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Tethered aminohydroxylation using acyclic homo-allylic sulfamate esters and sulfonamides as substrates

Martin N. Kenworthy* and Richard J. K. Taylor*

Department of Chemistry, University of York, Heslington, York, UK YO10 5DD.
E-mail: rjkt1@york.ac.uk; Fax: +44 (0) 1904 432523; Tel: +44 (0) 1904 432606

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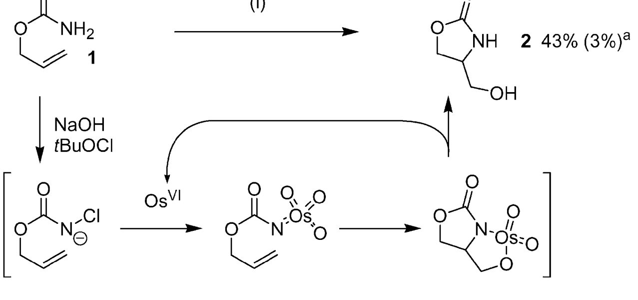
Homo-allylic sulfamate esters and sulfonamides are shown to be useful substrates for the tethered aminohydroxylation (TA) reaction. The sulfamate esters undergo the TA reaction delivering 1,2,3-oxathiazinane products whereas the sulfonamides give 1,2-thiazinane products. A range of acyclic homo-allylic sulfamate esters were prepared and subjected to the TA reaction to establish the scope of the process. Nucleophilic ring-opening reactions of the 1,2,3-oxathiazinane products are also described.

Introduction

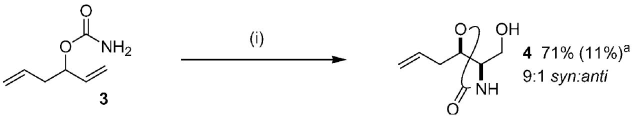
The vicinal amino alcohol unit is an important structural motif found widely in compounds isolated from nature, and also common in synthetic pharmaceuticals.[1] The most important uses of amino alcohols are as chiral building blocks, and components of catalysts and auxiliaries employed in asymmetric synthesis.[1] Consequently, a wide range of methods have been devised for their synthesis.[1] A major milestone in the preparation of these highly prized compounds came with the development of the asymmetric aminohydroxylation (AA) by Sharpless and co-workers.[2] The reaction was an extension of the Sharpless asymmetric dihydroxylation,[3] employing an *N*-haloamine salt as both the nitrogen source and stoichiometric oxidant, along with an osmium(VI) catalyst.[4] Addition of catalytic quantities of cinchona-derived ligands (*e.g.* $(DHQ)_2PHAL$) generally led to products in high enantiomeric excess. Initial studies concentrated on cinnamyl[5] and styrenyl[6] olefinic substrates raising regiochemistry questions. Although in some specific systems high levels of regiocontrol are observed,[7] the level of regiocontrol can be problematic.[2b]

An innovative solution to the regioselectivity problem was introduced by Donohoe and co-workers; they connected together the nitrogen source and the olefin in a reaction described as a tethered aminohydroxylation (TA).[8] The substrates employed in this reaction were carbamates (*e.g.* **1**), which are easily obtained from the corresponding allylic alcohols. The reaction proceeds by treatment of the allylic carbamate with NaOH and *t*BuOCl to form an *N*-chloroamine salt. Subsequently, treatment with catalytic potassium osmate(VI) and an amine ligand gave the oxazolidine product **2** in a totally regiocontrolled manner (Scheme 1). Although no enantioselectivity was observed when Sharpless' cinchona ligands were used,[8b] the reaction was found to be highly diastereoselective with both cyclic[8c] and acyclic[8d] substrates.



Scheme 1 *Reagents and conditions*: (i) nPrOH–H_2O, NaOH (0.92 eq.), *t*BuOCl (1.0 eq.), EtN(iPr)$_2$ (5 mol%), $K_2OsO_4·2H_2O$ (4 mol%). [a] Recovered starting material in parentheses.

Donohoe *et al.* also showed that the allylic/homo-allylic carbamate **3** demonstrates not only the high acyclic diastereoselectivity achievable, but also the preference for the reaction to proceed through a 5-membered ring-forming manifold in preference to a 6-membered variant, giving **4** in good yield (Scheme 2).[8a,d]



Scheme 2 *Reagents and conditions*: (i) nPrOH–H_2O, NaOH (0.92 eq.), *t*BuOCl (1.0 eq.), EtN(iPr)$_2$ (5 mol%), $K_2OsO_4·2H_2O$ (4 mol%). [a] Recovered starting material in parentheses.

We have recently used the TA reaction of the tertiary homo-allylic carbamate **5**, to prepare the TA product **6** which was used to gain access to simplified analogues **7** of the naturally occurring sphingomyelinase inhibitor, scyphostatin (Scheme 3).[9] The modest yield of the 6-membered ring carbamate **6** is consistent with the relatively low efficiency observed by Donohoe's group when forming 6-membered ring carbamates.[8a]

It has recently been reported that intramolecular C–H insertion[10,11] and aziridination[12] reactions of sulfamate esters **8** and **12** and sulfonamide **10**, in general, give excellent yields of 1,2,3-oxathiazinane **9** and **13**, and 1,2-thiazinane products **11** (Scheme 4). Moreover, in the case of C–H insertion reactions (Scheme 4a and b) the reactions actually proceeded exclusively through the 6-membered ring manifold, only forming 5-membered rings when the 6-ring option was not possible.[10] In the case of the sulfamate ester **8**, this behaviour was suggested to be due to the elongated nature of S–O and S–N bonds, along with the large bond angle of the N–S–O moiety.[10a]

The results in Scheme 4 suggested that it would be worthwhile investigating whether sulfamate esters **14** and sulfonamides **16** can be employed as substrates in 6-membered ring-forming TA reactions (Scheme 5), particularly with a view to possibly increasing the efficiency of the process and broadening the range of substrates which can be utilised in this reaction. Also, 1,2,3-oxathiazinane products **15**, obtained from the sulfamate esters **14**, could then be useful for further elaboration by nucleophilic ring-opening reactions,[13] delivering β-functionalised amino alcohols **18**.

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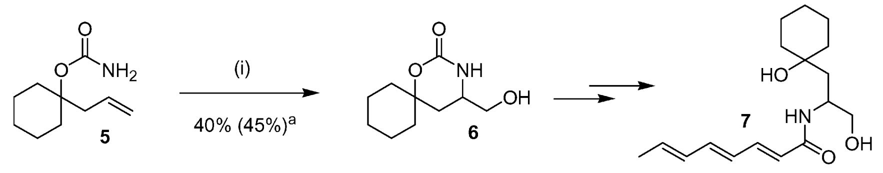
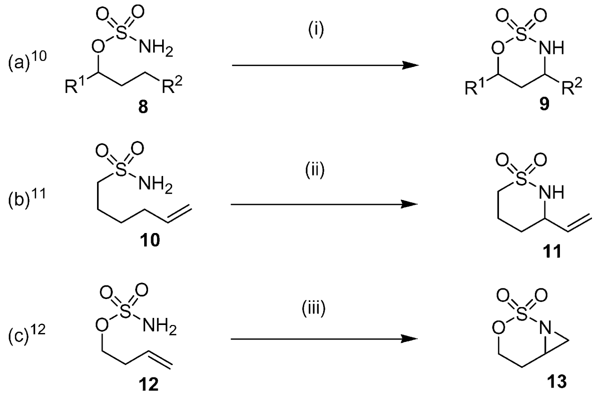


Scheme 3 *Reagents and conditions*: (i) nPrOH–H$_2$O, NaOH (0.92 eq.), tBuOCl (1.0 eq.), EtN(iPr)$_2$ (5 mol%), K$_2$OsO$_4$·2H$_2$O (4 mol%). [a]Recovered starting material in parentheses.



Scheme 4 *Reagents and conditions*: (i) PhI(OAc)$_2$, MgO, CH$_2$Cl$_2$, 40 °C, cat. Rh$_2$(OAc)$_4$; (ii) PhI(OAc)$_2$, Al$_2$O$_3$, CH$_2$Cl$_2$, 40 °C, Rh$_2$(OAc)$_4$; (iii) PhIO, CH$_3$CN, 3 Å mol. sieves., cat. Cu(CH$_3$CN)$_3$PF$_6$.

