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Studies on the Terpenoids and Related Alicyclic Compounds. XXXIV.[1] Total Synthesis of Highly Oxygenated Furanoeremophilanes: (±)-1β,10β-Epoxyfuranoeremophilane-6,9-dione and (±)-Epoxydecompositin

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A total synthesis of (±)-1β,10β-epoxyfuranoeremophilane-6,9-dione (**8**) and (±)-epoxydecompositin (**25**) is described. The key step in this synthesis is the epoxidation of the allylic alcohol (**10**). A model experiment was carried out using the readily available diketone (**7**) to give the desired 1β,10β-epoxide (**16**) stereoselectively in good overall yields. The diketone (**17**) was reduced with $NaBH_4$ to give the 9β,10α-diol (**18a**), which was treated with Ac_2O then dehydrated with $SOCl_2$ to give the unexpected rearranged product **19a**. The 9-hydroxyl group of **18a** was protected with a trimethylsilyl group to give **20**. The desired allylic alcohol (**10**) was derived from **20** *via* **21a** in excellent yield. Epoxidation followed by MnO_2 oxidation of **10** gave (±)-**8**. $NaBH_4$ reduction of (±)-**8** followed by acetylation with Ac_2O gave (±)-**25**.

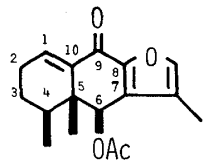
Keywords——sesquiterpenoid; furanoeremophilane; 1β,10β-epoxyfuranoeremophilane; epoxydecompositin; total synthesis; benzeneseleninic anhydride

In previous papers, the authors have reported[2-4] total syntheses of highly oxygenated furanoeremophilane-type natural products such as **1**—**4**. These compounds were synthesized from 10-hydroxyfuranoeremophilanes (**6** and **7**), which were derived from the ketone (**5**) *via* angular hydroxylation using benzeneseleninic anhydride.[5] Among the highly oxygenated furanoeremophilanes, especially C-10 oxygenated ones, we have already synthesized 1,(10)-ene compounds (**1** and **2**)[2] and 10β-hydroxy compounds (**3** and **4**)[4] but the furanoeremophilanes having a 1β,10β-epoxide have still remained to be synthesized. In this paper, we report the first total syntheses of the racemic forms of 1β,10β-epoxyfuranoeremophilane-6,9-dione (**8**), which was isolated from *Senecio smithii* DC. by Bohlmann *et al.*,[6] and epoxydecompositin (**25**), isolated from *Euryops othonnoides* (DC) B. Nord by Bohlmann *et al.*[7] and from *Lepidospartum squamatum* Gray by Flamm *et al.*[8]

Synthesis of 3,3-Ethylenedioxy-1β,10β-epoxyfuranoeremophilane-6,9-dione: A Model of the Natural Epoxide (8)

As all efforts to obtain the epoxide (**8**) directly from the enone (**9**)[2] were fruitless, we elected to use the highly stereoselective epoxidation of allylic alcohols using *tert*-butyl hydroperoxide in the presence of vanadyl acetylacetonate reported by Sharpless and Michaelson.[9a] The epoxidation method usually gives an epoxide which has the same orientation of the hydroxyl group. To get the natural product (**8**) by use of the method described above, 9β-hydroxyfuranoeremophil-1,(10)-en-6-one (**10**) was required. First of all we investigated the feasibility of the strategy by using a model compound (**7**)[4] which was easily available from **5** by the angular hydroxylation.[5]

Sodium borohydride ($NaBH_4$) reduction of **7** gave a diol (**13a**), mp 189.5—191 °C, in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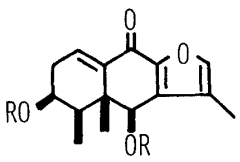
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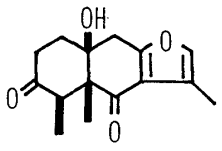
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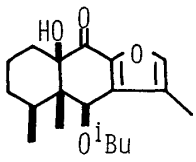
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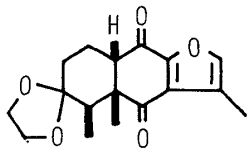
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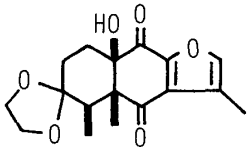
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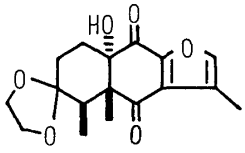
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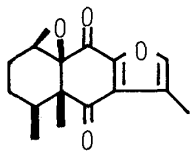
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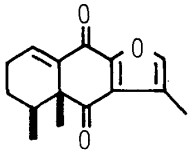
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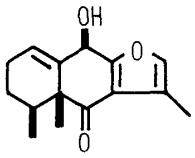
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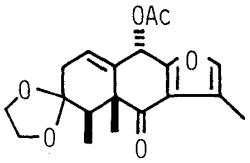
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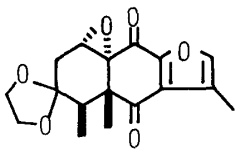
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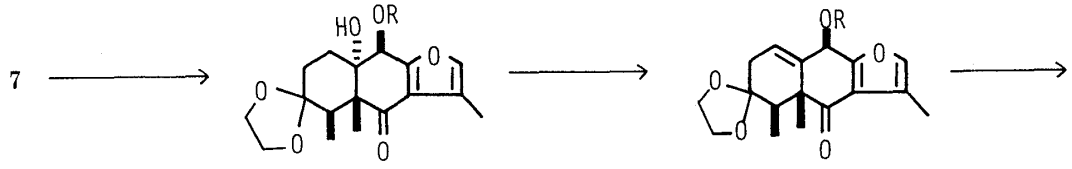
^{i}Bu = isobutyl

