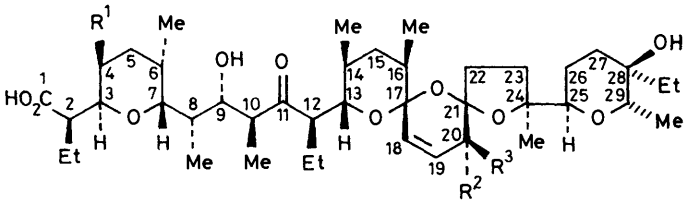
Chemistry of Bis-spiroacetals.[1] Synthesis of the 1,6,8-Trioxadispiro[4.1.5.3]-pentadecane Ring System

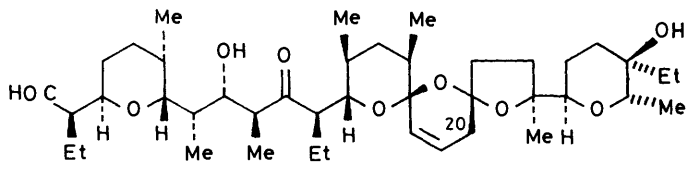
Raymond Baker *,† **and Margaret A. Brimble**
Department of Chemistry, The University, Southampton SO9 5NH

The syntheses of the unsaturated keto epoxide (**4**) and saturated keto epoxide (**18**) are described. In both cases, the key step was the nucleophilic addition of the acetylene (**10**) to δ-valerolactone. Cyclisation of the keto epoxide (**18**) in the presence of a catalytic amount of camphorsulphonic acid in dichloromethane led to isolation of a single saturated bis-spiroacetal (**21**). This selectivity can be explained by the preference of spiroacetals to adopt the conformation in which the ring oxygens are axial to the adjacent ring thus gaining stability from the anomeric effect. Analogous protic or Lewis acid-catalysed intramolecular cyclisation of the unsaturated keto epoxide (**4**) was not successful under a variety of reaction conditions. The unsaturated bis-spiroacetal (**24**), however, was prepared by an alternative strategy involving an acid-catalysed cyclisation of (**22**) to form the unsaturated spiroacetal (**23**) followed by subsequent conversion into a bis-spiroacetal utilising an oxy-radical generated by photolysis. Formation of the unsaturated bis-spiroacetal (**24**) from (**23**) was achieved *via* a Barton-type reaction involving irradiation of a solution of the spiroacetal (**23**), iodobenzene diacetate, and iodine in cyclohexane at room temperature.

The spiroacetal entity has adopted an important role in a host of natural products, notably, insect pheromones,[2] polyether antibiotics,[3] oxygenated terpenoids,[4] and the potent antiparasitic agents, the milbemycins and avermectins.[5] Consequently, a range of methods to construct the spiroacetal skeleton has been developed.[6] The polyether antibiotics, salinomycin (**1**),[7] narasin (**2**),[8] epi-17-deoxy-(O-8)-salinomycin (**3**),[9] noboritomycin,[10]



Salinomycin (**1**; $R^1 = R^3 = H$, $R^2 = OH$)
Narasin A (**2**; $R^1 = Me$, $R^2 = OH$, $R^3 = H$)



epi-17-Deoxy-(O-8)-salinomycin (**3**)

CP44,661,[11] and X-14766A[12] all incorporate a bis-spiroacetal entity namely, the 1,6,8-trioxadispiro[4.1.5.3]pentadecane ring system, as a prime functional group. In contrast to their bicyclic analogues, these tricyclic spiroacetals have generated comparatively little interest to date. The only synthesis of these naturally occurring bis-spiroacetals has been reported in a total synthesis of salinomycin and narasin by Kishi[13] and involved a stepwise assembly of the three rings. Two further methods for bis-spiroacetal formation have been reported, namely, the use of electrolytic alkoxylation[14] to construct the 1,6,8-trioxadispiro-[4.1.4.2]tridec-13-ene ring system and a Norrish type II reaction[15] to construct the 1,6,8-trioxadispiro[4.1.4.3]tetradecane ring system. We herein report, in full, our studies leading to the formation of the 1,6,8-trioxadispiro[4.1.5.3]pentadecane ring system present in the salinomycin series of antibiotics.

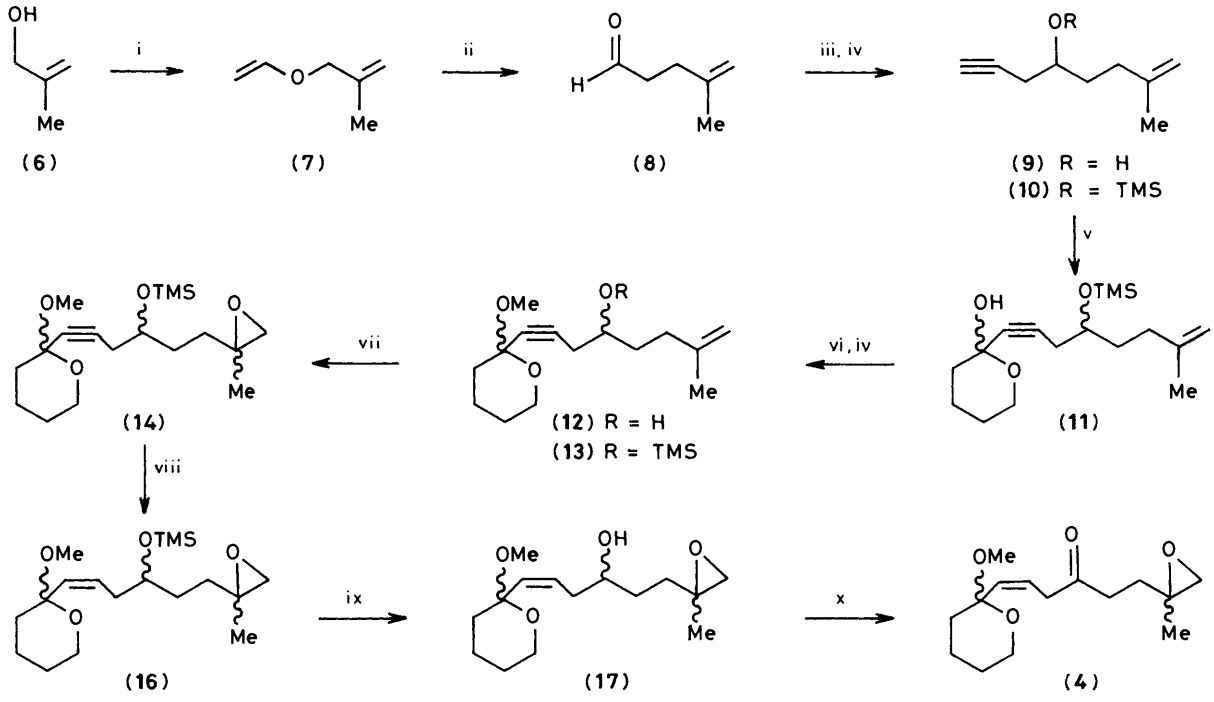
Initially the intramolecular acid catalysed cyclization of the keto epoxide (**4**) to the bis-spiroacetal (**5**) was studied (Scheme 1). The successful synthesis of the required cyclization precursor is outlined (Scheme 2). The starting point for the synthesis was

(**4**) (**5**)

Scheme 1.

