Basic Autoxidation of Friedelin[1)]

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Base-catalyzed autoxidation of a triterpene ketone, friedelin, in the presence of potassium *t*-butoxide gave four products, and their structures and formation mechanism were investigated. The common intermediate to these compounds was suggested to be 4-hydroperoxyfriedelan-3-one, not friedelane-2,3-dione. 3-Oxafriedel-1-ene-2-carboxylic acid was a dehydration product of the main product, 2-hydroxy-3-oxafriedelane-2-carboxylic acid.

Autoxidation of ketones with gaseous oxygen in the presence of strong bases is known as a convenient oxidation method for the syntheses of α-diketones from the corresponding α-methylene ketones and many investigations on synthesis of steroidal α-diketones were reported, but the yields were generally not good.[2)] The autoxidation of a triterpene with a 4,4-dimethyl-3-keto structure was examined by Hanna et al. and they reported a formation of the corresponding α-diketone in 68% yield together with a lactol which was derived by the further oxidation of the α-diketone.[3)] Thus it is generally difficult to control the oxidation reaction which often proceeds exceedingly, or aldol condensation may take place concomitantly. The reaction products, therefore, consist of a complex mixture of many compounds, and frequently the isolation of desired product is difficult. Consequently, applicability of this oxidation to organic synthesis is considerably restricted.

In connection with a study on effective degradation of triterpene ketones, friedelin (**1**)** was autoxidized in the presence of potassium *t*-butoxide and a dihydropyrancarboxylic acid (**2a**) was isolated as a ring-cleavage product in ca. 30% yield.[1)] Although this oxidation reaction was found to be not useful for a practical method to degradate the triterpene ketone effectively, examination on the complicated reaction mixture gave a different result from those obtained in steroids and triterpenes with the 4,4-dimethyl-3-keto structure and offered many interesting problems from the structural and mechanistic viewpoints. This paper describes the structures and formation mechanism of autoxidation products of friedelin (**1**) and some α-oxygenated derivatives.

The oxidation reaction of friedelin (**1**) was carried out in *t*-butyl alcohol and benzene using ten-molar excess of potassium *t*-butoxide with bubbling dry oxygen at room temperature. Although the absorption of oxygen usually stopped within 2 h, the reaction was continued for 24 h to be completed. The reaction mixture was acidified with hydrochloric acid and extracted with ether. The extract (A) was concentrated to afford a residue, which, on trituration with petroleum benzine-chloroform, was separated into a soluble fraction (B) and an insoluble materials (C).

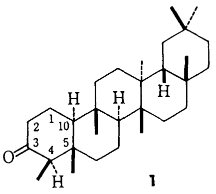
The insoluble material (C) was a crude carboxylic acid (**3a**) containing a trace amount of hydrochloric acid, and crystallized from chloroform–petroleum benzine to yield a less polar carboxylic acid (**2a**) in 20% yield, which was shown to be apparently different from **3a** by TLC examination. The insoluble material (C) was esterified with diazomethane. The crude ester (**3b**) was crystallized from the same solvents as above under acid-free conditions to yield a methyl ester (**3b**) in 35% yield, while on crystallization from the acid-containing solvents gave a less polar ester (**2b**) in 30% yield, which was identical with a methyl ester of **2a**. These observations, therefore, suggest that the less polar acid (**2a**) is a secondary reaction product derived from the polar acid (**3a**) by heating with a catalytic amount of acid.

Since the soluble fraction (B) was revealed to be a mixture of carboxylic acids, the whole extract (A) was methylated with diazomethane, separated by chromatography and recrystallized to afford four methyl esters, **3b**, **4b**, **5b**, and **6b** in 50—35, 20—3, 5—6, and 20—10% yields, respectively.

The methyl esters (**2b** and **3b**) gave the molecular formulas, $C_{31}H_{50}O_3$ and $C_{31}H_{52}O_4$, respectively, from elemental analysis and the mass spectra, and the latter showed the presence of a hydroxyl group by the IR spectrum. Therefore, **2b** was a dehydration product of **3b**. The ester (**2b**) showed the presence of α,β-unsaturated ester (IR: 1720 and 1640 cm^{-1}) with an oxygenfunction at α-position (UV: 253 nm). The ^1H NMR spectrum suggested the presence of a methoxycarbonyl (δ 3.8), -C-(C$\underline{H}_3$)-O- (δ 3.92, 1H, q, J=7 Hz), and -C=CH-CH- (δ 2.08 and 6.01, each 1H, d, J=2 Hz). These spectral data lead to the structure, methyl 3-oxafriedel-1-ene-2-carboxylate for **2b**. The structure proposed for **2b** was further confirmed including the configurations at C-4 and C-10 as follows. The oxidation of **2b** with ozone and hydrogen peroxide gave a ring-cleavage product (not isolated), which was subjected to partial reduction with lithium aluminium hydride (LAH), followed by a treatment with hydrochloric acid to afford a γ-lactone (**7**), $C_{28}H_{46}O_2$, IR 1765

**Friedelin (=friedelan-3-one); friedelane is used as a conventional skeletal name instead of D:A-friedooleanane throughout this paper.

cm^{-1}. The same γ-lactone (**7**) was also obtained by the following route from friedelin (**1**). 3a-Oxa-3a-homofriedelan-3-one (**8**)[4] derived from **1** was treated with phenylmagnesium bromide and then with acetic anhydride in acetic acid to give a diphenylethylene derivative (**9**). On oxidation with chromium trioxide, **9** afforded a δ-lactone, 3-oxafriedelan-2-one (**10**)[5], $C_{29}H_{48}O_2$. Then the δ-lactone (**10**) was submitted to a Grignard reaction using phenylmagnesiun bromide to yield 2-phenyl-3-oxafriedel-1-ene (**11**), $C_{35}H_{52}O$. Ozonolysis of **11** followed by a treatment with LAH yielded a γ-lactone (**7**) and a hemiacetal (**12**), $C_{28}H_{48}O_2$, and the latter (**12**) gave the γ-lactone (**7**) on oxidation with chromium trioxide. The dihydropyran derivative (**11**) was submitted to ozonization followed by a treatment with peracetic acid, and the reaction mixture was saponified with alkali. Acid treatment gave a mixture of two γ-lactones (**7** and **13**). One (**7**) of them was identical with that obtained by either route described above in every respect, and the configuration at C-10 was shown to be the same as that of friedelin (**1**). The other (**13**) is a C-10 epimer derived from a partial isomerization at C-10 under alkaline conditions and therefore possesses $C_{(10\beta)}$-H configuration. Since Baeyer-Villiger reaction is known to proceed with retention of the configuration of the chiral center α to the carbonyl group, the configuration at C-4 of the γ-lactone (**7**) is concluded to be the same 4R-configuration as that of friedelin (**1**). Thus the structure of 2a was deteremined to be 3-oxa-friedel-1-ene-2-carboxylic acid.



