Rearrangement Approaches to Cyclic Skeletons. IV. The Total Synthesis of (±)-Pinguisone and (±)-Deoxopinguisone Based on Photochemical [1,3] Acyl Migration of a Bicyclo[3.2.2]non-6-en-2-one[1]

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The total synthesis of (±)-Pinguisone (**2**) and (±)-deoxopinguisone (**3**), [5—6] fused-ring sesquiterpenes, has been achieved starting from 1-methoxy-3,4,5-trimethylbenzene. 1-Methoxy-4,5,*endo*-8-trimethylbicyclo[2.2.2]-non-5-en-2-one (**9**) was prepared selectively via facial selective Diels-Alder reaction of the diene derived from the benzene and 2-chloroacrylonitrile. Ring enlargement of **9** using $(CH_3)_3SiCHN_2$ and BF_3 etherate gave the corresponding bicyclo[3.2.2]oct-6-en-2-one (**8**). The photochemical [1,3] acyl migration of **8** gave the [5—6] fused-ring compound (**7**). The fourth methyl was introduced selectively by the conjugate addition of $(CH_3)_2CuLi$ to the spiro[bicyclo[4.3.0]non-8-ene-3,2′-[1,3]dioxolan]-7-one prepared from **7**. Each furan ring of **2** and **3** was constructed via the corresponding butenolide derived from the γ-keto acid by acid-catalyzed dehydration.

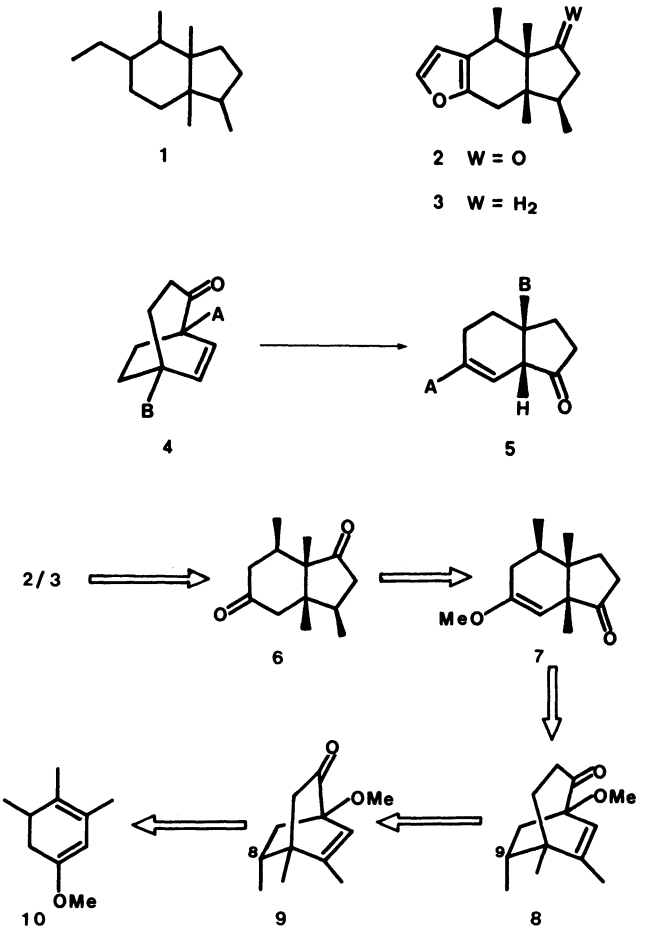
Pinguisane-type sesquiterpenes, possessing the unusual terpene skeleton (**1**),[3] have been found from various kinds of liverworts; such as pinguisone (**2**)[4] from *Aneura pinguis* (L.) Dum.[4b] and deoxopinguisone (**3**)[5] from *Ptilidium ciliare* (L.) Nees.[5a] These compounds are of particular interest in the total synthesis[6] since they have novel tricyclic furan skeletons with a cis-junction between the five- and six-membered rings and four adjacent cis-located methyl groups. Already it has been found that such polymethylated compounds do not belong to the simple cis-fused ring system whose convex and concave sides are predictable with ease.[6]

In connection with our program to develop methods for stereoselective syntheses of [*m*—*n*] fused-ring terpenoids from bridged bicyclic systems,[7] we have explored the photochemical reactions of bicyclo[3.2.2]-non-6-en-2-ones (**4**) and found a practical route to *cis*-bicyclo[4.3.0]non-4-en-7-ones (**5**) based on [1,3] acyl migration.[2] In this paper we describe the total synthesis of (±)-pinguisone (**2**) and (±)-deoxopinguisone (**3**), as the first application of this photochemical transformation to natural product syntheses.

Results and Discussion

Our synthetic plan is outlined in Scheme 1. The diketone **6**, possessing four adjacent cis methyl groups, should be an important precursor of the natural products. A key step in this plan is photochemical transformation of the bicyclo[3.2.2]non-6-en-2-one (**8**) to give the [5—6] fused ring system (**7**). The ketone **8** would be derived from the bridged bicyclooctenone **9** by ring enlargement. The stereochemistry of the 8-methyl of **9** should be controlled at the stage of cycloaddition to give the precursor of **9** by the approach of a ketene equivalent from the less hindered side to the diene **10**.

1-Methoxy-3,4,5-trimethyl-1,4-cyclohexadiene (**11**) was prepared from the corresponding anisole by dissolved metal reduction.[8] When **11** was heated with

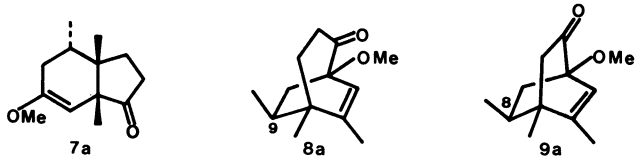


Scheme 1.

2-chloroacrylonitrile at 90°C in toluene, the 1,3-diene **10** was generated in situ and a mixture of the 1,4-addition products was obtained in 77% yield. Treating of the mixture with ethanolic sodium sulfide and potassium hydroxide[9] followed by Collins oxidation gave a ca. 10 to 1 mixture of **9** and **9a** in 57% yield. Prolongation of the treatment with sodium sulfide gave a large amount of the alcohols derived from **9** and **9a**. ^1H NMR spectrum of **9**, purified by HPLC,

shows the signals due to the 8-methyl at δ 0.89, whereas that of the isomer **9a** exhibits the corresponding signals at δ 1.01. This high-field shift of the former means that **9** is the 8-*endo*-methyl isomer. Their ^{13}C NMR spectra are also informative; that of **9** shows representative signals at δ 144.7 (5-C, s) and 47.7 (3-C, t) while those of **9a** are the singlet at δ 149.0 (5-C) and the triplet at 41.1 (3-C). These difference should be caused by the steric repulsion between the 5-carbon and the 8-*endo*-methyl in **9** and that between the 3-methylene and the 8-*exo*-methyl in **9a**.

Treatment of **9** with trimethylsilyldiazomethane and boron trifluoride etherate[10] in dichloromethane at −78 °C followed by desilylation with potassium carbonate in aqueous methanol gave the ring-enlargement product **8** in 79% yield. At higher temperature than −73 °C, the yield of **8** decreased definitely.

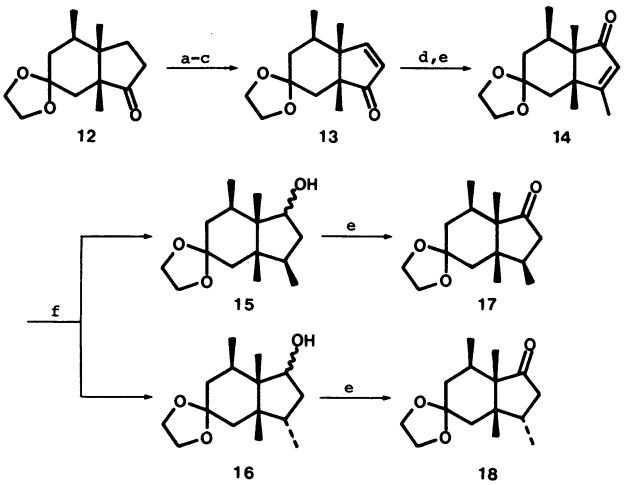


Photochemical transformation of **8** to give the cis [5—6] fused-ring system **7** was carried out in 59% yield by irradiation of its tetrahydrofuran (THF) solution using a high-pressure mercury lamp through a Pyrex filter. In practice, the mixture of **9** and **9a** was converted into a mixture of **7** and **7a** and then the desired ketone **7** was isolated by silica-gel column chromatography.