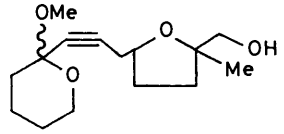
the mercury(II) trifluoroacetate-catalysed transetherification of methylallyl alcohol (**6**) with ethyl vinyl ether which provided the allyl vinyl ether (**7**) in 58% yield after distillation. Mercury(II) trifluoroacetate proved to be a better catalyst than mercury(II) acetate requiring a reaction time of only 2 h as opposed to the previously reported[16] time, 9 h. Claisen rearrangement of the resulting allyl vinyl ether (**7**) at 120 °C in a sealed tube for 24 h yielded the γ, δ-unsaturated aldehyde (**8**) in 79% yield after distillation. Addition of the aldehyde (**8**) to the organo-zinc reagent (2 equiv.) prepared from prop-2-ynyl bromide and an excess of activated zinc powder,[17] at 0 °C in tetrahydrofuran, afforded the acetylenic alcohol (**9**) in 77% yield which was subsequently protected as its trimethylsilyl ether (**10**) (92%). Generation of the lithium acetylide with butyl-lithium at −78 °C for 1.5 h followed by reaction with δ-valerolactone yielded the hemi-acetal (**11**). The hemi-acetal (**11**) was stirred overnight with Amberlite IR118 in methanol to effect cleavage of the trimethylsilyl group giving the methoxyacetal (**12**) in 84% yield. Analysis of the purified product by analytical t.l.c. showed only a single spot. G.l.c. analysis, however, was impeded by

† *Present address:* Merck Sharp & Dohme Research Laboratories, Neuroscience Research Centre, Terlings Park, Harlow, Essex CM20 2QR



Scheme 2. *Reagents and conditions:* 1, $EtOCH{=}CH_2$, $Hg(O_2CCF_3)_2$, 58%; ii, 120 °C, 24 h, 79%; iii, $HC{\equiv}CCH_2Br$, Zn, THF, 0 °C, 77%; iv, Me_3SiCl, Et_3N, THF, 92%; v, BuLi, THF, −78 °C, 1.5 h, δ-valerolactone, −78 °C; vi MeOH, Amberlite IR 118, 84% overall; vii, *m*-CPBA, CH_2Cl_2, NaOAc, room temp., 8 h, 76%; viii, H_2, 1 atm, 5% Pd on $CaCO_3$–$Pb(OAc)_2$, pentane, room temp., 3 h, 95%; ix, Bu_4NF, THF, room temp., 95%; x, TFAA, DMSO, Et_3N, CH_2Cl_2, −60 °C, 72%

decomposition of the product. Attempts to distil the product under reduced pressure also resulted in rapid decomposition with loss of the tertiary methoxy group. After reprotection as a trimethylsilyl ether (**13**), the alcohol (**12**) was treated with *m*-chloroperbenzoic acid for 8 h at room temperature to give a mixture of the epoxides (**14**) in 76% yield which were not separated. It was essential to buffer the reaction medium with sodium acetate in order to minimize competitive cyclization. Omission of sodium acetate gave a mixture of the alcohol (**15**)

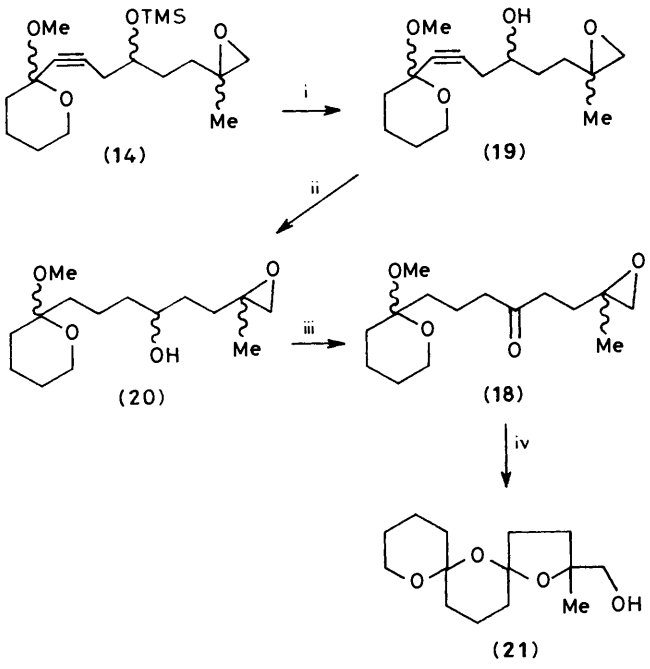


(**15**)

(41%) and the epoxide (**14**) (43%). Semi-hydrogenation of the epoxide (**14**) was then effected using Lindlar catalyst to yield the alkene (**16**) in 95% yield. The remaining step in the preparation of the epoxide cyclization precursor (**4**) required the transformation of the trimethylsilyl ether at C-4 to a ketone. Attempts to oxidize the trimethylsilyl ether (**16**) directly to the keto epoxide (**4**) using ceric ammonium nitrate, *N*-bromosuccinimide, triphenylcarbenium tetrafluoroborate, and Jones' reagent,[18] were unsuccessful. However, cleavage of the trimethylsilyl ether (**16**) with tetrabutylammonium fluoride in tetrahydrofuran liberated the alcohol (**17**) in 95% yield which was subsequently oxidized with dimethyl sulphoxide activated with trifluoroacetic anhydride[19] to the desired keto epoxide (**4**) in 72% yield. Although the product was unstable, nevertheless, its synthesis enabled attempts to induce an intramolecular cyclization to bis-spiroacetal (**5**) to be carried out.

A variety of protic and Lewis acids (*e.g.* boron trifluoride, zinc chloride, titanium tetrachloride, tin tetrachloride, camphorsulphonic acid, trifluoroacetic acid, K_{10} montmorillonite, and trimethylsilyl iodide) were tried to induce intramolecular cyclization of the keto epoxide (**4**). In the majority of cases, the starting material either decomposed to give a dark resinous material or yielded an unidentified polar product whose ^1H n.m.r. spectrum indicated the presence of a highly polarized double bond as well as substantial skeletal rearrangement. The apparent reactivity of the double bond suggested that a study of the analogous saturated keto epoxide (**18**) might be informative.

The keto epoxide (**18**) was easily prepared in a similar manner to the unsaturated analogue (**4**) (Scheme 3). The common intermediate, the trimethylsilyl ether (**14**) after deprotection to the unsaturated alcohol (**19**) using tetrabutylammonium fluoride, was hydrogenated over 10% palladium on charcoal in ethyl acetate to the saturated alcohol (**20**). Subsequent oxidation using dimethyl sulphoxide activated with trifluoroacetic anhydride afforded the desired keto epoxide (**18**) in 72% yield which when treated with a catalytic amount of camphorsulphonic acid (CSA) in dichloromethane gave the primary alcohol (**21**) in 63% yield after purification by 'flash' chromatography.[20] The observation of only one methyl resonance at δ_H 1.18 in the 360 MHz ^1H n.m.r. spectrum together with 14 carbon resonances in the ^{13}C n.m.r. spectrum suggested that the product isolated was, in fact, a single diastereoisomer. Whilst the stereochemistry of the five-membered ring and the hydroxymethyl substituent could not be assigned unambiguously, it was assumed that under the thermodynamic conditions used, the two six-membered rings adopted the conformation in which the ring oxygens are axial to the adjacent ring thus gaining stability from the anomeric effect.[21] The signal in the ^1H n.m.r. spectrum at δ_H 2.51—2.62 results from the characteristic deshielding of these protons (11′ ax-H and 14′ ax-H, Figure) owing to the 1,3-diaxial interaction with the oxygen of the adjacent ring.