quantitative yield. As the ultraviolet (UV) spectrum of **13a** showed λ maximum at 266 nm, which is due to the 6-oxofuranoeremophilane moiety,[10] **13a** should be the 9,10α-diol compound. In the borohydride reduction, it was reported that a hydroxyl group near a ketone assists the introduction of a hydride from the same side of the hydroxyl group, giving a *trans* diol[11] so the 9β,10α-*trans* stereochemistry of the diol (**13a**) is quite possible. The determination of this stereochemistry was carried out as follows. The diol (**13a**) was acetylated in the usual way to give **13b**, mp 185—187 °C, in 96% yield, and **13b** was then dehydrated by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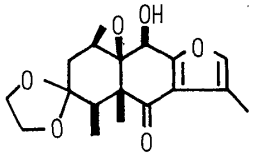
13a : R=H
13b : R=Ac

14a : R=Ac
14b : R=H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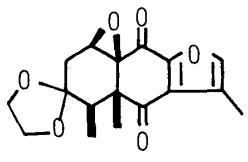
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Chart 1

treating it with thionyl chloride in pyridine to afford **14a**, mp 135—137 °C, in 79% yield. As all the spectral data of **14a** are different from those of the known compound (**11**)[2,4] the configuration of C-9 acetoxyl group of **14a** is β.

The acetate (**14a**) was hydrolyzed to give an allylic alcohol (**14b**), mp 134.5—136 °C, in 97% yield. The allylic alcohol (**14b**) was epoxidized by *tert*-butyl hydroperoxide in the presence of vanadyl acetylacetonate[9b] to give the epoxide (**15**), mp 158.5—161 °C, as a sole product in 82% yield. The alcohol (**15**) was oxidized with activated manganese dioxide (MnO_2) to give the desired ketone (**16**), mp 194—196 °C, in 85% yield. At this stage we compared the spectral data of **16** with those of the known compound **12**.[4] As all the spectral data of **16** were different from those of **12**, the configuration of the epoxide group of **16** must be 1β,10β. In the nuclear magnetic resonance (NMR) spectrum of **16**, the 1-H signal appears at δ 3.42 (dd, $J=5$, 0.5 Hz), which is very close to that of the natural compound **8** (δ 3.48, dd, $J=3$, 1.5 Hz), whereas the 1-H signal of **12** appears in the region of δ 3.7—4.1 (this signal overlaps with those of the ethylene ketal).[4]

Total Synthesis of (±)-1β,10β-Epoxyfuranoeremophilane-6,9-dione and (±)-Epoxydecompositin

The study of the synthesis of (±)-1β,10β-epoxyfuranoeremophilane (**8**) and (±)-epoxydecompositin (**25**) was started on the basis of the encouraging results described above. The diketone (**17**), which was reported previously,[2] was reduced with $NaBH_4$ to give a diol (**18a**), mp 166—168 °C, in 95% yield. The UV spectrum of **18a** (λ_{max} 265 nm) showed a 6-oxofuranoeremophilane moiety as described above. The 9-hydroxyl group was protected with acetic anhydride to give **18b**, mp 203.5—205 °C, in 94% yield, and **18b** was treated with thionyl chloride in pyridine at −20 °C. Unfortunately, the product of this reaction was not the desired product, but a rearranged one (**19a**), mp 88—91 °C, was formed in 73% yield. The UV spectrum of **19a** shows λ maximum at 329 nm, which suggests that the formed double bond is conjugated with the furan moiety. In the NMR spectrum of **19a**, the proton on the carbon bearing the acetoxyl group appears as a triplet (δ 5.51) $J=2$ Hz. Thus, the structure of the product (**19a**) was confirmed to be 1-acetoxyfuranoeremophil-9-en-6-one and the stereochemistry of the acetoxyl group was also confirmed to be β from the coupling constant (t, $J=2$ Hz) of the C-1 proton. We thought that the allylic acetate (**19a**) was derived from the dehydrated product (**21b**) *via* [3,3] sigmatropic rearrangement[12] as shown in Chart 2. From the

