Digilab FTS-15 FT-IR spectrum of synthetic isocycloseychellene. We also graciously thank Professor M. R. Willcott (University of Houston) and Dr. R. R. Inners (University of South Carolina) for their help with the 400-MHz NMR spectra of natural cycloseychellene and synthetic isocycloseychellene. J.-M.A. expresses his thanks for the Lynn Murray (1982–83) and Stella Ehrhardt Memorial (1984–85) Fellowships.

Total Syntheses of (±)-Seychellene and (±)-Cycloseychellene

Steven C. Welch,* John M. Gruber, and Paul A. Morrison

Department of Chemistry, University of Houston—University Park, Houston, Texas 77004

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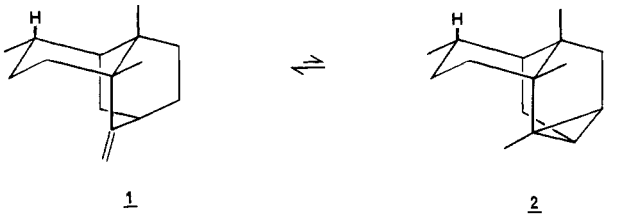
Total syntheses of (±)-seychellene (1) and (±)-cycloseychellene (2) are presented. The key step in these syntheses is the construction of tricyclic alcohols **13** by concomitant oxidative cyclization of diol **12**.

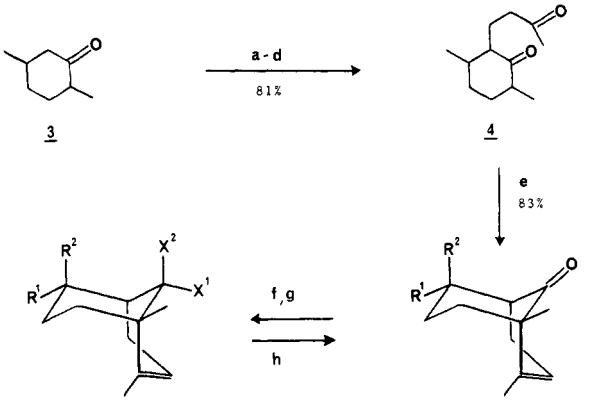
Both the tricyclic sesquiterpene seychellene (1) (Scheme I) and the tetracyclic hydrocarbon cycloseychellene (2) were isolated from Patchouli oil (*Pogostemon cablin* Benth.)[1,2] In the previous papers in this series we reported a structural revision for natural product **2**.[3] This structural assignment has been confirmed by Yamada and coworker's recent total synthesis of (±)-cycloseychellene (2).[4] Several successful total syntheses of seychellene (1) have been reported.[5] We now present, herein, the full details of our total syntheses of (±)-seychellene (1) and (±)-cycloseychellene (2) via a common tricyclic intermediate.[5]

The syntheses of sesquiterpenes **1** and **2** begin with 2,5-dimethylcyclohexanone (**3**, Scheme II). Treatment of ketone **3** with sodium hydride and ethyl formate in tetrahydrofuran followed by acidification gives a hydroxymethylene ketone. A Michael reaction of the latter substance with methyl vinyl ketone (MVK) in the presence of triethylamine followed by decarbonylation with 7.2 equiv of potassium carbonate in dilute aqueous ethanol affords diketones **4** in 81% overall yield from ketone **3**. Cyclization of diketone **4** to bicyclic ketones **5A** (R^1 = H, R^2 = CH_3) and **5E** (R^1 = CH_3, R^2 = H) was accomplished with 5.5 equiv of boron trifluoride in dichloromethane under conditions of high dilution (1.0 g of **4**/1.5 L of CH_2Cl_2, 3.4×10^{-3} M) at 0 °C for 2 h followed by 23 °C for 26 h. Under these conditions ketones **5A** and **5E** are produced in 83% yield as a 36:64 ratio of axial-CH_3 (R^1 = H, R^2 = CH_3): equatorial-CH_3 (R^1 = CH_3, R^2 = H) isomers, respectively.

Scheme I



Scheme II. Synthesis of Bicyclic Ketone 5E[a]



[a] (a) NaH, HCO_2Et, THF; (b) H_3O^+; (c) MVK, Et_3N; (d) 7.2 equiv of K_2CO_3, EtOH, H_2O, Δ, concentration 0.14 M; (e) 5.5 equiv of BF_3, CH_2Cl_2, concentration 3.4×10^{-3} M, 76 h; (f) L-Selectride, THF; −78 °C to 0 °C; (g) H_2O_2, OH^-; (h) H_2CrO_4, acetone.

These conditions represent a dramatic improvement over those used by Corey and Nozoe in the initial stages of their classic and elegant synthesis of (±)-helminthosporal.[6] Reduction of ketones **5AE** with L-Selectride (Aldrich) [Li(*sec*-Bu)$_3$H] in tetrahydrofuran from −78 °C to 0 °C and followed by a basic hydrogen peroxide workup affords three easily separable isomeric alcohols **6AA** [R^1 = H, R^2 = CH_3, X^1 = H, X^2 = OH; 31.4% yield], **6EA** [R^1 = CH_3, R^2 = H, X^1 = H, X^2 = OH; 34.9% yield], and **6EE** [R^1 = CH_3, R^2 = H, X^1 = OH, X^2 = H; 21.6% yield].[7] The stereochemistry of each isomer was established by analysis

(1) (a) Tsubaki, N.; Nishimura, K.; Hirose, Y. *Bull. Soc. Chem. Jpn.* **1967**, *40*, 597. (b) Wolff, G.; Ourisson, G. *Tetrahedron* **1969**, *25*, 4903.
(2) (a) Terhune, S. J.; Hogg, J. W.; Lawrence, B. M. *Tetrahedron Lett.* **1973**, 4705. (b) Paknikar, S. K. *Indian J. Chem.* **1974** *12*, 1016.
(3) (a) Welch, S. C.; Chou, C.-Y.; Gruber, J. M.; Assercq, J.-M. *J. Org. Chem.*, preceding paper in this issue. (b) Willcott, M. R.; Morrison, P. A.; Assercq, J.-M.; Welch, S. C.; Inners, R. *J. Org. Chem.* **1981**, *46*, 4819. (c) Welch, S. C.; Gruber, J. M.; Chou, C.-Y.; Willcott, M. R.; Inners, R. *J. Org. Chem.* **1981**, *46*, 4816.
(4) Niwa, H.; Ban, N.; Yamada, K. *Tetrahedron Lett.* **1983**, *24*, 937.
(5) (a) Piers, E.; De Waal, W.; Britton, R. W. *J. Am. Chem. Soc.* **1971**, *93*, 5113. (b) Mirrington, R. N.; Schmalzl, K. J. *J. Org. Chem.* **1972**, *37*, 2877. (c) Fukamiya, N.; Kato, M.; Yoshikoshi, A. *J. Chem. Soc., Perkin Trans.* **1973**, 1843. (d) Fráter, G. *Helv. Chim. Acta* **1974**, *57*, 172. (e) Spitzner, D. *Tetrahedron Lett.* **1978**, 3349. (f) Jung, M. E.; McCombs, C. A. *J. Am. Chem. Soc.* **1978**, *100*, 5207, (g) Yamada, K.; Kyotani, Y.; Manabe, S.; Suzuki, M. *Tetrahedron* **1979**, *35*, 293. (h) Jung, M. E.; Pan, Y.-G. *Tetrahedron Lett.* **1980**, 3127. (i) Welch, S. C.; Gruber, J. M.; Chou, C.-Y.; Willcott, M. R.; Inners, R. *J. Org. Chem.* **1981**, *46*, 4816. (j) Jung, M. E.; McCombs, C. A.; Takeda, Y.; Pan, Y.-G. *J. Am. Chem. Soc.* **1981**, *103*, 6677. (k) Welch, S. C.; Gruber, J. M.; Morrison, P. A. *Tetrahedron Lett.* **1984**, *25*, 5497.
(6) Corey, E. J.; Nozoe, S. *J. Am. Chem. Soc.* **1965**, *87*, 5728.
(7) Brown, H. C.; Krishnamurthy, S. *J. Am. Chem. Soc.* **1972**, *94*, 7159. Krishnamurthy, S.; Brown, H. C. *Ibid.* **1976**, *98*, 3383.

