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# Use of Winterfeldt's Template to Control the C-2′ Configuration in the Synthesis of Strigol-type Compounds*

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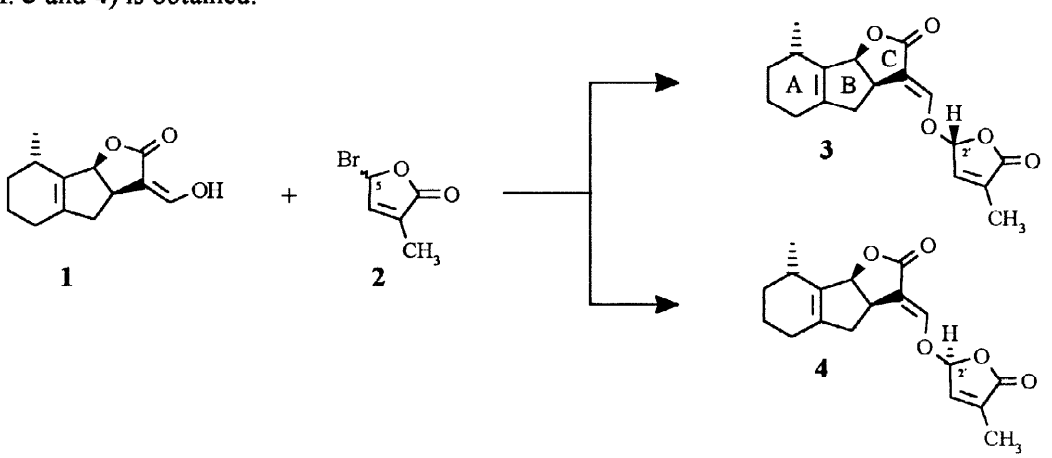
Abstract - A route comprising (i) a cycloaddition reaction of citraconic anhydride with the Winterfeldt auxiliary, (ii) hydride reduction of the cycloadduct, (iii) a (formal) ether formation, and (iv) a cycloreversion reaction allows efficient stereocontrol at C-2′ in the synthesis of strigol and its structural analogues.


## Introduction

As discussed in preceding publications control of the C-2′ configuration is one of the important problems in the synthesis of strigol-type compounds.[1] In the classical approach the configurationally labile bromobutenolide **2** is coupled to a hydroxymethylene lactone such as **1** and thus a 1:1 mixture of the C-2′ isomers (cf. **3** and **4**) is obtained.[2]




Scheme 1

The first attempt to solve this synthetic problem used a stereodirecting group at C-3′ (Michael addition/*retro*-Michael reaction sequence). However, this approach turned out to be synthetically unsatisfying.[3]
Subsequently, another method was used as indicated in Scheme 2. Cyclopentadiene on reaction with **6** furnished *rac*-**7**. After reduction *rac*-**8** was resolved by several methods.[4] In principle, one could also resolve

* Dedicated with respect and admiration to Professor Sir Derek Barton in honour of his 80th birthday

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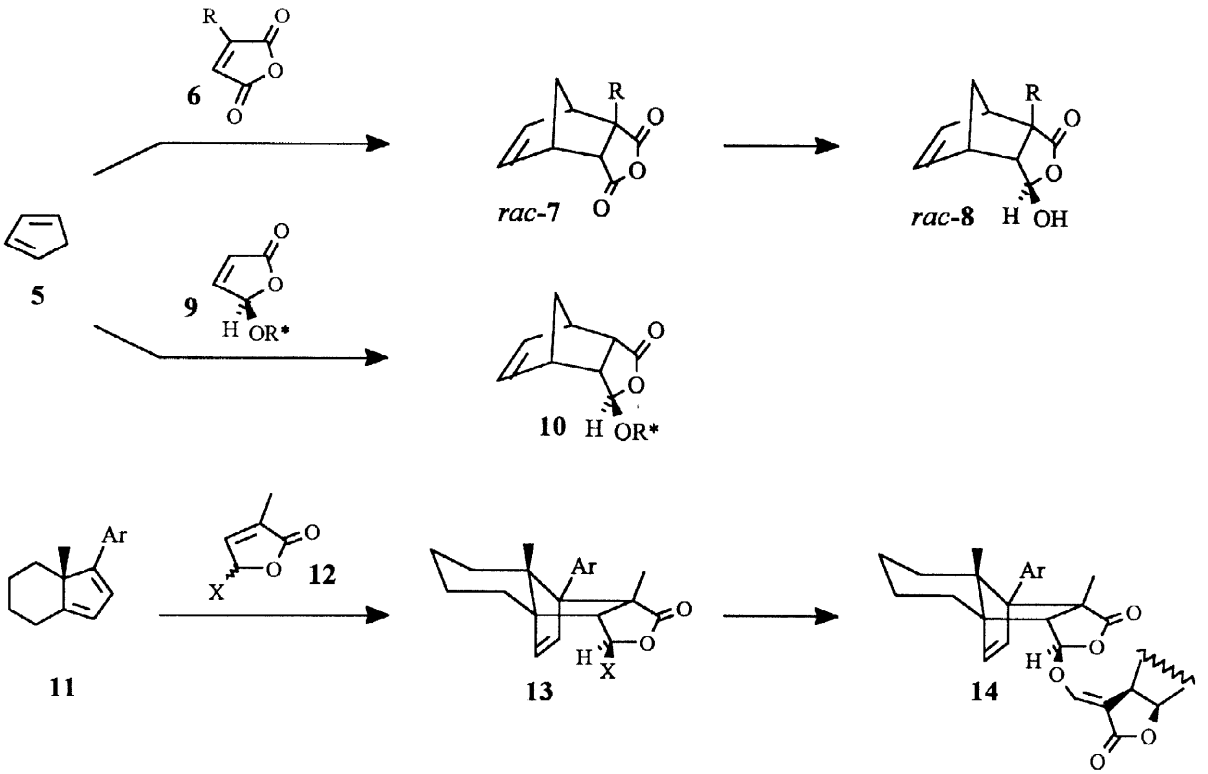
the dienophile first and then perform the cycloaddition (**5** + **9** → **10**).[5] **8** has been coupled stereoselectively to a hydroxymethylene lactone (of type **1**), and in the final step the desired compound was liberated by a *retro*-Diels-Alder reaction.[4] Although this process provides the desired stereocontrol it suffers from the fact that it involves a resolution step.




Scheme 2

We describe here a new synthetic scheme in which an optically active butenolide equivalent is prepared by enantioselective synthesis. In particular, we made use of Winterfeldt's auxiliary.[6,7]

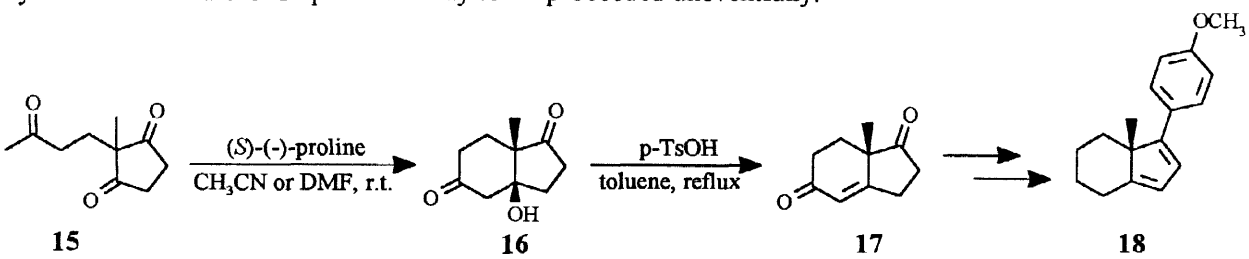
**Synthetic planning**

We envisaged stereoselective formation of cycloadduct **13** from Winterfeldt's diene and a substituted butenolide of type **12**. Coupling of a hydroxymethylene lactone (cf. **1**) was hoped to give **14** in a stereoselective fashion since the backside of the lactone ring is shielded by the etheno bridge. Finally, a *retro*-Diels-Alder reaction would liberate the desired strigol-type compound as well as the auxiliary.

**Preparation of the Winterfeldt auxiliary (18)**

**18** is easily available from the *Hajos-Wiechert* ketone (**17**).[8] The proline-catalyzed cyclization of **15** to give **16** is a highly appreciated example of an enantioselective reaction with a chiral nonracemic catalyst which has been studied and used in many laboratories.[9] Still, we had some problems in getting optically pure **16**. Determination of enantiomeric purity of both **16** and **17** was performed by GLC using a β-cyclodextrin-based stationary phase. For both compounds the enantiomers were baseline-separated. It was found that even under the best conditions the ee of **16** was in the range of 93 %. After elimination **17** could be enantiomerically enriched by crystallization from diethyl ether. After two crystallizations from the 93 % ee sample optically

pure **17** was obtained (in the limits of the GLC method). From a 83 % ee sample of **17** first the racemate crystallized. The further steps on the way to **18** proceeded uneventfully.[8]




