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7,7-Dimethyltricyclo[3.3.0.$0^{2,8}$]octan-3-ones as Synthetic Intermediates. I. Preparation and Cyclopropane Ring Opening of 7,7-Dimethyl-5-(2-propenyl)tricyclo[3.3.0.$0^{2,8}$]octan-3-one[1]

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7,7-Dimethyl-5-(2-propenyl)tricyclo[3.3.0.$0^{2,8}$]octan-3-one (**4**) was prepared from 4,4-dimethyl-2-cyclopentenone in several steps. The Birch reduction of **4** resulted in exclusive formation of a bicyclo[3.3.0]octanone (**14**) through C_2–C_8 bond cleavage, while its substitutional reactions yielded bicyclo[3.2.1]octanones (**15**) through C_1–C_2 bond cleavage as major products.

Keywords——cyclopropane ring opening; tricyclo[3.3.0.$0^{2,8}$]octane; bicyclo[3.3.0]octane; bicyclo[3.2.1]octane; Birch reduction; *S*N2 reaction

A large number of natural products containing more than one 5-membered ring (polyquinanes) have been isolated in recent times. Some of them are of much interest to organic chemists because of their biological activities, *e.g.*, quadrone,[2] pentalenolactones,[3] coriolin,[4] subergorgic acid[5] and so on. In connection with synthesis of these natural products, many versatile methods for construction of the polyquinane ring system have been developed to date.[6,7] We have focussed on the tricyclo[3.3.0.$0^{2,8}$]octane moiety (**1**) as a key intermediate for the following reasons:

a) It is readily obtainable by cyclopropanation of appropriate cyclopentene acetic acids or by photochemical oxadi-π-methane rearrangement of some bicyclo[2.2.2]octenones.

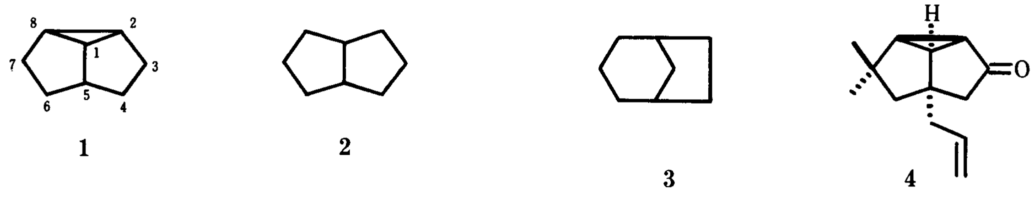
b) The cyclopropane ring cleavage at the C_2–C_8 bond in **1** affords a bicyclo[3.3.0]octane (**2**), which may serve as a key intermediate for a number of polyquinane natural products such as coriolin, silphinene, and pentalenene.

c) On the other hand, the cleavage at the C_1–C_2 bond leads to a bicyclo[3.2.1]octane (**3**), which is a potential synthon for quadrone, cedrene, gymnomitrol, *etc.*

In this paper, we describe the preparation of 7,7-dimethyl-5-(2-propenyl)tricyclo-[3.3.0.$0^{2,8}$]octan-3-one (**4**) and its ring-opening reactions.

Preparation of 7,7-Dimethyl-5-(2-propenyl)tricyclo[3.3.0.$0^{2,8}$]octan-3-one (4)

In general, tricyclo[3.3.0.$0^{2,8}$]octan-3-one compounds can be produced by oxadi-π-methane rearrangement of bicyclo[2.2.2]octenone derivatives[8] or intramolecular cyclopro-



1 2 3 4

Chart 1

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panation of 2-(3-diazo-2-oxopropyl)cyclopentene derivatives.[9] Since the former method seems to be unsuitable for the present purpose, the title compound was prepared by the latter method as follows.

Reaction of 4,4-dimethyl-2-cyclopentenone (**5**)[10] with allylmagnesium bromide in ether at 0 °C afforded quantitatively the 1,2-adduct (**6**), which, without purification, was subjected to chromic anhydride oxidation[11] affording the enone (**7**) in 80% yield. Lithium aluminum hydride reduction of **7** and treatment of the allylic alcohol (**8**) so obtained (97% yield) with a large excess of ethyl vinyl ether in the presence of mercuric acetate at an elevated temperature gave the labile aldehyde (**9**). Immediately, the crude product was oxidized with the Jones reagent to the carboxylic acid (**10**). The maximum yield of **10** from **8** was 43% and sometimes the yield fell below 20%. Therefore, an alternative route to **10** was examined. According to the known procedure,[12] the alcohol was reacted with triethyl orthoacetate using hydroquinone as a catalyst at 180 °C. After alkaline hydrolysis of the whole products, the desired carboxylic acid (**10**) was obtained in a reproducible, moderate yield (57%). The latter route is also satisfactory for large-scale operation.