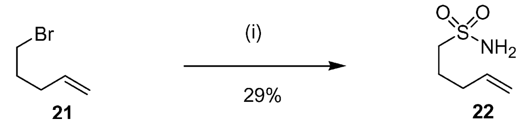
Results and discussion

Initial investigations

The sulfamate ester substrates **12** and **20a–i** were easily prepared in generally excellent yields by reaction of the requisite homo-allylic alcohol **19** with NH$_2$SO$_2$Cl, which is prepared simply by reaction of chlorosulfonyl isocyanate with formic acid (Table 1).[14] Condensation with the alcohols was then carried out using pyridine as base in dichloromethane,[10a] or by simple reaction without base in DMA.[15]

The sulfonamide **22** was prepared by reaction of 5-bromo-1-pentene (**21**) with sodium sulfite, followed by sulfonyl chloride formation, and finally reaction with ammonia (Scheme 6).[17]

Preliminary investigations into the tethered aminohydroxylation reaction of the homo-allylic sulfamate esters and the sulfonamides focused on the simplest systems **12** and **22** (Scheme 7). The optimum TA reaction conditions developed by Donohoe and co-workers were initially employed.[8] In this way, treatment of sulfamate ester **12** or sulfonamide **22** with aq. NaOH (0.92 equiv.) and tBuOCl (1 equiv.) in nPrOH to generate the *N*-chloroamine intermediates was followed by addition of EtN(iPr)$_2$ (5 mol%) and potassium osmate (4 mol%) to produce the oxathiazinane **23** and thiazinane **24**, respectively. The highest isolated product yield from the sulfamate ester **12** was obtained after 7 days reaction time, when the reaction colour turned black denoting end of turn-over of the osmium catalyst. This delivered an isolated yield of 68% of the product **23**, with 24% starting material **12** recovered. In the case of sulfonamide **22**, end of turn-over came after 3 days reaction time, delivering 59% isolated yield of the product **24**, with 29% starting material recovered.



Scheme 6 *Reagents and conditions*: (i) a) Na$_2$SO$_3$, H$_2$O, Δ, b) POCl$_3$, c) NH$_3$, CH$_3$CN.

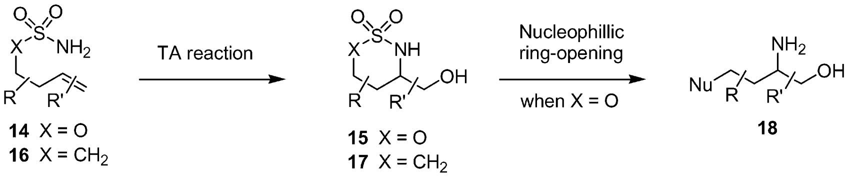
The rates of reaction of **12** and **22**, as indicated by the time taken for precipitation of osmium 'black' signifying end of turn-over, appeared to be relatively slow compared to that reported for the TA reaction of carbamate **1** (Scheme 1).[8b] In attempts to further probe this observation, we performed the reactions for fixed time periods (20 h and 40 h) (Scheme 7). When a 20 hour reaction time was employed with the sulfamate ester **12**, the reaction proceeded well delivering the product in 53% isolated yield. When this was extended to 40 hours, a small increase in yield was observed (59%) suggesting that the rate of the reaction slows over time. As a comparison the sulfonamide **22** gave only 35% of the isolated product **24** after 20 h, and 58% after 40 hours.

Optimisation of the sulfamate ester TA reaction

With these encouraging results in hand we proceeded to investigate the effects of different amine ligands upon the yield of the more synthetically interesting sulfamate ester TA reaction (see Table 2). Each reaction was carried out as before but the reaction time was kept to 3 days. Table 2 shows that the optimum ligand was indeed EtN(iPr)$_2$ (entry ii) as Donohoe and co-workers found in the original TA reaction employing carbamates (Scheme 1).[8b] Perhaps surprisingly, the reaction yield was very similar when no amine ligand was added to the reaction (entry i). Using one of Sharpless' original aminohydroxylation ligands, (DHQ)$_2$PHAL, the yield was somewhat reduced and, as Donohoe *et al.* had found,[8b] no enantiomeric induction was observed in the reaction. The use of both quinuclidine (entry iv) and DABCO (1,4-diazabicyclo[2.2.2]octane) (entry v) seemed to retard the reaction.

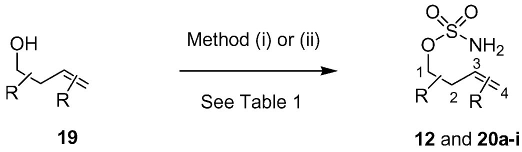
Investigations into the scope of the sulfamate ester TA reaction

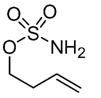
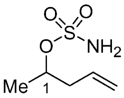
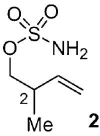
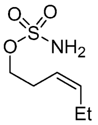
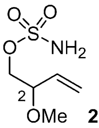
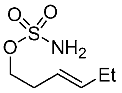
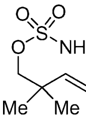
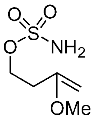
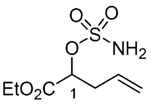
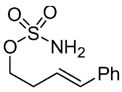
We next investigated the scope of the reaction by using differently substituted homo-allylic sulfamate esters **20a–i** using the optimised TA conditions (Table 3, entry i). Firstly, we established that a single substituent at the 2-position was compatible with the TA process, the 2-methyl and 2-methoxy analogues **20a** and **20b** giving good yields of the substituted oxathiazinane products **25** and **26**, respectively (entries ii and iii). Disappointingly, no diastereoselection was observed in either reaction, products **25** and **26** being obtained as separable 1 : 1 diastereomeric mixtures. We anticipated that the 2,2-dimethylated analogue **20c**, by virtue of the Thorpe–Ingold effect, would cyclise efficiently but unfortunately only trace quantities of oxathiazinane **27** were observed (entry iv). C-1 substitution was examined next, the



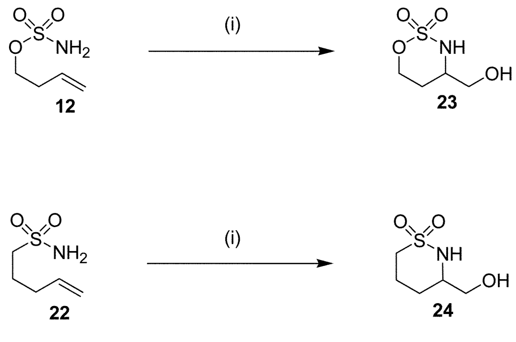
Scheme 5

Table 1 Yields and conditions used for synthesis of sulfamate esters **12** and **20a–i**[a]



Structure	Yield, Method	Structure	Yield, Method
 **12**[12]	92%, Method (i)	 **20e**[12]	84%, Method (i)
 **20a**	73%, Method (i)	 **20f**[12]	73%, Method (i)
 **20b**	78%, Method (ii)	 **20g**[12]	94%, Method (i)
 **20c**	—,[16] Method (i)	 **20h**[12]	89%, Method (i)
 **20d**	75%, Method (ii)	 **20i**	81%, Method (i)

[a] *Reagents and conditions*: (i) NH_2SO_2Cl, dimethylacetamide (DMA); (ii) NH_2SO_2Cl, pyridine, CH_2Cl_2.



reaction time	yield
7 days[b]	68% (24%)[a]
20 h	53% (21%)[a]
40 h	59% (21%)[a]

reaction time	yield
3 days[b]	59% (29%)[a]
20 h	35% (59%)[a]
40 h	58% (27%)[a]

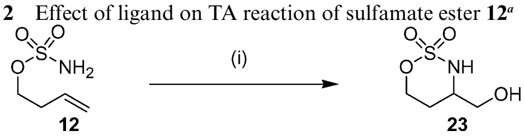
Scheme 7 *Reagents and conditions*: (i) *n*PrOH–H_2O, NaOH (0.92 equiv.), *t*BuOCl (1.0 equiv.), EtN(*i*Pr)$_2$ (5 mol%), $K_2OsO_4 \cdot 2H_2O$ (4 mol%). [a]Recovered starting material in parentheses. [b] Denotes the end of turn-over.

ester **20d** furnishing a reasonable yield of cyclised product **28** in a 4 : 1 diastereomeric ratio, with the *syn*-product shown predominating (entry v). This is an interesting result, not only due to the diastereoselectivity observed, but also because it is the first successful TA reaction in which the substrate bears an ester functionality (indicating that under these conditions the formation of the intermediate *N*-chloroamine salt, and the TA process are faster than saponification). We next investigated the TA of C-1 methyl analogue **20e**: surprisingly, no cyclisation was observed again demonstrating the unpredictably of this process (entry vi).

