Bicycloannulation of α-Bromo α,β-Unsaturated Esters; Synthesis of the Tricyclo[4.4.0.0^{1,5}]decane Framework and its Congeners

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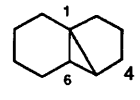
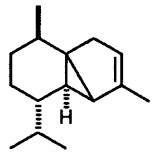
Reactions of the kinetic enolates **6** of 1-acetylcyclohexenes **5** with α-bromo α,β-unsaturated esters **7** proceed *via* a successive Michael–Michael-substitution pathway to give methyl 2-oxotricyclo-[4.4.0.0^{1,5}]decane-5-carboxylates **8** in a one-pot operation.

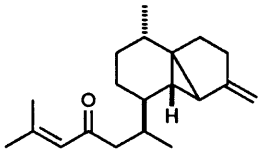
It is well recognised that there is a plethora of highly condensed carbocyclic frameworks, particularly in terpenoids.[1] Among such carbocyclic architectures, the tricyclo[4.4.0.0^{1,5}]decane framework **1**, which is contained in cubebene **2** and related compounds,[2] is unique and unusual, because five- and six-membered rings are fused by forming a three-membered ring. This tricyclo[4.4.0.0^{1,5}]decane framework has attracted much attention from synthetic organic chemists and has been synthesized so far by intramolecular addition of a keto carbenoid function in the synthesis of cubebene **2**[3] or photo-induced rearrangement of a cross-conjugated cyclohexadienone in the synthesis of (−)-9-anastreptone **4**.[4] In the course of our



Tricyclo[4.4.0.0^{1,5}]decane **1**



α-Cubebene **2**



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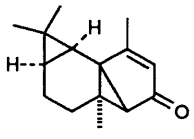
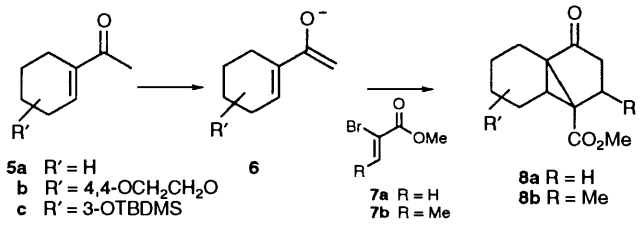


(−)-Anastreptone **4**

synthetic efforts directed towards annulation by successive Michael reactions,[5] we disclose herein an alternative reaction for the synthesis of tricyclo[4.4.0.0^{1,5}]decanes **8** and their congeners by successive Michael–Michael-substitution of 1-acetylcycloalkenes **5** and α-bromo α,β-unsaturated esters **7a** and **7b** (Scheme 1).[6] In this particular reaction, three carbon–carbon

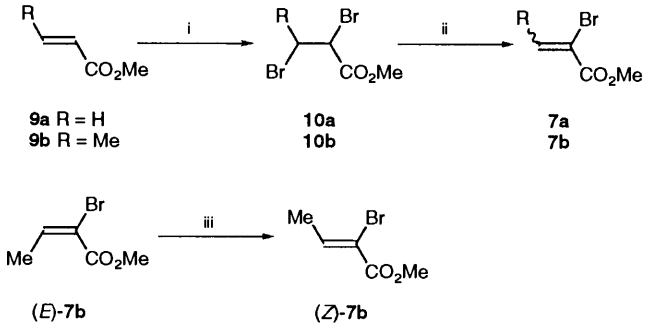


Scheme 1

bonds are formed successively, at first intermolecularly and then intramolecularly, twice, thereby making two rings (bicycloannulation) in a one-pot operation.

Results and Discussion

Methyl α-bromoacrylate **7a** was easily prepared by bromination of methyl acrylate **9a** in carbon tetrachloride followed by distillation from quinoline[7] and stored with a small amount of hydroquinone in a freezer. Methyl α-bromocrotonate **7b**[8] was also prepared in the same manner to give a mixture of *E* and *Z* isomers in a 1:2 ratio (NMR) which were separable by medium-pressure liquid chromatography (MPLC). The (*E*)-isomer of ester **7b** was quantitatively isomerised into the thermodynamically more stable (*Z*)-isomer (*A*-value, CO_2Me = 1.27, Br = 0.38 kcal mol^{-1})[9,†] by heating in ethanol. Since the presence of ethanol is essential for rapid isomerisation,[8a,c] the process probably proceeds *via* a Michael-type addition–elimination pathway, though the intermediary adduct of ethanol was not detected by monitoring of the isomerisation by NMR spectroscopy (Scheme 2). The geometries of the *E* and *Z* bromo-