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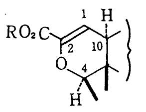
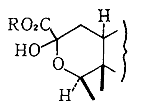


2a R = H
b R = Me



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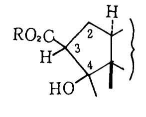
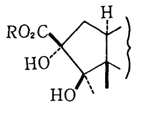
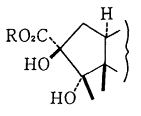
b R = Me



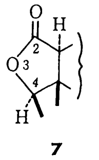
4a R = H
b R = Me



5a R = H
b R = Me



6a R = H
b R = Me



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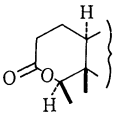

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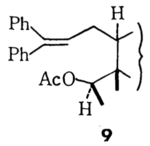

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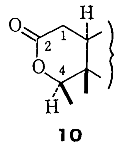

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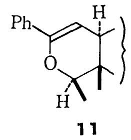

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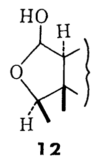

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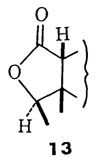

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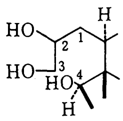

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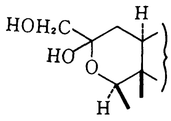

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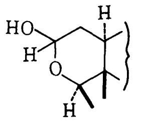

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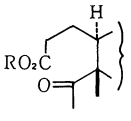
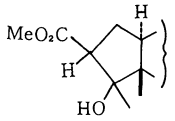
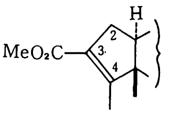


17a R = H
b R = Me



18 (a diastereomer of **4b**)



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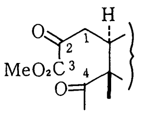
The structure of **3b** was deduced to be methyl 2-hydroxy-3-oxafriedelane-2-carboxylate from the spectral data and a chemical relation with **2b**. The fact that **3b** was easily converted into **2b** with $C_{(4\beta)}$-Me and $C_{(10\alpha)}$-H, implies that these configurations of **3b** are the same as those of **2b**. However, ^{1}H NMR signal due to $C_{(4\alpha)}$-H of **3b** was changed from a quartet into a multiplet on standing the solution, which indicates that **3b** in solution would exist in an equilibrium mixture of a pair of $C_{(2)}$-epimers.

Reduction of **3b** with LAH in THF under reflux gave 3,4-secofriedelane-2,3,4-triol (**14**), $C_{30}H_{54}O_3$, while in ether at room temperature afforded an unstable hemiacetal, 2-hydroxymethyl-3-oxafriedelan-2-ol (**15**) as an amorphous solid. When the hemiacetal (**15**) was warmed in benzene for recrystallization, dimerization occurred to give a dimeric ether, $C_{60}H_{100}O_4$, as a white powder, the structure of which was not further investigated. A treatment of the hemiacetal (**15**) with lead tetraacetate (LTA) gave a hemiacetal (**16**), $C_{29}H_{50}O_2$, which, on oxidation with chromium trioxide, yielded the δ-lactone (**10**). These derivations described above can be explained based on the structure **3b**.

The methyl ester (**4b**) gave the molecular formula, $C_{31}H_{52}O_3$ and showed the presence of a hydroxyl group by IR and -CH-CO- grouping (δ 2.5) by ^{1}H NMR spectrum. The ester (**4b**) did not react with lead tetraacetate nor with acetic anhydride in pyridine. The structure of **4b** was, therefore, inferred to be methyl 4-hydroxy-A(1)-norfriedelane-3-carboxylate and the structure was confirmed synthetically. Methyl 4-oxo-3,4-secofriedelan-3-oate (**17b**)[4] prepared from **1**, was refluxed with potassium *t*-butoxide in toluene and the aldol condensation mixture was esterified with diazomethane. Chromatographic separation of the product afforded a pair of hydroxy esters (**4b** and **18**) and methyl A(1)-norfriedel-3-ene-3-carboxylate (**19**).[4] One of the hydroxy ester, obtained as the major product, was identical with **4b**. The stereochemistry at C-3 and C-4 remains undetermined.

The methyl esters (**5b** and **6b**) gave the same molecular formulas, $C_{31}H_{52}O_4$, and the presence of two



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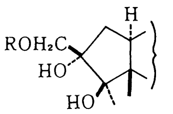
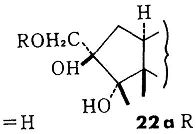
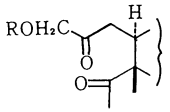


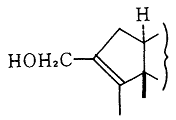
21a R = H
b R = Ac



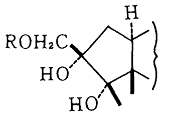
22a R = H
b R = Ac



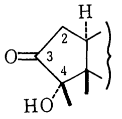
23a R = H
b R = Ac



24a R = H
b R = Ac



25a R = H
b R = Ac



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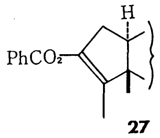

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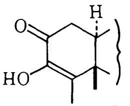

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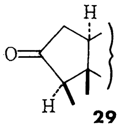

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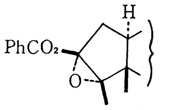

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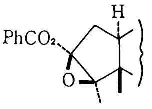

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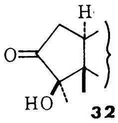

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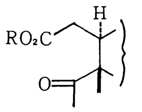


33a R = H
b R = Me

hydroxyl groups was shown from IR and chemical degradation (vide infra). No signal due to any hydrogen atom on a carbon bearing the hydroxyl group was observed in the ^{1}H NMR spectra and both esters resisted acetylation under normal conditions, indicating that two hydroxyl groups were tertiary. On treatment with LTA, **5b** and **6b** gave the same diketo ester, methyl 2,4-dioxo-3,4-secofriedelan-3-oate (**20**), structure of which was supported by the ^{1}H NMR spectrum (δ 2.07, 3H, CH_3CO-; 2.2—3.0, 2H, -CH_2CO-; and 3.80, 3H, -$COOCH_3$). From these observations, methyl 3,4-dihydroxy-A(1)-norfriedelane-3-carboxylate was proposed as a planar structure for **5b** and **6b**. Stereostructures for **5b** and **6b** were determined by following examination.

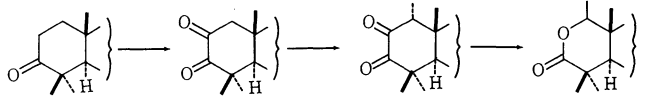
The methyl esters (**5b** and **6b**) were reduced with LAH to afford triols, **21a** and **22a**, which on acetylation gave monoacetates **21b** and **22b**, respectively. The monoacetates **21b** and **22b** were treated with LTA to afford the same diketo acetate (**23b**), $C_{32}H_{52}O_4$. The structure of **23b** was shown to be 2,4-dioxo-3,4-secofriedelan-3-yl acetate by the ^{1}H NMR spectrum, and was identical with a specimen prepared by the following route. The unsaturated ester (**19**) was subjected to reduction with LAH to afford an unsaturated alcohol (**24a**), which, after acetylation, was treated with osmium tetraoxide. The oxidizing reagent would attack the double bond from the less hindered α-side of the norfriedelene skeleton, giving rise to a *cis*-glycol acetate, 3β-acetoxymethyl-A(1)-norfriedelane-3α,4α-diol (**25b**). The glycol acetate (**25b**) was then treated with LTA to yield the diketo acetate (**23b**). The diol acetate (**25b**) was, however, not identical with **21b** nor **22b**, indicating that neither **21b** nor **22b** possesses the 3α,4α-diol structure.

The triol (**22a**) derived from **6b**, gave a norhydroxy ketone (**26**), $C_{29}H_{48}O_2$, as the sole reaction product on a treatment with LTA, while the triol (**25a**) gave a ring-cleavage product (**23a**), predominantly. These observations indicate that **6b** must possess a trans diol configuration.