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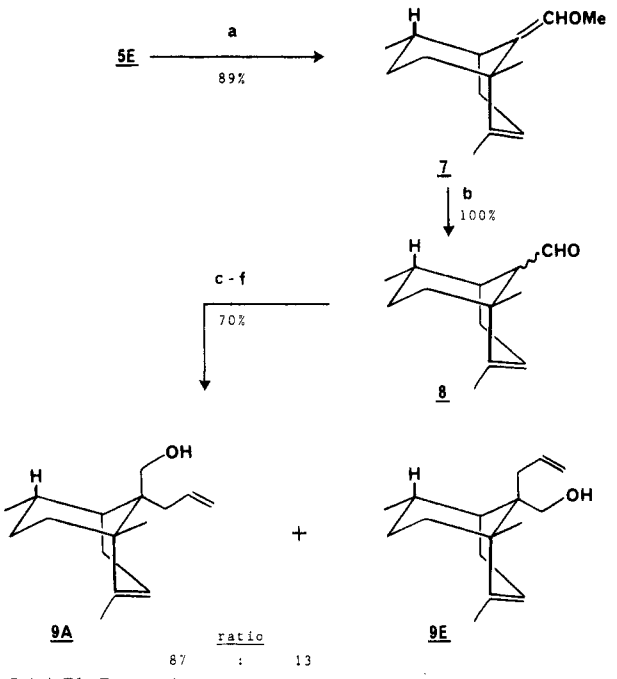
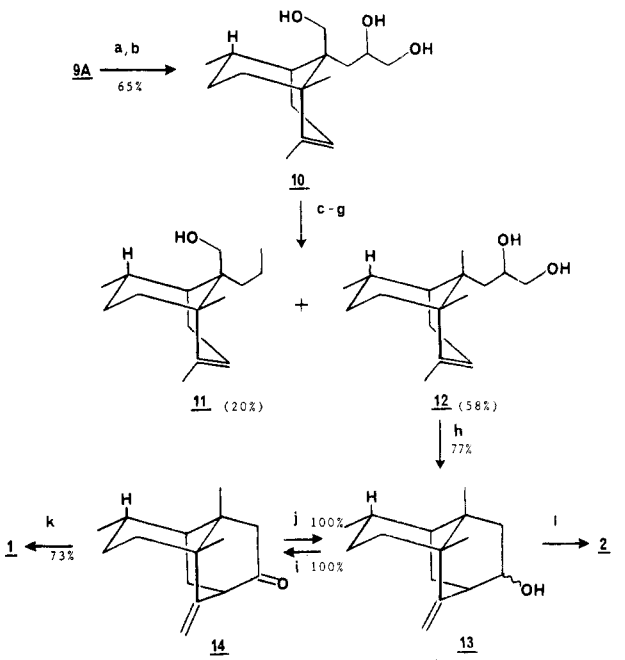
Scheme III. Synthesis of Bicyclic Alcohol 9A[a]



[a] (a) Ph_3P=CHOMe, Me_2SO; (b) 35% $HClO_4$, THF, 1 h, 23 °C; (c) Ph_3CK, DME, Me_2SO (cat.); (d) $BrCH_2CH$=CH_2; (e) $PhCH_3$, Δ, 26 h; (f) $LiAlH_4$, Et_2O, 0 °C.

Scheme IV. Syntheses of (±)-Seychellene (1) and (±)-Cycloseychellene (2)[a]



[a] (a) OsO_4 (cat.); 1.5-1.66 equiv of NMMO, H_2O, THF; (b) $NaHSO_3$; (c) acetone, $CaSO_4$, $MgSO_4$, HCl gas (cat.); (d) *n*-BuLi, THF, TMEDA; (e) $ClPO(NMe_2)_2$; (f) Li, $EtNH_2$, Et_2O, *t*-BuOH; (g) 10% HCl, MeOH; (h) 6.3 equiv of $NaIO_4$, H_2O, THF, 23 °C, 13 h; (i) H_2CrO_4, acetone; (j) $NaBH_4$, MeOH, −15 °C to 23 °C, ref 4; (k) $N_2H_4 \cdot H_2SO_4$, KOH, DEG, Δ, 4 h; (l) ref 4.

of the europium-induced NMR chemical shifts for the secondary-methyl group in each alcohol **6AA**, **6EA**, and **6EE**.[8] The magnitudes for these three europium-induced NMR shift experiments are quite different. Listed in Scheme II are the slopes for each NMR shift analysis of alcohols **6AA**, **6EA**, and **6EE** together with the distance of the secondary-methyl group to the hydroxyl group in each isomer.[8] The slopes for the europium-induced chemical shifts of all three secondary methyl groups in **6AA**, **6EA**, and **6EE** are inversely proportional to the distance of each methyl group from the europium-coordinated hydroxyl substituent. These europium-induced NMR shift experiments are consistent with the stereochemical assignments for **6AA**, **6EA**, and **6EE**. Chromic acid oxidation of alcohol **6AA** in acetone gives ketone **5A** (δ 0.93, d, J = 7 Hz, axial CH_3CH) in 87% yield.[9] Chromic acid oxidation of **6EA** and/or **6EE** in acetone affords ketone **5E** (δ 0.98, d, J = 6.3 Hz, equatorial CH_3CH) in 83% yield.[9]

Scheme III details the stereoselective construction of alcohol **9A**. A Wittig reaction on ketone **5E** with (methoxymethylene)triphenylphosphorane in anhydrous dimethyl sulfoxide produces vinyl ethers **7** in 89% yield.[10] Hydrolysis of vinyl ethers **7** with 35% aqueous perchloric acid in tetrahydrofuran for 1 h at 23 °C gives aldehydes **8** in quantitative yield. Alkylation of aldehydes **8** by generating the enolate anion with potassium triphenylmethanide in 1,2-dimethoxyethane coating a small amount of dimethyl sulfoxide at 23 °C followed by quenching with allyl bromide at 23 °C for 24 h produces a 55:45 ratio of O-:C-alkylated products. After workup this mixture was then heated at reflux in toluene for 26 h in order to promote the Claisen rearrangement of the O-alkylated intermediate to the desired C-alkylated product.[11] Finally, reduction of this latter alkylated aldehyde product with lithium aluminum hydride in diethyl ether at 0 °C produces after chromatographic separation alcohols **9A** and **9E** in 61% and 9% overall yields (87:13 ratio), respectively. Formation of the axial aldehyde precursor of alcohol **9A** as the major diastereomer was expected on the basis of stereochemical precedent report by House and co-workers.[11] The Claisen rearrangement is expected to occur with the carbon–carbon bond-forming process taking place from the less hindered equatorial direction at carbon-9. Raphael and co-workers have shown that in bicyclo[3.3.1]nonene ring systems the direction of less hindered approach at carbon-9 is from the side of alkene bridge.[12]

Scheme IV displays the completion of the syntheses of (±)-seychellene (**1**) and (±)-cycloseychellene (**2**). Several attempts were made to deoxygenate alcohol **9A** to a diene by Brown's Superhydride[13] and Ireland's phosphoramidate[14] reduction methodologies; however, these routes proved to be totally unsuccessful. However, selective oxidation of the monosubstituted alkene of alcohol **9A** under

(8) (a) Hinckley, C. C. *J. Am. Chem. Soc.* **1969**, *91*, 5160. (b) Demarco, P. V.; Elzey, J. K; Lewis, R. B.; Wenkert, E. *Ibid.* **1970**, *92*, 5734. The slopes for each 2°-CH_3 group in **6AA**, **6EA**, and **6EE** were calculated from a plot of $\Delta\delta_{Me}$ vs. Δ[Eu(DPM)$_2$/[ROH]. The distances between the 2°-CH_3 and the OH group in each isomer were measured by using Dreiding stereomodels.

(9) (a) Eisenbraun, E. J. "Organic Syntheses"; Wiley: New York, 1973; Collect. Vol. V, p 310. (b) Djerassi, C.; Engle, R. R.; Bauers, A. *J. Org. Chem.* **1956**, *21*, 1547.

