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Highly Chemoselective Osmium-Mediated Dihydroxylation of 2-Vinyl and 2-Allyl-1,3-dithiane 1-Oxides

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Abstract: Chemoselective dihydroxylation of the double bonds of alkenyl-substituted 1,3-dithiane 1-oxide derivatives takes place without competing sulfur oxidation using osmium trichloride and potassium ferricyanide.

Introduction

The osmium mediated *cis*-dihydroxylation of olefins is an important and widely used synthetic tool. In either stoicheiometric [1] or catalytic [2] mode it is the reaction of choice for converting alkenes to *cis*-1,2-diols. The most synthetically useful asymmetric version is the Sharpless system using catalytic osmium tetroxide and chiral alkaloid ligands.[3]

1,3-Dithiane 1-oxide (DiTOX) derivatives can act as combined chiral auxiliaries and asymmetric building blocks. Previously we have shown that 2-acyl substituted derivatives undergo a variety of transformations with up to excellent diastereoselectivities.[4] Asymmetric sulfur oxidation allows access to both diastereoisomers of the acyl dithiane unit with excellent enantioselectivities.[5] A chelation control model of these systems allows us to predict the stereochemical outcome of many of the reaction types studied to date. We are also interested in the potential degree of stereoselectivity attainable in reactions of non-acyl DiTOX derivatives, and, as a result, in the problem of chemoselective alkene oxidation in the presence of sulfide and sulfoxide moieties in these thioacetal monosulfoxide systems.

We report here our investigations into the osmium-catalysed *cis*-dihydroxylation of 2-vinyl, 2-allyl, and 2-alkenoyl 1,3-dithiane 1-oxide derivatives.

Substrate Preparation

A variety of 2-alkenyl and 2-alkenoyl-1,3-dithianes was prepared as described below.[6]

2-Allyl derivatives

Substrates **2a-e** and **3a-e** were constructed according to scheme 1. Generation of 2,2-disubstituted dithianes **1a-d** was accomplished through a one-pot deprotonation, alkylation, deprotonation, allylation sequence at low temperature, using butyllithium as base, **1e** was prepared from 2-phenyl-1,3-dithiane by deprotonation and treatment with allyl bromide. Oxidation of each of

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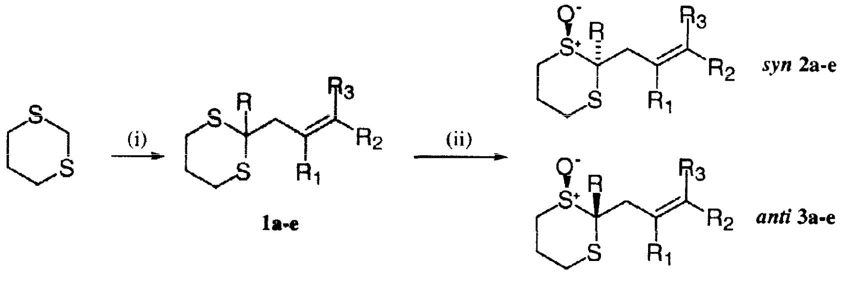
1a-e with sodium metaperiodate proceeded smoothly to give *syn* **2a-e** and *anti* **3a-e** diastereoisomers (Table I), which were separable by flash column chromatography.



i) *n*-BuLi (1.1 eq), THF, –20 °C, 1 h; RI, –20 °C to rt, 1 h; *n*-BuLi (1.1 eq), –20 °C, 1 h; $R_2R_3C{=}C(R_1)CH_2Br$, –20 °C to rt.
ii) $NaIO_4$ (1.1 eq), MeOH/H_2O, 0 °C, 16 h.

Scheme 1

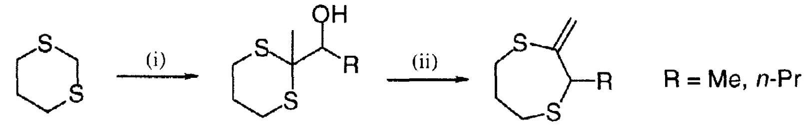
Table I Preparation of 2-Allyl-1,3-dithiane 1-Oxides

entry	R	R_1	R_2	R_3	yield 1/%	yield 2+3/%
a	Me	H	H	H	98	77
b	Me	Me	H	H	53	81
c	Me	H	Me	Me	71	84
d	Et	H	H	H	89	78
e	Ph	H	H	H	89†	74

† prepared from 2-phenyl-1,3-dithiane

2-Vinyl derivatives

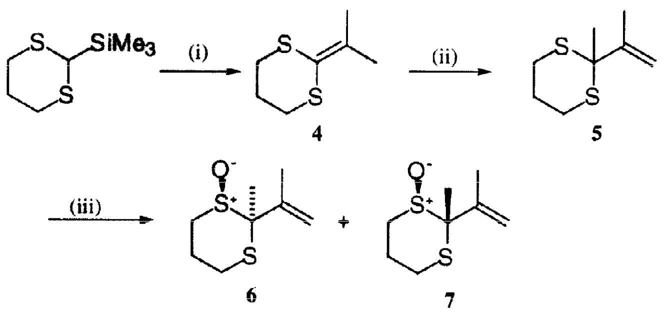
Initial attempts to prepare 2-vinyl substrates by elimination from 2-(1-mesyloxy)-1,3-dithianes resulted in rearrangement giving 2-methylene-1,4-dithiepanes (Scheme 2).[7]



(i) *n*-BuLi, (1.1 eq), THF, –20 °C, 1 h; MeI (1.1 eq), –20 °C to rt, 1 h; *n*-BuLi, (1.1 eq), –20 °C, 1 h; RCHO, (1.1 eq), –20 °C to rt, 1 h.
(ii) Et_3N (1.1 eq), THF, 0 °C, 0.5 h; MsCl (1.1 eq), 0 °C to rt, 1 h; Et_3N (1.1 eq), rt, 24-48 h.

Scheme 2

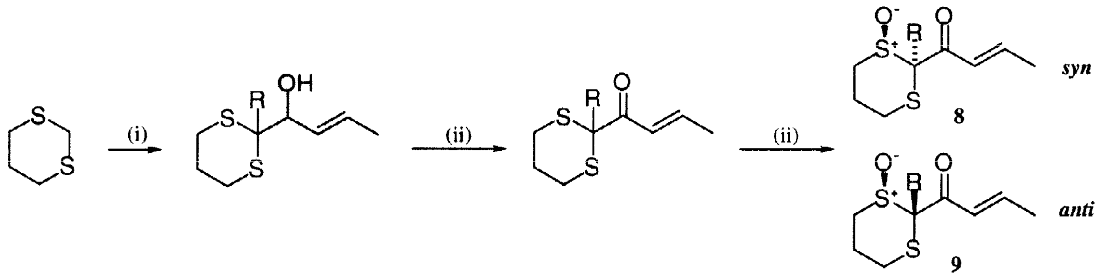
The successful synthesis of potential substrates **6** and **7** is shown in scheme 3. Treatment of 2-trimethylsilyl-1,3-dithiane with butyllithium at low temperature followed by condensation with acetone according to the method of Seebach gave ketene thioacetal **4** in excellent yield.[8] Methylation at the 2-position of **4** wth deconjugation of the double bond by deprotonation and treatment with methyl iodide in the presence of HMPA gave vinyl dithiane **5**. Finally, oxidation with sodium metaperiodate gave a 1:6 ratio of the *syn* **6** and *anti* **7** diastereoisomers, which were separated by chromatography.



i) n-BuLi, (1.1 eq), THF, –78 °C to 0 °C, 5 h; $(Me)_2CO$, –78 °C to rt, 16 h; H_2O (91%).
ii) n-BuLi (1.1 eq), THF/HMPA, –78 °C to rt, 2.5 h; MeI (1.1 eq), –78 °C, 1 h (66%).
iii) $NaIO_4$ (1.1 eq), $MeOH/H_2O$, 0 °C, 16 h (70%).
Scheme 3

2-Alkenoyl derivatives

Alkenoyl substrates *syn* **8** and *anti* **9** were prepared according to the literature procedure by deprotonation of the 2-alkyl dithiane and addition of the anion to crotonaldehyde. The resulting allylic alcohols were oxidized to the corresponding enones using manganese dioxide, and finally oxidized at sulfur with MMPP (Scheme 4). [9]



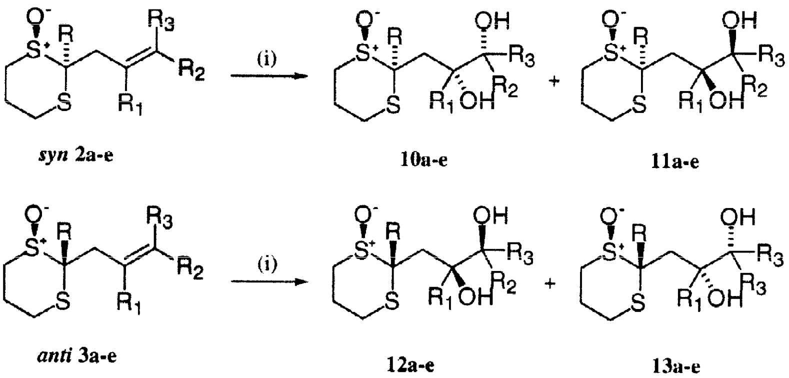
i) n-BuLi (1.1 eq), THF, –78° C, 1 h; RI, –78° C to rt, 2 h; n-BuLi (1.1 eq), –78°, 3 h;
$CH_3CH{=}CHCHO$, –78° C to rt, 16 h;
ii) MnO_2 (15 eq), CH_2Cl_2, rt; ii) MMPP (1.05 eq), $MeOH/CH_2Cl_2$, rt
Scheme 4

