The Reaction of Dammarane Derivatives: Reactions Involving C-20 Carbonium Ions

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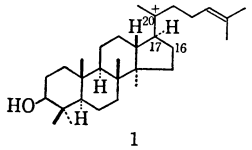
In order to investigate the reaction involving C-20 cation in dammarane derivatives, following reactions were examined: a) (20*S*)- and (20*R*)-dammaran-20-ols (**13** and **14**) with acids. b) dammar-20(22)-en-23-one (**15**) with hydrochloric acid, c) 20,21- and 20,22-epoxydammaranes (**16** and **17**) with boron trifluoride etherate, and d) hexanor- and pentanordammaran-20-ols (**18** and **19**) with phosphoryl chloride and with boron trifluoride etherate, *etc.*, and 20ξ-tosyloxyhexanordammarane (**46**) with silica gel. Either formation of a double bond in the framework or in the side chain (in the cases of **13**, **14**, **18**, **19**, and **46**), deconjugation of the double bond (in the case of **15**), or formation of a carbonyl group in the side chain (in the cases of **16** and **17**) was observed. However, D-homoannulation reaction was not observed in all cases.

The biogenetic pathway of triterpenes proposed by Ruzicka *et al.*[1] strongly suggests an intermediacy of a tetracyclic cation (**1**) with a dammarane-type skeleton as a primary cyclization product from squalene. The cation (**1**) is also suggested to be transformed into various triterpenes depending on characteristic enzyme action *in vivo*. For example, a $C_{(16)}$–$C_{(17)}$ bond migration to C-20 causes a formation of a baccharane skeleton (**2**) with the cation at C-20, which will be further derived into baccharis oxide (**3**) or shionone (**4**).



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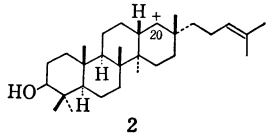

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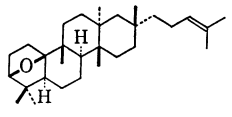

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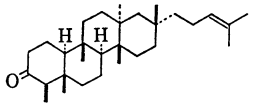

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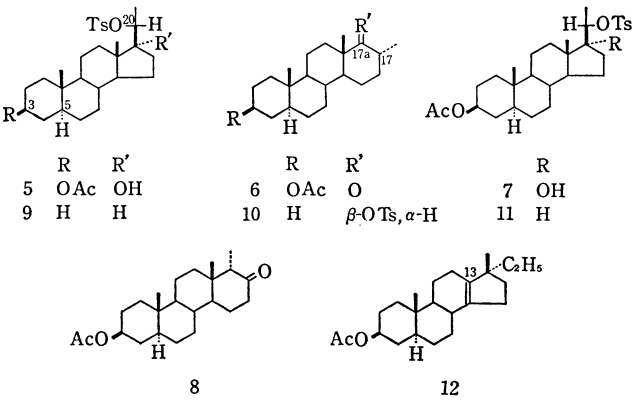
In the field of steroid chemistry, a number of investigations on backbone rearrangement and D-homoannulation reactions have been reported.[2] Among them, D-homoannulation of 20-tosylates has been shown to depend on the configuration at C-20 and also on the solvolytic conditions. For example, 3β-acetoxy-17α-hydroxy-5α-pregnan-20β-yl tosylate (**5**), on treatment with potassium acetate in aqueous acetone or with sodium iodide in acetone, gave 3β-acetoxy-17α-methyl-D-homo-5α-androstan-17a-one (**6**) as a principal product. While the epimeric 20α-tosylate (**7**) yielded 3β-acetoxy-17aα-methyl-D-homo-5α-androstan-17-one (**8**).[3] A solvolysis of 5α-pregnan-20β-yl tosylate (**9**) gave 17α-methyl-D-homo-5α-androstan-17aβ-yl tosylate (**10**) in a high yield.[4] The formolysis of 3β-acetoxy-5α-pregnan-20α-yl tosylate (**11**), however, proceeds predominantly without enlargement of the D-ring to afford 17β-methyl-18-nor-5α,17α-pregn-13-en-3β-yl acetate (**12**) as a main product.[2d]

Since Mills determined the structures of triterpenes of dammarane-type isolated from "Dammar Resin,"[5]



	R	R′
5	OAc	OH
9	H	H

	R	R′
6	OAc	O
10	H	β-OTs, α-H

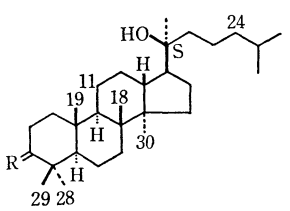
	R
7	OH
11	H

8 12

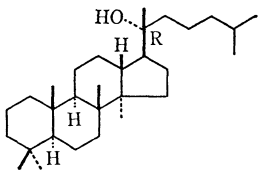
a variety of investigations on the reactions of dammarane derivatives have so far been carried out.[6,7] In order to examine the reaction of dammarane derivatives having a cationic center at C-20, following reactions have now been investigated: a) (20*S*)- and (20*R*)-dammaran-20-ols (**13** and **14**) with acids, b) dammar-20(22)-en-23-one (**15**) with hydrochloric acid, c) 20,21- and 20,22-epoxydammaranes (**16** and **17**) with boron trifluoride etherate, and d) hexanor- and pentanordammaran-20-ols (**18** and **19**) with phosphoryl chloride.

a) Reaction of (20S)- and (20R)-Dammaran-20-ols (13 and 14) with Acids. Although (20*S*)-dammaran-20-ol (**13**)[8] was easily prepared by Huang-Minlon reduction of (20*S*)-20-hydroxydammaran-3-one (**20**)[5b] derived from dipterocarpol (**21**),[5,6a–d] the epimeric (20*R*)-alcohol (**14**) was synthesized from **13** *via* hexanordammaran-20-one (**22**) or nordammaran-20-one (**23**).[9]

(20*S*)-Dammaran-20-ol (**13**) was treated with phosphoryl chloride in pyridine to afford an olefin mixture, which was subjected to separation by silver nitrate-impregnated silica gel TLC to give a mixture (*ca.* 1 : 1) of (20*R*)- and (20*S*)-dammar-13(17)-enes (**24a** and **24b**; yield 3%), a mixture of (*E*)- and (*Z*)-dammar-20(22)-enes (**25a** and **25b**; y. 65%), and dammar-20-ene (**26**; y. 25%). The structure of the former (**24**) was discussed below and those of the latter two (**25** and **26**) were determined by spectral data (*cf.* Experimental) and by their transformation into **22** and **23**, respectively. The olefin mixture, without separation, was subjected to ozonolysis and the resulting mixture was separated by chromatography to afford hexanordammaran-20-one



13 R = H_2
20 R = O
21 R = O; with Δ^{24}
34 R = β-OAc, α-H



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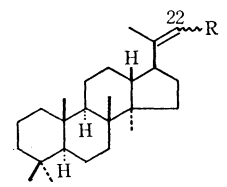
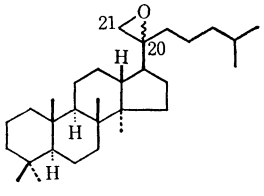


a: (E)-isomer
b: (Z)-isomer

15 R = $\overset{O}{\overset{\|}{C}}CH_2CH(CH_3)_2$
25 R = $(CH_2)_2CH(CH_3)_2$
37 R = CN
38 R = CO_2CH_3



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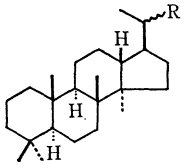
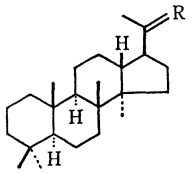
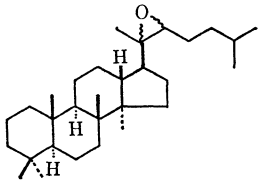


18 R = OH
42 R = $\overset{O}{\overset{\|}{C}}(CH_2)_2CH(CH_3)_2$
43 R = Cl
46 R = OTs



22 R = O
48 R = CH_2



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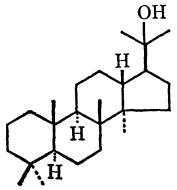

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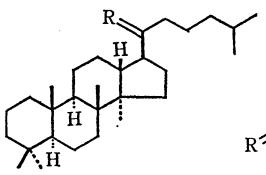
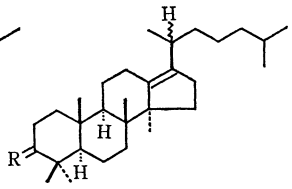
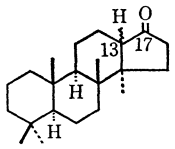


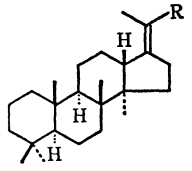
23 R = O
26 R = CH_2



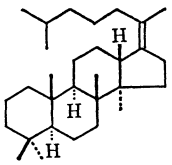
a: (20R)
b: (20S)
24 R = H_2
35 R = β-OAc, α-H



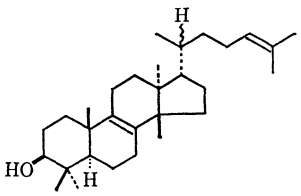
27 13α-H
28 13β-H



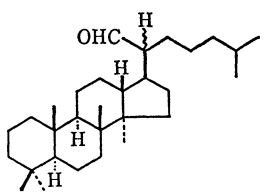
29a R = $(CH_2)_3CH(CH_3)_2$
47 R = CH_3



