Acid-catalyzed Backbone Rearrangement of 5,6-Epoxyalnusanes and Preparation of Daturadiol[1)]

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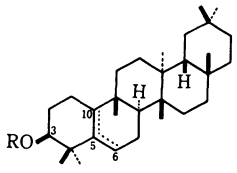
Epoxidation of alnus-5-en-3β-yl acetate with *m*-chloroperbenzoic acid gave a 5β,6β-epoxide as a main product together with a 5α,6α-epoxide as a minor product. Treatment of the α-epoxide with $BF_3 \cdot OEt_2$ afforded a 1(10),5-diene and a mixture of 6α-hydroxy-12- and -18-ene derivatives. The 12-ene was converted into daturadiol (=olean-12-ene-3β,6β-diol).

On treatment with acid, oleanene-, lupene-, and baccharene-type triterpenes undergo backbone rearrangement generally in the opposite direction from the biogenesis and afford a number of migrated triterpenes derived from intermediate cations or their equivalent species corresponding to various biogenetic stages.

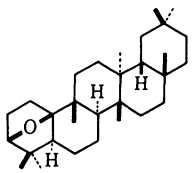
We have been investigating $BF_3 \cdot OEt_2$-catalyzed backbone rearrangement of 3β,4β-epoxyfriedelane,[2)] 3,4-epoxyshionanes,[3)] 3,4-epoxy-D:A-friedo-18β,19α*H*-lupanes,[4)] and 13,18-epoxybaccharan-3β-yl acetates,[5)] these epoxides possessing the epoxide ring on the terminal ring such as A or D ring. Epoxidation of alnus-5-en-3β-yl acetate (**1**) gives 5,6-epoxides, which on treatment with $BF_3 \cdot OEt_2$ would afford carbonium ions or their equivalents on B ring by cleavage of the epoxy ring. Now we examined behavior of the carbonium ions on B ring towards the backbone rearrangement. This paper describes the epoxidation of **1** and backbone rearrangement of epoxides catalyzed by $BF_3 \cdot OEt_2$. Conversion of dendropanoxide (**2**) into daturadiol (**3**) by utilizing these reactions is also described.

Acid treatment of dendropanoxide (**2**)[6)] gave a mixture of alnus-5-en-3β-ol (**4**) and alnus-5(10)-en-3β-ol (**5**),[7)] the former of which, after separation, was converted into its acetate (**1**). Sengupta *et al.*[8)] obtained an epoxide as the sole product by epoxidation of glut-5-en-3β-yl acetate (=alnus-5-en-3β-yl acetate (**1**)) with *m*-chloroperbenzoic acid (MCPBA) and assigned a 5α,6α-configuration to the epoxy-ring based on the steric consideration and ^1H NMR spectrum.

Epoxidation of **1** with MCPBA under the same conditions (in chloroform at 0 °C) as Sengupta's gave two epoxides. The major epoxide (**6**) was obtained in 77% yield and the minor one (**7**) in 16% yield, and the major epoxide (**6**) was found to be identical with the "Sengupta's epoxide." From the following observations, however, a question arose on the configuration of the epoxide ring which had been assigned by Sengupta. Two epoxides (**6** and **7**) were subjected to $BF_3 \cdot OEt_2$-catalyzed backbone rearrangement, respectively, and the mixtures of unsaturated hydroxy acetates were separated from the rearranged products (description on these reactions is given later). The mixture of hydroxy acetates obtained from the major epoxide (**6**) showed a broad singlet signal due to 6-H around δ 4.5 in the ^1H NMR, while that obtained from the minor epoxide (**7**) showed a broad signal due to 6-H around δ 4.0—4.1. Kocór *et al.*[9)] isolated a triterpene alcohol, daturadiol (**3**), from *Datura innoxia* Mill. (Solanaceae) and reported that the monoacetate of daturadiol (**8**) (=6β-hydroxyolean-12-en-3β-yl acetate) showed a broad singlet due to 6α-H at δ 4.45 in the ^1H NMR spectrum. This implies that the broad singlet signal which appeared at *ca.* δ 4.5 is assignable to the 6α-H and, therefore, the hydroxyl group in the hydroxy acetates derived from the major epoxide (**6**) locates in β-orientation. These observations lead to the conclusion that the major epoxide (**6**), the "Sengupta's epoxide," should be a 5β,6β-epoxide and attack of the oxidizing reagent took



1 5-ene; R=Ac
4 5-ene; R=H
5 5(10)-ene; R=H
9 5-ene; R=PhCO
14 5(10)-ene; R=Ac



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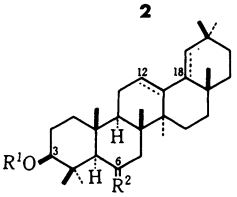
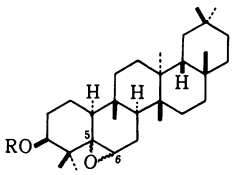
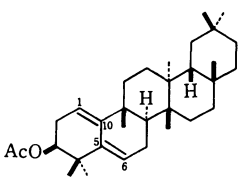


