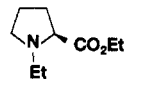
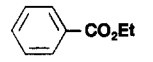
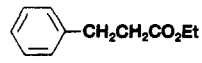
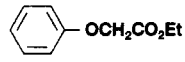
Table II. Aminolysis of Ethyl Esters with 9–10 M Ammonia, Methylamine, or Dimethylamine in Methanol at 50 °C

no.	ester[a]	amine	time,[b] h	conversion,[c] % no	conversion,[c] % NaCN[d]	isol yield,[e] %	characterization of amide[f]
1		NH_3	38	39	97	72[g,h]	MS (EI) 142 (M)[g]
		$MeNH_2$	8.5	46	88	84[j]	MS (CI) 157 (M + 1)[i]
		Me_2NH	96	0	8		MS (EI) 170 (M)[k]
4		NH_3	50	57	79	64[h]	mp 126–128 °C (lit.[26] 128 °C)
		$MeNH_2$	4	24	88	75[j]	mp 78.5–79 °C (lit.[27] 81.5–82 °C)
		Me_2NH	117	8	39		mp 38–39 °C (lit.[28] 43 °C)
5		NH_3	32	69	91	87[h]	mp 99–99.5 °C (lit.[29] 100–101 °C)
		$MeNH_2$	1.5	49	98	86[j]	mp 56–57 °C (lit.[30] 59–60 °C)
		Me_2NH	78	52	80	75[j]	oil,[31] MS (EI) 177 (M)
6		NH_3	0.25[l]	62	78	47[h]	mp 101–102 °C (lit.[32] 101 °C)

[a] The ester concentration was 0.35 M in all experiments. The reactions were carried out in capped glass tubes. [b] Trial experiments to determine the appropriate reaction times were done prior to the comparative experiments. [c] The degree of conversion was measured by capillary GLC in parallel experiments with and without (no) NaCN. [d] The concentration of NaCN was 10 mol %. [e] Refer to combined cyanide-catalyzed experiments. Purification was by bulb-to-bulb distillation or recrystallization; see the Experimental Section. [f] All compounds had satisfactory ^1H NMR and mass spectra. [g] See the Experimental Section for complete procedure. [h] Recrystallization. [i] Data: bp 170 °C (11 mmHg); $[\alpha]_D^{20}$ −140° (c 0.8, $CHCl_3$). Anal. Calcd for $C_8H_{16}N_2O$: C, 61.51; H, 10.32; N, 17.93. Found: C, 61.38; H, 10.26; N, 17.78. [j] Distillation. [k] Not isolated from the reaction mixture. [l] Reaction carried out at room temperature.

$MeNH_2 > NH_3 > Me_2NH$. Cyanide catalysis is especially suited for sensitive substrates like the *N*-ethylproline ester **1**, and it offers a methodology to be tested in the acylation of other nucleophiles under mild conditions.

Experimental Section

The experiments were conducted in small glass vials with gas-tight caps. The dead volume was minimized by the insertion of a glass rod. The glass vials were immersed in an oil bath at 50 °C. No vial was opened more than twice in connection with an experiment. The vials were cooled in dry ice/acetone before opening in order to minimize loss of ammonia or amine. All comparative experiments in Figures 1–4 and Table II were run simultaneously. GLCs were run on an SE-30 capillary column, and the amounts determined by a Hewlett-Packard 3390 A integrator, assuming identical response factors. ^1H NMR spectra were recorded on a Varian EM 360 A or a JEOL FX 200 spectrometer. Mass spectra were obtained on an LKB 9000 (EI/70 eV) or an LKB 2091 (EI/70 eV or CI/CH_4) instrument. Optical rotations were measured on an Optical Activity AA-100 polarimeter. Melting points of isolated amides were obtained on a Mettler FP 61 apparatus in open capillary tubes and are uncorrected. Elemental analyses were performed by Analytische Laboratorium, Elbach, West Germany, and are within ±0.4% of the theoretical values.

Esters **1** and **3** were synthesized by N-alkylation of the corresponding proline ester, and **4**–**6** were commercially available or made by conventional Fischer esterification.

