# Preparation of Several 1,5,5,11,11-Pentamethyltricyclo-[6.2.1.0$^{2,6}$]undecane Derivatives

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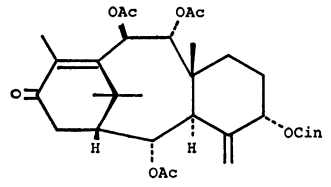
1,6-Diketone, available in eight steps from homocamphorquinone, was converted into 1,5,5,11,11-pentamethyltricyclo[6.2.1.0$^{2,6}$]undecan-7-one by treatment with potassium *t*-butoxide and then lithium dimethylcuprate, while α,α-dimethyl-γ-valerolactone, prepared in five steps from homocamphor, was converted into 1,5,5,11,11-pentamethyltricyclo[6.2.1.0$^{2,6}$]undec-2-en-4-one by treatment with diphosphorus pentoxide–methanesulfonic acid.

Taxinine (**1**), the major component isolated from the Japanese *Taxus cuspidata*,[1] has a unique carbon skeleton, named "taxane," containing an 8-membered ring as a part of the bicyclo[5.3.1]undecane system. Several attempts[2-4] to synthesize this compound have been reported, but none have succeeded.

In the course of our synthetic approach to this skeleton,[4] we were faced with the necessity to prepare a compound **2** having a 5-alkyl-1,5,11,11-tetramethyltricyclo[6.2.1.0$^{2,6}$]undecane system. This compound was thought to be derivable from a homocamphor framework by creating a 5-membered ring on it. The readily available ketone **3**, prepared by Büchi *et al.*[5] during their investigation of the synthesis of pachouli alcohol, was at first attractive, but our preliminary attempts at the conversion of **3** into **2** were unsuccessful, especially in the introduction of two alkyl groups at the C-5 position of the tricyclo[6.2.1.0$^{2,6}$]undecane system.

The present paper will describe the syntheses of two 1,5,5,11,11-pentamethyltricyclo[6.2.1.0$^{2,6}$]undecane derivatives (**26** and **39**) as possible model compounds for **2**. The synthetic efforts were mainly concentrated on the creation of a 5-membered ring with a geminate dimethyl group on the homocamphor framework.

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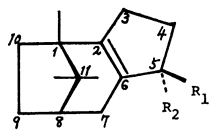
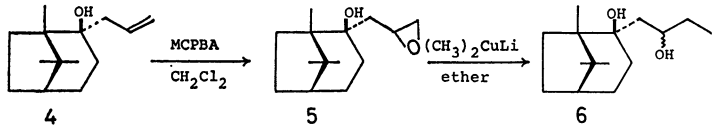



2 $R_1$=$CH_3$, $R_2$=Alkyl

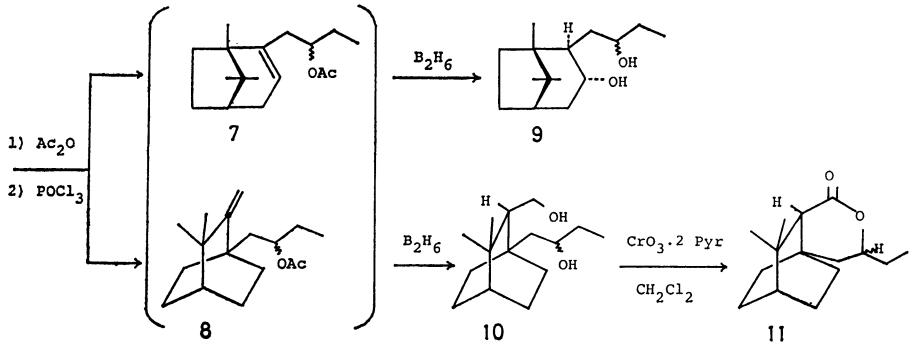
3 $R_1$=$R_2$=O

*Construction of a 5-Membered Ring Prior to the Introduction of a Methyl Group.* One of the methods most widely used to create the cyclopentane ring is an intramolecular aldol condensation of 1,4-diketones. An initial effort was directed at preparing a cyclopentenone, 1,5,11,11-tetramethyltricyclo[6.2.1.0$^{2,6}$]undec-5-en-4-one (**14**), from the 1,4-diketone **12**. The preparation of **12** from the easily avairable unsaturated alcohol **4**[5] is shown in Schemes 1 and 2.

The alcohol **4** was oxidized to the epoxy alcohol **5** by treatment with *m*-chloroperbenzoic acid. The direct dehydration of this epoxy alcohol **5** with phosphoryl chloride or thionyl chloride in pyridine gave no fruitful results; however, the introduction of a chlorine atom was recognized from the analysis of the mass spectrum. This is thought to arise from the participation of the epoxy group.[7] The trouble was overcome by opening the epoxy ring prior to the dehydration. Thus, when **5** was treated with lithium dimethylcuprate in ether, the diol **6** was obtained in 89% yield as a result of the selective opening of the epoxy ring into a secondary alcohol.[8] After the secondary hydroxyl group had been protected by acetylation, the tertiary one was dehydrated with phosphoryl chloride in pyridine to give a mixture of an unsaturated acetate **7** and a



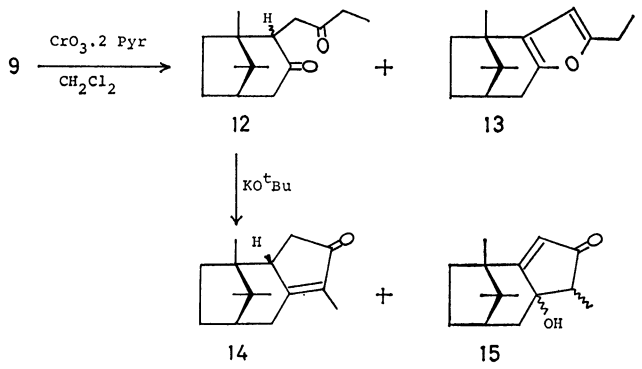

4 5 6




7 9 8 10 11

Scheme 1.

rearranged acetate **8**. The mixture, without the separation of its components, was converted into two diols, **9** and **10** (49 and 14% yields respectively from **6**), by hydroboration with diborane.[9] The structure of the rearranged diol **10** was determined by NMR spectroscopy. In the NMR spectrum of the diacetate of **10**, only two tertiary methyl signals are observed, at 0.99 and 1.04 ppm, while one –CH–OAc group and one –$CH_2$–OAc group are recognized at 4.8 and 4.1 ppm respectively. The structure was finally confirmed by the oxidation of **10** with chromium trioxide to afford a $\delta$-lactone **11** [$\nu(CCl_4)$: 1740 $cm^{-1}$; $\delta$ ($CDCl_3$): 4.0 (m, 1H) and 1.95 (s, 1H)]. The configurations at the newly formed asymmetric centers of the major diol are assigned as in **9** by considering the less-hindered-side attack of diborane.[10]



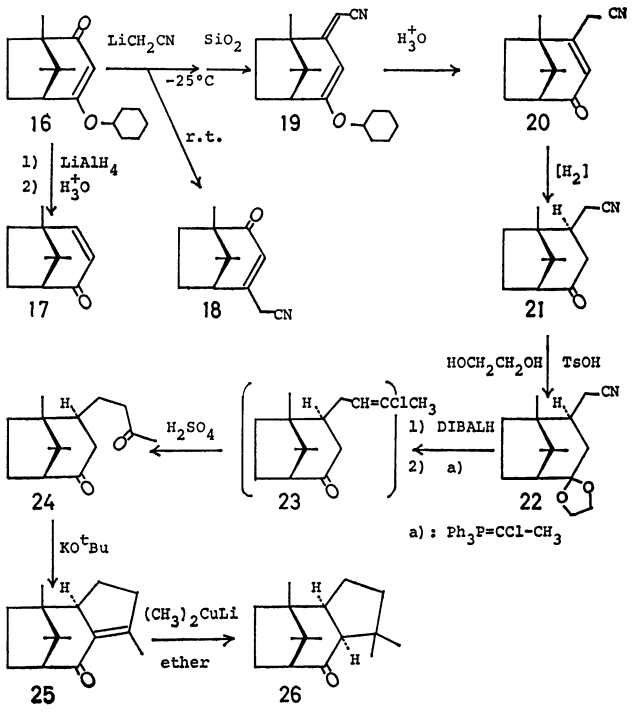

Scheme 2.

