# Oxymercuriation–Demercuriation of the Methyl Esters of Communic Acids. X-Ray Molecular Structure of Methyl (8*R*,12*R*)-8,12-Epoxyisopimar-15-en-19-oate

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The oxymercuriation–demercuriation (OM–DM) of methyl (*E*)-communate with mercury(II) acetate yielded mainly the hydration product of the 14,15-double bond. The isopimarane oxide methyl (8*R*,12*R*)-epoxyisopimar-15-en-19-oate, the endoperoxide methyl (8*S*,12*R*,13*S*)-13,17-epidioxy-8,12-epoxylabd-14-en-19-oate and the diorganomercurial bis-(4β-methoxycarbonyl-19-norlabda-8,12*E*-14-trien-17-yl)mercury were also obtained when $NaBH_4$–NaOH was used as the reducing agent. The organomercurial regenerated methyl (*E*)-communate on prolonged treatment with $NaBH_4$ in excess. The OM–DM of methyl (*E*)-communate using Na(Hg) as the reducing agent achieved partial isomerization of the 8(17)-double bond, giving methyl 14-hydroxylabda-8,12*E*-dien-19-oate and methyl labda-8,12*E*,14-trien-19-oate; the oxide methyl (8*S*,12*R*)-8,12-epoxylabd-13*E*-en-19-oate, instead of the aforementioned isopimarene oxide, endoperoxide, and diorganomercurial; relatively important amounts of the product of stereoselective 1,4-addition, methyl (12*R*)-12-hydroxylabda-8(17),13*E*-dien-19-oate, and the hydration product of the 8(17)-double bond on the (*a priori*) most hindered, β side, methyl (8*S*)-8-hydroxylabda-12*E*,14-dien-19-oate. Besides these, small amounts of the double-hydration product methyl (8*S*)-8,14-dihydroxylabd-12*E*-en-19-oate were also obtained. Finally, methyl (*Z*)-communate **2** showed similar behaviour to its *E*-isomer in OM–DM reactions.

Following our studies on the OM–DM of resin acids from species of the genus *Juniperus*,[1,2] we now report the results obtained with methyl (*E*)-communate **1** and methyl (*Z*)-communate **2**.

Few data concerning the behaviour of conjugated dienes in electrophilic additions with mercury(II) salts have been reported. Brown *et al.*[3] remarked that upon using mercury(II) acetate the 1,2-addition of water to the conjugated system takes place, yielding preferentially the allylic derivative, whereas when strongly dissociated salts are used [such as mercury(II) tetrafluoroborate or mercury(II) nitrate] the 1,4-adducts are the main products observed.[4,5]

## Results

The OM–DM reaction (under the usual conditions described by Brown and Geoghegan[6]) of compound **1** with $Hg(OAc)_2$ (in a 1:2 ratio)[1,2] and $NaBH_4$ as reducing agent yielded, as the main product, compound **3a** (43%),† together with by-products **4** (14%),† **5** (2%)† and organomercurial **6** (1%),† as well as a 26% recovery of starting material.‡

The structure and stereochemistry of by-product **4** have been proposed on the basis of its spectroscopic data. In spite of these data the configuration at C-13 was not completely clarified so, because of the novelty of our postulated mechanism of formation of compound **4**, a single-crystal X-ray diffraction study was finally performed. Fig. 1 shows a perspective diagram of the two molecules, A and B, in the asymmetric unit (supplementary material available).

The stereochemistry at C-8 for compound **5** corresponds to that of a β orientation in the C(8)–O–C(12) oxygen bridge, since the assignment carried out for the carbons of the decalinic system from $^{13}C$ NMR data showed a close parallelism with that corresponding to compound **4** (see Table 4, below). The configuration at C-13 has been established by comparison of the chemical shift of 13-*Me* with that of the corresponding carbon in compound **4** ($\delta$ 27.38) and its C-13 epimer **I**§ ($\delta$ 21.08); taking into account the intermediate value of the corresponding methyl group in **5** (C-16, $\delta$ 23.93) and given the additional shielding induced on it by the peroxide function, the only possibility that remains is that of a 13*S* configuration.

The diorganomercurial **6a** slowly deposits elementary mercury (when kept in solution) and partially regenerates methyl (*E*)-communate **1** when it is treated for several hours with $NaBH_4$ in excess. Its MS does not show a molecular ion, but it displays peaks at *m/z* 315 (13%) and 255 (29), corresponding to the initial fragmentation of the C(17)–Hg bond, followed by loss of methyl formate. The C(9)–C(11) cleavage affords the base peak at *m/z* 81. The $^1H$ NMR spectrum showed the 17-$H_2$ geminal hydrogens as an AB system (*J* 10.6 Hz) at δ 2.37 and 2.53, the satellite signals expected for $^2J_{H,Hg}$[8] not being observed.

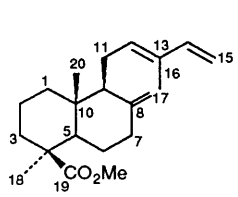
Two different possibilities are proposed in the oxymercuriation step for the origin of compounds **4** and **5** (Scheme 1). Both pathways converge at the same diacetoxymercurial **II** which, after reaction with $NaBH_4$, leads to the radical intermediate **III** (Scheme 2) that, by an $S_H i$ mechanism, gives compound **4** and, by previous trapping of a molecule of oxygen, compound **5** through the peroxyl radical **IV**.

When the OM–DM reaction for compound **1** was carried out with Na(Hg) as demercuriating agent, the products obtained were **3a** (29%), **7a** (17%), **8** (8%), **9a** (2%), **10** (< 1%), **11** (3%) and

† Percentage expressed weight for weight with respect to the reaction product.

‡ Percentage expressed mole for mole with respect to the starting material.

§ Compound **I** was obtained by reaction of the 12,13-oxiranes, produced from methyl (*Z*)-communate **2**, with $BF_3$·$Et_2O$ at 0 °C.[7]

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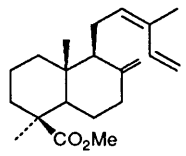


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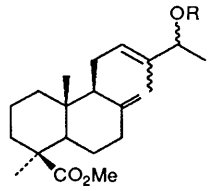
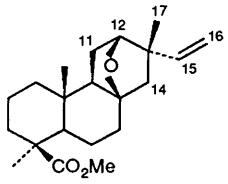



**3a**; $\Delta^{12E}$, R = H
**3b**; $\Delta^{12Z}$, R = H
**3c**; $\Delta^{12Z}$, R = Ac

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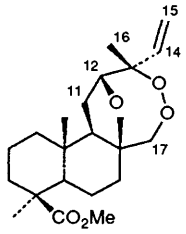


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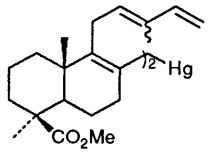
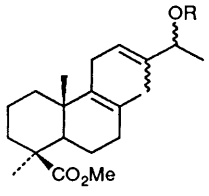
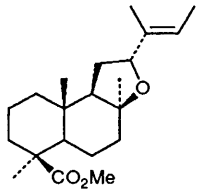



**6a**; $\Delta^{12E}$
**6b**; $\Delta^{12Z}$




**7a**; $\Delta^{12E}$, R = H **7b**; $\Delta^{12E}$, R = Ac
**7c**; $\Delta^{12Z}$, R = H **7d**; $\Delta^{12Z}$, R = Ac

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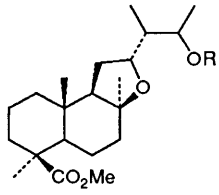
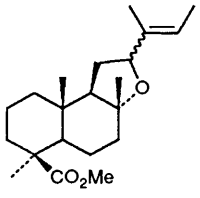
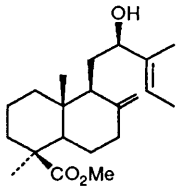


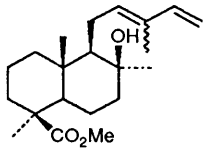

**9a**; R = H
**9b**; R = Ac



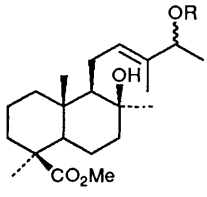

**10** (8*R*, 12*S*)
**11** (8*R*, 12*R*)



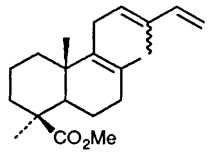

12




**13a**; $\Delta^{12E}$
**13b**; $\Delta^{12Z}$




**14a**; R = H
**14b**; R = Ac




**15a**; $\Delta^{12E}$
**15b**; $\Delta^{12Z}$

**13a** (2%), together with a 7% recovery of unaltered starting material and 6% of its isomerization product **15a**.

The mass spectrum of product **8** showed a base peak at *m*/*z* 175, which is typical of labdanes with an oxygenated bridge between positions C-8 and C-12.[9] Complete assignment of the NMR spectra was achieved with the aid of $^1H$–$^1H$ and $^1H$–$^{13}C$ 2D NMR correlations. The δ-value of Me-10 in the $^1H$ NMR spectrum (0.78) supported a β orientation of the oxygenated bridge, which is confirmed by the chemical shift of C-17 ($\delta_C$ 31.40) in the $^{13}C$ NMR spectrum, characteristic of a methyl group in an equatorial disposition.[10] The splitting pattern of 12-H (δ 4.28, br t, *J* 8.3 Hz) allowed us to assign the *R* configuration to C-12. Finally, the considerable shielding of the C-15 and C-16 signals in the $^{13}C$ NMR spectrum ($\delta_C$ 12.79 and 12.96, respectively) indicated an *E* configuration around the $\Delta^{13}$ system.

The stereochemistry of the oxides **9**–**11** has been established by comparison of their spectroscopic properties with those of compound **8**.

