Novel Opening of 15,16-Epoxybeyerane Diterpenes in Ruthenium-Catalyzed Rearrangement Processes. Formation of Antheridiogen-like Rings

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Rearrangement reactions of 15,16-epoxybeyeranes with acetoxy substituents at C-12 were carried out by treatment with ruthenium acetylacetonate. The stereochemistry of the acetoxy substituent group on C-12 decisively influences the process. In the case of the axial substituent, it aids in the stabilization of intermediate structures derived from an electron deficiency on C-15 that allows the formation of 8(15→9)-*abeo* and 8(14→9),13(12→16)-di*abeo* compounds. This promotion of a positive charge on C-15 of the beyerene skeleton has not yet been explored in classical studies of rearrangements of tetracyclic diterpenes. The formation of some chlorinated compounds, produced by the solvent used ($CHCl_3$), was also observed in this process. When the starting product had a C-12 acetoxy equatorial substituent, only migrations of the acetoxy group and some nucleophilic substitution processes were observed. The pathways of the rearrangements were proposed on the basis of findings obtained from rearrangement of C-12 deuterium labeled substrates.

Introduction

Numerous studies of the rearrangements of the C and D rings of tetracyclic diterpene compounds have appeared in the literature.[1-13] As a rule, these rearrangements involved epoxy compounds,[1-7] solvolytic reactions,[8-12] and/or thiocarbonate derivatives,[13] with a single functional group in the portion of the molecule able to undergo rearrangement.

Other functional groups located at strategic positions of the molecule notably influence the products obtained from the rearrangements and their yields.[14-17] For instance, the influence of different functional groups and configurations at C-14 of *ent*-15,16-epoxybeyerane compounds has been studied.[14] Subsequent work[15] examined the participation of hydroxyl groups at C-12 of *ent*-beyerene and *ent*-atisene products in solvolysis reactions. Thus, the influence of groups on C-14 of *ent*-beyerenes in the rearrangements obtained through solvolysis processes was demonstrated.[16] A more recent paper[17] reported the influence of hydroxyl groups of different stereochemistries at C-12 of *ent*-15,16-epoxybeyerane compounds, which occasionally induced retro-Prins processes.

To expand our understanding of the influence of the functional groups positioned near the rearranging portion of a diterpene, the rearrangement of epoxybeyerane compounds with acetoxy groups at C-12 were studied and the results are presented. Normally, the rearrangements of *ent*-15,16-epoxybeyerane compounds take place by opening of the epoxy group such that a carbocation is formed at C-16,[1-6] because anchimeric assistance by the 12/13 bond is observed.[2] The opposite mechanistic route, involving opening of the epoxy group such that electronic deficiency builds up at C-15 is infrequent.[7] In this paper the formation of some new rearranged products involving this rare epoxide opening is described.

Results and Discussion

The starting material for the preparation of epoxybeyerane compounds susceptible to treatment with ruthenium acetylacetonate was the natural product 1-acetyljativatriol (**1**),[18] which was deoxygenated[19] through its 17-chlorinated derivative to produce **2**.[17] Compound **2** was acetylated at C-12 to give the diacetylated compound **3**, which was then treated with *m*-CPBA to give the *ent*-1β,12α-diacetoxy-15α,16α-epoxy derivative **4** (see Figure 1). Treatment of this epoxybeyerane compound **4** with ruthenium acetylacetonate (Ru-acac) in the usual form[14] gave products **5** (16%), **6** (15%), **7** (9%), and **8** (12%). Mass spectrometry indicated that products **5** and **6** were chlorinated derivatives. The source of the chlorine, as in similar cases,[17] is the solvent, $CHCl_3$. The NMR data indicated that, in **5**, the chlorine was located at C-16, with *ent*-16β disposition and *trans* disposition with respect to the C-15 hydroxyl group ($J = 3.8$ Hz). Furthermore, the stereochemistry at carbons 15 and 16 had been proven by NOE experiments, using the C-20 methyl group as reference. This product is formed via the "normal"

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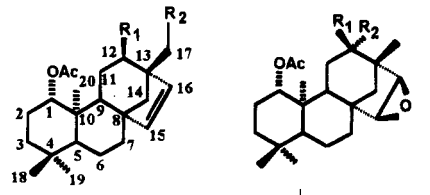
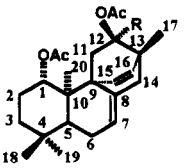
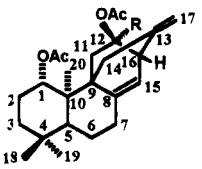


	R1	R2
1	OH	OH
2	OH	H
3	OAc	H

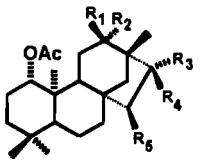
	R1	R2
4	OAc	H
9	=O	
10	OAc	D
11	H	OAc
12	D	OAc



7 R=H
15 R=D



8 R=H
16 R=D



	R1	R2	R3	R4	R5
5	OAc	H	Cl	H	OH
6	OAc	H	H	OH	Cl
13	OAc	D	Cl	H	OH
14	OAc	D	H	OH	Cl
17	OAc	H	Cl	H	OAc
18	OH	H	Cl	H	OH
19	OAc	H	H	OAc	Cl
20	Cl	H	OAc	H	OH
21	H	OH	OAc	H	OH
22	H	OAc	OH	H	OH
23	H	OAc	OAc	H	OH
24	Cl	D	OAc	H	OH
25	H	OAc	OAc	H	OAc
26	Cl	H	OAc	H	OAc
27	Cl	H	OH	H	OH
28	Cl	H	OAc	H	=O

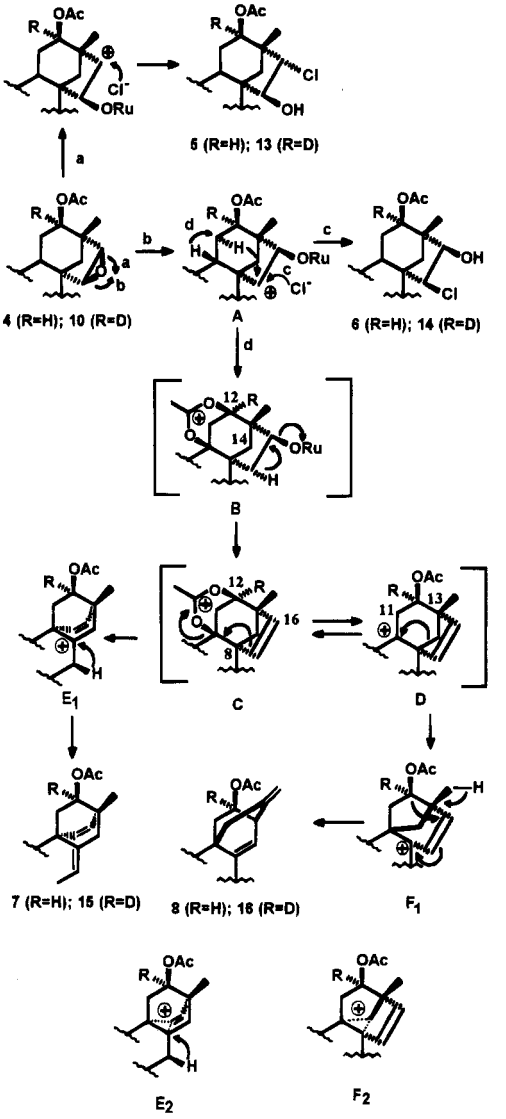
Figure 1. Structures of starting and rearranged products **1**–**28**.