The oxidation of the major diol **9** gave the desired 1,4-diketone **12** in 72% yield, accompanied by a small amount (17%) of a furan derivative **13**. When **12** was treated with potassium *t*-butoxide in *t*-butyl alcohol at room temperature (30 min), 1,5,11,11-tetramethyl-[6.2.1.$0^{2,6}$]undec-5-en-4-one (**14**) and 6-hydroxy-1,5,11,-11-tetramethyltricyclo[6.2.1.$0^{2,6}$]undec-2-en-4-one (**15**) were obtained in 79 and 9% yields respectively. The methyl group attached to the double bond of the major product **14** was recognized at 1.59 ppm in the NMR spectrum. The structure of the minor product **15** was deduced from the presence of one secondary methyl doublet (1.08 ppm, $J$=7 Hz) and one proton singlet on the double bond (5.77 ppm), which has no allylic proton coupled to it (*cf.* **39**). The stereochemistry of C-2 in **14** was assigned as is shown by the conformational analysis of the molecule. The mechanism for the formation of **15** during the cyclization of the diketone **12** was not clarified.

Several attempts to introduce an alkyl group into the C-5 position of **14** were unsuccessful: the treatment of **14** with allyl bromide–sodium hydride gave a 3-allyl derivatives, while a protected **14**, the 3,3-butylthiomethylene derivative, did not react with allyl bromide–sodium hydride in benzene or diglyme.

Another approach to the title compound is summarized in Scheme 3. Here, a 1,6-diketone **24** was chosen as the precursor because no epimerization at C-2 was anticipated during the alkaline cyclization.

The treatment of homocamphorquinone with cyclohexanol led to the regiospecific production of an enol




Scheme 3.

ether **16** in 73% yield, $\nu$(KBr): 1650 and 1600s $cm^{-1}$. None of the other isomers was detected in the reaction product. The structure of **16** was confirmed by reduction with lithium aluminum hydride, followed by hydrolysis with hydrochloric acid, to convert it into the known unsaturated enone **17**.[11] The lithioacetonitrile, prepared[12] from acetonitrile and butyllithium, was treated with the enol ether **16** at −78 °C, after which the mixture was brought to room temperature to give a cyanomethyl enone **18** in 95% yield. The structure of **18** was determined by comparison of its spectra with those of an isomer **20** (see below). The formation of **18** resulted from the 1,4-addition of the reagent to an $\alpha,\beta$-unsaturated ketone. When the reaction was controlled at lower temperatures (−25——−30 °C), the reaction proceeded by means of the 1,2-addition of the reagent; the initial product was dehydrated during the isolation procedure (silica gel chromatography) to give **19** exclusively. The NMR spectrum of **19** shows the presence of a cyclohexyloxy group (multiplet at 4.2 ppm) and two vinylic protons (singlets at 4.53 and 5.53 ppm). A similar temperature-dependence of the 1,2- *vs.* 1,4-addition of a reagent to an $\alpha,\beta$-unsaturated ketone system has recently been reported.[13]

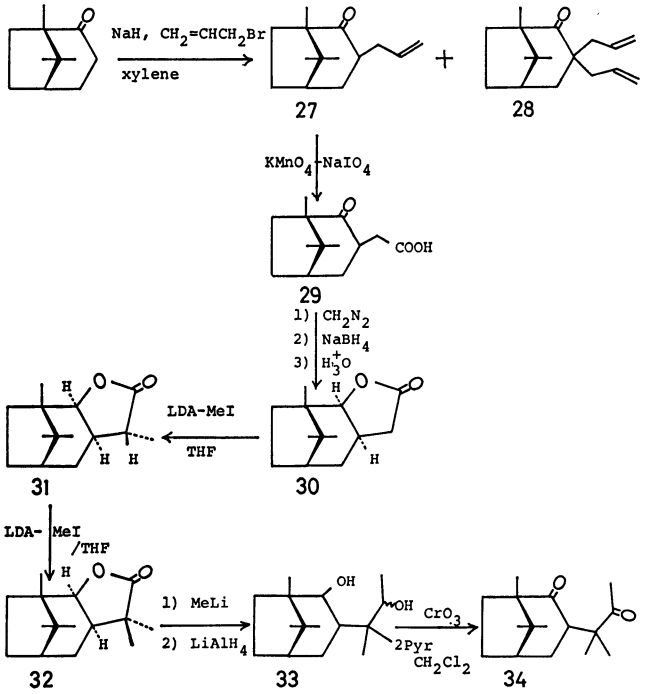
The acid hydrolysis of **19** afforded the desired cyanomethyl enone **20**. The double bond in **20** was readily hydrogenated over a palladized charcoal catalyst. The configuration of the side chain in the dihydro-compound **21** was postulated from the known reactions;[10] the hydrogen approaches **20** from the $\alpha$-side of the molecule.

After protecting the carbonyl group with ethylene glycol, the acetalized nitrile **22** (mp 83—84 °C) was reduced with diisobutyl aluminum hydride,[14] after which the intermediate imine was hydrolyzed in aqueous ammonium chloride, giving an aldehyde

[$\nu$($CCl_4$): 2700 and 1720 $cm^{-1}$; and $\delta$($CDCl_3$): 9.7 ppm (t, 1H)] in 90% yield. The treatment of the crude aldehyde with (1-chloroethylidene)triphenylphosphorane, a new reagent prepared according to the procedure of Seyferth *et al.*,[15] and the subsequent hydrolysis of the acetal group afforded a mixture of chlorovinyl ketones, **23** (a mixture of *E*- and *Z*-isomers), in 70% yield. **23** was then hydrolyzed with concentrated sulfuric acid to afford a crystalline 1,6-diketone **24**; mp 59—60 °C; $\nu$(KBr): 1705 and 1690 $cm^{-1}$.

The cyclization of **24** was effected by the use of potassium *t*-butoxide to give 1,5,11,11-tetramethyltricyclo-[6.2.1.0$^{2,6}$]undec-5-en-7-one (**25**); $\nu$($CCl_4$): 1675 and 1615 $cm^{-1}$: $\delta$($CCl_4$): 0.85, 0.90, 0.96 (each s, 3H), and 2.12 (br. s, 3H). The enone **25** was unstable, and even when it was left in an icebox under nitrogen, some unidentifiable crystalline substances resulted. **25** was, therfore, promptly converted into a stable compound, **26**; the freshly purified **25** was treated with lithium dimethylcuprate to afford the expected 1,5,5,11,11-pentamethyltricyclo[6.2.1.0$^{2,6}$]undecan-7-one (**26**) in 91% yield by the conjugate addition of methyl to an $\alpha,\beta$-unsaturated ketone.[16]

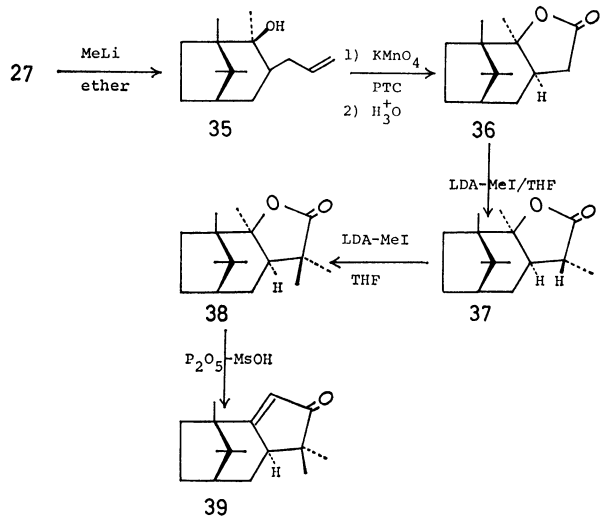
*Introduction of a Geminate Dimethyl Group Prior to the Formation of a 5-Membered Carbocyclic Ring.* Another approach to the title compound was to introduce a geminate dimethyl group before the construction of a 5-membered carbocyclic ring. $\gamma$-Lactones, such as **30** and **36**, were chosen as the starting materials.