As regards compound **12** the relationship between the C-12 configuration and δ-value of 17-$H_{endo}$ (the nearest hydrogen to the side-chain) for 12-hydroxylabd-8(17)-enes allowed us to

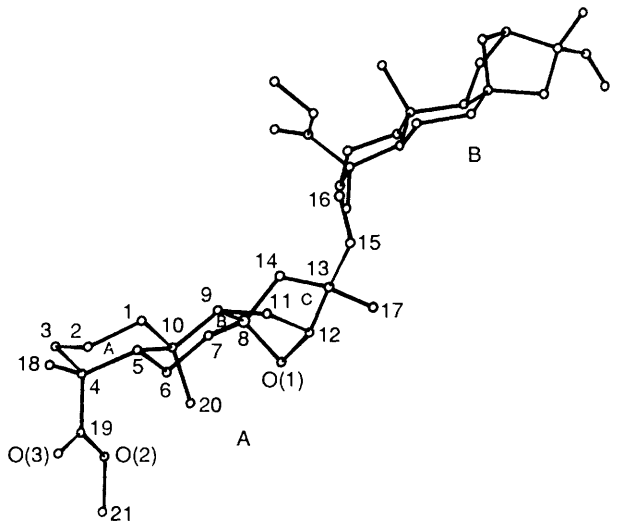
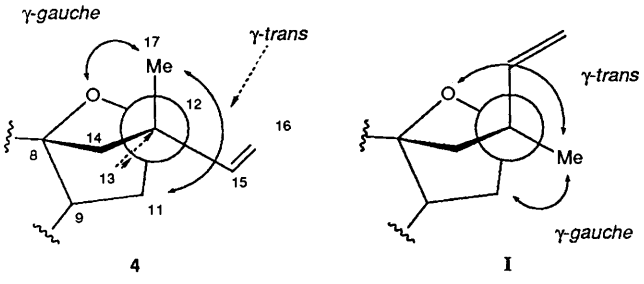



**Fig. 1** X-Ray molecular structure of methyl (8*R*,12*R*)-8,12-epoxy-isopimar-15-en-19-oate **4**. Diagram of the two molecules, A and B, in the asymmetric unit.




assign the *R* configuration to C-12,* and this was confirmed by Horeau's method.[12]

For compounds **13a** and **14a** (or **14b**), the β orientation of the C(8)-hydroxy group was established from the more deshielded value of 10-Me (δ 0.80) in the $^1$H NMR spectra with respect to those of 8α-hydroxylabdanes,[2,13] and by the δ change induced in the same methyl group by [$^2H_5$]pyridine (see Table 6, below).

The OM–DM reactions performed on methyl (*Z*)-communate **2** yielded very similar results to those obtained for compound **1** (see Experimental section).

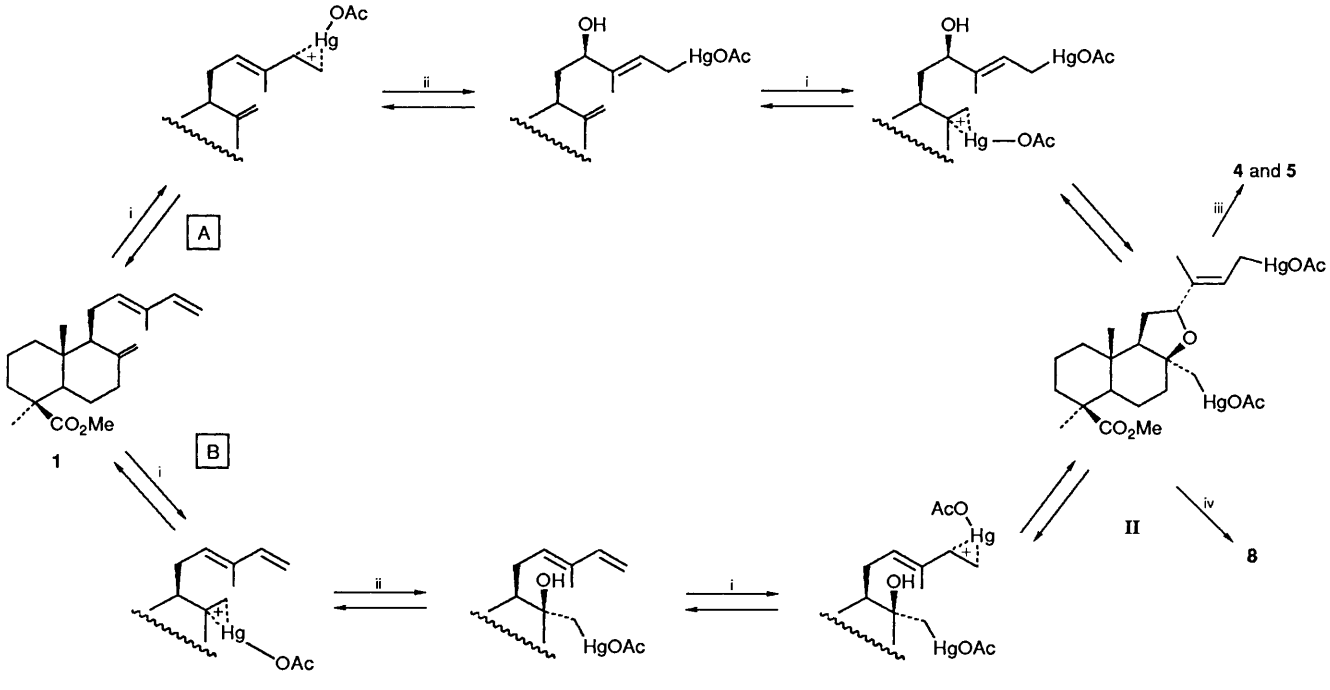
## Discussion

In OM–DM reactions of substrate **1** or **2**, using $NaBH_4$ as demercuriation agent, together with the main product **3**, the epoxides **4** and **5** were obtained *via* radical processes in the DM step.

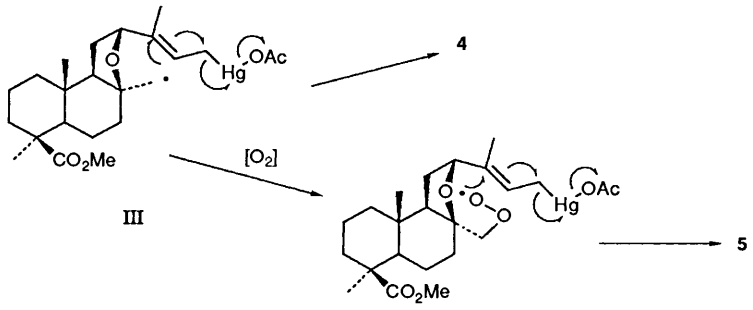
If these results are compared with those obtained when using Na(Hg) as reducing agent, the following may be observed: (a) the recovered starting material is accompanied by a significant amount of the product of isomerization of the exocyclic double bond, compound **15**. (b) The $\Delta^{14}$-hydration product **3** and the corresponding isomerized product **7** are the main products of the reaction. (c) The $\Delta^{12}$-double bond is the least reactive one probably due to the fact that it forms part of a conjugated system in which the other double bond, being more accessible, modifies its behaviour.† (d) The formation of the isopimarane oxide **4** (or the related product **5**) does not take place; however, compound **8**, resulting from the direct reduction of the diacetoxymercurial **II** (Scheme 1), and the oxides **9**–**11** were isolated. (e) Compound **12**, the product of stereoselective 1,4-addition of water to the conjugated diene system, was formed too. (f) Finally, hydration of the exocyclic double bond takes place on the β-side to afford compounds **13** and **14**.

* 17-$H_{endo}$ In compound **12** resonates at δ 4.45, a practically unaltered value with respect to that of products without a hydroxy group on C-12, whereas 17-$H_{endo}$ suffers a deshielding of ~0.25 ppm when the C-12 configuration is *S*.[11]

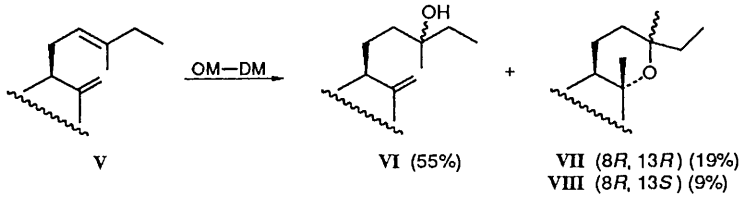
† The OM–DM of methyl labda-8(17),12*E*-dien-19-oate **V** with $Hg(OAc)_2$ and $NaBH_4$ as reducing agent (see Experimental section) allows us to establish that the low reactivity of the $\Delta^{12}$-bond observed for compounds **1** and **2** should not be justified by steric considerations (trisubstituted double bond) since substrate **V**, after only 1 h, yielded a 55% yield of the alcohol **VI** and a mixture of 14,15-dehydrogenated manoyl oxide derivatives **VII**/**VIII**, a 12% recovery of unchanged starting material **V** (Scheme 3).




**Scheme 1** *Reagents:* i, $Hg(OAc)_2$; ii, water; iii, $NaBH_4$; iv, Na(Hg)




Scheme 2




Scheme 3

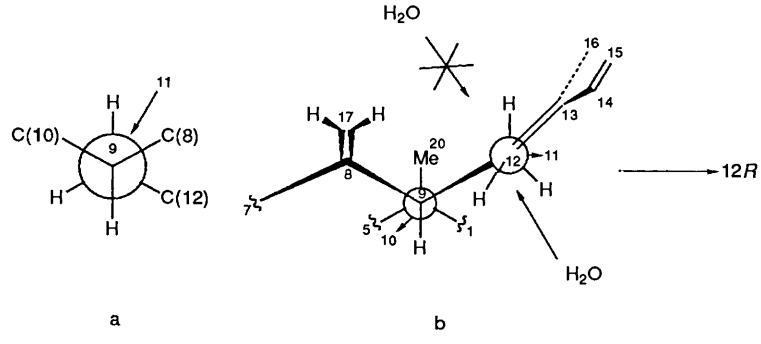



Fig. 2

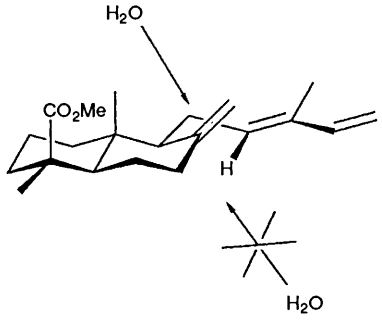



Fig. 3

The presence of 1,4-addition products **4**, **5** and **8**–**12** constitutes a novel result in OM–DM reactions with $Hg(OAc)_2$. It is important to point out that all these compounds, with the exception of compound **10**, show the *R* configuration at C-12. This marked stereoselectivity appears to be a result of the side-chain adopting a preferred conformation as the consequence of the interaction exerted by the bicyclic system (Fig. 2).* Considering that the position of the side-chain in the $\Delta^{14}$-mercurinium intermediate should be similar to that of the starting product (Fig. 2b), then nucleophilic attack on C-12 should take place on the less hindered α-side thereby giving 12*R*-derivatives.