The carboxylic acid (**10**) was transformed into the diazoketone (**12**) *via* the acid chloride (**11**) in the usual manner. Upon exposure of **12** to anhydrous cupric sulfate in boiling cyclohexane, cyclopropanation smoothly took place and the expected product (**4**) was isolated in 65% yield from **10**. Its structural assignment was based on spectral considerations. The mass spectrum (MS) and elementary analysis revealed that the product possessed the formula $C_{13}H_{18}O$, and its infrared (IR) spectrum showed a carbonyl band absorption at 1725 cm^{-1} due to the 5-membered ring ketone adjacent to the cyclopropane ring and bands at 1640, 995 and 920 cm^{-1} characteristic of a terminal olefin. The proton nuclear magnetic resonance (^{1}H-NMR) spectrum exhibited three olefinic proton multiplets at 4.8—5.2 (2H), and 5.4—6.0 ppm (1H) showing the presence of a non-substituted terminal C–C double bond functionality. Exclusive formation of **4** rather than its structural isomer (**13**) should be attributable to a difference of electron-donating abilities between two C–C double bonds on the starting material (**12**).

Cyclopropane Ring Opening of 7,7-Dimethyl-5-(2-propenyl)tricyclo[3.3.0.0^{2,8}]octan-3-one (4)

There have been many reports concerning cyclopropane ring-cleavage reactions of various kinds of tricyclo[3.3.0.0^{2,8}]octan-3-ones.[8] In all cases, the external bond (C_2–C_8

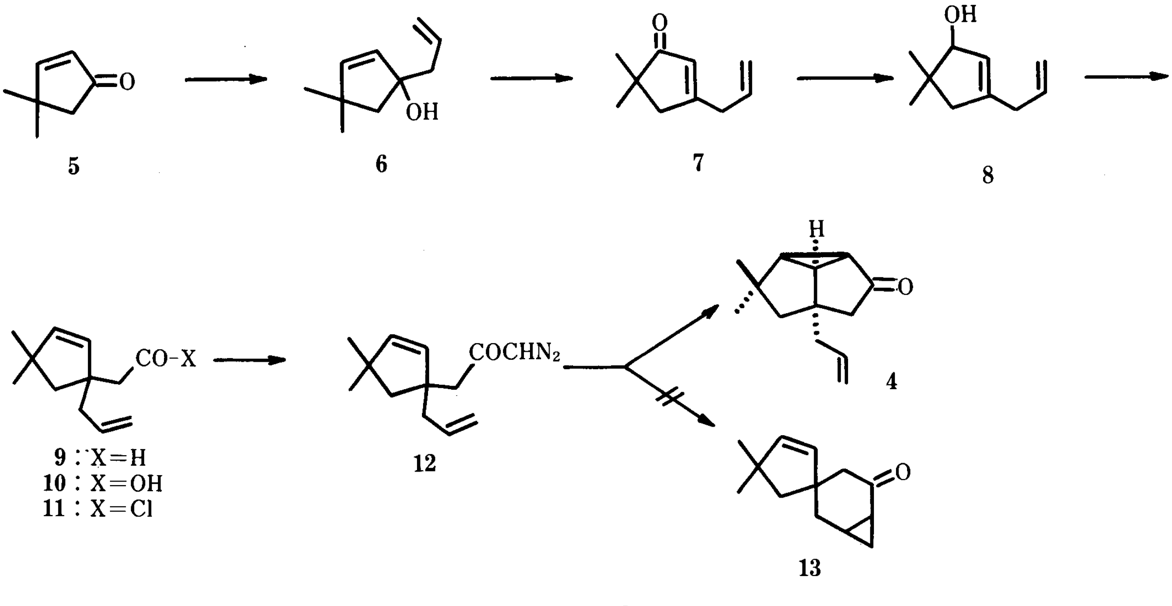

Chart 2

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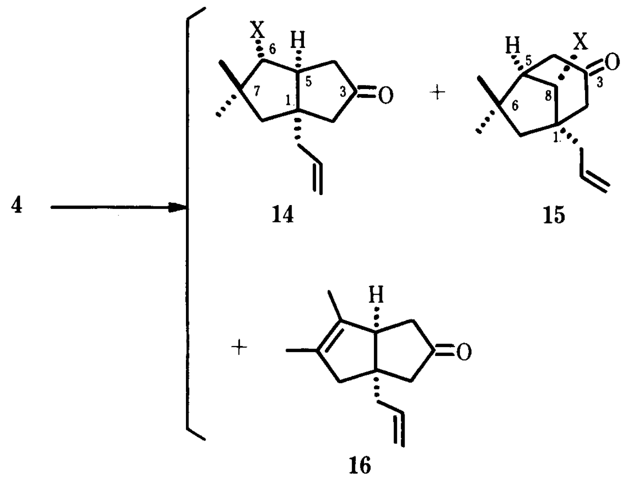
bond) was found to cleave more easily than the internal one (C_1–C_2 bond) in reductive or substitutional reactions, leading to the exclusive or predominant formation of bicyclo[3.3.0]octan-3-one derivatives. This phenomenon was well interpreted in terms of maximum overlapping theory.[13] Namely, in the rigid ring system, the C_2–C_8 σ-bond is well overlapped with the adjacent C=O π-orbital, while such overlap is not observed between the C_1–C_2 bond and the C=O. However, the tricyclooctanone (**4**) bearing *gem*-dimethyl groups at the C-7 position is expected to give the C_1–C_2 bond cleaved product with relative ease through *S*N2-like reactions, since steric hindrance would prevent a backside attack of nucleophiles at the C-8 center.