Oxidation Reactions

Initially, *cis*-dihydroxylation reactions were attempted with **3a** as substrate using catalytic osmium tetroxide/NMO in aqueous acetone.[2] As we had feared, concomitant oxidation to disulfoxide and to sulfoxide/sulfone in addition to dihydroxylation was observed, leading to a complex mixture of products. Solladié and Hauser have both observed oxidation to sulfones in unsaturated systems containing sulfoxides using this method.[10] More recently, catalytic osmium tetroxide/NMO has been used as a mild, selective method of conversion of sulfides to sulfones, even in the presence of alkenes.[11] It is therefore most interesting that osmium reagents are also among the very few oxidants able in some cases to oxidize an alkene in the presence of a sulfur atom without causing oxidation at sulfur: Sharpless has found his asymmetric dihydroxylation process to be remarkably selective for alkene double bonds in the presence of sulfides.[12] Warren has published a non-enantioselective modification of the reaction using osmium trichloride hydrate and potassium ferricyanide, which induces dihydroxylation of a range of olefins chemoselectively without oxidation of sulfide units in the substrate molecules.[13]

2-Allyl derivatives

We first investigated oxidation of the allyl DITOX derivatives *syn* **2a-e** and *anti* **3a-e**. *cis*-Dihydroxylation under the conditions of Warren at room temperature gave diastereoisomeric mixtures of the 1,2-diols in excellent yields and with no trace of oxidation at either sulfide or sulfoxide units, albeit with low stereoselectivity (Scheme 5, Table II).



(i) $OsCl_3$ (1 mol%), quinuclidine (4 mol%), $K_3Fe(CN)_6$ (3 eq), K_2CO_3 (3 eq), $MeSO_2NH_2$ (1 eq),‡ $^tBuOH/H_2O$ (1:1), rt, 2-24 h; $Na_2S_2O_3$
‡ Included only for non-terminal alkenes
Scheme 5

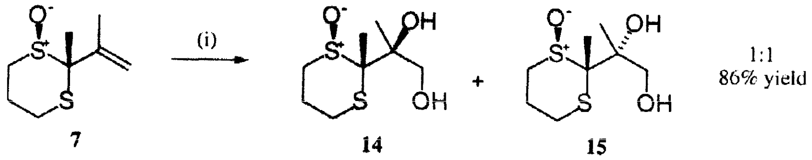
Table II Dihydroxylation of 2-Allyl-1,3-dithiane 1-Oxides

Entry	substrate	R	R_1	R_2	R_3	Ratio (10:11)[14]	yield (10+11)/%
1	*syn* 2a	Me	H	H	H	1.5:1	86
2	*syn* 2b	Me	Me	H	H	2.1:1	92
3	*syn* 2c	Me	H	Me	Me	2.2:1	89
4	*syn* 2d	Et	H	H	H	1.3:1	82
5	*syn* 2e	Ph	H	H	H	1.4:1	82
						Ratio (12:13)[14]	**yield (12+13)/%**
6	*anti* 3a	Me	H	H	H	1.5:1	85
7	*anti* 3b	Me	Me	H	H	1:1	88
8	*anti* 3c	Me	H	Me	Me	1.1:1	87
9	*anti* 3d	Et	H	H	H	1:1	80
10	*anti* 3e	Ph	H	H	H	1.7:1	80

Interestingly, reaction times in these systems were much shorter (<12 hours) than those reported by Warren for a variety of systems (96 hours).[13] Attempts to increase diastereoselectivities by reducing reaction temperatures or altering reaction times were unsuccessful.

2-Vinyl derivatives

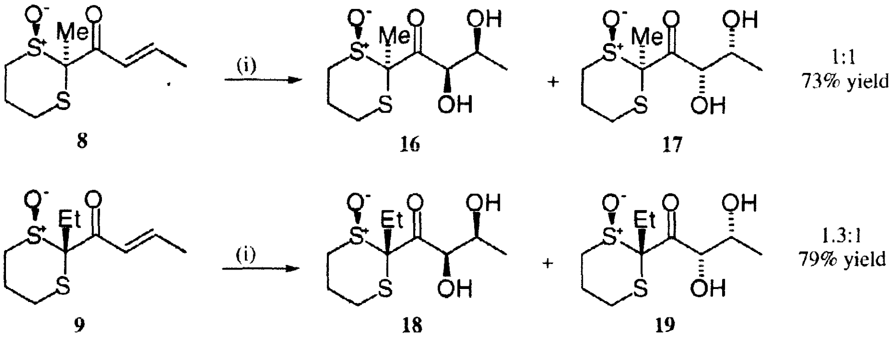
Dihydroxylation of **7** under identical conditions again gave a good yield of the diols, again with no trace of sufur oxidation; however, no diastereoselectivity was observed, **14** and **15** being formed in *ca* 1:1 ratio, as an inseparable mixture (Scheme 6). Attempted *cis*-dihydroxylation of the monosulfoxide derived from **4** was unsuccessful.



(i) $OsCl_3$ (1 mol%), quinuclidine (4 mol%), $K_3Fe(CN)_6$ (3 eq), K_2CO_3 (3 eq), $^tBuOH/H_2O$ (1:1), rt, 12 h; $Na_2S_2O_3$
Scheme 6

2-Alkenoyl derivatives

Finally, dihydroxylation of α,β-unsaturated systems **8** and **9** was undertaken (Scheme 7). These reactions, with electron-deficient substrates, were considerably faster than the others investigated, with completion times as low as two hours. Although the yields of the major isomers and the chemoselectivities of the reactions remained consistently high, diastereoselectivities were again low. The structure of 19 was confirmed by single crystal X-ray analysis.



(i) $OsCl_3$ (1 mol%), quinuclidine (4 mol%), $K_3Fe(CN)_6$ (3 eq), K_2CO_3 (3 eq), $MeSO_2NH_2$ (1 eq), $^tBuOH/H_2O$ (1:1), rt, 2-24 h; $Na_2S_2O_3$
Scheme 7

Conclusions

We have shown that osmium trichloride hydrate mediated dihydroxylation in alkenyl 1,3-dithiane systems proceeds in high yields and with remarkably high chemoselectivity, no concomitant sulfur oxidation being observed. Diastereocontrol in the reactions is low in all cases.

Acknowledgments

This investigation has enjoyed the support of the EPSRC and SmithKline Beecham Pharmaceuticals Ltd. We are indebted to the EPSRC service at Cardiff for single crystal X-ray structure determination.

Experimental Section

General experimental details have been previously reported.[15] Additional details:

Purification of Solvents

Methanol was distilled from magnesium. Dichloromethane and ^{t}butanol were used as supplied.

Procedures

2-Methyl-2-allyl-1,3-dithiane (1a)

A 2.4 M solution of ^{n}butyllithium in hexanes (1.1 eq, 38.2 mL, 91.7 mmol) was added to a stirring solution of 1,3 dithiane (10.0g, 83.3 mmol) in THF (200 mL) at –20 °C. After 1 hour methyl iodide (1.1 eq, 5.71 mL, 91.7 mmol) was added and the solution allowed to reach room temperature over

1 hour before recooling to −20 °C prior to further addition of a 2.4 M solution of ^{n}butyllithium in hexanes (1.1 eq, 38.2 mL, 91.7 mmol). The reaction mixture was stirred at this temperature for 1 hour, cooled to −20 °C and allyl bromide (1.1 eq, 7.93 mL, 91.6 mmol) added. The reaction mixture was allowed to reach room temperature over 2 hours. Normal work-up procedure gave **1a** as a pale orange oil (14.2g, 98%), ν_{max} (film) 3074 and 1637 cm^{-1}; δ_H (270 MHz, $CDCl_3$) 1.66 (3H, s), 1.98-2.08 (2H, m), 2.76 (2H, d, *J* = 7.2 Hz), 2.85-3.02 (4H, m), 5.18-5.24 (2H, m), 5.90-6.02 (1H, m); *m/z* 175.06142 (M+H$^+$); $C_8H_{15}S_2$ requires 175.06152.

