The stereoselective synthesis of oxetanes; exploration of a new, Mitsunobu-style procedure for the cyclisation of 1,3-diols

Martin Christlieb,[a] John E. Davies,[a] Jason Eames,[a,b] Richard Hooley[a] and Stuart Warren*[a]

[a] *University Chemical Laboratories, Lensfield Road, Cambridge, England CB2 1EW. E-mail: sw134@cam.ac.uk*
[b] *Queen Mary, University of London, London, England E1 4NS*

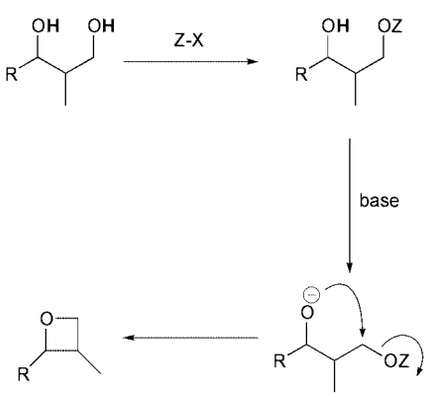
Received (in Cambridge, UK) 1st August 2001, Accepted 27th September 2001
First published as an Advance Article on the web 30th October 2001

A solution of 2-methyl-3-[1-(phenylsulfanyl)cyclohexyl]propane-1,3-diol **1** in toluene treated with triphenylphosphine, Ziram® **2** and DEAD, gave 3-methyl-2-[1-(phenylsulfanyl)cyclohexyl]oxetane **3** in 85% yield. A mechanistic study has been undertaken, optimal conditions have been found and the range of substrates for which the reaction is useful has been explored. We include the results of an X-ray study which shows that compound **33** (the oxidation product of diol **1**) is a sulfone rather than a sulfoxide as previously reported.

Introduction

The synthesis of oxetanes is an important challenge; oxetanes are both synthetic targets and potentially useful synthetic intermediates. Many natural products contain an oxetane ring; examples include: Taxol™,[1] laureacetal-A[2] and clementein.[3] Oxetanes have also been included in synthetic pharmaceutical compounds such as the antibiotic oxetin[4] and the antiviral agent oxetanocin.[5] Oxetanes may be used in synthesis as equivalents for the a^3-synthon as they are highly strained and readily opened by nucleophiles. Conditions have been reported which allow nucleophilic attack to open the ring without loss of the stereochemical information.[6]

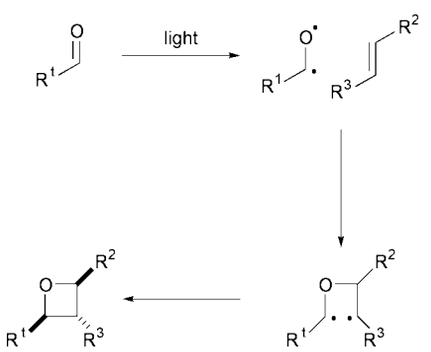
The synthesis of oxetanes has been reviewed, most recently by Lindeman.[7] One common method is *via* the dehydration of 1,3-diols, in which transformation of one of the two hydroxy groups into a leaving group followed by treatment with base causes cyclisation to the corresponding oxetane (Scheme 1).[8]



Scheme 1

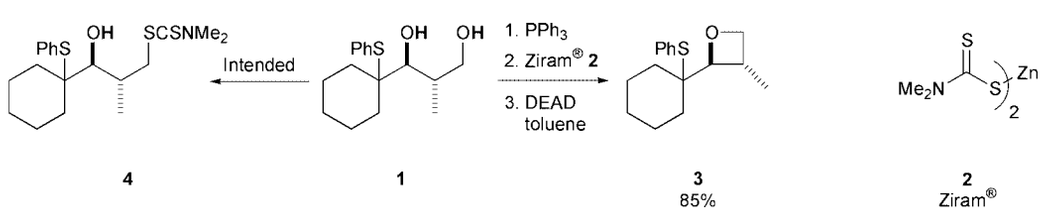
These reactions are occasionally very successful. The formation of the oxetane D-ring in Taxol proceeds in 85% yield,[1] but with many substrates the thermodynamic and kinetic barriers that stand in the way of four-membered ring formation dominate and yields are moderate at best, particularly with acyclic diols.[9]

The [2+2]-photocycloaddition reaction of an alkene and an aldehyde (Patternó–Büchi reaction) has been used with considerable success. Bach and co-workers have reported the synthesis of oxetanes in good yields and high stereoselectivities, both relative and absolute.[10] Although the stereoselectivity is usually excellent, the large substituents on the ring adopt an *anti*-relationship to each other, regardless of alkene stereochemistry. This relative configuration cannot be altered (Scheme 2) and is also observed in other oxetane syntheses.[11]



Scheme 2

During an attempt to form **4**, *via* a Mitsunobu[12] replacement of the primary hydroxy group of diol **1** with an *N,N*-dimethyldithiacarbamate we treated a solution of diol[13] **1** in toluene with triphenylphosphine, Ziram® (zinc *N,N*-dimethyldithiacarbamate) **2**, and DEAD at room temperature.[14] After 5 minutes the solution was filtered and purified to give oxetane **3** in 85% yield (Scheme 3).



4 **1** **3** 85% **2** Ziram®

Scheme 3

DOI: 10.1039/b106851b

The result outlined in Scheme 3 seemed to offer a solution to the problem of cyclising 1,3-diols in good yields. The reaction seemed particularly promising in light of the ease with which 1,3-diols can be synthesised using an aldol reaction with absolute control over the stereochemistry. The stereoselective synthesis of 1,3-diols has been amply reviewed [15] and will not be discussed further, except to point out the techniques used in the synthesis of our substrates.

Results and discussion

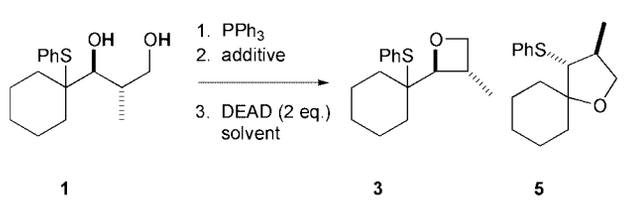
Optimisation of reaction conditions

We have explored the effect of conditions on the reaction, including the effect of changing the solvent, the additive (Ziram®, other zinc salts or benzyl sulfide) and the molar equivalents of Ziram® (Scheme 4). In all these experiments the proportions of triphenylphosphine and DEAD were maintained at 2.2 and 2 equivalents with respect to the diol substrate. Oxetane **3** and THF **5** were the only compounds isolated from or detected in these reactions. The formation of THF **5** will be explored in the next section.

The optimum quantity of Ziram® was found to be 2 equivalents with respect to diol **1**. Reducing the proportion of Ziram® reduced the yield of oxetane. Increasing the proportion of Ziram® not only reduced the yield but allowed the formation of THF **5** to dominate the product mixture (Scheme 4, Table 1, entries 1–3). A standard Mitsunobu reaction, *i.e.* omitting the Ziram®, gave a low yield of products with THF **5** dominating the mixture (Scheme 4, Table 1, entry 4).

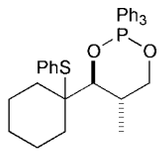
Changing Ziram® for an alternative zinc salt (zinc acetate or zinc bromide) gave both lower yields and lower ratios of oxetane **3** to THF **5**. Zinc bromide gave a better yield of oxetane **3** than zinc acetate, albeit at a slightly lower overall yield of products (Scheme 4, Table 1, entries 5 and 6). Changing Ziram® for an alternative sulfur nucleophile ($PhCH_2SH$) gave almost exclusively THF **5** in moderate yield (Scheme 4, Table 1, entry 7).

Using Ziram® as the additive we found that we obtained better yields of oxetane **3** with toluene as solvent than either tetrahydrofuran or dichloromethane. Use of dichloromethane as a solvent gave an equimolar mixture of THF **5** and oxetane **3** in moderate yield. Tetrahydrofuran as solvent gave a lower yield of both THF **5** and oxetane **3** and the yield of oxetane **3** was inferior to that obtained in toluene (Scheme 4, Table 1, entries 2, 8 and 9). A discussion of these results will be easier in light of the observations made during our NMR investigation of the mechanism of our modified Mitsunobu reaction (next section).



1 3 5

Scheme 4



6

δ_P = –55 ppm

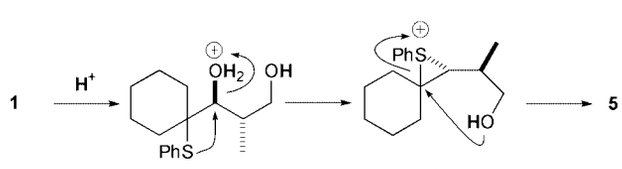
Fig. 1

Investigation of the role of Ziram® in our modified Mitsunobu reaction

During a typical Mitsunobu reaction a phosphorus atom undergoes changes in co-ordination number and oxidation state.[16] Since the chemical shift of a phosphorus atom changes greatly (and predictably) with changes in co-ordination number and oxidation state, we decided to follow the course of our modified Mitsunobu reaction by ^{31}P NMR with the aim of getting some mechanistic insight into the course of the reaction and the role that Ziram® was playing.

DEAD was added to a solution of triphenylphosphine and diol **1** in $CDCl_3$. An initial ^{31}P NMR showed a peak at −55 ppm; the ^1H NMR spectrum showed no evidence for the formation of either oxetane **3** or THF **5**. With time the peak at −55 ppm disappeared and a new peak at +29 ppm was observed (a ^{31}P NMR peak at +29 ppm has been reported for triphenylphosphine oxide [18]). The ^1H NMR spectrum revealed formation of THF **5** which was isolated in 21% yield. It is known that pentavalent phosphorus will give a ^{31}P NMR resonance in the −50 ppm region.[16] We suggest that the observed peak at −55 ppm corresponds to phosphorane **6** (Fig. 1).

From previous work we know that THF **5** may be formed, with the illustrated stereochemistry, by treating diol **1** with toluene-*p*-sulfonic acid in dichloromethane.[14] The observed stereochemistry suggests that the reaction starts by protonation of the secondary hydroxy group. The protonated hydroxy group is displaced, with inversion, by the neighbouring sulfur atom to give the three-membered sulfonium cation **8-H**. The primary hydroxy group then attacks the sulfonium cation at the more substituted carbon to give THF **5** (Scheme 5).



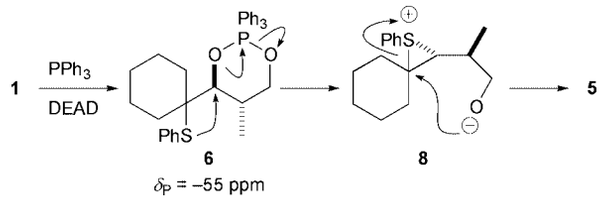
Scheme 5

We suggest that the reaction between diol **1** and triphenylphosphine–DEAD in $CDCl_3$ proceeds according to Scheme 6. Initially the diol **1** reacts with the triphenylphosphine–DEAD adduct to give the phosphorane **6**. Participation of the sulfur atom causes expulsion of triphenylphosphine oxide to give the *epi*-sulfonium zwitterion **8** which cyclises to give THF **5**.

The Mitsunobu reaction was repeated with the addition of $PhCH_2SH$ to the reaction mixture. ^{31}P NMR resonances at

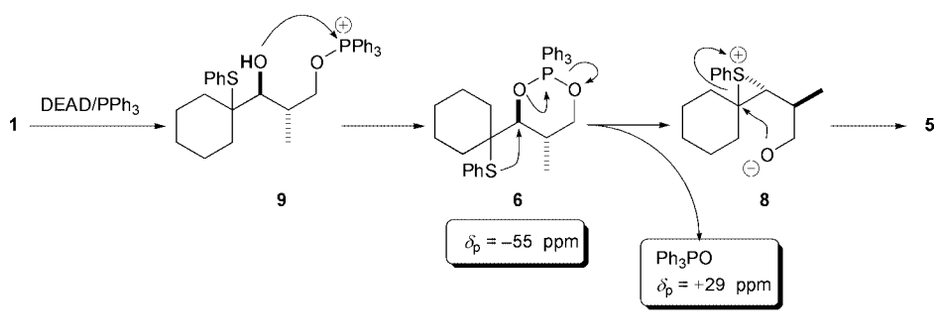
Table 1 Optimisation of reaction conditions for the transformation of diol **1** into oxetane **3**

Entry	PPh_3 (eq.)	Additive	Solvent	Yield (%)	Oxetane **3**–THF **5**
1	2.2	Ziram® (1 eq.)	Toluene	69	100 : 0
2	2.2	Ziram® (2 eq.)	Toluene	85	100 : 0
3	3.3	Ziram® (3 eq.)	Toluene	49	18 : 82
4	2.2	None	Toluene	21	20 : 80
5	2.2	$ZnBr_2$	Toluene	16	36 : 64
6	2.2	$Zn(OAc)_2$	Toluene	20	17 : 83
7	2.2	$PhCH_2SH$	Toluene	41	2 : 98
8	2.2	Ziram® (2 eq.)	CH_2Cl_2	43	58 : 42
9	2.2	Ziram® (2 eq.)	THF	73	88 : 12



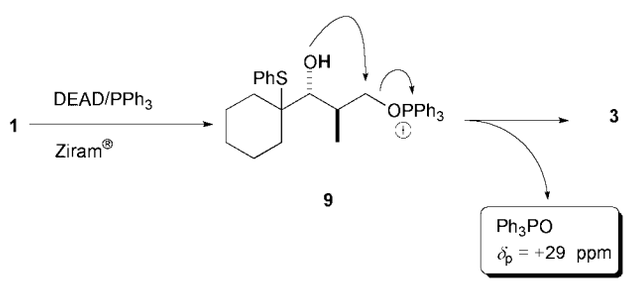
Scheme 6

+43 and +44 ppm, consistent with the intermediacy of phosphonium salts,[16] were observed. The peaks at +43 ppm and +44 ppm gave way to a peak at −55 ppm, consistent with phosphorane **6**. The peak at −55 ppm gave way to a new peak at +29 ppm (triphenylphosphine oxide). We suggest that, consistent with the accepted mechanism of the Mitsunobu reaction, triphenylphosphine attacks DEAD to give phosphonium salts which are attacked by diol **1** to give **9**. The phosphorus atom is then attacked by the secondary alcohol to give cyclic phosphorane **6** which rearranges, *via* **8**, to give THF **5** (Scheme 7).



Scheme 7

In contrast when DEAD was added to diol **1**, triphenylphosphine ($\delta_P = -5$ ppm), and Ziram® **2** in $CDCl_3$, a peak at +48 ppm (attributed to a phosphonium salt) was observed that directly gave rise to the peak at +29 ppm (Ph_3PO). Oxetane **3** was isolated from the reaction and we observed no resonance in the −55 ppm region (Scheme 8) so the phosphorane **6** was not formed under these conditions.



