Intramolecular Free Radical Cyclisations onto Enol Ethers. A General Synthesis of α-Alkyl-β-oxy- and α-Methylene-β-oxy-γ-butyrolactones

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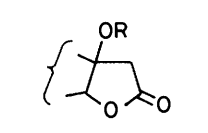
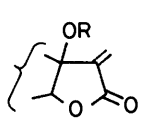
Radical cyclisation of the enol ether bromoacetals (**26**), (**28a—c**), (**29**), and (**37**) in the presence of tributylstannane, produces precursors [*viz.* (**30**), (**31a—c**), (**32**), and (**38**)] to the β-oxy-γ-butyrolactones (**33**), (**34a—c**), (**35**), and the α-methylene-β-oxy-γ-butyrolactone (**39**) in high overall yields. By contrast, treatment of (**26**) and (**28a—b**) with the cobalt(I) reagent derived from bis(dimethylglyoximato)(pyridine)cobalt(III) chloride (**40**), followed by oxidation of the intermediates (**43**) leads to the corresponding unsaturated β-oxy-γ-butyrolactones (**42**).

The β-oxy-γ-butyrolactone (**1**) and α-alkylidene-β-oxy-γ-butyrolactone (**2**) structural units are found in a wide range of unusual and biologically interesting natural products. Typical examples of natural β-oxy-γ-butyrolactones include alliacolide (**3**) produced by the fungus *Marasmius alliaceus*,[1] aeroplysinin-2 (**4**) found in the marine sponge *Aplysinga aerophoba*,[2] ginkgolide (**5**), a bitter principle from *Ginkgo biloba*,[3] and the mycotoxin austin (**6**) isolated from *Aspergillus ustus*.[4] The anti-leukaemic agents aplysistatin (**7**)[5] and allamcin (**8**),[6] from the sea hare *Aplysia angasia* and the shrub *Allamanda neriifolia* respectively, together with the obtusilactones (**9**) (*cf.* mahubanolides) found in *Licaria mahuba*[7] reflect the diversity of structure found amongst natural α-alkylidene-β-oxy-γ-butyrolactones.


(1)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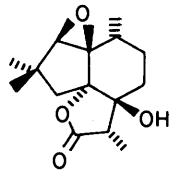
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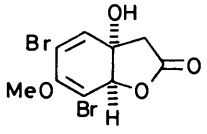
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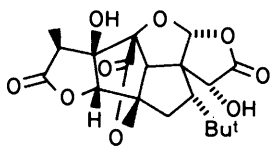
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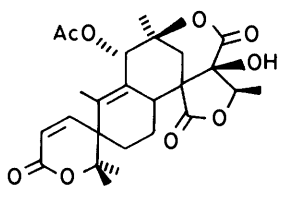
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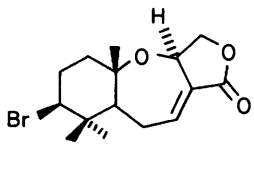
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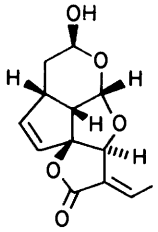
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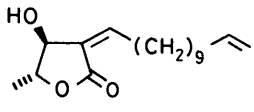
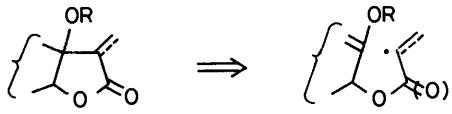
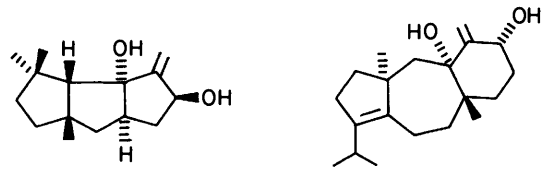

(9)

Although a few methodologies have been developed for the synthesis of the β-oxy-γ-butyrolactone units (**1**) and (**2**) present in molecules (**4**)→(**9**),[8] our interest in free-radical mediated reactions[9] attracted us to the possibility of elaborating the structural units (**1**) and (**2**) by intramolecular addition of an sp^3- or sp^2-carbon radical centre to the α-centre of an enol ether according to Scheme 1. In this paper we summarise the outcome of this idea, and illustrate the usefulness of the process by application to the synthesis of a range of fused ring β-oxy-γ-butyrolactones with the β-oxy residue located at the ring junction.[10] In one of the accompanying papers we show the development of the principles described here, in a total synthesis of (±)-alliacolide (**3**).[11] In a second accompanying paper, we describe a total synthesis of the anti-leukaemic substance (±)-allamcin (**8**) which uses a quite different strategy to elaborate the α-ethylidene-β-oxy-γ-butyrolactone unit.[12]

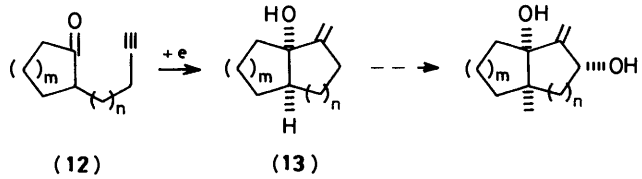

Scheme 1.

During previous work, directed towards the total syntheses of (±)-capnellenediol (**10**) and (±)-isoamijiol (**11**),[13] we have highlighted the scope for intramolecular reductive cyclisations of ω-acetylenic ketones to elaborate the ene-alcohol functionality associated with the ring-C portions in these molecules *i.e.*, (**12**)→(**13**).[14] Attempts to extend this general chemistry to the corresponding system (**15**), incorporating an *ether* linkage in the chain separating the carbonyl and acetylenic groups, met with total failure. Using the ether (**15a**) as a model, reaction with sodium naphthalene radical anion (NaNp)[15] led largely to the product (**16**) of a Claisen rearrangement.[16] In addition, cathodic or NaNp reduction of the analogue (**15b**) incorporating an angular methyl substituent, led only to total decomposition of the starting material.

To circumvent the problem of synthesis of the butyrolactone unit (**18**) *via* the cyclic ether (**14**) we decided to prepare the keto-vinyl bromide (**17**) and use this as a model to explore the possibilities for the carbonyl group function as a radicophile. Initiation of a radical cyclisation reaction from (**17**) proved inconvenient and difficult! Eventually, using tributylstannane in the presence of several equivalents of azoisobutyronitrile (AIBN),[17] under reflux in benzene for several *days*, we were able

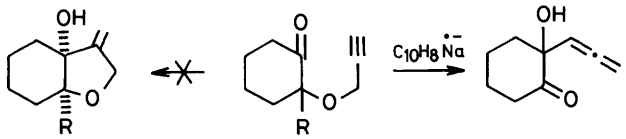


(10) (11)



(12) (13)

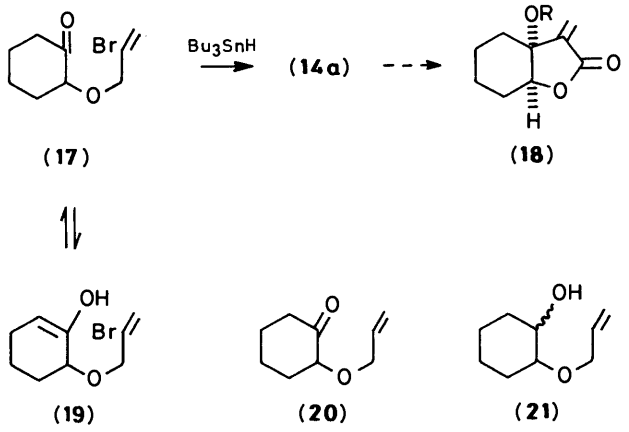
$m = 1,2$; $n = 0,1$



(14) (15) (16)

a ; R = H
b ; R = Me

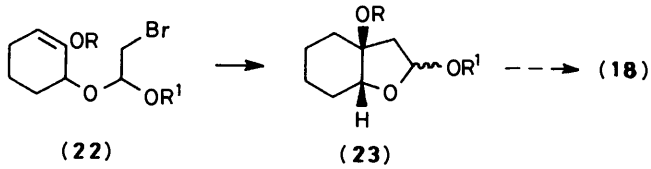
to prepare the bicyclic allylic alcohol (**14a**) in a meagre 10% yield. The major products were found to be those corresponding to simultaneous reduction of the vinyl bromide and carbonyl group in compound (**17**), *i.e.*, compounds (**20**) and (**21**).



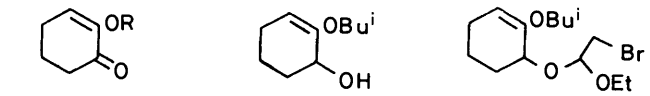
(17) (18) (14a) (19) (20) (21)

Enthalpy calculations, based upon bond dissociation energies, show that radical cyclisation onto the carbon terminus of a carbonyl group, in comparison to cyclisation onto a C=C double bond, is an endothermic process.[18] In addition the oxygen centre radical is a relatively high energy species. In the light of these facts, it is not so surprising therefore that only a low yield of (**14a**) was obtained from the radical cyclisation of the keto-vinyl bromide (**17**). By comparison, intermolecular polymerisations of enol ethers of carbonyl compounds are known to be extremely favourable free-radical processes.[19] It was in this context that we suggested to ourselves that the conversion (**17**)→(**14a**) most likely proceeded *via* radical addition to the enol (**19**) rather than to the carbonyl group, and furthermore through a favoured 5-*exo*-trig ring closure.[20] This serendipitous realisation prompted us to synthesize and investigate the intramolecular free-radical cyclisations of some alkyl enol ethers, which forms the basis of this paper.

The well documented rate-enhancing effects of β-alkoxy groups in radical cyclisations onto C=C double bonds,[21] together with the difficulty we encountered in oxidising the ether (**14a**) to the corresponding lactone (**18**),[22] led us to examine the cyclisations of a series of enol ether bromoacetals, *viz.* (**22**)→(**23**), as a synthetic entry to the β-oxy-γ-butyrolactone ring system.[23] Thus, the bromoacetal (**26**) was easily produced as a mixture of diastereoisomers, starting from the 2-isobutoxycyclohex-2-en-1-one (**24a**),[24] following reduction to the alcohol (**25**) using sodium borohydride–cerium trichloride,[25] and reaction with 1,2-dibromoethyl ethyl ether. In a similar manner, treatment of compound (**24a**) with methyl-lithium, followed by reaction between the resulting alcohol (**27a**) and 1,2-dibromoethyl ethyl ether led to the bromoacetal (**28a**). Likewise, addition of methyl-lithium to the methyl and methoxyethoxymethyl enol ethers (**24b**) and (**24c**), followed by reactions with 1,2-dibromoethyl ethyl ether produced the analogous ether bromoacetals (**28b**) and (**28c**) respectively. The more substituted bromoacetal (**29**) was secured by reaction between (**27b**) and 1,2-dibromopropyl ethyl ether.

