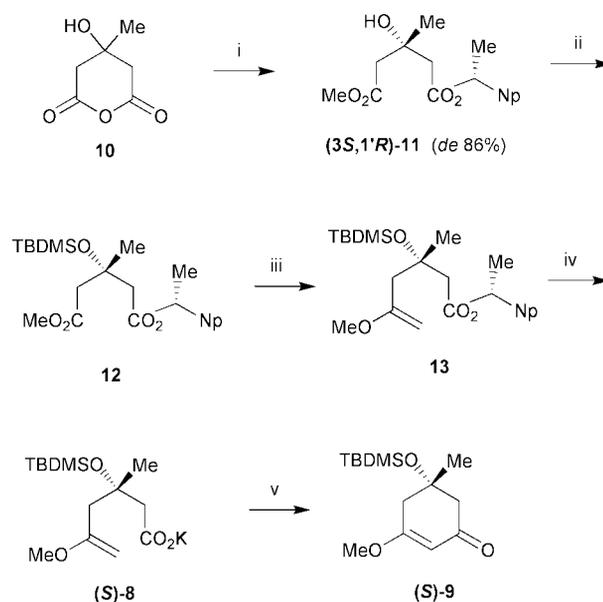


Scheme 2 Reagents and conditions: i, pig liver esterase, pH 8, 92%; ii, TBDMS-OTf, lutidine, CH₂Cl₂, 0→rt, 86%; iii, Tebbe reagent, THF, -78 °C, 30 min, then rt, 1 h, 61–85%; iv, aq. K₂CO₃, MeOH; v, Tf₂O, DMAP (each 10 equiv.), CH₂Cl₂, then (**R**)-**8**, -20 °C, 2 h, rt, 2 d, 40–80% over two steps.

butyldimethylsilyl (TBDMS) triflate¹⁸ yielded the TBDMS ester **6** with simultaneous protection of the tertiary hydroxy group.

The diester **6** was treated with one equivalent of Tebbe reagent.¹⁹ We were pleased to note that at -78 °C and on warming up to room temperature this reaction afforded only the desired enol ether **7** by reaction of the organometallic reagent with the less hindered methyl ester group. To our knowledge this is the first example of a regioselective diester olefination. Selective alkaline hydrolysis of the TBDMS ester with aqueous potassium carbonate²⁰ yielded the potassium salt (**R**)-**8**. The intramolecular cyclisation of the carboxylate salt (**R**)-**8** proved to be difficult. Thus, conversion of (**R**)-**8** into the corresponding acid chloride by the mild method of Ghosez *et al.*²¹ yielded none of the desired cyclohexenone (**R**)-**9**.²² Finally, the cyclisation was achieved by the reaction of (**R**)-**8** with *N*-triflyl-4-(dimethylamino)pyridinium triflate. This reagent, easily formed from triflic anhydride and DMAP,²³ afforded the enantiomerically pure 3-methoxycyclohexenone (**R**)-**9** in 40–80% yield. The varying yields for the cyclisation step may be explained by the differing quality of the potassium salt **8** from which water has to be completely removed.

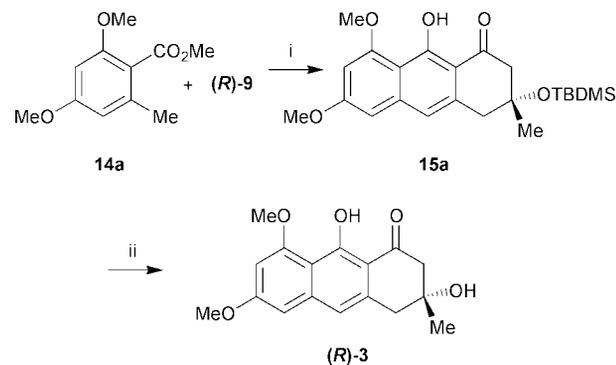
Although this five-step reaction sequence provides a short and efficient entry to enantiomerically pure (**R**)-3-methoxycyclohexenone, the method is limited to compounds of the (**R**)-series. Access to both enantiomers, however, is provided by the desymmetrisation of prochiral 3-hydroxy-3-methylpentanedioic anhydride (**10**) with (**R**)- or (**S**)-1-(1-naphthyl)ethanol, respectively, in the presence of DMAP at -60 °C²⁴ (Scheme 3). To achieve high diastereoselectivity the reaction has to be run for several days at this temperature. Subsequently, methanol and DCC²⁵ were added and the mixed ester (**3*S*,1'*R***)-**11** was thereby obtained starting from (**R**)-1-(1-naphthyl)ethanol in 75% chemical yield with 86% de.²⁶ In the same manner the enantiomeric diester (**3*R*,1'*S***)-**11** (86% de) was prepared from (**S**)-1-(1-naphthyl)ethanol. After protection of the tertiary hydroxy group with the TBDMS residue, treatment of diester **12** with one equivalent of Tebbe reagent at low temperature proceeded with high regioselectivity and afforded the desired methyl enol ether **13**, which was converted to cyclohexenone (**S**)-**9** (86% ee) with *N*-triflyl-DMAP triflate. Starting from diester (**3*R*,1'*S***)-**11** the (**R**)-enantiomer of cyclohexenone **9** was obtained by the same methodology.



Scheme 3 Reagents and conditions: i, (**R**)-1-(1'-naphthyl)ethanol, DMAP, CH₂Cl₂, -60 °C, 5 d, then MeOH (4 equiv.), DCC, -40 °C, 2 h, rt, 24 h, 75%; ii, TBDMS-OTf, lutidine (80%); iii, Tebbe reagent, THF, -50→-30 °C, 3 h, 66%; iv, 1 M KOH, EtOH, rt, 28 h; v, Tf₂O, DMAP (each 10 equiv.), CH₂Cl₂, then (**S**)-**8**, -20 °C, 2 h, rt, 2 d, 41% over two steps.

Synthesis of the dihydroanthracenones A

The TBDMS-protected (**R**)-torosachryson 8-methyl ether **15a** was prepared in 25% yield by condensation of the lithiated methylbenzoate **14a** with 3-methoxycyclohexenone (**R**)-**9** (Scheme 4). The removal of the TBDMS group from **15a** was

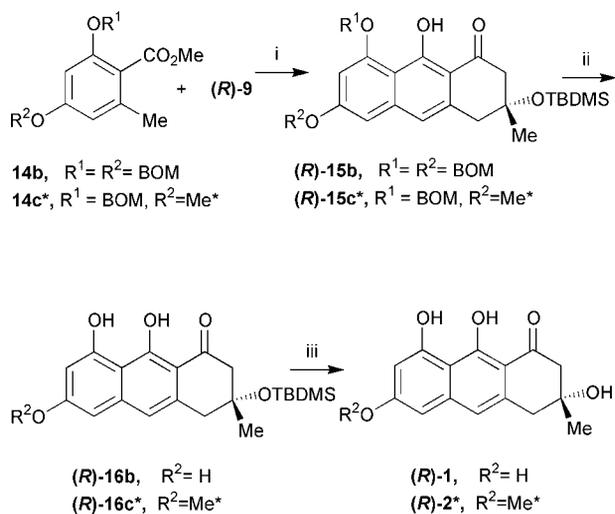


Scheme 4 Reagents and conditions: i, LDA, **14a**, THF, -78 °C, then (**R**)-**9**, 25%; ii, HF, CH₃CN, 78%.

best achieved with HF in acetonitrile.²⁷ The resulting enantiomerically pure (**R**)-torosachryson 8-methyl ether **3** showed the opposite optical rotation and CD curve to the (**S**)-compound from *Cortinarius splendens*.² All other analytical data were in complete agreement.

