2-Halogeno-1,3-dithiane 1,3-dioxide: a diastereoselective carbonyl anion equivalent in reactions with aldehydes

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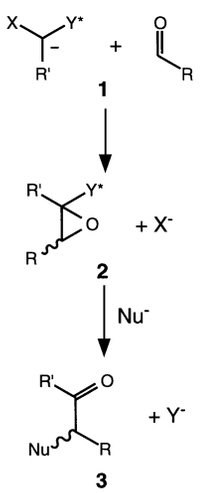
The metal anions of 2-halogeno-1,3-dithiane *trans*-1,3-dioxide react diastereoselectively with aldehydes. The scope and limitations of this reaction have been studied through variations in the metal counter-ion, halogen, aldehyde and reaction temperature, with a view to achieving umpolung asymmetric Darzens type reactions. Chlorohydrins were obtained with high diastereoselectivity by reaction of the lithium anion of 2-chloro-1,3-dithiane dioxide 4 with aromatic aldehydes under equilibrating conditions. Aliphatic aldehydes gave poor selectivities. Attempted stereospecific conversion of the chlorohydrins into epoxides resulted only in reversion to 4 and aldehyde. Use of sodium or potassium bases gave lower yields of chlorohydrins; epoxides were not isolated. It was possible to obtain aromatic bromohydrins with high selectivity using the magnesium anion of 2-bromo-1,3-dithiane 1,3-dioxide 5 as the nucleophile, but once again ring closure to form epoxides failed to compete with the facile retro-aldol process. Use of sodium bases with 5 resulted in capricious reactions from which a single isomer of epoxide could be isolated. There is evidence of decomposition of the target epoxides under the reaction conditions to α-substituted carbonyl compounds and 1,2-dithiolane 1-oxide.

Introduction

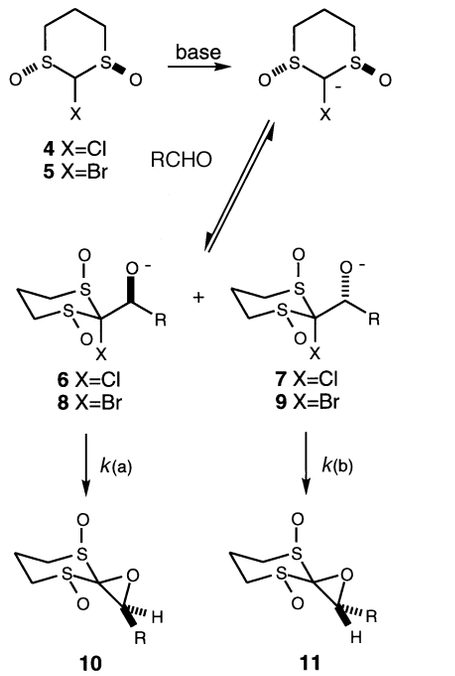
The use of chiral enolates in reactions with carbonyl compounds or imines for control of stereochemistry in the synthesis of β-substituted carbonyl compounds is well established.[1–6] However, it is more difficult to achieve stereochemical control using chiral nucleophiles in carbon–carbon bond disconnections of α-substituted carbonyl compounds. A number of chiral auxiliaries and chiral reagents for this type of transformation have been developed. Addition of 1,3-dithiane *trans*-1,3-dioxide to aromatic aldehydes has been shown to proceed with high disastereoselectivity[7] to afford adducts which can be converted into α-hydroxy thiol esters by a Pummerer reaction.[8] Eliel[9] has used the addition of 1,3-oxathianes to aldehydes to access secondary and tertiary α-hydroxy acids; the diastereoselectivity of aldehyde addition is poor, but high diastereoisomeric excesses are obtained after Swern oxidation and re-reduction of the adducts. A chiral dibromoolefin has been used as a carbonyl anion equivalent by Braun[10] who achieved high diastereoselectivity in additions to prochiral sulfonyl imines to provide precursors to N-protected α-amino aldehydes. In each of these cases, the range of possible α substituents in the product is limited by the range of electrophiles tolerated. A more versatile strategy towards stereocontrol in the assembly of 1,2-functionality is shown in Scheme 1. In the Scheme, Y is a chiral group capable of inducing asymmetry in the newly formed stereocentre and X is a leaving group. If Y = COR*, the first step represents an asymmetric Darzens condensation, a reaction which has previously been studied but only lately enjoyed success.[11–15] If Y = sulfinyl, there is an opportunity for preparing 1,2-related functional groups with asymmetric induction; nucleophilic opening of the epoxides **2** would furnish α-substituted carbonyl compounds **3** directly.

Satoh has studied the anion reactions of 1-halogenoalkyl aryl sulfoxides, but obtained only poor selectivity at the relevant centre in additions with aldehydes.[16] These reactions were under kinetic control. We reasoned that if the addition of **1** to aldehydes could be made reversible there would be an additional



Scheme 1

opportunity for stereochemical control in epoxide formation as, according to the Curtin–Hammett principle,[17] the ratio of epoxides would be dependent not only on the equilibrium ratio of the intermediate diastereoisomeric alkoxides but also on their relative rates of ring closure. Similar strategies have been successfully applied to enhance stereoselectivity in many chemical processes. For example, Durst found that diastereoisomeric bromo esters in rapid equilibrium can react at different rates with nucleophiles to yield α-amino and α-hydroxy esters with high diastereoselectivity.[18,19] To set up a dynamic system of equilibrating diastereoisomers we required a better anion stabilising group than the simple sulfinyl group and chose the bis-sulfoxides, 2-chloro- and 2-bromo-1,3-dithiane dioxides **4** and **5** (Scheme 2). Indeed, we have previously shown that such reagents can react with aldehydes under equilibrium control and that high diastereoselectivity can be obtained with aromatic aldehydes.[7,20] The C_2 symmetry of the chiral group simplifies the strategy shown in Scheme 1 such that R′ = Y*, so the



a R = Ph
b R = *p*-$NO_2C_6H_4$
c R = *p*-$MeOC_6H_4$
d R = 3,4-$(MeO)_2C_6H_3$
e R = *p*-ClC_6H_4
f R = 2-naphthyl
g R = 2-furfuryl
h R = 2,4,6-$Me_3C_6H_2$
i R = Bu
j R = Pr^i
k R = Bu^t

Scheme2

carbon atom which connects them does not become a chiral centre on addition to aldehydes.

Results

Preparation of 2-halogeno-1,3-dithiane 1,3-dioxide

Racemic *trans*-1,3-dithiane 1,3-dioxide was prepared by oxidation of 1,3-dithiane using *m*-CPBA.[21] Chlorination at the 2-position was achieved using *N*-chlorosuccinimide in CH_2Cl_2. This system has been reported by Yamakawa[22] to cause concomitant racemisation of the sulfoxide centre when used to α-chlorinate alkyl *p*-tolyl sulfoxides. He found that addition of K_2CO_3 caused the reaction to proceed at reduced rate and with clean inversion at sulfur. Drabowicz[23] has carried out α-chlorination of alkyl aryl sulfoxides using NCS on a silica gel support; he also reports inversion at sulfoxide. In the dithiane dioxide system, inversion of one sulfoxide would lead to the *meso cis* dioxide. Spectroscopic data revealed, however, that the chlorinated product **4** was exclusively *trans*. It has previously been shown that inversion of a sulfinyl group in 1,3-dithiane 1,3-dioxide occurs much less readily than in simple sulfoxides.[21] The chlorination is thought to proceed by a radical mechanism; it does not proceed in the dark or in the presence of K_2CO_3, and is solvent sensitive, occurring in dichloromethane but not in acetonitrile.