29b



36 a: (20R)
b: (20S)



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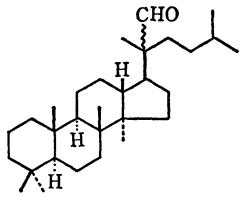

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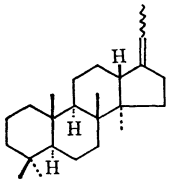

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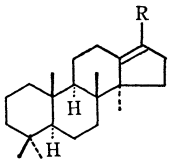
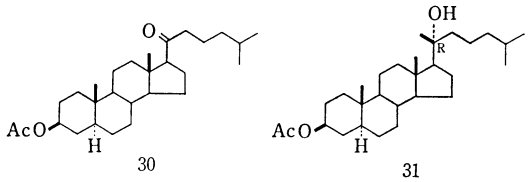


45 R = CH_2CH_3
49 R = $CH(CH_3)_2$

(**22**; 40%)[8,10] and nordammaran-20-one (**23**; 22%), together with 13α*H*-octanordammaran-17-one[11] (**27**; 0.4%) and octanordammaran-17-one[11] (**28**; 1.7%). It was therefore suggested that dammar-17(20)-enes (**29a** and/or **29b**) had also been present in a very small amount in the above olefin mixture.[7]

The structure of nordammaran-20-one (**23**) was confirmed by its conversion into dammaran-20-ols (**13** and **14**). Nordammaran-20-one (**23**) was treated with methylmagnesium iodide in ether to give a mixture of the epimeric alcohols (**13** and **14**) in a ratio of 1 : 2, while the Grignard reaction of hexanordammaran-20-one (**22**) with 1-bromo-4-methylpentane in tetrahydrofuran gave the same mixture in a ratio of 11 : 8.

The stereochemistry of the addition reaction of Grignard reagents to 20-keto steroids has been investigated. For example,[12] the addition of methylmagnesium bromide to 3β-acetoxy-21-nor-5α-cholestan-20-one (**30**) gave exclusively the corresponding (20*R*)-alcohol (**31**). On the contrary, the (20*S*)-epimeric alcohol (**32**) was obtained by addition of 4-methylpentylmagnesium bromide to 3β-acetoxy-5α-pregnan-20-one (**33**). The selectivity in these reactions seems to be attributable to the presence of the 13β-methyl group in the steroid skeleton. The lower selectivity to form the (20*S*)- or (20*R*)-alcohol in the case of the dammarane derivatives, compared with the reaction of 20-keto steroids, could be explained by the absence of the 13β-methyl group in the dammarane skeleton.[9]



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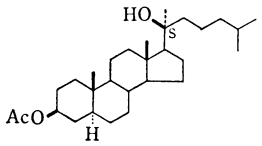

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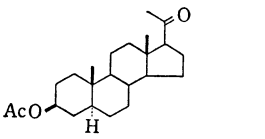


33

Mills showed that dammaranediol-II monoacetate (**34**) gave a mixture of isoeuphenyl acetate (**35a**) and isotirucallenyl acetate (**35b**) on treatment with 1 M sulfuric acid.[5b] Tanaka *et al.*[6e,13] reported acid treatments of (20*S*)-dammaran-20-ol (**13**), (20*S*)-dammar-24-en-20-ol, and of the corresponding 12-hydroxylated compounds to examine the epimerization at C-20.

Dehydration reaction of the epimeric (20*S*)- and (20*R*)-dammaran-20-ols (**13** and **14**) catalyzed by various acids has now been investigated under various conditions. i) Treatment of (20*S*)-dammaran-20-ol (**13**) in benzene with boron trifluoride etherate gave a hydrocarbon as a main product. This hydrocarbon was shown to be a mixture (*ca.* 1 : 1) of (20*R*)- and (20*S*)-dammar-13(17)-enes (**24a** and **24b**) by the following evidence. A mixture of euphol (**36a**) and tirucallol (**36b**), extracted from *Euphorbia kansui* Liou.,[14] was acetylated, hydrogenated, and then treated with hydrochloric acid in acetic acid according to the procedures described by Arigoni *et al.*,[15] to yield a mixture of isoeuphenyl acetate (**35a**) and isotirucallenyl acetate (**35b**).[15] This mixture (**35a** and **35b**) was subjected successively to alkaline hydrolysis, Jones oxidation, and Huang-Minlon reduction to afford a mixture of (20*R*)- and (20*S*)-dammar-13(17)-enes (**24a** and **24b**), which was found to be identical with the hydrocarbon obtained by boron trifluoride etherate treatment of **13**. The ratio (*ca.* 1 : 1) of **24a** and **24b** in the olefin mixture (**24**) was estimated from peak heights of the C-21 methyl signals (**24a**, δ 0.94; **24b**, δ 0.90)[16] and by gas chromatographic analysis. When (20*R*)-dammaran-20-ol (**14**) was treated with boron trifluoride etherate in benzene, the same mixture (**24a** and **24b**; *ca.* 1 : 1) was formed.

(20*S*)-Dammaran-20-ol (**13**) was then treated with the following conditions: ii) boron trifluoride etherate in dichloromethane at room temperature, iii) boron trifluoride etherate in acetic acid, iv) stannic chloride in benzene, v) picric acid in nitromethane,[17] vi) 1 M sulfuric acid in acetic acid under reflux according to Mills' procedure,[5b] and vii) formic acid in acetone under reflux. Treatment of (20*R*)-dammaran-20-ol (**14**) with i) boron trifluoride etherate in benzene, ii) boron trifluoride etherate in dichloromethane, or with iii) trifluoroacetic acid, was also examined. In each case, the same reaction products (**24a** and **24b**) were obtained. When protic acids were used, the formation of **25** and **26** was also observed. However, Lewis acid treatment afforded **24** as major products.

Removal of the hydroxyl group at C-20 of **13** or **14** by an acid catalyst may produce a cation at C-20. As this type of cation has rather a long life time, the hydrogen atom at C-17α can undergo 1,2-shift from both the back and the front sides of the cation, resulting in the formation of the epimeric mixtures at the C-20 carbon atom. A C-13β hydrogen atom is then removed to provide an unsaturated double bond $C_{(13)}$–$C_{(17)}$, the position of which is considered to be the most stable one in the dammarane skeleton.

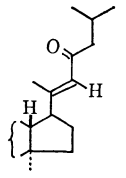
b) Synthesis of Dammar-20(22)-en-23-one (15) and Reaction with Hydrochloric Acid. It was unsuccessful to build up the side chain of **15** directly by the Wittig reaction of hexanordammaran-20-one (**22**) with dimethyl 4-methyl-2-oxopentylphosphonate;[18] an anion derived from the phosphonate was unreactive with the ketone (**22**) in dimethyl sulfoxide or in dimethoxyethane under reflux. Hexanordammaran-20-one (**22**), however, reacted with diethyl cyanomethylphosphonate in dimethoxyethane using sodium hydride as a base. The reaction proceeded quantitatively to yield pentanordammar-20(22)-ene-22-carbonitrile (**37**). Recrystallization from petroleum ether-ether furnished a major isomer, mp 179—180 °C, which was shown to be an (*E*)-isomer (**37a**) from the proton NMR[19] (*cf.* Experimental) and the ^{13}C-NMR spectral data (Table 1). An examination of the mother liquor showed also the presence of the (*Z*)-isomer (**37b**).

The structure of the α,β-unsaturated carbonitrile (**37**) was also supported by its conversion into the α,β-unsaturated ester (**38**). The (*E*)-isomer of the carbonitrile (**37a**) was treated with potassium hydroxide in boiling ethylene glycol followed by methylation with diazomethane to give a mixture of methyl (*E*)- and (*Z*)-tetranordammar-20(22)-en-23-oates (**38a** and **38b**), which was separated by TLC into each isomer.

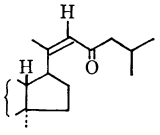
The residual C-4 unit was then introduced to the tetranordammarane skeleton (**37a**). Treatment of **37a** with isobutylmagnesium bromide gave an imine, which was hydrolyzed *in situ* with aqueous ammonium chloride.[20] The resulting products, consisting of (*E*)- and (*Z*)-dammar-20(22)-en-23-ones (**15a** and **15b**), were separated into each isomer by preparative TLC. Assignment of the geometry of the double bonds in **15a**

and **15b** was easily accomplished by NMR measurement.[21,22] The methyl group attached to an olefinic carbon atom at C-20 of the less polar (on TLC) isomer resonates at δ 1.79 (d, J=1.5 Hz) and that of the more polar one at δ 2.05 (d, J=1 Hz). The methyl group resonating in the lower field can be assigned as that of the (*E*)-isomer (**15a**).