2-Methyl-2-(3-(2-methyl-prop-1-ene))-1,3-dithiane (1b)

A 2.4 M solution of ^{n}butyllithium in hexanes (1.1 eq, 21.0 mL, 50.4 mmol) was added to a stirring solution of 1,3 dithiane (5.5g, 45.8 mmol) in THF (100 mL) at −20 °C. After 1 hour methyl iodide (1.1 eq, 3.14 mL, 50.4 mmol) was added and the solution allowed to reach room temperature over 1 hour before recooling to -20 °C prior to further addition of a 2.4 M solution of ^{n}butyllithium in hexanes (1.1 eq, 3.14 mL, 50.4 mmol). The reaction mixture was stirred at this temperature for 1 hour, cooled to −20 °C and 3-bromo-2-methyl propene (1.1 eq, 5.08 mL, 50.4 mmol) added. The reaction mixture was allowed to reach room temperature overnight. Normal work-up procedure and column chromatography using 10% ethyl acetate/ petroleum ether as eluent gave **1b** as a colourless, clear oil (4.60g, 53%), ν_{max} (film) 3073 and 1640 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.68 (3H, s), 1.92 (3H, s), 1.91-2.04 (2H, m), 2.69 (2H, s), 2.86-2.92 (4H, m), 4.82-4.85 (1H, m), 4.96-5.00 (1H, m); *m/z* 188.06928 (M$^+$), $C_9H_{16}S_2$ requires 188.06934.

2-Methyl-2-(1-(3-methyl-but-2-ene))-1,3-dithiane (1c)

A 2.4 M solution of ^{n}butyllithium in hexanes (1.1 eq, 19.1 mL, 45.8 mmol) was added to a stirring solution of 1,3 dithiane (5g, 41.7 mmol) in THF (100 mL) at −20 °C. After 1 hour methyl iodide (1.1 eq, 2.85 mL, 45.8 mmol) was added and the solution allowed to reach room temperature over 1 hour before recooling to -20 °C prior to further addition of a 2.4 M solution of ^{n}butyllithium in hexanes (1.1 eq, 19.1 mL, 45.8 mmol). The reaction mixture was stirred at this temperature for 1 hour, cooled to −20 °C and 4-bromo-2-methyl-2-butene (1.1 eq, 5.28 mL, 45.8 mmol) added. The reaction mixture was allowed to reach room temperature overnight. Normal work-up procedure and column chromatography using 10% ethyl acetate/petroleum ether as eluent gave **1c** as a colourless, clear oil (5.98g, 71%), ν_{max} (film) 1673 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.60 (3H, s), 1.66 (3H, s), 1.76 (3H, s), 1.91-2.03 (2H, m), 2.60-2.64 (2H, s), 2.83-2.89 (4H, m), 5.23-5.32 (1H, m); *m/z* 202.08535 (M$^+$), $C_{10}H_{18}S_2$ requires 202.08499.

2-Ethyl-2-allyl-1,3-dithiane (1d)

A 2.4 M solution of ^{n}butyllithium in hexanes (1.1 eq, 19.1 mL, 45.8 mmol) was added to a stirring solution of 1,3 dithiane (5g, 41.7 mmol) in THF (100 mL) at −20 °C. After 1 hour ethyl iodide (1.1 eq, 3.67 mL, 45.8 mmol) was added and the solution allowed to reach room temperature over 1 hour before recooling to −20 °C prior to further addition of a 2.4 M solution of ^{n}butyllithium in hexanes (1.1 eq, 19.1 mL, 45.8 mmol). The reaction mixture was stirred at this temperature for 1 hour, cooled to -20 °C and allyl bromide (1.1 eq, 3.97 mL, 45.8 mmol) added. The reaction mixture was allowed to reach room temperature over 4 hours. Normal work-up procedure and column chromatography using 10% ethyl acetate/ petroleum ether as eluent gave **1d** as a colourless, clear oil (6.97g, 89%), ν_{max} (film) 3076 and 1637 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.01 (3H, t, J = 7.4 Hz), 1.92 (2H, q, J = 7.4 Hz), 1.89-2.05 (1H, m), 2.66 (2H, d, J = 7.1 Hz), 2.79-2.90 (5H, m), 5.11-5.19 (2H, m), 5.78-5.99 (1H, m); *m/z* 188.06946 (M$^+$), $C_9H_{16}S_2$ requires 188.06934.

2-Phenyl-2-allyl-1,3-dithiane (1e)

A 2.4 M solution of ^{n}butyllithium in hexanes (1.1 eq, 11.7 mL, 28.1 mmol) was added to a stirring solution of 2-phenyl-1,3 dithiane (5.0g, 25.5 mmol) in THF (100 mL) at –20 °C. After 1 hour allyl bromide (1.1 eq, 2.49 mL, 28.1 mmol) was added and the solution allowed to reach room temperature over 2 hours. Normal work-up procedure and recrystallization from petroleum ether gave **1e** as a yellow, crystalline solid (6.97g, 89%), m.p. 40-42 °C; ν_{max} (Nujol) 3057 and 1638 cm^{-1}; δ_H(200 MHz, $CDCl_3$) 1.86-1.99 (2H, m), 2.66-2.76 (4H, m), 4.99-5.01 (1H, m), 5.07 (1H, s), 5.51-5.71 (1H, m), 7.22-7.42 (3H, m), 7.89-7.95 (2H, m); *m/z* 236.06962 (M^+), $C_{13}H_{16}S_2$ requires 236.06934. Calc for $C_{13}H_{16}S_2$: C, 66.04; H, 6.82. Found: C, 65.85; H, 6.93%.

General procedure for sulfoxidation

An aqueous solution of sodium metaperiodate (1.1 eq) was added dropwise to a stirring solution of sulfide in methanol at 0 °C over 30 minutes. Stirring was continued overnight at 0 °C, and the solution allowed to reach room temperature over 30 minutes. The white precipitate was removed by filtration and washed with dichloromethane. The filtrate was reduced in volume by evaporation to approximately 10% of the original volume and partitioned between water and dichloromethane. The aqueous layer was washed twice with dichloromethane, the combined organic layers dried over $MgSO_4$ and the solvents removed under reduced pressure to yield a crude mixture of diastereoisomeric sulfoxides, separated by column chromatography using ethyl acetate as eluent.

Syn and *anti*-2-methyl-2-allyl-1,3-dithiane 1-oxides (2a & 3a)

Treatment of **1a** (14.2g, 81.6 mmol) as described above with sodium metaperiodate (19.2g, 89.8 mmol) in water (200 mL) and methanol (300 mL) furnished the diastereoisomeric sulfoxides. Partial separation by column chromatography yielded both the less polar *syn* (**2a**) and more polar *anti* (**3a**) diastereoisomers as pale yellow oils (12.0g, 77%).

For *syn* **2a**: ν_{max} (film) 3075, 1638 and 1034 cm^{-1}; δ_H (270 MHz, $CDCl_3$) 1.59 (3H, s), 2.22-2.36 (1H, m), 2.44-2.56 (2H, m), 2.70-2.95 (3H, m), 2.79 (1H, d, J = 7.2 Hz), 3.06-3.15 (1H, m), 5.30-5.38 (2H, m), 5.92-6.07 (1H, m); *m/z* 190.0486 (M^+), $C_8H_{14}OS_2$ requires 190.0486.

For *anti* **3a**: ν_{max} (film) 3081, 1638 and 1033 cm^{-1}; δ_H (270 MHz, $CDCl_3$) 1.67 (3H, s), 2.16-2.33 (1H, m), 2.38-2.51 (2H, m),2.71 (2H, d, J = 7.2 Hz), 2.73-2.83 (2H, m), 3.06-3.14 (1H, m), 5.23-5.30 (2H, m), 5.86-6.01 (1H, m); δ_C (68 MHz, $CDCl_3$) 13.8, 24.7, 28.4, 42.1, 46.2, 61.2, 120.2, 130.4; *m/z* 190.0486 (M^+), $C_8H_{14}OS_2$ requires 190.0486.

Syn and *anti*-2-methyl-2-(3-(2-methyl-prop-1-enyl))-1,3-dithiane 1-oxide (2b & 3b)

Treatment of **1b** (4.50g, 23.9 mmol) as described above with sodium metaperiodate (5.63g, 26.3 mmol) in water (20 mL) and methanol (150 mL) furnished the diastereoisomeric sulfoxides. Partial separation by column chromatography yielded the less polar *syn* (**2b**) diastereoisomer as a colourless crystalline solid and the more polar *anti* (**3b**) diastereoisomer as a colourless, clear oil (3.97g, 81%).

For *syn* **2b**: m.p. 76-78 °C, ν_{max} (Nujol) 3073, 1642 and 1034 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.51 (3H, s), 1.96 (3H, s), 2.21-2.46 (3H, m), 2.60-2.86 (4H, m), 2.96-3.03 (1H, m), 4.92 (1H, s), 5.02-5.04 (1H, m); *m/z* 204.06445 (M^+); $C_9H_{16}OS_2$ requires 204.06425. Calc for $C_9H_{16}OS_2$: C, 52.90; H, 7.89. Found: C, 52.81; H, 7.92%.

For *anti* **3b**: ν_{max} (film) 3074, 1642 and 1035 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.64 (3H, s), 1.90 (3H, s), 2.09-2.46 (3H, m), 2.62-2.82 (4H, m), 3.01-3.11 (1H, m), 4.89-4.91 (1H, m), 5.01-5.04 (1H, m); *m/z* 204.06445 (M^+); $C_9H_{16}OS_2$ requires 204.06425.

