Reactions of Dithiane Derived Alcohols: Promotion of the Thorpe-Ingold Effect by Trimethylsilyl and t-Butyl Substituents

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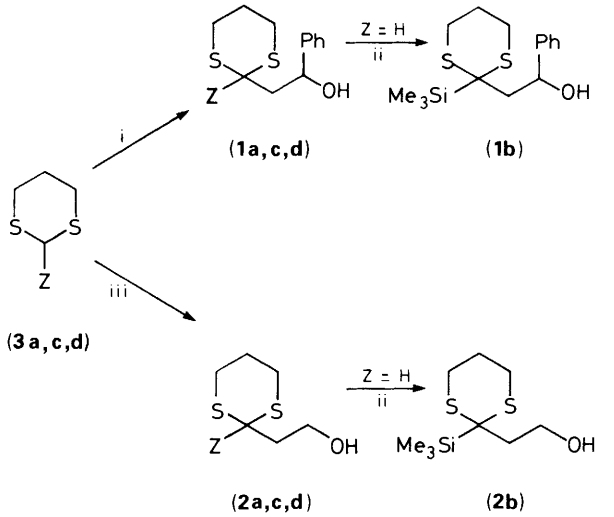
A range of 2-(2-hydroxyethyl)-1,3-dithianes has been prepared and treated with halogenating agents. 2-Monosubstituted dithiane alcohols gave the expected halides whereas 2,2-disubstituted dithiane alcohols underwent elimination to give styrenes (if the substituent was 2-hydroxy-2-phenylethyl) or ring expansion to give 1,5-dithiacyclo-oct-2-enes (if the substituent was 2-hydroxyethyl). Elimination and ring expansion were observed with Me, Bu^t, and Me_3Si as the 'anchoring' substituents at C-2, these processes being facile with the larger groups. A rationalization of these results is presented which indicates that the Bu^t and Me_3Si groups are particularly effective at promoting the Thorpe-Ingold effect.

As part of a project to prepare analogues of the anti-leukaemic natural product rocaglamide by a benzofuranone cyclopentaannellation procedure[1] we required a range of dithiane-based alkylating agents derived from the alcohols (**1**) and (**2**). As shown in Scheme 1, alcohols (**1a**,**c**,**d**) and (**2a**,**c**,**d**) were easily prepared from the dithiane (**3a**) or its 2-methyl (**3c**)[2] or 2-t-butyl derivatives (**3d**)[3] by anion formation followed by trapping with styrene oxide[3] or ethylene oxide[4] using standard procedures.

The silylated benzyl alcohol (**1b**) has been prepared from 2-trimethylsilyldithianyl-lithium and styrene oxide in a similar way but a yield of only 17% was obtained due to silyl migration.[5] We found that (**1b**) could be obtained as a crystalline solid in almost quantitative yield by the double deprotonation-silylation of the alcohol (**1a**). A similar dianion procedure was employed to obtain the silylated alcohol (**2b**) from (**2a**) in 80% yield.

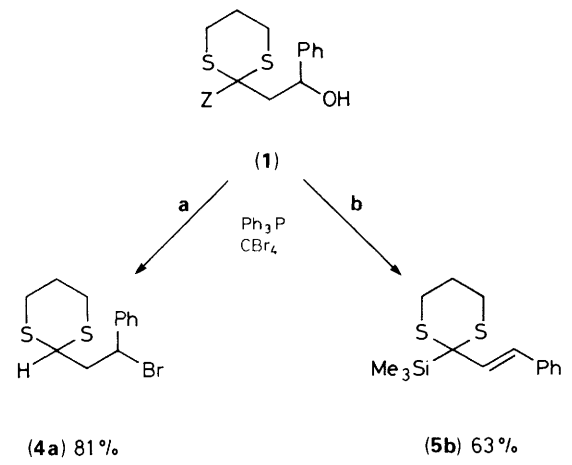
With the parent alcohols in hand, initial attempts to prepare the halogeno derivatives were carried out on the 2-monosubstituted (Z = H) and 2-trimethylsilyl (Z = Me_3Si) series using carbon tetrabromide/triphenylphosphine[6] as brominating agent (Scheme 2). The reactions of (**1a**) and (**2a**) (Z = H) were straightforward, the expected bromides (**4a**) (contaminated by *ca.* 5% of the corresponding dehydrobrominated styrene) and (**6a**) being produced in good yields. Somewhat surprisingly, all attempts to apply these procedures to the silylated alcohols (**1b**) and (**2b**) (Z = Me_3Si) resulted only in elimination or rearrangement; the corresponding bromides were never observed. Thus, treatment of the benzylic alcohol (**1b**) with carbon tetrabromide/triphenylphosphine[6] at 0 °C gave the crystalline styrene (**5b**), as the *E*-isomer (*J* 15.5 Hz), in 63% yield and treatment of the alcohol (**2b**) at −15 °C to room temperature with the same reagents gave an unusual ring expansion reaction producing 2-trimethylsilyl-1,5-dithiacyclo-oct-2-ene (**7b**) in almost quantitative yield. The structure of the dithiacyclo-octene (**7b**) was confirmed by ^{1}H n.m.r. [δ 6.16 (1 H, t, *J* 8 Hz, 3-H) and 3.58 (2 H, d, *J* 8 Hz, 4-H)], ^{13}C n.m.r. [δ 140.5 (s, C-2), 138.2 (d, C-3), and 35.7 (t, C-4)], i.r. and high resolution mass spectrometry and elemental analysis (C, H, and S). Similar results were obtained with a range of halogenating reagents as can be seen from Table 1. The effect of C-2 silyl substitution on the outcome of these reactions is dramatic. The alcohol (**1a**; Z = H) is readily converted into the corresponding bromide or iodide (**4a**; X = Br or I) with little or no styrene formation. In contrast, the silylated alcohol (**1b**; Z = $SiMe_3$) undergoes facile conversion into the styrene (**5b**) on treatment with CBr_4/Ph_3P, 1,2-bis(diphenylphosphino)ethane, (diphos)·Br_2,[7] NaI/BF_3[8]