Scheme 8

We conclude that in the absence of Ziram® cyclisation of **9** to give the six-membered ring phosphorane **6** is faster than cyclisation of **9** to give four-membered ring oxetane **3**, as might be expected. Ziram® either prevents the formation of phosphorane **6** or slows its formation enough to allow formation of oxetane **3** *via* the attack of the secondary hydroxy group on the primary carbon. The nature of the interaction between the zinc cation and the substrate that inhibits formation of **9** is not understood, but may involve chelation of the sulfur and secondary hydroxy group preventing the secondary hydroxy group participating in the formation of phosphorane **9**.

The effect of substituent bulk on the yield of oxetane

To assess the contribution of the Thorpe–Ingold effect[17] we made a brief survey of the effect of substituent bulk and stereochemistry on the cyclisation of 1,3-diols using our Ziram® method. The chosen diols, **19**, **20** and **21** (Scheme 9), **25** and **27** (Scheme 10) were synthesised using the methods of DeGroot and Jansen,[18] Heathcock[19] and Masamune.[20] Oxidation of the sulfide to the sulfone prevented the sulfur-assisted rearrangement; the resulting oxetanes, **28**–**32**, were stable to toluene-*p*-sulfonic acid in refluxing dichloromethane.

DEAD was added to a mixture of triphenylphosphine, Ziram® **2** and substrate diol in toluene at room temperature. Filtration of the solution through cotton wool and purification gave the corresponding oxetanes (Scheme 11). Tertiary sulfones, **20** and **21**, cyclise in better yield than the secondary sulfone **19** and *gem*-dimethyl groups, as in **21**, between the two hydroxys are better than a single methyl group, as in **25** and **27**, for promoting cyclisation.

In the case of diols **25** and **27**, differing only in their relative stereochemistry, *anti*-diol **27** gave a better yield than the corresponding *syn*-diol **27** (Scheme 12).

Assignment of diols **19**–**21**, **25** and **27** as sulfones rather than the corresponding sulfoxides is not trivial. The ^{1}H NMR, ^{13}C NMR and IR spectra are not diagnostic. Mass spectra give fragments that could be assigned to M − SO_2Ph or M − SOPh and are therefore not diagnostic either. In an earlier publication we had erroneously assigned these compounds as sulfoxides.[21] To resolve the ambiguity, diol **1** was oxidised to **33** and converted to 3,5-dinitrobenzoate **34** (Scheme 13). X-Ray quality crystals were grown by the liquid drop method.[22] X-Ray analysis of these crystals gave confirmation that **33** was indeed a sulfone (Fig. 2).

Assessing the scope of the cyclisation reaction

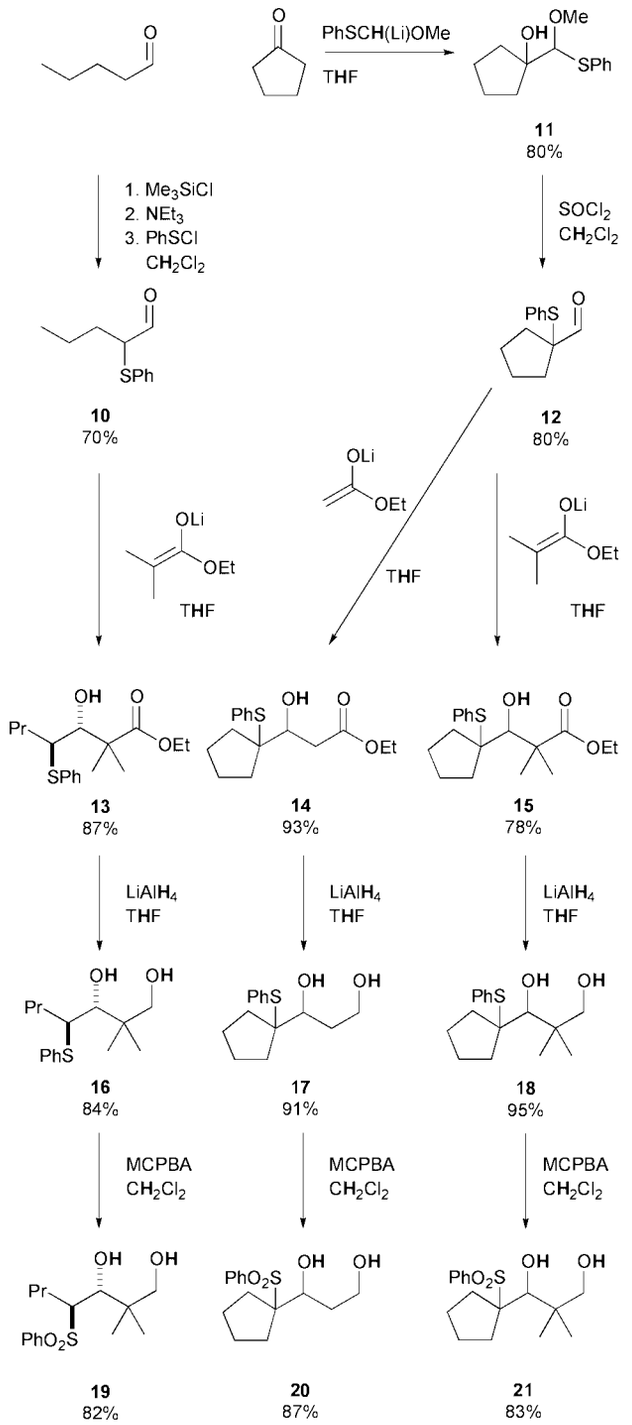
A wider range of 1,3-diols was synthesised by aldol reactions followed by reduction. Aldol reactions were conducted following the methods reported by Heathcock[19] and Masamune.[20] The aldol products were reduced using lithium aluminium hydride in tetrahydrofuran. The synthesis of *syn*- and *anti*-diols is shown below starting from aldehydes (Schemes 14–17, Tables 2 and 3).

DEAD (or DIAD) was added to a solution of triphenylphosphine, Ziram® and diol in toluene to give the product after purification. DIAD (diisopropyl azodicarboxylate) was used instead of DEAD for some reactions as the reduced DIAD was occasionally easier to separate from the product oxetane than reduced DEAD.

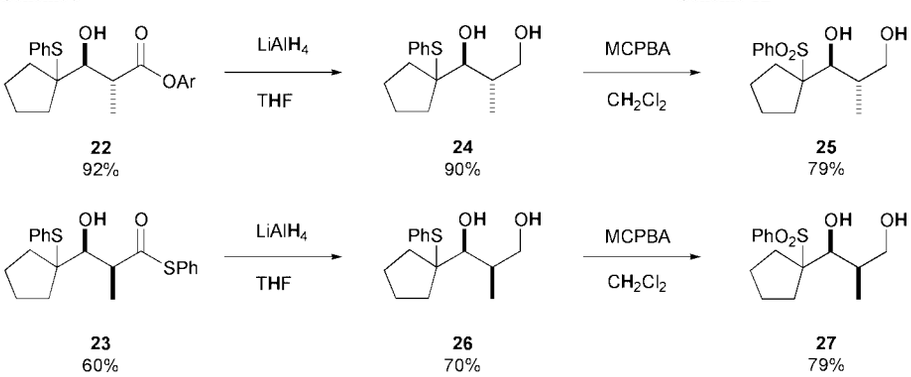
The diols used were chosen to represent a range of steric and electronic characteristics not present in the preceding examples. Each diol was treated to our Ziram® reaction; we also tried a selection of the diols with a commonly used cyclisation protocol. The results are shown below (Schemes 18 and 19 and Table 4).

The *anti*-diols give higher yields of oxetane than the corresponding *syn*-diols. The yields of oxetane obtained from diols **1**, **19**–**21**, **25**, **27** and **61** (containing the PhS/PhO_2S group) and diol **47** (with a bulky ^{t}Bu group) were good. With those diols that lacked the bulky groups only moderate to poor yields were observed. It would seem that 1,3-diols require the very large steric bulk represented by Me_3C, $R_2(SPh)C$ or $R_2(SO_2Ph)C$

groups in order to cyclise well. Conditions have been reported that remove sulfur from organic compounds in all of its three common oxidation states. As examples, sulfides may be removed to leave a hydrogen in its place,[23] sulfoxides have been thermally removed to leave alkenes[23,24] and sulfones have been eliminated with bases.[23,24]



Scheme 9



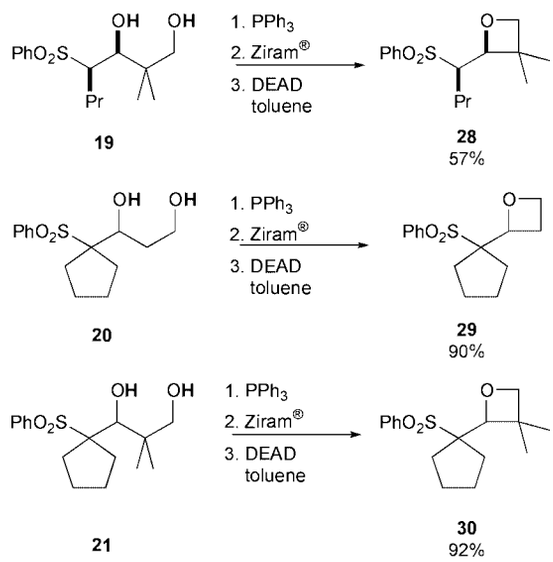
Scheme 10 (Ar = 2,6-dimethylphenyl).

1,3-Disubstituted-1,3-diols

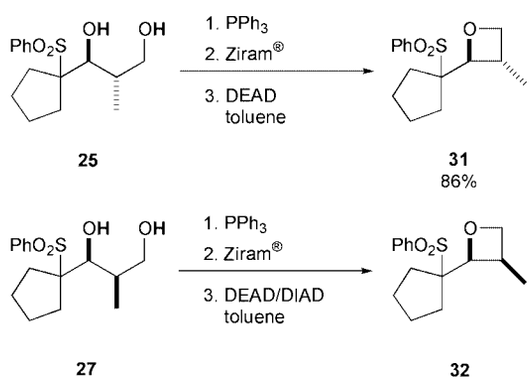
Diols **77** and **78** were synthesised by unselective reduction of hydroxyketone **76** and separation of the diastereoisomers (Scheme 20). Diols **77** and **78** were subjected to our Ziram® reaction; THFs **79** and **80** were isolated in quantitative yield. Although diols **77** and **78** both bear an SPh group no oxetane is observed.

Conclusion

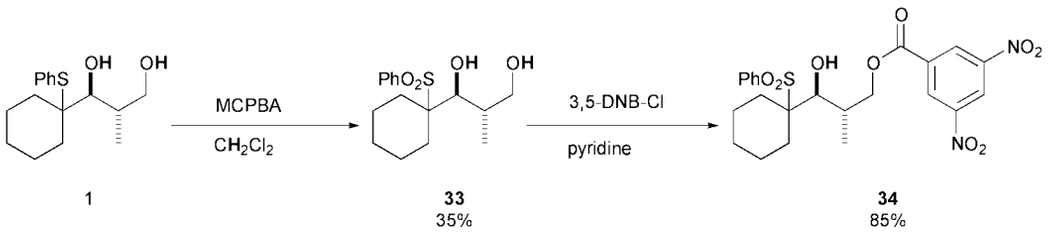
We have shown that treatment of certain 1,3-diols with Ziram® **2**, DEAD and triphenylphosphine in toluene gives the corresponding oxetane. The reaction gives good results with



Scheme 11



Scheme 12



Scheme 13

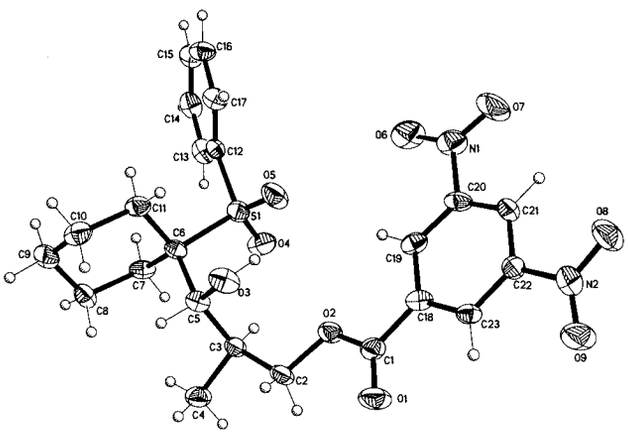
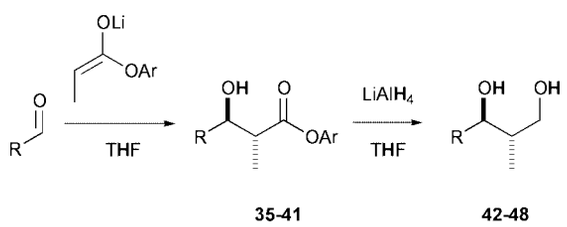


Fig. 2 ORTEP representation of sulfone **34**.

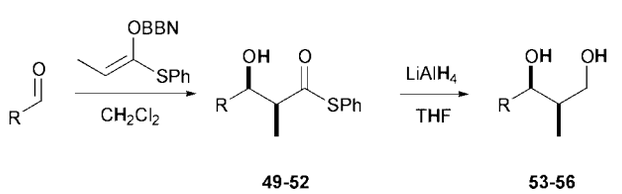


Scheme 14

Table 2 Hydroxyesters and diols from *anti*-selective aldol reactions

R	Yield of hydroxyester	Yield of 1,3-diol
Ph	**35**[a] 66%	**42** 78%
^{n}Bu	**36**[b] 64%	**43** 61%
$PhCH_2OCH_2$	**37**[b] 70%	**44** 67%
2-Furyl	**38**[b] 81%	**45** 95%
^{i}Pr	**39**[c] 91%	**46** 95%
^{t}Bu	**40**[c] 52%	**47** 93%
^{c}Hex	**41**[c] 91%	**48** 86%

[a] Ar = 2,6-di-*tert*-butyl-4-methylphenyl. [b] Ar = 2,6-di-*tert*-butyl-4-methoxyphenyl. [c] Ar = 2,6-dimethylphenyl.

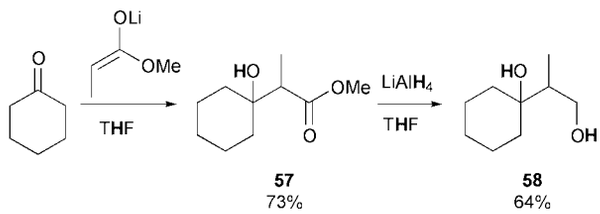


Scheme 15

Table 3 Thioesters and diols from the *syn*-selective aldol reactions

R	Yield of thioester	Yield of 1,3-diol
Ph	**49** 70%[a]	**53** 50%
^{n}Bu	**50** 64%	**54** 82%
$PhCH_2OCH_2$	**51**[b]	**55** 40%[c]
2-Furyl	**52** 90%[d]	**56** 84%

[a] 7 : 1 Mixture of diastereoisomers. [b] Inseparable from BBN-OH. [c] Yield over two steps. [d] 9 : 1 Mixture of diastereoisomers.