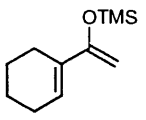
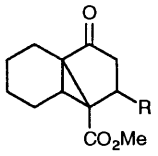
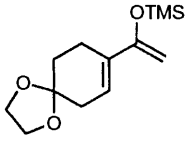
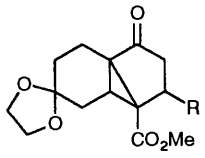
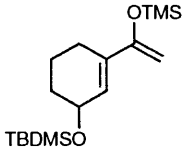
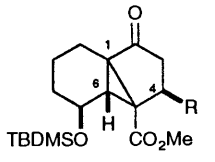
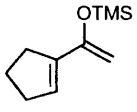
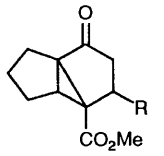
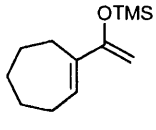
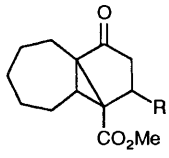
Scheme 2 *Reagents and conditions:* i, Br_2, CCl_4; ii, quinoline, distillation; iii, ethanol, reflux

crotonates **7b** were assigned by comparison of the chemical-shift-values of the olefinic protons[8c,10] (see Experimental section).

The requisite 1-acetylcycloalkenes and their trimethylsilyl enol ethers **11**, **13**, **15**, **17** and **19** were prepared according to the known procedures.[11] Reaction of the kinetic enolate **6a** of 1-acetylcyclohexene **5a**, generated from the trimethylsilyl enol ether **11** by reaction with methyllithium in tetrahydrofuran (THF), with methyl α-bromoacrylate **7a** gave methyl 2-oxotricyclo[4.4.0.0^{1,5}]decane-5-carboxylate **12a** in 51% yield (Scheme 1 and Table 1, entry 1). The reaction with methyl (*Z*)-α-bromocrotonate **7b** afforded methyl 4-methyl-2-oxotricyclo-[4.4.0.0^{1,5}]decane-5-carboxylate **12b** in 62% yield (Table 1, entry 2). The kinetic enolate **6** (R′ = H), generated directly from 1-acetylcyclohexene **5a** by treatment with lithium diisopropylamide (LDA), resulted in the recovery of the starting enone **5**, probably because the extra diisopropylamide initiated polymerisation of the α-bromo α,β-unsaturated esters **7a** and

† 1 cal = 4.184 J.

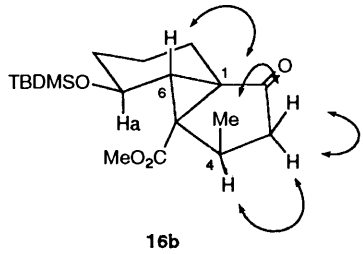
Table 1 Bicycloannulation of 1-acetylcycloalkene with α-bromo α,β-unsaturated ester

Entry	Starting material	Product	
			
	11		
1		**12a** R = H	51%
2		**12b** R = Me	62% (76%)[a]
3			61%[b]
4			62%[c]
			
	13		
5		**14a** R = H	37%
6		**14b** R = Me	20% (28%)[a]
7			18%[b]
			
	15		
8		**16a** R = H	38%
9		**16b** R = Me	33% (41%)[a]
10			33%[b]
			
	17		
11		**18a** R = H	52%
12		**18b** R = Me	51%
			
	19		
13		**20a** R = H	37%
14		**20b** R = Me	38%

[a] Yield calculated from consumed 1-acetylcyclohexene. [b] Yield from the reaction in the presence of HMPA. [c] Yield from the reaction in the presence of cyclohexene.

7b. Similarly, the trimethylsilyl enol ethers **13** and **15** from substrates **5b** and **5c** gave the corresponding tricyclic compounds **14** and **16** in 20–38% yield (Table 1, entries 5–10). Addition of hexamethylphosphoric triamide (HMPA) did not improve the yield (Table 1, entries 3, 7 and 10). The major by-product in these reactions was the recovered 1-acetylcyclohexene (Table 1, entries 2, 6 and 9). The cyclopentene **17** and cycloheptene derivatives **19** also underwent the bicycloannulation to give the tricyclic analogues **18** and **20** in 37–52% yield, respectively.