Syn and *anti*-2-methyl-2-(1-(3-methyl-but-2-enyl))-1,3-dithiane 1-oxide (2c & 3c)

Treatment of **1c** (4.10g, 19.7 mmol) as described above with sodium metaperiodate (4.77g, 22.3 mmol) in water (50 mL) and methanol (300 mL) furnished the diastereoisomeric sulfoxides. Partial separation by column chromatography yielded the less polar *syn* (**2c**) diastereoisomer as a colourless, clear oil and the more polar *anti* (**3c**) diastereoisomer as a colourless crystalline solid

(3.74g, 84%).
For *syn* **2c**: ν_{max} (film) 1672 and 1034 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.49 (3H, s), 1.70 (3H, s), 1.79 (3H, s), 2.05-3.07 (8H, m), 5.24-5.33 (1H, m); *m/z* 218.08023 (M$^+$), $C_{10}H_{18}OS_2$ requires 218.07991.
For *anti* **3c**: m.p. 62-64 °C; ν_{max} (Nujol) 1672 and 1021 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.61 (3H, s), 1.66 (3H, s), 1.76 (3H, s), 2.05-2.44 (3H, m), 2.50-2.78 (4H, m), 2.99-3.10 (1H, m), 5.02-5.31 (1H, m); *m/z* 204.06445 (M$^+$), $C_{10}H_{18}OS_2$ requires 204.06425.

Syn and *anti*-2-ethyl-2-allyl-1,3-dithiane 1-oxide (2d & 3d)

Treatment of **1d** (6.80g, 36.2 mmol) as described above with sodium metaperiodate (8.50g, 39.7 mmol) in water (50 mL) and methanol (200 mL) furnished the diastereoisomeric sulfoxides. Separation by column chromatography yielded both the less polar *syn* (**2d**) and more polar *anti* (**3d**) diastereoisomers as colourless, clear oils.
For *syn* **2d**: (2.74g, 37%), ν_{max} (film) 3077, 1636 and 1033 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.11 (3H, t, J = 7.4 Hz), 1.75-2.27 (3H, m), 2.36-2.48 (2H, m), 2.60-2.91 (4H, m), 3.02-3.19 (1H, m), 5.23-5.32 (2H, m), 5.84-6.05 (1H, m); *m/z* 204.06445 (M$^+$), $C_9H_{16}OS_2$ requires 204.06425.
For *anti* **3d**: (3.02g, 41%), ν_{max} (film) 3078, 1638 and 1036 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.11 (3H, t, J = 7.4 Hz), 1.88-2.23 (3H, m), 2.36-2.43 (2H, m), 2.49-2.92 (4H, m), 3.00-3.07 (1H, m), 5.19-5.32 (2H, m), 5.87-6.08 (1H, m); *m/z* 204.06426 (M$^+$), $C_9H_{16}OS_2$ requires 204.06425.

Syn and *anti*-2-phenyl-2-allyl-1,3-dithiane 1-oxide (2e & 3e)

Treatment of **1e** (5.40g, 22.9 mmol) as described above with sodium metaperiodate (5.38g, 25.2 mmol) in water (50 mL) and methanol (250 mL) furnished the diastereoisomeric sulfoxides. Separation by column chromatography yielded both the less polar *syn* (**2e**) and more polar *anti* (**3e**) diastereoisomers as colourless crystalline solids.
For *syn* **2e**: (1.37g, 24%), m.p. 88-90 °C; ν_{max} (Nujol) 1641 and 1042 cm^{-1}; δ_H (400 MHz, $CDCl_3$) 2.26-2.30 (1H, m), 2.35-2.45 (2H, m), 2.64-2.80 (2H, m), 2.89-2.96 (2H, m), 3.16-3.21 (1H, m), 5.08-5.12 (2H, m), 5.55-5.65 (1H, m), 7.35-7.39 (1H, m), 7.42-7.46 (2H, m), 7.99-8.01 (2H, m); δ_C (50 MHz, $CDCl_3$) 26.8, 29.7, 44.7, 47.0, 69.9, 119.9, 128.2, 128.6, 128.8, 130.0, 135.7; *m/z* 252.06430 (M$^+$); $C_{13}H_{16}OS_2$ requires 252.06425. Calc for $C_{13}H_{16}OS_2$: C, 61.86; H, 6.39. Found: C, 62.06; H, 6.42%.
For *anti* **3e**: (2.86g, 50%), m.p. 62-64 °C; ν_{max} (Nujol) 1639 and 1032 cm^{-1}; δ_H (400 MHz, $CDCl_3$) 1.70-1.74 (1H, m), 2.44-2.56 (3H, m), 2.72-2.78 (1H, m), 2.83-2.87 (2H, m), 2.94-2.99 (1H, m), 5.05-5.11 (2H, m), 5.40-5.50 (1H, m), 7.34-7.37 (1H, m), 7.43-7.47 (2H, m), 7.65-7.67 (2H, m); δ_C (50 MHz, $CDCl_3$) 16.1, 25.3, 41.3, 42.1, 69.1, 119.7, 127.8, 128.1, 128.9, 129.6, 135.8; *m/z* 252.06430 (M$^+$); $C_{13}H_{16}OS_2$ requires 252.06425. Calc for $C_{13}H_{16}OS_2$: C, 61.86; H, 6.39. Found: C, 61.96; H, 6.39%.

2-(2-Propylidene)-1,3-dithiane (4)

A 2.4 M solution of ^{n}butyllithium in hexanes (1.1 eq, 4.76 mL, 11.4 mmol) was added to a stirring solution of 2-trimethylsilyl-1,3-dithiane (2.0 g, 10.4 mmol) in THF (20 mL) at −78 °C over 2 minutes. The solution was allowed to reach 0 °C over 5 hours, recooled to −78 °C, acetone (1.1 eq, 0.84 mL, 11.4 mmol) added, and the mixture allowed to reach room temperature overnight. The reaction mixture was poured onto water (40 mL), extracted with dichloromethane (3 x 30 mL), dried (Na_2SO_4) and evaporated under reduced pressure to give **4** as a pale yellow oil (1.52g, 91%); ν_{max} (film) 2907 and 1422 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.92 (6H, s), 2.05-2.17 (2H, m), 2.83-2.89 (4H, m); δ_C (50 MHz, $CDCl_3$) 22.0, 24.8, 30.1, 91.0, 118.1; *m/z* 160.03822 (M$^+$); $C_7H_{12}S_2$ requires 160.03806.

2-(2-Propylidene)-1,3-dithiane 1-Oxide

A solution of sodium metaperiodate (2.94 g, 13.7 mmol) in water (20 mL) was added dropwise to a stirring solution of 2-(2-propylidene)-1,3-dithiane (2.0 g, 12.5 mmol) in methanol (75 mL) at 0 °C. After 16 h the solution was allowed to reach room temperature over 0.5 hours, filtered, and the filtrate concentrated to 30 mL. Extraction with dichloromethane, drying ($MgSO_4$), evaporation under reduced pressure, and recrystallization from diethyl ether gave the title compound as a colourless solid (1.63g, 74%), m.p. 98-100 °C; ν_{max} (Nujol) 2925 and 1041 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.81-1.96 (1H, m), 2.07 (3H, s), 2.15 (3H, s), 2.54-2.71 (2H, m), 2.74-3.00 (2H, m), 3.08-3.18 (1H, m); δ_C (100 MHz, $CDCl_3$) 15.0, 21.2, 23.3, 30.2, 47.9, 130.2, 148.8; *m/z* 176.03311 (M^+); $C_7H_{12}S_2O$ requires 176.03297. Calc for $C_7H_{12}S_2O$: C, 47.69; H, 6.86. Found: C, 47.78; H, 6.88%.

2-Methyl-2-(2-propene)-1,3-dithiane (5)

A 2.4 M solution of ^{n}butyllithium in hexanes (1.1 eq, 4.30 mL, 10.3 mmol) was added to a stirring solution of **4** (1.5g, 9.4 mmol) in THF (20 mL) and HMPA (3 eq, 4.88 mL) at −78 °C. The solution was allowed to reach room temperature over 2.5 hours, recooled to −78 °C, methyl iodide (1.1 eq, 0.64 mL, 10.3 mmol) added, and the mixture allowed to reach room temperature over 1 hour. Normal work-up and column chromatography using 10% ethyl acetate/ petroleum ether as eluent gave **5** as a pale yellow oil (1.08g, 66%); ν_{max} (film) 2971 and 1632 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.63 (3H, s), 1.82-2.11 (2H, m), 1.93 (3H, s), 2.57-2.92 (4H, m), 5.14-5.17 (1H, m), 5.49 (1H, m); *m/z* 175.06111 (M^+); $C_8H_{14}S_2$ requires 175.06152.

Syn & *anti*-2- methyl-2-(2-propene)-1,3-dithiane 1-oxide (6 & 7)

Treatment of **5** (1.00g, 5.7 mmol) as described above with sodium metaperiodate (1.35g, 6.3 mmol) in water (10 mL) and methanol (50 mL) furnished the diastereoisomeric sulfoxides. Separation by column chromatography yielded both the less polar *syn* (**6**) and more polar *anti* (**7**) diastereoisomers as pale yellow oils.