The presence of substituents on the alkene was investigated next (entries vii–x). Substrates containing a terminal *E*-phenyl group **20i**, a terminal *E*-ethyl group **20g** and a terminal *Z*-ethyl group **20f** all gave little or no cyclisation. Finally, substrate **20h**, containing a methyl substituent on the internal alkene site, was prepared but again no TA reaction was observed (entry ix). It therefore appears that the sulfamate TA process is limited to monosubstituted alkenes, possibly for steric reasons.

Crystal structures were obtained of both diastereoisomers of methoxy-substituted product **26** (Fig. 1).[18] The crystal structures show the conformation of both diastereoisomers to be classically chair-like with the C-4 appended hydroxymethyl substituents equatorially oriented in both diastereoisomers and the C-5 methoxy then taking either the axial or equatorial position.

Table 2 Effect of ligand on TA reaction of sulfamate ester **12**[a]



Entry	Amine ligand	Yield
i	no ligand	62% (18%)[b]
ii	EtN(*i*Pr)$_2$	64% (20%)[b]
iii	(DHQ)$_2$PHAL	42% (26%)[b]
iv	quinuclidine	18% (63%)[b]
v	DABCO	21% (65%)[b]

[a] *Reagents and conditions*: (i) *n*PrOH–H$_2$O, NaOH (0.92 equiv.), *t*BuOCl (1.0 equiv.), ligand (5 mol%), K$_2$OsO$_4$·2H$_2$O (4 mol%), 3 days. [b] Recovered starting material in parentheses.

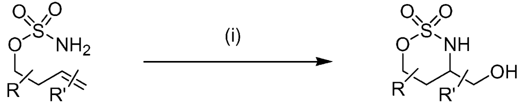
These X-ray data were valuable when rationalising the diastereoselectivity observed in the TA reactions of **20a** and **20b**. We invoked 6-membered chair-like transition states **33a,b** and **34a,b** (Scheme 8), resembling the conformations observed in the crystal structures. In the case of the C-1 ester substituted example **20d**, likely transition states **33a** and **33b** shown in Scheme 8, indicate that diaxial [1,3]-strain between the ester substituent and the axial sulfonyl oxygen in *anti*-**33b** is likely to favour *syn*-**33a** and hence the production of *syn*-**28a** (formed in 80 : 20 dr). No diastereoselectivity was observed with either C-2 substituted substrate (**20a** or **20b**), possibly due the lack of sufficient diaxial [1,3]-strain in the proposed cyclic transition state, in which the methoxy substituent and a lone pair of electrons on the ring oxygen occupy 1,3-diaxial positions, *i.e. syn*-**34a**. An additional factor deciding the outcome of the diastereoselectivities of the these reactions could be the elongated nature of O–S and S–N bonds, as discussed above, perhaps allowing the reactive N=Os=O moiety to reach relatively unhindered to either diastereomeric face of the olefin.

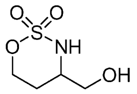
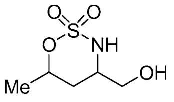
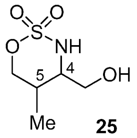
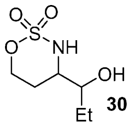
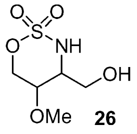
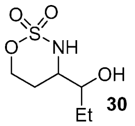
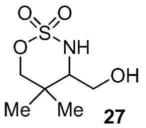
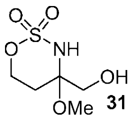
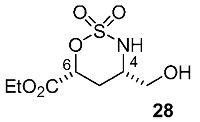
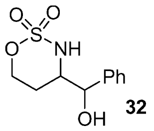
Ring-opening reactions of 1,2,3-oxathiazinane products

In recent years 1,2,3-oxathiazinanes (cyclic sulfamidates) have been used as the electrophilic participants in a range of nucleophilic ring-opening reactions.[13] We felt that the use of this methodology in conjunction with the sulfamate ester TA process would deliver useful new β-functionalised amino alcohol building blocks. To illustrate this potential we briefly studied the elaboration of the parent cyclic sulfamidate **23** (Scheme 9).

Treatment of the primary alcohol **23** with TBSCl/imidazole followed by *N*-protection with CbzCl/*t*BuONa gave fully protected oxathiazinane **35**. Reaction of *N*-Cbz oxathiazinane **35** with morpholine in acetonitrile led to attack at the sulfamidate C-6 position, acidic hydrolysis (1 M HCl) of the subsequent reaction mixture giving the ring-opened, silyl-deprotected product **36** in 86% yield (Scheme 9). The ring-opening reaction could also be carried out with phenylthiolate, hydrolysis of the ensuing reaction mixture with 1 M aqueous KH$_2$PO$_4$ then giving sulfide **37** in good yield. Finally, we were able to carry out intramolecular nucleophilic ring-opening. Treatment of the oxathiazinane **35** with TBAF gave 3-aminotetrahydrofuran as its Cbz-sulfamic acid derivative **38** in reasonable yield, presumably *via* desilylation and cyclisation of the intermediate tetrabutylammonium alkoxide **39**, as shown.

Table 3 Investigations into scope of the sulfamate ester TA process[a]



Entry	s.m.	Product	Yield, ratio	Entry	s.m.	Product	Yield, ratio
i	**12**	 **23**	68% (24%)[b]	vi	**20e**	 **29**	—
ii	**20a**	 **25**	65% (21%),[b] 1 : 1[c]	vii	*Z*-**20f**	 **30**	—
iii	**20b**	 **26**	67% (11%),[b] 1 : 1[c]	viii	*E*-**20g**	 **30**	—
iv	**20c**	 **27**	—	ix	**20h**	 **31**	—
v	**20d**	 **28**	50% (28%),[b] 4 : 1[c]	x	**20i**	 **32**	—

[a] *Reagents and conditions*: (i) *n*PrOH–H$_2$O, NaOH (0.92 equiv.), *t*BuOCl (1.0 equiv.), EtN(*i*Pr)$_2$ (5 mol%), K$_2$OsO$_4$.2H$_2$O (4 mol%). [b] Recovered starting material in parenthesis. [c] Diastereomeric ratios were obtained from ^{1}H NMR analysis of crude mixture.