Comparative studies on catalysts (Table I) were done with ethyl ester **1** (50 mg, 0.29 mmol) and catalyst (0.03 mmol) in 1.5 mL of ca. 9 M NH_3 in MeOH.

Aminolysis of esters **1**, **4**, **5**, and **6** (Table II) was done with 0.8 mmol of ester and 0.08 mmol of NaCN in 2.3 mL of 9–10 M NH_3, $MeNH_2$, or Me_2NH in MeOH.

Amides were isolated from combined cyanide-catalyzed experiments. The reaction mixture was treated with brine and extracted with CH_2Cl_2, EtOAc, or Et_2O. The organic extracts were combined, dried ($MgSO_4$), and evaporated to yield a residue, which was purified by bulb-to-bulb distillation or by recrystallization.

(−)-(*S*)-1-Ethyl-2-pyrrolidinecarboxamide (2). A mixture of ethyl (*S*)-1-ethyl-2-pyrrolidinecarboxylate (**1**; 6.00 g, 35 mmol) and NaCN (70 mg, 3.5 mmol) in 100 mL of 9 M ammonia in methanol was heated to 45 °C in a sealed glass flask for 40 h. The solvent was evaporated, and the residue was dissolved in 250 mL of CH_2Cl_2 and washed with 100 mL of H_2O. The aqueous layer was extracted with 200 mL of CH_2Cl_2. The organic phases were combined, dried ($MgSO_4$), and evaporated to give 4.78 g (96%) of amide with 98% purity. Recrystallization from hexane/*i*-Pr_2O (5:1) gave 3.58 g (72%) of the pure title amide: mp 110–111 °C; MS (EI, 70 eV) *m/z* (rel intens) 142 (M, 0.2%), 98 (100%), 70 (21%); $[\alpha]_D^{20}$ −123° (c 0.8, $CHCl_3$). The enantiomeric purity was determined by chromatography on a chiral GLC column (Chirasil-Val, 25 m) and found to be >99% *S* isomer. Anal. Calcd for $C_7H_{14}N_2O$: C, 59.13; H, 9.92; N, 19.70. Found: C, 58.95; H, 9.87; N, 19.58.

Chiral Building Blocks for Fused Cyclopentanoids: Enantioselective Synthesis of 5-Methylbicyclo[3.3.0]oct-1-ene-3,6-dione and Derivatives

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Received November 24, 1986

An efficient enantioselective synthesis of (*R*)- or (*S*)-5-methylbicyclo[3.3.0]oct-1-ene-3,6-dione, a potentially useful chiral building block for natural product synthesis, is described that demonstrates the utility of asymmetric monoreduction of a suitable prochiral dione substrate by bakers' yeast.

Microorganisms might be considered as microscopic reaction vessels containing numerous enzymes complete with cofactors that can potentially react with unnatural substrates and thus provide asymmetric transformations

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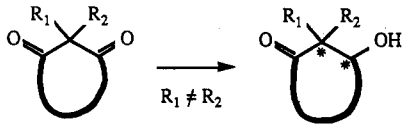
Scheme I. Asymmetric Monoreduction