Scheme 3. *Reagents:* i, Bu_4NF, THF, room temp., 95%; ii, H_2, 1 atm, 10% Pd–C, EtOAc, room temp. 84%; iii, DMSO, TFAA, Et_3N, CH_2Cl_2, −60 °C, 72%; iv, CSA, CH_2Cl_2, room temp., 0.25 h, 64%

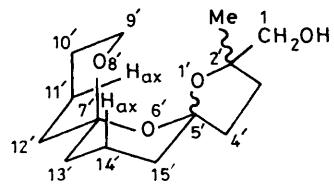
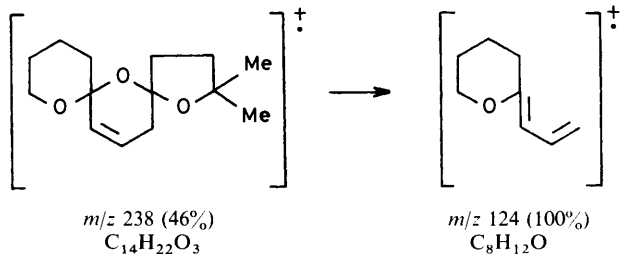


Figure.

Whilst the acid-catalysed cyclization of the keto epoxide (**18**) provided a route to the 1,6,8-trioxadispiro[4.1.5.3]pentadecane ring system, entry to the 1,6,8-trioxadispiro[4.1.5.3]pentadec-13-ene ring system present in the salinomycin series of polyether antibiotics rested on a somewhat different approach. This involved an initial cyclization to form a spiroacetal derivative which was subsequently converted into a bis-spiroacetal derivative utilizing an oxy-radical generated by photolysis (Scheme 4). Treatment of the previously prepared (*Z*)-ene epoxide (**16**) with lithium aluminium hydride in diethyl ether for 2 h yielded the tertiary alcohol (**22**) in 89% yield. Cyclization of the alcohol (**22**) to the spiroacetal (**23**) was then achieved with a catalytic amount of camphorsulphonic acid in dichloromethane in 93% yield. The ^{13}C n.m.r. spectrum, showing only 14 carbon resonances, combined with t.l.c. and g.l.c. analysis indicated that the product was diastereoisomerically pure. Irradiation of a solution of the spiroacetal (**23**) in cyclohexane containing iodobenzene diacetate and iodine at room temperature for 24 h [22] did provide the required unsaturated bis-spiroacetal (**24**) in 53% yield after purification by 'flash' chromatography.[20] In an analogous fashion to its precursor (**23**), t.l.c. and g.l.c. analysis combined with the observation of only 14 carbon resonances in the ^{13}C n.m.r. spectrum established that the product was diastereoisomerically pure.

Bis-spiroacetal formation was indicated not only by the absence of an hydroxy group absorption in the i.r. spectrum but also by the two diastereotopic methyl groups, resonating at δ_H 1.24 and 1.48 in the ^1H n.m.r. spectrum. Note that in the precursor (**23**) the methyl groups were in fact coincident, resonating at δ_H 1.24. Mass spectrometry gave a molecular ion at *m/z* 238 (46%) consistent with the molecular formula $C_{14}H_{22}O_3$. In addition, the base peak at *m/z* 124 (100%) consistent with the molecular formula $C_8H_{12}O$, probably arises from a retro-Diels-Alder fragmentation (Scheme 5). A similar

Scheme 4. *Reagents:* i, $LiAlH_4$ (0.5 eq.), Et_2O, heat 2 h, 89%; ii, CSA, CH_2Cl_2, 0.5 h, room temp. 93%; iii, $PhI(OAc)_2$ (1 equiv.), I_2 (0.5 equiv.), cyclohexane, 24 h, *hν*, room temp., 53%

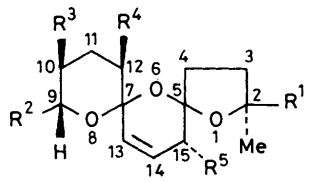


Scheme 5.

fragmentation is observed in the mass spectrum of *epi*-17-deoxy-(O-8)-salinomycin (**3**).[9] The 360 MHz ^1H n.m.r. spectrum of the bis-spiroacetal (**24**) was assigned with the aid of the two-dimensional COSY spectrum and has been reported earlier.[23] More importantly, in this earlier communication it was shown, using n.O.e. difference experiments, that the relative stereochemistry of bis-spiroacetal (**24**) about the spiro centres was the same as that found in the natural product, *epi*-17-deoxy-(O–8)-salinomycin (**3**).

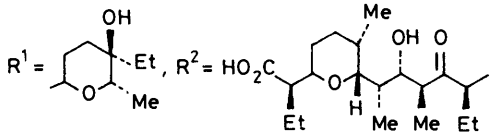
In summary, the use of the Barton-type reaction of a substituted hydroxy spiroacetal has demonstrated a novel means of constructing the 1,6,8-trioxadispiro[4.1.5.3]pentadec-13-ene ring system required for the synthesis of the salinomycin series of antibiotics. Moreover, the stereochemistry of the model bis-spiroacetal (**24**) prepared in this manner was shown to be the same as that found in *epi*-17-deoxy-(O-8)-salinomycin (**3**). This is highlighted by a comparison of the ^1H n.m.r. data for the model compound (**24**) with *epi*-17-deoxy-(O-8)-salinomycin (**3**) (Tables 1 and 2).[24] Treatment of the bis-spiroacetal (**24**) isolated from the Barton-type reaction with camphorsulphonic acid at room temperature for 24 h did not result in epimerization at the spirocentres thus suggesting that the bis-spiroacetal isolated was in fact the thermodynamic product. This observation was in keeping with that reported by Kishi[13] wherein it was demonstrated that in the absence of the allylic hydroxy group equilibration under acidic conditions results predominantly in

Table 1. Chemical shifts[a,b] for the 1,6,8-trioxadispiro[4.1.5.3]pentadec-13-ene ring system

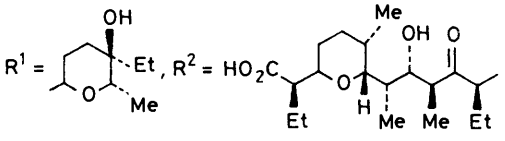


Model bis-spiroacetal (**24**): R^1 = Me, R^2 = R^3 = R^4 = R^5 = H

epi-17-Deoxy-(O-8)-salinomycin (**3**): R^3 = R^4 = Me, R^5 = H,



Salinomycin (**1**): R^3 = R^4 = Me, R^5 = OH,



Compd.	2-Me	2′-Me	12′	11_{eq}	10,10′	12	4′	3′	11_{ax}	3	15′	15	4	9_{eq}	9_{ax}	13	14
(**24**)	1.24 (s)	1.48 (s)	1.49–1.64 (m)	1.49–1.64 (m)	1.49–1.64 (m)	1.72–1.83 (m)	1.72–1.83 (m)	1.72–1.83 (m)	1.86–1.99 (m)	2.04–2.12 (m)	2.16 (ddd)	2.45 (ddd)	2.59–2.70 (m)	3.67 (m)	4.02 (ddd)	5.59 (ddd)	5.86 (ddd)
(**3**)	—	1.43	1.54 (ax)	*c*	1.70 (ax)	—	1.59	1.95	*c*	2.09	2.03	2.40	3.01	—	3.80	5.46	5.88
(**1**)	—	1.48	1.71 (ax)	1.61	1.72 (ax)	—	2.09	1.84	1.09	2.23	—	3.98[d]	2.40	—	3.89	5.98	6.03

[a] Obtained from 360 MHz ^{1}H n.m.r. spectrum in $CDCl_3$. [b] Expressed in p.p.m. downfield from TMS (δ_H). [c] Not reported. [d] Allylic carbinol proton.

