

Rapid synthesis of medium-ring fused polycarbocyclic systems by rearrangement of carbenoid-derived oxonium ylides

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Supporting Information

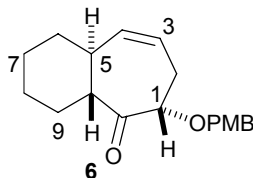
General procedure for rhodium(II) acetate catalysed ylide formation and rearrangement.

A solution of the α -diazo ketone (0.46 mmol) in CH₂Cl₂ (60 mL) was added dropwise over 1.25 h to a stirred solution of rhodium(II) acetate dimer (2 mol%, 9 μ mol) in CH₂Cl₂ (45 mL) at room temperature under an atmosphere of argon. After addition was complete, the reaction mixture was concentrated *in vacuo* to give a green oil and the crude product was then purified by flash column chromatography on silica gel.

General procedure for copper(II) hexafluoroacetylacetonate catalysed ylide formation and rearrangement.

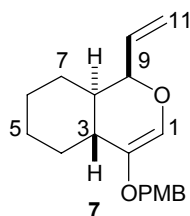
A solution of the α -diazo ketone (0.46 mmol) in CH₂Cl₂ (60 mL) was added dropwise over 1 h to a stirred solution of copper(II) hexafluoroacetylacetonate (2 mol%, 9 μ mol) in CH₂Cl₂ (45 mL) heated at reflux under an atmosphere of argon. After addition was complete, the reaction mixture was stirred for a further 30 min. Then the reaction mixture was concentrated *in vacuo* to a green oil and then purified by flash column chromatography.

Bicyclic Ketone 6.



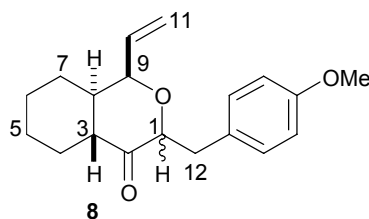
ν_{\max} (CHCl₃) 3012, 2928, 2856, 1715, 1612 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 7.28 (2H, d, J = 8.6 Hz, Ar-*H*), 6.87 (2H, d, J = 8.6 Hz, Ar-*H*), 5.63 (1H, dddd, J = 2.5, 4.8, 6.9, 11.8 Hz, H-3), 5.47 (1H, d, J = 11.8 Hz, H-4), 4.63 (1H, d, J = 11.5 Hz, CHHPh), 4.39 (1H, d, J = 11.5 Hz, CHHPh), 4.01 (1H, dd, J = 5.0, 7.8 Hz, H-1), 3.80 (3H, s, OCH₃), 2.66 (1H, ddddd, J = 1.2, 1.2, 5.0, 6.9, 16.4 Hz H-2), 2.38–2.30 (1H, m, H-10), 2.24 (1H, dddd, J = 2.1, 2.1, 4.8, 7.8, 16.4 Hz, H-2), 2.02 (1H, bt, J = 10.7 Hz, H-5), 1.94–1.88 (1H, m, CH₂), 1.81–1.66 (3H, m, CH₂), 1.35–1.10 (4H, m, CH₂); ¹³C NMR (400 MHz, CDCl₃) δ 212.3 (C), 159.3 (C), 137.0 (CH), 129.8 (C), 129.5 (CH), 124.0 (CH), 113.7 (CH), 83.3 (CH), 71.4 (CH₂), 55.2 (CH₃), 53.4 (CH), 39.5 (CH), 34.3 (CH₂), 31.2 (CH₂), 26.9 (CH₂), 25.8 (CH₂), 24.8 (CH₂); HRMS (ESI) calcd for C₁₉H₂₄O₃Na [M+Na]⁺: 323.1623, found: 323.1618.

Hexahydroisochromene 7.