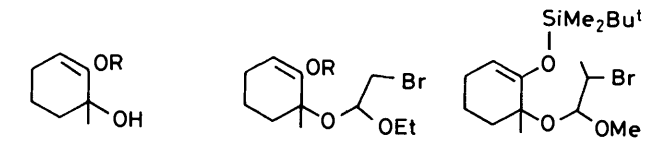


(22) (23) (18)



(24) (25) (26)

a ; R = Bu^i
b ; R = Me
c ; R = MEM
d ; R = SiMe$_2$Bu^t



(27) (28) (29)

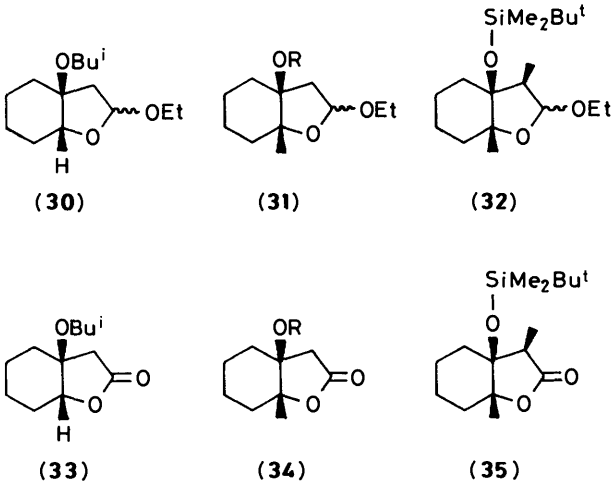
a ; R = Bu^i
b ; R = SiMe$_2$Bu^t
c ; R = Me
d ; R = MEM

a ; R = Bu^i
b ; R = Me
c ; R = MEM

When a solution of the bromoacetal (**26**) in dry benzene was treated with Bu_3SnH in the presence of AIBN at 80 °C for 1 h, smooth cyclisation occurred leading to the ring-fused cyclic acetal (**30**) as a mixture of C-2 anomers, in a combined yield of 91%. In a similar manner, the bromoacetals (**28a**), (**28b**), (**28c**), and (**29**) produced the corresponding cyclic acetals (**31a**), (**31b**), (**31c**), and (**32**) respectively in yields between 60—90%. Treatment of the cyclic acetals (**30**), (**31a**), (**31b**), (**31c**), and (**32**) with either Jones' reagent or with pyridinium chlorochromate then resulted in simultaneous hydrolysis–oxidation leading to

Table 1. Fractional atomic co-ordinates with standard deviations in parentheses

Atom	*x/a*	*y/b*	*z/c*
C(1)	0.9040(5)	0.6919(4)	0.3202(2)
C(2)	0.9889(7)	0.8458(5)	0.3823(3)
C(3)	0.8353(8)	0.9365(5)	0.3812(3)
C(4)	0.6319(8)	0.8155(6)	0.3955(3)
C(5)	0.5366(6)	0.6647(5)	0.3323(2)
C(6)	0.6856(5)	0.5709(3)	0.3248(2)
C(7)	0.7434(5)	0.4752(4)	0.3963(2)
C(8)	0.9487(6)	0.4667(4)	0.3874(2)
C(9)	0.9240(9)	0.7442(6)	0.2374(3)
C(10)	0.5865(9)	0.3077(6)	0.4060(3)
C(11)	0.3187(11)	0.5314(7)	0.1247(3)
C(12)	0.1631(8)	0.2544(8)	0.2289(4)
C(13)	0.4509(6)	0.2150(5)	0.1251(2)
C(14)	0.5139(10)	0.0846(6)	0.1788(4)
C(15)	0.2611(14)	0.1216(15)	0.0575(6)
C(16)	0.6363(11)	0.3108(8)	0.0897(4)
O(1)	1.0368(3)	0.5877(3)	0.3424(1)
O(6)	0.6048(3)	0.4509(2)	0.2559(1)
O(8)	1.0345(5)	0.3694(3)	0.4145(2)
Si(1)	0.3879(1)	0.3679(1)	0.187 05(5)



a ; R = Bu^i, b ; R = Me , c ; R = MEM

the required β-oxy-γ-butyrolactones (**33**), (**34a**) (**34b**), (**34c**), and (**35**) respectively, in yields which varied between 61% and 98%.

Inspection of ^{1}H- and ^{13}C-n.m.r. data recorded for the butyrolactones (**33**), and (**34**), and (**35**), demonstrated conclusively that each was a single ring-fused isomer. By analogy with results obtained by other researchers with related ring-fused systems,[26] and assuming that the cyclisations will take place *via* least strained transition states we believe that each of the butyrolactones (**33**), (**34**), and (**35**) possess *cis*-fused ring junctions. In the case of radical cyclisation followed by hydrolysis–oxidation of the bromoacetal (**29**), a single crystalline lactone was obtained whose structure and *cis*-ring fused stereochemistry [*i.e.*, (**35**)] was established unambiguously by a single crystal *X*-ray analysis (See Tables 1—3 and Figure).

The general method established for the synthesis of the β-oxy-γ-butyrolactones (**33**)→(**35**), described above, could be conveniently adapted to accommodate the simultaneous introduction of an α-methylene residue.[27] Thus, when a solution of the enol ether (**36**) was treated with methoxyallene in the presence of *N*-bromosuccinimide, chromatography led to a good yield of the bromoacetal (**37**). Radical cyclisation of the bromoacetal (**37**) through the 5-*exo*-trig mode, in the presence of Bu_3SnH–AIBN, then led to the cyclic acetal (**38**), which was converted into the α-methylene-β-oxy-γ-butyrolactone (**39**) using Jones' reagent.

As a corollary to our investigations we also examined the cyclisations of the bromoacetals (**26**), (**28a**) and (**28b**) in the presence of the cobalt(I) reagent [abbreviated here to Co(I)] derived from reduction of bis(dimethylglyoximato)(pyridine)-

Table 2. Bond lengths (Å) with standard deviations in parentheses

C(1)–C(2)	1.532(4)
C(1)–C(6)	1.537(4)
C(1)–C(9)	1.518(5)
C(1)–O(1)	1.470(4)
C(2)–C(3)	1.506(5)
C(3)–C(4)	1.512(6)
C(4)–C(5)	1.522(5)
C(5)–C(6)	1.525(4)
C(6)–C(7)	1.528(4)
C(6)–O(6)	1.428(3)
C(7)–C(8)	1.498(5)
C(7)–C(10)	1.498(5)
C(8)–O(1)	1.345(4)
C(8)–O(8)	1.206(4)
C(11)–Si(1)	1.872(5)
C(12)–Si(1)	1.840(5)
C(13)–C(14)	1.550(7)
C(13)–C(15)	1.523(7)
C(13)–C(16)	1.530(7)
C(13)–Si(1)	1.883(4)
O(6)–Si(1)	1.629(2)

Table 3. Bond angles (°) with standard deviations in parentheses

C(2)–C(1)–C(6)	112.5(3)
C(2)–C(1)–C(9)	111.8(3)
C(2)–C(1)–O(1)	107.3(3)
C(6)–C(1)–C(9)	115.2(3)
C(6)–C(1)–O(1)	103.0(3)
C(9)–C(1)–O(1)	106.2(3)
C(1)–C(2)–C(3)	112.8(3)
C(2)–C(3)–C(4)	110.3(3)
C(3)–C(4)–C(5)	110.7(3)
C(4)–C(5)–C(6)	113.9(3)
C(1)–C(6)–C(5)	112.7(3)
C(1)–C(6)–C(7)	100.9(2)
C(1)–C(6)–O(6)	107.9(2)
C(5)–C(6)–C(7)	115.7(3)
C(5)–C(6)–O(6)	112.0(3)
C(7)–C(6)–O(6)	106.9(2)
C(6)–C(7)–C(8)	101.6(2)
C(6)–C(7)–C(10)	118.3(3)
C(8)–C(7)–C(10)	114.4(3)
C(7)–C(8)–O(1)	110.9(3)
C(7)–C(8)–O(8)	128.4(4)
O(1)–C(8)–O(8)	120.7(3)
C(14)–C(13)–C(15)	109.6(6)
C(14)–C(13)–C(16)	108.0(4)
C(14)–C(13)–Si(1)	109.6(3)
C(15)–C(13)–C(16)	109.2(6)
C(15)–C(13)–Si(1)	110.2(4)
C(16)–C(13)–Si(1)	110.2(3)
C(1)–O(1)–C(8)	109.2(2)
C(6)–O(6)–Si(1)	138.8(2)
C(11)–Si(1)–C(12)	108.0(3)
C(11)–Si(1)–C(13)	110.7(2)
C(11)–Si(1)–O(6)	112.2(2)
C(12)–Si(1)–C(13)	110.6(2)
C(12)–Si(1)–O(6)	112.5(2)
C(13)–Si(1)–O(6)	102.9(1)

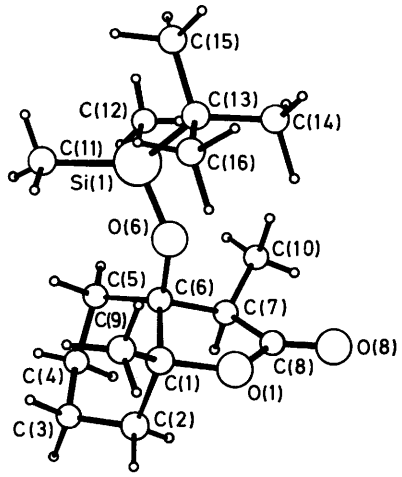
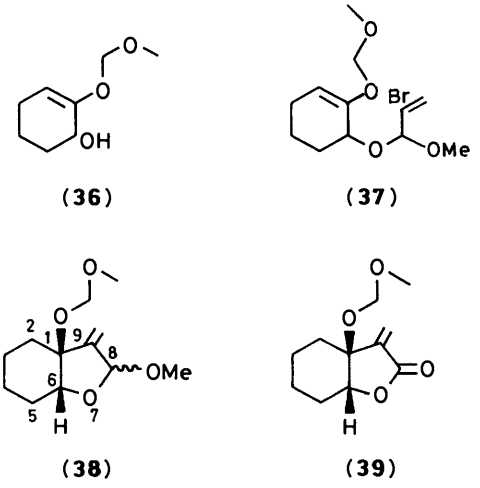


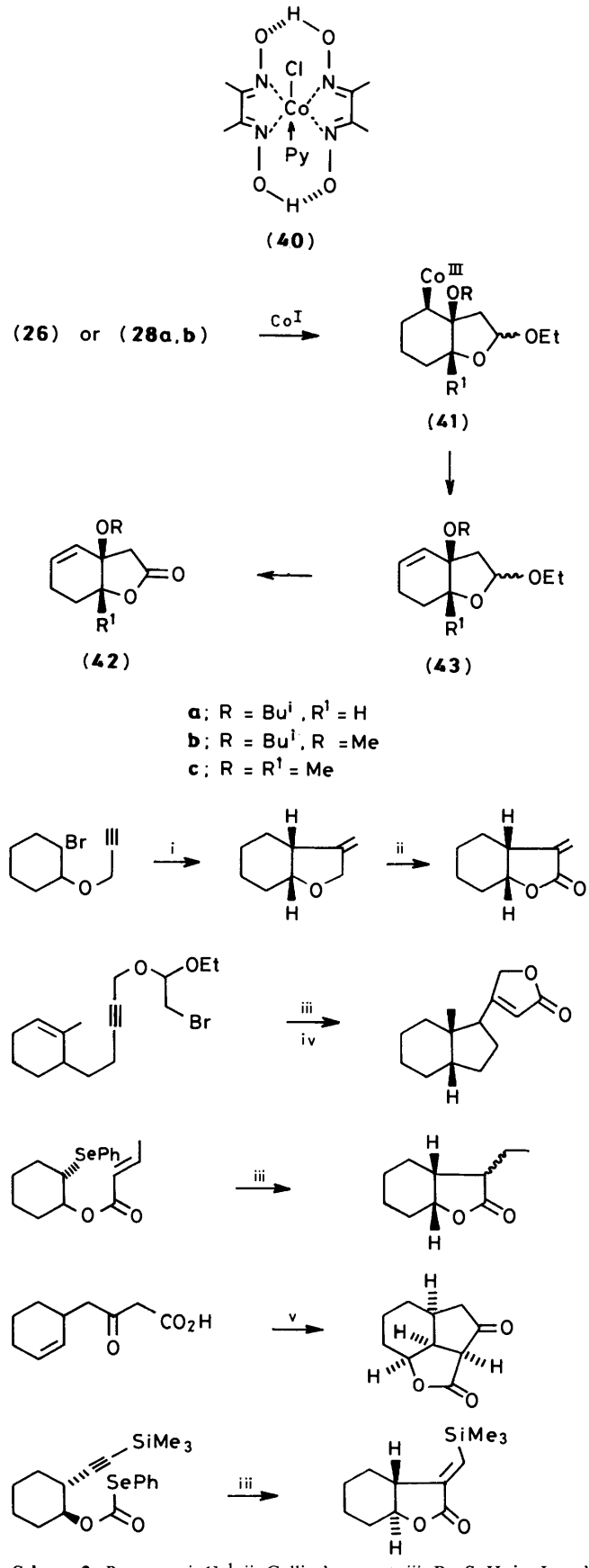
Figure Crystal structure of compound (**35**)