Table 2. Coupling constants (*J*/Hz)[a] for the 1,6,8-trioxadispiro[4.1.5.3]pentadec-13-ene ring system

Compd.	$9_{ax},9_{eq}$	$9_{ax},10_{eq}$	$9_{ax},10_{eq}$	13,14	13,15	13,15′	14,15	14,15′	15,15′
(**24**)	11.3	11.3	3.3	10.0	2.6	1.2	2.6	5.8	16.9
(**3**)	—	10.2	—	10.0	3.0	1.0	2.0	6.4	16.8
(**1**)	—	10.2	—	10.9	—	0.6	—	1.7	—

[a] Obtained from 360 MHz ^{1}H n.m.r. spectrum in $CDCl_3$.

formation of the bis-spiroacetal system with the same stereochemistry as that found in *epi*-17-deoxy-(O-8)-salinomycin (**3**).

Experimental

Melting points were determined in sealed capillaries on an electrothermal melting point apparatus and are uncorrected. I.r. spectra were recorded on a Perkin-Elmer 157-G or a Pye-Unicam SP-100 spectrophotometer, either as thin films or Nujol mulls between sodium chloride discs, or as solutions in sodium chloride cells. ^{1}H N.m.r. spectra were recorded at 60 MHz using a Hitachi-Perkin-Elmer R-24B spectrometer, at 100 MHz on a Varian Associates XL-100-12 instrument, and at 360 MHz using a Bruker AM360 instrument, for solutions in deuteriochloroform with tetramethylsilane as internal standard. Mass spectra were recorded on a Kratos-AEI MS 30 spectrometer. Petroleum refers to light petroleum with a b.p. in the range 40—60 °C. Solutions were dried over anhydrous sodium sulphate. Solvents were purified and dried according to the methods of Perrin, Perrin, and Armarego.[25] Column chromatography was carried out on MN-Kieselgel 60 (230—400 mesh) with the solvents described according to the method of Still.[20]

2-*Methylprop*-2-*enyl Vinyl Ether* (**7**).—Mercuric trifluoroacetate (730 mg, 1.7 mmol) was added to a solution of 2-methylprop-2-en-1-ol (**6**) (20 g, 280 mmol) in ethyl vinyl ether (150 ml) and the mixture heated under reflux under a nitrogen atmosphere for 2 h. The reaction mixture was cooled in an ice-bath and 10% aqueous sodium carbonate (100 ml) added. The organic layer was separated, washed with water (2 × 50 ml), and dried (K_2CO_3). Removal of solvent by distillation at atmospheric pressure followed by repeated fractionation of the residue gave the title ether (**7**) (16 g, 58%) as a colourless liquid, b.p. 76—80 °C/760 mmHg (lit.,[16] b.p. 78—80 °C/758 mmHg).

4-*Methylpent*-4-*en*-1-*al* (**8**).—2-Methylprop-2-enyl vinyl ether (**7**) (5 g, 51 mmol) was heated in an evacuated sealed tube at 120 °C for 24 h. The ^{1}H n.m.r. spectrum of the crude product indicated an 85% conversion into the aldehyde. Direct distillation provided 4-methylpent-4-en-1-al (**8**) (4 g, 79%) as a colourless liquid, b.p. 99—102 °C/760 mmHg (lit.,[16] b.p. 100—103 °C/758 mmHg).

7-*Methyloct*-7-*en*-1-*yn*-4-*ol* (**9**).—Activated zinc powder (2.4 g, 37 mmol), prepared according to the method of Vogel,[17] was covered with dry tetrahydrofuran (5 ml) and a few drops of a solution of prop-2-ynyl bromide (80% solution in toluene; 3.6 ml, 24 mmol) in dry tetrahydrofuran (25 ml) added under nitrogen. The flask was heated gently to induce reaction. After the initial effervescence the reaction mixture was cooled in an ice-bath and the remainder of the prop-2-ynyl bromide added

dropwise over 1.5 h. 4-Methylpent-4-en-1-al (**8**) (1.2 g, 12 mmol) in dry tetrahydrofuran (20 ml) was then added. After being stirred at 0 °C for 2 h, the reaction mixture was poured into acidified iced water (100 ml) and extracted with diethyl ether (3 × 75 ml). The ethereal extract was washed with concentrated aqueous ammonium sulphate (2 × 50 ml), water (2 × 20 ml), and brine (50 ml), and dried (Na_2SO_4). Evaporation of the solvent gave an orange oil (2 g) which was purified by flash chromatography. Elution with light petroleum–diethyl ether (1:1) followed by Kugelrohr distillation afforded the *title alcohol* (1.3 g, 77%) as a colourless oil, b.p. 70—72 °C/20 mmHg. Conversion into the tetrahydropyranyl ether, b.p. 67—69 °C/20 mmHg, afforded an analytical sample (Found: C, 75.65; H, 9.6 $C_{14}H_{22}O_2$ requires C, 75.6; H, 9.9%); $\nu_{max.}$ (thin film) 3 650—3 100br s (OH), 3 300s (≡CH), 3 090m (=CH), 2 140w (C≡C), 1 640w (C=C), and 895s cm^{-1} ($R_2C{=}CH_2$); δ_H(100 MHz; $CDCl_3$) 1.56—1.85 (2 H, m, CH_2CHOH), 1.74 (3 H, s, Me), 1.98—2.24 [3 H, m, CH_2(Me)C–C and C≡CH)], 2.26—2.48 (2, m, $CH_2C{\equiv}C$), 3.76 (1 H, p, *J* 6 Hz, C*H*OH), 3.80—3.98 (1 H, br s, exchangeable on deuteriation, OH), and 4.74 (2 H, m, $C{=}CH_2$); δ_C(25.2 MHz; $CDCl_3$) 22.4 (q, Me), 27.3 (t, C-5), 33.8 (t, C-3 or C-6), 33.9 (t, C-6 or C-3), 69.6 (d, C-4), 70.8 (d, C-1), 80.8 (s, C-2), 110.3 (t, C-8), and 145.3 (s, C-7); *m/z* 123 (*M* − CH_3, 3%), 105 (*M* − H_2O − CH_3, 28), 82 (22), 81 (95), 69 (C_5H_9, 19), 55 (89), 43 (98), and 41 (100).