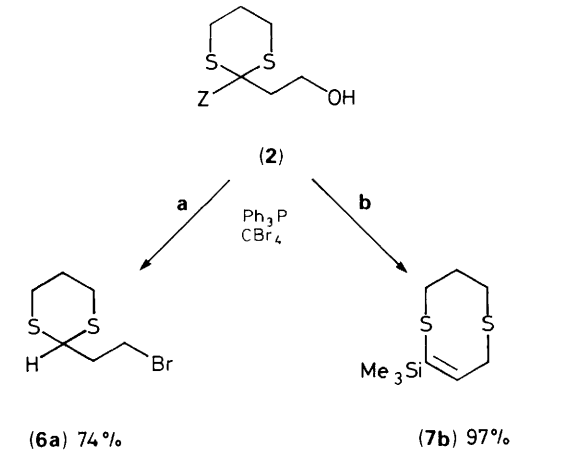


Scheme 1. **a**, Z = H; **b**, Z = Me_3Si; **c**, Z = Me; **d**, Z = Bu^t. *Reagents:* i, BuLi then PhCHCH$_2$O [(**1a**)[3] 78%; (**1c**)[3] 78%; (**1d**) 81%]; ii, BuLi then Me_3SiCl [(**1b**) 98%; (**2b**) 80%]; iii, BuLi then CH$_2$CH$_2$O [(**2a**)[4] 77%; (**2c**) 71%; (**2d**) 76%]

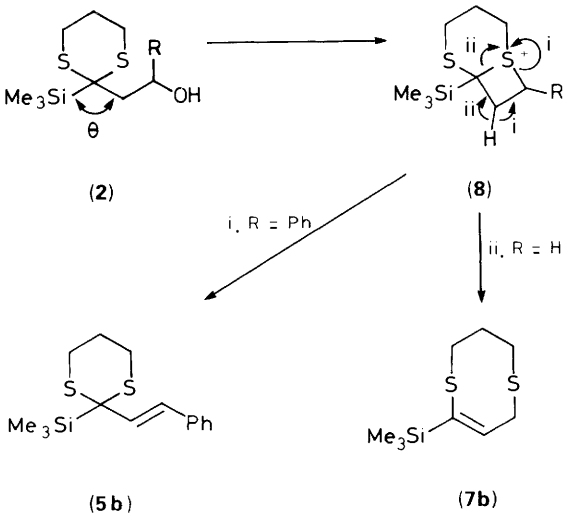
and PCl_5 under extremely mild conditions, all attempts to isolate the corresponding halides being unsuccessful. Similarly, the non-silylated alcohol (**2a**) is readily converted into the corresponding halides (**6a**) whereas the analogous silylated alcohol (**2b**) undergoes ring expansion with CBr_4/Ph_3P, PCl_5, and $POCl_3$ [and when bromide (**6b**) is obtained using diphos·Br_2 it readily undergoes thermolytic ring expansion to give dithiacyclo-octene (**7b**)]. It should be noted that all attempts to effect the corresponding ring expansion of the halides (**6a**; Z = H, X = Br or I), *e.g.* in refluxing toluene or pyridine, were unsuccessful.

These results encourage speculation concerning the reaction mechanisms for the formation of the styrene (**5b**) and dithiacyclo-octene (**7b**) and the role of silicon in these processes. A number of mechanisms can be presented,[9] perhaps the most plausible of which involves the intermediacy of the bicyclic sulphonium salt (**8**), formed either directly from the alcohol or *via* the corresponding halide (Scheme 3). Deprotonation of the intermediate (**8**) would give the styrene (**5b**) and deprotonation/ring expansion would lead to dithiacyclo-octene (**7b**), the



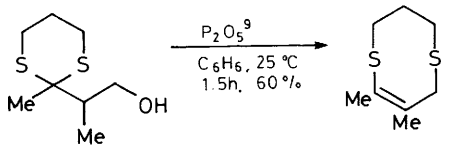


Scheme 2. a, Z = H; b, Z = $SiMe_3$



Scheme 3.

eventual outcome of the reaction presumably being determined by product stability. The sulphonium salt (**8**) would seem to be a reasonable intermediate given that related sulphonium salts are known[4] [indeed the sulphonium salt derived from 2-(3-bromopropyl)-1,3-dithiane is a crystalline solid[4]] and its formation should be facilitated by the well documented[10] silicon β-effect. It is also possible that the transition state leading to the bicyclic sulphonium salt (**8**) is stabilised by the recently described[11] silicon γ-effect.



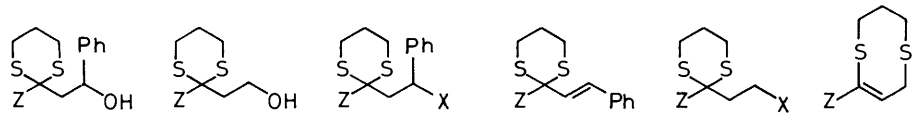
Scheme 4.

The trimethylsilyl substituent is not an essential requirement for the dithiane to dithiacyclo-octene ring expansion, however. A literature search revealed that Nickon *et al.* described[9] three related examples (*e.g.* Scheme 4), all with 2,2-dialkylated dithianyl alcohols, in which P_2O_5 in benzene at room temperature and $POCl_3$ in refluxing pyridine were used to effect ring expansion. Nickon's results[9] indicate that the dramatic substituent effects observed in the present work are due to the steric, rather than the electronic influence of the 2-trimethylsilyl group. This was confirmed when the reactions of the corresponding 2-methyl and 2-t-butyl dithianyl alcohols (**1c,d**) and (**2c,d**) were studied (Table 2). It should be noted that whereas the $POCl_3$–pyridine ring expansion conditions described by Nickon *et al.*[9] were successfully employed in the present work the use of P_2O_5–benzene (Scheme 4)[9] with the alcohols (**2a**) and (**2c**) gave extensive decomposition and no sign of ring expansion.