The enol methyl ether **7** underwent disproportionation slowly upon standing at ambient temperature. Terefore, **7** was treated with 2-ethyl-2-methyl-1,3-dioxolane and *p*-toluenesulfonic acid (TsOH) in benzene to give the acetal **12**, a remarkably stable compound.

In order to introduce the fourth methyl group stereoselectively, we first attempted the dissolved metal reduction route as shown in Scheme 2. The ketone **12** was converted into the α,β-unsaturated carbonyl compound **13** in 61% yield by successive treatment with 1) lithium diisopropylamide (LDA) and *S*-phenyl benzenethiosulfonate[11] and 2) sodium periodate in aqueous methanol, followed by 3) pyrolysis with calcium carbonate in toluene at 90 °C. Treatment of **13** with methyllitium and then with pyridinium chlorochromate (PCC)[12] gave the oxidative rearrangement product **14** in 79% yield. Reduction of **14** with lithium and *t*-butyl alcohol in liquid ammonia–THF gave the mixtures of the isomeric alcohols (**15** and **16**) in 33 and 58% yields, respectively. Each of them was converted quantitatively into the corresponding ketone by PCC oxidation in the presence of sodium acetate.

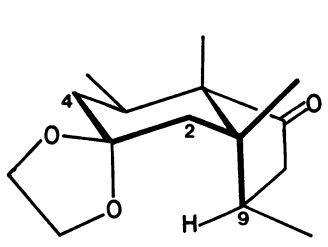
Stereochemistry of the fourth methyl group of the ketones **17** and **18** were determined on the basis of their ^{1}H NMR spectra. The spectrum of **17** shows the signals



Scheme 2. Preparation of the *cis*-tetramethyl-*cis*-perhydroindanone (**17**).[a)]
a) (a): LDA, $PhSSO_2Ph$, THF, (b): $NaIO_4$, MeOH–H_2O, (c): $CaCO_3$, PhMe, 90 °C, (d): MeLi, ether, (e): PCC, NaOAc, CH_2Cl_2, (f): Li, NH_3, *t*-BuOH, THF.

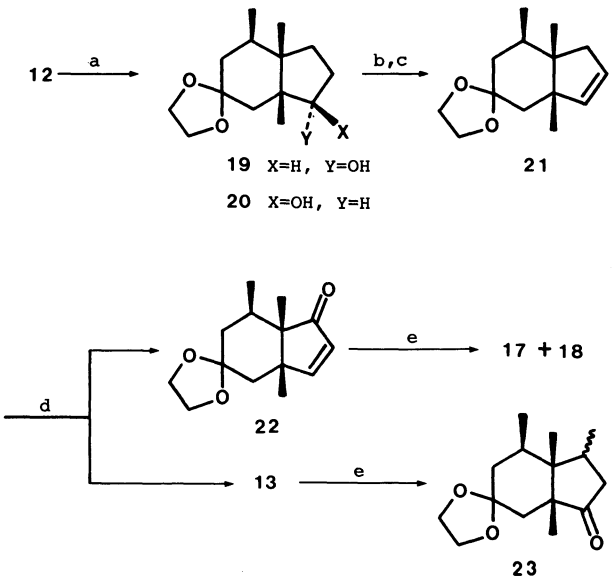
due to the 9-methine proton at δ 3.04. On the other hand, the signals due to the corresponding proton of **18** appear at the higher field than δ 2.5. This remarkable difference means the presence of large deshielding effect to the proton of **17**.

The 200 MHz NMR spectrum of **17** suggests that its presumable conformation is **17a**, as depicted. The coupling pattern of the 5-methine proton (δ=2.07, $J_{5,4}$= 13.0 and 3.8 Hz) reflects that this is an axial proton of a chair cyclohexane ring. The spin–spin coupling between one of the 4-protons (δ=1.49, $J_{4,5}$=3.8 Hz and $J_{4,2}$=2.3 Hz) and one of the 2-protons (δ=1.75, $J_{2,4}$= 2.3 Hz) should be the "W"-shape long-range coupling. This means both of the protons are present at the equatrial positions of a chair six-membered ring. Thus, the C_1–C_9 bond should be axial-like and the 9-proton approaches to the axial-like oxygen of the acetal part. The nonbonding distance between this oxygen and the 9-proton is estimated to be ca. 1.9 Å based on Dreiding model study. The low-field shift of the 9-methine proton signals should be caused by this steric compression. The isomer **18** may have a different conformation from that of **17**. The ^{13}C NMR spectrum of **17** shows the signals due to the methine carbons

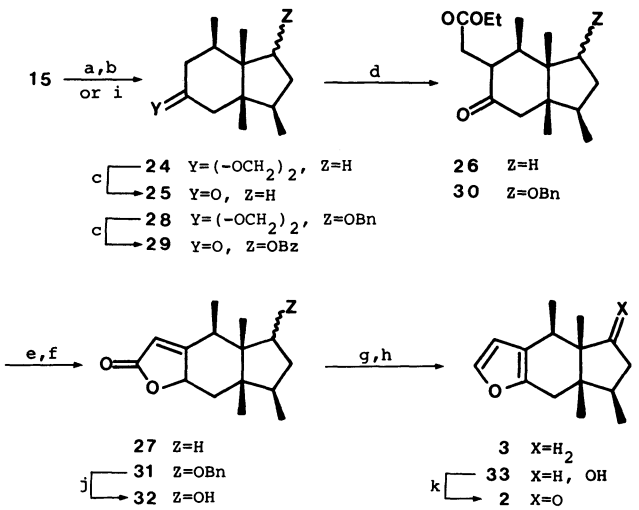


17a

at δ 30.3 and 29.2 while that of **18** exhibits the corresponding ones at δ 36.9 and 32.2. These remarkable



Scheme 3. An alternative route to the *cis*-tetramethyl-*cis*-perhydroindanone (**17**).[a)]
a) (a): $LiAlH_4$, ether, (b): MsCl, Py, (c): *t*-BuOK, DMSO, (d): CrO_3-3,5-DMP, CH_2Cl_2, (e): $(CH_3)_2CuLi$, ether.



Scheme 4. Completion of the synthesis of (±)-pinguisone (**2**) and (±)-deoxopinguisone (**3**).[a)]
a) (a): NaH, CS_2, THF, then MeI, (b): $(n\text{-Bu})_3SnH$, PhMe, reflux, (c): HCl, H_2O-acetone, (d): LDA, ICH_2CO_2Et, THF-HMPA, (e): K_2CO_3, MeOH-H_2O, (f): TsOH, PhH, reflux, (g): DIBAH, THF, (h): 1 M H_2SO_4, (i): NaH, $PhCH_2Br$, $(n\text{-Bu})_4NI$, DME, (j): BBr_3, CH_2Cl_2, (k): $(Ac)_2O$, DMSO.

differences also suggest the conformational difference between **17** and **18** and the presence of the large steric compression in the former.

Catalytic hydrogenation of **14** using 5% palladium on charcoal in ethanol gave a 1 to 1 mixture of **17** and **18**.