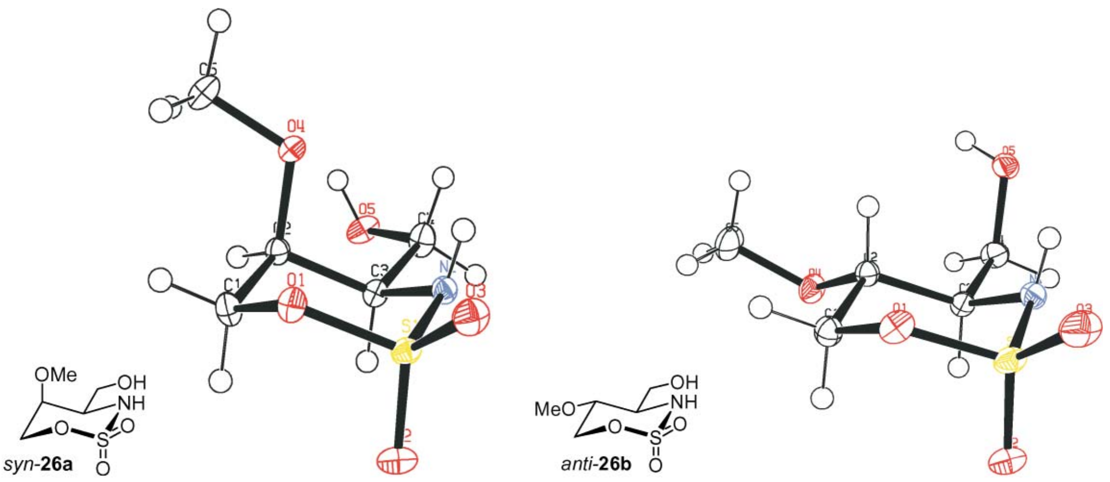
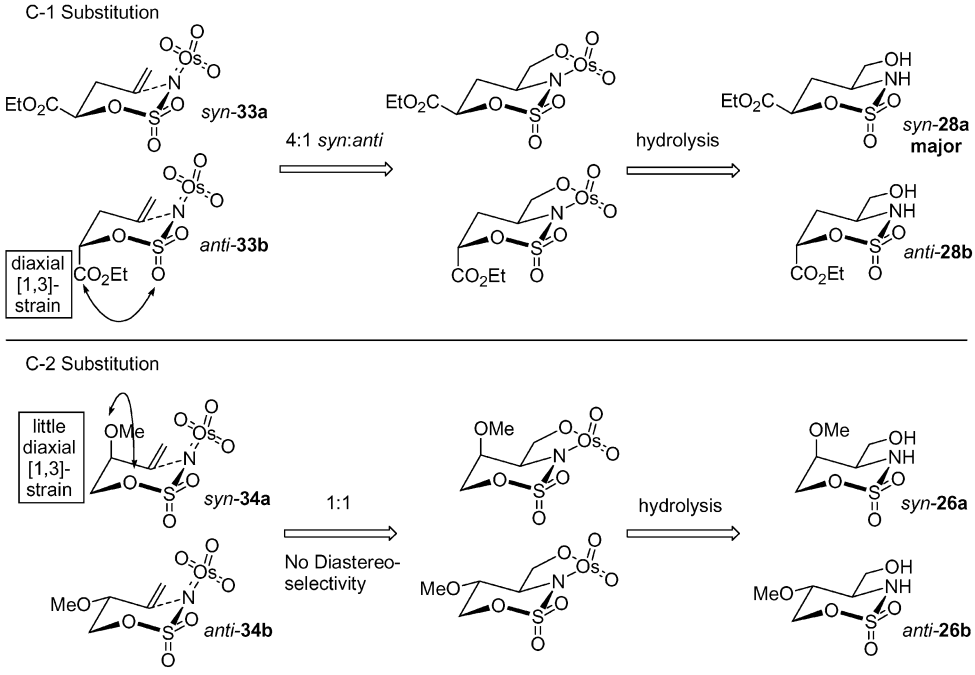
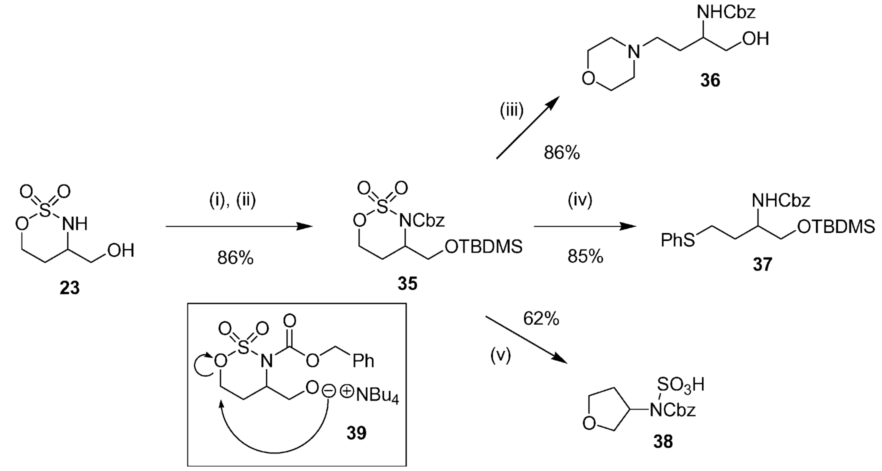


Fig. 1 ORTEP drawing of compounds *syn*-**26a** and *anti*-**26b** (50% probability thermal ellipsoids).[18]



Scheme 8 Possible diastereomeric transition states.



Scheme 9 *Reagents and conditions*: (i) TBDMSCl, imdazole, DMF; (ii) *t*BuONa, CbzCl, DME; (iii) a) morpholine, CH_3CN, b) 1 M HCl; (iv) a) PhSH, K_2CO_3, CH_3CN, b) 1 M KH_2PO_3; (v) TBAF, THF.

Conclusion

We have reported the first use of both homo-allylic sulfamate esters and a sulfonamide in tethered aminohydroxylation (TA) reactions, delivering good yields of certain cyclic sulfamidate/thiazinane products. Investigations into the sulfamate ester substrates showed that yields and diastereoselectivities of the reactions were substrate dependent, and that further alkene substitution does not appear to be compatible with the process. We also studied elaboration of one of cyclic sulfamidate TA products, showing that nucleophilic ring-opening reactions can be used to prepare functionalised acyclic β-amino alcohols and functionalised 3-aminotetrahydrofuran building blocks.

Experimental

NMR spectra were recorded on a Jeol EX-270 or Jeol EX-400 instrument (specified below); chemical shifts are quoted in parts per million (ppm) calibrated to residual non-deuterated solvent. Infrared spectra were recorded on a ThermoNicolet IR100 spectrometer with NaCl plates. Chemical ionization (CI) and high resolution mass spectra were recorded on a Micromass Autospec spectrometer. Melting points were recorded on Gallenkamp apparatus and are uncorrected. Thin layer chromatography was performed on aluminium plates coated with Merck Silica gel 60 F_{254}. Flash column chromatography was carried out using Fluka flash silica gel 60 and the eluent is specified. Dichloromethane was distilled from calcium hydride prior to use. Except where specified, all reagents were purchased from commercial sources and used without further purification.

Sulfamate esters (**12**, **20e**, **20f**, **20g** and **20h**)[12] and the sulfonamide (**24**)[17] were prepared by literature procedures. All homo-allylic alcohols were obtained from commercial sources except; 2-methoxy-but-3-en-1-ol,[19] 2,2-dimethyl-but-3-en-1-ol,[20] ethyl 2-hydroxy-pent-4-enoate[21] and (*E*)-4-phenyl-but-3-en-1-ol.[22]

General procedure for synthesis of sulfamate esters

Procedure A: Formic acid (0.33 ml, 8.72 mmol, 1.5 equiv.) was added dropwise to vigorously stirred, ice-cooled neat chlorosulfonyl isocyanate (0.76 ml, 8.72 mmol, 1.5 equiv., **CAUTION**: gas evolved) under an atmosphere of Ar. The resulting viscous solid/suspension was warmed to rt and stirred overnight. The solid was dissolved in dry DMA (10 ml) at 0 °C, then stirred at rt for a further 30 min. The homo-allylic alcohol (5.81 mmol, 1 equiv.) was added dropwise at 0 °C and stirring was continued at rt for ~4 h (consumption of starting material (s.m.) by TLC). The reaction was partitioned between EtOAc (30 ml) and H_2O (20 ml). The aqueous phase was separated and extracted with EtOAc (2 × 20 ml) and the combined organics washed with H_2O (2 × 20 ml) and brine (20 ml). The organics were dried (Na_2SO_4) and evaporated under reduced pressure and the crude residue was purified on silica gel.

Procedure B: Formic acid (0.19 ml, 5.08 mmol, 1.5 equiv.) was added dropwise to vigorously stirred, ice-cooled neat chlorosulfonyl isocyanate (0.44 ml, 5.08 mmol, 1.5 equiv., **CAUTION**: gas evolved) under an atmosphere of Ar. The resulting viscous solid/suspension was warmed to rt and stirred overnight. The solid was then dissolved in dry dichloromethane (8 ml) at 0 °C, and stirred at rt for a further 30 min. A solution of homo-allylic alcohol (3.38 mmol, 1 equiv.) and dry pyridine (0.41 ml, 5.08 mmol, 1.5 equiv.) in dry dichloromethane (2 ml) was then added dropwise at 0 °C, then stirring was continued at rt for ~3 h (consumption of s.m. by TLC). The reaction mixture was partitioned between EtOAc (20 ml) and H_2O (15 ml). The aqueous phase was separated and extracted with EtOAc (2 × 20 ml) and the combined organics were dried (Na_2SO_4) and evaporated under reduced pressure. The crude residue was then purified on silica gel.

2-Methyl-but-3-enyl sulfamate 20a. Prepared by means of procedure A, using formic acid (0.33 ml, 8.72 mmol), chlorosulfonyl isocyanate (0.76 ml, 8.72 mmol), DMA (10 ml) and 2-methyl-but-3-en-1-ol (0.6 ml, 5.81 mmol) gave the *title compound* **20a** (696 mg, 73%) as a colourless oil; R_f 0.09 (2 : 1, petrol(bp 40–60 °C)–Et_2O); ν_{max}(film)/cm^{-1} 3370, 3283, 2978, 1361, 1182, 979, 923; δ_H(400 MHz; $CDCl_3$) 5.75 (1H, m, C*H*-3), 5.2–5.05 (2H, m, CH_2-4), 4.81 (2H, br s, NH_2), 4.10 (1H, dd, *J* 9.5, 6.5, C$H_A$$H_B$-1), 4.04 (1H, dd, *J* 9.5, 7, C$H_A$$H_B$-1), 2.63 (1H, m, C*H*-2), 1.10 (3H, d, *J* 6.5, CH_3); δ_C(100 MHz; $CDCl_3$) 138.7, 116.2, 75.0, 37.1, 16.2; *m/z* (CI) 183.0809 (100%, M + NH_4^+, $C_5H_{15}N_2O_3S$ requires 183.0803), 86 (5) and 68 (25).