Scheme 4.

The allyl group was introduced into the C-2 position of homocamphor according to Fried's procedure.[17] The resulting **27**, separated from the dially derivative **28** by fractional distillation, was subjected to Lemiux's oxidation, thus giving a keto acid **29**. The methyl ester of **29** was then reduced with sodium borohydride in methanol, followed by acid treatment, to afford a $\gamma$-lactone **30** in 90% yield from **27**. The stereochemistry of **30** was deduced from the facts that the coupling constant, $J$=5 Hz, between the protons on the ring junctures of the lactone ring requires a *cis* relationship of these two protons, and that the hydride in the sodium borohydride reduction of **29** attacks from the rear side of the molecule.[10] The methylation of **30** with one equivalent of lithium diisopropylamide (LDA)[18] and methyl iodide afforded $\alpha$-methyl-$\gamma$-lactone **31** in a quantitative yield. Because of the concave shape of **30**, reagents were expected to attack exclusively from the convex side of the molecule. The further treatment of **31** with excess LDA–methyl iodide gave dimethyl-$\gamma$-lactone **32**. The conversion of **32** into a diketone **34** was achieved by successive treatment with methyllithium in ether, lithium aluminum hydride in ether, and chromium trioxide–pyridine complex in dichloromethane.

Several attempts at the cyclization of **34** to cyclopentenone under alkaline (*t*-BuOK/*t*-BuOH, NaH/benzene, or NaOH/EtOH) or acid conditions ($Et_3N$·$C_6H_5COOH$/xylene or TsOH/benzene) were unsuccessful. This failure is thought to have arisen from a severe steric repulsion in the transition state as a result of changing the hybridization of the C-2 carbon from $sp^2$ to $sp^3$. These difficulties were finally overcome by using the $\gamma$-valerolactone derivative described in Scheme 5 and by cyclizing under acid conditions, where the carbon bearing the oxygen atom changes hybridization from $sp^3$ to $sp^2$.




Scheme 5.

Allylhomocamphor (**27**) was treated with methyllithium to give an alcohol **35**. The stereochemistry of **35** was deduced from the rear-side attack of the reagent. **35** was oxidized with potassium permanganate in the presence of alkyldimethylbenzylammonium chloride[19] to afford a $\gamma$-valerolactone derivative **36**. The methylation with LDA–methyl iodide proceeded much as in the case of **30**; the dimethyl derivative **38** was thus obtained in a quantitative yield.

The transformation of $\gamma$-valerolactone into cyclopentenone had been reported by only Fisini and Manjean; 7a-methylperhydro-2-benzofuranone was con-

verted into hexahydroindenone by treatment with polyphosphoric acid, but in only 25% yield, accompanied by the same amount of a rearranged product.[20] As will be shown in the Experimental section, we used diphosphorus pentoxide–methanesulfonic acid, a more effective reagent[21] than polyphosphoric acid; the yield of hexahydroindenone could thus be raised to 59%.

The treatment of **38** with diphosphorus pentoxide–methanesulfonic acid at 70 °C for 2 h afforded the expected 1,5,5,11,11-pentamethyltricyclo[6.2.1.$0^{2,6}$]-undec-2-en-4-one (**39**) in 50% yield; $\nu(CCl_4)$: 1700 and 1605 $cm^{-1}$. Besides five methyl singlets, at 0.78, 0.91, 0.98, 1.03, and 1.12 ppm, one vinylic proton is recognized at 5.51 ppm; it couples to an allylic proton with a coupling constant of 2 Hz.

In conclusion, 1,5,5,11,11-pentamethyltricyclo-[6.2.1.$0^{2,6}$]undecane derivatives have been successfully prepared through two different routes (**16**→**24**→**26** and **36**→**38**→**39**). Further investigations of the conversion of an appropriate intermediate (*e.g.*, 5α-allyl instead of 5α-methyl in **38**) to a taxane framework *via* **2** are in progress.

## Experimental

All the melting points are uncorrected. The NMR spectra were obtained with Hitachi H-60 and JEOL MH-100 spectrophotometers, using TMS as the internal standard; the chemical shifts are given in δ values. The IR spectra were taken on a Hitachi 215 grating spectrophotometer. *dl*-Camphor was used in all cases.

*Epoxidation of the Unsaturated Alcohol 4.* To a cooled mixture of **4** (4.4 g, prepared according to Büchi's procedure[5]) in 40 ml of dichloromethane there was added a solution of *m*-chloroperbenzoic acid (4.3 g) in 80 ml of dichloromethane. After having been stirred overnight at room temperature, the mixture was extracted with ether. The extract was washed with aqueous sodium hydroxide (10%), water, and brine, and was dried over anhydrous sodium sulfate. The subsequent evaporation of the solvent afforded a crystalline epoxide, **5** (4.5 g, 94%), which was recrystallized from pentane; mp 61—62 °C; $\nu(CHCl_3)$: 3500, 2950, 1260, and 1240 $cm^{-1}$; $\delta(CDCl_3)$: 0.87 (s, 3H), 0.90 (s, 3H), 1.22 (s, 3H), 2.45 (dd, 1H, $J$=4.5 and 2 Hz), 2.80 (t, 1H, $J$=4.5 Hz), and 3.17 (m, 1H). Found: C, 75.02; H, 10.63%. Calcd for $C_{14}H_{24}O_2$: C, 74.95; H, 10.78%.

*Reaction of 5 with Lithium Dimethylcuprate.*[22] To a suspension of 6.46 g (34 mmol) of copper(I) iodide in 40 ml of anhydrous ether at 0 °C, there was added 88 ml (68 mmol) of a methyllithium–ether solution over a 15-min period. After 10 more min of stirring, a solution of 1.99 g (9 mmol) of **5** in 30 ml of ether was added over a 10-min peroid, and the mixture was stirred at 0—5 °C for 20 h.[8] The whole was treated with aqueous ammonium chloride (30 ml), and the products were extracted with ether. The extract was washed with water and brine, and then dried over anhydrous sodium sulfate. The solvent was evaporated to give a crystalline diol, **6**, (1.93 g 89%), which was subsequently recrystallized from ethyl acetate to afford a pure **6**; mp 104 °C; $\nu$(KBr): 3430, 3360, 2950, 1390, 1380, 1370, 1080, 1060, and 1030 $cm^{-1}$; $\delta(CDCl_3)$: 0.85 (s, 3H), 0.95 (s, 3H), 0.95 (t, 3H, $J$=7 Hz), 1.22 (s, 3H), 2.7 (br. s, 2H), and 3.9 (m, 1H). Found: C, 74.82; H, 12.00% Calcd for $C_{15}H_{28}O_2$: C, 74.95; H, 11.74%.