The reactions of the t-butyl derivatives (**1d**) and (**2d**) mirror those of the silyl analogues (**1b**) and (**2b**); the benzyl alcohol (**1d**) underwent almost quantitative conversion into the styrene (**5d**) on treatment with diphos·Br_2 and the hydroxyethyl analogue (**2d**) gave 2-t-butyl-1,5-dithiacyclo-oct-2-ene (**7d**) in 98% yield on treatment with $POCl_3$ in pyridine at room temperature for 5 min. Dithiacyclo-oct-2-ene (**7d**) was also formed from the reaction between the alcohol (**2d**) and diphos·Br_2. In contrast, the 2-methyl substituted dithianyl alcohols (**1c**) and (**2c**) underwent styrene formation and ring expansion only under forcing conditions. For example, the conversion of the alcohol (**2c**) into 2-methyl-1,5-dithiacyclo-oct-2-ene (**7c**) using $POCl_3$ in pyridine occurred only on prolonged heating and was low-yielding, other unidentified by-products being formed. It should be noted that the methyl substituted bromide (**6c**) has been prepared before and converted into the corresponding phosphonium salt by treatment with triphenylphosphine in refluxing toluene.[12] In agreement with these results,[12] we found that bromide (**6c**) did not undergo ring expansion in refluxing toluene but that the use of refluxing pyridine did produce 2-methyl-1,5-dithiacyclo-oct-2-ene (**7c**) in 61% yield.

These results indicate that the presence of a second substituent at C-2 is an essential requirement for the styrene formation/ring expansion reactions of dithianyl alcohols (**1b—d**) and (**2b—d**) respectively. This would seem to be an interesting example of the Thorpe-Ingold (or gem-dialkyl) effect:[13–15] the monosubstituted dithianyl alcohols (**1a**) and (**2a**) undergo the expected substitution reactions whereas the presence of an additional substituent Z at C-2 leads to a totally different product distribution, presumably by facilitating cyclisation to the bicyclic sulphonium salts (**8**) (Scheme 3). It seems likely that the larger substituents lead to a greater expansion of the Z–C(2)–C bond angle θ [see (**2**), Scheme 3] resulting in the closer proximity of the dithiane sulphur and β-carbon of the hydroxyl side chain.[14] Such an effect would be expected to be important where cyclisation to give small rings was concerned.[14] The effect of the additional 2-substituent (Z) can be seen most clearly from the $POCl_3$-induced ring expansion reactions of the 2-(2-hydroxyethyl)dithianes (**2**). The parent alcohol (**2a**; Z = H) gives the corresponding alkyl chloride (4 h

Table 1.

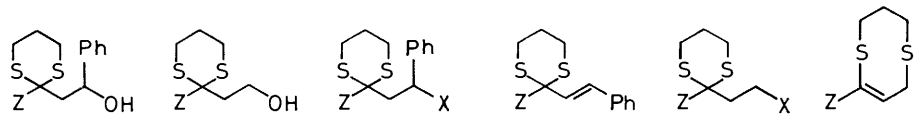


(1) (2) (4) (5) (6) (7)

Alcohol	Reagent	Product(s) (Yield)	Comments
(**1a**; Z = H)[a]	CBr_4/Ph_3P	(**4a**; X = Br) + (**5a**) (86%, *ca.* 94:6)	No elimination on heating at 56 °C[b]
	Diphos·I_2	(**4a**; X = I) (92%)[b]	
(**1b**; Z = Me_3Si)	CBr_4/Ph_3P	(**5b**) (63%)	
	Diphos·Br_2	(**5b**) (92%)	
	NaI/BF_3	(**5b**) (90%)	
	PCl_5	(**5b**) (76%)	
(**2a**; Z = H)[c,d]	CBr_4/Ph_3P	(**6a**; X = Br) (74%)	No reaction on heating at 115 °C
	Diphos·Br_2	(**6a**; X = Br) (83%)	
	CCl_4/PPh_3	(**6a**; X = Cl) (78%)	
	$POCl_3$, heat	(**6a**; X = Cl) (17%)	
(**2b**; Z = Me_3Si)	CBr_4/Ph_3P	(**7b**) (97%)	
	Diphos·Br_2	(**6b**; X = Br) (82%)	(**6b**) ⟶ (**7b**) on heating[e]
	PCl_5	(**7b**) (65%)	
	$POCl_3$, heat	(**7b**) (70%)	

[a] Attempts to form the mesylate or tosylate derived from (**1a**) gave the chloride (**4a**; X = Cl) (10—15%). [b] (**4a**; X = I) was also prepared from (**1a**) using $NaI–BF_3$[8] (38%) and from (**4a**; X = Br) and NaI in refluxing acetone (79%). [c] Treatment with tosyl chloride–pyridine gave the corresponding tosylate in 50% yield. Treatment with P_2O_5[9] gave a complex mixture of products. [d] (**6a**; X = I) was also prepared from (**6a**; X = Cl) and NaI in refluxing acetone (74%). [e] In pyridine [64% from the bromide (**6b**)].

Table 2.