For *syn* **6**: (0.11g, 10%); ν_{max} (film) 3093, 1627 and 1039 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.76 (3H, s), 2.00 (3H, d, J = 1.7 Hz), 2.11-2.33 (1H, m), 2.37-2.72 (3H, m), 2.88-3.00 (1H, m), 3.11-3.25 (1H, m), 5.31 (1H, t, J = 1.7 Hz), 5.69 (1H, s); δ_C (50 MHz, $CDCl_3$) 20.4, 23.3, 25.3, 26.4, 45.5, 66.2, 117.8, 141.2; *m/z* 190.04876 (M^+), $C_8H_{14}OS_2$ requires 190.04861.

For *anti* **7**: (0.66g, 60%); ν_{max} (film) 1639 and 1032 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.75 (3H, s), 1.97 (3H, d, J = 1.7 Hz), 2.02-2.24 (1H, m), 2.33-2.83 (4H, m), 3.01-3.13 (1H, m), 5.29 (1H, q, J = 1.7 Hz), 5.39 (1H, s); δ_C (50 MHz, $CDCl_3$) 14.7, 19.9, 25.1, 25.2, 45.5, 65.3, 117.3, 141.7; *m/z* 190.04876 (M^+), $C_8H_{14}OS_2$ requires 190.04861.

General procedure for $OsCl_3$ mediated dihydroxylation

A round bottomed flask was charged with potassium ferricyanide (3.0 eq), potassium carbonate (3.0 eq), quinuclidine (4.0 mol%), osmium (III) chloride hydrate (1.0 mol%) and methanesulfonamide (1.0 eq)*. A 1:1 mixture of water and ^{t}butanol (50 mL/g) was added and the solution stirred using a mechanical stirrer until all the solids had dissolved. Substrate was added and the solution stirred vigorously for an appropriate length of time at room temperature. Anhydrous sodium sulfite (12 eq) was added, stirring continued for one hour, and dichloromethane (50 mL/g) added. After a further 5 minutes of stirring the organic phase was separated, the aqueous phase extracted with dichloromethane (4 x 100 mL/g), and the combined organic extracts washed with 2 M potassium hydroxide* (10 ml). Drying ($MgSO_4$), evaporation under reduced pressure, and separation by column chromatography using 10% methanol/ ethyl acetate as eluent gave the diastereoisomeric 1,2-diols.

* Only included for non-terminal alkenes.

Syn-2-methyl-2-(3-(propane-1,2-diol))-1,3-dithiane 1-oxides (10a & 11a)

Treatment of **2a** (1.0g, 5.3 mmol) as described above with potassium ferricyanide (5.20g, 15.8

mmol), potassium carbonate (2.18g, 15.8 mmol), quinuclidine (23.4 mg, 0.2 mmol) and osmium (III) chloride hydrate (15.6 mg, 0.05 mmol) in water (25 mL) and ^{t}butanol (25 mL) for 3 hours, followed by addition of sodium sulfite (7.96g, 63.2 mmol) and work up furnished the diastereoisomeric alcohols. Separation by column chromatography yielded both diastereoisomers as clear, colourless, semicrystalline oils.

For **10a** (less polar): (0.550g, 51%); ν_{max} (film) 3372 and 1015 cm^{-1}; δ_H (400 MHz, DMSO-d6) 1.53 (3H, s), 1.80-1.86 (1H, m), 1.99-2.08 (1H, m), 2.20-2.38 (3H, m), 2.63-2.80 (2H, m), 2.99-3.03 (1H, m), 3.23-3.31 (2H, m), 3.78-3.82 (1H, m), 4.74-4.78 (2H, m); δ_C (100 MHz, $CDCl_3$) 22.6, 25.0, 30.1, 39.6, 45.7, 60.3, 66.2, 66.6; *m/z* 225.06197 (M+H$^+$); $C_8H_{17}O_3S_2$ requires 225.06191.

For **11a** (more polar): (0.376g, 35%); ν_{max} (film) 3381 and 1017 cm^{-1}; δ_H (400 MHz, DMSO-d6) 1.49 (3H, s), 1.83-2.09 (3H, m), 2.23-2.29 (1H, m), 2.44-2.48 (2H, m), 2.72-2.80 (2H, m), 2.95-2.99 (1H, m), 3.21-3.27 (1H, m), 3.74-3.79 (1H, m), 4.60 (1H, d, J = 5.2 Hz), 4.68 (1H, t, J = 5.2 Hz); *m/z* 225.06197 (M+H$^+$); $C_8H_{17}O_3S_2$ requires 225.06191.

***Anti*-2-methyl-2-(3-(propane-1,2-diol))-1,3-dithiane 1-oxides (12a & 13a)**

Treatment of **3a** (1.0g, 5.3 mmol) as described above with potassium ferricyanide (5.20g, 15.8 mmol), potassium carbonate (2.18g, 15.8 mmol), quinuclidine (23.4 mg, 0.2 mmol) and osmium (III) chloride hydrate (15.6 mg, 0.05 mmol) in water (25 mL) and ^{t}butanol (25 mL) for 3 hours followed by addition of sodium sulfite (7.96g, 63.2 mmol) and work up furnished the diastereoisomeric alcohols. Separation by column chromatography yielded both diastereoisomers as clear, colourless, viscous oils.

For **12a** (less polar): (0.552g, 51%); ν_{max} (film) 3372 and 1013 cm^{-1}; δ_H (270 MHz, DMSO-d6) 1.59 (3H, s), 1.79-2.03 (3H, m), 2.21-2.29 (1H, m), 2.42-2.51 (1H, m), 2.64-2.76 (2H, m), 2.97-3.05 (1H, m), 3.10-3.19 (1H, m), 3.27-3.35 (1H, m), 3.70-3.74 (1H, m), 4.66 (1H, t, J = 5.6 Hz), 4.74 (1H, d, J = 5.0 Hz); δ_C (68 MHz, $CDCl_3$) 12.7, 24.9, 28.7, 45.8, 46.1, 60.0, 66.3, 66.8; *m/z* 225 (M+H$^+$).

For **13a** (more polar): (0.372g, 34%); ν_{max} (film) 3380 and 1014 cm^{-1}; δ_H (270 MHz, DMSO-d6) 1.56 (3H, s), 1.58-1.66 (1H, m), 1.90-2.11 (2H, m), 2.19-2.28 (1H, m), 2.37-2.49 (1H, m), 2.63-2.76 (2H, m), 2.92-2.98 (1H, m), 3.09-3.18 (1H, m), 3.24-3.30 (1H, m), 3.72-3.79 (1H, m), 4.56 (1H, d, J = 5.8 Hz), 4.64 (1H, t, J = 5.8 Hz); δ_C (68 MHz, $CDCl_3$) 15.5, 24.9, 27.9, 42.2, 46.1, 60.4, 66.9, 68.6; *m/z* 225 (M+H$^+$).

***Syn*-2-methyl-2-(3-(2-methyl-propane-1,2-diol))-1,3-dithiane 1-oxides (10b & 11b)**

Treatment of **2b** (0.50g, 2.5 mmol) as described above with potassium ferricyanide (2.42g, 7.3 mmol), potassium carbonate (1.02g, 7.4 mmol), quinuclidine (11.0 mg, 0.1 mmol) and osmium (III) chloride hydrate (7.3 mg, 0.02 mmol) in water (12 mL) and ^{t}butanol (12 mL) for 4 hours followed by addition of sodium sulfite (3.71g, 29.4 mmol) and work up furnished the diastereoisomeric alcohols. Separation by column chromatography yielded both diastereoisomers as clear, colourless, viscous oils.

For **10b** (less polar): (0.361g, 62%); ν_{max} (film) 3391 and 1016 cm^{-1}; δ_H (400 MHz, DMSO-d6) 1.21 (3H, s), 1.61 (3H, s), 1.98-2.12 (3H, m), 2.24-2.28 (1H, m), 2.38-2.42 (1H, m), 2.75-2.93 (3H, m), 3.29-3.33 (1H, m), 3.49-3.53 (1H, m), 4.42 (1H, s), 4.71 (1H, t, J = 5.2 Hz); δ_C (100 MHz, $CDCl_3$) 24.2, 25.5, 26.7, 28.5, 37.5, 45.4, 61.0, 70.1, 73.3; *m/z* 239.07782 (M+H$^+$); $C_9H_{19}O_3S_2$ requires 239.07756.

For **11b** (more polar): (0.177g, 30%); ν_{max} (film) 3372 and 1014 cm^{-1}; δ_H (400 MHz, DMSO-d6) 1.29 (3H, s), 1.62 (3H, s), 1.99-2.18 (3H, m), 2.26-2.30 (1H, m), 2.40-2.43 (1H, m), 2.66-2.81 (2H, m), 2.90-2.93 (1H, m), 3.14-3.24 (2H, m), 4.37 (1H, s), 4.81 (1H, m); *m/z* 239.07782 (M+H$^+$); $C_9H_{19}O_3S_2$ requires 239.07756.

***Anti*-2-methyl-2-(3-(2-methyl-propane-1,2-diol))-1,3-dithiane 1-oxides (12b & 13b)**

Treatment of **3b** (0.50g, 2.5 mmol) as described above with potassium ferricyanide (2.42g, 7.3 mmol), potassium carbonate (1.02g, 7.4 mmol), quinuclidine (11.0 mg, 0.1 mmol) and osmium (III) chloride hydrate (7.3 mg, 0.02 mmol) in water (12 mL) and ^{t}butanol (12 mL) for 2.5 hours followed addition of sodium sulfite (3.71g, 29.4 mmol) and work up furnished the diastereoisomeric alcohols as an inseparable mixture of clear, colourless, viscous oils (0.512g, 88%).