Scheme 3

**Cycloaddition reactions**

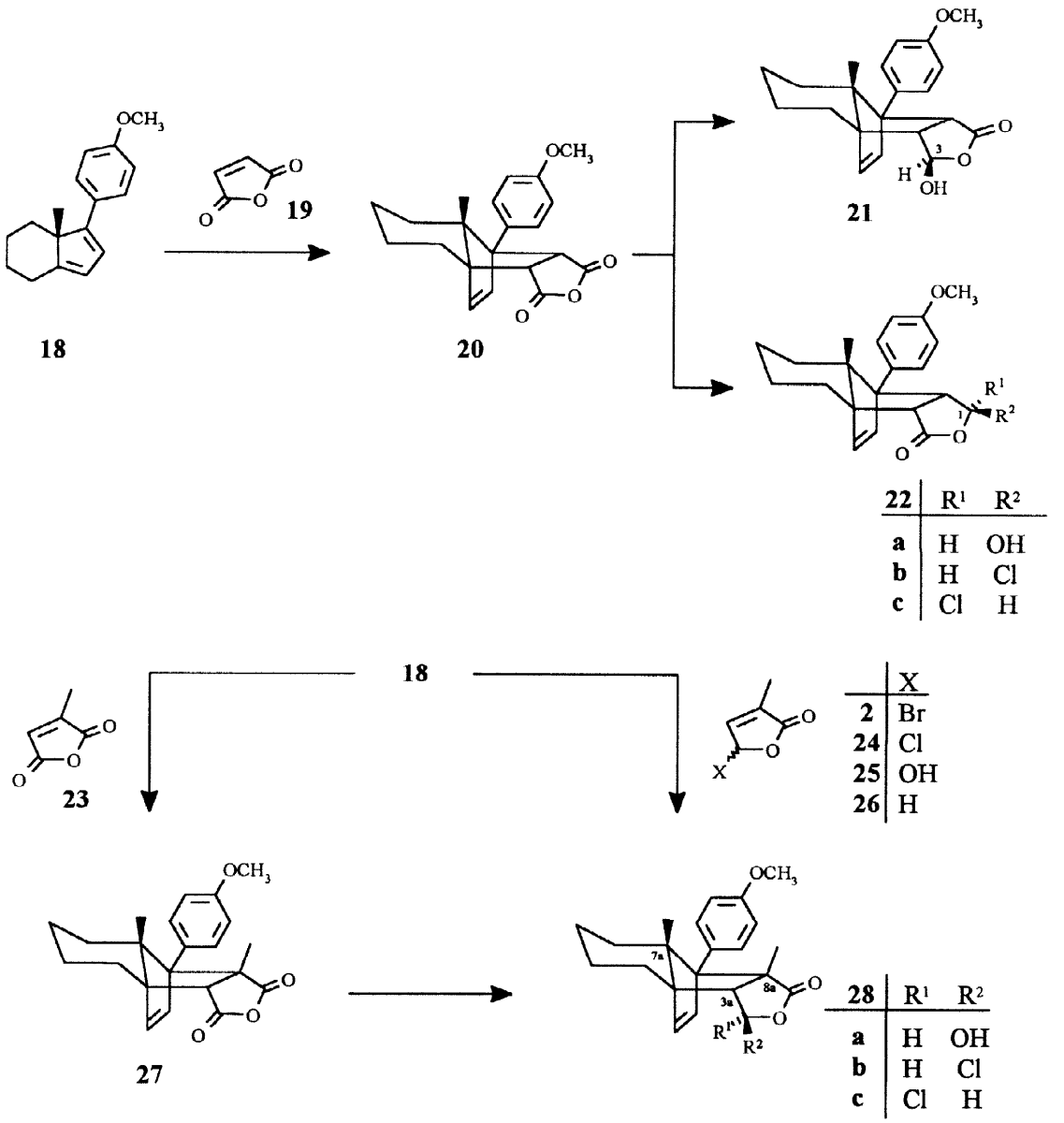
Initially, it was planned to use the bromo- and chlorobutenolide **2** and **24**, respectively, as dienophiles. It could be expected that only one of the enantiomers would react and we thought that added tetra-*n*-butylammonium bromide or chloride would equilibrate the remaining enantiomer by *in-situ* anomerization.[10] Thus, we hoped to convert all the racemic halobutenolide into a single cycloaddition product.[11] In the event, **18** and **2** in $CH_2Cl_2$ solution under high-pressure conditions did not yield the desired cycloadduct. From the reaction mixture the bromobutenolide was almost entirely reisolated whereas the diene was completely consumed. One product was isolated that according to the spectral data was a dimer of **18**. The FAB mass spectrum displayed a peak at m/z = 480.3 corresponding to $[M+H-H]^+$. The $^1H$ NMR spectrum showed signals of two $CH_3$ and two $OCH_3$ groups, two doublets of doublets each corresponding to one H, and one olefinic singlet. In the $^{13}C$ NMR spectrum also two sets of signals appeared with the exception of one aliphatic $CH_2$, one aliphatic CH, a quaternary C and an olefinic CH. The data would be accommodated by either of the structures **29I** or **29II**. The way how this dimer is formed remains unclear. On attempted cycloaddition of **18** and the chlorobutenolide **24** the same dimer was isolated. Obviously the desired cycloaddition did not take place even under high-pressure conditions. This assumption is in agreement with the fact that hydroxybutenolide **25** did not react. The unsubstituted butenolide **26** did react but very slowly. After 3 d at 20°C and 11 kbar a cycloadduct was isolated but only in 5 % yield. It should be mentioned, however, that in the latter two reactions the dimer (**29I** or **II**) was not found.

Recourse was then made to the cycloaddition of citraconic acid anhydride (**23**). In a model series **18** and maleic acid anhydride (**19**) reacted cleanly at 20°C as described by Winterfeldt[8] to provide *endo* cycloadduct **20**. For the cycloaddition reaction between **18** and **23** high-pressure conditions were required as already found by Winterfeldt.[12] Here again the *endo* product **27** was obtained. The configuration of **27** was determined by a careful NMR analysis at a later stage (vide infra).

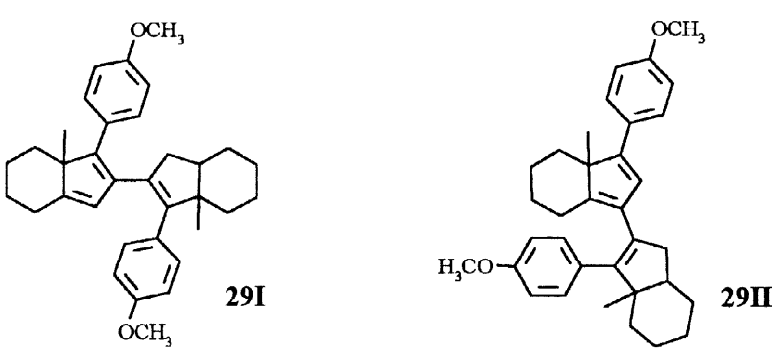
**Reduction of 20 and 27, and configurational assignment of the cycloadducts**

Reduction of **20** with $Li(OtBu)_3AlH$[13] provided **21** and **22a** in a 1:10 ratio. The $^1H$ NMR spectrum of **22a** displayed the signals of the etheno bridge at δ = 6.07 and 6.14. The δ = 6.07 proton showed a NOED with the ortho protons of the aromatic ring and could thus be identified as 10-H. There was another informative NOED between 10-H and the proton at the hemiacetal position (1-H). This NOE proves (i) the *endo* mode of the cycloaddition reaction (vide supra), (ii) which of the CO groups had been reduced, and (iii) the configuration at C-1, i.e. that this hydrogen is cis to the etheno bridge. In agreement with the configurational assignment at C-1 the coupling constant $J_{(1,8a)}$ was very small (1.5 Hz).

From the $^1$H NMR spectrum of the second reduction product $J_{(3,3a)}$ = 1.5 Hz was obtained and thus 3-H also is trans to the neighbouring proton. This is in agreement with structure **21**.



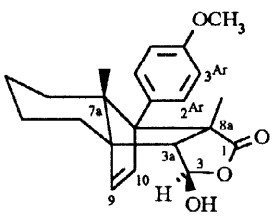

Scheme 4




Scheme 5

When **27** was reduced under identical conditions, the extra methyl group directed the hydride addition to the distant CO group and only one product (**28a**) was formed. Again a NOED of one proton of the etheno bridge with the aromatic ring ortho protons permitted to assign the 9-H and 10-H resonances. The hemiacetal hydrogen (3-H) showed a NOED with 9-H. It follows (i) the *endo* mode of the cycloaddition reaction, (ii) which of the CO groups had been reduced, (iii) that the hemiacetal hydrogen points to the etheno bridge. In $CDCl_3$ solution the methyl groups had almost identical chemical shifts whereas in $C_6D_6$ solution their chemical shifts differed considerably ($\Delta\delta$ = 0.4 ppm). Highly informative NOEDs were observed involving the methyl groups (see Table 1) and the aromatic hydrogens. These NOEs clearly demonstrate the *endo* structure and that the methyl group is at C-8a rather than at C-3a. The NOE between 3a-H and 8a-$CH_3$ was much stronger than that between 3a-H and 7a-$CH_3$. This observation was used to assign the two methyl group signals.
In all reaction products the OH group was ß, i.e. trans to the etheno bridge. The compounds are obviously not the primary reduction products and are formed via the ring-opened aldehyde-carboxylate-intermediate. In neither case we have been able to detect the original reduction products.

Table 1. NOED-experiments for **28a** (200 MHz, $C_6D_6$)



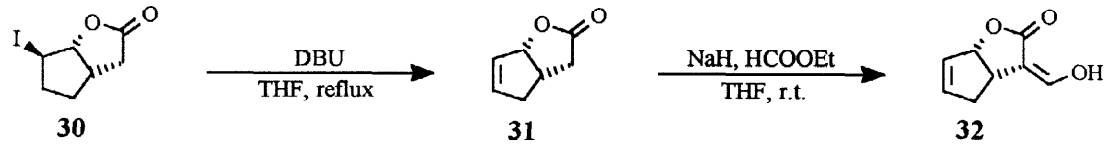
**28a**

| saturated signal | observed NOED |
|---|---|
| 9-H | 10-H, 3-H |
| 10-H | $2^{Ar}$-H, 9-H, cyclohexane Hs |
| $2^{Ar}$-H | $3^{Ar}$-H, 10-H, 7a-$CH_3$, 8a-$CH_3$ |
| $3^{Ar}$-H | $2^{Ar}$-H, $OCH_3$ |
| 3-H | 9-H, 3a-H |
| 3a-H | 3-H, 7a-$CH_3$, 8a-$CH_3$ |
| $OCH_3$ | $3^{Ar}$-H |
| 7a-$CH_3$ | $2^{Ar}$-H, 3a-H, 8a-$CH_3$ |
| 8a-$CH_3$ | $2^{Ar}$-H, 3a-H, 7a-$CH_3$ |

**Formation of the coupling products 34b or 37**

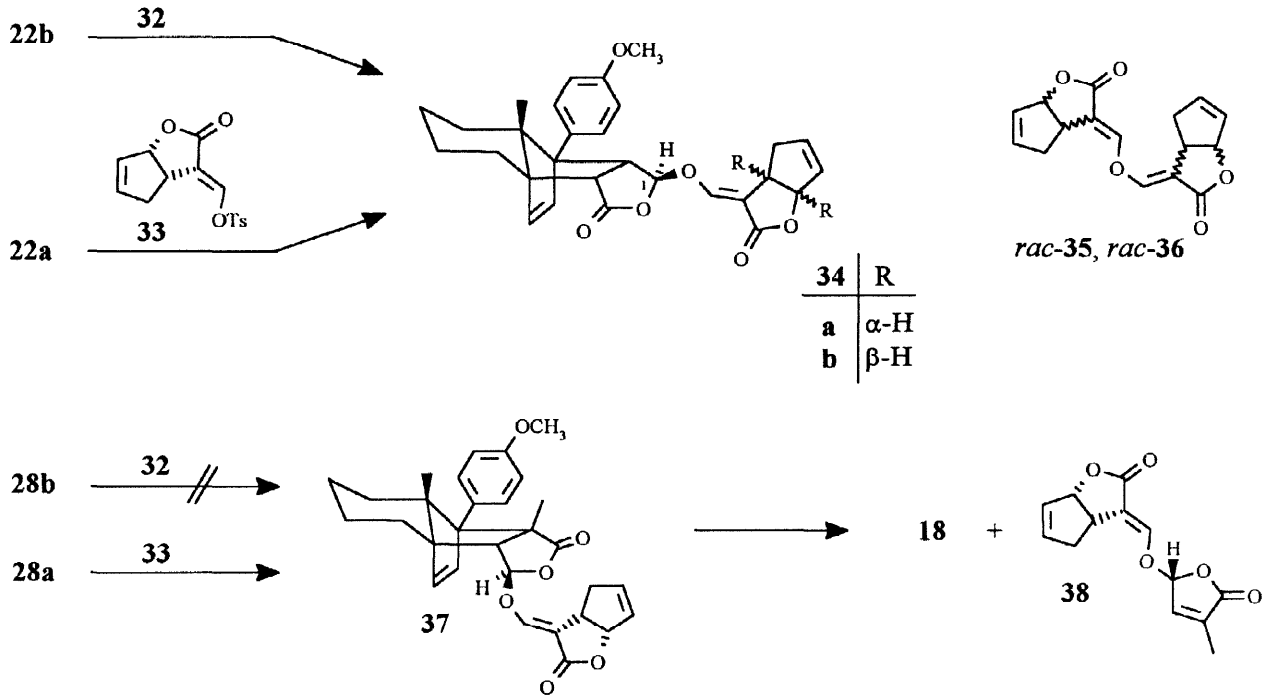
Recently, Helmchen and coworkers have developed a very elegant Pd-mediated asymmetric synthesis of 2-cyclopenten-1-ylacetic acid.[14] Depending on which enantiomer of the Pd-catalyst is used both enantiomers of cyclopentenylacetic acid are available. For enantiomeric enrichment by crystallization the iodo lactone **30** and its enantiomer, respectively, were formed. These compounds are convenient starting materials for the strigol analogue GR28 and its enantiomer, respectively. Since Prof. Helmchen provided us with a generous gift of **30** we decided to use this compound for testing the efficiency of our new approach of configuration control at C-2′. The final product would then be *ent*-2′-*epi*-GR28 (**38**).