Cleavage of the cyclopropane ring of **4** was examined under various conditions, and the results are summarized in Table I. The Birch reduction of **4** afforded the bicyclo[3.3.0]octanone (**14**: X=H) exclusively and in other cases moderate amounts of the bicyclo[3.2.1]octanone (**15**) were obtained along with **14** and **16**. In particular, when the nucleophile (X:) was halogen, the C_1–C_2 bond-cleaved product (**15**) was predominant (see runs 7—9). Structural assignment of the products was based on spectral considerations and chemical behavior. Compound **15** showed a carbonyl band at 1710—1720 cm^{-1} characteristic



$$14 + 15(X{=}Br\ or\ I) \longrightarrow 4$$

Chart 3

Table I. Cyclopropane Ring Opening of **4**

Run	Reaction conditions	X	Yield (%)[a]		
			14	**15**	**16**
1	Li/NH_3 −78 °C→−33 °C	H	60		
2	conc. H_2SO_4–MeOH r.t.	OMe	19	60	
3	1) HCOOH 90 °C 2) OH^-	OH	22	25	16
4	1) *p*-TsOH–HCOOH 80 °C 2) OH^-	OH	20	29	18
5	1) conc. H_2SO_4–HCOOH 90 °C 2) OH^-	OH	20	43	16
6	*p*-TsOH–PhCOOH/C_6H_6 ref. 1	OTs	9	43	
7	TMSCl–NaI/CH_2Cl_2 r.t.	I	8[b]	82[b]	
8	TMSCl–LiBr/CH_2Cl_2 r.t.	Br	6[b]	85[b]	
9	AcOMs–Me_4NBr/CH_3CN r.t.	Br		70	

a) Isolated yield. *b*) The ratio was calculated by GLC analysis. r.t., room temperature.

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of a 6-membered ring ketone and **14** exhibited a 5-membered ring ketone band at 1740 cm^{-1} in the IR spectra. MS and ^{1}H-NMR spectra, and other evidence were consistent with the proposed structures. Such reactions are known to proceed *via* a *S*N2-like mode[14)] and a mixture of **14** (X = Br or I) and **15** (X = Br or I) was converted exclusively into the starting material (**4**) on treatment with 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) in benzene. Therefore, the stereochemistry of **14** and **15** was confirmed as shown in Chart 3. On the other hand, the third product (**16**) possessed the formula $C_{13}H_{18}O$, and its ^{1}H-NMR spectrum exhibited a singlet (6H) at 1.66 ppm due to two methyl groups attached to a vinyl carbon. Since a prolonged reaction time was found to increase the yield of **16**, the olefin (**16**) should be obtained *via* the Wagner–Meerwein type rearrangement of the C_2–C_8 bond-cleaved product initially formed. In turn, the exclusive formation of **14** (X = H) by Birch reduction is easily rationalized as a result of the C_2–C_8 bond cleavage prior to the substitution of proton.

This paper presents the first example of predominant cleavage of the C_1–C_2 bond in tricyclo[3.3.0.0^{2,8}]octan-3-one compounds.

Experimental

The IR spectra were recorded with a Hitachi 260-10 spectrometer. ^{1}H-NMR spectra were measured with a Hitachi R-20 (60 MHz), R-22 (90 MHz) or a JNM-FX 90Q (90 MHz), and the chemical shifts are given on a δ (ppm) scale with tetramethylsilane as an internal standard. The ultraviolet (UV) spectrum was recorded with a Hitachi 124 spectrometer. The MS and high-resolution MS (High MS) were obtained with a Shimadzu QP-1000 or a JEOL JMS-D300 mass spectrometer. Gas-liquid chromatography (GLC) was run on a Shimadzu GC-8A gas chromatograph with a flame ionization detector using a glass column (1 m). High-pressure liquid chromatography (HPLC) was carried out on a Waters instrument. For column chromatography, Silica gel 60 (E. Merck AG, Darmstadt) was used. After drying over anhydrous sodium sulfate or magnesium sulfate, all organic extracts were concentrated under reduced pressure.

5,5-Dimethyl-3-(2-propenyl)-2-cyclopentenone (7)——A solution of **5** (17.5 g, 0.16 mol) in dry ether (30 ml) was added dropwise to a stirred solution of allylmagnesium bromide, prepared from Mg (8.9 g) and allyl bromide (37.7 g), in dry ether (80 ml) under ice cooling. After the addition, the reaction mixture was stirred at room temperature for another 3 h and then was poured into ice water (300 ml). The resulting mixture was acidified with 2 N HCl and the organic layer was separated. The aqueous layer was extracted with ether (100 ml × 3) and the combined ethereal layer was washed with saturated $NaHCO_3$ and brine. The organic extract containing 4,4-dimethyl-1-(2-propenyl)-2-cyclopentenol (**6**) was used for the next step without purification. Concentration of a small amount of the above extract left **6** as a colorless oil. IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3590, 3460, 1640, 995, 920. ^{1}H-NMR (CCl_4) δ: 1.06 (3H, s, 4-CH_3), 1.16 (3H, s, 4-CH_3), 1.70 (1H, d, J = 14 Hz, 5-H), 1.75 (1H, d, J = 14 Hz, 5-H), 2.31 (2H, br d, J = 8 Hz, 1-CH_2), 2.6—2.9 (1H, br, OH), 4.7—5.2 (2H, m, $CH=C\underline{H}_2$), 5.39 (1H, br d, J = 5.5 Hz, 3-H), 5.52 (1H, br d, J = 5.5 Hz, 2-H), 5.4—6.2 (1H, m, $C\underline{H}=CH_2$).