opening of the epoxy compound toward C-15 (path **a** in Scheme 1) and entry of chlorine at C-16. The structure of **5** was further verified by deacetylation to **18**, a known compound.[17]

Epoxy compound **4** also underwent an epoxide opening in the less usual way (toward C-16, path **b** in Scheme 1) to give intermediate **A** and then chlorohydrin **6**. Compound **6** showed spectroscopic properties characteristic of the original *ent*-beyerane skeleton. The substituents on C-15 and C-16 had a *cis* disposition, as judged by the coupling constant of 6.5 Hz. Furthermore, NOE experiments showed positive dipolar coupling between the protons of C-15, C-16, and C-12 and the C-20 methyl group, which indicated that groups at both C-15 and C-16 had an *ent*-α disposition.

^{1}H NMR spectroscopy indicated that **7** was a diene compound obtained by a rearrangement from the original *ent*-epoxybeyerane compound through the "rare" opening of the epoxy group toward C-16 (structure **A** in Scheme 1). Subsequently, hydride migration from C-11 to C-15 and from C-9 to C-11 occurred (path **d** in Scheme 1) with the formation of a carbocation at C-9 that could be

Scheme 1. Proposed Mechanism of Rearrangement of Epoxy Compounds 4 and 10



stabilized by the participation of the axial acetoxy group at C-12 (structure **B**). This cationic species then lost the C-15 proton and the C-16 hydroxyl group to form a double bond between C-15 and C-16 (**C** or **D** cationic structures). From structure **C**, a migration of the C-8/C-15 bond occurred to form a C-9/C-15 bond and a C-8 cation (structure $\mathbf{E_1}$). Finally, a proton was lost from C-7 with formation of the C-7/C-8 double bond. The cation $\mathbf{E_1}$ may be better represented as the nonclassical cation $\mathbf{E_2}$.

Theoretical calculations[20] of homonuclear vicinal couplings in **7** coincided satisfactorily with the values observed. The stereochemistry was further verified by NOE experiments. Thus, an NOE effect was detected between the C-20 hydrogens (δ, 1.13) and H-15 (δ, 6.44), which fixes the disposition of the C-15/C-16 unsaturated bridge. On the other hand, irradiation of C-17 (δ 1.06) revealed a dipolar coupling with *ent*-H-12β (δ, 4.63), proton 14-*exo* (δ, 2.47), and H-16 (δ, 5.85). Irradiation of the C-12 proton allowed for verification of the chemical shift of the C-11 *exo* proton (δ, 1.92). Irradiation of H-11-*exo* showed it to be near *ent*-H-1β.

The other product isolated from this rearrangement (**8**) possesses spectroscopic properties that indicate that

(20) Program P.C. MODEL available from SerenaSoftware, P.O. Box 3076, Bloomington, IN 47402-3076.

it is also a diene compound (δ 4.80, br d, 1H; 4.73 br d, 1H; 5.48 d, 1H). The signals at δ 4.80 and 4.73 were assigned to protons of an exocyclic double bond formed on the C-17 methyl group in the rearrangement process. There were three angular methyl group signals at δ 1.14, 0.93, and 0.80. Furthermore, the signal for another proton of a new endocyclic double bond with a quaternary carbon appeared at δ 5.48 (d, J = 7.0 Hz). The structure was further confirmed by the ^{13}C NMR spectrum of product **8**. Several double-resonance experiments were performed to verify the coupling between these proton signals; these experiments suggested that product **8** has an endocyclic double bond whose proton is coupled with a doubly allylic proton (δ 3.15, J_1 = 7.0 Hz, J_2 = 3.6 Hz, H-16). In addition, this allylic proton is vicinally coupled with the geminal proton of the acetoxy group at C-12 (δ 4.59, J_1 = 9.7 Hz, $J_2 = J_3$ = 3.6 Hz). On the other hand, NOE experiments were carried out using the methyl group at C-20 as the starting point, which confirmed the stereochemistry proposed. Irradiation of the C-20 methyl group (δ 0.93) produced an NOE with *ent*-11β-H (δ 1.98). Irradiation of this C-11 proton produced NOEs with its geminal proton (*ent*-11α-H) (δ 0.97), the C-20 methyl group, and the *ent*-12β-H (δ 4.59).

The formation of **8** in the rearrangement process can be explained starting from cation **D** (Scheme 1). This structure would give rise to the rearrangement 8(14→9) to form the $\mathbf{F_1}$ cationic structure, which again may be better represented as the delocalized cation $\mathbf{F_2}$. Finally, a 13(12→16) rearrangement and the loss of a C-17 proton could occur, yielding product **8**. Cycles **C** and **D** of **8** are similar to those found in antheridic acid,[21] the major antheridiogen isolated from *Anemia phyllitidis*, and the proposed intermediate $\mathbf{F_2}$ is also similar to the cyclopropane structure of another antheridiogen isolated from *A. mexicana*.[22]

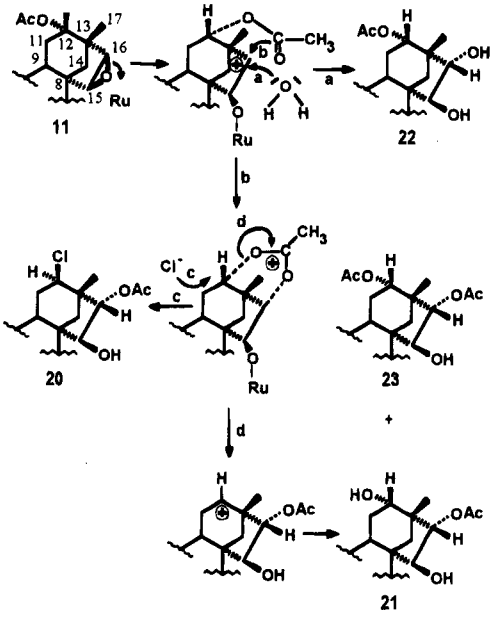
To determine the influence of the stereochemistry of the acetoxy group at this position on the rearrangement processes, the corresponding epimer at C-12 of substrate **4** (product **11**) was synthesized. The substrates deuterated at C-12 with axial (product **10**) and equatorial (product **12**) acetoxy groups were also obtained. To corroborate the proposed mechanisms, the deuterated substrates were rearranged and their rearrangement products were studied.