3 12-ene; R^1=H, R^2=β-OH,α-H
8 12-ene; R^1=Ac, R^2=β-OH,α-H
15 18-ene; R^1=Ac, R^2=α-OH,β-H
16 12-ene; R^1=Ac, R^2=α-OH,β-H
17 18-ene; R^1=Ac, R^2=O
18 12-ene; R^1=Ac, R^2=O
19 18-ene; R^1=H, R^2=O
20 12-ene; R^1=H, R^2=O
22 18-ene; R^1=Ac, R^2=β-OH,α-H



6 5β,6β-; R=Ac
7 5α,6α-; R=Ac
10 5β,6β-; R=H
11 5α,6α-; R=PhCO
12 5β,6β-; R=PhCO



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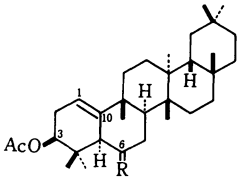

21 R=β-OH,α-H
23 R=O

place preferentially from β-face of the molecule in epoxidation of alnus-5-en-3β-yl acetate (**1**).

This conclusion was supported by the epoxidation reaction of alnus-5-en-3β-ol (**4**) and its benzoate (**9**) carried out under the same conditions as above. Epoxidation of alnus-5-en-3β-ol (**4**) gave a single epoxide (**10**). On acetylation, the epoxide (**10**) yielded an acetate, which was idential with the major epoxide (**6**). On the other hand, the benzoate (**9**) was epoxidized to give α- and β-epoxides (**11** and **12**) in a 1 : 1 ratio. Since the 3α-hydrogens of alnus-5-en-3β-ol (**4**), -3β-yl acetate (**1**), and -3β-yl benzoate (**9**) were observed as triplets at δ 3.48 (t-like, J=3 Hz), δ 4.66 (J=3 Hz), and δ 4.94 (J=3 Hz), respectively, in the ^{1}H NMR spectra, the substituents at C-3β are shown to exist in an axial-conformation.

Table 1. Atomic positional parameters (×10⁴) and isotropic thermal parameters (×10²) for non-hydrogen atoms of 5β,6β-epoxyalnusan-3β-yl acetate (**6**) with estimated standard deviations in parentheses

Atom	x	y	z	B_{eq}[a]
C (1)	−904(3)	5468(1)	5282(6)	390(5)
C (2)	−1666(3)	5182(1)	4202(6)	409(6)
C (3)	−1113(3)	4792(1)	3520(5)	351(5)
C (4)	−70(3)	4862(1)	2423(5)	331(5)
C (5)	598(2)	5198(1)	3370(5)	299(4)
C (6)	1737(3)	5223(1)	2947(6)	368(5)
C (7)	2327(32)	5625(12)	2939(68)	419( )
C (8)	1538(2)	5996(1)	3004(5)	296(4)
C (9)	718(3)	5946(1)	4621(5)	299(4)
C (10)	7(2)	5587(1)	3915(5)	285(4)
C (11)	18(3)	6336(1)	4650(6)	368(5)
C (12)	625(3)	6737(1)	4666(6)	369(5)
C (13)	1398(2)	6776(1)	2889(5)	292(4)
C (14)	2202(2)	6412(1)	2945(5)	298(4)
C (15)	2891(3)	6424(1)	1060(6)	386(5)
C (16)	3036(3)	6848(1)	103(6)	439(6)
C (17)	2975(3)	7224(1)	1492(6)	377(5)
C (18)	2036(3)	7187(1)	3008(5)	315(5)
C (19)	1293(3)	7562(1)	2903(6)	394(5)
C (20)	1860(3)	7980(1)	2965(6)	425(6)
C (21)	2726(3)	7997(1)	1379(7)	533(7)
C (22)	2812(3)	7602(1)	188(7)	489(6)
C (23)	524(3)	4453(1)	2290(7)	484(6)
C (24)	−334(3)	5002(1)	329(6)	458(6)
C (25)	1140(4)	5873(1)	6715(6)	457(6)
C (26)	699(3)	6768(1)	1011(5)	373(5)
C (27)	2947(3)	6441(1)	4725(6)	407(5)
C (28)	4063(3)	7268(1)	2498(7)	512(7)
C (29)	1007(4)	8308(1)	2563(9)	657(9)
C (30)	2320(4)	8055(1)	5004(8)	575(7)
C (31)	−1563(4)	4251(1)	5695(6)	485(6)
C (32)	−1163(5)	4003(1)	7396(8)	747(10)
O (1)	−870(2)	4548(1)	5265(4)	417(4)
O (2)	−2383(2)	4199(1)	4862(6)	692(6)
O (3)	1368(2)	5066(1)	4817(4)	416(4)

a) $B_{eq}=8\pi^2(u_1^2+u_2^2+u_3^2)/3$.

From these facts, the results obtained in these epoxidation reactions are explained reasonably as follows; in the epoxidation of alnus-5-en-3β-ol (**4**), the hydrogen-bond assisted an exclusive attack of the reagent from β-face of the molecule of **4**, while in the case of the benzoate (**9**), the attack from β-face was sterically hindered by the bulky benzoyloxyl group, resulting in a 1 : 1 ratio of the α- and β-epoxides (**11** and **12**), and in the case of the acetate (**1**), the reagent attacked preferentially from the β-side to give the β-epoxide (**6**) as the main product.

