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The Synthesis of Ar-abietatrien-12,16-oxide and Its C-15 Epimer

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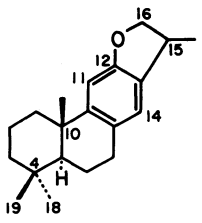
In order to elucidate the absolute configuration of C-15 in natural ar-abietatrien-12,16-oxide, (15*R*)-12,16-epoxy-8,11,13-abietatriene (**1a**) and its (15*S*)-epimer (**1b**) have been synthesized. Treatment of (15*R*)-8,11,13-abietatriene-12,16-diol with a mixture of chloromethyl methyl ether, dicyclohexano-18-crown-6, and potassium carbonate afforded **1a** as a minor product and (15*R*)-12-methoxymethyl ether as a major product. The latter was further converted into **1a**. A similar treatment of (15*S*)-8,11,13-abietatriene-12,16-diol gave **1b**. Catalytic hydrogenations of 12,16-epoxy-8,11,13,15-abietatetraene, methyl 12,16-epoxy-8,11,13,15-abietatetraen-19-oate (**5**), and methyl 12,16-epoxy-8,11,13,15-abietatetraen-18-oate (**7**) afforded the corresponding (15*R*)-dihydrobenzofuran derivatives and their (15*S*)-epimers. Conversions of the hydrogenation products from **5** and **7** into **1a** and **1b** were also carried out. The synthetic **1a** was identical with natural ar-abietatrien-12,16-oxide.

The two new abietane-type diterpenes, ar-abietatrien-12,16-oxide and 16-hydroxyferruginol, have been isolated from the seed of *Thujopsis dolabrata* Sieb. et Zucc. var. *dolabrata* by Hasegawa and Hirose.[1] On the basis of chemical and spectroscopic studies they deduced the structures of ar-abietatrien-12,16-oxide and 16-hydroxyferruginol to be 12,16-epoxy-8,11,13-abietatriene (**1**) and 8,11,13-abietatriene-12,16-diol (**2**), respectively. However, the absolute configurations of C-15 in both natural compounds remained unsettled. On the other hand, in the course of the synthetic work of coleon C tri-*O*-methyl ether (**3**) Burnell et al.[2] carried out the conversion of 12,16-epoxy-8,11,13,15-abietatetraene (**4**)[3] into a mixture of the C-15 epimeric dihydrobenzofuran derivatives (**1a** and **1b**) by catalytic hydrogenation. Although this mixture could not be separated at this stage, they assigned the stereochemistry of C-15 in the major product to be R-configuration from an examination of molecular models; that is, the hydrogenation is selectively from the convex β-face of **4**. The same assignment[4] was also reported on the catalytic hydrogenation products of methyl 12,16-epoxy-8,11,13,15-abietatetraen-19-oate (**5**).[5] However, it seems to be necessary to confirm the stereochemistry of the catalytic hydrogenation of these benzofuran derivatives by unambiguous methods. In a previous paper,[6] we reported the total syntheses of (15*R*)-8,11,13-abietatriene-12,16-diol (**2a**) and its (15*S*)-epimer (**2b**); synthetic **2a** was shown to be identical with natural 16-hydroxyferruginol. In order to elucidate the absolute configuration of C-15 in natural ar-abietatrien-12,16-oxide we have now attempted syntheses of the C-15 epimeric 12,16-epoxy-8,11,13-abietatrienes (**1a** and **1b**). This paper describes the syntheses of **1a** and **1b** starting from methyl 12-methoxy-8,11,13-abietatrien-18-oate (**6**),[7] and the stereochemistries of the catalytic hydrogenations of three benzofuran derivatives, **4**, **5**, and methyl 12,16-epoxy-8,11,13,15-abietatetraen-18-oate (**7**).



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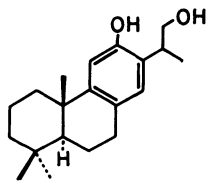

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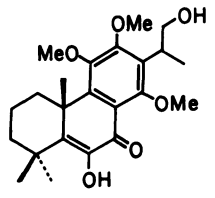

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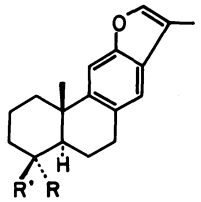


4 R=R'=Me
5 R=Me, R'=CO_2Me
7 R=CO_2Me, R'=Me

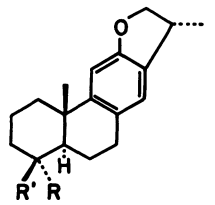
Reduction of **6** with lithium aluminium hydride in ether, followed by tosylation of the resulting alcohol **8** with *p*-toluenesulfonyl chloride in pyridine at 80—85 °C, afforded a tosylate **9**. This was treated with sodium iodide and zinc powder in *N*,*N*-dimethylformamide at 120—125 °C to give the corresponding 4,4-dimethyl compound **10** in 84.7% yield from **6**. According to the method of Akita and Oishi[8] with slight modifications, compound **10** was converted into 13-acetyl-8,11,13-podocarpatrien-12-ol (**11**: 4.2%) and its methyl ether (**12**: 74.5%) by a treatment with acetyl chloride and anhydrous aluminium chloride in dichloromethane at room temperature for 40 min. Demethylation of **12** with anhydrous aluminium chloride in refluxing dichloromethane afforded **11** (94.6%) which gave back **12** (88.2%) by methylation with methyl iodide and potassium *t*-butoxide in refluxing *t*-butyl alcohol. The acetyl methoxy compound **12** was further converted into (15*R*)-8,11,13-abietatriene-12,16-diol (**2a**) and its (15*S*)-epimer (**2b**) as reported in our previous papers.[9,10]

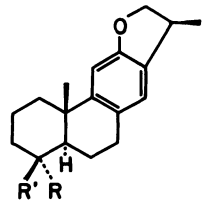
The (15*R*)-diol **2a** was then refluxed with a mixture

of chloromethyl methyl ether, dicyclohexano-18-crown-6, and anhydrous potassium carbonate in tetrahydrofuran–dichloromethane (1 : 1) to give (15*R*)-12,16-epoxy-8,11,13-abietatriene (**1a**: 10.3%) and 12-methoxymethyl ether (**13a**: 61.2%) along with small amounts of 16-methoxymethyl ether (**14a**: 8.5%) and 12,16-dimethoxymethyl ether (**15a**: 4.1%). The major product **13a** was mesylated with methanesulfonyl chloride in pyridine to give a mesylate **16a** which was converted into an iodide **17a** by refluxing with sodium iodide in ethyl methyl ketone. Hydrolysis of the methoxymethyl group in **17a** was carried out by refluxing with dilute hydrochloric acid in tetrahydrofuran; the resulting phenolic compound **18a** was cyclized with anhydrous potassium carbonate in refluxing ethyl methyl ketone to give the crystalline **1a**[11] in 60.2% yield from **13a**. Synthetic **1a** was identical with natural ar-abietatrien-12,16-oxide.