7-*Methyl*-4-*trimethylsilyloxyoct*-7-*en*-1-*yne* (**10**).—Chlorotrimethylsilane (200 mg, 1.8 mmol) was added to a mixture of 7-methyloct-7-en-1-yn-4-ol (**9**) (250 mg, 1.8 mmol) and dry triethylamine (360 mg, 3.6 mmol) in dry tetrahydrofuran (25 ml) at room temperature under nitrogen. The reaction mixture was stirred at room temperature for 2 h whereupon a white precipitate formed. Water (3 ml) was added and the reaction mixture extracted with diethyl ether (3 × 30 ml). The ethereal extract was washed with water (10 ml) and brine (10 ml) and dried (K_2CO_3). Removal of solvent at reduced pressure afforded a pale yellow oil (380 mg) which was purified by flash chromatography using light petroleum–diethyl ether (9:1) as eluant to give the *title compound* (**10**) (350 mg, 92%) as a colourless oil, δ_H (60 MHz; $CDCl_3$) 0.13 (9 H, s, Me_3Si), 1.54—1.87 (2 H, m, CH_2CHOSi), 1.75 (3 H, s, 7-Me), 1.95—2.12 [3 H, m, CH_2(Me)C=C and –C≡CH], 2.20—2.43 (2 H, dd, *J* 3 and 6 Hz, $CH_2C{\equiv}C$), 3.78 (1 H, p, *J* 6 Hz, CHOSi), and 4.72 (2 H, m, $C{=}CH_2$); *m/z* 121 (*M* − C_3H_9OSi, 3%), 95 (12), 81 (C_6H_9, 100), 75 (17), 73 (C_3H_9Si, 58), 55 (13), 43 (15), and 41 (12).

7-*Methyl*-1-(*tetrahydro*-2-*methoxypyran*-2-*yl*)*oct*-7-*en*-1-*yn*-4-*ol* (**12**).—To a solution of 7-methyl-4-trimethylsilyloxyoct-7-en-1-yn-4-ol (**10**) (500 mg, 2.4 mmol) in dry tetrahydrofuran (30 ml) cooled to −78 °C, was added butyl-lithium (1.6 mol l^{-1} solution in hexane; 1.5 ml, 2.4 mmol) dropwise under nitrogen. After the mixture had been stirred at −78 °C for 1.5 h a solution of δ-valerolactone (240 mg, 2.4 mmol) in dry tetrahydrofuran (15 ml) was added in one portion. The mixture was allowed to warm to −40 °C over 1.5 h after which saturated aqueous sodium dihydrogen phosphate (2 ml) was added. The reaction mixture was extracted with diethyl ether (3 × 50 ml), and the extract washed with brine (30 ml), dried (Na_2SO_4), and evaporated under reduced pressure to give a yellow oil (760 mg). This was redissolved in dry methanol (30 ml) and stirred overnight with Amberlite IR 118 resin. The Amberlite was filtered off and the filtrate evaporated under reduced pressure to yield an orange oil (770 mg) which was purified by flash chromatography (light petroleum–diethyl ether, 1:1) to give the *title alcohol* (**12**) (500 mg, 84%) as a colourless oil, $\nu_{max.}$($CHCl_3$) 3 600—3 200br s (OH), 3 080m (=CH), 2 260w (C≡C), 1 640m (C=C), 1 030s (CO), and 900s cm^{-1} ($R_2C{=}CH_2$); δ_H (100 MHz; $CDCl_3$) 1.43—1.98 (8 H, m, 4 × CH_2), 1.76 (3 H, s, 7-Me), 2.01—2.29 [2 H, m, $-CH_2$(Me)C=C], 2.38—2.61 (2 H, m, $CH_2C{\equiv}C$), 2.81—2.98 (1 H, br d, *J* 2 Hz, exchangeable on deuteriation, OH), 3.40 (3 H, s, OMe), 3.62—3.91 (3 H, m, C*H*OH and OCH_2), and 4.68—4.80 (2 H, m, $C{=}CH_2$); δ_C (25.2 MHz; $CDCl_3$) 19.1 (t, C-4′) 22.5 (q, 7-Me), 24.7 (t, C-5′), 27.5 (t, C-5), 33.8 (t, C-6 or C-3′), 34.2 (t, C-3′ or C-6), 36.7 (t, C-3), 50.5 (q, OMe), 62.2 (t, C-6′), 69.6 (d, C-4), 80.3 (s, C-2), 82.2 (s, C-1), 95.0 (s, C-2′), 110.3 (t, C-8), and 145.3 (s, C-7); *m/z* 221 (*M* − OCH_3, 13%), 203 (*M* − OCH_3–H_2O, 8), 122 ($C_8H_{10}O$, 84), 81 (82), 67 (63), 66 (48), 55 (100), 43 (65), and 41 (60).

7-*Methyl*-1-(*tetrahydro*-2-*methoxypyran*-2-*yl*)-4-*trimethylsilyloxyoct*-7-*en*-1-*yne* (**13**).—Using the procedure described for the preparation of 7-methyl-4-trimethylsilyoxyoct-7-en-1-yne (**10**), the *title compound* (**13**) was prepared in 91% yield from the alcohol (**12**) and chlorotrimethylsilane, δ_H (60 MHz; $CDCl_3$) 0.13 (9 H, s, Me_3Si), 1.45—1.99 (8 H, m, 4 × CH_2), 1.74 (3 H, s, 7-Me), 1.98—2.20 [2 H, m, CH_2(Me)C=C], 2.31—2.49 (2 H, m, $CH_2C{\equiv}C$), 3.40 (3 H, s, OMe), 3.59—3.92 (3 H, m, CHOSi and OCH_2), and 4.62—4.79 (2 H, m, $C{=}CH_2$).

7-*Methyl*-1-(*tetrahydro*-2-*methoxypyran*-2-*yl*)-4-*trimethylsilyloxy*-7,8-*epoxyoct*-1-*yne* (**14**).—To a solution of 7-methyl-1-(tetrahydro-2-methoxypyran-2-yl)-4-trimethylsilyloxyoct-7-en-1-yne (**13**) (580 mg, 1.8 mmol) and sodium acetate (300 mg, 3.7 mmol) in dry dichloromethane (25 ml), cooled to 0 °C, was added 80% *meta*-chloroperbenzoic acid (390 mg, 1.8 mmol) in small portions. The resulting suspension was stirred at 0 °C for 1 h and then left at room temperature for 8 h. After filtration to remove the major portion of *meta*-chlorobenzoic acid, the dichloromethane solution was washed sequentially with saturated aqueous sodium sulphite (2 × 15 ml), 5% aqueous sodium hydrogen carbonate (2 × 15 ml), water (1 × 10 ml), and brine (10 ml) and dried (K_2CO_3). Removal of solvent at reduced pressure yielded a pale yellow oil (560 mg) which was purified by flash chromatography. Elution with light petroleum–diethyl ether gave (a) the *title compound* (**14**) (460 mg, 76%) as a colourless oil, $\nu_{max.}$($CHCl_3$) 3 600—3 200br s, (OH), 3 080m (=CH), 2 260w (C≡C), 1 640m (C=C), 1 030s (CO), and 900s cm^{-1} ($R_2C{=}CH_2$); δ_H (100 MHz; $CDCl_3$), 0.13 (9 H, s, Me_2Si), 1.32 (3 H, s, 7-Me), 1.37—1.98 (10 H, br m, 5 × CH_2), 2.32—2.84 (4 H, m, CH_2 C≡C and CH_2 epoxide), 3.41 (3 H, s, OMe), and 3.61—3.92 (3 H, m, OCH_2 and CHOSi); δ_C (25.2 MHz; $CDCl_3$) 0.29 (q, Me_3Si), 19.3 (t, C-4′), 21.0 (q, 7-Me), 24.8 (t, C-5′), 27.7, 32.2, 32.5 (t, C-6, C-3′ or C-4′), 36.8 (t, C-3), 50.6 (q, OMe), 53.5 (t, C-8), 53.8 (s, C-7), 62.2 (t, C-6′), 70.8 (d, C-4), 80.0 (s, C-2), 82.3 (s, C-1), and 95.1 (s, C-2′); *m/z* 187 ($C_9H_{19}O_2Si$, 14%), 129 (16), 97 (C_6H_9O, 12), 89 ($OSiMe_3$, 9), 83 (C_5H_7O, 10), 73 ($SiMe_3$, 100), 69 (20), 55 (18), and 43 (16).