Thus the epoxide ring of the major epoxide (**6**) has been determined to exist in β-configuration. Unambiguous proof for the structure of the major epoxide (**6**) was given by single-crystal X-ray analysis. The crystals belong to orthorhombic space group $P2_12_12_1$, and the lattice parameters are a=12.618(4), b=32.776(9), and c=6.837(2) Å and D_c=1.14 g cm^{-3} with four molecules in a unit cell. Intensity data were measured on a Philips PW1100 automatic four-circle diffractometer using monochromated Cu $K\alpha$ radiation. A total of 2702, non-zero independent reflections with $3\leq\theta\leq$ 78 were obtained by $2\theta-\theta$ scanning mode. The structure was solved by the direct method using MULTAN program and was refined by the block-diagonal least-squares method. All hydrogen atoms were located on a difference electron density map. The final R-value was 0.047 assuming the anisotropic temperature factors for the non-hydrogen atoms and the isotropic ones for the hydrogen atoms. The final atomic coordinates are listed in Table 1 and bond lengths and bond angles are listed in Tables 2 and 3.[10] Figure 1 is a computer-generated perspective

Table 2. Bond lengths of 5β,6β-epoxyalnusan-3β-yl acetate (**6**) with estimated standard deviations in parentheses

Bond length		(l/Å)	Bond length		(l/Å)
Atom 1	Atom 2		Atom 1	Atom 2	
C (1)	-C (2)	1.533(5)	C (12)	-C (13)	1.542(5)
C (1)	-C (10)	1.532(5)	C (13)	-C (14)	1.568(4)
C (2)	-C (3)	1.528(5)	C (13)	-C (18)	1.571(4)
C (3)	-C (4)	1.532(5)	C (13)	-C (26)	1.559(5)
C (3)	-O (1)	1.470(4)	C (14)	-C (15)	1.555(5)
C (4)	-C (5)	1.530(4)	C (14)	-C (27)	1.541(5)
C (4)	-C (23)	1.540(5)	C (15)	-C (16)	1.549(5)
C (4)	-C (24)	1.540(5)	C (16)	-C (17)	1.556(5)
C (5)	-C (6)	1.468(4)	C (17)	-C (18)	1.578(5)
C (5)	-C (10)	1.524(4)	C (17)	-C (22)	1.542(5)
C (5)	-O (3)	1.452(4)	C (17)	-C (28)	1.543(5)
C (6)	-C (7)	1.513(40)	C (18)	-C (19)	1.546(4)
C (6)	-O (3)	1.456(5)	C (19)	-C (20)	1.548(5)
C (7)	-C (8)	1.537(40)	C (20)	-C (21)	1.540(6)
C (8)	-C (9)	1.562(5)	C (20)	-C (29)	1.545(6)
C (8)	-C (14)	1.570(4)	C (20)	-C (30)	1.530(7)
C (9)	-C (10)	1.559(4)	C (21)	-C (22)	1.533(6)
C (9)	-C (11)	1.553(4)	C (31)	-C (32)	1.507(7)
C (9)	-C (25)	1.546(5)	C (31)	-O (1)	1.341(5)
C (11)	-C (12)	1.539(4)	C (31)	-O (2)	1.194(6)

drawing of the molecule of the major epoxide, 5β, 6β-epoxyalnusan-3β-yl acetate (**6**).

5α,6α-Epoxyalnusan-3β-yl acetate (**7**) was treated with $BF_3 \cdot OEt_2$ in benzene to give a complex mixture, which was separated by column chromatography into two fractions. The less polar fraction (25%) was found to consist of mainly alnusa-1(10), 5-dien-3β-yl acetate (**13**) accompanied with a small amount of an unidentified product by GLC. The authentic sample of **13** was prepared by reaction of alnus-5(10)-en-3β-yl acetate (**14**) with selenium dioxide.[11]

The polar fraction (73%) was inferred to be a mixture of Δ^{18}- and Δ^{12}-hydroxy acetates (**15** and **16**) in a ratio of 1:1 by spectral inspection. Two signals at δ 4.85 (0.5H) and δ 5.17 (0.5H) in the ^{1}H NMR and two fragment ions at *m/z* 177 and *m/z* 218 in the mass spectrum[12] were indicative of the presence of Δ^{18}- and Δ^{12}-oleanene derivatives. Separation of the mixture was attempted by various chromatographic techniques, but all attempts failed. The mixture of hydroxy acetates (**15** and **16**) was converted into a mixture of keto acetates (**17** and **18**), which could not be separated at all. Then the mixture of **17** and **18** was subjected to alkaline hydrolysis to give a mixture of hydroxy ketones (**19** and **20**). Separation of the mixture was attained by HPLC to afford 3β-hydroxyolean-18-en-6-one (**19**; t_R=15.7 min) and -12-en-6-one (**20**; t_R=16.3 min). 3β-Hydroxyolean-18-en-6-one (**19**), mp 217.5—219 °C, showed a molecular ion at *m/z* 440.3659 ($C_{30}H_{48}O_2$) and a fragment ion at *m/z* 177.1623 ($C_{13}H_{21}$) which is characteristic of Δ^{18}-oleanene derivatives.[12] In the ^{1}H NMR spectrum, a singlet signal appeared at δ 4.88 assignable to 19-H. On the other hand, the other hydroxy ketone (**20**) with a longer retention time showed mp 243—245 °C