(**36**) (**37**) (**38**) (**39**)

cobalt(III) chloride (**40**), which is a comparatively recent method used for generation of carbon radicals from alkyl halides.[28] These radical cyclisation reactions followed a new and interestingly pathway, which added even more scope for the process developed above for the synthesis of β-oxy-γ-butyrolactones. Thus, when the bromoacetals (**26**), (**28a**), and (**28b**) were treated with Co(I) using the general conditions described by Tada *et al*,[28] we isolated the cyclised cyclo*hexenes* (**43a**—**c**) in 40—70% yields. The cyclohexenes (**43a**—**c**) could then be oxidised to the corresponding ring-fused γ-butyrolactones (**42a**—**c**) using Jones' reagent. The formation of the cyclohexenes (**43a**—**c**) can be rationalised in terms of well-precedented 1,2-elimination of Co-H from the intermediate cobaloximato species (**41**) produced by initial radical cyclisations onto the enol ethers (**26**) and (**28**).[29] Our more recent work has shown that the Co(I)-mediated cyclisations, represented by (**28**)→(**43**) can be carried out more conveniently and in higher yields using electrochemical procedures.[30] In addition, we have also been able to show, that Co(III)-complexes, similar to compound (**41**), can be intercepted and characterised, under appropriate conditions, and then used as valuable intermediates in general synthesis.[31]

The present paper highlights for the first time, the suitability of 5-*exo*-trig radical cyclisations onto enol ethers in the synthesis of both α-alkyl-β-oxy- and α-methylene-β-oxy-γ-butyrolactones. This new procedure should be compared and contrasted with alternative radical cyclisations, some of which have been published contemporaneously, leading to tetrahydrofuranyl ethers;[32] some of these are highlighted in Scheme 2.



Scheme 2. *Reagents:* i, Co^{I}; ii, Collins' reagent; iii, Bu_3SnH; iv, Jones' reagent; v, Mn^{III}

Experimental

For general experimental details see ref. 33.

Preparation of 2-(*Prop*-2-*ynyloxy*)- *and* 2-(*Prop*-2-*enyloxy*)-*cyclohexan*-1-*ols. General Procedure.*—A solution of the 7-oxabicyclo[4.1.0]heptane[34] (10 mmol) in dry dichloromethane (1 ml) was added dropwise over 6 h to a stirred and cooled (15—20 °C) solution of prop-2-ynol (or prop-2-enol) (100 mmol) in dry dichloromethane (30 ml) containing boron trifluoride-diethyl ether (1.1 mmol) under argon. The mixture was stirred at 25 °C for 0.5 h, and then triethylamine (excess) was added. The mixture was evaporated to dryness, and the oily residue was then purified by chromatography on Kieselgel H using 30—60% diethyl ether–light petroleum (b.p. 40—60 °C) as eluant.

2-(*Prop*-2-*ynyloxy*)*cyclohexan*-1-*ol.* By the general procedure, the alcohol was obtained (72%) as a colourless oil which showed $\nu_{max.}$(film) 3 450 (br), 3 300 (s), 2 120 (w), and 1 100 (s) cm^{-1}, δ_H 4.2 (app. t, *J* 3 Hz, CH_2O), 3.3 (m, 2 × CHO), 3.0 (OH), 2.45 (app. t, *J* 3 Hz, =C*H*), and 2.2—1.0 (m, 8 H) (Found: *m/z* 155.1071. $C_9H_{15}O_2$ requires *M* + 1, 155.1072).

2-*Methyl*-2-(*prop*-2-*ynyloxy*)*cyclohexan*-1-*ol.* By the general procedure, the alcohol was obtained (46%) as a colourless oil, which showed $\nu_{max.}$(film) 3 420 (s), 3 300 (s), 2 120 (w), and 1 070 (s) cm^{-1}; δ_H 4.1 (d, *J* ~ 3 Hz, CH_2O), 3.6 (m, C*H*OH) 2.35 (t, *J* 3 Hz, ≡CH), 2.0—1.2 (m, 8 H), and 1.2 (Me) (Found: *m/z* 168.1156. $C_{10}H_{16}O_2$ requires *M*, 168.1150).

2-(2-*Bromoprop*-2-*enyloxy*)*cyclohexan*-1-*ol.* By the general procedure, the alcohol was obtained (62%) as a colourless oil, $\nu_{max.}$(film) 3 450 (br), 1 640 (m), and 1 080 (s) cm^{-1}; δ_H 6.0 (app. t, *J* 1 Hz, =C*H*H), 5.08 (br, =CH*H*), 4.2 (CH_2O), 3.85 (m, C*H*OH), 3.54 (m, C*H*OR), 2.3 (OH), and 2.1—1.1 (m, 8 H); δ_C 130.4 and 130.2, 117.8 (d) and 117.5 (d), 83.4 (d) and 78.7 (d), 73.6 (d), 68.9 (d), 72.9 (t) and 72.5 (t), 32.3 (t), 30.5 (t), 29.4 (t), 267 (t), 24.1 (t), 23.9 (t), and 22.0 (t), 21.4 (t) p.p.m.

Preparation of 2-(*Prop*-2-*ynyloxy*)- *and* 2-(*Prop*-2-*enyloxy*)-*cyclohexan*-1-*ones. General Procedure.*—Pyridinium chlorochromate was added over 10 min to a rapidly stirred and cooled (15—25 °C) solution of the corresponding cyclohexanol in dry dichloromethane. The mixture was stirred at 25 °C until inspection by t.l.c. analysis showed that the oxidation was complete. The mixture was filtered and the filtrate was then evaporated to dryness. Chromatography of the residue on Kieselgel G using diethyl ether–light petroleum (b.p. 40—60 °C) as eluant then gave the pure cyclohexanones, as colourless oils (55—88%).

2-(*Prop*-2-*ynyloxy*)*cyclohexan*-1-*one* (**15a**). The ketone showed b.p. 126 °C at 20 mmHg; $\nu_{max.}$(film) 3 260 (m), 2 120 (w), 1 720 (s), and 1 110 (s) cm^{-1}; δ_H 4.4 (t, *J* 3 Hz, CH_2O), 4.2 (m, CHO), 2.5 (t, *J* 3 Hz, =CH), and 2.4—1.4 (m, 8 H); δ_C 209.3, 80.0 (d), 79.5 (d), 75.0 (d), 57.0 (t), 40.7 (t), 34.4 (t), 27.6 (t), and 23.3 (t), p.p.m. (Found: *m/z* 153.0898. $C_9H_{13}O_2$ requires *M* + 1, 153.0915).

2-(2-*Bromoprop*-2-*enyloxy*)*cyclohexan*-1-*one* (**17**). The ketone showed b.p. 74—76 °C at 0.3 mmHg, $\nu_{max.}$(film) 1 720, 1 640, and 1 120 cm^{-1}; δ_H 5.96 (app. t, *J* ~ 1 Hz, =C*H*H), 5.62 (app. t, *J* 1 Hz, =CH*H*), 4.37 (d, *J* 14 Hz, –C*H*HO), 4.06 (d, *J* 14 Hz, CH*H*O), 3.9 (m, CHO), and 2.6—1.5 (m, 8 H); δ_C 209.1, 129.3, 117.7 (t), 82.0 (d), 73.7 (t), 40.6 (t), 34.5 (t), 27.5 (t), and 23.2 (t) p.p.m.

2-*Methyl*-2-(*prop*-2-*ynyloxy*)*cyclohexan*-1-*one* (**15b**).—The ketone showed b.p. 75—76 °C at 0.4 mmHg; $\nu_{max.}$(film) 3 300 (s), 2 150 (w), 1 730 (s), and 1 070 (s) cm^{-1}; δ_H 4.17 (app. dd, *J* 14 and 3 Hz, CH*H*O), 3.96 (app. dd, *J* 14 and 3 Hz, –C*H*HO), 2.4 (t, *J* 3 Hz, ≡CH), 2.4—1.4 (m, 8 H), and 1.3 (Me); δ_C 211.7, 81.4, 80.3, 74.4 (d), 52.0 (t), 40.8 (t), 39.0 (t), 28.1 (t), 20.3 (t), and 19.1 (q) p.p.m. (Found: *m/z* 167.1072. $C_{10}H_{15}O_2$ requires *M* + 1, 167.1072).

Radical Anion Reductive Cyclisations. General Procedure.—A solution of sodium naphthalenide[15] in tetrahydrofuran (THF) or hexamethylphosphoramide (*ca.* 0.65M) was added dropwise to a stirred solution of the 2-(prop-2-ynyloxyl) or 2-(prop-2-enyloxy)cyclohexan-1-one in dry THF (0.02M for the 2-methyl substituted ketones; 0.05M for the unsubstituted compounds), maintained at room temperature under argon. The addition was continued until either a persistent green end-point was observed, or until the required quantity of the radical anion had been added. After being stirred for a further 10 mins, the mixture was acidified with dilute hydrochloric acid (10%), the THF was evaporated off at reduced pressure, and the aqueous residue was extracted with diethyl ether (3 × 40 ml). The combined ethereal extracts were washed with dilute hydrochloric acid (10%, 1 × 20 ml) and saturated aqueous sodium hydrogen carbonate (1 × 20 ml), then dried, and concentrated under reduced pressure to leave the crude product as an oil, which was purified by chromatography.

Attempted Radical Anion Mediated Cyclisation of 2-(*Prop*-2-*ynyloxy*)*cyclohexan*-1-*one* (**15a**).—According to the general procedure, reaction between a solution of sodium naphthalenide radical anion in THF (5.0 ml × 0.67M, 3.3 mmol) and a solution of 2-(prop-2-ynyloxy)cyclohexan-1-one (460 mg, 3.0 mmol) in anhydrous THF (60 ml, 0.05M) gave, after work-up, a yellow slurry. The residual naphthalene was removed from the crude product by chromatography on Kieselgel G (20 g), eluting with hexane and then diethyl ether, to give a yellow oil. The oil was further purified by chromatography on Kieselgel G (100 g), using diethyl ether–hexane (30%) as eluant to give: (i) 2-*hydroxy* 2-(*propa*-1,2-*dienyl*)*cyclohexan*-1-*one* (**16**) (27 mg, 6%) (eluted first) as a clear colourless oil, b.p. (oven temp.) 80 °C at 0.1 mmHg; $\nu_{max.}$(film) 3 450 (br), 1 950 (s), 1 720 (s), and 1 100 (s) cm^{-1}; δ_H 5.28 (t, *J* 7 Hz, CH=), 5.00 (d, *J* 7 Hz, =CH_2), 4.20 (OH), and 2.8—1.6 (m, 8 H); δ_C 210.9, 207.8, 94.3(d), 78.7 (t), 77.7, 40.4 (t), 38.6 (t), 27.5 (t), and 22.6 (t) (Found: *m/z* 152.0848. $C_9H_{12}O_2$ requires *M*, 152.0838), and (ii) 1-*oxo*-7-*oxaspiro*-[5.4]*dec*-9-*ene* (27 mg, 6%) (eluted second) as a pale yellow oil, b.p. (oven temp.) 70 °C at 0.1 mmHg; $\nu_{max.}$(film) 3 100 (w), 1 730 (s), 1 620 (w), and 1 100 (s) cm^{-1}; δ_H 6.08 (app. s, 2 × CH), 4.76 (CH_2O), 2.8—2.2 (m, CH_2CO), and 2.0—1.5 (m, 6 H); δ_C 207.6, 127.9 (d), 128.1 (d), 94.9, 74.5 (t), 39.5 (t), 39.0 (t), 26.7 (t), and 22.1 (t) p.p.m. (Found: *m/z* 152.0823. $C_9H_{12}O_2$ requires *M*, 152.0838).