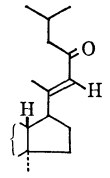
The conformation of each enone (**15a** and **15b**) was also inferred by the solvent effect on the chemical shifts of the proton NMR spectrum.[21a,23] In benzene-d_6, the chemical shift of the $C_{(21)}$–Me of the (*E*)-isomer (**15a**) was observed in the lower field ($\delta_{CDCl_3}-\delta_{C_6D_6}=-0.14$), although the olefinic proton resonated in the higher field ($\delta_{CDCl_3}-\delta_{C_6D_6}=+0.03$). As for the (*Z*)-isomer (**15b**), both of the signals suffered appreciable upfield shifts ($\delta_{CDCl_3}-\delta_{C_6D_6}=+0.15$ for the methyl and +0.12 for the olefinic proton signals). These spectral data suggest the conformation depicted as in **15a**-1 and **15b**-1 (not as in **15a**-2 and **15b**-2) for **15a** and **15b**, respectively, in the solution.



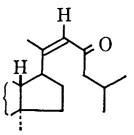
15a-1



15b-1



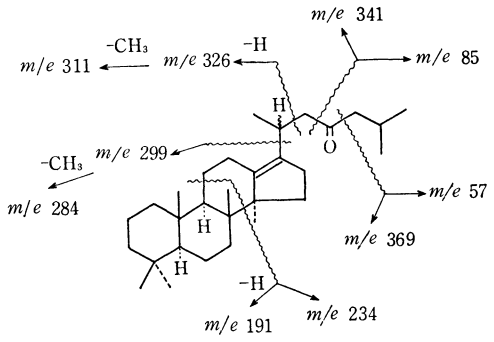
15a-2



15b-2

Treatment of the (*E*)-isomer (**15a**) with *p*-toluenesulfonic acid in ether gave a mixture of the (*E*)- and (*Z*)-isomers (**15a** and **15b**). The (*Z*)-isomer (**15b**) also afforded the same mixture on the same treatment. Similar results were obtained upon treatment with boron trifluoride etherate.

The (*E*)-isomer (**15a**) was refluxed with concd hydrochloric acid in ethanol. Two products were obtained in about equal amounts. The IR spectrum of the less polar product (on TLC) shows bands at 1700 and 1600 cm^{-1} and that of the more polar one at 1705 cm^{-1}. Mass spectra of both compounds closely resemble each other. These observations suggest the similarity of the whole structure of both compounds having a deconjugated double bond. Since NMR spectra show no olefinic proton, the presence of a tetrasubstituted double bond is suggestive. A carbonyl function at C-23 is indicated by fragment peaks at *m/e* 369 and *m/e* 57 and also at *m/e* 341 and *m/e* 85. The location of the tetrasubstituted double bond is also suggested by the mass spectrum (*cf.* **39**). The structure of the two products are therefore considered to be (20ξ_1)- and (20ξ_2)-dammar-13(17)-en-23-ones (**39**).



39

Protonation at $C_{(23)}$–O function of **15a** provokes of a generation of a cationic center at C-20. Successive 1,2-shift of a hydride from the C-17α to the C-20 carbon atom and deprotonation of $C_{(13\beta)}$–H, or a mechanism involving 1,3-shift, would give rise to a tetrasubstituted double bond between C-13 and C-17. Direct protonation at the double bond of **15a** could also illustrate the formation of the cationic center at C-20.

*c) Synthesis of 20,21- and 20,22-Epoxydammaranes (**16** and **17**) and Reaction with Boron Trifluoride Etherate.* Epoxidation of dammar-20-ene (**26**) with *m*-chloroperbenzoic acid in dichloromethane gave an epoxide (**16**). A signal due to two protons of the epoxide ring terminus appeared at δ 2.59 (br. s, $W_{1/2}$ 2 Hz). As this epoxide was thought to be a mixture of (20*S*)- and (20*R*)-configurations, it was reduced with lithium aluminium hydride in ether. (20*S*)-Dammaran-20-ol (**13**) and (20*R*)-dammaran-20-ol (**14**) were obtained in a ratio of 2: 3. No formation of other alcohols was detected. Consequently, the epoxide mixture was suggested to consist of the (20*S*)- and (20*R*)-20,21-epoxydammaranes (**16**) in a ratio of *ca.* 2: 3. Further separation was not attempted.

Treatment of this mixture of epoxide (**16**) with boron trifluoride etherate in benzene at room temperature for 10 min gave an aldehyde (**40**). Its IR (2680 and 1720 cm^{-1}) and NMR [δ 9.55 and 9.68 (each *ca.* 0.5H, d, J=3 Hz)] spectra suggested the presence of an aldehyde group attached to a secondary carbon atom. And the NMR spectrum also indicated the presence of a pair of C-20 isomeric aldehydes.

Epoxidation of the mixture of dammar-20(22)-enes (**25a** and **25b**) gave an epoxide mixture (**17**). An HPLC examination of **17** suggested the presence of four possible stereoisomers, one of which was the major. The mixture of the epoxides (**17**) including four stereoisomers was treated with boron trifluoride etherate in benzene at room temperature for 20 min. Three products were obtained after usual work-up. The least polar product (on TLC) showed bands at 2660 and 1720 cm^{-1} in its IR spectrum. Its mass spectrum showed peaks at *m/e* 428 (M^+), 399 (M−CHO), 357 ($M-C_5H_{11}$), and 301 ($M-C_8H_{15}O$). These observations suggest the presence of a tertiary aldehyde function and lead to the structure of (20ξ_1)-26,27-dinor-20,24-dimethyldammaran-21-al [(20ξ_1)-**41**] for this product. The spectral data of the second product [(20ξ_2)-**41**] were

very similar to those of the first one. This fact indicates that these two products are epimers at C-20 each other. However, the configuration of each compound has been left undetermined. The most polar product showed a band at 1710 cm^{-1} and peaks at *m/e* 428 (M^+), 357 ($M-C_5H_{11}$), and 329 ($M-C_6H_{11}O$). This product can be formulated as (20ξ)-dammaran-22-one (**42**) by these spectral data and mechanistic consideration.

An attack of boron trifluoride etherate to the oxygen atom of the epoxide and subsequent ring opening by the $C_{(20)}$–O bond cleavage may generate the cationic center at C-20. In the former (**16**) case, a hydride at C-21 migrates to the C-20 carbon atom to afford the aldehyde (**40**). The configuration at C-20 must be determined by the original configuration of the epoxide: *i.e.*, the hydride which migrates is considered to be introduced from the back side of the oxygen atom of the epoxide. In the latter (**17**) case, there are two possible migrating group, *i.e.*, a hydrogen atom and an isopentyl group on the C-22 carbon atom. When the hydrogen atom migrates to C-20, it may result in formation of the ketone (**42**), while the aldehyde (**41**) may be obtained when the isopentyl group undergoes a 1,2-shift to C-20. Neither hydride shift from C-17α to C-20 nor $C_{(17)}$–$C_{(13\text{ or }16)}$ bond migration was observed. A factor of stabilization for the formation of a carbonyl group seems to be larger than that for an en-ol structure. Recently, similar results using cholestane derivatives have been reported by Ikekawa et al.[24] and others.[25,26] All the isomers of the 20(22)-epoxides were synthesized independently and their chemical reactions were discussed.

d) *Reaction of Hexanor- and Pentanordammarane Derivatives.* Hexanordammaran-20-one (**22**) was reduced with sodium borohydride in ethanol to yield a mixture of alcohols (**18**) which could not be separated. This secondary alcohol (**18**) was dehydrated with phosphoryl chloride in pyridine to afford a mixture, which showed two spots on TLC of silica gel. The more polar product (on TLC) was shown to be a mixture of (20*S*)- and (20*R*)-20-chlorohexanordammarane (**43**) (*cf.* Experimental). The less polar part (hydrocarbon) showed one major peak along with two minor ones on GLC analysis. A signal due to an olefinic proton was observed around δ 5.0 ppm (diffused). In order to determine the exact position of the double bond, a solution of this hydrocarbon mixture in carbon tetrachloride was treated with ruthenium tetraoxide in the same solvent at room temperature. On separation by preparative TLC, octanordammaran-17-one (**28**) was obtained, which was identical with an authentic sample.[11] A solution of the hydrocarbon mixture in dry tetrahydrofuran was subjected to hydroboration-oxidation to yield hexanordammaran-20-ol (**18**). The formation of hexadammar-17(20)-enes (**44**) and of **43** from **18** was therefore shown.

Treatment of hexanordammaran-20-ol (**18**) with *p*-toluenesulfonyl chloride in pyridine gave a tosylate (**46**). The tosylate (**46**) was passed through a column of silica gel to give a single product (**45**), mp 104—106 °C, after recrystallization from methanol–chloroform. The elemental analysis and mass spectrum showed a molecular formula, $C_{24}H_{40}$, for this compound. The NMR spectrum showed the presence of an ethyl group and the absence of olefinic proton. In view of the above facts the most reasonable structure of this olefin is hexanordammar-13(17)-ene (**45**).

Hexanordammaran-20-one (**22**) was methylated with methylmagnesium iodide in ether to give a tertiary alcohol (**19**). The alcohol (**19**) was dehydrated with phosphoryl chloride in pyridine to afford two hydrocarbons, which were separated by preparative TLC on silver nitrate-impregnated silica gel. The less polar product could be formulated as pentanordammar-17(20)-ene (**47**) from its NMR spectrum showing the presence of an isopropylidene group. The NMR spectrum of the more polar product indicated the presence of an isopropenyl group; this led to the structure of pentanordammar-20-ene (**48**) for this hydrocarbon.