2-Methoxy-but-3-enyl sulfamate 20b. Prepared by means of procedure B, using formic acid (0.19 ml, 5.08 mmol), chlorosulfonyl isocyanate (0.44 ml, 5.08 mmol), 2-methoxy-but-3-en-1-ol (345 mg, 3.38 mmol), pyridine (0.41 ml, 5.08 mmol) and dichloromethane (10 ml) gave the *title compound* **20b** (476 mg, 78%) as a colourless oil; R_f 0.29 (1 : 3, petrol(bp 40–60 °C)–Et_2O); ν_{max}(film)/cm^{-1} 3364, 3278, 3096, 1369, 1182, 993; δ_H(400 MHz; $CDCl_3$) 5.70 (1H, m, C*H*-3), 5.46–5.35 (2H, m, CH_2-4), 5.08 (2H, br s, NH_2), 4.25 (1H, m, C*H*-2), 4.19 (1H, dd, *J* 10, 6.5, C$H_A$$H_B$-1), 3.94 (1H, m, C$H_A$$H_B$-1), 3.36 (3H, s, C$H_3$); δ_C(100 MHz; $CDCl_3$) 132.9, 120.7, 80.6, 72.5, 56.8; *m/z* (CI) 199.0750 (100%, M + NH_4^+, $C_5H_{15}N_2O_4S$ requires 199.0753), 182 (5, M + H^+).

2,2-Dimethyl-but-3-enyl sulfamate 20c. Prepared by means of procedure A. Due to the volatility of 2,2-dimethyl-but-3-en-1-ol a yield of the product could not be obtained. Product obtained as a colourless oil; R_f 0.22 (1 : 1, petrol(bp 40–60 °C)–Et_2O); ν_{max}(film)/cm^{-1} 3371, 3286, 2972, 1364, 1163, 976, 925, 834; δ_H(400 MHz; $CDCl_3$) 5.81 (1H, dd, *J* 11, 17.5, C*H*-3), 5.15–5.05 (2H, m, CH_2-4), 4.67 (2H, br s, NH_2), 3.95 (2H, s, CH_2-1), 1.11 (6H, s, C(CH_3)$_2$); δ_C(100 MHz; $CDCl_3$) 143.4, 113.7, 78.6, 37.5, 23.7; *m/z* (CI) 197.0957 (100%, M + NH_4^+, $C_6H_{17}N_2O_3S$ requires 197.0960), 115 (10), 88 (5), 82 (15).

Ethyl 2-sulfamoyloxy-pent-4-enoate 20d. Prepared by means of procedure B, using formic acid (0.2 ml, 5.21 mmol), chlorosulfonyl isocyanate (0.45 ml, 5.21 mmol), 2-hydroxy-pent-4-enoic acid ethyl ester (500 mg, 3.47 mmol), pyridine (0.42 ml, 5.21 mmol) and dichloromethane (10 ml) gave the *title compound* **20d** (579 mg, 75%) as a colourless oil; R_f 0.32 (1 : 2, petrol(bp 40–60 °C)–Et_2O); ν_{max}(film)/cm^{-1} 3370, 3282, 2986, 1742, 1377, 1187, 926; δ_H(400 MHz; $CDCl_3$) 5.79 (1H, m, C*H*-3), 5.25–5.15 (4H, m, CH_2-4, NH_2), 5.01 (1H, dd, *J* 5, 7, C*H*-1), 4.35–4.2 (2H, m, CH_2CH_3), 2.75–2.6 (2H, m, CH_2-2), 1.31 (3H, t, *J* 7, CH_2CH_3); δ_C(100 MHz; $CDCl_3$) 169.9, 130.9, 119.9, 79.2, 62.5, 36.2, 14.3; *m/z* (CI) 241.0858 (100%, M + NH_4^+, $C_7H_{17}N_2O_5S$ requires 241.0858) and 127 (10).

(*E*)-4-Phenyl-but-3-enyl sulfamate 20i. Prepared by means of procedure A, using formic acid (0.15 ml, 4.05 mmol), chlorosulfonyl isocyanate (0.35 ml, 4.05 mmol), (*E*)-4-phenyl-but-3-en-1-ol (400 mg, 2.70 mmol) and DMA (5 ml) gave the *title compound* **20i** (498 mg, 81%) as a cream coloured solid, m.p. 84–86 °C (from Et_2O–petrol); R_f 0.15 (1 : 1 petrol(bp 40–60 °C)–Et_2O); ν_{max}(film)/cm^{-1} 3406, 3313, 1359, 1179, 968, 931; δ_H(400 MHz; $CDCl_3$) 7.4–7.2 (5H, m, Ph*H*), 6.52 (1H, d, *J* 16, C*H*-4), 6.17 (1H, dt, *J* 16, 7, C*H*-3), 4.76 (2H, br s, NH_2), 4.64 (2H, t, *J* 7, CH_2-1), 2.67 (2H, q, *J* 7, CH_2-2); δ_C(100 MHz; $CDCl_3$) 136.7, 133.2, 128.4, 127.4, 126.0, 123.8, 70.3, 32.2; *m/z* (CI) 245.0962 (85%, M + NH_4^+, $C_{10}H_{17}N_2O_3S$ requires 245.0960), 148 (15), 131 (100), 115 (5).

General procedure for tethered aminohydroxylation (TA) reactions[23]

An aqueous solution of NaOH (0.92 equiv., 0.08 M, kept a small portion for later) was added to a stirred solution of sulfamate ester or sulfonamide (1 equiv.) in *n*PrOH (12 ml $mmol^{-1}$). After

5 min, *t*BuOCl[24] (1 equiv.) was added dropwise. After a further 5 min, the ligand (5 mol%) was added. Finally, to the reaction was added $K_2OsO_4\cdot 2H_2O$ (4 mol%), dissolved in a small portion of the aqueous 0.08 M NaOH solution prepared earlier. The reaction was then stirred until the solution turned black, or until a specified time, and then solid Na_2SO_3 (500 mg) was added to the reaction. After ~30 min, the reaction was extracted with EtOAc (3×). The combined organics were filtered through a plug of Na_2SO_4, and evaporated under reduced pressure. The crude residue was then purified on silica gel.

(2,2-Dioxo-[1,2,3]oxathiazinan-4-yl)-methanol 23. Prepared by means of the general TA procedure over 7 days, using sulfamate ester **12** (500 mg, 3.31 mmol), *n*PrOH (40 ml), NaOH (122 mg, 3.05 mmol), H_2O (38 ml), *t*BuOCl (359 mg, 3.31 mmol), EtN(*i*Pr)$_2$ (29 µl, 0.166 mmol), $K_2OsO_4\cdot 2H_2O$ (49 mg, 0.132 mmol) gave recovered starting material (121 mg, 24%) along with the *title compound* **23** (376 mg, 68%) as a colourless viscous oil; R_f 0.20 (Et_2O); ν_{max}(film)/cm^{-1} 3260, 1425, 1357, 1185, 1091, 1011, 785; δ_H(400 MHz; $CDCl_3$) 4.76 (1H, dt, *J* 2.5, 11.5, CH_AH_B-6), 4.62 (1H, ddd, *J* 11.5, 5, 1.5, CH_AH_B-6), 4.49 (1H, br d, *J* 7.5, N*H*), 3.9–3.8 (2H, m, CH_AH_BOH, C*H*-4), 3.75 (1H, m, CH_AH_BOH), 2.16 (1H, m, CH_AH_B-5), 1.67 (1H, t, *J* 4.5, O*H*), 1.62 (1H, m, CH_AH_B-5); δ_C(100 MHz; d^6-acetone) 73.8, 65.2, 59.5, 27.9; *m*/*z* (CI) 185.0594 (100%, M + NH_4^+, $C_4H_{13}N_2O_4S$ requires 185.0596), 88 (5), 56 (10).