cis-3-*Methylene*-1-*oxabicyclo*[4.3.0]*nonane* (**14a**).—A solution of azoisobutyronitrile (150 mg, 900 μmol) in tributylstannane (4.9 ml, 18 mmol) was added dropwise over 4 h to a stirred, degassed solution of 2-(2-bromoprop-2-enyloxy)cyclohexanone (1 g, 4.3 mmol) in dry benzene (215 ml) heated under reflux in an argon atmosphere. The mixture was heated for a further 64 h, then evaporated to dryness *in vacuo* whereupon the residue was diluted with acetonitrile (50 ml). The organic extract was washed with hexane (15 ml), then dried, and evaporated. The residual oil was purified by chromatography on Kieselgel G using 40% diethyl ether–hexane as eluant to give: (i) 2-(prop-2-enyloxy)cyclohexan-1-one (0.11 g, 17.2%) (eluted first), (ii) 2-(prop-2-enyloxy)cyclohexan-1-ol (54 mg, 8.2%) (eluted second), and (iii) the bicyclononane (71 mg, 11%) (eluted last) as a colourless oil, $\nu_{max.}$ (film) 3 400(br), 3 080(w), 1 670(w), and 1 030(s) cm^{-1}; δ_H 5.15 (app. t, *J* 3 Hz, =C*H*H), 4.97 (app. t, *J* ~ 3 Hz, =CH*H*), 4.5 (t, *J* 3 Hz, CH_2O), 3.68 (t, *J* 4 Hz, CHO), 2.35 (OH), and 1.9—1.3 (m, 8 H); δ_C 154.1, 103.2(t), 81.9(d), 76.4, 68.8(t), 33.4(t), 26.4(t), 21.8(t), and 20.9(t) p.p.m. (Found: *m/z* 154.0995. $C_9H_{14}O_2$ requires *M*, 154.0994).

2-(*Methoxyethoxymethoxy*)*cyclohex*-2-*en*-1-*one* (**24c**).—A solution of cyclohexane-1,2-dione (1.12 g, 10 mmol) in dry THF

(10 ml) was added dropwise over 15 min to a stirred solution of lithium di-isopropylamide [from di-isopropylamine (1.54 ml, 11.0 mmol), BuLi–hexane (6.7 ml × 1.65M, 11.1 mmol); 0 °C, 15 min] in dry THF (10 ml) maintained at −78 °C and under argon. The mixture was allowed to warm to −20 °C over 0.5 h, and was then re-cooled to −78 °C, whereupon methoxyethoxymethyl chloride (1.37 ml, 12.0 mmol) was slowly added dropwise. The cooling bath was removed and the solution was then stirred at 25 °C for 12 h, before water (10 ml) was added. The THF was removed by concentration under reduced pressure, and the residue was then extracted with ethyl acetate. The combined organic extracts were washed with saturated aqueous brine (1 × 10 ml), then dried, and evaporated at reduced pressure to leave an oil. The oil was adsorbed onto silica (Woelm), and then subjected to chromatography on Kieselgel H (37 g), using 80% diethyl ether–light petroleum as eluant to give the *enol ether* (0.87 g, 43%) as a pale yellow oil; $\nu_{max.}$(film) 1 690 (s), 1 650 (m), and 1 100 (s) cm^{-1}; δ_H 6.45 (t, *J* 7, =CH), 5.12 (OCH_2O), 3.9—3.5 (m, OCH_2CH_2O), 3.40 (OMe), 2.6—2.3 (m, 4 H), and 2.15—1.90 (m, 2 H); δ_C 194.3, 149.6, 124.5 (d), 93.7 (t), 71.6 (t), 67.8 (t), 58.9 (q), 38.8 (t), 24.7 (t), and 22.8 (t) p.p.m. (Found: *m/z* 200.1086. $C_{10}H_{16}O_4$ requires *M*, 200.1047).

2-(*Dimethyl-t-butylsilyloxy*)*cyclohex-2-en-1-one* (**24d**).—A solution of cyclohexane-1,2-dione (1.12 g, 10 mmol) in dry THF (10 ml) was added dropwise over 0.25 h to a stirred solution of lithium di-isopropylamide [from di-isopropylamine (1.5 ml, 11 mmol), BuLi–hexane (9.1 ml × 1.22M, 11 mmol); −10 °C, 0.5 h] in dry tetrahydrofuran (10 ml) maintained at −10 °C under argon. The cooling bath was removed, and the mixture was then allowed to warm to *ca.* 5 °C for 15 min, before it was re-cooled to 0 °C. A solution of dimethyl t-butylchlorosilane (2.26 g, 15 mmol) in dry THF (2 ml) was added, and the mixture was then stirred at 25 °C for 12 h. The solution was concentrated under reduced pressure, and the residue was filtered through a short column of Kieselgel H (10 g), eluting with diethyl ether, to give the *enol ether* (2.25 g) as a pale orange oil which was used without further purification; $\nu_{max.}$(film) 1 680 (s), 1 630 (m), 1 360 (m), 1 260 (s), and 840 (s) cm^{-1}; δ_H 6.20 (t, *J* 3 Hz, =CH). 2.40 (m, 4 H), 1.90 (m, 2 H), 0.90 (9 H, Bu^{t}Si), 0.05 (6 H, Me_2Si).

2-*Isobutoxycyclohex-2-en-1-ol* (**25**).—(*a*) A solution of di-isobutylaluminium hydride in hexane (7.5 ml, 2.0M) was added dropwise over 35 min to a stirred, cooled (0—10 °C) solution of 2-isobutoxycyclohex-2-en-1-one (346 mg, 2.1 mmol) in anhydrous diethyl ether (25 ml) maintained under argon. The mixture was stirred at 15—25 °C for 0.25 h, and then dry methanol (7 ml) followed by magnesium sulphate (*ca.* 50 mg) was cautiously added. The mixture was stirred at room temperature for 12 h and the precipitated aluminium salts removed by filtration through a pad of silica (Woelm). The pad was washed thoroughly with diethyl ether (2 × 30 ml) and the combined filtrates were concentrated under reduced pressure to leave an oil. The oil was diluted with diethyl ether (40 ml), and the organic solution was dried, and then evaporated under reduced pressure to leave an oil. Distillation gave the alcohol (0.31 g, 88%) as a colourless oil, b.p. 102—106 °C at 11 mmHg; $\nu_{max.}$(film) 3 400 (br s), 1 660 (s) and 1 200 (s) cm^{-1}; δ_H 4.20 (t, *J* 4 Hz, =CH), 4.20 (m, C*H*OH), 3.43 (d, *J* 7 Hz, CH_2O), 2.35 (br, OH), 2.2—1.5 (m, 7 H), and 0.97 (d, *J* 7 Hz, 2 × Me); δ_C 155.0, 96.3 (d), 73.2 (t), 66.5 (d), 31.1 (t), 28.1 (d), 24.0 (t), 19.4 (q), and 18.9 (t) p.p.m. (Found: *m/z* 170.1280. $C_{10}H_{18}O_2$ requires *M*, 170.1305).

(*b*) Sodium borohydride (113 mg, 3.0 mmol) was added in small portions over 10 min to a stirred solution of 2-isobutoxycyclohex-2-en-1-one (500 mg, 3.0 mmol) and cerium(III) chloride heptahydrate (1.11 g, 3.0 mmol) in methanol (7.5 ml, 0.4M) cooled in a water bath. After a further 20 min, the reaction was judged to be complete by t.l.c. analysis, and the mixture was concentrated under reduced pressure. The residue was diluted with water (10 ml) and then extracted with diethyl ether (3 × 10 ml). Evaporation of the dried ether extracts at reduced pressure left an oil which was purified by filtration through a short Florisil column, eluting with diethyl ether, to give the *alcohol* as a clear, colourless oil (420 mg, 85%), showing identical spectral data to those described above.

Preparation of Bromoacetals from sec-Alcohols. General Procedure.—A solution of 1,2-dibromoethyl ethyl ether was prepared by dropwise addition of bromine to a stirred solution of ethyl vinyl ether in dichloromethane maintained at −78 °C under argon. The solution was allowed to slowly warm to room temperature with stirring over 15—30 min, and then a solution of the sec-alcohol in anhydrous triethylamine was added dropwise over *ca.* 5 min (cooling with a water-bath was necessary to control the slight exotherm). The resulting mixture was stirred at room temperature for 1—6 h, and then concentrated under reduced pressure. The residue was purified by chromatography on Kieselgel H to give the *bromoacetal* as an oil.

2-*Bromo*-1-*ethoxy*-1-(2-*isobutoxycyclohex*-2-*enyloxy*)*ethane* (**26**).—According to the general procedure, reaction between 2-isobutoxycyclohex-2-en-1-ol and 1,2-dibromoethyl ethyl ether followed by chromatography on Kieselgel H (40 g), eluting with 5% diethyl ether–pentane gave a mixture of diastereoisomers of the *bromoacetal* (82%) as a clear, colourless oil, $\nu_{max.}$(film) 1 660 (m), 1 200 (s), 1 100 (s), and 1 020 (s) cm^{-1}; δ_H 4.93 and 4.86 (dd, *J* 7.0, 3.5 Hz and t, *J* 5.4 Hz, 1 H, OCHO), 4.80 and 4.74 (2 × m, 1 H, =CH), 4.10—3.95 (m, 1 H, CCHO), 3.85—3.25 (m, 6 H, 2 × CH_2O and CH_2Br), 2.21—1.85 (m, 3 H), 1.8—1.6 (m, 3 H), 1.35—1.25 (m, 4 H, *Me*CH_2O and C*H*Me), and 1.0—0.85 (6 H, 2 × CHC*Me*); δ_C 153.8, 153.2, 102.5 (d), 99.2(d), 98.6 (d), 97.9 (d), 73.1 (t), 72.5 (d), 70.9 (d), 62.3 (t), 60.3 (t), 32.5 (t), 30.3 (t), 28.9 (t), 28.2 (d), 23.6 (t), 19.7 (q), 19.4 (q), 18.2 (t), 17.4 (t), and 15.2 (q) p.p.m.

Preparation of t-Alcohols from Keto-enol Ethers. General Procedure.—A solution of methyl-lithium in diethyl ether (5 mmol) was added dropwise to a cold, stirred solution of the keto-enol ether (3.5 mmol) in anhydrous diethyl ether under argon, such that the temperature was maintained at −10 to 0 °C. The mixture was stirred at 0 °C for 5—30 min and anhydrous methanol (1 equiv. with respect to methyl-lithium) was cautiously added. This procedure was repeated a total of three times, and then water (*ca.* 5 ml per mmol) was added. The pH was carefully adjusted to pH 7—8 (dilute hydrochloric acid), the organic phase was separated, and the aqueous layer extracted with diethyl ether (3 × 5 ml per mmol). The combined organic solutions were dried and the solvent evaporated at reduced pressure to leave the crude *t-alcohol* as an oil, which was purified by column chromatography.

2-*Isobutoxy*-1-*methylcyclohex*-2-*en*-1-*ol* (**27a**).—According to the general procedure, addition of methyl-lithium to the keto-enol ether (**24a**), followed by chromatography on Kieselgel H using diethyl ether–light petroleum (30%) as eluant gave the *t-alcohol* (88%) as a clear, colourless oil, b.p. (oven temp.) 170 °C at 2.0 mmHg; $\nu_{max.}$(film) 3 450(brs), 1 660(m), and 1 180(s) cm^{-1}; δ_H 4.12 (t, *J* 4 Hz, =CH), 3.43 (d, *J* 7 Hz, CH_2), 2.35 (OH), 2.2—1.5 (m, 7 H), 1.40 (CMe), and 0.96 (d, *J* 7 Hz, 2 × CHMe); δ_C (20.15 MHz), 156.9, 94.7 (d), 73.0 (t), 69.9, 38.2 (t), 28.2 (d), 27.4 (q), 24.3 (t), 19.9 (t), 19.4 (q), and 19.3 (q) p.p.m. (Found: *m/z* 184.1450. $C_{11}H_{20}O_2$ requires *M*, 184.1462).