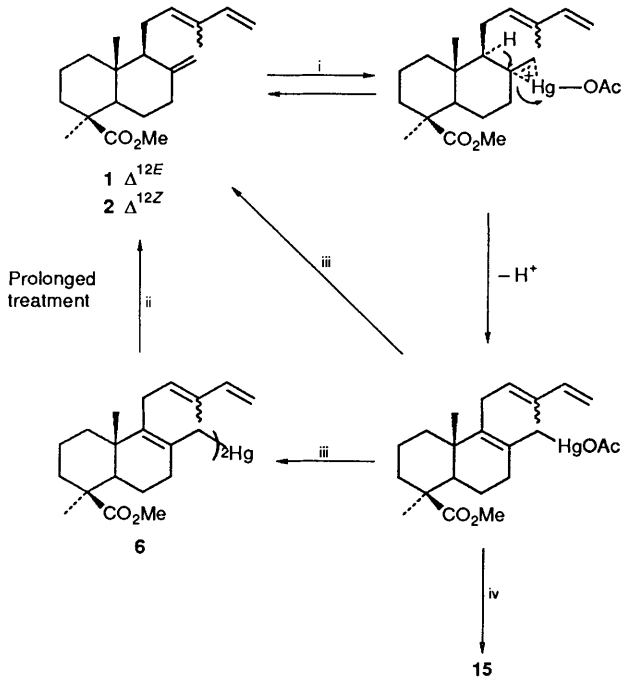
On the other hand, the products of oxymercuriation of the 8(17) double bond, compounds **13** and **14**, correspond exclusively to the entry of water on the β side. Again, the justification of this result can be found in the preferential conformation of the chain which, as it is preferentially located on the α side, gives rise to higher steric hindrance than that exerted by 10-Me (Fig. 3).†

Another fact related to the hindrance toward attack by external nucleophiles on the $\Delta^{8(17)}$ double bond is the isomerization of the exocyclic double bond in compounds **6**, **7** and **15**. This hindrance should lengthen the average lifetime of the mercurinium ion on $\Delta^{8(17)}$, favouring its evolution by loss of the neighbouring 9-H hydrogen (Scheme 4). In OM–DM using $NaBH_4$ no products of isomerization of the exocyclic double bond were observed, which indicates that in the reduction step a new completely stereoselective isomerization of compound **6**, or a related $\Delta^{8}$-intermediate, had occurred. On the other hand, these organomercurials led directly to isomerization products when Na(Hg) was used (Scheme 4).

It is remarkable that in OM–DM reactions of substrate **1** or **2**,

* It has been established for labd-8(17)-enes that preferred rotamers exist around C(9)–C(11) (Fig. 2a)[14] and C(11)–C(12) (Fig. 2b)[15] bonds in order to minimize the interaction of the chain with the decalin ring.

† However, on studying the OM–DM of methyl labda-8(17),13(16),14-trien-19-oate under the same conditions as described here,[2] it was established that the addition of water to the $\Delta^{8(17)}$-double bond took place mainly from the α side.




**Scheme 4** *Reagents:* i, $Hg(OAc)_2$; ii, $NaBH_4$ (excess); iii, $NaBH_4$, $OH^-$; iv, Na(Hg).

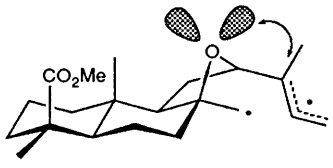



**Fig. 4**

using $NaBH_4$, the same and sole isopimarane oxide **4** is obtained accompanied by the corresponding endoperoxide derivative **5**. This fact could be explained if stereoelectronic control is exerted by the annular oxygen during the cyclization process (Fig. 4).

## Experimental

M.p.s were determined using a Reichert-type Kofler microscope with hot slide and are uncorrected. Optical rotations were determined on a Perkin-Elmer Model 141 polarimeter with a 1 dm microcell, using $CHCl_3$ as solvent (the concentration is expressed in centigrams $cm^{-3}$). Mass spectra were registered on Hewlett-Packard Models 5980A and 5988A mass spectrometers using an ionizing voltage of 70 eV. IR spectra were obtained on Pye Unicam SP 1000 and Perkin-Elmer Models 782 and 983G spectrometers with samples between sodium chloride plates or as potassium bromide pellets. $^1H$ NMR spectra were performed on Bruker WP 80 SY (80 MHz) and Bruker AM 300 (300 MHz) spectrometers using $SiMe_4$ as internal standard and $CDCl_3$ as solvent. Chemical shifts ($\delta$) are reported in parts per million downfield from tetramethylsilane and coupling constants ($J$) are in Hz. $^{13}C$ NMR spectra were run on Bruker WP 80 SY (20 MHz) and Bruker AM 300 (75 MHz) spectrometers. NOE experiments were achieved on a Bruker WP 200 SY (200 MHz) spectrometer. 2D NMR ($^1H$–$^1H$, one-bond and long-range $^1H$–$^{13}C$ correlations) experiments were performed on Bruker SP 200 SY and Bruker AM 300 spectrometers. Chromatographic separations were carried out by conventional column chromatography on Merck silica gel 60 (70–230 mesh) and by flash column on Merck silica gel 60 (230–400 mesh and < 230 mesh), with solvent mixtures of gradually increasing polarity from hexane through to diethyl ether. Analytical TLC was performed on 0.25 mm-thick layers of Merck silica gel 60G, activated for 2 h at 120 °C. Development of spots was achieved by spraying of the plate with a 7% phosphomolybdic acid solution (in ethanol) and heating for a few minutes. Preparative TLC (PLC) was carried out on a 1 mm-thick layers of Merck silica gel 60 $PF_{254}$ (coated on 20 × 20 cm glass plates) dried in air for 1 h and then activated for 3 h at 120 °C. Visualization of bands was achieved with the help of 254 nm UV light. Mixtures of compounds with the same $R_f$-value in TLC were chromatographed on a column on 20% $AgNO_3$/silica gel ($^1H$ NMR and $AgNO_3/SiO_2$ TLC monitoring).

Methyl (*E*)-communate **1** used in this study was obtained from the acid fraction (previously sterified with diazomethane in $Et_2O$) of the hexane extract of the wood of *Juniperus sabina* L. and *J. oxycedrus* L.,[16] while methyl (*Z*)-communate **2** was obtained from berries of *J. communis* L.[17] Solvents for chromatography and general use were treated as described in ref. 18 and 1.2% sodium amalgam was prepared according to the literature.[19]

*Oxymercuriation–Demercuriation using* $NaBH_4$ *as Reducing Agent.*—The general procedure described by Brown and Geoghegan was followed.[6]

*Oxymercuriation–Demercuriation of Methyl (E)-Communate* **1**.—*Reaction A* [$Hg(OAc)_2$:**1** *molar ratio* 2:1]. $Hg(OAc)_2$ (8.10 g, 25 mmol), THF–water (10 $cm^3$–12 $cm^3$), **1** in THF [4 g (12.7 mmol) in 15 $cm^3$], oxymercuriation time 6 h, $NaBH_4$–3 mol $dm^{-3}$ NaOH (500 mg in 50 $cm^3$), demercuriation time 1 h. An aliquot (4.20 g) of reaction mixture was subjected to column chromatography over silica gel (50 g) (< 230 mesh) to yield the following products, in addition to recovery of substrate **1** (1.04 g).*

(a) Methyl (8*R*,12*R*)-8,12-epoxyisopimar-15-en-19-oate **4** (340 mg) eluted with hexane–$Et_2O$ (9:1) as crystals, m.p. 77–78 °C (from MeOH); $[\alpha]_D$ +17.7° (*c* 1.00); $\nu_{max}$(KBr)/$cm^{-1}$ 3084, 1640, 995, 913 (CH=$CH_2$); 1722, 1230, 1190, 1158 ($CO_2Me$); 1092 and 1030 (C–O–C); *m/z* 332 ($M^+$, 36%), 317 ($M^+ - CH_3$, 96), 273 ($M^+ - CO_2Me$, 7), 263 (10), 257 ($M^+ - CH_3 - HCO_2Me$, 6), 223 (13), 203 (8), 135 (13), 121 (42), 107 (40), 91 (60), 83 (23), 69 (32), 65 (19) and 55 (100); $^1H$ NMR data are in Table 1; $^{13}C$ NMR data in Table 4. Data from X-ray crystal-structure determination have been deposited as supplementary material.

(b) Methyl (8*S*,12*R*, 13*S*)-13,17-epidioxy-8,12-epoxylabd-14-en-19-oate **5** (50 mg) eluted with hexane–$Et_2O$ (8:2); purification by PLC [hexane–$Et_2O$ (8:2)] and crystallization from methanol yielded crystals, m.p. 91–93 °C; $[\alpha]_D$ +53.0° (*c* 0.10); $\nu_{max}$(KBr)/$cm^{-1}$ 3080, 1646, 1000, 927 (CH=$CH_2$); 1041 (C–O–O); 1096 (C–O–C); 1723, 1233, 1195 and 1153 ($CO_2Me$); *m/z* 364 ($M^+$, 8%), 332 ($M^+ - O_2$, 8), 317 ($M^+ - O_2 - CH_3$, 57), 279 ($M^+ - O_2 - C_4H_5$, 71), 264 ($M^+ - O_2 - CH_3 - C_4H_5$, 100), 189 (33) and 121 (71); $^1H$ NMR data in Table 1; $^{13}C$ NMR data in Table 4.

(c) Bis-(4β-methoxycarbonyl-19-norlabda-8,12*E*,14-trien-17-yl)mercury **6a** (32 mg) eluted with hexane–$Et_2O$ (7:3), oil, $[\alpha]_D$ +50.8° (*c* 0.21); $\nu_{max}$(neat)/$cm^{-1}$ 3085, 1640, 1605, 986, 890 (conjugated CH=$CH_2$); 1665 (C=C); 1720, 1234, 1195 and 1157 ($CO_2Me$); *m/z* 315 (13%), 255 (29), 173 (29), 105 (41), 91 (61), 81 (100), 67 (29), 55 (66) and 41 (76); $^1H$ NMR data in Table 2.

When an excess of $NaBH_4$ was added at room temperature to a solution of compound **6a** (15 mg) in $Et_2O$ (1 $cm^3$) a progressive darkening of the mixture was observed throughout

* Every given weight is referred to the isolated pure product plus the corresponding calculated weight from fractions containing a mixture of products.