28 Table 3. Bond angles of 5β,6β-epoxyalnusan-3β-yl acetate (**6**) with estimated standard deviations in parentheses

Bond angle			φ/°	Bond angle			φ/°
Atom 1	Atom b	Atom 3		Atom 1	Atom 2	Atom 3	
C (2)	-C (1)	-C (10)	109.4(3)	C (14)	-C (13)	-C (18)	108.7(2)
C (3)	-C (2)	-C (1)	111.9(3)	C (14)	-C (13)	-C (26)	111.9(3)
C (4)	-C (3)	-C (2)	114.5(3)	C (12)	-C (13)	-C (18)	110.2(3)
C (4)	-C (3)	-O (1)	107.5(3)	C (12)	-C (13)	-C (26)	107.6(3)
C (2)	-C (3)	-O (1)	107.6(3)	C (18)	-C (13)	-C (26)	110.4(3)
C (5)	-C (4)	-C (3)	112.0(3)	C (15)	-C (14)	-C (8)	108.8(3)
C (5)	-C (4)	-C (23)	112.5(3)	C (15)	-C (14)	-C (13)	108.7(3)
C (5)	-C (4)	-C (24)	107.3(3)	C (15)	-C (14)	-C (27)	108.2(3)
C (3)	-C (4)	-C (23)	108.4(3)	C (8)	-C (14)	-C (13)	109.9(2)
C (3)	-C (4)	-C (24)	108.3(3)	C (8)	-C (14)	-C (27)	109.7(3)
C (23)	-C (4)	-C (24)	108.1(3)	C (13)	-C (14)	-C (27)	111.5(3)
C (6)	-C (5)	-C (4)	119.9(3)	C (16)	-C (15)	-C (14)	116.1(3)
C (6)	-C (5)	-C (10)	118.6(3)	C (17)	-C (16)	-C (15)	116.6(3)
C (6)	-C (5)	-O (3)	59.8(2)	C (18)	-C (17)	-C (16)	112.2(3)
C (4)	-C (5)	-C (10)	115.8(3)	C (18)	-C (17)	-C (22)	109.9(3)
C (4)	-C (5)	-O (3)	116.3(3)	C (18)	-C (17)	-C (28)	112.5(3)
C (10)	-C (5)	-O (3)	114.2(3)	C (16)	-C (17)	-C (22)	106.9(3)
C (7)	-C (6)	-C (5)	122.2(16)	C (16)	-C (17)	-C (28)	107.6(3)
C (7)	-C (6)	-O (3)	118.0(16)	C (22)	-C (17)	-C (28)	107.5(3)
C (5)	-C (6)	-O (3)	59.6(2)	C (19)	-C (18)	-C (13)	111.5(3)
C (8)	-C (7)	-C (6)	112.9(27)	C (19)	-C (18)	-C (17)	111.3(3)
C (9)	-C (8)	-C (7)	111.3(16)	C (13)	-C (18)	-C (17)	114.6(3)
C (9)	-C (8)	-C (14)	117.2(3)	C (20)	-C (19)	-C (18)	115.0(3)
C (7)	-C (8)	-C (14)	112.5(16)	C (21)	-C (20)	-C (19)	109.9(3)
C (10)	-C (9)	-C (8)	105.3(2)	C (21)	-C (20)	-C (29)	110.1(3)
C (10)	-C (9)	-C (11)	107.3(3)	C (21)	-C (20)	-C (30)	111.5(3)
C (10)	-C (9)	-C (25)	111.6(3)	C (19)	-C (20)	-C (29)	106.9(3)
C (8)	-C (9)	-C (11)	108.6(3)	C (19)	-C (20)	-C (30)	110.0(3)
C (8)	-C (9)	-C (25)	115.5(3)	C (29)	-C (20)	-C (30)	108.4(3)
C (11)	-C (9)	-C (25)	108.2(3)	C (22)	-C (21)	-C (20)	113.2(3)
C (1)	-C (10)	-C (5)	107.7(3)	C (17)	-C (22)	-C (21)	112.4(3)
C (1)	-C (10)	-C (9)	115.8(3)	C (32)	-C (31)	-O (1)	110.1(4)
C (5)	-C (10)	-C (9)	115.2(3)	C (32)	-C (31)	-O (2)	125.6(4)
C (12)	-C (11)	-C (9)	114.0(3)	O (1)	-C (31)	-O (2)	124.3(4)
C (13)	-C (12)	-C (11)	112.6(3)	C (3)	-O (1)	-C (31)	116.0(3)
C (14)	-C (13)	-C (12)	108.1(3)	C (5)	-O (3)	-C (6)	60.6(2)