Epoxidation of compound **2** with *m*-CPBA gave the known epoxybeyerane.[17] Treatment of this with Jones reagent gave epoxybeyeranone **9**.[17] Reduction of **9** with $NaBH_4$ yielded two previously known C-12 epimers.[17] The major product (70%) has the hydroxyl group at C-12 in the *ent*-β position. The immediate acetylation of this pair of epimers yielded **11** and a smaller amount of **4**. Ketone **9** was also reduced with $NaBD_4$ and, after acetylation, gave the deuterated analogs (major product **12** and minor product **10**).

The ruthenium-catalyzed rearrangement of the deuterated epoxybeyerane compound with the axial acetoxy group at C-12 (product **10**) gave **13**, **14**, **15**, and **16** in yields similar to those obtained from the nondeuterated epoxybeyerane derivative (product **4**). The observation that the deuterium remained at C-12 in the skeleton of all the products is consistent with the mechanisms proposed in Scheme 1.

Rearrangement of the epoxybeyerane **11**, which has the C-12 acetoxy group in the equatorial position, gave

Scheme 2. Proposed Mechanism of Rearrangement of Epoxy Compound 11



products **20** (60%), **21** (9%), **22** (4%), and **23** (3%). The major product of this rearrangement (**20**) has a mass spectrum characteristic of a chlorinated compound; furthermore, the NMR spectrum suggested that the chlorine was axially disposed at C-12. Multiple NOE difference experiments verified the structure. Irradiation of the C-20 methyl group (δ 1.03, 3H, s) produced an NOE effect on the geminal proton of the hydroxyl group at C-15 (δ 3.92, dd, 1H, $J_1 = J_2$ = 2.4 Hz), which displayed a scalar coupling with the geminal proton to the acetoxy group at C-16 (δ 4.34, d, 1H, J = 2.4 Hz). Irradiation of this C-15 proton also produced NOE on the C-20 methyl group. Thus, the C-20 methyl group and H-15 are proximate, and the acetoxy and the hydroxyl groups are contiguous. Moreover, irradiation of H-16 produced NOE of the 3H of C-17. Irradiation of the C-17 methyl group gave NOE of H-12 (δ 4.20, dd, 1H, J_1 = 4.8 Hz, J_2 = 2.9 Hz) and H-16, and irradiation of H-12 produced NOE of the 3H of C-17 and H-11. Structural assignments for **21**, **22**, and **23** were made by chemical correlations. Thus, total acetylation, partial saponification, and oxidation of the major product **20** yielded **26**, **27**, and **28**, characterized by their physical and spectroscopic properties. Moreover, total acetylation of **21**, **22**, and **23** gave a single tetracetylated product (product **25**).

The mechanism proposed in Scheme 2 explains the formation of these rearrangement products. According to this scheme, the opening of the epoxy group toward C-15 is assumed to give a carbocation at C-16 which could undergo hydration yielding the *trans* diol **22** (path **a** in Scheme 2). The carbocation at C-16 can also trap the equatorial acetoxy group of C-12, giving a 1,3-dioxolonium ring (path **b** in Scheme 2), susceptible to a concerted attack at C-12 by chloroform. This would invert the configuration of this carbon (path **c** in Scheme 2) and thus produce the major product **20**. The 1,3-dioxolonium ring can also open, via path **d**, to a carbocation at C-12. The subsequent attack by water at C-12 would produce **21**, and if an acetoxy group entered this position, **23** would be obtained.

Once again, to further corroborate the proposed mechanism, the C-12 deuterium-labeled epoxybeyerane (product **12**) was rearranged, producing only major product

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Table 1. ^{13}C NMR Chemical Shifts of Compounds 3–15[a,b]

C	3	4	5	6	7	8	10	11	12	13	14	15
1	81.9	82.3	82.6	82.2	77.4	79.6	82.4	82.6	82.6	82.6	82.2	77.5
2	25.0	24.9	24.9	24.9	24.4	24.1	25.0	24.8	24.8	24.9	24.9	24.4
3	39.4	39.9	39.3	39.2	39.4[a]	39.6[a]	39.9	39.2	39.3	39.3	39.2	39.3[a]
4	33.1	33.0	33.0	33.0	32.9	33.6	33.1	33.0	33.0	33.0	33.1	32.9
5	55.1	55.2	55.4	55.5	44.1	46.2[b]	55.2	55.0[a]	55.1[a]	55.4	55.5	44.1
6	19.8	19.4	19.6	19.1	22.9	18.0	19.5	19.5	19.5	19.6	19.1	23.3
7	37.0	33.0	32.7	35.7	117.5	29.0	33.0	32.3	32.5	32.7	35.8	117.5
8	49.5	44.6	45.2[a]	46.6[a]	137.9	156.7	44.7	44.4	44.5	45.1	46.5[a]	137.9
9	49.1	52.0	51.9	51.7	40.6[b]	37.9	52.1	55.1[a]	55.4[a]	51.9	51.7	40.6[b]
10	41.7	41.9	42.4	42.3	38.5[b]	41.9	42.0	42.3[b]	42.3[b]	42.4	42.3	38.4[b]
11	29.3	28.5	27.2	27.5	38.2	39.2[a]	28.5	28.5	28.4	27.1	27.4	38.2
12	73.7	74.4	74.3	75.1	76.2	72.3		78.5				
13	46.9	43.1	46.0[a]	47.7[a]	48.7	144.4	43.1	42.7[b]	42.7[b]	46.0	47.8[a]	48.7
14	53.8	39.3	46.7	45.0	39.7[a]	43.0	39.3	43.9	43.9	46.7	45.0	39.7[a]
15	138.1	55.5	80.6	68.8	135.9[c]	116.6	55.6	55.6[a]	55.4[a]	80.6	68.9	135.9[c]
16	136.5	59.1	76.7	76.0	136.2[c]	45.8[b]	59.6	57.9	57.9	76.7	76.0	136.3[c]
17	21.1	17.5	20.7	17.6	22.9	107.3	17.5	17.4	17.3	20.7	15.5	22.9
18	33.0	33.0	33.2	33.2	33.4	31.4	33.1	33.0	33.0	33.2	33.2	33.4
19	21.6	21.5	21.7	21.7	21.1	20.5	21.6	21.5	21.5	21.7	21.7	21.1
20	10.7	12.3	11.2	11.2	12.5	16.7	12.4	12.7	12.7	11.3	11.2	12.5
Me	21.9	21.7	21.8	21.3	21.9	21.5	21.8	21.7	21.7	21.7	21.3	21.7
Me	21.5	21.2	21.3	21.3	21.5	21.2	21.3	21.1	21.1	21.3	21.3	21.4
CO	171.3	170.8	170.9	170.8	171.2	170.9	170.7	170.5	170.4	170.9	170.8	171.1
CO	170.8	170.6	170.7	170.7	170.1	170.6	170.7	170.5	170.4	170.7	170.7	170.1

[a] ^{13}C chemical shifts are given in δ values (ppm) relative to $CDCl_3$ signals. [b] For each compound, the numbers designated by superscripts a, b, or c may be interchanged.