(10) (a) Levine, S. G. *J. Am. Chem. Soc.* **1958**, *80*, 6150. (b) Wittig, G.; Krauss, E. *Angew. Chem.* **1959**, *71*, 127. (c) Maercker, A. *Org. React. (N.Y.)* **1965**, *14*, 270.

(11) House, H. O.; Lubinkowski, J.; Good, J. J. *J. Org. Chem.* **1975**, *40*, 86.

(12) (a) Martin, J.; Parker, W.; Raphael, R. A. *J. Chem. Soc. C* **1971**, 348; (b) *J. Chem. Soc.* **1964**, 289.

(13) Krishnamurthy, S.; Brown, H. C. *J. Org. Chem.* **1976**, *41*, 3064; **1983**, *48*, 3085. Failure of this method was very surprising since a similar reduction of the tosylate ether of alcohol **18** in ref 3a proceeds in 50% yield.

(14) (a) Ireland, R. E.; Muchmore, D. C.; Hengartner, U. *J. Am. Chem. Soc.* **1972**, *94*, 5098. Lithium in ethylamine or methylamine reduction of an intermediate phosphoramidate ester of alcohol **9A** at 0–16 °C resulted in the concomitant reduction of the monosubstituted alkene moiety.

Van Rheenan's conditions was successful.[15] Treatment of alcohol **9A** with a catalytic amount of osmium tetroxide and 1.15–1.66 equiv of 4-methylmorpholine *N*-oxide (NMMO) in aqueous tetrahydrofuran gives triol **10** in 65% as a mixture of diastereomers.[15] The glycol portion of triol **10** was protected as an acetonide. A solution of triol **10** in acetone in the presence of anhydrous calcium sulfate (Drierite 8-mesh)–magnesium sulfate (powdered) and a catalytic amount of hydrogen chloride gas as 23 °C for 22 h produces a mixture intermediate acetonides.[16] Esterification of the primary alcohol groups was accomplished with *n*-butyllithium in tetramethylethylenediamine–tetrahydrofuran followed by bis(dimethylamino)phosphorochloridate.[14] Reduction of these phosphoramidate esters with lithium metal in ethylamine–ether–*tert*-butyl alcohol followed by acid-catalyzed methanolysis of the acetonide protecting groups affords after chromatography on silica gel alcohol **11** and glycol **12** in 20% and 58% yields, respectively.[14] Apparently alcohol **11** arises from a seven-membered-ring acetonide from glycol **10** and glycol **12** comes from the corresponding five-membered-ring acetonide. Experiments aimed at kinetic and selective formation of the five-membered-ring acetonide with zinc chloride were unsuccessful at 0 °C to 23 °C. The five-membered-ring acetonide does form faster than the seven-membered-ring acetonide as indicated by TLC (silica gel); however, by the time all the starting triol **10** is consumed, there is significant equilibration between the two acetonides. Glycol **12** on oxidation with 6.3 equiv of sodium metaperiodate in aqueous tetrahydrofuran for 13 h spontaneously and serendipitously undergoes concomitant oxidative cleavage and intramolecular Prins (ene) reaction to produce tricyclic alcohols **13** in 77% yield as a 3:1 mixture of diastereomers.[7] Examination of a Dreiding stereomodel of the intermediate aldehyde reveals the fact that the trisubstituted alkene and aldehyde moieties are stereochemically perfectly situated for a very facile intramolecular ene process.[18] Yamada and co-workers have prepared (±)-cycloseychellene (**2**) from alcohols **13** (prepared by sodium borohydride reduction of ketone **14** in quantitative yield) via a four-step sequence of reactions.[4] Thus our synthesis of alcohols **13** represent another total synthesis of (±)-cycloseychellene (**2**). Chromic acid oxidation of alcohols **13** in acetone affords crystalline tricyclic ketone **14** in quantitative yield.[9] Our ketone **14** was found to be identical with that prepared by Yamada and coworkers with respect to IR and NMR spectra.[4] Finally Wolff–Kishner reduction of ketone **12** with hydrazine sulfate and potassium hydroxide in diethylene glycol at 200 °C for 4 h gives (±)-seychellene (**1**) in 73% yield.[19] Synthetic seychellene was found to be identical with a sample of the natural product with respect to GC–MS, IR, NMR (^{1}H and ^{13}C), and GLC.[5]

Experimental Section

Materials and Techniques.[20] **3,6-Dimthyl-2-(3-oxobutyl)cyclohexanone (4).** Sodium hydride (70% w/w as an oil dispersion, 70.8 g, 2.05 mol) was washed with dry THF (3 × 50 mL) and then suspended in dry THF (1.5 L) This suspension was cooled to 0 °C under N_2 and ethyl formate (500 mL, 6.20 mol) was added dropwise. Then ketone **3** (64.6 g, 0.512 mol) dissolved in dry THF (50 mL) was added dropwise. One hour after the ketone addition was completed, the reaction was allowed to warm to 23 °C and to stir for an additional 24 h. At this point the reaction mixture was poured into a mixture of saturated NH_4Cl solution (1250 mL), 10% HCl (500 mL), and ice (750 g). This mixture was divided in half and each half was extracted with Et_2O (4 × 300 mL). Each set of ethereal extracts was then washed with saturated NaCl solution (2 × 500 mL). The organic material was concentrated in vacuo and distilled (bulb-to-bulb) to afford 75.2 g (95%) of hydroxymethylene ketone: bp 50–55 °C (0.1 mmHg); NMR (CCl_4) δ 1.10 (d, 3, J = 3 Hz, CH-CH_3), 1.16 (d, 3, J = 3 Hz, CH_3CH), 1.3–2.8 (br m, 6), 8.7 (s, C=C*H*OH). This material was used immediately in the next step without further purification. Dry Et_3N (35 mL, 0.25 mmol) was added to a stirred mixture of hydroxymethylene ketone (23.1 g, 148 mmol) and freshly distilled methyl vinyl ketone (40 mL, 0.493 mmol) at 0 °C under N_2. The resulting yellow solution was stirred at 0 °C for 1 h. It was then stirred at 23 °C for 3 days. The excess Et_3N and MVK were removed in vacuo and the residue was dissolved in Et_2O (250 mL). This ethereal solution was washed with 10% HCl (100 mL), 5% NaOH (100 mL), H_2O (25 mL), and saturated NaCl solution (25 mL), dried ($MgSO_4$), filtered ($MgSO_4$), and concentrated in vacuo to give 34.0 g (101%) of yellow liquid. This liquid was dissolved in a solution of 95% EtOH (1.0 L), H_2O (75 mL), and K_2CO_3 (2.82 g, 20.5 mmol). This solution was heated at reflux for 20 h under N_2. The EtOH was removed in vacuo andd the residue was extracted with Et_2O (3 × 100 mL). The combined ethereal extracts were washed with water (50 mL) and saturated NaCl solution (50 mL), dried ($MgSO_4$), filtered ($MgSO_4$), and concentated in vacuo to give 28.8 g (98.0%) of crude diketone. Distillation (bulb-to-bulb) gave 24.9 g (84.8%) of diketone **4**: bp 110–120 °C (1.0 mmHg); IR (CCl_4) 2950, 2920, 2860, 1720 (C=O), 1710 (C=O) cm^{-1}; NMR ($CDCl_3$) δ 0.90 (d, 3, J = 6 Hz, CH_3CH), 1.00 (d, 3, J = 6 Hz, CH_3CH), 1.15–2.60 (br m, 11), 2.12 (s, 3, CH_3CO). Anal. Calcd for $C_{12}H_{20}O_2$: C, 73.43; H, 10.27. Found: C, 72.98; H, 10.16.