*A Mixture of Two Unsaturated Acetates, 7 and 8.* A solution of 3.15 g of **6** in 15 ml of pyridine and 15 ml of acetic anhydride was allowed to react for 17 h at room temperature. A subsequent, usual work-up gave 3.68 g of a monoacetat $\nu(CCl_4)$: 3580, 3500, 2950, 1740, 1390, 1370, 1250, 1230, 1110, 1080, 1020, and 960 $cm^{-1}$; $\delta(CDCl_3)$: 0.85 (s, 3H), 0.89 (t, 3H, $J$=7 Hz), 0.93 (s, 3H), 1.20 (s, 3H), 2.07 (s, 3H), 4.8 (m, 1H), and 5.1 (m, 1H). The monoacetate (3.68 g) was placed in a sturdy flask with 80 ml of pyridine, 16 ml of phosphoryl chloride was then added, the flask was stoppered tightly, and the contents were heated on an oil bath at 95 °C for 6 h. After colling, the dark mixture was cautiously poured onto 500 g of ice and stirred briefly. The mixture was extracted with pentane, and the extract was washed with water, dried, and evaporated to yield an oil (3.05 g). By chromatography on silica gel (50 g), 2.75 g of a mixture of unsaturated acetates (**7** and **8**) were obtained; $\nu(CCl_4)$: 2950, 1730, 1630w, 1380, 1370, 1245, 1020, and 960 $cm^{-1}$. The oil showed two peaks on VPC (5% OV-1, glass column 3$\phi$× 1.7 m, 170 °C), but was used directly in the subsequent reaction without any separation of the components.

*Hydroboration of the Mixture of 7 and 8.* A solution of 2.87 g of the mixture (**7** and **8**) in 50 ml of THF was treated with diborane as usual[9] to give an oil (2.94 g). The oil was chromatographed on silica gel (three times with 20 g each). From hexane–ethyl acetate (100 : 10) eluates, 385 mg (14%) of **9** were obtained. From hexane–ethyl acetate (50 : 50), 1.28 g of **10** resulted.

**9**, mp 113.5—116 °C (from hexane); $\nu$(KBr): 3200br, 1045, 1005, 980, 970, and 955 $cm^{-1}$; $\delta$(100 MHz, $CDCl_3$): 0.89 (t, 3H, $J$=7 Hz), 0.90 (s, 3H), 1.04 (s, 3H), 3.60—3.8 (m, 5H; the addition of $D_2O$ changes the area to 3H). Found: C, 74.80; H, 11.95%. Calcd for $C_{15}H_{28}O_2$: C, 74.94; H, 11.74%.

Diacetate of **9**, bath temp 136—139 °C/0.25 mmHg (Kugelrohr dist); $\nu(CCl_4)$: 1735 and 1240 $cm^{-1}$; $\delta$(100 MHz, $CCl_4$): 0.84 (t, 3H, $J$=7 Hz), 0.99 (s, 3H), 1.04 (s, 3H), 1.90 (s, 3H), 1.96 (s, 3H), 4.1 (m, 2H), and 4.8 (m, 1H). Found: C, 70.22; H, 9.93%. Calcd for $C_{19}H_{32}O_4$: C, 70.33; H, 9.94%.

**10**, mp 131—133.5 °C (from hexane); $\nu$(KBr): 3300br, 1035, and 960 $cm^{-1}$; $\delta$(100 MHz, $CDCl_3$): 0.81 (s, 3H), 0.86 (s, 3H), 0.88 (s, 3H), 0.94 (t, 3H, $J$=7 Hz), 2.9 (br. s, 2H, -OH×2), 3.8 (m, 1H), 3.86 (br. d, 1H, $J$=6 Hz). Found: C, 74.93; H, 12.07%. Calcd for $C_{15}H_{28}O_2$: C, 74.94; H, 11.74%.

Diacetate of **10**, bath temp 127—130 °C/0.25 mmHg (Kugelrohr dist); $\nu(CCl_4)$: 1730 and 1250 $cm^{-1}$; $\delta$(100 MHz, $CCl_4$): 0.83 (s, 3H), 0.88 (t, 3H, $J$=7 Hz), 0.91 (s, 6H), 1.91 (s, 3H), 1.97 (s, 3H), 4.7 (m, 1H), and 4.82 (br. d, 1H, $J$= 6 Hz). Found: C, 70.23; H, 9.99%. Calcd for $C_{19}H_{32}O_4$: C, 70.33; H, 9.94%.

*Oxidation of 9.* To a solution of 300 mg of chromium trioxide and 0.49 ml of pyridine in 8 ml of dichloromethane[23] there was added a solution of 60 mg of **9** in 5 ml of dichloromethane in one portion. After stirring for 3 h at room temtemperature, the solution was decanted and the residue was washed with 10 ml of ether. The combined organic solutions were washed successively with 5% aqueous sodium hydroxide (3×5 ml), 5% hydrochloric acid (5 ml), 5% aqueous sodium hydrogencarbonate (5 ml), and saline, and were dried over anhydrous sodium sulfate. The subsequent evaporation of the solvent afforded an oil, which was then chromatographed on silica gel (5 g). From hexane–ethyl acetate (100 : 2), 29 mg (49%) of a crystalline **11** were obtained. Recrystallization from hexane gave a pure **11**; mp 77—78 °C; $\nu(CCl_4)$: 1740, 1200, and 1195 $cm^{-1}$; $\delta$(100 MHz, $CDCl_3$): 0.96 (t, 3H, $J$=7 Hz), 1.10 (s, 3H), 1.37 (s, 3H), 1.95 (s, 1H), and 4.0 (m, 1H). Found: C, 76.28; H, 10.35%. Calcd for $C_{15}H_{24}O_2$:

C, 76.22; H, 10.24%.

*1,5,11,11-Tetramethyltricyclo[6.2.1.$0^{2,6}$]undec-5-en-one (14).* By the same procedure as in the case of **10**, **9** (240 mg) was oxidized with 1.2 g of chromium trioxide. The crude oil was chromatographed on silica gel (5 g) to give 38 mg (17%) of a furan derivative **13** from the hexane eluates. Pure **13**, mp 65—66 °C (from pentane, at −70 °C); $\nu$(KBr): 1620, 1560, 930, and 800 cm$^{-1}$; $\delta$($CCl_4$): 0.82 (s, 3H), 0.94 (s, 3H), 1.08 (s, 3H), 1.18 (t, 3H, $J$=7 Hz), 2.53 (q, 2H, $J$=7 Hz), and 5.62 (s, 1H); Found: C, 82.43; H, 10.27%. Calcd for $C_{15}H_{22}O$: C, 82.51; H, 10.15%. Further elution with hexane–ethyl acetate (10 : 1) gave 171 mg (72%) of **12**, $\nu$($CCl_4$): 1710 and 1690 cm$^{-1}$; two peaks on VPC.

A solution of the diketone **12** (171 mg), without any separation of the components, in 5 ml of *t*-butyl alcohol was added to a stirred solution of potassium *t*-butoxide (prepared from 53 mg of potassium) in 5 ml of *t*-butyl alcohol, after which the mixture was stirred at room temperature for 30 min. Water was added, and the products were extracted with ether. The ether layer was washed with water and dried over anhydrous sodium sulfate. By flash chromatography (hexane–ethyl acetate=5 : 1), 124 mg (79%) of a cyclopentenone **14** were obtained. Bath temp: 99—101 °C/0.2 mmHg (Kugelrohr dist); mp 44—46 °C from pentane, at −70 °C); $\nu$($CCl_4$): 1700 and 1645 cm$^{-1}$; $\delta$ ($CCl_4$): 0.87 (s, 3H), 0.94 (s, 3H), 1.12 (s, 3H), and 1.59 (br. s, 3H). Found: C, 82.40; H, 10.18%. Calcd for $C_{15}H_{22}O$: C, 82.51; H, 10.15%.