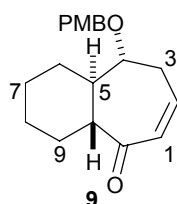
ν_{\max} (CHCl₃) 2929, 2857, 1613, 991, 908 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 7.26 (2H, d, J = 8.6 Hz, Ar-*H*), 6.88 (2H, d, J = 8.6 Hz, Ar-*H*), 6.12 (1H, d, J = 2.0 Hz, H-11) 5.49 (1H, ddd, J = 6.4, 10.6, 17.1 Hz, H-2), 5.24–5.19 (2H, m, H-1), 4.58 (1H, d, J = 11.0 Hz, CHHPh), 4.50 (1H, d, J = 11.0 Hz, CHHPh), 4.27 (1H, dd, J = 4.4, 6.4 Hz, H-3), 3.81 (3H, s, OCH₃), 2.25–2.19 (1H, m, CH₂), 1.98 (1H, dddd, J = 2.0, 3.3, 13.8 Hz, H-9), 1.82–1.79 (2H, m, CH₂), 1.76–1.69 (1H, m, H-4), 1.63–1.59 (1H, m, CH₂), 1.37–1.18 (2H, m, CH₂), 1.11–1.00 (2H, m, CH₂); ¹³C NMR (400 MHz, CDCl₃) δ 159.2 (C), 140.8 (C), 132.9 (CH), 129.8 (C), 129.0 (CH), 123.9 (CH), 117.2 (CH₂), 113.7 (CH), 78.4 (CH), 70.0 (CH₂), 55.2 (CH₃), 42.1 (CH), 35.9 (CH), 28.0 (CH₂), 27.8 (CH₂), 26.3 (CH₂), 25.8 (CH₂); HRMS (ESI) calcd for C₁₉H₂₄O₃Na [M + Na]⁺: 323.1618, found: 323.1613.

Ketone 8.



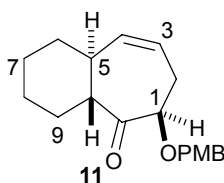
ν_{\max} (liquid film) 2929, 2856, 1719, 1611 cm^{-1} . ^1H NMR (400 MHz, CDCl_3) δ 7.17 (2H, d, $J = 8.6$ Hz, Ar-*H*), 6.81 (2H, d, $J = 8.6$ Hz, Ar-*H*), 6.15 (1H, ddd, $J = 6.0, 10.6, 17.0$ Hz, H-10), 5.36 (1H, ddd, $J = 1.6, 10.6$ Hz, H-11), 5.27 (1H, ddd, $J = 1.6, 17.0$ Hz, H-11), 4.34–4.31 (2H, m, H-1, H-9), 3.78 (3H, s, OCH_3), 3.17 (1H, dd, $J = 4.2, 14.6$ Hz, H-12), 2.75 (1H, dd, $J = 7.8, 14.6$ Hz, H-12), 2.19–2.13 (1H, m, H-3), 2.09–1.90 (1H, m, H-6, CH_2), 1.88–1.73 (3H, m, CH_2), 1.62–1.58 (1H, m, CH_2), 1.28–1.11 (3H, m, CH_2); ^{13}C NMR (400 MHz, CDCl_3) δ 208.8 (C), 157.9 (C), 131.4 (CH), 130.5 (C), 130.4 (CH), 120.4 (CH_2), 113.5 (CH), 77.2 (CH), 77.1 (CH), 55.2 (CH_3), 48.0 (CH), 46.0 (CH), 34.9 (CH_2), 28.5 (CH_2), 25.2 (CH_2), 25.1 (CH_2), 24.6 (CH_2); HRMS (ESI) calcd for $\text{C}_{19}\text{H}_{24}\text{O}_3\text{Na}$ $[\text{M}+\text{Na}]^+$: 323.1618, found: 323.1616.

Bicyclic Ketone 9.



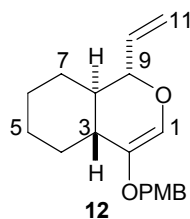
ν_{\max} (CHCl_3) 3011, 2932, 2857, 1672, 1613 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 7.16 (2H, d, $J = 8.6$ Hz, Ar-*H*), 6.84 (2H, d, $J = 8.6$ Hz, Ar-*H*), 6.41 (1H, ddd, $J = 3.0, 8.3, 11.4$ Hz, H-2), 6.18 (1H, dd, $J = 3.1, 11.4$ Hz, H-1), 4.31 (1H, d, $J = 11.5$ Hz, CHHPh), 4.22 (1H, d, $J = 11.5$ Hz, CHHPh), 3.78 (3H, s, OCH_3), 3.53 (1H, d, $J = 6.0$ Hz, H-4), 2.79 (1H, ddd, $J = 6.0, 8.3, 17.7$ Hz, H-3), 2.53 (1H, ddd, $J = 3.0, 3.1, 17.7$ Hz, H-3), 2.29 (1H, dt, $J = 2.4, 10.9, 11.6$ Hz, H-9), 1.82–1.76 (4H, m, CH_2), 1.70–1.64 (1H, m, H-5), 1.62–1.52 (1H, m, CH_2), 1.38–1.10 (3H, m, CH_2); ^{13}C NMR (400 MHz, CDCl_3) δ 204.2 (C), 159.0 (C), 138.5 (CH), 135.0 (CH), 130.3 (C), 128.8 (CH), 113.7 (CH), 81.0 (CH), 69.0 (CH_2), 55.2 (CH_3), 54.3 (CH), 47.2 (CH), 31.7 (CH_2), 30.5 (CH_2), 29.7 (CH_2), 27.2 (CH_2), 26.0 (CH_2), 25.1 (CH_2); HRMS (EI) calcd for $\text{C}_{19}\text{H}_{24}\text{O}_3$ $[\text{M}]^+$: 300.1725, found: 300.1727.