(1) (2) (4) (5) (6) (7)

Alcohol	Reagent	Product(s) (Yield)	Comments
(**1c**; Z = Me)	Diphos·Br_2	(**4c**; X = Br) + (**5c**) (81%, *ca.* 89:11)[a]	(**4c**) + (**5c**) ⟶ (**5c**) on heating[b]
(**1d**; Z = Bu^t)	Diphos·Br_2	(**5d**) (96%)	
(**2c**; Me)[c]	CBr_4/Ph_3P	(**6c**; X = Br) (80%)	(**6c**) ⟶ (**7c**) on heating[d]
	Diphos·Br_2	(**6c**; X = Br) (82%)	
	$POCl_3$, heat	(**7c**) (*ca.* 39%)[e]	
(**2d**; Z = Bu^t)	Diphos·Br_2	(**6d**; X = Br) + (**7d**) (78%, *ca.* 41:59)[a,f]	(**6d**) + (**7d**) ⟶ (**7d**) on heating[g]
	$POCl_3$	(**7d**) (98%)	

[a] The ratio varied with the reaction time. [b] In toluene [74% from mixture of (**4c**) + (**5c**)]. [c] Treatment with P_2O_5[9] gave a complex mixture of products [no (**7c**) by t.l.c.]. [d] In pyridine [61% from bromide (**6c**); no reaction occurs in refluxing toluene. [e] Together with a small amount (< 10%) of a second component believed to be (**6c**; X = Cl). [f] Tentative structural assignments. [g] In pyridine or toluene (*ca.* 40% from mixture of (**6d**) and (**7d**).

reflux, 17%), the 2-methyl derivative (**2c**) gives the dithiacyclooctene in low yield (8.5 h reflux, 39%), the 2-trimethylsilyl derivative (**2b**) undergoes ready ring expansion (15 min reflux, 70%), and the t-butyl derivative (**2d**) gives the dithiacyclooctene in quantitative yield after 5 min at room temperature. These results are in accord with the generalisation[16] that the steric effect of the trimethylsilyl group is less than that of the t-butyl group because of the relatively long C–Si bond length (189 pm).

De Clercq and his colleagues have recently reported[15] that the rates of certain intramolecular Diels–Alder reactions can be significantly enhanced by the presence of an 'anchoring' t-butyl group but to our knowledge the effectiveness of the trimethylsilyl group as a promoter of the Thorpe-Ingold effect has not previously been noted. This fact should be of general interest, as should the observation that substituent size (Bu^t > Me_3Si > Me ≫ H) can play an important role in determining the outcome and rate of cyclisation reactions.

Experimental

M.p.s were recorded on a Kofler hot-stage melting point apparatus, and are uncorrected. I.r. spectra ($\nu_{max.}$) were recorded using a Perkin-Elmer 597 or 297 grating spectrometer. ^1H N.m.r. spectra were recorded using a JEOL JNM-PMX60 or Perkin-Elmer R32 instrument and 25.05 MHz ^{13}C n.m.r. spectra were recorded using a JEOL FX-100 instrument. Samples of n.m.r. spectrometry were prepared as solutions in deuteriochloroform, containing tetramethylsilane as an internal standard. Mass spectra (*m/z*) were recorded on Kratos MS25, MS30, and VG Zab-E instruments.

All reactions involving organometallic reagents were carried out in a nitrogen atmosphere, using flame-dried apparatus. Butyl-lithium (in hexane) was purchased from the Aldrich Chemical Company and was titrated[17] before use. Diphos [1,2-bis(diphenylphosphino)ethane] was prepared by a literature procedure,[18] all other starting materials being obtained commercially. Ether refers to diethyl ether, and petroleum refers to a petroleum fraction of boiling range 40—60 °C, which was redistilled before use. Tetrahydrofuran (THF) was dried over sodium and distilled immediately before use and dichloromethane was distilled from calcium hydride. A standard work-up procedure consisted of two extractions with the specified solvent, washing of the combined extracts twice with water, drying ($MgSO_4$), and removal of the solvent on a rotary evaporator under reduced pressure. Chromatography refers to column chromatography carried out at medium pressure using a column of silica gel (Merck 9385 or May and Baker Sorbsil C60). Known compounds prepared by literature procedures gave consistent ^1H n.m.r. and i.r. spectral data. Bromoalkanes (**4c**), (**6b**), (**6c**), and (**6d**) are relatively unstable compounds which undergo elimination on chromatography and polymerisation on storage under nitrogen in a freezer. They were therefore characterised by n.m.r. spectroscopy and high resolution mass spectrometry only.

General Procedure for the Preparation of the Alcohols (**1a,c,d**) *and* (**2a,c,d**).—To a 0.25—0.35M solution of the dithiane (**3a,c,d**) (5.90—83.2 mmol) in THF at *ca.* −15 °C under nitrogen was added a solution of butyl-lithium in hexane (1.05 mol equiv.) at a rate of 3—5 ml/min. After the mixture had been stirred at −20 °C [(**3a**) 2.5 h; (**3c**) 22 h; (**3d**) 23 h], styrene oxide/ethylene oxide (1 mol equiv.) was added and the reaction vessel was sealed under a nitrogen atmosphere and stored at room temperature or below [(**1a**) 50 h, r.t.; (**1c**) 50 h, −20 °C; (**1d**) 50 h, −20 °C; (**2a**) 42 h, −20 °C; (**2c**) 46 h, −20 °C; (**2d**) 2.5 d, −20 °C]. The reaction was then acidified (dilute hydrochloric acid) and diluted with ether, a standard ether work-up giving: (i) 2-(2-hydroxy-2-phenylethyl)-1,3-dithiane (**1a**)[3] (75 mmol scale, 78%) as an off-white solid (from Pr^i_2O), m.p. 84.5—85.5 °C (lit.,[3] oil); (ii) 2-(2-hydroxy-2-phenylethyl)-2-methyl-1,3-dithiane (**1c**)[3] (7.43 mmol scale, 78%) as an oil; (iii) 2-*t-butyl*-2-(2-*hydroxy*-2-*phenylethyl*)-1,3-*dithiane* (**1d**) (5.90 mmol scale, 81%), as a white crystalline solid (from ether–petroleum), m.p. 50—52 °C; R_F 0.52 (petroleum–ether, 7:3); δ 7.30 (5 H, m), 5.40—5.20 (1 H, m), 4.45 (1 H, s, exch.), 3.20—1.60 (8 H, m), and 1.20 (9 H, s); *m/z* 296 (M^+) (Found: C, 64.9; H, 8.4; S, 21.8. $C_{16}H_{24}OS_2$ requires C, 64.8; H, 8.2; S, 21.6%); (iv) 2-(2-hydroxyethyl)-1,3-dithiane (**2a**)[4] (30 mmol scale, 77%) as an almost colourless oil after Kugelrohr distillation (b.p. 160—170 °C/0.5 mmHg); (v) 2-(2-*hydroxyethyl*)-2-*methyl*-1,3-*dithiane* (**2c**)[12] (37.24 mmol scale, 71%) as an oil after chromatography (ether–petroleum, 1:1), R_F 0.32 (ether–petroleum, 1:1); $\nu_{max.}$(film) 3 600—3 000, 2 990—2 760, 1 440, 1 410, 1 270, 1 070, and 1 035 cm^{-1}; δ 3.85 (2 H, t, *J* 6.3 Hz), 3.00—2.80 (4 H, m), 2.55 (1 H, s, exch.), 2.30 (2 H, t, *J* 6.3 Hz), 2.20—1.80 (2 H, m), and 1.65 (3 H, s); *m/z* 178 (M^+) (Found: C, 47.1; H, 8.0; S, 35.9. $C_7H_{14}OS_2$ requires C, 47.15; H, 7.9; S, 36.0%); (vi) 2-*t-butyl*-2-(2-*hydroxyethyl*)-1,3-*dithiane* (**2d**) (28.36 mmol scale, 76%), as a white crystalline solid (from ether–petroleum), m.p. 50—52 °C; R_F 0.38 (petroleum–ether, 1:1); $\nu_{max.}$(Nujol) 3 400—3 000, 1 410, 1 390, 1 270, 1 240, 1 230—1 140, and 1 080—1 050 cm^{-1}; δ 4.00 (2 H, t, *J* 6.5 Hz), 3.05—2.70 (4 H, m), 2.57 (1 H, s, exch.), 2.35 (2 H, t, *J* 6.5 Hz), 2.10—1.75 (2 H, m), and 1.15 (9 H, s); *m/z* 220 (M^+) and 163 (M^+ − Bu) (Found: C, 54.7; H, 9.15; S, 29.1. $C_{10}H_{20}OS_2$ requires C, 54.5; H, 9.15; S, 29.1%).