24, which is similar to **20** obtained before, with *ent*-12β deuterium. This reaction confirmed the migration of the acetoxy group from C-12 to C-16 and thus demonstrated that this functional group participated decisively in the course of the rearrangement. Hence, the equatorial acetoxy group of C-12 blocked the possible skeletal rearrangements.

Experimental Section

Deoxygenation of 1. A 3 g sample of **1**[18] was first treated with Py/CCl_4/Ph_3P and then with tri-*n*-butyltin hydride/azoisobutyronitrile/toluene.[19] After column chromatography over silica gel using as solvent CH_2Cl_2 containing increasing amounts of acetone, 1.8 g of *ent*-1β-acetoxy-12α-hydroxybeyer-15-ene (**2**, 60%)[17] was obtained.

Acetylation of 2. An amount of 300 mg of **2** was dissolved in 6 mL of Ac_2O and 12 mL of Py with stirring for 2 h at 25 °C. The reaction mixture was diluted with water, extracted with CH_2Cl_2, washed with saturated $KHSO_4$, and dried with anhydrous Na_2SO_4. Chromatography over silica gel (CH_2Cl_2/Me_2CO) yielded 270 mg of *ent*-1β,12α-diacetoxybeyer-15-ene (**3**, 90%): syrup; $[\alpha]_D$ −24.7 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 3020, 1734, 1248; ^1H NMR δ 5.77 (1H, d, J = 5.7 Hz), 5.54 (1H, d, J = 5.7 Hz), 4.73 (1H, m), 4.47 (1H, dd, J_1 = 4.9 Hz, J_2 = 10.8 Hz), 2.01 and 1.95 (3H each, s), 0.92, 0.85, 0.83, and 0.81 (3H each, s); ^{13}C NMR see Table 1; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 389 (2.0), 329 (8.0), 269 (100.0).

Epoxidation of 3. A 250 mg amount of **3** was dissolved in $CHCl_3$ (10 mL) and epoxidized with *m*-CPBA (250 mg) for 12 h at room temperature, washed with aqueous $FeSO_4$ (10%), aqueous $NaHCO_3$ (5%), and water, dried with $MgSO_4$, and concentrated under vacuum. After column chromatography (CH_2Cl_2/Me_2CO), *ent*-1β,12α-diacetoxy-15α,16α-epoxybeyerane (237 mg, **4**, 95%) was obtained: mp 173–75 °C; $[\alpha]_D$ −26.3 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 1733, 1258; ^1H NMR δ 4.81 (1H, m), 4.46 (1H, dd, J_1 = 4.9 Hz, J_2 = 10.8 Hz), 3.34 (1H, d, J = 2.8 Hz), 3.02 (1H, d, J = 2.8 Hz), 1.99 and 1.93 (3H each, s), 1.02, 0.95, 0.84, and 0.81 (3H each, s); ^{13}C NMR see Table 1; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 405 (2.0), 387 (1.0), 345 (25.0), 285 (100.0).

Rearrangement of 4. A sample (200 mg) of **4** was dissolved in $CHCl_3$ (10 mL), and ruthenium acetylacetonate (20 mg) was added. The mixture was heated at 140 °C in a sealed tube (6 h). Then, when the solution cooled to room temperature, it was concentrated and directly chromatographed (CH_2Cl_2/Me_2CO) to give 32 mg of *ent*-1β,12α-diacetoxy-16β-chloro-15α-hydroxybeyerane (**5**, 16%) [mp 94–96 °C; $[\alpha]_D$ +4.4 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 3479, 1733, 1255; ^1H NMR δ 4.85 (1H, ddd, J_1 = 3.4 Hz, J_2 = J_3 = 1.9 Hz), 4.52 (1H, dd, J_1 = 5.4 Hz, J_2 = 10.7 Hz), 4.25 (1H, dd, J_1 = 3.8 Hz, J_2 = 2.1 Hz), 3.69 (1H, d, J = 3.8 Hz), 2.03 and 1.99 (3H each, s), 1.06, 0.94, 0.85, and 0.81 (3H each, s); ^{13}C NMR see Table 1; EIMS, *m*/*z* (rel intensity) $[M]^+$ 440 (1.0), 382 (1.0), 380 (1.0), 344 (1.0), 322 (3.0), 320 (7.5), 284 (11.2), 43 (100.0)], 30 mg of *ent*-1β,12α-diacetoxy-15α-chloro-16α-hydroxybeyerane (**6**, 15%) [mp 208–10 °C; $[\alpha]_D$ −28.6 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 3494, 1731, 1247; ^1H NMR δ 4.73 (1H, dd, J_1 = 6.5 Hz, J_2 = 1.1 Hz), 4.62 (1H, ddd, J_1 = 3.4 Hz, J_2 = J_3 = 1.7 Hz), 4.51 (1H, dd, J_1 = 5.8 Hz, J_2 = 10.0 Hz), 3.69 (1H, br d, J = 6.5 Hz), 2.04 and 1.97 (3H each, s), 1.07, 0.94, 0.86, and 0.83 (3H each, s); ^{13}C NMR (δ, $CDCl_3$) see Table 1; EIMS, *m*/*z* (rel intensity) $[M]^+$ 440 (1.0), 382 (1.0), 380 (1.0), 344 (1.0), 322 (1.5), 320 (4.5), 285 (11.4), 43 (100.0)], 18 mg of *ent*-1β,12α-diacetoxy-8(15→9)-*abeo*-beyera-7,15-diene (**7**, 9%) [mp 110–12 °C; $[\alpha]_D$ +17.6 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 1737, 1241; ^1H NMR δ 6.44 (1H, d, J = 8.6 Hz), 5.85 (1H, d, J = 8.6 Hz), 5.45 (1H, m), 4.76 (1H, dd, J_1 = 6.7 Hz, J_2 = 9.0 Hz), 4.63 (1H, ddd, J_1 = 9.6 Hz, J_2 = J_3 = 1.8 Hz), 2.47 (1H, br d, J = 14.8 Hz), 2.04 and 1.99 (3H each, s), 1.13, 1.06, 0.96, and 0.90 (3H each, s); ^{13}C NMR see Table 1; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 387 (3.6), 327 (100.0), 267 (44.0)], and 24 mg of *ent*-1β,12α-diacetoxy-8(14→9),13(12→16)-*diabeo*-beyera-8(15),13(17)-diene (**8**, 12%) mp 128–30 °C; $[\alpha]_D$ +115.0 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 3070, 1733, 1242; ^1H NMR δ 5.48 (1H, d, J = 7.0 Hz), 4.80 (1H, br d, J = 4.1 Hz), 4.76 (1H, dd, J_1 = 4.7 Hz, J_2 = 11.3 Hz), 4.73 (1H, br d, J = 4.1 Hz), 4.59 (1H, ddd, J_1 = 9.7 Hz, J_2 = J_3 = 3.6 Hz), 3.15 (1H, dd, J_1 = 7.0 Hz, J_2 = 3.6 Hz), 2.17 (1H, ddd, J_1 = 16.1 Hz, J_2 = J_3 = 2.1 Hz), 2.03 and 2.00 (3H each, s), 1.14, 0.93 and 0.80 (3H each, s); ^{13}C NMR see Table 1; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 387 (9.9), 327 (84.8), 267 (100.0).