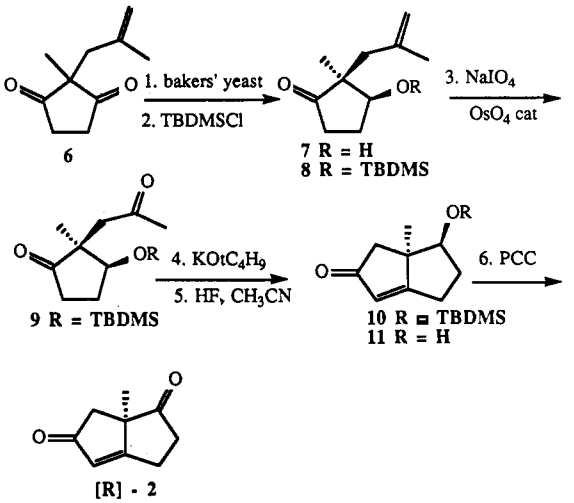


that may prove useful for synthetic applications.[1] Asymmetric microbial reduction of the carbonyl group by common bakers' yeast (*Saccharomyces cerevisiae*) has become a useful method to obtain optically active secondary hydroxy compounds.[2] The ability of certain enzymes to (1) differentiate stereoheterotopic faces of a trigonal atom such as the carbon of a carbonyl function or (2) distinguish two enantiotopic homomorphic groups attached to a prochiral center can lead to asymmetric transformations resulting in enantiomerically pure products from an achiral substrate. Prochiral 2,2-disubstituted cycloalkanediones offer the opportunity for both of these types of distinctions since they have two trigonal carbonyl centers with stereoheterotopic faces and one prochiral tetrahedral carbon center. Enzyme-catalyzed asymmetric monoreduction of this type of substrate generates two stereogenic centers as shown in Scheme I.

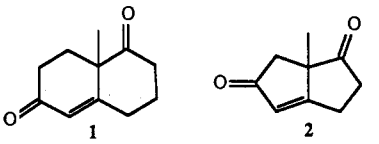
We have reported the results of this type of microbial reduction for 2,2-disubstituted-1,3-cyclopentanediones,[3] -cyclohexanediones,[4] and -cycloheptanediones.[5] Microbial asymmetric transformations of achiral substrates to provide optically pure intermediates for synthesis is an alternative complementary strategy to methods involving resolution of racemates, chiral pool templates, and asymmetric synthetic reagents.

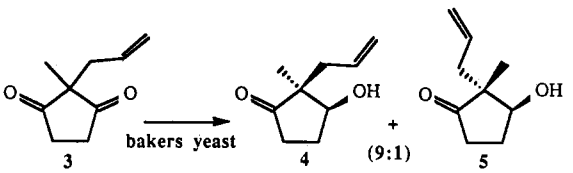
Just as the Wieland–Miescher ketone **1** has been used as a building block for fused six-membered ring natural products,[6] the bicyclo[3.3.0] analogue, enedione **2**, is a potentially useful precursor for the synthesis of fused five-membered ring natural products. Trost and Curran[7]

Scheme II. Synthesis of (*R*)-5-Methylbicyclo[3.3.0]oct-1-ene-3,6-dione



reported a synthesis of enedione **2** via a Pd(0)-directed C-alkylation of 2-methyl-1,3-cyclopentanedione and subsequent intramolecular Wittig cyclization which was adaptable to asymmetric synthesis by the use of chiral phosphine ligands providing **2** with up to 77% ee. We also reported an enantioselective synthesis and a chemical correlation of the absolute configuration of (*R*)-**2** (>98% ee).[3] A major disadvantage of this synthesis was the fact that bakers' yeast reduction of the allyl dione **3** provided a mixture of diastereomeric ketols **4** and **5** (9:1). Ketol **4** was separated from **5** by chromatography on silica gel and subsequently converted by a fairly involved sequence to the desired target (*R*)-**2** (30% overall yield from **4**).





A more efficient synthesis of (*R*)-**2** is described as follows. A simple modification of the dione substrate for yeast reduction by replacing the allyl group with a methallyl group led to the dione substrate **6**, which was monoreduced with fermenting bakers' yeast to provide the chiral ketol **7** as the sole product in 75% conversion according to the fermentation procedure described in the Experimental Section. The enantiomeric composition of ketol **7** was determined by analysis of the ^1H NMR and ^{19}F NMR spectra of the corresponding (+)-α-methoxy-α-(trifluoromethyl)phenylacetic acid (MTPA) ester[8] by using the same racemic ketol (obtained by $NaBH_4$ reduction of the dione **6**) as a standard. The two methyl signals of the (+)-MTPA diastereomers formed from the racemic ketol **7** were clearly separated in the ^1H NMR spectrum at 470 MHz and the CF_3 signals were separated by 20 Hz at 188 MHz in the ^{19}F NMR spectrum. The enantiomeric purity of the yeast derived ketol **7** was >98%.[9] The improved stereoselec-

(1) For pertinent reviews of this topic refer to the following: (a) *Enzymes in Organic Synthesis*; Ciba Foundation Symposium 111, Pitman, London, 1985. (b) Whitesides, G. M.; Wong, C. H. *Aldrichimica Acta* **1983**, *16*, 27. (c) Sih, C. J.; Rosaza, J. P. *Applications of Biochemical Systems in Organic Chemistry*; Jones, J. B., Sih, C. J., Perlman, D., Eds.; Wiley: New York, 1976; Part I, Chapter III. (d) Kieslich, K. *Microbial Transformations of Chemical Compounds Excluding Steroids and Noncyclic Structures*; G. Thieme Verlag: Stuttgart, 1976.