**Table 1** $^1$H NMR data[a] of compounds **1–5** [$\delta$ (mult.: $J$/Hz)]

| H | 1[b] | 2[b] | 3a[b] | 3b[b] | 3c[b] | 4[c] | 5[b] |
|---|---|---|---|---|---|---|---|
| 12 | 5.41 (br t; 7) | 5.32 (t; 7) | 5.30 (br t; 7) | 5.12 (br t; 7) | 5.14 (br t; 6) | 3.83 (d; 5.5) | 4.00 (dd; 10, 6) |
| 14 | 6.32 (dd; 18, 10) | 6.80 (dd; 18, 10) | 4.18 (q; 6) | 4.81 (q; 7) | 5.71 (q; 7) | 1.18 (d; 12.2)[d] | 5.83 (dd; 11.2, |
| 14′ | | | | | | 1.50 (d; 12.2)[d] | 16.0) |
| 15 | 4.86 (br d; 10) | 5.10 (br d; 10) | 1.23 (d; 6) | 1.24 (d; 7) | 1.28 (d; 7) | 5.86 (dd; 18.7, | 5.17 (dd; 11.2, |
| | | | | | | 10.1) | 2.4) |
| 15′ | 5.02 (br d; 18) | 5.17 (br d; 18) | | | | | 5.34 (dd; 16.0, |
| | | | | | | | 2.4) |
| 16 | 1.75 (br s) | 1.78 (br s) | 1.62 (br s) | 1.67 (d; 1.5) | 1.64 (br s) | 5.00 (dd; 18.7, | 1.29 (s) |
| 16′ | | | | | | 1.2) | |
| | | | | | | 5.01 (dd; 10.1, | |
| | | | | | | 1.2) | |
| 17 | 4.45 (br s) | 4.51 (br s) | 4.43 (br s) | 4.45, 4.50 | 4.42, 4.53 | 1.09 (s) | 3.65 (d; 14) |
| | | | | (2 br s) | (2 br s) | | |
| 17′ | 4.82 (br s) | 4.87 (br s) | 4.82 (br s) | 4.85 (br s) | 4.84 (br s) | | 4.09 (d; 14) |
| 18 | 1.18 (s) | 1.20 (s) | 1.20 (s) | 1.18 (s) | 1.19 (s) | 1.17 (s) | 1.20 (s) |
| 20 | 0.55 (s) | 0.57 (s) | 0.55 (s) | 0.52 (s) | 0.54 (s) | 0.67 (s) | 0.75 (s) |
| $CO_2Me$ | 3.61 (s) | 3.62 (s) | 3.62 (s) | 3.60 (s) | 3.63 (s) | 3.60 (s) | 3.64 (s) |
| 14-OAc | | | | | 2.03 (s) | | |

[a] Values are relative to $SiMe_4$ in $CDCl_3$. [b] 80 MHz. [c] 300 MHz. [d] Assignment from C/H correlation experiments.

**Table 2** $^1$H NMR data[a] of compound **6–9** [$\delta$ (mult.; $J$/Hz)]

| H | 6a[c] | 6b[b] | 7b[c] | 7c[b] | 7d[b] | 8[c] | 9a[b] | 9b[b] |
|---|---|---|---|---|---|---|---|---|
| 11 | 2.85 (dd; 18.0, 6.0) | 2.83–3.08 (m) | 2.55 (dd; 15.0, 6.0) | 2.60–2.80 (m) | 2.61–2.88 (m) | | | |
| 11′ | 2.93 (dd; 18.0, 6.0) | | 2.71 (dd; 15.0, 6.0) | | | | | |
| 12 | 5.22 (br t; 6) | 5.13 (m) | 5.16–5.26 (m) | 5.00 (br t; 6) | 5.02 (br t; 6) | 4.28 (br t; 8.3) | 3.40–4.10 (m) | 3.40–3.75 (m) |
| 14 | 6.34 (dd; 11.0, 18.0) | 6.87 (dd; 10, 17) | 5.16–5.26 (m) | 4.85 (q; 7) | 5.77 (q; 7) | 5.53 (br q; 6.8) | 3.40–4.10 (m) | 5.29 (dq; 7, 4) |
| 15 | 5.00 (d; 11.0) | 5.21 (br d; 10) | 1.23 (d; 6) | 1.25 (d; 7) | 1.28 (d; 17) | 1.57 (d; 6.8) | 1.12 (d; 7) | 1.14 (d; 7) |
| 15′ | 5.12 (d; 18.0) | 5.30 (br d; 17) | | | | | | |
| 16 | 1.80 (d; 1.5) | 1.88 (br s) | 1.61 (br s) | 1.68 (d; 1.7) | 1.66 (d; 1.7) | 1.55 (br s) | 0.92 (d; 7) | 0.76 (d; 7) |
| 17 | 2.37 (d; 10.6) | 2.30 (d; 10.5) | 1.47 (d; 2.4) | 1.53 (s) | 1.52 (s) | 1.08 (s) | 1.17 (s) | 1.14 (s) |
| 17′ | 2.53 (d; 10.6) | 2.55 (d; 10.5) | | | | | | |
| 18 | 1.20 (s) | 1.21 (s) | 1.17 (s) | 1.18 (s) | 1.19 (s) | 1.18 (s) | 1.17 (s) | 1.19 (s) |
| 20 | 0.77 (s) | 0.79 (s) | 0.72 (s) | 0.75 (s) | 0.75 (s) | 0.78 (s) | 0.77 (s) | 0.73 (s) |
| $CO_2Me$ | 3.63 (s) | 3.65 (s) | 3.59 (s) | 3.62 (s) | 3.62 (s) | 3.60 (s) | 3.62 (s) | 3.62 (s) |
| 14-OAc | | | 1.99 (s) | | 2.02 (s) | | | 2.02 (s) |

[a] Values are relative to $SiMe_4$ in $CDCl_3$. [b] 80 MHz. [c] 300 MHz.

6 h. The $^1$H NMR spectrum of the filtered solution (two spots on TLC) indicated that it was a mixture of substrate **6a** and methyl (*E*)-communate **1** in a 1:4 ratio.

(d) Methyl 14ξ-hydroxylabda-8(17),12*E*-dien-19-oate **3a** (1.01 g) eluted with hexane–$Et_2O$ (3:2) and (1:1), oil, $[\alpha]_D$ +24.4° (*c* 1.00); $\nu_{max}$(neat)/cm$^{-1}$ 3400, 1030 (allylic secondary OH);[20] 1728, 1230, 1190, 1155 ($CO_2Me$); 3080, 1660 and 890 (C=$CH_2$); $^1$H NMR data in Table 1; $^{13}$C NMR data in Table 4.

*Oxymercuriation–Demercuriation of Methyl* (Z)-*Communate* **2**.—*Reaction B.* $Hg(OAc)_2$ (2.02 g, 6.33 mmol), THF–water (5 cm$^3$/3 cm$^3$), **2**–THF [1 g, (3.16 mmol) in 5 cm$^3$], oxymercuriation time 1.5 h, $NaBH_4$–3 mol dm$^{-3}$ NaOH (127 mg in 13 cm$^3$), demercuriation time 1 h. An aliquot (1.14 g) of crude product was chromatographed on silica gel (25 g) (70–230 mesh) to yield recovered substrate **2** (125 mg) [hexane–$Et_2O$ (95:5)] and compound **4** (70 mg) [hexane–$Et_2O$ (9:1)]. Finally, the following products were isolated.

(a) Bis-(4β-methoxycarbonyl-19-norlabda-8,12*Z*,14-trien-17-yl)mercury **6b** (13 mg) eluted with hexane–$Et_2O$ (8:2), oil, $[\alpha]_D$ +47.1° (*c* 0.80); $\nu_{max}$(neat)/cm$^{-1}$ 3079, 1645, 1600, 986, 909 (conjugated CH=$CH_2$); 1665 (C=C); 1722, 1233, 1192 and 1157 ($CO_2Me$); $^1$H NMR data in Table 2. Treatment of compound **6b** with $NaBH_4$ in excess (for 10 h) led to methyl (*Z*)-communate as the sole product (see the corresponding reaction for compound **6a**).

(b) Methyl 14ξ-hydroxylabda-8(17),12*Z*-dien-19-oate **3b** (255 mg) eluted with hexane–$Et_2O$ (4:1) and (1:1), oil, $[\alpha]_D$ + 36.1° (*c* 1.21); $\nu_{max}$(neat)/cm$^{-1}$) 3424, 1032 (allylic secondary OH);[20] 3082, 1643, 891 (C=$CH_2$), 1721, 1229 and 1195 ($CO_2Me$); *m/z* 319 ($M^+ - CH_3$, 1%), 317 ($M^+ - OH$, 8), 316 ($M^+ - H_2O$, 22), 301 ($M^+ - CH_3 - H_2O$, 9), 257 ($M^+ - H_2O - CO_2Me$, 14), 241 (14), 175 (28), 147 (18), 135 (24), 121 (80), 105 (47), 91 (66), 81 (55), 79 (70), 67 (61), 59 (69) and 55 (100); $^1$H NMR data in Table 1; $^{13}$C NMR data in Table 4.

Compound **3b** (116 mg) was acetylated with $Ac_2O$ and pyridine in the usual way to yield methyl 14ξ-acetoxylabda-8(17),12*Z*-dien-19-oate **3c** (80 mg) eluted with hexane–$Et_2O$ (9:1), oil, $[\alpha]_D$ +30.9° (*c* 1.03); $\nu_{max}$(neat)/cm$^{-1}$ 3080, 1644, 889 (C=$CH_2$); 1727, 1033 (AcO); 1727, 1245, 1190 and 1154 ($CO_2Me$); $^1$H NMR data in Table 1.

*Reaction C.* In a magnetically stirred flask equipped with a nitrogen bubbling device were placed compound **2** (1 g, 3.16 mmol), $Hg(OAc)_2$ (2.02 g, 6.33 mmol), water (3 cm$^3$) and THF (9 cm$^3$). After 1.5 h a solution (also bubbled with nitrogen) of $NaBH_4$ (127 mg) in 3 mol dm$^{-3}$ NaOH (13 cm$^3$) was added, and the mixture was stirred under $N_2$ for 1 h more. After usual work-up, the crude (1.20 g) was chromatographed on silica gel (30 g)

(70–230 mesh) to yield compounds **2** (140 mg recovery), **4** (128 mg), **6b** (21 mg) and **3b** (370 mg).

*Reaction D.* To a stirred suspension of $Hg(OAc)_2$ (1.39 g, 4.44 mmol) in water (2 $cm^3$) and THF (5 $cm^3$) was added a solution of compound **2** (700 mg, 2.22 mmol) in THF (3 $cm^3$). After 1.5 h at room temperature the mixture was bubbled with oxygen (which process was kept throughout the reduction step) and a solution of $NaBH_4$ (90 mg) in NaOH (9 $cm^3$), previously bubbled with oxygen, was added. After 1 h the mixture was worked up in the usual way to obtain a crude product (750 mg). Finally, compounds **4** and **5** were isolated by column chromatography in the approximate ratio 5:1.

*Oxymercuriation–Demercuriation using 1.2% Na(Hg) as Reducing Agent.*—Once the oxymercuriation stage[6] was completed, 1.2% Na(Hg) (7 g) (3.7 mmol of Na) per mmol of $Hg(OAc)_2$ and an excess of water were added.[21] After being stirred for 15 h at room temperature, the mixture was extracted with hexane (4 × 25 $cm^3$) and the organic phases were dried over anhydrous $Na_2SO_4$ then filtered, and the solvent was evaporated off.