Epoxidation and Oxidation of 2. An amount of 1.2 g of product **2** was epoxidized with *m*-CPBA (1.2 g) for 12 h at room temperature, washed with aqueous $FeSO_4$ (10%), aqueous $NaHCO_3$ (5%), and water, dried with $MgSO_4$, and concentrated under vacuum. After column chromatography (CH_2Cl_2/Me_2CO) *ent*-1β-acetoxy-15α,16α-epoxy-12α-hydroxybeyerane (1.14 g, 95%)[17] was obtained. This product was dissolved in acetone and was oxidized with Jones reagent, the reaction was stopped with a few drops of methanol, and the solution was diluted with water, extracted with CH_2Cl_2, dried with $MgSO_4$, and evaporated under vacuum. After column chromatography, 1.08 g of *ent*-1β-acetoxy-15α,16α-epoxybeyeran-12-one[17] was isolated (**9**, 95%).

Reduction of 9. A solution of **9** (500 mg) in 20 mL of EtOH was treated with 50 mg of $NaBH_4$ at room temperature. The mixture was stirred for 8 h. The solution was slowly acidified with HCl, diluted with water, and extracted with CH_2Cl_2. The organic layer was treated with $MgSO_4$ and concentrated under vacuum. After column chromatography (CH_2Cl_2/Me_2CO), 125 mg of *ent*-1β-acetoxy-15α,16α-epoxy-12α-hydroxybeyerane (25%)[17] and 350 mg of *ent*-1β-acetoxy-15α,16α-epoxy-12β-hydroxybeyerane (70%)[17] were obtained.

Acetylation of *ent*-1β-Acetoxy-15α,16α-epoxy-12β-hydroxybeyerane. This product (300 mg) was dissolved in Ac_2O (6 mL) and Py (12 mL) with stirring for 2 h at 25 °C. The reaction mixture was diluted with water, extracted with CH_2Cl_2, washed with saturated $KHSO_4$, and dried with anhydrous Na_2SO_4. Chromatography over silica gel (CH_2Cl_2/Me_2CO) yielded 290 mg of *ent*-1β,12β-diacetoxy-15α,16α-epoxybeyerane (**11**, 95%): mp 198−200 °C; $[\alpha]_D$ +34.5 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 1735, 1458, 1246; ^1H NMR δ 4.66 (1H, ddd, J_1 = 6.7 Hz, $J_2 = J_3$ = 9.4 Hz), 4.45 (1H, dd, J_1 = 4.7 Hz, J_2 = 10.9 Hz), 3.43 (1H, d, J = 3.0 Hz), 3.29 (1H, d, J = 3.0 Hz), 2.04 and 1.92 (3H each, s), 1.09, 1.02, 0.87, and 0.84 (3H each, s); ^{13}C NMR see Table 1; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 405 (11.0), 387 (1.0), 345 (56.0), 327 (3.0), 285 (100.0).

Reduction of 9 with $NaBD_4$. A solution of **9** (500 mg) in 15 mL of EtOH was treated with 50 mg of $NaBD_4$ at room temperature under conditions similar to those above to obtain 350 mg of *ent*-1β-acetoxy-12α-deuterio-15α,16α-epoxy-12β-hydroxybeyerane[17] (70%) and 125 mg of *ent*-1β-acetoxy-12β-deuterio-15α,16α-epoxy-12α-hydroxybeyerane (25%).[17]

Acetylation of *ent*-1β-acetoxy-12β-deuterio-15αg,16α-epoxy-12α-hydroxybeyerane. This product (110 mg) was dissolved in Ac_2O (2 mL) and Py (4 mL) and stirred for 2 h. The reaction mixture was treated as indicated above, and after column chromatography (CH_2Cl_2/Me_2CO), 105 mg of *ent*-1β,-12α-diacetoxy-12β-deuterio-15α,16α-epoxybeyerane was isolated (**10**, 95%): mp 150−52 °C; $[\alpha]_D$ −42.4 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 1734, 1250; ^1H NMR δ 4.50 (1H, dd, J_1 = 5.8 Hz, J_2 = 8.1 Hz), 3.37 (1H, d, J = 2.9 Hz), 3.05 (1H, d, J = 2.9 Hz), 2.03 and 1.97 (3H each, s), 1.05, 0.99, 0.87, and 0.85 (3H each, s); ^{13}C NMR see Table 1; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 406 (1.0), 388 (1.0), 346 (16.0), 286 (100.0).

Acetylation of *ent*-1β-Acetoxy-12α-deuterio-15α,16α-epoxy-12β-hydroxybeyerane. This product (300 mg) was dissolved in Ac_2O (6 mL) and Py (12 mL) and stirred for 2 h. Workup proceeded in the usual manner, and after column chromatography (CH_2Cl_2/Me_2CO), 285 mg of *ent*-1β,12β-diacetoxy-12α-deuterio-15α,16α-epoxybeyerane was isolated (**12**, 95%): mp 199−201 °C; $[\alpha]_D$ +44.4 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 1733, 1253; ^1H NMR δ 4.45 (1H, dd, J_1 = 4.6 Hz, J_2 = 10.0 Hz), 3.43 (1H, d, J = 3.0 Hz), 3.28 (1H, d, J = 3.0 Hz), 2.04 and 1.92 (3H each, s), 1.09, 1.02, 0.87, and 0.85 (3H each, s); ^{13}C NMR see Table 1; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 406 (3.0), 346 (32.0), 286 (100.0).