On the other hand, A(1)-norfriedel-3-en-3-yl benzoate (**27**) was prepared from friedelane-2,3-dione (**28**) via A(1)-norfriedelan-3-one (**29**),[7] and subjected to epoxidation with peracetic acid. Since the double bond would be attacked by the reagent from the less hindered α-side, it was expected that the α-epoxide (**30**) would be formed as the major product. Therefore, the epoxide mixture (**30** and **31**) was hydrolyzed with potassium hydroxide to afford 4α-hydroxy-A(1)-norfriedelan-3-one (**26**) as the major product and 4β-hydroxy isomer (**32**) as the minor product. Both hydroxy norketones (**26** and **32**) gave the same keto norester (**33**)[4] on a treatment with LTA followed by methylation. The major hydroxy ketone (**26**) was identical with a specimen obtained from triol (**22a**) (vide supra). A support for the assignment of configuration at C-4 was observed on IR measurement. The pseudoequatorial[8] 4β-hydroxyl of **32** was considered to form stronger intramolecular hydrogen bond with carbonyl group than pseudoaxial 4α-hydroxyl of **26**.[9] Actually, absorption bands due to hydroxyl groups of **26** and **32** in dilute carbon tetrachloride solution appeared at 3606 and 3563 cm^{-1} respectively.

Since the hydroxyl group at C-4 of **26** was shown to be located in α-configuration and the relative configuration of $C_{(3)}$-OH and $C_{(4)}$-OH of **22b** is trans, the hydroxyl group at C-3 of **22b** and therefore that of **6b** is concluded to be in β-configuration.

The oxidation of **21a** with LTA was found to give a complicated reaction mixture, from which the hydroxy norketone (**32**) was isolated along with a small amount of the ring-cleavage diketo alcohol (**23a**). Since this observation implies that **21a** possesses a trans 3,4-diol with 4β-hydroxy configuration, the



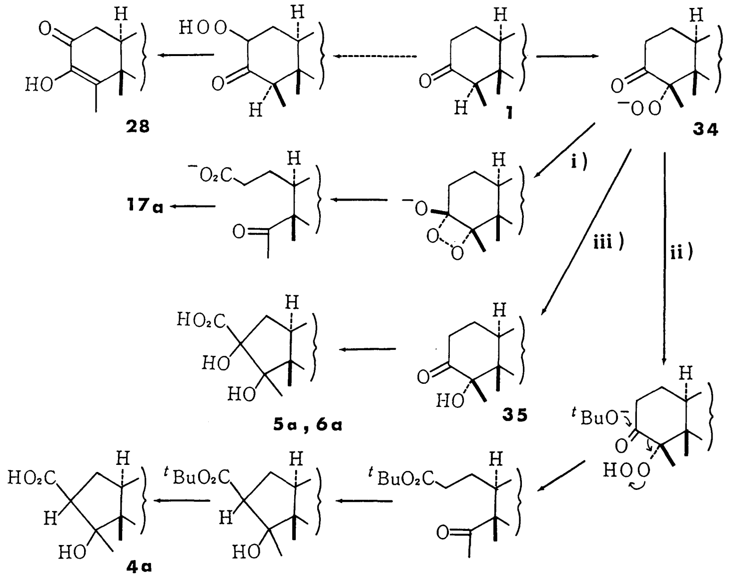
Scheme 1.

hydroxyl group at C-3 should be in α-configuration.

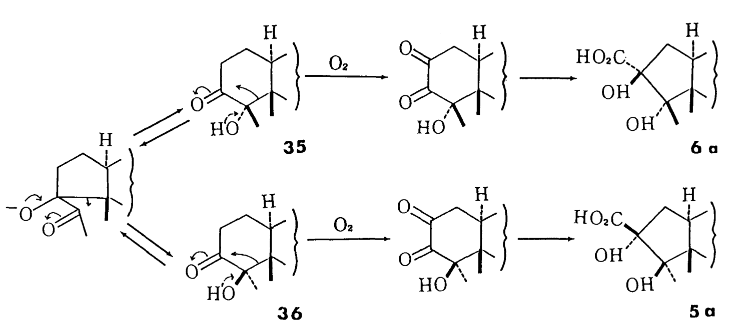
From these observations described above, it is concluded that **5a** and **6a** are formulated as 3α,4β-dihydroxy-A(1)-norfriedelane-3β-carboxylic acid and 3β,4α-dihydroxy-A(1)-norfriedelane-3α-carboxylic acid, respectively.

The basic autoxidation of ketones is known to proceed by an initial formation of α-keto carbanion (enolate anion) and followed by an attack of oxygen to yield α-hydroperoxy ketone. If the α-hydroperoxide is primary or secondary, it usually converts rapidly into the corresponding α-diketone, and then the α-diketone would be submitted to further oxidation. Many examples are reported in steroids and triterpenes with the 4,4-dimethyl-3-keto structure.[2] In the latter case, the primary oxidation product is a 2,3-dione, which is converted into a lactol via 1-hydroperoxy-2,3-dione with elimination of carbon monoxide[3] (Scheme 1). The basic autoxidation of friedelin (**1**) is not the case. The Δ^3-enolate anion being more stable than the Δ^2-enolate anion, attack of oxygen must occur at C-4 to afford a tertiary hydroperoxide (**34**) preferentially. Attack to C-2 yielding friedelane-2,3-dione (**28**) would be the minor process. In fact friedelane-2,3-dione (**28**) and several oxidation products derived from **28** were detected in the autoxidation product of **1** but in very minute quantities, and therefore, it is concluded that the process through 2,3-dione (**28**) would be of no importance.

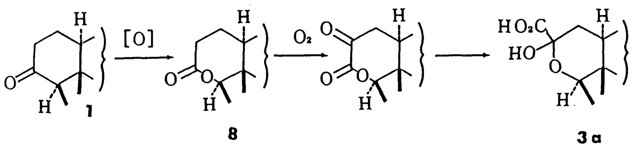
From product analysis of the autoxidation of friedelin (**1**), it is inferred that the hydroperoxy ketone (**34**) would be submitted to the following reactions;[10] i) an attack of the hydroperoxide anion of **34** to the carbonyl carbon followed by the $C_{(3)}$-$C_{(4)}$ bond fission, ii) the participation with a *t*-butoxide anion followed by the $C_{(3)}$-$C_{(4)}$ bond fission, iii) a reaction with friedelin (**1**) or some unknown process yielding 4α-hydroxyfriedelin (**35**) (Scheme 2). Process i) would produce 4-oxo-3,4-secofriedelan-3-oic acid (**17a**), but the keto acid (**17a**) was not detected in the reaction mixture. Since a separate experiment revealed that the keto acid (**17a**) was fairly stable in the autoxidation conditions and survived for long time, no detection of **17a** would deny the occurrence of process i). Process ii) would at least, partially, be responsible for the formation of 4-hydroxy-A(1)-norfriedelane-3-carboxylic acid (**4a**).



Scheme 2.



Scheme 3.



Scheme 4.

Process iii) was revealed to be the main route leading to dihydroxy carboxylic acids (**5a** and **6a**). 4α-Hydroxyfriedelan-3-one (**35**), the important intermediate in the process iii), and its 4β-hydroxy isomer (**36**) were prepared from friedelin (**1**) through an epoxidation of 3-friedelen-3-yl benzoate. The epoxidation gave a mixture of α- and β-epoxides, and the former was the main product from the reasons described for **27**. The 4α-hydroxyfriedelan-3-one (**35**) was subjected to the autoxidation under the same conditions as in the case of **1**. The reaction products, after methylation, were shown to be **5b** and **6b**. The autoxidation of 4β-hydroxy isomer (**36**) gave also **5b** and **6b** after methylation. Therefore, a rapid interconversion between **35** and **36** was suggested prior to the autoxidation and the autoxidation of **35** and **36** is considered to proceed as depicted in Scheme 3.

Since 2-hydroxy-3-oxafriedelane-2-carboxylic acid (**3a**) was not detected in the autoxidation product of **35** nor **36**, these two compounds were not intermediates leading to **3a**. A speculative formation process leading to **3a** was given in Scheme 4, and the investigation on the formation process is now under way.