For the coupling of the hydroxy methylene compound **32** to **22a** and **28a**, respectively, two modes could be envisaged. Either **32** could be coupled with an alkylation reagent derived from **22a** and **28a**, respectively, or tosylate **33** to the hemiacetals (**22a** or **28a**) by an addition/elimination process.




30 31 32

Scheme 6



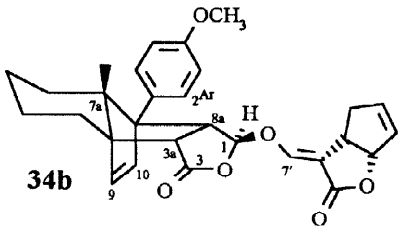

Scheme 7

First we studied the conversion of **22a** and **28a** into the corresponding halo lactones. When **22a** was treated with thionyl chloride in pyridine solution a 5:1 mixture of **22b** and **22c** was obtained whereas in $CH_2Cl_2$ solution practically solely **22b** was formed. Similarly, treatment of **28a** with thionyl chloride in pyridine let to the formation of **28b** and **28c** (2:1 mixture) whereas in $CH_2Cl_2$ solution the reaction was selective and provided **28b** almost exclusively.

Reaction of **22b** with **32** furnished the desired coupling product **34b** in 96 % yield whereas we were unable to achieve the coupling between **28b** and **32**. The substitution reactions at the acetal carbon of the furanone ring are obviously complex and do not follow a simple $S_N$ reaction pathway.

In a model reaction hydroxylactone **22a** could also be coupled to *rac*-**33**. When the reaction was preformed in THF solution with NaH as base a 1:1 mixture of **34a,b** was isolated in 47 % yield. In addition 12 % of the dimers *rac*-**35**, *rac*-**36**[15] were formed and 24 % of **22a** were recovered. Fortunely, under these conditions also **28a** and **33** did react to provide **37** in 54 % yield. Interestingly, a second coupling product was isolated (3 % yield) which according to the spectral data ($J_{(3,3a)}$ = 7 Hz) was the C-3-epimer of **37**. The structure of the coupling product **34b** was carefully analyzed by NMR spectra. The most important NOEDs are collected in Table 2.

Table 2. NOED-experiments for **34b** (400 MHz, $CDCl_3$)

| | saturated signal | observed NOED |
|---|---|---|
|  **34b** | 10-H | $2^{Ar}$-H, 1-H, 9-H |
| | 9-H | 10-H, cyclohexane Hs |
| | 1-H | 10-H, 8a-H, 7′-H |
| | 8a-H | 3a-H, 1-H, 7a-$CH_3$, $2^{Ar}$-H |
| | 3a-H | 8a-H, 7a-$CH_3$ |

**Formation of 38 by pyrolysis of 37**

On flash vacuum pyrolysis (500°C, $10^{-6}$ bar) the *retro*-Diels-Alder cleavage occurred and provided the desired strigol and sorgolactone analogue **38** (*ent*-2′-*epi*-GR28) in 59 % yield. Winterfeldt's template **18** was recovered in 81 % yield. **38** is the enantiomer of a compound obtained previously using the Michael addition/elimination approach.[15] The spectral data of **38** confirm the structural assignment. Most specifically, the CD at 270 nm was negative. We have previously shown that the sign of the CD around 270 nm can directly be correlated with the configuration at C-2′ and that a negative sign corresponds to the (*R*)-configuration at C-2′.[16]

**Conclusion**

We have performed a concise synthesis of the strigol and sorgolactone analogue **38** with efficient control of the C-2′ configuration using a Diels-Alder/ *retro*-Diels-Alder approach.

In contrast to previous work no resolution step was required neither was it necessary to separate diastereoisomers. The important chiral materials used in the synthesis, Winterfeldt's template and Helmchen's iodo lactone, are available by enantioselective reaction under the control of chiral catalysts.

## EXPERIMENTAL

General:

Enantiomeric excess determinations by GLC: HP 5890 Series II (Fa. Hewlett Packard), carrier gas: $H_2$, FID, column: WCOT fused Silica (Fa. Chrompack), stationary phase: CP-Chirasil-Dex CB, column length: 25 m, ID: 0.25 mm, film thickness: 0.25 mm.- Usual workup means partitioning the reaction mixture between an aqueous and an organic solvent (given in parentheses) for five times, drying the combined organic layers over $MgSO_4$ and filtering, and subsequent removal of the solvent by distillation under reduced pressure.- For instrumentation and abbreviations see ref.[17] - High pressure experiments were carried out in a 14 kbar system containing a 100 ml vessel manufactured by A. Hofer Hochdrucktechnik GmbH.

**(+)-(3a*S*,7a*S*)-3a-Hydroxy-7a-methyl-hexahydro-indeno-1,5-dione (16)**

a. Reaction in acetonitrile.

A suspension of (*S*)-(-)-proline (7.4 mg, 0.064 mmol) in acetonitrile (60 µL) was stirred under argon at 23°C for 30 min and then **15**[18] (11.6 mg, 0.064 mmol) in acetonitrile (90 µL) was added. The reaction mixture was protected from light and stirred for 6 d at 20°C. Subsequently, (*S*)-(-)-proline was removed by filtration and the solvent was evaporated. FC (petrol-chloroform-methanol 8:4:0.1) furnished **16** (9.7 mg, 83 %) as a light-yellow, crystalline solid. Determination of ee: GLC (150°C): *ent*-**16**: ($t_R$ = 28.3 min, 34 %), **16**: ($t_R$ = 31.0 min, 66 %).

b. Reaction in dimethylformamide.

A suspension of (*S*)-(-)-proline (359.5 mg, 3.12 mmol) in dimethylformamide (10 mL) was stirred under argon at 14°C for 10 min and then **15** (18.70 g, 102.65 mmol) in dimethylformamide (90 mL) was added. The reaction mixture was protected from light and stirred for 3 d at 14°C. Subsequently, (*S*)-(-)-proline was removed by filtration and the solvent was evaporated. FC (petrol-ethyl acetate 1:1) furnished **16** (16.27 g, 87 %) as a light-yellow, crystalline solid.- $R_f$ (petrol-chloroform-methanol 8:8:1) = 0.14.- Determination of ee: GLC (150°C): *ent*-**16**: ($t_R$ = 28.3 min, 14 %), **16**: ($t_R$ = 31.0 min, 86 %).-$^1$H NMR (200 MHz, $CDCl_3$): δ = 1.24 (s, 3H, 7a-$CH_3$), 1.60 - 1.86 (m, 2H), 1.94 - 2.04 (m, 2H), 2.22 - 2.60 (m, 4H), 2.12 (broad s, 1H, OH), 2.60 (s, 2H, $CH_2$-4).

**(+)-(7a*S*)-Methyl-3,6,7,7a-tetrahydro-2*H*-indeno-1,5-dione (17)**

A solution of **16** (516.4 mg, 2.83 mmol) and anhydrous p-toluenesulfonic acid (49.7 mg, 0.29 mmol) in toluene (4.6 mL) was stirred in a Soxhlet apparatus containing molecular sieves (4Å, 2 g) for 5 h under reflux. After cooling the reaction mixture to ambient temperature the solvent was evaporated. FC (petrol-chloroform-methanol 8:4:0.2) furnished **17** (438.1 mg, 94 %).

Enantiomerically pure **17** was obtained by crystallization in diethyl ether at -18°C: From a solution of **17** with an ee of 83 % first the racemate crystallized at -18°C and the mother liquid contained enriched **17**. After two crystallizations from the combined mother liquids enantiomerically pure **17** could be obtained. From a solution of **17** with an ee of 93 % enantiomerically pure **17** could be obtained by two crystallizations at -18°C.- $R_f$ (petrol-chloroform-methanol 8:8:1) = 0.33.- Determination of ee: GLC (150°C): *ent*-**17** ($t_R$ = 6.6 min) was not detected, **17**: ($t_R$ = 7.0 min, 100 %).- $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.30 (s, 3H, 7a-$CH_3$), 1.73 - 3.06 (m, 8H, 4•$CH_2$), 5.95 (d, 1H, 4-H).- $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 21.04 (7a-$CH_3$), 27.29, 29.68, 33.37, 36.34, 49.16 (C-7a), 124.36 (C-4), 170.18 (C-3a), 198.57 (C-5), 216.94 (C-1).- $[\alpha]_D^{25°C}$ = +369 (c 1.00, $C_6H_6$), ref.[19] : $[\alpha]_D$ = +367 (c 1.00, $C_6H_6$).

**Reaction of diene 18 with 5-bromo-3-methyl-2(5*H*)-furanone (*rac*-2)**

a. Reaction in the presence of tetra-*n*-butylammonium bromide.

**18** (50.3 mg, 0.209 mmol), *rac*-**2** (37.5 mg, 0.212 mmol) and tetra-*n*-butylammonium bromide (39.0 mg, 0.117 mmol) were dissolved in dichloromethane (1 mL) under argon at 23°C. The reaction mixture was placed into a Teflon hose and submitted to 10.8 kbar in a high pressure autoclave at 22°C for 23 h. In the course of reaction the initially colourless solution turned blue. Subsequently, the solvent was evaporated. FC (petrol-toluene 1:1) furnished recovered **18** (1.7 mg, 3 %), **29** (14 mg, 28 %) as a light-blue oil, recovered, slightly impure *rac*-**2** (39.4 mg, ≈ 100 %) and 7.7 mg of a very polar, not identified side product.

b. Reaction without added tetra-*n*-butylammonium bromide.
A solution of **18** (49.4 mg, 0.206 mmol) and *rac*-**2** (87.1 mg, 0.492 mmol) in dichloromethane (1 mL) was submitted to 9 kbar in a high pressure autoclave under argon at 21°C for 4 d. In the course of reaction the initially colourless solution turned blue-green. Subsequently, the solvent was evaporated. FC (petrol-toluene 1.5:1) furnished **29** (5.4 mg, 11 %) as a light-blue oil, and 77.7 mg of slightly impure *rac*-**2** were recovered.

**Dimer 29**
$R_f$ (petrol-toluene 1:3) = 0.31.- $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.05 (s, 3H, $CH_3$), 1.15 (s, 3H, $CH_3$), 1.25 - 1.75 (m), 1.94 - 2.09 (m, 1H), 2.17 - 2.28 (dm, 1H, J = 12.1 Hz), 2.40 (dd, 1H, J = 15.7 Hz, 7.0 Hz; m, 1H), 2.66 (dd, 1H, J = 15.7 Hz, 7.0 Hz), 3.76 (s, 3H, $OCH_3$), 3.81 (s, 3H, $OCH_3$), 6.47 (s, 1H), 6.74 (m, 2H, $J_o$ = 8.8 Hz, arom.-$H^a$), 6.84 (m, 2H, $J_o$ = 8.8 Hz, arom.-$H^b$), 7.03 (m, 2H, $J_o$ = 8.8 Hz, arom.-$H^a$), 7.37 (m, 2H, $J_o$ = 8.8 Hz, arom.-$H^b$).- $^{13}$C NMR (50 MHz, APT, DEPT, $CDCl_3$): δ = 20.05 (q), 22.09 (t), 22.61 (t), 23.42 (t), 25.28 (t), 25.58 (q), 27.73 (t), 28.42 (t), 35.32 (t), 37.76 (t), 40.24 (t), 45.76 (d), 49.44 (s), 54.13 (s), 55.58 (q), 55.68 (q), 113.47 (d), 114.17 (d), 127.49 (d), 127.69 (d), 129.70 (s), 130.74 (d), 131.04 (s), 131.59 (s), 133.30 (s), 148.94 (s), 151.07 (s), 153.60 (s), 158.39 (s), 158.41 (s).- $C_{34}H_{40}O_2$ (480.69), FAB MS: m/z = 480.3 $[M+H-H]^+$, also a peak at m/z = 497.3 was detected.