Rearrangement of 10. A 100 mg sample of **10** was treated with ruthenium acetylacetonate for 6 h using the above-indicated reaction conditions and directly chromatographed (CH_2Cl_2/Me_2CO) to give 15 mg of *ent*-1β,12α-diacetoxy-16β-chloro-12β-deuterio-15α-hydroxybeyerane (**13**, 15%) [mp 92−94 °C; $[\alpha]_D$ +4.3 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 3475, 1734, 1459; ^1H NMR δ 4.52 (1H, dd, J_1 = 5.4 Hz, J_2 = 10.6 Hz), 4.25 (1H, m), 3.69 (1H, d, J = 3.8 Hz), 2.03 and 1.99 (3H each, s), 1.06, 0.93, 0.85, and 0.81 (3H each, s); ^{13}C NMR see Table 1; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 442 (1.0), 384 (3.0), 382 (7.0), 324 (34.0), 322 (100.0)], 15 mg of *ent*-1β,12α-diacetoxy-15α-chloro-12β-deuterio-16α-hydroxybeyerane (**14**, 15%) [mp 210−12 °C; $[\alpha]_D$ −29.9 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 3498, 1732, 1245; ^1H NMR δ 4.51 (1H, dd, J_1 = 5.7 Hz, J_2 = 10.1 Hz), 4.77 (1H, dd, J_1 = 6.3 Hz, J_2 = 1.0 Hz), 3.69 (1H, br d, J = 6.3 Hz), 2.04 and 1.99 (3H each, s), 1.07, 0.94, 0.86, and 0.83 (3H each, s); ^{13}C NMR see Table 1; EIMS, *m*/*z* (rel intensity) $[M]^+$ 441 (4.0), 405 (4.1), 387 (29.0), 383 (6.5), 381 (12.0), 323 (32.0), 321 (100.0)], 8 mg of *ent*-1β,12α-diacetoxy-12β-deuterio-8(15→9)-*abeo*-beyera-7,15-diene (**15**, 8%) [mp 108−10 °C; $[\alpha]_D$ +25.3 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 1733, 1247; ^1H NMR δ 6.44 (1H, d, J = 8.7 Hz), 5.85 (1H, d, J = 8.7 Hz), 5.44 (1H, m), 4.75 (1H, dd, J_1 = 6.6 Hz, J_2 = 9.2 Hz), 2.47 (1H, br d, J = 15.0 Hz), 2.04 and 1.99 (3H each, s), 1.13, 1.06, 0.96, and 0.90 (3H each, s); ^{13}C NMR see Table 1; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 388 (13.0), 328 (100.0), 268 (70.0)], and 11 mg of *ent*-1β,12α-diacetoxy-12β-deuterio-8(14→9),13(12→16)-*diabeo*-beyera-8(15),13(17)-diene (**16**, 11%) [mp 126−28 °C; $[\alpha]_D$ +109.0 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 1736, 1241; ^1H NMR δ 5.48 (1H, d, J = 7.2 Hz), 4.80 (1H, br d, J = 4.1 Hz), 4.72 (1H, br d, J = 4.1 Hz), 3.15 (1H, d, J = 7.2 Hz), 2.16 (1H, ddd, J_1 = 16.0 Hz, $J_2 = J_3$ = 2.0 Hz), 2.03 and 2.00 (3H each, s), 1.14, 0.93 and 0.80 (3H each, s); ^{13}C NMR see Table 2; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 388 (6.0), 328 (100.0), 268 (29.0)].

Acetylation of 5. A solution of **5** (10 mg) in Ac_2O (0.2 mL) and Py (0.4 mL) was maintained with stirring for 12 h at reflux. The reaction mixture was diluted with water, extracted with CH_2Cl_2, washed with saturated $KHSO_4$, and dried with anhydrous Na_2SO_4. Chromatography over silica gel (CH_2Cl_2/Me_2CO) yielded 9 mg of *ent*-1β,12α,15α-triacetoxy-16β-chlorobeyerane (**17**, 90%): mp 69−71 °C; $[\alpha]_D$ −68.4 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 1738 and 1237; ^1H NMR δ 5.52 (1H, dd, J_1 = 3.7 Hz, J_2 = 2.3 Hz), 4.88 (1H, ddd, J_1 = 3.6 Hz, $J_2 = J_3$ = 1.9 Hz), 4.52 (1H, dd, J_1 = 4.9 Hz, J_2 = 10.8 Hz), 3.47 (1H, d, J = 3.7 Hz), 2.13, 2.04, and 2.00 (3H each, s), 1.17, 0.97, 0.83, and 0.80 (3H each, s); ^{13}C NMR see Table 2; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 483 (1.0), 447 (6.2), 425 (1.2), 423 (3.6), 365 (10.1), 363 (29.9), 305 (34.5), 303 (100.0).

Partial Saponification of 5. An amount of 10 mg of product **5** was dissolved in of MeOH/H_2O/KOH (70/30/5) and refluxed for 6 h, diluted with H_2O, neutralized with HCl (2 N), extracted with CH_2Cl_2, dried with $MgSO_4$, and concentrated under vacuum. After column chromatography (CH_2Cl_2/Me_2CO), *ent*-1β-acetoxy-16β-chloro-12α,15α-dihydroxybeyerane (8 mg, **18**, 75%)[17] was isolated.

Acetylation of 6. Product **6** (10 mg) was dissolved in Ac_2O (0.2 mL) and Py (0.4 mL) with stirring for 12 h at reflux. The reaction mixture was diluted with water, extracted with CH_2Cl_2, washed with saturated $KHSO_4$, and dried with anhydrous Na_2SO_4. Chromatography over silica gel (CH_2Cl_2/Me_2CO) yielded 8 mg of *ent*-1β,12α,16α-triacetoxy-15α-chlorobeyerane (**19**, 85%): mp 79−81 °C; $[\alpha]_D$ −38.3 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 1737 and 1241; ^1H NMR δ 4.84 (1H, br d, J = 7.4 Hz), 4.67 (1H, br d, J = 7.4 Hz), 4.65 (1H, m), 4.50 (1H, dd, J_1 = 5.7 Hz, J_2 = 10.1 Hz), 2.12, 2.04, and 1.98 (3H each, s), 1.07, 0.87, 0.86, and 0.83 (3H each, s); ^{13}C NMR see Table 2; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 483 (0.6), 447 (5.7), 425 (6.9), 423-(21.3), 365(34.0), 363(100.0), 305(2.2), 303(6.3).