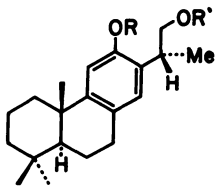
Similar methoxymethylation of (15*S*)-diol **2b** afforded (15*S*)-12,16-epoxy-8,11,13-abietatriene (**1b**: 8.4%), 12-methoxymethyl ether (**13b**: 60.1%), 16-methoxymethyl ether (**14b**: 10.3%), and 12,16-dimethoxymethyl ether (**15b**: 3.6%). The major product **13b** was further converted into an oily **1b** in 56.8% yield from **13b** via a mesylate **16b**, an iodide **17b**, and a phenol **18b**.

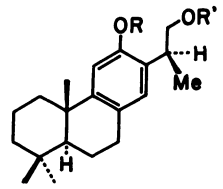
Subsequently, methyl 12,16-epoxy-8,11,13,15-abietatetraen-18-oate (**7**) was prepared as follows. Treatment of **6** with acetyl chloride and anhydrous aluminium chloride in dichloromethane at room temperature afforded three 13-acetyl compounds; **19** (15.9%), **20** (75.9%), and **21** (4.8%). Hydrolysis of **21** with dilute hydrochloric acid in refluxing ethanol produced **19** (97.9%), which was methylated to **20** (97.8%) by refluxing with methyl iodide and potassium *t*-butoxide in *t*-butyl alcohol. Demethylation of **20** with anhydrous aluminium chloride in refluxing dichloromethane afforded **19** (95.0%). The phenolic compound **19** was refluxed with ethyl bromoacetate and anhydrous potassium carbonate in ethyl methyl ketone, and the resulting ester **22** was then hydrolyzed with aqueous sodium hydroxide in refluxing ethanol to give the corresponding acid **23**.



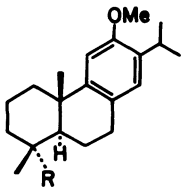


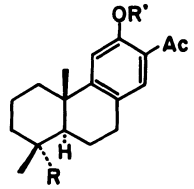
1a R=R'=Me **1b**
24a R=Me, R'=CO_2Me **24b**
25a R=Me, R'=CHO **25b**
26a R=CO_2Me, R'=Me **26b**



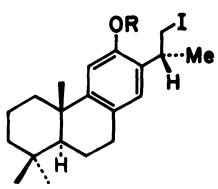


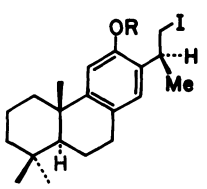
2a R=R'=H **2b**
13a R=CH_2OMe, R'=H **13b**
14a R=H, R'=CH_2OMe **14b**
15a R=R'=CH_2OMe **15b**
16a R=CH_2OMe, R'=Ms **16b**





6 R=CO_2Me
8 R=CH_2OH
9 R=CH_2OTs
10 R=Me
11 R=Me, R'=H
12 R=R'=Me
19 R=CO_2Me, R'=H
20 R=CO_2Me, R'=Me
21 R=CO_2Me, R'=Ac
22 R=CO_2Me, R'=CH_2CO_2Et
23 R=CO_2Me, R'=CH_2CO_2H





17a R=CH_2OMe **17b**
18a R=H **18b**

Table 1. Catalytic Hydrogenation of 12, 16-Epoxy-8, 11, 13, 15-abietatetraene Derivatives

Substrate	Condition		Product	
	Catalyst	Solvent[a]	(15R) : (15S)	Yield/%
4	10%Pd-C	AP	1 : 3	95
		A	1 : 4	91
		EA	1 : 5	93
	PtO_2	AP	2 : 3	74
		A	1 : 2	82
5	10%Pd-C	AP	1 : 5	97
		A	1 : 5	98
		EA	1 : 5	98
	PtO_2	AP	1 : 3	95
		A	1 : 3	91
7	10%Pd-C	AP	1 : 1	99
		A	2 : 3	97
		EA	1 : 2	96
	PtO_2	AP	1 : 1	92
		A	1 : 1	98

a) AP: AcOH+$HClO_4$, A: AcOH, EA: AcOEt

This was cyclized by refluxing with acetic anhydride and sodium acetate to yield **7** in 54.1% yield from **19**.

In order to ascertain the results of Burnell et al.[2,4] the catalytic hydrogenations of the three benzofuran derivatives **4**, **5**, and **7** were carried out at room temperature under an atmosphere of hydrogen. The conditions used and the results are summarized in Table 1. The ratio of the C-15 epimers was estimated by the intensities of doublet signals due to the C-15 methyls in the ^{1}H NMR spectrum[12] of the mixture. The hydrogenation mixture from **5** was separated by repeated column chromatography on silica gel and recrystallization to give the pure crystalline methyl (15*R*)-12,16-epoxy-8,11,13-abietatrien-19-oate (**24a**) and its (15*S*)-epimer (**24b**). The absolute configurations of C-15 in these epimers were determined by the following correlation. Reductions of **24a** and **24b** with lithium aluminium hydride in ether, followed by oxidation of the resulting alcohols with pyridinium chlorochromate in dichloromethane, afforded the corresponding aldehydes. These aldehydes, **25a** and **25b**, were converted, respectively, into the known **1a** and **1b** by Huang-Minlon reductions. The hydrogenation mixture from **7** was also separated to the pure methyl (15*R*)-12,16-epoxy-8,11,13-abietatrien-18-oate (**26a**) and its (15*S*)-epimer (**26b**), which were, respectively, converted into **1a** and **1b** by a series of reactions; reduction with lithium aluminium hydride in ether, tosylation with *p*-toluenesulfonyl chloride in pyridine, and treatment with sodium iodide and zinc powder in *N*,*N*-dimethylformamide. In the catalytic hydrogenations of **4** and **5** the major products were apparently the (15*S*)-epimers (**1b** and **24b**), but not the (15*R*)-epimers (**1a** and **24a**) as reported by Burnell et al.[2,4] The stereoselectivity can be explained as follows. Since the β-faces in these compounds are hindered by axial substituents at C-4 and C-10, hydrogen attacks predominantly the less hindered α-faces to give the (15*S*)-epimers as the major products. The less stereoselectivity of **7** is due to the presence of a bulky methoxycarbonyl group in the α-face; that is, the α-face approach of hydrogen is somewhat hindered by a methoxycarbonyl group. The hydrogenations over less active Pd-C catalyst were more stereoselective than those over more active PtO_2 catalyst.