When the residue was eluted with hexane–ethyl acetate (3 : 1), 16 mg (9%) of 6-hydroxy-1,5,11,11-tetramethyltricyclo[6.2.1.$0^{2,6}$]undec-2-en-4-one (**15**) were obtained in a crystalline form; mp 141—142 °C (from pentane); $\nu$($CCl_4$): 3500, 1700, and 1600 cm$^{-1}$; $\delta$($CDCl_3$): 0.74 (s, 3H), 1.00 (s, 3H), 1.08 (d, 3H, $J$=7 Hz), 1.13 (s, 3H), and 5.77 (s, 1H). Found: C, 77.16; H, 9.66%. Calcd for $C_{15}H_{22}O_2$: C, 76.88; H, 9.46%.

*Preparation of the Enol Ether 16.* In a flask fitted with a water separator there was placed a solution of 1.03 g of homocamphorquinone, 50 mg of *p*-toluenesulfonic acid, and 0.6 ml of cyclohexanol in 90 ml of toluene. The mixture was then heated to boiling, the azeotrope composed of toluene and water being removed continuously. Several hours later, the water separator was filled with a molecular sieve of the 4A type and heating was continued for 2 more days. The solution was washed with 10% aqueous sodium hydroxide (10 ml×2), water (10 ml×3), and brine. After having been dried over anhydrous sodium sulfate, the solvent was evaporated to give an oil, which crystallized when chilled in pentane (1.1 g, 73%). Recrystallization from pentane gave a pure **16**; mp 74—76 °C; $\nu$($CCl_4$): 1650, 1600, and 1210 cm$^{-1}$; $\delta$($CDCl_3$): 0.94 (s, 6H), 1.07 (s, 3H), 4.1 (br. m, 1H), and 5.14 (br. s, 1H). Found: C, 77.95; H, 9.98%. Calcd for $C_{17}H_{26}O_2$: C 77.82; H, 9.99%.

*Conversion of 16 to the Known Enone 17.* A solution of 100 mg of **16** in 10 ml of dry THF was refluxed for 1 h with $LiAlH_4$. After the excess reagents had then been decomposed by the careful addition of water, a 5-ml portion of 10% sulfuric acid was added and the mixture was stirred at room temperature for 30 min. The products were taken up in ether, and the ether extract was evaporated to give an oil, which was subsequently chromatographed on alumina (10 g). From the benzene eluates, 47 mg (75%) of the enone **17** were obtained. The NMR spectrum of **17** [$\delta$($CDCl_3$): 0.92 (s, 6H), 1.14 (s, 3H) 5.88 (dd, 1H, $J$=10 and 1.5 Hz), 6.73 (d, 1H, $J$=10 Hz) was in accord with the previously reported value.[11]

*Treatment of 16 with Lithioacetonitrile. A) At −25—−30 °C:* A solution of 5.25 g (18.4 mmol) of **16** in 25 ml of THF was added, drop by drop, over a 5-min period to 4 eq of $LiCH_2CN$ (prepared from 56 ml of a 1.6 M buthyllithium–hexane solution and 4.2 ml of acetonitrile in 30 ml of THF at −78 °C)[12] at −78 °C, after which the mixture was stirred at that temperature for 1.5 h. The temperature was then raised to −25 °C and stirring was continued for 3 h at −25 ——30 °C. A saturated ammonium chloride solution (30 ml) was added, drop by drop, while the temperature was kept below −25 °C by the occasional cooling of the flask. Water (30 ml) was added, and an organic layer was separated. The aqueous layer was extracted with ether, and the combined extracts were washed with a small portion of water and saline, and dried over anhydrous sodium sulfate. The evaporation of the solvent gave an oil, which was then chromatographed on silica gel (150 g). Elutions with 50% benzene–hexane and then with benzene gave 3.64 g (64%) of **19**.

**19**, mp 76—77 °C (from pentane); $\nu$($CCl_4$): 2210, 1610, and 1215 cm$^{-1}$; $\delta$($CCl_4$): 0.85 (s, 3H), 0.95 (s, 3H), 1.05 (s, 3H), 4.2 (m, 1H), 4.53 (s, 1H), and 5.53 (br. s, 1H). Found: C, 80.08; H, 9.62; N, 5.18%. Calcd for $C_{19}H_{27}NO$: C, 79.95; H, 9.53; N, 4.90%.

*B) At Room Temperature*: A mixture of 130 mg of **16** and 10 eq of $LiCH_2CN$ was stirred at −78 °C for 1.5 h, at −25 ——30 °C for 3 h, and finally at room temperature for 1 h. By a subsequent work-up as in A), 95 mg (95%) of **18** were obtained.

**18**, mp 67—70 °C (from ether); $\nu$($CHCl_3$): 2220 and 1670 cm$^{-1}$; $\delta$($CDCl_3$): 0.90 (s, 3H), 0.99 (s, 3H), 1.07 (s, 3H), 3.31 (d, 2H, $J$=2 Hz), and 6.00 (br. s, 1H). Found: C, 76.93; H, 8.49; N, 6.89%. Calcd for $C_{13}H_{17}NO$: C, 76.80; H, 8.42; N, 6.89%.

*Cyanomethyl Enone 20.* A solution of 5.13 g of **19** in 110 ml of methanol and 30 ml of water containing 2 ml of concd sulfuric acid was stirred at room temperature for 20 h. After the addition of solid sodium hydrogencarbonate (6.3 g), the solution was neutralized with aqueous sodium hydrogencarbonate and diluted with 80 ml of water. The **20** thus precipitated (2.18 g) was collected, and the filtrate was extracted with ethyl acetate. Evaporating the solvent afforded solids, from which a further 0.96 g of **20** was obtained by recrystallization from benzene–hexane. The total yield was 3.14 g (86%).

**20**, mp 117—118 °C (from ether); $\nu$(KBr); 2250, 1660, and 1610 cm$^{-1}$; $\delta$($CDCl_3$): 0.95 (s, 3H), 0.99 (s, 3H), 1.18 (s, 3H), 3.3 (d, 2H, $J$=2 Hz), and 6.17 (q, 1H, $J$=2 Hz). Found: C, 76.80; H, 8.44; N, 6.73%. Calcd for $C_{13}H_{17}NO$: C, 76.80; H, 8.42; N, 6.89%.

*Hydrogenation of 20.* A mixture of 2.17 g of **20** and 1 g of 10% Pd–C in 120 ml of ethanol was shaken under a hydrogen atmosphere. The hydrogen uptake ceased after 305 ml of hydrogen had been absorbed (27 h). The catalyst was removed by filtration, and the filtrate was evaporated to give an oil, which was then purified through alumina (40 g). From the benzene eluates, 2.03 g (92%) of **21** were obtained.

**21**, mp 114—115 °C (from ether): $\nu$(KBr): 2230 and 1700 cm$^{-1}$; $\delta$($CDCl_3$): 0.95 (s, 6H) and 1.10 (s, 3H). Found: C, 75.80; H, 9.27; N, 6.64%. Calcd for $C_{13}H_{19}NO$: C, 76.05; H, 9.33; N, 6.82%.

*Acetalization of 21.* A solution of 3.45 g of **21**, 100 mg of *p*-toluenesulfonic acid, and 5 ml of ethylene glycol in 120 ml of benzene was heated under reflux *via* a water separator. After 40 ml of an azeotropic distilate had been removed, a molecular sieve (4A) was placed in the water separator and heating was continued for further 20 h. The mixture was then cooled and diluted with water. The organic phase thus separated was washed with aqueous sodium hydrogen-

carbonate, water, and brine. The subsequent evaporation of the solvent gave a crude acetal (4.09 g), which was chromatographed on alumina (90 g). Elution with hexane–benzene (1 : 1) gave 3.38 g (81%) of a solid acetal, **22**; mp 83—84 °C (from pentane); $\nu$(KBr): 2240 cm$^{-1}$; $\delta$($CDCl_3$): 0.83 (s, 3H), 0.98 (s, 3H), 1.10 (s, 3H), and 4.85 (m, 4H). Found: C, 72.25; H, 9.22; N, 5.42%. Calcd for $C_{15}H_{23}NO_2$: C, 72.25; H, 9.30; N, 5.62%.