Bicyclic Ketone 11.



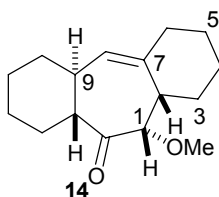
ν_{\max} (CHCl₃) 3011, 2936, 2857, 1712, 1613 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 7.26 (2H, d, J = 8.6 Hz, Ar-*H*), 6.87 (2H, d, J = 8.6 Hz, Ar-*H*), 5.49 (1H, dddd, J = 2.3, 4.8, 4.8, 11.7 Hz, H-3), 5.41–5.35 (1H, m, H-4), 4.53 (1H, d, J = 11.5 Hz, CHHPh), 4.45 (1H, dd, J = 6.0, 9.7 Hz, H-1), 4.29 (1H, d, J = 11.5 Hz, CHHPh), 3.80 (3H, s, OCH₃), 2.57–2.38 (3H, m, H-2, H-10), 2.22–2.12 (1H, m, H-5), 1.91–1.84 (1H, m, CH₂), 1.82–1.72 (3H, m, CH₂), 1.43–1.12 (4H, m, CH₂); ¹³C NMR (400 MHz, CDCl₃) δ 213.5 (C), 159.4 (C), 135.7 (CH), 129.7 (C), 129.7 (CH), 124.3 (CH), 113.9 (CH), 79.9 (CH), 71.4 (CH₂), 55.3 (CH₃), 54.0 (CH), 39.0 (CH₂), 33.3 (CH₂), 33.0 (CH₂), 28.5 (CH₂), 25.9 (CH₂), 25.1 (CH₂); HRMS (EI) calcd for C₁₉H₂₄O₃ [M]⁺: 300.1725, found: 300.1727.

Hexahydroisochromene 12.



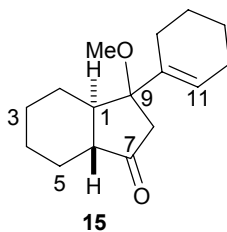
ν_{\max} (CHCl₃) 3012, 2935, 2857, 1614, 991 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 7.27 (2H, d, J = 8.6 Hz, Ar-*H*), 6.88 (2H, d, J = 8.6 Hz, Ar-*H*), 6.21 (1H, d, J = 2.0 Hz, H-11) 5.79 (1H, ddd, J = 7.7, 10.3, 17.3 Hz, H-2), 5.30 (1H, dd, J = 1.5, 17.3 Hz, H-1), 5.26 (1H, dd, J = 1.5, 10.3 Hz, H-1), 4.58 (1H, d, J = 10.9 Hz, CHHPh), 4.50 (1H, d, J = 10.9 Hz, CHHPh), 3.84 (1H, dd, J = 7.7, 9.9 Hz, H-3), 3.81 (3H, s, OCH₃), 2.23–2.09 (2H, m, H-9, CH₂), 1.86–1.76 (2H, m, CH₂), 1.73–1.66 (1H, m, CH₂) 1.44–1.18 (3H, m, H-4, CH₂), 1.02 (1H, dq, J = 3.3, 12.5 Hz, CH₂), 0.91 (1H, dq, J = 3.6, 12.6 Hz, CH₂); ¹³C NMR (400 MHz, CDCl₃) δ 159.2 (C), 141.9 (C), 136.4 (CH), 129.8 (C), 129.0 (CH), 124.7 (CH), 118.4 (CH₂), 113.8 (CH), 80.7 (CH), 69.9 (CH₂), 55.3 (CH₃), 43.5 (CH), 41.1 (CH), 28.0 (CH₂), 27.9 (CH₂), 26.1 (CH₂), 25.7 (CH₂); HRMS (EI) calcd for C₁₉H₂₄O₃ [M]⁺: 300.1725, found: 300.1723. Found C, 76.09; H, 8.05; C₁₉H₂₄O₃ requires C, 75.97; H, 8.05.