*Oxymercuriation–Demercuriation of Methyl (Z)-Communate* **2** *(Alternative Reaction)* **2.**—$Hg(OAc)_2$ (8.08 g, 25.3 mmol), THF–water (20 $cm^3$–13 $cm^3$) **2** in THF [4 g (12.7 mmol) in 17 $cm^3$], oxymercuriation time 2 h; 1.2% Na(Hg)/water (180 g/30 $cm^3$); demercuriation time 15 h. An aliquot (4.25 g) of reaction product was subjected to column chromatography over silica gel (140 g) (70–230 mesh) to afford seven fractions eluted with mixtures of hexane–$Et_2O$ (98:2) (fraction A), (92:8) (frac. B), (92:8) and (88:12) (frac. C), (85:15) (frac. D), (85:15), (4:1) and (1:1) (frac. E), (1:1) and (3:7) (frac. F), and finally with $Et_2O$ (frac. G).

Fraction A was chromatographed on 20% $AgNO_3$/silica gel (70–230 mesh) to give compound **2** (296 mg recovery) [hexane–$Et_2O$ (7:3) and (1:1)] and compound **15b**.

(a) Methyl labda-8,12*Z*,14-trien-19-oate **15b** (317 mg) eluted with hexane–$Et_2O$ (97:3) and (94:6), oil, $[\alpha]_D$ +50.7° (*c* 1.01); $\nu_{max}$(neat)/$cm^{-1}$ 3089, 1660sh, 1610sh, 980, 911 (conjugated CH=$CH_2$): 1722, 1233, 1192 and 1156 ($CO_2Me$); $^1H$ NMR data in Table 3; $^{13}C$ NMR data in Table 5.

(b) Methyl (8*S*,12*R*)-8,12-epoxylabd-13*E*-en-19-oate **8**; fraction B contained the title compound **8** (242 mg), m.p. 63–65 °C (from MeOH); $[\alpha]_D$ +50.1° (*c* 1.23); $\nu_{max}$(KBr)/$cm^{-1}$ 3030sh, 1680, 820 (CH=C); 1728, 1233, 1195, 1152 ($CO_2Me$); 1051 and 898 (five-membered cyclic ether);[22] *m/z* 334 ($M^+$, 33%), 319 ($M^+ - CH_3$, 9), 279 ($M^+ - C_4H_7$, 2), 275 ($M^+ - CO_2Me$, 3), 259 ($M^+ - CH_3 - HCO_2Me$, 3), 235 ($M^+ - C_4H_7 - C_2H_4O$, 32), 175 ($235^+ - HCO_2Me$, 100), 121 (40), 95 (39) and 55 (56); $^1H$ NMR data in Table 2; $^{13}C$ NMR data in Table 5.

(c) Methyl (8*R*,12*S*)-8,12-epoxylabd-13*E*-en-19-oate **10** and Methyl (8*R*,12*R*)-8,12-epoxylabd-13*E*-en-19-oate **11**: fraction C was chromatographed over silica gel (70–230 mesh) to yield a mixture of compounds **10** and **11** (40 mg) [hexane–$Et_2O$ (94:6)] in the approximate ratio 1.4:1: $^1H$ NMR in Table 3 (see below in OM–DM reaction of compound **1**).

(d) Methyl (12*R*)-12-hydroxylabda-8(17),13*E*-dien-19-oate **12**; fraction D was purified by chromatography over silica gel (70–230 mesh) and elution with hexane–$Et_2O$ (85:15) to afford compound **12** (180 mg), oil, $[\alpha]_D$ +68.8° (*c* 1.07); $\nu_{max}$(neat)/$cm^{-1}$ 3438, 1035 (allylic secondary OH);[20] 3078, 1641, 889 (C=$CH_2$); 1660, 822 (C=CH); 1723, 1229, 1205 and 1155 ($CO_2Me$); *m/z* 334 ($M^+$, 1%), 317 ($M^+$ – OH, 1), 316 ($M^+ - H_2O$, 2), 301 (5), 275 ($M^+ - CO_2Me$, 1), 257 ($M^+ - H_2O - CO_2Me$, 2), 250 (7), 149 (25), 121 (100)* and 85 ($C_5H_9O^+$, 71); $^1H$ NMR data in Table 3; $^{13}C$ NMR data in Table 5. Absolute configuration at C-12 was determined as *R* through Horeau's method[12] (optical rotation +0.105°, corresponding to an optical yield of 21.3%). The α-phenylbutyric ester of the alcohol **12** (55 mg) was isolated: $\delta_H$(80 MHz; $CDCl_3$) 0.45 (3 H, s, 10-Me), 0.92 (3 H, t, *J* 7, 4′-H), 1.17 (3 H, s, 4-Me), 1.47 (3 H, s, 13-Me), 1.57 (3 H, d, *J* 5, 14-Me), 3.38 (1 H, dd, *J* 8 and 6, 2-H′), 3.60 (3 H, s, COMe), 4.42 (1 H, br s, 17-H), 4.82 (1 H, br s, 17-$H_{endo}$), 5.12 (1 H, br d, *J* 9, 12-H), 5.36 (1 H, br q, *J* 6, 14-H) and 7.30 (5 H, s, Ph).

Fraction E upon chromatography over 20% $AgNO_3$/silica gel (70–230 mesh) yielded compound **7c** (470 mg) [hexane–$Et_2O$ (4:1), (3:1) and (7:3)], compound **13b** (74 mg) [hexane–$Et_2O$ (1:1)] and compound **3b** (430 mg) [hexane–$Et_2O$ (45:55), (2:3) and (3:7)].

(e) Methyl 14ξ-hydroxylabda-8,12*Z*-dien-19-oate **7c**, oil, $[\alpha]_D$ +104.8° (*c* 1.14); $\nu_{max}$(neat)/$cm^{-1}$ 3411, 1035 (allylic secondary OH);[20] 1723, 1231, 1192 and 1152 ($CO_2Me$); *m/z* 334 ($M^+$, 1%), 316 ($M^+ - H_2O$, 10), 289 ($M^+ - C_2H_5O$, 4), 257 ($M^+ - H_2O - CO_2Me$, 3), 235 (6), 175 (45), 159 (30), 121 (30), 119 (69), 105 (58), 91 (72) and 55 (100); $^1H$ NMR data in Table 2; $^{13}C$ NMR data in Table 4. Compound **7c** (96 mg) was acetylated in the usual way, yielding [hexane–$Et_2O$ (9:1)] methyl 14ξ-acetoxylabda-8,12*Z*-dien-19-oate **7d** (58 mg), oil, $[\alpha]_D$ +95.7° (*c* 0.96); $\nu_{max}$(neat)/$cm^{-1}$ 1726, 1242, 1192, 1156 ($CO_2Me$), 1666, 851 (C=CH); 1726, 1242 and 1035 (AcO–); $^1H$ NMR data in Table 2.

(f) Methyl 8β-hydroxylabda-12*Z*,14-dien-19-oate **13b**, oil, $[\alpha]_D$ +37.0° (*c* 1.14); $\nu_{max}$(neat)/$cm^{-1}$ 3506, 1097 (tertiary OH);[20] 3080, 1639, 1600, 986, 902 (conjugated CH=$CH_2$); 1723, 1233, 1195 and 1153 ($CO_2Me$); *m/z* 317 ($M^+$ – OH, 1%), 316 ($M^+ - H_2O$, 3), 257 ($M^+ - H_2O - CO_2Me$, 1), 235 (3), 175 (13), 121 (22), 119 (36), 105 (27), 91 (42), 81 (99), 79 (97) and 55 (100); $\delta_H$(80 MHz; [$^2H_5$]pyridine), 1.17 (3 H, s, 10-Me), 1.25 (3 H, s, 4-Me), 1.33 (3 H, s, 8-Me), 1.91 (3 H, br s, 13-Me), 3.56 (3 H, s, $CO_2Me$), 5.21 (1 H, br d, *J* 11, 15-H), 5.27 (1 H, br d, *J* 18, 15-H′), 5.55 (1 H, br t, *J* 7, 12-H) and 7.03 (1 H, dd, *J* 11 and 18, 14-H); $^1H$ NMR data ($CDCl_3$) in Table 3; $^{13}C$ NMR data in Table 5.

(g) Methyl 14ξ-hydroxylabda-8(17),12*Z*-dien-19-oate **3b**; fraction F was acetylated with $Ac_2O$ and pyridine in the usual way to give acetylation products (400 mg) which upon chromatography over silica gel (70–230 mesh) yielded compound **9b** (207 mg) (hexane–$Et_2O$ (86:14) and (85:15)].

(h) Methyl (8*S*,12*R*)-14-acetoxy-8,12-epoxylabdan-19-oate **9b**, oil, $[\alpha]_D$ +39.1° (*c* 1.18); $\nu_{max}$(neat)/$cm^{-1}$ 1726, 1247, 1198, 1153 ($CO_2Me$); 1726, 1247, 1037 (AcO–): and 1081 (C–O–C); $^1H$ NMR data in Table 2; $^{13}C$ NMR data in Table 5; $\delta_H$(double resonance) irradiated hydrogen (affected hydrogens) 14-Me (14-H, d, *J* 4), 13-Me (13-H, modification in 1.75 ppm), 13-H (13-Me and 14-H, q, *J* 7) and 14-H (14-Me).

Fraction G was acetylated with $Ac_2O$–pyridine and the product was chromatographed over silica gel (70–230 mesh) to yield compound **14b** (250 mg) [hexane–$Et_2O$ (4:1), (77:23), (3:1)].

(i) Methyl 14-acetoxy-8β-hydroxylabd-12*E*-en-19-oate **14b**, oil, $[\alpha]_D$ +16.7° (*c* 0.79); $\nu_{max}$(neat)/$cm^{-1}$ 3531, 1073 (tertiary OH);[20] 1724, 1242, 1033 (AcO–); 1724, 1242, 1190, 1152 ($CO_2Me$), 1671 and 821 (CH=C); $^1H$ NMR data in Table 3; $\delta_H$(80 MHz; [$^2H_5$]pyridine) 1.15 (3 H, s, 10-Me), 1.23 (3 H, s, 4-Me), 1.29 (3 H, s, 8-Me), 1.33 (3 H, d, *J* 7, 14-Me), 1.71 (3 H, br s, 13-Me), 2.02 (3 H, s, 14-OAc), 3.55 (3 H, s, $CO_2Me$), 5.52 (1 H, q, *J* 7, 14-H) and 5.64 (1 H, t, *J* 6, 12-H); $^{13}C$ NMR data in Table 5.