From the present study, the stereochemistry of C-15 in natural ar-abietatrien-12,16-oxide was conclusively assigned as R-configuration.

Experimental

All melting points are uncorrected. The IR spectra and optical rotations were measured in chloroform, and the ^{1}H NMR spectra in carbon tetrachloride at 90 MHz with tetramethylsilane as an internal standard unless otherwise stated; s: singlet, bs: broad singlet, d: doublet, bd: broad doublet, dd: double doublet, t: triplet, m: multiplet. The column chromatography was performed using Merck silica gel (0.063 mm).

12-Methoxy-8,11,13-abietatriene (10). A solution of methyl 12-methoxy-8,11,13-abietatrien-18-oate (**6**)[7] (50.760 g) in dry ether (130 ml) was added dropwise to a stirred suspension of lithium aluminium hydride (3.635 g) in dry ether (180 ml) over a period of 20 min with cooling in an ice-water bath. The mixture was refluxed for 1 h. After the excess of lithium aluminium hydride had been decomposed with ethyl acetate, the mixture was poured into a mixture of ice and dilute hydrochloric acid, and extracted with ether. The ether extract was washed with brine, dried over sodium sulfate, and evaporated in vacuo to give 12-methoxy-8,11,13-abietatrien-18-ol (**8**) (47.547 g) which, without purification, was used in the next reaction.

A mixture of the crude **8** (47.547 g) and *p*-toluenesulfonyl chloride (33.710 g) in pyridine (200 ml) was heated at 80—85 °C for 3.5 h. The mixture was cooled, poured into a mixture of ice and dilute hydrochloric acid, and extracted with chloroform. The chloroform extract was washed with brine, dried over sodium sulfate, and evaporated in vacuo to give 12-methoxy-18-tosyloxy-8,11,13-abietatriene (**9**) (66.066 g) as a solid which, without purification, was used in the next reaction. The crude **9** obtained from another experiment was recrystallized from acetone-petroleum benzine, mp 147—149 °C. Found: C, 71.18; H, 7.97%. Calcd for $C_{28}H_{38}O_4S$: C, 71.45; H, 8.14%.

A stirred mixture of the crude **9** (66.066 g), sodium iodide (110.441 g), and zinc powder (48.170 g) in *N*,*N*-dimethylformamide (400 ml) was heated at 120—125 °C for 6 h. The mixture was cooled, diluted with benzene, and then filtered. The filtrate was poured into dilute hydrochloric acid and extracted with ether. The ether extract was washed successively with aqueous sodium thiosulfate and brine, dried over sodium sulfate, and evaporated in vacuo. The crude product was chromatographed on silica gel (350 g), using hexane-benzene (9:1) as eluent, to give **10** as an oil (37.481 g: 84.7% from **6**). ^{1}H NMR (60 MHz) δ=0.97 (6H, s, $-C(CH_3)_2$), 1.17 (6H, d, J=7 Hz, $-CH(CH_3)_2$), 1.18 (3H, s, $C_{10}-CH_3$), 3.75 (3H, s, $-OCH_3$), 6.58 (1H, s) and 6.69 (1H, s) (C_{11}-H and C_{14}-H). Found: C, 83.88; H, 10.84%. Calcd for $C_{21}H_{32}O$: C, 83.94; H, 10.73%.

13-Acetyl-8,11,13-abietatrien-12-ol (11) and 13-Acetyl-12-methoxy-8,11,13-abietatriene (12). Anhydrous aluminium chloride (10.982 g) was added to a stirred solution of **10** (12.373 g) and acetyl chloride (5.9 ml) in dichloromethane (80 ml) at 5—10 °C over a 10-min period. The mixture was further stirred at 5 °C for 10 min and at room temperature for 40 min, poured into a mixture of ice and dilute hydrochloric acid, and then extracted with ether. The ether extract was washed successively with aqueous sodium hydrogencarbonate and brine, dried, and evaporated in vacuo. The crude product was chromatographed on silica gel (250 g), using hexane-benzene (6:4) and ether-benzene (3:97) as eluents, to give **11** (0.500 g: 4.2%), mp 129—131 °C (from methanol), IR 1640 cm^{-1}, ^{1}H NMR (60 MHz) δ=2.52 (3H, s, $-COCH_3$), 6.73 (1H, s, C_{11}-H), 7.27 (1H, s, C_{14}-H), and **12** (9.222 g: 74.5%), mp 79—81 °C (from hexane), IR 1670 cm^{-1}, ^{1}H NMR (60 MHz) δ=2.48 (3H, s, $-COCH_3$), 3.86 (3H, s, $-OCH_3$), 6.72 (1H, s, C_{11}-H), 7.31 (1H, s, C_{14}-H). Anal. of **11**, Found: C, 79.51; H, 9.18%. Calcd for $C_{19}H_{26}O_2$: C, 79.68; H, 9.15%. Anal. of **12**, Found: C, 79.83; H, 9.53%.

Calcd for $C_{20}H_{28}O_2$: C, 79.95; H, 9.39%.

Demethylation of 12. A stirred mixture of **12** (2.240 g) and anhydrous aluminium chloride (1.988 g) in dichloromethane (25 ml) was refluxed for 2 h. The mixture was cooled, poured into dilute hydrochloric acid, and extracted with ether. The ether extract was washed with brine, dried, and evaporated in vacuo. The residue was chromatographed on silica gel (30 g), using benzene as eluent, to give **11** (2.019 g: 94.6%), mp 129—131 °C (from methanol).

Methylation of 11. A mixture of **11** (321 mg) and potassium *t*-butoxide (151 mg) in *t*-butyl alcohol (4.0 ml) was stirred at room temperature for 10 min. After the addition of methyl iodide (0.14 ml), the mixture was stirred at room temperature for 20 min and then refluxed for 2 h. The mixture was evaporated in vacuo, acidified with dilute hydrochloric acid, and extracted with ether. The ether extract was washed successively with water, aqueous sodium thiosulfate, and water. The dried solution was evaporated in vacuo. The residue was chromatographed on silica gel (10 g), using benzene as eluent, to give **12** (297 mg: 88.2%), mp 79—81 °C (from hexane).