Bromination of dithiane dioxide was similarly achieved using NBS in CH_2Cl_2, without isomerisation of the sulfoxides. The chloride **4** and bromide **5** are soluble in a range of organic solvents, so anion reactions can be carried out in neat THF, thus simplifying reaction and work-up conditions; pyridine–THF mixtures are required to solublise dithiane dioxide itself.[7]

The halogen substituent can adopt either an axial or equatorial position in the ring, the two conformations being rapidly interconverted in solution by chair–chair isomerism. Low temperature (183 K) ^{1}H NMR spectra of **4** and **5** show that the conformation with the halogen substituent axial is favoured by

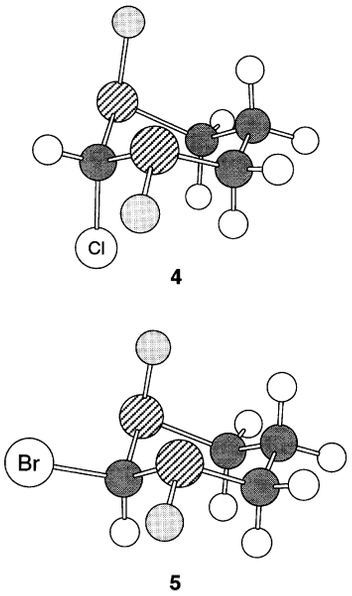
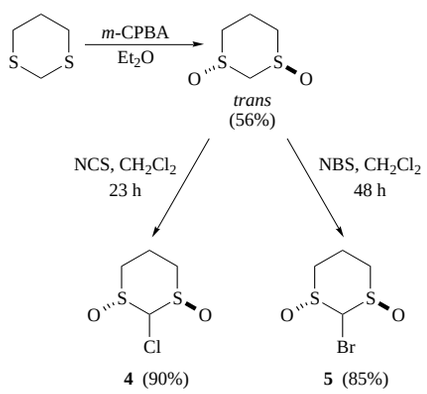


Fig. 1 X-Ray crystal structures of 2-chloro- and 2-bromo-1,3-dithiane *trans*-1,3-dioxide[25]



around 1 kcal mol^{-1} in both cases. This has been attributed to a combination of anomeric and dipole repulsion effects between the sulfoxides and the C–X bond.[24] The X-ray crystal structure of **4** is consistent with the NMR data, with Cl occupying the axial position, while crystalline **5** adopts the conformation with Br equatorial (Fig. 1). This discrepancy has been attributed to crystal packing effects.

Reactions of 2-chloro-1,3-dithiane dioxide with aldehydes

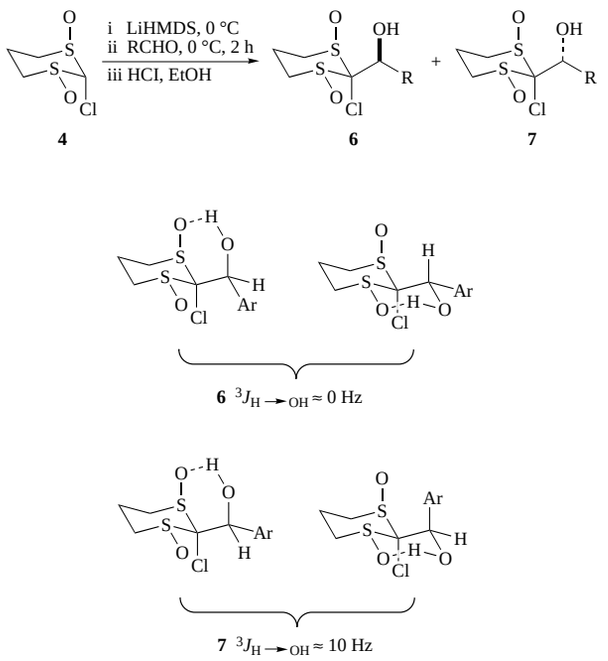
Deprotonation of **4** using LiHMDS and addition to benzaldehyde at −78 °C led to the formation of two diastereoisomeric chlorohydrins in a 68:32 ratio (**6a**:**7a**). When the reaction was carried out at 0 °C, an 8:92 ratio (**6a**:**7a**) was obtained within 2 h (Table 1, entry 1). Separation of the minor isomer **6a** and resubjection to LiHMDS at 0 °C for 2 h returned a 10:90 mixture of diastereoisomers (**6a**:**7a**) together with dissociated benzaldehyde (12%) and **4** (12%), showing that equilibration is occurring at this temperature. The diastereoselectivity in these thermodynamically controlled reactions is strongly dependent on the nature of the aldehyde; Table 1 shows the results of addition of lithiated **4** to a variety of aldehydes at 0 °C. The stereochemistry of the major isomer was determined for **7a** by X-ray crystallography (Fig. 5).

In general, reactions with aromatic aldehydes proceeded in good yield with high diastereoselectivity at the β-position. The α-position is not a chiral centre due to the C_2 symmetric nature of dithiane dioxide. Low yields were obtained with sterically hindered aldehydes, as the equilibrium favours dissociation to the starting materials (entries 8, 10, 11). In reactions with aromatic aldehydes having electron-withdrawing substituents

Table 1 Summary of results from reactions of Li-**4** with aldehydes

Entry	Aldehyde	Ratio **6**:**7**[a]	Isolated % yield of **7**
1	C_6H_5CHO	8:92	64 (92[b])
2	*p*-$NO_2C_6H_4CHO$	18:82	50 (55[b])
3	*p*-$MeOC_6H_4CHO$	6:94	48 (70[b])
4	3,4-$(MeO)_2C_6H_3CHO$	7:93	38 (62[b])
5	*p*-ClC_6H_4CHO	6:94	66 (76[b])
6	2-Naphthaldehyde	2:98	61 (69[b])
7	2-Furaldehyde	11:89	32 (35[b])
8	2,4,6-$Me_3C_6H_2CHO$	—	0
9	BuCHO	51:49	[71 (81[b])][c]
10	Pr^iCHO	43:57	8 (13[b])
11	Bu^tCHO	—	0

[a] Ratios determined by ^{1}H NMR integration of crude reaction mixture. [b] Yields based on recovered starting material. [c] Combined yield of **6i** and **7i**; diastereoisomers were inseparable by column chromatography.



(entry 2) the diastereoselectivity was lower than with electron-donating substituents (entries 3, 4); however the proportion of addition products to recovered starting materials was higher.

Very poor selectivities were obtained with aliphatic aldehydes. These reactions have been shown to be similarly under thermodynamic control, so the lower diastereoselectivities must be due to smaller energy differences between the diastereoisomeric lithium alkoxides. Similarly low diastereoselectivities with aliphatic aldehydes were observed in the anion chemistry of 1,3-dithiane 1,3-dioxide.[7]

The coupling constants in the ^{1}H NMR ($CDCl_3$) spectra of the chlorohydrins provide evidence for the ability of a small cation to chelate the alkoxide oxygen with a sulfoxide oxygen intramolecularly. The spectra of the minor adducts **6** show the C*H*-OH portion of the molecule as two singlets, while the major adducts **7** show a 10 Hz vicinal coupling. This is consistent with intramolecular OH→S(O) hydrogen bonding,[26] which would restrict rotation around the C–O bond to give dihedral angles of 180° and close to 90° in the major and minor adducts, respectively. The O*H* signals generally appear between 4 and 5 ppm and are around 0.5 ppm further downfield in the major adducts than in the corresponding minor ones.

In proposing a rationale for the stereochemical outcome of the reactions, only the relative stabilities of the two diastereoisomeric lithium alkoxides need to be considered, as the reactions are under thermodynamic control. These alkoxides can each adopt two possible conformations (**6**$_{ax}$, **6**$_{eq}$, **7**$_{ax}$, **7**$_{eq}$) depending on whether chelation of the lithium counter-ion occurs with the axial or equatorial sulfoxide (Fig. 2). The X-ray crystal structure of 1,3-dithiane 1,3-dioxide itself shows that the axial S–O bond is bent towards the equatorial sulfoxide, the O(1)–S(2) distance being shorter than expected and the S(2)–S(1)–O(1) angle being 81° (Fig. 3).[27] This suggests the possibility of a favourable electrostatic interaction between the axial sulfoxide oxygen and the equatorial sulfoxide. Related transannular interactions between sulfide and sulfoxide groups have been observed in X-ray studies of 1,5-dithiacyclooctane 1-oxides.[28] In the lithiated chlorohydrin adducts **6** and **7**, chelation of the lithium counter-ion to the axial sulfoxide (**6**$_{ax}$, **7**$_{ax}$) would allow two possible O→S–O interactions to occur whereas chelation to the equatorial sulfoxide (**6**$_{eq}$, **7**$_{eq}$) allows only one. Of the two axially chelated diastereoisomeric alkoxides **6**$_{ax}$ and **7**$_{ax}$, isomer **7** would then be preferred, as electronic repulsion between lone pairs of the equatorial sulfinyl oxygen and π electrons of the aryl group destabilises isomer **6**. The destabilisation would be expected to be greater for electron-rich Ar groups, which may help to explain the increased diastereoselectivity obtained in these cases (Table 1, entries 3 and 4). The low selectivities observed with aliphatic aldehydes (entries 9 and 10) are also consistent with this hypothesis.