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* Typical base peak of labdanes with $\Delta^{8(17)}$-unsaturation and an alkoxycarbonyl group on C-4.[23]

**Table 3** $^1$H NMR data[a] of compounds **10–15** [$\delta$ (mult.; $J$/Hz)]

| H | 10[c] | 11[c] | 12[c] | 13a[b] | 13b[b] | 14a[b] | 14b[b] | 15a[c] | 15b[c] |
|---|---|---|---|---|---|---|---|---|---|
| 11 | | | | | | | | 2.71 (dd; 16.8, 6.4) | 2.76 (dd; 16.6, 6.8) |
| 11′ | | | | | | | | 2.83 (dd; 16.8, 6.4) | 2.89 (dd; 16.6, 6.8) |
| 12 | 4.28 (br t; 7.8) | 4.38 (dd; 9.4, 2.9) | 3.99 (br d; 9.1) | 5.42 (br t; 6) | 5.32 (br t; 7) | 5.35 (br t; 7) | 5.40 (br t; 6) | 5.29 (br t; 6.4) | 5.18 (m)[d] |
| 14 | 5.56 (br q; 7.1) | 5.51 (br q; 5.9) | 5.42 (br q; 6.6) | 6.33 (dd; 16, 10) | 6.85 (dd; 11, 18) | 4.17 (q; 7) | 5.24 (q; 7) | 6.32 (dd; 10.7, 17.4) | 6.81 (br dd; 10.8, 17.2) |
| 15 | 1.57 (d; 7.1) | 1.58 (d; 5.9) | 1.57 (d; 6.6) | 4.89 (br d; 10) | 5.07 (br d; 11) | 1.22 (d; 7) | 1.26 (d; 7) | 4.88 (br d; 10.7) | 5.08 (br d; 10.8) |
| 15′ | | | | 5.05 (br d; 16) | 5.15 (br d; 18) | | | 5.04 (br d; 17.4) | 5.17 (br d; 17.2) |
| 16 | 1.57 (s) | 1.57 (s) | 1.61 (br s) | 1.76 (d; 1.5) | 1.78 (br s) | 1.65 (br s) | 1.64 (br s) | 1.74 (s) | 1.80 (d; 1.5) |
| 17 | 1.12 (s) | 1.15 (s) | 4.45 (br s) | 1.09 (s) | 1.10 (s) | 1.11 (s) | 1.07 (s) | 1.52 (s) | 1.57 (s) |
| 17′ | | | 4.84 (d; 1.3) | | | | | | |
| 18 | 1.17 (s) | 1.18 (s) | 1.16 (s) | 1.17 (s) | 1.19 (s) | 1.17 (s) | 1.18 (s) | 1.18 (s) | 1.23 (s) |
| 20 | 0.66(s) | 0.66 (s) | 0.47 (s) | 0.80 (s) | 0.80 (s) | 0.81 (s) | 0.80 (s) | 0.75 (s) | 0.80 (s) |
| $CO_2Me$ | 3.64 (s) | 3.64 (s) | 3.59 (s) | 3.62 (s) | 3.62 (s) | 3.62 (s) | 3.63 (s) | 3.61 (s) | 3.62 (s) |
| 14-OAc | | | | | | | 2.02 (s) | | |

[a] Values are relative to $SiMe_4$ in $CDCl_3$. [b] 80 MHz. [c] 300 MHz. [d] Overlapped at 15-H signal.

**Table 4** $^{13}$C NMR chemical shifts[a] of compounds **1–5** and **7**

| C | 1[b] | 2[b] | 3a[b] | 3b[b] | 4[c,d] | 5[b] | 7b[c] | 7c[b] |
|---|---|---|---|---|---|---|---|---|
| 1 | 39.24 | 39.08 | 38.97 | 38.94 | 41.49 | 40.99 | 36.82 | 36.78 |
| 2 | 19.90 | 19.75 | 19.68 | 19.62 | 18.73 | 18.86 | 20.81 | 19.33 |
| 3 | 38.19 | 38.03 | 37.92 | 37.88 | 38.28 | 38.15 | 37.66 | 37.45 |
| 4 | 44.19 | 44.04 | 43.98 | 43.95 | 43.86 | 43.79 | 43.79 | 43.56 |
| 5 | 56.37[e] | 56.50[e] | 56.15[e] | 56.54[e] | 54.61 | 55.85 | 53.50 | 53.36 |
| 6 | 25.96 | 25.80 | 25.74 | 25.72 | 20.79 | 19.15 | 20.81 | 20.62 |
| 7 | 38.43 | 38.32 | 38.36 | 38.23 | 32.20 | 31.44[e] | 34.43 | 34.19 |
| 8 | 147.78 | 147.55 | 147.74 | 147.49 | 85.58 | 82.99 | 127.75 | 127.22 |
| 9 | 56.25[e] | 56.08[e] | 55.98[e] | 55.96[e] | 55.47 | 53.92 | 138.08 | 138.40 |
| 10 | 40.06 | 39.95 | 39.83 | 39.86 | 36.61 | 36.16 | 39.41 | 39.30 |
| 11 | 23.22 | 22.05 | 22.17 | 21.40, 21.53 | 26.91 | 30.11[e] | 26.20 | 25.38 |
| 12 | 133.61 | 133.57 | 124.95, 125.06 | 126.10, 126.20 | 84.22 | 82.34 | 128.60 | 126.76, 126.93 |
| 13 | 133.26 | 131.18 | 137.62 | 136.93, 137.03 | 48.31 | 88.41 | 132.55 | 136.19 |
| 14 | 141.48 | 131.30 | 72.70, 72.81 | 65.23, 65.32 | 50.08 | 138.62 | 75.52 | 65.24 |
| 15 | 109.67 | 112.85 | 21.26 | 20.66, 20.83 | 144.05 | 113.93 | 18.99 | 20.62 |
| 16 | 11.64 | 19.39 | 11.18, 11.35 | 16.69 | 113.03 | 23.93 | 11.86 | 16.65 |
| 17 | 107.44 | 107.47 | 107.13 | 107.10, 107.21 | 27.38 | 86.49 | 19.47 | 19.33 |
| 18 | 28.70 | 28.53 | 28.49 | 28.46 | 28.80 | 28.65 | 28.36 | 28.13 |
| 19 | 177.30 | 117.02 | 177.26 | 177.30 | 177.92 | 177.71 | 178.13 | 177.73 |
| 20 | 12.51 | 12.40 | 12.32 | 12.27 | 14.75 | 13.67 | 17.45 | 17.36 |
| $CO_2Me$ | 50.83 | 50.67 | 50.74 | 50.73 | 51.09 | 51.18 | 51.01 | 50.73 |
| 14-O-COMe | | | | | | | 170.36 | |
| 14-O-CO*Me* | | | | | | | 21.32 | |

[a] $\delta$-Values in ppm from $SiMe_4$ in $CDCl_3$ solution; assignments aided by DEPT pulse sequence. [b] 20 MHz. [c] 75 MHz. [d] Assignment from C/H correlations experiments. In long-range $^1$H–$^{13}$C 2D NMR spectrum, the response of correlation resonance was optimized for $^nJ_{C,H}$ 7.3 Hz. [e] These signals may be interchanged.

**1** (*Alternative Procedure*).—$Hg(OAc)_2$ (3.23 g, 10.13 mmol), THF–water (10 cm$^3$–6 cm$^3$) **1** in THF [1.6 g (5.06 mmol) in 8 cm$^3$], oxymercuriation time 2 h; 1.2% Na(Hg)/water 72 g/10 cm$^3$, demercuriation time 15 h. An aliquot (1.75 g) of the reaction product was chromatographed over silica gel (60 g) (230–400 mesh) to afford eight fractions eluted with mixtures of hexane–$Et_2O$: (98:2) (fraction A), (96:4) (frac. B), (96:4) and (95:5) (frac. C), (92:8) and (91:9) (frac. D), (9:1) and (88:12) (frac. E), (88:12), (85:15), (4:1) and (75:25) (frac. F), (1:1) (frac. G), and finally with $Et_2O$ (frac. H).

(a) Fraction A contained a 4:3 mixture of compounds **2** and methyl labda-8,12*E*,14-trien-19-oate **15a** (203 mg); $^1$H NMR data of compound **15a** in Table 3; $^{13}$C NMR data of compound **15a** in Table 5.

(b) Fraction B contained compound **8** (109 mg).

(c) Fraction C (60 mg), a mixture of compounds **8**, **10** and **11**, was fractionated by PLC [hexane–$Et_2O$ (7:3)] to afford a mixture of compounds **10** and **11** which, after column chromatography over silica gel [pentane–$Et_2O$ (98:2)], a mixture (6 mg) of compounds **10** and **11** (1:3 ratio); $\nu_{max}$(neat)/cm$^{-1}$ 1725, 1231, 1190, 1154 ($CO_2Me$) and 1037 (C–O–C); $m/z$ 334 ($M^+$, 13%), 279 ($M^+ - C_4H_7$, 3), 275 ($M^+ - CO_2Me$, 7), 259 ($M^+$ –

**Table 5** $^{13}C$ NMR chemical shifts[a] of compounds **8**, **9b** and **12–15**

| C | 8[c,d] | 9b[b] | 12[c,d] | 13b[b] | 14b[c] | 15a[c] | 15b[c] |
|---|---|---|---|---|---|---|---|
| 1 | 41.89 | 41.85 | 39.01 | 39.74 | 39.70 | 36.90 | 36.92 |
| 2 | 19.10 | 19.15 | 19.84 | 18.87[e] | 18.86[e] | 19.49 | 19.42 |
| 3 | 38.14 | 38.19 | 38.15 | 38.07 | 38.03 | 37.68 | 37.60 |
| 4 | 43.78 | 43.79 | 44.25 | 43.90 | 43.90 | 43.82 | 43.77 |
| 5 | 53.89 | 54.04 | 56.17 | 56.75 | 56.65 | 53.58 | 53.53 |
| 6 | 19.73 | 19.91 | 26.13 | 19.76[e] | 19.73[e] | 20.83 | 20.76 |
| 7 | 36.73 | 36.98 | 38.65 | 42.78 | 42.75 | 34.43 | 34.33 |
| 8 | 81.66 | 81.75 | 148.59 | 72.89 | 72.83 | 127.76 | 127.69 |
| 9 | 57.77 | 57.42 | 51.83 | 59.03 | 58.73 | 138.25 | 138.21 |
| 10 | 36.39 | 36.20 | 39.81 | 39.32 | 39.20 | 39.43 | 39.46 |
| 11 | 32.75 | 33.36 | 30.25 | 23.22 | 23.41 | 26.95 | 25.92 |
| 12 | 81.56 | 79.67 | 75.61 | 134.49 | 131.01 | 134.36 | 133.61 |
| 13 | 133.67 | 45.01 | 139.22 | 130.50 | 132.25 | 133.81 | 130.51 |
| 14 | 116.00 | 72.10 | 119.13 | 133.85 | 75.55 | 141.55 | 131.87 |
| 15 | 12.79 | 13.97 | 12.89 | 113.28 | 18.93 | 109.91 | 113.16 |
| 16 | 12.96 | 10.12 | 11.31 | 19.76 | 12.04 | 11.69 | 19.42 |
| 17 | 31.40 | 31.62 | 106.53 | 30.96 | 30.85 | 19.57 | 19.53 |
| 18 | 28.60 | 28.69 | 28.76 | 28.70 | 28.72 | 28.39 | 28.33 |
| 19 | 117.62 | 178.06 | 117.73 | 177.70 | 177.85 | 178.01 | 178.06 |
| 20 | 14.59 | 14.55 | 12.62 | 13.18 | 13.20 | 17.54 | 17.50 |
| $CO_2Me$ | 51.14 | 51.19 | 51.06 | 51.13 | 51.20 | 51.02 | 51.02 |
| 14-OCOMe | | 170.37 | | | 170.33 | | |
| 14-OCO*Me* | | 21.48 | | | 21.36 | | |

[a] δ-Values in ppm from $SiMe_4$ in $CDCl_3$ solution; assignments aided by DEPT pulse sequence. [b] 20 MHz. [c] 75 MHz. [d] Assignment from $^1H$–$^1H$ and $^1H$–$^{13}C$ correlation experiments. [e] These signals may be interchanged.