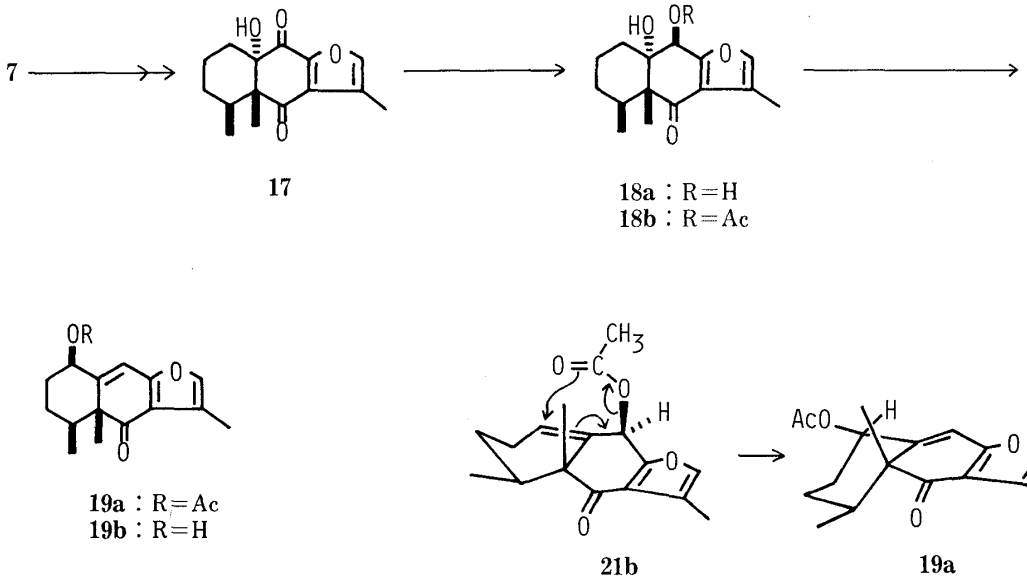

Chart 2

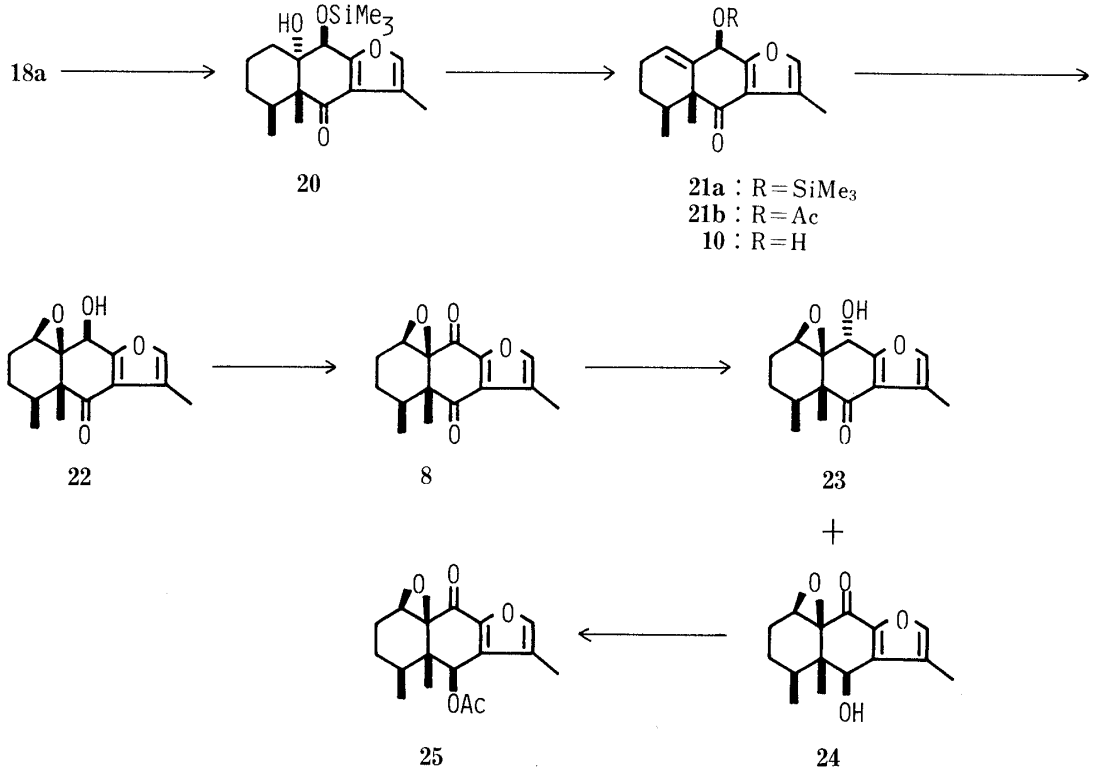

Chart 3

mechanism of the allylic rearrangement, the stereochemistry of the acetoxyl group of **18b** should be β.