Tricyclic Ketone 14.



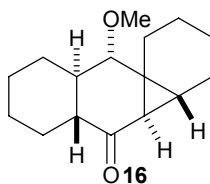
ν_{\max} (CHCl₃) 2933, 2857, 1693 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 5.15 (1H, m, H-8), 3.59 (1H, d, J = 3.6 Hz, H-1), 3.46 (3H, s, OCH₃), 3.11–3.02 (1H, m, H-9), 2.26–2.19 (1H, m, H-2), 2.18–2.12 (1H, m, CH₂), 2.08 (1H, ddd, J = 3.3, 11.2, 12.4 Hz, H-14), 1.96–1.90 (2H, m, CH₂), 1.87–1.80 (2H, m, CH₂), 1.78–1.71 (3H, m, CH₂), 1.64–1.54 (2H, m, CH₂), 1.49–1.19 (5H, m, CH₂), 1.06 (1H, dq, J = 3.4, 12.6 Hz, CH₂); ¹³C NMR (400 MHz, CDCl₃) δ 216.2 (C), 139.0 (C), 128.0 (CH), 93.0 (CH), 60.2 (CH₃), 58.1 (CH), 45.4 (CH), 39.0 (CH₂), 34.5 (CH), 33.9 (CH₂), 30.9 (CH₂), 30.5 (CH₂), 28.1 (CH₂), 26.5 (CH₂), 26.1 (CH₂), 26.1 (CH₂); HRMS (EI) calcd for C₁₆H₂₄O₂ [M]⁺: 248.1776, found: 248.1775.

Octahydroindenone 15.



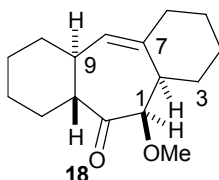
ν_{\max} (CHCl₃) 3008, 2936, 2858, 1733, 1686 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 5.74–5.70 (1H, m, H-11), 3.08 (3H, s, OCH₃), 2.53 (1H, dd, J = 1.1, 18.9 Hz, H-8), 2.33–2.25 (1H, m, H-6), 2.31 (1H, d, J = 18.9 Hz, H-8), 2.14–2.08 (3H, m, H-12, CH₂), 1.99–1.88 (3H, m, H-12, CH₂), 1.84–1.58 (4H, m, CH₂), 1.55–1.45 (3H, m, H-1, CH₂), 1.22–1.02 (4H, m, CH₂); ¹³C NMR (400 MHz, CDCl₃) δ 217.0 (C), 135.6 (C), 124.6 (CH), 84.9 (C), 51.9 (CH), 51.5 (CH), 51.4 (CH₃), 44.5 (CH₂), 30.4 (CH₂), 26.5 (CH₂), 26.3 (CH₂), 25.9 (CH₂), 25.7 (CH₂), 25.2 (CH₂), 23.0 (CH₂), 22.3 (CH₂); HRMS (ESI) calcd for C₁₆H₂₄O₂Na [M+Na]⁺: 271.1669, found: 271.1652.

Cyclopropyl Ketone 16.



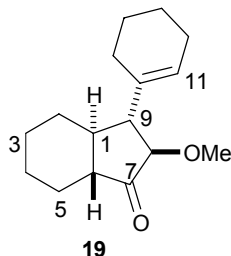
^{13}C NMR (400 MHz, CDCl_3) δ 209.8 (C), 87.1 (CH), 60.8 (CH_3), 48.1 (CH), 44.6 (CH), 39.0 (CH), 34.3 (C), 31.8 (CH), 31.4 (CH_2), 25.3 (CH_2), 25.0 (CH_2), 24.9 (CH_2), 24.0 (CH_2), 23.1 (CH_2), 21.0 (CH_2), 20.7 (CH_2); HRMS (ESI) calcd for $\text{C}_{16}\text{H}_{24}\text{O}_2\text{Na}$ $[\text{M}+\text{Na}]^+$: 271.1669, found: 271.1661.