Methoxymethylation of (15*R*)-8,11,13-Abietatriene-12,16-diol (2a). A mixture of **2a** (314.0 mg), dicyclohexano-18-crown-6 (54.9 mg), and anhydrous potassium carbonate (287.0 mg) in tetrahydrofuran–dichloromethane (1:1, 10 ml) was stirred at room temperature for 30 min. After the addition of chloromethyl methyl ether (0.16 ml), the mixture was refluxed for 3 h, cooled, and then diluted with ether. The ether solution was washed with brine, dried, and evaporated in vacuo. The residue was chromatographed on silica gel (30 g), using hexane–benzene (8:2) as eluent, to give (15*R*)-12,16-epoxy-8,11,13-abietatriene (**1a**) (30.4 mg: 10.3%), mp 54—56 °C (from ether), $[\alpha]_D$ +57.3° (*c* 0.89). Elution with ether–benzene (1:99) gave 12,16-dimethoxymethyl ether **15a** as an oil (16.5 mg: 4.1%) and 16-methoxymethyl ether **14a** as an oil (30.5 mg: 8.5%), IR 3600 and 3330 cm^{-1}. ^1H NMR ($CDCl_3$) of **15a** δ=0.91 (3H, s) and 0.93 (3H, s) (-C(CH$_3$)$_2$), 1.17 (3H, s, C_{10}-CH_3), 1.27 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.30 (3H, s, C_{16}-OCH_2OCH_3), 3.47 (3H, s, C_{12}-OCH_2OCH_3), 4.60 (2H, s, C_{16}-OCH_2O-), 5.13 (2H, s, C_{12}-OCH_2O-), 6.84 (1H, s) and 6.94 (1H, s) (C_{11}-H and C_{14}-H). ^1H NMR ($CDCl_3$) of **14a** δ=0.91 (3H, s) and 0.93 (3H, s) (-C(CH$_3$)$_2$), 1.17 (3H, s, C_{10}-CH_3), 1.31 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.30 (3H, s, C_{16}-OCH_2OCH_3), 4.63 (2H, s, C_{16}-OCH_2O-), 6.75 (1H, s) and 6.78 (1H, s) (C_{11}-H and C_{14}-H), 7.11 (1H, s, C_{12}-OH). Further elution with ether–benzene (1:9) gave 12-methoxymethyl ether **13a** (220 mg: 61.2%), $[\alpha]_D$ +66.6° (*c* 5.44), ^1H NMR ($CDCl_3$) δ=0.91 (3H, s) and 0.93 (3H, s) (-C(CH$_3$)$_2$), 1.17 (3H, s, C_{10}-CH_3), 1.23 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.47 (3H, s, C_{12}-OCH_2OCH_3), 3.69 (2H, bd, *J*=7 Hz, -CH_2OH), 5.14 (2H, s, C_{12}-OCH_2O-), 6.84 (1H, s) and 6.97 (1H, s) (C_{11}-H and C_{14}-H). Found: C, 76.18; H, 10.03%. Calcd for $C_{22}H_{34}O_3$: C, 76.26; H, 9.89%.

Methoxymethylation of (15*S*)-8,11,13-Abietatriene-12,16-diol (2b). A mixture of **2b** (283.0 mg), dicyclohexano-18-crown-6 (49.5 mg), anhydrous potassium carbonate (258.6 mg), and chloromethyl methyl ether (0.14 ml) in tetrahydrofuran–dichloromethane (1:1, 10.0 ml) was treated as described above. The crude product was chromatographed on silica gel to give four oily products, (15*S*)-12,16-epoxy-8,11,13-abietatriene (**1b**) (22.4 mg: 8.4%),$[\alpha]_D$ +60.7° (*c* 1.12), 12,16-dimethoxymethyl ether **15b** (13.2 mg: 3.6%), 16-methoxymethyl ether **14b** (33.4 mg: 10.3%), IR 3600 and 3330 cm^{-1}, and 12-methoxymethyl ether **13b** (194.7 mg: 60.1%), $[\alpha]_D$ +46.5°(*c* 4.59). Found: C, 76.42; H, 10.07%. Calcd for $C_{22}H_{34}O_3$: C, 76.26; H, 9.89%. ^1H NMR ($CDCl_3$) of **15b** δ=0.91 (3H, s) and 0.93 (3H, s) (-C(CH$_3$)$_2$), 1.17 (3H, s, C_{10}-CH_3), 1.24 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.30 (3H, s, C_{16}-OCH_2OCH_3), 3.47 (3H, s, C_{12}-OCH_2OCH_3), 4.60 (2H, s, C_{16}-OCH_2O-), 5.13 (2H, s, C_{12}-OCH_2O-), 6.84 (1H, s) and 6.94 (1H, s) (C_{11}-H and C_{14}-H). ^1H NMR ($CDCl_3$) of **14b** δ=0.92 (6H, s, -C(CH$_3$)$_2$), 1.17 (3H, s, C_{10}-CH_3), 1.31 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.30 (3H, s, C_{16}-OCH_2OCH_3), 4.63 (2H, s, C_{16}-OCH_2O-), 6.77 (1H, s) and 6.79 (1H, s) (C_{11}-H and C_{14}-H), 7.09 (1H, s, C_{12}-OH). ^1H NMR ($CDCl_3$) of **13b** δ=0.92 (6H, s, -C(CH$_3$)$_2$), 1.17 (3H, s, C_{10}-CH_3), 1.22 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.47 (3H, s, C_{12}-OCH_2OCH_3), 3.70 (2H, bd, *J*=7 Hz, -CH_2OH), 5.14 (2H, s, C_{12}-OCH_2O-), 6.84 (1H, s) and 6.97 (1H, s) (C_{11}-H and C_{14}-H).

Conversion of 13a into 1a. A mixture of **13a** (196 mg) and methanesulfonyl chloride (0.09 ml) in pyridine (1.5 ml) was heated at 75—80 °C for 2.5 h. The mixture was cooled, diluted with ether, and washed successively with dilute hydrochloric acid and brine. The dried solution was evaporated in vacuo to give a crude mesylate **16a** as an oil (225 mg), IR 1350 and 1170 cm^{-1}, ^1H NMR (60 MHz, $CDCl_3$) δ=0.96 (6H, s, -C(CH$_3$)$_2$), 1.18 (3H, s, C_{10}-CH_3), 1.35 (3H, d, *J*=7 Hz, C_{15}-CH_3), 2.84 (3H, s, -OSO_2CH_3), 3.49 (3H, s, -OCH_2OCH_3), 5.18 (2H, s, -OCH_2O-), 6.84 (1H. s) and 6.99 (1H, s) (C_{11}-H and C_{14}-H).