2-(2-*Hydroxy*-2-*phenylethyl*)-2-*trimethylsilyl*-1,3-*dithiane* (**1b**).—To a stirred solution of the alcohol (**1a**)[3] (100 mg, 0.40 mmol) in THF (2 ml) under nitrogen at −17 °C was added butyl-lithium in hexane (1.44M; 0.60 ml, 0.87 mmol) dropwise over 5 min. The reaction was stirred at the same temperature for 2 h and then trimethylsilyl chloride (173 mg, 1.60 mmol) was added dropwise. The reaction was then stirred and heated at 50 °C for 3 h. After cooling, the mixture was stirred with dilute hydrochloric acid (5%; 5 ml) for 45 min after which ether (5 ml) was added; a standard ether work-up gave the title compound (**1b**) as a light red solid, m.p. 107—110 °C (lit.,[5] m.p. 109—111 °C) which exhibited spectroscopic data identical with those of a sample prepared by the literature[5] procedure. It was used without further purification.

2-(2-*Hydroxyethyl*)-2-*trimethylsilyl*-1,3-*dithiane* (**2b**).—To a stirred solution of alcohol (**2a**)[4] (2.14 g, 13.0 mmol) in THF (70 ml) under nitrogen at −15 °C was added butyl-lithium in hexane (1.44M; 18.05 ml, 26.0 mmol) dropwise over 5 min. The reaction was stirred at the same temperature for 2 h and then trimethylsilyl chloride (3.51 g, 32.0 mmol) was added dropwise. The reaction mixture was then stirred and heated at reflux for 2 h. After cooling, the mixture was stirred with dilute hydrochloric acid (5%; 100 ml) for 30 min and then left overnight. A standard ether work-up followed by Kugelrohr distillation (160—165 °C/0.5 mmHg) gave an oil which solidified. Recrystallisation (petroleum) gave the *title compound* (**2b**) as a colourless solid (2.46 g, 80%), m.p. 53—56 °C; R_F 0.4 (ether–petroleum, 2:1); $\nu_{max.}$(film) 3 240 at 1 250 cm^{-1}; δ 3.60 (2 H, t, *J* 7 Hz), 3.40—1.40 (9 H, m), and 0.24 (9 H, s) (Found: C, 46.0; H, 8.7; S, 27.3. $C_9H_{20}OS_2Si$ requires C, 45.7; H, 8.5; S, 27.1%).

General Procedure for the CX_4/Ph_3P *Reactions.*[6] CX_4 (1 equiv.) was added in portions to a stirred solution of the alcohol (1 equiv.) and triphenylphosphine (2 equiv.) in dichloromethane (2—5 ml/mmol of alcohol) at 0 to −15 °C under nitrogen. The reaction mixture was then stirred at 0 °C—room temperature for 90 min—17h; any precipitate formed was filtered off and the solvent was removed under reduced pressure.

General Procedure for the Diphos·X_2 *Reactions.*[7]—Br_2 or I_2 (2.5 equiv.) in dichloromethane was added in portions to 1,2-bis-(diphenylphosphino)ethane (1.25 equiv.) in dichloromethane (*ca.* 5 ml/mmol of alcohol) at 0 °C under N_2 at such a rate as to maintain the temperature < 10 °C. The alcohol (1 equiv.) in dichloromethane was then added in one portion and the reaction mixture stirred and allowed to warm to room temperature. After a further period of stirring at room temperature (1.5—3 h), ether and petroleum were added to precipitate undesired by-products followed by Florisil. The mixture was then filtered and the solution concentrated under reduced pressure.

General Procedure for the $POCl_3$ *Reactions.*—$POCl_3$ (3 equiv.) was added to the alcohol (1 equiv.) in pyridine (*ca.* 7 ml/mmol of alcohol) and the mixture was refluxed or stirred under nitrogen for 5 min—8.5 h under N_2. The reaction was then given a standard ether work-up incorporating a wash with 1M hydrochloric acid. If necessary, alkene products were purified by column chromatography.