Experimental

General Procedures. All melting points were uncorrected. Infrared spectra (IR) were taken on Perkin Elmer "Infracord," or Hitachi EPI-G2 spectrometer in Nujol mull. Ultra violet spectra (UV) were measured on a Hitachi EPS-3 spectrometer. ^{1}H NMR spectra were taken using Hitachi R-24 (60 MHz), Varian A-60 (60 MHz), or Varian EM-390 (90 MHz) and mass spectra (MS) were run on a Hitachi RMU-6L or JEOL DX-300 mass spectrometer at 70 eV unless otherwise noted and the relative intensities were indicated in parentheses. High performance liquid chromatography (HPLC) was run on Waters Associates 6000A with μ-PORASIL (silica gel) column and RI detector. Reduction with lithium aluminium hydride (LAH), acetylation with acetic anhydride-pyridine, methylation with diazomethane, and oxidation of glycols with lead tetraacetate (LTA) in acetic acid were done in usual manner unless specially noted.

Materials and Solvents. Friedelin (**1**) was extracted from "cork smoker wash solid"[6] (not available now) or cork powder and purified by column chromatography (alumina, benzene) and by crystallization from ethyl acetate, mp 261 °C. Friedelane-2,3-dione (**28**) was extracted from "cork smoker wash solid" and the crude material was subjected to column chromatography on alumina eluted with benzene-ethyl acetate followed by crystallization from the same solvent, mp 222 °C. Benzene was distilled before use. Dry *t*-butyl alcohol was prepared by distillation from a solution of *t*-butyl alcohol (100 parts) containing sodium *t*-butoxide (1 part). Potassium *t*-butoxide solution was prepared by dissolving potassium (1 g) in dry *t*-butyl alcohol (100 ml).

Autoxidation of Friedelin (1) with Potassium *t*-Butoxide. A solution of friedelin (**1**; 1 g) in dry benzene (100 ml) was placed in a two-necked Erlenmeyer flask equipped with a gas buret. The air inside was transferred by oxygen, and the potassium *t*-butoxide solution (100 ml) was added through a rubber septum cap. The solution, kept at 25 °C, was stirred for 24 h. A rapid absorption of oxygen was observed within first 30 min and the absorption stopped when about 85 ml of oxygen was consumed. Ether and 1 M hydrochloric acid (1 M=1 mol dm^{-3}) were added and the organic layer (A) was washed once with water and concentrated under reduced pressure to afford a residue. The residue was triturated with petroleum benzine and a soluble fraction (B) and an insoluble material (C) were obtained. A part of the insoluble material (C) crystallized from benzine-chloroform to afford 3-oxafriedel-1-ene-2-carboxylic acid (**2a**) in ca. 20% yield, mp 241—245 °C (needles from ether); IR 2360, 2340, 1705, 1640, 1460, 1390, 1285, 1140, 1120, and 1080 cm^{-1}; ^{1}H NMR (90 MHz, CDCl$_3$) δ=2.1 (1H, d, *J*=2 Hz; C$_{(10)}$H), 3.9 (1H, q, *J*=5 Hz, -O-C$\underline{\text{H}}$-CH$_3$), 6.1 (1H, d, *J*=2 Hz; C$_{(1)}$H), and 7.5 (1H, br s; COOH); MS *m/z* (%) 456 (M$^+$; 11), 441 (7), 426 (37), 411 (11), 382 (27), 341 (53), 205 (100), 135 (55), 123 (62), and 109 (84). The remaining part of C was esterified with diazomethane. Recrystallization from the same solvents gave a methyl ester (**2b**) of **2a** in 30% yield, while recrystallization, after the solvents were free from acid, gave methyl 2-hydroxy-3-oxafriedelane-2-carboxylate (**3b**) in 35% yield. **2b**; Mp 214.5—215 °C; IR 1720 and 1640 cm^{-1}; UV (EtOH) 253 nm (ε 8900); ^{1}H NMR (60 MHz, CDCl$_3$) δ=2.08 (1H, d, *J*=2 Hz; C=CH-C$\underline{\text{H}}$), 3.79 (3H, s; COOCH$_3$), 3.92 (1H, q, *J*=7 Hz; -O-C$\underline{\text{H}}$-CH$_3$), and 6.01 (1H, d, *J*=2 Hz; C=C$\underline{\text{H}}$-CH); MS *m/z* 470 (M$^+$); Found: C, 78.70; H, 10.79%. Calcd for C$_{31}$H$_{50}$O$_3$: C, 79.10; H, 10.71%. **3b**; Mp 204.5—205 °C (from petroleum benzine); IR 3670, 1740, and 1640 cm^{-1}; ^{1}H NMR (60 MHz, CDCl$_3$) δ=3.7 (1H, m; -OC$_{(4)}$H) and 3.8 (3H, s; -COOCH$_3$); MS (20 eV) *m/z* (%) 488 (M$^+$; 13), 470 (47), 429 (50), 341 (38), 218 (33), and 205 (100); Found: C, 76.04; H, 10.73%. Calcd for C$_{31}$H$_{52}$O$_4$: C, 76.18; H, 10.72%.

The extract (A) was treated with diazomethane until a yellow color persisted for 5 min. Removal of the solvent in vacuo and the residue was chromatographed on silica gel. Elution with benzene gave methyl 2-hydroxy-3-oxafriedelane-2-carboxylate (**3b**), methyl 4-hydroxy-A(1)-norfriedelane-3-carboxylate (**4b**), methyl 3α,4β-dihydroxy-A(1)-norfriedelane-3β-carboxylate (**5b**), and methyl 3β,4α-dihydroxy-A(1)-norfriedelane-3α-carboxylate (**6b**) in turn. **4b**; Needles from methanol, mp 224—225 °C; IR 3630 and 1725 cm^{-1}; ^{1}H NMR (60 MHz, CDCl$_3$) δ=2.5 (1H, m; -CH-CO) and 3.9 (3H, s; COOCH$_3$); MS *m/z* (%) 472 (M$^+$; 33), 454 (19), 356 (16), 274 (44), 205 (73), and 109 (100); Found: C, 78.88; H, 11.09%. Calcd for C$_{31}$H$_{52}$O$_3$: C, 78.76; H, 11.09%. **5b**; Needles from petroleum benzine, mp 205—205.5 °C; IR 3700, 3500, and 1720 cm^{-1}; ^{1}H NMR (60 MHz, CDCl$_3$) δ=3.8 (3H, s; -COOCH$_3$); MS *m/z* (%) 488 (M$^+$; 70), 428 (49), 341 (36), 205 (83), and 109 (100); Found: C, 75.59; H, 10.59%. Calcd for C$_{31}$H$_{52}$O$_4$: C, 76.18; H, 10.72%. **6b**; Needles from petroleum benzine, mp 240—241 °C; IR 3500 and 1725 cm^{-1}; ^{1}H NMR (60 MHz, CDCl$_3$) δ=3.75 (3H, s; -COOCH$_3$); MS *m/z* (%) 488 (M$^+$; 100), 428 (46), 205 (64), 149 (46), 123 (68), and 109 (92); Found: C, 75.94; H, 10.65%. Calcd for C$_{31}$H$_{52}$O$_4$: C, 76.18; H, 10.72%.

Oxidation of 2b with Ozone and Hydrogen Peroxide. Ozone was introduced to a solution of **2b** (100 mg) in dichloromethane (50 ml), kept at −78 °C, until the solution developed blue color. A mixture of hydrogen peroxide (30%, 20 ml), acetic acid (20 ml), and sulfuric acid (1 ml) was added and the solution was heated at 100 °C. After 30 min, the solution was cooled to room temperature, neutralized with an aqueous solution of sodium carbonate, and extracted with ether. The ether layer was concentrated and chromatographed (silica gel-benzene). 3-Oxa-A(1)-norfriedelan-2-one (**7**; 53 mg) was obtained, mp 263—264 °C (from ethyl acetate); IR 1780, 1170, 1060, 1015, and 920 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=2.1 (1H, s; $C_{(10)}H$) and 4.05 (1H, q, J=7 Hz; $-OC_{(4)}H$); MS m/z (%) 414 (M^+; 23), 399 (14), 290 (70), 262 (84), 247 (26), 221 (20), and 205 (44); Found: C, 81.24; H, 11.32%. Calcd for $C_{28}H_{46}O_2$: C, 81.10; H, 11.18%.