In order to prepare the ketone **17** selectively, an alternative route was examined (Scheme 3). Reduction of **12** with $LiAlH_4$ gave the alcohols **19** and **20** in 82 and 17% yields, respectively. Treatment of the methanesulfonate (mesylate) of **19** with potassium *t*-butoxide in DMSO gave the olefin **21** in 95% yield (from **19**), whereas **21** was not derived from the mesylate of **20**. Allylic oxidation of **21** with chromium trioxide-3,5-dimethylpyrazole complex[13] at −20 °C gave a 9 to 2 mixture of the ketones **22** and **13** in 79% yield. Reaction of this mixture with lithium dimethylcuprate(I) formed a mixture of **17** and **18**, in a ratio of 94 to 6, in 76% yield and **23**, derived from **13**, in 17% yield. Remarkable stereoselectivity of the conjugate addition to **22** is caused by steric approach control due to the steric bulk of the acetal. Reduction of the mixture of **17** and **18** by $LiAlH_4$ gave the alcohols (**15** and **16**) quantitatively.

The final stages of the (±)-deoxopinguisone (**3**) synthesis is shown in Scheme 4. The alcohols **15** were converted into the xanthates.[14] Treatment of them with tributyltin hydride in toluene gave the deoxo derivative **24** in 84% yield from **15**. Cleavage of the acetal yielded the ketone **25** (97%). The kinetic enolate of **25** generated by treating with LDA was reacted with ethyl iodoacetate in THF–hexamethylphosphoric triamide (HMPA)[15] to produce **26**, alkylated at the appropriate position, in 63% yield and 26% recovery of **25**. Hydrolysis of **26** and then heating under reflux with TsOH in benzene[16] gave the butenolide **27** in 72% yield. Reduction of **27** with diisobutylaluminium hydride (DIBAH) followed by an acid work-up produced a colorless oil, in 69% yield, whose ^1H NMR was identical with that of natural deoxopinguisone (**3**).

In order to prepare (±)-pinguisone (**2**) from **15**, the hydroxyl group was protected as a benzyl ether (**28**, 92%), and the synthetic route of (±)-deoxopinguisone was traced as shown in Scheme 4. The 1,3-dioxolane was cleaved by hydrochloric acid in acetone to yield **29** in 91% yield. Selective alkylation of **29** by treating with LDA and ethyl iodoacetate gave **30** in 68% yield and 24% recovery of **29**. Hydrolysis of **30** followed by the treatment with TsOH provided the butenolide **31** in 52% yield. Cleavage of the benzyl ether by boron tribromide[17] in dichloromethane at 0 °C gave **32** in 82% yield. DIBAH reduction of **32** follwed by an acid work-up gave the furan **33** in 66% yield. Oxidation of **33** with DMSO–acetic anhydride[18] provided the ketone, as a colorless oil (62%), whose spectral characteristics were identical with those of natural pinguisone ((+)-**2**, lit[4a,6b] mp 63 °C).

Thus, we have demonstrated that the photochemical [1,3] acyl migration of the bicyclo[3.2.2]nonenone system is incorporated into the synthetic route of the [5—6] fused-ring sesquiterpenes.

Experimental

General. Boiling points are uncorrected. Melting points were determined with a Yamato MP-21 capillary melting point apparatus and are uncorrected. UV and IR spectra (in CCl_4, unless otherwise mentioned) were recorded on Hitachi

Model 323 and 215 spectrometers, respectively. ^{1}H NMR spectra (in CCl_4, unless otherwise noted) were obtained on JEOL JNM-PMX60, Varian EM-390 90 MHz, and/or Varian XL-200 NMR specrometers, using tetramethylsilane as an internal standared. ^{13}C NMR spectra (in $CDCl_3$) were recorded on a JEOL FX 90Q NMR spectrometer. The mass spectral studies were conducted using a Hitachi M-52 spectrometer. THF and ether were distilled from benzophenone ketyl under argon, immediately prior to use. 1,2-Dimethoxyethane (DME) was distilled from lithium aluminium hydride under argon immediately prior to use. Dichloromethane was distilled from P_2O_5 and stored on 4A molecular sieves. Benzene and toluene were distilled from P_2O_5 and stored over sodium wire. *S*-Phenyl benzenethiosulfonate,[11] *N*-nitroso-*N*-trimethylsilylmetylurea,[19] and PCC[20] were prepared by using literature procedures. All reactions were monitored by analytical TLC using E. Merck precoated silica gel $60F_{254}$ plates. Column chromatography was carried out with E. Merck silica gel 60 (70—230 mesh ASTM). HPLC was performed on a Warters Associates Model R-401 liquid chromatograph using a 25 cm×8 mm stainless-steel column packed with Lichrosorb SI 100. Analytical VPC was carried out using a Hitachi 663-50 gas chromatograph, outfitted with a 3 m×3 mm stainless-steel column packed with 10% FFAP on 60/80 Uniport B.

1-Methoxy-4,5,*endo*-8-trimethylbicyclo[2.2.2]oct-5-en-2-one (9). To a solution of 9.85 g (62.9 mmol) of 1-methoxy-3,4,5-trimethyl-1,4-cyclohexadiene (**11**)[8] in 10 ml of toluene were added 11.0 g (125.7 mmol) of 2-chloroacrylonitrile and 0.23 g (2.1 mmol) of hydroquinone. The mixture was heated at 90 °C overnight, cooled, and concentrated. Distillation of the residue (bp 118 °C/0.1 Torr (1 Torr=133.322 Pa)) yielded 11.55 g (48.2 mmol, 77%) of a mixture of the isomeric addition products as a pale yellow oil which solidified upon standing.

A solution of 4.52 g (18.8 mmol) of the adducts was added to a mixture of 6.8 g (28.3 mmol) of sodium sulfide, 3.9 g (56.5 mmol) of potassium hydroxide, and 9.4 ml of water. After heated under reflux for 8 h, the reaction mixture was diluted with water, and extracted with three portions of ether. The extracts were combined, washed with water and saturated brine, and dried over $MgSO_4$. Evaporation of the solvent, followed by chromatography of the residue (2.83 g) using 100 g of silica gel (8:1 then 3:1hexane–ethyl acetate) gave 1.84 g (9.47 mmol, 50%) of a mixture of **9** and the *exo*-8-methyl isomer **9a** and 0.24 g (1.22 mmol, 7%) of the alcohols, which were converted quantitatively into **9** and **9a** by Collins oxidation. The ratio of **9** and **9a**, 10 to 1, was determined by VPC (200 °C). Pure **9** and **9a** were obtained by repeated HPLC (10:1 hexane–ethyl acetate). **9**: Colorless oil; IR 1740 (s) cm^{-1}; ^{1}H NMR δ=0.89 (3H, d, J=6.9 Hz), 1.06 (1H, dd, J=12.4 and 4.5 Hz), 1.17 (3H, s), 1.6—2.0 (1H, m), 1.81 (3H, d, J=1.5 Hz), 1.87 (2H, broad s), 2.19 (1H, dd, J=12.2 and 9.8 Hz), 3.40 (3H, s), and 5.82 (1H, broad s); ^{13}C NMR δ=209.8 (s), 144.7 (s), 122.1 (d), 84.3 (s), 52.9 (q), 47.7 (t), 42.1 (s), 38.3 (d), 37.1 (t), 19.5 (q), 19.3 (q), and 19.1 (q); MS (25 eV) m/z (rel intensity) 194 (M$^+$, 1), 166 (8), and 137 (100). Found: C, 74.11; H, 9.52%. Calcd for $C_{12}H_{18}O_2$: C, 74.19, H, 9.34%. **9a**: Colorless oil; IR 1745 (s) cm^{-1}; ^{1}H NMR δ=1.01 (3H, d, J=6.9 Hz), 1.10 (3H, s), 1.35 (1H, dd, J=10.5 and 4.4 Hz), 1.5—1.9 (3H, m), 1.80 (3H, d, J=1.5 Hz), 2.12 (1H, d, J=18.3 Hz), 3.83 (3H, s), and 5.75 (1H, broad s); ^{13}C NMR δ=209.2 (s), 149.0 (s), 122.3 (d), 84.1 (s), 52.9 (q), 41.3 (s), 41.1 (t), 36.9 (t), 35.9 (d), 18.8 (q), 17.5 (q), and 16.0 (q); MS (25 eV) m/z (rel intensity) 194 (M$^+$, 21) and 103 (100).