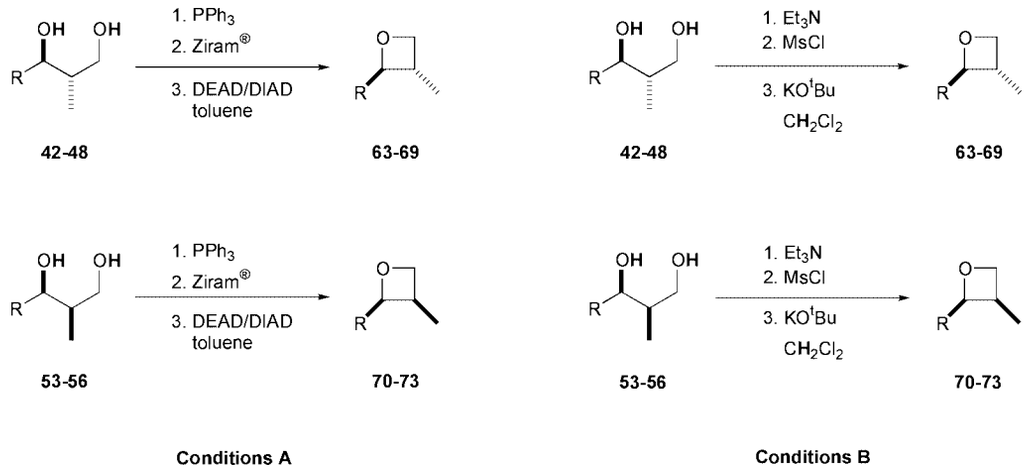
Scheme 16

Scheme 17

1,2-disubstituted-1,3-diols containing a tertiary phenylsulfanyl group, phenylsulfonyl group or *tert*-butyl group adjacent to the secondary hydroxy group. Indeed, our reaction is essential for cyclisation of diols containing a phenylsulfanyl group next to the secondary hydroxy.

Experimental

All solvents were distilled before use. Tetrahydrofuran and diethyl ether were freshly distilled from lithium aluminium hydride whilst dichloromethane, toluene, diisopropylamine, triethylamine and diisopropylethylamine were freshly distilled from calcium hydride. Triphenylmethane was used as an indicator for the tetrahydrofuran distillation. All non-aqueous reactions were carried out in oven or flame dried glassware under an argon atmosphere. All aqueous reagents are saturated unless otherwise stated. All reagents were used as supplied or distilled before use. Brine refers to a saturated solution of sodium chloride in water. Thin layer chromatography was carried out on commercially available pre-coated plates (Merck Kieselgel $60F_{254}$ silica). Flash column chromatography was carried out slightly above atmospheric pressure using Merck Kieselgel 60 (230–400 mesh). HPLC was performed using a Dynamax pre-packed column with a Gilson model 303 pump and a Cecil Instruments CE 212A UV detection system measuring the absorption between 245–247 nm. Melting points were measured on a Stuart Scientific SMP1 apparatus and are uncorrected. IR spectra were recorded on a Perkin Elmer 1600 series FT-IR spectrophotometer and were recorded against a background of chloroform solvent. NMR spectra were

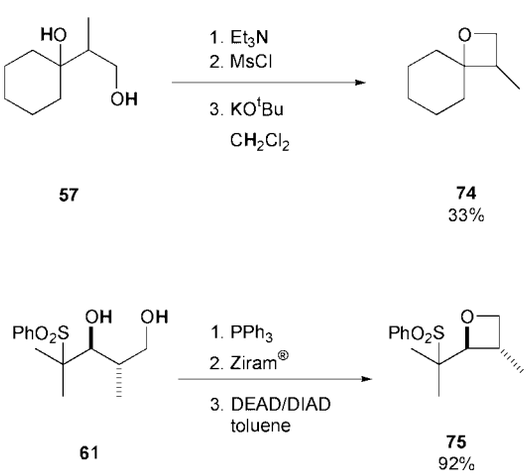


Scheme 18

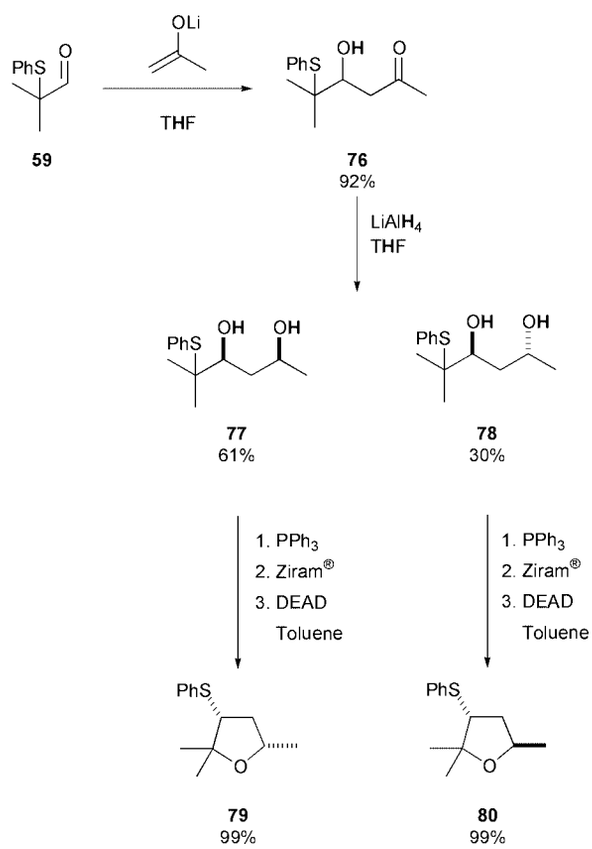
Table 4 Yields of oxetanes **63**–**73** obtained from cyclisation of *anti*-diols **42**–**48** and **53**–**56**

R (Diol)	Conditions A	Conditions B	R (Diol)	Conditions A	Conditions B
Ph (**42**)	**63** 20%	**63** 79%	Ph (**53**)	**70** 11%	**70** 50%
^{n}Bu (**43**)	**64** <17%[a]	**64** 28%	^{n}Bu (**54**)	**71** 0%	**71** 34%
$PhCH_2OCH_2$ (**44**)	**65** 50%	**65** 67%	$PhCH_2OCH_2$ (**55**)	**72** <35%[a]	**72** 32%
2-Furyl (**45**)	**66** 0%	**66** 0%	2-Furyl (**56**)	**73** 0%	**73**[b]
^{i}Pr (**46**)	**67** 5%	**67**[b]	[c]	[b]	[b]
^{t}Bu (**47**)	**68** 85%	**68**[b]	[c]	[b]	[b]
^{c}Hex (**48**)	**69** 3%	**69**[b]	[c]	[b]	[b]

[a] Product inseparable from impurities. [b] Not performed. [c] Substrate not synthesised.



Scheme 19



Scheme 20

recorded on Bruker Instruments AC-200, WM-250, AC/DPX250, AM-400 and DRX 500 MHz machines. Chemical shifts are measured relative to chloroform, $\delta_H = 7.2$ ppm $\delta_C = 77$ ppm and 85% phosphoric acid, $\delta_P = 0$ ppm. Chemical shifts are given in ppm and couplings in Hertz. Proton signals denoted '*' were observed to disappear after shaking the NMR solution of the compound with two drops of D_2O. Mass spectra were recorded on KRATOS MS890 and DS503 double focusing magnetic sector instruments. Light petroleum refers to the fraction boiling between 40–60 °C. Ether refers to diethyl ether.

(2*S**,3*S**)-3-Methyl-2-[(1′-phenylsulfanyl)cyclohexyl]oxetane 3 {and (3*R**,4*R**)-3-methyl-4-(phenylsulfanyl)-1-oxaspiro[4.5]-decane 5}

Table 1, entry 1 DEAD (60 mg, 0.35 mmol) was added to a solution of diol **1**[13] (100 mg, 0.35 mmol), Ziram® (105 mg, 0.35 mmol) and triphenylphosphine (100 mg, 0.39 mmol) in toluene (3 ml). The solution was stirred for 5 min before being filtered through cotton wool. The solvent was removed under reduced pressure and the residue purified by column chromatography eluting with light petroleum–ether (1 : 1) to give *oxetane* **3** (64 mg, 69%) as an oil, R_f (light petroleum–ether 9 : 1) 0.45; ν_{max}(film, $CHCl_3$)/cm^{-1} 1530 (SPh); δ_H(250 MHz; $CDCl_3$) 7.59–7.27 (5 H, m, SPh), 4.46 (1 H, dd, *J* 8.2 and 5.8, CH_AH_BO), 4.17 (1 H, dd, *J* 8.1 and 6.2, CH_AH_BO), 4.14 (1 H, t, *J* 5.9, CHO),

2.91 (1 H, m, C*H*Me), 2.01–1.05 (10 H, m, 5 × CH_2) and 1.25 (1 H, d, *J* 7.1, CH*Me*); δ_C(63 MHz; $CDCl_3$) 137.4, 131.0, 128.7, 128.5, 93.0, 74.0, 55.7, 31.4, 29.1, 28.3, 25.8, 21.9, 21.2 and 19.2; *m*/*z*(+CI) 262.1 (30%, M), 161.1 (100, C_4H_7SPh), 153.0 (40, M − SPh), 149.0 (35, C_3H_4SPh), 109.0 (20, PhSH) and 82.0 (25, C_5H_9) (Found: M^+, 262.1389. $C_{16}H_{22}OS$ requires *M*, 262.1391).

Table 1, entries 2–9: DEAD (60–120 mg), diol **1** (100 mg) and triphenylphosphine (100–300 mg) were combined with additives as described in Table 1. Oxetane **3** and THF **5** were obtained in the ratios quoted in Table 1. Data for THF **5** were in accordance with that obtained previously.[25]

Study of the reaction of diol 1 with triphenylphosphine and DEAD

DEAD (30 mg, 0.17 mmol) was added to a solution of triphenylphosphine (50 mg, 0.19 mmol) and diol **1** (50 mg, 0.17 mmol) in $CDCl_3$ (2 ml). The solution was stirred for 1 min. ^{31}P and ^1H NMR spectra were acquired after 5 min. δ_P (100 MHz; $CDCl_3$) −55 ppm, ^1H NMR showed neither oxetane **3** nor THF **5**. Further ^{31}P and ^1H NMR spectra were acquired after 1 h. δ_P(100 MHz; $CDCl_3$) +29 ppm, ^1H NMR showed THF **5** was formed.

Study of the reaction of diol 1 with triphenylphosphine, benzylthiol and DEAD

DEAD (30 mg, 0.17 mmol) was added to a solution of triphenylphosphine (50 mg, 0.19 mmol), $PhCH_2SH$ (21 mg, 0.17 mmol) and diol **1** (50 mg, 0.17 mmol) in $CDCl_3$ (2 ml). The solution was stirred for 1 min. ^{31}P and ^1H NMR spectra were acquired after 5 min. δ_P (100 MHz; $CDCl_3$) +43 and +44 ppm, ^1H NMR showed neither oxetane **3** nor THF **5**. Further ^{31}P and ^1H NMR spectra were acquired after 30 min δ_P (100 MHz; $CDCl_3$) −55 ppm. After 2 h δ_P (100 MHz; $CDCl_3$) +29 ppm, ^1H NMR showed THF **5** was formed.

Study of the reaction of diol 1 with triphenylphosphine, Ziram® and DEAD

DEAD (30 mg, 0.17 mmol) was added to a solution of triphenylphosphine (50 mg, 0.19 mmol), Ziram® (52 mg, 0.17 mmol) and diol **1** (50 mg, 0.17 mmol) in $CDCl_3$ (2 ml). The solution was stirred for 1 min. ^{31}P and ^1H NMR spectra were acquired after 5 min. δ_P (100 MHz; $CDCl_3$) +48 ppm (major) and +29 ppm (minor), ^1H NMR showed neither oxetane **3** nor THF **5**. Further ^{31}P and ^1H NMR spectra were acquired after 2 h. δ_P (100 MHz; $CDCl_3$) +48 ppm (minor) and +29 ppm (major), ^1H NMR showed peaks identical to those observed for oxetane **3**.

Ethyl (3*R**,4*S**)-2,2-dimethyl-3-hydroxy-4-phenylsulfanylheptanoate 13

n-Butyllithium (7.76 ml, 1.3 M in hexanes, 10.1 mmol) was added to a solution of diisopropylamine (1.29 g, 12.8 mmol) in tetrahydrofuran (80 ml) at −78 °C and the mixture stirred for 30 min. A solution of ethyl isobutyrate (1.12 g, 9.63 mmol) in tetrahydrofuran (10 ml) was added and the mixture stirred at −78 °C for 30 min. A solution of aldehyde[26] **10** (1.78 g, 9.15 mmol) in tetrahydrofuran (10 ml) was added and the mixture stirred at −78 °C for 30 min. Aqueous ammonium chloride (15 ml) was added and the solution warmed to room temperature. The aqueous layer was extracted with ether (3 × 80 ml), the combined organic extracts were dried ($MgSO_4$) and the solvent removed under reduced pressure. The residue was purified by column chromatography eluting with light petroleum–ether (9 : 1) to give *ester* **13** (2.47 g, 87%) as an oil, R_f (light petroleum–ether 9 : 1) 0.10; ν_{max} (film, $CDCl_3$)/cm^{-1} 3300 (OH) and 1700 (CO); δ_H(200 MHz; $CDCl_3$) 7.46–7.22 (5 H, m, SPh), 4.11 (1 H, q, *J* 7.1, C$H_A$$H_B$O), 4.09 (1 H, q, *J* 7.1, C$H_A$$H_B$O), 3.86 (1 H, dd, *J* 6.7 and 2.5, C*H*OH), 3.23 (1 H, dt, *J* 8.8 and 3.0, C*H*SPh), 3.03 (1 H, d, *J* 6.7, OH), 1.71–1.39 (4 H, m, 2 × CH_2), 1.22 (3 H, t, *J* 7.0, *Me*CH_2O), 1.18 (3 H, s, Me), 1.14 (3 H, s, Me) and 0.90 (3 H, t, *J* 6.7, *Me*CH_2); δ_C(51 MHz; $CDCl_3$) 178.0, 135.6, 132.2, 128.8, 127.0, 78.9, 60.8, 52.8, 46.1, 23.1, 22.4, 20.8 and 13.9; *m*/*z* 310.2 (20%, M) (Found: M^+, 310.1608. $C_{17}H_{26}O_3S$ requires *M*, 310.1602).

Ethyl 3-hydroxy-3-(1′-phenylsulfanylcyclopentyl)propanoate 14

In the same way aldehyde **12** (1.5 g, 7.2 mmol) and ethyl acetate (665 mg, 7.6 mmol) gave, after column chromatography eluting with light petroleum–ether (9 : 1) the ester **14** (2 g, 93%) as an oil, R_f (light petroleum–ether 9 : 1) 0.10 and identified by IR and NMR spectroscopy; ν_{max} (film, $CDCl_3$)/cm^{-1} 3300 (OH) and 1750 (RCO_2Et); δ_H(200 MHz; $CDCl_3$) 7.59–7.26 (5 H, m, SPh), 4.18 (2 H, q, *J* 7.5, C$H_2$$CH_3$), 4.05 (1 H, dt, *J* 8.5 and 3.8, C*H*OH), 3.13 (1 H, d, *J* 3.8, OH), 2.91 (1 H, dd, *J* 13.2 and 3.8, C$H_A$$H_B$O), 2.57 (1 H, dd, *J* 13.2 and 8.6, C$H_A$$H_B$O), 2.01–1.56 (8 H, m, 4 × CH_2) and 1.29 (3 H, t, *J* 7.5, *Me*CH_2); δ_C(51 MHz; $CDCl_3$) 173.0, 136.7, 132.0, 128.3, 128.2, 72.2, 65.2, 60.7, 37.9, 33.9, 33.9, 24.5, 24.4 and 14.1.