A solution of CrO_3 (23.8 g, 0.24 mol) in 5% H_2SO_4 (238 ml) was added dropwise to the above ethereal solution with vigorous stirring under ice cooling over a period of 1 h. Stirring was continued for another 2 h at room temperature and the organic layer was separated. The aqueous layer was extracted with ether (100 ml × 2) and the combined organic layer was washed continuously with brine, saturated $NaHCO_3$, and brine. Evaporation of the solvent left an oily residue, which was distilled under reduced pressure to give **7** (19.0 g, 80% from **5**) as a colorless oil, bp 60—80 °C (8 mmHg). *Anal.* Calcd for $C_{10}H_{14}O$: C, 79.95; H, 9.39. Found: C, 79.69; H, 9.63. IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3080, 1705, 1640, 1620, 990, 920. ^{1}H-NMR (CCl_4) δ: 1.04 (6H, s, 5-CH_3 × 2), 2.40 (2H, m, 4-H), 3.07 (2H, br d, J = 7 Hz, 3-CH_2), 4.8—5.3 (2H, m, $CH=C\underline{H}_2$), 5.5—6.2 (2H, m, $C\underline{H}=CH_2$ and 2-H). MS m/z (%): 150 (M$^+$, 11.9), 58 (100). UV λ_{max}^{EtOH} nm (log ε): 228 (4.19).

5,5-Dimethyl-3-(2-propenyl)-2-cyclopentenol (8)——$LiAlH_4$ (2.1 g, 0.060 mol) was added portionwise to a stirred solution of **7** (16.6 g, 0.11 mol) in dry ether (150 ml) under ice cooling over a period of 20 min. The stirring was further continued for 2 h under cooling. The excess reagent and the complex of the product were decomposed by the addition of saturated potassium sodium tartrate aqueous solution. The precipitate formed was filtered off and the filtrate was dried. Evaporation of the solvent gave **8** (16.3 g, 97%) as a colorless oil. IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3610, 3360, 3090, 1640, 990, 915. ^{1}H-NMR (CCl_4) δ: 1.00 (3H, s, 5-CH_3), 1.03 (3H, s, 5-CH_3), 2.01 (1H, d, J = 18 Hz, 4-H), 2.14 (1H, d, J = 18 Hz, 4-H), 2.76 (2H, br d, J = 7 Hz, 3-CH_2), 4.00 (1H, br, 1-H), 4.12 (1H, br s, OH), 4.8—5.2 (2H, m, $CH=C\underline{H}_2$), 5.3—5.5 (1H, m, 2-H), 5.5—6.0 (1H, m, $C\underline{H}=CH_2$). MS m/z (%): 152 (M$^+$, 3.0), 55 (100). High MS Calcd for $C_{10}H_{16}O$: 152.1199. Found: 152.1188.

4,4-Dimethyl-1-(2-propenyl)cyclopent-2-ene-1-acetic Acid (10)——a) By Use of the Claisen Rearrangement: A mixture of **8** (2.26 g, 14.8 mmol), ethyl vinyl ether (50 ml), and Hg (OAc)$_2$ (0.6 g) was heated under reflux for 4 h.

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Glacial acetic acid (0.15 ml) was then added and the whole was stirred at room temperature for 1 h. Dilution of the reaction mixture with ether was followed by washing with 5% NaOH and brine. Evaporation of the solvent afforded an oily residue, which was taken up in dry dioxane (20 ml). The solution was heated in a sealed tube at 200 °C for 93 h. Evaporation of the dioxane left the crude aldehyde (**9**) as an oil. IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3080, 3045, 2730, 1720, 1635, 990, 915. ^{1}H-NMR (CCl_4) δ: 1.10 (6H, s, 4-CH_3), 1.70 (2H, s, 5-H), 2.23 (2H, d, $J=6$ Hz, 1-$C\underline{H}_2CH=CH_2$), 2.40 (2H, d, $J=3$ Hz, 1-$C\underline{H}_2CHO$), 4.7—5.2 (2H, m, $CH=C\underline{H}_2$), 5.44 (2H, s, 2- and 3-H), 5.2—6.0 (1H, m, $C\underline{H}=CH_2$), 9.62 (1H, t, $J=3$ Hz, CHO). Without purification the aldehyde was dissolved in purified acetone (10 ml) and 8 N Jones reagent was added dropwise to the stirred solution under ice cooling until the color of the oxidant did not disappear within a few minutes. After decomposition of the excess oxidant with iso-PrOH, almost all of the solvent was evaporated off. A small amount of water was added to the resulting mixture and the aqueous mixture was extracted thoroughly with ether. The extract was washed with brine and evaporated to leave an oil, which was chromatographed on silica gel with $CHCl_3$ to give **10** (1.21 g, 43%) as a colorless oil. *Anal.* Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 73.82; H, 9.64. IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3500—3000, 1705, 1640, 995, 920. ^{1}H-NMR ($CDCl_3$) δ: 1.09 (6H, s, 4-CH_3), 1.74 (2H, s, 5-H), 2.29 (2H, d, $J=7$ Hz, 1-$C\underline{H}_2CH=CH_2$), 2.43 (2H, s, 1-$C\underline{H}_2COOH$), 4.7—5.2 (2H, m, $CH=C\underline{H}_2$), 5.44 (2H, s, 2- and 3-H), 5.4—6.0 (1H, m, $C\underline{H}=CH_2$), 10.1—10.4 (1H, br, COOH). CI-MS m/z (%): 195 ($M^+ +1$, 100).