1,2,6-Trimethylbicyclo[3.3.1]non-2-en-9-one (5AE). A solution of diketone **4** (1.01 g, 5.13 mmol) in dry CH_2Cl_2 (1.5 L) was cooled to 0 °C under N_2, and then BF_3 (1.90 g, 28.0 mmol) was slowly bubbled (gas dispersion tube) into the rapidly stirred solution at 0 °C. The resulting reddish orange solution was stirred at 0 °C for 2 h. The reaction was then allowed to warm to 23 °C. After 26 h at 23 °C, GLC analysis (column a) indicated that 10% of the starting diketone remained, so additional BF_3 (0.01 g, 0.15 mmol) was added. The reaction was allowed to continue stirring at 23 °C for 48 h. At that time GLC monitoring (column a) indicated <5% of starting diketone remaining. The reaction mixture was poured onto a mixture of ice (30 g) and 10% NaOH solution (30 mL). After separation, the aqueous phase was extracted with CH_2Cl_2 (2 × 50 mL) and the combined organic solutions were washed with H_2O (200 mL) and dried ($MgSO_4$), and the solvent was removed in vacuo. Distillation (bulb-to-bulb) provided 0.76 g (82.7%) of the bicycloketone **5AE**: bp 65–70 °C (0.5 mmHg); IR (CCl_4) 3020 (C=CH), 2960, 2920, 1715 (C=O), 1670 (C=C) cm^{-1}; ^{1}H NMR ($CDCl_3$, 80 MHz) δ 0.91 (d, 0.4, J = 7 Hz)8 0.98 (d, 0.6, J = 6 Hz), 1.07 (s, 1.8, CH_3), 1.08 (s, 1.2, CH_3), 5.59 (brs, 1, C=CH); ^{13}C NMR ($CDCl_3$, 20.2 MHz) ppm 122.99 (C=CH, axial isomer), 123.75 (C=CH, equatorial isomer), 136.38 (C=C), 216.09 (C=O). Anal. Calcd for $C_{12}H_{18}O$: C, 80.85; H, 10.17. Found: C, 80.80; H, 10.20.

(1α,5α,6α,9*S)-1,2,6-Trimethylbicyclo[3.3.1]non-2-en-9-ol (6AA), (1α,5α,6β,9*S**)-1,2,6-Trimethylbicyclo[3.3.1]non-2-en-9-ol (6EA), and (1α,5α,6β,9*R**)-1,2,6-Trimethylbicyclo[3.3.1]non-2-en-9-ol (6EE).** Ketone **5AE** (7.83 g, 43.8 mmol) was dissolved in THF (50 mL) under N_2 and cooled to −78 °C (dry ice/acetone). L-Selectride (48.3 mL, 48.3 mmol, 1 M) was added to the solution dropwise over a period of 20 min. The resulting yellow solution was stirred at −78 °C for 1 h and then at 0 °C (ice bath) for 2 h. Another portion of L-Selectride (50 mL, 50 mmol) was added and the reaction was stirred for one additional hour at 0 °C. The reaction was quenched by the dropwise addition of 10% NaOH (100 mL) and 30% H_2O_2 (60 mL) at 0 °C. After 20 min this mixture was partitioned with Et_2O (100 mL). The

(15) Van Rheenan, V.; Cha, D. Y.; Hartley, W. M. *Org. Synth.* (*N.Y.*) **1978**, *58*, 44.
(16) (a) Lewhart, M. L.; Schneider, J. J. *J. Org. Chem.* **1969**, *34*, 3505. (b) Clode, D. M. *Chem. Rev.* **1979**, *79*, 491.
(17) (a) France, D. J.; Hand, J. J.; Los, M. *J. Org. Chem.* **1970**, *35*, 468. (b) Jackson, E. L. *Org. React.* (*N.Y.*) **1944**, *2*, 341.
(18) (a) Snider, B. B. *Acc. Chem. Res.* **1980**, *13*, 426. (b) Oppolzer, W.; Snieckus, V. *Angew, Chem., Int. Ed. Engl.*, **1978**, *17*, 476. (c) Marshall, J. A.; Anderson, N. H.; Johnson, P. C. *J. Org. Chem.* **1970**, *35*, 186.
(19) (a) Todd, D. *Org. React.* (*N.Y.*) **1948**, *4*, 378. (b) Mukawa, F.; Nagata, W. *Bull. Chem. Soc. Jpn.* **1972**, *45*, 574.
(20) Please refer to the Materials and Techniques portion of the previous paper in this issue, ref 3a.

aqueous portion was then extracted with Et_2O (4 × 25 mL). The combined ethereal extracts were washed with H_2O (4 × 50 mL), saturated NaCl solution (50 mL), and dried ($MgSO_4$). The excess *sec*-BuOH was removed by azetropic distillation with C_6H_6 (3 × 25 mL). Concentration in vauco gave 6.95 g of crude alcohols **6AA**, **6AE**, and **6EE**. Medium pressure liquid chromatography (MPLC)[20] on silica gel using ether–petroleum ether (10:90, respectively) as eluant afforded **6AA**, **6AE**, and **6EE** in the ratio 35.7:39.7:24.6 with a combined yield of 87.9%.

6AA: IR (CCl_4) 3640, 3500 (OH), 3025 (C=C), 2960, 2930, 2875, 1450, 1065, 1060, 1035 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$, 80 MHz) δ 1.04 (s, 3, CH_3), 1.18 (d, 3, J = 7 Hz, $CHCH_3$), 3.63 (d, 1, J = 2 Hz, $CHOH$), 5.41 (m, 1, C=CH); ^{13}C NMR ($CDCl_3$, 20.2 MHz) ppm 18.65, 21.88, 22.47, 22.68, 23.48, 25.87, 34.57, 34.85, 39.26, 40.03, 75.87 (COH), 122.55 (C=*C*H), 136.76 (*C*=CH); mass spectrum, m/e (relative intensity) 180 (M^+, 7), 43 (56), 41 (100), 39 (70), 28 (100); high-resolution mass spectroscopy (m/z) calcd for $C_{12}H_{20}O$ 180.1514; found 180.1514; 0.0 ppm error.

6EA: IR (CCl_4) 3630, 3490 (OH), 3030 (C=CH), 2960, 2925, 1460, 1070, 1050, 1025, 1010 (C—O) cm^{-1}; ^1H NMR ($CDCl_3$, 80 MHz) δ 0.87 (d, 3, J = 6.6 Hz, $CHCH_3$), 1.04 (s, 3, CH_3), 1.58 (m, 3, CH_3C=C), 3.66 (d, 1, J = 2 Hz, $CHOH$), 5.40 (m, 1, C=CH); ^{13}C NMR ($CDCl_3$, 20.2 MHz) ppm 18.63, 19.06, 21.67, 25.60, 27.71, 28.34, 29.46, 38.70, 39.82, 75.45 (COH), 123.31 C=*C*H), 136.64 *C*=CH). Anal. Calcd for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 80.03; H, 11.29.

6EE: IR (CCl_4) 3630, 3580, 3470 (OH), 2950, 2920, 2850, 1450, 1090, 1075, 1055, 1030, 1015 (C—O) cm^{-1}; ^1H NMR ($CDCl_3$, 80 MHz) δ 0.90 (d, 3, J = 6.5 Hz, $CHCH_3$), 1.10 (s, 3, CH_3), 3.31 (d, 1, J = 2 Hz, $CHOH$), 5.58 (m, 1, C=*C*H); ^{13}C NMR ($CDCl_3$, 20.2 MHz) ppm 19.06, 19.28, 21.76, 22.76, 27.11, 36.01, 36.24, 39.60, 40.44, 78.58 (COH), 123.90 nC=*C*H), 134.49 (*C*=CH). Anal. Calcd for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 80.01; H, 11.25.

(1α,5α,6α)-1,2,6-Trimethylbicyclo[3.3.1]non-2-en-9-one (5A). Alcohol **6AA** (2.48 g, 13.8 mmol) was dissolved in reagent-grade acetone (100 mL) and cooled at 0 °C. Chromic acid reagent[9] (2.67 M, 3.7 mL, 9.88 mmol) was added dropwise. After the addition was completed the reaction was allowed to warm to 23 °C for 20 min. The reaction was quwnched with *i*-PrOH (1.0 mL). Water (200 mL) was added to the reaction and the mixture was extracted with Et_2O (5 × 25 mL). The combined organic solutions were washed with saturated NaCl solution (50 mL), dried ($MgSO_4$), and concentrated in vacuo. Distillation (bulb-to-bulb) gave 2.14 g (87.2%) of **5A**: bp 66–70 °C (1.0 mmHg); IR (CCl_4) 3030 (C=CH), 2960, 2930, 2880, 2850, 2830, 1720 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$, 80 MHz) δ 0.93 (d, 3, J = 7 Hz, $CHCH_3$), 1.09 (s, 3, CH_3), 1.61 (m, 3, C=CCH_3), 5.56 (m, 1, C=CH); ^{13}C NMR ($CDCl_3$, 20.2 MHz) ppm 18.23, 18.56, 18.83, 24.58, 33.91, 35.62, 40.94, 49.30, 51.09, 123.10 (C=*C*H), 136.39 (*C*=CH)8 224.17 (C=O). Anal. Calcd for $C_{12}H_{18}O$: C, 80.85; H, 10.18. Found: C, 80.84; H, 10.15.