3a-Oxa-3a-homofriedelan-3-one (8). To a solution of friedelin (**1**; 5 g) in chloroform (300 ml) was added 39% peracetic acid (40 ml) and the mixture was stirred overnight at 60 °C. Water was added and the organic layer was washed with water several times, concentrated, and crystallized from ethyl acetate to yield **8** (3.2 g), mp 292—293 °C; IR 1730, 1290, and 1230 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=2.5—2.7 (2H, m; $C_{(2)}H_2-CO-$) and 4.23 (1H, q, J=6 Hz; $-OC_{(4)}H-$); MS m/z (%) 442 (M^+; 16), 398 (25), 274 (19), 245 (23), 218 (42), 205 (61), 123 (79), and 109 (100); Found: C, 81.39; H, 11.38%. Calcd for $C_{30}H_{50}O_2$: C, 81.40; H, 11.60%.

Diphenylethylene Acetate (9). 3a-Oxa-3a-homofriedelan-3-one (**8**; 2 g) was treated with 10 molar excess of phenylmagnesium bromide in usual manner and the reaction product was dissolved in benzene, dried over sodium sulfate, and then concentrated. The residue was dissolved in a mixture (1 : 1, 200 ml) of acetic anhydride and acetic acid containing sodium acetate (2 g), and the solution was refluxed overnight. The usual work-up and chromatography (silica gel-petroleum benzine) afforded diphenylethylene acetate (**9**) as an amorphous solid, IR 1725, 1595, 1235, 1040, and 760 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=1.95 (3H, s; AcO-), 2.0—2.3 (2H, m; $C_{(1)}H_2-C=C$), 4.77 (1H, q, J=7 Hz; $-OC_{(4)}H$), 5.99 (1H, t, J=7 Hz; $-C=C_{(2)}H$), and 7.3—7.5 (5H, br s; C_6H_5-).

3-Oxafriedelan-2-one (10). Chromium trioxide (1 g) was added to a solution of **9** (1 g) in acetic acid (200 ml) with stirring at room temperature and the solution was stirred for 10 h. After removal of the solvent in vacuo, the residue was shaken with ether and 1% sulfuric acid. The organic layer was concentrated, dissolved in a mixture of dioxane (100 ml) and concd sulfuric acid (1 g). The solution was refluxed for 1 h and then poured into water to yield precipitates, which recrystallized from methanol. 3-Oxafriedelan-2-one (**10**; 300 mg) was obtained, mp 263—264 °C; IR 1735, 1245, 1080, and 1050 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=2.0—2.6 (2H, m; CH_2CO-) and 4.05 (1H, q, J=7 Hz); MS m/z (%) 428 (M^+; 9), 304 (28), 276 (23), 205 (74), 203 (20), 123 (74), 107 (69), and 109 (100); Found: C, 81.29; H, 11.35%. Calcd for $C_{29}H_{48}O_2$: C, 81.25; H, 11.29%.

2-Phenyl-3-oxafriedel-1-ene (11). One gram of **10** was added to 3 molar excess of phenylmagnesium bromide solution in ether, and the solution was refluxed for 1 h. After dil hydrochloric acid was added, the ether layer was concentrated to give a residue. The residue was chromatographed (silica gel-petroleum benzine) and crystallized from ethyl acetate to afford 2-phenyl-3-oxa-1-friedelene (**11**; 650 mg) as lustrous platelets, mp 223—225 °C; MS m/z (%) 488 (M^+; 23), 300 (9), 205 (17), and 185 (23).

Ozonolysis of 11 by Reductive Treatment. A solution of 2-phenyl-3-oxa-1-friedelene (**11**; 500 mg) in dichloromethane (200 ml) was cooled in Dry Ice-methanol bath and ozone was bubbled into the solution until the color of the solution changed to blue. A solution of LAH (200 mg) in ether (50 ml) was added and the mixture was allowed to warm up to room temperature. After addition of a small amount of acetone, the mixture was shaken with dil hydrochloric acid. The organic layer was concentrated and chromatographed (silica gel-benzene) to afford 3-oxa-A(1)-norfriedelan-2-one (**7**; 155 mg) and 3-oxa-A(1)-norfriedelan-2-ol (**12**; 75 mg), mp 236—238 °C (from benzene); IR 3200, 1100, 1060, 1010, and 730 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ=3.55 (1H, q, J=6.5 Hz; $-OC_{(4)}H$) and 3.6—3.7 (2H, m; $C_{(1)}\underline{H}OH$); MS m/z (%) 398 ($[M-18]^+$; 15), 356 (17), 341 (6), 205 (56), 123 (100), and 109 (97); Found: C, 80.70; H, 11.82%. Calcd for $C_{28}H_{48}O_2$: C, 80.71; H, 11.61%. 3-Oxa-A(1)-norfriedelan-2-ol (**12**; 35 mg) in acetic acid (20 ml) was oxidized with chromium trioxide (50 mg) at reflux temperature for 1 h to afford **7** (25 mg).

Ozonolysis of 11 by Alkaline Treatment. Ozonation of **11**(500 mg) in dichloromethane was carried out in the same manner as above and the reaction product was treated with 39% peracetic acid (20 ml). The mixture was heated up to 100 °C in a hood until no peroxide was detected with a potassium iodide-acetic acid solution. After the solvent was removed in vacuo, an excess ethanolic potassium hydroxide solution was added and the alkaline mixture was refluxed for 1 h. The solution was then acidified to pH ca. 1 by addition of dil hydrochloric acid and left for 1 h at 80 °C. The reaction product was extracted with ether and subjected to separation by chromatography (silica gel-benzene) to yield 3-oxa-A(1)-norfriedelan-2-one (**7**; 75 mg) and 10-epi-3-oxa-A(1)-norfriedelan-2-one (**13**; 53 mg), mp 181—181.5 °C (from ethyl acetate); IR 1760, 1140, 1120, and 1055 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=3.90 (1H, q, J=7 Hz; $-OC_{(4)}H$), 2.0 (1H, s; $C_{(10)}HCO-$), and 3.0—3.6 (1H, m; $C_{(11)}H$); MS m/z (%) 414 (M^+; 17), 399 (20), 290 (57), 261 (100), 235 (38), and 205 (45); Found: C, 81.03; H, 11.33%. Calcd for $C_{28}H_{46}O_2$: C, 81.10; H, 11.18%.

Reduction of Methyl 2-Hydroxy-3-oxafriedelane-2-carboxylate (3b) with LAH. A solution of **3b** (500 mg) in tetrahydrofuran (THF) (100 ml) was refluxed with excess LAH for 6 h and the usual work-up gave 3,4-secofriedelane-2,3,4-triol (**14**; 280 mg) as needles, mp 203—203.5 °C (from benzene); IR 3400, 3250, 3150, 1095, 1080, and 680 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) 3.5—3.8 (4H, m; -OCH-); MS m/z (%) 462 (M^+; trace), 413 (11), 273 (7), 219 (11), 205 (40), and 109 (100); Found: C, 78.06; H, 11.71%. Calcd for $C_{30}H_{54}O_3$: C, 77.86; H, 11.76%.