2-*Methoxy*-1-*methylcyclohex*-2-*en*-1-*ol* (**27c**).—According to the general procedure, addition of methyl-lithium to the methoxy ketoenol ether (**24b**) followed by chromatography on Kieselgel H, using diethyl ether–light petroleum (20%) as eluant gave the *t-alcohol* (67%) as a clear, colourless oil, b.p. (oven temp.) 145 °C at 11 mmHg; $\nu_{max.}$(film) 3 450 (br), 1 660 (s), 1 220 (s), and 1 160 (s) cm^{-1}; δ_H 5.67 (t, *J* 4 Hz, =CH), 3.55 (OMe) 2.25 (OH), 2.2—2.0 (m, 2 H), 1.9—1.5 (m, 4 H), 1.35 (CMe) [Found: *m/z* 142 (M^+, 14%), 127(100), 109(19), 98(16), 84(11)].

2-(*Methoxyethoxymethoxy*)-1-*methylcyclohex*-2-*en*-1-*ol* (**27d**).—According to the general procedure, addition of methyl-lithium to the MEM keto-enol ether (**24c**) followed by chromatography on Kieselgel H using diethyl ether, as eluant gave the *t-alcohol* (80%) as a clear, colourless oil; $\nu_{max.}$(film) 3 450 (br), 1 660 (m), and 1 100 (s) cm^{-1}; δ_H 5.1 (OCH_2O), 5.05 (t, *J* 4 Hz, =CH), 3.9–3.55 (2 × m, OCH_2CH_2O), 3.43 (OMe), 2.50 (OH), 2.2—1.5 (m, 6 H), and 1.40 (CMe); δ_C 155.3, 100.2 (d), 93.2, 71.8 (t), 69.5 (t), 67.7 (t), 58.9 (q), 38.4 (t), 27.1 (q), 24.3 (t), and 19.6 (t) p.p.m. (Found: *m/z* 216.1360. $C_{11}H_{20}O_4$ requires *M*, 216.1360).

1-*Methyl*-2-(*dimethyl*-*t*-*butylsilyloxy*)*cyclohex*-2-*en*-1-*ol* (**27b**).—According to the general procedure, addition of methyl-lithium to the TBDMS keto-enol ether (**24d**), followed by chromatography on Kieselgel H using diethyl ether–light petroleum (16%) as eluant gave the *t-alcohol* (46%) as a clear, colourless oil; $\nu_{max.}$(film) 3 450 (br s), 1 670 (m), 1 260 (s), and 850 (s) cm^{-1}; δ_H 4.30 (t, *J* 4 Hz, =CH), 2.15 (OH), 2.1—1.5 (m, 6 H), 1.30 (CMe), 0.92 (Bu^{t}Si), and 0.14 (Me_2Si).

Preparation of Bromoacetals from t-Alcohols. General Procedure.—A solution of 1,2-dibromoethyl ethyl ether was prepared by dropwise addition of bromine to a stirred solution of ethyl vinyl ether in anhydrous chloroform maintained at −10 °C under argon. The solution was allowed to warm to room temperature over 0.5 h, and was then warmed to 50 °C. A solution of the t-alcohol (1.6 mmol) and triethylamine (600 µl) in chloroform (3 ml) containing 4-DMAP (0.75 mmol) was then added in one portion, and the mixture stirred at 50 °C for 1—18 h. The solution was allowed to cool to room temperature, water (*ca.* 10 ml per mmol) was added, and the organic phase was separated. The aqueous layer was extracted with dichloromethane (*ca.* 2 × 15 ml per mmol), and the combined organic solutions were washed with saturated aqueous sodium chloride (1 × 10 ml), and then dried. The solvent was evaporated off at reduced pressure to leave an oil, which was purified by chromatography on Kieselgel H, to produce mixtures of diastereoisomers of the bromoacetals.

2-*Bromo*-1-*ethoxy*-1-(2-*isobutoxy*-1-*methylcyclohex*-2-*enyloxy*)*ethane* (**28a**).—According to the general procedure, reaction between the t-alcohol (**27a**) and 1,2-dibromoethyl ethyl ether, followed by chromatography on Kieselgel H using diethyl ether–light petroleum (4%) as eluant, gave the *bromoacetal* (60%) as a clear, colourless oil; $\nu_{max.}$(film) 1 660 (m), 1 380 (m), 1 200 (s), and 1 050 (s) cm^{-1}; δ_H 5.2—4.5 (m, OCHO and =CH), 3.9—3.2 (m, 2 × CH_2O), 3.36 (d, *J* 6 Hz, CH_2Br), 2.2—1.4 (m, 7 H), 1.40 (CMe), 1.20 (t, *J* 7 Hz, $MeCH_2O$), and 0.96 (d, *J* 7 Hz, 2 × CHMe); δ_C 155.5, 101.6, 98.1 (d), 97.7 (d), 97.3 (d), 96.8 (d), 75.9, 74.4, 62.5 (t), 62.1, 59.5 (t), 54.0 (t), 54.0 (d), 53.9 (d), 38.6 (t), 37.7 (t), 33.8 (t), 33.2 (t), 31.8 (t), 25.0, 24.3 (t), 24.2 (t), 23.6, 19.2 (t), 18.4 (t), and 15.2 (q) p.p.m.

2-*Bromo*-1-*ethoxy*-1-(2-*methoxy*-1-*methylcyclohex*-2-*enyloxy*)*ethane* (**28b**).—According to the general procedure, reaction between 2-methoxy-1-methylcyclohex-2-en-1-ol and 1,2-dibromoethyl ethyl ether followed by column chromatography on Kieselgel H using diethyl ether–light petroleum (2—3%) as eluant, gave the *bromoacetal* (74%) as a clear, colourless oil; $\nu_{max.}$(film) 1 660 (w), 1 140 (s), and 1 020 (s) cm^{-1}; δ_H 5.06—4.84 (m, OCHO, =CH; one isomer), 4.70 (t, *J* 5 Hz, =CH; second isomer) 3.9—3.2 (m, CH_2Br and OCH_2Me), 3.45 (OMe), 2.2—1.4 (m, 6 H), 1.40 (CMe), and 1.24 (t, *J* 7 Hz, $MeCH_2O$); δ_C 154.7, 154.6, 101.25, 98.5 (d), 97.8 (d), 96.9 (d), 96.7 (d), 76.1, 75.4, 72.9 (q), 62.4 (t), 62.0, 59.4 (t), 38.7 (t), 37.7 (t), 33.8 (t), 33.3 (t), 31.8 (t), 25.2, 24.4 (t), 24.3 (t), 23.4, 19.6 (t), 19.1 (t), 18.2 (t), 15.2 (q), and 15.1 (q) p.p.m.

2-*Bromo*-1-*ethoxy*-1-(2-*methoxyethoxymethoxy*-1-*methylcyclohex*-2-*enyloxy*)*ethane* (**28c**).—According to the general procedure, reaction between the t-alcohol (**27d**) and 1,2-dibromoethyl ethyl ether followed by chromatography on Kieselgel H using diethyl ether–light petroleum (6–100%) as eluant, gave the *bromoacetal* (50%) as a clear, colourless oil; $\nu_{max.}$(film) 1 660 (m), 1 460 (m), 1 380 (m), and 1 100 (s) cm^{-1}; δ_H 5.15 (m, OCHO and =CH), 5.10 (OCH_2O), 2.9—3.2 (m, 8 H, CH_2Br, OCH_2Me and OCH_2CH_2O), 3.45 (OMe), 2.3—1.3 (m, 6 H), 1.35 (CMe), and 1.20 (t, *J* 7 Hz, $MeCH_2O$).

2-*Bromo*-1-*methoxy*-1-(1-*methyl*-2-*dimethylbutylsilyloxy*-*cyclohex*-2-*enyloxy*)*propane* (**29**).—According to the general procedure, reaction between the t-alcohol (**27b**) and 1,2-dibromopropyl ethyl ether followed by chromatography on Kieselgel H using diethyl ether–light petroleum (84%) as eluant gave the *bromoacetal* (51%) as a clear, colourless oil; $\nu_{max.}$(film) 1 660 (m), 1 280 (m), 1 200 (m) and 1 140 (s) cm^{-1}; δ_H 5.12 and 4.95 (d, *J* 3 Hz, OCHO), 4.90 (t, *J* 4 Hz, =CH), 4.10 and 4.00 (m, CHBr), 3.64 (q, *J* 7 Hz, $MeCH_2O$), 2.2—1.4 (6 H), 1.74 (d, *J* 7 Hz, *Me*CH), 1.30 (CMe), 1.20 (t, *J* 7 Hz, OCH_2Me), 0.90 (Bu^{t}Si), and 0.15 and 0.10 (6 H, Me_2Si).

Radical Mediated Cyclisations Using Tributylstannane. General Procedure.—A solution of azoisobutyronitrile (AIBN) in dry benzene (1 ml per 50 µmol AIBN) was added dropwise over 10 min to a stirred, degassed solution of the bromoacetal and tributylstannane in dry benzene (0.019–0.021M) maintained at 80 °C under argon. The mixture was heated at 80 °C for 1 h, then cooled to room temperature, and evaporated directly onto silica (Woelm). Purification by chromatography on Kieselgel H, gave a mixture of C-1 anomers of the *cyclic acetal* as a clear, colourless oil. The reactions were conveniently monitored by t.l.c. or g.l.c. analysis. The ratios of the anomers obtained varied from one case to another. Where the anomers were separated, their spectral data have been recorded separately.

cis-8-*Ethoxy*-1-*isobutoxy*-7-*oxabicyclo*[4.3.0]*nonane* (**30**).—According to the general procedure, reaction between the bromoacetal (**26**) (150 mg, 467 µmol) and tributylstannane (163 µl, 608 µmol) in benzene (25 ml) containing AIBN (8 mg, 49 µmol) followed by chromatography on Kieselgel H (10 g) using diethyl ether–light petroleum (5%) as eluant gave the *cyclic acetal* (103 mg, 91%) as a clear, colourless oil; $\nu_{max.}$(film) (one anomer) 1 460 (s), 1 340 (s), 1 260 (s), 1 190 (s), 1 380 (s), and 1 100 (s); (other anomer) 1 460 (s), 1 380 (s), 1 190 (s), and 1 100 (s) cm^{-1}; δ_H (one anomer) 5.08 (t, *J* 5 Hz, OCHO), 3.95 (m, $OCHCH_2$), 3.9—2.9 (m, OCH_2 and OC*H*), 2.00 (d, *J* 6 Hz, CC*H*HCH), 1.94 (d, *J* 6 Hz, CCH*H*CH), 2.0—1.3 (m, 9 H), 1.20 (t, *J* 7 Hz, $MeCH_2O$), 0.87 (d, *J* 7 Hz, 2 × CH*Me*); (second anomer) 5.25 (dd, *J* 6 and 4 Hz, OCHO), 3.95—2.95 (m, $OCHCH_2$, OC*H*, and CH_2O), 2.22 (dd, *J* 14 and 6 Hz, CC*H*HCH), 1.90 (dd, *J* 14 and 5 Hz, CCH*H*CH), 1.9—1.3 (m, 9 H), 1.2 (t, *J* 7 Hz, *Me*CH_2O), and 0.90 (d, *J* 7 Hz, 2 × CH*Me*); δ_C (one anomer) 102.4(d), 79.2, 76.5(d), 70.5 (t), 63.4 (t), 43.8 (t), 30.3 (t), 29.0 (d), 25.2 (t), 20.8 (t), 20.0 (t), 19.5 (q), and 15.3 (q) p.p.m.; (second anomer) 103.7 (d), 81.6, 80.9 (d), 69.3 (t), 63.7 (t),