(1α,5α,6β)-1,2,6-Trimethylbicyclo[3.3.1]non-2-en-9-one (5E). To a stirred solution of alcohols **6EA** and **6EE** (2.44 g, 13.6 mmol) in reagent-grade acetone (35 mL) at 0 °C was added chromic acid reagent[9] (2.68 M, 3.4 mL, 9.11 mmol) dropwise. An additional quantity of the H_2CrO_4 reagent (0.4 mL, 1.07 mmol) was added to maintain a orange-red color in the reaction for 20 min. The reaction was then quenched with *i*-PrOH (1.0 mL). The organic portion was decanted and the aqueous portion was diluted with H_2O (150 mL). This solution was extracted with Et_2O (2 × 50 mL). The combined organic solutions were washed with saturated $NaHCO_3$ solution (75 mL) and saturated NaCl solution (75 mL) and then dried ($MgSO_4$). The solvent was removed in vacuo and distillation (bulb-to-bulb) afforded 2.02 g (83.4%) of ketone **5E**: bp 50–55 °C (0.05 mmHg); IR (CCl_4) 2960, 2940, 1720 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$, 80 MHz) δ 0.98 (d, 3, J = 6.3 Hz, CH_3CH), 1.08 (s, 3, CH_3), 1.61 (brs, 3, C=CCH_3), 2.37 (brs, 2, CH_2C=C), 5.58 (brs, 1, C=*C*H); ^{13}C NMR ($CDCl_3$, 20.2 MHz) ppm 17.91, 18.05, 26.70, 27.25, 38.04, 38.97, 48.07 (4°), 49.83, 123.61 C=*C*H), 136.19 (*C*=CH), 215.17 (C=O); mass spectrum, m/z (relative intensity) 178 (M^+, 31), 107 (84), 93 (86), 41 (100), 39 (92); high-resolution mass spectroscopy (m/z) calcd for $C_{12}H_{18}O$ 178.1358, found 178.1353; 2.8 ppm error.

9-(Methoxymethylene)-1,2,6-trimethylbicyclo[3.3.1]non-2-ene (7). Sodium hydride (70% dispersion in oil, 2.39 g, 99.7 mmol) was washed with dry Et_2O (3 × 10 mL). Dry Me_2SO (100 mL) was then added and this suspension was heated to 55 °C for 5.5 h, at which point H_2 evolution has ceased and the solution has turned dark gray. The solution was then cooled to ~15 °C and the Wittig salt [$Ph_3PCH_2OCH_3Cl$, 31.1 g, 90.7 mmol] was added under heavy N_2 flow. The mixture turned a burgundy color as it warmed to 23 °C and was stirred for 20 min. The starting ketone **10** (2.02 g, 11.3 mmol) was transferred into the ylide mixture by using Me_2SO (3 × 10 mL), and additional Me_2SO (70 mL) was added to the reaction mixture. The reaction was heated to 55 °C for 12 h. The reaction was then cooled to 23 °C and diluted with H_2O (300 mL), and this mixture was extracted with Et_2O (7 × 200 mL). The combined organic material was washed with H_2O (5 × 200 mL) and saturated NaCl solution (2 × 200 mL). The mixture was dried ($MgSO_4$) and the solvent was removed in vacuo to give a brownish oil. Distillation (bulb-to-bulb) gave vinyl ether **7** which contained some (Ph_3P). Medium pressure liquid chromatography (MPLC)[20] on silica gel using 3% ethyl acetate–hexane as eluant afforded 2.07 g (88.5%); bp 100 °C (8 mmHg); IR (CCl_4) 3020 (C=CH), 2955, 2925, 1720 (C=CHOMe), 1680 (C=C), 1120 (C—O) cm^{-1}; ^1H NMR ($CDCl_3$, 80 MHz) δ 0.91 (d, 3, J = 6 Hz, CH_3CH), 1.07 (s, 3, CH_3), 1.59 (m, 3, CH_3C=C), 2.07 (m, 1, CH_2C=C), 3.45 (s, OCH_3) and 3.54 (s, OCH_3), 5.49 (bs, 1, C=*C*H), 5.71 and 5.75 (2 s, 1, C=*C*HO); ^{13}C NMR ($CDCl_3$, 20.2 MHz) ppm 19.06, 19.50, 21.84, 26.62, 28.28, 33.66, 37.36, 37.56, 38.97, 59.42 (OCH_3), 124.71 (C=*C*HO), 127.50 (*C*=CH), 135.85 (*C* = CHO), 137.75 (C=*C*H); mass spectrum, m/z (relative intensity) 206 (M^+, 24), 191 (22), 159 (55), 149 (89), 119 (99), 105 (74), 91 (100); high-resolution mass spectroscopy (m/z) calcd for $C_{14}H_{22}O$ 206.1671, found 206.1675; 1.9 ppm error.

1,2,6-Trimethylbicyclo[3.3.1]non-2-ene-9-carboxaldehyde (8). A solution of vinyl ether **7** (1.00 g, 4.85 mmol) in THF (150 mL) was treated with 35% $HClO_4$ (15 mL) for 1 h at 23 °C. The reaction was neutralized with saturated $NaHCO_3$ solution (75 mL). The aqueous layer was extracted with Et_2O (2 × 75 mL), and the combined organic solutions were dried ($MgSO_4$). Concentration in vacuo and distillation (bulb-to-bulb) afforded 0.935 g (99.9%) of aldehyde **8**: bp 78–82 °C (1.2 mmHg); IR (CCl_4) 3015 (C=CH), 2730, 2680 (CHO), 1720 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$, 80 MHz) δ 0.88 and 0.92 (2d, J = 7 Hz, and 6 Hz, CH_3CH), 1.16 and 1.20 (2 s, 3, CH_3), 5.53 (brs, 1, C=CH), 9.78 and 10.03 (2 s, CHO); ^{13}C NMR ($CDCl_3$, 20.2 MHz) ppm 58.01 (*C*CHO), 61.38 (*C*CHO), 65.73 (4°), 67.80 (4°), 123.93 (C=*C*H), 124.91 (C=*C*H), 135.97 (*C*=CH), 137.79 (*C*=CH), 205.71 (CHO); mass spectrum, m/z (relative intentisy) 192 (M^+, 3), 163 (7), 161 (5), 159 (5), 107 (76), 91 (100), 41 (76), 29 (62); high-resolution mass spectroscopy (m/z) calcd for $C_{13}H_{20}O$ 192.1514; found 192.1513; 0.5 ppm error.

(1α,5α,6β,9*S)-1,2,6-Trimethyl-9-(2-propenyl)bicyclo[3.3.1]non-2-ene-9-methanol (9A) and (1α,5α,6β,9*R**)-1,2,6-Trimethyl-9-(2-propenyl)bicyclo[3.3.1]non-2-ene-9-methanol (9E).** Potassium hydride (35% dispersion in oil, 1.14 g, 28.5 mmol) was washed with dry Et_2O (4 × 10 mL) under N_2. To the KH was added Me_2SO (5 drops), and, after the H_2 evolution had ceased, Ph_3CH (6.31 g, 25.9 mmol) dissolved in dry DME (30 mL) was added. This mixture was stirred at 50 °C for 45 min, where upon it turned red. The solution was then cooled to 23 °C and a portion (16 mL, 9.74 mmol) was added to aldehyde **8** (1.73 g, 9.01 mmol) in dry DMF (20 mL) until the red color persisted. Dry allyl bromide (3.9 mL, 45.0 mmol) was added to the reaction and this mixture was stirred at 23 °C for 24 h. The reaction mixture was poured into a saturated $NaHCO_3$ solution (200 mL). This mixture was extracted with Et_2O (4 × 100 mL). The organic material was then dried ($MgSO_4$) and concentrated in vacuo to afford a mixture of C- and O-alkylated products: ^1H NMR ($CDCl_3$, 80 MHz) δ 2.35 (brd, 2, J = 8 Hz, $OHCCCH_2CH$=CH_2), 4.16 (d, 2, J = 5 Hz, C=$CHOCH_2CH$=CH_2), 5.78 (s, 1, C=C*H*O), 9.83 (s, 1, C*H*O); ^{13}C NMR ($CDCl_3$, 20.2 MHz) δ 72.4 (OCH_2CH=CH_2).