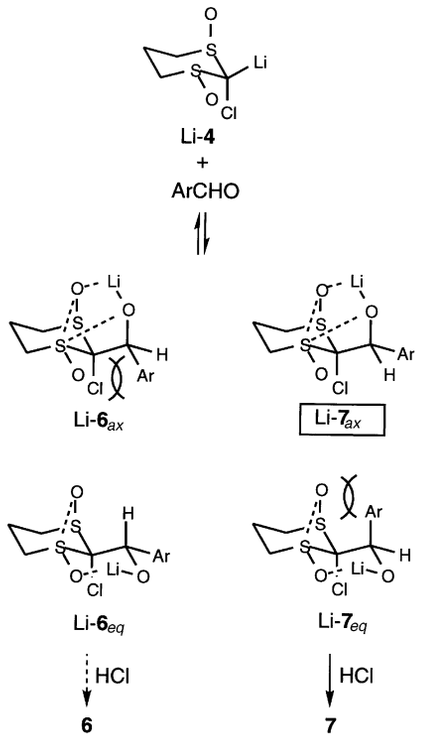


Fig. 2 The most stabilised alkoxide conformation Li-**7**$_{ax}$ leads to the observed thermodynamic product **7**

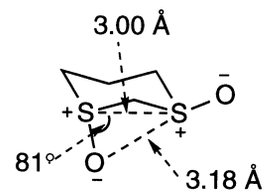


Fig. 3 X-Ray crystal structure of 1,3-dithiane 1,3-dioxide

In order for epoxide formation to occur, an antiperiplanar relationship between the C–O and C–Cl bonds is required, as exists in conformations Li-**6**$_{ax}$ and Li-**7**$_{ax}$ (Fig. 2). The transition state for formation of epoxide **10** from chlorohydrin **6** would therefore involve a repulsive non-bonding interaction between the aromatic ring and the equatorial sulfoxide, while formation of **11** from **7** would be expected to be more favourable. The

Table 2 Addition of metallated 2-chloro-1,3-dithiane dioxide **4** to benzaldehyde

			Product distribution (% yields)				
Entry	Base	*T*/°C	Adducts (**6a** and **7a**)	Recovered **4**[b]	Side product **12**	Epoxides **10a** and **11a**	Radio **6a**:**7a**[a]
1	LiHMDS	−78	62	36	—	—	68:32
2	LiHMDS	0	70	30	—	—	8:92
3	NaHMDS	−78	45	12	Trace	—	20:80
4	NaHMDS	0	8	17	31	—	24:76
5	KHMDS	−78	5	50	Trace	—	44:56
6	KHMDS	0	5	17	23	Trace	30:70

[a] Ratios determined by ^{1}H NMR integration of crude reaction mixture. [b] Entries 3–6 were worked up by CH_2Cl_2 extraction, resulting in loss of some unchanged starting material to the aqueous phase.

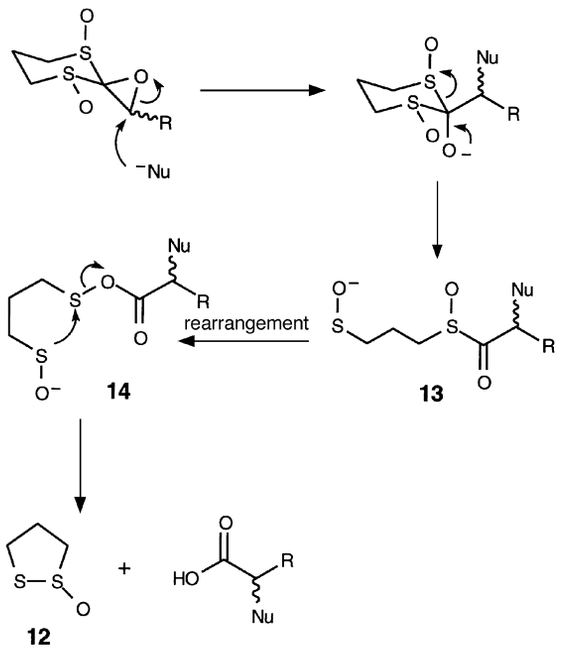


Fig. 4 Epoxide opening which results in the formation of 1,2-dithiolane 1-oxide **12**

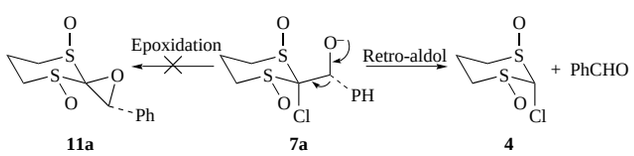
relative rate constants in Scheme 1 would then be in the order $k_{(b)} > k_{(a)}$, giving increased selectivity in epoxide formation in the (theoretical) one-pot process. In fact, epoxide formation was not observed in the reactions of lithiated **4** with aldehydes. This probably reflects the ability of lithium to stabilise the chlorohydrins by strong intramolecular chelation. It was felt that use of a less oxophilic metal counter-ion would encourage ring closure by increasing the nucleophilicity of the alkoxide oxygen. The effect of changing the metal counter-ion was studied by deprotonation of **4** using a range of bases and addition to benzaldehyde at −78 °C and 0 °C. The results are shown in Table 2.

With sodium as counter-ion (Table 2, entries 3, 4), the reactions were under thermodynamic control even at −78 °C. The yields of chlorohydrins were lower than with lithium and side products were observed, especially at higher temperatures. This trend continued on moving from sodium to potassium (entries 5 and 6).

The major side-product in the reactions at 0 °C with sodium and potassium bases was found to be 1,2-dithiolane 1-oxide **12**. This product is thought to arise from the ring-closure of the chlorohydrins to give epoxides **10** and **11**, followed by decomposition of the epoxides under the reaction conditions. A possible mechanism for this decomposition is shown in Fig. 4. Opening of the epoxides begins a reaction cascade which leads to the α-substituted carboxylic acid *via* a series of reactive intermediates. The initially formed alkoxide closes to a carbonyl group, displacing one sulfoxide and opening the dithiane dioxide ring to give α-keto sulfoxide **13**. Compounds of this class have been postulated as intermediates in the oxidation of thiol esters, but have never been isolated due to facile disproportionation[29] or S–CO bond cleavage.[30,31] It is not known whether in this case the α-keto sulfoxide rearranges as shown, is attacked intramolecularly by the displaced sulfoxide oxygen (leading to the same intermediate **14**) or is attacked by an external nucleophile, releasing propanedisulfenic acid which would undergo dehydrative cyclisation to form **12**.[32]

Attempted ring closure of chlorohydrins to epoxides

With the chlorohydrins **7** in hand, conditions were sought for their stereospecific conversion into epoxides. It was hoped that the use of silver(I) would assist epoxide formation by improving the ability of Cl^- to act as a leaving group. Chlorohydrin **7a** was, therefore, subjected to different combinations of silver salt ($AgClO_4$, $AgBF_4$, Ag_2O) and solvent (pyridine, THF, acetone, DMF), with and without added amine or inorganic bases. All of the basic systems resulted in slow reversion of **7a** into 2-chloro-1,3-dithiane dioxide **4** and benzaldehyde by a retro-aldol mechanism; in the neutral systems the starting material did not react over several days at room temperature.

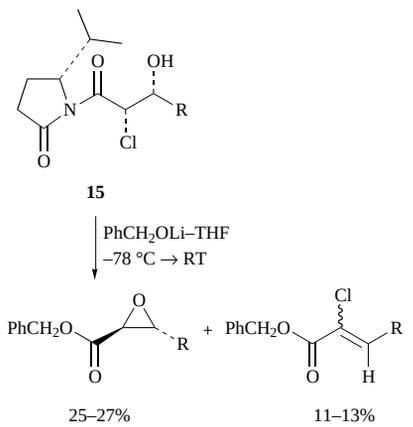


Substitution of Cl for a better leaving group was attempted using the Finkelstein reaction.[33] The precipitation of sodium chloride from acetone would drive the reaction to completion if substitution occurred at C-2. There was no precipitation, however, on addition of sodium iodide to solutions of chlorohydrin in acetone. Instead, the starting material slowly underwent the unwanted retro-aldol type reaction to give **4** and benzaldehyde as before. These results indicate that no nucleophilic substitution at the 2-position has taken place. Such a reaction is disfavoured by the electron deficiency of the carbon centre[34] and the reluctance of chloride to act as a leaving group. Abdelmagid *et al.*[15] found that chlorohydrins **15** formed by the aldol condensation of chiral α-chloroimides with aldehydes could not be cyclised to epoxides under various mildly basic conditions without epimerisation and loss of yield. This is thought to be due to the prevalence of the retro-aldol process. Conversely, the analogous bromohydrins were stereospecifically and cleanly converted into *cis* epoxides using lithium benzyl oxide. An exhaustive study of the effects of counter-ion, solvent and potential leaving group on the reaction of chiral imide enolates with α-halogeno ketones has been carried out by Bartroli.[35] He similarly found that it was necessary to use bromine rather than chlorine as the leaving group in order to obtain significant yields of epoxides from the halogenohydrin adducts. It was therefore decided that addition of 2-bromo-1,3-dithiane dioxide to aldehydes would give a better opportunity for epoxide formation in the system under study.