A solution of **3b** (200 mg) in ether (100 ml) was reduced with LAH (50 mg) at room temperature. After 24 h, the reaction mixture was cooled with an ice bath, and treated with a small amount of acetone and then dil hydrochloric acid. The ether layer was washed with water several times and then concentrated in vacuo to give 2-hydroxymethyl-3-oxafriedelan-2-ol (**15**; ca. 150 mg) as an amorphous solid. The hemiacetal (**15**; 100 mg) was dissolved in benzene (200 ml) and the solvent was evaporated slowly on a water bath. The residue was chromatographed (silica gel-benzene) to give the dimeric ether (73 mg) as white powder, which crystallized from benzene, mp 298—299 °C; IR 1280, 1110, 1090, 1050, 980, 970, and 795 cm^{-1}. ^1H NMR (60 MHz, $CDCl_3$) δ=3.2—4.0 (6H, m; -OCH); MS m/z (%) 888 (M^+; trace), 440 (0.9), 438 (1), 424 (20), 409 (21), 341 (17), 229 (20), 205 (55), 191

(24), 138 (100), 137 (54), 123 (35), and 109 (40); Found: C, 81.20; H, 11.16%. Calcd for $C_{60}H_{100}O_4$: C, 81.39; H, 11.38%.

3-Oxafriedelan-2-ol (16). An ethereal solution of **15** (120 mg) obtained by the reduction of **3b** was added to a solution of LTA (300 mg) in acetic acid (100 ml) and the mixture was stirred for 1 h at room temperature. Ethylene glycol was added and the reaction mixture was worked up as usual to afford 3-oxafriedelan-2-ol (**16**; 83 mg), mp 228—232 °C (from benzene); IR 3400, 1270, 1245, 1105, 1050, 990, 950, and 725 cm^{-1}; MS *m/z* (%) 430 (M^+; trace), 412 (16), 218 (22), 205 (46), 135 (43), 123 (61), 121 (46), and 109 (100); Found: C, 80.67; H, 11.72%. Calcd for $C_{29}H_{50}O_2$: C, 80.87; H, 11.70%. Poor ^1H NMR spectrum was obtained due to the low solubility.

Modified Preparation of 4-Oxa-3,4-secofriedelan-3-oic Acid (17a). A solution of friedel-3-en-3-yl benzoate[6] (3 g) in dichloromethane (300 ml) was cooled in an ice-salt bath and ozone was passed though the solution until the blue color did not fade. A solution of chromium trioxide (3 g) in 90% acetic acid (300 ml) was added, and the mixture was heated at 60 °C for 1 h. Water and ether were added and the ether layer was worked up as usual. The residue crystallized from acetone-water to afford 4-oxo-3,4-secofriedelan-3-oic acid (**17a**; 2.1 g), mp 205—207 °C (needles from ether); IR 3100 (br), 1735, 1670, 1365, 1290, 1240, and 1190 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=2.1 (3H, s; Ac), 2.2—2.5 (2H, m; -CH_2-CO-), and 7.0—7.6 (1H, br s; -COOH); MS (20 eV) *m/z* (%) 458 (M^+; 18), 415 (14), 219 (41), and 205 (100). Preparation of **17a** by this method is more convenient than by chromic acid-oxidation of **1**.[4] On methylation, **17a** afforded methyl 4-oxo-3,4-secofriedelan-3-oate (**17b**), mp 157—158 °C (silky needles from methanol); IR 1735, 1695, and 1165 cm^{-1}. ^1H NMR (60 MHz $CDCl_3$) δ=2.1 (2H, t, *J*=3 Hz; -CH_2CO-), 2.15 (3H, s; CH_3CO-), and 3.65 (3H, s; -$COOCH_3$); MS *m/z* (%) 472 (M^+; 9), 429 (42), 205 (95), 123 (66), 121 (42), 109 (100), and 107 (45).

Aldol Condensation of 17b. To a solution of methyl 4-oxo-3,4-secofriedelan-3-oate (**17b**; 1 g) in toluene (200 ml) was added 200 ml of the potassium *t*-butoxide solution (the same solution as that used for the basic autoxidation) under nitrogen atmosphere and the mixture was refluxed for 24 h. After 2% hydrochloric acid (500 ml) was added, the organic layer was treated with diazomethane. The usual work-up afforded a residue, which was separated by chromatography on silica gel. Elution with benzene yielded methyl 4-hydroxy-A(1)-norfriedelane-3-carboxylate (**4b**; 143 mg), the stereoisomer (**18**; 118 mg) of **4b**, and methyl A(1)-norfriedel-2-ene-3-carboxylate (**19**; 85 mg) successively. **18**; Mp 226—228 °C (from benzene-cyclohexane); IR 3400, 1710, 1230, 1210, 1180, 1150, 1110, 1040, and 900 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ=2.8—3.1 (1H, m; -$C_{(3)}$HCO-) and 3.7 (3H, s; $COOCH_3$); MS *m/z* (%) 472 (M^+; 16), 356 (11), 273 (26), 218 (39), 205 (76), 137 (59), 123 (84), and 109 (100); Found; C, 78.75; H, 10.96%. Calcd for $C_{31}H_{52}O_3$: C, 78.76; H, 11.09%. **19**; Mp 230—231.5 °C (platelet from methanol); IR 1710, 1630, 1310, 1215, and 1065 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=1.95 (3H, br s; CH_3-C=C-), 2.1—2.5 (2H, m; $C_{(1)}H_2$-C=C), and 3.70 (3H, s; -$COOCH_3$); MS *m/z* (%) 454 (M^+; 30), 235 (38), 234 (37), 233 (43), 205 (60), 191 (36), 165 (53), 123 (70), and 109 (100).

Oxidation of 5b and 6b with Lead Tetraacetate. An ethereal solution of **5b** (72 mg) was added dropwise to a solution of LTA (200 mg) in acetic acid. The usual work-up and crystallization from methanol aforded methyl 2,4-dioxo-3,4-secofriedelan-3-oate (**20**; 53 mg), mp 134—135 °C; IR 1730, 1695, 1365, 1275, 1265, and 1085 cm^{-1}. ^1H NMR (90 MHz, $CDCl_3$) δ=2.07 (3H, s; Ac), 2.2—3.0 (2H, m; -$C_{(1)}H_2$CO-), and 3.80 (3H, s; -$COOCH_3$); MS *m/z* (%) 486 (M^+; 15), 443 (39), 427 (29), 205 (83), 149 (56), 123 (78), and 109 (100); Found: C, 76.78; H, 10.42%. Calcd for $C_{31}H_{50}O_4$: C, 76.50; H, 10.36%. The same diketo ester (**20**; 32 mg) was obtained from **6b** (55 mg) by the same treatment.

3β-Hydroxymethyl-A(1)-norfriedelane-3α,4β-diol (21a) and Its Monoacetate (21b). Reduction of **5b** with LAH afforded **21a**, mp 260 °C (with decomp) (from petroleum benzine); IR 3430, 1365, and 1275 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ=3.3—3.9 (2H, m; -CH_2OH); MS *m/z* (%) 442 ($[M-18]^+$; 4), 424 (20), 409 (21), 406 (27), 231 (26), 218 (68), 205 (94), 191 (45), 163 (42), 123 (64), and 109 (100); Found: C, 78.06; H, 11.16%. Calcd for $C_{30}H_{52}O_3$: C, 78.20; H, 11.38%. On acetylation, **21a** gave 3β-acetoxymethyl-A(1)-norfriedelane-3α,4β-diol (**21b**), mp 198.5—199 °C (from ether-cyclohexane); IR 3500, 1730, 1285, and 1055 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=2.10 (3H, s; AcO-) and 4.20 (2H, s; -OH); MS *m/z* (%) 502 (M^+; 1), 442 (1), 399 (7), 273 (11), 205 (57), and 109 (100); Found: C, 76.36; H, 10.78%. Calcd for $C_{32}H_{54}O_4$: C, 76.44; H, 10.83%.