For the synthesis of atrochryson **1** and torosachryson **2** a phenol protecting group that can be removed under very mild conditions had to be attached to the orsellinate fragment. We selected the benzyloxymethyl (BOM) group²⁸ and prepared methyl 2,4-bis(benzyloxymethoxy)-6-methylbenzoate **14b** and 2-benzyloxymethoxy-4-[¹³C]methoxy-6-methylbenzoate **14c*** by standard procedures. The ¹³C-labelled compound **14c*** was needed for the synthesis of both enantiomers of labelled torosachryson for biosynthetic studies.²⁹

Condensation of the BOM-protected orsellinic acid derivatives **14b** and **14c*** with 3-methoxycyclohexenone (**R**)-**9** afforded the pre-anthraquinones (**R**)-**15b** and (**R**)-**15c***, respectively, in moderate to good yields (Scheme 5). The BOM groups were smoothly removed by catalytic hydrogenation to give the



Scheme 5 Reagents and conditions: i, LDA, **14**, THF, $-78\text{ }^{\circ}\text{C}$, then **(R)-9**; ii, H₂, Pd/C; iii, HF, CH₃CN; * = ¹³C label.

dihydroanthracenones **(R)-16b** and **(R)-16c***, which were desilylated with HF in acetonitrile to yield optically pure **(R)**-atrochrysonone **(R)-1** and **(R)**-torosachrysonone **(R)-2***, respectively. The use of **(S)-9** instead of the **(R)**-enantiomer afforded **(S)-1** and **(S)-2***. Since the optical purity of the products depends on that of the starting enone **9**, the ee values of the **(S)**-compounds were in the range of 86%. The spectroscopic data of the synthetic pre-anthraquinones were identical with those of the natural products.

Our new method allows the synthesis of both enantiomers of pre-anthraquinones from a single starting material. It demonstrates the use of a regioselective Tebbe reaction and the potential of *N*-triflyl-4-(dimethylaminopyridinium) triflate for effecting the intramolecular acylation of enol ethers. Work on the synthesis of biologically active vismiones along these lines is in progress.

Experimental

General methods

The reactions were performed using oven-dried (130 °C) glassware under an argon atmosphere. CH₂Cl₂ was distilled from Sicapent® (Merck) and THF from potassium immediately prior to use. Light petroleum ether (boiling range 40–60 °C) and ethyl acetate were distilled through a glass column at atmospheric pressure. Melting points and boiling points are uncorrected. ¹H NMR and ¹³C NMR were recorded on Bruker AMXR 300 and Varian VXR 400 S spectrometers in CDCl₃ as solvent with chemical shift values reported in ppm relative to residual chloroform ($\delta_{\text{H}} = 7.26$ or $\delta_{\text{C}} = 77.0$) as internal standard unless otherwise stated. Mass spectra were determined at an ionising voltage of 70 eV and the spectral data are tabulated as *m/z*. Optical rotations were measured on a Perkin-Elmer 241 polarimeter. Infrared spectra were recorded using Perkin-Elmer 1420 and Bruker IFS 45 spectrometers. CD- and UV-spectra were recorded on an S. A. Jobin Yvon CD-6-Dichrograph. Elemental analysis were performed at the Microanalytical Laboratory of the Department of Chemistry, LMU München. Unless otherwise noted, flash chromatography was carried out on silica gel (Merck Kieselgel 60 F₂₅₄, particle size 0.040–0.063 mm). TLC was performed on silica gel 60 F₂₅₄ (Merck).

The known **4**,³⁰ **10**³¹ and methyl 2,4-dihydroxy-6-methylbenzoate³² were prepared by published procedures. **(R)**- and **(S)**-1-(1-naphthyl)ethanol (>98% ee) were obtained as described by Klibanov³³ or purchased from Fluka. Compound **14a** was purchased from Lancaster, pig liver esterase (EC 3.1.1.1) from Sigma.

(S)-3-Hydroxy-3-methylpentanedioic acid monomethyl ester **5**

To a solution of dimethyl 3-hydroxy-3-methylpentanedioate (**4**) (2.50 g, 13.1 mmol) in 1 M phosphate buffer (20 cm³, pH 8) was added 1 mg of pig liver esterase (PLE, 1500 U). The pH was kept within the range 7.5–8.0 by addition of aqueous 1 M NaOH. The mixture was incubated for 24 h at 25 °C, after which additional diester **4** (2.50 g) and PLE (1 mg) were added. This was repeated for up to a total of 150 g (78.8 mmol) of diester **4**. The reaction mixture was stirred for an additional 2 d, after which the pH was adjusted to 8.5 and the unreacted starting material extracted with ethyl acetate (50 cm³). The aqueous phase was adjusted to pH 2 and saturated with NaCl prior to extraction with ethyl acetate (3 × 50 cm³). The combined organic phases were dried over MgSO₄ and concentrated to afford 12.7 g (92%) of enantiomerically pure **5** as a colourless oil; $[\alpha]_{\text{D}}^{20} + 1.8$ (*c* 1.0, CHCl₃); ν_{max} (NaCl)/cm⁻¹ 3500, 3010, 2985, 1720, 1435, 1405, 1375, 1345; δ_{H} (400 MHz) 1.4 (3H, s), 2.65 (1H, d, *J* 15.8 Hz), 2.67 (1H, d, *J* 15.5 Hz), 2.73 (1H, d, *J* 15.8 Hz), 2.74 (1H, d, *J* 15.5 Hz), 3.73 (3H, s); δ_{C} (100.6 MHz) 27.2, 44.3, 44.9, 51.9, 69.8, 172.5, 175.6; *m/z* (EI) 177 [M⁺ + H, 0.5%], 143 (5), 117 (5), 43 (100) (Found M⁺ + H: 177.0757. Calc. for C₇H₁₃O₅: 177.0764).

tert-Butyldimethylsilyl methyl **(R)**-3-(*tert*-butyldimethylsilyloxy)-3-methylpentanedioate **6**

2,6-Lutidine (9.10 cm³, 78 mmol) and *tert*-butyldimethylsilyl trifluoromethanesulfonate (15 cm³, 65.0 mmol) were added to a solution of **5** (4.60 g, 26 mmol) in CH₂Cl₂ (25 cm³) at $-10\text{ }^{\circ}\text{C}$. The mixture was stirred for 2 h at rt, then hydrolysed with water and extracted with ethyl acetate (3×). The combined organic phases were washed with aqueous NH₄Cl and brine, dried (MgSO₄) and concentrated. Column chromatography (15:1 light petroleum ether–EtOAc) afforded the product (9.05 g, 86%) as a colourless oil; bp 130 °C/4 × 10⁻² Torr (bulb-to-bulb distillation); $[\alpha]_{\text{D}}^{25} - 0.9$ (*c* 1.0, CHCl₃); ν_{max} (NaCl)/cm⁻¹ 3490, 2870, 1730, 1710, 1465, 1355, 1340, 1250, 1200, 1150, 1100, 830; δ_{H} (400 MHz) 0.10 (6H, s), 0.26 (6H, s), 0.83 (9H, s), 0.93 (9H, s), 1.47 (3H, s), 2.68 (1H, d, *J* 15 Hz), 2.77 (2H, s), 2.85 (1H, d, *J* 15 Hz), 3.64 (3H, s); δ_{C} (100.6 MHz) -4.8 , -4.7 , -2.2 , -2.1 , 17.6, 18.0, 25.6, 25.7, 28.5, 45.9, 48.0, 51.2, 73.1, 171.2, 171.3.