Ring Enlargement of 9 Using $TMSCHN_2$ and BF_3 Etherate. Preparation of 1-Methoxy-5,endo-6,9-trimethylbicyclo-[3.2.2]non-6-en-2-one (8). In a flask equipped with a Dry Ice condenser were placed 4.59 g (25.67 mmol) of *N*-nitroso-*N*-trimethylsilylmethylurea and 5 ml of pentane. To the mixture was added 2.0 ml of 20% aqueous potassium hydroxide solution at 0 °C. After 1.5 h stirring at 0 °C, the organic layer was diluted with pentane, separated, washed with water, and dried over Na_2SO_4. This solution was concentrated carefully to ca. 2 ml, and diluted with 6.6 ml of dichloromethane. To a solution of 446.6 mg (2.3 mmol) of **9** in 8.9 ml dichloromethane was added 0.41 ml (3.45 mmol) of BF_3 etherate at −78 °C under argon and the mixture was stirred for 5 min. To this reaction mixture was added that $TMSCHN_2$ solution over a period of 30 min. After 1 h stirring, to the solution was added 20 ml of saturated aqueous $NaHCO_3$ solution. The mixture was allowed to warm to room temperature with stirring. After 2 h stirring the organic layer was separated, washed with saturated brine, dried over $MgSO_4$, and concentrated in vacuo. The residual oil was a mixture of **8** and its α-silylated derivatives. This mixture was diluted with 4.5 ml of methanol and treated with 0.3 g of K_2CO_3 and 1.5 ml of water for 2 h at room temperature. After dilution with water, the mixture was extracted with ether. The extracts were combined, washed with water and brine, and dried over $MgSO_4$. Evaporation of the solvent, followed by silica-gel chromatography (20 g; 8:1 hexane–ethyl acetate) of the residue (611.3 mg) gave 378.3 mg (1.82 mmol, 79%) of **8**: Colorless oil; UV (cyclohexane) 302 nm (ε 186); IR 1725 cm^{-1};^{1}H NMR δ=0.93 (3H, d, J=6.5 Hz), 1.06 (3H, s), 1.1—2.1 (4H, m), 1.75 (3H, d, J=1.5 Hz), 2.2—2.8 (3H, m), 3.15 (3H, s), and 5.47 (1H, broad s); ^{13}C NMR δ=205.0 (s), 144.6 (s), 124.3 (d), 82.4 (s), 51.3 (q), 40.7 (t), 40.4 (s), 38.6 (t), 37.9 (t), 35.2 (d), 24.1 (q), 21.7 (q), and 20.0 (q); MS (25 eV) m/z (rel intensiity) 208 (M$^+$, 13) and 147 (100). The 2,4-DNP derivative: Mp 146.5—147 °C. Found: C, 58.74, H, 6.37; N, 14.45%. Calcd for $C_{19}H_{24}N_4O_5$: C, 58.75; H, 6.23; N, 14.42%.

Photochemical Transformation of 8 into 4-Methoxy-*r*-1,*c*-2,*c*-6-trimethylbicyclo[4.3.0]non-4-en-7-one (7). A solution of 203.9 mg (1.15 mmol) of **8** in 100 ml of THF was placed in an immersion well equipped with a Pyrex filter and degassed by sonication. The solution under nitrogen was irradiated using a 100-W Rikou high pressure Hg lamp for 4 h. From the crude photolysate (208.6 mg), 120.0 mg (0.58 mmol, 59%) of **7** was isolated by column chromatography (15 g of SiO_2; 20:1 hexane–ethyl acetate). **7**: Colorless oil; IR 1740 (s) and 1675 (m) cm^{-1}; ^{1}H NMR δ=0.89 (3H, s), 0.98 (3H, s), 1.02 (3H, d, J=6.3 Hz), 1.4—2.3 (7H, m), 3.49 (3H, s), and 4.27 (1H, broad s); MS (25 eV) m/z (rel intensity) 208 (M$^+$, 30) and 137 (100).

***r*-1,*c*-5,*c*-6-Trimethylspiro[bicyclo[4.3.0]nonane-3,2′-[1,3]-dioxolan]-9-one (12).** A mixture of 38.1 mg (0.19 mmol) of **7**, 0.5 ml each of 2-ethyl-2-methyl-1,3-dioxolane and benzene, and 3 mg of TsOH was allowed to stand at room temperature for 2 d. This reaction mixture was diluted with ether, washed successively with saturated aqueous $NaHCO_3$ and NaCl solutions, and dried over $MgSO_4$. Concentration followed by chromatography (1.5 g of SiO_2; 5:1 hexane–ethyl acetate) gave 43.3 mg (99%) of **12** as colorless prisms. **12**: Mp 66.5—67.5 °C; IR 1745 (s) cm^{-1}; ^{1}H NMR δ=0.83 (3H, s), 0.90 (3H, s), 0.93 (3H, d, J=1.5 Hz), 1.1—1.3 (9H, m), and 3.4—4.0 (4H, m); ^{13}C NMR δ=220.6 (s), 107.5 (s), 64.2

(t), 63.7 (t), 54.1 (s), 40.8 (s), 38.9 (t), 37.2 (t), 33.5 (t), 33.3 (d), 28.6 (t), 22.9 (q), 168. (q), and 14.0 (q); MS (25 eV) *m/z* (rel intensity) 238 (M^+, 18) and 113 (100). Found: C, 70.61; H, 9.47%. Calcd for $C_{14}H_{22}O_3$: C, 70.56; H, 9.47%.

***r*-1,*c*-5,*c*-6-Trimethylspiro[bicyclo[4.3.0]non-7-ene-3,2'-[1,3]dioxolan]-9-one (13).** To a solution of 0.11 ml (2.5 mmol) of diisopropylamine in 2 ml of dry THF, prepared under argon, was added 0.47 ml (0.78 mmol) of 1.56 M[†] hexane solution of *n*-BuLi at 0°C, stirred for 10 min, and cooled to −78°C. To this LDA solution was added a solution of 166.5 mg (0.70 mmol) of **12** in 2 ml of THF via a double-ended needle, and kept at −78°C for 15 min. To the enolate solution was added a solution of 175.0 mg (0.70 mmol) of *S*-phenyl benzenethiosulfonate in 2 ml of THF. After stirring at −78°C for 1 h and then at room temperature for an additional hour, the reaction was quenched by addition of saturated aqueous ammonium chloride, and extracted with three portions of ether. The ethereal extracts were combined, washed with saturated aqueous $NaHCO_3$ and saturated brine, and dried over $MgSO_4$. Evaporation of the solvent, followed by chromatography (5 g of SiO_2; 30:1 benzene–ethyl acetate) of the residue (256.6 mg) gave 199.1 mg (0.57 mmol, 82%) of the α-phenylthio ketone as a colorless oil. This ketone was dissolved in a mixture of 11 ml of methanol and 1.4 ml of water and treated with 134 mg (0.63 mmol) of sodium periodate at room temperature overnight. The reaction mixture was poured into saturated aqueous $NaHCO_3$ solution, and extracted with three portions of dichloromethane. The combined extracts were washed with saturated brine and dried over $MgSO_4$. After removal of the solvent, the residue (249.5 mg) was purified by chromatography (10:1 benzene–ethyl acetate) to give 196.5 g (0.54 mmol, 95%) of a mixture of the sulfoxides. To a solution of the sulfoxides in 6 ml of toluene was added 0.1 g of $CaCO_3$. The mixture was heated at 90°C for 12 h and then under reflux for 6 h. After filtration through an alumina layer, concentration of the filtrate gave 174.1 mg of a colorless oil. Chromatography on silica gel (5 g; 5:1 hexane–ethyl acetate) gave 99 mg (0.42 mmol, 78%) of **13**: Colorless needles; mp 58—60°C; IR 1720 (s) cm^{-1}; ^1H NMR δ=0.95 (3H, s), 0.97 (3H, d, *J*=6.0 Hz), 1.00 (3H, s), 1.37 (1H, d, *J*=14.1 Hz), 1.3—1.8 (3H, m), 2.00 (1H, dd, *J*=14.1 and 1.0 Hz), 3.8 (4H, m), 5.89 (1H, d, *J*=5.7 Hz), and 7.35 (1H, d, *J*=5.7 Hz); MS (25 eV) *m/z* (rel intensity) 236 (M^+, 16) and 113 (100). Found: C, 71.45; H, 8.45%. Calcd for $C_{14}H_{20}O_3$: C, 71.16; H, 8.53%.