(2) For typical examples of synthetically useful yeast reductions of carbonyl containing compounds, see: (a) Deol, B. S.; Ridley, D. D.; Simpson, G. W. *Aust. J. Chem.* **1976**, *29*, 245. (b) Zhou, B.; Gopalan, A. S.; VanMiddlesworth, F.; Shieh, W. R.; Sih, C. J. *J. Am. Chem. Soc.* **1983**, *105*, 5925. (c) Hirama, M.; Shimizu, M.; Iwashita, M. *J. Chem. Soc., Chem. Commun.* **1983**, 599. (d) Sih, C. J.; Chen, C.-S. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 570. (e) Seebach, D.; Renaud, P.; Schweizer, W. B.; Zuger, M. F.; Brienne, M. J. *Helv. Chim. Acta.* **1984**, *67*, 1843. (f) Fuganti, C.; Grasselli, P.; Casati, P.; Carmeno, M. *Tetrahedron Lett.* **1985**, *26*, 101. (g) Mori, K.; Mori, H.; Sugai, T. *Tetrahedron* **1985**, *41*, 919. (h) Ushio, K.; Inouye, K.; Nakamura, K.; Oka, S.; Ohno, A. *Tetrahedron Lett.* **1986**, *27*, 2657. (i) Guanti, G.; Banfi, L.; Narisano, E. *Ibid.* **1986**, *27*, 3547.

(3) Brooks, D. W.; Grothaus, P. G.; Irwin, W. L. *J. Org. Chem.* **1982**, *47*, 2820.

(4) Brooks, D. W.; Mazdiyasni, H.; Chakrabarti, S. *Tetrahedron Lett.* **1984**, *25*, 1241.

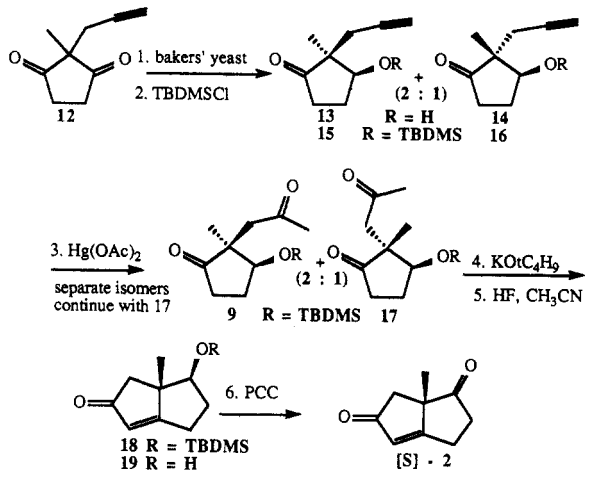
(5) Brooks, D. W.; Mazdiyasni, H.; Sallay, P. *J. Org. Chem.* **1985**, *50*, 3411.

(6) (a) Stork, G. *Pure Appl. Chem.* **1964**, *9*, 131. (b) Eder, V.; Saver, G.; Wiecher, R. *Angew. Chem., Int. Ed. Engl.* **1971**, *10*, 496. (c) Hajos, Z. G.; Parrish, D. R. *J. Org. Chem.* **1974**, *39*, 1615. (d) Gutzwiller, J.; Meier, W.; Furst, A. *Helv. Chim. Acta* **1977**, *60*, 2258. (e) Buchschacher, P.; Cassal, J. M.; Furst, A; Meier, W. *Helv. Chim. Acta* **1977**, *60*, 2747. (f) Ireland, R. E.; Aristoff, P. A.; Hoyng, C. F. *J. Org. Chem.* **1979**, *44*, 4318.

(7) (a) Trost, B. M.; Curran, D. P. *J. Am. Chem. Soc.* **1980**, *102*, 5699. (b) Trost, B. M.; Curran, D. P. *Tetrahedron Lett.* **1981**, *22*, 4929.