A mixture of the crude **16a** (225 mg) and sodium iodide (170 mg) in ethyl methyl ketone (5.0 ml) was refluxed for 4 h. The mixture was cooled, diluted with ether, and then washed successively with water, aqueous sodium thiosulfate, and brine. The dried solution was evaporated in vacuo to give a crude iodide **17a** (240 mg). ^1H NMR (60 MHz, $CDCl_3$) δ=0.95 (6H, s, -C(CH$_3$)$_2$), 1.18 (3H, s, C_{10}-CH_3), 3.48 (3H, s, -OCH_2OCH_3), 5.13 (2H, s, -OCH_2O-) 6.84 (1H, s) and 6.99 (1H, s) (C_{11}-H and C_{14}-H).

A mixture of the crude **17a** (240 mg) and dilute hydrochloric acid (15%: 0.2 ml) in tetrahydrofuran (5.0 ml) was refluxed for 3 h. The mixture was cooled, diluted with ether, and washed with brine. The dried solution was evaporated in vacuo to give a crude phenolic compound **18a** (234 mg), IR 3595 and 3325 cm^{-1}. ^1H NMR (60 MHz, $CDCl_3$) δ=0.96 (6H, s, -C(CH$_3$)$_2$), 1.17 (3H, s, C_{10}-CH_3), 1.39 (3H, d, *J*=6.5 Hz, C_{15}-CH_3), 6.61 (1H, s) and 6.79 (1H, s) (C_{11}-H and C_{14}-H).

A mixture of the crude **18a** (234 mg) and anhydrous potassium carbonate (600 mg) in ethyl methyl ketone (5.0 ml) was refluxed for 2.5 h. The mixture was cooled, diluted with water, and extracted with ether. The ether extract was washed with brine, dried, and evaporated in vacuo. The residue was chromatographed on silica gel (20 g), using hexane–benzene (3:1) as eluent, to give **1a** (97 mg: 60.2% from **13a**) which was recrystallized from ether, mp 54—56 °C, $[\alpha]_D$ +59.8° (*c* 3.33), IR (KBr) 1620, 1485, 1240, and 995 cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.91 (3H, s) and 0.93 (3H, s) (-C(CH$_3$)$_2$), 1.17 (3H, s, C_{10}-CH_3), 1.27 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.44 (1H, m, C_{15}-H), 3.98 (1H, dd, *J*=7

and 8 Hz) and 4.61 (1H, t, J=8 Hz) ($-CH_2O-$), 6.70 (1H, s) and 6.80 (1H, s) (C_{11}–H and C_{14}–H). Found: C, 84.64; H, 10.21%. Calcd for $C_{20}H_{28}O$: C, 84.45; H, 9.92%. The synthetic **1a** was identical with natural ar-abietatrien-12,16-oxide (lit,[1] mp 49—52 °C).

Conversion of 13b into 1b. A mixture of **13b** (195 mg) and methanesulfonyl chloride (0.09 ml) in pyridine (1.5 ml) was heated at 75—80 °C for 2.5 h to give a crude mesylate **16b** (230 mg), IR 1350 and 1170 cm^{-1}, ^{1}H NMR (60 MHz, $CDCl_3$) δ=0.97 (6H, s, $-\dot{C}(CH_3)_2$), 1.19 (3H, s, C_{10}–CH_3), 1.35 (3H, d, J=7 Hz, C_{15}–CH_3), 2.84 (3H, s, $-OSO_2CH_3$), 3.50 (3H, s, $-OCH_2OC\underline{H}_3$), 5.19 (2H, s, $-OCH_2O-$) 6.86 (1H, s) and 7.00 (1H, s) (C_{11}–H and C_{14}–H).

A mixture of the crude **16b** (230 mg) and sodium iodide (169 mg) in ethyl methyl ketone (5.0 ml) was refluxed for 4 h to give a crude iodide **17b** (240 mg), ^{1}H NMR (60 MHz, $CDCl_3$) δ=0.97 (6H, s, $-\dot{C}(CH_3)_2$), 1.19 (3H, s, C_{10}–CH_3), 3.50 (3H, s, $-OCH_2OC\underline{H}_3$), 5.18 (2H, s, $-OCH_2O-$), 6.81 (1H, s) and 6.98 (1H, s) (C_{11}–H and C_{14}–H).

The crude **17b** (240 mg) was hydrolyzed with dilute hydrochloric acid (15%: 0.2 ml) in refluxing tetrahydrofuran (5.0 ml) for 3 h to give a crude phenolic compound **18b** (227 mg), IR 3600 and 3325 cm^{-1}, ^{1}H NMR (60 MHz, $CDCl_3$) δ=0.95 (6H, s, $-\dot{C}(CH_3)_2$), 1.15 (3H, s, C_{10}–CH_3), 1.37 (3H, d, J=6.5 Hz, C_{15}–CH_3), 6.61 (1H, s) and 6.80 (1H, s) (C_{11}–H and C_{14}–H).

A mixture of the crude **18b** (227 mg) and anhydrous potassium carbonate (600 mg) in ethyl methyl ketone (5.0 ml) was refluxed for 2.5 h. The crude product was chromatographed on silica gel (30 g), using hexane–benzene (3:1) as eluent, to give an oily **1b** (91 mg: 56.8% from **13b**), $[\alpha]_D$ +61.3° (c 1.88), IR (KBr) 1620, 1485, 1240, and 995 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=0.92 (6H, s, $-\dot{C}(CH_3)_2$), 1.17 (3H, s, C_{10}–CH_3), 1.28 (3H, d, J=7 Hz, C_{15}–CH_3), 3.45 (1H, m, C_{15}–H), 3.98 (1H, dd, J=7 and 8 Hz) and 4.61 (1H, t, J=8 Hz) ($-CH_2O-$), 6.70 (1H, s) and 6.80 (1H, s) (C_{11}–H and C_{14}–H). Found: C, 84.42; H, 10.21%. Calcd for $C_{20}H_{28}O$: C, 84.45; H, 9.92%.