Treatment of the alcohol (**19**) with boron trifluoride etherate in benzene at room temperature for 1 h furnished two products. The more polar product (on TLC) was identical with **48**. The NMR spectrum of the less polar product showed the presence of an isopropyl group and the absence of olefinic proton; the structure of pentanordammar-13(17)-ene (**49**) was suggested for this product.

These characteristic dehydration reactions are mainly dependent on both of the acids and the solvents used. When a base such as pyridine is present in the reaction system, a proton adjacent to a hydroxyl group is easy to be abstracted. It is known that dammarane-type triterpenes having a normal side chain produce 20(22)- and 20-enes as major products[5] (*vide supra*). However, when the side chain is small, a base such as pyridine can abstract the hydrogen atom at C-17α to afford a 17(20)-ene. This is the remarkable difference between the two. In the case of boron trifluoride etherate, a hydride shift and a subsequent deprotonation can occur to yield the more stable 13(17)-ene, as the life time of the cationic center is longer.

Although all the reactions were attempted for aiming at the chemically induced rearrangements of the C-20 cation of the dammarane-type into baccharane-type skeleton, neither tertiary cation nor secondary cation at C-20 underwent such rearrangement.

^{13}C-NMR Spectra. Recently, O. Tanaka and his co-workers reported the assignments of carbon signals of dammarane-type triterpenes and discussed the chemical shift difference between (20*S*)- and (20*R*)-dammarane-12,20-diol derivatives.[27,28] Remarkable differences were observed owing to a hydrogen bonding between $C_{(12)}$–OH and $C_{(20)}$–OH groups.

We examined the ^{13}C-NMR spectra of some dammarane derivatives without $C_{(3)}$–oxygen function. The assignment of carbon signals of dipterocarpol (**21**) by O. Tanaka et al.[28] made it possible to assign the $C_{(24)}$ and $C_{(25)}$ carbon atoms of dihydrodipterocarpol (**20**; (20*S*)-20-hydroxydammaran-3-one). The accuracy of the assignment was confirmed by the hexanor derivative (**22**). Signals due to $C_{(1)}$—$C_{(6)}$, $C_{(28)}$, and $C_{(29)}$ of (20*S*)- and (20*R*)-dammaran-20-ols (**13** and **14**) were easily assigned by considering the additivity and the effects of substituents and also from comparison of the spectra from compound to compound.

Table 1. ^{13}C-NMR chemical shifts, δ_C, of some derivatives of dammarane-type in $CDCl_3$[1)]

	21[2)]	**20**	**13** 20(*S*)	**14** 20(*R*)	***S*-*R***[3)]	**22**	**37a**
C-1	39.9	39.9[b)]	40.6[c)]	40.6[c)]	0	40.7[c)]	40.8[c)]
2	34.0	34.0	18.7	18.6	+0.1	18.6	18.6
3	217.6	217.8	42.2[c)]	42.1[c)]	+0.1	42.1[c)]	42.2[c)]
4	47.3	47.3	33.4	33.4	0	33.4	33.4
5	55.3	55.4	57.0	57.0	0	57.0	57.0
6	19.6	19.7	18.7	18.6	+0.1	18.6	18.6
7	34.5	34.6	35.3	35.3	0	35.5	35.4
8	40.3	40.3	40.6	40.6	0	40.7	40.8
9	50.0	50.1	50.8	50.7	+0.1	50.8	50.9
10	36.8	36.8	37.5	37.4	+0.1	37.5	37.6
11	22.0	22.1	21.5	21.4	+0.1	21.1	21.1
12	25.4	25.6	25.6	25.3	+0.3	25.7[d)]	24.9
13	42.3	42.4	42.2	42.1	+0.1	45.2	45.8
14	50.2	50.3	50.4	50.1	+0.3	50.1	49.9
15	31.2	31.2	31.2	31.0	+0.2	31.5	31.6
16	27.5	27.6	27.6	27.6	0	25.9[d)]	27.9
17	49.7	49.7	49.8	49.6	+0.2	54.3	49.9
18	16.0[a)]	16.0[a)]	16.2[a)]	16.2[a)]	0	15.9[a)]	15.9[a)]
19	15.2[a)]	15.2[a)]	15.6[a)]	15.6[a)]	0	15.6[a)]	15.7[a)]
20	75.1	75.2	75.3	75.5	−0.2	211.9	168.3
21	24.8	24.8	24.8	23.9	+0.9	29.9	18.3
22	40.6	41.2	41.1	42.4	−1.3	—	94.5
23	22.6	21.5	21.5	21.1	+0.4	—	117.5
24	124.8	39.8[b)]	39.8	39.7	+0.1	—	—
25	131.2	28.0	28.0	28.0	0	—	—
26	25.7	22.7	22.7	22.7	0	—	—
27	17.7	22.7	22.7	22.7	0	—	—
28	26.7	26.7	33.4	33.4	0	33.4	33.4
29	21.0	21.0	21.5	21.5	0	21.5	21.6
30	16.3	16.4	16.5	16.4	+0.1	16.2	16.3

a,b,c,d) Assignments may be reversed in each vertical column. 1) FT measurement conditions were as follows: spectral width, 4000 Hz; acquisition time, 1.0 s; number of data points, 8192; pulse width, 3 μs. 2) Ref. 28. 3) Difference of the chemical shift values (δ_C) between (20*S*)-dammaran-20-ol (**13**) and (20*R*)-dammaran-2-ol (**14**).

The unsaturated carbonitrile (**37a**) was deduced to be pure (*vide supra*), showing 26 peaks.

The chemical shift difference between the (20*S*)- and (20*R*)-isomers was very small except for $C_{(21)}$ and $C_{(22)}$ carbon atoms as described by O. Tanaka *et al.*[28)] (Table 1).

Experimental

General Procedures. All melting points were measured on a Mel-temp capillary melting point apparatus (Laboratory Devices) and uncorrected. Optical rotations were determined in chloroform solutions on a JASCO polarimeter DIP-SL. Ultraviolet absorption (UV) spectra and infrared (IR) spectra were measured on a Hitachi EPS-2 and a Hitachi EPI-G2 spectrometer, respectively. Mass (MS) spectra were run on a Hitachi RMU-6-Tokugata mass spectrometer and high resolution mass spectra on a Hitachi RMH-2 mass spectrometer operating at 70 eV with a direct inlet system. The relative intensity was expressed in % in the parentheses. Proton nuclear magnetic resonance (NMR) spectra were taken in deuteriochloroform ($CDCl_3$) using a Hitachi R-20B (60 MHz), a JEOL JNM PS-100 (100 MHz), or a JEOL JNM FX-60 spectrometer. Chemical shifts were expressed in ppm downfield from tetramethylsilane (TMS) as an internal standard (δ value) and coupling constants in Hz. ^{13}C NMR spectra were recorded on a JEOL JNM FX-60 FT NMR spectrometer at 15.04 MHz in $CDCl_3$ with TMS as an internal reference (δ_C O) in 8-mm spinning tube. Gas chromatography (GLC) was carried out using Shimadzu 4A-PF or CG-2C equipped with a hydrogen flame ionization detector. Liquid Chromatograph Model ALC/GPC 202/401 (Waters Assoc.) was used for high performance liquid chromatography (HPLC); Column: μ-PORASIL 1/8 (inch) × 1 (foot); Solvent system: 1 or 10% ether–hexane; Flow rate: 1.0 or 1.2 ml/min; Pressure: *ca.* 500 psi; with an RI or UV detector at room temperature. Thin layer chromatography (TLC) was carried out on Kieselgel PF_{254} (E. Merck) or Wako Alumina B-10F (Wako) in 0.25 or 0.5 mm thickness. Wakogel C-200 (Wako) was used for column chromatography.

*(20S)-Dammaran-20-ol (**13**).* A mixture of (20*S*)-20-hydroxydammaran-3-one[5b)] (**20**; 8 g), potassium hydroxide (4 g), hydrazine hydrate (*ca.* 100%; 3.5 g), and diethylene glycol (60 ml) was refluxed for 1.5 h. After removal of excess hydrazine and water, the reaction mixture was heated under reflux for 4 h. It was poured into water and extracted with chloroform five times. The extracts were combined, washed with water and brine, dried over magnesium sulfate, and evaporated to give a residue. The residue was crystallized from methanol to furnish *(20S)-dammaran-20-ol* (**13**; 5.5 g) as

white crystals; mp 86—87 °C (lit,[8] 85 °C); $[\alpha]_D$ +36° (*c* 1.4) (lit,[8] +34.6°); IR (KBr) 3570 and 3450 cm^{-1}; NMR δ 0.81—0.97 (7×Me) and 1.14 (3H, s, $C_{(20)}$-Me); MS *m/e* 415 (M−15; 2), 412 (M−18; 5), 397 (6), 345 (21), 327 (6), 302 (30), 287 (15), 231 (17), and 191 (100); Found: C, 83.39; H, 12.49%. Calcd for $C_{30}H_{54}O$: C, 83.65; H, 12.64%.