(8) Dale, J. A.; Dull, D. L.; Mosher, H. S. *J. Org. Chem.* **1969**, *34*, 2543.

Scheme III. Synthesis of (*S*)-5-Methylbicyclo[3.3.0]oct-1-ene-3,6-dione



tivity of the yeast reduction is likely due to the greater difference in size between a methyl and methallyl group as compared to a methyl and allyl group in the former case. In addition, the methallyl ketol **7** was converted to the target dione (*R*)-**2** by a simpler and more efficient sequence of reactions as outlined in Scheme II. Protection of the hydroxy group as the *tert*-butyldimethylsilyl ether **8** was followed by oxidation of the olefin with $NaIO_4$ and a catalytic amount of OsO_4 to provide the dione **9** (84%). Treatment of **9** with KO-*t*-C_4H_9 resulted in intramolecular aldol condensation and dehydration to provide the bicyclo enone **10** (83%). Deprotection of the silyl ether with HF (1 M in acetonitrile) gave the bicyclo ketol **11** (94%) which was oxidized with pyridinium chlorochromate to the enedione (*R*)-**2** (82% and 53% overall from **7**). The absolute configuration of the enedione (*R*)-**2** was established by direct comparison with the same compound previously correlated by us.[3] The antipodal enedione (*S*)-**2** is available (Scheme III) by bakers' yeast monoreduction of the alkynyl dione **12** which provided a diastereomeric mixture of ketols **13** and **14** (2:1, 60% conversion).[3] Protection of the hydroxy group as the *tert*-butyldimethylsilyl ether provided **15** and **16** (2:1, 95%). Treatment of this mixture with mercuric acetate and pyridine[10] gave the diones **9** and **17** (2:1, 70%) which were readily separated by chromatography on silica gel. The dione **17** was subjected to the conditions previously used for cyclization to provide the bicyclo silyl ether **18** which was deprotected to the alcohol **19**[11] and oxidation provided the enedione (*S*)-**2** (53% yield overall from **17**).

Trost and Curran[12] have demonstrated the application of enedione **2** as a key intermediate in an elegant total synthesis of the fused cyclopentanoid, coriolin. (*R*)-**2** represents the optically active intermediate for natural coriolin. With an efficient source of chiral bis-nor-Wieland–Miescher ketone (**2**) available, further applications of this useful building block for enantioselective syntheses of fused cyclopentanoid systems is possible. Microbial reduction of appropriate 2,2-disubstituted-1,3-cycloalkanediones to provide chiral ketol intermediates is a useful strategy for asymmetric synthesis of natural products.[13]

(9) A control experiment established a minimal level of detection of 1% of diastereomeric MTPA esters in the ^1H NMR spectrum at 470 MHz.

(10) Geetha, G.; Raju, N.; Rajagopalan, K.; Swaminathan, S. *Indian J. Chem. Sect. B.* **1981**, *20*, 238.

(11) The alcohol **19** was identical with the same alcohol (racemic) reported by Trost and Curran in ref 7b.

(12) Trost, B. M.; Curran, D. P. *J. Am. Chem. Soc.* **1981**, *103*, 7380.

Experimental Section

All experiments requiring anhydrous conditions were conducted under a dry nitrogen atmosphere. Reactions were performed at room temperature unless indicated otherwise and with stirring by using a magnetically driven stir bar. Reactions were monitored by thin layer chromatography (TLC) on precoated silica gel 60 F-254 plates (0.25 mm). The plates were visualized by spraying or dipping with a *p*-anisaldehyde solution (1350 mL of ethanol, 50 mL of concentrated H_2SO_4, 15 mL of glacial acid acid, 37 mL of *p*-anisaldehyde) followed by heating the plate (125–150 °C). Chromatography was performed with 230–400-mesh silica gel. Solvents were evaporated on a rotary evaporator at aspirator pressure (ca. 20 mm). Nuclear magnetic resonance (NMR) spectra were acquired on a Nicolet 470 MHz NMR for proton and a Varian XL-200 for carbon. Chemical shifts are reported in ppm downfield relative to tetramethylsilane as standard.