3α-Hydroxymethyl-A(1)-norfriedelane-3β,4α-diol (22a) and Its Monoacetate (22b). By the same treatment as above, methyl 3β,4α-dihydroxy-A(1)-norfriedelane-3α-carboxylate (**6b**) afforded **22a** and 3α-acetoxymethyl-A(1)-norfriedelane-3β,4α-diol (**22b**). **22a**; Mp 255 °C (with decomp) (from ethyl acetate); IR 3400, 1135, 1070, 1060, 940, 920, and 890 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ=3.55 and 3.93 (each 1H, d, *J*=12 Hz); MS *m/z* (%) 442 ($[M-18]^+$; 4), 427 (4), 399 (10), 273 (8), 219 (12), 205 (55), 142 (100), 113 (63), and 109 (88); Found: C, 78.15; H, 11.08%. Calcd for $C_{30}H_{52}O_3$: C, 78.20; H, 11.38%. **22b**; Mp 156—157 °C (from ether-cyclohexane); IR 3700, 3460, 1760, 1735, 1270, 1220, and 1045 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=2.10 (3H, s; AcO-), 4.13 and 4.36 (each 1H, d, *J*=10 Hz); MS *m/z* (%) 502 (M^+; trace), 442 (2), 427 (3), 409 (3), 399 (7), 381 (2), 371 (3), 341 (5), 273 (8), 205 (54), 123 (68), 121 (61), and 109 (100); Found: C, 76.25; H, 10.84%. Calcd for $C_{32}H_{54}O_4$: C, 76.44; H, 10.83%.

Treatment of 21b and 22b with Lead Tetraacetate. 3β-Acetoxymethyl-A(1)-norfriedelane-3α,4β-diol (**21b**) was treated with LTA to afford 2,4-dioxo-3,4-secofriedelan-3-yl acetate (**23b**), mp 196—197 °C (from petroleum benzine); IR 1760, 1745, 1695, 1230, 1060, and 1040 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=2.10 and 2.13 (each 3H, s; AcO- and Ac), 2.2—2.5 (2H, m; $C_{(1)}H_2$CO-), 4.50 and 4.73 (each 1H, d, *J*=18 Hz, AcO$\underline{CH_2}$-CO-); MS *m/z* (%) 500 (M^+; 1), 457 (38), 341 (20), 205 (100), 137 (52), 135 (45), 123 (66), 121 (56), 109 (80), and 107 (47); Found: C, 76.95; H, 10.68%. Calcd for $C_{32}H_{52}O_4$: C, 76.75; H, 10.47%. The same treatment of **22b** with LTA gave the same diketo acetate (**23b**).

3-Acetoxymethyl-A(1)-norfriedel-3-ene (24b). A solution of methyl A(1)-norfriedel-3-ene-3-carboxylate (**19b**) in ether was treated with LAH to give 3-hydroxymethyl-A(1)-norfriedel-3-ene (**24a**), mp 234—236 °C (from benzene); IR 3400 (br), 1640, 995, 720, and 410 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=4.10 (2H, s; =C-CH_2OH); MS *m/z* (%) 426 (M^+; 5), 411 (84), 205 (95), 137 (100), 123 (98), 121 (89), 119 (87), 109 (67), 107 (93), and 105 (62); Found: C, 84.61; H, 11.84%. Calcd for $C_{30}H_{50}O$; C, 84.44; H, 11.81%. Acetylation of **24a** yielded 3-acetoxymethyl-A(1)-norfriedel-3-ene (**24b**), mp 179—183.5 °C (from methanol); IR 1735, 1665, 1260, and 1030 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ=2.10 (3H, s; Ac); MS m/z (%) 468 (M^+; 2), 453 (18), 408 (14), 393 (33), 273 (11), 259 (14), 205 (42), 123 (72), 121 (78), 119 (67), 109 (100), 107 (83), and 105 (53); Found: C, 81.77; H, 11.11%. Calcd for $C_{32}H_{54}O_3$: C, 81.99; H, 11.18%.

3β-Hydroxymethyl-A(1)-norfriedelane-3α,4,α-diol (25a). To a solution of 3-acetoxymethyl-A(1)-norfriedel-3-ene (**24b**; 300 mg) in ether (20 ml) was added osmium tetraoxide (0.3 g) and the solution was allowed to stand for 1 week. After addition of ether and excess LAH, the mixture was refluxed for 30 min and then a small amount of acetone was added. The usual work-up followed by chromatographic separation (silica gel-benzene and ether) gave 3β-hydroxymethyl-A(1)-norfriedelane-3α,4α-diol (**25a**; 185 mg), mp 263—267 °C (with decomp) (from ethyl acetate); IR 3850, 1120, 1060, 1045, 1005, and 940 cm^{-1}. ^{1}H NMR (90 MHz, $CDCl_3$) δ=3.60 (2H, s; $-CH_2O-$); MS m/z (%) 460 (M^+; trace), 442 (10), 417 (68), 343 (21), 273 (23), 219 (30), 205 (100), 191 (34), 142 (55), and 109 (80); Found: C, 78.06; H, 11.21%. Calcd for $C_{30}H_{52}O_3$: C, 78.20; H, 11.38%.

3β-Acetoxymethyl-A(1)-norfriedelane-3α,4α-diol (25b). On acetylation of **25a** afforded the acetate (**25b**), mp 212—214 °C (needles from ether–cyclohexane); IR 3500, 3300, 1750, 1730, 1260, and 1065 cm^{-1}. ^{1}H NMR (60 MHz, $CDCl_3$) δ=2.10 (3H, s; CH_3COO-) and 4.10 (2H, s; $-CH_2OOC-$); MS m/z (%) 460 (M^+; trace), 442 (10), 417 (68), 273 (23), 219 (30), 205 (100), 191 (34), 142 (55), and 109 (80); Found: C, 76.17; H, 10.67%. Calcd for $C_{32}H_{54}O_4$: C, 76.44; H, 10.83%.

4α-Hydroxy-A(1)-norfriedelan-3-one (26) and 4β-Hydroxy-A(1)-norfriedelan-3-one (32). Friedelane-2,3-dione (**28**; 5 g) and potassium hydroxide (5 g) were dissolved in diethylene glycol (400 ml) and the mixture was heated at 200 °C for 10 h under a nitrogen atmosphere. The solution was then poured into 2% hydrochloric acid (1 l) with formation of white precipitates, which were collected on a filter paper and dried. Although the benzilic acid rearrangement product consisted of a mixture of stereoisomers, further purification was not done.

The crude product obtained above, was suspended in acetic acid (300 ml) and LTA was added until no starting material was detected on TLC. Then the reaction mixture was poured into water and extracted with ether. The ether layer was worked up as usual and chromatographed (silica gel-benzene) to give a mixture of A(1)-norfriedelan-3-one (**29**) and its 4-epimer.

The mixture (1 g) of **29** and its 4-epimer was refluxed with benzoyl chloride (30 ml) for 1 h. After cooling, pyridine (10 ml) and then water (10 ml) were added dropwise, and the mixture was allowed to stand until the exothermic reaction ceased. Ether was added and the ethereal solution was washed with dil hydrochloric acid. The organic layer was worked up in usual manner and subjected to chromatography on silica gel. Elution with benzene-petroleum benzine afforded A(1)-norfriedel-3-en-3-yl benzoate (**27**; 0.93 g), mp 206—209 °C (from dichloromethane-cyclohexane); IR 1740, 1685, 1250, 1100, and 710 cm^{-1}; ^{1}H NMR (60 MHz, $CDCl_3$) δ=7.3—8.3 (5H, m; C_6H_5-); MS m/z (%) 516 (M^+; 0.4), 501 (4), 155 (5), 135 (7), 121 (11), 109 (14), 107 (14), and 105 (100); Found: C, 83.41; H, 10.14%. Calcd for $C_{36}H_{52}O_2$: C, 83.66; H, 10.14%.