Conversion of Methyl 12-Methoxy-8,11,13-abietatrien-18-oate (6) into 13-Acetyl Derivatives 19, 20, and 21. Anhydrous aluminium chloride (1.463 g) was added to a stirred solution of **6**[7] (1.260 g) and acetyl chloride (0.52 ml) in dichloromethane (10 ml) at 6—9 °C over a 7 min period. After stirring at this temperature for 13 min and at room temperature for 40 min, the mixture was poured into a mixture of ice and dilute hydrochloric acid, and then extracted with ether. The ether extract was washed with brine, dried, and evaporated in vacuo. The residue was chromatographed on silica gel (30 g), using benzene as eluent, to give methyl 13-acetyl-12-hydroxy-8,11,13-abietatrien-18-oate (**19**) (0.192 g: 15.9%) which was recrystallized from methanol, mp 154—155 °C, $[\alpha]_D$ +74.7° (c 5.25), IR 1723 and 1640 cm^{-1}. ^{1}H NMR (60 MHz) δ=1.20 (3H, s) and 1.23 (3H, s) (C_4–CH_3 and C_{10}–CH_3), 2.52 (3H, s, $-COCH_3$), 3.63 (3H, s, $-CO_2CH_3$), 6.70 (1H, s, C_{11}–H), 7.27 (1H, s, C_{14}–H), 11.77 (1H, s, C_{12}–OH). Found: C, 72.49; H, 8.24%. Calcd for $C_{20}H_{26}O_4$: C, 72.70; H, 7.93%.

Elution with ether–benzene (1:99) afforded methyl 13-acetyl-12-methoxy-8,11,13-abietatrien-18-oate (**20**) (0.956 g: 75.9%) which was recrystallized from hexane, mp 86—87 °C, $[\alpha]_D$ +62.0° (c 4.32), IR 1721 and 1670 cm^{-1}, ^{1}H NMR (60 MHz) δ=1.19 (3H, s) and 1.22 (3H, s) (C_4–CH_3 and C_{10}–CH_3), 2.44 (3H, s, $-COCH_3$), 3.61 (3H, s, $-CO_2CH_3$), 3.83 (3H, s, $-OCH_3$), 6.67 (1H, s, C_{11}–H), 7.26 (1H, s, C_{14}–H).

Further elution with ether–benzene (5:95) afforded methyl 12-acetoxy-13-acetyl-8,11,13-abietatrien-18-oate (**21**) (0.066 g: 4.8%) which was recrystallized from acetone-hexane, mp 107—108 °C, $[\alpha]_D$ +71.7° (c 3.78), IR 1757, 1716, and 1680 cm^{-1}; ^{1}H NMR (60 MHz) δ=1.21 (3H, s) and 1.24 (3H, s) (C_4–CH_3 and C_{10}–CH_3), 2.23 (3H, s, $-OCOCH_3$), 2.40 (3H, s, $-COCH_3$), 3.62 (3H, s, $-CO_2CH_3$), 6.78 (1H, s, C_{11}–H), 7.34 (1H, s, C_{14}–H). Found: C, 71.07; H, 7.64%. Calcd for $C_{22}H_{28}O_5$: C, 70.94; H, 7.58%.

Hydrolysis of 21. A solution of **21** (2.587 g) and dilute hydrochloric acid (15%: 2.5 ml) in ethanol (20 ml) was refluxed for 1.5 h. After the usual work-up, the crude product was recrystallized from methanol to give **19** (2.248 g: 97.9%), mp 154—155 °C.

Methylation of 19. A mixture of **19** (5.148 g) and potassium t-butoxide (2.098 g) in t-butyl alcohol (60 ml) was stirred for 10 min. After the addition of methyl iodide (1.92 ml), the stirred mixture was refluxed for 2 h, and then treated as described above. The crude product was chromatographed on silica gel (35 g), using ether–benzene (5:95) as eluent, to give **20** (5.248 g: 97.8%), mp 86—87 °C (from hexane).

Demethylation of 20. A stirred mixture of **20** (200 mg) and anhydrous aluminium chloride (271 mg) in dichloromethane (4.0 ml) was refluxed for 3 h. After the work-up, as described above, the crude product was chromatographed on silica gel (10 g), using benzene as eluent, to give **19** (182 mg: 95.0%), mp 154—155 °C (from methanol).

Methyl 12,16-Epoxy-8,11,13,15-abietatetraen-18-oate (7). A mixture of **19** (4.00 g), ethyl bromoacetate (2.29 ml), and anhydrous potassium carbonate (10.0 g) in ethyl methyl ketone (30 ml) was refluxed for 8 h. The mixture was cooled, diluted with ether, and washed successively with water, aqueous sodium thiosulfate, and water. The dried solution was evaporated in vacuo to give a crude ester **22** (5.82 g), IR 1725 and 1665 cm^{-1}, ^{1}H NMR (60 MHz) δ=1.18 (3H, s, C_{10}–CH_3), 1.22 (3H, s, C_4–CH_3), 1.28 (3H, t, J=7 Hz, $-CO_2CH_2C\underline{H}_3$), 2.55 (3H, s, $-COCH_3$), 3.61 (3H, s, $-CO_2CH_3$), 4.18 (2H, q, J=7 Hz, $-CO_2C\underline{H}_2CH_3$), 4.61 (2H, s, $-OCH_2CO_2-$), 6.64 (1H, s, C_{11}–H), 7.29 (1H, s, C_{14}–H).

The crude **22** (5.82 g) was hydrolyzed with aqueous sodium hydroxide (10%: 10 ml) in refluxing ethanol (20 ml) for 1 h. The mixture was evaporated in vacuo, acidified with dilute hydrochloric acid, and extracted with chloroform. The chloroform extract was washed with brine, dried, and evaporated in vacuo to give a crude acid **23** (5.01 g), IR 3500—2400, 1720, and 1660 cm^{-1}; ^{1}H NMR (60 MHz, $CDCl_3$) δ=1.21 (3H, s) and 1.29 (3H, s) (C_4–CH_3 and C_{10}–CH_3), 2.65 (3H, s, $-COCH_3$), 3.68 (3H, s, $-CO_2CH_3$), 4.72 (2H, s, $-OC\underline{H}_2CO_2H$), 6.78 (1H, s, C_{11}–H), 7.42 (1H, s, C_{14}–H), 10.32 (1H, bs, $-CO_2H$).