2-Isobutenyl-2-methyl-1,3-cyclopentanedione (6). To a solution of 2-methyl-1,3-cyclopentanedione (40 g, 0.36 mol) in triethylamine (200 mL) was added 3-chloro-2-methylpropene (200 mL, 2.4 mol) and the mixture was refluxed for 16 h. Dichloromethane (250 mL) was added and the mixture was washed with 1 N HCl (250 mL) and aqueous saturated NaCl (250 mL). The organic extract was dried over $MgSO_4$ and the solvent was evaporated to give crude product, which was purified by distillation (bp 65–70 °C at 0.2 mm) to give 2-isobutenyl-2-methyl-1,3-cyclopentanedione (**6**) (49 g, 84%): ^1H NMR ($CDCl_3$, 470 MHz) 1.13 (3 H, s), 1.65 (3 H, s), 2.42 (2 H, s), 2.75 (4 H, m), 4.55 (1 H, s), 4.80 (1 H, s); ^{13}C NMR ($CDCl_3$, 50.3 MHz), 20.5 (CH_3), 24.0 (CH_3), 35.6 ($2CH_2$), 43.7 (CH_2), 57.4 (C), 115.0 (=CH_2), 140.8 (C=), 216.7 (2CO); MS, M^+ 166. Anal. Calcd for $C_{10}H_{14}O_2$: C, 72.26; H, 8.49. Found: C, 72.09; H, 8.54.

(2*S*,3*S*)-3-Hydroxy-2-isobutenyl-2-methylcyclopentanone (7). To a solution of D-glucose (150 g) and yeast extract (4 g) in water (1.0 L) at 35 °C, with vigorous magnetically driven stirring open to the air, was added dry active bakers' yeast (Fleischmanns, Standard Brands, 150 g) and the mixture was stirred for 15 min after which the dione substrate **6** (10 g, 60 mmol) was added dropwise over 30 min. The mixture was stirred vigorously open to the air for 24 h at 30 °C. The mixture was transferred to a continuous extraction apparatus and extracted with dichloromethane (1 L) for 48 h. The organic extract was evaporated and the residue was purified by chromatography (silica gel, 25% ethyl acetate in hexane), providing recovered starting material **6** (2.5 g) and desired ketol **7** (6.9 g): ^1H NMR ($CDCl_3$, 470 MHz), 1.00 (3 H, s), 1.80 (3 H, s), 1.9–2.5 (6 H, m), 4.25 (1 H, m), 4.90 (1 H, s), 4.95 (1 H, s); ^{13}C NMR ($CDCl_3$, 50.3 MHz) 19.9 (CH_3), 24.2 (CH_3), 27.9 (CH_2), 33.4 (CH_2), 38.1 (CH_2), 53.5 (C), 77.4 (CHOH), 114.4 (=CH_2), 143.0 (C=), 220.7 (CO); $[\alpha]_D$ +99.0° (*c* 7.6, $CHCl_3$); MS, M^+ 168. Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.45; H, 9.70.

(2*S*,3*S*)-3-[(*tert*-Butyldimethylsilyl)oxy]-2-isobutenyl-2-methylcyclopentanone (8). To a solution of ketol (2.5 g, 15 mmol) in DMF (10 mL) were added imidazole (3 g, 44 mmol), (dimethylamino)pyridine (0.37 g, 3 mmol), and *tert*-butyldimethylsilyl chloride (3.38 g, 22.4 mmol). The mixture was heated at 60 °C under a nitrogen atmosphere for 24 h. After being cooled to room temperature, dichloromethane (100 mL) was added and the solution was washed with water (3 × 50 mL) and aqueous saturated NaCl (50 mL). The organic extract was dried over $MgSO_4$ and the solvent was evaporated to give a crude product which was purified by chromatography (silica gel, 10% ether in hexane), affording silyl ether **8** (4.15 g, 98%): ^1H NMR ($CDCl_3$, 470 MHz) 0.08 (3 H, s), 0.10 (3 H, s), 0.90 (9 H, s), 0.98 (3 H, s), 1.73 (3 H, s), 1.6–2.5 (6 H, m), 4.06 (1 H, t), 4.75 (1 H, s), 4.85 (1 H, s); MS, M^+ 282.