**Reaction of diene 18 with 5-chloro-3-methyl-2(5*H*)-furanone (*rac*-24)**
**18** (46.1 mg, 0.192 mmol) and *rac*-**24**[20,21] (41.7 mg, 0.315 mmol) were dissolved in dichloromethane (500 µL) under argon. The reaction mixture was submitted to 11 kbar at 21°C for 3 d. In the course of reaction the initially colourless solution turned greenish black. Subsequently, the mixture was concentrated under reduced pressure. FC (petrol-ethyl acetate 10:1 → 2:1) furnished **29** (4.3 mg, 9 %) and recovered *rac*-**24** (39.1 mg, 94 %).

**Reaction of diene 18 with 5-hydroxy-3-methyl-2(5*H*)-furanone (*rac*-25)**
**18** (50.0 mg, 0.208 mmol) and *rac*-**25** (55.6 mg, 0.487 mmol) were dissolved in dichloromethane (300 µL) under argon at 23°C. The reaction mixture was submitted to 11 kbar at 22°C for 3 d. Subsequently, the solvent was evaporated. FC (petrol-toluene 3:1) furnished recovered diene **18** (41.3 mg, 83 %) and *rac*-**25** (55.2 mg, 100 %).

**Reaction of diene 18 with 3-methyl-2(5*H*)-furanone (26)**
To a vigorously stirred solution of 2-methyl-3-butenoic acid (1.5 mL, 1.45 g, 14.5 mmol) in dichloromethane (6 mL) a solution of bromine (745 µL, 2.32 g, 14.5 mmol) in dichloromethane (6 mL) was added dropwise within 1 h. When the bromine colour had faded, the solvent was removed under reduced pressure. The remaining residue was dissolved in dichloromethane (5 mL) and added dropwise to a solution of triethylamine (4.00 mL, 2.93 g, 29.00 mmol) in chloroform (5 mL). The reaction mixture was stirred under reflux for 4 h. On cooling to ambient temperature the mixture formed a precipitate which was removed by filtration. 3-Methyl-2(5*H*)-furanone (**26**) (1.27 g, 89 %) was obtained from the filtrate by solvent evaporation and high-vacuum distillation (43°C, 0.68 mbar).
**18** (11.3 mg, 0.047 mmol) and **26** (8.1 mg, 0.083 mmol) were dissolved in dichloromethane (70 µL) under argon at 23°C. The reaction mixture was submitted to 10 kbar at 21°C for 72 h. In the course of reaction the initially yellow solution became colourless. Subsequently, the solvent was evaporated. FC (petrol-ethyl acetate 10:1) furnished recovered **18** (10.1 mg, 90 %) and a cycloadduct (0.8 mg, 5 %) as a colourless solid.-

$R_f$ (petrol-ethyl acetate 1:1) = 0.57.- $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.40 (broad d, 3H, 7a-$CH_3$ or 8a-$CH_3$), 1.43 (s, 3H, 8a-$CH_3$ or 7a-$CH_3$), 3.15 (s, 1H), 3.81 - 3.84 (m, 5H, therein: s, 3H, $OCH_3$), 6.04 (d, 1H, $J_{(9,10)}$ = 5.9 Hz, 9-H or 10-H), 6.51 (d, 1H, $J_{(9,10)}$ = 5.9 Hz, 10-H or 9-H), 6.87 (d, 1H, J = 8.8 Hz, this signal could not be assigned), 6.93 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 8.8 Hz, $3^{Ar}$-H), 7.58 (m, 2H, $J_{(2^{Ar},3^{Ar})}$ = 8.8 Hz, $2^{Ar}$-H).- $C_{22}H_{26}O_3$ (338.45), MS: m/z (%) = 338 (9) [$M^{+\bullet}$], 266 (15), 251 (16), 240 (100) [RDA], 197 (12).

**Cycloaddition of maleic anhydride (19) and diene 18**

**18** (200.7 mg, 0.835 mmol) and **19** (106.3 mg, 1.084 mmol) were dissolved in dichloromethane (1.3 mL) under argon at 23°C, and left at 23°C for 1h. In the course of reaction the initially orange colour of the solution faded. The mixture was concentrated under reduced pressure. FC (toluene) yielded **20** (275.6 mg, 97 %) as a colourless, crystalline solid.

**(3b*S*)-8-(4-Methoxyphenyl)-7a-methyl-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno [1,2-*c*]furan-1,3-dione (20)**

$R_f$ (petrol-ethyl acetate 1:1) = 0.47.- M.p.: 182 - 183°C (petrol-dichloromethane).- $^1$H NMR (200 MHz, $CDCl_3$): δ = 0.71 - 0.84 (dm, 1H), 0.79 (s, 3H, 7a-$CH_3$), 1.16 - 1.63 (m), 1.68 - 1.81 (m, 1H), 1.95 - 2.04 (tm, 1H), 2.26 - 2.38 (dm, 1H), 3.41 (d, 1H, $J_{(8a,3a)}$ = 7.7 Hz, 8a-H or 3a-H), 3.83 (s, 3H, $OCH_3$), 4.27 (d, 1H, 3a-H or 8a-H), 6.23 (d, 1H, $J_{(9,10)}$ = 5.9 Hz, 9-H or 10-H), 6.28 (d, 1H, 10-H or 9-H), 6.94 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 8.8 Hz, $3^{Ar}$-H), 7.29 (m, 2H, $J_{(2^{Ar},3^{Ar})}$ = 8-9 Hz, $2^{Ar}$-H).- $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 15.51 (7a-$CH_3$), 21.29, 23.49, 26.31, 29.34, 50.07, 52.13, 55.75 ($OCH_3$), 62.25, 67.73, 69.18, 114.38 (C-$3^{Ar}$), 127.66 (C-$1^{Ar}$), 129.00 (C-$2^{Ar}$), 138.00 (C-10 or C-9), 139.52 (C-9 or C-10), 159.49 (C-$4^{Ar}$), 171.36 (C-1 or C-3), 171.80 (C-3 or C-1).- MS: m/z (%) = 338 (14) [$M^{+\bullet}$], 310 (6), 266 (17), 251 (16), 240 (100) [RDA], 225 (7).- IR (KBr): $\tilde{\nu}$ = 1852, 1776, 1612, 1516, 1450, 1259, 1181, 1091, 1025, 923 $cm^{-1}$.- UV (MeOH): $\lambda_{max}$ (ε [$10^3$ $cm^2$ $mol^{-1}$]) = 227 (15267), 276 (1900), 283 nm (1645).- $[\alpha]_D^{23°C}$ = -140 (c 0.60, $CHCl_3$), ref.[8]: $[\alpha]_D$ = -143 (c 0.60, $CHCl_3$).- CD (c 29.55 μmol $L^{-1}$, acetonitrile): $\lambda_{max}$ (Δε) = 224 (+5.6), 241 nm (-22.6).- HRMS: calcd for $C_{21}H_{23}O_4$ [M+H]$^+$: 339.1596, found: 339.1599.

**Cycloaddition of citraconic anhydride (23) and diene 18**

**18** (52.6 mg, 0.219 mmol) and **23** (30.1 mg, 0.269 mmol) were dissolved in dichloromethane (500 μL) under argon at 23°C. The reaction mixture was submitted to 10 kbar at 21°C for 72 h. In the course of reaction the initially orange colour of the solution faded. The solvent was evaporated. FC (petrol → petrol-ethyl acetate 6:1) furnished **27** (57.8 mg, 75 %) as a colourless, crystalline solid and recovered starting material **18** (10.7 mg, 20 %).

**(3b*S*)-8-(4-Methoxyphenyl)-7a,8a-dimethyl-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno[1,2-*c*]furan-1,3-dione (27)**

$R_f$ (petrol-ethyl acetate 1:1) = 0.49.- M.p.: 111 - 113°C (decomp., petrol-dichloromethane).- $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.40 (d, 3H, J = 1 Hz, 8a-$CH_3$ or 7a-$CH_3$), 1.43 (s, 3H, 7a-$CH_3$ or 8a-$CH_3$), 1.23 - 1.78 (m), 1.83 - 2.05 (m, 1H), 2.13 - 2.25 (dm, 1H), 3.15 (s, 1H, 3a-H), 3.82 (s, 3H, $OCH_3$), 6.04 (d, 1H, $J_{(9,10)}$ = 5.9 Hz, 9-H or 10-H), 6.51 (d, 1H, 10-H or 9-H), 6.92 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 9.2 Hz, $3^{Ar}$-H), 7.58 (m, 2H, $2^{Ar}$-H).- $^{13}$C NMR (50 MHz, APT, $CDCl_3$): δ = 18.08 (-), 19.81 (-), 20.78 (+), 22.93 (+), 24.82 (+), 31.24 (+), 55.68 (-), 57.26 (-), 61.16 (+), 61.99 (+), 65.72 (+), 68.79 (+), 114.27 (-) (C-$3^{Ar}$), 128.74 (+) (C-$1^{Ar}$), 130.41 (-) (C-$2^{Ar}$), 136.53 (-) (C-10 or C-9), 142.93 (-) (C-9 or C-10), 159.08 (+) (C-$4^{Ar}$), 171.87 (+) (C-3

or C-1), 176.05 (+) (C-1 or C-3).- MS: m/z (%) = 352 (0.43) [$M^{+\cdot}$], 240 (100) [RDA], 225 (14), 212 (9), 197 (9), 160 (8).- IR (KBr): $\tilde{\nu}$ = 1848, 1771, 1614, 1519, 1451, 1252, 1189, 1043, 1013, 917 $cm^{-1}$.- UV (MeOH): $\lambda_{max}$ ($\varepsilon$ [$10^3$ $cm^2$ $mol^{-1}$]) = 204 (end absorption, 14703), 229 (13349), 275 (1410), 282 nm (1200).- CD (c 28.37 µmol $L^{-1}$, acetonitrile): $\lambda_{max}$ ($\Delta\varepsilon$) = 202 (-14.1), 214 (+9.0), 242 nm (-19.9).- HRMS: calcd for $C_{22}H_{25}O_4$ $[M+H]^+$: 353.1753, found: 353.1753.

**Reduction of cycloadduct 20**

a. with L-selectride.

To a solution of **20** (14.9 mg, 0.044 mmol) in tetrahydrofuran (500 µL) at -78°C under argon a solution of L-selectride in tetrahydrofuran (1 M, 45 µL, 0.045 mmol) was added. After stirring for 45 min the reaction mixture was quenched with sat. aq. ammonium chloride solution (500 µL) and diluted with dichloromethane. Usual workup ($CH_2Cl_2$) and FC (petrol-ethyl acetate 5:1) yielded **22a** (10.5 mg, 70 %) and **21** (3.4 mg, 23 %) as colourless, crystalline solids.

b. with lithium tri-*tert*-butoxyaluminium hydride.