***Syn*-2-methyl-2-(1-(3-methyl-butan-2,3-diol))-1,3-dithiane 1-oxides (10c & 11c)**

Treatment of **2c** (0.50g, 2.3 mmol) as described above with potassium ferricyanide (2.27g, 6.9 mmol), potassium carbonate (0.95g, 6.9 mmol), quinuclidine (10.2mg, 0.1 mmol), osmium (III) chloride hydrate (6.8 mg, 0.02 mmol) and methanesulfonamide (0.22g, 2.3 mmol) in water (12 mL) and ^{t}butanol (12 mL) for 24 hours followed by addition of sodium sulfite (3.47g, 27.5 mmol) and work up furnished the diastereoisomeric alcohols. Separation by column chromatography yielded the diastereoisomers as a clear, colourless, viscous oil (10c) and a colourless crystalline solid (11c).

For **10c** (more polar): (0.352g, 61%); ν_{max} (film) 3381 and 997 cm^{-1}; δ_H (400 MHz, DMSO-d6) 1.02 (3H, s), 1.09 (3H, s), 1.48 (3H, s), 1.81 (1H, dd, J = 13.0 and 8.4 Hz), 1.92-2.01 (1H, m), 2.19 (1H, d, J = 13.0 Hz), 2.25-2.28 (1H, m), 2.42-2.47 (1H, m), 2.74-2.83 (2H, m), 2.95-2.99 (1H, m), 3.44-3.48 (1H, m), 4.28 (1H, s), 4.57 (1H, d, J = 6.0 Hz); δ_C (100 MHz, $CDCl_3$) 22.9, 24.0, 25.2, 25.7, 26.1, 30.6, 44.9, 59.9, 72.7, 74.1; *m/z* 253.09319 (M+H$^+$); $C_{10}H_{21}O_3S_2$ requires 253.09321.

For **11c** (less polar): (0.164g, 28%), m.p. 133-135 °C; ν_{max} (Nujol) 3376, and 1004 cm^{-1}; δ_H (400 MHz, DMSO-d6) 1.05 (3H, s), 1.14 (3H, s), 1.51 (3H, s), 1.77 (1H, dd, J = 14.8 and 9.2 Hz), 1.99-2.09 (1H, m), 2.27-2.33 (3H, m), 2.66-2.73 (1H, m), 2.76-2.83 (1H, m), 2.98-3.02 (1H, m), 3.52-3.56 (1H, m), 4.42 (1H, s), 4.70 (1H, d, J = 6.4 Hz); δ_C (100 MHz, $CDCl_3$) 22.7, 24.4, 25.0, 26.0, 30.2, 38.5, 45.9, 60.3, 72.0, 72.3. Calc for $C_{10}H_{20}O_3S_2$: C, 47.59; H, 7.99. Found: C, 47.43; H, 7.97%.

***Anti*-2-methyl-2-(1-(3-methyl-butan-2,3-diol))-1,3-dithiane 1-oxides (12c & 13c)**

Treatment of **3c** (0.50g, 2.3 mmol) as described above with potassium ferricyanide (2.27g, 6.9 mmol), potassium carbonate (0.95g, 6.9 mmol), quinuclidine (10.2 mg, 0.1 mmol), osmium (III) chloride hydrate (6.8 mg, 0.02 mmol) and methanesulfonamide (0.22g, 2.3 mmol) in water (12 mL) and ^{t}butanol (12 mL) for 12 hours followed by addition of sodium sulfite (3.47g, 27.5 mmol) and work up furnished the diastereoisomeric alcohols. Separation by column chromatography yielded both diastereoisomers as colourless crystalline solids.

For **12c** (less polar): (0.264g, 46%), m.p. 151-152 °C; ν_{max} (Nujol) 3395, 3327 and 993 cm^{-1}; δ_H (400 MHz, DMSO-d6) 0.97 (3H, s), 1.06 (3H, s), 1.57 (3H, s), 1.75 (1H, dd, J = 14.8 and 9.2 Hz), 1.90-1.96 (1H, m), 2.00 (1H, d, J = 14.8 Hz), 2.22-2.26 (1H, m), 2.44-2.49 (1H, m), 2.64-2.75 (2H, m), 2.99-3.04 (1H, m), 3.42-3.46 (1H, m), 4.31 (1H, s), 4.74 (1H, d, J = 5.6 Hz); δ_C (50 MHz, $CDCl_3$) 12.7 24.0, 24.8, 25.5, 28.6, 44.4, 45.6, 60.1, 72.3; *m/z* 253.09319 (M+H$^+$); $C_{10}H_{21}O_3S_2$ requires 253.09321. Calc for $C_{10}H_{20}O_3S_2$: C, 47.59; H, 7.99. Found: C, 47.63; H, 8.03%.

For **13c** (more polar): (0.236g, 41%), m.p. 118-120 °C; ν_{max} (Nujol) 3409, 3367 and 1013 cm^{-1}; δ_H (200 MHz, DMSO-d6) 0.96 (3H, s), 1.05 (3H, s), 1.56 (3H, s), 1.55 (1H, dd, J = 14.8 and 9.3 Hz), 1.93-2.05 (1H, m), 2.19-2.26 (1H, m), 2.35-2.44 (1H, m), 2.62-2.75 (2H, m), 2.91-3.00 (2H, m), 3.45-3.53 (1H, m), 4.27 (1H, s), 4.58 (1H, d, J = 6.6 Hz); δ_C (50 MHz, $CDCl_3$) 15.1, 23.8, 24.7, 25.6, 27.9, 40.9, 45.8, 60.6, 72.6, 74.1; *m/z* 253.09344 (M+H$^+$); $C_{10}H_{21}O_3S_2$ requires 253.09321. Calc for $C_{10}H_{20}O_3S_2$: C, 47.59; H, 7.99. Found: C, 47.55; H, 8.03%.

***Syn*-2-ethyl-2-(3-(propane-1,2-diol))-1,3-dithiane 1-oxides (10d & 11d)**

Treatment of **2d** (0.50g, 5.3 mmol) as described above with potassium ferricyanide (2.42g, 7.3 mmol), potassium carbonate (1.01g, 7.3 mmol), quinuclidine (10.9 mg, 0.1 mmol) and osmium (III) chloride hydrate (7.2 mg, 0.02 mmol) in water (12 mL) and ^{t}butanol (12 mL) for 4 hours followed by addition of sodium sulfite (3.71g, 29.4 mmol) and work up furnished the diastereoisomeric alcohols. Separation by column chromatography yielded both diastereoisomers as clear, colourless, viscous oils.

For **10d** (more polar): (0.271g, 46%); ν_{max} (film) 3381 and 1018 cm^{-1}; δ_H (200 MHz, DMSO-d6) 1.02 (3H, t, J = 7.4 Hz), 1.85-2.01 (4H, m), 2.10-2.28 (2H, m), 2.39-2.51 (2H, m), 2.70-2.89 (2H, m), 2.96-3.06 (1H, m), 3.16-3.40 (1H, m), 3.79-3.89 (1H, m), 4.61 (1H, t, J = 5.0 Hz), 4.72 (1H, d, J = 5.7 Hz); δ_C (50 MHz, CDCl$_3$) 8.2, 24.6, 26.1, 28.3, 31.3, 44.7, 64.4, 66.8, 68.1; *m/z* 239.07782 (M+H$^+$); $C_9H_{19}O_3S_2$ requires 239.07756.

For **11d** (less polar): (0.210g, 36%); ν_{max} (film) 3363 and 1010 cm^{-1}; δ_H (200 MHz, DMSO-d6) 1.00 (3H, t, J = 7.4 Hz), 1.89-2.09 (4H, m), 2.26-2.50 (3H, m), 2.66-2.92 (2H, m), 3.04-3.10 (1H, m), 3.18-3.47 (2H, m), 3.68-3.85 (1H, m), 4.81 (1H, t, J = 5.5 Hz), 4.88 (1H, d, J = 4.4 Hz); δ_C (50 MHz, CDCl$_3$) 6.9, 24.1, 27.2, 30.1, 37.3, 45.2, 65.2, 65.7, 66.5; *m/z* 239.07782 (M+H$^+$); $C_9H_{19}O_3S_2$ requires 239.07756.

Anti-2-ethyl-2-(3-(propane-1,2-diol))-1,3-dithiane 1-oxides (12d & 13d)

Treatment of **3d** (0.50g, 5.3 mmol) as described above with potassium ferricyanide (2.42g, 7.3 mmol), potassium carbonate (1.01g, 7.3 mmol), quinuclidine (10.9 mg, 0.1 mmol) and osmium (III) chloride hydrate (7.2 mg, 0.02 mmol) in water (12 mL) and ^{t}butanol (12 mL) for 3 hours followed by addition of sodium sulfite (3.71g, 29.4 mmol) and work up furnished the diastereoisomeric alcohols. Separation by column chromatography yielded both diastereoisomers as clear, colourless, viscous oils.