(b) *Tetrahydro*-2-*methyl*-5-[3-(*tetrahydro*-2-*methoxypyran*-2-*yl*)*prop*-2-*ynyl*]*furan*-2-*ylmethanol* (**15**) (58 mg, 12%), as a colourless oil, $\nu_{max.}$($CHCl_3$) 3 650—3 200s (OH), 2 260w (C≡C), 1 030 and 1 060s cm^{-1} (CO); δ_H (60 MHz; $CDCl_3$) 1.24 (3 H, s, Me), 1.41—2.26 (10 H, br m, 5 × CH_2), 2.31—2.62 (2 H, m, $CH_2C{\equiv}C$), 3.34 (3 H, s, OMe), 3.39 (2 H, s, CH_2OH), 3.50—3.82 (2 H, m, OCH_2), and 3.82—4.32 (2 H, m, CHO and OH); *m/z* 236 (*M* –CH_3OH, 2%), 205 (*M* − CH_2OH–CH_3OH, 18), 115 ($C_6H_{11}O_2$, 54), 97 (C_6H_9O, 24), 83 (C_5H_7O, 12), 71 (44), 69 (44), 57 (30), 55 (33), and 43 (100).

(Z)-7-*Methyl*-1-(*tetrahydro*-2-*methoxypyran*-2-*yl*)-4-*trimethylsilyloxy*-7,8-*epoxyoct*-1-*ene* (**16**).—A solution of 7-methyl-1-(tetrahydro-2-methoxypyran-2-yl)-4-trimethylsilyloxyoct-1-yne (**14**) (300 mg, 0.9 mmol) in dry pentane was stirred with activated charcoal (30 mg) for 2 h. The charcoal was removed by filtration through a Celite pad, and Lindlar catalyst (20 mg) and potassium carbonate (50 mg) were added

to the filtrate. The resultant suspension was stirred at room temperature under a balloon of hydrogen for 3 h. Removal of the catalyst by filtration and evaporation of solvent afforded the *title compound* (**16**) (290 mg, 95%) as a colourless oil, $\nu_{max.}(CCl_4)$ 3 040 (m, =CH), 1 660 (w, C=C), 1 250 and 850 cm^{-1} (s, CO epoxide); δ_H (360 MHz; $CDCl_3$) 0.11 (9 H, s, Me_3Si), 1.31 (3 H, s, 7-Me), 1.45—1.93 (10 H, br m, 5 × CH_2), 2.36—2.54 (2 H, m, CH_2C=C), 2.55—2.64 (2 H, m, CH_2 epoxide), 3.17 (3 H, s, OMe), 3.61—3.77 (3 H, m, OCH_2 and CHOSi), 5.28—5.39, and 5.48—5.61 (2 H, m, HC=CH); δ_C (90.6 MHz; $CDCl_3$) 0.3 (q, Me_3Si), 19.2 (t, C-4′), 21.0 (q, 7-Me), 24.7 (t, C-5′), 32.4, 35.2, 35.5, 35.6 (t, C-3, C-3′, C-5 or C-6), 48.3 (q, OMe), 53.4 (t, C-8), 53.8 (s, C-7), 60.8 (t, C-6′), 72.2 (d, C-4), 98.9 (s, C-2′), 129.8 (d, C-1), and 132.3 (d, C-2); *m/z* 187 ($C_9H_{19}O_2Si$, 19%), 129 (35), 75 (21), 73 ($SiMe_3$, 100), 69 (25), 55 (31), 43 (15), and 41 (17).

(Z)-7-*Methyl*-1-(*tetrahydro*-2-*methoxypyran*-2-*yl*)-7,8-*epoxyoct*-1-*en*-4-*ol* (**17**).—To a solution of the octene (**16**) (240 mg, 0.7 mmol) in dry tetrahydrofuran (20 ml) was added tetrabutylammonium fluoride (1 mol l^{-1} solution in tetrahydrofuran; 0.7 ml, 0.7 mmol) at room temperature under a nitrogen atmosphere. The mixture was stirred at room temperature for 0.25 h, after which saturated aqueous sodium dihydrogen phosphate (0.5 ml) was added. The reaction mixture was extracted with diethyl ether (3 × 20 ml) and the extract washed with brine (10 ml), dried (K_2CO_3), and evaporated under reduced pressure to yield a pale yellow oil (190 mg) which was purified by passage through a short column of Florisil to give the *title alcohol* (**17**) (180 mg, 95%) as a colourless oil, $\nu_{max.}$ (thin film) 3 600—3 150br s (OH), 3 040m (=C–H), 1 660w (C=C), 1 230, 1 030, and 820s cm^{-1} (CO); δ_H (60 MHz; $CDCl_3$) 1.31 (3 H, s, 7-Me), 1.42—2.14 (10 H, br m, 5 × CH_2), 2.31—2.73 (4 H, m, CH_2C=C and CH_2 epoxide), 3.14 (3 H, s, OMe), 3.28—3.47 (1 H, br s, exchangeable on deuteriation, OH), 3.47—3.80 (3 H, m, OCH_2 and C*H*OH), and 5.14—5.78 (2 H, m, HC=CH).

(Z)-7-*Methyl*-1-(*tetrahydro*-2-*methoxypyran*-2-*yl*)-7,8-*epoxyoct*-1-*en*-4-*one* (**4**).—To a solution of dry dimethyl sulphoxide (120 mg, 1.4 mmol) in dichloromethane (10 ml) cooled to −60 °C, was slowly added a solution of trifluoroacetic anhydride (150 mg, 0.7 mmol) in dichloromethane (5 ml) under nitrogen. A white precipitate quickly formed which was stirred at this temperature for 0.25 h. To this was then added a solution of (**17**) (190 mg, 0.7 mmol) in dichloromethane (10 ml) and the mixture stirred at −60 °C for 0.5 h. Dry triethylamine (210 mg, 2.1 mmol) was added and the reaction mixture gradually warmed to −30 °C over 0.75 h. After being quenched with water (1 ml) The reaction mixture was extracted with dichloromethane (3 × 25 ml) and the extract washed with brine (10 ml), dried (K_2CO_3), and evaporated under reduced pressure to afford a pale yellow oil (160 mg) which was purified by flash chromatography. Elution with light petroleum–diethyl ether (1:1) gave the *title compound* (136 mg, 72%) as a colourless oil, $\nu_{max.}$ (thin film) 3 040 (m, =CH), 1 710 (s, C=O), 1 660 (w, C=C), 1 070, 1 060, 1 030 (s, CO), 890 and 810 cm^{-1} (m, CO epoxide); δ_H (360 MHz; $CDCl_3$) 1 31 (3 H, s, 7-Me), 1.41—2.02 (8 H, br m, 4 × CH_2), 2.51 (2 H, t, *J* 7.4 Hz, CH_2CO), 2.58, 2.61 (2 H, 2 × d, *J* 4 Hz, CH_2 epoxide), 3.13 (3 H, s, OMe), 3.49 (2 H, d, *J* 5.9 Hz, HC=C–CH_2CO), 3.64 (2 H, m, OCH_2), 5.42 (2 H, d, *J* 10.8 Hz, HC=C), and 5.75 (2 H, dt, $J_{2,3}$ 5.9 and $J_{1,2}$ 10.8 Hz, C=C*H*CH_2); δ_C (90.6 MHz; $CDCl_3$) 18.8 (t, C-4′), 21.3 (q, 7-Me), 24.9 (t, C-5′), 29.9, 35.1 (t, C-6 or C-3′), 37.6 (t, C-5), 41.7 (t, C-3), 48.8 (q, OMe), 53.6 (t, C-8), 56.1 (s, C-7), 60.9 (t, C-6′), 99.3 (s, C-2′), 124.6 (d, C-1), and 134.1 (d, C-2); *m/z* 237 (*M* − OCH_3, 2%), 236 (*M* − CH_3OH, 4), 151 ($C_9H_{11}O_2$, 14), 123 ($C_8H_{11}O$, 22), 95 (22), 85 (C_5H_9O, 17), 69 (28), 55 (63), 43 (75), and 32 (100).