(2*S*,3*S*)-3-[(*tert*-Butyldimethylsilyl)oxy]-2-(2-oxopropyl)-2-methylcyclopentanone (9). To a solution of silyl ether **8** (2.0 g, 7.1 mmol) in dioxane (20 mL) was added a solution of sodium acetate (10 mL, 1.8 M) and 4-methylmorphine 4-oxide (1.0 g, 7.4 mmol) followed by a catalytic amount of OsO_4 (1 mL of a stock solution consisting of 1 g of OsO_4, (*CAUTION* severe poison) dissolved in 200 mL of *tert*-butyl alcohol containing 1 mL

(13) Brooks, D. W.; Grothaus, P. G.; Mazdiyasni, H. *J. Am. Chem. Soc.* **1983**, *105*, 4472.

of *tert*-butyl hydroperoxide). The mixture was stirred for 48 h after which $NaIO_4$ (3.0 g, 14 mmol) was added followed by a speck of bromocresol green indicator and the pH of the solution was adjusted to the yellow color endpoint (pH 3–4) by dropwise addition of 1 N HCl. The mixture was stirred for 48 h after which a slurry of silica gel (2 g) and NaS_2O_4 (50 mg) was added followed by ether and ethyl acetate (1:1, 30 mL). The mixture was filtered through a pad of Celite and the solids were washed with ether (2 × 20 mL). The organic extract was washed with water (20 mL) and aqueous saturated NaCl (20 mL) and dried over $MgSO_4$, and the solvent was evaporated. Purification of the residue by chromatography (silica gel, 5% ether in dichloromethane) gave the dione **9** (1.7 g, 84%): ^{1}H NMR (CDCl3, 470 MHz) –0.02 (3 H, s), 0.10 (3 H, s), 0.83 (9 H, s);, 1.05 (3 H, s); 1.95 (1 H, m), 2.1 (3 H, s), 2.15 (1 H, m), 2.27 (1 H, m), 2.42 (1 H, m), 2.69 (1 H, AB q, J = 18 Hz), 2.74 (1 H, AB q, J = 18 Hz), 4.43 (1 H, t); $[\alpha]_D$ +58.1° (*c* 11.9, $CHCl_3$).

(5*R*,6*S*)-6-[(*tert*-Butyldimethylsilyl)oxy]-5-methylbicyclo[3.3.0]oct-1-en-3-one (10). To a solution of the dione **9** (40 mg, 1.4 mmol) in *tert*-butyl alcohol (10 mL) was added potassium *tert*-butoxide (160 mg, 1.4 mmol), and the mixture was stirred under nitrogen for 3 h. The solution was cooled to 0 °C and 1 N HCl (2 mL) was added. A mixture of ether and ethyl acetate (1:1, 100 mL) was added followed by water (5 mL). The organic extract was collected and evaporated. The residue was purified by chromatography (silica gel, 10% ethyl acetate in hexane) to afford the silyl eneone **10** (310 mg, 83%): ^{1}H NMR ($CDCl_3$, 470 MHz) 0.04 (3 H, s), 0.06 (3 H, s), 0.83 (9 H, s), 1.1 (3 H, s), 1.83 (1 H, m), 2.04 (1 H, AB q, J = 15 Hz), 2.45 (1 H, m), 2.64 (2 H, m), 2.69 (1 H, AB q, J = 15 Hz), 3.93 (1 H, d, J = 4.0 Hz), 5.8 (1 H, s); MS, M^+ 266.

(5*R*,6*S*)-6-Hydroxy-5-methylbicyclo[3.3.0]oct-1-en-3-one (11). To a solution of silyl ether **10** (280 mg, 1.05 mmol) in acetonitrile (2 mL) was added HF (3.2 mL of a 1 M solution in acetonitrile), and the mixture was stirred for 6 h, after which $NaHCO_3$ (355 mg, 4.2 mmol) and water (0.5 mL) were added. The solvent was evaporated and the residue was directly chromatographed (silica gel, 40% ether in dichloromethane) to give ketol **11** (150 mg, 94%): ^{1}H NMR ($CDCl_3$, 470 MHz) 1.05 (3 H, s), 1.5–2.8 (6 H, m), 4.0 (1 H, d, J = 6.0 Hz), 5.88 (1 H, s); ^{13}C NMR ($CDCl_3$, 50.3 MHz), 23.1 (CH_2), 24.2 (CH_3), 34.2 (CH_2), 44.5 (CH_2), 55.9 (C), 75.0 (CHOH), 125.0 (CH=), 191.7 (=C), 211.2 (CO); MS, M^+ 152; $[\alpha]_D$ +148° (*c* 7.5, $CHCl_3$). Anal. Calcd for $C_9H_{12}O_2$: C, 71.03; H, 7.95. Found: C, 71.15; H, 7.89.