Table 3 Addition of metallated 2-bromo-1,3-dithiane dioxide **5** to benzaldehyde

Entry	Base	T/°C	t/h	Product distribution (% yields) Adducts **8a** and **9a**	Recovered **5**	Side prod. **12**	Epoxides **10a** and **11a**	Ratio **8a**:**9a**[a] (**10a**:**11a**)[b]
1	LiHMDS	−78	4	—	100	—	—	—
2	1 equiv. Bu^{t}MgCl	−78	3	17	35	—	—	34:66
3	1 equiv. Bu^{t}MgCl	0	2	23	35	—	—	43:57
4	1 equiv. Bu^{t}MgCl	0–5	15	19	33	Trace	—	3:97
5	10 equiv. Bu^{t}MgCl	0	2.5	—	—	10	—	—
6	NaHMDS	0	4	—	27	29	15	(0:100)
7	NaH	0–20	72	—	60	26	7	(0:100)

[a] Ratios determined by ^{1}H NMR integration of crude mixture. [b] Only one epoxide is isolated after chromatography. The crude NMRs are messy, so selectivity is ambiguous.



Reactions of 2-bromo-1,3-dithiane dioxide with aldehydes

Deprotonation of **5** and addition to benzaldehyde was attempted under a range of different conditions. The results are shown in Table 3.

The presence of bromine instead of chlorine in the 2-position increases the steric crowding around the anion and this is reflected in the reactions of **5** with benzaldehyde, in which the equilibrium lies much more in favour of dissociation to the starting materials. No addition occurred with the lithium base at −78 °C (entry 1). A more strongly chelating metal counter-ion was necessary to stabilise bromohydrin adducts **8** and **9**; their isolation was achieved in low yield when *tert*-butylmagnesium chloride was used as the base.[36] The equilibration time required under these conditions was much longer; the diastereoisomeric excess improved from 14% after 2 h (entry 3) to 94% after 15 h (entry 4) at 0–5 °C. Use of a large excess of base[37] resulted in destruction of the products (entry 5). As with the chlorohydrins, separation of the diastereoisomeric bromohydrins was possible by column chromatography. The major isomer **9a** was shown to have the same relative stereochemistry as chlorohydrin **7a** by X-ray crystallography (Fig. 5). The NMR spectra of the adducts are very similar to those of the corresponding chlorohydrins; only the major isomer exhibits a C*H*-O*H* coupling and its magnitude is around 10 Hz. It is therefore assumed that the origin of the diastereoselectivity is the same in both series. Use of sodium as the counter-ion resulted in successful formation and isolation of an epoxide, although the yields were low and the reactions capricious (entries 6 and 7). Only one diastereoisomer of the epoxide was observed; it is uncertain whether this is due to selectivity in the formation of the epoxides or in their decomposition.

Stereospecific closure of the bromohydrin **9a** to epoxide **11a** was attempted using the same methods which were unsuccessfully applied to the chlorohydrin. Once again, however, dissociation of the adduct to 2-bromo-1,3-dithiane dioxide **5** and benzaldehyde took place more readily than epoxide formation.

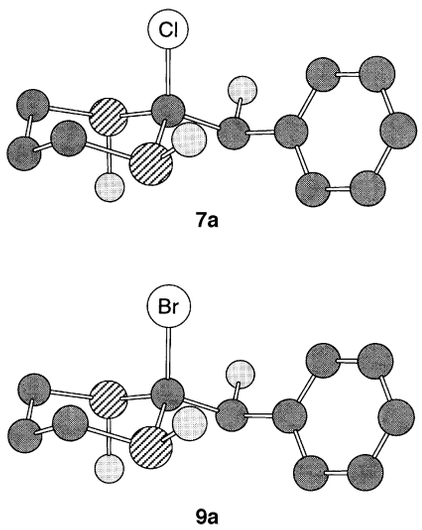


Fig. 5 X-Ray crystal structures of chlorohydrin **7a** and bromohydrin **9a**[25]

The results indicate that replacement of chlorine by bromine as the potential leaving group does not activate the C-2 position enough to allow efficient ring closure. The low reactivity at this position must be attributable to the presence of two adjacent sulfoxide groups. Analogous ring closures are known, however, at carbon centres with a single adjacent sulfoxide[16] or with an adjacent carbonyl group. Hayami *et al.*[34] have shown that the rate of chlorine isotopic exchange reactions adjacent to sulfoxide are 3×10^5 times slower than those adjacent to sulfide and 10^7 times slower than those adjacent to carbonyl. The sulfone group was found to be 300 times more deactivating than sulfoxide. It was therefore postulated that the activation barrier to nucleophilic substitution increases with increasing electronegativity of the neighbouring functional group. The relative ease of nucleophilic substitution α to a carbonyl group appears to be anomalous, as the electronegativities of C=O and S–O are similar. It was suggested that the reaction α to carbonyl is accelerated due to an initial complexation between the carbonyl carbon and the incoming nucleophile.[34] In the Darzens reaction, the incoming nucleophile is already tethered to the other adjacent carbon atom, so there is no advantage in complexation and the relationship between electron deficiency and deactivation in this type of system will be more direct. The additive effect of the two electron-withdrawing sulfoxide groups in 2-halogeno-1,3-dithiane 1,3-dioxide is therefore likely to be responsible for the comparative inefficiency of ring closure of its aldehyde adducts.

Conclusions

2-Chloro- and 2-bromo-1,3-dithiane *trans*-1,3-dioxides can be easily prepared from 1,3-dithiane *trans*-1,3-dioxide using *N*-

halogenosuccinimide. Their metal anions react with aldehydes to form two possible diastereoisomers of chlorohydrin or bromohydrin addition products. These reactions are reversible at 0 °C. Use of a metal counter-ion which can strongly chelate the alkoxide and sulfoxide oxygen atoms favours a high equilibrium ratio of the halogenohydrin adducts. For example, reaction of the lithium anion of 2-chloro-1,3-dithiane dioxide with aromatic aldehydes under equilibrating conditions affords chlorohydrins in moderate to good yields with high diastereoselectivity. The anion of 2-bromo-1,3-dithiane dioxide is more hindered and it is necessary to use magnesium as the counter-ion in order to obtain bromohydrin adducts. Equilibration control again results in high diastereoselectivity.

In both series, use of less strongly chelating metals (Na, K) alters the position of the equilibrium in favour of dissociation to the starting materials. The adducts in these cases are more prone to epoxide formation as the alkoxide oxygen is more nucleophilic; in cases where epoxide formation occurs, the alkoxides are irreversibly removed from the equilibrium mixture and epoxides and/or epoxide decomposition products are observed. The process of epoxide formation is slow due to the low equilibrium concentration of halogenohydrins and the high activation barrier to an S_N2 reaction at the electron deficient C-2 position. No epoxides are isolable from the anion reactions of 2-chloro-1,3-dithiane dioxide with aldehydes as the rate of displacement of chloride ion at C-2 by the alkoxide oxygen is lower than the rate of epoxide decomposition in each case. The S_N2 process is slightly more favourable for the bromohydrin adducts, so it is possible for epoxides to accumulate in the reaction mixture. For example, addition of the sodium anion of 2-bromo-1,3-dithiane dioxide to benzaldehyde results in the formation of the corresponding epoxide (15%, single diastereoisomer) and 1,2-dithiolane 1-oxide (29%). The dithiolane oxide is a decomposition product generated by opening of the epoxide under the reaction conditions.

Experimental

THF was distilled from sodium immediately before use. Dichloromethane was distilled from calcium hydride. All anion reactions were performed in dried apparatus under a nitrogen atmosphere. Aldehydes were recrystallised or distilled before use and stored under nitrogen until required. Proton and ^{13}C NMR spectra were recorded on a Bruker 250 MHz instrument. Coupling constants are given in Hz. In the 1,3-dithiane 1,3-dioxide ring, position 1 is arbitrarily assigned to the sulfur with oxygen equatorial. 1,3-Dithiane *trans*-1,3-dioxide was prepared as previously described.[21]

(1*RS*,3*RS*)-2-Chloro-1,3-dithiane 1,3-dioxide 4

trans-1,3-Dithiane 1,3-dioxide (250 mg, 1.6 mmol) was dissolved in dichloromethane (10 ml) under nitrogen with stirring and *N*-chlorosuccinimide (242 mg, 1.8 mmol) was added to the solution. The reaction mixture was stirred at room temperature for 23 h after which it was evaporated *in vacuo*. Purification of the residue by flash column chromatography, eluting with 10% EtOH–EtOAc, yielded **4** (275 mg, 90%); R_f (10% EtOH–EtOAc) 0.16; mp 141–142 °C (Found: C, 25.8; H, 3.8; S, 34.1; Cl, 18.75. $C_4H_7ClS_2O_2$ requires C, 25.7; H, 3.8; S, 34.35; Cl, 19.0%); ν_{max}(KBr)/cm^{-1} 2950 (CH), 1035, 1045 and 1055 (SO); δ_H($CDCl_3$) 2.32 (1 H, dm, J_d 15.9, 5-H$_{eq}$), 2.77 (1 H, m, 5-H$_{ax}$), 2.96 (1 H, dm, J_d 14.7, 4-H$_{eq}$), 3.15–3.30 (3 H, m, 4-H$_{ax}$, 6-H$_{ax}$ and 6-H$_{eq}$) and 5.91 (1 H, s, 2-H); δ_C 14.5 (C-5), 41.5 (C-4), 45.4 (C-6), 75.3 (C-2); *m/z* 188, 186 (M^+, 46, 78%), 103 (66), 90 (73) and 73 (100).