Dehydration of (20S)-Dammaran-20-ol (13). Phosphoryl chloride (2 ml) was added portionwise to a solution of (20*S*)-dammaran-20-ol (**13**; 574 mg) in pyridine (20 ml) at 0 °C. After standing overnight at room temperature, the reaction mixture was poured into ice–water and extracted with petroleum ether five times. The combined extracts were washed with 2M hydrochloric acid, water, and with brine, dried over magnesium sulfate, evaporated, and passed through a short column of silica gel to give a residue (511 mg; y. 93%); IR (film) 1630 and 885 cm^{-1}; NMR δ 1.52 (Me–C=CH–), 4.68 (H_2C=C–), and 5.10 (Me–C=CH–).

The residue was chromatographed on a column of silica gel (60 g) impregnated with silver nitrate (10 g) and eluted with petroleum ether (each 50 ml). Frs. 3—6 afforded a mixture (*ca.* 1:1) of (20*R*)- and (20*S*)-dammar-13(17)-enes (**24a** and **24b**; 17 mg, y. 3%; spectral data are registered later), frs. 8—20 a mixture of (*E*)- and (*Z*)-dammar-20(22)-enes (**25a** and **25b**; 357 mg, y. 65%, after crystallization from pentane), and frs. 26—61 gave dammar-20-ene (**26**; 135 mg, y. 25%). *Mixture of (E)- and (Z)-dammar-20(22)-enes (25)*: amorphous solid, IR (film) 1650 and 860 cm^{-1}; NMR δ 1.53 (3H, br. s, Me–C=CH–) and 5.10 (1H, t, J=*ca.* 6 Hz; Me–C=CH–); MS *m/e* 412 (M^+; 17), 397 (5), 380 (4), 328 (21), 313 (8), 299 (8), 286 (21), 273 (12), 259 (25), 231 (46), and 191 (100); MW Found: 412.4216. Calcd for $C_{30}H_{52}$: 412.4066. This mixture was inferred to consist of the (*E*)- and (*Z*)-isomers[29] by silver nitrate-impregnated silica gel TLC examination. However separation into each isomer was unsuccessful. *Dammar-20-ene (26)*: an oil, IR (film) 3060, 1635, and 885 cm^{-1}; NMR δ 0.84—1.00 (7×Me) and 4.70 (2H, br. s, $W_{1/2}$ 3 Hz; H_2C=C–); MS *m/e* 412 (M^+; 14), 397 (6), 380 (2), 342 (8), 327 (4), 300 (6), 299 (6), 286 (9), 259 (7), 239 (6), 231 (42), and 191 (100).

Nordammaran-20-one (23) and Hexanordammaran-20-one (22). The reaction mixture, obtained by dehydration of (20*S*)-dammaran-20-ol (**13**; 11.5 g) was dissolved in dichloromethane (300 ml) and a slow stream of ozone was bubbled through the solution kept at −78 °C for 2.5 h. After standing at room temperature for 1 h, acetic acid (200 ml) and zinc dust (5 g) were added under cooling. The solution was allowed to stand overnight at room temperature, concentrated to half volume, poured into water, and was extracted with ether. Usual work-up furnished a residue (*ca.* 10 g), which was chromatographed on a column of silica gel (950 g) and eluted with the following solvent system: frs. 1—29, petroleum ether; frs. 30—35, petroleum ether–benzene (20:1); frs. 36—69, (15:1); frs. 70—107, (5:1). From frs. 41—68 nordammaran-20-one (**23**; 2.4 g, y. 22%) was eluted and from frs. 72—94 hexanordammaran-20-one (**22**; 3.7 g, y. 40%, after crystallization from methanol) was obtained. 13α*H*-Octanordammaran-17-one[11] (**27**; 32 mg, y. 0.4%) and octanordammaran-17-one[11] (**28**; 155 mg, y. 1.7%) were eluted from frs. 95—100 and frs. 101—107, respectively. *Nordammaran-20-one (23)*: gum, $[\alpha]_D$ +65° (*c* 0.81); IR (film) 1700 cm^{-1}; NMR δ 0.81—1.00 (7×Me); MS *m/e* 414 (M^+; 8), 399 (6), 329 (3), 301 (42), and 191 (100); MW Found: 414.3739. Calcd for $C_{29}H_{50}O$: 414.3858. *Hexanordammaran-20-one (22)*: mp 130—131 °C (lit,[8] 110—130 °C; lit,[10] 121—132 °C); $[\alpha]_D$ +60° (*c* 1.3) (lit,[8] +61.7°; lit.[10] +60°); IR (KBr) 1705 and 1165 cm^{-1}: NMR δ 0.82, 0.87, 0.87, 0.90, and 1.00 (each 3H, s, *t*-Me) and 2.16 (3H, s, -COMe); MS *m/e* 344 (M^+; 7), 329 (9), 305 (60), 231 (4), 219 (9), 205 (13), and 191 (100); Found: C, 83.66; H, 11.90%. Calcd for $C_{24}H_{40}O$: C, 83.65; H, 11.70%.

Grignard Reaction of Nordammaran-20-one (23) with Methyl Iodide. An ethereal solution of methylmagnesium iodide was prepared from magnesium (300 mg) and methyl iodide (1.5 g) in dry ether under a nitrogen atmosphere. To this solution was added at room temperature a solution of nordammaran-20-one (**20**; 466 mg) in ether (8 ml). The mixture was stirred at reflux temperature for 1 h and then at room temperature for 2 h. After decomposition by addition of saturated ammonium chloride solution, the reaction product was extracted with ether. The organic solution was washed with water, 5% sodium hydrogencarbonate solution and then with brine and dried over magnesium sulfate. The solvent was removed to give a residue, which was chromatographed over silica gel. On elution with petroleum ether–benzene (5:1), (20*S*)-dammaran-20-ol (**13**; 106 mg) and (20*R*)-dammaran-20-ol (**14**; 233 mg) were obtained.

Grignard Reaction of Hexanordammaran-20-one (22) with 4-Methylpentyl Bromide. To the Grignard reagent prepared from 4-methylpentyl bromide (bp 146—149 °C; 1.5 g) and magnesium in dry tetrahydrofuran was added hexanordammaran-20-one (**22**; 340 mg) in tetrahydrofuran. The whole was heated under reflux for 30 min and stirred 3 h at room temperature. The same treatment as mentioned above afforded (20*S*)-dammaran-20-ol (**13**; 108 mg) and (20*R*)-dammaran-20-ol (**14**; 80 mg), together with the starting material (**22**; 13 mg) and an unidentified olfin mixture (114 mg). *(20S)-Dammaran-20-ol (13)*: mp 86—87 °C. Other physical and spectral data are given above. *(20R)-Dammaran-20-ol (14)*: Amorphous solid, $[\alpha]_D$ +32° (*c* 2.0); IR (KBr) 3600 and 3460 (br) cm^{-1}; NMR δ 0.80—0.96 (7×Me) and 1.11 (3H, s, $C_{(20)}$-Me); MS *m/e* 412 (M—18) and 191 (base peak); High resolution MS *m/e* 412.3978. Calcd for $C_{30}H_{52}$ (M–H_2O): 412.4066.

Acid-catalyzed Dehydration of (20S)-Dammaran-20-ol (13).
i) With Boron Trifluoride Etherate in Benzene: To a solution of (20*S*)-dammaran-20-ol (**13**; 10 mg) in anhydrous benzene (0.5 ml), boron trifluoride etherate (1 ml) was added at room temperature with stirring. After 15 min, 10% sodium hydrogencarbonate solution was added to the reaction mixture, which was extracted with benzene. The benzene extract was washed with 10% sodium carbonate solution, water, and then with brine and evaporated after drying over magnesium sulfate. The residue was subjected to separation by preparative TLC (SiO_2–$AgNO_3$; developed with petroleum ether) to give a mixture (10.3 mg; R_f *ca.* 0.7) of (20*R*)- and (20*S*)-dammar-13(17)-enes (**24a** and **24b**) as a main product. *(20R)- and (20S)-Dammar-13(17)-enes (24a and 24b)*: an oil; IR (film) 1460, 1380, and 1360 cm^{-1}; NMR δ 0.80—0.88 (6×Me), 0.90 (*ca.* 1.5H, d, J=7 Hz; $C_{(20)}$-Me of **24b**)[16], 0.94 (*ca.* 1.5H, d, J=7 Hz; $C_{(20)}$-Me of **24a**)[16], and 1.08 (3H, s, *t*-Me), neither olefinic proton nor olefinic methyl signal was observed; MS *m/e* 412 (M^+), 397, 327, 299, 220, 205, and 191 (base peak); and GLC examination showed that the mixture consisted of **24a** (R_t 4.8 min) and **24b** (R_t 5.2 min) in a ratio of *ca.* 1:1 [column: SE 30 (0.7 %), 1.5 m; column temperature: 250 °C; carrier gas flow rate: N_2, 27 ml/min].

ii) With Boron Trifluoride Etherate in Dichloromethane: A solution of **13** (19 mg) in dichloromethane (3 ml; purified by passing through a column of Al_2O_3) was treated with boron trifluoride etherate (1 ml) at room temperature for 15 min with agitation. Usual treatment gave the same mixture (**24a** and **24b**; 11 mg), whose IR and NMR spectra were identical with those of the specimen above obtained.

iii) With Boron Trifluoride Etherate in Acetic Acid: A solution of **13** (9.5 mg) in acetic acid (2 ml) was treated with boron trifiuoride etherate (0.7 ml) at room temperature for 15 min with stirring. The same reaction products (**24a** and **24b**) were obtained quantitatively after usual treatment.