Preparation of the Tebbe reagent

A solution of trimethylaluminium (48 mmol) in toluene (2 M, 24 cm³) was added to a stirred solution of dicyclopentadienylium titanium dichloride (5.98 g, 24 mmol) over 1 h. After the mixture had been stirred for 72 h at rt, another portion of the AlMe₃ solution (9.6 cm³) was added dropwise. After stirring for an additional 48 h the solution was ready for use in the subsequent steps. The Tebbe reagent is stable for 2 months under argon.

tert-Butyldimethylsilyl **(R)**-3-(*tert*-butyldimethylsilyloxy)-5-methoxy-3-methylhex-5-enoate **7**

The Tebbe solution (20 cm³, 7 mmol) was slowly added at $-78\text{ }^{\circ}\text{C}$ to a solution of diester **6** (2.02 g, 5.00 mmol) in THF (10 cm³). The solution was warmed to rt and stirred for 3 h. The mixture was quenched with 2 M NaOH (10 cm³), diluted with diethyl ether (40 cm³) and stirred for 12 h at rt. After filtration through Celite, the residue was rinsed with diethyl ether. The filtrate was washed with aqueous NaHCO₃ and brine, dried (Na₂SO₄) and evaporated. The residue was chromatographed (15:1 light petroleum ether–EtOAc) to yield **7** (1.23 g, 61%) as a colourless oil; bp 130 °C/7 × 10⁻² Torr (bulb-to-bulb distillation); $[\alpha]_{\text{D}}^{20} - 2.4$ (*c* 1.0, CHCl₃); ν_{max} (NaCl)/cm⁻¹ 2940, 2920, 2850, 1710, 1645, 1465, 1455, 1245, 1190, 1155, 1100, 830; δ_{H} (400 MHz) 0.06 (6H, s), 0.23 (3H, s), 0.24 (3H, s), 0.82 (9H, s), 0.91 (9H, s), 1.37 (3H, s), 2.38 (1H, d, *J* 13 Hz), 2.53 (2H, s), 2.56 (1H, d, *J* 13 Hz), 3.45 (3H, s), 3.93 (2H, s); δ_{C} (75.5 MHz) -4.8 , -2.0 , 17.6, 18.2, 25.7, 25.9, 28.2, 47.9, 48.5, 54.5, 74.1.

84.3, 161.3, 171.6; m/z (EI) 402 [M^+ , 0.1%], 401 [$M^+ - H$, 0.5%], 387 (0.5), 273 (2), 213 (5), 147 (28), 73 (100) (Found M^+ : 402.2622. Calc. for $C_{20}H_{42}O_4Si_2$: 402.2650).

(R)-5-(tert-Butyldimethylsilyloxy)-3-methoxy-5-methylcyclohex-2-en-1-one (R)-9

A solution of enol ether **7** (700 mg, 1.72 mmol) in THF (3.5 cm^3) was treated with K_2CO_3 (340 mg, dissolved in 13.5 cm^3 1:3 water-methanol). After stirring for 2 h at rt, the solvent was removed *in vacuo* and the remaining salt (**R**)-**8** dried at 0.1 mbar for 1 h.

The suspension, prepared by slowly adding trifluoromethanesulfonic anhydride (1.7 cm^3 , 10 mmol) to a solution of DMAP (2.40 g, 20.0 mmol) in dry CH_2Cl_2 (80 cm^3) at $-20^\circ C$ under argon, was transferred *via* a double-tipped needle into a second flask containing (**R**)-**8** at $-20^\circ C$. After stirring for 2 h, the suspension was allowed to warm to rt, and stirring was continued for 24 h. The mixture was poured into aqueous $NaHCO_3$, the organic phase dried (Na_2SO_4) and concentrated. The residue was purified by column chromatography (2:1 light petroleum ether-EtOAc) yielding (**R**)-**9** (380 mg, 81%) as a colourless oil; bp $75^\circ C/2 \times 10^{-3}$ Torr (Found: C, 62.55, H 9.78; Calc. for $C_{14}H_{26}O_3Si$: C, 62.18, H, 9.69%); R_f 0.14 (3:1 light petroleum-EtOAc); $[a]_D^{25} -38.7$ (c 1.0, $CHCl_3$); λ_{max}/nm (MeOH) 224 (E_{rel} 0.65), 251 (0.8); CD λ/nm (MeOH): 256 ($\Delta\epsilon_{max} -1.26$), 295 (0.18); ν_{max} (NaCl film)/ cm^{-1} 2950, 2920, 2850, 1650, 1605, 1370, 1250, 1220, 1135, 1110, 1025, 835; δ_H (400 MHz) 0.01 (3H, s), 0.02 (3H, s), 0.73 (9H, s), 1.32 (3H, s), 2.33 (1H, d, J 16 Hz), 2.47 (1H, d, J 16 Hz), 2.47 (1H, d, J 17 Hz), 2.49 (1H, d, J 17 Hz), 3.63 (3H, s), 5.33 (1H, s); δ_C (100.6 MHz) -2.5 , -2.4 , 17.9, 25.6, 29.2, 44.0, 51.9, 55.8, 73.4, 101.4, 175.8, 198.1; m/z (EI) 269 [$M^+ - H$, 0.3%], 255 (5), 215 (3), 214 (12), 213 (100), 195 (7), 181 (42), 171 (10), 139 (10), 89 (12) (Found $M^+ - H$: 269.1573. Calc. for $C_{14}H_{25}O_3Si$: 269.1587).

Methyl (R)-1-(1-naphthyl)ethyl (S)-3-hydroxy-3-methylpentanedioate (3S,1'R)-11

To a solution of anhydride **10** (1.54 g, 10.7 mmol) and (*R*)-1-(1-naphthyl)ethanol (2.00 g, 11.6 mmol) in dry acetone- CH_2Cl_2 1:1 (30 cm^3) at $-60^\circ C$ was added dropwise with stirring a solution of DMAP (1.42 g, 11.6 mmol) in CH_2Cl_2 (10 cm^3). The suspension was kept for 5 d at this temperature.²⁶ After warming to $-40^\circ C$, methanol (1.80 cm^3 , 44.5 mmol) and DCC (2.40 g, 11.6 mmol) in CH_2Cl_2 (10 cm^3) were added, and the solution was stirred for 2 h at $-40^\circ C$ and for 24 h at rt. CH_2Cl_2 (10 cm^3) was added and the mixture filtered. The filtrate was dried (Na_2SO_4) and concentrated and the residue purified by column chromatography (3:1 light petroleum ether-EtOAc) to yield (**3S,1'R**)-**11** (2.65 g, 75%) as a colourless oil [14:1 mixture of diastereomers by 1H NMR spectroscopic analysis of the methyl ester signals, δ 3.67 (major), δ 3.64 (minor)] (Found: C, 69.3; H, 6.6. Calc. for $C_{19}H_{22}O_5$: C, 69.1; H, 6.7%); $[a]_D^{25} +15.4$ (c 4.0, $CHCl_3$); ν_{max} (KBr)/ cm^{-1} 2981, 1735, 1598, 1512, 1439, 1349, 1199, 1069, 1044; δ_H (300 MHz) 1.35 (3H, s), 1.73 (3H, d, J 6.5 Hz), 2.64-2.84 (4H, m), 3.67 (3H, s), 4.05 (1H, s), 6.69 (1H, q, J 6.5 Hz), 7.44-7.58 (3H, m), 7.59 (1H, d, J 7.0 Hz), 7.81 (1H, d, J 8.3 Hz), 7.88 (1H, d, J 8.5 Hz), 8.07 (1H, d, J 8.3 Hz); δ_C (75.5 MHz) 21.7, 27.3, 44.8, 45.0, 51.7, 69.7, 69.9, 122.9, 123.2, 125.3, 125.7, 126.4, 128.6, 128.9, 130.1, 133.8, 137.0, 171.3, 172.1; m/z (EI) 330 [M^+ , 22%], 170 (15), 155 (100) (Found M^+ : 330.1501. Calc. for $C_{19}H_{22}O_5$: 330.1467).