This crude residue was taken up in dry $PhCH_3$ (50 mL) and heated at reflux for 26 h. The $PhCH_3$ was removed by distillation under N_2 to afford a crude mixture of aldehydes: IR (CCl_4) 3070 (C=CH_2), 3030 (C=C, 2720 nCHO), 1720 nCHO), 1640 (CH=CH_2), 1450, 990, 915 (CH=CH_2) cm^{-1}; NMR ($CDCl_3$, 80 MHz) δ 0.86 (d, 3, J = 10 Hz, CH_3CH), 1.22 (s, 3, CH_3), 1.56 (m, 3, C=CCH_3), 2.36 (d, 2, J = 12 Hz, $OHCCCH_2CH$=CH_2), 4.90 and 5.08 (2 m, 2, CH=CH_2), 5.55 (m, 1, C=CH), 5.70 (br m, 1, C—C*H*=CH_2), 9.84 (s, 1, CHO); ^{13}C NMR ($CDCl_3$, 20.2 MHz) ppm 18.80, 18.90, 19.78, 21.73, 27.93, 32.18, 34.04, 34.81, 35.57, 40.13, 54.59 (*C*CHO), 118.06 (C=CH_2), 124.06 (C=*C*H), 133.83 (C*H*=

CH_2), 135.14 (C=CH), 184.95 nCHO); high-resolution mass spectroscopy (m/z) calcd for $C_{16}H_{24}O$ 232.1827, found 232.1821; 2.6 ppm error.

This mixture of aldehydes was added to a solution of $LiAlH_4$ (184 mg, 4.38 mmol) in dry Et_2O (30 mL) at 0 °C. The reaction was warmed to 23 °C and stirred for 2 h. It was then quenched by the addition of 10% NaOH solution (12 mL). The reaction mixture was combined with H_2O (50 mL) and extracted with Et_2O (4 × 50 mL). The combined ethereal extracts were washed with saturated NaCl solution (50 mL) and dried ($MgSO_4$). After concentration in vacuo, the residue was purified by medium pressure liquid chromatography (MPLC)[20] on silica gel using 6% ethyl acetate–hexane as the eluant to afford 1.28 g (61%) of **9A** and 0.19 g (9%) of **9E** (combined yield of 69.7%; 87.1:12.9 ratio, respectively).

9A: IR (CCl_4) 3650, 3590, 3460 (OH), 3075 (CH=CH_2), 3051 (C=CH), 1635 (CH=CH_2), 1005 (C—O), 990, 915 (CH=CH_2) cm^{-1}; ^1H NMR ($CDCl_3$, 80 MHz) δ 0.85 (d, 3, J = 8 Hz, $CHCH_3$), 0.94 (s, 3, CH_3), 1.53 (brs, 3, CH_3C=C), 3.90 (s, 2, CH_2OH), 4.95 and 5.16 (3 m, 2, CH=CH_2), 5.50 (m, 1, C=CH), 5.80–6.40 (brm, 1, CH=CH_2); ^{13}C NMR ($CDCl_3$, 20.2 MHz) ppm 13.91, 19.05, 20.03, 22.59, 27.32, 30.10, 31.52, 32.59, 36.30, 37.96, 43.87 (4°), 65.84 (COH), 116.42 (C=CH_2), 123.80 nC=CH), 136.34 (C=CH), 138.25 (CH=CH_2); CI mass spectrum, m/z (relative intensity)8 235 (M^+d + 1, 9.7), 234 (4), 233 (11)8 219 (7), 217 (100), 175 (96)8 161 (82), 149 (70). Anal. Calcd for $C_{16}H_{26}O$: 234.1984. Found: 234.1986. 0.8 ppm error by high resolution mass spectroscopy.

9E: IR (CCl_4) 3640, 3580 (OH), 3075 (CH=CH_2), 3015 (C=CH), 1690, 1630 (C=C), 995, 910 (CH=CH_2) cm^{-1}; NMR (CCl_4, 60 MHz) δ 0.87 (d, 3, J = 6 Hz, CH_3CH), 2.30 (brd, 2, J = 8 Hz, CH_2C=C), 3.90 (brm, 2, CH_2OH), 4.30 (brm, 1, OH), 4.95 and 5.15 (3 m, 2, CH=CH_2), 5.50 (m, 1, C=CH), 5.7–6.5 (brm, 1, CH=CH_2); ^{13}C NMR ($CDCl_3$, 25.2 MHz) ppm 16.79, 21.53, 22.02, 22.82, 28.03, 31.75, 36.64, 37.36, 37.61, 39.65, 43.88, 65.45 (COH), 116.61 (C=CH_2), 122.69 (C=CH), 133.99 (C=CH), 138.43 (C-H=CH_2); high-resolution mass spectroscopy (m/z) calcd for $C_{16}H_{26}O$ 234.1984, found 234.1980; 1.7 ppm error.

3-[9-(Hydroxymethyl)-1,2,6-trimethylbicyclo[3.3.1]non-2-en-9-yl]-1,2-propanediol (10). To a rapidly stirred two-phase mixture of **9A** (784 mg, 3.34 mmol), NMMO·H_2O (0.748 g, 5.53 mmol), reagent-grade acetone (1.0 mL), and H_2O (1.0 mL) was added OsO_4/H_2O (1.0 mL, 0.016 M, 4 mg/mL, 0.016 mmol). The resulting orange-yellow reaction mixture was stirred rapidly for 26 h at 23 °C. The reaction was quenched with $NaHSO_3$ (0.1 g) and filtered through Celite-Florisil with Et_2O (5 × 10 mL) and H_2O (5 × 10 mL). The filtrate mixture was separated and the aqueous layer was acidified with 10% HCl (2.0 mL) and extracted with Et_2O (10 × 10 mL). Sodium chloride (1 g) was added to the aqueous layer and it was extracted with EtOAc (5 × 10 mL). The combined organic extracts were dried ($Na_2SO_4/MgSO_4$) and concentrated in vacuo to give 0.836 g (93%) of crude yellow oil. Chromatography on silica gel 60 (75 g) using 50% EtOAc/hexane as the eluant gave 0.580 mg (64.6%) of pure triol **10**: IR ($CHCl_3$) 3620, 3340 (OH), 3000 nC=CH), 1100, 1070, 1040 (C—O), 880, 865 (C=CH) cm^{-1}; NMR n$CDCl_3$, 80 MHz) δ 0.88 (brs, 6, 2 CH_3), 1.52 (brs, 3, CH_3C=CH), 3.1–4.2 (cm, 5, $CHOH$, 2 CH_2OH), 4.50 (brs, 3, 3 OH), 5.49 (brs, 1, C=CH); mass spectrum, m/z (relative intensity) 268 (M^+, 3), 250 (21), 219 (50), 201 (53), 163 (49), 119 (100), 107 (63), 95 (55); high-resolution mass spectroscopy (m/z) calcd for $C_{16}H_{28}O_3$ 268.2038, found 268.2039; 0.4 ppm error.

(1α,5α,6β,9S*)-1,2,6-Trimethyl-9-propylbicyclo[3.3.1]non-2-ene-9-methanol (11) and 3-(1,2,6,9-Tetramethylbicyclo-[3.3.1]non-2-en-9-yl)-1,2-propanediol (12). A mixture of the triol **10** (0.558 g, 2.08 mmol) in reagent acetone (8.0 mL, dried over $CaSO_4/MgSO_4$), Drierite (1.04 g, 8 mesh), anhydrous $MgSO_4$ (1.28 g, powdered) and HCl gas (1 mL) was stirred under N_2 at 23 °C for 22 h. The reaction was quenched with anhydrous Na_2CO_3 (1.04 g), filtered ($MgSO_4$) with Et_2O (5 × 10 mL), and concentrated in vacuo to give 597 mg (93%) of clear oil: IR ($CHCl_3$) 3630, 3480 (OH), 3030 (C=CH), 1235, 1160, 1075, 1070, 1050 (C—O), 880, 855 825 (C=CH) cm^{-1}; NMR ($CDCl_3$, 60 MHz) δ 0.87 (d, 3, J = 7 Hz, CH_3CH), 0.94 (s, 3, CH_3), 1.44 (s, 6, 2 CH_3), 1.54 (brs, 3, CH_3C=CH), 3.2–4.7 (m, 5, CHO, 2 CH_2O), 5.64 (brs, 1, C=CH).