Rearrangement of 11. Product **11** (250 mg) was treated with ruthenium acetylacetonate for 8 h under the above-indicated reaction conditions and directly chromatographed (CH_2Cl_2/Me_2CO) to give 150 mg of *ent*-1β,16β-diacetoxy-12α-chloro-15α-hydroxybeyerane (**20**, 60%) [mp 188−90 °C; $[\alpha]_D$ −89.6 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 3534, 1733, 1242; ^1H NMR δ 4.53 (1H, dd, J_1 = 5.0 Hz, J_2 = 10.5 Hz), 4.34 (1H, d, J = 2.4 Hz), 4.20 (1H, dd, J_1 = 4.8 Hz, J_2 = 2.9 Hz), 3.92 (1H, dd, $J_1 = J_2$ = 2.4 Hz), 2.15 and 2.00 (3H each, s), 1.07, 1.03, 0.84, and 0.79 (3H each, s); ^{13}C NMR see Table 2; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 441 (4.0), 425 (35.0), 423 (83.0), 405 (33.0), 383 (24.0), 381 (75.0), 365 (37.0), 363 (100.0), 323 (7.0), 321 (21.0)], 22 mg of *ent*-1β,16β-diacetoxy-12β,15α-dihydroxybeyerane (**21**, 9%) [syrup; $[\alpha]_D$ −14.9 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 3523, 1731, 1248; ^1H NMR δ 4.51 (1H, dd, J_1 = 5.2 Hz, J_2 = 10.5 Hz), 4.35 (1H, dd, J_1 = 2.8 Hz, J_2 = 1.4 Hz),), 4.03 (1H, dd, $J_1 = J_2$ = 2.8 Hz), 3.36 (1H, dd, J_1 = 5.8 Hz, J_2 = 9.5 Hz), 2.18 and 2.03 (3H each, s), 1.13, 1.08, 0.84, and 0.80 (3H each, s); ^{13}C NMR see Table 2; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 423 (1.2), 405 (61.0), 387 (5.0), 363 (13.2), 345 (100.0); 303 (10.5)], 10 mg of *ent*-1β,12β-diacetoxy-15α,16β-dihydroxybeyerane (**22**, 4%) [syrup; $[\alpha]_D$ +34.9 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 3440, 1732, 1250; ^1H NMR δ 4.75 (1H, dd, J_1 = 4.8 Hz, J_2 = 10.7 Hz), 4.48 (1H, dd, J_1 = 4.8 Hz, J_2 = 10.7 Hz), 4.20 (1H, br d, J = 2.0 Hz), 3.68 (1H, br d, J = 2.0 Hz), 2.04 and 1.93 (3H each, s), 1.13, 1.04, 0.86, and 0.82 (3H each, s); ^{13}C NMR see Table 2; CIMS, *m*/*z* (rel intensity) $[M + 1]^+$ 423 (1.0), 387 (1.6), 363 (8.7), 345 (20.7), 303 (49.6), 285 (81.3), 279 (100.0); 253 (55.7)], and 8 mg of *ent*-1β,12β,16β-triacetoxy-15α-hydroxybeyerane (**23**, 3%) [syrup; $[\alpha]_D$ −15.9 ($CHCl_3$, *c* 1); IR ν_{max} (neat, cm^{-1}) 3508, 1735, 1246; ^1H NMR δ 4.69 (1H, dd, J_1 = 5.7 Hz, J_2 = 9.6 Hz), 4.48 (1H, dd, J_1 = 4.7 Hz, J_2 = 10.2

Table 2. ^{13}C NMR Chemical Shifts of Compounds 16–28[a,b]

C	16	17	19	20	21	22	23	24	25	26	27	28
1	79.9	82.6	82.2	82.9	82.7	82.9	83.1	83.0	82.8	82.7	82.9	81.5
2	24.3	25.1	24.9	24.7	24.7	24.5	24.6	24.7	24.6	24.8	24.7	24.9
3	39.7[a]	39.4	39.2	39.1	39.1	39.1	39.2	39.1	39.1	39.1	39.0	39.3
4	33.9	32.8	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.2
5	46.3[b]	55.7	55.6	55.4	55.7[a]	55.2	55.1[a]	55.4	55.4[a]	55.5	55.3	54.7
6	18.2	19.3	19.1	19.6	19.8	19.8	19.7	19.6	19.4	19.4	19.7	18.9
7	29.2	33.2	35.8	32.5	32.4	32.5	32.5	32.5	32.8	33.1[a]	32.0[a]	33.7[a]
8	156.9	45.3[a]	48.1	42.3	44.7	44.3[a]	44.5[b]	45.8[a]	44.9[b]	45.6[b]	45.5[b]	50.4
9	38.1	52.1	51.6	50.7	55.3[a]	55.2	55.3[a]	50.8	55.3[a]	51.0	51.0	51.6
10	42.1	42.1	42.3	45.7[a]	42.7	42.7	42.8	42.3	42.7	42.1	42.3	42.3
11	39.4[a]	27.2	27.5	31.9	33.0	28.6	28.2	31.8	28.0	31.9[a]	32.7[a]	33.2[a]
12		74.2[b]	74.6	65.1	77.4	79.7	77.2		78.0	65.2	66.3	64.5
13	144.5	45.9[a]	45.7	45.5[a]	45.2	44.7[a]	45.0[b]	45.6[a]	45.3[b]	46.2[b]	46.2[b]	44.4
14	43.1	47.5	45.8	45.6	50.8	50.7	50.6	45.8	51.6	46.4	46.0	43.3
15	116.8	81.2	64.5	76.9	77.4	79.7	77.9	77.0	79.0	78.5	79.8	216.0
16	46.0[b]	73.6[b]	76.9	94.6	96.6	92.3	93.9	94.6	87.5	88.1	91.3	83.6
17	107.6	21.9[c]	17.6	23.1	21.3	21.2[b]	21.0	23.1	21.0[c]	22.8	23.3	23.0
18	31.8	33.3	33.2	33.2	33.2	33.2	33.2	33.2	33.1	33.2	33.2	33.4
19	20.8	21.8[c]	21.6	21.7	21.6	21.6[b]	21.7	21.7	21.0[c]	21.8	21.7	22.0
20	16.9	10.8	11.4	11.7	11.6	11.6	11.7	11.7	11.5	11.5	12.0	9.3
Me	21.8	21.4	21.8	22.0	22.1	21.7	21.8	22.0	21.0[c]	21.1	22.0	22.0
Me	21.3	21.4	21.3	21.1	21.3	21.2	21.2	21.0	21.1[c]	21.1		20.7
Me		20.7	20.8						21.6[c]	22.0		
Me									21.7[c]			
CO	171.1	170.7	170.7	173.2	172.7	170.5	173.5	173.2	173.8	170.3	170.5	169.9
CO	170.8	170.4	170.6	170.2	170.7	169.6	170.4	170.2	173.1	170.3		170.2
CO		169.6	170.1						170.3	170.3		
CO									170.6			

[a] ^{13}C chemical shifts are given in δ values (ppm) relative to $CDCl_3$ signals. [b] For each compound, the numbers designated by superscripts a, b, or c may be interchanged.

Hz), 4.06 (1H, dd, $J_1 = J_2 = 2.8$ Hz), 4.34 (1H, dd, $J_1 = 2.8$ Hz, $J_2 = 1.2$ Hz), 2.16, 2.01, and 1.96 (3H each, s), 1.09, 0.99, 0.85, and 0.81 (3H each, s); ^{13}C NMR see Table 2; CIMS, m/z (rel intensity) $[M + 1]^+$ 465 (1.0), 447 (3.0), 405 (32.0), 387 (21.0), 345 (100.0), 285 (20.0)].