b) By Use of the Orthoester Claisen Rearrangement: A mixture of **8** (10.3 g, 68 mmol), triethyl orthoacetate (40 ml) and hydroquinone (trace) was heated with stirring at 180 °C for 3 d. During this period the ethanol formed was removed by distillation. After evaporation of the excess orthoester, a mixture of the residue, methanol (190 ml), and 10% NaOH (190 ml) was heated at 60 °C for 8 h. Methanol was removed by evaporation, and the aqueous mixture was washed with $CHCl_3$, then acidified with concentrated HCl. The resulting mixture was extracted with $CHCl_3$ and the crude product was purified by a short column chromatography on silica gel to give **10** (7.5 g, 57%).

7,7-Dimethyl-5-(2-propenyl)tricyclo[3.3.0.0^{2,8}]octan-3-one (4)——Oxalyl chloride (6.55 g, 52 mmol) was added to a stirred solution of **10** (2.0 g, 10 mmol) in dry benzene (20 ml) under ice cooling. Stirring under cooling was continued for 2 h and the solvent and the excess reagent were removed by evaporation to leave the acyl chloride (**11**) as an oil. IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1810. A solution of the acyl chloride in dry benzene (15 ml) was added to a stirred solution of a large excess of CH_2N_2 in ether and the mixture was stirred for 30 min under ice cooling. Concentration of the reaction mixture to dryness gave the crude diazoketone (**12**) as an oil. IR $\nu_{max}^{CCl_4}$ cm^{-1}: 2100, 1640. A solution of the above diazoketone in cyclohexane (30 ml) was added dropwise to a stirred and boiled mixture of anhydrous $CuSO_4$ (5.0 g) and cyclohexane (170 ml) over a period of 1 h, and the whole mixture was further heated under reflux with stirring for 3.5 h. After filtration to remove the inorganic substances, evaporation of cyclohexane left an oil, which was chromatographed on silica gel with benzene to give **4** (1.27 g, 65%) as a colorless oil. *Anal.* Calcd for $C_{13}H_{18}O$: C, 82.06; H, 9.54. Found: C, 81.72; H, 9.82. IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3080, 3040, 3010, 1725, 1640, 995, 920. ^{1}H-NMR (CCl_4) δ: 1.06 (3H, s, 7-CH_3), 1.20 (3H, s, 7-CH_3), 1.47 (1H, d, $J=12.5$ Hz, 6-H), 1.88 (1H, d, $J=12.5$ Hz, 6-H), 4.8—5.2 (2H, m, $CH=C\underline{H}_2$), 5.4—6.0 (1H, m, $C\underline{H}=CH_2$). MS m/z (%): 190 (M^+, 20), 93 (100). High MS Calcd for $C_{13}H_{18}O$: 190.1357. Found: 190.1367.

The Reaction of 4 with Lithium in Ammonia (Run 1)——Lithium (25 mg, 3.6 mg-atom) was added to a stirred solution of **4** (99 mg, 0.52 mmol) in a mixture of ether (2 ml) and liquid ammonia (15 ml) at -78 °C and the mixture was stirred at -33 °C for 30 min. After addition of NH_4Cl, ammonia was evaporated off and then water was added to the residue. The resulting aqueous solution was extracted with ether. The extract was washed with brine, dried, and evaporated to leave an oily residue, which was chromatographed on silica gel with $CHCl_3$ to give 7,7-dimethyl-1-(2-propenyl)bicyclo[3.3.0]octan-3-one (**14**; X = H) (60 mg, 60%) as a colorless oil. IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3080, 3045, 1740, 1640, 990, 920. ^{1}H-NMR (CCl_4) δ: 1.10 (6H, s, 7-CH_3). 4.8—5.2 (2H, m, $CH=C\underline{H}_2$), 5.2—6.0 (1H, m, $C\underline{H}=CH_2$). MS m/z (%): 192 (M^+, 19), 109 (100). High MS Calcd for $C_{13}H_{20}O$: 192.1514. Found: 192.1544.

The Reaction of 4 with Concentrated Sulfuric Acid in Methanol (Run 2)——A solution of **4** (19 mg, 0.10 mmol) in MeOH (2 ml) containing concentrated H_2SO_4 (1 drop) was stirred at room temperature for 4 d. After neutralization with $NaHCO_3$, the reaction mixture was evaporated and the residue was extracted with AcOEt. The extract was washed with brine, dried, and evaporated to leave an oil, which was chromatographed on silica gel with benzene to give *rel*-(5*R*,8*S*)-8-methoxy-6,6-dimethyl-1-(2-propenyl)bicyclo[3.2.1]octan-3-one (**15**; X = OMe) (13 mg, 60%) from the first eluate and *rel*-(5*R*,6*S*)-6-methoxy-7,7-dimethyl-1-(2-propenyl)bicyclo[3.3.0]octan-3-one (**14**; X = OMe) (4.3 mg, 19%) from the second eluate.