Crystal data for $C_4H_7ClO_2S_2$; M = 186.67 Crystallises from dichloromethane as colourless blocks; crystal dimensions 0.54 × 0.25 × 0.25 mm. Orthorhombic, a = 6.937(2), b = 7.996(2), c = 12.910(6) Å, U = 716.1(4) Å^3, Z = 4, D_c = 1.731 Mg m^{-3}, space group $P2_12_12_1$ (D_2^4, No. 19), Mo-Kα radiation ($\bar{\lambda}$ = 0.710 73 Å), μ(Mo-Kα) = 1.037 mm^{-1}, F(000) = 384.

Three-dimensional, room-temperature X-ray data were collected in the range $3.5 < 2\theta < 45°$ on a Siemens P4 diffractometer by the omega scan method. Of the 840 reflections measured, all of which were corrected for Lorentz and polarisation effects (but not for absorption), 721 independent reflections exceeded the significance level $|F|/\sigma(|F|) > 4.0$. The structure was solved by direct methods and refined by full matrix least-squares on F^2. Hydrogen atoms were included in calculated positions and refined in riding mode. Refinement converged at a final R = 0.0261 ($wR2$ = 0.0703, for all 736 data 82 parameters, mean and maximum δ/σ 0.000, 0.000), with allowance for the thermal anisotropy of all non-hydrogen atoms. Minimum and maximum final electron density −0.291 and 0.230 e Å^{-3}. A weighting scheme $w = 1/[\sigma^2(F_o^2) + (0.0439 * P)^2 + 0.230 * P]$ where $P = (F_o^2 + 2 * F_c^2)/3$ was used in the latter stages of refinement. Complex scattering factors were taken from the program package SHELXL93[38] as implemented on the Viglen 486DX computer.

(1*RS*, 3*RS*)-2-Bromo-1,3-dithiane 1,3-dioxide 5

trans-1,3-Dithiane 1,3-dioxide (500 mg, 3.3 mmol) was dissolved in dichloromethane (20 ml) under nitrogen with stirring and *N*-bromosuccinimide (880 mg, 4.9 mmol) was added to the solution. The reaction mixture was stirred at room temperature for 45 h after which it was evaporated *in vacuo*. Purification of the residue by flash column chromatography, eluting with 10% EtOH–EtOAc, yielded **5** (644 mg, 85%). An analytical sample was recrystallised from $CHCl_3$–light petroleum; R_f (10% EtOH–EtOAc) 0.16; mp 157–158 °C (Found: C, 20.65; H, 3.15; S, 27.75; Br, 34.7. $C_4H_7BrS_2O_2$ requires C, 20.8; H, 3.0; S, 27.7; Br, 34.6%); ν_{max}(KBr)/cm^{-1} 2980, 2950, 2930 (CH), 1030 and 1040 (SO); δ_H($CDCl_3$) 2.26 (1 H, dm, J_d 16.3, 5-H$_{eq}$), 2.75 (1 H, ddddd, J 16.3, 12.5, 11.5, 3.3, 2.9, 5-H$_{ax}$), 2.93 (1 H, dm, J_d 14.9, 4-H$_{eq}$), 3.09 (1 H, ddd, J 13.1, 11.5, 2.8, 6-H$_{ax}$), 3.15 (1 H, m, 6-H$_{eq}$), 3.36 (1 H, ddd, J 14.9, 12.5, 3.0, 4-H$_{ax}$) and 6.00 (1 H, t, J 1.5, 2-H); δ_C 14.8 (C-5), 41.0 (C-4), 46.5 (C-6) and 68.3 (C-2); *m/z* 232, 230 (M^+, 20, 19%), 136 (99), 103 (34), 90 (83), 87 (42) and 73 (100).

Crystal data for $C_4H_7BrO_2S_2$; M = 231.13, crystallises from dichloromethane as clear oblong shaped crystals; crystal dimensions 0.65 × 0.35 × 0.20 mm. Monoclinic, a = 7.917(9), b = 10.688(7), c = 9.427(5) Å, β = 106.04(5)° U = 766.6(11) Å^3, Z = 4, D_c = 2.003 Mg m^{-3}, space group $P2_1/n$ (a non-standard setting of $P2_1/_cC_2^5{}_h$, No. 14), Mo-Kα radiation ($\bar{\lambda}$ = 0.710 73 Å), μ(Mo-Kα) = 5.833 mm^{-1}, F(000) = 456.

Three-dimensional, room temperature X-ray data were collected in the range $3.5 < 2\theta < 45°$ on a Siemens P4 diffractometer by the omega scan method. Of the 1321 reflections measured, all of which were corrected for Lorentz and polarisation effects (but not for absorption), 759 independent reflections exceeded the significance level $|F|/\sigma(|F|) > 4.0$. The structure was solved by direct methods and refined by full matrix least-squares methods on F^2. Hydrogen atoms were included in calculated positions and refined in riding mode. Refinement converged at a final R = 0.0606 ($wR2$ = 0.1774 for all 932 data, 82 parameters, mean and maximum δ/σ 0.000, 0.000), with allowance for the thermal anisotropy of all non-hydrogen atoms. Minimum and maximum final electron density −0.713 and 0.903 e A^{-3}. A weighting scheme $w = 1/[\sigma^2(F_o^2) + (0.1202 * P)^2 + 0.00 * P]$ where $P = (F_o^2 + 2 * F_c^2)/3$ was used in the latter stages of refinement. Complex scattering factors were taken from the program package SHELXL93[38] as implemented on the Viglen 486DX computer.

SR-[(1*RS*,3*RS*)-2-Chloro-1,3-dioxo-1λ^4,3λ^4-dithian-2-yl]-phenylmethanol 6a

2-Chloro-1,3-dithiane dioxide **4** (150 mg, 0.80 mmol) was suspended in THF (6 ml) under nitrogen with stirring. The solu-

tion was cooled to 0 °C, and LiHMDS (1.0 M soln. in THF, 0.96 ml) was added to it. The mixture was then cooled to −78 °C and benzaldehyde (127 mg, 120 mmol) was added to it. After the mixture had been stirred at −78 °C for 3 h, it was transferred by syringe into a rapidly stirring mixture of ethanol (19.5 ml) and aqueous HCl (10 M; 0.5 ml). Evaporation of the mixture gave a crude product, found by ^{1}H NMR to contain **6a** and **7a** in the ratio 68:32. This was purified by flash chromatography using 5% EtOH–EtOAc as eluent, to afford **6a** as a white powder (98.7 mg, 42%); R_f (10% EtOH–EtOAc) 0.29; mp 60–62 °C; ν_{max}(KBr)/cm^{-1} 3400 (OH), 1495, 1630 (Ph), 1030 and 1060 (SO); δ_H($CDCl_3$) 2.26 (1 H, ddddd, *J* 15.7, 4.4, 4.3, 4.2, 2.5, 5-H$_{eq}$), 2.73–2.95 (2 H, overlapping m, 4-H$_{eq}$ and 5-H$_{ax}$), 3.22 (1 H, ddd, *J* 15.0, 13.5, 3.5, 4-H$_{ax}$), 3.27–3.37 (2 H, overlapping m, 6-H$_{eq}$ and 6-H$_{ax}$), 4.14 (1 H, s, OH), 6.10 (1 H, s, C*H*OH) 7.36 (3 H, m, ArH), 7.65 (2 H, m, ArH); δ_C 14.4 (C-5), 42.5 (C-4), 47.3 (C-6), 78.0 (C-OH), 90.5 (C-2), 128.2, 128.6, 129.6 and 134.3 (Ph) (Found: M$^+$, 293.9945 and 291.9998. $C_{11}H_{13}S_2O_3{}^{35}Cl$ requires 293.9965, $C_{11}H_{13}S_2O_3{}^{37}Cl$ requires 291.9995); *m*/*z* 294, 292 (M$^+$, 15, 36%), 186 (38), 154 (92), 105 (54) and 77 (100).