Ethyl 3-hydroxy-2,2-dimethyl-3-(1′-phenylsulfanylcyclopentyl)-propanoate 15

In the same way as ester **13**, aldehyde **12** (2 g, 9.7 mmol) gave, after column chromatography eluting with light petroleum–ether (9 : 1) the *ester* **15** (2.53 g, 78%) as an oil, R_f (light petroleum–ether 9 : 1) 0.10; ν_{max} (film, $CDCl_3$)/cm^{-1} 1750 (RCO_2Et); δ_H(200 MHz; $CDCl_3$) 7.57–7.31 (5 H, m, SPh), 4.09–3.80 (3 H, m, C*H*OH and CH_2O), 3.46 (1 H, d, *J* 5.2, OH), 2.12–1.35 (8 H, m, 4 × CH_2), 1.31 (3 H, s, Me), 1.28 (3 H, s, Me) and 1.02 (3 H, t, *J* 7.2, *Me*CH_2); δ_C(51 MHz; $CDCl_3$) 179.6, 138.4, 134.6, 130.6, 130.5, 81.6, 70.9, 62.5, 48.3, 37.6, 36.9, 27.9, 25.6, 25.3, 23.1 and 15.5; *m*/*z* 322.2 (50%, M), 277.1 (80, M − OCH_2Me), 177.1 (85, C_5H_8SPh), 110.0 (40, PhSH) and 97.1 (100, C_5H_8CHO) (Found: M^+, 322.1598. $C_{18}H_{26}O_3S$ requires *M*, 322.1602).

(3*R**,4*S**)-2,2-Dimethyl-4-phenylsulfanylheptane-1,3-diol 16

$LiAlH_4$ (0.25 g, 6.7 mmol) was added to a solution of ester **13** (0.7 g, 2.2 mmol) in ether (100 ml) at 0 °C. The solution was stirred for 3 h at room temperature and poured onto ice–brine. **Caution!**. Aqueous sodium hydroxide (20 ml, 10%) was added and the aqueous layer extracted with ether (3 × 100 ml). The combined organic extracts were dried ($MgSO_4$) and the solvent removed under reduced pressure. The residue was purified by column chromatography eluting with ether to give the *diol* **16** (0.51 g, 84%) as an oil, R_f (ether) 0.70; ν_{max} (film, $CDCl_3$)/cm^{-1} 3400–3300 (OH); δ_H(200 MHz; $CDCl_3$) 7.45–7.21 (5 H, m, SPh), 3.67 (1 H, dd, *J* 3.2 and 1.4, C*H*OH), 3.43–3.27 (3 H, m, CH_2OH), 2.90 (1 H, dd, *J* 6.5 and 4.8, C*H*SPh), 2.83 (1 H, d, *J* 3.2, OH), 1.92–1.75 (2 H, m, CH_2), 1.59–1.40 (2 H, m, CH_2), 0.97 (3 H, t, *J* 6.9, *Me*CH_2), 0.93 (3 H, s, Me) and 0.78 (3 H, s, Me); δ_C(51 MHz; $CDCl_3$) 134.5, 131.2, 129.6, 128.3, 80.2, 73.5, 52.3, 39.7, 30.8, 23.5, 22.3, 20.8 and 14.5; *m*/*z* 268.1 (70%, M), 166.1 (100, C_4H_8SPh + H), 123.0 (50, PhSCH + H) and 109.0 (10, SPh) (Found: M^+, 268.1484. $C_{15}H_{24}O_4S$ requires *M*, 268.1496).

3-(1′-Phenylsulfanylcyclopentyl)propane-1,3-diol 17

In the same way the ester **14** (1.5 g, 5.0 mmol) gave, after column chromatography eluting with ether the *diol* **17** (1.15 g, 91%) as an oil, R_f (ether) 0.45; ν_{max} (film, $CDCl_3$)/cm^{-1} 3600–3300 (OH); δ_H(200 MHz; $CDCl_3$) 7.58–7.29 (5 H, m, SPh), 3.91–3.67 (3 H, m, CH_2O and C*H*OH), 3.39 (1 H, d, *J* 2.7, OH), 2.74 (1 H, t, *J* 6.7, OH) and 2.01–1.49 (10 H, m, 5 × CH_2); δ_C(51 MHz; $CDCl_3$) 136.8, 131.6, 129.0, 128.8, 74.9, 67.3, 62.1, 34.5, 33.3, 33.2, 24.9 and 24.6; *m*/*z* 252.1 (5%, M), 177.1 (75, C_5H_8SPh), 143.1 (40, M − SPh), 109.0 (70, PhS), 77.1 (30, Ph)

and 67.1 (C_5H_7) (Found: M^+, 252.1183. $C_{14}H_{20}O_2S$ requires *M*, 252.1006).

2,2-Dimethyl-3-(1′-phenylsulfanylcyclopentyl)propane-1,3-diol 18

In the same way the ether **15** (1.25 g, 3.31 mmol) gave, after column chromatography eluting with ether, the *diol* **18** (0.88 g, 95%) as an oil, R_f (ether) 0.60; ν_{max} (film, $CDCl_3$)/cm^{-1} 3550–3300 (OH); δ_H(200 MHz; $CDCl_3$) 7.61–7.29 (5 H, m, SPh), 3.61 (1 H, d, *J* 3.7, OH), 3.48 (2 H, AB quartet, *J* 5.4, CH_2O), 2.24 (1 H, dd, *J* 7.3 and 3.7, C*H*OH), 2.21–1.59 (9 H, m, 4 × CH_2 and OH), 1.12 (3 H, s, Me) and 0.91 (3 H, s, Me); δ_C(51 MHz; $CDCl_3$) 136.3, 132.4, 128.7, 82.1, 74.1, 70.0, 40.2, 36.1, 35.9, 24.9, 23.6, 23.3 and 20.5; *m*/*z* 280.1 (20%, M), 262.1 (25, M − H_2O), 207.1 (70, C_6H_9OSPh + H), 177.1 (100, C_5H_8SPh) and 109.0 (30, PhS) (Found: M^+, 280.1485. $C_{16}H_{24}O_2S$ requires *M*, 280.1496).

(3*R**,4*S**)-2,2-Dimethyl-4-phenylsulfonylheptane-1,3-diol 19

MCPBA (0.38 g, 2.46 mmol) was added to a solution of diol **16** (0.33 g, 1.23 mmol) and Na_2HPO_4 (0.52 g, 3.69 mmol) in CH_2Cl_2 (100 ml) at 0 °C. The solution was stirred for 6 h. Aqueous ammonium chloride (10 ml) was added and the aqueous layer extracted with ether (3 × 100 ml). The combined organic extracts were dried ($MgSO_4$) and the solvent removed under reduced pressure. The residue was purified by column chromatography eluting with ether to give the *sulfone* **19** (0.28 g, 82%) as an oil, R_f (ether) 0.20; ν_{max} (film, $CDCl_3$)/cm^{-1} 3500–3300 (OH); δ_H(200 MHz; $CDCl_3$) 7.53–7.42 (5 H, m, SOPh), 3.95 (1 H, s, OH), 4.90–3.60 (1 H, br s, OH), 3.26 (2 H, AB quartet, CH_2O), 2.45 (1 H, t, *J* 6.0, C*H*OH), 2.00 (2 H, m, C*H*SOPh and CH_AH_B), 1.72–1.38 (3 H, m, CH_2 and CH_AH_B), 0.99 (3 H, t, *J* 7.5, *Me*CH_2), 0.71 (3 H, s, CH_3) and 0.32 (3 H, s, CH_3); δ_C(51 MHz; $CDCl_3$) 141.4, 130.8, 124.3, 72.7, 71.7, 65.6, 38.8, 27.0, 22.0, 21.1, 19.4 and 13.9; *m*/*z* 211.1 (60%, M − C_4H_9O), 177.1 (1, C_4H_8PhSO), 159.1 (50, M − PhSO), 126.0 (100, PhSOH) and 109.0 (25, SPh) [Found: $(M - C_4H_9O)^+$, 211.0787. $C_{11}H_{15}O_2S$ requires *M* − C_4H_9O, 211.0792].

3-(1′-Phenylsulfonylcyclopentyl)propane-1,3-diol 20

In the same way the diol **17** (0.2 g, 0.78 mmol) gave, after column chromatography eluting with ether the *sulfone* **20** (0.18 g, 87%) as an oil, R_f (ether) 0.25; ν_{max} (film, $CDCl_3$)/cm^{-1} 3500–3300 (OH); δ_H(200 MHz; $CDCl_3$) 7.91 (2 H, m, 2 × CH, *o*-SPh), 7.72–7.51 (3 H, m, 3 × CH, *p*- and *m*-SPh), 4.46 (1 H, m, OH), 4.23 (1 H, dt, *J* 9.9 and 1.2, C*H*OH), 3.87–3.72 (2 H, br s, CH_2O), 2.83 (1 H, br s, OH) and 2.48–1.36 (10 H, m, 5 × CH_2); δ_C(51 MHz; $CDCl_3$) 135.7, 134.0, 130.2, 129.0, 76.3, 72.2, 61.1, 33.1, 32.1, 27.7, 26.6 and 26.5; *m*/*z* 210.1 (40%, M − C_2H_6O), 177.1 (10, C_5H_8SPh), 109.0 (5, PhS), 77.0 (60, PhS) and 69.1 (100, C_5H_9) [Found: $(M - C_2H_6O)^+$, 210.0717. $C_{11}H_{14}O_2S$ requires *M* − C_2H_6O, 210.0714).

2,2-Dimethyl-3-(1′-phenylsulfonylcyclopentyl)propane-1,3-diol 21

In the same way the diol **18** (0.3 g, 1.07 mmol) gave, after column chromatography eluting with ether, the *sulfone* **21** (0.26 g, 83%) as an oil, R_f (ether) 0.40; ν_{max} (film, $CDCl_3$)/cm^{-1} 3500–3250 (OH); δ_H(200 MHz; $CDCl_3$) 7.95–7.56 (2 H, m, 2 × CH, *o*-SPh), 7.72–7.51 (3 H, m, 3 × CH, *p*- and *m*-SPh), 4.42 (1 H, d, *J* 5.0, CHO*H*), 4.08 (1 H, d, *J* 5.0, C*H*OH), 3.49–3.35 (2 H, m, CH_2O), 3.20 (1 H, br t, *J* 6.6, CH_2OH), 2.45–2.31 (2 H, m, CH_2), 2.13–1.98 (2 H, m, CH_2), 1.74–1.45 (4 H, m, 2 × H_2), 1.04 (3 H, s, Me) and 0.85 (3 H, s, Me); δ_C(51 MHz; $CDCl_3$) 135.7, 134.0, 130.3, 129.0, 80.5, 78.5, 74.3, 40.7, 32.5, 28.8, 26.1, 24.9, 24.3 and 19.3; *m*/*z* 281.1 (2%, M − Me), 171.1 (25, M − PhSO), 125.0 (40, PhSO), 97.1 (100, C_5H_8CHO + H) and 67.1 (80, C_5H_7) [Found: $(M - Me)^+$, 281.1211. $C_{15}H_{21}O_3S$ requires *M* − Me, 281.1211].

S-Phenyl (2*S**,3*S**)-3-hydroxy-2-methyl-3-(1′-phenylsulfanylcyclopentyl)thiopropanoate 23

9-BBN-OTf (8 ml, 1 M solution in toluene, 8 mmol) was added dropwise to a solution of *S*-phenyl thiopropionate (1.32 g, 7.9 mmol) and diisopropylethylamine (0.8 g, 8 mmol) in dichloromethane (40 ml) at 0 °C. The mixture was stirred at 0 °C for 5 min and at −78 °C for 45 min. A solution of aldehyde **12** (1.5 g, 7.2 mmol) in dichloromethane (10 ml) was added and the mixture stirred at room temperature for 18 h. A pH 7 phosphate buffer (7 ml) and hydrogen peroxide (5 ml, 10% in water) were added and the mixture washed with brine (20 ml). The aqueous layer was extracted with dichloromethane (2 × 30 ml) and the combined organic extracts dried ($MgSO_4$) and the solvent removed under reduced pressure. The residue was purified by column chromatography eluting with light petroleum–ether (9 : 1) to give the *ester* **23** (1.6 g, 60%) as an oil, R_f (light petroleum–ether 9 : 1) 0.13; ν_{max} (film, $CDCl_3$)/cm^{-1} 3200 (OH) and 1600–1500 (SPh); δ_H(200 MHz; $CDCl_3$) 7.61–7.28 (10 H, m, 2 × SPh), 4.08 (1 H, t, *J* 5.0, C*H*OH), 3.67 (1 H, qd, *J* 7.8 and 5.1, C*H*Me), 2.71 (1 H, d, *J* 5.1, OH), 2.01–1.58 (8 H, m, 4 × CH_2) and 1.37 (3 H, d, *J* 7.7, *Me*CH); δ_C(50 MHz; $CDCl_3$) 136.7, 134.9, 132.7, 131.5, 129.3, 129.1, 128.9, 128.8, 74.4, 58.5, 37.0, 34.8, 34.2, 24.2, 23.6 and 13.8; *m*/*z* 263.1 (80%, M − SPh), 207.1 (10, C_6H_9OSPh + H), 177.1 (70, C_5H_8SPh), 167.1 (5, C_3H_5OSPh + H), 109.0 (100, PhS), 77.0 (30, Ph) and 67.1 (65, C_5H_8) [Found: $(M - SPh)^+$, 263.1115. $C_{15}H_{19}O_2S$ requires *M* − SPh, 263.1110].

(2*S**,3*R**)-2-Methyl-3-(1′-phenylsulfonylcyclopentyl)propane-1,3-diol 25

In the same way as sulfone **19**, diol **24**[25] (282 mg, 1 mmol) gave, after column chromatography eluting with ether, the *sulfone* **25** (0.25 g, 79%) as an oil, R_f (ether) 0.45; ν_{max} (film, $CDCl_3$)/cm^{-1} 3600–3300 (OH); δ_H(200 MHz; $CDCl_3$) 7.91–7.49 (5 H, m, SPh), 4.41 (1 H, d, *J* 3.7, OH), 3.97 (1 H, t, *J* 3.7, C*H*OH), 3.82–3.51 (2 H, m, CH_2O), 3.25 (1 H, t, *J* 6.4, CH_2OH), 2.46–1.31 (9 H, m, C*H*Me and 4 × CH_2) and 1.00 (3 H, d, *J* 7.2, Me); δ_C(51 MHz; $CDCl_3$) 136.0, 133.9, 130.1, 128.9, 77.9, 68.5, 65.9, 35.9, 31.1, 29.7, 26.6, 25.9 and 18.1; *m*/*z* 239.1 (80%, M − C_3H_7), 157.1 (60, M − PhSO), 109.1 (30, PhS), 77.0 (40, Ph) and 69.1 (100, C_5H_9) [Found: $(M - C_3H_7)^+$, 239.0747. $C_{12}H_{15}O_3S$ requires M − C_3H_7, 239.0741].