To a suspension of lithium tri-*tert*-butoxyaluminium hydride (91.9 mg, 0.375 mmol) in tetrahydrofuran (1.0 mL) a solution of **20** (101.0 mg, 0.298 mmol) in tetrahydrofuran (5 mL) was added under argon at -40°C. The reaction mixture was allowed to warm slowly to ambient temperature. After stirring for 2.5 h the mixture was quenched with sat. aq. ammonium chloride solution. Usual workup ($CH_2Cl_2$) and FC (petrol-ethyl acetate 5:1 → 3:1) furnished **22a** (76.7 mg, 76 %) and **21** (7.9 mg, 8 %) as colourless, crystalline solids.

**(3b*S*)-1*t*-Hydroxy-8-(4-methoxyphenyl)-7a-methyl-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno[1,2-*c*]furan-3(1*H*)-one (22a)**

$R_f$ (petrol-ethyl acetate 1:1) = 0.36.- M.p.: 179 - 181°C (decomp., petrol-dichloromethane).- $^1$H NMR (200 MHz, homodecoupling, NOED, $CDCl_3$): δ = 0.68 - 0.95 (dm, 1H), 0.76 (s, 3H, 7a-$CH_3$), 1.21 - 1.54 (m, 4H), 1.62 - 1.74 (m, 1H), 1.86 - 2.08 (tm, 1H), 2.20 - 2.31 (dm, 1H), 3.22 (d, 1H, 3a-H), 3.70 (dd, 1H, $J_{(8a,3a)}$ = 8.4 Hz, J = 1.5 Hz, 8a-H), 3.82 (s, 3H, $OCH_3$), 4.17 (m, 1H, OH), 5.20 (m, 1H, 1-H), 6.07 (d, 1H, $J_{(10,9)}$ = 5.9 Hz, 10-H), 6.14 (d, 1H, 9-H), 6.91 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 8.8 Hz, $3^{Ar}$-H), 7.26 (m, 2H, $2^{Ar}$-H).- $^{13}$C NMR (50 MHz, APT, $CDCl_3$): δ = 15.21 (-) (7a-$CH_3$), 21.34 (+), 23.76 (+), 26.16 (+), 29.21 (+), 52.40 (-) (C-3a or C-8a), 53.46 (-) (C-8a or C-3a), 55.75 (-) ($OCH_3$), 62.01 (+), 66.56 (+), 66.74 (+), 100.08 (-) (C-1), 114.35 (-) ($C\text{-}3^{Ar}$), 129.27 (-) ($C\text{-}2^{Ar}$), 129.67 (+) ($C\text{-}1^{Ar}$), 137.05 (-) (C-10 or C-9), 140.16 (-) (C-9 or C-10), 159.20 (+) ($C\text{-}4^{Ar}$), 178.33 (+) (C-3).- MS: m/z (%) = 340 (51) [$M^{+\cdot}$], 266 (21), 251 (22), 240 (100) [RDA], 225 (19), 212 (15), 188 (30).- IR (KBr): $\tilde{\nu}$ = 1745, 1616, 1516, 1461, 1251, 1182, 1127 $cm^{-1}$.- UV (MeOH): $\lambda_{max}$ ($\varepsilon$ [$10^3$ $cm^2$ $mol^{-1}$]) = 203 (end absorption, 11828), 227 (10959), 277 (1168), 283 nm (986).- CD (c 14.69 µmol $L^{-1}$, acetonitrile): $\lambda_{max}$ ($\Delta\varepsilon$) = 206 (+19.7), 225 nm (-25.8).- $C_{21}H_{24}O_4$ (340.42): calcd: C 74.09, H 7.11, found: C 73.62, H 6.92.

**(3b*S*)-3*c*-Hydroxy-8-(4-methoxyphenyl)-7a-methyl-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno[1,2-*c*]furan-1(3*H*)-one (21)**

$R_f$ (petrol-ethyl acetate 1:1) = 0.33.- M.p.: 179 - 181°C (decomp., petrol-dichloromethane).- $^1$H NMR (200 MHz, $CDCl_3$): δ = 0.63 - 0.75 (m, 1H), 0.77 (s, 3H, 7a-$CH_3$), 1.20 - 1.55 (m), 1.62 - 1.77 (m, 2H), 1.85 - 2.06 (m, 2H), 2.83 (dd, 1H, $J_{(3a,8a)}$ = 8.1 Hz, J = 1.5 Hz, 3a-H), 3.81 (s, 3H, $OCH_3$), 4.11 (d, 1H, 8a-H, 1H, OH), 5.27 (m, 1H, 3-H), 6.09 (d, 1H, $J_{(9,10)}$ = 5.9 Hz, 10-H or 9-H), 6.19 (d, 1H, 9-H or 10-H), 6.90 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 8.8 Hz, $3^{Ar}$-H), 7.28 (m, 2H, $2^{Ar}$-H).- $C_{21}H_{24}O_4$ (340.42), MS: m/z (%) = 340 (90) [$M^{+\cdot}$], 266

(41), 251 (43), 240 (100) [RDA], 225 (20), 211 (20), 197 (28), 188 (51).- IR (KBr): $\tilde{\nu}$ = 1752, 1613, 1515, 1316, 1284, 1243, 1180, 1114, 944 $cm^{-1}$.- UV (EtOH): $\lambda_{max}$ ($\varepsilon$ [$10^3$ $cm^2$ $mol^{-1}$]) = 206 (16826), 228 (12915), 275 nm (1632).- CD (c 14.69 µmol $L^{-1}$, acetonitrile): $\lambda_{max}$ ($\Delta\varepsilon$) = 205 (-2.9), 217 (+0.9), 234 nm (-19.6).

**Reduction of cycloadduct 27 with lithium tri-*tert*-butoxyaluminium hydride**

To a suspension of lithium tri-*tert*-butoxyaluminium hydride (16.9 mg, 0.069 mmol) in tetrahydrofuran (200 µL) a solution of **27** (20.2 mg, 0.057 mmol) in tetrahydrofuran (400 µL) was added under argon at -40°C. The reaction mixture was allowed to warm slowly to ambient temperature. After stirring for 6 h the mixture was quenched with sat. aq. ammonium chloride solution. Usual workup ($CH_2Cl_2$) and FC (petrol-ethyl acetate 5:1) furnished **28a** (19.4 mg, 96 %) as a colourless, crystalline solid.

**(3b*S*)-3*t*-Hydroxy-8-(4-methoxyphenyl)-7a,8a-dimethyl-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno[1,2-*c*]furan-1(3*H*)-one (28a)**

$R_f$ (petrol-ethyl acetate 1:1) = 0.42.- M.p.: 136 - 138°C (petrol-dichloromethane).- $^1$H NMR (200 MHz, $D_2O$-exchange, NOED, $CDCl_3$): $\delta$ = 0.82 - 0.97 (m, 2H), 1.22 - 1.73 (m), 1.40 (d, 3H, 8a-$CH_3$ or 7a-$CH_3$), 1.41 (s, 3H, 7a-$CH_3$ or 8a-$CH_3$), 1.85 - 1.97 (dm, 2H), 2.61 (s, 1H, 3a-H), 3.68 - 3.78 (m, 1H, OH), 3.82 (s, 3H, $OCH_3$), 5.29 (d, 1H, J = 3.3 Hz, 3-H), 5.92 (d, 1H, $J_{(9,10)}$ = 5.9 Hz, 9-H), 6.37 (d, 1H, 10-H), 6.90 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 8.8 Hz, $3^{Ar}$-H), 7.61 (m, 2H, $2^{Ar}$-H).- $^1$H NMR (200 MHz, H,H COSY, NOED, $C_6D_6$): $\delta$ = 1.04 (s, 3H, 8a-$CH_3$), 1.48 (s, 3H, 7a-$CH_3$), 1.76 - 1.96 (m, 1H), 2.47 (m, 1H, 3a-H), 3.37 (s, 3H, $OCH_3$), 4.98 (m, 1H, 3-H), 5.60 (d, 1H, $J_{(9,10)}$ = 5.9 Hz, 9-H), 6.45 (d, 1H, 10-H), 6.88 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 8.8 Hz, $3^{Ar}$-H), 7.77 (m, 2H, $J_{(2^{Ar},3^{Ar})}$ = 8.8 Hz, $2^{Ar}$-H).- $^{13}$C NMR (50 MHz, $CDCl_3$): $\delta$ = 18.17, 21.14, 21.36, 22.91, 25.09, 31.21, 55.64 ($OCH_3$), 58.39, 58.92, 64.26, 68.88, 97.37 (C-3), 113.96 (C-$3^{Ar}$), 130.12 (C-$1^{Ar}$), 130.65 (C-$2^{Ar}$), 135.53 (C-10 or C-9), 142.04 (C-9 or C-10), 158.69 (C-$4^{Ar}$), 181.27 (C-1).- MS: m/z (%) = 354 (0.9) [$M^{+\cdot}$], 240 (100) [RDA], 225 (14), 212 (9), 197 (10).- IR (KBr): $\tilde{\nu}$ = 1747, 1614, 1517, 1444, 1292, 1252, 1185, 1109, 963 $cm^{-1}$.- UV (EtOH): $\lambda_{max}$ ($\varepsilon$ [$10^3$ $cm^2$ $mol^{-1}$]) = 203 (13301), 229 (11553), 274 nm (1106).- CD (c 14.11 µmol $L^{-1}$, acetonitrile): $\lambda_{max}$ ($\Delta\varepsilon$) = 204 (-17.7), 216 (+0.4), 233 nm (-23.3).- HRMS: calcd for $C_{22}H_{27}O_4$ $[M+H]^+$: 355.1909, found: 355.1889.

**OH→Cl exchange of 22a**

a. Reaction with thionyl chloride in pyridine.

To a solution of **22a** (25.0 mg, 0.073 mmol) in pyridine (60 µL, 58.8 mg, 0.743 mmol) thionyl chloride (107 µL, 175 mg, 1.47 mmol) was added under argon at 0°C. After stirring for 7 h the mixture was allowed to warm to ambient temperature and stirred for another 2 h. Then excess thionyl chloride was removed under reduced pressure and, subsequently, the precipitated pyridine•HCl salt was removed by filtration through silica gel. FC (petrol-ethyl acetate 8:1) furnished **22b** (16.9 mg, 64 %) and **22c** (3.5 mg, 13 %) as colourless, crystalline solids.

b. Reaction with thionyl chloride in dichloromethane.

To a solution of **22a** (25.0 mg, 0.073 mmol) in dichloromethane (500 µL) thionyl chloride (53 µL, 17 mg, 0.73 mmol) was added under argon at 23°C. After stirring the reaction mixture for 1 d excess thionyl chloride and the solvent were removed under reduced pressure. FC (petrol → petrol-ethyl acetate 9:1) furnished **22b** (25.6 mg, 98 %) and **22c** (0.4 mg, 1 %) as colourless, crystalline solids.