General procedure for the reaction of lithiated 2-chloro-1,3-dithiane dioxide 4 with aldehydes under equilibrating conditions

2-Chloro-1,3-dithiane dioxide (100 mg, 0.54 mmol) was suspended in THF (4 ml) under N_2 with stirring. The solution was cooled to 0 °C, and LiHMDS (1.0 M in THF; 0.59 ml, 1.1 equiv.) was added to it followed by the aldehyde (0.81 mmol, 1.5 equiv.). The mixture was stirred for 2 h at 0 °C, after which it was transferred by syringe into a rapidly stirred mixture of ethanol (19.5 ml) and aqueous HCl (10 M; 0.5 ml). Evaporation of the mixture gave a crude product from which the diastereoisomeric ratio **6**:**7** was determined by ^{1}H NMR spectroscopy.

RS-[(1*RS*,3*RS*)-2-Chloro-1,3-dioxo-1λ^4,3λ^4-dithian-2-yl]-phenylmethanol 7a

The crude product contained **6a** and **7a** in the ratio 8:92. Flash chromatography (5% EtOH–EtOAc) afforded **7a** (101 mg, 64.1%). An analytical sample was recrystallised from $CHCl_3$–light petroleum; R_f (10% EtOH–EtOAc) 0.22; mp 167–171 °C (Found: C, 45.0; H, 4.2; S, 21.7; Cl, 12.0. $C_{11}H_{13}ClS_2O_3$ requires C, 45.1; H, 4.4; S, 21.9; Cl, 12.1%); ν_{max}(KBr)/cm^{-1} 3230 (OH), 1495, 1630 (Ph), 1040 and 1070 (SO); δ_H($CDCl_3$) 2.28 (1 H, dm, J_d 15.9, 5-H$_{eq}$), 2.89 (1 H, ddddd, *J* 15.9, 13.0, 13.1, 2.9, 2.6, 5-H$_{ax}$) 2.95 (1 H, dm, J_d 15.0, 4-H$_{eq}$), 3.12 (1 H, ddd, *J* 15.0, 13.0, 3.1, 4-H$_{ax}$), 3.22 (1 H, ddd, *J* 13.1, 12.9, 2.3, 6-H$_{ax}$), 3.42 (1 H, dddd, *J* 12.9, 5.9, 2.6, 1.2, 6-H$_{eq}$), 4.58 (1 H, d, *J* 10.9, OH), 5.55 (1 H, d, *J* 10.9, C*H*OH), 7.42 (3 H, m, ArH) and 7.62 (2 H, m, ArH); δ_C 14.4 (C-5), 42.8 (C-4), 46.5 (C-6), 76.8 (C-OH), 90.1 (C-2), 128.3, 128.5, 129.2 and 135.1 (Ph); *m*/*z* 294, 292 (M$^+$, 10, 24%), 186 (39), 154 (67), 105 (71) and 77 (100).

Crystal data for $C_{11}H_{13}ClO_3S_2$; *M* = 292.78, crystallises from chloroform–light petroleum (bp 40–60 °C) clear oblong shaped crystals; crystal dimensions 0.85 × 0.40 × 0.25 mm. Monoclinic, *a* = 10.540(3), *b* = 7.656(2), *c* = 16.212(4) Å, *β* = 102.44(2)° *U* = 1277.5(6) Å^3, *Z* = 4, D_c = 1.522 Mg m^{-3}, space group $P2_1/n$ (a non-standard setting of $P2_1/_cC_2{}^5{}_h$, No. 14), Mo-K*α* radiation ($\bar{\lambda}$ = 0.710 69 Å), μ(Mo-K*α*) = 0.618 mm^{-1}, *F*(000) = 608.

Three-dimensional, room-temperature X-ray data were collected in the range 3.5 < 2*θ* < 40° on a Siemens P4 diffractometer by the omega scan method. Of the 1800 reflections measured, all of which were corrected for Lorentz and polarisation effects (but not for absorption), 1058 independent reflections exceeded the significance level |*F*|/*σ*(|*F*|) > 4.0. The structure was solved by direct methods and refined by full matrix least-squares on F^2. Hydrogen atoms were included in calculated positions and refined in riding mode. Refinement converged at a final *R* = 0.0299 (*wR*2 = 0.0853, for all 1195 data, 154 parameters, mean and maximum *δ*/*σ* 0.000, 0.000), with allowance for the thermal anisotropy of all non-hydrogen atoms. Minimum and maximum final electron density −0.183 and 0.181 e A^{-3}. A weighting scheme $w = 1/[\sigma^2(F_o^2) + (0.0565 * P)^2 + 0.27 * P]$ where $P = (F_o^2 + 2 * F_c^2)/3$ was used in the latter stages of refinement. Complex scattering factors were taken from the program package SHELXTL93[38] as implemented on the Viglen 486DX computer.

RS-[(1*RS*,3*RS*)-2-Chloro-1,3-dioxo-1λ^4,3λ^4-dithian-2-yl](4-nitrophenyl)methanol 7b

The crude product contained **6b** and **7b** in the ratio 18:82. Flash chromatography using 8% EtOH–EtOAc as eluent afforded **7b** (91.1 mg, 50.3%); R_f (10% EtOH–EtOAc) 0.23; decomposes 210–214 °C (Found: C, 39.4; H, 3.5; N, 4.1; S, 19.1; Cl, 10.5. $C_{11}H_{12}ClNS_2O_5$ requires C, 39.1; H, 3.6; N, 4.2; S, 19.0; Cl, 10.5%); ν_{max}(KBr)/cm^{-1} 3250 (OH), 1600, 1610 (Ar), 1510, 1350 (NO_2), 1030, 1045 and 1080 (SO); δ_H($CDCl_3$) 2.30 (1 H, dm, J_d 15.9, 5-H$_{eq}$), 2.85 (1 H, ddddd, *J* 15.9, 13.1, 12.9, 2.9, 2.6, 5-H$_{ax}$) 2.95 (1 H, dm, J_d 15.1, 4-H$_{eq}$), 3.14 (1 H, ddd, *J* 15.1, 12.9, 3.2, 4-H$_{ax}$), 3.23 (1 H, ddd, *J* 13.1, 12.9, 2.1, 6-H$_{ax}$), 3.43 (1 H, dddd, *J* 12.9, 5.9, 2.6, 1.1, 6-H$_{eq}$), 4.87 (1 H, d, *J* 9.4, OH), 5.67 (1 H, br d, *J* 9.4, C*H*OH), 7.82 (2 H, AA′BB′ system, J_{AB} 8.5, H_B) and 7.62 (2 H, AA′BB′ system, J_{AB} 8.5, H_A); δ_C(DMSO) 14.2 (C-5), 42.2 (C-4), 47.0 (C-6), 73.0 (C-OH), 92.9 (C-2), 122.9, 130.5, 146.0 and 147.8 (Ph); *m*/*z* 339, 337 (M$^+$, 12%), 237 (4), 199 (21), 186 (23), 151 (100), 122 (48), 90 (68) and 73 (95).

RS-[(1*RS*,3*RS*)-2-Chloro-1,3-dioxo-1λ^4,3λ^4-dithian-2-yl](4-methoxyphenyl)methanol 7c

The crude product contained **6c** and **7c** in the ratio 6:94. Flash chromatography using 5% EtOH–$CHCl_3$ as eluent afforded **7c** (83.4 mg, 48.2%); R_f (5% EtOH–$CHCl_3$) 0.24; mp 154–155 °C; ν_{max}(KBr)/cm^{-1} 3400 (OH), 1610, 1510 (Ar), 1050, 1070 (SO); δ_H($CDCl_3$) 2.28 (1 H, dm, J_d 15.8, 5-H$_{eq}$), 2.82 (1 H, m, 5-H$_{ax}$) 2.95 (1 H, dm, J_d 14.9, 4-H$_{eq}$), 3.12 (1 H, ddd, *J* 14.9, 13.0, 3.1, 4-H$_{ax}$), 3.20 (1 H, ddd, *J* 13.0, 12.9, 2.4, 6-H$_{ax}$), 3.41 (1 H, dddd, *J* 12.9, 5.7, 2.8, 1.0, 6-H$_{eq}$), 3.85 (3 H, s, OCH_3), 4.45 (1 H, d, *J* 10.4, OH), 5.52 (1 H, d, *J* 10.4, C*H*OH), 6.97 (2 H, A A′ B B′ system, J_{AB} 8.8, H_A) and 7.53 (2 H, A A′ B B′ system, J_{AB} 8.8, H_B); δ_C 14.4 (C-5), 42.8 (C-4), 46.5 (C-6), 55.3 (OMe), 76.6 (C-OH), 90.1 (C-2), 113.7, 126.8, 129.7 and 160.2 (Ph) (Found: M$^+$, 322.0091. $C_{12}H_{15}S_2O_4{}^{35}Cl$ requires 322.0100); *m*/*z* 324, 322 (M$^+$, 3, 7%), 186 (14), 137 (90), 135 (100) and 77 (37).