41.0 (t), 30.3 (t), 29.8 (t), 29.0 (d), 22.0 (t), 20.0 (t), 19.5 (q), and 15.4 (q) p.p.m. (Found: *m/z* 243.1930, 243.2004. $C_{14}H_{27}O_3$ requires *M*, 243.1959).

cis-8-*Ethoxy*-1-*isobutoxy*-6-*methyl*-7-*oxabicyclo*[4.3.0]-*nonane* (**31a**).—According to the general procedure, reaction between the bromoacetal (**28a**) (3.0 g, 9.0 mmol) and tributylstannane (2.7 ml, 9.9 mmol) in benzene (450 ml) containing AIBN (147 mg, 900 μmol) followed by chromatography on Kieselgel H (200 g) using diethyl ether–light petroleum (2—3%) as eluant gave the *cyclic acetal* (1.8 g, 78%) as a clear, colourless oil; $\nu_{max.}$(film) 1 460 (m), 1 390 (s), 1 100 (s), 1 100 (s) cm^{-1}; δ_H 5.28, and 5.12 (t, *J* 6 Hz, OCHO), 3.95—2.85 (m, 2 × CH_2O), 2.18 (dd, *J* 14 and 7 Hz, CCH_2CH), 2.0—1.3 (m, 9 H), 1.24 (m, *Me*CH_2 and MeC), and 0.93 (d, *J* 7 Hz, 2 × CH*Me*); δ_C 102.6 (d), 102.1 (d), 85.1, 82.9, 82.3, 80.6, 70.8 (t), 68.7 (t), 63.6 (t), 63.3 (t), 42.6 (t), 38.9 (t), 37.7 (t), 34.0 (t), 30.8 (t), 30.0 (t), 29.2 (d), 24.3 (q), 23.2 (t), 22.7 (t), 21.7 (t), 21.2 (t), 19.9, 19.6 (q), 19.5, 15.5 (q), and 15.4 (q) p.p.m. (Found: *m/z* 256.2019. $C_{15}H_{28}O_3$ requires *M*, 256.2037).

cis-8-*Ethoxy*-1-*methoxy*-6-*methyl*-7-*oxabicyclo*[4.3.0]*nonane* (**31b**).—According to the general procedure, reaction between the bromoacetal (**28b**) (493 mg, 1.68 mmol) and tributylstannane (500 μl, 1.86 mmol) in benzene (100 ml) containing AIBN (27 mg, 170 μmol) followed by chromatography on Kieselgel H (50 g) using diethyl ether–light petroleum (5—10%) as eluant gave the *cyclic acetal* (202 mg, 56%) as a clear, colourless oil; δ_H (one anomer) 5.10 (t, *J* 6 Hz, OCHO), 4.1—3.4 (m, CH_2O), 3.30 (3 H, MeO), 2.10 (d, *J* 7 Hz, CCH_2CH), 1.8—1.2 (m, 8 H), 1.25 (MeC), and 1.20 (t, *J* 7 Hz, MeCH_2O); (other anomer) 5.25 (dd, *J* 7 and 6 Hz, OCHO), 4.05—3.30 (m, CH_2O), 3.28 (OMe), 2.45 (dd, *J* 14 and 6 Hz, CC*H*HCH), 2.05 (dd, *J* 14 and 6 Hz, CCH*H*CH), 2.0—1.3 (m, 8 H), 1.25 (MeC), and 1.25 (t, *J* 7 Hz, *Me*CH_2O) (Found: *m/z* 214.1571. $C_{12}H_{22}O_3$ requires *M*, 214.1568).

cis-8-*Ethoxy*-1-(*methoxyethoxymethoxy*)-6-*methyl*-7-*oxabicyclo*[4.3.0]*nonane* (**31c**).—According to the general procedure, reaction between the bromoacetal (**28c**) (470 mg, 1.36 mmol) and tributylstannane (439 μl, 1.63 mmol) in benzene (70 ml) containing AIBN (27 mg, 170 μmol) followed by chromatography on Kieselgel H (30 g) using diethyl ether–light petroleum (25—100%) as eluant gave the *cyclic acetal* (326 mg, 90%) as a clear, colourless oil; $\nu_{max.}$(film) 1 460 (m), 1 380 (m), and 1 100 (s) cm^{-1}; δ_H 5.25 and 5.06 (t, *J* 6 Hz, OCHO), 4.85 (CH_2O), 3.39—2.4 (m, OCH_2CH_2O and MeCH_2O), 3.40 (MeO) 2.55 (dd, *J* 14 and 6 Hz, CC*H*HCH), 2.12 (dd, *J* 14 and 5 Hz, CCH*H*CH), 1.9—1.3 (m, 8 H), 1.28 (MeC), and 1.20 (t, *J* 7 Hz, *Me*CH_2O).

cis-8-*Ethoxy*-6,9-*dimethyl*-1-(*dimethyl*-*t*-*butylsilyloxy*)-7-*oxabicyclo*-[4.3.0]*nonane* (**32**).—According to the general procedure, reaction between the bromoacetal (**29**) (420 mg, 1.0 mmol) and tributylstannane (first: 277 μl, 1.04 mmol; then after 1 h: 80 μl, 300 μmol) in benzene (50 ml) containing AIBN (first: 20 mg, 130 μmol; then after 1 h: 10 mg, 62 μmol) (heating under reflux for a total of 2 h) followed by chromatography on Kieselgel H (27 g) using diethyl ether–light petroleum (4%) as eluant gave the *cyclic acetal* (136 mg, 60%) as a clear, colourless oil; $\nu_{max.}$(film) 1 470 (m), 1 260 (m), and 1 120 (s) cm^{-1}; δ_H 4.80 and 4.94 (d, *J* 7 Hz, OCHO), 3.9—3.2 (m, CH_2O), 2.0—1.2 (m, 9 H), 1.23 (d, *J* 7 *Me*CH), 1.25—1.0 (m, *Me*CH_2 and MeC), 0.90 (Bu^{t}Si), and 0.07 (Me_2Si).

2-(*Methoxymethoxy*)*cyclohex*-2-*en*-1-*one*.—A solution of cyclohexane-1,2-dione (1.12 g, 10 mmol) in dry dichloromethane (4 ml) was added to a stirred solution of di-isopropylethylamine (4.5 ml, 26 mmol) and chloromethyl methyl ether (1.52 ml, 18 mmol) in dry dichloromethane (15 ml) at room temperature under argon. The mixture was stirred at 25 °C for 48 h, and then concentrated under reduced pressure, whereupon the residue was taken up in diethyl ether (30 ml). The organic solution was washed with water (3 × 10 ml), dried, and then evaporated at reduced pressure to leave an oil, which was subjected to chromatography on Kieselgel H. Elution with diethyl ether–light petroleum (50%) gave the *enol ether* (0.5 g, 32%) as a pale yellow oil; $\nu_{max.}$(film) 1 680 (s), 1 630 (m), 1 150 (s), and 1 000 (s) cm^{-1}; δ_H 6.40 (t, *J* 4 Hz, =CH), 5.05 (OCH_2O), 3.45 (OMe), 2.7—2.5 (m, 4 H), and 2.3—1.9 (m, 2 H) (Found: *m/z* 154.0601. $C_8H_{10}O_3$ requires *M*, 154.0630).

2-(*Methoxymethoxy*)*cyclohex*-2-*en*-1-*ol* (**36**).—A solution of di-isobutylaluminium hydride in diethyl ether (30 ml × 1.0M, 30 mmol) was added dropwise over 10 min to a stirred, cooled (ice-water) solution of 2-(methoxymethoxy)cyclohex-2-en-1-one (3.0 g, 19.2 mmol) in anhydrous diethyl ether (55 ml) under argon. The cooling bath was removed and the mixture stirred at room temperature for 1 h, whereupon anhydrous methanol (10 ml) was added cautiously. After being stirred for a further 1 h, a white gel formed. Solid magnesium sulphate (2—3 g) was added and the mixture was then stirred vigorously until flocculation occurred. The resulting suspension was filtered and the filtrate washed with diethyl ether until it was dry and powdery (3 × 30 ml). The solvent was evaporated from the combined organic filtrates under reduced pressure to leave a yellow oil, which was purified by chromatography on Kieselgel H (70 × 80 mm). Elution with diethyl ether–light petroleum (60%) gave the *alcohol* (1.9 g, 63%) as a clear, colourless oil; $\nu_{max.}$(film) 3 400 (br), 1 670 (m), 1 160 (s), and 1 060 (s) cm^{-1}; δ_H 5.15 (t, *J* 4 Hz, =CH), 5.02 (OCH_2O), 4.20 (m, C*H*OH), 3.48 (OMe), 2.10 (OH), 2.3—2.2 (m, 2 H), and 2.0—1.5 (m, 4 H) (Found: *m/z* 158.0952. $C_8H_{14}O_3$ requires *M*, 158.0941).

2-*Bromo*-1-*methoxy*-1-(2-*methoxymethoxycyclohex*-2-*enyloxy*)-1-*prop*-2-*ene* (**37**).—A solution of methoxyallene (147 mg, 2.1 mmol) and 2-(methoxymethoxy)cyclohex-2-en-1-ol (500 mg, 3.16 mmol) in carbon tetrachloride (2.0 ml) was added dropwise to a stirred suspension of *N*-bromosuccinimide (376 mg, 2.1 mmol) in carbon tetrachloride (3.0 ml), maintained at −5 °C under argon. The mixture was allowed to warm to room temperature over 18 h, and then the succinimide was removed by filtration. The solvent was evaporated at reduced pressure, and the residue purified by column chromatography on Kieselgel H (40 × 100 mm), using diethyl ether–light petroleum (10%) as eluant to give the *bromoacetal* (467 mg, 48%) as a colourless oily mixture of diastereoisomers; $\nu_{max.}$(film) 1 679 (m), 1 150 (s), and 1 020 (s) cm^{-1}; δ_H (one isomer) 6.30 (m, C*H*H), 5.84 (m, =CH*H*), 5.23 (OCHO), 5.20 (t, *J* 4 Hz, =CH), 5.00 (OCH_2O), 4.16 (m, CCHO), 3.98 (OMe), 3.40 (OMe), and 2.2—1.6 (m, 6 H); (other isomer) 6.20 (m, =C*H*H), 5.80 (m, =CH*H*), 5.20 (t, *J* 4 Hz, =CH), 5.04 (OCHO), 5.00 (OCH_2O), 4.08 (m, CCHO), 3.45 (OMe), 3.40 (OMe), and 2.2—1.5 (m, 6 H) (Found: *m/z* 277.0222 and 275.0257. $C_{11}H_{16}BrO_3$ requires *M*, 277.0260 and 275.0281).

cis-8-*Methoxy*-1-(*methoxymethoxy*)-9-*methylene*-7-*oxabicyclo*[4.3.0]*nonane* (**38**).—A solution of tributylstannane (320 μl, 1.2 mmol) and AIBN (32 mg, 199 μmol) in dry benzene (4.0 ml) was added dropwise over 4 h to a stirred, degassed solution of the bromoacetal (**37**) (300 mg, 980 μmol) in dry benzene (45.0 ml, 0.022M) at 80 °C under argon. Heating was continued for a further 18 h, and then the mixture was allowed to cool to room temperature, whereupon the benzene was evaporated off at reduced pressure. The residual oil was preadsorbed onto silica (Woelm) and subjected to chromatography on Kieselgel H (40 × 100 mm), using diethyl ether–light petroleum (20%) as

eluant to give the *bicyclic acetal* (110 mg, 50%) as a clear, colourless oily mixture of C-1 anomers; $\nu_{max.}$(film) 1 660 (w), 1 450 (m), 1 330 (m), and 1 040 (s) cm^{-1}; δ_H (one anomer) 5.45 (OCHO), 5.25 (OCH_2O), 4.90 (d, *J* 7 Hz, =C*H*H), 4.6 (d, *J* 7 Hz, =CH*H*), 4.30 (t, *J ca.* 3 Hz, CCHO), 3.50 (OMe), 3.48 (OMe), 2.0—1.2 (m, 8 H); (second anomer) 5.64 (OCHO), 5.40 (OCH_2O), 4.76 (d, *J* 7 Hz, =C*H*H), 4.64 (d, *J* 7 Hz, =CH*H*), 4.06 (dd, *J* 11 and 7 Hz, CCHO), 3.52 (OMe), 3.40 (OMe), and 2.1—1.1 (m, 8 H).