Methyl (S)-1-(1-naphthyl)ethyl (R)-3-hydroxy-3-methylpentanedioate (3R,1'S)-11

The above procedure was repeated with (*S*)-1-(1-naphthyl)ethanol yielding (**3R,1'S**)-**11** as a colourless oil; $[a]_D^{25} -15.0$ (c 4.0, $CHCl_3$); its spectral characteristics were identical with those of the enantiomer.

Methyl (R)-1-(1-naphthyl)ethyl (S)-3-(tert-butyldimethylsilyloxy)-3-methylpentanedioate 12

To a solution of (**3S,1'R**)-**11** (202 mg, 0.61 mmol) in CH_2Cl_2 (20 cm^3) were added 2,6-lutidine (215 μl , 1.84 mmol) and *tert*-butyldimethylsilyl trifluoromethanesulfonate (225 μl , 0.98 mmol) at $-20^\circ C$. The mixture was stirred for 2 h at rt, then hydrolysed with water and extracted with ethyl acetate (2 \times). The combined organic phases were washed with saturated aqueous $NaHCO_3$, aqueous NH_4Cl and brine, dried (Na_2SO_4) and concentrated. Column chromatography (10:1 light petroleum ether-EtOAc) afforded the product (216 mg, 80%) as a colourless oil (Found: C, 67.6; H, 8.1. Calc. for $C_{22}H_{30}O_5Si$: C, 67.5; H, 8.2%); R_f 0.52 (3:1 light petroleum-EtOAc); $[a]_D^{25} +15.5$ (c 1.1, MeOH); ν_{max} (KBr)/ cm^{-1} 2954, 2931, 2857, 1739, 1600, 1512, 1473, 1464, 1376, 1345, 1254, 1104; δ_H (300 MHz) 0.08 (6H, s), 0.76 (9H, s), 1.47 (3H, s), 1.70 (3H, d, J 6.6 Hz), 2.65-2.93 (4H, m), 3.63 (3H, s), 6.65 (1H, q, J 6.6 Hz), 7.43-7.60 (4H, m), 7.79 (1H, d, J 8.3 Hz), 7.87 (1H, d, J 7.6 Hz), 8.07 (1H, d, J 8.1 Hz); δ_C (75.5 MHz) -2.2 , 17.9, 21.8, 25.5, 28.4, 46.2, 46.6, 51.2, 69.3, 73.1, 123.1, 123.2, 125.3, 125.6, 126.2, 128.3, 128.9, 130.2, 133.8, 137.4, 170.0, 171.2; m/z (CI) 445 [$M^+ + H$, 5%], 391 (2), 291 (21), 233 (5), 197 (6), 155 (100).

(R)-1-(1-Naphthyl)ethyl (S)-3-(tert-butyldimethylsilyloxy)-5-methoxy-3-methylhex-5-enoate 13

The Tebbe reagent solution (7.00 cm^3 , 2.45 mmol) was slowly added at $-50^\circ C$ to a solution of diester **12** (683 mg, 1.54 mmol) in THF (25 cm^3). The mixture was then warmed to $-30^\circ C$ and stirred for 3 h. After the addition of 2 M NaOH (3 cm^3 , gas evolution!) and dilution with diethyl ether (14 cm^3), the mixture was stirred for 12 h at rt. After filtration through Celite, the residue was rinsed with diethyl ether. The combined filtrates were washed with aqueous $NaHCO_3$ and brine, dried (Na_2SO_4) and evaporated *in vacuo*. The residue was chromatographed (10:1 light petroleum ether-EtOAc) to yield **13** (450 mg, 66%) as a colourless oil (Found: C, 70.7, H, 8.5; Calc. for $C_{26}H_{38}O_4Si$: C, 70.6, H, 8.6%); R_f 0.39 (10:1 light petroleum ether-EtOAc); $[a]_D^{25} +10.1$ (c 1.7, MeOH); ν_{max} (KBr)/ cm^{-1} 3051, 2953, 2930, 2855, 1737, 1655, 1599, 1253, 1155, 1066, 836, 800, 776; δ_H (300 MHz) 0.06 (3H, s), 0.09 (3H, s), 0.82 (9H, s), 1.42 (3H, s), 1.71 (3H, d, J 6.5 Hz), 2.39-2.82 (4H, m), 3.42 (3H, s), 3.92 (2H, s), 6.66 (1H, q, J 6.5 Hz), 7.44-7.63 (4H, m), 7.79 (1H, d, J 8.1 Hz), 7.86 (1H, d, J 7.8 Hz), 8.11 (1H, d, J 8.4 Hz); δ_C (75.5 MHz) -2.1 , -2.0 , 18.1, 21.9, 25.8, 28.0, 47.0, 48.2, 54.5, 69.1, 74.2, 84.3, 123.3, 123.4, 125.3, 125.6, 126.2, 128.3, 128.8, 130.3, 133.8, 137.7, 161.0, 170.3.

(S)-5-(tert-Butyldimethylsilyloxy)-3-methoxy-5-methylcyclohex-2-en-1-one (S)-9

A solution of enol ether **13** (189 mg, 0.43 mmol) in 1 M ethanolic KOH (1.00 cm^3) was stirred for 28 h at rt. The solvent was carefully removed *in vacuo* and the residual (**S**)-**8** dried at 0.1 mbar for 3 h.

Trifluoromethanesulfonic anhydride (600 μl , 3.66 mmol) was slowly added to a solution of DMAP (600 mg, 4.91 mmol) in dry CH_2Cl_2 (100 cm^3) at $-20^\circ C$ under argon. The suspension was transferred *via* a double-tipped needle into a second flask containing the carboxylate (**S**)-**8** at $-50^\circ C$. After stirring for 2 h, the suspension was allowed to warm to rt and poured into aqueous $NaHCO_3$. Work-up as described for the (*R*)-compound afforded (**S**)-**9** (48 mg, 41%) as a colourless oil; $[a]_D^{25} +40.2$ (c 1.0, $CHCl_3$); CD λ/nm (MeOH) 256 ($\Delta\epsilon_{max}$ 1.26), 295 (-0.17); all other spectral characteristics were identical with those of the enantiomeric material (**R**)-**9**.

Methyl 2,4-bis(benzyloxymethoxy)-6-methylbenzoate 14b

Methanol (1.50 cm^3) and sodium methoxide (81 mg, 1.50 mmol) were added to methyl 2-hydroxy-4- $[^{13}C]$ methoxy-6-

methylbenzoate (118 mg, 0.60 mmol), and the mixture was concentrated *in vacuo*. The residue was suspended in dry THF (5 cm³), treated with triethylamine (600 μ l, 4 mmol) and benzyl chloromethyl ether (400 μ l, 2.40 mmol) and stirred for 12 h at rt. The reaction mixture was washed with aqueous NaHCO₃ and brine, dried (Na₂SO₄) and the solvent removed. Purification by column chromatography (5:1 light petroleum ether–EtOAc) yielded **14b** (338 mg, 80%) as a colourless oil; δ_{H} (400 MHz) 2.29 (3H, s), 3.90 (3H, s), 4.69 (2H, s), 4.71 (2H, s), 5.25 (2H, s), 5.26 (2H, s), 6.60 (1H, d, *J* 2.3 Hz), 6.80 (1H, d, *J* 2.3 Hz), 7.28–7.36 (10H, m); δ_{C} (100.6 MHz) 19.8, 52.1, 70.0, 70.1, 92.1, 92.6, 101.4, 111.0, 127.9, 127.9, 128.0, 128.1, 128.4, 128.5, 137.1, 137.1, 138.1, 155.5, 158.8, 168.5; *m/z* (EI) 422 [M⁺, 4%], 392 (10), 362 (5), 181 (20), 91 (100) (Found M⁺: 422.1731. Calc. for C₂₅H₂₆O₆: 422.1728).