(2*S**,3*S**)-2-Methyl-3-(1′-phenylsulfanylcyclopentyl)propane-1,3-diol 26

In the same way as diol **16**; the ester **23** (1.5 g, 4.0 mmol) gave, after column chromatography eluting with ether, the diol **26** (0.75 g, 70%) as an oil, R_f (ether) 0.50; ^{1}H NMR consistent with that reported previously.[27]

(2*S**,3*S**)-2-Methyl-3-(1′-phenylsulfonylcyclopentyl)propane-1,3-diol 27

In the same way as sulfone **19**, the diol **26** (0.17 g, 0.63 mmol) gave, after column chromatography eluting with ether, the sulfone **27** (0.14 g, 79%) as an oil, R_f (ether) 0.10 and was identified by IR, NMR and mass spectroscopy; ν_{max} (film, $CDCl_3$)/cm^{-1} 3400–3300 (OH); δ_H(200 MHz; $CDCl_3$) 7.78–7.68 (2 H, m, 2 × CH, *o*-SPh), 7.59–7.43 (3 H, m, 3 × CH, *p*- and *m*-SPh), 4.26 (1 H, d, *J* 0.9, C*H*OH), 3.61 (2 H, d, *J* 5.0, CH_2O), 2.36–1.28 (11 H, m, 4 × CH_2, C*H*CH_2 and 2 × OH) and 1.12 (3 H, d, *J* 6.5, *Me*CH); δ_C(51 MHz; $CDCl_3$) 138.7, 131.7, 128.8, 126.6, 74.6, 73.6, 67.0, 37.0, 29.3, 25.7, 25.2 and 11.21; *m*/*z* 156.1 (40%, PhSOH), 138.1 (25, PhSOCH), 125.0 (45, M − PhSO), 109.0 (25, PhS), 97.1 (100, C_5H_8CHO) and 67.1 (75, C_5H_7).

(2*S,1′*R**)-3,3-Dimethyl-2-[(1′*R**)-1′-phenylsulfonylbutyl]-oxetane 28**

In the same way as oxetane **3** (Table 1; entry 2), sulfone **19** (78 mg, 0.27 mmol) gave, after column chromatography eluting with light petroleum–ether (1 : 1), oxetane **28** (41 mg, 57%) as an oil; R_f (light petroleum–ether, 1 : 1) 0.3; ν_{max} (film, $CDCl_3$)/cm^{-1} 3100 (CH); δ_H(200 MHz; $CDCl_3$) 7.63–7.48 (5 H, m, SOPH), 4.75 (1 H, d, *J* 8.9, CHO), 4.32 (1 H, d, *J* CH_AH_BO), 3.97 (1 H, d, *J* 5.3, CH_AH_BO), 1.53–1.23 (4 H, m, 2 × CH_2), 1.20 (3 H, s, Me), 1.05 (3 H, s, Me) and 0.83 (3 H, t, *J* 6.34, *Me*CH_2); *m*/*z* 267.1 (50%, M + H), 141.2 (30, M − PhSO) and 125.0 (100, PhSO).

2-[1′-Phenylsulfonylcyclopentyl]oxetane 29

In the same way as oxetane **3** (Table 1; entry 2), sulfone **20** (45 mg, 0.17 mmol) gave, after column chromatography eluting with light petroleum–ether (1 : 1), oxetane **29** (37 mg, 90%) as an oil, R_f (light petroleum–ether, 1 : 1) 0.25; ν_{max} (film, $CDCl_3$)/cm^{-1} 1500 (SPh); δ_H(200 MHz; $CDCl_3$) 7.87 (2 H, d, *J* 8.7, 2 × Ph-H), 7.69–7.52 (3 H, m, 3 × Ph-H), 5.06 (1 H, t, *J* 7.5, CHO), 4.59 (1 H, td, *J* 8.22 and 5.94, CH_AH_BO), 4.35 (1 H, td, *J* 7.7 and 6.1, CH_AH_BO) and 2.46–1.64 (10 H, m, 5 × CH_2); δ_C(101 MHz; $CDCl_3$) 137.5, 133.7, 130.0, 129.1, 82.1, 68.4, 65.9, 30.4, 28.3, 26.7, 24.7 and 22.6; *m*/*z* 125.1 (65%, PhSO and M − PhSO), 95.1 (10, $C_5H_8CHCH_2$), 77.1 (85, Ph), 69.1 (100, C_5H_9) and 57.1 (25, C_3H_5O).

3,3-Dimethyl-2-(1′-phenylsulfonylcyclopentyl)oxetane 30

In the same way as oxetane **3** (Table 1; entry 2), sulfone **21** (100 mg, 0.33 mmol) gave, after column chromatography eluting with light petroleum–ether (1 : 1), oxetane **30** (86 mg, 92%) as an oil, R_f (light petroleum–ether, 1 : 1) 0.3; ν_{max} (film, $CDCl_3$)/cm^{-1} 1500 (SPh); δ_H(400 MHz; $CDCl_3$) 7.90 (1 H, d, *J* 8.13, 2 × Ph-CH), 7.64 (1 H, td, *J* 7.2 and 0.8, Ph-H), 7.54 (2 H, t, *J* 7.4, 2 × Ph-H), 4.90 (1 H, s, CHO), 4.28 (1 H, AB quartet, *J* 5.3, CH_AH_BO), 4.13 (1 H, AB quartet, *J* 5.3, CH_AH_BO), 2.52–1.54 (8 H, m, 4 × CH_2), 1.39 (3 H, s, Me) and 1.36 (3 H, m, Me); δ_C(101 MHz; $CDCl_3$) 137.5, 133.7, 130.4, 128.8, 90.1, 81.4, 65.9, 41.6, 32.8, 28.8, 27.2, 25.5, 28.6 and 22.2; *m*/*z* 221.1 (5%, M − C_4H_8), 153.1 (100, M − PhSO), 125.0 (85, PhSO), 77.0 (60, Ph), 69.1 (60, C_5H_9) and 56.1 (65, C_4H_8).

(2*R,3*S**)-3-Methyl-2-(1′-phenylsulfonylcyclopentyl)oxetane 31**

In the same way as oxetane **3** (Table 1; entry 2), sulfone **25** (100 mg, 0.35 mmol) gave, after column chromatography eluting with light petroleum–ether (1 : 1), oxetane **31** (76 mg, 86%) as an oil, R_f (light petroleum–ether, 1 : 1) 0.45; ν_{max} (film, $CDCl_3$)/cm^{-1} 1500 (SPh); δ_H(400 MHz; $CDCl_3$) 7.90 (2 H, dd, *J* 7.1 and 1.3, 2 × Ph-H), 7.64 (1 H, t, *J* 6.5, Ph-H), 7.53 (2 H, t, *J* 7.2, 2 × Ph-H), 4.71 (1 H, d, *J* 6.4, CHO), 4.48 (1 H, dd, *J* 8.5 and 5.9, CH_AH_BO), 4.18 (1 H, dd, *J* 6.9 and 6.1, CH_AH_BO), 3.05–2.96 (1 H, m, C*H*Me), 2.49–1.51 (8 H, m, 4 × CH_2) and 1.31 (3 H, d, *J* 6.8, *Me*CH); δ_C(101 MHz; $CDCl_3$) 137.0, 133.6, 130.3, 128.8, 89.2, 75.9, 75.6, 32.6, 30.5, 28.8, 26.9, 26.7 and 18.4; *m*/*z* 177.1 (45%, C_5H_8SPh), 139.1 (50, M − PhSO), 109.0 (10, PhS), 77.0 (80, Ph) and 69.1 (100, C_5H_9).

(2*R,3*R**)-3-Methyl-2-(1′-phenylsulfonylcyclopentyl)oxetane 32**

In the same way as oxetane **3** (Table 1; entry 2); sulfone **27** (33 mg, 0.1 mmol) gave, after column chromatography eluting with light petroleum–ether (1 : 1), *oxetane* **32** (20 mg, 65%) as an oil, R_f (light petroleum–ether, 1 : 1) 0.25; ν_{max} (film, $CDCl_3$)/cm^{-1} 1500 (SPh); δ_H(200 MHz; $CDCl_3$) 7.59–7.49 (5 H, m, SPh), 4.77 (1 H, dd, *J* 8.2 and 5.8, CH_AH_BO), 4.71 (1 H, d, *J* 8.0, CHO), 4.15 (1 H, t, *J* 8.2, CH_AH_BO), 2.46 (1 H, m, C*H*Me), 1.56–1.18 (8 H, m, 4 × CH_2) and 1.23 (3 H, d, *J* 6.8, *Me*CH); *m*/*z* 248.1 (40%, M), 193.1 (1, C_5H_8PhSO), 177.1 (5, C_5H_8SPh), 164.1 (100, $PhSC_4H_7$), 150.1 (40, $PhSC_3H_5$), 123.0 (20, M − PhSO), 109.0 (20, PhS and $C_5H_8CHCHMe$), 77.1 (15, Ph) and 67.1 (25, C_5H_9) (Found: M^+, 248.1234. $C_{15}H_{20}OS$ requires *M*, 248.1234).

(2*S,3*R**)-2-Methyl-1-[1′-(phenylsulfonyl)cyclohexyl]propane-1,3-diol 33**

In the same way as sulfone **19**, diol **1** (0.31 g, 1.1 mmol) gave, after column chromatography eluting with ether, the sulfone **33** (0.12 g, 35%) as an oil, R_f (ether) 0.32; ν_{max} (film, $CDCl_3$)/cm^{-1} 3498 (OH) and 1074 (SO); δ_H(200 MHz; $CDCl_3$) 8.10–7.35 (5 H, m, Ph-H), 4.01 (1 H, d, *J* 6.5, C*H*OH), 3.91 (1 H, dd, *J* 11.4 and 3.5, CH_AH_BOH), 3.70 (1 H, dd, *J* 11.4 and 5.9, CH_AH_BOH), 2.59 (1 H, m, C*H*Me), 2.23–1.10 (10 H, m, 5 × CH_2) and 1.06 (3 H, d, *J* 6.9, Me); δ_C(101 MHz; $CDCl_3$) 136.1, 134.0, 130.3, 129.0, 75.8, 69.9, 66.8, 36.4, 29.7, 26.7, 24.7, 21.5, 21.0 and 18.3.

(2*R,3*S**)-3-Hydroxy-2-methyl-3-[1-(phenylsulfonyl)cyclohexyl]propyl 3,5-dinitrobenzoate 34**

3,5-Dinitrobenzoyl chloride (0.97 g, 0.84 mmol) was added to a solution of sulfone **33** (0.12, 0.8 mmol) in pyridine (2 ml) at room temperature. The solution was stirred for 1 h and the colour turned pale yellow. The mixture was diluted with ether (4 ml) and HCl (2 M in water) was added to make the aqueous layer acidic. The aqueous layer was extracted with ether (3 × 10 ml). The combined organic extracts were dried ($MgSO_4$) and the solvent removed under reduced pressure. The product was recrystallised from dichloromethane–hexane to give *sulfone* **34** (0.34 g, 85%) as needles, mp 141–144 °C; R_f (ether) 0.50; ν_{max} (film, $CDCl_3$)/cm^{-1} 3404 (OH), 1720 (C=O), 1602 (Ar), 1585 (Ar), 1452 (NO_2), 1454 (NO_2) and 1176 (SO); δ_H(200 MHz; $CDCl_3$) 9.19 (3 H, m, Ph-H), 8.10–7.35 (5 H, m, SPh), 4.79 (1 H, dd, *J* 11.0 and 5.0, CH_AH_BOH), 4.64 (1 H, dd, *J* 11.0 and 6.0, CH_AH_BOH), 4.22 (1 H, d, *J* ????,C*H*OH), 3.20 (1 H, quin, *J* 6.5, C*H*Me), 2.47 (1 H, dd, *J* 14.0 and 2.0, CH), 2.34 (1 H, dd, *J* 14.0 and 2.0, CH), 2.16 (1 H, s, CH), 1.8–0.9 (7 H, m, CH) and 1.30 (3 H, d, *J* 6.5, CH*Me*); δ_C(51 MHz; $CDCl_3$) 169.0, 162.0, 149.0, 136.0, 134.0, 130.0, 129.0, 128.0, 122.0, 73.0, 70.0, 69.0, 35.0, 31.0, 28.0, 24.5, 21.5, 21.0 and 18.5; *m*/*z*(+CI) 524.3 (100%, M + NH_4).

X-Ray structure determination and refinements for 34

Crystal data for 34. $C_{23}H_{26}N_2O_9S$, M_r 506.52, space group monoclinic. $P2_{1/C}$. Crystals were obtained from dichloromethane–hexane. The specimen used for X-ray analysis had dimensions of 0.25 × 0.25 × 0.20 mm. Lattice constants (Å, degrees) *a* = 17.086 (11), 90°, *b* = 6.566 (7), 101.53 (4)°, *c* = 20.949 (9), 90°, cell volume *V* = 2303 (3) Å^3, formula units/cell *Z* = 4, X-ray density ρ_x = 1.461 Mg m^{-3}, number of independent reflections 4039, absorption coefficient 0.199 mm^{-1}, R_1 = 0.0695, ωR_2 = 0.1457. CCDC reference number 168126. See http://www.rsc.org/suppdata/p1/b1/b106851b/ for crystallographic files in .cif or other electronic format.