To avoid the rearrangement, ether type protecting groups for the 9-hydroxyl group of **18a** were examined.[13] Of the several protecting reagents examined, only trimethylsilyl chloride seemed effective, affording the 9-trimethylsilyloxy compound (**20**) in good yield. Since the ether (**20**) is unstable, the crude **20** was dehydrated with thionyl chloride in pyridine at $-20\,^{\circ}C$ to afford **21a**. Treatment of **21a** with potassium carbonate in methanol afforded the desired allylic alcohol (**10**) as an oil in 88% overall yield from **18a**. The spectral data of **10** are consistent with the 9-hydroxyfuranoeremophil-1,(10)-en-6-one structure. The allylic alcohol (**10**) was oxidized with *tert*-butylhydroperoxide in the presence of vanadyl acetylacetonate to give an epoxide (**22**), mp 136—137 °C, in 84% yield. The hydroxyl group of **22** was oxidized with MnO_2 to afford the desired (±)-1β,10β-epoxyfuranoeremophilane-6,9-dione (**8**), mp 101—103 °C, in 62% yield. The NMR, infrared (IR), and mass spectral data of (±)-**8** were in good agreement with those of (−)-**8** isolated from *Senecio smithii* DC by Bohlmann *et al.*[6]

Sodium borohydride reduction of (±)-**8** gave the 9-hydroxy compound (**23**) (UV λ_{max} 268 nm), mp 147—149 °C, and the 6-hydroxy compound (**24**) (UV λ_{max} 287.5 nm), oil, in 56 and 44% yields, respectively. The stereochemistry of the hydroxyl group of **23** was obviously α as the physical and spectral data were different from those of **22**. Acetylation of the hydroxyl group of **24** gave the desired (±)-epoxydecompositin (**25**), mp 149—151.5 °C, in 72% yield. The NMR, IR, and mass spectral data of (±)-**25** were in good agreement with those of (+)-**25** isolated from *Euryops othonnoides* (DC) B. Nord[7] and *Lepidospartum squamatum* Gray[8] by Bohlmann *et al.* and Flamm *et al.*, respectively.

Experimental

All melting points are uncorrected. IR spectra were measured in KBr disks with a Hitachi 215 spectrometer. UV spectra were measured with a Hitachi 200 spectrometer. NMR spectra were measured in $CDCl_3$ solution on a JEOL

JNM-FX-100 pulse Fourier transform spectrometer (100 MHz) using Me_4Si as an internal standard. Mass spectra (MS) were taken on a Hitachi M-80 double focusing spectrometer at 70 eV by direct insertion. High-resolution mass spectra were determined with a Hitachi datalyzer 003 system connected on-line with the mass spectrometer. Wako silica gel C-200 (200 mesh) containing 2% fluorescence reagent 254 was used in column chromatography. Preparative thin-layer chromatography (TLC) was carried out using Merck silica gel HF_{254}.

3,3-Ethylenedioxy-9β,10α-dihydroxyfuranoeremophilan-6-one (13a)——$NaBH_4$ (31 mg) was added to a stirred solution of 202 mg of **7** in MeOH (15 ml) at 0 °C and the reaction mixture was stirred for 15 min. Powdered NH_4Cl was added to the reaction mixture and the solvent was evaporated off. The residue was extracted with AcOEt, and the extract was washed with sat. aq. NH_4Cl and dried. After removal of the solvent, the residue was recrystallized from AcOEt–hexane to afford 201 mg (98%) of **13a** as colorless prisms, mp 189.5—191 °C. High-resolution mass spectrum for $C_{17}H_{22}O_6$: Mol. Wt. 322.1415. Observed: M^+ 322.1428. IR cm^{-1}: 3500, 3450 (OH), 1665 (CO); UV λ_{max}^{EtOH} 266 nm (ε 3200); NMR (DMSO-d_6) δ: 1.02 (3H, d, J=7 Hz, 4-CH_3), 1.20 (3H, s, 5-CH_3), 2.06 (3H, d, J=1 Hz, 11-CH_3), 2.43 (1H, q, J=7 Hz, 4-H), 3.7—4.1 (4H, m, $-OCH_2CH_2O-$), 4.26 (1H, d, J=7 Hz, 9-H, $+D_2O$ gave a singlet signal), 4.61 (1H, s, 10-OH, D_2O-erasable), 6.04 (1H, d, J=7 Hz, 9-OH, D_2O-erasable), 7.40 (1H, q, J=1 Hz, 12-H); MS m/z (% Rel. int.): 322 (M^+, 6), 275 (4), 99 (100), 86 (10).

3,3-Ethylenedioxy-9β-acetoxy-10α-hydroxyfuranoeremophilan-6-one (13b)——A solution of **13a** (170 mg) in a mixture of acetic anhydride (1 ml), pyridine (4 ml), and CH_2Cl_2 (4 ml) was allowed to stand at room temperature for 16 h. The reaction mixture was evaporated to dryness and the residue was purified by silica gel column chromatography followed by recrystallization (AcOEt–hexane) to give 184 mg (96%) of **13b** as colorless prisms, mp 185—187 °C. *Anal.* Calcd for $C_{19}H_{24}O_7$: C, 62.63; H, 6.64; Mol. Wt. 364.1520. Found: C, 62.81; H, 6.74; M^+ 364.1499. IR cm^{-1}: 3500 (OH), 1730, 1690 (CO), 1250 (COC); UV λ_{max}^{EtOH} 265.5 nm (ε 4100); NMR δ: 1.18 (3H, d, J=7 Hz, 4-CH_3), 1.37 (3H, s, 5-CH_3), 2.15 (3H, s, $COCH_3$), 2.16 (3H, d, J=1 Hz, 11-CH_3), 2.66 (1H, q, J=7 Hz, 4-H), 3.8—4.1 (4H, m, $-OCH_2CH_2O-$), 5.82 (1H, s, 9-H), 7.14 (1H, q, J=1 Hz, 12-H); MS m/z (% Rel. int.): 364 (M^+, 0.6), 304 (1.6), 275 (1.6), 99 (100).