Determination of Stereochemistry.—The tricyclic compounds thus obtained were spectroscopically and chromatographically homogeneous. A phase-sensitive NOESY experiment on compound **16b** (400 MHz) showed nuclear Overhauser effects (NOE) between the methyl group and the protons as indicated by arrows (Fig. 1). Especially diagnostic for determination of

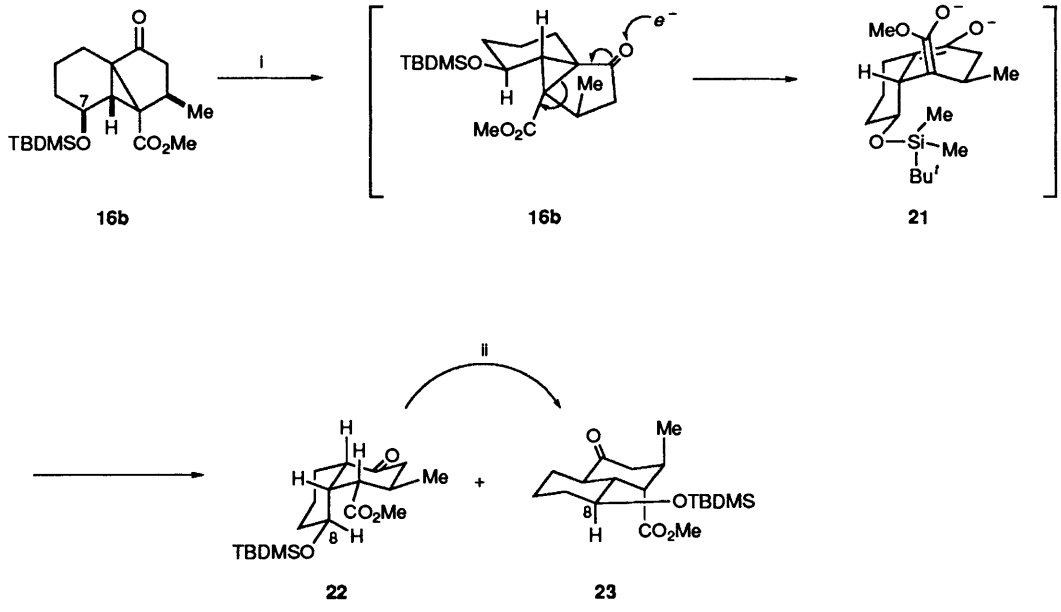


16b

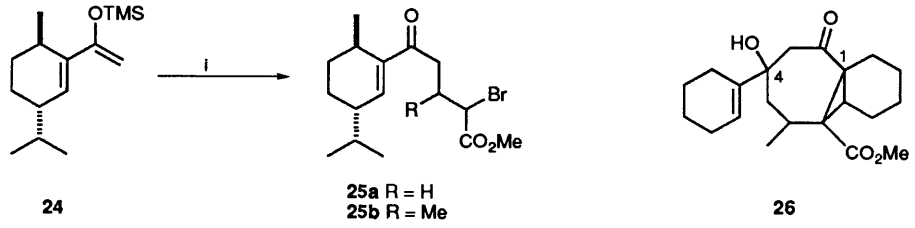
Fig. 1 Result of phase-sensitive NOESY of compound **16b**

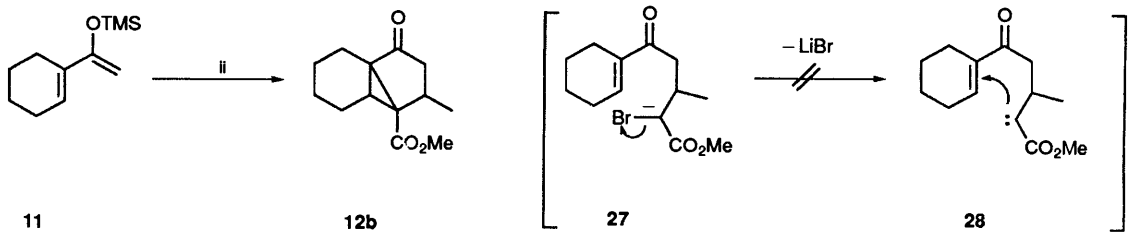
the relative stereochemistry from C-1 to C-6 are the NOEs between the methyl group at C-4 and the proton at C-6, establishing the *syn* relationship between these two groups. The relative stereochemistry at C-7, however, was ambiguous from its coupling constant of the proton at C-7 (unresolved broad multiplet, $w_{\frac{1}{2}}$ 12 Hz), probably because of distortion of the six-membered ring which fused with a cyclopropane ring. Then, treatment of compound **16b** with lithium in liquid ammonia cleaved the cyclopropane ring to afford two known decalones **22** and **23**[12] in 59% yield (ratio 1:1.2) (Scheme 3). The less polar decalone **22** isomerised, by treatment with sodium methoxide in methanol, to the more polar compound **23** in 94% yield. Both decalones **22** and **23** exhibited clear coupling patterns of triplets of doublets at δ 3.47 (1 H, td, J 10.1 and 3.5 Hz) and δ 3.81 (1 H, td, J 9.8 and 4.3 Hz), respectively, indicating that the protons on the carbons bearing the *tert*-butyldimethylsiloxy groups at C-8 are axial. Stereochemical aspects of the reductive ring opening with lithium in liquid ammonia are explained as follows. Successive transfers of an electron to the tricyclic compound **16** provided the dienolate **21** whose *tert*-butyldimethylsiloxy group occupied an equatorial position. A proton approached the ester enolate of the dienolate **21** from the β-face of the molecule, thereby avoiding steric hindrance due to the *tert*-butyldimethylsiloxy group. Axial protonation occurred at the ketone enolate of the dienolate **21**. As a result, the decalone **22** having a *cis*-steroidal conformation was formed as a primary product. Since both decalones **22** and **23** are starting materials for the synthesis of (+)-dihydrocompactin, and since the relative stereochemistry of the more stable decalone **22** was fully assigned from the 600 MHz NMR spectrum,[12] the relative stereochemistry of the tricyclic compound **16** was determined as depicted in Fig. 1. Even after prolonged heating with sodium methoxide, the methoxycarbonyl group at C-5 kept its axial orientation. Other tricyclic compounds **12**, **14**, **16**, **18** and **20** seem to have the same stereostructures, deduced from the narrow distribution of chemical-shift-values of the secondary methyl (δ 1.16 ± 0.02) and the methoxy (δ 3.73 ± 0.02) groups.