Methyl 2-hydroxy-4-[¹³C]methoxy-6-methylbenzoate³⁴

To a suspension of K₂CO₃ (453 mg, 3.28 mmol) in dry acetone (3 cm³), a solution of methyl 2,4-dihydroxy-6-methylbenzoate (300 mg, 1.65 mmol) and iodo[¹³C]methane (102 μ l, 1.65 mmol) in acetone (1.5 cm³) was added at rt. After heating the reaction mixture for 3 h at reflux, the precipitate was dissolved in H₂O. The mixture was concentrated *in vacuo* and extracted with ethyl acetate (3 \times). The combined organic layers were washed with brine (2 \times), dried (Na₂SO₄) and the solvent removed *in vacuo*. The crude material was purified by column chromatography (8:1 light petroleum ether–EtOAc) to yield methyl 2-hydroxy-4-[¹³C]methoxy-6-methylbenzoate (295 mg, 91%) as colourless needles, mp 66 °C; *R*_f 0.42 (5:1 light petroleum ether–EtOAc); ν_{max} (KBr)/cm⁻¹ 3046, 2982, 2950, 1649, 1617, 1578, 1456, 1295, 1269, 1218, 1198, 1155, 1041, 816; δ_{H} (300 MHz) 2.49 (3H, s), 3.79 (3H, d, *J* 144 Hz), 3.92 (3H, s), 6.28 (1H, dd, *J* 2.6, 0.8 Hz), 6.32 (1H, d, *J* 2.6 Hz), 11.78 (1H, s); δ_{C} (75.5 MHz, CDCl₃) 24.0, 51.5, 55.0 [¹³C], 98.5 (d, *J* 4.7), 105.0, 110.8 (d, *J* 3.5), 142.9, 163.7 (d, *J* 2.0), 165.4, 171.9; *m/z* (EI) 197 [M⁺, 39%], 165 (100.0), 137 (35), 121 (12) (Found M⁺: 197.0777. Calc. for C₉¹³C₁H₁₂O₄: 197.0768).

Methyl 2-benzyloxymethoxy-4-[¹³C]methoxy-6-methylbenzoate **14c***

To methyl 2-hydroxy-4-[¹³C]methoxy-6-methylbenzoate (118 mg, 0.60 mmol) were added methanol (1.5 cm³) and sodium methoxide (81 mg, 1.50 mmol), and the mixture was concentrated *in vacuo*. The residue was suspended in dry THF (5 cm³), treated with triethylamine (120 μ l, 0.80 mmol) and benzyl chloromethyl ether (100 μ l, 0.66 mmol) and stirred for 12 h at rt. The reaction mixture was washed with aqueous NaHCO₃ and brine, dried (Na₂SO₄) and the solvent removed. Purification by column chromatography (5:1 light petroleum ether–EtOAc) yielded **14c*** (162 mg, 85%) as a colourless oil; mp 19 °C; *R*_f 0.32 (5:1 light petroleum ether–EtOAc); ν_{max} (KBr)/cm⁻¹ 3065, 3032, 2951, 1728, 1607, 1270, 1189, 1155, 1059, 740; δ_{H} (300 MHz) 2.29 (3H, s), 3.36 (3H, d, *J* 144 Hz), 3.88 (3H, s), 4.70 (2H, s), 5.25 (2H, s), 6.39 (1H, d, *J* 2.2 Hz), 6.62 (1H, d, *J* 2.2 Hz), 7.29–7.33 (5H, m); δ_{C} (75.5 MHz) 19.9, 51.9, 55.4 [¹³C], 70.0, 92.7, 99.3 (d, *J* 4 Hz), 108.9 (d, *J* 4 Hz), 117.5, 127.9, 128.1, 128.4, 137.1, 138.1, 155.8, 161.2, 168.5; *m/z* (EI) 317 [M⁺, 5%], 287 (26), 255 (11), 228 (7), 165 (10), 91 (100) (Found M⁺: 317.1347. Calc. for C₁₇¹³C₁H₂₀O₅: 317.1344).

General procedure for the condensation of the orsellinates **14** with cyclohexenone **9**

To a solution of diisopropylamine (220 μ l, 1.72 mmol) in dry THF (30 cm³) was added 2.5 M *n*-butyllithium in hexane (600 μ l, 1.50 mmol) at 0 °C. The mixture was stirred for 10 min at 0 °C and then for 10 min at –78 °C. Within 30 s the orsellinate **14** (500 μ mol) dissolved in dry THF (3 cm³) was added, which produced a deep red solution. After 10 min of stirring, cyclo-

hexenone **9** (219 mg, 800 μ mol) was added. Stirring was continued at –70 °C for 15 min and the mixture allowed to warm to rt within 30 min. After hydrolysis with saturated aqueous NH₄Cl (200 cm³), the organic layer was extracted with diethyl ether (3 \times 50 cm³). The combined organic phases were washed with water and brine, and dried over MgSO₄. The solvent was removed and the residue purified by chromatography on silica gel (2:1 light petroleum ether–EtOAc).

(R)-3-(tert-Butyldimethylsilyloxy)-9-hydroxy-6,8-dimethoxy-3-methyl-3,4-dihydroanthracen-1(2H)-one **15a.** From **2,4-dimethoxy-6-methylbenzoate 14a** and **(R)-9** (>99% ee) in 25% yield, light yellow oil; λ_{max} /nm (MeOH) 227 (*E*_{rel} 0.55), 268 (0.8), 313 (0.15), 388 (0.27); CD λ /nm (MeOH) 213 ($\Delta\epsilon_{\text{max}}$ 0.9), 231 (–1.5), 254 (1.6), 280 (–0.32), 295 (0.45), 309 (0.35), 320 (0.75), 385 (–1.05); δ_{H} (400 MHz) 0.01 (3H, s), 0.06 (3H, s), 0.62 (9H, s), 1.41 (3H, s), 2.73 (1H, d, *J* 16.8 Hz), 2.83 (1H, dd, *J* 16.8, 1.7 Hz), 2.98 (1H, d, *J* 16.1 Hz), 3.04 (1H, d, *J* 16.1 Hz), 3.90 (3H, s), 3.98 (3H, s), 6.42 (1H, d, *J* 2.2 Hz), 6.55 (1H, d, *J* 2.2 Hz), 6.82 (1H, s), 15.04 (1H, s); *m/z* (EI) 416 [M⁺, 27%], 359 (100), 341 (15), 317 (34), 285 (15) (Found M⁺: 416.2019. Calc. for C₂₃H₃₂O₅Si: 416.2017).