3,3-Ethylenedioxy-9β-acetoxyfuranoeremophil-1(10)-en-6-one (14a)——Thionyl chloride (48 μl) was added to a solution of **13b** (40 mg) in dry pyridine (3 ml) at −20 °C with stirring and the mixture was stirred for 30 min. Sat. aq. $NaHCO_3$ was added to the reaction mixture and the whole was extracted with AcOEt. The extract was washed with sat. aq. $NaHCO_3$, dried and concentrated. The residue was purified by silica gel preparative TLC followed by recrystallization (AcOEt–hexane) to give 30 mg (79%) of **14a**, mp 135—137 °C. High-resolution mass spectrum for $C_{19}H_{22}O_6$: Mol. Wt. 346.1414. Observed: M^+ 346.1399. IR cm^{-1}: 1750, 1685 (CO), 1235 (COC); UV λ_{max}^{EtOH} 267 nm (ε 4400); NMR δ: 1.05 (3H, d, J=7 Hz, 4-CH_3), 1.35 (3H, s, 5-CH_3), 2.02 (1H, ddd, J=18, 5.5, 1.5 Hz, 2α-H), 2.08 (3H, s, $COCH_3$), 2.21 (3H, d, J=1 Hz, 11-CH_3), 2.56 (1H, dd, J=18, 2.7 Hz, 2β-H), 2.86 (1H, dq, J=7, 1.5 Hz, 4-H), 3.7—4.2 (4H, m, $-OCH_2CH_2O-$), 6.09 (1H, dd, J=5.5, 2.7 Hz, 1-H), 6.33 (1H, s, 9-H), 7.15 (1H, q, J=1 Hz, 12-H); MS m/z (% Rel. int.): 346 (M^+, 4), 287 (100), 269 (4), 242 (5), 214 (40), 199 (17), 159 (5), 128 (11), 100 (50).

3,3-Ethylenedioxy-9β-hydroxyfuranoeremophil-1(10)-en-6-one (14b)——Potassium carbonate (9 mg) was added to a stirred solution of **14a** (16 mg) in MeOH (2 ml) and the mixture was stirred at room temperature for 30 min. Powdered NH_4Cl was then added to the reaction mixture and the solvent was evaporated off. The residue was extracted with AcOEt. The extract was washed with sat. aq. NH_4Cl, dried and concentrated. The residue was purified by silica gel preparative TLC followed by recrystallization to afford 14 mg (97%) of **14b** as colorless prisms, mp 134.5—136 °C. *Anal.* Calcd for $C_{17}H_{20}O_5$: C, 67.09; H, 6.62; Mol. Wt. 304.1219. Found: C, 67.07; H, 6.66; M^+ 304.1319. IR cm^{-1}: 3450 (OH), 1670, 1650 (CO); UV λ_{max}^{EtOH} 265.5 nm (ε 3700); NMR δ: 1.09 (3H, d, J=7 Hz, 4-CH_3), 1.44 (3H, s, 5-CH_3), 2.02 (1H, ddd, J=18, 5.5, 1.5 Hz, 2α-H), 2.19 (3H, d, J=1 Hz, 11-CH_3), 2.50 (1H, d, J=3 Hz, OH, D_2O-erasable), 2.56 (1H, dd, J=18, 2.7 Hz, 2β-H), 2.84 (1H, dq, J=7, 1.5 Hz, 4-H), 3.6—4.2 (4H, m, $-OCH_2CH_2O-$), 5.23 (1H, d, J=3 Hz, 9-H, $+D_2O$ gave a singlet signal), 5.89 (1H, dd, J=5.5, 2.7 Hz, 1-H), 7.14 (1H, q, J=1 Hz, 12-H); MS m/z (% Rel. int.): 304 (M^+, 12), 260 (7), 242 (12), 214 (18), 175 (5), 128 (3), 100 (36), 86 (100).