Radical Mediated Cyclisation using Cobaloxime(III). *General Procedure.*—Sodium borohydride was added to a stirred, degassed mixture of aqueous sodium hydroxide (10M) and ethanol (0.02M) through which argon was slowly and continuously bubbled. The bromoacetal was added, and the mixture heated to and maintained at 50—60 °C whilst bis-(dimethylglyoximato)pyridiniumcobalt(III) chloride was added in small portions (*ca.* 2 mg) at intervals of *ca.* 10 min, until a persistent black end-point [Co(I)] was observed (*ca.* 1 h). After being stirred for a further 2.5 h, the mixture was allowed to cool to room temperature, and the ethanol evaporated off under reduced pressure. The residue was diluted with saturated aqueous sodium chloride (*ca.* 15 ml per mmol) and the aqueous emulsion extracted with diethyl ether (*ca.* 4 × 15 ml per mmol). The combined ethereal extracts were dried, and the solvent evaporated at reduced pressure to leave the crude *unsaturated cyclic acetal* as an oil. The oil was preadsorbed onto silica (Woelm), and then purified by chromatography on Kieselgel H.

cis-8-*Ethoxy*-1-*isobutoxy*-7-*oxabicyclo*[4.3.0]*non*-2-*ene* (**43a**).—According to the general procedure, reaction of the bromoacetal (**26**) (325 mg, 1.0 mmol) and sodium borohydride (76 mg, 2.0 mmol) in a mixture of aqueous sodium hydroxide (0.2 ml × 10M, 2.0 mmol) and ethanol (50 ml) with bis-(dimethylglyoximato)pyridiniumcobalt(III) chloride at 50—60 °C for a total of 2 h, followed by chromatography on Kieselgel H (10 g), using diethyl ether–light petroleum (5%) as eluant gave the *unsaturated cyclic acetal* (97 mg, 40%) as a clear, colourless oily mixture of C-1 anomers; $\nu_{max.}$(film) 1 460 (m), 1 380 (m), 1 360 (m), 1 260 (m), 1 120 (s), and 1 070 (s) cm^{-1}; δ_H (one anomer) 6.1—5.6 (m, 2 × CH), 5.05 (t, *J* 5 Hz, OCHO), 4.30 (m, CHO), 4.0—3.3 (m, $MeCH_2O$), 3.17 (d, *J* 7 Hz, OCH_2CH), 2.20 (d, *J* 5 Hz, CCH_2CH), 2.1—1.3 (m, 5 H), 1.23 (t, *J* 7 Hz, C*H*MeO), and 0.90 (d, *J* 7 Hz, 2 × MeCH); (second anomer) 6.1—5.6 (m, 2 × CH), 5.25 (dd, *J* 6 and 4 Hz, OCHO), 4.20 (t, *J* 7 Hz, $OCHCH_2$), 4.0—3.3 (m, $MeCH_2O$), 3.15 (d, *J* 7 Hz, OCH_2CH), 2.45 (dd, *J* 14 and 6 Hz, CCHHCH), 2.1—1.6 (m, 5 H), 2.20 (t, *J* 7 Hz, $MeCH_2O$), 2.00 (dd, *J* 14 and 5 Hz, CCH*H*CH), and 0.90 (d, *J* 7 Hz, 2 × *Me*CH); δ_C (one anomer) 129.8 (d), 129.1 (d), 102.3 (d), 78.1, 77.5 (d), 71.3 (t), 63.1 (t), 45.7 (t), 29.1 (d), 23.3 (t), 19.7 (t), 19.5 (q), 19.4 (q), and 15.3 (q) p.p.m.; (second anomer) 130.5 (d), 129.1 (d), 103.7 (d), 81.3, 79.6 (d), 70.4 (t), 63.5 (t), 46.0 (t), 29.1 (d), 28.4 (t), 22.0 (t), 19.5 (q), 19.4 (q), and 15.3 (q) p.p.m.

cis-8-*Ethoxy*-1-*isobutoxy*-6-*methyl*-7-*oxabicyclo*[4.3.0]*non*-2-*ene* (**43b**).—According to the general procedure, reaction of the bromoacetal (**28a**) (340 mg, 1.0 mmol) and sodium borohydride (80 mg, 2.1 mmol) in a mixture of aqueous sodium hydroxide (0.2 ml × 10M, 2.0 mmol) and ethanol (50 ml) with bis-(dimethylglyoximato)pyridiniumcobalt(III) chloride at 50—60 °C for a total of 3.5 h, followed by chromatography on Kieselgel H (22 g), using diethyl ether–light petroleum (3%) as eluant gave the *unsaturated cyclic acetal* (193 mg, 75%) as a clear, colourless oily mixture of C-1 anomers; $\nu_{max.}$(film) 1 680 (w), 1 460 (m), 1 380 (m), 1 100 (s), and 1 000 (s) cm^{-1}; δ_H (one anomer) 6.1—5.5 (m, 2 × =CH), 4.90 (t, *J* 7 Hz, OCHO), 4.0—3.3 (m, OCH_2Me), 3.16 (d, *J* 7 Hz, OCH_2CH), 2.26 (d, *J* 7 Hz, CCH_2CH), 2.1—1.3 (m, 5 H), 1.20 (MeC), 1.10 (t, *J* 7 Hz, $MeCH_2O$), and 0.90 (d, *J* 7 Hz, 2 × *Me*CH); (second anomer) 6.0—5.6 (m, 2 × =CH), 5.06 (dd, *J* 7 and 3 Hz, OCHO), 3.9—3.2 (m, $MeCH_2O$), 3.14 (d, *J* 7 Hz, $CHCH_2O$), 2.48 (dd, *J* 14 and 7 Hz, CCHHCH), 1.96 (dd, *J* 14 and 3 Hz, CCH*H*CH), 2.1—1.3 (m, 5 H), 1.20 (MeC), 1.10 (t, *J* 7 Hz, $MeCH_2O$), and 0.86 (d, *J* 7 Hz, 2 × *Me*CH); δ_C (one anomer) 130.4 (d), 128.9 (d), 101.5 (d), 81.5, 79.0, 71.0 (t), 63.3 (t), 44.3 (t), 31.3 (t), 29.2 (d), 24.4 (q), 21.2 (t), 19.5 (q), and 15.4 (q) p.p.m.; (second anomer), 129.4 (d), 128.8 (d), 101.2 (d), 84.0, 80.0, 71.0 (t), 63.1 (t), 44.4 (t), 33.2 (t), 29.3 (d), 22.8 (q), 22.2 (t), 19.5 (q), and 15.3 (q) p.p.m.

In this experiment the first eluted anomer was contaminated by *ca.* 7% of the corresponding saturated cyclic acetal (a mixture of both anomers).

cis-8-*Ethoxy*-1-*methoxy*-6-*methyl*-7-*oxabicyclo*[4.3.0]*non*-2-*ene* (**43c**).—According to the general procedure, reaction of the bromoacetal (**28b**) (110 mg, 375 μmol) and sodium borohydride (40 mg, 1.06 mmol) in a mixture of aqueous sodium hydroxide (0.1 ml × 10M, 1.0 mmol) and ethanol (19 ml) with bis-(dimethylglyoximato)pyridiniumcobalt(III) chloride at 50—60 °C for a total of 3.5 h, followed by chromatography on Kieselgel H (5 g), using diethyl ether–light petroleum (4–10%), as eluant gave the *unsaturated cyclic acetal* (31 mg, 41%) as a clear, colourless oily mixture of C-1 anomers; δ_H 6.2—5.5 (m, 2 × =CH), 5.15 and 4.92 (dd, *J* 7 and 3 Hz, and t, *J* 3 Hz, OCHO), 4.0—3.3 (m, $MeCH_2O$), 3.30 (MeO), 2.58 and 2.20 (dd, *J* 14 and 7 Hz, and dd, *J* 7 and 5 Hz, 2 H, CCH_2CH), 2.30—1.50 (m, 6 H), 1.40 (3 H, MeC), and 1.20 (m, *Me*CHO).

Oxidation of Cyclic Acetals to Lactones using Jones' Reagent. General Procedure.—Jones' reagent was added dropwise to a stirred, cooled (ice-water) solution of the acetal in acetone (*ca.* 16 ml per mmol). The mixture was stirred until t.l.c. or g.l.c. indicated the reaction to be complete (0.5—2.0 h), and during this time, the cooling bath was allowed to warm to room temperature. The precipitated chromium salts were removed by filtration, washed with a small amount of acetone, and the combined filtrates concentrated under reduced pressure. The residue was diluted with diethyl ether (*ca.* 50 ml per mmol) and washed with saturated aqueous sodium hydrogen carbonate (1 × 15 ml per mmol). Evaporation of the dried organic solution left the crude *lactone*, which was purified by column chromatography on Kieselgel H, and crystallisation, as appropriate.

cis-1-*Isobutoxy*-7-*oxabicyclo*[4.3.0]*nonan*-8-*one* (**33**).—According to the general procedure, reaction between freshly prepared Jones' reagent (2.8 ml) and the isobutoxy acetal (**30**) (100 mg, 413 μmol) in acetone (10 ml) for 2 h, followed by chromatography on Kieselgel H (2.5 g), using diethyl ether–light petroleum (20%), as eluant gave the *lactone* (61 mg, 71%) as a clear, colourless oil; $\nu_{max.}$(film) 1 780 (s), 1 460 (s), 1 220 (s), and 1 090 (s) cm^{-1}; δ_H 4.35 (t, *J* 5 Hz, OCH), 3.15 (m, OCH_2 CH), 2.58 ($COCH_2$), 2.0—1.2 (m, 9 H), and 0.92 (d, *J* 7 Hz, 2 × *Me*CH); δ_C 174.8, 81.9 (d), 78.3, 69.9 (t), 39.6 (t), 29.2 (t), 28.9 (d), 27.5 (t), 20.9 (t), 20.5 (t), and 19.3 (q) p.p.m. (Found: *m/z* 212.1408. $C_{12}H_{20}O_3$ requires *M*, 212.1412).

cis-1-*Isobutoxy*-6-*methyl*-7-*oxabicyclo*[4.3.0]*nonan*-8-*one* (**34a**).—According to the general procedure, reaction between freshly prepared Jones' reagent (1.5 ml) and the isobutoxy acetal (**31a**) (107 mg, 420 μmol) in acetone (5 ml) for 2 h, followed by chromatography on Kieselgel H (5 g), using diethyl ether–light petroleum (20—25%) as eluant, gave the *lactone* (77 mg, 82%) as a clear, colourless oil; $\nu_{max.}$(film) 1 780 (s), 1 470 (s), 1 240 (s), and 950 (s) cm^{-1}; δ_H 3.1 (m, OCH_2), 2.76 (d, *J* 14 Hz, COCHH), 2.58 (d, *J* 14 Hz, COCH*H*), 2.1—1.9 (m, 9 H), 1.42 (CMe), and

0.9 (d, *J* 7 Hz, 2 × CH*Me*); δ_C 174.6, 88.0, 79.8, 69.2 (t), 34.5 (t), 36.2 (t), 29.2 (t), 29.0 (d), 21.9 (t), 21.7 (t), 19.9 (q), and 19.4 (q) p.p.m. (Found: *m/z* 226.1566. $C_{13}H_{20}O_3$ requires *M*, 226.1569).