RS-[(1*RS*,3*RS*)-2-Chloro-1,3-dioxo-1λ^4,3λ^4-dithian-2-yl](3,4-dimethoxyphenyl)methanol 7d

The crude product contained **6d** and **7d** in the ratio 7:93. Flash chromatography using 10% EtOH–$CHCl_3$ as eluent afforded **7d** (72.4 mg, 38.3%); R_f (5% EtOH–$CHCl_3$) 0.19; mp 72–76 °C; ν_{max}(KBr)/cm^{-1} 3430 (OH), 1520 (Ar), 1020 and 1050 (SO); δ_H($CDCl_3$) 2.25 (1 H, dm, J_d 15.8, 5-H$_{eq}$), 2.79 (1 H, m, 5-H$_{ax}$) 2.95 (1 H, ddd, *J* 14.6, 3.6, 3.3, 4-H$_{eq}$), 3.05–3.24 (2 H, overlapping m, 4-H$_{ax}$ and 6-H$_{ax}$), 3.39 (1 H, ddd, *J* 12.8, 5.3, 2.5, 6-H$_{eq}$), 3.89 (3 H, s, OCH_3), 3.90 (3 H, s, OCH_3), 4.75 (1 H, br s, OH), 5.49 (1 H, br s, C*H*OH), 6.90 (1 H, d, *J* 7.5, Ar) and 7.13–7.18 (2 H, overlapping m, Ar); δ_C 14.8 (C-5), 43.2 (C-4), 46.5 (C-6), 56.0, 56.2 (OMe), 76.4 (C-OH), 110.7, 111.5, 121.2, 127.4, 148.7 and 149.7 (Ph); C-2 not observed (Found: M$^+$, 352.0209. $C_{13}H_{17}S_2O_5{}^{35}Cl$ requires 352.0206); *m*/*z* 354, 352 (M$^+$, 4, 9%), 186 (37), 166 (100) and 73 (96).

RS-[(1*RS*,3*RS*)-2-Chloro-1,3-dioxo-1λ^4,3λ^4-dithian-2-yl](4-chlorophenyl)methanol 7e

The crude product contained **6e** and **7e** in the ratio 6:94. Flash chromatography using 8% EtOH–EtOAc as eluent afforded **7e** as a white solid (116.6 mg, 65.8%); R_f (10% EtOH–EtOAc) 0.25; mp 104–106 °C (Found: C, 40.3; H, 3.8. $C_{11}H_{12}Cl_2S_2O_3$ requires C, 40.4; H, 3.7%); ν_{max}(KBr)/cm^{-1} 3200 (OH), 1490,

1595 (Ar), 1030 and 1055 (SO); $\delta_H(CDCl_3)$ 2.02 (1 H, dm, J_d 15.5, 5-H_{eq}), 2.57 (1 H, m, 5-H_{ax}) 2.75 (1 H, ddd, *J* 14.9, 3.2, 3.3, 4-H_{eq}), 2.85–3.05 (2 H, overlapping m, 4-H_{ax} and 6-H_{ax}), 3.13 (1 H, ddd, *J* 12.8, 5.9, 1.3, 6-H_{eq}), 5.34 (1 H, d, *J* 6.6, OH), 6.25 (1 H, d, *J* 6.6, C*H*OH), 7.14 (2 H, AA′BB′ system, J_{AB} 8.6, H_B) and 7.38 (2 H, AA′BB′ system, J_{AB} 8.6 H_A); δ_C 14.3 (C-5), 42.8 (C-4), 46.7 (C-6), 75.6 (C-OH), 90.8 (C-2), 128.3, 130.0, 134.4 and 135.0 (Ph); *m*/*z* 330, 328, 326 (M^+, 1, 4, 6%), 186 (48), 139 (71), 111 (35), 84 (80), 73 (57) and 66 (100).

_RS_-[(1_RS_,3_RS_)-2-Chloro-1,3-dioxo-1λ⁴,3λ⁴-dithian-2-yl]-naphthylmethanol 7f

The crude product contained **6f** and **7f** in the ratio 2:98. Flash chromatography using 10% EtOH–$CHCl_3$ as eluent yielded a mixture of **6f** and **7f** (120.6 mg, 64.2%); R_f (10% EtOH–$CHCl_3$) 0.54, from which **7f** (114 mg, 60.7%) was separated by recrystallisation; mp 109 °C; ν_{max}(KBr)/cm^{-1} 3350 (OH), 1510, 1600 (Ar), 1045 and 1055 (SO); $\delta_H(CDCl_3)$ 2.27 (1 H, dm, J_d 15.9, 5-H_{eq}), 2.74–2.98 (2 H, overlapping m, 5-H_{ax} and 4-H_{eq}) 3.09 (1 H, ddd, *J* 15.0, 13.4, 3.4, 4-H_{ax}), 3.22 (1 H, ddd, *J* 12.5, 13.1, 1.9, 6-H_{ax}), 3.42 (1 H, ddd, *J* 12.5, 5.0, 2.2, 6-H_{eq}), 4.81 (1 H, d, *J* 11.4, OH), 5.72 (1 H, d, *J* 11.4, C*H*OH), 7.52 (2 H, m, Ar), 7.24 (1 H, dd, *J* 7.8, 1.3, Ar) 7.84–7.93 (3 H, overlapping m, Ar) 8.10 (1 H, d, *J* 0.3, Ar); δ_C 14.3 (C-5), 42.8 (C-4), 46.5 (C-6), 76.7 (C-OH), 90.6 (C-2), 125.8, 126.5, 126.8, 127.7, 127.9, 128.3, 128.4 (naphthalene CH), 132.7, 132.9 and 133.6 (naphthalene quaternary C); *m*/*z* 344, 342 (M^+, 9, 18%), 254 (20), 226 (14), 186 (7), 156 (100), 155 (83) and 127 (79).

_RS_-[(1_RS_,3_RS_)-2-Chloro-1,3-dioxo-1λ⁴,3λ⁴-dithian-2-yl]-2-fufurylmethanol 7g

The crude product contained **6g** and **7g** in the ratio 11:89. Flash chromatography using 20% EtOH–$CHCl_3$ as eluent afforded **7g** (48.3 mg, 31.6%); R_f (20% EtOH–$CHCl_3$) 0.65; decomposes 138 °C; ν_{max}(KBr)/cm^{-1} 3220 (OH), 1050, 1055 and 1060 (SO); $\delta_H(CDCl_3)$ 2.29 (1 H, dm, J_d 15.8, 5-H_{eq}), 2.81 (1 H, ddddd, *J* 15.8, 12.7, 12.6, 3.2, 3.1, 5-H_{ax}), 3.01 (1 H, ddd, *J* 13.8, 3.5, 3.4, 4-H_{eq}), 3.12–3.29 (2 H, overlapping m, 4-H_{ax} and 6-H_{ax}), 3.40 (1 H, ddd, *J* 12.8, 6.3, 2.7, 6-H_{eq}), 4.38 (1 H, d, *J* 11.9, OH), 5.55 (1 H, d, *J* 11.9, C*H*OH), 6.45 (1 H, dd, *J* 3.8, 1.9, Ar), 6.59 (1 H, d, *J* 3.8, Ar) and 7.53 (1 H, d, *J* 1.9, Ar); δ_C 14.3 (C-5), 43.2 (C-4), 46.3 (C-6), 71.5 (C-OH), 90.0 (C-2), 110.6, 111.8, 118.2 and 148. 1 (Ar) (Found: M^+, 281.9788. $C_9H_{11}S_2O_4{}^{35}Cl$ requires 281.9787); *m*/*z* 284, 282 (M^+, 7, 16%), 186 (46), 144 (48), 96 (86), 95 (100) and 73 (55).

[(1_RS_,3_RS_)-2-Chloro-1,3-dioxo-1λ⁴,3λ⁴-dithian-2-yl]butylmethanol 6i and 7i

The crude product contained **6i** and **7i** in the ratio 51:49. Flash chromatography using 10% EtOH–EtOAc as eluent yielded an inseparable mixture of **6i** and **7i** (108.1 mg, 70.9%); R_f (10% EtOH–EtOAc) 0.27.