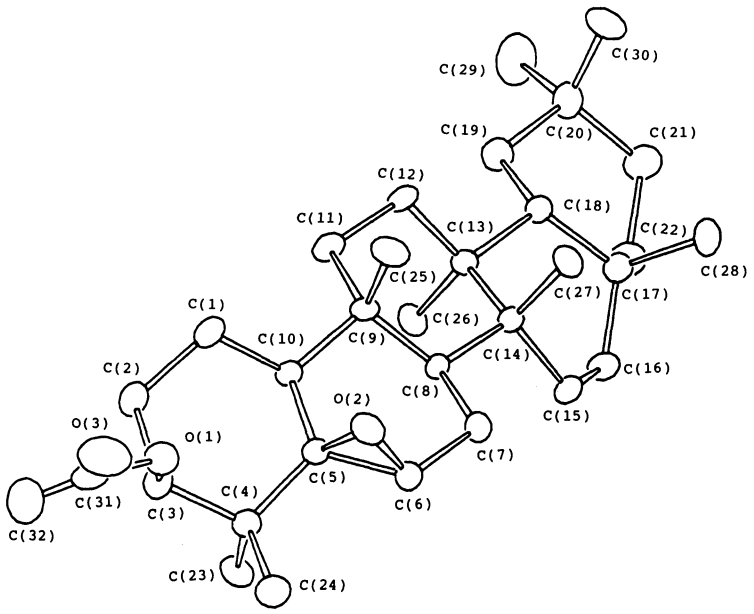

Fig. 1. Perspective view of 5β,6β-epoxyalnusan-3β-yl acetate(**6**).

(decomp), a triplet signal at δ 5.21 in the ^{1}H NMR, and a base peak at *m/z* 218.2027 ($C_{16}H_{26}$), these spectral data being compatible with 3β-hydroxyolean-12-en-6-one. Therefore the polar fraction obtained by the backbone rearrangement of the minor epoxide (**7**) was confirmed to be a mixture of 6α-hydroxyolean-18-en-3β-yl acetate (**15**) and -12-en-3β-yl acetate (**16**).

The hydroxy ketones (**19** and **20**), on acetylation, gave pure 6-oxoolean-18-en-3β-yl acetate (**17**) and -12-en-3β-yl acetate (**18**), respectively. The spectral data of the latter compound (**18**) were identical with those reported for a keto acetate derived from natural daturadiol (**3**).[9] The hydroxy ketone (**20**) was converted by lithium aluminium hydride-reduction into olean-12-ene-3β,6β-diol, spectra of which were completely identical with those of daturadiol (**3**).[9] On acetylation, the diol (**3**) gave a monoacetate (**8**), which is isomeric with the 6α-hydroxy acetate (**16**). The 6α-H of **8** appeared at δ 4.55 as a broad singlet signal in the ^{1}H NMR spectrum, from which the structural revision of "Sengupta's epoxide" had originated.

The major epoxide (**6**) was subjected to $BF_3 \cdot OEt_2$-catalyzed backbone rearrangement, followed by the usual work-up to give alnusa-1(10), 5-dien-3β-yl acetate (**13**; 3% yield) containing an unidentified diene-mixture, a hydroxy acetate (**21**; 74% yield), and a mixture (11% yield) of 6β-hydroxyolean-12-en-3β-yl acetate (**8**) and -18-en-3β-yl acetate (**22**). The new compound (**21**) showed a molecular ion peak at *m/z* 484.3934 ($C_{32}H_{52}O_3$), and the presence of a hydroxyl group, an acetoxyl group, and a trisubstituted double bond. The position of the double bond was determined by chemical conversion and ^{1}H NMR measurement. The hydroxy acetate (**21**) was dehydrated with phosphoryl chloride in pyridine to afford the diene (**13**). Oxidation of **21** with Jones reagent gave a keto acetate (**23**), whose ^{1}H NMR spectrum showed signals at δ 2.01(s, OAc), *ca.* 2.23(m, $C_{(2)}$–H_2; overlapping with $C_{(7)}$–H_2), 3.12 (br s, $C_{(5)}$–H), 4.82 (t, *J*=5 Hz, $C_{(3\alpha)}$–H), and 5.30(m, $C_{(1)}$–H). These spectral data suggest the presence of a 3β-acetoxy-1(10)-ene moiety, which was confirmed by a decoupling measurement of ^{1}H NMR spectrum. On irradiation around δ 2.23, the multiplet signal at δ 5.30 due to $C_{(1)}$–H changed into a doublet signal coupled with $C_{(5)}$–H (*J*=3 Hz) and the triplet signal at δ 4.82 due to $C_{(3\alpha)}$–H changed into a singlet. From these observations, the structure of hydroxy acetate (**21**) was determined to be 6β-hydroxyalnus-1(10)-en-3β-yl acetate.