*(1-Chloroethyl)triphenylphosphonium Bromide.* According to Seyferth's procedure,[15] 30 g (0.115 mol) of triphenylphosphine and 12.9 g (0.13 mol) of 1,1-dichloroethane in 200 ml of anhydrous ether were treated at −30——40 °C by the drop-by-drop addition of a butyllithium–hexane solution (0.10 mol) under vigorous stirring. When the cooling bath was then removed and hydrogen bromide was bubbled into the flask, the orange colour was immediately lost and white solids were formed. The solids were collected on a glass filter, washed with benzene and petroleum ether, and dried *in vacuo* at 70 °C overnight. The dried product weighed 44 g.

The purification was done as follows: a 40-ml portion of water was added to 2.0 g of the crude product, and the undissolved materials were removed by filtration. The filtrate was evaporated to give solids (1.0 g), which were then recrystallized from water (6 ml) to afford 0.5 g of pure (1-chloroethyl)-triphenylphosphonium bromide. An analytical sample was obtained by repeated recrystallizations from water and by heating at 100 °C over $P_2O_5$ *in vacuo* for 24 h; mp 203—205 °C. Found: C, 59.40; H, 4.56%. Calcd for $C_{20}H_{19}PClBr$: C, 59.21; H, 4.72%.

The reagent should be dried at 80 °C *in vacuo* just before use.

*Conversion of 22 into the Diketone 24.* To a solution of 1.00 g of **22** in 4 ml of toluene, 3.5 ml (1.5 eq) of a DIBAL-H solution was added, drop by drop, at −78 °C, after which the mixture was stirred at that temperature for 1 h. Methanol (0.3 ml) was then added, the cold bath was removed, and 5 ml of a saturated ammonium chloride solution was added. The whole was stirred at room temperature for 1 h. The ether extract was evaporated to give an oil, from which an oily, acetalized aldehyde [900 mg, 90%; $\nu$($CCl_4$): 2700, 1720, and 1090 cm$^{-1}$] was isolated by chromatography on silica gel (20 g) with benzene–ethyl acetate (19 : 1). The aldehyde was used directly in the next reaction without any further purification.

To a suspension of 1.34 g (3.3 mmol) of (1-chloroethyl)-triphenylphosphonium bromide in 5 ml of THF, 2.2 ml (3.2 mmol) of a butyllithium–hexane solution was added, drop by drop, at −78 °C, after which the dark red mixture was stirred for 30 min at that temperature. A solution of 410 mg (1.6 mmol) of the acetalized aldehyde in 2 ml of THF was added, and the whole was stirred at −78 °C for 30 min, at room temperature for 30 min, and finally under reflux for 2 h. After cooling, 4 ml of 6 M hydrochloric acid was added, and the mixture was stirred for 30 min. The products were taken up in ether, and the ether extract was evaporated to give an oil which contained some triphenylphosphine oxide. The residue was heated with 10 ml of hexane, and the hexane solution was chromatographed on silica gel (20 g). The benzene eluates afforded a mixture of vinyl chloride **23** (295 mg, 71%; two peaks on VPC). The components are separable by repeated chromatography (see below).

A mixture of vinyl chloride, **23**(295 mg), was stirred overnight with 5 ml of concd sulfuric acid. The red solution was then poured onto ice, and the products were taken up in ether. The ether extract was evaporated to give an oil, which was subsequently purified by flash chromatography (hexane–ethyl acetate=5 : 3) to afford a crystalline diketone **24** (208 mg, 76%); mp 59—60.5 °C (from pentane); $\nu$(KBr): 1705br and 1690 cm$^{-1}$; $\delta$ ($CDCl_3$): 0.90 (s, 3H), 0.92 (s, 3H), 1.08 (s, 3H), and 2.12 (s, 3H). Found: C, 76.28; H, 10.27%. Calcd for $C_{15}H_{24}O_2$: C, 76.22; H, 10.23%.

*Separation of Z and E Isomers of 23.* **23** was chromatographed repeatedly on silica gel; two vinyl chlorides were thus isolated in a pure state.

(**A**): liquid, $\delta$($CDCl_3$): 0.91 (s, 6H), 1.06 (s, 3H), 2.03 (br.s, 3H), and 5.38 (br. t, 1H, $J$=7 Hz).

The acetal, prepared with ethylene glycol and *p*-toluenesulfonic acid in benzene, of (**A**): mp 51—52 °C (from pentane, at −78 °C). Found: C, 68.63; H, 9.16%. Calcd for $C_{17}H_{27}ClO_2$: C, 68.32; H, 9.10%.

(**B**): liquid; $\delta$($CDCl_3$): 0.90 (s, 3H), 0.95 (s, 3H), 1.07 (s, 3H), 2.08 (br. s, 3H), and 5.33 (br. t, 1H, $J$=7 Hz).

The acetal of (**B**): mp 66—67 °C (from pentane, at −78 °C). Found: C, 68.23; H, 9.14%. Calcd for $C_{17}H_{27}ClO_2$: C, 68.32; H, 9.10%.

*1,5,11,11-Tetramethyltricyclo[6.2.1.0$^{2,6}$]undec-5-en-7-one (25).* To a stirred portion of potassium *t*-butoxide (1 mmol) in 5 ml of *t*-butyl alcohol, 133 mg (0.5 mmol) of **24** in 2 ml of *t*-butyl alcohol was added, after which the mixture was stirred at room temperature for 30 min. The whole was then poured into ether, and the solution was well washed with water. After drying over anhydrous sodium sulfate and after the solvent had been evaporated, a crude oil (120 mg) was chromatographed on silica gel (5 g). From hexane–ethyl acetate (100 : 1), 107 mg (88%) of an enone **25** was obtained; $\nu$($CCl_4$); 1675 and 1615 cm$^{-1}$; $\delta$($CCl_4$): 0.85 (s, 3H), 0.90 (s, 3H), 0.96 (s, 3H), and 2.12 (br. s, 3H).

**25** can be purified by flash chromatography (hexane–ethyl acetate=10 : 1), but it is apt to change to an unidentified crystalline material even when standing overnight under nitrogen and in an ice-box. Therefore, freshly purified **25** was used immediately in the subsequent reaction.

*1,5,5,11,11-Pentamethyltricyclo[6.2.1.0$^{2,6}$]undecan-7-one(26).* To a stirred suspension of 190 mg (1 mmol) of copper (I) iodide in 5 ml of dry ether, 5 ml of a methyllithium–ether solution (2 mmol) was added, drop by drop, at 0 °C. A solution of 107 mg (0.5 mmol) of **25** in 5 ml of ether was then added to this almost colorless solution . The resulting yellow suspension was stirred for 30 min at 0 °C. After then being allowed to warm to room temperature (5 min), the whole was poured into 50 ml of a saturated ammonium chloride solution. The solids were removed by filtration, and the products were extracted with ether. Evaporating the solvent gave an oil, which was chromatographed on silica gel (5 g) to afford 103 mg (91%) of **26**; bath temp 79—83 °C/0.1 mmHg (Kugelrohr dist); $\nu$($CCl_4$): 1710 and 1695 cm$^{-1}$; $\delta$($CCl_4$): 0.87 (s, 3H), 0.93 (s, 3H), 1.01 (s, 3H), 1.08 (s, 3H), and 1.20 (s, 3H). Found: C, 81.45; H, 11.24%. Calcd for $C_{16}H_{26}O$: C, 81.99; H, 11.18%.