Rearrangement of 12. An amount of 200 mg of **12** was treated with ruthenium acetylacetonate for 8 h under the above-indicated reaction conditions and directly chromatographed (CH_2Cl_2/Me_2CO) to give 130 mg of *ent*-1β,16β-diacetoxy-12α-chloro-12β-deuterio-15α-hydroxybeyerane (**24**, 65%): mp 192–94 °C; $[\alpha]_D$ −86.6 ($CHCl_3$, *c* 1); IR υ_{max} (neat, cm^{-1}) 3536, 1735, 1242; ^1H NMR δ 4.53 (1H, dd, $J_1 = 5.0$ Hz, $J_2 = 10.4$ Hz), 3.94 (1H, dd, $J_1 = J_2 = 2.5$ Hz), 4.35 (1H, d, $J = 2.5$ Hz), 2.15 and 2.01 (3H each, s), 1.08, 1.04, 0.86, and 0.81 (3H each, s); ^{13}C NMR see Table 2; CIMS, m/z (rel intensity) $[M + 1]^+$ 442 (2.0), 407 (25.0), 384 (12.0), 382 (40.0), 368 (40.0), 366 (100.0).

Acetylation of Products 21, 22, and 23. Products **21**, **22**, and **23** (5 mg each) were dissolved separately in Ac_2O/Py (1/2) with stirring for 12 h at reflux. The reaction mixture was diluted with water, extracted with CH_2Cl_2, washed with saturated $KHSO_4$, and dried with anhydrous Na_2SO_4. Chromatography over silica gel (CH_2Cl_2/Me_2CO) yielded the same product (4 mg each), *ent*-1β,12β,15α,16β-tetraacetoxybeyerane (**25**, 91%): mp 182–84 °C; $[\alpha]_D$ +18.8 ($CHCl_3$, *c* 1); IR υ_{max} (neat, cm^{-1}) 1737, 1239; ^1H NMR δ 5.44 (1H, dd, $J_1 = J_2 = 2.8$ Hz), 4.90 (1H, dd, $J_1 = 2.8$ Hz, $J_2 = 1.2$ Hz), 4.68 (1H, ddd, $J_1 = 10.6$ Hz, $J_2 = 4.9$ Hz, $J_3 = 1.2$ Hz), 4.48 (1H, dd, $J_1 = 4.9$ Hz, $J_2 = 10.6$ Hz), 2.11, 2.09, 1.98, and 1.96 (3H each, s), 1.20, 1.01, 0.83, and 0.80 (3H each, s); ^{13}C NMR see Table 2; CIMS, m/z (rel intensity) $[M + 1]^+$ 507 (1.2), 447 (26.5), 387 (100), 327 (31.0), 267 (4.5).

Acetylation of 20. A sample of 10 mg of product **20** was dissolved in Ac_2O/Py (1/2) with stirring for 12 h at reflux. The reaction mixture was diluted with water, extracted with CH_2Cl_2, washed with saturated $KHSO_4$, and dried with anhydrous Na_2SO_4. Chromatography over silica gel (CH_2Cl_2/Me_2CO) yielded 8 mg of *ent*-1β,15α,16α-triacetoxy-12α-chlorobeyerane (**26**, 80%): mp 126–28 °C; $[\alpha]_D$ −45.4 ($CHCl_3$, *c* 1); IR υ_{max} (neat, cm^{-1}) 1740, 1238; ^1H NMR δ 5.28 (1H, dd, $J_1 = 1.9$ Hz, $J_2 = 2.7$ Hz), 4.92 (1H, d, $J = 2.7$ Hz), 4.55 (1H, dd, $J_1 = 5.1$ Hz, $J_2 = 10.3$ Hz), 4.16 (1H, ddd, $J_1 = 4.3$ Hz, $J_2 = J_3 = 2.1$ Hz), 2.11, 2.10, and 2.03 (3H each, s), 1.15, 1.06, 0.84, and 0.79 (3H each, s); ^{13}C NMR see Table 2; CIMS, m/z (rel intensity) $[M + 1]^+$ 483 (2.5), 447 (7.6), 425 (23.9), 423 (68.7), 365 (34.7), 363 (100.0).

Partial Saponification of 20. Product **20** (10 mg) was dissolved in MeOH/H_2O/KOH (70/30/5) and refluxed for 12 h, diluted with H_2O, neutralized with HCl (2 N), extracted with CH_2Cl_2, dried with $MgSO_4$, and concentrated under vacuum. After column chromatography (CH_2Cl_2/Me_2CO), 9 mg of *ent*-1β-acetoxy-12α-chloro-15α,16β-dihydroxybeyerane (**27**, 90%) was isolated: mp 160–62 °C; $[\alpha]_D$ −21.5 ($CHCl_3$, *c* 1); IR υ_{max} (neat, cm^{-1}) 3411, 1708, 1260; ^1H NMR δ 4.54 (1H, dd, $J_1 = 4.9$ Hz, $J_2 = 10.5$ Hz), 4.23 (1H, ddd, $J_1 = 4.3$ Hz, $J_2 = J_3 = 2.2$ Hz), 4.08 (1H, dd, $J_1 = J_2 = 2.8$ Hz), 3.75 (1H, d, $J = 2.8$ Hz), 2.00 (3H, s), 1.09, 1.08, 0.86, and 0.82 (3H each, s); ^{13}C NMR see Table 2; CIMS, m/z (rel intensity) $[M + 1]^+$ 399 (2.0), 381 (20.5), 364 (3.5), 363 (14.6), 341 (10.9), 339 (36.0), 323 (37.5), 321 (100.0).

Oxidation of 20. Product **20** (10 mg) was dissolved in acetone (15 mL) and oxidized with Jones reagent, the reaction was stopped with a few drops of methanol, and the solution was diluted with water, extracted with CH_2Cl_2, dried with $MgSO_4$, and evaporated under vacuum. After column chromatography (CH_2Cl_2/Me_2CO), 8 mg of *ent*-1β,16β-diacetoxy-12α-chloro-beyeran-15-one (**28**, 85%) was obtained: mp 169–71 °C; $[\alpha]_D$ +16.6 ($CHCl_3$, *c* 1); IR υ_{max} (neat, cm^{-1}) 1741, 1230; ^1H NMR δ 5.12 (1H, s), 4.51 (1H, dd, $J_1 = 7.5$ Hz, $J_2 = 9.2$ Hz), 4.21 (1H, ddd, $J_1 = 4.2$ Hz, $J_2 = J_3 = 2.1$ Hz), 2.17 and 2.01 (3H each, s), 1.18, 0.98, 0.87, and 0.86 (3H each, s); ^{13}C NMR see Table 2; CIMS, m/z (rel intensity) $[M + 1]^+$ 439 (18.9), 403 (5.8), 381 (31.5), 379 (93.9), 319 (2.5), 79 (100.0).

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Supporting Information Available: ^1H NMR spectra of **3–8**, **10–17**, and **19–28** (24 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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