These experiments clearly show that there was a remarkable difference in reaction behaviors between 5α,6α-epoxide (**7**) and 5β,6β-epoxide (**6**) towards the $BF_3 \cdot OEt_2$-catalyzed backbone rearrangement; the α-epoxide (**7**) gave mainly 18-ene and 12-ene derivatives (**15** and **16**; in 73% yield), while the β-epoxide (**6**) afforded 1(10)-ene and 1(10), 5-diene derivatives (**21** and **13**; in 77% yield) predominantly. One of the reasons why the backbone rearrangement of β-epoxide (**6**) did not proceed to C- and D-rings is likely to be ascribed to a steric factor. On attack of $BF_3 \cdot OEt_2$, the 5β,6β-epoxide ring would be cleaved to produce a carbonium ion on C-5, to which a migration of a hydride from C-10α would follow immediately to afford a cation at C-10. If a methyl group at C-9β migrates to the cationic center at C-10, a 1,3-diaxial steric hindrance would be brought about between the methyl group created on C-10β and a bulky BF_3-coordinated oxygen function in an axial-like configuration at C-6β. This steric hindrance might impede the backbone rearrangement of **6** towards C- and D-rings.

The conversion of dendropanoxide (**2**) into daturadiol (**3**) was thus accomplished *via* alnus-5-en-3β-yl acetate (**1**) and the 5α,6α-epoxide (**7**), which implies a formal total-synthesis of daturadiol (**3**), because a total synthesis of friedelin[13] and a conversion of friedelin into dendropanoxide (**2**)[14] have been carried out.

Experimental

General Procedures. Melting points were measured on a Mel-temp capillary melting point apparatus (Laboratory Devices) and are uncorrected. Infrared (IR) and ultraviolet absorption (UV) spectra were measured with a Hitachi 260-30 and a Hitachi 340 spectrometer, respectively. Mass (MS) spectra were run on a JEOL JMS-D300 mass spectrometer operating at 70 eV. Proton nuclear magnetic resonance (^{1}H NMR) spectra were taken in deuteriochloroform using a Varian EM 390 (90 MHz) or JEOL FX 90Q (90 MHz) spectrometer. Chemical shifts were expressed in δ downfield from tetramethylsilane as an internal standard and coupling constants in Hz. Gas-liquid chromatography (GLC) was carried out on a Shimadzu Gas Chromatograph GC-6A equipped with an FID (column: Dexsil 300GC, temperature: 270 °C, N_2: 70 mL/min). Analytical and preparative high performance liquid chromatography (HPLC) was carried out on a Waters Liquid Chromatograph ALC/GPC 202/401 at room temperature with an RI detector (column: μPORASIL 1/8″×1′, solvent: 20% ether–hexane, flow rate: 2.0 mL/min). Thin-layer chromatography (TLC) was carried out on Kieselgel 60 GF_{254} (E. Merck) and silica-gel column chromatography was done using Wakogel C-200 (Wako).

Epoxidation of Alnus-5-en-3β-yl Acetate (1). Alnus-5-en-3β-ol (**4**), prepared from dendropanoxide (**2**), was acetylated by the usual manner to give alnus-5-en-3β-yl acetate (**1**). The acetate (**1**; 290 mg) was dissolved in chloroform (12 mL) and treated with MCPBA (270 mg) at 0 °C. The usual work-up gave a residue (281 mg), which was separated by silica gel (60 g) column chromatography. Elution with benzene–ether (99:1) afforded 5α,6α-epoxide (**7**; 33 mg), mp 234—235 °C (from chloroform–acetone); IR (KBr) 1730, 1250, 1030, and 980 cm^{-1}; ^{1}H NMR δ=2.04 (3H, s) 3.23 (1H, t, J=2 Hz) and 4.88 (1H, dd, J=9 and 6 Hz); MS m/z (%) 484 (M^+; 5), 466 (10), 406 (70), 391 (37), 274 (62), 259 (68), 248 (40), 205 (89), 201 (48), 187 (72), 171 (72), and 95 (100), and 5β,6β-epoxide (**6**; 215 mg), mp 220.5—221 °C (from chloroform–acetone); IR (KBr) 1735 and 1255 cm^{-1}; ^{1}H NMR δ=2.08 (3H, s), 3.07 (1H, t, J=3 Hz), and 4.76 (1H, t, J=3 Hz); MS m/z (%) 484 (M^+; 2), 424 (7), 406 (20), 391 (11), 259 (16), 205 (38), 187 (24), and 95 (100).

Epoxidation of Alnus-5-en-3β-ol (4) and Alnus-5-en-3β-yl Benzoate (9). Alnus-5-en-3β-ol (**4**) and its benzoate (**9**) were epoxidized under the same conditions as above. The reaction product obtained from **4** was acetylated with acetic anhydride in pyridine to give 5β,6β-epoxyalnusan-3β-yl acetate (**6**) as the sole product.

The reaction product from **9** was shown to be a 1:1 mixture of 5α,6α-epoxide (**11**; ^{1}H NMR δ *ca.* 3.27, t-like; 6β-H) and 5β,6β-epoxide (**12**; ^{1}H NMR δ *ca.* 3.11, m; 6α-H) by TLC and ^{1}H NMR spectral measurement.