Reaction Pathway.—The reaction of the kinetic enolate, generated from the trimethylsilyl enol ether **24**, with α-bromo



Scheme 3 *Reagents:* i, Li, liq. NH_3; ii, MeONa, MeOH

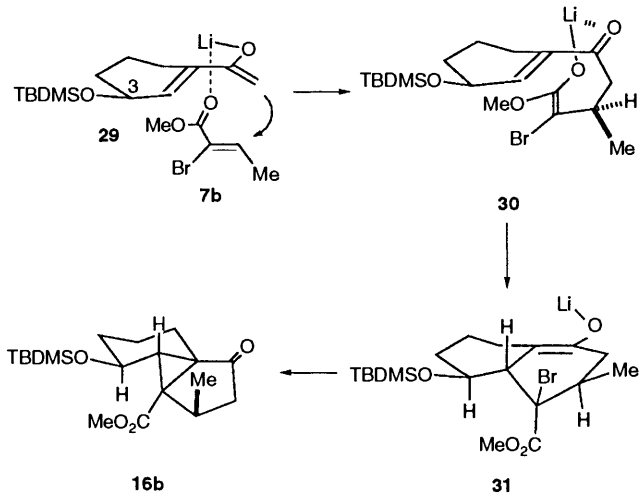




Scheme 4 *Reagents:* i, MeLi, α-bromo α,β-unsaturated ester **7**; ii, MeLi, cyclohexene, methyl (*Z*)-bromocrotonate **7b**

α,β-unsaturated esters **7a** and **7b** gave only the single Michael adduct **25a** and **25b** in 20 and 11% yield, respectively. Also, the 2:1 adduct **26** of 1-acetylcyclohexene **5a** and methyl α-bromocrotonate **7b** was isolated as a minor constituent. The formation of adduct **26** is explained by the Michael addition of the enolate **27** to 1-acetylcyclohexene **5a** followed by intramolecular aldol condensation. There are two alternative pathways for the formation of a cyclopropane ring, the Michael-substitution or a carbenoid addition pathway **27** → **28** → **12b** (Scheme 4). However, the latter pathway was denied by the following experiment. The addition of one mole equivalent of cyclohexene (Table 1, entry 4) provided only the tricyclic compound **12b** in 62% yield. No adduct with cyclohexene was isolated.