iv) With Stannic Chloride in Benzene: To a solution of **13** (10.8 mg) in anhydrous benzene (1 ml) was added anhydrous stannic chloride (*ca.* 0.3 ml) with stirring at room temperature for 20 min. After the same treatment, the same reaction mixture (**24a** and **24b**; 9.7 mg) was obtained.

v) With Picric Acid in Nitromethane: To a solution of **13** (11 mg) in nitromethane (1 ml; dried over calcium chloride) containing 5 drops of dichloromethane, was added a solution of picric acid (12.8 mg) in nitromethane (1 ml) with stirring at room temperature for 8 days. Usual treatment gave a residue, which was chromatographed over silica gel. Fractions eluted with petroleum ether were combined and subjected to separation by preparative TLC (SiO_2–$AgNO_3$; developed with petroleum ether). As amain product the same hydrocarbon mixture (**24a** and **24b**; 5.1 mg) was obtained. The formation of dammar-20-ene (**26**) and dammar-20(22)-ene (**25**) was also shown by TLC.

vi) With Sulfuric Acid in Acetic Acid. A solution of **13** (13.1 mg) in glacial acetic acid (2 ml) containing sulfuric acid (1M; 0.2 ml) was heated under reflux for 2 h. After cooling, the reaction mixture was poured into ice–water and extracted with petroleum ether. The organic layer was worked up in a usual manner to yield the same reaction product (**24a** and **24b**). The formation of **25** and **26** was also observed.

vii) With Formic Acid in Acetone. A solution of **13** (6.1 mg) in acetone (3 ml) containing formic acid (99%, 0.5 ml) was heated under reflux for 17 h. The reaction mixture was treated as usual to give a residue, which was subjected to separation by preparative TLC (SiO_2–$AgNO_3$). A mixture of (20*R*)- and (20*S*)-dammar-13(17)-enes (**24a** and **24b**; 1.2 mg), dammar-20(22)-ene (**25**; 2.1 mg), and dammar-20-ene (**26**; 0.3 mg) were isolated.

Acid-catalized Dehydration of (20R)-Dammaran-20-ol (14). (20*R*)-Dammaran-20-ol (**14**) was treated with acids at room temperature under conditions described below and the reaction mixture was worked up as in the case of **13**. In each case, a mixture of (20*R*)- and (20*S*)-dammar-13(17)-enes (**24a** and **24b**) was obtained as a main product: i) A solution of **14** (15.7 mg) in anhydrous benzene (0.5 ml) with boron trifluoride etherate (1 ml) for 15 min; ii) A solution of **14** (12.2 mg) in dichloromethane (2 ml) with boron trifluoride etherate (1 ml) for 15 min; iii) **14** (7.7 mg) with trifluoroacetic acid (1 ml) for 20 min.

Mixture of (20R)- and (20S)-Dammar-13(17)-enes (24a and 24b). A mixture of isoeuphenyl acetate (**35a** and isotirucallenyl acetate (**35b**) was prepared from a mixture of euphol (**36a**) and tirucallol (**36b**) according to the known procedures.[15] Alkaline hydrolysis, Jones oxidation, and successive Huang-Minlon reduction of this mixture (**35a** and **35b**; 36 mg) by the usual manner gave a mixture (*ca.* 1: 1) of (20*R*)- and (20*S*)-dammar-13(17)-enes (**24a** and **24b**; 5.5 mg), which was identical (IR, MS, and TLC) with a specimen (*vide supra*) obtained by acid-catalyzed rearrangement of (20*S*)- and (20*R*)-dammaran-20-ols (**13** and **14**). The NMR spectra of these specimens (derived from **35, 13,** and **14**) were virtually identical in respect to numbers of signals and their δ-values except their relative intensities.

Pentanordammar-20(22)-ene-22-carbonitrile (37). Sodium hydride (50%; 297 mg) and dry dimethoxyethane (*ca.* 10 ml) were placed in a flask and diethyl cyanomethylphosphonate (624 mg) was added with stirring at room temperature under a nitrogen atmosphere. After 30 min hexanordammaran-20-one (**22**; 493 mg) in dry dimethoxyethane (*ca.* 5 ml) was added to the solution of the anion and stirring was continued for 18 h. The reaction mixture was poured into water and extracted with ether five times. The organic layer was washed with 2M hydrochloric acid, water, and brine. After drying over magnesium sulfate, the solvent was removed to give a residue, which was crystallized from petroleum ether–ether to yield a white crystalline product (164 mg) of (*E*)-pentanordammar-20(22)-ene-22-carbonitrile (**37a**). The mother liquor was subjected to separation by column chromatography on silica gel (100 g; elution with benzene) and by preparative TLC to furnish the additional (*E*)-isomer (**37a**; 315 mg, recrystallized from petroleum ether; total 479 mg, y. 91%) and (*Z*)-isomer (**37b**). *(E)-Pentanordammar-20(22)-ene-22-carbonitrile (37a)*: mp 179—180 °C; IR (KBr) 2200, 1615, and 815 cm^{-1}; NMR δ 1.99 (3H, d, J=1 Hz; Me–C=CHCN) and 5.09 (1H, br. s, $W_{1/2}$ 3 Hz; Me–C=CHCN)[19]; MS *m/e* 367 (M^+; 68), 352 (45), 231 (37), 191 (100), and 137 (92); Found: C, 84.77; H, 11.04; N, 3.79%. Calcd for $C_{26}H_{41}N$: C, 84.95; H, 11.24; N, 3.81%. *(Z)-Pentanordammar-20(22)ene-22-carbonitrile (37b)*: amorphous solid; NMR δ 1.82 (3H, d, J=1 Hz, Me–C=CHCN) and 5.09 (1H, br. s, $W_{1/2}$ 3 Hz; Me–C=CHCN).[19]

Methyl (E)- and (Z)-Tetranordammar-20(22)-en-23-oates (38a and 38b). (*E*)-Pentanordammar-20(22)-ene-22-carbonitrile (**37a**; 315 mg) and potassium hydroxide (2 g) in ethylene glycol (80 ml) were refluxed under a nitrogen atmosphere for 6.5 h. The reaction mixture was poured into ice-water and extracted with chloroform four times. After usual work-up, a residue, without purification, was dissolved in ether and treated with diazomethane at 0 °C for 4 h. Usual work-up gave a residue, which was chromatographed on a column of silica gel (100 g). Solvent system (petroleum ether–benzene, 10: 1—10: 2) was used for elution (each 50 ml). Frs. 21—30 gave an (*E*)- and (*Z*)-mixture (195 mg) and frs. 31—40 afforded the (*E*)-isomer (16 mg). The mixture was further separated by preparative TLC into each isomer. The (*E*)-isomer was combined with the crops (16 mg) above obtained, and recrystallized from methanol to give *methyl (E)-tetranordammar-20(22)-en-23-oate* (**38a**; 41 mg), mp 87.5—88 °C; IR (film) 1720, 1635, and 860 cm^{-1}; NMR δ 2.10 (3H, d, J=1 Hz; Me–C=CH–), 3.68 (3H, s, –COOMe), and 5.67 (1H, br. s, $W_{1/2}$ 3H; Me–C=CH–); MS *m/e* 400 (M^+; 7), 385 (4), 369 (3), 231 (32), and 191 (100); Found: C, 80.75; H, 11.35%. Calcd for $C_{27}H_{44}O_2$: C, 80.94; H, 11.07%. The (*Z*)-isomer fraction was crystallized from methanol to afford 41 mg of *methyl (Z)-tetranordammar-20(22)-en-23-oate (38b)*; mp 174—174.5 °C; IR (KBr) 1720, 1630, and 855 cm^{-1}; NMR δ 1.82 (3H, d, J=1 Hz; Me–C=CH–), 3.66 (3H, s, –COOMe), and 5.69 (1H, q-like, J=1 Hz; Me–C=CH–); MS *m/e* 400 (M^+; 36), 385 (9), 369 (5), 368 (7), 231 (48), and 191 (100); Found: C, 81.00; H, 11.36%. Calcd for $C_{27}H_{44}O_2$: C, 80.94; H, 11.07%.