To a solution of this crude ketal–alcohol (597 mg, 1.94 mmol) in dry THF (15 mL) and TMEDA (4.0 mL) containing a trace of 2,2′-bipyridine stirred at −15 °C (ice–MeOH) under N_2 was added *n*-BuLi/hexane (1.68 mL, 2.59 mmol, 1.55 M, Aldrich). After 15 min at −15 °C $ClPO(NMe_2)_2$ (0.60 mL, 4.05 mmol) was added and the resulting yellow solution was stirred at 23 °C for 22 h. The reaction was quenched with saturated $NaHCO_3$ solution (20 mL) and the resulting two-phase mixture was stirred rapidly for 2.5 h. The mixture was diluted with H_2O (30 mL) and extracted with Et_2O (10 × 10 mL). The combined ethereal extracts were washed with H_2O (4 × 10 mL) and saturated NaCl solution (10 mL), dried n$MgSO_4$), filtered ($MgSO_4$), and concentrated in vacuo to give 856 mg (100%) of light yellow phosphoramidate ester: IR n$CHCl_3$) 3000 (C=CH), 1305, 1235, 1185 [$OPO(NMe_2)_2$], 1160, 1050 (C—O), 985, 860 (C=CH) cm^{-1}; NMR ($CDCl_3$, 60 MHz) δ 0.73, 0.86, 0.91, 1.00 (4 s, 6, 2 CH_3), 1.32 and 1.35 (2 s, 6, Me_2CO_2), 1.54 (brs, 3, CH_3C=CH), 2.58 and 2.76 (2 s, 12, 2 NMe_2), 3.2–4.73 (m, 5, CHO, 2 CH_2O), 5.66 (brs, 1, C=CH).

To a solution of this crude phosphoramidate ester (856 mg, 1.93 mmol) in Et_2O (10 mL) containing *t*-BuOH (0.40 mL, 4.24 mmol) was added $EtNH_2$ (30 mL, distilled from Na/Li metals). To this solution stirred at 0 °C was added Li metal (8.0 cm, 45 mg/cm, 360 mg, 51.9 mmol, cut in 20 pieces). The resulting light yellow heterogeneous mixture was stirred at 0 °C for 45 min and then the color turned dark blue. After stirring for an additional 1 h at 0 °C, *t*-BuOH (0.40 mL, 4.24 mmol) was added followed by NH_4Cl (1 g) after 15 min. When all the lithium had reacted the $EtNH_2$ was evaporated with the aid of a warm water bath. The residue was diluted with H_2O (50 mL) and extracted with Et_2O (5 × 20 mL). The combined ethereal extracts were washed with ice-cold 5% HCl (2 × 20 mL), saturated $NaHCO_3$ solution (20 mL), H_2O (20 mL), and saturated NaCl solution, dried (Na_2SO_4), filtered ($MgSO_4$), and concentrated in vacuo to give 491 mg (85.9%) of clear oil: IR n$CHCl_3$) 3010 (C=CH), 1245, 1160, 1060 nC—O), 860 (C=CH) cm^{-1}; NMR ($CDCl_3$, 60 MHz) δ 0.81 (d, 3, J = 6 Hz, CH_3CH), 0.90 (s, 6, 2 CH_3), 1.35 and 1.38 (2 s, 6, Me_2CO_2), 1.55 (brs, 3, CH_3C=CH), 3.08–4.43 (m, 3, CH_2O, CHO), 5.50 (brs, 1, C=CH).

A solution of the above crude ketal (491 mg, 1.66 mmol) in MeOH (15 mL) and 10% HCl (2.0 mL) was stirred at 24 °C for 6 h. The solution was diluted with saturated NaCl solution and extracted with Et_2O (5 × 20 mL). The combined ethereal extracts were washed with saturated NaCl solution (20 mL), dried (Na_2SO_4), filtered ($MgSO_4$), and concentrated in vacuo to give 419 mg (100%) of a clear liquid. Purification by chromatography on silica gel (60 g) with 10% EtOAc/hexane as the eluant gave 100 mg (23.9%, 20.4% overall from triol **10**) of alcohol **11**: IR ($CHCl_3$) 3620 (OH), 3000 (C=CH), 1030 (C—O); NMR ($CDCl_3$, 80 MHz) δ 0.87 (t, 3, J = 6.4 Hz, CH_3CH_2), 0.95 (s, 3, CH_3), 0.85 (d, 3, J = 8.9 Hz, CH_3CH), 1.55 (brs, 3, CH_3C=CH), 3.84 (AB, 2, J = 11.6 Hz, CH_2O), 5.45 (brs, 1, C=CH); mass spectrum, m/z (relative intensity) 236 (M^+, 12), 205 (100), 107 (90), 55 (84), 43 (77), 41 (82); high-resolution mass spectroscopy (m/z) calcd for $C_{16}H_{28}O$ 236.2140, found 236.2140; 0.0 ppm error.

Further elution of the above chromatography with 30% EtOAc/hexane afforded 303 mg (72.3%, 57.7% overall from triol **10**) of glycol **12**: IR ($CHCl_3$) 3580, 3370 (OH), 3000 (C=CH), 1070, 1035 (C—O) cm^{-1}; NMR ($CDCl_3$, 80 MHz) δ 0.83 (d, 3, J = 5.7 Hz, CH_3CH), 0.87 (s, 3, CH_3), 1.54 (brs, 3, CH_3C=CH), 3.1–4.1 (m, 5, CH_2OH, CHOH), 5.43 (brs, 1, CH_3C=CH); mass spectrum, m/z (relative intensity) 252 (M^+, 34), 234 (93), 221 (82), 121 (100), 107 (72), 95 (71), 55 (69), 41 (68); high-resolution mass spectroscopy (m/z) calcd for $C_{16}H_{28}O_2$ 252.2089, found 252.2086; 1.2 ppm error.

Decahydro-1,4,8a-trimethyl-9-methylene-1,6-methanonaphthalen-7-ol (13). Method A. A mixture of glycol **12** (290 mg, 1.15 mmol), $NaIO_4$ (1.56 g, 7.20 mmol) in THF (4.0 mL), and H_2O (4.0 mL) was stirred at 23 °C for 13 h. The resulting reaction mixture was diluted with H_2O (40 mL) and extracted with Et_2O (10 × 10 mL). The combined ethereal extracts were washed with saturated NaCl solution (20 mL), dried (Na_2SO_4), filtered ($MgSO_4$), and concentrated in vacuo to give 253 mg (100%) of a clear oil. Distillation (bulb-to-bulb) gave 195 mg (77%) of a 3:1 (GLC, column a) mixture of tricyclic alcohols **13**: bp 100–105 °C (1.0 mmHg); GLC (column a, 3:1 ratio at 12.7 and 13.8 min, respectively); IR ($CHCl_3$) 3600, 3520, 3290 (OH), 1640 nC=CH_2), 1100, 1030 (nC—O), 890 (C=CH_2) cm^{-1}; NMR ($CDCl_3$, 80 MHz) δ 0.80 (d, 3, J = 7 Hz, CH_3CH), 0.86 (s, 3, CH_3), 1.02 (s, 3, CH_3), 3.25–4.25 (m, 1, CHO), 4.93 (d, 2, J = 5 Hz, C=CH_2); mass spectrum, m/z

(relative intensity) 200 (M^+, 3), 202 (2), 121 (77), 119 (87), 105 (98), 91 (83), 81 (90), 41 (100); high-resolution mass spectroscopy (m/z) calcd for $C_{15}H_{24}O$ 220.1827, found 220.1824; 1.4 ppm error.