These results indicate that the present reaction was initiated at first by Michael addition of the kinetic enolate of 1-acetylcycloalkene to an α-bromo α,β-unsaturated ester **7** and the formation of the cyclopropane ring proceeded *via* the successive Michael-substitution reaction pathway. The stereochemical course of the reaction drawn from these results is as follows. Methyl *Z*-α-bromocrotonate **7b** approaches the enolate **29** from the opposite face of the *tert*-butyldimethylsiloxy group. After intermolecular chelation of the lithium cation on the kinetic enolate **29** with the methoxycarbonyl group of compound **7b**, the first Michael addition occurred *via* the s-*cis* conformation of ester **7b**. It is noteworthy that 1,6 remote stereocontrol was realised in this particular process, since the configuration of the secondary methyl group of adduct **30** was controlled by the stereochemistry at C-3 of the enolate **29**. Then the intramolecular second Michael addition proceeded from the α-face of the α,β-unsaturated carbonyl moiety of adduct **30** by keeping intramolecular chelation between the lithium cation on the ester enolate and carbonyl group to give bicycle **31**. Finally, an intramolecular substitution completed the tricyclo-[4.4.0.$0^{1,5}$]decane framework (Scheme 5). In the case when methyl (*E*)-α-bromocrotonate **7b** was used for the reaction with the kinetic enolate **6c**, the products isolated were 1-acetyl-3-(*tert*-butyldimethylsiloxy)cyclohexene **5c** and a small amount of methyl (*Z*)-α-bromocrotonate **7b**. Supposing that the present reaction proceeds *via* the s-*cis* conformation of the (*E*)-crotonate **7b**, the steric interference between the olefinic methyl group of (*E*)-**7b** and the enolate moiety of compound **29** might disturb the formation of a cyclic and closed chelated structure in the initial intermolecular Michael reaction, which proceeded *via* an open non-chelated transition state. Consequently, the enolate of the single Michael adduct with methyl (*E*)-α-bromocrotonate **7b** could not proceed to the second intramolecular Michael addition, and the retro-Michael reaction



Scheme 5

resulted in isomerisation of the *E* isomer to the thermodynamically more stable *Z* isomer.

In summary, the present reaction offers easy access to tricyclo[4.4.0.0^{1,5}]decane and related frameworks, making two rings stereoselectively by three successive bond-forming reactions (bicycloannulation) in a one-pot operation.

Experimental

IR spectra were recorded on a JASCO A-3 spectrophotometer for solutions in carbon tetrachloride. ^{1}H NMR spectra were obtained for solutions in deuteriochloroform with Bruker AM-400 (400 MHz), CXP-300 (300 MHz), AC-250 (250 MHz) and JEOL PMX-60 (60 MHz) instruments with tetramethylsilane as internal standard. ^{13}C NMR spectra were obtained for solutions in deuteriochloroform with the AC-250 spectrometer. *J* Values are given in Hz. Mass spectra were run on a JEOL JMS-DX300 spectrometer with a JMA-3500 data system. Gas chromatography (GLC) was performed with an OV-1 column (1%, 1 m) with the mass spectrometer as a detector. Medium-pressure liquid chromatography (MPLC) was carried out on a JASCO PRC-50 instrument with a silica gel-packed column. Microanalysis was carried out in the microanalytical laboratory of this Institute. Anhydrous sodium sulfate was used for drying organic extracts. THF was distilled from $LiAlH_4$ before use. Upon typical work-up, product was extracted with solvent (2 × 20 cm^3 for 1–10 mmol-scale reaction). The organic layer was washed successively with water once and brine once. After being dried over sodium sulfate, the extracts were evaporated under reduced pressure.

Methyl (Z)-α-*Bromocrotonate* **7b**.—To a stirred solution of methyl crotonate **9b** (13.9 g, 139 mmol) in carbon tetrachloride (15 cm^3) was added bromine (7.55 cm^3, 147 mmol, 1.05 mol equiv.) at 0 °C. After the mixture had been stirred for 30 min at that temperature, the solvent was evaporated off under reduced pressure. Addition of quinoline (18.0 g, 1 mol equiv.) followed by repeated distillation (2 × 106 °C/65 mmHg) afforded a mixture of the geometrical isomers (13.3 g, 74.3 mmol, 53.3% in two steps) which were separable by MPLC [eluent hexane–ethyl acetate (4:1)]. Methyl (*E*)-α-bromocrotonate **7b** has δ(60 MHz) 2.04 (3 H, d, *J* 7.8), 3.81 (3 H, s) and 6.75 (1 H, q, *J* 7.8). Methyl (*Z*)-α-bromocrotonate **7b** has δ(60 MHz) 1.93 (3 H, d, *J* 6.8), 3.79 (3 H, s) and 7.32 (1 H, q, *J* 6.8).

A solution of methyl (*E*)-α-bromocrotonate (96.2 mg, 0.54 mmol) in ethanol (4 cm^3) was heated under reflux for 2 h under nitrogen. Evaporation of the solvent followed by MPLC purification gave recovered methyl (*Z*)-α-bromocrotonate **7b** quantitatively.