**(3b*S*)-1*t*-Chloro-8-(4-methoxyphenyl)-7a-methyl-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno[1,2-*c*]furan-3(1*H*)-one (22b)**

$R_f$ (petrol-ethyl acetate 1:1) = 0.61.- M.p.: 154 - 156°C (petrol-dichloromethane).- $^1$H NMR (200 MHz, $CDCl_3$): δ = 0.71 - 0.83 (m, 1H), 0.78 (s, 3H, 7a-$CH_3$), 1.08 - 1.55 (m, 4H), 1.66 - 1.77 (m, 1H), 1.86 - 2.06 (tm, 1H), 2.24 - 2.35 (dm, 1H), 3.29 (d, 1H, 3a-H), 3.83 (s, 3H, $OCH_3$), 4.16 (dd, 1H, $J_{(8a,3a)}$ = 8.4 Hz, $J_{(8a,1)}$ = 1.5 Hz, 8a-H), 5.68 (d, 1H, 1-H), 6.12 (d, 1H, $J_{(10,9)}$ = 5.9 Hz, 10-H), 6.21 (d, 1H, 9-H), 6.94 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 8.8 Hz, $3^{Ar}$-H), 7.24 (m, 2H, $2^{Ar}$-H).- $^{13}$C NMR (50 MHz, APT, $CDCl_3$):δ = 15.21 (-) (7a-$CH_3$), 21.26 (+), 23.69 (+), 26.05 (+), 29.12 (+), 51.69 (-), 55.77 (-) ($OCH_3$), 56.39 (-), 62.62 (+), 66.77 (+), 68.15 (+), 90.42 (-) (C-1), 114.56 (-) (C-$3^{Ar}$), 128.71 (C-$1^{Ar}$), 129.20 (-) (C-$2^{Ar}$), 136.30 (-) (C-10), 140.89 (-) (C-9), 159.47 (+) (C-$4^{Ar}$), 175.93 (+) (C-3).- MS: m/z (%) = 360 (32) / 358 (93) [$M^{+\cdot}$], 345 (10) / 343 (29), 277 (14), 251 (16), 240 (100) [RDA], 197 (26), 165 (18), 121 (18).- IR (KBr): $\tilde{\nu}$ = 1793, 1614, 1515, 1463, 1252, 1184, 1151, 1029, 986, 720 $cm^{-1}$.- UV (MeOH): $\lambda_{max}$ (ε [$10^3$ $cm^2$ $mol^{-1}$]) = 203 (6298), 227 (6180), 276 nm (661).- CD (c 27.87 μmol $L^{-1}$, acetonitrile): $\lambda_{max}$ (Δε) = 208 (+21.4), 227 nm (-21.9).- $C_{21}H_{23}O_3Cl$ (358.86): calcd: C 70.29, H 6.46, Cl 9.88, found: C 70.33, H 6.58, Cl 9.95.

**(3b*S*)-1*c*-Chloro-8-(4-methoxyphenyl)-7a-methyl-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno[1,2-*c*]furan-3(1*H*)-one (22c)**

$R_f$ (petrol-ethyl acetate 1:1) = 0.50.- M.p.: 183 - 186°C (decomp., petrol-dichloromethane).- $^1$H NMR (200 MHz, $CDCl_3$): δ = 0.52 - 0.66 (dm, 1H), 0.80 (s, 3H, 7a-$CH_3$), 1.18 - 1.60 (m), 1.64 - 1.76 (m, 1H), 1.87 - 2.06 (tm, 1H), 2.26 - 2.37 (dm, 1H), 3.30 (d, 1H, $J_{(3a,8a)}$ = 8.5 Hz, 3a-H), 3.82 (s, 3H, $OCH_3$), 4.24 (dd, 1H, 8a-H), 6.17 (d, 1H, $J_{(9,10)}$ = 5.9 Hz, 10-H or 9-H), 6.32 (d, 1H, $J_{(1,8a)}$ = 7.6 Hz, 1-H), 6.54 (d, 1H, 9-H or 10-H), 6.91 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 8.8 Hz, $3^{Ar}$-H), 7.20 (m, 2H, $2^{Ar}$-H).- $C_{21}H_{23}O_3Cl$ (358.86), MS: m/z (%) = 360 (33) / 358 (93) [$M^{+\cdot}$], 345 (7) / 343 (18), 265 (15), 251 (21), 240 (100) [RDA], 211 (15), 197 (29), 185 (20), 165 (15).- IR (KBr): $\tilde{\nu}$ = 1789, 1612, 1515, 1463, 1248, 1181, 1159, 1032, 985, 795 $cm^{-1}$.- UV (MeOH): $\lambda_{max}$ (ε [$10^3$ $cm^2$ $mol^{-1}$]) = 203 (end absorption, 10359), 227 (8943), 277 nm (1276).- CD (c 13.93 μmol $L^{-1}$, acetonitrile): $\lambda_{max}$ (Δε) = 197 (-11.7), 207 (+7.7), 228 nm (-18.0).

**(3a*S*,6a*R*)-3,3a,4,6a-Tetrahydro-cyclopenta[*b*]furan-2-one (31)**

To a solution of **30** (837.4 mg, 3.32 mmol) in tetrahydrofuran (5 mL) DBU (600 μL, 612 mg, 4.02 mmol) was added under argon. The reaction mixture was stirred for 2 h at 50°C and then for 90 min at 70°C. On cooling to ambient temperature the mixture formed a colourless precipitate which was dissolved by addition of water. Dichloromethane was added and the aqueous layer was extracted with dichloromethane for six times. The combined organic layers were washed with sodium chloride solution and again the aqueous layer was extracted with dichloromethane. The combined organic layers were dried ($NaSO_4$), filtered and concentrated under reduced pressure. FC (petrol-ethyl acetate-*i*-propanol 6:1:1) furnished **31** (359.0 mg, 87 %) as a colourless oil.- $R_f$ (petrol-ethyl acetate-*i*-propanol 2:1:1) = 0.46.- Determination of ee: GLC (120°C): *ent*-**31**: ($t_R$ = 14.3 min, 0.3 %), **31**: ($t_R$ = 15.5 min, 99.7 %).- $[\alpha]_D^{20°C}$ = +134 (c 1.00, $CH_2Cl_2$), ref.[15]: $[\alpha]_D^{20°C}$ = +132.6 (c 0.97, $CH_2Cl_2$).

**(3a*S*,6a*R*)-3-Hydroxymethylene-3,3a,4,6a-tetrahydro-cyclopenta[*b*]furan-2-one (32)**

To sodium hydride (592.9 mg, 55-60 per cent dispersion in mineral oil, washed with tetrahydrofuran) **31** (359.0 mg, 2.89 mmol) in tetrahydrofuran (5 mL), and subsequently, formic acid ethylester (2.40 mL, 2.18 g, 29.5 mmol) were added under argon. After stirring for 20 h at 23°C the reaction mixture was quenched with

5 per cent HCl. Dichloromethane was added and the aqueous layer was extracted with dichloromethane for five times. The combined organic layers were washed with water, with sat. aq. sodium chloride solution and with water, dried ($NaSO_4$), filtered and concentrated under reduced pressure. FC (petrol-ethyl acetate 3:2) furnished **32** (342.0 mg, 78 %) as a colourless, crystalline solid.- $R_f$ (petrol-ethyl acetate 1:2) = 0.27.- $[\alpha]_D^{22°C}$ = -100 (c 0.40, $CHCl_3$).- CD (c 32.86 µmol $L^{-1}$, acetonitrile): $\lambda_{max}$ ($\Delta\varepsilon$) = 195 (+14.4), 237 (-6.5), 271 nm (-2.4).

**(3b*S*)-8-(4-Methoxyphenyl)-7a-methyl-1*t*-((3*E*,3a*S*-cis)-2-oxo-4,6a-dihydro-2*H*-cyclopenta[*b*]furan-3(3a*H*)-ylidenemethoxy)-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno[1,2-*c*]furan-3(1*H*)-one (34b)**

**32** (17.1 mg, 0.112 mmol) and potassium *tert*-butoxide (10.3 mg, 0.092 mmol) were dissolved in tetrahydrofuran (500 µL) under argon at 20°C. The mixture was stirred for 15 min. After about 5 min a colourless precipitate formed. Then a solution of **22b** (28.9 mg, 0.080 mmol) in tetrahydrofuran (1.1 mL) was added. After stirring for 28 h at 20°C the reaction mixture was quenched with water. Usual workup ($CH_2Cl_2$) and FC (petrol-ethyl acetate 5:1) furnished **22b** (0.7 mg, 3 %) and **34b** (36.8 mg, 96 %) as colourless solids.- $R_f$ (petrol-ethyl acetate 1:1) = 0.43.- M.p.: 95 - 99°C (petrol-dichloromethane).- $^1$H NMR (200 MHz, H,H COSY, NOED, $CDCl_3$): δ = 0.70 - 0.82 (m, 1H), 0.81 (s, 3H, 7a-$CH_3$), 1.11 - 1.57 (m), 1.65 - 1.77 (m, 1H), 1.88 - 2.06 (m, 1H), 2.23 - 2.35 (dm, 1H), 2.43 - 2.60 (dddd, 1H, $J_{(4',4^{*'})}$ = 17.6 Hz, $J_{(4',3a')}$ = 2.6 Hz, J = 5.1 Hz, 2.6 Hz, 4'-H), 2.88 - 3.07 (ddddd, 1H, $J_{(4^{*'},3a')}$ = 8.8 Hz, J ≈ 1 Hz, 4*'-H), 3.26 (d, 1H, 3a-H), 3.67 - 3.80 (dddd, 1H, 3a'-H), 3.82 (s, 3H, $OCH_3$), 3.87 (dd, 1H, $J_{(8a,3a)}$ = 8.4 Hz, $J_{(8a,1)}$ = 1.5 Hz, 8a-H), 5.19 (d, 1H, 1-H), 5.49 - 5.59 (dm, 1H, $J_{(6a',3a')}$ = 7.3 Hz, 6a'-H), 5.84 - 5.92 (ddd, 1H, $J_{(6',5')}$ = 5.5 Hz, J = 4.4 Hz, 2.2 Hz, 6'-H), 6.04 - 6.11 (m, 1H, 5'-H), 6.15 (d, 1H, $J_{(10,9)}$ = 5.8 Hz, 10-H), 6.22 (d, 1H, 9-H), 6.91 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 8.8 Hz, $3^{Ar}$-H), 7.20 (m, 2H, $2^{Ar}$-H), 7.29 (d, 1H, $J_{(7',3a')}$ = 2.6 Hz, 7'-H).- $^{13}$C NMR (50 MHz, DEPT 45, C,H COSY, $CDCl_3$): δ = 15.30 (q) (7a-$CH_3$), 21.25 (t), 23.68 (t), 26.08 (t), 29.06 (t), 37.86 (d) (C-3a'), 39.14 (t) (C-4'), 51.10 (d) (C-8a), 52.58 (d) (C-3a), 55.79 (q) ($OCH_3$), 62.47 (s) (C-3b or C-7a or C-8), 66.82 (s) (C-3b or C-7a or C-8), 87.94 (d) (C-6a'), 104.87 (d) (C-3), 113.36 (s) (C-3'), 114.61 (d) ($C\text{-}3^{Ar}$), 128.73 (s) ($C\text{-}1^{Ar}$), 128.93 (d) ($C\text{-}2^{Ar}$), 129.45 (d) (C-6'), 136.77 (d) (C-10), 137.40 (d) (C-5'), 140.62 (d) (C-9), 151.99 (d) (C-7'), 159.51 (s) ($C\text{-}4^{Ar}$), 171.74 (s) (C-2'), 176.07 (s) (C-1).- FAB MS: m/z = 497.2 $[M+Na]^+$, 475.2 $[M+H]^+$, 460.1, 323.1 $[M+H\text{-}C_8H_8O_3]^+$, 240.1 [RDA].- IR (KBr): $\tilde{\nu}$ = 1782, 1748, 1679, 1616, 1515, 1349, 1250, 1186, 1154, 1075, 1016, 972 $cm^{-1}$.- UV (EtOH): $\lambda_{max}$ (ε [$10^3$ $cm^2$ $mol^{-1}$]) = 228 (21520), 276 (2127), 283 nm (1881).- CD (c 10.54 µmol $L^{-1}$, acetonitrile): $\lambda_{max}$ ($\Delta\varepsilon$) = 194 (-19.0), 205 (+15.8), 224 (-12.7), 238 nm (+9.3).- HRMS: calcd for $C_{29}H_{31}O_6$ $[M+H]^+$: 475.2120, found: 475.2119.