For **12d** (less polar): (0.236g, 40%); ν_{max} (film) 3367 and 1036 cm^{-1}; δ_H (200 MHz, DMSO-d6) 0.99 (3H, t, J = 7.4 Hz), 1.54-1.66 (1H, m), 1.79-2.05 (3H, m), 2.09-2.31 (2H, m), 2.40-2.57 (2H, m), 2.79-2.93 (1H, m), 3.04-3.21 (2H, m), 3.32-3.42 (1H, m), 3.63-3.71 (1H, m), 4.74 (1H, t, J = 5.8 Hz), 4.93 (1H, d, J = 3.3 Hz); δ_C (50 MHz, CDCl$_3$) 6.2, 15.0, 24.1, 28.2, 41.4, 44.6, 64.0, 66.0, 66.2; *m/z* 239.07782 (M+H$^+$); $C_9H_{19}O_3S_2$ requires 239.07756.

For **13d** (more polar): (0.232g, 40%); ν_{max} (film) 3369 and 1022 cm^{-1}; δ_H (200 MHz, DMSO-d6) 1.02 (3H, t, J = 7.4 Hz), 1.69-1.81 (1H, m), 1.87-2.11 (4H, m), 2.15-2.25 (1H, m), 2.35-2.61 (2H, m), 2.74-2.88 (1H, m), 2.92-3.03 (1H, m), 3.07-3.31 (2H, m), 3.86-3.92 (1H, m), 4.57 (1H, d, J = 5.5 Hz), 4.68 (1H, t, J = 5.5 Hz); δ_C (50 MHz, CDCl$_3$) 6.7, 18.8, 24.3, 26.9, 37.6, 44.8, 64.6, 66.9, 68.2; *m/z* 239.07782 (M+H$^+$); $C_9H_{19}O_3S_2$ requires 239.07756.

Syn-2-phenyl-2-(3-(propane-1,2-diol))-1,3-dithiane 1-oxides (10e & 11e)

Treatment of **2e** (0.50g, 2.0 mmol) as described above with potassium ferricyanide (1.96g, 6.0 mmol), potassium carbonate (0.82g, 6.0 mmol), quinuclidine (8.8 mg, 0.08 mmol) and osmium (III) chloride hydrate (5.9 mg, 0.02 mmol) in water (12 mL) and ^{t}butanol (12 mL) for 4 hours followed by addition of sodium sulfite (3.00g, 23.8 mmol) and work up furnished the diastereoisomeric alcohols. Separation by column chromatography yielded both diastereoisomers as clear, colourless, semicrystalline oils.

For **10e** (less polar): (0.286g, 50%); ν_{max} (film) 3363 and 1021 cm^{-1}; δ_H (400 MHz, DMSO-d6) 2.10-2.16 (1H, m), 2.20-2.35 (3H, m), 2.44-2.48 (1H, m), 2.59-2.66 (2H, m), 3.01-3.05 (1H, m), 3.18-3.25 (2H, m), 3.43-3.47 (1H, m), 4.52 (1H, d, J = 4.4 Hz), 4.59 (1H, t, J = 5.8 Hz), 7.36 (1H, t, J = 7.2 Hz), 7.44 (2H, t, J = 7.6 Hz), 7.87 (2H, d, J = 7.6 Hz); δ_C (100 MHz, CDCl$_3$) 26.7, 30.2, 46.9, 48.6, 66.5, 66.7, 68.9, 128.7, 128.8, 129.3, 135.8; *m/z* 287.07714 (M+H$^+$); $C_{13}H_{19}O_3S_2$ requires 287.07756.

For **11e** (more polar): (0.173g, 30%); ν_{max} (film) 3374 and 1019 cm^{-1}; δ_H (400 MHz, DMSO-d6) 1.88-1.94 (1H, m), 2.19-2.22 (2H, m), 2.39-2.55 (3H, m), 2.66-2.69 (1H, m), 2.86-2.94 (2H, m), 2.99-3.05 (1H, m), 3.23-3.26 (1H, m), 4.50 (1H, t, J = 5.6 Hz), 4.54 (1H, d, J = 5.6 Hz), 7.37-7.40 (1H, m), 7.44-7.47 (2H, m), 7.89-7.92 (2H, m); δ_C (100 MHz, $CDCl_3$) 27.3, 29.1, 43.6, 46.9, 66.6, 68.8, 69.6, 128.7, 128.8, 129.1, 135.6; *m/z* 287.07714 $(M+H^+)$; $C_{13}H_{19}O_3S_2$ requires 287.07756.

***Anti*-2-phenyl-2-(3-(propane-1,2-diol))-1,3-dithiane 1-oxides (12e & 13e)**

Treatment of **3e** (0.50g, 2.0 mmol) as described above with potassium ferricyanide (1.96g, 6.0 mmol), potassium carbonate (0.82g, 6.0 mmol), quinuclidine (8.8 mg, 0.08 mmol) and osmium (III) chloride hydrate (5.9 mg, 0.02 mmol) in water (12 mL) and ^{t}butanol (12 mL) for 4 hours followed by addition of sodium sulfite (3.00g, 23.8 mmol) and work up furnished the diastereoisomeric alcohols. Separation by column chromatography yielded both diastereoisomers as clear, colourless, semicrystalline oils.

For **12e** (less polar): (0.273g, 48%); ν_{max} (film) 3350 and 1015 cm^{-1}; δ_H (400 MHz, DMSO-d6) 1.88-1.95 (1H, m), 2.28-2.34 (1H, m), 2.41-2.43 (2H, m), 2.57-2.63 (1H, m), 2.76-2.94 (3H, m), 3.26-3.43 (3H, m), 4.61 (1H, d, J = 4.4 Hz), 4.66 (1H, t, J = 4.4 Hz), 7.34-7.38 (1H, m), 7.42-7.45 (2H, m), 7.65-7.68 (2H, m); *m/z* 287.07794 $(M+H^+)$; $C_{13}H_{19}O_3S_2$ requires 287.07756.

For **13e** (more polar): (0.195g, 34%); ν_{max} (film) 3362 and 1035 cm^{-1}; δ_H (400 MHz, DMSO-d6) 1.83-1.89 (1H, m), 2.14-2.20 (1H, m), 2.28-2.34 (1H, m), 2.51-2.69 (3H, m), 2.77-2.94 (2H, m), 3.01-3.15 (2H, m), 3.32-3.40 (1H, m), 4.53 (1H, d, J = 4.4 Hz), 4.62 (1H,bs), 7.35-7.39 (1H, m), 7.43-7.47 (2H, m), 7.61-7.67 (2H, m); *m/z* 287.07780 $(M+H^+)$; $C_{13}H_{19}O_3S_2$ requires 287.07756.

2-(1-Hydroxyethyl)-2-methyl-1,3-dithiane

A 2.4 molar solution of ^{n}butyllithium in hexanes (1.1 eq, 38.2 mL, 91.6 mmol) was added to a solution of 1,3-dithiane (10.0g, 83.3 mmol) in THF (250 mL) at –20 °C. After one hour methyl iodide (1.1 eq, 5.70 mL, 91.6 mmol) was added and the solution allowed to reach room temperature. After 1 hour the solution was recooled to –20 °C and ^{n}butyllithium (1.1 eq, 38.2 mL, 91.6 mmol) added. After a further hour acetaldehyde (1.1 eq, 5.11 mL 91.6 mmol) was added and the solution allowed to reach room temperature over 1 hour. Normal work-up, extraction with dichloromethane, drying over $MgSO_4$ and flash column chromatography with 10% ethyl acetate/petroleum ether as eluent yielded the title compound as a colourless oil (10.1g, 68%); ν_{max} (film) 3490 cm^{-1}; δ_H (400MHz, $CDCl_3$) 1.34 (3H, d, J = 6.4 Hz), 1.40 (3H, s), 1.80-1.90 (1H, m), 2.07-2.13 (1H, m), 2.07-2.13 (1H, m), 2.59-2.65 (3H, m), 2.97-3.06 (2H, m), 4.25 (1H, q, J = 6.4 Hz); *m/z* (EI) 178.04882 (M^+); $C_7H_{14}OS_2$ requires 178.04861. Calc for $C_7H_{14}OS_2$: C, 47.15; H, 7.91. Found: C, 47.39; H, 8.00%.

2-(1-Hydroxybutyl)-2-methyl-1,3-dithiane

A 2.3 molar solution of ^{n}butyllithium in hexanes (1.1 eq, 23.9 mL, 55.0 mmol) was added to a solution of 1,3-dithiane (6.0g, 50.0 mmol) in THF (150 mL) at –20 °C. After 1 hour methyl iodide (1.1 eq, 3.42 mL, 55.0 mmol) was added and the solution allowed to reach room temperature. After 1 hour the solution was recooled to –20 °C and ^{n}butyllithium (1.1 eq, 23.9 mL, 55.0 mmol) added. After a further hour butyraldehyde (1.1 eq, 4.95 mL 55.0 mmol) was added and the solution allowed to reach room temperature over 1 hour. Normal work-up, extraction with dichloromethane, drying over $MgSO_4$ and flash column chromatography with 10% ethyl acetate/petroleum ether as eluent yielded the title compound as a colourless oil (9.01g, 87%); ν_{max} (film) 3480 cm^{-1}; δ_H (200MHz, $CDCl_3$) 1.34 (3H, t, J = 7.2 Hz), 1.29-1.51 (2H, m), 1.39 (3H, s), 1.57-2.17 (4H, m), 2.56-2.67 (2H, m), 2.79-2.86 (1H, m), 2.90-3.08 (2H, m), 3.93-3.98 (1H, m); *m/z* (EI) 206.07957 (M^+); $C_9H_{18}OS_2$ requires 206.07991.