(R)-6,8-Bis(benzyloxymethoxy)-3-(tert-butyldimethylsilyloxy)-9-hydroxy-3-methyl-3,4-dihydroanthracen-1(2H)-one (R)-15b. From **14b** and **(R)-9** (>99% ee) in 50% yield, yellow oil; [α]_D²⁵ –2.4 (*c* 1.5, CHCl₃); CD λ /nm (MeOH) 215 ($\Delta\epsilon_{\text{max}}$ 2.28), 231 (–2.1), 267 (2.7), 282 (–0.23), 293 (0.43), 305 (0.25), 320 (0.6), 382 (–1.29); ν_{max} (KBr)/cm⁻¹ 2955, 2929, 2860, 1624, 1583, 1381, 1171, 1061, 1023, 836; δ_{H} (400 MHz) 0.02 (3H, s), 0.09 (3H, s), 0.67 (9H, s), 1.43 (3H, s), 2.74 (1H, d, *J* 16.9 Hz), 2.84 (1H, dd, *J* 16.9, 1.7 Hz), 2.98 (1H, d, *J* 16.0 Hz), 3.05 (1H, d, *J* 16.0 Hz), 4.75 (2H, s), 4.88 (2H, s), 5.37 (2H, s), 5.38 (2H, s), 6.86 (1H, s), 6.87 (1H, d, *J* 2.3 Hz), 6.94 (1H, d, *J* 2.3 Hz), 7.28–7.41 (10H, m), 14.97 (1H, s); δ_{C} (100.6 MHz) –2.4, –2.2, 17.9, 25.5, 28.9, 44.6, 53.2, 70.3, 70.4, 73.5, 92.1, 93.6, 103.5, 104.0, 110.3, 117.1, 127.8, 128.0, 128.1, 128.1, 128.2, 128.4, 128.5, 137.0, 137.2, 137.3, 142.0, 158.3, 159.1, 165.2, 203.0; *m/z* (EI) 628 [M⁺, 32%], 598 (28), 541 (30), 511 (26), 508 (19), 451 (16), 421 (33), 91 (100) (Found M⁺: 628.2856. Calc. for C₃₇H₄₄O₇Si: 628.2911).

(S)-6,8-Bis(benzyloxymethoxy)-3-(tert-butyldimethylsilyloxy)-9-hydroxy-3-methyl-3,4-dihydroanthracen-1(2H)-one (S)-15b. From **14b** and **(S)-9** (86% ee) in 35% yield, yellow oil; [α]_D²⁵ +2.2 (*c* 1.4, CHCl₃); CD λ /nm (MeOH) 215 ($\Delta\epsilon_{\text{max}}$ –2.28), 231 (2.1), 267 (–2.7), 282 (2.3), 293 (–0.43), 305 (–0.25), 320 (–0.59), 382 (1.29); all other spectral data were identical with those of the enantiomer **(R)-15b**.

(R)-8-Benzyloxymethoxy-3-(tert-butyldimethylsilyloxy)-9-hydroxy-6-[¹³C]methoxy-3-methyl-3,4-dihydroanthracen-1(2H)-one (R)-15c*. From **14c*** and **(R)-9** (>99% ee) in 36% yield, light yellow oil; [α]_D²⁵ –4.0 (*c* 1.7, CHCl₃); λ_{max} /nm (MeOH) 225 (*E*_{rel} 0.46), 268 (0.68), 313 (0.12), 383 (0.25); CD λ /nm (MeOH) 203 ($\Delta\epsilon_{\text{max}}$ –3.19), 216 (0.98), 230 (–1.90), 261 (2.2), 281 (–0.6), 320 (0.82), 385 (–1.05); ν_{max} (KBr)/cm⁻¹ 2956, 2930, 2900, 2860, 1616, 1583, 1375, 1165, 1064, 836; δ_{H} (400 MHz) 0.01 (3H, s), 0.08 (3H, s), 0.64 (9H, s), 1.44 (3H, s), 2.74 (1H, d, *J* 16.9 Hz), 2.84 (1H, dd, *J* 16.9, 1.7 Hz), 2.99 (1H, d, *J* 16.0 Hz), 3.05 (1H, d, *J* 16.0 Hz), 3.87 (3H, d, *J* 144.3 Hz), 4.85 (2H, s), 5.45 (2H, s), 6.63 (1H, d, *J* 2.5 Hz), 6.75 (1H, d, *J* 2.5 Hz), 6.83 (1H, s), 7.28–7.39 (5H, m), 14.94 (1H, s); δ_{C} (100.6 MHz) –2.4, –2.2, 17.9, 25.5, 28.9, 44.7, 53.2, 55.4 [¹³C], 70.4, 73.4, 93.4, 100.7 (d, *J* 4.4 Hz), 102.8 (d, *J* 3.8 Hz), 110.1, 116.8, 127.8, 128.1, 128.4, 137.2, 137.4, 141.7, 158.2, 161.6 (d, *J* 2.4 Hz), 165.2, 202.8; *m/z* (EI) 523 [M⁺, 23%], 493 (38), 436 (100), 418 (12), 394 (25), 346 (35), 330 (32) (Found M⁺: 523.2486. Calc. for C₂₉¹³C₁H₃₈O₆Si: 523.2471).

(S)-8-Benzyloxymethoxy-3-(tert-butyltrimethylsilyloxy)-9-hydroxy-6-¹³C]methoxy-3-methyl-3,4-dihydroanthracen-1(2H)-one (S)-15c*. From **14c*** and **(S)-9** (86% ee) in 46% yield, light yellow oil; $[\alpha]_{\text{D}}^{25} +3.9$ (*c* 1.7, CHCl₃); CD λ/nm (MeOH) 203 ($\Delta\epsilon_{\text{max}}$ 3.20), 216 (−1.0), 230 (1.9), 261 (−2.2), 281 (0.6), 320 (−0.8), 385 (1.0); all other spectral data were identical with those of the enantiomer **(R)-15c***.

General procedure for the deprotection of the BOM derivatives

A flask containing a stirred solution of the BOM-protected dihydroanthracenone **15** (50.0 μmol) in MeOH (10 cm³) was degassed (4 \times) and refilled with argon. Then, 10% palladium on charcoal (4.5 mg) was added and the atmosphere replaced with hydrogen gas (4 \times). The solution was stirred for 12 h at 25 °C in the dark. After replacing the hydrogen atmosphere with argon, the suspension was passed through a short plug of Celite, washed with MeOH, and concentrated *in vacuo*. Purification was performed by column chromatography on Sephadex LH 20 (Pharmacia) with methanol as eluent.

(R)-3-(tert-Butyldimethylsilyloxy)-6,8,9-trihydroxy-3-methyl-3,4-dihydroanthracen-1(2H)-one (R)-16b. From **(R)-15b** in 51% yield, yellow crystals; mp 164–165 °C; $[\alpha]_{\text{D}}^{25} -3.5$ (*c* 0.5, CHCl₃); δ_{H} (300 MHz) 0.00 (3H, s), 0.07 (3H, s), 0.64 (9H, s), 1.43 (3H, s), 2.73 (1H, d, *J* 17.0 Hz), 2.85 (1H, dd, *J* 17.0, 1.5 Hz), 2.96 (1H, d, *J* 15.8 Hz), 3.02 (1H, d, *J* 15.8 Hz), 5.43 (1H, br s), 6.41 (1H, d, *J* 2.2 Hz), 6.51 (1H, d, *J* 2.2 Hz), 6.77 (1H, s), 9.89 (1H, s), 16.08 (1H, s); *m/z* (EI) 388 [M⁺, 25%], 332 (22), 331 (100), 313 (28), 298 (5), 289 (30), 256 (8) (Found M⁺: 388.1673. Calc. for C₂₁H₂₈O₅Si: 388.1706).

(S)-3-(tert-Butyldimethylsilyloxy)-6,8,9-trihydroxy-3-methyl-3,4-dihydroanthracen-1(2H)-one (S)-16b. From **(S)-15b** in 51% yield, yellow crystals; mp 164–165 °C; $[\alpha]_{\text{D}}^{25} +3.3$ (*c* 0.6, CHCl₃); all other spectral characteristics were identical with those of the enantiomer **(R)-16b**.