2-(2-*Bromo*-2-*phenylethyl*)-1,3-*dithiane* (**4a**; X = Br).—This was prepared from 2-(2-hydroxy-2-phenylethyl)-1,3-dithiane (**1a**) (6.11 g, 25.4 mmol) and CBr_4–PPh_3 using the general procedure (stir at room temp. for 17 h). The resulting oil (obtained by solvent evaporation at 35 °C) was triturated with petroleum to give a solid which was subjected to continuous extraction using petroleum (700 ml, 4 d). The extract was then concentrated (to *ca.* 400 ml), filtered, and the filtrate plus ether (100 ml) filtered through Florisil [it should be noted that the

bromide (**4a**) is unstable to chromatography on silica, to storage when impure, and to sunlight]. Exhaustive solvent removal at room temperature gave the title compound (**4a**) as a yellow solid (6.60 g, 86%) containing *ca.* 5% (n.m.r.) of the styrene (**5a**). One recrystallisation (petroleum) gave 2-(2-*bromo*-2-*phenylethyl*)-1,3-*dithiane* (**4g**; X = Br) as analytically pure yellow crystals, m.p. 44—46 °C; R_F 0.43 (CH_2Cl_2–petroleum, 1:2); $\nu_{max.}$(film) 760 and 695 cm^{-1}; δ 7.78—7.12 (5 H, m), 5.22 (1 H, dd, *J* 8 Hz, 7 Hz), 3.95 (1 H, dd, *J* 8 Hz, 7 Hz), 3.32—2.28 (6 H, m), and 2.28—1.50 (2 H, m); *m/z* 302 and 304 (M^+) (Found: C, 47.8; H, 4.8; Br, 26.2; S, 21.25. $C_{12}H_{15}BrS_2$ requires C, 47.5; H, 5.0; Br, 26.35; S, 21.1%).

2-(2-*Iodo*-2-*phenylethyl*)-1,3-*dithiane* (**4a**; X = I).—(i) This was prepared from 2-(2-hydroxy-2-phenylethyl)-1,3-dithiane (**1a**) (19.2 g, 0.08 mol) and diphos·I_2 using the general procedure. Solvent evaporation in the dark gave the title compound as a pale yellow solid (25.9 g, 92%) which was pure by ^1H n.m.r. One recrystallisation (petroleum) gave 2-(2-*iodo*-2-*phenylethyl*)-1,3-*dithiane* (**4a**; X = I) as analytically pure crystals, m.p. 61—62 °C; R_F 0.7 (ether–petroleum, 3:7); $\nu_{max.}$(Nujol) 907, 762, and 700 cm^{-1}; δ 7.30 (5 H, m), 5.36 (1 H, t, *J* 7.5 Hz), 3.88 (1 H, t, *J* 7.5 Hz), and 3.05—1.52 (8 H, m) (Found: C, 41.4; H, 4.35; I, 36.3. $C_{12}H_{15}IS_2$ requires C, 41.15; H, 4.3; I, 36.2%). It should be noted that the iodide (**4a**) is unstable to chromatography on silica, to storage when impure, and to sunlight.

(ii) The iodide (**4a**) was also prepared from the bromide (**4a**) (37 mmol scale, 79%) by treatment with NaI in refluxing acetone.

(E)-2-*Styryl*-2-*trimethylsilyl*-1,3-*dithiane* (**5b**).—(i) Freshly distilled BF_3·OEt_2 (142 mg, 1.0 mmol) in acetonitrile (1 ml) was added over 10 min to a stirred solution of sodium iodide (150 mg, 1 mmol) and 2-(2-hydroxy-2-phenylethyl)-2-trimethylsilyl-1,3-dithiane (**1b**) (156 mg, 0.5 mmol) in dry acetonitrile (2 ml) at 0 °C under nitrogen. The mixture was stirred at room temperature for 45 min and then ice–water (10 ml) and aqueous sodium thiosulphate (15%; 15 ml) were added. A standard ether work-up followed by recrystallisation (EtOH) gave the title compound (**5b**) (132 mg, 90%) as off-white crystals, m.p. 101—102 °C (lit.,[19] m.p. 100—101.5 °C); R_F 0.34 (CH_2Cl_2–petroleum, 1:3); $\nu_{max.}$(Nujol) 1 245, 845, 840, 740, and 695 cm^{-1}; δ 7.60—7.08 (5 H, m), 6.76 (1 H, d, *J* 15.5 Hz), 6.36 (1 H, d, *J* 15.5 Hz), 3.68—1.66 (6 H, m), and 0.19 (9 H, s) (Found: C, 61.2; H, 7.6; S, 21.5. $C_{15}H_{22}S_2Si$ requires C, 61.2; H, 7.5; S, 21.8%).

(ii) Compound (**5b**) was also obtained on treatment of the alcohol (**1b**) with CBr_4–Ph_3P (63%), diphos·Br_2 (92%) (following the general procedures), and PCl_5, petroleum, room temperature (76%).

2-(2-*Bromo*-2-*phenylethyl*)-2-*methyl*-1,3-*dithiane* (**4c**).—This was prepared from 2-(2-hydroxy-2-phenylethyl)-2-methyl-1,3-dithiane (**1c**) (0.40 g, 1.57 mmol) and diphos·Br_2 using the general procedure (stir for 2 h). Solvent evaporation gave a solid (0.47 g, 97%) which was a mixture of the title compound (**4c**) and the styrene (**5c**) (89:11 according to ^1H n.m.r. spectroscopy). This ratio varied with reaction time, *e.g.* after stirring for 3.5 h the (**4c**):(**5c**) ratio was 57:43. Recrystallisation (ether–petroleum) afforded 2-(2-*bromo*-2-*phenylethyl*)-2-*methyl*-1,3-*dithiane* (**4c**) (0.40 g, 81%) as off-white crystals, R_F 0.40 (ether–petroleum, 3:7); δ 7.60—7.20 (5 H, m), 5.30 (1 H, m), 3.20—1.60 (8 H, m), and 1.30 (3 H, s) (Found: C, 49.15; H, 5.5; Br, 25.1; S, 20.15. $C_{13}H_{17}BrS_2$ requires C, 49.2; H, 5.4; Br, 25.2; S, 20.2%).