**Table 6** $^1H$ NMR [$^2H_5$]pyridine-induced chemical shifts for compounds **13b** and **14b**

| | δ([$^2H_5$]pyridine) − δ($CDCl_3$) (ppm) | |
|---|---|---|
| H | **13b** | **14b** |
| 12 | +0.23 | +0.24 |
| 14 | +0.18 | +0.28 |
| 15′ | +0.14 | |
| 15′ | +0.12 | |
| 4-Me | +0.06 | +0.05 |
| 8-Me | +0.23 | +0.22 |
| 10-Me | +0.37 | +0.35 |
| 13-Me | +0.13 | +0.07 |
| 14-Me | | +0.07 |
| $CO_2Me$ | −0.06 | −0.08 |
| 14-OAc | | 0.00 |

$CH_3$ − $HCO_2Me$, 4), 250 (17), 235 ($M^+$ − $C_4H_7$ − $C_2H_4O$, 100), 191 (27), 175 (235$^+$ − $HCO_2Me$, 78), 121 (97), 109 (53), 95 (46) and 55 (48); $^1H$ NMR data of compounds **10** and **11** in Table 3.

(d) Fraction D contained compound **12** (122 mg).

(e) Fraction E contained compound **3a** (420 mg).

Fraction F was acetylated with $Ac_2O$–pyridine and the product was chromatographed over silica gel (70–230 mesh) [hexane–$Et_2O$ (95:5)] to yield (f) methyl 14-acetoxylabda-8,12*E*-dien-19-oate **7b**; $^1H$ NMR data in Table 2; $^{13}C$ NMR data in Table 4; and (g) [hexane–$Et_2O$ (85:15)] methyl 8β-hydroxylabda-12*E*,14-dien-19-oate **13a** (25 mg); $^1H$ NMR data in Table 3.

(h) Fraction G contained 22 mg of methyl (8*S*,12*R*)-8,12-epoxy-14-hydroxylabdan-19-oate **9a**; $^1H$ NMR data in Table 2. Compound **9a** was converted by acetylation into compound **9b**.

(i) Fraction H (150 mg) contained methyl 8β,14-dihydroxylabd-12*E*-en-19-oate **14a**; $^1H$ NMR data in Table 3. Compound **14a** was acetylated with $Ac_2O$–pyridine to give compound **14b**.

*Oxymercuriation–Demercuriation of Methyl Labda-8(17),12E-dien-19-oate* **V**.—Compound **V** has been obtained by hydrogenation of compound **1** catalysed with Pd on $BaSO_4$ (5% Pd).[24] The OM–DM reaction sequence of **V** was carried out according to the general procedure described by Brown and Geoghegan.[6]

$Hg(OAc)_2$ (490 mg, 1.55 mmol), THF–water (3 $cm^3$–1 $cm^3$), **V** in THF [245 mg, (0.77 mmol) in 1 $cm^3$] oxymercuriation time 1 h, $NaBH_4$ in 3 mol $dm^{-3}$ NaOH: (30 mg in 3 $cm^3$), demercuriation time 1 h. An aliquot (242 mg) of crude reaction products was chromatographed over silica gel (70–230 mesh) (20 g) to give [hexane–$Et_2O$ (96:4)] compound **V** (30 mg), [hexane–$Et_2O$ (9:1)] a mixture of compounds **VII** and **VIII** (55 mg), and [hexane–$Et_2O$ (1:1)] compound **VI** (108 mg).

(a) Methyl (8*R*,13*R*)-8,13-epoxylabdan-19-oate **VII** and methyl (8*R*,13*S*)-8,13-epoxylabdan-19-oate **VIII**; crystallization of a mixture of these from MeOH deposited a solid 2:1 mixture, m.p. 78–90 °C; $[\alpha]_D$ +33.0° (*c* 0.99); $\nu_{max}$(KBr)/$cm^{-1}$ 1725, 1232, 1185, 1155 ($CO_2Me$); 1113 and 838 (C–O–C); *m*/*z* 321 ($M^+$ − $CH_3$, 7%), 307 ($M^+$ − $C_2H_5$, 33), 289 ($M^+$ − $C_2H_5$ − $H_2O$, 37), 247 ($M^+$ − $C_2H_5$ − $CO_2Me$, 17), 229 (247$^+$ − $H_2O$, 47), 121 (38), 55 (43) and 43 ($CH_3CO^+$, 100); $\delta_H$(80 MHz; $CDCl_3$) 0.61 (s, 10-Me in **VII** and **VIII**), 0.85 (t, *J* 7, 14-Me in **VIII**), 0.87 (t, *J* 7, 14-Me in **VII**), 1.09 (s, 3-Me in **VII** and **VIII**), 1.18 (s, 4-Me in **VII** and **VIII**), 1.27 (s, 8-Me in **VII** and **VIII**) and 3.64 (s, $CO_2Me$ in **VII** and **VIII**); $\delta_C$(75 MHz; $CDCl_3$) assignable values to compound **VII**: 39.46 (C-1), 19.13 (C-2), 38.18 (C-3), 43.87 (C-4), 56.84 (C-5), 21.54 (C-6), 43.51 (C-7), 74.46 (C-8), 57.19 (C-9), 37.35 (C-10), 15.49 (C-11), 36.92 (C-12), 73.52 (C-13), 33.37 (C-14), 9.00 (C-15), 29.56 (C-16), 23.70 (C-17), 28.59 (C-18), 177.77 (C-19), 13.19 (C-20) and 51.09 (C-21); assignable values to **VIII**: 39.46 (C-1), 19.13 (C-2), 38.18 (C-3), 43.87 (C-4), 56.84 (C-5), 21.41 (C-6), 42.98 (C-7), 74.16 (C-8), 57.77 (C-9), 37.35 (C-10), 15.55 (C-11), 37.89 (C-12), 72.94 (C-13), 35.80 (C-14), 8.00 (C-15), 27.40 (C-16), 24.75 (C-17), 28.59 (C-18), 177.77 (C-19), 13.25 (C-20) and 51.09 (C-21).

(b) Methyl 13ξ-hydroxylabd-8(17)-en-19-oate **VI**, oil, $[\alpha]_D$ +39.1° (*c* 1.34); $\nu_{max}$(neat)/$cm^{-1}$ 3430 and 1154 (tertiary OH);[20] 3080, 1642, 890 (C=$CH_2$); 1722, 1228, 1190 and 1154 ($CO_2Me$); $\delta_H$(80 MHz; $CDCl_3$) 0.52 (3 H, s, 10-Me), 0.88 (3 H, t, *J* 7, 14-Me), 1.15 (3 H, s, 13-Me), 1.18 (3 H, s, 4-Me), 3.61 (3 H, s, $CO_2Me$), 4.52 (1 H, br s, 17-H) and 4.85 (1 H, br s, 17-H′); $\delta_C$(20 MHz; $CDCl_3$) 39.21 (C-1), 19.98 (C-2), 38.30 (C-3),

**Table 7** Fractional atomic co-ordinates (Å) (esds in parentheses) for compound **4**

| Atom | *X/a* | *Y/b* | *Z/c* |
|---|---|---|---|
| O(1A) | 0.0712(4) | −0.3481(0) | 0.4570(4) |
| O(2A) | −0.0366(3) | −0.6323(8) | 0.1631(3) |
| O(3A) | −0.0826(3) | −0.4151(9) | 0.0730(3) |
| C(1A) | 0.0620(5) | −0.0431(11) | 0.2185(5) |
| C(2A) | 0.0232(6) | −0.0736(12) | 0.1289(5) |
| C(3A) | 0.0654(5) | −0.2309(13) | 0.0931(5) |
| C(4A) | 0.0628(5) | −0.4094(11) | 0.1405(5) |
| C(5A) | 0.0992(4) | −0.3741(11) | 0.2343(5) |
| C(6A) | 0.1020(6) | −0.5393(13) | 0.2903(6) |
| C(7A) | 0.1622(6) | −0.5062(13) | 0.3717(5) |
| C(8A) | 0.1424(5) | −0.3294(13) | 0.4143(5) |
| C(9A) | 0.1174(5) | −0.1694(11) | 0.3571(5) |
| C(10A) | 0.0598(5) | −0.2132(11) | 0.2743(4) |
| C(11A) | 0.0769(7) | −0.0433(15) | 0.4156(6) |
| C(12A) | 0.0784(6) | −0.1690(17) | 0.4917(6) |
| C(13A) | 0.1656(7) | −0.1744(19) | 0.5458(6) |
| C(14A) | 0.2134(6) | −0.2728(15) | 0.4853(5) |
| C(15A) | 0.1954(9) | 0.0149(24) | 0.5730(7) |
| C(16A) | 0.2647(11) | 0.0887(27) | 0.5676(9) |
| C(17A) | 0.1606(9) | −0.2865(25) | 0.6247(6) |
| C(18A) | 0.1171(5) | −0.5493(14) | 0.1057(5) |
| C(19A) | −0.0283(5) | −0.4805(12) | 0.1217(5) |
| C(20A) | −0.0317(5) | −0.2559(13) | 0.2827(5) |
| C(21A) | −0.1190(5) | −0.7133(13) | 0.1466(6) |
| O(1B) | 0.6751(3) | −0.1308(9) | 0.9410(3) |
| O(2B) | 0.5506(5) | −0.2684(13) | 0.6272(4) |
| O(3B) | 0.5999(6) | −0.5261(13) | 0.5898(5) |
| C(1B) | 0.6500(7) | −0.6865(14) | 0.8349(6) |
| C(2B) | 0.6348(8) | −0.7690(17) | 0.7489(9) |
| C(3B) | 0.5466(8) | −0.7349(17) | 0.7085(7) |
| C(4B) | 0.5206(6) | −0.5311(16) | 0.7023(6) |
| C(5B) | 0.5428(5) | −0.4404(13) | 0.7894(5) |
| C(6B) | 0.5241(5) | −0.2404(13) | 0.7948(5) |
| C(7B) | 0.5261(5) | −0.1781(13) | 0.8830(5) |
| C(8B) | 0.6021(4) | −0.2434(13) | 0.9423(5) |
| C(9B) | 0.6339(5) | −0.4320(12) | 0.9284(5) |
| C(10B) | 0.6326(5) | −0.4868(12) | 0.8356(5) |
| C(11B) | 0.7234(5) | −0.4157(16) | 0.9821(5) |
| C(12B) | 0.7275(5) | −0.2203(15) | 1.0084(5) |
| C(13B) | 0.6797(5) | −0.1857(13) | 1.0808(5) |
| C(14B) | 0.5896(5) | −0.2238(13) | 1.0340(5) |
| C(15B) | 0.7112(6) | −0.2989(18) | 1.1550(7) |
| C(16B) | 0.6743(9) | −0.4036(27) | 1.1926(9) |
| C(17B) | 0.6901(7) | 0.0137(17) | 1.1064(7) |
| C(18B) | 0.4259(6) | −0.5067(20) | 0.6702(6) |
| C(19B) | 0.5642(7) | −0.4471(18) | 0.6344(6) |
| C(20B) | 0.6998(5) | −0.3846(14) | 0.7973(5) |
| C(21B) | 0.5861(11) | −0.1757(24) | 0.5629(7) |

