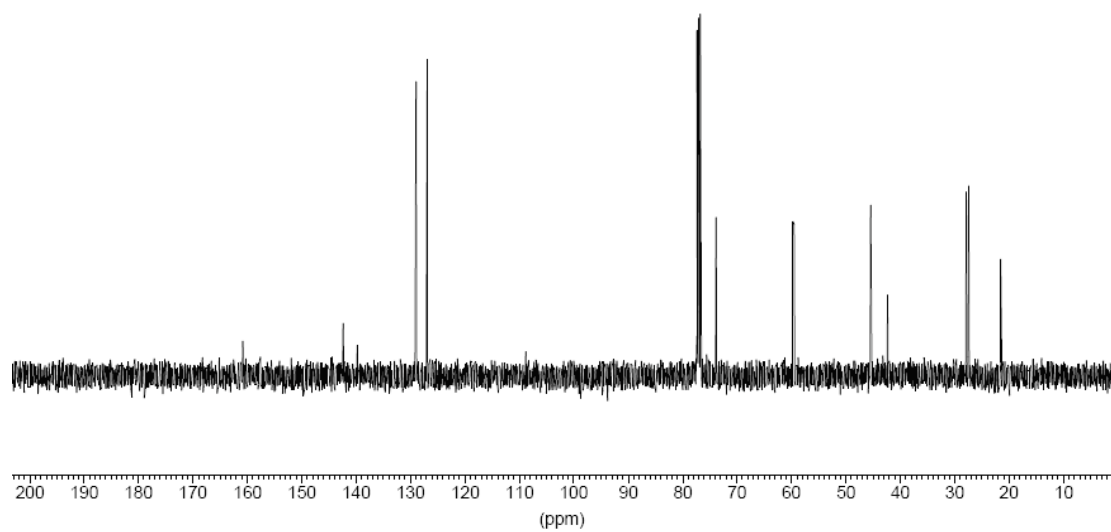


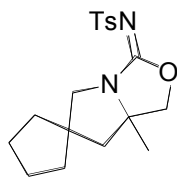




White solid. ^1H NMR (400 MHz, CDCl_3) δ 1.10 (3H, s), 1.13 (3H, s), 1.45 (1H, dd, $J_1 = 8.4$ Hz, $J_2 = 12.4$ Hz), 1.86 (1H, dd, $J_1 = 6.0$ Hz, $J_2 = 12.4$ Hz), 2.39 (3H, s), 3.00 (1H, d, $J = 11.2$ Hz), 3.42 (1H, d, $J = 11.2$ Hz), 4.21-4.29 (2H, m), 4.68-4.73 (1H, m), 7.27 (2H, d, $J = 8.0$ Hz), 7.87 (2H, d, $J = 8.0$ Hz). ^{13}C NMR (100 MHz, CDCl_3) δ 21.46, 27.42, 27.82, 42.32, 45.43, 59.41, 59.63, 73.80, 126.95, 128.99, 139.81, 142.32, 160.77. IR (cm^{-1}): 2960, 1597, 1466, 1424, 1300, 1265, 1155, 1091, 825, 814, 735, 703, 661. MS (ESI-LCMS): m/z (%): 309 $[\text{M}+\text{H}]^+$ (100). HRMS calcd. For $\text{C}_{15}\text{H}_{20}\text{Na}_1\text{N}_2\text{O}_3\text{S}_1$: 331.1087, found: 331.1123.







White solid. ^1H NMR (400 MHz, CDCl_3) δ 1.19-1.24 (1H, m), 1.35 (3H, s), 1.37-1.40 (1H, m), 1.55-1.59 (6H, m), 1.80 (2H, s), 2.38 (3H, s), 2.94 (1H, d, $J = 12.0$ Hz), 3.63 (1H, d, $J = 12.0$ Hz), 4.25-4.34 (2H, m), 7.22 (2H, d, $J = 8.0$ Hz), 7.82 (2H, d, $J = 8.0$ Hz). ^{13}C NMR (100 MHz, CDCl_3) δ 21.41, 23.97, 24.04, 26.44, 37.51, 38.91, 49.98, 52.85, 57.68, 66.50, 80.74, 126.89, 128.91, 139.76, 142.25, 161.50. IR (cm^{-1}): 2954, 2863, 1595, 1434, 1300, 1265, 1156, 1080, 855, 734, 703, 667. MS (ESI-LCMS): m/z (%): 349 $[\text{M}+\text{H}]^+$ (100). HRMS calcd. For $\text{C}_{18}\text{H}_{24}\text{N}_2\text{O}_3\text{S}_1$: 371.1400, found: 371.1353.