Tricyclic Ketone 18.



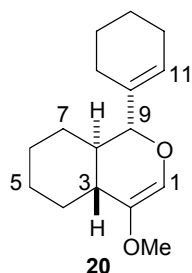
ν_{max} (CHCl_3) 3011, 2932, 2856, 1710 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 5.06 (1H, br s, H-8), 4.81 (1H, d, $J = 5.3$ Hz, H-1), 3.29 (3H, s, OCH_3), 2.64–2.56 (1H, m, H-2), 2.55–2.45 (1H, m, H-9), 2.18–2.12 (1H, m, CH_2), 2.08–1.95 (4H, m, H-14, CH_2), 1.89–1.72 (5H, m, CH_2), 1.39–1.06 (6H, m, CH_2), 0.80 (1H, dq, $J = 3.6, 12.7$ Hz, H-3); ^{13}C NMR (400 MHz, CDCl_3) δ 212.0 (C), 140.6 (C), 126.9 (CH), 83.2 (CH), 57.5 (CH_3), 56.7 (CH), 45.8 (CH), 38.6 (CH_2), 36.0 (CH), 34.0 (CH_2), 30.2 (CH_2), 28.7 (CH_2), 28.4 (CH_2), 26.1 (CH_2), 25.9 (CH_2), 25.6 (CH_2); HRMS (EI) calcd for $\text{C}_{16}\text{H}_{24}\text{O}_2$ $[\text{M}]^+$: 248.1776, found: 248.1775.

Octahydroindenone 19.



ν_{max} (CHCl_3) 2933, 2856, 1742 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 5.62–5.59 (1H, m, H-11), 3.52 (3H, s, OCH_3), 3.49 (1H, d, $J = 9.6$ Hz, H-8), 2.21 (1H, dd, $J = 9.6, 11.5$ Hz, H-9), 2.13–2.08 (1H, m, CH_2), 2.07–2.02 (2H, m, H-12), 1.97–1.87 (3H, m, CH_2), 1.84–1.77 (2H, m, CH_2), 1.74–1.70 (1H, m, H-6), 1.69–1.57 (4H, m, CH_2), 1.32–1.08 (4H, m, H-1, CH_2), 1.07–0.97 (1H, m, CH_2); ^{13}C NMR (400 MHz, CDCl_3) δ 214.9 (C), 134.6 (C), 124.8 (CH), 84.9 (CH), 58.8 (CH_3), 55.9 (CH), 54.1 (CH), 39.9 (CH), 30.2 (CH_2), 26.1 (CH_2), 25.8 (CH_2), 25.4 (CH_2), 25.3 (CH_2), 25.2 (CH_2), 22.9 (CH_2), 22.6 (CH_2); HRMS (EI) calcd for $\text{C}_{16}\text{H}_{24}\text{O}_2$ $[\text{M}]^+$: 248.1776, found: 248.1774.

Hexahydroisochromene 20.



ν_{\max} (CHCl₃) 2926, 2855, 1737, 1447 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 6.01 (1H, d, J = 2.5 Hz, H-1), 5.72 (1H, br s, H-11), 3.96 (1H, d, J = 10.3 Hz, H-9), 3.41 (3H, s, OCH₃), 2.52–2.45 (1H, m, CH₂), 2.24 (1H, dddd, J = 2.5, 2.9, 11.3, 11.5 Hz, H-3), 2.09–1.98 (3H, m, H-12, CH₂), 1.93–1.85 (1H, m, CH₂), 1.81–1.48 (7H, m, H-8, CH₂), 1.36–1.18 (4H, m, CH₂), 1.06 (1H, dq, J = 3.1, 12.0 Hz, CH₂); ¹³C NMR (400 MHz, CDCl₃) δ 148.8 (C), 135.0 (C), 126.7 (CH), 125.5 (CH), 88.7 (CH), 60.9 (CH₃), 48.4 (CH), 46.6 (CH), 28.0 (CH₂), 27.2 (CH₂), 25.9 (CH₂), 25.7 (CH₂), 25.2 (CH₂), 23.5 (CH₂), 22.6 (CH₂), 22.5 (CH₂); HRMS (EI) calcd for C₁₆H₂₄O₂ [M]⁺: 248.1776, found: 248.1778.