44.34 (C-4), 56.83* (C-5), 26.30 (C-6), 38.83 (C-7), 148.24 (C-8), 56.43* (C-9), 40.57 (C-10), 17.78 (C-11), 40.57 (C-12), 73.20 (C-13), 34.13, 34.44 (C-14), 8.20 (C-15), 26.30 (C-16), 106.40 (C-17), 28.82 (C-18), 177.72 (C-19), 12.57 (C-20) and 51.08 (C-21).

* Interchangeable signals.

### X-Ray Crystal Structure Determination of Compound 4

## Discussion

Both molecules, A and B, in the asymmetric unit are closely similar as regards bond lengths, bond angles, and torsion angles. The conformation of the molecule can be described by means of the torsion angles. The six-membered rings A and B have the chair conformation; ring A exhibits torsion angles of −51° to 57° and ring B of −40° to 66°. This more distorted chair conformation for ring B may result from the fusion with ring C, which presents a boat conformation with torsion angles between 6°/8° and 80°, as expected from the presence of the intraannular oxygenated ring. The ring fusions A/B and B/C are *trans*. The molecule is not planar since the angle between rings A and B is 15°, and that between rings B and C is 35°. There are no intermolecular distances between non-H atoms of less than 3.2 Å.

## Experimental

*Crystal Data.*—$C_{21}H_{32}O_3$, M = 332.48. Monoclinic, $a$ = 16.216(3), $b$ = 7.386(1), $c$ = 16.410(4) Å, β = 99.77(2)°, $V$ = 1936.9(7) Å$^3$. Accurate cell dimensions were determined by least-squares analysis of setting angles of 28 reflections ($10° < \theta < 34°$), using graphite-monochromated Cu-Kα radiation ($\lambda$ = 1.5418 Å), space group $P2_1$, $Z$ = 4, $D_c$ = 1.1401 g cm$^{-3}$. Crystal dimensions 0.20 × 0.30 × 0.28 mm; μ(Cu-Kα) = 5.508 cm$^{-1}$.

*Data Collection and Processing.*—Philips PW 1100 diffractometer $\omega/2\theta$ mode, ω scan width = 1.5, scan speed 0.05, detector aperturer 1 × 1, 1 min ref$^{-1}$, two reflections were measured every 90 reflections to ascertain crystal stability; no significant variation was observed. Graphite-monochromated Cu-Kα radiation; 3581 reflections measures ($2° < \theta < 65°$), 2230 unique reflections with $I > 2\sigma(I)$. All reflections were corrected for Lorentz and polarization effects, but no absorption correction was applied.

*Structure Analysis and Refinement.*—Direct methods, MULTAN[25] and DIRDIF[26] revealed part of the molecule, the remaining non-H atoms by difference Fourier technique. Non-H atoms were refined anisotropically by full-matrix least-squares procedures (in one block). H-Atoms were located by difference Fourier synthesis, but those from methyl groups and C-15, C-16 were positioned at calculated positions (the temperature factors for these atoms are quite large); all H-atoms were considered as fixed contributors, their thermal parameters were set at $U_{iso}$ of the attached atom. Maximum peak height in final difference map was 0.24 e Å$^{-3}$. Final $R$ and $R_w$-values were 0.076 and 0.087. An empirical weighting scheme was applied so as to give no dependence of $<w\Delta^2F>$ *vs.* $<F_o>$ and $<\sin\theta/\lambda>$. Programs used and sources of scattering factor data are given in ref. 27. Calculations were performed on a VAX 6410 computer. The absolute configuration was not determined by the crystallographic analysis as it was fixed by chemical synthesis, the two crystallographically independent molecules having the same configuration. Fractional co-ordinates are listed in Table 7. Tables of bond lengths and bond angles, theremal parameters, and the hydrogen co-ordinates are available on request from the CCDC.†

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† For details, see Instructions for Authors (1991), *J. Chem. Soc., Perkin Trans. 1*, 1991, Issue 1.

## References

1 A. F. Barrero, J. F. Sánchez and J. Altarejos, *Tetrahedron Lett.*, 1988, **29**, 3713.
2 A. F. Barrero, A. Ramírez, S. Salido and J. Altarejos, *An. Quim.*, 1990, **86**, 786.
3 H. C. Brown, P. J. Geoghegan, Jr., G. J. Lynch and J. T. Kurek, *J. Org. Chem.*, 1972, **37**, 1941.
4 A. J. Bloodworth, M. G. Hutchings and A. J. Sotowicz, *J. Chem. Soc., Chem. Commun.*, 1976, 578.

5 J. Barluenga, J. Pérez-Prieto and G. Asensio, *J. Chem. Soc., Perkin Trans. 1*, 1984, 629.
6 H. C. Brown and P. J. Geoghegan, Jr., *J. Am. Chem. Soc.*, 1967, **89**, 1522.
7 A. F. Barrero, R. Quintana and J. Altarejos, unpublished work.
8 R. Wells and W. Kitching, *Tetrahedron Lett.*, 1963, 1531.
9 F. Bohlmann and J. Jakupovic, *Phytochemistry*, 1979, **18**, 1987.
10 M. Suzuki, E. Kurosawa and K. Kurata, *Phytochemistry*, 1988, **27**, 1209.
11 R. A. Bell, M. B. Gravestok and V. Y. Taguchi, *Can. J. Chem.*, 1975, **53**, 2869.
12 A. Horeau, *Tetrahedron Lett.*, 1961, 506; A. Horeau and H. B. Kagan, *Tetrahedron*, 1964, **20**, 2431.
13 N. S. Bhacca and D. H. Williams, *Applications of NMR Spectroscopy in Organic Chemistry. Illustrations from the Steroid Field*, Holden-Day, San Franciso, 1966, p. 151; A. San Feliciano, M. Medarde, J. L. López, J. M. Miguel del Corral, P. Puebla and A. F. Barrero, *Phytochemistry*, 1988, **27**, 2241.
14 B. L. Buckwalter, I. R. Burfitt, A. A. Nagel, E. Wenkert and F. Näf, *Helv. Chim. Acta*, 1975, **58**, 1567.
15 J. A. Turner and W. Herz, *J. Org. Chem.*, 1977, **42**, 1900.
16 A. F. Barrero, J. F. Sánchez and J. Altarejos, *Ars. Pharmaceutica*, 1987, **28**, 449.
17 J. de Pascual Teresa, A. San Feliciano and A. F. Barrero, *An. Quim.*, 1973, **69**, 1065.
18 H. Becker, W. Berger, G. Domschke, E. Fanghänel, J. Faust, M. Fischer, F. Gentz, K. Gewald, R. Gluch, R. Mayer, K. Müller, D. Pavel, H. Schmidt, K. Schollberg, K. Schwetlick, E. Seiler and G. Zeppenfeld, *Organicum. Practical Handbook of Organic Chemistry*, Pergamon, Oxford, 1973, pp. 667–690.
19 L. Fieser and M. Fieser, *Reagents for Organic Synthesis*, Wiley, New York, 1967, vol. 1, p. 1030.
20 K. Nakanishi and P. H. Solomon, *Infrared Absorption Spectroscpy*, Holden-Day, San Francisco, 1977.
21 R. P. Quirk and R. E. Lea, *J. Am. Chem. Soc.*, 1976, **98**, 5973 and references cited therein.
22 G. M. Barrow and S. Searles, *J. Am. Chem. Soc.*, 1953, **75**, 1175.
23 C. R. Enzell and R. Ryhage, *Arkiv. Kemi.*, 1965, **23**, 367.
24 A. F. Barrero, J. F. Sánchez, J. E. Oltra, J. Altarejos, S. Salido and F. Vega, unpublished work.
25 P. Main, S. J. Fisque, S. E. Hull, L. Lessinger, G. Germain, J. P. Declercq and M. M. Woolfson, MULTAN 80, A System of Computing Programs for the Automatic Solution of Crystal Structure from X-Ray Diffraction Data, Universities of York, England and Louvain, Belgium, 1980.
26 P. T. Beurskens, W. P. Bosman, H. M. Doesburg, R. O. Gould, Th. E. M. Van Der Hark, P. A. J. Prick, J. H. Noordik, G. Beurskens, V. Parsthasarathy, H. J. Bruins Slot, R. C. Haltiwanger and J. M. M. Smits, DIRDIF System, Crystallography Laboratory, Toernooiveld, Nijmegen, The Netherlands, 1984.
27 J. M. Stewart, P. A. Machin, C. W. Dickinson, H. L. Ammon, H. Heck and H. Flack, The X-Ray 76 System, Tech. Rep. TR-446, Computer Science Center, University of Maryland, College Park, Maryland, 1976; International Tables for X-Ray Crystallography, Kynoch Press, Birmingham (present distributor D. Reidel, Dordrecht), 1974, vol. IV.

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