3,3-Ethylenedioxy-1β,10β-epoxy-9β-hydroxyfuranoeremophilan-6-one (15)——A solution of 105 μl of dry *tert*-BuOOH (3.8 M in toluene; 0.39 mmol) was added dropwise through a syringe to a solution of **14a** (54 mg) and VO $(acac)_2$ (3.8 mg) in 2.5 ml of dry benzene under an N_2 atmosphere at room temperature. The reaction mixture was stirred at ambient temperature for 1.5 h then another 2 mg of VO $(acac)_2$ was added and the whole was stirred for 30 min. When the reaction was completely over, the solvent was evaporated off and the residue was dissolved in ether. This solution was passed through a short pad of florisil. The eluate was concentrated and purified by silica gel preparative TLC followed by recrystallization from AcOEt–hexane to afford 44.6 mg (82%) of **15** as colorless prisms, mp 158.5—161 °C. High-resolution mass spectrum for $C_{17}H_{20}O_6$: Mol. Wt. 320.1258. Observed: M^+ 320.1260. IR cm^{-1}: 3490, 3420 (OH), 1660 (CO); UV λ_{max}^{EtOH} 261 nm (ε 3100); NMR δ: 1.05 (3H, d, J=7 Hz, 4-CH_3), 1.45 (3H, s, 5-CH_3), 1.88 (1H, ddd, J=16, 6, 2 Hz, 2α-H), 2.24 (3H, d, J=1 Hz, 11-CH_3), 2.40 (1H, d, J=16 Hz, 2β-H), 2.78 (1H, dq, J=7, 2 Hz, 4-H), 2.98 (1H, d, J=2 Hz, 9-OH, D_2O-erasable), 3.35 (1H, d, J=6 Hz, 1-H), 3.5—4.1 (4H, m, $-OCH_2CH_2O-$), 4.35 (1H, d, J=2 Hz, 9-H), $+D_2O$ gave a singlet signal), 7.20 (1H, q, J=1 Hz, 12-H); MS m/z (% Rel. int): 320 (M^+, 97), 291 (80), 206 (28), 177 (56), 137 (15), 115 (100).

3,3-Ethylenedioxy-1β,10β-epoxyfuranoeremophilane-6,9-dione (16)——Finely powdered activated MnO_2 (282 mg) was added to a solution of **15** (18 mg) in $CHCl_3$ (3 ml) and the suspension was stirred at ambient temperature

for 2 h. The MnO_2 was filtered off and the filtrate was concentrated. The residue was recrystallized from AcOEt–hexane to give 15 mg (85%) of **16** as colorless prisms, mp 194—196 °C. High-resolution mass spectrum for $C_{17}H_{18}O_6$: Mol. Wt. 318.1102. Observed: M^+ 318.1095. IR cm^{-1}: 1700, 1680 (CO); UV λ_{max}^{EtOH} 245.5 nm (ε 6800), 305 nm (ε 12000); NMR δ: 1.05 (3H, d, J=7 Hz, 4-CH_3), 1.36 (3H, s, 5-CH_3), 1.94 (1H, ddd, J=15, 6, 2 Hz, 2α-H), 2.31 (3H, d, J=1 Hz, 11-CH_3), 2.39 (1H, dd, J=15, 0.5 Hz, 2β-H), 2.90 (1H, dq, J=7, 2 Hz, 4-H), 3.42 (1H, dd, J=5, 0.5 Hz, 1-H), 3.6—4.1 (4H, m, $-OCH_2CH_2O-$), 7.51 (1H, q, J=1 Hz, 12-H); MS *m/z* (% Rel. int.): 318 (M^+, 60), 303 (7), 289 (98), 100 (100).

9β,10α-Dihydroxyfuranoeremophilan-6-one (18a)——$NaBH_4$ (5 mg) was added to a stirred solution of **17** (46 mg) in MeOH (5 ml) at 0 °C and the reaction mixture was stirred at 0 °C for 30 min. After work-up in the usual way, recrystallization from AcOEt–hexane afforded 44 mg (95%) of **18a** as colorless prisms, mp 166—168 °C. High-resolution mass spectrum for $C_{15}H_{20}O_4$: Mol. Wt. 264.1360. Observed: M^+ 264.1367. IR cm^{-1}: 3480 (OH), 1650 (CO); UV λ_{max}^{EtOH} 265 nm (ε 3100); NMR δ: 1.15 (3H, d, J=7 Hz, 4-CH_3), 1.24 (3H, s, 5-CH_3), 2.16 (3H, d, J=1 Hz, 11-CH_3), 4.37 (1H, s, 9-H), 7.12 (1H, q, J=1 Hz, 12-H); MS *m/z* (% Rel. int.): 264 (M^+, 8), 246 (11), 138 (100), 110 (34).

9β-Acetoxy-10α-hydroxyfuranoeremophilan-6-one (18b)——The diol (**18a**) was acetylated in the usual way to give 48 mg (94%) of **18b** as colorless prisms, mp 203.5—205 °C. High-resolution mass spectrum for $C_{17}H_{22}O_5$: Mol. Wt. 306.1465. Observed: M^+ 306.1454. IR cm^{-1}: 3480 (OH), 1720, 1690 (CO), 1245 (COC); UV λ_{max}^{EtOH} 265.5 nm (ε 4500); NMR δ: 1.17 (3H, d, J=7 Hz, 4-CH_3), 1.25 (3H, s, 5-CH_3), 2.14 (3H, s, $COCH_3$), 2.17 (3H, d, J=1 Hz, 11-CH_3), 5.76 (1H, s, 9-H), 7.14 (1H, q, J=1 Hz, 12-H); MS *m/z* (% Rel. int.): 306 (M^+, 6), 288 (34), 246 (100), 138 (97).