Method B. To a solution of ketone 14 (34.2 mg, 0.15 mmol) in reagent MeOH (2.0 mL) stirred at −15 °C (ice–MeOH bath) under N_2 was added powdered $NaBH_4$ (0.288 g, 7.61 mmol). The resulting mixture was allowed to stir for 30 min at −15 °C and then warmed to room temperature over a period of 1 h. The reaction mixture was diluted with H_2O (15 mL) and extracted with Et_2O (5 × 10 mL). The combined ethereal extracts were washed with H_2O (2 × 10 mL) and saturated NaCl solution (10 mL), dried Na_2SO_4), filtered ($MgSO_4$), and concentrated in vacuo to give 34.5 mg (100%) of tricyclic alcohols **13**, the GLC, TLC, and spectra of which were nearly identical with the above data.

(1α,4aβ,6α,8aβ)-Octahydro-1,4,8a-trimethyl-9-methylene-1,6-methanonaphthalen-7(1*H*)-one (14). Chromic acid reagent[9] (2.67 M, 2 drops) was added to a solution of alcohols **13** (14.7 mg, 0.067 mmol) in reagent acetone (0.5 mL) at 23 °C. After being stirred for 5 min, the orange mixture was quenched with *i*-PrOH (3 drops) and H_2O (10 mL). The aqueous solution was extracted with Et_2O (5 × 10 mL). The combined ethereal extracts were washed with saturated $NaHCO_3$ solution (5 mL) and saturated NaCl solution (5 mL), dried Na_2SO_4), filtered $MgSO_4$), and concentrated in vacuo to give 14.6 mg (100%) of white crystalline tricyclic ketone **14**: mp 35.5–36.5 °C; IR ($CHCl_3$) 3080, 1640, 900 (C=CH_2), 1380, 1370 (CH_3), 1715 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 0.820 (d, 3, J = 6.78 Hz, CH_3CH), 0.952 (s, 3, CH_3), 0.992 (s, 3, CH_3), 1.92, 1.99, 2.35, 2.42 (AB, 2, J_{AB} = 19.6 Hz, CH_2CO), 2.91 (t, 1, J = 2.9 Hz, CH_2=CC*H*CO); 4.84 and 5.02 (2 s, 2, C=CH_2); ^{13}C NMR ($CDCl_3$, 20.2 MHz) ppm 18.90, 19.54, 24.24, 24.51, 25.92, 29.41, 36.74, 38.83 (4°), 39.97 (4°), 43.21, 48.13, 55.95, 110.16 (C=*C*H_2), 153.38 (C=CH_2), 212.50 (CO); mass spectrum, m/z (relative intensity) 218 (M^+, 39), 111 (56), 120 (80), 105 (78), 91 (81), 81 (58), 41 (100); high-resolution mass spectroscopy (m/z) calcd for $C_{15}H_{22}O$ 218.1671, found 218.1675; 1.8 ppm error.

(±)-Seychellene (1). A mixture of ketone **14** (67 mg, 0.306 mmol), KOH (535 mg, 8.1 mmol), and N_2H_4·H_2SO_4 (340 mg, 2.61 mmol) was heated slowly under N_2 from 23 °C to 200 °C over a period of 2 h and then held at 200 °C for an additional 2 h. The reaction was cooled to 23 °C, diluted with H_2O (40 mL), and extracted with Et_2O (5 × 10 mL). The combined ethereal extracts were washed with H_2O (5 × 10 mL) and saturated NaCl solution (10 mL), dried Na_2SO_4), filtered ($MgSO_4$), and concentrated in vacuo to give 55 mg (87%) of a pale yellow oil. Chromatography on silica gel (1 g) using hexane as the eluant produced 46 mg (73%) of pure (±)-seychellene (**1**): IR ($CHCl_3$) 3070, 1640, 885 (C=CH_2), 1370, 1380 (CH_3); ^1H NMR ($CDCl_3$, 300 MHz) δ 0.752 (d, 3, J = 6.77 Hz, CH_3CH), 0.830 (s, 3, CH_3), 0.961 (s, 3, CH_3), 2.20 (m, 1, CH_2=CC*H*), 4.59 and 4.79 (2 d, 2, J = 1.4 Hz, C=CH_2); ^{13}C NMR ($CDCl_3$, 20.2 MHz) 18.75, 20.71, 24.94, 26.44, 26.56, 27.81, 29.90, 31.65, 35.16, (4°), 37.26, 37.66, 39.81 (4°), 44.77, 103.49 (C=*C*H_2), 162.41 (*C*=CH_2); mass spectrum, m/z (relative intensity) 204 (M^+, 12), 189 (5), 122 (100), 93 (33), 41 (27); high-resolution mass spectroscopy (m/z) calcd for $C_{15}H_{24}$ 204.1878, found 204.1879; 0.5 ppm error.

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Competitive Photochemical $\sigma^2 + \pi^2$ Addition and Electron Transfer in the *N*-Methylphthalimide–Alkene System

Paul H. Mazzocchi,* Saeko Minamikawa, and Paul Wilson

Department of Chemistry, University of Maryland, College Park, Maryland 20742

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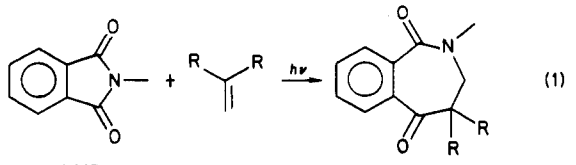
N-Methylphthalimide (NMP) undergoes a pair of competing photochemical reactions in the presence of alkenes. In one of these reactions the alkene adds to the C(O)–N bond of NMP in a concerted $\pi^2 + \sigma^2$ process that ultimately leads to 2-benzazepine-1,5-diones (**5**). A competing electron-transfer process results in the formation of a radical cation–radical anion pair which can be efficiently trapped in alcohol solvents such as **4**. The regiochemistry of these products is consistent with expectations for addition of an alcohol to a radical cation. Calculations using the Weller equation accurately predict when electron transfer should dominate the $\pi^2 + \sigma^2$ process, when the $\pi^2 + \sigma^2$ process should dominate the electron-transfer process, and when the two should be directly competitive. Product studies on the formation of **4** and **5** for various alkenes in methanol solution are entirely consistent with this hypothesis.

The photochemistry of phthalimides in the presence of alkenes is characterized by three major processes:[1] (1) The addition of the alkene to the C(O)–N bond resulting in the formation of a ring expanded benzazepinedione[2] (eq 1).



NMP (1)

This reaction is regiospecific and stereospecific, and studies indicate that it is a concerted process that probably occurs through the zwitterionic "enolate" of the imide.[3] The reaction has some generality in that it occurs with alkenes, dienes, vinyl ethers, vinyl esters, and an allene.[2d]

(1) For reviews see: Mazzocchi, P. H. "Organic Photochemistry"; Padwa, A.; Ed.; Marcel Dekker: New York, 1981; Vol. 5. Kanaoka, Y. *Acc. Chem. Res.* **1978**, *11*, 407.

(2) (a) Mazzocchi, P. H.; Bowen, M.; Narian, N. *J. Am. Chem. Soc.* **1977**, *99*, 7063. (b) Mazzocchi, P. H., Minamikawa, S.; Bowen, M. *Heterocycles* **1978**, *9*, 1713. (c) Mazzocchi, P. H.; Minamikawa, S.; Bowen, M. *J. Org. Chem.* **1978**, *43*, 3079. (d) Mazzocchi, P. H.; Minamikawa, S.; Wilson, P.; Bowen, M.; Narain, N. *Ibid.* **1981**, *46*, 4846. (e) Maruyama, K.; Kubo, Y. *Chem. Lett.* **1978**, 769.

(3) (a) Mazzocchi, P. H.; Minamikawa, S.; Wilson, P. *J. Org. Chem.* **1979**, *44*, 1186. (b) Mazzocchi, P. H.; Wilson, P.; Khachik, F.; Klingler, L.; Minamikawa, S. *Ibid.* **1983**, *48*, 2981. (c) Mazzocchi, P. H.; Khachik, F.; Wilson, P. *J. Am. Chem. Soc.* **1981**, *103*, 6498.

0022-3263/85/1950-2681$01.50/0