**2-Oxo-(3aS)-(3a*r*,6a*c*)-3a,6a-dihydro-4*H*-cyclo-penta[*b*]furan-3-(*E*)-ylidene-methyl-toluene 4-sulfonate (33)**

To a solution of hydroxymethylene lactone **32** (24.8 mg, 0.163 mmol) in tetrahydrofuran (1.25 mL) triethylamine (91 µL, 66 mg, 0.651 mmol) was added under argon at -30°C and subsequently a solution of p-toluenesulfonyl chloride (39.6 mg, 0.208 mmol) in tetrahydrofuran (250 µL). After stirring for 1 h the mixture was quenched with sat. aq. sodium hydrogen carbonate solution. Usual workup ($CH_2Cl_2$) and FC (petrol-ethyl acetate 6:1) furnished **33** (47.7 mg, 96 %) as a colourless, crystalline solid.- $R_f$ (petrol-ethyl acetate 1:1) = 0.42.- $^1$H NMR (200 MHz, homodecoupling, $CDCl_3$): δ = 2.18 - 2.31 (dddd, 1H, $J_{(4,4^*)}$ = 17.6 Hz, $J_{(4,3a)}$ = 2.6 Hz, J = 5.1 Hz, 2.6 Hz, 4-H), 2.47 (s, 3H, $1^{Ar}$-$CH_3$), 2.78 - 2.95 (ddddd, 1H, $J_{(4^*,3a)}$ = 9.2 Hz, J = 2.2 Hz, 2.2 Hz, 1.1 Hz, 4*-H), 3.57 - 3.71 (dddd, 1H, 3a-H), 5.46 - 5.55 (dm, 1H, $J_{(6a,3a)}$ =

7.7 Hz, 6a-H), 5.78 - 5.86 (ddd, 1H, $J_{(6,5)}$ = 5.5 Hz, J = 2.2 Hz, 6-H), 5.95 - 6.03 (m, 1H, 5-H), 7.40 (m, 2H, arom.-H), 7.59 (d, 1H, $J_{(7,3a)}$ = 2.9 Hz, 7-H), 7.82 (m, 2H, arom.-H).- $^{13}$C NMR (50 MHz, APT, $CDCl_3$): δ = 22.25 (-) ($1^{Ar}$-$CH_3$), 37.81 (-) (C-3a), 39.18 (+) (C-4), 88.44 (-) (C-6a), 119.85 (+) (C-3), 128.56 (-) (C-$2^{Ar}$), 128.83 (-) (C-6), 130.91 (-) (C-$3^{Ar}$), 132.23 (+) (C-$1^{Ar}$), 137.94 (-) (C-5), 144.41 (-) (C-7), 147.07 (+) (C-$4^{Ar}$), 170.37 (+) (C-2).- $C_{15}H_{14}O_5S$ (306.33), MS: m/z (%) = 306 (3) [$M^{+\cdot}$], 242 (6), 240 (7), 155 (66), 134 (79), 91 (100).- CD (c 16.32 μmol $L^{-1}$, acetonitrile): $\lambda_{max}$ (Δε) = 207 (+4.4), 227 (-3.3), 268 (-1.3), 275 nm (-1.5).

**Reaction of 22a with *rac*-33 in the presence of sodium hydride**

To a suspension of sodium hydride (55-60 per cent dispersion in mineral oil, 2.8 mg, 0.064 mmol) in tetrahydrofuran (100 μL) a solution of **22a** (15.2 mg, 0.045 mmol) in tetrahydrofuran (500 μL) was added dropwise under argon at 23°C. After stirring for 15 min the reaction suspension was cooled down to 0°C and a solution of *rac*-**33** (13.7 mg, 0.045 mmol) in tetrahydrofuran (500 μL) was added. After stirring for 24 h at 0°C and 4 d at 23°C the suspension (colour change to pale-yellow) was quenched with 5 per cent aqueous HCl (1 mL). Usual workup and FC (petrol-ethyl acetate 6:1) furnished **34a,b** (5.9 mg, 28 %), 6.4 mg of mixture of **34a,b** and **22a**, recovered **22a** (1.5 mg, 10 %), *rac*-**35** (0.6 mg) and *rac*-**36** (1.1 mg). *Rac*-**35** and *rac*-**36** were identified by TLC-comparision (petrol-ethyl acetate 1:1) with authentic samples.[15] HPLC (LiChrosorb Si 60, 10 μm; L = 250 mm, ID = 20 mm, petrol-ethyl acetate 2:1 → ethyl acetate; 10 mL $min^{-1}$, 10 bar, UV detection: λ = 226 nm) separated the **34a,b**-**22a** mixture to yield **34a,b** (4.0 mg, 19 %) and **22a** (2.1 mg, 14 %).

**OH→Cl exchange with 28a**

a. Reaction with thionyl chloride in pyridine.

A solution of **28a** (10.0 mg, 0.028 mmol) in pyridine (23 μL, 22.5 mg, 0.285 mmol) was cooled to 0°C under argon and thionyl chloride (31 μL, 51 mg, 0.43 mmol) was added. After 25 h excess thionyl chloride was removed under reduced pressure and the precipitated pyridine•HCl salt was removed by filtration through silica gel. FC (petrol-ethyl acetate 10:1) furnished **28b** (5.2 mg, 50 %) as a colourless oil and **28c** (2.5 mg, 25 %) as a colourless, crystalline solid.

b. Reaction with thionyl chloride in dichloromethane.

To a solution of **28a** (10.0 mg, 0.0282 mmol) in dichloromethane (200 μL) thionyl chloride (20 μL, 34 mg, 0.28 mmol) was added under argon at 23°C. After stirring the reaction mixture for 9 h excess thionyl chloride and the solvent were removed under reduced pressure. FC (petrol → petrol-ethyl acetate 9:1) furnished **28b** (10.1 mg, 96 %) as a colourless oil and **28c** (0.3 mg, 3 %) as a colourless, crystalline solid.

**(3b*S*)-3*t*-Chloro-8-(4-methoxyphenyl)-7a,8a-dimethyl-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno[1,2-*c*]furan-1(3*H*)-one (28b)**

$R_f$ (petrol-ethyl acetate 1:1) = 0.66.- $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.21 - 1.51 (m), 1.43 (d, 3H, J ≈ 1 Hz, 8a-$CH_3$ or 7a-$CH_3$), 1.48 (s, 3H, 7a-$CH_3$ or 8a-$CH_3$), 1.65 - 1.73 (m, 1H), 1.85 - 1.98 (m, 2H), 3.05 (s, 1H, 3a-H), 3.83 (s, 1H, $OCH_3$), 5.84 (d, 1H, J ≈ 1 Hz, 3-H), 5.94 (d, 1H, $J_{(9,10)}$ = 5.9 Hz, 9-H), 6.40 (d, 1H, 10-H), 6.92 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 9.1 Hz, $3^{Ar}$-H), 7.59 (m, 2H, $2^{Ar}$-H).- $^{13}$C NMR (200 MHz, APT, $CDCl_3$): δ = 18.14 (-), 20.69 (-) (7a-$CH_3$ and 8a-$CH_3$), 20.91 (+), 22.69 (+), 24.90 (+), 31.15 (+), 55.60 (-) ($OCH_3$), 59.55 (+), 59.76 (+), 62.73 (-) (C-3a), 64.47 (+), 69.32 (+), 88.87 (-) (C-3), 114.10 (-) (C-$3^{Ar}$), 129.45 (+) (C-$1^{Ar}$), 130.60 (-) (C-$2^{Ar}$), 134.85 (-) (C-9), 142.70 (-) (C-10), 158.94 (+) (C-$4^{Ar}$), 179.51 (+) (C-1).- FAB MS:

m/z = 373 $[M+H]^+$, 371.2, 337.2 $[M+H-HCl]^+$, 327.0, 240.1 [RDA].- IR (KBr): $\tilde{\nu}$ = 1786, 1616, 1516, 1254, 1034, 1006 $cm^{-1}$.- CD (c 26.82 µmol $L^{-1}$, acetonitrile): $\lambda_{max}$ ($\Delta\varepsilon$) = 205 (-3.0), 217 (+1.2), 234 nm (-13.0).- HRMS: calcd for $C_{22}H_{24}O_3Cl$ $[M+H-H_2]^+$: 371.1414, found: 371.1421.

**(3b*S*)-3*c*-Chloro-8-(4-methoxyphenyl)-7a,8a-dimethyl-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno[1,2-*c*]furan-1(3*H*)-one (28c)**

$R_f$ (petrol-ethyl acetate 1:1) = 0.63.- $^1H$ NMR (200 MHz, $CDCl_3$): δ = 1.15 - 1.75 (m), 1.35 (s, 3H, 8a-$CH_3$ or 7a-$CH_3$), 1.41 (d, 3H, J ≈ 1 Hz, 7a-$CH_3$ or 8a-$CH_3$), 1.85 - 2.05 (m, 1H), 2.45 - 2.55 (m, 1H), 3.04 (d, 1H, $J_{(3a,3)}$ = 7.0 Hz, 3a-H), 3.80 (s, 3H, $OCH_3$), 6.25 (d, 1H, 3-H), 6.31 (d, 1H, $J_{(9,10)}$ = 5.9 Hz, 9-H or 10-H), 6.44 (d, 1H, 10-H or 9-H), 6.90 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 9.0 Hz, $3^{Ar}$-H), 7.61 (m, 2H, $2^{Ar}$-H).- $C_{22}H_{25}O_3Cl$ (372.89), MS: m/z (%) = 372 (< 0.1) $[M^{+\cdot}]$, 240 (100), 225 (9), 212 (7), 197 (7).- IR (KBr): $\tilde{\nu}$ = 1774, 1612, 1517, 1253, 1117, 987 $cm^{-1}$.- UV (MeOH): $\lambda_{max}$ (ε [$10^3$ $cm^2$ $mol^{-1}$]) = 229 (6913), 275 (667), 282 nm (573).- CD (c 13.41 µmol $L^{-1}$, acetonitrile): $\lambda_{max}$ ($\Delta\varepsilon$) = 205 (-32.3), 219 (-5.0), 234 nm (-42.9).