7-*Methyl*-1-(*tetrahydro*-2-*methoxypyran*-2-*yl*)-7,8-*epoxyoctan*-4-*ol* (**20**).—To a solution of 7-methyl-1-(tetrahydro-2-methoxypyran-2-yl)-7,8-epoxyoct-1-yn-4-ol (**19**) (80 mg, 0.3 mmol) in ethyl acetate (25 ml) was added 10% palladium on charcoal (7 mg) and potassium carbonate (25 mg). The resultant suspension was stirred under a balloon of hydrogen for 24 h. The catalyst was filtered off and the filtrate evaporated to afford a colourless oil (76 mg) which was purified by passage through a short column of Florisil using light petroleum–ethyl acetate (1:1) as eluant to give the *title compound* (**20**) (68 mg, 84%) as a colourless oil, $\nu_{max.}(CCl_4)$ 3 650—3 300br, s (OH), 2 950s (CH), 1 030s, 1 060s, and 1 100s cm^{-1} (CO); δ_H (360 MHz; $CDCl_3$) 1.32 (3 H, s, 7-Me), 1.38—2.13 (16 H, br m, 8 × CH_2), 2.59—2.70 (2 H, m, CH_2 epoxide), 3.18 (3 H, s, OMe), and 3.38—3.72 (4 H, m, OCH_2, C*H*OH, and OH); *m/z* 241 (*M* − OCH_3, 8%), 240 (*M* − CH_3OH, 2), 209 (34), 115 ($C_6H_{11}O_2$, 79), 111 (37), 98 (21), 83 (26), 71 (29), 55 (64), and 43 (100).

7-*Methyl*-1-(*tetrahydro*-2-*methoxypyran*-2-*yl*)-7,8-*epoxyoctan*-4-*one* (**18**).—Using the procedure described for the preparation of 7-methyl-1-(tetrahydro-2-methoxypyran-2-yl)-7,8-epoxyoct-1-en-4-one (**4**), the *title compound* (**18**) was prepared in 72% yield from 7-methyl-1-(tetrahydro-2-methoxypyran-2-yl)-7,8-epoxyoctan-4-ol (**20**) as a colourless oil, $\nu_{max.}$ (thin film) 2 940s (CH), 1 710s (C=O), 1 100, 1 060, 1 040s (CO), 890 and 810 cm^{-1} (CO epoxide); δ_H (360 MHz; $CDCl_3$) 1.31 (3 H, s, 7-Me), 1.40—2.01 (12 H, br m, 6 × CH_2), 2.44 (2 H, t, *J* 7.2 Hz, CH_2CO), 2.49 (2 H, t, *J* 7.3 Hz, CH_2CO), 2.57—2.62 (2 H, m, CH_2 epoxide), 3.19 (3 H, s, OMe), and 3.56—3.72 (2 H, m, OCH_2); *m/z* 239 (*M* − OCH_3, 5%), 238 (*M* − CH_3OH, 3), 115 ($C_6H_{11}O_2$, 100), 111 (45), 110 (31), 98 (34), 91 (81), 55 (76), 43 (62), and 32 (51).

1-(2-*Methyl*-1,6,8-*trioxadispiro*[4.1.5.3]*pentadecan*-2-*yl*)-*methanol* (**21**).—To a solution of 7-methyl-1-(tetrahydro-2-methoxypyran-2-yl)-7,8-epoxyoctan-4-one (**18**) (70 mg, 0.26 mmol) in dichloromethane (25 ml) was added a few crystals of camphorsulphonic acid and the mixture stirred at room temperature for 0.25 h under a nitrogen atmosphere. Removal of solvent at reduced pressure afforded a pale yellow oil (72 mg) which was purified by flash chromatography. Elution with light petroleum–diethyl ether (1:1) afforded the *title compound* (**21**) (42 mg, 64%) as a colourless oil (Found: C, 65.2; H, 9.3. $C_{14}H_{22}O_4$ requires C, 65.6; H, 9.4%); $\nu_{max.}(CCl_4)$ 3 470s (OH), 1 050s, 1 070s, and 1 090s cm^{-1} (CO); δ_H (350 MHz; $CDCl_3$) 1.18 (3 H, s, Me), 1.41—1.98 (14 H, br m, CH_2), 2.51—2.62 (2 H, m, 11′$_{ax}$-H and 14′$_{ax}$-H), 3.38 (1 H, t, *J* 11.1 Hz, collapses to a doublet, *J* 11.1 Hz, upon deuteriation, CH_AH_BOH), 3.59 (1 H, d, *J* 11.1 Hz, CH_AH_BOH), and 3.62—3.83 (3 H, m, OCH_2 and OH); δ_C (90.6 MHz; $CDCl_3$) 17.4, 18.7, 25.3 (t, C-10′, C-11′, or C-14′), 24.3 (q, 2′-Me), 30.7, 35.3, 35.9, 36.6, 37.0 (t, C-12′, C-4′, C-3′, C-13′, or C-15′), 61.5 (t, C-9′), 67.8 (t, CH_2OH), 85.9 (s, C-2′), 98.5 (s, C-7′), and 107.9 (s, C-5′); *m/z* 238 (*M* − H_2O, 5%), 225 (*M* − CH_2OH, 51), 128 ($C_7H_{12}O_2$, 20), 111 ($C_7H_{11}O$, 100), 98 ($C_6H_{10}O$, 62), 97 (C_6H_9O, 39), 55 (83), 43 (68), and 41 (31).