A mixture of the crude **23** (5.01 g) and sodium acetate (9.0 g) in acetic anhydride (20 ml) was refluxed for 7.5 h. The mixture was cooled, diluted with ether, and washed successively with water, aqueous sodium hydrogencarbonate, and water. The dried solution was evaporated in vacuo to give the crude benzofuran derivative (1.70 g). The alkaline washing was acidified with dilute hydrochloric acid, and extracted with chloroform. The chloroform extract was washed with brine, dried, and evaporated in

vacuo to give the recovered **23** (3.00 g). This was also submitted to cyclization to give the crude benzofuran derivative (1.04 g) and the recovered **23** (1.40 g). The combined crude benzofuran derivative was chromatographed on silica gel (30 g), using benzene as eluent, to give **7** (2.14 g: 54.1%) which was recrystallized from hexane, mp 123.5—124 °C, $[\alpha]_D$ +68.6° (*c* 9.50), IR 1721 cm^{-1}, ^1H NMR (60 MHz, $CDCl_3$) δ=1.23 (3H, s) and 1.30 (3H, s) (C_4-CH_3 and C_{10}-CH_3), 2.17 (3H, d, *J*=1 Hz, C_{15}-CH_3), 3.67 (3H, s, -CO_2CH_3), 7.12 (1H, s) and 7.29 (1H, s) (C_{11}-H and C_{14}-H), 7.24 (1H, m, overlap, C_{16}-H). Found: C, 77.21; H, 8.17%. Calcd for $C_{21}H_{26}O_3$:C, 77.27; H, 8.03%.

Catalytic Hydrogenation of 12,16-Epoxy-8,11,13,15-abietatetraene Derivatives 4, 5, and 7. a) A mixture of 12,16-epoxy-8,11,13,15-abietatetraene (**4**)[3] (303 mg) and 10% Pd-C (100 mg) in acetic acid (10 ml) containing four drops of 70% perchloric acid was hydrogenated at room temperature under an atmosphere of hydrogen for 7 h. After the usual work-up, the crude product was chromatographed on silica gel (20 g), using hexane–benzene (8:2) as eluent, to give a mixture (1:3) of (15*R*)-12,16-epoxy-8,11,13-abietatriene (**1a**) and its (15*S*)-epimer (**1b**) (291 mg: 95.4%).

b) A mixture of methyl 12,16-epoxy-8,11,13,15-abietatetraen-19-oate (**5**)[5] (100 mg: mp 130—131.5 °C) and PtO_2 (20 mg) in acetic acid (10 ml) was hydrogenated at room temperature under an atmosphere of hydrogen for 35 min. After the usual work-up, the crude product was chromatographed on silica gel (10 g), using benzene as eluent, to give a mixture (1:3) of methyl (15*R*)-12,16-epoxy-8,11,13-abietatrien-19-oate (**24a**) and its (15*S*)-epimer (**24b**) (91 mg: 90.7%). This mixture was separated by repeated column chromatography on silica gel using hexane–benzene (1:1) as eluent and recrystallization to give **24a**, mp 160—162 °C (from hexane), $[\alpha]_D$ +128.1° (*c* 0.96), and **24b**, mp 150—151.5 °C (from hexane), $[\alpha]_D$ +132.4° (*c* 3.70). Anal. of **24a**, Found: C, 76.63; H, 8.77%. Calcd for $C_{21}H_{28}O_3$: C, 76.79; H, 8.59%. Anal of **24b**, Found: C, 76.81; H, 8.81%. Calcd for $C_{21}H_{28}O_3$:C, 76.79; H, 8.59%. ^1H NMR ($CDCl_3$) of **24a** δ=1.01 (3H, s, C_{10}-CH_3), 1.25 (3H, s, C_4-CH_3), 1.27 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.64 (3H, s, -CO_2CH_3), 3.99 (1H, dd, *J*=7 and 8 Hz) and 4.62 (1H, t, *J*=8 Hz) (-OCH_2-), 6.67 (1H, s) and 6.79 (1H, s) (C_{11}-H and C_{14}-H). ^1H NMR ($CDCl_3$) of **24b** δ=1.01 (3H, s, C_{10}-CH_3), 1.25 (3H, s, C_4-CH_3), 1.28 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.64 (3H, s, -CO_2CH_3), 3.99 (1H, dd, *J*=7 and 8 Hz) and 4.62 (1H, t, *J*=8 Hz) (-OCH_2-), 6.67 (1H, s) and 6.79 (1H, s) (C_{11}-H and C_{14}-H).

c) A mixture of **7** (100 mg) and 10% Pd-C (30 mg) in ethyl acetate (10 ml) was hydrogenated at room temperature under an atmosphere of hydrogen for 6.5 h. After the usual work-up, the crude product was chromatographed on silica gel (10 g), using benzene as eluent, to give a mixture (1:2) of methyl (15*R*)-12,16-epoxy-8,11,13-abietatrien-18-oate (**26a**) and its (15*S*)-epimer (**26b**) (97 mg: 96.3%). This mixture was separated by repeated column chromatography on silica gel using hexane–benzene (4:6) as eluent and recrystallization to give **26a**, mp 142.5—143.5 °C (from hexane), $[\alpha]_D$ +63.7° (*c* 3.33), and **26b** as an oil, $[\alpha]_D$ +56.3° (*c* 2.90). ^1H NMR ($CDCl_3$) of **26a** δ=1.17 (3H, s) and 1.25 (3H, s) (C_4-CH_3 and C_{10}-CH_3), 1.27 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.66 (3H, s, -CO_2CH_3), 3.99 (1H, dd, *J*=7 and 8 Hz) and 4.62 (1H, t, *J*=8 Hz) (-OCH_2-), 6.67 (1H, s) and 6.78 (1H, s) (C_{11}-H and C_{14}-H). ^1H NMR ($CDCl_3$) of **26b** δ=1.17 (3H, s) and 1.25 (3H, s) (C_4-CH_3 and C_{10}-CH_3), 1.28 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.66 (3H, s, -CO_2CH_3), 3.99 (1H, dd, *J*=7 and 8 Hz) and 4.62 (1H, t, *J*=8 Hz) (-OCH_2-), 6.67 (1H, s) and 6.78 (1H, s) (C_{11}-H and C_{14}-H). Anal of **26a**, Found: C, 76.84; H, 8.80%. Calcd for $C_{21}H_{28}O_3$: C, 76.79; H, 8.59%. Anal. of **26b**, Found: C, 76.75; H, 8.74%. Calcd for $C_{21}H_{28}O_3$: C, 76.79; H, 8.59%. The other hydrogenations were summarized in Table 1.

(15*R*)-12,16-Epoxy-8,11,13-abietatrien-19-al (25a) and Its (15*S*)-Epimer (25b). a) A suspension of **24a** (128.0 mg) and lithium aluminium hydride (14.8 mg) in dry ether (5.0 ml) was stirred at room temperature for 1 h and then refluxed for 20 min. The mixture was poured into dilute hydrochloric acid and extracted with ether. The ether extract was washed with water, dried, and evaporated in vacuo to give a crude alcohol (120.0 mg).