(1,1-Dioxo-[1,2]thiazinan-3-yl)-methanol 24. Prepared by means of the general TA procedure over 3 days, using sulfonamide **22** (140 mg, 0.94 mmol), *n*PrOH (11 ml), NaOH (35 mg, 0.864 mmol), H_2O (11 ml), *t*BuOCl (106 µl, 0.94 mmol), EtN(*i*Pr)$_2$ (8 µl, 47 µmol), $K_2OsO_4\cdot 2H_2O$ (14 mg, 38 µmol) gave recovered starting material (40 mg, 29%) along with the *title compound* **24** (91 mg, 59%) as cubic colourless crystals, m.p. 101–102 °C (from EtOAc–petrol(bp 40–60 °C)); R_f 0.08 (Et_2O); ν_{max}(film)/cm^{-1} 3544, 3428, 3254, 1324, 1294, 1152; δ_H(400 MHz; d^6-acetone) 5.23 (1H, br s, N*H*), 4.01 (1H, br s, O*H*), 3.65–3.55 (2H, br m, CH_2OH), 3.43 (1H, br m, C*H*-3), 3.09 (1H, dt, *J* 13.5, 3.5, CH_AH_B-6), 2.90 (1H, dt, *J* 4.5, 13.5, CH_AH_B-6), 2.22 (1H, double quintet, *J* 14.5, 4, CH_AH_B-5), 2.11 (1H, m, CH_AH_B-5), 1.76 (1H, dq, *J* 14, 3, CH_AH_B-4), 1.48 (1H, dq, *J* 4, 14, CH_AH_B-4); δ_C(100 MHz; d^6-acetone) 65.0, 59.2, 49.7, 26.9, 23.7; *m*/*z* (CI) 183 (100%, M + NH_4^+), 166.0534 (45%, M + H^+, $C_5H_{12}NO_3S$ requires 166.0538), 134 (5), 70 (15).

(5-Methyl-2,2-dioxo-[1,2,3]oxathiazinan-4-yl)-methanol 25. Prepared by means of the general TA procedure over 3 days, using sulfamate ester **20a** (100 mg, 0.61 mmol), *n*PrOH (7 ml), NaOH (22 mg, 0.56 mmol), H_2O (7 ml), *t*BuOCl (66 mg, 0.61 mmol), EtN(*i*Pr)$_2$ (5 µl, 30 µmol), $K_2OsO_4\cdot 2H_2O$ (9 mg, 24 µmol) gave recovered starting material (21 mg, 21%) along with the *title compound* **25** (77 mg, 65%) as a mixture of 2 separable diastereoisomers. Characterisation of *anti*-4(*SR*),5(*RS*) diastereoisomer: colourless cubic crystals, mp 138–139 °C (from EtOAc–petrol(bp 40–60 °C)); R_f 0.37 (Et_2O); ν_{max}(film)/cm^{-1} 3542, 3263, 1418, 1357, 1186, 979, 793; δ_H(400 MHz; d^6-acetone) 5.83 (1H, br d, *J* 9, N*H*), 4.55 (1H, dd, *J* 5, 11.5, CH_AH_B-6), 4.37 (1H, t, *J* 11.5, CH_AH_B-6), 4.24 (1H, t, *J* 5, O*H*), 3.96 (1H, dt, *J* 11.5, 4.5, CH_AH_BOH), 3.82 (1H, ddd, *J* 3, 6, 11.5, CH_AH_BOH), 3.46 (1H, m, C*H*-4), 2.30 (1H, m, C*H*-5), 1.05 (1H, d, *J* 7.5, CH_3); δ_C(100 MHz; d^6-acetone) 3486, 3190, 1427, 1347, 1184, 1098; characterisation of *syn*-4(*SR*),5(*SR*) diastereoisomer: colourless plate crystals, mp 129–130 °C (from EtOAc–petrol(bp 40–60 °C)); R_f 0.27 (Et_2O); ν_{max}(film)/cm^{-1} 3267, 2925, 1431, 1360, 1186, 1035, 967, 791; δ_H(400 MHz; d^6-acetone) 6.30 (1H, br d, *J* 10, N*H*), 4.90 (1H, dd, *J* 2, 11.5, CH_AH_B-6), 4.48 (1H, dd, *J* 1.5, 11.5, CH_AH_B-6), 4.20 (1H, t, *J* 6, O*H*), 4.04 (1H, m, C*H*-4), 3.85–3.7 (2H, m, CH_2OH), 2.13 (1H, m, C*H*-5), 1.27 (3H, d, *J* 7.5, CH_3); δ_C(100 MHz; d^6-acetone) 3563, 3134, 1462, 1355, 1188, 1004, 910; *m*/*z* (CI) 199.0746 (100%, M + NH_4^+, $C_5H_{15}N_2O_4S$ requires 199.0753), 102 (5), 60 (10).

(5-Methoxy-2,2-dioxo-[1,2,3]oxathiazinan-4-yl)-methanol 26. Prepared by means of the general TA procedure over 4 days, using sulfamate ester **20b** (105 mg, 0.58 mmol), *n*PrOH (7 ml), NaOH (21 mg, 0.53 mmol), H_2O (7 ml), *t*BuOCl (74 µl, 0.58 mmol), EtN(*i*Pr)$_2$ (5 µl, 29 µmol), $K_2OsO_4\cdot 2H_2O$ (9 mg, 23 µmol) gave recovered starting material (11 mg, 11%) along with the *title compound* **26** (77 mg, 67%) as a mixture of 2 separable diastereoisomers. Characterisation of *anti*-4(*RS*),5(*RS*) diastereoisomer: colourless cubic crystals, mp 118–119 °C (from EtOAc–petrol(bp 40–60 °C)); R_f 0.27 (Et_2O); ν_{max}(film)/cm^{-1} 3542, 3263, 1418, 1357, 1186, 979, 793; δ_H(400 MHz; d^6-acetone) 6.26 (1H, br d, *J* 9, N*H*), 4.71 (1H, dd, *J* 4, 11.5, CH_AH_B-6), 4.35 (1H, dd, *J* 8, 11.5, CH_AH_B-6), 4.22 (1H, br s, O*H*), 3.89 (1H, dd, *J* 11.5, 4.5, CH_AH_BOH), 3.76 (1H, dd, *J* 11.5, 6, CH_AH_BOH), 3.64 (1H, dt, *J* 4, 8, C*H*-5), 3.49 (1H, m, C*H*-4), 3.45 (3H, s, OCH_3); δ_C(100 MHz; d^6-acetone) 71.5, 70.6, 61.0, 60.5, 58.2; characterisation of *syn*-4(*RS*),5(*SR*) diastereoisomer: colourless cubic crystals, mp 114–115 °C (from EtOAc–petrol(bp 40–60 °C)); R_f 0.15 (Et_2O); ν_{max}(film)/cm^{-1} 3267, 2925, 1431, 1360, 1186, 1035, 967, 791; δ_H(400 MHz; d^6-acetone) 6.11 (1H, br d, *J* 11, N*H*), 4.81 (1H, dd, *J* 13, 1.5, CH_AH_B-6), 4.59 (1H, d, *J* 13, CH_AH_B-6), 4.05 (1H, m, C*H*-5), 3.86 (1H, m, C*H*-4), 3.75 (1H, dt, *J* 11, 7.5, CH_AH_B-OH), 2.32 (1H, dt, *J* 11, 5, CH_AH_BOH), 3.48 (1H, br s, O*H*), 3.45 (3H, s, OCH_3); δ_C(100 MHz; d^6-acetone) 72.8, 69.7, 61.6, 61.0, 57.0; *m*/*z* (CI) 215.0702 (100%, M + NH_4^+, $C_5H_{15}N_2O_5S$ requires 215.0702), 91 (5), 58 (55).

4-Hydroxymethyl-2,2-dioxo-[1,2,3]oxathiazinane-6-carboxylic acid ethyl ester 28. Prepared by means of the general TA procedure over 2 days, using sulfamate ester **20d** (114 mg, 0.51 mmol), *n*PrOH (6 ml), NaOH (19 mg, 0.47 mmol), H_2O (6 ml), *t*BuOCl (58 µl, 0.51 mmol), EtN(*i*Pr)$_2$ (5 µl, 26 µmol), $K_2OsO_4\cdot 2H_2O$ (8 mg, 20 µmol) gave recovered starting material (24 mg, 21%) along with the *title compound* **28** (61 mg, 50%) as a 4 : 1 mixture of diastereoisomers. Characterisation of the major *syn*-4(*SR*),6(*RS*) diastereoisomer: colourless oil; R_f 0.26 (Et_2O); ν_{max}(film)/cm^{-1} 3529, 3261, 1744, 1372, 1191, 1102, 1046, 886, 829; δ_H(400 MHz; d^6-acetone) 5.06 (1H, dd, *J* 12.5, 3, C*H*-6), 4.02 (2H, q, *J* 7.5, CH_2CH_3), 3.96 (1H, br s, N*H*), 3.25 (1H, m, C*H*-4), 2.93 (1H, ddd, *J* 4, 6, 11, CH_AH_BOH), 2.73 (1H, dt, *J* 11, 3.5, CH_AH_BOH), 3.22 (1H, dt, *J* 14, 12.5, CH_AH_B-5), 1.34 (1H, *J* 14, 3, CH_AH_B-5), 1.03 (3H, t, *J* 7.5, CH_2CH_3); δ_C(100 MHz; d^6-acetone) 167.0, 78.5, 63.1, 62.6, 55.5, 27.8, 14.0; *m*/*z* (CI) 257.0808 (100%, M + NH_4^+, $C_7H_{17}N_2O_6S$ requires 257.0807), 128 (15).