General Procedure for the Reaction of the Kinetic Enolate of a 1-*Acetylcycloalkene with* α-*Bromo* α,β-*Unsaturated Ester* **7**.—To a stirred solution of the trimethylsilyl enol ether of 1-acetylcyclohexene **5** in THF (1 mol dm^3) was added MeLi (1.1 mol dm^3 solution in diethyl ether) at −78 °C under nitrogen. After being stirred at that temperature for 20 min and then at 0 °C for 20 min, the mixture was treated with a solution of α-bromo α,β-unsaturated ester **7** (2 mol equiv.) in THF (1.3 mol dm^3). In the experiments in entries 3, 7 and 10, HMPA (4 mol equiv.) was also added. The resulting solution was allowed to warm to room temperature for 3–5 h. The reaction was quenched by the addition of aq. ammonium chloride and the product was extracted with diethyl ether. Purification by MPLC afforded the *tricyclic compound.*

Methyl 2-*oxotricyclo*[4.4.0.0^{1,5}]*decane*-5-*carboxylate* **12a** (51.3%); ν_{max}/cm^{-1} 1740, 1725, 1440, 1200 and 1120; δ_H(60 MHz) 0.97–2.9 (13 H, m) and 3.73 (3 H, s); δ_C(62.5 MHz) 212.6, 170.6, 51.6, 41.4, 41.1, 31.6, 28.2, 24.5, 20.3, 20, 19.4 and 16.4; *m*/*z* 208 (M$^+$, 31%), 180 (M$^+$ − CO, 100), 166 (42), 149 (36), 134 (39), 107 (51), 106 (42), 105 (31), 91 (52) and 79 (51) (Found: M$^+$, 208.1099. $C_{12}H_{16}O_3$ requires *M*, 208.1099).

Methyl 4-*methyl*-2-*oxotricyclo*[4.4.0.0^{1,5}]*decane*-5-*carboxylate* **12b** (62.2%); ν_{max}/cm^{-1} 1735, 1140, 1220 and 1120; δ_H(60 MHz) 1.15 (3 H, d, *J* 6), 1.25–3.06 (12 H, m) and 3.75 (3 H, s); δ_C(62.5 MHz) 212, 170.2, 51.6, 45.8, 42.7, 39.7, 31.3, 24.8, 20.5, 20.2, 19.6, 16.7 and 16.6; *m*/*z* 222 (M$^+$, 31%), 194 (M$^+$ − CO, 100), 180 (65), 163 (43), 148 (82), 121 (76), 120 (67), 119 (44), 105 (69), 93 (69), 92 (40), 91 (92), 81 (32), 79 (78), 77 (65), 67 (32), 65 (39), 59 (33), 55 (44), 53 (42), 41 (84) and 39 (68) (Found: M$^+$, 222.1256. $C_{13}H_{18}O_3$ requires *M*, 222.1256).

Methyl 8,8-*ethylenedioxy*-2-*oxotricyclo*[4.4.0.0^{1,5}]*decane*-5-*carboxylate* **14a** (36.7%); ν_{max}/cm^{-1} 1745, 1735, 1445, 1360, 1300, 1200 and 1080; δ(60 MHz) 0.73–3.23 (11 H, m), 3.74 (3 H, s) and 4.88 (4 H, s) (Found: C, 63.0; H, 6.8. $C_{14}H_{18}O_5$ requires C, 63.0; H, 6.8%).

Methyl 8,8-*ethylenedioxy*-4-*methyl*-2-*oxotricyclo*[4.4.0.0^{1,5}]-*decane*-5-*carboxylate* **14b**, an inseparable mixture of 1-acetyl-4,4-ethylenedioxycyclohexene **5b** and compound **14b**. The ratio was determined to be 3:2 by analytical GLC (19.6% yield; ν_{max}/cm^{-1} 1740, 1735, 1680, 1650, 1440, 1370, 1150 and 1130; δ(60 MHz) 1.18 (d, *J* 6, Me of **14b**), 2.29 (Ac of **5b**), 3.1–1.4 (m), 3.75 (s), 3.9 (s), 3.99 (s) and 6.9–6.67 (m, olefinic H of **5b**); *m*/*z* 280 (M$^+$, 16.7%), 221 (M$^+$ − CO_2Me, 100) and 86 (47) (Found: M$^+$, 280.1311. $C_{15}H_{20}O_5$ requires *M*, 280.1311).

Methyl 7-(*tert*-butyldimethylsiloxy)-2-oxotricyclo[4.4.0.-0^{1,5}]decane-5-carboxylate **16a** (37.7%); ν_{max}/cm^{-1} 1740, 1735, 1440, 1260, 1200 and 900; δ(60 MHz) 0.05 (6 H, s, Me_2Si), 0.86 (9 H, s, Bu^t), 1.16–2.76 (11 H, m), 3.7 (3 H, s, OMe) and 3.92 (1 H, m, 7-H); *m*/*z* 282 (24%), 281 (M$^+$ − C_4H_9, 100), 249 (33), 239 (49), 89 (31), 75 (62) and 73 (45).