Backbone Rearrangement of 5α,6α-Epoxyalnusan-3β-yl Acetate (7). 5α,6α-Epoxyalnusan-3β-yl acetate (**7**; 33 mg) in benzene (6 mL) was treated with $BF_3 \cdot OEt_2$ (0.05 mL) at room temperature for 20 min. The reaction product, after addition of a saturated sodium hydrogencarbonate solution, was worked up as usual to give a residue, which was chromatographed on silica gel (8 g). Elution with benzene afforded a less polar product (8 mg; 25%) and a polar product (24 mg; 73%). The less polar product was shown to be identical with an authentic alnusa-1(10), 5-dien-3β-yl acetate (**13**; t_R=16.5 min) together with a small amount of unknown product (t_R=12.3 min) by GLC examination. The authentic sample of **13** was prepared by the dehydrogenation of alnus-5(10)-en-3β-yl acetate (**14**)[11] with selenium dioxide in boiling acetic acid. **13**: mp 207—208 °C (from chloroform–methanol); ^{1}H NMR δ=2.06 (3H, s), 4.71 (1H, dd, J=10 and 6 Hz), 5.21 (1H, m), and 5.67 (1H, t, J=4 Hz); MS m/z (%) 466 (M^+; 0.3), 406 (100), 391 (19), 274 (50), 259 (56), 205 (61), 171 (50), and 132 (65); UV (ethanol) λ_{max} (ε) 232 (14000), 238 (16000), and 245 nm (10000).

The polar product, a mixture of **15** and **16**, showed ^{1}H NMR δ=2.06 (3H, s), 4.04 (1H, m), 4.45 (1H, dd, J=9 and 6 Hz), 4.85 (0.5H, s), and 5.17 (0.5H, t, J=3 Hz); MS m/z 484 (M^+), 469, 466, 406, 391, 218 (base peak), 205, 204, 189, and 177.

Oxidation of the Mixture of Hydroxy Acetates (15 and 16). The mixture (25 mg) of **15** and **16**, dissolved in acetone (2 mL), was kept at 0 °C and oxidized with Jones reagent (0.05 mL) to give a mixture of 6-oxoolean-18-en-3β-yl acetate (**17**) and -12-en-3β-yl acetate (**18**); ^{1}H NMR δ=2.05 (3H, s), 4.41 (1H, dd, J=9 and 6 Hz), 4.90 (0.5H, s), and 5.21 (0.5H, t, J=3 Hz); MS m/z 482 (M^+), 467, 422, 407, 218 (base peak), 205, 189, and 177.

Alkaline Hydrolysis of the Mixture of Keto Acetates (17 and 18). The oxidation product (**17** and **18**), above obtained, was treated with 5% potassium hydroxide in methanol (3 mL) under a nitrogen atmosphere at room temperature for 15 h, and the usual work-up gave a mixture (18 mg) of hydroxy ketones (**19** and **20**). HPLC separation of the mixture gave a satisfactory result. 3β-Hydroxyolean-18-en-6-one (**19**; 9 mg), mp 217.5—219 °C (from chloroform-methanol), HPLC t_R= 15.7 min, showed IR (film) 3450 and 1710 cm^{-1}; ^{1}H NMR δ =3.13 (1H, dd, J=9 and 6 Hz) and 4.88 (1H, s); MS m/z (%) 440 (M^+; 51), 425 (34), 205 (48), 204 (47), 189 (34), and 177 (100); high resolution MS m/z 440.3659 (Calcd for $C_{30}H_{48}O_2$: M, 440.3654) and m/z 177.1623 (Calcd for $C_{13}H_{21}$: 177.1643). 3β-Hydroxyolean-12-en-6-one (**20**; 9 mg), mp 243—245 °C (decomp) (from ether–hexane), HPLC t_R=16.3 min, showed IR (film) 3450 and 1705 cm^{-1}; ^{1}H NMR δ=3.16 (1H, dd, J=9 and 6 Hz) and 5.21 (1H, t, J=3 Hz); MS m/z (%) 440 (M^+; 20), 425 (7), 218 (100), 205 (22), 203 (26), and 189 (10); high resolution MS m/z 440.3613 (Calcd for $C_{30}H_{48}O_2$: M, 440.3653) and m/z 218.2027 (Calcd for $C_{16}H_{26}$: 218.2033).

Acetylation of 3β-Hydroxyolean-18-en-6-one (19) and -12-en-6-one (20). The Δ^{18}-hydroxy ketone (**19**; 8 mg) was acetylated with acetic anhydride in pyridine to give 6-oxoolean-18-en-3β-yl acetate (**17**; 7 mg), mp 220.5—222 °C (from ether–methanol); IR (film) 1730, 1710, and 1250 cm^{-1}; ^{1}H NMR δ=2.04 (3H, s), 4.40 (1H, dd, J=8 and 6 Hz), and 4.89 (1H, s); MS m/z (%) 482 (M^+; 77), 467 (54), 205 (84), 204 (66), 189 (59), and 177 (100); high resolution MS m/z 482.3741 (Calcd for $C_{32}H_{50}O_3$: M, 482.3758) and m/z 177.1634 (Calcd for $C_{13}H_{21}$: 177.1642).