(*R*)-5-Methylbicyclo[3.3.0]oct-1-ene-3,6-dione ((*R*)-2). A solution of alcohol **11** (150 mg, 1 mmol) in dichloromethane (1 mL) was added to a suspension of pyridinium chlorochromate (320 mg, 1.5 mmol) and NaOAc (400 mg) in dichloromethane (15 mL). The mixture was stirred for 2 h after which ether (30 mL) was added and the mixture was filtered through a pad of silica gel and washed with ether (2 × 25 mL). The solvent was evaporated and the residue was chromatographed (silica gel, 25% ether in dichloromethane) to provide the dione (*R*)-**2** (110 mg, 82%): ^{1}H NMR ($CDCl_3$, 470 MHz) 1.37 (3 H, s), 2.35 (1 H, d, J = 18 Hz), 2.47 (1 H, m), 2.62 (1 H, d, J = 18 Hz), 2.93–3.18 (3 H, m), 5.99 (1 H, s); ^{13}C NMR ($CDCl_3$, 50.3 MHz) 23.3 (CH_2), 24.5 (CH_3), 38.3 (CH_2), 44.8 (CH_2), 56.8 (C), 126.2 (CH=), 184.6 (=C), 207.5 (CO), 212.4 (CO); MS, M^+ 150; $[\alpha]_D$ –129° (*c* 0.36, $CHCl_3$). Anal. Calcd for $C_9H_{10}O_2$: C, 71.98; H, 6.71. Found: C, 71.76; H, 6.92.

(2*S*,3*S*)- and (2*R*,3*S*)-3-[(*tert*-Butyldimethylsilyl)oxy]-2-(2-oxopropyl)-2-methylcyclopentanone (9 and 17). To a solution of silyl ethers **15** and **6** (2:1, 1.0 g, 3.76 mmol) in ethanol (25 mL) were added $(CH_3CO_2)_2Hg$ (2.4 g, 7.5 mmol) and pyridine (0.6 g, 7.5 mmol), and the solution was refluxed for 4 h. After cooling in an ice bath, the solution was acidified to pH 1 by dropwise addition of 1 N HCl. A precipitate formed, the mixture was filtered through a pad of Celite, and the solids were washed with ether (3 × 20 mL). The filtrate was evaporated and the residue was dissolved in ether (50 mL) and water (50 mL). The ether layer was washed with saturated aqueous NaCl (25 mL), dried over $MgSO_4$, filtered and evaporated to give a mixture of isomeric diones **9** and **17** (2:1). The isomers were separated by chromatography (silica gel, 2–5% ether in dichloromethane) to yield the first eluted dione **9** (490 mg, 46%) followed by the dione **17** (255 mg, 24%). Dione **17**: ^{1}H NMR ($CDCl_3$, 470 MHz) 0.02 (3 H, s), 0.05 (3 H, s), 0.88 (3 H, s);, 0.9 (6 H, s);, 1.75 (1 H, m), 2.09 (3 H, s), 2.18 (1 H, m), 2.45 (2 H, m), 2.69 (1 H, AB q, J = 18 Hz), 2.86 (1 H, AB q, J = 18 Hz), 4.42 (1 H, dd, J = 10, 7.5 Hz); MS, M^+ 284; $[\alpha]_D$ –16.7° (*c* 7.5, $CHCl_3$).

Acknowledgment. Parts of this work were conducted in the Department of Chemistry, Purdue University, and the use of departmental NMR (NSF CHE 8004241) and the Purdue University Biological Magnetic Resonance Laboratory (NIH RR01077) facilities is appreciated.