*2-Allylhomocamphor (27).* Homocamphor[24] (6.66 g) was dissolved in 70 ml of xylene, and then 40 ml of the xylene was distilled off.[17] To the solution, a 4-g portion of 50% sodium hydride (washed two times with xylene) was added, after which the mixture was refluxed for 2 h. After it had then cooled to room temperature, a 8-ml portion of allyl bromide was added and the whole was heated to 130 °C, whereupon massy precipitates resulted. Heating was continued at that temperature for 20 h. After the solution had then cooled to room temperature, water was added and the organic layer was separated. The aqueous layer was extracted with ether, and the combined organic extracts were washed with water and saline. The subsequent evaporation of the solvent gave an oil, which distilled fractionally at 3

mmHg to give 2-allylhomocamphor (**27**) (bp 75—90 °C; 5 g) and 2,2-diallylhomocamphor (**28**) (bp>110 °C).

**27**, bp 110—113 °C/8 mmHg; $\nu(CCl_4)$: 3070, 1700, 1635, 990, and 910 cm$^{-1}$; $\delta(CCl_4)$: 0.71 (s, 3H), 0.91 (s, 6H), and 4.7—6.2 (m, 3H); *m/e*: 206 ($M^+$), 191, 163, 95. Found: C, 81.38; H, 10.62%. Calcd for $C_{14}H_{22}O$: C, 81.49; H, 10.74%.

**28**, bp 113—116 °C/3 mmHg; $\nu(CCl_4)$: 3070, 1695sh, 1685, 1630, 985, and 910 cm$^{-1}$; $\delta(CCl_4)$: 0.78 (s, 3H), 0.93 (s, 6H), and 4.7—6.2 (m, 6H). *m/e*: 246 ($M^+$), 231, 95.

*2-(Carboxymethyl)homocamphor (29).* 2-Allylhomocamphor (**27**, 4.1 g) in 500 ml of *t*-butyl alcohol was mixed with a solution of 24 g of $NaIO_4$ and 100 mg of $KMnO_4$ in 1 liter of water. To the mixture there was then added 40 ml of 5% aqueous potassium carbonate, and the whole was stirred at room temperature for 2 d.[25] The products were taken up in ether, and the acidic materials were extracted with a 5% aqueous sodium hydroxide solution to give a crystalline **29** (4.4 g, 100%).

**29**, mp 94—94.5 °C (from pentane); $\nu$(KBr): 3300—2400 and 1695br cm$^{-1}$. Found: C, 69.39; H, 8.85%. Calcd for $C_{13}H_{20}O_3$: C, 69.61; H, 8.99%.

*γ-Lactone 30.* **29** (1.0 g) was converted into its methyl ester by treating it with ethereal diazomethane. After evaporating off the ether, a residual oil (1.07 g) was dissolved in 20 ml of methanol and was treated with 400 mg of $NaBH_4$ at 0 °C. After 2 h, a further 200 mg of $NaBH_4$ was added and stirring was continued for another 2 h. Concd hydrochloric acid (2 ml) was then added, drop by drop, and the whole was stirred for 10 min. After it had then been concentrated to a small volume, the products were extracted with ether. The extract was evaporated to give a crystalline oil (918 mg), from which 772 mg (89%) of γ-lactone **30** was collected.

**30**, mp 85—86 °C (from pentane); $\nu$(KBr): 1755sh, 1735, and 1410 cm$^{-1}$; $\delta(CDCl_3)$: 0.89 (s, 3H), 1.00 (s, 3H), 1.10 (s, 3H), and 4.08 (d, 1H, $J$=5.5 Hz). Found: C, 74.95; H, 9.57%. Calcd for $C_{13}H_{20}O_2$: C, 74.96; H, 9.68%.

*α-Methyl-γ-lactone 31.* To a mixture of 5 ml of dry THF and 3.4 ml of a butyllithium–hexane solution (5.6 mmol) there was added 0.8 ml (5.7 mmol) of diisopropylamine (freshly distilled over NaH) at 0 °C, after which the mixture was stirred at that temperature for 45 min.[18] The whole was then cooled to −78 °C, and 1.03 g (5 mmol) of **30** in 10 ml of THF was added, drop by drop, during a 15-min period. Some excess methyl iodide (1 ml) was added all at once, and the mixture was stirred for 15 min. A saturated ammonium chloride solution (5 ml) was added to the mixture, and the products were taken up in ether. The ether extract was evaporated to give a crystalline residue (1.12 g). Recrystallization from pentane gave α-methyl-γ-lactone **31** (1.07 g, 97%); mp 116—117 °C (sublimable); $\nu$(KBr): 1750 cm$^{-1}$; $\delta(CDCl_3)$: 0.87 (s, 3H), 0.99 (s, 3H), 1.10 (s, 3H), 1.27 (d, 3H, $J$=7.5 Hz), and 4.17 (d, 1H, $J$=5.5 Hz). Found: C, 75.43; H, 9.92%. Calcd for $C_{14}H_{22}O_2$: C, 75.67; H, 9.97%.

*Dimethyl-γ-lactone 32.* To lithium diisopropylamide (5.6 mmol) prepared as above, 972 mg (4.4 mmol) of **31** in 10 ml of THF was added, drop by drop, at −78 °C; the mixture was then stirred at that tempreature for 15 min. After 0.5 ml of HMPA had then been added, the whole was warmed to room temperature and 1 ml of methyl iodide was added. After 30 min stirring, 5 ml of a saturated ammonium chloride solution was added and the products were extracted with ether. The ether was evaporated to give a crystalline oil (1.01 g). Crystallization from pentane gave 909 mg (88%) of the dimethyl-γ-lactone, **32**, mp 106—107 °C; $\nu$(KBr): 1755 cm$^{-1}$; $\delta(CDCl_3)$: 0.88 (s, 3H), 0.98 (s, 3H), 1.10 (s, 3H), 1.16 (s, 3H), 1.27 (s, 3H), and 4.13 (d, 1H, $J$=5.5 Hz). Found: C, 75.94; H, 10.17%. Calcd for $C_{15}H_{24}O_2$: C, 76.22; H, 10.23%.

*Diol 33.* To a solution of 845 mg of **32** in 20 ml of dry ether, an excess methyllithium–ether solution was added at 0 °C; the mixture was then stirred unitl **32** disappeared (VPC analysis). A large excess (1 g) of $LiAlH_4$ was added to the mixture, and the whole was refluxed for 1.5 h. After cooling to room temperature, the excess $LiAlH_4$ was carefully decomposed by the addition of ethyl acetate, and then an aqueous ammonium chloride solution. The ether extract, when evaporated, gave crystals (905 mg, 100%). The crystals showed two spots on TLC, and two recrystallizations from pentane afforded one isomer; mp 94—95 °C; $\nu$(KBr): 3300br, 1110, and 1075 cm$^{-1}$; $\delta(CDCl_3)$: 0.82 (s, 3H), 0.89 (s, 3H), 0.98 (s, 6H), 1.14 (s, 3H), 1.17 (d, 3H, $J$=7 Hz), 3.60 (br. d. 1H $J$=4 Hz), and 3.82 (q, 1H, $J$=7 Hz). Found: C, 75.53; H, 11.91%. Calcd for $C_{16}H_{30}O_2$: C, 75.53; H, 11.88%.

*Diketone 34.* To a stirred solution of 2.4 g (24 mmol) of chromiun trioxide and 3.9 g (48 mmol) of pyridine in 60 ml of dichloromethane, 490 mg (1.9 mmol) of **33** in 10 ml of dichloromethane were added all at once, after which the mixture was stirred at room temperature for 15 min. The black materials were removed by filtration, and the filtrate was evaporated to give a brown residue. The residue was heated under reflux with 50 ml of pentane, and the undissolved material was removed by filtration. The filtrate was then evaporated to give colorless crystals (415 mg). Recrystallization from pentane afforded 280 mg of a diketone **34**. The mother liquor was chromatographed on silica gel (5 g, hexane–benzene=1 : 1) to give a further 78 mg of **34**.