(Z)-2-*Methyl*-8-(*tetrahydro*-2-*methoxypyran*-2-*yl*)-5-*trimethylsilyloxyoct*-7-*en*-2-ol (**22**).—To a suspension of lithium aluminium hydride (6 mg, 0.15 mmol), in sodium-dried diethyl ether (25 ml) was added a solution of (*Z*)-7-methyl-1-(tetrahydro-2-methoxypyran-2-yl)-4-trimethylsilyloxy-7,8-epoxyoct-1-ene (**16**) (100 mg, 0.3 mmol) in diethyl ether (3 ml) dropwise under nitrogen. After being heated under reflux for 2 h, the reaction mixture was quenched with saturated aqueous ammonium chloride (2 ml) and extracted with diethyl ether (3 × 50 ml). The combined extracts were washed with water (10 ml) and brine (10 ml), dried (K_2CO_3), and evaporated under

reduced pressure to afford a colourless oil (94 mg) which was purified by flash chromatography using light petroleum–diethyl ether (1:1) as eluant to give the *title compound* (**22**) (89 mg, 89%) as a colourless oil, $\nu_{max.}$ (CCl_4) 3 600–3 200s (OH), 3 040w (=CH), 1 660w (C=C), 1 070s, and 1 030s cm^{-1} (CO); δ_H (360 MHz; $CDCl_3$) 0.12 (9 H, s, Me_3Si), 1.22 (6 H, s, 2 × Me), 1.42—2.21 (10 H, br m, 5 × CH_2), 2.37—2.57 (2 H, m, CH_2C=C), 3.16 (3 H, s, OMe), 3.59—3.74 (3 H, m, OCH_2 and CHOSi), 5.24—5.33, and 5.44—5.59 (2 H, m, HC=CH); δ_C (90.6 MHz; $CDCl_3$) 0.4 (q, Me_3Si), 18.8 (t, C-4′), 25.0 (t, C-5′), 29.3, 29.6 (q, 2 × Me), 31.7, 35.1, 35.4, 39.5 (t, C-3′, C-3, C-4 or C-6), 48.7 (q, OMe), 60.9 (t, C-6′), 70.4 (s, C-2), 72.8 (d, C-5), 99.3 (s, C-2′), 129.9 (d, C-8), and 132.5 (d, C-7); *m/z* 313 ($M - OCH_3$, 0.3%), 172 ($C_9H_{20}OSi$, 12), 171 ($C_9H_{19}OSi$, 83), 156 (34), 124 ($C_8H_{12}O$, 55), 83 (C_5H_7O, 39), 81 (C_6H_9, 100), 73 ($SiMe_3$, 75), 55 (46), 43 (59), and 41 (36).

4-(1,7-*Dioxaspiro*[5.5]*undec*-4-*en*-2-*yl*)-2-*methylbutan*-2-*ol* (**23**).—To a solution of 2-methyl-8-(tetrahydro-2-methoxypyran-2-yl)-5-trimethylsilyloxyoct-7-en-2-ol (**22**) (400 mg, 1.2 mmol) in dichloromethane (30 ml) was added a few crystals of camphorsulphonic acid. After being stirred at room temperature for 0.5 h, the mixture was evaporated under reduced pressure to give a pale yellow oil (276 mg) which was purified by flash chromatography. Elution with light petroleum–diethyl ether (1:1) afforded the *title compound* (**23**) (261 mg, 93%) as a colourless oil (Found: M^+, 240.1706. $C_{14}H_{24}O_3$ requires M, 240.1725); $\nu_{max.}$(CCl_4) 3 640—3 260s (OH), 3 040m (=CH), 1 660w (C=C), and 1 010s cm^{-1} (CO); δ_H (360 MHz; $CDCl_3$) 1.24 (6 H, s, 2 × Me), 1.49—2.34 (12 H, br m, 6 × CH_2), 3.58—3.69 (1 H, m, CHO), 3.80—3.91 (2 H, m, OCH_2), 5.58—5.62 (1 H, m, HC=C), and 5.86—5.92 (1 H, m, C=C*H*CH_2); δ_C (90.6 MHz; $CDCl_3$) 18.6 (t, C-10′), 25.1 (t, C-9′), 29.3, 29.5 (q, 2 × Me), 30.4, 30.8, 35.1, 39.9 (t, C-3, C-3′, C-4 or C-11′), 61.0 (t, C-8′), 67.5 (d, C-2′), 70.6 (s, C-2), 94.1 (s, C-6′), 127.6 (d, C-5′), and 130.6 (d, C-4′); *m/z* 240 (M^+, 1%), 222 ($M - H_2O$, 4), 207 ($M - H_2O$–CH_3, 9), 184 (12), 166 (12), 153 ($C_9H_{13}O_2$, 17), 124 ($C_8H_{12}O$, 77), 108 (60), 99 (60), 95 (51), 81 (56), 69 (57), 59 (49), 55 (66), and 43 (100).

2,2-*Dimethyl*-1,6,8-*trioxadispiro*[4.1.5.3]*pentadec*-13-*ene* (**24**).—To a solution of 4-(1,7-dioxaspiro[5.5]undec-4-en-2-yl)-2-methylbutan-2-ol (**23**) (30 mg, 0.13 mmol) in cyclohexane (30 ml) was added iodobenzene diacetate (40 mg, 0.13 mmol) and iodine (16 mg, 0.06 mmol). After irradiation for 24 h at room temperature with a 150 W tungsten filament lamp, the reaction mixture was poured into diethyl ether (50 ml). The mixture was then washed with 10% aqueous sodium thiosulphate (20 ml) and water (10 ml), dried (K_2CO_3), and evaporated under reduced pressure to afford a colourless oil (53 mg) which was purified by flash chromatography using light petroleum–diethyl ether (9:1) as eluant to give the *title compound* (**24**) (16 mg, 53%) as a colourless oil (Found: M^+, 238.1599. $C_{14}H_{22}O_3$ requires M, 238.1569); $\nu_{max.}$(CCl_4) 3 040 (w, =CH), 2 940 (s, CH), and 1 050 cm^{-1} (m, CO); δ_H (360 MHz; $CDCl_3$), 1.24 (3 H, s, Me), 1.48 (3 H, s, Me), 1.49—1.64 (4 H, m, 10-H, 10′-H, 11_{eq}-H, 12′-H), 1.72—1.83 (3 H, m, 3′-H, 4′-H, 12-H), 1.86—1.99 (1 H, m, 11_{ax}-H), 2.04—2.12 (1 H, m, 3-H), 2.16 (1 H, ddd, $J_{13,15}$, 1.2, $J_{14,15}$, 5.8, and $J_{15,15}$, 16.9 Hz, 15′-H), 2.45 (1 H, ddd, $J_{13,15}$ 2.6, $J_{14,15}$ 2.6, and $J_{15,15}$, 16.9 Hz, 15-H), 2.59—2.70 (1 H, m, 4-H), 3.67 (1 H, m, 9_{eq}-H), 4.02 (1 H, ddd, J $J_{9ax,10eq}$ 3.3, $J_{9ax,10ax}$ 11.3, and $J_{9ax,9eq}$ 11.3 Hz, 9_{ax}-H), 5.59 (1 H, ddd, $J_{13,15}$ 1.2, $J_{13,15}$ 2.6, and $J_{13,14}$ 10.0 Hz, 13-H), and 5.86 (1 H, ddd, $J_{14,15}$ 2.6, $J_{14,15}$ 5.8, and $J_{13,14}$ 10.0 Hz, 14-H); δ_C (90.6 MHz; $CDCl_3$) 18.8, 25.3 (t, C-10 or C-11), 28.9, 30.1 (q, 2 × Me), 35.0, 36.4, 36.7, 37.7 (t, C-3, C-4, C-12 or C-15), 61.5 (t, C-9), 82.7 (s, C-2), 99.3 (s, C-7), 106.8 (s, C-5), 125.1 (d, C-13), and 130.1 (d, C-14); *m/z* 238 (M^+, 46%), 151 ($C_9H_{11}O_2$, 32), 138 (88), 124 ($C_8H_{12}O$, 100), 75 (78), 69 (49), 55 (44), 43 (53) 41 (59), and 39 (44).

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