4-(*tert*-Butyldimethylsilanyloxymethyl)-2,2-dioxo-[1,2,3]oxathiazinane-3-carboxylic acid benzyl ester 35. a) Imidazole (49 mg, 0.72 mmol), *tert*-butyldimethylchlorosilane (108 mg, 0.72 mmol) and (2,2-dioxo-[1,2,3]oxathiazinan-4-yl)-methanol **23** (100 mg, 0.60 mmol) were stirred in anhydrous dimethylformamide (2 ml) under an atmosphere of Ar for 14 h. The reaction was then diluted with Et_2O (15 ml), then washed with H_2O (2 × 5 ml) and brine (10 ml). The organics were dried (Na_2SO_4) and evaporated. The subsequent crude residue was the purified on silica gel, eluting with Et_2O–petrol(bp 40–60 °C) 2 : 1, delivering 4-(*tert*-butyldimethylsilanyloxymethyl)-[1,2,3]-oxathiazinane 2,2-dioxide (160 mg, 95%) as a white solid; mp 89–91 °C (from Et_2O); R_f 0.30 (1 : 1, Et_2O–petrol(bp 40–60 °C)); ν_{max}(film)/cm^{-1} 3266, 2925, 2856, 1405, 1363, 1119, 797; δ_H(400 MHz; $CDCl_3$) 4.75 (1H, dt, *J* 2.5, 11.5, CH_AH_B-6), 4.57 (1H, ddd, *J* 11.5, 5, 1.5, CH_AH_B-6), 4.40 (1H, br d, *J* 10.5, N*H*), 3.85–3.75 (2H, m, CH_AH_BO, C*H*-4), 3.65 (1H, dd, *J* 11, 2.5, CH_AH_BO), 2.16 (1H, m, CH_AH_B-5), 1.52 (1H, m, CH_AH_B-5), 0.91 (9H, s, C(CH_3)$_3$), 0.08 (6H, s, Si(CH_3)$_3$)); δ_C(100 MHz; $CDCl_3$) 71.6, 64.2, 56.4, 26.0, 25.6, 18.5, −4.37, −5.41; *m*/*z* (CI) 299.1458 (100%, M + NH_4^+, $C_{10}H_{27}N_2O_4SiS$

requires 299.1461), 282 (30, M + H$^+$), 224 (25, M − *t*Bu), 116 (20).

b) A solution of 4-(*tert*-butyldimethylsilanyloxymethyl)-[1,2,3]oxathiazinane 2,2-dioxide (100 mg, 0.36 mmol) in anhydrous DME (3 ml) was added dropwise to a solution of sodium *tert*-butoxide (51 mg, 0.53 mmol) in anhydrous DME (1 ml) under an atmosphere of Ar. The suspension was stirred for 1.5 h then benzyl chloroformate (80 µl, 0.53 mmol) was added dropwise and the reaction stirred for a further 14 h. The reaction was the partitioned between EtOAc (10 ml) and H_2O (10 ml). After separation, the aqueous phase was dried ($MgSO_4$) and evaporated. The crude residue was then purified on silica gel, eluting with Et_2O–petrol(bp 40–60 °C) 1 : 1, delivering the *title compound* **35** (133 mg, 90%) as a colourless oil; R_f 0.39 (1 : 1, Et_2O–petrol(bp 40–60 °C)); ν_{max}(film)/cm^{-1} 2954, 2930, 2857, 1740, 1392, 1282, 1179, 839; δ_H(400 MHz; $CDCl_3$) 7.5–7.3 (5H, m, Ar*H*), 5.31 (2H, AB q, OCH_2Ph), 4.75 (1H, dt, *J* 6, 11.5, CH_AH_B-6), 4.7–4.6 (2H, m, CH_AH_B-6, C*H*-4), 3.85–3.75 (2H, m, CH_2O), 2.40 (1H, m, CH_AH_B-5), 2.27 (1H, m, CH_AH_B-5), 0.87 (9H, s, $C(CH_3)_3$), 0.05 (6H, s, $Si(CH_3)_2$); δ_C(100 MHz; $CDCl_3$) 152.2, 134.8, 128.8, 128.6, 128.0, 70.3, 69.6, 61.6, 58.4, 25.9, 22.4, 18.3, −5.3, −5.4; *m/z* (CI) 433.1825 (100%, M + NH_4^+, $C_{18}H_{33}N_2O_6SiS$ requires 433.1829), 299 (20), 246 (20), 228 (15), 108 (45).

(1-Hydroxymethyl-3-morpholin-4-yl-propyl)-carbamic acid benzyl ester 36. Morpholine (19 µl, 0.21 mmol) was added to a solution of *N*-Cbz **35** (44 mg, 0.11 mmol) in acetonitrile (1 ml) at rt under an atmosphere of Ar. The reaction was stirred for 14 h then diluted with EtOAc (2 ml) and 1 M aqueous HCl (2 ml). After stirring for 1 h, 2 M aqueous NaOH (3 ml) was added and the mixture was extracted with EtOAc (2 × 5 ml). The organics were dried (Na_2SO_4) and evaporated and the crude residue was purified on silica gel, eluting with EtOAc (10% MeOH), delivering the *title compound* **36** (28 mg, 86%) as a slightly yellow oil; R_f 0.21 (EtOAc (10% MeOH)); ν_{max}(film)/cm^{-1} 3316, 2955, 2857, 1697, 1538, 1252, 1162, 1069; δ_H(270 MHz; $CDCl_3$) 7.4–7.3 (5H, m, ArH), 5.77 (1H, br d, *J* 10, N*H*), 5.08 (2H, br s, OCH_2Ph), 3.9–3.5 (7H, br m, C*H*N, CH_2OH, 2 × OCH_2CH_2N), 2.7–2.2 (6H, br m, NCH_2, 2 × OCH_2CH_2N), 1.90 (1H, m, CH_AH_BOH), 1.77 (1H, m, CH_AH_BOH); δ_C(67.5 MHz; $CDCl_3$) 156.2, 136.6, 128.6, 128.2, 128.1, 66.8, 66.6, 64.8, 53.7, 53.4, 51.4, 28.5; *m/z* (CI) 309.1816 (20%, M + H$^+$, $C_{16}H_{25}N_2O_2$ requires 309.1814), 201 (100, M − BnOH$^+$), 100 (20).

[1-(*tert*-Butyldimethylsilanyloxymethyl)-3-phenylsulfanylpropyl]-carbamic acid benzyl ester 37. Thiophenol (26 µl, 0.25 mmol) and potassium carbonate (35 mg, 0.25 mmol) were added to a stirred solution of *N*-Cbz **35** (46 mg, 0.11 mmol) in acetonitrile (1 ml) at rt under an atmosphere of Ar. The reaction was then diluted with EtOAc (3 ml) and 1 M aqueous KH_2PO_4 (2 ml) then stirred for a further 20 h. The reaction was then treated with 2 M aqueous NaOH (5 ml) and extracted with EtOAc (10 ml). After separation, the aqueous was extracted again with EtOAc (2 × 5 ml) then the combined organics were dried (Na_2SO_4) and evaporated. The crude residue was then purified on silica, eluting with Et_2O–petrol(bp 40–60 °C) 1 : 3, to give the *title compound* **37** (42 mg, 85%) as a light yellow oil; R_f 0.28 (1 : 3, Et_2O–petrol(bp 40–60 °C)); ν_{max}(film)/cm^{-1} 2952, 2928, 1701, 1526, 1255, 1063; δ_H(400 MHz; $CDCl_3$) 7.4–7.1 (10H, m, Ph*H*), 5.11 (2H, br s, OCH_2Ph), 4.95 (1H, br d, *J* 8.5, N*H*), 3.85 (1H, br m, C*H*N), 3.59 (2H, m, CH_2O), 2.96 (2H, m, SCH_2), 1.85 (2H, m, $CH_2CH_2CH_2$), 0.86 (9H, s, $C(CH_3)_3$), 0.02 (6H, s, $Si(CH_3)_2$); δ_C(100 MHz; $CDCl_3$) 156.2, 136.7, 136.3, 134.9, 129.5, 129.0, 128.7, 128.3, 126.2, 22.9, 64.9, 52.0, 31.8, 30.6, 26.0, 18.4, −5.4; *m/z* (CI) 446.2177 (100%, M + H$^+$, $C_{24}H_{36}NO_3SiS$ requires 446.2185), 388 (20), 228 (15), 314 (10), 131 (10), 108 (10), 91 (30).