1β-Acetoxyfuranoeremophil-9-en-6-one (19a)——A solution of **18b** (55 mg) in dry pyridine (3.7 ml) was treated with $SOCl_2$ (65 μl) at −20 °C for 20 min. Sat. aq. $NaHCO_3$ (1 ml) was added to the reaction mixture and the whole was extracted with ether. The extract was washed with sat. aq. $NaHCO_3$, dried and concentrated. The residue was purified by silica gel preparative TLC followed by recrystallization to give 38 mg (73%) of **19a** as colorless prisms, mp 88—89 °C. High-resolution mass spectrum for $C_{17}H_{20}O_4$: Mol. Wt. 288.1360. Observed: M^+ 288.1359. IR cm^{-1}: 1740, 1650 (CO), 1260 (COC); UV λ_{max}^{EtOH} 240, 329 nm; NMR δ: 1.18 (3H, d, J=7 Hz, 4-CH_3), 1.33 (3H, s, 5-CH_3), 2.05 (3H, s, $COCH_3$), 2.23 (3H, d, J=1 Hz, 11-CH_3), 5.51 (1H, t, J=2 Hz, 1-H), 6.68 (1H, s, 9-H), 7.07 (1H, q, J=1 Hz, 12-H); MS *m/z* (% Rel. int.): 288 (M^+, 15), 246 (64), 213 (23), 189 (22), 171 (10), 140 (30), 107 (53), 77 (16), 43 (100).

1β-Hydroxyfuranoeremophil-9-en-6-one (19b)——The acetate (**19a**) (12 mg) was treated with K_2CO_3 (17 mg) in MeOH (2 ml) as described for **14b** at room temperature for 5.5 h to give 9.3 mg (90%) of **19b** as colorless prisms, mp 175—177.5 °C. High-resolution mass spectrum for $C_{15}H_{18}O_3$: Mol. Wt. 246.1254. Observed: M^+ 246.1241. IR cm^{-1}: 3420 (OH), 1540, 1630 (CO), 1610 (C=C); UV λ_{max}^{EtOH} 240 nm (ε 7700), 329 nm (ε 7000); NMR δ: 1.19 (3H, d, J=7 Hz, 4-CH_3), 1.47 (3H, s, 5-CH_3), 2.24 (3H, d, J=1 Hz, 11-CH_3), 4.61 (1H, t, J=2 Hz, 1-H), 6.53 (1H, s, 9-H), 7.07 (1H, q, J=1 Hz, 12-H); MS *m/z* (% Rel. int.): 246 (M^+, 100), 213 (25), 189 (25), 171 (16), 139 (52), 107 (97).

9β-Hydroxyfuranoeremophil-1(10)-en-6-one (10)——Chlorotrimethylsilane (114 μl) was added to a solution of **18a** (79 mg) in 1 ml of dry pyridine under an N_2 atmosphere and the reaction mixture was stirred at room temperature for 30 min. The reaction was monitored by TLC (Merck, Kieselgel 60 F_{254}; *Rf* values: **18a**=0.14, **20**=0.50; hexane : AcOEt=3 : 1). When the starting material was gone, the reaction mixture was diluted with 1 ml of dry pyridine and cooled to −20 °C. To this solution, $SOCl_2$ (60 μl) in 0.2 ml of dry pyridine was added dropwise through a syringe and the reaction mixture was stirred at −20 °C under an N_2 atmosphere for 30 min (*Rf* values: **20**=0.19, **21a**=0.64; hexane : AcOEt=6 : 1). When this reaction was completed, sat. aq. $NaHCO_3$ was added and the whole was extracted with AcOEt. The organic layer was washed with sat. aq. $NaHCO_3$, dried, and evaporated to give a residue, which was dissolved in MeOH (5 ml). To this solution, K_2CO_3 (41.5 mg) was added and the whole was stirred at room temperature for 1 h (*Rf* values: **21a**=0.75, **10**=0.38; hexane : AcOEt=3 : 1). Powdered NH_4Cl was added and the solvent was evaporated off *in vacuo* and the residue was extracted with AcOEt, washed with sat. aq. NH_4Cl and dried. The solvent was removed and the residue was purified by silica gel preparative TLC to afford 65 mg (88% overall from **18a**) of **10** as a colorless viscous oil. High-resolution mass spectrum for $C_{15}H_{18}O_3$: Mol. Wt. 246.1255. Observed: M^+ 246.1255. IR cm^{-1}: 3450 (OH), 1675 (CO), 1655 (C=C); UV λ_{max}^{EtOH} 246 nm; NMR δ: 1.22 (3H, d, J=7 Hz, 4-CH_3), 1.44 (3H, s, 5-CH_3), 2.19 (3H, d, J=1 Hz, 11-CH_3), 2.48 (1H, br s, 9-OH), 5.12 (1H, s, 9-H), 6.00 (1H, t, J=4 Hz, 1-H), 7.14 (1H, q, J=1 Hz, 12-H); MS *m/z* (% Rel. int.): 246 (M^+, 100), 213 (38), 177 (69), 139 (62), 107 (78).