**34**, mp 114—115 °C; $\nu$(KBr): 1690sh and 1685 cm$^{-1}$: $\delta(CDCl_3)$: 0.73 (s, 3H), 0.88 (s, 3H), 0.92 (s, 3H), 1.15 (s, 3H), and 2.18 (s, 3H). Found: C, 76.59; H, 10.40%. Calcd for $C_{16}H_{26}O_2$: C, 76.75; H, 10.46%.

*γ-Valerolactone 36.* To a cooled solution (0 °C) of 3.82 g of **27** in 60 ml of dry ether, 20 ml of a 5% methyllithium–ether solution was added, drop by drop, after which the whole was stirred at room temperature for 1 h. An aqueous ammonium chloride solution was then added, and the products were taken up in ether. Evaporating the solvent gave a crude **35** (3.95 g); $\delta(CCl_4)$: methyl signals at 0.82, 0.92, 1.12, and 1.15.

To a stirred solution of 3.16 g of $KMnO_4$ in 12 ml of water and 6 ml of benzene containing 75 mg of $R(CH_3)_2C_6H_5CH_2N^+Cl^-$, 1.06 g of the above alcohol **35** was added, drop by drop, during a 10-min period. The temperature of the mixture was kept at 35—40 °C during addition. The mixture was then stirred at that temperature for 1 h,[19] and the precipitates were removed by filtration. The products were divided into a neutral part (0.81 g) and an acid part; the former was chromatographed on silica gel (10 g) to give a pure lactone **36** (0.48 g, 45%) in a crystalline form.

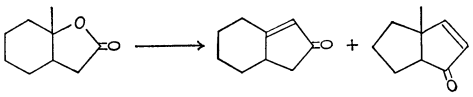
**36**, mp 95—97 °C (from pentane, in a sealed tube); $\nu$(KBr): 1750 and 930 cm$^{-1}$; $\delta(CCl_4)$: 0.92 (s, 3H), 1.02 (s, 3H), 1.08 (s, 3H), 1.34 (s, 3H), 2.0 (d, 1H, $J$=17 Hz), 2.8 (dd, 1H, $J$=17 and 7 Hz). Found: C, 75.45; H, 9.70%. Calcd for $C_{14}H_{22}O_2$: C, 75.63; H, 9.97%.

*α-Methyl-γ-valerolactone 37.* To a stirred lithium diisopropylamide (0.65 mmol) in THF, 135 mg (0.61 mmol) of **36** in 15 ml of THF were added, drop by drop. After 15 min, 0.2 ml of methyl iodide was added all at once and stirring was continued for a further 15 min. A saturated ammonium chloride solution was added, and the products were taken up in ether to give crystalline **37** (143 mg, 100%).

**37**, mp 72—74 °C (from pentane, sublimable); $\nu$(KBr): 1750 cm$^{-1}$; $\delta(CCl_4)$: 0.92 (s, 3H), 0.98 (s, 3H), 1.08 (s, 3H),

TABLE 1. REACTIONS OF 7a-METHYLPERHYDRO-2-BENZOFURANONE WITH $P_2O_5$–METHANESULFONIC ACID

| Lactone(vi) | $P_2O_5$–MsOH | $t$/°C | h | Yield/% | | Ratio vii/viii | Remarks |
|---|---|---|---|---|---|---|---|
| mg | g | | | vii | viii | | |
| 500 | 5 | 80 | 1 | 59 | 34 | 1.7 | |
| 503 | 5 | 50 | 24 | 56 | 23 | 2.4 | Some recovery |
| 510 | 5 | 30 | 143 | 52 | 8 | 6.5 | 12% recovery |
| | PPA[19] | 70—80 | 3 | 25 | 25 | 1.0 | |
| | PPA[19] | 120 | vacuum dist | 5 | 20 | 0.3 | 20% indane |



vi vii viii

1.42 (d, 3H, $J$=7 Hz), 1.43 (s, 3H), and 2.32 (br. q, 1H, $J$= 7 Hz). Found: C, 76.18; H, 10.25%. Calcd for $C_{15}H_{24}O_2$: C, 76.22; H, 10.24%.

*Dimethyl-γ-valerolactone 38.* α-Methyl-γ-valerolactone **37** was converted into the dimethyl derivative, **38**, in a quantitative yield when treated with excess lithium diisopropylamide and methyl iodide in the presence of HMPA.

**38**, mp 99—100 °C (from pentane); $\nu$(KBr): 1740 $cm^{-1}$; $\delta$($CCl_4$): 0.88 (s, 3H), 0.90 (s, 3H), 1.08 (s, 3H), 1.23 (s, 3H), 1.46 (s, 3H), and 1.56 (s, 3H). Found: C, 76.71; H, 10.51%. Calcd for $C_{16}H_{26}O_2$: C, 76.75; H, 10.47%.

*$P_2O_5$–Methanesulfonic Acid Treatment of 7a-Methylperhydro-2-benzofuranone (vi).* General procedure: The lactone (vi) was heated at a given temperature with 10 parts (weight) of a $P_2O_5$–methanesulfonic acid (1 : 10) solution.[21] The dark red solution was then poured into ice water, and the products were taken up in ether. The ether extract was washed with water and saline, and dried over anhydrous sodium sulfate. In every case, only two products (vii) and (viii) were recognized on VPC. The products were separated by column chromatography on silica gel. The results are shown on Table 1.

*1,5,5,11,11-Pentamethyltricyclo[6.2.1.0$^{2,6}$]undec-2-en-4-one (39)* To a stirred solution of 10 g of $P_2O_5$–methanesulfonic acid, there was added 395 mg of **38**, after which the mixture was heated at 70 °C for 2 h. After cooling, the red solution was poured into water (50 ml) and extracted with chloroform. The chloroform layer was washed with water, aqueous sodium hydrogencarbonate, and saline and dried over anhydrous sodium sulfate. The subsequent evaporation of the solvent gave an oil (380 mg), which was then chromatographed on silica gel (20 g). The elution with chloroform afforded 195 mg (50%) of a cyclopentenone **39** as an oil.

**39**, bath temp 83—86.5 °C/0.05 mmHg (Kugelrohr dist); mp 38—40 °C (from pentane, −78 °C); $\nu$($CCl_4$): 1700 and 1605 $cm^{-1}$; $\delta$($CCl_4$; the $\Delta$ values show the pseudocontact shift upon the addition of 0.05 eq of Eu-FOD): 0.78 (s, 3H, $\Delta$ 0.17), 0.91 (s, 3H, $\Delta$ 0.52), 0.98 (s, 3H, $\Delta$ 0.07), 1.03 (s, 3H, $\Delta$0.51), 1.12 (s, 3H, $\Delta$0.11), 2.58 (ddd, 1H, $J$=2, 9, and 11.5 Hz, $\Delta$ 0.38), and 5.51 (d, 1H, $J$=2 Hz, $\Delta$ 0.97). Found: C, 82.68; H, 10.49%. Calcd for $C_{16}H_{24}O$: C, 82.70; H, 10.41%.

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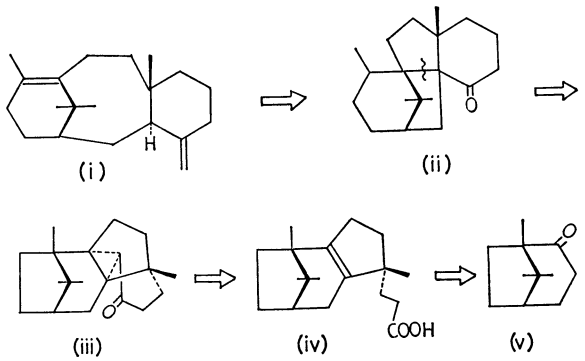


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