2-Methylene-3-methyl-1,4-dithiepane

Triethylamine (1.1 eq., 6.24 mL, 44.8 mmol) was added to a stirring solution of 2-(1-hydroxyethyl)-2-methyl-1,3-dithiane (7.25g, 40.7 mmol) in THF (250 mL) at 0 °C. After 30 minutes mesyl chloride (1.1 eq., 3.48 mL, 44.8 mmol) was added and the solution allowed to reach room temperature over

1 hour. After a further addition of triethylamine (1.5 eq., 9.36 mL, 61.1 mmol) the solution was stirred at room temperature for 2 days. Normal work-up, extraction with dichloromethane, drying over $MgSO_4$ and column chromatography with 10% ethyl acetate/ petroleum ether as eluent yielded the title compound as a colourless oil (5.70 g, 87%); ν_{max} (film) 1596 cm^{-1}; δ_H (200MHz, $CDCl_3$) 1.48 (3H, d, J = 7.1 Hz), 1.95-2.30 (2H, m), 2.65-2.92 (2H, m), 2.98-3.12 (2H, m), 3.90 (1H, q, J = 7.1 Hz), 5.21 (1H, s), 5.36 (1H, s); *m/z* (CI) 161.04602 (M+H$^+$); $C_7H_{13}S_2$ requires 161.04587.

2-Methylene-3-propyl-1,4-dithiepane

Triethylamine (1.1 eq., 6.33 mL, 45.4 mmol) was added to a stirring solution of 2-(1-hydroxybutyl)-2-methyl-1,3-dithiane (8.5g, 41.3 mmol) in THF (150 mL) at 0 °C. After 30 minutes mesyl chloride (1.1 eq., 3.51 mL, 45.4 mmol) was added and the solution allowed to reach room temperature over 1 hour. After a further addition of triethylamine (1.5 eq., 8.63 mL, 62.0 mmol) the solution was stirred at room temperature for 24 hours. Normal work-up, extraction with dichloromethane, drying over $MgSO_4$ and column chromatography with 10% ethyl acetate/ petroleum ether as eluent yielded the title compound as a colourless oil (6.52 g, 87%); ν_{max} (film) 3083 and 1595 cm^{-1}; δ_H (200MHz, $CDCl_3$) 0.94 (3H, t, J = 7.2 Hz), 1.32-1.52 (2H, m), 1.59-2.30 (4H, m), 2.63-2.76 (1H, m), 2.91-2.98 (2H, m), 2.97-3.08 (1H, m), 3.78 (1H, t, J = 7.1 Hz), 5.22 (1H, s), 5.44 (1H, s); δ_C (50MHz, $CDCl_3$) 13.7, 20.4, 28.7, 32.1, 33.3, 36.6, 50.2, 116.1, 146.2; *m/z* (CI) 189.07738 (M+H$^+$); $C_9H_{17}S_2$ requires 189.07717.

***Anti*-2-methyl-2-(2-(propan-1,2-diol))-1,3-dithiane 1-oxides (14 & 15)**

Treatment of **7** (0.50g, 2.0 mmol) as described above with potassium ferricyanide (2.60g, 7.9 mmol), potassium carbonate (1.09g, 7.9 mmol), quinuclidine (11.7 mg, 0.1 mmol) and osmium (III) chloride hydrate (7.8 mg, 0.02 mmol) in water (12 mL) and ^{t}butanol (12 mL) for 12 hours followed by addition of sodium sulfite (3.98g, 31.6 mmol) and work up furnished the diastereoisomeric alcohols as an inseparable mixture of clear, colourless, viscous oils (0.506g, 86%); *m/z* 225.06218 (M+H$^+$); $C_8H_{17}S_2O_3$ requires 225.06191.

***Syn*-2-methyl-2-(1-(2,3-dihydroxybutanoyl))-1,3-dithiane 1 oxides (16 & 17)**

Treatment of **8** (0.20g, 0.86 mmol) as described above with potassium ferricyanide (0.91g, 2.8 mmol), potassium carbonate (0.38g, 2.8 mmol), quinuclidine (4.1 mg, 0.04 mmol) and osmium (III) chloride hydrate (2.7 mg, 0.009 mmol) in water (6 mL) and ^{t}butanol (6 mL) for 2 hours followed by addition of sodium sulfite (1.39g, 11.0 mmol) and work up furnished the diastereoisomeric alcohols (16 and 17) as an inseparable mixture of clear, colourless, viscous oils (0.168g, 73%); *m/z* 253.05721 (M+H$^+$); $C_9H_{17}S_2O_4$ requires 253.05683.

***Anti*-2-ethyl-2-(1-(2,3-dihydroxybutanoyl))-1,3-dithiane 1 oxides (18 & 19)**

Treatment of **9** (0.20g, 0.86 mmol) as described above with potassium ferricyanide (0.85g, 2.6 mmol), potassium carbonate (0.36g, 2.6 mmol), quinuclidine (3.8 mg, 0.03 mmol) and osmium (III) chloride hydrate (2.6 mg, 0.009 mmol) in water (6 mL) and ^{t}butanol (6 mL) for 2 hours followed by addition of sodium sulfite (1.27g, 10.1 mmol) and work up furnished the diastereoisomeric alcohols (18 and 19). Partial separation by column chromatography yielded both diastereoisomers as colourless crystalline solids (0.180g, 79%).

For **18** (less polar): m.p. 116-118 °C; ν_{max} (Nujol) 3408, 1697 and 1023 cm^{-1}; δ_H (400 MHz, DMSO-d6) 0.93 (3H, t, J = 7.4 Hz), 1.12 (3H, d, J = 6.4 Hz), 1.66-1.72 (1H, m), 1.90-2.04 (2H, m), 2.09-2.18 (1H, m), 2.47-2.51 (1H, m), 2.64-2.70 (1H, m), 2.87-2.94 (1H, m), 3.02-3.06 (1H, m), 4.12-4.16 (1H, m), 4.33 (1H, dd, J = 8.0 and 4.0 Hz), 4.64 (1H, d, J = 6.4 Hz), 5.42 (1H, d, J = 8.0 Hz); *m/z* 267.07271 (M+H$^+$); $C_{10}H_{19}O_4S_2$ requires 267.07248. Calc for $C_{10}H_{18}O_4S_2$: C, 45.10; H, 6.81. Found: C, 45.18; H, 6.84%.

For **19** (more polar): m.p. 106-108 °C; ν_{max} (Nujol) 3383, 1687 and 1025 cm^{-1}; δ_H (400 MHz, DMSO-d6) 0.92 (3H, t, J = 7.4 Hz), 1.13 (3H, d, J = 6.4 Hz), 1.65-1.73 (1H, m), 1.88-2.07 (2H, m), 2.11-2.21 (1H, m), 2.71-2.78 (2H, m), 2.98-3.02 (1H, m), 3.31-3.33 (1H, m), 4.07-4.11 (1H, m), 4.53 (1H, dd, J = 6.0 and 3.6 Hz), 4.72 (1H, d, J = 6.8 Hz), 5.20 (1H, d, J = 8.0 Hz); δ_C (50 MHz, CDCl$_3$) 7.8, 14.3, 20.2, 25.8, 26.8, 43.2, 68.0, 74.6, 79.6, 209.5; *m/z* 267.07271 (M+H$^+$); $C_{10}H_{19}O_4S_2$ requires 267.07248. Calc for $C_{10}H_{18}O_4S_2$: C, 45.10; H, 6.81. Found: C, 44.96; H 6.84%.

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14 For the structural assignment of major and minor diastereoisomers of products, single crystal X-ray analysis was conducted on **10e**, **11a**, **11c**, **13c**, and **13e** (entry nos. 1, 3, 5, 8, 10). The reactions giving **12/13b** and **12/13d** (entry nos. 7, 9) are unselective, the **12/13b** mixture proved inseparable. All attempts to obtain suitable crystals of the remaining compounds (**10/11b**, **10/11d** and **12/13a**) (entry nos. 2, 4, 6) proved unsuccessful. Several derivatives of these compounds were prepared, including mono-benzyl ethers, mono-trityl ethers, cyclic carbonates, di-acetates and aldehydes, but none proved to be crystalline. There is no discernible pattern in the NMR spectra or TLC behaviour of these compounds. In all cases where we were able to establish the structures unequivocally however, the major isomer is the product of dihydroxylation *syn* to the dithiane 2-position substituent R as drawn. The structural assignment

of the products in all other cases is based on the assumption that this pattern holds for all cases, and must therefore be regarded as tentative.

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