(E)-2-*Methyl*-2-*styryl*-1,3-*dithiane* (**5c**).—The mixture of (**4c**) and (**5c**) prepared above (89:11, 40 mg) was dissolved in toluene (3 ml) and heated under reflux for 3 h. Evaporation of the solvent followed by chromatography (ether–petroleum, 3:7) gave the title compound (**5c**) (22.5 mg, 74%) as an oil, R_F 0.72 (ether–petroleum, 3:7); δ 7.60—7.20 (5 H, m), 6.80 (1 H, d, *J* 16 Hz), 6.28 (1 H, d, *J* 16 Hz), 3.20—1.80 (6 H, m), and 1.70 (3 H, s) (consistent with literature[19] n.m.r. data); *m/z* 236 (M^+).

(E)-2-*t*-*Butyl*-2-*styryl*-1,3-*dithiane* (**5d**).—This was prepared from 2-t-butyl-2-(2-hydroxy-2-phenylethyl)-1,3-dithiane (**1d**) (0.29 g, 1.01 mmol) and diphos·Br_2 using the general procedure. Solvent evaporation and recrystallisation (ether–petroleum) gave (E)-2-*t*-*butyl*-2-*styryl*-1,3-*dithiane* (**5d**) (0.26 g, 96%) as white crystals, R_F 0.78 (ether–petroleum, 1:4); δ 7.60—7.20 (5 H, m), 6.85 (1 H, d, *J* 15.5 Hz), 6.30 (1 H, d, *J* 15.5 Hz), 3.20—1.60 (6 H, m), and 1.20 (9 H, s); *m/z* 278 (M^+) (Found: M^+, 278.11586. $C_{16}H_{22}S_2$ requires M^+, 278.11630).

2-(2-*Bromoethyl*)-1,3-*dithiane* (**6a**; X = Br).—This was prepared from 2-(2-hydroxyethyl)-1,3-dithiane (**2a**) (409 mg, 2.5 mmol) and CBr_4/Ph_3P using the general procedure (stir for 4 h). Filtration, solvent evaporation, trituration with petroleum, and extraction of the resulting solid with petroleum (3 × 10 ml), and solvent removal gave an oil. Kugelrohr distillation of this oil gave 2-(2-*bromoethyl*)-1,3-*dithiane* (**6a**) (420 mg, 74%) as a clear liquid, b.p. 95—100 °C/0.1 mmHg; R_F 0.90 (ether–petroleum, 2:3); $\nu_{max.}$(film) 1 425, 1 360, 1 300, and 910 cm^{-1}; δ 4.18 (1 H, t, *J* 7 Hz), 3.56 (2 H, t, *J* 7 Hz), 3.16—2.72 (4 H, m), and 2.56—1.55 (4 H, m) (Found: C, 31.9; H, 5.1; Br, 35.3; S, 28.2. $C_6H_{11}BrS_2$ requires C, 31.7; H, 4.9; Br, 35.2; S, 28.2%).

(ii) Compound (**6a**; X = Br) was also obtained by treatment of the alcohol (**2a**) with diphos·Br_2 using the general procedure (83%).

2-(2-*Chloroethyl*)-1,3-*dithiane* (**6a**; X = Cl).—(i) This was prepared from 2-(2-hydroxyethyl)-1,3-dithiane (**2a**) (410 mg, 2.5 mmol) and CCl_4–Ph_3P using the general procedure (stir for 6 h). Solvent evaporation and trituration with petroleum gave a solid which was continuously extracted with petroleum (80 ml) for 5 h. Solvent removal gave an oil which on Kugelrohr distillation gave 2-(2-*chloroethyl*)-1,3-*dithiane* (**6a**) (355 mg, 78%) as a clear liquid, b.p. 85—90 °C/0.1 mmHg (lit.,[4] b.p. 84.5—86 °C/0.2 mmHg).

(ii) Compound (**6a**; X = Cl) was also obtained by treatment of the alcohol (**2a**) with $POCl_3$ using the general procedure (4-h reflux, 17%). No other products were isolated from this reaction although all of the starting material was consumed.

2-(2-*Bromoethyl*)-2-*trimethylsilyl*-1,3-*dithiane* (**6b**; X = Br).—This was prepared from 2-(2-hydroxyethyl)-2-trimethylsilyl-1,3-dithiane (**2b**) (0.30 g, 1.27 mmol) and diphos·Br_2 using the general procedure. Solvent evaporation gave the *title compound* (**6b**) (0.31 g, 82%) as a dark brown liquid, R_F 0.92 (petroleum–ether, 7:3); δ 3.50 (2 H, t, *J* 9 Hz), 3.20—1.60 (8 H, m), and 0.20 (9 H, s); *m/z* 298.302 (M^+) (Found: MH^+, 298.995 33. $C_9H_{19}BrS_2Si$ requires MH^+, 298.995 90).

2-*Trimethylsilyl*-1,5-*dithiacyclo*-*oct*-2-*ene* (**7b**).—(i) This was prepared from 2-(2-hydroxyethyl)-2-trimethylsilyl-1,3-dithiane (**2b**) (156 mg, 0.66 mmol) and CBr_4/Ph_3P using the general procedure (stir for 4 h). Filtration, solvent evaporation, and chromatography (dichloromethane–petroleum, 1:3) gave an oil which on Kugelrohr distillation gave the title compound (**7b**) (139 mg, 97%) as an oil, b.p. 100—110 °C/0.04 mmHg; R_F 0.85 (petroleum–ether, 95:5); $\nu_{max.}$(film) 1 245, 840, and 750 cm^{-1}; δ_H 6.16 (1 H, t, *J* 8 Hz), 3.58 (2 H, d, *J* 8 Hz), 3.00—1.96 (6 H, m), and 0.20 (9 H, s); δ_C 140.5 (s), 138.2 (d), 35.7 (t), 34.8 (t), 29.5 (t), 27.2 (t), −1.5 (q); *m/z* 218 (M^+) (Found: C, 49.2; H, 8.2; S, 29.1. $C_9H_{18}S_2Si$ requires C, 49.5; H, 8.3; S, 29.35%).