(E)- and (Z)-Dammar-20(22)-en-23-ones (15a and 15b). Magnesium powder (150 mg) and dry ether (*ca.* 1 ml) were placed in a flask under nitrogen atmosphere. Isobutyl bromide (809 mg) was added with stirring carefully so that the reaction proceeded smoothly at room temperature. After 1 h, ether was distilled off and anhydrous benzene (*ca.* 10 ml) was poured into the Grignard reagent. The (*E*)-α,β-unsaturated carbonitrile (**37a**; 24 mg) in anhydrous benzene (*ca.* 1 ml) was added portionwise to the Grignard solution and stirred at room temperature for 45 min. The solution was refluxed for 6 h and allowed to stand at room temperature overnight. The reaction mixture was poured into a mixture of ice and saturated aqueous ammonium chloride solution, and extracted

with ether three times. The organic layer was washed with water and brine, dried over magnesium sulfate, and evaporated to dryness. The residue was separated by preparative TLC to give (*Z*)-dammar-20(22)-en-23-one (**15b**; 4 mg, y. 14%) and (*E*)-dammar-20(22)-en-23-one (**15a**; 11 mg, y. 40%), respectively. *(Z)-Dammar-20(22)-en-23-one (**15b**)*: an oil, IR (film) 1685, 1610, and 980 cm^{-1}; NMR δ 1.79 (3H, d, J=1.5 Hz; Me–C=CH–), 2.22 (2H, d, J=2 Hz, –CO–CH_2–CH), and 6.03 (1H, q-like, J=1.5 Hz; Me–C=CH–CO–); MS *m/e* 426 (M^+; 95), 411 (5), 369 (9), 314 (6), 300 (11), 299 (11), 205 (51), 191 (63), 153 (51), and 95 (100); MW Found: 426.3808. Calcd for $C_{30}H_{50}O$: 426.2858. *(E)-Dammar-20(22)-en-23-one (**15a**)*: an oil, IR (film) 1680 and 1605 cm^{-1}; NMR δ 2.05 (3H, d, J=1 Hz; Me–C=CH–), 2.23 (2H, d, J=1.5 Hz; –CO–CH_2–CH–), and 6.02 (1H, br. s, $W_{1/2}$ 3 Hz; Me–C=CH–CO–); MS *m/e* 426 (M^+; 15), 411 (2), 369 (13), 341 (3), 326 (2), 274 (2), 259 (3), 191 (55), 153 (88), and 95 (100); *MW* Found: 426.3806. Calcd for $C_{30}H_{50}O$: 426.3858.

*Acid Treatment of (E)-Dammar-20(22)-en-23-one (**15a**).* To a solution of (*E*)-dammar-20(22)-en-23-one (**15a**; 23 mg) in ethanol (5 ml) was added 8M hydrochloric acid (0.5 ml) and the whole was refluxed for 18 h. The reaction mixture was poured into ice–water and extracted with ether three times. Usual work-up gave a residue, which was separated by preparative TLC to afford (20ξ_1)-dammar-13(17)-en-23-one [(20ξ_1)-**39**; 7 mg] and (20ξ_2)-dammar-13(17)-en-23-one [(20ξ_2)-**39**; 7 mg] as major products. *(20ξ_1)-Dammar-13(17)-en-23-one [(20ξ_1)-**39**]*: an oil, IR (film) 1700 and 1600 cm^{-1}; NMR δ 0.92 (3H, d, J=7 Hz) and 3.06 (1H, m); MS *m/e* 426 (M^+; 11), 411 (3), 341 (8), 326 (34), 311 (6), 299 (10), 297 (11), 284 (31), 245 (7), 234 (26), 221 (42), 191 (100), 121 (85), 85 (57), and 57 (63). *(20ξ_2)-Dammar-13(17)-en-23-one [(20ξ_2)-**39**]*: an oil, IR (film) 1705 cm^{-1}; NMR δ 0.96 (3H, d, J=7 Hz) and 3.03 (1H, m); MS *m/e* 426 (M^+; 9), 411 (2), 341 (9), 326 (26), 311 (5), 299 (6), 297 (8), 284 (21), 245 (6), 234 (28), 221 (42), 191 (100), 121 (82), 85 (64), and 57 (76).

*20,21-Epoxydammarane (**16**).* To a solution of dammar-20-ene (**26**; 163 mg) in dichloromathane (10 ml), *m*-chloroperbenzoic acid (214 mg) in dichloromethane (10 ml) was added at 0 °C and the reaction mixture was stirred for 1 h. After 10% aqueous sodium sulfite (3 ml) was added, the mixture was extracted with ether and the organic layer was washed with 10% aqueous sodium carbonate and brine, and dried over magnesium sulfate. The solvent was removed to afford an epoxide (178 mg). This epoxide is extraordinary labile and easily decomposed during storage. *20,21-Epoxydammarane (**16**)*: an oil, IR (film) 1080, 1040, and 855 cm^{-1}; NMR δ 0.82—0.97 (7×Me) and 2.59 (2H, br. s, $W_{1/2}$ 2 Hz; $C_{(21)}$–H); MS *m/e* 428 (M^+; 20), 413 (5), 410 (12), 395 (5), 380 (7), 343 (6), 300 (27), 205 (31), 192 (62), and 191 (100); MW Found: 428.3969. Calcd for $C_{30}H_{52}O$: 428.4015.

*Reduction of 20,21-Epoxydammarane (**16**) with Lithium Aluminium Hydride.* 20,21-Epoxydammarane (**16**; 3.1 mg) was reduced with lithium aluminium hydride in ether under reflux for 1.5 h and left at room temperature overnight. Usual work-up and preparative TLC furnished (20*R*)-dammaran-20-ol (**14**; 1.8 mg) and (20*S*)-dammaran-20-ol (**13**; 1.2 mg).

*Dammaran-21-al (**40**).* A solution of 20,21-epoxydammarane (**16**; 25 mg) in dry benzene (5 ml) was treated with boron trifluoride etherate (1 drop) at room temperature for 10 min. After addition of 10% aqueous sodium hydrogencarbonate, usual work-up furnished dammaran-21-al (**40**) as an oil. This aldehyde was also labile. *Dammaran-21-al (**40**)*: IR (film) 2680 and 1720 cm^{-1}; NMR δ 0.82—0.94 (7×Me), 9.55 and 9.68 (each *ca.* 0.5H, d, J=3 Hz); MS *m/e* 428 (M^+; 2), 413 (3), 300 (32), 285 (6), 205 (15), and 191 (100); *MW* Found: 428.4000. Calcd for $C_{30}H_{52}O$: 428.4015.

*20,22-Epoxydammarane (**17**).* To a solution of dammar-20(22)-ene (**25**; 74 mg) in dichloromethane (15 ml), *m*-chloroperbenzoic acid (81 mg) in dichloromethane (10 ml) was added at 0 °C. After stirring for 30 min at 0 °C, 10% aqueous sodium sulfite (10 ml) was added. Extraction with dichloromethane and usual work-up gave an epoxide (75 mg). *20,22-Epoxydammarane (**17**)*: an oil. IR (film) 980, 880, and 790 cm^{-1}; NMR δ 1.19 ($C_{(20)}$–Me) and *ca.* 2.6 (m, $C_{(22)}$–H); MS *m/e* 428 (M^+; 25), 413 (3), 410 (3), 399 (3), 395 (2), 385 (1), 357 (3), 325 (5), 311 (5), 300 (25), 299 (27), 285 (12), 231 (10), 205 (31), and 191 (100); *MW* Found: 428.4046. Calcd for $C_{30}H_{52}O$: 428.4016. An examination by HPLC revealed that this epoxide consisted of four isomers, one (t_R 11.8 min) of which was the major product (HPLC: μ-PORASIL, 1% ether–hexane, 1.0 ml/min; t_R 9.0, 10.8, 11.8, and 13.7 min).

*Treatment of 20, 22-Epoxydammarane (**17**) with Boron Trifluoride Etherate.* 20,22 Epoxydammarane (**17**; 73 mg) in dry benzen (7 ml) was treated with boron trifluoride etherate (0.5 ml) at room temperature for 20 min. The solution was poured into water and extracted with ether. After usual work-up a residue (65 mg) was obtained, which was separated by preparative TLC to afford (20ξ_1)-26,27-dinor-20,24-dimethyldammarane-21-al [(20ξ_1)-**41**; 6 mg], (20ξ_2)-26,27-dinor-20,24-dimethyldammaran-21-al [(20ξ_2)-**41**; 3 mg], and (20ξ)-dammaran-22-one (**42**; 25 mg), together with a small quantity of hydrocarbons. *(20ξ_1)-26,27-Dinor-20,24-dimethyldammaran-21-al [(20ξ_1)-**41**]*: an oil, IR (film) 2660 and 1720 cm^{-1}; NMR δ 9.41 (1H, s, –CHO); MS *m/e* 428 (M^+; 3), 413 (3), 399 (5), 385 (2), 357 (2), 329 (2), 301 (20), 300 (22), 285 (10), 205 (22), 192 (51), and 191 (100); *MW* Found: 428.3951. Calcd for $C_{30}H_{52}O$: 428.4014. *(20ξ_2)-26,27-Dinor-20,24-dimethyldammaran-21-al [(20ξ_2)-**41**]*: an oil, IR (film) 2660 and 1720 cm^{-1}; NMR δ 9.41 (1H, s, –CHO); MS *m/e* 428 (M^+). *(20ξ)-Dammaran-22-one (**42**)*: an oil, IR (film) 1710 cm^{-1}; NMR δ 0.82—0.95 (7×Me), 1.07 (3H, d, J=7 Hz), and 2.41 (3H, m); MS *m/e* 428 (M^+; 2), 413 (3), 357 (1), 329 (2), 300 (46), 285 (16), 205 (53), 192 (100), and 191 (76); *MW* Found: 428.3942. Calcd for $C_{30}H_{52}O$: 428.4015.