**Reaction of 28a with 33 in the presence of sodium hydride**

To a suspension of sodium hydride (55-60 per cent dispersion in mineral oil, 4.4 mg, 0.101 mmol) in tetrahydrofuran (150 µL) a solution of **28a** (13.3 mg, 0.038 mmol) in tetrahydrofuran (250 µL) was added under argon at 22°C. Subsequently, a solution of **33** (16.1 mg, 0.053 mmol) in tetrahydrofuran (100 µL) was added dropwise. After stirring for 16 h at 22°C (colour change to orange) the reaction suspension was quenched with 5 per cent aqueous HCl (3 mL). Usual workup ($CH_2Cl_2$) and FC (petrol-ethyl acetate 6:1) furnished 1.9 mg of an unidentified side product, **37** (6.1 mg, 34 %), 8.7 mg of a mixture of **37**/**28a** and the 3-epimer of **37** (0.6 mg, 3 %) as colourless solids. HPLC (LiChrosorb Si 60, 10 µm; L = 250 mm, ID = 20 mm, petrol-ethyl acetate 2:1 → ethyl acetate; 10 mL $min^{-1}$, 10 bar, UV detection: λ = 229 nm) of the mixture furnished **37** (3.8 mg, 20 %) and **28a** (2.2 mg, 16 %).

**(3b*S*)-8-(4-Methoxyphenyl)-7a,8a-dimethyl-3*t*-((3*E*,3a*S*-cis)-2-oxo-4,6a-dihydro-2*H*-cyclopenta[*b*]furan-3(3a*H*)-ylidenemethoxy)-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno[1,2-*c*]furan-1(3*H*)-one (37)**

$R_f$ (petrol-ethyl acetate 1:1) = 0.43.- M.p.: 158 - 162°C (decomp., petrol-dichloromethane).- $^1H$ NMR (200 MHz, homodecoupling, $CDCl_3$): δ = 0.76 - 0.98 (m, 1H), 1.40 (s, 3H, 8a-$CH_3$ or 7a-$CH_3$), 1.43 (d, 3H, 7a-$CH_3$ or 8a-$CH_3$), 1.22 - 1.54 (m), 1.67 - 1.77 (m, 1H), 1.87 - 2.02 (m, 2H), 2.39 - 2.54 (dddd, 1H, $J_{(4',4^{*\prime})}$ = 17.6 Hz, $J_{(4',3a')}$ = 2.6 Hz, J = 5.2 Hz, 2.6 Hz, 4′-H), 2.72 - 2.89 (m, 1H, $J_{(4^{*\prime},3a')}$ = 8.8 Hz, J = 2.6 Hz, 2.6 Hz, ≈ 1 Hz, 4*′-H), 2.79 (s, 1H, 3a-H), 3.63 - 3.75 (dddd, 1H, 3a′-H), 3.82 (s, 3H, $OCH_3$), 5.28 (s, 1H, 3-H), 5.50 - 5.58 (dm, 1H, $J_{(6a',3a')}$ = 7.7 Hz, 6a′-H), 5.81 - 5.89 (ddd, 1H, $J_{(6',5')}$ = 5.5 Hz, J = 4.4 Hz, 2.2 Hz, 6′-H), 5.96 (d, 1H, $J_{(10,9)}$ = 5.9 Hz, 10-H), 5.99 - 6.05 (dddd, 1H, J = 2.2 Hz, 2.2 Hz, ≈ 1 Hz, 5′-H), 6.41 (d, 1H, 9-H), 6.92 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 8.8 Hz, $3^{Ar}$-H), 7.39 (d, 1H, $J_{(7',3a')}$ = 2.9 Hz, 7′-H), 7.60 (m, 2H, $2^{Ar}$-H).- $^{13}C$ NMR (50 MHz, APT, C,H COSY, $CDCl_3$): δ = 18.21 (-), 20.83 (-) (8a-$CH_3$ and 7a-$CH_3$), 21.05 (+), 22.79 (+), 25.13 (+), 31.14 (+), 37.84 (-) (C-3a′), 38.88 (+) (C-4′), 55.66 (-) ($OCH_3$), 57.77 (-) (C-3a), 58.51 (+), 59.96 (+), 64.54 (+), 69.07 (+), 88.04 (-) (C-6a′), 103.01 (-) (C-3), 113.36 (+) (C-3′), 114.09 (-) ($C\text{-}3^{Ar}$), 129.17 (-) (C-6′), 129.46 (+) ($C\text{-}1^{Ar}$), 130.58 (-) ($C\text{-}2^{Ar}$), 135.17 (-) (C-10 or C-9), 137.62 (-) (C-5′), 142.53 (-) (C-9 or C-10), 152.12 (-) (C-7′), 158.88 (+) ($C\text{-}4^{Ar}$), 171.90 (+) (C-1), 179.67 (+) (C-2′).- FAB MS: m/z = 511.2 $[M+Na]^+$, 489.3 $[M+H]^+$, 460.1, 240.2 [RDA].- IR (KBr): $\tilde{\nu}$ = 1775, 1751, 1618, 1517, 1347, 1255, 1191, 1164, 1065, 982 $cm^{-1}$.- UV (EtOH): $\lambda_{max}$ (ε [$10^3$ $cm^2$ $mol^{-1}$]) = 202 (end absorption,

12843), 233 (15096), 275 (949), 282 nm (816).- CD (c 10.23 µmol $L^{-1}$, acetonitrile): $\lambda_{max}$ ($\Delta\varepsilon$) = 194 (+54.9), 209 (Schulter, +0.7), 233 nm (-39.2).- HRMS: calcd for $C_{30}H_{33}O_6$: 489.2277, found: 489.2273.

**(3b*S*)-8-(4-Methoxyphenyl)-7a,8a-dimethyl-3*c*-((3*E*,3a*S*-cis)-2-oxo-4,6a-dihydro-2*H*-cyclopenta[*b*]furan-3(3a*H*)-ylidenemethoxy)-3a*t*,4,5,6,7,7a*t*,8,8a*t*-octahydro-3b*r*,8*c*-etheno-3b*H*-indeno[1,2-*c*]furan-1(3*H*)-one (3-epimer of 37)**

$R_f$ (petrol-ethyl acetate 1:1) = 0.39.- $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.26, 1.38, 1.44 (broad s, s, broad s, 3*3H, 8a-$CH_3$, 7a-$CH_3$, and the signal of an impurity (δ = 1.26)), 1.22 - 1.54 (m), 1.93 - 2.09 (m, 1H), 2.11 - 2.21 (m, 1H), 2.44 - 2.60 (dm, 1H, $J_{(4',4*')}$ = 17.6 Hz, 4'-H), 2.83 - 3.01 (m, 1H, 4*'-H), 3.03 (d, 1H, $J_{(3a,3)}$ = 6.6 Hz, 3a-H), 3.72 - 3.85 (m, 1H, 3a'-H), 3.82 (s, 3H, $OCH_3$), 5.53 - 5.61 (dm, 1H, $J_{(6a',3a')}$ = 7.7 Hz, 6a'-H), 5.85 (d, 1H, $J_{(3,3a)}$ = 7.0 Hz, 3-H), 5.89 - 5.98 (m, 1H, $J_{(6',5')}$ = 5.5 Hz, J = 4.4 Hz, 2.2 Hz, 6'-H), 6.05 - 6.11 (m, 1H, 5'-H), 6.13 (d, 1H, $J_{(10,9)}$ = 5.9 Hz, 10-H), 6.39 (d, 1H, 9-H), 6.91 (m, 2H, $J_{(3^{Ar},2^{Ar})}$ = 9.2 Hz, $3^{Ar}$-H), 7.40 (d, 1H, $J_{(7',3a')}$ = 2.6 Hz, 7'-H), 7.63 (m, 2H, $2^{Ar}$-H).- $C_{30}H_{33}O_6$: (489.23), FAB MS: m/z = 511.2 $[M+Na]^+$, 489.3 $[M+H]^+$, 460.1, 240.2 [RDA].

**Pyrolysis of coupling product 37**

**37** (16.7 mg, 0.034 mmol) was placed into a flash vacuum pyrolysis apparatus preheated to 230°C at $10^{-6}$ bar. The sample was pyrolized in a pyrolysis tube (30 cm x 1 cm quartz glas) heated to 500°C. The pyrolysis products were allowed to condense at a cold finger cooled with liquid nitrogen. After 15 min the starting material was gone. After 45 min the pyrolysis reaction was stopped and a yellow oil was obtained as raw material. FC (petrol-ethyl acetate 10:1 → 2:1) yielded **18** (6.6 mg, 81 %) and **38** (5.0 mg, 59 %) as colourless solids. **38** was compared with GR28, its enantiomer and the corresponding 2'-epimers[15] by TLC-comparision (petrol-ethyl acetate 1:2) and CD.

**3-[(2*R*)-4-Methyl-5-oxo-2,5-dihydro-furan-2-yloxymethylene]-(3a*S*)-(3a*r*,6a*c*)-3,3a,4,6a-tetrahydro-cyclopenta[*b*]furan-2-one (38)**

$R_f$ (petrol-ethyl acetate 1:2) = 0.31.- M.p.: 141 - 143°C (petrol-dichloromethane).- $^1$H NMR (200 MHz, homodecoupling, $CDCl_3$): δ = 2.04 (dd, 3H, $J_{(4'-CH_3,3')}$ = 1.5 Hz, $J_{(4'-CH_3,2')}$ = 1.5 Hz, 4'-$CH_3$), 2.41 - 2.56 (dddd, 1H, $J_{(4,4*)}$ = 17.6 Hz, $J_{(4,3a)}$ = 2.6 Hz, J = 5.1 Hz, 2.6 Hz, 4-H), 2.74 - 2.92 (ddddd, 1H, $J_{(4*,4)}$ = 18.0 Hz, J = 2.2 Hz, 2.2 Hz, 1.1 Hz, 4*-H), 3.63 - 3.75 (dddd, 1H, $J_{(3a,4*)}$ = 8.8 Hz, 3a-H), 5.51 - 5.59 (dm, 1H, $J_{(6a,3a)}$ = 7.7 Hz, 6a-H), 5.83 - 5.90 (ddd, 1H, $J_{(6,5)}$ = 5.9 Hz, J = 4.4 Hz, 2.2 Hz, 6-H), 6.02 - 6.09 (dddd, 1H, J = 2.2 Hz, 2.2 Hz, ≈ 1 Hz, 5-H), 6.13 - 6.17 (dq, 1H, $J_{(2',3')}$ = 1.5 Hz, 2'-H), 6.92 - 6.97 (dq, 1H, 3'-H), 7.45 (d, 1H, $J_{(7,3a)}$ = 2.6 Hz, 7-H).- $^{13}$C NMR (50 MHz, APT, $CDCl_3$): δ = 11.14 (4'-$CH_3$), 37.76 (-) (C-3a), 38.98 (+) (C-4), 88.22 (-) (C-6a), 101.08 (-) (C-2'), 114.28 (+) (C-3), 129.10 (-) (C-6), 136.47 (+) (C-4'), 137.85 (-) (C-5), 141.45 (-) (C-3'), 151.14 (C-7), 170.78 (C-2), 171.90 (C-5').- FAB MS: m/z = 271.0 $[M+Na]^+$, 249.0 $[M+H]^+$.- IR (KBr): $\tilde{\nu}$ = 1785, 1740, 1677, 1348, 1185, 1092, 1019, 957 $cm^{-1}$.- UV (EtOH): $\lambda_{max}$ ($\varepsilon$ [$10^3$ $cm^2$ $mol^{-1}$]) = 233 nm (14833).- CD (c 40.29 µmol $L^{-1}$, acetonitrile): $\lambda_{max}$ ($\Delta\varepsilon$) = 198 (+16.9), 209 (+8.3), 221 (+14.6), 253 (-4.6), 270 nm (< 0).- HRMS: calcd for $C_{13}H_{13}O_5$: 249.0763, found: 249.0769.

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