15 (X = OMe): A colorless oil. IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3080, 1720, 1645, 990, 920. ^{1}H-NMR (CCl_4) δ: 0.96 (3H, s, 6-CH_3), 1.19 (3H, s, 6-CH_3), 1.42 (1H, d, $J=13$ Hz, 7-H), 1.70 (1H, dd, $J=13$, 2 Hz, 7-H), 3.33 (3H, s, OCH_3), 3.53 (1H, s, 8-H), 4.8—5.1 (2H, m, $CH=C\underline{H}_2$), 5.4—6.0 (1H, m, $C\underline{H}=CH_2$). MS m/z (%): 222 (M^+, 14), 107 (100). High MS Calcd for $C_{14}H_{22}O_2$: 222.1617. Found: 222.1590.

14 (X = OMe): A colorless oil. IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3100, 1740, 1640, 990, 920. ^{1}H-NMR (CCl_4) δ: 0.97 (3H, s, 7-CH_3), 1.11 (3H, s, 7-CH_3), 1.50 (1H, d, $J=14$ Hz, 8-H), 1.77 (1H, d, $J=14$ Hz, 8-H), 2.9—3.1 (1H, m, 6-H), 3.39 (3H, s, OCH_3), 4.8—5.2 (2H, m, $CH=C\underline{H}_2$), 5.3—5.9 (1H, m, $C\underline{H}=CH_2$). MS m/z (%): 222 (M^+, 4.1), 121 (100). High MS Calcd for $C_{14}H_{22}O_2$: 222.1617. Found: 222.1596.

The Reaction of 4 with Formic Acid (Run 3)——A solution of **4** (0.50 g, 2.6 mmol) in 98—100% formic acid (15 ml) was heated with stirring at 90 °C for 24 h. After evaporation of the formic acid, methanol (15 ml) and 20%

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NaOH aqueous solution (5 ml) were added to the residue and the whole mixture was stirred at room temperature for 20 min. Methanol was removed by evaporation, and the resulting mixture was acidified with concentrated HCl, then extracted with $CHCl_3$. The extract was washed with brine, dried, and concentrated to give an oily residue, which was chromatographed on silica gel with benzene and then with $CHCl_3$ to afford 6,7-dimethyl-1-(2-propenyl)-bicyclo[3.3.0]oct-6-en-3-one (**16**) (79 mg, 16%), the starting material (62 mg), *rel*-(5*R*,8*S*)-8-hydroxy-6,6-dimethyl-1-(2-propenyl)bicyclo[3.2.1]octan-3-one (**15**; X = OH) (135 mg, 25%), and *rel*-(5*R*,6*S*)-6-hydroxy-7,7-dimethyl-1-(2-propenyl)bicyclo[3.3.0]octan-3-one (**14**; X = OH) (118 mg, 22%), successively.

16: A colorless oil. IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 3100, 3045, 1740, 1640, 990, 920. ^{1}H-NMR (CCl_4) δ: 1.56 (6H, br s, 6- and 7-CH_3), 1.9—2.6 (8H, m), 2.7—3.0 (1H, m, 5-H), 4.8—5.2 (2H, m, $CH=C\underline{H}_2$), 5.4—5.9 (1H, m, $C\underline{H}=CH_2$). MS *m/z* (%): 190 (M$^+$, 17), 120 (100). High MS Calcd for $C_{13}H_{18}O$: 190.1358. Found: 190.1361.

15 (X = OH): A colorless oil. IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 3620, 3460, 3075, 1710, 1640, 995, 920. ^{1}H-NMR (CCl_4) δ: 0.96 (3H, s, 6-CH_3), 1.27 (3H, s, 6-CH_3), 1.3—2.7 (10H, m), 4.06 (1H, s, 8-H), 4.8—5.2 (2H, m, $CH=C\underline{H}_2$), 5.4—6.0 (1H, m, $C\underline{H}=CH_2$). MS *m/z* (%): 208 (M$^+$, 2.8), 190 (100). High MS Calcd for $C_{13}H_{20}O_2$: 208.1461. Found: 208.1460.

14 (X = OH): A colorless oil. IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 3620, 3450, 3080, 1740, 1640, 995, 920. ^{1}H-NMR (CCl_4) δ: 0.95 (3H, s, 7-CH_3), 1.02 (3H, s, 7-CH_3), 1.52 (1H, d, J = 14 Hz, 8-H), 1.78 (1H, d, J = 14 Hz, 8-H), 1.8—2.5 (7H, m), 3.10 (1H, br s, OH), 3.2—3.5 (1H, m, 6-H), 4.9—5.2 (2H, m, $CH=C\underline{H}_2$), 5.4—6.0 (1H, m, $C\underline{H}=CH_2$). MS *m/z* (%): 208 (M$^+$, 2.2), 83 (100). High MS Calcd for $C_{13}H_{20}O_2$: 208.1463. Found: 208.1463.

The Reaction of 4 with Formic Acid and *p*-Toluenesulfonic Acid (Run 4)——A mixture of **4** (0.050 g, 0.26 mmol), *p*-TsOH · H_2O (trace), and 98—100% formic acid (3 ml) was heated with stirring at 90 °C for 18 h. The usual work-up afforded an oil, which was subjected to alkaline hydrolysis as described above to give a crude oily product. Column chromatography of the product on silica gel afforded **14** (X = OH) (11 mg, 20%), **15** (X = OH) (16 mg, 29%), and **16** (9.0 mg, 18%).