2,6-Di-*tert*-butyl-4-methylphenyl (2′*S,3′*R**)-3′-hydroxy-2′-methyl-3′-phenylpropanoate 35**

In the same way as ester **13**, 2,6-di-*tert*-butyl-4-methylphenyl propanoate (1 g, 3.62 mmol) and benzaldehyde (366 mg, 3.45 mmol) gave, after column chromatography eluting with light petroleum–ether (9 : 1) and separation by HPLC eluting with light petroleum–ether (1 : 1), the hydroxyester **35** (0.87 g, 100%) as a yellow oil, R_f (light petroleum–ether, 9 : 1) 0.13; ν_{max}($CHCl_3$)/cm^{-1} 3425 (OH), 1755 (C=O), 1600 and 1500 (C=C); δ_C(51 MHz; $CDCl_3$) 176.5, 146.5, 142.0, 141.0, 135.0, 128.5, 128.0, 127.5, 127.0, 75.8, 47.5, 35.3, 31.5, 22.0 and 14.0; *m*/*z*(EI) 276 (43%, M × PhCHO), 220 (100, phenol) and 57 (50, $MeCH_2CO$). ^{1}H NMR consistent with that reported previously.[28]

2,6-Di-*tert*-butyl-4-methoxyphenyl (2′*S,3′*R**)-3′-hydroxy-2′-methylheptanoate 36**

In the same way as ester **13**, pentanal (0.5 ml, 4.71 mmol) and 2,6-di-*tert*-butyl-4-methylphenyl propanoate (1.38 g, 4.72 mmol) gave, after column chromatography eluting with ethyl acetate–light petroleum (1 : 9), the *ester* **36** (1.14 g, 64%) as a yellow oil and a single diastereoisomer, R_f (ethyl acetate–light petroleum 1 : 9) 0.25; $\nu_{max}(CHCl_3)/cm^{-1}$ 3440 (OH), 1760 (C=O) and 1600 (C=C); δ_H(250 MHz; $CDCl_3$) 6.84 (2 H, s, Ar-H), 3.82 (1 H, m, RC*H*OH), 3.78 (3 H, s, $PhOCH_3$), 3.48 (1 H, d, *J* 5, OH), 2.76 (1 H, quin, *J* 7.5, C*H*Me), 1.70–1.30 (9 H, m, 3 × CH_2 and CH_2*Me*), 1.45 (3 H, d, *J* 7.5, CH*Me*), 1.32 (9 H, s, CMe_3) and 1.30 (9 H, s, CMe_3); δ_C(51 MHz; $CDCl_3$) 177.0, 156.5, 143.5, 143.0, 141.5, 111.5, 72.7, 55.0, 46.3, 35.5, 35.0, 33.5, 32.3, 27.5, 22.5, 14.0 and 13.5; *m*/*z*-(+CI) 379.2 (25%, MH^+), 323 (37, M − ^{t}Bu), 236 (100, $C_{14}H_{20}O_3$) (Found: MH^+, 379.2842, $C_{23}H_{39}O_4$ requires *M*H, 379.2848).

2,6-Di-*tert*-butyl-4-methoxyphenyl (2′*S,3′*R**)-4′-benzyloxy-3′-hydroxy-2′-methylbutanoate 37**

In the same way as ester **13**, benzyloxyacetaldehyde (0.47 ml, 3.33 mmol) and 2,6-di-*tert*-butyl-4-methylphenyl propanoate (0.97 g, 3.33 mmol) gave, after column chromatography eluting with light petroleum–ether (9 : 1 to 1 : 1), *ester* **37** (1.05 g, 70%) as a colourless oil, R_f (light petroleum–ether 1 : 1) 0.43; $\nu_{max}(CHCl_3)/cm^{-1}$ 3540 (OH), 1740 (C=O) and 1590 (C=C); δ_H(200 MHz; $CDCl_3$) 7.35 (5 H, m, Ph-H), 6.89 (2 H, s, Ph-H), 4.68 (1 H, d, *J* 12.5, $PhCH_AH_BO$), 4.54 (1 H, d, *J* 12.5, $PhCH_AH_BO$), 4.09 (1 H, m, C*H*OH), 3.80 (1 H, s, $PhOCH_3$), 3.67 (1 H, dd, *J* 5 and 7.5, $PhCH_2OCH_AH_B$), 3.59 (1 H, t, *J* 7.5, $PhCH_2OCH_AH_B$), 3.14 (1 H, quin, *J* 7.5, C*H*Me), 1.48 (3 H, d, *J* 7.5, CH*Me*), 1.36 (9 H, s, CMe_3) and 1.32 (9 H, s, CMe_3); δ_C(51 MHz; $CDCl_3$) 176.1, 156.4, 141.7, 138.0, 128.4, 127.8, 127.8, 111.7, 111.6, 73.6, 71.9, 71.3, 55.2, 43.0, 35.6, 35.5, 31.4, 31.3 and 13.0; *m*/*z* (+CI) 443.2 (63%, MH^+), 335 (30, MH − $PhCH_2O$), 236 (100, ArOH), 207 (70, $PhCH_2OCH_2CHMeCO$) and 181 (40, MH − ArOCO) (Found: MH^+, 443.28130. $C_{12}H_{39}O_5$ requires *M*H, 443.2797).

2,6-Di-*tert*-butyl-4-methoxyphenyl (2′*R,3′*S**)-3′-furan-2-yl-3′-hydroxy-2′-methylpropanoate 38**

In the same way as ester **13**, 2-furaldehyde (0.86 ml, 10.4 mmol) and 2,6-di-*tert*-butyl-4-methylphenyl propanoate (3.0 g, 10.9 mmol) gave, after column chromatography eluting with light petroleum–ether (4 : 1), *ester* **38** (3.15 g, 81%) as a colourless oil, R_f (light petroleum–ether 4 : 1) 0.12; $\nu_{max}(CHCl_3)/cm^{-1}$ 3400 (OH), 1740 (C=O), 1720 (C=C furan) and 1580 (C=C); δ_H(400 MHz; $CDCl_3$) 7.24 (1 H, s, furan-H), 6.87 (2 H, s, Ph-H), 6.35 (2 H, s, furan-H), 4.93 (1 H, dd, *J* 8.2 and 4.2, C*H*OH), 4.04 (1 H, d, *J* 4.2, OH), 3.79 (3 H, s, Ar-OMe), 3.33 (1 H, quin, *J* 7.6, C*H*Me), 1.32 (3 H, d, *J* 7.4, CH*Me*), 1.32 (9 H, s, CMe_3) and 1.31 (9 H, s, CMe_3); δ_C(101 MHz; $CDCl_3$) 176.2, 156.5, 154.1, 143.6, 142.3, 141.7, 111.8, 111.7, 110.4, 108.3, 69.7, 55.3, 45.4, 35.7, 35.6, 31.4 and 13.5; *m*/*z*(+CI) 388.3 (20%, M^+), 317 (25, M − OH), 236 (100, ArOC); *m*/*z*(+ESI) 411.2 (100, MNa) [Found: $(M + Na)^+$, 411.2148, $C_{23}H_{32}O_5Na$ requires *M* + Na, 411.2141].

2,6-Dimethylphenyl (2′*R,3′*R**)-2′,4′-dimethyl-3′-hydroxypentanoate 39**

In the same way as ester **13**, 2,6-dimethylphenyl propanoate (2.59 g, 14.9 mmol) and 2-methylpropanal (1 g, 13.8 mmol) gave, after column chromatography eluting with light petroleum–ether (9 : 1), ester **39** (3.2 g, 91%) as an oil; R_f (light petroleum–ether (9 : 1), ester **39**(3.2 g, 91%) as an oil: R_f (light petroleum–ether 9 : 1) 0.1; ^{1}H NMR consistent with that reported previously.[19]

2,6-Dimethylphenyl (2′*S,3′*R**)-3′-hydroxy-2′,4′,4′-trimethylpentanoate 40**

In the same way as ester **13**, 2,6-dimethylphenyl propanoate (2.59 g, 14.9 mmol) and *tert*-butaldehyde (1.18 g, 13.8 mmol) gave, after column chromatography eluting with light petroleum–ether (9 : 1), ester **40** (2.6 g, 52%) as an oil, R_f (light petroleum–ether 9 : 1) 0.15; ν_{max} (film, $CDCl_3$)/cm^{-1} 1700 (CO); δ_C(101 MHz; $CDCl_3$) 175.1, 147.5, 130.0, 128.7, 128.6, 125.9, 82.6, 39.0, 35.8, 26.4, 19.0 and 16.6. ^{1}H NMR consistent with that reported previously.[29]

2,6-Dimethylphenyl (2′*R,3′*R**)-3′-cyclohexyl-3′-hydroxy-2′-methylpropanoate 41**

In the same way as **13**, 2,6-dimethylphenyl propanoate (3.33 g, 18.7 mmol) and cyclohexylcarbaldehyde (2 g, 17.8 mmol) gave, after column chromatography eluting with light petroleum (40–60 °C)–ether (9 : 1), *ester* **41** (4.71 g, 91%) as an oil, R_f (light petroleum–ether 9 : 1) 0.2; ν_{max} (film, $CDCl_3$)/cm^{-1} 3300 (OH) and 1650 (CO); δ_H(400 MHz; $CDCl_3$) 7.03 (3 H, s, OAr), 3.51–3.45 (1 H, m, C*H*OH), 3.03 (1 H, quint, *J* 7.1, C*H*Me), 2.63 (1 H, q, *J* 7.6, $CH(CH_2)_6$), 2.52 (1 H, d, *J* 8.1, OH), 2.15 (6, H, s, 2 × Me, Ar), 1.94–1.10 (10 H, m, 5 × CH_2) and 1.45 (3 H, d, *J* 7.2, *Me*CH); δ_C(101 MHz; $CDCl_3$) 174.5, 147.9, 130.0, 128.5, 126.0, 77.7, 42.0, 41.0, 30.1, 26.3, 26.1, 25.9, 25.6, 16.4 and 15.3; *m*/*z* 290.2 (20%, M) and 122.1 (100, OAr) (Found: M^+, 290.1891. $C_{18}H_{26}O_3$ requires *M*, 290.1881).

(2*S,3*R**)-2-Methyl-1-phenylpropane-1,3-diol 42**

Hydroxyester **35** (1.5 g, 3.93 mmol) in tetrahydrofuran (20 ml) was added to a suspension of lithium aluminium hydride (0.51 g, 13.7 mmol) in tetrahydrofuran (20 ml). The mixture was brought to reflux and stirred overnight at this temperature. After cooling, the reaction was poured onto ice (10 g); **Caution!** The mixture was diluted with aqueous NaOH (40 ml) and extracted with ether (4 × 20 ml). The combined organic extracts were dried ($MgSO_4$) and the residue purified by column chromatography eluting with light petroleum–ether (1 : 1) to yield diol **42** (0.51 g, 78%) as a colourless oil, R_f (ether) 0.40; $\nu_{max}(CHCl_3)/cm^{-1}$ 3520 (OH), 1642 and 1603 (C=C); δ_C(51 MHz; $CDCl_3$) 143.1, 128.1, 127.5, 126.6, 80.1, 67.3 and 13.5; *m*/*z*(EI) 166.1 (7.5%, M^+), 148 (42, M − H_2O), 107 (100, PhCHOH) and 77 (60, Ph) (Found: M^+, 166.0994. $C_{10}H_{14}O_2$, requires *M*, 166.0993). ^{1}H NMR consistent with that reported.[30]

(2*S,3*R**)-2-Methylheptane-1,3-diol 43**

In the same way as diol **42**, hydroxyester **36** (1.13 g, 3.0 mmol) gave, after column chromatography eluting with light petroleum–ethyl acetate (1 : 1), diol **43** (265 mg, 61%) as a colourless oil, R_f (light petroleum–ethyl acetate 1 : 1) 0.24; $\nu_{max}(CHCl_3)/cm^{-1}$ 3560–3120 (OH); ^{1}H NMR consistent with that reported previously.[31]

(2*S,3*R**)-4-Benzyloxy-2-methylbutane-1,3-diol 44**

In the same way as diol **42**, hydroxyester **37** (827 mg, 1.87 mmol) gave, after column chromatography eluting with ethyl acetate–light petroleum (1 : 1), *diol* **44** (264 mg, 67%) as a colourless oil, R_f (ethyl acetate–light petroleum 1 : 1) 0.18; $\nu_{max}(CHCl_3)/cm^{-1}$ 3570–3100 (OH); δ_H(400 MHz; $CDCl_3$) 7.33 (5 H, m, Ph-H), 4.58 (1 H, d, *J* 11.9, $PhCH_AH_BO$), 4.53 (1 H, d, *J* 11.9, PhH_AH_BO), 3.73 (1 H, dt, *J* 3.1 and 7.7, C*H*OH), 3.66 (2 H, d, *J* 3.2 $CHCH_AH_BO$), 3.60 (1 H, dd, *J* 3.1 and 9.5, OCH_AH_BCHOH), 3.44 (1 H, dd, *J* 7.5 and 9.5, OCH_AH_BCO), 2.94 (2 H, br s, OH), 1.83 (1 H, sept, *J* 7.5, C*H*Me) and 0.87 (3 H, d, *J* 7.0, CH*Me*); δ_C(101 MHz; $CDCl_3$) 137.7, 128.5, 127.9, 127.8, 75.6, 73.5, 72.9, 67.4, 37.5 and 13.7; *m*/*z*(+CI) 211.1 (100%, MH^+), 91 (66, $PhCH_2$) (Found: MH^+, 211.1326. $C_{12}H_{19}O_3$ requires *M*H, 211.1334).

(2*S,3*R**)-1-Furan-2-yl-2-methylpropane-1,3-diol 45**

In the same way as diol **42**, hydroxyester **38** (1.0 g, 2.69 mmol) gave, after column chromatography eluting with light petroleum–ethyl acetate (1 : 1), *diol* **45** (400 mg, 95%) as a colourless oil, R_f (light petroleum–ethyl acetate 1 : 1) 0.18; $\nu_{max}(CHCl_3)/cm^{-1}$ 3460–3050 (OH); δ_H(400 MHz; $CDCl_3$) 7.36 (1 H, dd, *J* 1.9 and 0.7, furan-H), 6.32 (1 H, dd, *J* 8.1 and 3.2, furan-H), 6.26 (1 H, d, *J* 3.2, furan-H), 4.58 (1 H, d, *J* 8.5, C*H*OH), 3.78 (1 H, dd, *J* 11.0 and 3.6, CH_AH_BOH), 3.67 (1 H, dd, *J* 10.9 and 7.3, CH_AH_BOH), 3.22 (1 H, br s, OH), 2.85 (1 H, br s, OH), 2.23 (1 H, d sex, *J* 8.5 and 3.6, C*H*Me) and 0.76 (3 H, d, *J* 7.0, CH*Me*); δ_C(101 MHz; $CDCl_3$) 155.7, 142.1, 110.2, 107.1, 73.4, 67.4, 39.5 and 13.5; *m*/*z*(+CI) 156.1 (28%, M^+), 139 (100, M − OH) and 81 (14, furan-CH_2) (Found: M^+, 156.0776. $C_8H_{12}O_3$, requires *M*, 156.0786).