*Hexanordammaran-20-ol (**18**).* Hexanordammaran-20-one (**22**; 230 mg) in ethanol was treated with sodium borohydride (107 mg) and allowed to stand at room temperature for 4 h. The excess of the reagent was decomposed by addition of acetic acid, and the reaction mixture was extracted with ether. After usual work-up, the residue was crystallized from ethanol to furnish *a mixture of hexanordammaran-20-ols (**18**;* 207 mg), mp 116—118.5 °C; IR (film) 3350 (br) cm^{-1}; NMR δ 0.81—0.98 (5×Me), 1.11 and 1.21 (each *ca.* 1.5H, s; $C_{(20)}$-Me), and 3.70 (1H, m, $C_{(20)}$–H); MS *m/e* 346 (M^+; 8), 331 (5), 328 (4), 313 (6), 301 (35), 191 (88), and 109 (100); Found: C, 83.29; H, 12.02%. Calcd for $C_{24}H_{42}O$: C, 83.17; H, 12.22%. This mixture was inferred to consist of the (20*S*)- and (20*R*)-isomers from the NMR data. However, separation into each isomer was unsuccessful.

*Dehydration of Hexanordammaran-20-ol (**18**) with Phosphoryl Chloride.* To a solution of hexanordammaran-20-ol (**18**; 36 mg) in pyridine (3 ml), phosphoryl chloride (0.3 ml) was added portionwise at 0 °C. After stirring for 4 h, the solution was poured into ice–water and extracted with ether three times. Usual work-up and separation by preparative TLC gave crude hydrocarbon (**44**; 17 mg) and a chloride mixture (**43**; 10 mg). *Mixture of (20S)- and (20R)-20-Chlorohexanordammaranes (**43**)*: mp 114—115 °C (crystallized from CH_2Cl_2–MeOH), IR (KBr) 645 cm^{-1}; NMR δ 1.48 (3H, d,

J=7 Hz; $C_{(20)}$–Me) and 3.46 and 4.17 (each *ca.* 0.5H, q-like, J=7 Hz; $C_{(20)}$–H); *MW* Found: 364.3002 and 366.2898 (in a ratio of *ca.* 3:1). Calcd for $C_{24}H_{41}Cl$: 364.2895 and 366.2866. *Crude Hydrocarbon (44)*: an oil, IR (film) 1635, 840, 820, and 810 cm^{-1}; NMR δ *ca.* 5.0 (1H); MS *m/e* 328 (M^+; 28), 313 (13), 299 (8), 205 (44), 192 (77), and 191 (100). This crude hydrocarbon showed one major peak (R_t 4.1 min) accompanied by two minor peaks in GLC analysis (SE-30, 0.7%; 200 °C; N_2 flow rate: 55 ml/min). Crude **44**, without further separation, was subjected to the following reactions.

Oxidation of the Crude Hydrocarbon (44) with Ruthenium Tetraoxide. A solution of the crude hydrocarbon (**44**; 16 mg) in carbon tetrachloride was added to a solution of ruthenium tetraoxide (10 mg) in carbon tetrachloride with stirring and the stirring was continued for 2 h at room temperature. After addition of isopropyl alcohol (0.5 ml), ruthenium dioxide was filtered off and the filtrate was evaporated. The residue was separated by preparative TLC to afford octanordammaran-17-one[11] (**28**; 3.4 mg) as a major product.

Hydroboration of the Crude Hydrocarbon (44). A solution of the crude hydrocarbon (**44**; 7 mg) in dry tetrahydrofuran (2 ml) was treated with diborane in tetrahydrofuran at 0 °C for 40 min and then at room temperature for 30 min. After 10% aqueous sodium hydroxide solution (6 ml) and 30% hydrogen peroxide (3 ml) were added, the solution was allowed to stand at 60 °C for 1 h. Usual treatment gave hexanordammaran-20-ol (**18**) (*vide supra*).

Tosylation of Hexanordammaran-20-ol (18). A solution of hexanordammaran-20-ol (**18**; 422 mg) and *p*-toluenesulfonyl chloride (540 mg) in pyridine (10 ml) was stored in a refrigerator for 20 days. The solution was poured into ice–water and extracted with ether. Usual work-up furnished a residue, which was crystallized from pentane to give *a tosylate* (**46**) as an oil, IR (film) 1190, 1180, 900, 810, and 655 cm^{-1}; NMR δ 2.42 and 2.47 (total 3H, each s, $-OSO_2-C_6H_4Me$), *ca.* 4.26 (1H, dq, J=12 and 6 Hz; Me–CH–OTs), and 7.28 and 7.72; 7.34 and 7.86 (total 4H, each ABq, J=8 Hz; $-OSO_2-C_6H_4Me$).

Treatment of the Tosylate (46) with Silica Gel. The tosylate (**46**) prepared from hexanordammaran-20-ol (**18**; 84 mg) and *p*-toluenesulfonyl chloride (96 mg) in pyridine was passed through a column of silica gel (10 g). Elution with petroleum ether–benzene (10:1) and crystallization from methanol–chloroform gave *hexanordammar-13(17)-ene (45*; 40 mg*)* as a sole product; mp 104—106 °C, IR (KBr) 1630 cm^{-1}; NMR δ 0.93 (3H, t, J=7 Hz; $C_{(21)}$–H) and 1.08 (3H, s, $C_{(14\alpha)}$–Me); MS *m/e* 328 (M^+; 51), 313 (16), 299 (12), 273 (5), 260 (7), 205 (54), 192 (79), and 191 (100); Found: C, 87.66; H, 12.19%. Calcd for $C_{24}H_{40}$: C, 87.73; H, 12.27%.

Pentanordammaran-20-ol (19). To a solution of methylmagnesium iodide prepared from magnesium powder (94 mg) and methyl iodide (400 mg) in dry ether, hexanordammaran-20-one (**22**; 88 mg) was added at room temperature with stirring. After refluxing for 2 h, the reaction mixture was poured into a mixture of ice and saturated aqueous ammonium chloride, and extracted with ether three times. Washing with water and brine, drying over magnesium sulfate, and evaporation gave a residue (73 mg) of *pentanordammaran-20-ol (19)*, mp 138—138.5 °C (crystallized from MeOH), IR (KBr) 3450 cm^{-1}; NMR δ 0.83, 0.86, 0.86, 0.91, and 0.99 (each 3H, s, *t*-Me) and 1.19 (6H, s, Me_2C–OH); MS *m/e* 360 (M^+; trace), 345 (1), 342 (6), 327 (4), 302 (11), 287 (5), 191 (100), and 95 (93); Found: C, 81.08; H, 12.80%. Calcd for $C_{25}H_{44}O \cdot 1/2\ H_2O$: C, 81.23; H, 12.27%.

Dehydration of Pentanordammaran-20-ol (19) with Phosphoryl Chloride. To a solution of pentanordammaran-20-ol (**19**; 19 mg) in pyridine, phosphoryl chloride (27 drops) was added at 0 °C. After stirring at room temperature for 4 h, the solution was poured into ice–water and extracted with ether three times. Usual treatment and separation by preparative TLC (SiO_2–$AgNO_3$) furnished pentanordammar-17(20)-ene (**47**; 11 mg) and pentanordammar-20-ene (**48**; 8 mg). *Pentanordammar-17(20)-ene (47)*: amorphous solid, IR (KBr) 1630 cm^{-1}; NMR δ 0.83, 0.88 (each 6H, s, *t*-Me), 1.00 (3H, s, *t*-Me), and 1.58 (6H, br. s, $Me_2C{=}C-$); MS *m/e* 342 (M^+; 17), 327 (3), 299 (11), 273 (8), 192 (31), 191 (37), 121 (83), and 95 (100); *MW* Found: 342.3285. Calcd for $C_{25}H_{42}$: 342.3284. *Pentanordammar-20-ene (48)*: amorphous solid, IR (KBr) 3060, 1635, and 885 cm^{-1}; NMR δ 0.81, 0.89, 0.99 (each 3H, s, *t*-Me), 0.86 (6H, s, *t*-Me), 1.67 (3H, d, J=1 Hz; $Me{-}C{=}CH_2$), and 4.65 (2H, d, J=1 Hz; $Me{-}C{=}CH_2$); MS *m/e* 342 (M^+; 7), 327 (4), 299 (3), 231 (31), 191 (100), and 95 (65); *MW* Found: 342.3285. Calcd for $C_{25}H_{42}$: 342.3284.

Treatment of Pentanordammaran-20-ol (19) with Boron Trifluoride Etherate. A solution of pentanordammaran-20-ol (**19**: 22 mg) in benzene (3 ml) was treated with boron trifluoride etherate (0.6 ml) at room temperature for 1 h. To the solution was added 10% aqueous sodium hydrogencarbonate solution and the reaction mixture was extracted with ether three times. After usual treatment and separation by preparative TLC (SiO_2–$AgNO_3$), pentanordammar-13(17)-ene (**49**; 9 mg) and pentanordammar-20-ene (**48**; 11 mg) were obtained. *Pentanordammar-13(17)-ene (49)*: amorphous solid, IR (KBr) 1630 cm^{-1}; NMR δ 0.81 (6H, s, *t*-Me), 0.86, 0.87 (each 3H, s, *t*-Me), 0.93, 0.98 (each 3H, d, J=7 Hz; $Me_2CH{-}C{=}C-$), and 1.09 (3H, s, $C_{(14\alpha)}$–Me); MS *m/e* 341 (M^+; 32), 327 (5), 299 (23), 205 (41), 191 (67), 121 (89), and 95 (100); *MW* Found: 342.3432. Calcd for $C_{25}H_{42}$: 342.3284.

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