The Reaction of 4 with Concentrated Sulfuric Acid and Formic Acid (Run 5)——A mixture of **4** (100 mg, 0.53 mmol), concentrated H_2SO_4 (trace), and 98—100% formic acid (5 ml) was heated with stirring at 90 °C for 18 h. The usual work-up afforded an oil, which was subjected to alkaline hydrolysis as described above to give a crude oily product. Column chromatography of the product on silica gel afforded **14** (X = OH) (22 mg, 20%), **15** (X = OH) (46 mg, 43%), and **16** (16 mg, 16%).

The Reaction of 4 with Benzoic Acid and *p*-Toluenesulfonic Acid (Run 6)——A mixture of **4** (21 mg, 0.11 mmol), benzoic acid (20 mg, 0.16 mmol), *p*-TsOH · H_2O (31 mg, 0.16 mmol), and dry benzene (3 ml) was heated under reflux for 15 h. The usual work-up afforded an oil, which was chromatographed on silica gel with hexane–AcOEt (5 : 1) to afford a mixture of *rel*-(5*R*,6*S*)-7,7-dimethyl-1-(2-propenyl)-6-(*p*-toluenesulfonyloxy)bicyclo[3.3.0]octan-3-one (**14**; X = OTs) and *rel*-(5*R*,8*S*)-6,6-dimethyl-1-(2-propenyl)-8-(*p*-toluenesulfonyloxy)bicyclo[3.2.1]octan-3-one (**15**; X = OTs) (21 mg; total 52%). The ratio of the products was found to be **14** (X = OTs)/**15** (X = OTs) = *ca.* 1/5 by means of HPLC analysis (μ-Porasil 7.8 mm × 60 cm, hexane–AcOEt = 5 : 1, R401 differential refractometer). A small amount of each component was separated by the HPLC.

14 (X = OTs): A colorless oil. IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 1745, 1640, 1600, 975, 920. ^{1}H-NMR (CCl_4) δ: 0.92 (3H, s, 7-CH_3), 1.03 (3H, s, 7-CH_3), 2.44 (3H, s, Ar-CH_3), 4.38 (1H, d, J = 9 Hz, 6-H), 4.7—5.4 (2H, m, $CH=C\underline{H}_2$), 5.4—6.0 (1H, m, $C\underline{H}=CH_2$), 7.34 (2H, d, J = 8 Hz, aromatic H), 7.77 (2H, d, J = 8 Hz, aromatic H). MS *m/z* (%): 362 (M$^+$, 0.4), 149 (100). High MS Calcd for $C_{20}H_{26}O_4S$: 362.1549. Found: 362.1528.

15 (X = OTs): A colorless oil. IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 1720, 1640, 1600, 980, 920. ^{1}H-NMR (CCl_4) δ: 0.94 (3H, s, 6-CH_3), 1.15 (3H, s, 6-CH_3), 1.47 (1H, d, J = 14 Hz, 7-H), 1.71 (1H, dd, J = 14 and 2 Hz, 7-H), 2.45 (3H, s, Ar-CH_3), 4.7—5.1 (2H, m, $CH=C\underline{H}_2$), 4.77 (1H, s, 8-H), 5.2—5.8 (1H, m, $C\underline{H}=CH_2$), 7.29 (2H, d, J = 8 Hz, aromatic H), 7.72 (2H, d, J = 8 Hz, aromatic H). MS *m/z* (%): 362 (M$^+$, 0.2), 190 (100). High MS Calcd for $C_{20}H_{26}O_4S$: 362.1549. Found: 362.1574.

The Reaction of 4 with Chlorotrimethylsilane and Sodium Iodide (Run 7)——Trimethylsilyl chloride (TMSCl) (86 mg, 0.80 mmol) was added to a suspension of **4** (0.10 g, 0.53 mmol) and NaI (160 mg, 1.1 mmol) in dry CH_2Cl_2 (5 ml). The resulting mixture was stirred at room temperature for 2 h, poured into dilute KF aqueous solution, and then extracted with ether. The extract was washed with saturated $Na_2S_2O_3$ and brine, dried, and concentrated. The oily residue was chromatographed on silica gel with hexane–AcOEt (20 : 1) to give a mixture of *rel*-(5*R*,6*S*)-6-iodo-7,7-dimethyl-1-(2-propenyl)bicyclo[3.3.0]octan-3-one (**14**; X = I) and *rel*-(5*R*,8*S*)-8-iodo-6,6-dimethyl-1-(2-propenyl)bicyclo[3.2.1]octan-3-one (**15**; X = I) (150 mg, total 90%). The ratio of the products was found to be **14** (X = I)/**15** (X = I) = *ca.* 1/10 by means of GLC analysis (OV-17). Each component was separated by preparative HPLC (μ-Porasil, hexane–AcOEt = 20 : 1).

14 (X = I): A colorless oil. IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 3080, 1740, 1640, 990, 920. ^{1}H-NMR (CCl_4) δ: 1.03 (3H, s, 7-CH_3), 1.11 (3H, s, 7-CH_3), 1.63 (1H, br d, J = 14 Hz, 8-H), 2.03 (1H, d, J = 14 Hz, 8-H), 2.16 (2H, d, J = 7 Hz, 1-CH_2), 3.73 (1H, d, J = 12 Hz, 6-H), 4.9—5.2 (2H, m, $CH=C\underline{H}_2$), 5.4—6.0 (1H, m, $C\underline{H}=CH_2$). MS *m/z* (%): 318 (M$^+$, 0.7), 107 (100). High MS Calcd for $C_{13}H_{19}IO$: 318.0482. Found: 318.0458.