Methyl 7-(*tert*-butyldimethylsiloxy)-4-methyl-2-oxotricyclo-[4.4.0.0^{1,5}]decane-5-carboxylate **16b** (33%); ν_{max}/cm^{-1} 1740, 1730, 1440, 1300 and 1200; δ_H(250 MHz) 0.079 (3 H, s, MeSi), 0.099 (3 H, s, MeSi), 0.92 (9 H, s, Bu^t), 1.19 (3 H, d, *J* 6.5, 4-Me), 1.2–1.4 (2 H, m), 1.56 (1 H, d, *J* 2.5, 6-H), 1.45–1.65 (3 H, m), 1.82 (1 H, dd, *J* 18.5 and 9.9, 3β-H), 2.31 (1 H, dd, *J* 18.4 and 9.2, 3α-H), 2.41 (1 H, m, 8α-H), 3.08 (1 H, ddq, *J* 9.9, 9.1 and 6.5, 4α-H), 3.75 (3 H, s, MeO) and 4.15 (1 H, m, $w_{\frac{1}{2}}$ 16, 7α-H); δ_C(62.5 MHz) 211.3, 170.2, 65.3, 51.9, 44.6, 44.0, 39.8, 34.7, 31.4, 31.1, 25.8, 18.1, 17.8, 17, 16.3, −4.81 and −4.85; *m*/*z* 295 (M$^+$ − C_4H_9, 100%), 263 (35), 253 (33), 89 (32), 75 (59) and 73 (46).

Methyl 2-*oxotricyclo*[4.3.0.0^{1,5}]*nonane*-5-*carboxylate* **18a** (52.3%); ν_{max}/cm^{-1} 1730, 1440, 1340, 1300, 1240 and 1060; δ(60 MHz) 0.97–2.81 (11 H, m) and 3.74 (3 H, s); *m*/*z* 194

(M^+, 37%), 166 (88), 152 (54), 135 (34), 120 (67), 107 (41), 93 (100), 92 (61), 91 (78), 79 (47), 77 (50), 41 (32) and 39 (40) (Found: M^+, 194.0943. $C_{11}H_{14}O_3$ requires *M*, 194.0943).

Methyl 4-methyl-2-oxotricyclo[4.3.0.$0^{1,5}$]*nonane-5-carboxylate* **18b** (50.6%); ν_{max}/cm^{-1} 1730, 1440, 1235, 1220 and 1055; δ(60 MHz) 1.14 (3 H, d, *J* 6.2), 1.24–3.04 (10 H, m) and 3.72 (3 H, s); *m/z* 208 (M^+, 38%), 180 (73), 166 (70), 134 (100), 107 (76), 106 (39), 105 (41), 91 (56), 79 (54), 77 (37), 41 (36) and 39 (32) (Found: M^+, 208.1098. $C_{12}H_{16}O_3$ requires *M*, 208.1099).

Methyl 11-oxotricyclo[5.4.0.$0^{1,8}$]*undecane-8-carboxylate* **20a** (37.4%); ν_{max}/cm^{-1} 1730, 1440, 1290, 1240 and 1155; δ(60 MHz) 0.7–2.77 (15 H, m) and 3.73 (3 H, s); *m/z* 222 (M^+, 23%), 194 (M^+ − CO, 100), 163 (32), 91 (30) and 79 (32) (Found: M^+, 222.1255. $C_{13}H_{18}O_3$ requires *M*, 222.1256).

Methyl 9-methyl-11-oxotricyclo[5.4.0.$0^{1,8}$]*undecane-8-carboxylate* **20b** (38.3%); ν_{max}/cm^{-1} 1730, 1440, 1285, 1240 and 1150; δ(60 MHz) 1.14 (3 H, d, *J* 6.4), 0.78–3.13 (14 H, m) and 3.72 (3 H, s); *m/z* 236 (M^+, 19%) and 208 (M^+ − CO, 100) (Found: M^+, 236.1412. $C_{14}H_{20}O_3$ requires *M*, 236.1412).