***r*-1,*c*-5,*c*-6,9-Tetramethylspiro[bicyclo[4.3.0]non-8-ene-3,2'-[1,3]dioxolan]-9-one (14).** To a solution of 99 mg (0.42 mmol) of **13** in 10 ml of dry ether was added 0.49 ml (0.63 mmol) of 1.3 M methyllithium solution in ether at 0°C under argon and stirred for 30 min. To the reaction mixture was added saturated aqueous ammonium chloride solution and extracted with three portions of ether. The combined extracts were washed with water and saturated brine, and dried over $MgSO_4$. After removal of the solvent, the remaining oil (97.2 mg) was chromatographed on silica gel (3 g; 5:1 then 2:1 hexane–ethyl acetate) to yield 94.8 mg (0.38 mmol, 90%) of the allylic alcohols. To a solution of these alcohols in 3 ml of dichloromethane were added 62 mg of sodium acetate and 164 mg (0.76 mmol) of PCC at room temperature, and the mixture was stirred for 2.5 h. After addition of 4 ml of ether, the solution was decanted from the black solid. The residue was washed in turn with several portions of ether. The combined ethereal extracts were passed through a silica-gel layer to give 92.8 mg of a colorless oil. Chromatography (3 g of silica gel; 5:1 hexane–ethyl acetate) of the oil gave 83.5 mg (0.33 mmol, 87%) of **14**: Colorless oil; IR 1715 (s) and 1625 (m) cm^{-1}; ^1H NMR δ=0.86 (3H, d, *J*=7.1 Hz), 0.89 (3H, s), 0.99 (3H, s), 1.2—1.6 (3H, m), 1.7—2.1 (2H, m), 2.01 (3H, d, *J*=1.5 Hz), 3.83 (4H, m), and 5.51 (1H, brosd s).

***r*-1,*c*-5,*c*-6,*c*-9- and *r*-1,*c*-5,*c*-6,*t*-9-Tetramethylspiro[bicyclo-[4.3.0]nonane-3,2'-[1,3]dioxolan]-7-ols (15 and 16, Respectively).** To a flask containing 60.1 mg (0.24 mmol) of **14** were added ca. 30 ml of ammonia, distilled from sodium, 0.5 ml (5.3 mmol) of *t*-butyl alcohol, 5 ml of THF, and 16 mg (2.4 mmol) of litium at −78°C under argon. The mixture was allowed to warm to room temperature very slowly, and treated with water. This mixture was extracted with ether, and the extracts were combined, washed with water and saturated brine, and dried over $MgSO_4$. After evaporation of the solvent, silica-gel chromatography (8 g; 5:1 hexane–ethyl acetate) of the residue (83 mg) gave 20.3 mg (0.08 mmol, 33%) of the less polar alcohols (**15**) and 35.9 mg (0.14 mmol, 58%) of the more polar alcohols (**16**).

***r*-1,*c*-5,*c*-6,*c*-9-Tetramethylspiro[bicyclo[4.3.0]nonane-3,2'-[1,3]dioxolan]-7-one (17).** To a solution of 5.2 mg (0.02 mmol) of **15** in 0.5 ml of dichloromethane were added 40 mg (1.32 mmol) of PCC and 10 mg of sodium acetate. After 11 h stirring, to the reaction mixture was added 3 ml of ether and the ethereal solution was filtered through a silica-gel layer. Concentration of the filtrate gave 8.3 mg of an oil. Chromatography on silica gel (1 g; 10:1 hexane–ethyl acetate) gave 5.1 mg (0.02 mmol, 100%) of **17**: Mp 58.5—59°C; IR 1735 (s) cm^{-1}; ^1H NMR δ=0.60 (3H, s), 0.73 (3H, d, *J*=6.9 Hz), 0.76 (3H, s), 0.88 (3H, d, *J*=6.8 Hz), 1.31 (1H, d, *J*=14.9 Hz), 1.35 (1H, dd, *J*=13.8 and 13.0 Hz), 1.49 (1H, ddd, *J*=13.8, 3.8, and 2.3 Hz), 1.73 (1H, dd, *J*=19.3 and 11.0 Hz), 1.75 (1H, dd, *J*=14.9 and 2.3 Hz), 2.07 (1H, ddd, *J*=13.0, 6.9, and 3.8 Hz), 2.47 (1H, dd, *J*=19.3 and 9.0 Hz), 3.04 (1H, ddq, *J*=11.0, 9.0, and 6.8 Hz), 3.8—4.6 (4H, m); ^{13}C NMR δ=219.8 (s), 108.4 (s), 64.7 (t), 63.4 (t), 55.9 (s), 45.7 (s), 41.8 (t), 38.3 (t), 38.1 (t), 30.3 (d), 29.2 (d), 19.2 (q), 15.7 (q), 13.8 (q), and 8.2 (q); MS (25 eV) *m/z* (rel intensity) 252 (M^+, 2) and 113 (100). Found: C, 71.59; H, 9.70%. Calcd for $C_{15}H_{24}O_3$: C, 71.39; H, 9.59%.

***r*-1,*c*-5,*c*-6,*t*-9-Tetramethylspiro[bicyclo[4.3.0]nonane-3,2'-[1,3]dioxolan]-7-one (18).** Alcohols **16** (7.8 mg, 0.03 mmol) was treated with PCC (40 mg) and sodium acetate (10 mg) dry CH_2Cl_2 (0.5 ml) at room temperature for 11 h. A workup similar to that employed for the synthesis of **17** gave a colorless oil (8.1 mg). Chromatography on silica gel (1.4 g; 10:1 hexane–ethyl acetate) gave 7.8 mg (0.03 mmol, 100%) of pure **18**: Colorless needles; mp 63—64°C; IR 1740 (s) cm^{-1}; ^1H NMR δ=0.89 (3H, s), 0.97 (3H, d, *J*=6.6 Hz), 1.10 (3H, d, *J*=7.5 Hz), 1.17 (3H, s), 1.1—1.6 (4H, m), 1.6—2.5 (4H, m), and 3.6—4.0 (4H, m); ^{13}C NMR δ=220.6 (s), 109.3 (s), 64.6 (t), 62.9 (t), 55.2 (s), 44.3 (s), 41.1 (t), 38.1 (t), 37.6 (t), 36.9 (d), 32.2 (d), 20.2 (q), 17.4 (q), 16.1 (q), and 12.5 (q); MS (25 eV) *m/z* (rel intensity) 252 (M^+, 4) and 113 (100).