(ii) Compound (**7b**) was also obtained by treatment of the

alcohol (**2b**) with $POCl_3$ using the general procedure (reflux for 15 min, chromatography not necessary, 70%) and PCl_5, petroleum, room temperature (65%).

(iii) Compound (**7b**) was also obtained by heating the bromide (**6b**) (66.9 mg, 0.23 mmol) in pyridine (20 ml) under nitrogen for 1 h. The cooled reaction was then given a standard ether work-up incorporating a wash with 1M hydrochloric acid and the crude product purified by column chromatography (petroleum–ether, 95:5) giving the title compound (**7b**) (31.3 mg, 64%) identical to the above sample by t.l.c. and n.m.r.

2-(2-*Bromoethyl*)-2-*methyl*-1,3-*dithiane* (**6c**; X = Br).[12]—(i) This was prepared from 2-(2-hydroxyethyl)-2-methyl-1,3-dithiane (**2c**) (1.0 g, 5.61 mmol) and diphos·Br_2 using the general procedure. Solvent evaporation gave the *title compound* (**6c**) (1.104 g, 82%) as a dark yellow liquid, R_F 0.86 (petroleum–ether, 3:2); δ 3.50 (2 H, t, *J* 7 Hz), 3.10—1.80 (8 H, m), and 1.55 (3 H, s); *m/z* 240.242 (M^+) (Found: M^+, 239.963 27. $C_7H_{13}BrS_2$ requires M^+, 239.964 22).

(ii) Compound (**6c**) was also obtained on treatment of the alcohol (**2c**) with CBr_4–Ph_3P (2.5 h) following the general procedure (80%).

2-*Methyl*-1,5-*dithiacyclo-oct*-2-*ene* (**7c**).—(i) A solution of 2-(2-bromoethyl)-2-methyl-1,3-dithiane (**6c**) (0.206 g, 0.86 mmol) in pyridine (25 ml) was boiled under reflux for 1.5 h. The cooled solution was poured onto crushed ice, given a standard ether work-up incorporating a wash with 1M hydrochloric acid. The crude product was then purified by column chromatography (petroleum–ether, 7:3) giving 2-*methyl*-1,5-*dithiacyclo-oct*-2-*ene* (**7c**) (83 mg, 61%) as a light yellow liquid, R_F 0.88 (petroleum–ether, 7:3); δ 5.90 (1 H, t, *J* 6 Hz), 3.50 (2 H, d, *J* 6 Hz), 3.00—2.15 (6 H, m), and 2.10 (3 H, s); *m/z* 160 (M^+) and 145 (M^+ − Me) (Found: M^+, 160.038 40. $C_7H_{12}S_2$ requires M^+, 170.038 08). Ring expansion did not occur using refluxing toluene (2.75 h) in place of pyridine, starting material (**7c**) being recovered.

(ii) Compound (**7c**) was also prepared from 2-(2-hydroxyethyl)-2-methyl-1,3-dithiane (**2c**) (100 mg, 0.56 mmol) and $POCl_3$ using the general procedure (reflux for 8.5 h). The crude product was dissolved in ether and filtered through silica gel to remove polar impurities. Analysis of the resulting clear oil (43 mg) by ^1H n.m.r. spectroscopy and t.l.c. indicated that it was predominantly the *title compound* (**7c**) (*ca.* 39%) containing a small quantity of the chloride (**6c**; X = Cl).

2-*t-Butyl*-1,5-*dithiacyclo-oct*-2-*ene* (**7d**).—(i) This was prepared from 2-t-butyl-2-(2-hydroxyethyl)-1,3-dithiane (**2d**) (0.15 g, 0.68 mmol) and $POCl_3$ using the general procedure (stir for 5 min at room temp., chromatography was not necessary). Solvent evaporation gave the *title compound* (**7d**) (0.135 mg, 98%) as a colourless liquid, R_F 0.74 (petroleum–ether, 95.5); δ 6.10 (1 H, t, *J* 6 Hz), 3.60 (2 H, d, *J* 6 Hz), 2.80—2.00 (6 H, m), and 1.20 (9 H, s); *m/z* 202 (M^+), 145 (M^+ − Bu^t) (Found: M^+, 202.084 97. $C_{10}H_{18}S_2$ requires M^+, 202.084 99).

(ii) Compound (**7d**) was also obtained from 2-t-butyl-2-(2-hydroxyethyl)-1,3-dithiane (**2d**) (0.38 g, 1.73 mmol) and diphos·Br_2 using the general procedure (stir for 3.5 h). Solvent evaporation gave a dark brown liquid (0.38 g, 94%) containing two components (*ca.* 59:41 by ^1H n.m.r. spectroscopy), believed to be 2-t-butyl-1,5-dithiacyclo-oct-2-ene (**7d**) and *bromide* (**6d**) (Found: M^+ 284.006 95. $C_{10}H_{19}BrS_2$ requires M^+, 284.009 115). The product ratio varied with reaction time, *e.g.* after stirring for 2 h the (**7d**):(**6d**) ratio was 34:66.

Heating the crude mixture of bromide (**7d**) and (**6d**) (59:41, 250 mg) in toluene (25 ml) at reflux under nitrogen for 1 h, solvent removal under reduced pressure and purification of the resulting brown oil by column chromatography (petroleum–ether, 95:5) gave the title compound (**7d**) (89 mg, 40%) identical with the above sample by t.l.c. and n.m.r. The use of pyridine (1 h reflux) gave a yield of 41% of (**7d**) after chromatography.

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