_RS_-[(1_RS_,3_RS_)-2-Chloro-1,3-dioxo-1λ⁴,3λ⁴-dithian-2-yl](1-methylethyl)methanol 7j

The crude product contained **6j** and **7j** in the ratio 43:57. Flash chromatography using 5% EtOH–$CHCl_3$ as eluent afforded **7j** (10.4 mg, 7.5%); R_f (10% EtOH–EtOAc) 0.22; mp 211–212 °C (Found: C, 37.15; H, 5.6; S, 24.7. $C_8H_{15}ClS_2O_3$ requires C, 37.1; H, 5.8; S, 24.8%); ν_{max}(KBr)/cm^{-1} 3250 (OH) and 1040 (SO); $\delta_H(CDCl_3)$ 1.17 (3 H, d, *J* 6.7, CH_3), 1.23 (3 H, d, *J* 6.6, CH_3), 2.25 (1 H, dm, *J* 15.6, 5-H_{eq}), 2.45 [1 H, dqn, J_d 3.9, J_{qn} 6.6, C*H*(CH_3)$_2$], 2.80 (1 H, ddddd, *J* 15.6, 13.1, 12.9, 2.9, 2.4, 5-H_{ax}), 3.04 (1 H, ddd, *J* 14.9, 2.9, 2.7, 4-H_{eq}), 3.15–3.42 (4 H, overlapping m, 6-H_{eq}, 6-H_{ax}, 4-H_{ax} and OH) and 4.35 (1 H, dd, *J* 11.3, 3.1, C*H*OH); δ_C 14.0 (C-5), 17.5 (CH_3), 22.4 (CH_3), 30.3 [*C*H(CH_3)$_2$], 42.6 (C-4), 46.1 (C-6) and 77.8 (C-OH); (C-2) not observed; *m*/*z* 260, 258 (M^+, 25, 57%), 217 (28), 215 (67), 122 (45), 90 (100) and 73 (85).

_RS_-[(1_RS_,3_RS_)-2-Bromo-1,3-dioxo-1λ⁴,3λ⁴-dithian-2-yl]phenylmethanol 9a

2-Bromo-1,3-dithiane dioxide **5** (100 mg, 0.43 mmol) was dissolved in THF (4 ml) under N_2 with stirring. The solution was cooled to 0 °C, and Bu^{t}MgCl (1.0 M soln. in THF; 0.52 ml) followed by benzaldehyde (66 μl, 69 mg, 0.65 mmol) were added to it. The mixture was stirred for 15 h at 0–5 °C and then transferred by syringe to a rapidly stirred solution of HCl in water (0.2 M; 10 ml). The mixture was extracted with CH_2Cl_2 (4 × 10 ml) and the combined extracts were dried (Na_2SO_4) and evaporated under reduced pressure. A ^{1}H NMR spectrum of the crude product indicated a mixture of **8a** and **9a** in the ratio 3:97. Flash chromatography using 8% EtOH–EtOAc as eluent afforded **9a** (27.4 mg, 18.8%). An analytical sample was recrystallised from CH_2Cl_2–light petroleum R_f (10% EtOH–EtOAc) 0.28; decomposes 165 °C (Found: C, 39.4; H, 4.1; S, 19.2; Br, 23.7. $C_{11}H_{13}S_2O_3Br$ requires C, 39.2; H, 3.9; S, 19.0; Br, 23.7%); ν_{max}(KBr)/cm^{-1} 3220 (OH), 1490 (Ph), 1060, 1040 and 1025 (SO); $\delta_H(CDCl_3)$ 2.26 (1 H, dm, J_d 15.9, 5-H_{eq}), 2.83 (1 H, dtdd, *J* 15.9, 13.1, 2.8, 2.6, 5-H_{ax}), 2.99 (1 H, ddd, *J* 15.1, 3.9, 2.8, 4-H_{eq}), 3.17 (1 H, td, *J* 13.2, 2.2, 6-H_{ax}), 3.33 (1 H, ddd, *J* 15.1 13.2, 2.5, 4-H_{ax}), 3.38 (1 H, overlapping m, 6-H_{eq}), 4.78 (1 H, d, *J* 10.3, OH), 5.64 (1 H, d, *J* 10.3, C*H*OH), 7.39–7.45 (3 H, m, ArH) and 7.62–7.68 (2 H, m, ArH); δ_C 14.7 (C-5), 43.1 (C-4), 47.8 (C-6), 77.4 (C-OH), (C-2) not observed, 128.2, 128.9, 129.3 and 135.4 (Ph); *m*/*z* 338, 336 (M^+, 6, 6%), 232, 230 (15, 14), 200, 198 (25, 26), 105 (61) and 77 (100).

Crystal data for $C_{11}H_{13}BrO_3S_2$; *M* = 337.24, crystallises from acetone as colourless blocks; crystal dimensions 0.55 × 0.43 × 0.31 mm. Monoclinic, *a* = 10.600(3), *b* = 7.643(2), *c* = 16.228(5) Å, *β* = 101.86(2)° *U* = 1286.7(6) Å^3, *Z* = 4, D_c = 1.741 Mg m^{-3}, space group $P2_1/_c$ ($C_2{}^5{}_h$, No. 14), Mo-K*α* radiation ($\bar{\lambda}$ = 0.710 73 Å), μ(Mo-K*α*) = 3.512 mm^{-1}, *F*(000) = 680.

Three-dimensional, room-temperature X-ray data were collected in the range $3.5 < 2\theta < 45°$ on a Siemens P4 diffractometer by the omega scan method. Of the 2359 reflections measured, all of which were corrected for Lorentz and polarisation effects (but not for absorption), 1542 independent reflections exceeded the significance level $|F|/\sigma(|F|) > 4.0$. The structure was solved by direct methods and refined by full matrix least-squares methods on F^2. Hydrogen atoms were included in calculated positions and refined in riding mode. Refinement converged at a final $R = 0.0582$ ($wR2 = 0.1494$ for all 1679 reflections, 154 parameters, mean and maximum δ/σ 0.000, 0.000), with allowance for the thermal anisotropy of all non-hydrogen atoms. Minimum and maximum final electron density −1.406 and 1.613 e Å^{-3}. A weighting scheme $w = 1/[\sigma^2(F_o{}^2) + (0.1143 * P)^2 + 0.6289 * P]$ where $P = (F_o{}^2 + 2 * F_c{}^2)/3$ was used in the latter stages of refinement. Complex scattering factors were taken from the program package SHELXL93[38] as implemented on the Viglen 486DX computer.

(2_RS_,4_RS_)-4,8-Dioxo-2-phenyl-1-oxa-4λ⁴,8λ⁴-dithiaspiro[2.5]-octane 11a and 1,2-dithiolane 1-oxide 12

2-Bromo-1,3-dithiane dioxide **5** (100 mg, 0.43 mmol) was dissolved in THF (4 ml) under N_2 with stirring. The solution was cooled to 0 °C, and NaHMDS (1.0 M soln in THF; 0.48 ml) followed by benzaldehyde (66 μl, 69 mg, 0.65 mmol) were added to it. The mixture was stirred for 4 h at 0 °C and then transferred by syringe to a rapidly stirred solution of HCl in water (0.2 M; 10 ml). The mixture was extracted with CH_2Cl_2 (4 × 10 ml) and the combined extracts were dried (Na_2SO_4) and evaporated. Flash chromatography of the residue using 8% EtOH–EtOAc as eluent afforded 1,2-dithiolane 1-oxide **12** (15.2 mg, 28.8%); R_f (10% EtOH–EtOAc) 0.36; $\delta_H(CDCl_3)$ 2.83–2.98 (3 H, m), 3.23–3.34 (1 H, m) 3.57–3.63 (1 H, m), 3.69–3.77 (1 H, m) [lit.,[39] δ_H 2.85–3.00 (3 H, m), 3.25–3.38 (1 H, m) 3.60–3.66 (1 H, m) and 3.72–3.80 (1 H, m)]; δ_C 29.9, 38.2 and 63.4 (lit.,[40] δ_C 29.98, 38.28 and 63.65).

Further elution afforded the epoxide **11a** (16.4 mg, 14.8%). An analytical sample was recrystallised from CH_2Cl_2–light petroleum; R_f (10% EtOH–EtOAc) 0.26; mp 116–118 °C (Found: C, 51.3; H, 4.8; S, 25.0. $C_{11}H_{12}S_2O_3$ requires C, 51.5; H, 4.7; S, 25.0%); ν_{max}(KBr)/cm^{-1} 2930, 2960 (CH), 1050, 1055, 1060 and 1075 (SO); δ_H($CDCl_3$) 2.25–2.45 (2 H, overlapping m, 5-H_{eq} and 5-H_{ax}), 2.85–3.06 (3 H, overlapping m, 4-H_{eq}, 4-H_{ax} and 6-H_{ax}), 3.78 (1 H, m, 6-H_{eq}), 4.87 (1 H, s, 7-H) and 7.38–7.45 (5 H, overlapping m, Ph); δ_C 14.2 (C-5), 47.4 (C-4), 53.7 (C-6), 55.3 (C-7), 87.9 (C-2), 126.2, 128.9, 129.6 and 129.6 (Ph); *m*/*z* 256 (M^+, 12%), 240 (51), 122 (24), 118 (100) and 90 (59).

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