A mixture of the crude alcohol (120.0 mg) and pyridinium chlorochromate (126.0 mg) in dichloromethane (5.0 ml) was stirred at room temperature for 1.5 h. After the addition of ether and aqueous sodium hydrogencarbonate, the mixture was extracted with ether. The ether extract was washed successively with aqueous sodium hydrogencarbonate and water, dried, and evaporated in vacuo. The residue was chromatographed on silica gel (10 g), using benzene as eluent, to give **25a** (94.4 mg: 81.2%) which was recrystallized from ethanol, mp 150—152 °C, $[\alpha]_D$ +89.4° (*c* 1.23), IR 2730 and 1716 cm^{-1}, ^1H NMR (60 MHz, $CDCl_3$) δ=1.03 (3H, s) and 1.09 (3H, s) (C_4-CH_3 and C_{10}-CH_3), 1.27 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.2—3.7 (1H, m, C_{15}-H), 3.97 (1H, dd, *J*=7 and 8 Hz) and 4.60 (1H, t, *J*=8 Hz) (-OCH_2-), 6.68 (1H, s) and 6.81 (1H, s) (C_{11}-H and C_{14}-H), 9.81 (1H, d, *J*=1.5 Hz, -CHO). Found: C, 80.51; H, 8.73%. Calcd for $C_{20}H_{26}O_2$: C, 80.49; H, 8.78%.

b) A suspension of **24b** (498.0 mg) and lithium aluminium hydride (57.5 mg) in dry ether (7.0 ml) was stirred at room temperature for 1 h and then refluxed for 20 min. The crude alcohol (503.0 mg) was immediately oxidized with pyridinium chlorochromate (490.3 mg) in dichloromethane (5.0 ml) at room temperature for 1.5 h. After the work-up, as described in **a)**, the crude product was chromatographed on silica gel (15 g), using benzene as eluent, to give **25b** (334.0 mg: 73.8%) which was recrystallized from ethanol, mp 138—140 °C, $[\alpha]_D$ +94.4° (*c* 3.13), IR 2730 and 1712 cm^{-1}, ^1H NMR (60 MHz, $CDCl_3$) δ=1.06 (3H, s) and 1.10 (3H, s) (C_4-CH_3 and C_{10}-CH_3), 1.30 (3H, d, *J*=7 Hz, C_{15}-CH_3), 3.2—3.7 (1H, m, C_{15}-H), 3.97 (1H, dd, *J*=7 and 8 Hz) and 4.60 (1H, t, *J*=8 Hz) (-OCH_2-), 6.65 (1H, s) and 6.78 (1H, s) (C_{11}-H and C_{14}-H), 9.78 (1H, d, *J*=1.5 Hz, -CHO). Found: C, 80.28; H, 9.00%. Calcd for $C_{20}H_{26}O_2$: C, 80.49; H, 8.78%.

Conversion of 25a into 1a. A mixture of **25a** (82.6 mg) and 80% hydrazine hydrate (0.42 ml) in diethylene glycol (4.0 ml) was refluxed for 2.5 h and powdered sodium hydroxide (443 mg) was then added. The mixture was heated at 185—190 °C for 3 h, cooled, diluted with water, and extracted with ether. The ether extract was washed with water, dried, and evaporated in vacuo. The residue was chromatographed on silica gel (10 g), using hexane–benzene (85:15) as eluent, to give **1a** (32.8 mg: 41.7%), mp 53—55 °C (from ether), $[\alpha]_D$ +58.0° (*c* 0.81).

Conversion of 25b into 1b. A mixture of **25b** (291.0 mg) and 80% hydrazine hydrate (1.8 ml) in diethylene glycol (10 ml) was refluxed for 2.5 h and powdered sodium

hydroxide (1.560 g) was then added. The mixture was heated at 185—190 °C for 3 h. The crude product was chromatographed on silica gel (10 g), using hexane–benzene (7:3) as eluent, to give **1b** as an oil (139.9 mg: 50.4%), $[\alpha]_D$ +61.6° (*c* 4.39).

Conversion of 26a into 1a. A suspension of **26a** (334 mg) and lithium aluminium hydride (39 g) in dry ether (10 ml) was stirred at room temperature for 1.5 h. The mixture was poured into dilute hydrochloric acid and extracted with ether. The ether extract was washed with water, dried, and evaporated in vacuo to give a crude alcohol (343 mg).

The crude alcohol was tosylated with *p*-toluenesulfonyl chloride (388 mg) in pyridine (3.0 ml) at 95—100 °C for 5.5 h. The mixture was cooled, poured into dilute hydrochloric acid, and extracted with chloroform. The chloroform extract was washed with aqueous sodium hydrogencarbonate and water, dried, and evaporated in vacuo to give a crude tosylate (650 mg).

A mixture of the crude tosylate, sodium iodide (762 mg), and zinc powder (333 mg) in *N,N*-dimethylformamide (5.0 ml) was heated at 120—125 °C for 7 h. The mixture was cooled, poured into dilute hydrochloric acid, and extracted with ether. The ether extract was washed successively with water, aqueous sodium thiosulfate, and brine. The dried solution was evaporated in vacuo and the residue was chromatographed on silica gel (10 g), using hexane–benzene (85:15) as eluent, to give **1a** (241 mg: 83.3%) which was recrystallized from ether, mp 52—55 °C, $[\alpha]_D$ +59.7° (*c* 0.75).

Conversion of 26b into 1b. The ester **26b** (198 mg) was reduced with lithium aluminium hydride (23 mg) in dry ether (3.0 ml) at room temperature for 1 h to give a crude alcohol (208 mg).

The above alcohol was tosylated with *p*-toluenesulfonyl chloride (345 mg) in pyridine (2.0 ml) at 95—100 °C for 5.5 h to afford a crude tosylate (400 mg).

A mixture of the crude tosylate, sodium iodide (452 mg), and zinc powder (197 mg) in *N,N*-dimethylformamide (3.0 ml) was heated at 120—125 °C for 7 h. The crude product was purified by column chromatography on silica gel (10 g), using hexane–benzene (7:3) as eluent, to give **1b** as an oil (90 mg: 52.4%), $[\alpha]_D$ +59.4° (*c* 0.96).

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11) A personal communication from Professor Hirose informed us that the treatment of natural 16-hydroxyferruginol with *p*-toluenesulfonyl chloride in pyridine at room temperature for 39 h or in acetone in the presence of potassium carbonate, produced ar-abietatrien-12,16-oxide in 11 or 6% yields, respectively.

12) The ^{1}H NMR spectra (90 MHz) of the C-15 epimers were identical except doublet signals due to the C-15 methyls.