The Δ^{12}-hydroxy ketone (**20**), on acetylation, gave 6-oxoolean-12-en-3β-yl acetate (**18**), mp 246—248 °C (from methanol); ^{1}H NMR δ=0.81, 0.89, 0.95, 0.98, and 1.00 (each 3H, s), 1.25 (6H, s), 1.30 (3H, s), 2.05 (3H, s), 4.42 (1H, t, J=7 Hz), and 5.23 (1H, t, J=3 Hz); MS m/z (%) 482 (M^+; 21), 467 (8), 218 (100), 205 (61), 203 (30), and 189 (22); high resolution MS m/z 482.3743 (Calcd for $C_{32}H_{50}O_3$: M, 482.3758) and m/z 218.1998 (Calcd for $C_{16}H_{26}$: 218.2033).

Reduction of 3β-Hydroxyolean-12-en-6-one (20). The hydroxy ketone (**20**; 9 mg) in tetrahydrofuran (1.5 mL) was treated with an excess of lithium aluminium hydride (20 mg) under reflux for 5 h and the reaction product was worked up as usual to give olean-12-ene-3β,6β-diol (**3**; 7 mg) as the sole product, mp 258—260 °C (chloroform–methanol), ^{1}H NMR δ =0.86 (3H, s), 0.90 (6H, s), 1.10, 1.13, 1.23, 1.30, and 1.35 (each 3H, s), 3.15 (1H, dd, J=8 and 6 Hz), 4.56 (1H, br s), and 5.24 (1H, t-like, J=3 Hz); MS m/z (%) 442 (M^+; 16), 218 (100), 205 (14), 203 (32), and 189 (13); high resolution MS m/z 442.3829 (Calcd for $C_{30}H_{50}O_2$: M, 442.3811) and m/z 218.2055 (Calcd for $C_{16}H_{26}$: 218.2035); these spectral data were found to be identical with those of daturadiol (**3**).[9]

Acetylation of Daturadiol (3). Daturadiol (**3**) was treated with acetic anhydride in pyridine to give daturadiol 3-monoacetate (**8**), ^{1}H NMR (FT) δ=0.84 (3H, s), 0.88 (6H, s), 0.95, 1.10, (each 3H, s), 1.26 (6H, s), 1.35 (3H, s), 2.06 (3H, s), 4.45 (1H, m), 4.55 (1H, br s), and 5.23 (1H, t, J=3 Hz); MS m/z (%) 484 (M^+; 13), 218 (100), 205 (22), 203 (24), and 189 (15).

Backbone Rearrangement of 5β,6β-Epoxyalnusan-3β-yl Acetate (6). 5β,6β-Epoxide (**6**; 168 mg) in benzene was treated with $BF_3 \cdot OEt_2$ at room temperature. After the usual work-up, the reaction product was subjected to separation by silica-gel column chromatography. Elution with benzene gave alnusa-1(10),5-dien-3β-yl acetate (**13**; 5 mg), 6β-hydroxyalnus-1(10)-en-3β-yl acetate (**21**; 125 mg), and a mixture (18 mg) of 6β-hydroxyolean-12-en-3β-yl acetate (**8**) and -18-en-3β-yl acetate (**22**). 6β-Hydroxyolean-1(10)-en-3β-yl acetate (**21**) showed mp 233—233.5 °C (from acetone–methanol); IR (KBr) 3570, 3400, 1720, and 1260 cm^{-1}; ^{1}H NMR δ =2.04 (3H, s), 4.26 (1H, br s), 5.21 (1H, dd, J=10 and 5 Hz), and 5.39 (1H, m); MS m/z 484 (M^+), 424 (base peak), 406, 391, 302, 274, 259, 205, 150, and 122; Found: m/z 484.3943. Calcd for $C_{32}H_{52}O_3$: M, 484.3917. The mixture of **8** and **22** showed IR (Nujol) 3550, 1710, 1270, and 1255 cm^{-1}; ^{1}H NMR δ=2.05 (3H, s), 4.46 (1H, m), 4.52 (1H, br s), 4.86 (0.7H, s), and 5.23 (0.3H, t-like J=3 Hz); MS m/z (%) 484 (M^+; 40), 469 (9), 391 (6), 218 (100), 205 (74), 204 (83), 189 (58), and 177 (48).

Derivatization of 6β-Hydroxyalnus-1(10)-en-3β-yl Acetate (21). Hydroxy acetate (**21**) was treated with phosphoryl chloride in pyridine to give the 1(10), 5-diene (**13**), which was shown to be identical with an authentic sample by GLC examination.

On oxidation with Jones reagent, the hydroxy acetate (**21**) afforded 6-oxoalnus-1(10)-en-3β-yl acetate (**23**), mp 199—201 °C (from benzene–methanol); ^{1}H NMR δ=2.01 (3H, s), 2.23 (m), 3.12 (1H, br s), 4.82 (1H, t, J=5 Hz) and 5.30 (1H, m); MS m/z (%) 482 (M^+; 11), 422 (62), 407 (100), 273 (14), 259 (5), 205 (9), and 149 (22); Found: m/z 482.3754. Calcd for $C_{32}H_{50}O_3$: M, 482.3759.

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