(R)-3-(tert-Butyldimethylsilyloxy)-8,9-dihydroxy-6-¹³C]-methoxy-3-methyl-3,4-dihydroanthracen-1(2H)-one (R)-16c*. From **(R)-15c*** in 70% yield, light yellow crystals; mp 127 °C; $[\alpha]_{\text{D}}^{20} -4.5$ (*c* 2.2, CHCl₃); $\lambda_{\text{max}}/\text{nm}$ (MeOH) 209 (log ϵ 0.80), 225 (1.42), 240 (0.74), 270 (2.47), 296 (0.26), 314 (0.42), 339 (0.19), 392 (0.65); ν_{max} (KBr)/cm^{−1} 2956, 2931, 2856, 1639, 1585, 1155, 1023, 839; δ_{H} (300 MHz) 0.00 (3H, s), 0.07 (3H, s), 0.64 (9H, s), 1.43 (3H, s), 2.72 (1H, d, *J* 17.0 Hz), 2.83 (1H, dd, *J* 17.0, 1.5 Hz), 2.96 (1H, d, *J* 15.7 Hz), 3.02 (1H, d, *J* 15.7 Hz), 3.87 (3H, d, *J* 144.4 Hz), 6.46 (1H, d, *J* 2.3 Hz), 6.52 (1H, d, *J* 2.3 Hz), 6.81 (1H, s), 9.79 (1H, s), 16.01 (1H, s); δ_{C} (100.6 MHz) −2.3, −2.2, 17.9, 25.5, 29.1, 44.3, 52.4, 55.5 [¹³C], 73.7, 99.6 (d, *J* 4.9 Hz), 100.9 (d, *J* 3.9 Hz), 108.0, 108.6, 117.3, 136.5, 141.0, 159.7, 163.3 (d, *J* 2.0 Hz), 165.5, 202.8; *m/z* (EI) 403 [M⁺, 32%], 347 (23), 346 (100), 328 (25), 304 (30) (Found M⁺: 403.1876. Calc. for C₂₁¹³C₁H₃₀O₅Si: 403.1896).

(S)-3-(tert-Butyldimethylsilyloxy)-8,9-dihydroxy-6-¹³C]-methoxy-3-methyl-3,4-dihydroanthracen-1(2H)-one (S)-16c*. From **(S)-15c*** in 82% yield, light yellow oil; mp 127 °C; $[\alpha]_{\text{D}}^{20} +4.3$ (*c* 2.2, CHCl₃); CD λ/nm (MeOH) 214 ($\Delta\epsilon_{\text{max}}$ −0.1), 231 (0.15), 261 (−0.39), 283 (−0.03), 300 (−0.12), 310 (−0.1), 321 (−0.15), 393 (0.21); all other spectral data were identical with those of the enantiomer **(R)-16c***.

General procedure for the deprotection of the TBDMS derivatives

A 10 cm³ flask charged with a solution of silyl ether **15a** or **16** (50.0 μmol) in acetonitrile (3 cm³) was purged with argon. Then, 4 drops of a 40% aqueous HF solution were added, and the mixture was stirred for 2–3 h at 50 °C in the dark. The solution was poured in a separating funnel containing a mixture

of aqueous CaCl₂ and ethyl acetate. The organic layer was washed with water (2 \times), dried (MgSO₄) and the solvent removed *in vacuo*. Purification of the residue by column chromatography on Sephadex LH 20 (Pharmacia) with methanol as eluent yielded the deprotected pre-anthraquinones.

(R)-Torosachryson 8-methyl ether (R)-3. From **15a** in 70% yield, yellow crystals; $\lambda_{\text{max}}/\text{nm}$ (MeOH) 225 (*E*_{rel} 0.35), 269 (0.82), 320 (0.24), 332 (0.27), 365 (0.34); CD λ/nm (MeOH) 213 ($\Delta\epsilon_{\text{max}}$ −1.92), 231 (0.26), 239 (−0.32), 253 (0.56), 267 (−0.11), 278 (−1.08), 293 (0.57), 302 (0.35), 322 (1.36), 385 (−0.20); δ_{H} (400 MHz) 1.40 (3H, s), 2.79 (1H, d, *J* 17.5 Hz), 2.84 (1H, d, *J* 17.5 Hz), 3.02 (1H, d, *J* 17.0 Hz), 3.06 (1H, d, *J* 17.0 Hz), 3.88 (3H, s), 3.96 (3H, s), 6.41 (1H, d, *J* 2.0 Hz), 6.53 (1H, d, *J* 2.0 Hz), 6.85 (1H, s), 15.1 (1H, s); *m/z* (EI) 302 [M⁺, 100%], 284 (10), 269 (20), 245 (17), 244 (37), 229 (10), 226 (15) (Found M⁺: 302.1154. Calc. for C₁₇H₁₈O₅: 302.1110).

(R)-Atrochryson (R)-1. From **(R)-16b** in 70% yield, yellow powder; $\lambda_{\text{max}}/\text{nm}$ (MeOH) 225 (*E*_{rel} 0.56), 271 (0.8), 321 (0.14), 333 (0.13), 394 (0.24); CD λ/nm (MeOH) 251 ($\Delta\epsilon_{\text{max}}$ 0.43), 254 (0.39), 258 (0.46), 264 (−0.29), 266 (−0.26), 276 (−1.68), 296 (0.89), 312 (0.53), 324 (0.75), 403 (−0.46); δ_{H} (400 MHz, CDCl₃ + [²H₆]acetone) 1.35 (3H, s), 2.71 (1H, d, *J* 17.3 Hz), 2.76 (1H, d, *J* 17.3 Hz), 2.94 (2H, br s), 4.02 (1H, br s), 6.36 (1H, d, *J* 2.3 Hz), 6.46 (1H, d, *J* 2.3 Hz), 6.7 (1H, br s), 8.38 (1H, br s), 9.77 (1H, d, *J* 0.6 Hz), 16.2 (1H, d, *J* 0.6 Hz); *m/z* (EI) 274 [M⁺, 100%], 256 (71), 232 (12), 216 (27), 213 (11), 190 (5) (Found M⁺: 274.0834. Calc. for C₁₅H₁₄O₅: 274.0841).

(S)-Atrochryson (S)-1. From **(S)-16b** in 70% yield, yellow powder; CD λ/nm (MeOH) 262 ($\Delta\epsilon_{\text{max}}$ −0.57), 277 (0.75), 296 (−0.73), 310 (−0.56), 324 (−0.72), 395 (0.17); all other spectral characteristics were identical with those of the enantiomer **(R)-1**.

(R)-[methoxy-¹³C]Torosachryson (R)-2*. From **(R)-16c*** in 75% yield, yellow crystals; $\lambda_{\text{max}}/\text{nm}$ (MeOH) 226 (*E*_{rel} 0.45), 271.5 (0.85), 316 (0.13), 394 (0.22); CD λ/nm (MeOH) 213 ($\Delta\epsilon_{\text{max}}$ −1.55), 231 (0.19), 238 (−0.15), 259 (0.86), 278 (−0.43), 294 (0.92), 309 (0.72), 322 (1.18), 413 (−0.56); ν_{max} (KBr)/cm^{−1} 2967, 2933, 1638, 1586, 1391, 1346, 1155; δ_{H} (400 MHz) 1.45 (3H, s), 1.79 (1H, br s), 2.84 (2H, m), 3.04 (2H, m), 3.88 (3H, d, *J* 144.5 Hz), 6.48 (1H, d, *J* 2.2 Hz), 6.53 (1H, d, *J* 2.2 Hz), 6.86 (1H, br s), 9.79 (1H, s), 16.1 (1H, s); δ_{C} (100.6 MHz, [²H₆]acetone) 29.3, 43.6, 51.4, 55.8 [¹³C], 70.8, 100.1, 101.3, 108.4, 109.4, 118.0, 138.2, 142.1, 160.4, 164.3, 166.3, 204.4; *m/z* (EI) 289 [M⁺, 100%], 272 (9), 271 (49), 256 (5), 247 (13), 232 (15), 231 (25), 204 (7) (Found M⁺: 289.1063. Calc. for C₁₅¹³C₁H₁₆O₅: 289.1031).