(Tetrahydrofuran-3-yl)-carbamic acid benzyl ester sulfamic acid 38. A solution of TBAF (0.17 ml, 0.17 mmol, 1 M in THF) was added dropwise to a stirred solution of *N*-Cbz **35** (36 mg, 0.09 mmol). The reaction was stirred for 1 h, then diluted with EtOAc (5 ml) and 1 M aqueous KH_2PO_4 (5 ml) and stirring was continued for 1 h. The aqueous was then separated and extracted with EtOAc (3 × 5 ml). The organics were dried (Na_2SO_4) and evaporated and the subsequent crude residue was purified on silica gel, eluting with Et_2O–petrol(bp 40–60 °C) 2 : 1, delivering the *title compound* **38** (16 mg, 62%) as a light yellow oil; R_f 0.16 (2 : 1, Et_2O–petrol(bp 40–60 °C)); ν_{max}(film)/cm^{-1} 3252, 1749, 1424, 1367, 1270, 1189, 783; δ_H(400 MHz; $CDCl_3$) 7.45–7.35 (5H, m, Ar*H*), 5.18 (2H, s, OCH_2Ph), 4.86 (1H, m, CH_AH_B-5), 4.56 (1H, ddd, *J* 12, 5, 2, CH_AH_B-5), 4.50 (1H, br d, *J* 10.5, O*H*), 4.30 (1H, dd, *J* 4, 11, CH_AH_B-2), 4.24 (1H, dd, *J* 3.5, 11, CH_AH_B-2), 4.02 (1H, m, C*H*-3), 2.01 (1H, m, CH_AH_B-4), 1.67 (1H, dq, *J* 14.5, 2.5, CH_AH_B-4); δ_C(100 MHz; $CDCl_3$) 154.7, 134.7, 129.1, 128.9, 128.6, 71.4, 70.6, 68.3, 54.6, 25.8; *m/z* (CI) 319.0974 (100%, M + NH_4^+, $C_{12}H_{19}N_2O_6S$ requires 319.0964), 222 (10), 211 (25), 185 (5), 108 (25), 91 (10).

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References

1 (*a*) D. J. Ager, I. Prakash and D. R. Schaad, *Chem. Rev.*, 1996, **96**, 835; (*b*) S. C. Bergmeier, *Tetrahedron*, 2000, **56**, 2561.
2 (*a*) G. Li, H.-T. Chang and K. B. Sharpless, *Angew. Chem., Int. Ed. Engl.*, 1996, **35**, 451; (*b*) for review articles see J. A. Bodkin and M. D. McLeod, *J. Chem. Soc., Perkin Trans. 1*, 2002, 2733; P. O’Brien, *Angew. Chem., Int. Ed.*, 1999, **38**, 326.
3 H. C. Kolb, M. S. VanNieuwenhze and K. B. Sharpless, *Chem. Rev.*, 1994, **94**, 2483.
4 For review of imido-osmium complexes see K. Muñiz, *Chem. Soc. Rev.*, 2004, **33**, 166.
5 B. Tao, G. Schlingloff and K. B. Sharpless, *Tetrahedron Lett.*, 1998, **39**, 2507.
6 (*a*) K. L. Reddy and K. B. Sharpless, *J. Am. Chem. Soc.*, 1998, **120**, 1207; (*b*) P. O’Brien, S. A. Osborne and D. D. Parker, *J. Chem. Soc., Perkin Trans. 1*, 1998, 2519.
7 (*a*) R. Angelaud, O. Babot, T. Charvet and Y. Landais, *J. Org. Chem.*, 1999, **64**, 9613; (*b*) H. Han, C.-W. Cho and K. D. Janda, *Chem. Eur. J.*, 1999, **5**, 1565.
8 (*a*) T. J. Donohoe, P. D. Johnson and R. J. Pye, *Org. Biomol. Chem.*, 2003, **1**, 2025; (*b*) T. J. Donohoe, P. D. Johnson, M. Helliwell and M. Keenan, *Chem. Commun.*, 2001, 2078; (*c*) T. J. Donohoe, P. D. Johnson, A. Cowley and M. Keenan, *J. Am. Chem. Soc.*, 2002, **124**, 12934; (*d*) T. J. Donohoe, P. D. Johnson, R. J. Pye and M. Keenan, *Org. Lett.*, 2004, **6**, 2583.
9 M. N. Kenworthy, G. D. McAllister and R. J. K. Taylor, *Tetrahedron Lett.*, 2004, **45**, 6661.
10 (*a*) C. G. Espino, P. M. Wehn, J. Chow and J. Du Bois, *J. Am. Chem. Soc.*, 2001, **123**, 6935; (*b*) P. M. Wehn and J. Du Bois, *J. Am. Chem. Soc.*, 2002, **124**, 12950; (*c*) P. M. Wehn, J. Lee and J. Du Bois, *Org. Lett.*, 2003, **5**, 4823; (*d*) J. J. Fleming, K. W. Fiori and J. Du Bois, *J. Am. Chem. Soc.*, 2003, **125**, 2028; (*e*) K. W. Fiori, J. J. Fleming and J. Du Bois, *Angew. Chem., Int. Ed.*, 2004, **43**, 4349.
11 J.-L. Liang, S.-X. Yuan, P. W. H. Chan and C.-M. Che, *Org. lett.*, 2002, **4**, 4507.
12 F. Duran, L. Leman, A. Ghini, G. Burton, P. Dauban and R. Dodd, *Org. Lett.*, 2002, **4**, 2481.
13 For review see R. E. Meléndez and W. D. Lubell, *Tetrahedron*, 2003, **59**, 2581.
14 J. W. Timberlake, W. J. Ray Jr. and C. L. Klein, *J. Org. Chem.*, 1989, **54**, 5824.
15 M. Okada, S. Iwashita and N. Koizumi, *Tetrahedron Lett.*, 2000, **41**, 7047.
16 A yield could not be obtained from this reaction due to the volatility of 2,2-dimethyl-but-3-en-1-ol.
17 P. Dauban and R. H. Dodd, *Org. Lett.*, 2000, **2**, 2327.
18 Crystal data for **26a**: $C_5H_{11}NO_5S$, M = 197.21, triclinic, a = 7.3712(5), b = 7.4301(5), c = 9.0586(6) Å, V = 404.73(5) Å^3, T = 115(2) K, space group $P\bar{1}$, Z = 2, μ(Mo-Kα) = 0.385 mm^{-1}, 2291

reflections measured ($R_{int} = 0.0149$). The final R value was 0.0310 (all data). Crystal data for **26b**: $C_5H_{11}NO_5S$, $M = 197.21$, monoclinic, $a = 7.4175(4)$, $b = 8.7683(5)$, $c = 12.4464(7)$ Å, $V = 809.46(8)$ Å^3, $T = 115(2)$ K, space group $P2(1)/n$, $Z = 4$, μ(Mo-Kα) = 0.385 mm^{-1}, 2345 reflections measured ($R_{int} = 0.0239$). The final R value was 0.0296 (all data). CCDC reference numbers 253422 (**26a**) and 253423 (**26b**). See http://www.rsc.org/suppdata/ob/b4/b416477f/ for crystallographic data in .cif or other electronic format.

19 P. D. Bartlett and S. D. Ross, *J. Am. Chem. Soc.*, 1948, **70**, 926.

20 (*a*) R. Näf-Müller, W. Pickenhagen and B. Willhalm, *Helv. Chim. Acta*, 1981, **131**, 1424; (*b*) P. Wipf and D. C. Aslan, *J. Org. Chem.*, 2001, **66**, 337.

21 J. A. Macritchie, A. Silcock and C. L. Willis, *Tetrahedron: Asymmetry*, 1997, **23**, 3895.

22 A. Padwa, G. D. Kennedy and M. W. Wannamaker, *J. Org. Chem.*, 1985, **50**, 5334.

23 Adapted from a procedure developed by Donohoe *et al.*, see ref. 8.

24 M. J. Mintz and C. Walling, *Org. Synth.*, 1973, **Coll. Vol. 5**, 184.