Reduction of 12. Preparation of *t*-1,*t*-5,*t*-6-Trimethylspiro[bicyclo[4.3.0]nonane-3,2'-[1,3]dioxolan]-*r*-8-ol (19). To a suspension of 92 mg (2.42 mmol) of $LiAlH_4$ in 4 ml of dry ether was added a solution of 577.2 mg (2.42 mmol) of **12** in 3 ml of ether at 0°C. After 5 min stirring, to the reaction mixture were added successively 0.09 ml of water, 0.09 ml of 15% aq NaOH, and 0.27 ml of water. After stirring

[†] 1 M=1 mol dm^{-3}.

until a granular precipitate was formed, $MgSO_4$ was added to the mixture and filtered. Concentration of the filtrate gave 578.5 mg of a colorless oil. Chromatography on silica gel (20 g; 3:1 hexane–ethyl acetate) gave 475.1 mg (1.98 mmol, 82%) of **19** and 101.9 mg (0.42 mmol, 17%) of the C-9 isomer (**20**). **19**: Colorless oil; IR 3480 (m), 2980 (s), and 2890 (m) cm^{-1}; ^1H NMR δ=0.81 (3H, s), 0.84 (3H, s), 0.88 (3H, d, J=6.8 Hz), 1.0—2.3 (9H, m), 3.62 (1H, dd, J=6.0 and 3.5 Hz), 3.74 (1H, broad s), and 3.8—4.0 (4H, m); ^{13}C NMR δ=108.9 (s), 83.0 (d), 64.4 (t), 64.0 (t), 49.5 (s), 44.6 (s), 40.1 (t), 38.8 (t), 33.7 (t), 33.7 (d), 32.2 (t), 27.4 (q), 17.0 (q), and 15.4 (q); MS (25 eV) m/z (rel intensity) 240 (M^+, 19) and 113 (100). Found: C, 69.96; H, 10.24%. Calcd for $C_{14}H_{24}O_3$: C, 69.96; H, 10.07%. **20**: IR 3640 (w) and 3500 (w) cm^{-1}; ^1H NMR δ=0.6—2.0 (10H, m), 0.73 (3H, s), 0.79 (3H, s), 0.82 (3H, d, J=6.3 Hz), 3.7—4.0 (4H, m), and 4.6 (1H, m), ^{13}C NMR δ= 108.8 (s), 74.5 (d), 64.6 (t), 63.3 (t), 47.7 (s), 44.3 (s), 38.8 (t), 33.4 (d), 31.7 (t), 28.8 (t), 17.8 (q), and 14.2 (q); MS (25 eV) m/z (rel intensity) 240 (M^+, 13) and 113 (100).

***r*-1,*c*-5,*c*-6-Trimethylspiro[bicyclo[4.3.0]non-8-ene-3,2′[1,3]-dioxolane] (21).** To a solution of 475.0 mg (1.98 mmol) of **19** in 10 ml of pyridine was added 0.18 ml (2.37 mmol) of methanesulfonyl chloride at 0 °C, and the mixture was allowed to warm to room temperature. After stirring overnight, the mixture was diluted with saturated aqueous NH_4Cl solution and extracted with ether. The ethereal solution was washed successively with water and saturated brine, dried over $MgSO_4$, and then concentrated to give 632.6 mg of the crude mesylate as a pale yellow oil.

To a solution of this oil in 10 ml DMSO was added 490 mg (4.37 mmol) of potassium *t*-butoxide under a nitrogen atmosphere, and the mixture was stirred overnight at room temperature. After addition of 20 ml of saturated aqueous NH_4Cl, the mixture was extracted with three portions of ether. The ethereal extracts were combined, washed with water and saturated brine, and dried over $MgSO_4$. Evaporation of the solvent gave 436.8 mg of a yellow oil. Silica-gel column chromatography (10 g; 15:1 hexane–ethyl acetate) of the oil gave 418.8 mg (1.88 mmol, 95%) of **21**: Colorless oil; IR 3070 (w) and 1090 (s) cm^{-1}; ^1H NMR δ=0.82 (3H, s), 0.84 (3H, d, J=6.0 Hz), 0.88 (3H, s), 1.2—2.0 (5H, m), 2.12 (2H, m), 3.8 (4H, m), 5.30 (1H, dt, J=6.0 and 2.2 Hz), and 5.52 (1H, dm, J=6.0 Hz); MS (25 eV) m/z (rel intensity) 222 (M^+, 95) and 113 (100). Found: C, 75.74; H, 10.16%. Calcd for $C_{14}H_{22}O_2$: C, 75.63; H, 9.97%.

Allylic Oxidation of 21. Preparation of *r*-1,*c*-5,*c*-6-Trimethylspiro[bicyclo[4.3.0]non-8-ene-3,2′-[1,3]dioxolan]-7-one (22). Chromium trioxide (3.76 g, 37.6 mmol) was placed in a reaction flask, dried at 40 °C in vacuo (0.2 Torr) overnight, and dissolved in 32 ml of dry CH_2Cl_2. To this solution was added 3.64 g (37.6 mmol) of 3,5-dimethylpyrazole bellow −20 °C (ice–methanol bath) and stirred for 15 min. A solution of **21** (418.8 mg, 1.88 mmol) in dichloromethane (1 ml) was added to the solution of the complex and stirred for 4 h at −20 °C. Into the reaction flask was poured 16 ml of 5 M aqueous sodium hydroxide solution and the mixture was stirred for 1 h at 0 °C. To the mixture was added 100 ml of ether, and the organic layer was separeted. The ethereal solution was washed with three portions of water, two portions of 0.5 M hydrochloric acid, and a portion of saturated brine, and then dried over $MgSO_4$. Removal of the solvent under reduced pressure gave 1.38 g of white solids. Silica-gel chromatography (30 g; 5:1 hexane–ethyl acetate) gave 305.5 mg (1.29 mmol, 69%) of a 9 to 2 mixture of **22** and **13**. Repeated HPLC (10:1 hexane–ethyl acetate) gave pure **22** as colorless needles. **22**: Mp 74.0—75.0 °C; IR 1715 (s) cm^{-1}; ^1H NMR δ=0.85 (3H, d, J=6.8 Hz), 0.90 (3H, s), 0.97 (3H, s), 1.2—1.5 (2H, m), 1.6—1.8 (2H, m), 1.92 (1H, dq, J=8.3 and 6.8 Hz), 3.83 (4H, m), 5.74 (1H, d, J=5.9 Hz), and 7.22 (1H, d, J=5.9 Hz); MS (25 eV) m/z (rel intensity) 236 (M^+, 51) and 221 (100). Found: C, 71.36; H, 8.62%. Calcd for $C_{14}H_{20}O_3$: C, 71.16; H, 8.53%.

Reaction of 22 and Lithium Dimethylcuprate(I). An Alternative Route to 17. To a suspension of 1.47 g (7.69 mmol) of copper(I) iodide in 25 ml of ether was added dropwise 10.5 ml (1.42 M, 14.88 mmol) of ethereal methyllithium at 0 °C under argon, and the mixture was stirred for 5 min. To this clear solution was added a solution of the 9 to 2 mixture of **22** and **13** (294.1 mg, 1.24 mmol) in ether (2 ml). After stirring 2 h at 0 °C, this reaction mixture was poured into 60 ml of saturated aqueous NH_4Cl solution and extracted with ether. The extracts were combined, washed successively with water and saturated brine, and dried over $MgSO_4$. Evaporation of the solvent gave 309.9 mg of a colorless oil. Chromatography (10 g of silica gel; 10:1 hexane–ethyl acetate) of the oil gave 238.6 mg (0.95 mmol, 76%) of a mixture of **17** and **18**, in a ratio of 94 to 6, and 54.3 mg (0.22 mmol, 17%) of **23**.

Lithium Aluminium Hydride Reduction of a Mixture of 17 and 18. An Alternative Route to 15. To a suspension of 50 mg (1.32 mmol) of $LiAlH_4$ in 5 ml of dry ether was added a solution of 238.6 mg (0.95 mmol) of the mixture of **17** and **18** derived from **22**, in 5 ml of ether at 0 °C. After 5 min stirring, to the reaction mixture were added successively 0.05 ml of water, 0.05 ml of 15% aq NaOH, and 0.15 ml of water. After stirring for 30 min, to the mixture was added $MgSO_4$ and filtered through a Celite layer. Concentration of the filtrate gave 239.3 mg of colorless needles. Chromatography (14 g of silica gel; 5:1 hexane ethyl acetate) of the products gave 225.9 mg (0.89 mmol, 94%) of **15**, as a ca. 1:1 mixture of the C-7 epimers, and 14.4 mg (0.06 mmol, 6%) of **16**.