(2*R,3*R**)-2,4-Dimethylpentane-1,3-diol 46**

In the same way as diol **16**, ester **39** (4 g, 13.6 mmol) gave, after column chromatography eluting with ether, diol **46** (2.0 g, 86%) as an oil, R_f (ether) 0.45; ν_{max} (film, $CDCl_3$)/cm^{-1} 3500–3220 (OH); δ_C(101 MHz; $CDCl_3$) 81.8, 68.0, 40.6, 36.3, 30.1, 26.5, 26.3, 25.8 and 14.0; *m*/*z* 154.1 (70%, M), 89.1 (90, M − C_6H_{11}) and 83.1 (100, C_6H_{11}) (Found $(M - H_2O)^+$, 154.1353. $C_{10}H_{18}O$ requires M − H_2O, 154.1326). ^{1}H NMR consistent with that reported previously.[32]

(2*S,3*R**)-2,4,4-Trimethylpentane-1,3-diol 47**

In the same way as diol **16**, ester **40** (2.6 g, 9.77 mmol) gave, after column chromatography on silica gel eluting with ether the diol **47** (1.3 g, 93%) as an oil, R_f (ether) 0.65; ν_{max} (film, $CDCl_3$)/cm^{-1} 3500–3200 (OH); ^{1}H NMR consistent with that reported previously.[33]

(2′*R,3′*R**)-3-Cyclohexyl-2-methylpropane-1,3-diol 48**

In the same way as diol **16**, ester **41** (4 g, 13.6 mmol) gave, after column chromatography on silica gel eluting with ether the diol **48** (2.0 g, 86%) as an oil, R_f (ether) 0.45; ν_{max} (film, $CDCl_3$)/cm^{-1} 3500–3220 (OH); δ_C(101 MHz; $CDCl_3$) 81.8, 68.0, 40.6, 36.3, 30.1, 26.5, 26.3, 25.8 and 14.0; *m*/*z* 154.1 (70%, M), 89.1 (90, M − C_6H_{11}) and 83.1 (100, C_6H_{11}) [Found: $(M - H_2O)^+$, 154.1353. $C_{10}H_{18}O$ requires *M* − H_2O, 154.1326]. ^{1}H NMR and mass spectrum consistent with those reported previously.[33]

***S*-Phenyl (2*S**,3*S**)-3-hydroxy-2-methyl-3-phenylthiopropanoate 49**

In the same way as thioester **23**, *S*-phenyl thiopropionate (1.2 ml, 7.8 mmol) and benzaldehyde (0.397 ml, 3.9 mmol) gave, after column chromatography eluting with light petroleum–ether (9 : 1 to 0 : 1), thioester **49** (0.74 g, 70%) as an oil, R_f (light petroleum–ether 9 : 1) 0.1; $\nu_{max}(CHCl_3)/cm^{-1}$ 3440 (OH), 1650 (C=O), 1580 and 1560 (Ph); ^{1}H NMR and mass spectrum consistent with those reported previously.[34]

***S*-Phenyl (2*S**,3*S**)-3-hydroxy-2-methylthioheptanoate 50**

In the same way as thioester **23**, pentanal (0.41 cm^3, 3.9 mmol) gave, after column chromatography eluting with light petroleum–ethyl acetate (4 : 1), hydroxyester **50** (0.97 g) as a single diastereoisomer that was inseparable from impurities. R_f (light petroleum–ethyl acetate 4 : 1) 0.28; δ_H(250 MHz; $CDCl_3$) 7.38 (5 H, s, Ph-H), 3.92 (1 H, m, C*H*OH), 2.78 (1 H, qd, *J* 7 and 4, C*H*Me), 2.48 (1 H, d, *J* 4, OH), 1.58–1.23 (6 H, m, alkyl-H), 1.26 (3 H, d, *J* 7, CH*Me*) and 0.89 (3 H, t, *J* 7, Me).

***S*-Phenyl (2*S**,3*S**)-4-benzyloxy-3-hydroxy-2-methylthiobutanoate 51**

In the same way as thioester **23**, benzyloxyacetaldehyde (0.54 mg, 3.6 mmol) gave, after column chromatography eluting with light petroleum–ether (3 : 2), thioester **51** as an inseparable mixture with cleaved 9-BBN. R_f (light petroleum–ether 3 : 2) 0.18; δ_H(250 MHz; $CDCl_3$) 7.46–7.27 (10 H, m, Ph-H and SPh), 4.56 (2 H, s, PhCH_2O), 4.08 (1 H, m, C*H*OH), 3.55 (2 H, m, CH_2O), 3.02 (1 H, quin, *J* 7.5, C*H*Me), 2.61 (1 H, d, *J* 4, OH), 1.33 (3 H, d, *J* 7.5, CH*Me*) and 2.00–1.39 (10 H, m, 9-BBN).

***S*-Phenyl (2*S**,3*S**)-3-furan-2-yl-3-hydroxy-2-methylthiopropanoate 52**

In the same way as thioester **23**, 2-furaldehyde (0.43 ml, 5 mmol) gave *hydroxyester* **52** (1.23 g, 90%) as a colourless oil, R_f (light petroleum–ether 4 : 1) 0.12; $\nu_{max}(CHCl_3)/cm^{-1}$ 3360 (OH), 1780 (C=O) and 1680 (C=C); δ_H(200 MHz; $CDCl_3$) 7.39 (6 H, m, Ph-H and furan-H), 6.36 (1 H, dd, *J* 1.8 and 3.3, furan-H), 6.33 (1 H, td, *J* 3.3 and 0.6, furan-H), 5.07 (1 H, t, *J* 5, C*H*OH), 3.27 (1 H, dq, *J* 7.5 and 5.0, C*H*Me), 2.76 (1 H, d, *J* 5, OH) and 1.49 (3 H, d, *J* 7.5, CH*Me*); δ_C(51 MHz; $CDCl_3$) 201.0, 153.4, 142.2, 134.5, 129.3, 128.5, 127.5, 110.5, 107.0, 68.5, 52.3 and 14.3; *m*/*z* (CI) 245.0 (100%, M − OH), 152 (33%, M − PhSH) and 110 (60%, PhSH) (Found: M − OH, 245.0635. $C_{14}H_{13}O_2S$ requires *M* − OH, 245.0636).

(2*S,3*S**)-2-Methyl-1-phenylpropane-1,3-diol 53**

In the same way as diol **42**, hydroxyester **49** (0.5 g, 1.8 mmol) gave after column chromatography eluting with dichloromethane–hexane (1 : 1), diol **53** (130 mg, 50%) as a colourless oil, R_f (dichloromethane–hexane 3 : 2) 0.13; $\nu_{max}(CHCl_3)/cm^{-1}$ 3480 (OH) and 1600 (C=C); δ_H(400 MHz; $CDCl_3$), 7.36–7.24 (5 H, m, Ph-H), 4.93 (1 H, d, *J* 3.74, PhC*H*OH), 3.70–3.62 (2 H, m, CH_AH_BOH), 2.93 (1 H, br s, OH), 2.42 (1 H, br s, OH), 2.09–2.01 (1 H, m, C*H*Me) and 0.83 (3 H, d, *J* 7.09, CH*Me*); δ_C(101 MHz; $CDCl_3$) 142.7, 128.3, 127.3, 126.1, 76.7, 66.5, 41.4 and 10.8; *m*/*z*(+EI) 166.1 (40%, M^+), 148 (20, M − H_2O) and 107 (100, PhCHOH). ^{1}H NMR is consistent with that reported previously.[35]

(2*S,3*S**)-2-Methylheptane-1,3-diol 54**

In the same way as diol **42**, hydroxyester **50** (1.2 g, 4.76 mmol) gave, after column chromatography eluting with ethyl acetate, diol **54** (570 mg, 82%) as a colourless oil, R_f (ethyl acetate) 0.30; $\nu_{max}(CHCl_3)/cm^{-1}$ 3480 (OH); ^{1}H NMR consistent with that reported previously.[31]

(2*S, 3*S**)-4-Benzyloxy-2-methylbutane-1,3-diol 55**

In the same way as diol **42**, hydroxyester **51** (impure) gave, after column chromatography eluting with ethyl acetate–light petroleum (1 : 1), *diol* **55** (300 mg, 40% over two steps) as a colourless oil, R_f (ethyl acetate–light petroleum 1 : 1) 0.12; $\nu_{max}(CHCl_3)/cm^{-1}$ 3460–3120 (OH) and 1590 (C=C); δ_H(400 MHz; $CDCl_3$) 7.37–7.27 (5 H, m, Ph-H), 4.58 (1 H, d, *J* 11.9, PhCH_AH_BO), 4.53 (1 H, d, *J* 11.9, PhCH_AH_BO), 3.99 (1 H, dt, *J* 5.7 and 3.7, C*H*OH), 3.70 (1 H, dd, *J* 11.2 and 5.0, OCH_AH_BCHO), 3.61 (1 H, dd, *J* 11.5 and 5.0 OCH_AH_BCHO), 3.51 (2 H, d, *J* 5.8, CH_2OH), 1.87 (1 H, m, C*H*Me) and 0.91 (3 H, d, *J* 7.1, CH*Me*); δ_C(101 MHz; $CDCl_3$) 137.8, 128.5, 127.9, 127.8, 73.5, 72.9, 72.6, 67.3, 37.4 and 11.1; *m*/*z* (+CI) (78%, MH^+) (Found: M^+, 211.1329. $C_{12}H_{19}O_3$ requires *M*, 211.1334).

(2*S,3*S**)-3-Furan-2-yl-2-methylpropane-1,3-diol 56**

In the same way as diol **42**, thioester **52** (1.23 g, 4.7 mmol) gave, after column chromatography eluting with light petroleum-ethyl acetate (1 : 1), *diol* **56** (0.616 g, 84%) as a colourless oil, R_f (light petroleum–ethyl acetate 1 : 1) 0.13; $\nu_{max}(CHCl_3)/cm^{-1}$ 3510–3050 (OH); δ_H(200 MHz; $CDCl_3$) 7.37 (1 H, dd, *J* 2.9 and 2.1, furyl-H), 6.34 (1 H, dd, *J* 3.2 and 1.8, furyl-H), 6.26 (1 H, d, *J* 3.3, furyl-H), 4.88 (1 H, d, *J* 4.1, C*H*OH), 3.64 (2 H, m, CH_2OH), 2.92 (1 H, br s, OH), 2.22 (1 H, m, C*H*Me), 1.69 (1 H,

br s, OH) and 0.91 (3 H, d, *J* 7.1, CH*Me*); δ_C(101 MHz; $CDCl_3$) 155.5, 141.8, 110.2, 106.6, 71.3, 66.2, 39.8 and 11.5; *m*/*z*(+CI) 156.1 (8%, M^+), 139.0 (100, M − OH) and 96.0 (7, furan CHO) (Found: M^+, 156.0787. $C_8H_{12}O_3$ requires *M*, 156.0786).

Methyl 2-(1-hydroxycyclohexyl)propanoate 57

In the same way as ester **15**, methyl propionate (1 ml, 10 mmol) and cyclohexanone (1 ml, 9.9 mmol) gave, after column chromatography eluting with light petroleum–ether (9 : 1 to 1 : 1), hydroxyester **57** (0.772 g, 73%) as a colourless oil, R_f (light petroleum–ether 9 : 1) 0.30; ν_{max}($CHCl_3$)/cm^{-1} 3520 (OH) and 1750 (C=O); δ_C(51 MHz; $CDCl_3$) 178.0, 70.0, 52.0, 48.0, 37.0, 33.0, 25.0, 22.0, 21.5 and 11.0; *m*/*z*(+CI) 187.1 (64%, MH^+) and 169.1 (88, M − H_2O) (Found: MH^+, 187.1320. $C_{10}H_{19}O_3$ requires *M*H, 187.1334). ^{1}H NMR consistent with that reported earlier.[36]

1-(2-Hydroxy-1-methylethyl)cyclohexanol 58

In the same way as diol **36**, hydroxyester **57** (0.772 g, 4.0 mmol) gave, after column chromatography with ethyl acetate–light petroleum (3 : 2), diol **58** (0.456 g, 64%) as a colourless oil, R_f (ethyl acetate–light petroleum 3 : 2) 0.31; ν_{max}($CHCl_3$)/cm^{-1} 3440 (OH); δ_C(101 MHz; $CDCl_3$) 74.7, 65.3, 42.7, 36.5, 32.6, 25.8, 21.7, 21.3 and 12.2; *m*/*z*(+CI) 158.2 (88%, M^+), 141 (100, M − OH), 123 (58, M − C_2H_6O) and 98 (59, c-hexyl). ^{1}H NMR consistent with that reported previously.[36]

2,6-Dimethylphenyl 2,4-dimethyl-3-hydroxy-4-phenylsulfanyl-pentanoate 60

In the same way as ester **13**, 2,6-dimethylphenyl propanoate (2.2 g, 12.6 mmol) and aldehyde **59**[18b] (2.5 g, 13.9 mmol) in tetrahydrofuran (100 ml) gave, after column chromatography eluting with light petroleum–ether (9 : 1), ester **60** (4.6 g, 94%) as an oil, R_f (light petroleum–ether 9 : 1) 0.18; ν_{max} (film, $CDCl_3$)/cm^{-1} 1750 (RCO_2Ar); ^{1}H NMR consistent with that reported previously.[37]

2,4-Dimethyl-4-phenylsulfanylpentane-1,3-diol 61

In the same way as diol **16**, ester **60** (0.5 g, 1.46 mmol) gave, after column chromatography eluting with light petroleum–ether (1 : 1), diol **61** (0.34 g, 97%) as an oil, R_f (ether) 0.45; ν_{max} (film, $CDCl_3$)/cm^{-1} 3500–3200 (OH); ^{1}H NMR consistent with that reported earlier.[37]

2,4-Dimethyl-4-phenylsulfonylpentane-1,3-diol 62

In the same way as sulfone **19**, diol **61** (0.2 g, 0.83 mmol) gave, after column chromatography eluting with ether, *sulfone* **62** (0.18 g, 80%) as an oil, R_f (ether) 0.3; ν_{max} (film, $CDCl_3$)/cm^{-1} 3400–3200 (OH); δ_H(400 MHz; $CDCl_3$) 7.87 (2 H, dd, *J* 8.0 and 5.2, *o*-SPh), 7.69 (1 H, t, *J* 7.4, *p*-SPh), 7.59 (2 H, t, *J* 7.4, *m*-SPh), 4.19 (1 H, br s, OH), 4.11 (1 H, d, *J* 4.8, C*H*OH), 3.66 (2 H, m, CH_2O), 2.95 (1 H, br s, OH), 1.92 (1 H, m, C*H*Me), 1.44 (3 H, s, Me), 1.23 (3 H, s, Me) and 1.00 (3 H, d, *J* 7.0, *Me*CH); δ_C(101 MHz; $CDCl_3$) 134.6, 134.1, 130.4, 129.0, 76.6, 67.4, 65.7, 36.0, 20.1, 17.9 and 15.6; *m*/*z* 273.1 (5%, M + H), 125.0 (40, PhSO), 77.0 (70, Ph) and 71.1 (100, C_4H_7O) (Found: MH^+, 273.1142. $C_{13}H_{21}O_4S$ requires *M*H, 273.1142).

(2*S,3*R**)-3-Methyl-2-phenyloxetane 63**

Method A: modified Mitsunobu reaction. Triphenylphosphine (0.32 g, 1.2 mmol) was added to a solution of diol **42** (100 mg, 0.6 mmol) in toluene (5 ml). When the solution was again clear, Ziram® (0.28 g, 0.9 mmol) was added followed by diisopropyl azodicarboxylate (0.24 ml, 1.2 mmol). The solution was stirred for 18 hours and filtered through Celite®. Dichloromethane (10 ml) was added and the solvent removed under reduced pressure. The residue was purified by column chromatography eluting with light petroleum–ether (9 : 1) to yield *oxetane* **63** (19 mg, 20%).