Cleavage of the Cyclopropane Ring of Tricycle **16b** *by Lithium in Liquid Ammonia.*—To stirred liquid NH_3 (~ 10 cm^3; distilled from Na) was added Li (5.9 mg, 0.84 mmol) at −78 °C. After this had been stirred for 10 min, a solution of tricycle **16b** (61 mg, 0.17 mmol) and water (6 mm^3, 0.34 mmol) in THF (3 cm^3) was added and the mixture was stirred at −78 °C for 3 min. The reaction was quenched by careful addition of aq. ammonium chloride. Extraction with diethyl ether followed by MPLC separation afforded methyl (1*S**, 2*R**, 4a*S**, 8*S**, 8a*R**)-8-(*tert*-butyldimethylsiloxy)-2-methyl-2-oxoperhydronaphthalene-1-carboxylate **22** (16.4 mg, 26.7%); δ(300 MHz) 0.05 (6 H, s, Me_2Si), 0.86 (9 H, s, Bu^t), 1.17 (3 H, d, *J* 5.5, 2-Me), 1.20–1.33 (2 H, m), 1.49–1.65 (2 H, m), 1.84–2.01 (2 H, m), 2.08–2.19 (2 H, m), 2.33–2.73 (4 H, m), 3.47 (1 H, td, *J* 10.1 and 3.5, 8-H) and 3.67 (3 H, s, OMe), and methyl (1*S**, 2*R**, 4a*R**, 8*S**, 8a*R**)-8-(*tert*-butyldimethylsiloxy)-2-methyl-4-oxoperhydronaphthalene-1-carboxylate **23** (19.8 mg, 32.3%); δ(300 MHz) 0.04 (6 H, s, Me_2Si), 0.89 (9 H, s, Bu^t), 1.06 (3 H, d, *J* 7.14, 2-Me), 1.11–1.4 (3 H, m), 1.58–1.83 (2 H, m), 1.88–2.01 (2 H, m), 2.07–2.17 (1 H, m, 3β-H), 2.57–2.68 (1 H, m), 2.71 (1 H, dd, *J* 13.5 and 5.9, 3α-H), 2.92–3.05 (2 H, m, 4a- and 1-H), 3.71 (3 H, s, OMe) and 3.81 (1 H, td, *J* 9.8 and 4.3, 8-H).

To a stirred solution of sodium methoxide prepared from sodium hydride (50%; 9.2 mg, 0.2 mmol) in anhydrous methanol (1 cm^3) was added a solution of the decalone **22** (16.4 mg, 0.046 mmol) in methanol (1 cm^3). The resulting solution was heated under reflux for 2.5 h. The reaction was quenched by addition of dil. HCl. Extraction with diethyl ether followed by treatment of the extract with diazomethane gave an oil (21.8 mg), which was purified by MPLC to give the decalone **23** (15.4 mg, 94%). The spectral data were identical with those obtained in the previous experiment.

Methyl 2-Bromo-5-(3-isopropyl-6-methylcyclohex-1-enyl)-5-oxopentanoate **25a**.—According to the general procedure, the reaction of the trimethylsilyl enol ether **24** (253.3 mg, 1 mmol) with methyl α-bromoacrylate **7a** (334 mg, 2 mmol) gave the single Michael adduct **25a** (154.1 mg, 58%); ν_{max}/cm^{-1} 1749, 1672, 1629, 1437, 1243 and 1216; δ(60 MHz) 0.66–3.04 (21 H, m), 3.79 (3 H, s) and 6.53–6.69 (1 H, m).

Methyl 2-Bromo-5-(3-isopropyl-6-methylcyclohex-1-enyl)-3-methyl-5-oxopentanoate **25b**.—According to the general procedure, the reaction of the trimethylsilyl enol ether **24** (253.3 mg, 1 mmol) with methyl α-bromocrotonate **7b** (0.24 cm^3, 2 mmol) gave the single Michael adduct **25b** (55.7 mg, 20%); ν_{max}/cm^{-1} 1750, 1675, 1630, 1465, 1275 and 1155; δ(60 MHz) 0.76–3.33 (23 H, m), 3.77 (3 H, s) and 6.63–6.8 (1 H, m).

Methyl 4-(cyclohex-1-enyl)-4-hydroxy-6-methyl-2-oxotricyclo[5.5.0.$0^{1,8}$]dodecane-7-carboxylate **26** (5%); ν_{max}/cm^{-1} 3481, 1727, 1655 and 1194; δ(300 MHz) 0.98 (3 H, d, *J* 6.4), 1.03–2.42 (20 H, m), 2.77 (1 H, dd, B part of AB-type q, *J* 16.6 and 2, 3-H), 3.04 (1 H, d, A part of AB-type q, *J* 16.6, 3-H), 3.72 (3 H, s), 4.76 (1 H, br s; intensity was decreased by D_2O addition) and 6.99 (1 H, m, $w_{\frac{1}{2}}$ 10, olefinic H); *m/z* 346 (M^+, 3%), 328 ($M^+ - H_2O$, 2), 314 (4), 180 (14), 109 (100) and 81 (61).

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