(S)-[methoxy-¹³C]Torosachryson (S)-2*. From **(S)-16c*** in 75% yield, yellow crystals; mp 186 °C; $[\alpha]_{\text{D}}^{20} +7.1$ (*c* 1.5, dioxane); CD λ/nm (MeOH) 213 ($\Delta\epsilon_{\text{max}}$ 1.55), 231 (−0.19), 238 (0.15), 259 (−0.86), 278 (0.43), 294 (−0.92), 309 (−0.72), 322 (−1.18), 413 (0.56); all other spectral characteristics were identical with those of the enantiomeric material **(R)-2***.

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References

- 1 M. Gill and W. Steglich, *Progr. Chem. Org. Nat. Prod.*, 1987, **51**, 1 and references cited therein.
- 2 W. Steglich and B. Oertel, *Sydowia*, 1984, **37**, 284.

- 3 M. Gill, A. Giménez, A. G. Jhingran and A. F. Smrdel, *Phytochemistry*, 1989, **28**, 2647.
- 4 S. N. Eagle, M. Gill, S. Saubern and J. Yu, *Nat. Prod. Lett.*, 1993, **2**, 151.
- 5 M. Gill, *Nat. Prod. Rep.*, 1996, **13**, 513 (p. 519).
- 6 S. Takahashi, M. Takido, U. Sankawa and S. Shibata, *Phytochemistry*, 1976, **15**, 1295.
- 7 M. Takido, S. Takahashi, K. Masuda and K. Yasukawa, *Lloydia*, 1977, **40**, 191.
- 8 M. Endo and H. Naoki, *Tetrahedron*, 1980, **36**, 2449.
- 9 W. Mammo, E. Dagne and W. Steglich, *Phytochemistry*, 1992, **31**, 3577.
- 10 R. H. Thomson, *Naturally Occurring Quinones III: Recent Advances*, Chapman and Hall, London, 1987.
- 11 Review: F. Delle Monache, *Rev. Latinoam. Quim.*, 1985, **16**, 5.
- 12 G. François, T. Steenackers, L. A. Assi, W. Steglich, K. Lamottke, J. Holenz and G. Bringmann, *Parasitol. Res.*, 1999, **85**, 582.
- 13 M. S. J. Simmonds, W. M. Blaney, F. Delle Monache, M. Marquina Mac-Quhae and G. B. Marini Bettolo, *J. Chem. Ecol.*, 1985, **11**, 1593.
- 14 G. Billen, U. Karl, T. Scholl, K. D. Stroeck and W. Steglich, in *Natural Product Chemistry III*, eds. Atta-ur-Rahman and P. W. Le Quesne, Springer-Verlag, Berlin, 1988, p. 305.
- 15 (a) J. H. Dodd and S. M. Weinreb, *Tetrahedron Lett.*, 1979, **20**, 3593; (b) J. H. Dodd, R. S. Garigipati and S. M. Weinreb, *J. Org. Chem.*, 1982, **47**, 4045; (c) cf. G. E. Evans, F. J. Leeper, J. A. Murphy and J. Staunton, *J. Chem. Soc., Chem. Commun.*, 1979, 205.
- 16 (a) Y. Kawakami, J. Hiratake, Y. Yamamoto and J. Oda, *J. Chem. Soc., Chem. Commun.*, 1984, 779; (b) J. Hiratake, Y. Yamamoto and J. Oda, *J. Chem. Soc., Chem. Commun.*, 1985, 1717; (c) cf. K. Brown, J. A. Devlin and D. J. Robins, *J. Chem. Soc., Perkin Trans. 1.*, 1983, 1819.
- 17 F.-C. Huang, L. F. H. Lee, R. S. D. Mittal, P. R. Ravikumar, J. A. Chan, C. J. Sih, E. Caspi and C. R. Eck, *J. Am. Chem. Soc.*, 1975, **97**, 4144.
- 18 (a) E. J. Corey and A. Venkateswarlu, *J. Am. Chem. Soc.*, 1972, **94**, 6190; (b) E. J. Corey, H. Cho, C. Rücker and D. H. Hua, *Tetrahedron Lett.*, 1981, **22**, 3455.
- 19 F. N. Tebbe, G. W. Parshall and G. S. Reddy, *J. Am. Chem. Soc.*, 1978, **100**, 3611.
- 20 D. R. Morton and J. L. Thompson, *J. Org. Chem.*, 1978, **43**, 2102.
- 21 A. Devos, J. Remion, A.-M. Frisque-Hesbain, A. Colens and L. Ghosez, *J. Chem. Soc., Chem. Commun.*, 1979, 1180.
- 22 F. Effenberger, *Angew. Chem., Int. Ed. Engl.*, 1980, **19**, 151 and references cited therein.
- 23 *N*-Trifluoromethanesulfonyl-(4-dimethylamino)pyridinium trifluoromethanesulfonate has been characterised by its spectroscopic and analytical data and by its X-ray structure: U. Hamacher-Baumann, PhD Thesis, University of Bonn, 1996.
- 24 (a) P. D. Theisen and C. H. Heathcock, *J. Org. Chem.*, 1988, **53**, 2374; (b) P. D. Theisen and C. H. Heathcock, *J. Org. Chem.*, 1993, **58**, 142.
- 25 B. Neises and W. Steglich, *Angew. Chem., Int. Ed. Engl.*, 1978, **17**, 552.
- 26 On extending the reaction time for the first step to 3 weeks at $-60\text{ }^{\circ}\text{C}$ the de value could be raised to 90%.
- 27 R. F. Newton, D. P. Reynolds, M. A. W. Finch, D. R. Kelly and S. M. Roberts, *Tetrahedron Lett.*, 1979, 3981.
- 28 (a) A. J. Hill and D. T. Keach, *J. Am. Chem. Soc.*, 1926, **48**, 257; (b) G. Stork and M. Isobe, *J. Am. Chem. Soc.*, 1975, **97**, 6260.
- 29 Unpublished results.
- 30 (a) C. D. Hurd and J. L. Abernethy, *J. Am. Chem. Soc.*, 1941, **63**, 976; (b) A. H. Yavrouian, R. A. Sanchez, J. K. Pollard, Jr. and E. K. Metzner, *Synthesis*, 1981, 791.
- 31 P. Lewer and J. MacMillan, *J. Chem. Soc., Perkin Trans. 1.*, 1983, 1417.
- 32 (a) J. Chiarello and M. M. Joullié, *Tetrahedron*, 1988, **44**, 41; (b) cf. A. G. M. Barrett, T. M. Morris and D. H. R. Barton, *J. Chem. Soc., Perkin Trans. 1.*, 1980, 2272.
- 33 G. Kirchner, M. P. Scollar and A. M. Klibanov, *J. Am. Chem. Soc.*, 1985, **107**, 7072.
- 34 G. Nicollier, M. Rebetez, R. Tabacchi, H. Gerlach and A. Thalmann, *Helv. Chim. Acta*, 1978, **61**, 2899.