To a solution of the benzoate (**27**; 1 g) in dichloromethane (300 ml) was added 39% peracetic acid solution (20 ml, a trace amount of sulfuric acid in the solution was neutralized by addition of potassium acetate before use). The reaction mixture was kept in a dark place for a week, and then the remaining peroxide was decomposed with an aqueous solution of potassium iodide and sodium sulfite. The organic layer was washed with sodium carbonate solution and concentrated to yield a residue, which was hydrolyzed with ethanolic potassium hydroxide solution at room temperature for 2 d. After most of ethanol was removed in vacuo, the residue was extracted with benzene and chromatographed on silica gel. Elution was performed with benzene to afford 4α-hydroxy-A(1)-norfriedelan-3-one (**26**; 530 mg) and the 4β-epimer (**32**; 3 mg) in turn. **26**; mp 286 °C (with decomp) (from benzene); IR 3450, 1740, 1090, and 915 cm^{-1}; ν^{OH} (0.001 M carbon tetrachloride solution) 3606 cm^{-1}; ^{1}H NMR (90 MHz, $CDCl_3$) δ=2.18 (1H, s; -OH); MS m/z (%) 428 (M^+; 36), 341 (63), 205 (69), 137 (56), 135 (46), 123 (72), 121 (53), and 109 (100); Found: C, 80.95; H, 11.02%. Calcd for $C_{29}H_{48}O_2$: C, 81.25; H, 11.29%. **32**; Mp 214—216.5 °C (from cyclohexane); IR 3450, 3400, 1755, and 1745 cm^{-1}; ν^{OH} (0.001 M carbon tetrachloride solution) 3563 cm^{-1}; ^{1}H NMR (90 MHz, $CDCl_3$) δ=2.0 (1H, s; -OH); MS m/z 428 (M^+; 38), 341 (50), 205 (78), 137 (46), 123 (75), 121 (54), 109 (100), and 107 (54); Found: m/z 428.3624. Calcd for $C_{29}H_{48}O_2$: M, 428.3654.

Methyl 4-Oxo-3,4-seco-A(1)-norfriedelan-3-oate (33b). 4-Oxo-3,4-seco-A(1)-norfriedelan-3-oic acid (**33a**) was prepared from friedelane-2,3-dione (**28**) by the same procedure as that for the preparation of 4-oxo-3,4-secofriedelan-3-oic acid (**17a**) from friedel-3-en-3-yl benzoate (vide supra). **33a**; Mp 215—217 °C (from ethanol); IR 3450, 1740, 1200, 1180, 1150, 1070, 1050, 1010, 990, and 900 cm^{-1}; ^{1}H NMR (60 MHz, $CDCl_3$) δ=2.20 (3H,s; Ac) and 1.9—2.5 (2H, m; $-C\underline{H_2}-COOH$); MS m/z (%) 444 (M^+; 2), 401 (40), 219 (19), 205 (100), 137 (28), 135 (26), 123 (48), 121 (37), and 109 (88). On methylation with diazomethane, **33a** afforded methyl 4-oxo-3,4-seco-A(1)-norfriedelan-3-oate (**33b**), mp 166—167 °C (from ethanol); IR 1740, 1695, 1295, 1170, and 995 cm^{-1}; ^{1}H NMR (60 MHz, $CDCl_3$) δ=2.20 (3H, s; Ac) and 3.63 (3H, s; $-COOCH_3$); MS m/z (%) 458 (M^+; 6), 415 (35), 219 (12), 205 (45), 163 (20), 135 (50), 121 (78), and 109 (100).

4α-Hydroxyfriedelan-3-one (35) and 4β-Hydroxyfriedelan-3-one (36). The preparation procedure of **35** and **36** was almost the same as that of 4α- and 4β-hydroxy-A(1)-norfriedelan-3-ones (**26** and **32**) from friedelane-2,3-dione (**28**). **35**; Mp 269—271 °C (from ethyl acetate); IR 3440, 1710, 1110, and 1070 cm^{-1}; ν^{OH} (0.001 M carbon tetrachloride solution) 3620 cm^{-1}; ^{1}H NMR (60 MHz, $CDCl_3$) no signals below δ 2.5 were observed. MS m/z (%) 442 (M^+; 40), 205 (74), 123 (81), 121 (52), 109 (100), and 107 (56); Found: C, 81.16; H, 11.11%. Calcd for $C_{30}H_{50}O_2$: C, 81.39; H, 11.38%. **36**; Mp 234.5—236 °C (from ethyl acetate); IR 3470, 1720, 1160, and 1125 cm^{-1}; ν^{OH} (0.001M carbon tetrachloride solution) 3520 cm^{-1}; ^{1}H NMR (60 MHz, $CDCl_3$) δ=2.55 (2H, m; $C_{(2)}H_2CO-$) and 3.9 (1H, s; -OH); MS m/z (%) 442 (M^+; 19), 399 (5), 205 (39), 189 (17), 135 (39), 121 (64), and 109 (100).

References

1) T. Nishihama and T. Takahashi, *Bull. Chem. Soc. Jpn.*, **39**, 200 (1966).

2) E. J. Bailey, D. H. R. Barton, J. Elks, and J. F. Templeton, *J. Chem. Soc.*, **1962**, 1578; B. Camerio, B. Patelli, and R. Sciaky, *Tetrahedron Lett.*, **1961**, 554; H. Mori, V. S. Gandhi, and E. Schwenk, *Chem. Pharm. Bull.*, **10**, 842 (1962).

3) R. Hanna and G. Ourisson, *Bull. Soc. Chim. Fr.*, **1961**, 1945.

4) N. L. Drake and J. K. Wolfe, *J. Am. Chem. Soc.*, **61**, 3074 (1939).

5) The Baeyer–Villiger reaction was known to proceed with the retention of the configuration of the chiral carbon α to the carbonyl group; this is exigent of the 4R-configuration for **10**. The other δ-lactone,[4] 4-epi-3-oxafriedelan-2-one (**10′**), obtained by reduction of **33a** with sodium and 1-propanol was not identical with **10**. This leads to the 4S-configuration for **10′**. The alcohol (**10′**) was also obtained by $NaBH_4$ reduction of **33b** in a quantitative yield. The presence of **10** was not detected in the reaction product. **10′**; IR 1720, 1215, 1198, 1175, 1062, 1055, and 977 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) $\delta=2.3$—2.5 (2H, m; CH_2CO-) and 4.05 (1H, q, $J=7$ Hz); MS m/z (%) 428 (M^+; 2.2), 342 (12), 304 (13), 276 (13), 235 (18), 205 (39), and 109 (100).

6) T. Tsuyuki, R. Aoyagi, S. Yamada, and T. Takahashi, *Tetrahedron Lett.*, **1968**, 5263.

7) V. V. Kane and R. Stevenson, *J. Org. Chem.*, **25**, 1394 (1960).

8) F. V. Brutcher, Jr. and W. Bauer, Jr., *J. Am. Chem. Soc.*, **84**, 2236 (1962). Ring D of steroidal 16-one is known to adopt a half chair conformation. The conformational situation of ring A in **26** and **32** is considered to be almost the same as that of the steroidal ring D.

9) M. Oki, H. Iwamura, J. Aihara, and H. Iida, *Bull. Chem. Soc. Jpn.*, **41**, 176 (1968); L. Joris and P. von R. Schleyer, *J. Am. Chem. Soc.*, **90**, 4599 (1968).

10) T. Matsuura, "Sanso-sanka-hanno," Maruzen, Tokyo, (1977), p. 174.