15 (X = I): A colorless oil. IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 3080, 1720, 1640, 995, 920. ^{1}H-NMR (CCl_4) δ: 0.99 (3H, s, 6-CH_3), 1.55 (3H, s, 6-CH_3), 1.60 (1H, dd, J = 14 and 2 Hz, 7-H), 1.96 (1H, d, J = 14 Hz, 7-H), 2.22 (2H, d, J = 7 Hz, 1-CH_2), 4.46 (1H, d, J = 2 Hz, 8-H), 4.95—5.3 (2H, m, $CH=C\underline{H}_2$), 5.45—6.0 (1H, m, $C\underline{H}=CH_2$). MS *m/z* (%): 318 (M$^+$, 6.1),

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107 (100). High MS Calcd for $C_{13}H_{19}IO$: 318.0482. Found: 318.0484.

A solution of the above mixture (**14**+**15**) (74 mg, 0.23 mmol) and DBU (70 mg, 0.46 mmol) in dry benzene (2 ml) was stirred at room temperature for 3 h. The organic solution was washed with 1 N HCl and water, dried, and concentrated to leave an oil, which was chromatographed on silica gel with hexane–AcOEt (5 : 1) to give **4** (38 mg, 86%).

The Reaction of 4 with Chlorotrimethylsilane and Lithium Bromide (Run 8)——TMSCl (86 mg, 0.80 mmol) was added to a suspension of **4** (0.10 g, 0.53 mmol) and LiBr (92 mg, 1.1 mmol) in dry CH_2Cl_2 (5 ml) and the mixture was stirred at room temperature for 2 h. Work-up as usual gave a mixture of *rel*-(5*R*,6*S*)-6-bromo-7,7-dimethyl-1-(2-propenyl)bicyclo[3.3.0]octan-3-one (**14**; X = Br) and *rel*-(5*R*,8*S*)-8-bromo-6,6-dimethyl-1-(2-propenyl)bicyclo-[3.2.1]octan-3-one (**15**; X = Br) (129 mg, total 91%). The ratio of **14**/**15** was found to be *ca.* 1/15 by means of GLC analysis.

14 (X = Br): A colorless oil. IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 3080, 1740, 1640, 995, 920. ^{1}H-NMR (CCl_4) δ: 1.09 (3H, s, 7-CH_3), 1.12 (3H, s, 7-CH_3), 1.60 (1H, br d, J = 14 Hz, 8-H), 2.00 (1H, d, J = 14 Hz, 8-H), 2.16 (2H, d, J = 8 Hz, 1-CH_2), 3.60 (1H, d, J = 12 Hz, 6-H), 4.9—5.2 (2H, m, CH=$C\underline{H}_2$), 5.4—6.0 (1H, m, $C\underline{H}$=CH_2). MS m/z (%): 272 (M^+ for ^{81}Br, 3.1), 270 (M^+ for ^{79}Br, 3.0), 107 (100). High MS Calcd for $C_{13}H_{19}BrO$: 272.0600 (for ^{81}Br), 270.0620 (for ^{79}Br). Found: 272.0640, 270.0636.

15 (X = Br): A colorless oil. IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 3080, 1720, 1640, 995, 920. ^{1}H-NMR (CCl_4) δ: 1.00 (3H, s, 6-CH_3), 1.46 (3H, s, 6-CH_3), 1.57 (1H, dd, J = 14 and 2 Hz, 7-H), 1.98 (1H, d, J = 14 Hz, 7-H), 2.23 (2H, d, J = 7 Hz, 1-CH_2), 4.45 (1H, d, J = 1 Hz, 9-H), 4.9—5.3 (2H, m, CH=$C\underline{H}_2$), 5.5—6.0 (1H, m, $C\underline{H}$=CH_2). MS m/z (%): 272 (M^+ for ^{81}Br, 1.8), 270 (M^+ for ^{79}Br, 1.8), 107 (100). High MS Calcd for $C_{13}H_{19}BrO$: 272.0600 (for ^{81}Br), 270.0620 (for ^{79}Br). Found: 272.0624, 270.0637.

A solution of the above mixture of **14** and **15** (X = Br) (123 mg, 0.45 mmol) and DBU (137 mg, 0.90 mmol) in dry benzene (3 ml) was stirred at room temperature for 5 h. The usual work-up followed by chromatography on silica gel with benzene gave **4** (0.070 g, 81%).

The Reaction of 4 with Tetramethylammonium Bromide and Methanesulfonyl Acetate (Run 9)——A suspension of **4** (17 mg, 0.09 mmol), MsOAc (25 mg, 0.18 mmol), and Me_4NBr (21 mg, 0.14 mmol) in dry acetonitrile (2 ml) was stirred at room temperature for 3 d. The solvent was evaporated off and water was added to the residue. The resulting mixture was extracted with AcOEt and the extract was washed with brine. The dried extract was concentrated to leave an oil, which was chromatographed on silica gel with benzene to give **15** (17 mg, 70%).

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