cis-1-*Methoxy*-6-*methyl*-7-*oxabicyclo*[4.3.0]*nonan*-8-*one* (**34b**).—According to the general procedure, reaction between freshly prepared Jones' reagent (6 ml) and the methoxy acetal (**31b**) (300 mg, 1.4 mmol) in acetone (30 ml) for 15 min, followed by chromatography on Kieselgel H (7 g), using diethyl ether–light petroleum (25—35%), as eluant, gave the *lactone* (246 mg, 96%) as a white solid which crystallised from hexane as colourless needles, m.p. 58—58.5 °C; $\nu_{max.}$ (KBr) 1 780 (s), 1 470 (m), 1 240 (s), 1 100 (s), and 950 (s) cm^{-1}; δ_H 3.30 (MeO), 2.77 (d, *J* 18 Hz, COC*H*H), 2.62 (d, *J* 18 Hz, COCH*H*), 1.9—1.3 (m, 8 H), and 1.43 (MeC); δ_C 194.5, 87.9, 80.5, 50.4 (q), 36.7 (t), 36.5 (t), 28.5 (t), 21.9 (t), 21.8 (t), and 19.6 (q) p.p.m. (Found: C, 64.9; H, 8.6. $C_{10}H_{16}O_3$ requires C, 65.2; H, 8.8%).

cis-1-(*Methoxyethoxymethoxy*)-6-*methyl*-7-*oxabicyclo*-[4.3.0]*nonan*-8-*one* (**34c**).—According to the general procedure, reaction between freshly prepared Jones' reagent (2.5 ml) and the MEM acetal (**31c**) (154 mg, 570 μmol) in acetone (10 ml) for 1.5 h, followed by chromatography on Florisil, using diethyl ether as eluant, gave the *lactone* (96 mg, 70%) as a clear, colourless oil; $\nu_{max.}$(film) 1 780 (s), 1 460 (m), 1 230 (s), 1 100 (s), and 1 040 (s) cm^{-1}; δ_H 4.85 (app. q, *J* 7 Hz, OCH_2O), 3.9—3.5 (m, OCH_2CH_2O), 3.42 (MeO), 2.98 (d, *J* 14 Hz, COC*H*H), 2.69 (d, *J* 14 Hz, COCH*H*), 2.1—1.2 (m, 8 H), and 1.45 (MeC); δ_C 174.3, 90.3 (t), 87.3, 80.7, 71.5 (t), 67.1 (t), 58.7 (q), 38.8 (t), 35.7 (t), 30.0 (t), 21.5 (t), and 19.8 (q) p.p.m.

cis-6,9-*Dimethyl*-1-(*dimethyl*-*t*-*butylsilyloxy*)-7-*oxabicyclo*-[4.3.0]*nonan*-8-*one* (**35**).—According to the general procedure, reaction between freshly prepared Jones' reagent (1.3 ml) and the TBDMS acetal (**32**) (100 mg, 300 μmol) in acetone (5 ml) for 1.5 h, followed by chromatography on Florisil using diethyl ether as eluant, gave the *lactone* (56 mg, 61%) as a white solid which crystallised from hexane as colourless needles, m.p. 113—113.5 °C; $\nu_{max.}$(film) 1 760 (s), 1 460 (w), 1 260 (s), 1 060 (s), and 830 (s) cm^{-1}; δ_H 2.84 (q, *J* 7 Hz, C*H*Me), 2.1—1.2 (m, 8 H), 1.38 (MeC), 1.09 (d, *J* 7 Hz, *Me*CH), 0.84 (Bu^{t}Si), and 0.10 and 0.08 (Me_2Si); δ_C 177.6, 87.4, 82.9, 42.4 (d), 38.0 (t), 31.4 (t), 26.1 (q) 23.2 (t), 19.5 (q), 18.9 (q), 7.8 (q), −1.2 p.p.m. (Found: C, 64.3; H, 10.1. $C_{16}H_{30}SiO_3$ requires C, 64.4; H, 10.1%).

Crystallographic Analysis of the Bicyclononanone (**35**). *Crystal Data*.—$C_{16}H_{30}O_3Si$, *M* 298.46. Monoclinic, *a* = 6.969(6), *b* = 8.390(2), *c* = 17.221(9) Å, α = 90.39(3), β = 102.87(6), γ = 109.77(5)°, *U* = 920.06 $Å^{-3}$, *Z* = 2, D_C = 1.08 g cm^{-3}, *F*(000) = 328, space group $P\bar{1}$, Cu-K_α radiation, λ = 1.54178 Å, μ(Cu-K_α) = 11.38 cm^{-1}.

A crystal of approximate dimensions 0.45 × 0.45 × 0.4 mm^3 was mounted on an Enraf–Nonius CAD4 diffractometer and 15 reflections were used to determine accurate lattice parameters. Intensity data were collected using an $\omega - \frac{2}{3}\theta$ scan for $1° < \theta < 76°$. A total of 3 836 independent reflections was measured of which 2 513 had $I > 3\sigma(I)$ and were considered observed and used in the subsequent refinement. The data were corrected for Lorentz and polarisation factors but no absorption corrections were made. Crystallographic calculations were performed using the CRYSTALS system of programs.[35] The structure was solved by direct methods using the MULTAN program.[36] Least squares refinement including anisotropic thermal parameters for non-hydrogen atoms and isotropic refinement of hydrogen atoms located in a difference Fourier synthesis terminated at *R* 0.0611 (R_w 0.0793). A final difference map showed two peaks of 0.28 e $Å^{-3}$ in the neighbourhood of the silicon atom and no other features in excess of 0.2 e $Å^{-3}$.

The crystal structure is shown in the Figure. The cyclohexane ring adopts the expected chair conformation while the lactone ring is in the envelope conformation with C(6) 0.59 Å above the plane containing the other four atoms. Curiously the C(6)–O(6) bond is eclipsed with the C(5)–C(6)–O(6)–Si torsion angle only 8.7°. The bond angle at O(6) is much enlarged to 138.8°. The remaining geometric data are unexceptional. Final atomic co-ordinates, bond lengths and bond angles are collected in the Tables. Thermal parameters and hydrogen atom co-ordinates are available on request from the Cambridge Crystallographic Data Centre.*

cis-1-(*Methoxymethoxy*)-9-*methylene*-7-*oxabicyclo*-[4.3.0]*nonan*-8-*one* (**39**).—According to the general procedure, reaction between freshly prepared Jones' reagent (2.1 ml) and the MOM acetal (**38**) (105 mg, 0.46 mmol) in acetone (5 ml) for 0.5 h, followed by chromatography on neutral alumina using diethyl ether as eluant gave the *lactone* (87 mg, 90%) as a clear, colourless oil; $\nu_{max.}$(film) 1 780 (s) and 760 (m) cm^{-1}; δ_H 6.67 (=C*H*H), 5.85 (=C*H*H), 4.73 (OCH_2O), 4.60 (m, CCHO), 3.42 (OCH_3), and 2.1—1.1 (m, 8 H); δ_C 164.1, 132.5, 118.4 (t), 86.4 (t), 76.7 (d), 76.1, 50.5 (q), 26.5 (t), 24.6 (t), 16.4 (t), and 15.7 (t) p.p.m. (Found: *m/z* 212.1073. $C_{11}H_{16}O_4$ requires *M*, 212.1048).

cis-1-*Isobutoxy*-7-*oxabicyclo*[4.3.0]*non*-2-*en*-5-*one* (**42a**).—Dilute hydrochloric acid (10%, 5 ml) was added to a stirred solution of the isobutoxy acetal (**43a**) (97 mg, 404 μmol) in THF (10 ml) and the resulting mixture was stirred at room temperature for 2 h. The solution was concentrated under reduced pressure, and the residue taken up in diethyl ether (20 ml), and dried. Evaporation of the solvent at reduced pressure left the crude *lactol* as a mixture of diastereoisomers.

The crude lactol was diluted with dry benzene (12 ml), then PCC on alumina (1.23 g, *ca.* 1.0 mmol) was added followed by concentrated hydrochloric acid (1 drop). The mixture was stirred at room temperature for 48 h, and the oxidant was then removed by filtration and washed thoroughly with diethyl ether (2 × 15 ml). The combined filtrates were concentrated under reduced pressure, and the residue was then diluted with diethyl ether (20 ml). After being washed with saturated sodium hydrogen carbonate (10 ml), the organic solution was dried and evaporated at reduced pressure to leave an oil, which was preadsorbed onto silica (Woelm) and subjected to chromatography on Kieselgel H (5 g). Elution with diethyl ether–light petroleum (30%) gave the *lactone* (40 mg, 48%) as a clear, colourless oil; $\nu_{max.}$(film) 1 780 (s), 1 680 (w), and 1 060 (s) cm^{-1}; δ_H 6.3—6.05 (m, =CH), 5.8—5.6 (m, =CH), 4.70 (t, *J* 5 Hz, CHO), 3.22 (d, *J* 7 Hz, OCH_2CH), 2.85 (d, *J* 14 Hz, COC*H*H), 2.65 (d, *J* 14 Hz, COCH*H*), 2.3—1.7 (m, 5 H), and 0.93 (d, *J* 7 Hz, 2 × *Me*CH); δ_C 174.4, 132.2 (d), 126.5 (d), 80.9 (d), 76.7, 70.9 (t), 42.1 (t), 28.9 (t), 25.3 (t), 20.4 (t), and 19.3 (q) p.p.m. (Found: *m/z* 182.0939. $C_{10}H_{14}O_3$ requires *M*, 182.0943).

cis-1-*Isobutoxy*-6-*methyl*-7-*oxabicyclo*[4.3.0]*non*-2-*en*-8-*one* (**42b**).—According to the general procedure, reaction between freshly prepared Jones' reagent (860 μl) and the isobutoxy acetal (**43b**) (91 mg, 360 μmol) in acetone (5 ml) for 1 h, followed by chromatography on Kieselgel H (6 g), using diethyl ether–light petroleum (20%) as eluant, gave the *lactone* (53 mg, 68%) as a clear colourless oil; $\nu_{max.}$(film) 1 780 (s), 1 670 (w), 1 240 (s), 1 090 (s), and 950 (s) cm^{-1}; δ_H 6.3—6.05 (m, =CH), 5.75—5.6 (m, =CH), 3.2 (d, *J* 7 Hz, OCH_2CH), 2.8 (d, *J* 17 Hz, COC*H*H), 2.05

* For details see para. 5.6.3 in 'Instructions for Authors,' *J. Chem. Soc., Perkin Trans. 1*, 1988, Issue 1.

(d, *J* 17 Hz, COCH*H*), 2.3—1.5 (m, 5 H), 1.48 (CMe), and 0.91 (d, *J* 7 Hz, 2 × CH*Me*); δ_C 173.4, 131.9 (d), 126.7 (d), 86.5, 76.8, 71.7 (t), 41.3 (t), 30.9 (t), 29.1 (d), 22.1 (q), 20.8 (t), and 19.3 (q); (Found: *m/z* 224.1410. $C_{13}H_{20}O_3$ requires *M*, 224.1412).

cis-1-*Methoxy*-6-*methyl*-7-*oxabicyclo*[4.3.0]*non*-2-*en*-8-*one* (**42c**).—According to the general procedure, reaction between freshly prepared Jones' reagent (500 μl) and the methoxy acetal (**43c**) (31 mg, 146 μmol) in acetone (3 ml) for 2 h, followed by chromatography on Kieselgel H (5 g), using diethyl ether–light petroleum (25—30%), as eluant, gave the *lactone* (16 mg, 61%) as a clear colourless oil; $\nu_{max.}$(film) 1 770 (s), 1 240 (s), 1 070 (s), and 950 (s) cm^{-1}; δ_H 6.35—6.15 (m, =CH), 5.75—5.60 (m, =CH), 3.35 (MeO), 2.98 (d, *J* 17 Hz, COC*H*H), 2.55 (d, *J* 17 Hz, COCH*H*), 2.2—1.9 (m, 4 H), and 1.47 (MeC) (Found: *m/z* 182.0939. $C_{10}H_{14}O_3$ requires *M*, 182.0943).

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