1β,10β-Epoxy-9β-hydroxyfuranoeremophilan-6-one (22)——A solution of 100 μl of dry *tert*-BuOOH (3.8 M in toluene) was added to a solution of 44 mg of **10** and VO $(acac)_2$ (7 mg) in 3 ml of dry benzene at room temperature and the reaction mixture was stirred for 1 h. After work-up in the manner described for **15**, 39 mg (84%) of the epoxide (**22**) was obtained. Recrystallization from AcOEt–hexane gave colorless needles, mp 136—137 °C. *Anal.* Calcd. for $C_{15}H_{18}O_4$: C, 68.68; H, 6.92; Mol. Wt. 262.1203. Found: C, 68.87; H, 6.89; M^+ 262.1202. IR cm^{-1}: 3390 (OH), 1680 (CO); UV λ_{max}^{EtOH} 263 nm (ε 3500); NMR δ: 1.10 (3H, d, J=7 Hz, 4-CH_3), 1.44 (3H, s, 5-CH_3), 2.23 (3H, d, J=1 Hz, 11-CH_3), 3.30 (1H, dd, J=4.5, 1.5 Hz, 1-H), 4.31 (1H, s, 9-H), 7.21 (1H, q, J=1 Hz, 12-H); MS *m/z* (% Rel. int.): 262 (M^+, 39), 244 (20), 201 (20), 178 (100), 138 (31), 110 (23).

(±)-1β,10β-Epoxyfuranoeremophilane-6,9-dione (8)——Finely powdered activated MnO_2 (233 mg) was added to a solution of **22** (8 mg) in $CHCl_3$ (2 ml) and the suspension was stirred at room temperature for 2.5 h to give 4.8 mg

(62%) of **8** as a colorless powder after recrystallization from AcOEt–hexane, mp 101—103 °C. High-resolution mass spectrum for $C_{15}H_{16}O_4$: Mol. Wt. 260.1048. Observed: M^+ 260.1074. IR cm^{-1}: 1690 (CO); UV λ_{max}^{EtOH} 241 nm (ε 5800), 305 nm (ε 8700); NMR δ: 1.15 (3H, d, J=7 Hz, 4-CH_3), 1.38 (3H, s, 5-CH_3), 2.30 (3H, d, J=1 Hz, 11-CH_3), 3.48 (1H, dd, J=3, 1.5 Hz, 1-H), 7.50 (1H, q, J=1 Hz, 12-H); MS *m/z* (% Rel. int.): 260 (M^+, 100), 232 (15), 217 (36), 176 (22), 161 (12), 137 (7), 109 (14).

(±)-Epoxydecompositin (25)——$NaBH_4$ (0.6 mg) was added to a stirred solution of 11 mg of **8** in 2 ml of MeOH at 0 °C and the reaction mixture was stirred for 20 min. Usual work-up as described for **13a** followed by silica gel preparative TLC separation gave 6.2 mg (56%) of **23**, mp 147—149 °C, and 4.8 mg (44%) of **24** as an oil (UV λ_{max}^{EtOH} 287.5 nm). **23**: High-resolution mass spectrum for $C_{15}H_{18}O_4$: Mol. Wt. 262.1204. Observed: M^+ 262.1196. IR cm^{-1}: 3500 (OH), 1675, 1635 (CO); UV λ_{max}^{EtOH} 268 nm (ε 3300); NMR δ: 1.10 (3H, d, J=7 Hz, 4-CH_3), 1.30 (3H, s, 5-CH_3), 2.22 (3H, d, J=1 Hz, 11-CH_3), 2.61 (1H, m, 2β-H), 2.65 (1H, d, J=3 Hz, 9-OH, D_2O-erasable), 3.72 (1H, dd, J=5, 0.5 Hz, 1α-H), 5.26 (1H, d, J=3 Hz, 9β-H, $+D_2O$ gave a singlet signal), 7.18 (1H, q, J=1 Hz, 12-H); MS *m/z* (% Rel. int.): 262 (M^+, 29), 248 (28), 205 (89), 178 (100), 137 (53), 125 (47), 110 (48). The 6-hydroxy compound (**24**) was acetylated (without further purification) with acetic anhydride and pyridine to afford 4 mg (72%) of (±)-epoxydecompositin (**25**), mp 149—151.5 °C, as colorless needles recrystallized from AcOEt–hexane. High-resolution mass spectrum for $C_{17}H_{20}O_5$: Mol. Wt. 304.1309. Observed: M^+ 304.1285. IR cm^{-1}: 1740, 1730, 1690 (CO), 1240 (COC); UV λ_{max}^{EtOH} 250 nm (ε 4200), 285.5 nm (ε 9700); NMR δ: 1.04 (3H, d, J=7 Hz, 4-CH_3), 1.21 (3H, s, 5-CH_3), 1.97 (3H, d, J=1 Hz, 11-CH_3), 2.23 (3H, s, $COCH_3$), 3.36 (1H, dd, J=4, 0.5 Hz, 1-H), 6.59 (1H, s, 6-H), 7.42 (1H, q, J=1 Hz, 12-H); MS *m/z* (% Rel. int.): 304 (M^+, 17), 262 (38), 205 (27), 178 (56), 43 (100).

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