***r*-1,*c*-5,*c*-6,*c*-9-Tetramethylspiro[bicyclo[4.3.0]nonane-3,2′-[1,3]dioxolane] (24).** Sodium hydride (50% dispersion in mineral oil, 64 mg, 1.34 mmol) was washed with three portions of THF under argon, and suspended in 2 ml of THF. To this mixture was added a solution of 225.9 mg (0.89 mmol) of **15** and 20 mg of imidazole in 3 ml of THF, and heated under reflux for 30 min. After addition of 0.27 ml (4.49 mmol) of carbon disulfide, the mixture was heated under reflux for 2 h and then cooled to room temperature. To the resulting yellow solution was added 0.27 ml (4.34 mmol) of iodomethane, and the mixture was stirred for 5 min. Saturated aqueous NH_4Cl solution was added, and extracted with three portions of ether. The extracts were combined, washed with water and saturated brine, and then dried over $MgSO_4$. Removal of the solvent gave 350 mg of a yellow oil. Chromatography (10 g of silica gel; 10:1 hexane–ethyl acetate) of this oil gave 300.4 mg (0.87 mmol, 98 %) of the xanthates as a colorless oil.

To a boiling solution of 0.25 ml (0.92 mmol) of tributyltin hydride in 5 ml of toluene was added a solution of 244.2 mg (0.71 mmol) of the xanthates in 3 ml of toluene and the reaction was continued for 6 h. The reaction mixture was concentrated in vacuo and then the residue was chromatographed on 10 g of silica gel (10:1 then 5:1 hexane–

ethyl acetate) to give 145.4 mg (0.61 mmol, 86%) of **24**: Colorless oil; IR 1105 (s) cm^{-1}; ^1H NMR δ=0.62 (3H, s), 0.78 (3H, d, J=7.1 Hz), 0.79 (3H, s), 0.84 (3H, d, J=6.5 Hz), 1.0—2.0 (9H, m), 2.65 (1H, m), and 3.6—3.9 (4H, m); MS (25 eV) m/z (rel intensity) 238 (M^+, 2) and 113 (100). Found: C, 75.76; H, 11.22%. Calcd for $C_{15}H_{26}O_2$: C, 75.58; H, 10.99%.

***r*-1,*c*-5,*c*-6,*c*-9-Tetramethylbicyclo[4.3.0]nonan-3-one (25).** To a solution of 127.6 mg (0.54 mmol) of **24** in 2 ml of acetone was added 0.5 ml (4.34 mmol) of 1 M hydrochloric acid at room temperature, and the mixture was allowed to stand for 4 h. To the solution was added 30 ml of ether, the aqueous layer was removed. The organic layer was washed successively with saturated aqueous $NaHCO_3$ and NaCl solutions and then dried over $MgSO_4$. The solvent was removed carefully, and the residue was chromatographed (10 g of silica gel; 10:1 hexane–ethyl aetate) to yield 100.4 mg (0.52 mmol, 97%) of **25** as a volatile oil. **25**: IR 1710 (s) cm^{-1}; ^1H NMR δ=0.74 (3H, s), 0.89 (3H, d, J=6.2 Hz), 0.93 (3H, d, J=6.0 Hz), 0.96 (3H, s), and 1.0—2.0 (10H, m); MS (25 eV) m/z (rel intensity) 194 (M^+, 2) and 109 (100). The 2,4-DNP derivative of **25**: Mp 159.0—160.0° C. Found: C, 60.89; H, 7.21; N, 14.91%. Calcd for $C_{19}H_{26}N_4O_4$: C, 60.95; H, 7.00; N, 14.96%.

Ethyl *r*-1,*c*-2,*c*-6,*c*-7-Tetramethyl-4-oxobicyclo[4.3.0]non-3-yl Acetate (26). LDA was generated from 0.18 ml (1.30 mmol) of diisopropylamine and 0.18 ml (1.04 mmol) of 1.5 M butyllithium in 4 ml of THF at −78° C. To this solution were added 0.5 ml of hexamethylphosphoric triamide (HMPA) and a solution of 100.4 mg (0.52 mmol) of **25** in 2 ml of THF at 0° C, and the mixture was stirred for 30 min at 0° C. To the enolate solution was added 0.12 ml (1.04 mmol) of ethyl iodoacetate, and the mixture was allowed to stand at 0° C for 4 h. Saturated aqueous NH_4Cl solution was added, and the mixture was extracted with three potions of ether. The extracts were combined washed with two portions of water and a portion of saturated brine, and then dried over $MgSO_4$. Concentration of the solution gave 183.4 mg of a yellow oil. Silica-gel chromatography (12 g; 10:1 then 5:1 hexane–ethyl acetate) gave 92.3 mg (0.33 mmol, 63%) of **26** and 13.4 mg (0.07 mmol, 13%) of **25**. **26**: Colorless oil; IR 1735 (s), and 1715 (s) cm^{-1}; ^1H NMR δ=0.7—3.0 (11H, m), 0.77 (3H, s), 0.88 (3H, d, J=6.5 Hz), 1.05 (3H, s), 1.25 (3H, t, J=6.5 Hz), and 4.04 (2H, q, J=6.5 Hz).

Preparation of *r*-4,*c*-4a,*c*-7,*c*-7a-Tetramethyl-4,4a,5,6,7,7a,-8,8a-octahydroindeno[5,6-*b*]furan-2-one (27). Into a flask containing 22.9 mg (0.082 mmol) of **26** were added 3 ml of methanol, 0.7 ml of water, and 60 mg of K_2CO_3. This mixture was stirred at room temperature overnight, and then acidifed with 6 M HCl. The aqueous solution was extracted with three portions of ether. The ethereal extracts were combined, washed with saturated brine, dried over $MgSO_4$, and then concentrated to give 18.3 mg of a colorless oil. A solution of the oil and a small amount of TsOH in benzene (20 ml) was placed in a flask equipped with a Soxhlet extracter containing 3A Molecular sieves and heated under reflux for 2 d. The benzene solution was washed with saturated aqueous $NaHCO_3$ and NaCl solutions, and dried over $MgSO_4$. Evaporation of the solvent gave 21.0 mg of a yellow oil. Column chromatography (3 g of silica gel; 10:1 then 5:1 hexane–ethyl acetate) gave 13.8 mg (0.059 mmol, 72%) of **27**: Colorless needles; mp 89—90°C; IR 1800 (m) and 1765 (s) cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.72 (3H, s), 0.73 (3H, s), 0.97 (3H, d, J=7 Hz, 7-Me), 1.16 (3H, d, J=6.7 Hz, 4-Me), 1.18 (1H, dd, J=13.7 and 10.4 Hz), 1.2—2.05 (4H, m), 2.28 (2H, m), 2.39 (1H, dd, J=13.7 and 6.5 Hz), 4.93 (1H, dddd, J=11.2, 6.7, 1.3 and 1 Hz), and 5.69 (1H, dd, J=2.0 and 1.3 Hz); MS (25 eV) m/z (rel intensity) 234 (M^+, 42) and 109 (100). Found: C, 76.58; H, 9.36%. Calcd for $C_{15}H_{22}O_2$: C, 76.88; H, 9.46%.

(±)-Deoxopinguisone (3). A 1.5 M solution of DIBAH in hexane (0.06 ml) was added to a solution of 13.8 mg (0.059 mmol) of the butenolide **27** in 2 ml of THF at −20°C under an argon atmosphere, and the mixture was stirred for 5 min. To the solution was added 1 M sulfuric acid and the mixture was stirred at 0°C for 30 min. The reaction mixture was diluted with water and extracted with ether. The ethereal extracts were washed with saturated aqueous $NaHCO_3$ and NaCl solutions, and dried over $MgSO_4$. Evaporation of the solvent gave 11.8 mg of a colorless oil. Column chromatography (2 g of silica gel; hexane) of the oil gave 8.9 mg (0.041 mmol, 69%) of (±)-**3**: Colorless oil; IR 2960 (s), 2885 (s), 1645 (w), 1510 (w), 1475 (m), 1460 (m), 1388 (sh), 1385 (m), 1165 (w), 1142 (m), 1045 (m), 903 (m), and 725 (s); ^1H NMR ($CDCl_3$) δ=0.73 (3H, s), 0.82 (3H, s), 0.85 (3H, d, J=6.5 Hz), 1.12 (3H, d, J=7.2), 1.3—2.7 (8H, s), 6.16 (1H, d, J=1.8 Hz), and 7.20 (1H, dd, J=1.8 and 1.0 Hz); ^1H NMR (CCl_4) δ=0.74 (3H, s), 0.83 (3H, s), 0.89 (3H, d, J=6.5 Hz), 1.12 (3H, d, J=7.2 Hz), 1.0—2.7 (8H, m), 6.02 (1H, d, J=1.8 Hz), and 7.06 (1H, dd, J=1.8 and 1.0 Hz). MS (25 eV) m/z (rel intensity) 218 (M^+, 11), 161 (7), 119 (17), and 118 (100).

7-Bezyloxy-*r*-1,c-5,*c*-6,*c*-9-tetramethylbicyclo[4.3.0]nonan-3-ones (29). Sodium hydride (50% dispersion in mineral oil, 50 mg, 1.08 mmol) was washed with dry DME under argon and then suspended in 2 ml of DME. To this suspension was added a solution of 22.9 mg (0.09 mmol) of **15**, 166.6 mg (0.45 mmol) of tetrabutylammonium iodide and 0.05 ml (0.45 mmol) of α-bromotoluene in 3 ml of DME and the mixture was heated under reflux overnight. To this solution was added saturated aqueous NH_4Cl solution, and the mixture was extraced with three portions of ether. Combined extracts were washed with water and saturated brine, and then dried over $MgSO_4$. Concentration of the solution followed by chromatography (3 g of silica gel; 20:1 hexane–ethyl acetate) of the residue (55 mg) gave 28.6 mg of the isomeric mixture of the benzyl ethers (**28**) as a colorless oil.

A mixture of 28.6 mg (0.083 mmol) of **28**, 1 ml of acetone, and 0.3 ml of 1 M HCl was allowed to stand at room temperature for 2 h. The mixture was diluted with 20 ml of ether, washed with saturated $NaHCO_3$ and NaCl solutions, and then dried over $MgSO_4$. Concentration of the solution gave 25.8 mg of a colorless oil. Chromatography of (3 g of silica gel, 20:1 then 10:1 hexane–ethyl acetate) the oil gave 22.7 mg (0.076 mmol, 91%) of **29** as the 1:1 mixture of the C-7 epimers. Each of the stereoisomers was separated by repeated HPLC (20:1 hexane–ethyl acetate). **29a**: Colorless oil: IR 1720 (s) cm^{-1}; ^1H NMR δ=0.72 (3H, s), 0.88 (3H, d, J=6.8 Hz), 1.01 (3H, s), 1.04 (3H, d, J=6.8 Hz), 1.2—2.8 (8H, m), 3.70 (1H, dd, J=6.8 and 4.5 Hz), 4.38 (1H, d, J=12.0 Hz), 4.42 (1H, d, J=12.0 Hz), and 7.18 (5H, broad s); MS (25 eV) m/z (rel intensity) 209 ($M^+-C_7H_7$, 28) and 161 (100). **29b**: Colorless oil: IR 1725 (m) cm^{-1}; ^1H NMR δ=0.88 (3H, d, J=6.0 Hz), 0.90 (3H, s), 0.91 (3H, d, J=6.0 Hz), 1.06 (3H, s), 1.2—2.5 (8H, m), 3.49 (1H, dd, J=7.7 and 3.5 Hz), 4.40 (1H, d, J=12.0 Hz), 4.42 (1H, d, J=12.0 Hz), and 7.21 (5H, broad s); MS (25 eV) m/z (rel intensity) 300 (M^+, 2), 209 ($M^+-C_7H_7$, 28) and 161 (100).

(±)-Pinguisone (2). In order to prepare 5-benzyloxy deriv-

atives of **27** (**31**), we adopted a similar procedure to that used for the synthesis of **27** from **25**. A reaction of the enolates derived from 80.2 mg (27 mmol) of **29** with ethyl iodoacetate gave 69.8 mg (0.18 mmol, 68%) of keto esters **30** as a colorless oil and 8.8 mg (11%) of the recovery. Hydrolysis of **30** (69.8 mg) followed by acid-catalyzed dehydration gave 32.0 mg (0.094 mmol, 52%) of a mixture of the butenolides (**31**). **31a**: Colorless oil; IR 1805 (s) and 1770 (s) cm^{-1}. **31b**: Colorless oil; IR 1798 (s) and 1760 (s) cm^{-1}; ^1H NMR δ=0.80 (3H, s), 0.89 (3H, s), 1.03 (3H, d, J=6.5 Hz), 1.08 (3H, d, J=6.8 Hz), 1.0—2.6 (6H, m), 3.53 (1H, dd, J=7.5 and 3.0 Hz), 4.26 (1H, d, J=12.0 Hz), 4.54 (1H, d, J=12.0 Hz), 4.68 (1H, broad dd, J=11.5 and 8.0 Hz), 5.52 (1H, dd, J=1.8 and 1 Hz), and 7.19 (5H, s).

To a solution of 12.9 mg (0.038 mmol) of **31** in 0.5 ml of CH_2Cl_2 was added 0.64 ml of 0.22 M BBr_3 solution in CH_2Cl_2 at 0 °C. After 5 min stirring at 0 °C, to the reaction mixture were added 0.5 ml of saturated aqueous $NaHCO_3$ solution and 20 ml of ether. The organic layer was separated, washed with saturated brine, and then dried over $MgSO_4$. Concentration of the solution gave 9.6 mg of a yellow oil. Chromatography (1.5 g of silica gel; 5:1 then 1:1 hexane–ethyl acetate) of the oil gave 7.9 mg (0.032 mmol, 83%) of a mixture of hydroxy lactones **32**. **32a**: Colorless oil: IR 3630 (w), 3450 (broad w), 1798 (m), 1760 (s), and 1750 (sh) cm^{-1}; ^1H NMR δ=0.75 (3H, s), 0.86 (3H, s), 0.96 (3H, d, J=7.0 Hz), 1.40 (3H, d, J=6.5 Hz), 4.16 (1H, dd, J=9.0 and 6.5 Hz), 4.83 (1H, broad dd, J=11.0 and 6.5 Hz), and 5.57 (1H, dd, J=1.5 and 1.5 Hz).

In a procedure similar to that employed for the synthesis of (±)-deoxopinguisone, **32** (7.9 mg, 0.032 mmol) was transformed into **33** (4.9 mg, 0.021 mmol, 66%) which was purified by silica-gel chromatography (1.5 g; 5:1 hexane–ethyl acetate). A mixture of 4.9 mg of **33**, 0.5 ml of DMSO, and 0.5 ml of acetic anhydride, was stirred overnight at room temperature. This reaction mixture was diluted with 20 ml of ether, washed with two portions of saturated aqueous $NaHCO_3$ and with a portion of saturated brine, and then dried over $MgSO_4$. Concentration of the solution followed by purification using a silica-gel column (2 g; 20:1 hexane–ethyl acetate) gave 3.0 mg (0.013 mmol, 62%) of a colorless oil (**3**) whose spectral characteristics are identical with those of natural pinguisone. (±)-**3**: IR 2980 (m), 1745 (s), 1460 (m), 1390 (m), 1152 (w), 1138 (w), 1075 (w), 1050 (w), 908 (w), and 832 (s) cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.82 (3H, s), 0.88 (3H, s), 1.06 (3H, d, J=6.8 Hz, 6-Me), 1.10 (3H, J=7.0 Hz, 3-Me), 1.90 (1H, dd, J=19.2 and 11.0 Hz, 5-H), 2.33 (1H, ddd, J= 18.2, 3.2, and 1.0 Hz, 7-H), 2.39 (1H, ddq, J=10.0, 8.0, and 6.8 Hz, 6-H), 2.71 (1H, dd, J=19.2 and 8.6 Hz, 5-H), 2.78 (1H, dd, J=18.2 and 2.0 Hz, 7-H), 2.80 (1H, broad, 3-H), 6.27 (1H, d, J=2.0 Hz, 2-H), and 7.31 (1H, J=2.0 and 0.8 Hz, 1-H).

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