Method B: *via* formation of mesylate. Triethylamine (0.20 ml, 1.47 mmol) and methanesulfonyl chloride (0.057 ml, 0.73 mmol) were added to a solution of diol **42** (115 mg, 0.73 mmol) in dichloromethane (10 ml) at 0 °C. The mixture was left to stir overnight before the addition of potassium *tert*-butoxide (246 mg, 2.20 mmol). The solution was stirred for 18 hours then water (5 ml) was added and the product extracted with dichloromethane (10 ml). The organic extract was dried (($MgSO_4$) and the solvent removed under reduced pressure to yield *oxetane* **63** (85 mg, 79%), R_f (light petroleum–ether 4 : 1) 0.45; ν_{max}($CHCl_3$)/cm^{-1} 965 (CO) and 910 (CO); δ_H(500 MHz; $CDCl_3$) 7.45 (2 H, d, *J* 7.3, Ph *ortho*-H), 7.40 (2 H, t, *J* 7.4, Ph *meta*-H), 7.31 (1 H, t, *J* 7.2, Ph *para*-H), 5.26 (1 H, d, *J* 6.7, PhC*H*OH), 4.75 (1 H, dd, *J* 8.0 and 5.9, C$H_A$$H_B$O), 4.43 (1 H, t, *J* 6.53, $CH_A$$H_B$O), 2.99 (1 H, sept, *J* 7.1, C*H*Me) and 1.34 (3 H, d, *J* 6.8, CH*Me*); δ_C(101 MHz; $CDCl_3$) 142.9, 128.5, 127.9, 125.2, 90.4, 75.1, 39.7 and 17.7; *m*/*z*(+EI) 148.1 (95%, M^+), (100, M − [CH_2=CHMe]) and 77 (25, Ph) (Found: M^+, 148.0889. $C_{10}H_{12}O$ requires *M*, 148.0888).

(2*S,3*R**)-2-Butyl-3-methyloxetane 64**

In the same way as oxetane **63**, method A, diol **43** (100 mg, 0.69 mmol) gave *oxetane* **64** (15 mg, <17%) inseparable from impurities. In the same way as oxetane **63**, method B, diol **43** (95 mg, 0.66 mmol) gave *oxetane* **64** (23.7 mg, 28%) as a colourless oil, R_f (light petroleum–ether 9 : 1) 0.25; ν_{max}($CHCl_3$)/cm^{-1} 970 and 920 (C-O); δ_H(400 MHz; $CDCl_3$) 4.57 (1 H, dd, *J* 8.1 and 5.8, C$H_A$$H_B$O), 4.35 (1 H, q, *J* 6.5, RC*H*O), 4.21 (1 H, dd, *J* 7.0 and 5.9, $CH_A$$H_B$O), 2.65 (1 H, sept, *J* 6.9, C*H*Me), 1.80–1.21 (6 H, m, CH_2), 1.19 (3 H, d, *J* 6.9, CH*Me*) and 0.91 (3 H, t, *J* 6.9, Me); δ_C(101 MHz; $CDCl_3$) 90.1, 75.0, 36.9, 36.0, 26.2, 22.7, 17.9 and 14.0; *m*/*z*(+CI) 129 (10%, MH), 111 (76, M − H_2O), 93 (64, M − 2 × H_2O), 69 (30, $MeCH_2CH_2CH_2CH$) and 58 (17, $MeCHCH_2O$) (Found: MH, 129.1275. $C_8H_{17}O_1$ requires *M*H, 129.1279).

(2*S,3*R**)-2-Benzyloxymethyl-3-methyloxetane 65**

In the same way as oxetane **63**, method A diol **44** (100 mg, 0.48 mmol) gave oxetane **65** (46 mg, 50%). In the same way as oxetane **63**, method B; diol **44** (144 mg, 0.68 mmol) gave oxetane **65** (88 mg, 67%) as a colourless oil, R_f (light petroleum–ether 4 : 1) 0.15; ν_{max}($CHCl_3$)/cm^{-1} 1644.4 (C=C), 963.8 (ring CO) and 906.6 (ring CO); δ_H(400 MHz; $CDCl_3$) 7.33 (5 H, m, Ph), 4.65 (1 H, dd, *J* 8.1 and 5.7, ring C$H_A$$H_B$O), 4.61 (2 H, d, *J* 7.2, PhCH_2O), 4.53 (1 H, m, ring-CHO), 4.24 (1 H, t, *J* 6.4, ring-C$H_A$$H_B$O), 3.65 (1 H, dd, *J* 11.1 and 4.9, OC$H_A$$H_B$CO), 3.60 (1 H, dd, *J* 11.1 and 3.6, OC$H_A$$H_B$C), 2.90 (1 H, sept, *J* 7.0, C*H*Me) and 1.21 (3 H, d, *J* 6.9, CH*Me*); δ_C(101 MHz; $CDCl_3$) 138.3, 128.3, 127.8, 127.6, 88.3, 75.8, 73.5, 72.8, 31.9 and 17.8; *m*/*z*(+CI) 192.1 (52%, M^+), 161 (28, M − CH_2O), 107 (66, PhCH_2O) and 91 (100, PhCH_2).

(2*S,3*R**)-2-Isopropyl-3-methyloxetane 67**

In the same way as oxetane **3** (Table 1, entry 2), the diol **46** (0.13 g, 0.94 mmol), gave, after column chromatography eluting with light petroleum–ether (1 : 1) the oxetane **67** (5.6 mg, 5%) as an oil, R_f (light petroleum–ether 9 : 1) 0.3; ν_{max} (film, $CDCl_3$)/cm^{-1} 3100 (OH); δ_H(400 MHz; $CDCl_3$) 4.51 (1 H, dd, *J* 7.6 and 5.7, C$H_A$$H_B$O), 4.18 (1 H, d, *J* 6.2, CHO), 4.16 (1 H, t, *J* 7.6, $CH_A$$H_B$O), 2.91 (1 H, m, C*H*Me), 1.89 (1 H, m, C*H*$(Me)_2$), 1.31 (3 H, d, *J* 7.9, *Me*CH), 0.84 (3 H, d, *J* 2.8, Me_ACHMe_B) and 0.82 (3 H, d, *J* 2.8, Me_ACH*Me*$_B$); δ_C(101 MHz; $CDCl_3$) 94.0, 74.5, 36.0, 31.6, 18.7, 18.4 and 17.3; *m*/*z* 115.2 (95%, M + H), 86.1 (100, M − CH_2O) and 72.0 (25, M − C_3H_6).

(2*S,3*R**)-2-*tert*-Butyl-3-methyloxetane 68**

In the same way as oxetane **3** (Table 1, entry 2), the diol **47** (0.2 g, 1.36 mmol), gave, after column chromatography eluting with light petroleum–ether (9 : 1) the oxetane **68** (0.15 g, 85%) as an oil, R_f (light petroleum–ether 9 : 1) 0.35; ν_{max} (film, $CDCl_3$)/cm^{-1} 3100 (CH); δ_H(400 MHz; $CDCl_3$) 4.40 (1 H, dd, *J* 8.2 and 5.7, CH_AH$_B$O), 4.14 (1 H, br t, *J* 6.1, CH$_A$$H_B$O), 3.99 (1 H, d, *J* 6.4, CHO), 2.73 (1 H, m, C*H*Me), 1.18 (3 H, d, *J* 6.8, *Me*CH) and 0.88 (9 H, s, ^{t}Bu); δ_C(101 MHz; $CDCl_3$) 97.4, 74.4, 31.8, 29.0, 23.8 and 18.7; *m*/*z* 84.1 (5%, ^{t}BuCHCH$_2$), 71.1 (75, M − ^{t}Bu) and 57.1 (100, ^{t}Bu).

(2*S,3*R**)-2-Cyclohexyl-3-methyloxetane 69**

In the same way as oxetane **3** (Table 1, entry 2), the diol **48** (0.2 g, 1.16 mmol), gave, after column chromatography eluting with light petroleum–ether (9 : 1) the oxetane **69** (5.3 mg, 3%) as an oil, R_f (light petroleum–ether 9 : 1) 0.25; ν_{max} (film, $CDCl_3$)/cm^{-1} 3100 (CH). ^{1}H NMR consistent with that reported previously.[38]

(2*S,3*S**)-3-Methyl-2-phenyloxetane 70**

In the same way as oxetane **63**, method A; diol **53** (0.1 g, 0.60 mmol) gave oxetane **70** (10 mg, 11%). In the same way as oxetane **63**, method B; diol **53** (50 mg, 0.30 mmol) gave oxetane **70** (22.4 mg, 50%) as a colourless oil, R_f (light petroleum–ether 4 : 1) 0.28; ν_{max}($CHCl_3$)/cm^{-1} 1600 (C=C), 980 and 920 (C-O). ^{1}H NMR consistent with that reported previously.[30]

(2*S,3*S**)-2-Butyl-3-methyloxetane 71**

In the same way as oxetane **63**, method B; diol **54** (100 mg, 0.69 mmol) gave *oxetane* **71** (30 mg, 34%) as a colourless oil, R_f (light petroleum–ether 9 : 1) 0.25; ν_{max}($CHCl_3$)/cm^{-1} 970 and 920 (C-O); δ_H(500 MHz; $CDCl_3$) 4.80 (1 H, td, *J* 7.9 and 5.5, RC*H*O), 4.75 (1 H, dd, *J* 7.4 and 5.8, CH_AH$_B$O), 4.05 (1 H, t, *J* 5.6, CH$_A$$H_B$O), 2.99 (1 H, sept, *J* 7.0, C*H*Me), 1.77–1.17 (6 H, m, CH_2), 1.16 (3 H, d, *J* 7.2, CH*Me*) and 0.89 (3 H, t, *J* 7.2, Me); δ_C(101 MHz; $CDCl_3$) 85.0, 75.6, 32.0, 31.5, 29.7, 26.9, 14.0 and 13.5; *m*/*z*(+CI) 111.1 (100%, MH − OH_2), 69.1 (35, CH_3-$CH_2CH_2CH_2$C) and 58.1 (40, OCH_2CHCH_3) [Found: (MH − OH_2)$^+$, 111.1177. C_8H_{15} requires *M*H − OH_2, 111.1174].

(2*S,3*S**)-2-Benzyloxymethyl-3-methyloxetane 72**

In the same way as oxetane **63**, method A, diol **55** (100 mg, 0.49 mmol) gave *oxetane* **72** (33 mg, <35%) inseparable from impurities. In the same way as oxetane **63**, method B, diol **55** (102 mg, 0.49 mmol) gave *oxetane* **72** (30 mg, 32%) as a colourless oil, R_f (light petroleum–ether 4 : 1) 0.10; ν_{max}($CHCl_3$)/cm^{-1} 1644 (C=C), 964 (ring CO) and 907 (ring CO); δ_H(400 MHz; $CDCl_3$) 7.37–7.24 (5 H, m, Ph), 4.95 (1 H, td, *J* 11.8 and 3.8, CHO), 4.75 (1 H, dd, *J* 7.9 and 5.6, ring-CH_AH$_B$O), 4.58 (1 H, d, *J* 10.1, PhH_AH$_B$O), 4.53 (1 H, d, *J* 10.1, PhH$_A$$H_B$O), 4.19 (1 H, t, *J* 6.0, ring CH$_A$$H_B$O), 3.72 (2 H, d, *J* 5.8, OCH_2CHO), 3.14 (1 H, sept, *J* 7.1, C*H*Me) and 1.16 (3 H, d, *J* 7.1, CH*Me*); δ_C(101 MHz; $CDCl_3$) 138.2, 128.6, 127.8, 127.7, 83.0, 76.8, 73.5, 72.8, 31.3 and 13.4; *m*/*z*(+CI) 193.1 (33%, MH$^+$), 108.1 (23, $PhCH_2OH$), 91.1 (100, $PhCH_2$) and 85.1 (73, C_4H_7O) (Found: MH$^+$, 193.1218. $C_{12}H_{17}O_2$ requires *M*H, 193.1228).

3-Methyl-1-oxaspiro[3.5]nonane 74

In the same way as oxetane **63**, method B, diol **57** (104 mg, 0.72 mmol) gave *oxetane* **74** (30 mg, 33%) as a colourless oil, R_f (light petroleum–ether 9 : 1) 0.25; ν_{max}($CHCl_3$)/cm^{-1} 970 and 920 (C-O); δ_H(400 MHz; $CDCl_3$) 4.56 (1 H, dd, *J* 5.9 and 8.1, CH_AH$_B$O), 4.01 (1 H, t, *J* 6.3, CH$_A$$H_B$O), 2.62 (1 H, sex, *J* 7.1, C*H*Me), 1.84–1.26 (10 H, m, CH_2) and 1.13 (3 H, d, *J* 5.1 CH*Me*); δ_C(101 MHz; $CDCl_3$) 87.8, 72.4, 39.8, 38.1, 32.6, 25.4, 22.3, 22.2 and 13.7; *m*/*z*(+CI) 141.1 (13%, MH$^+$), 123.0 (27, MH − OH_2), 84.2 (18, c-hexyl − 2 × H) and 59.1 (22, $HOCH_2CHCH_3$) (Found: MH$^+$, 141.1280. $C_9H_{17}O$ requires *M*H, 141.1279).

2-(1-Phenylsulfonyl-1-methylethyl)-3-methyloxetane 75

In the same way as oxetane **3** (Table 1, entry 3), sulfone **61** (55 mg, 0.21 mmol) gave, after column chromatography eluting with light petroleum–ether (1 : 1), the oxetane **75** (47 mg, 92%), R_f (light petroleum–ether 1 : 1) 0.4; ν_{max}($CHCl_3$)/cm^{-1} 3100 (CH); δ_H(500 MHz; $CDCl_3$) 7.86 (2 H, d, *J* 7.5, Ph-H), 7.64 (1 H, t, *J* 7.4, Ph-H), 7.54 (2 H, t, *J* 7.8, Ph-H), 4.73 (1 H, d, *J* 6.4, CHO), 4.47 (1 H, dd, *J* 8.3 and 5.9, CH_AH$_B$O), 4.21 (1 H, t, *J* 6.1, CH$_A$$H_B$O), 2.99 (1 H, m, C*H*Me), 1.35 (3 H, s, Me), 1.33 (3 H, s, Me) and 1.30 (3 H, d, *J* 6.8, CH*Me*); δ_C(101 MHz; $CDCl_3$) 136.5, 133.7, 130.3, 128.7, 89.1, 75.7, 65.4, 31.9, 18.3, 17.5 and 14.4; *m*/*z* 125.0 (30%, PhSOH), 113.1 (100, M − PhSOH) and 71.1 (25, M − C_3H_6SOPh).

4-Hydroxy-5-methyl-5-phenylsulfanylhexan-2-one 76

In the same way as ester **13**, acetone (0.61 g, 0.8 ml, 10.5 mmol) and aldehyde **59**[18b] (1.8 g, 10 mmol) gave, after column chromatography eluting with light petroleum–ether (1 : 1), the ketone **76** (2.2 g, 92%) as an oil, R_f (light petroleum–ether 1 : 1) 0.5; ν_{max} (film, $CDCl_3$)/cm^{-1} 3300 (OH) and 1715 (CO); δ_H(200 MHz; $CDCl_3$) 7.59–7.29 (5 H, m, SPh), 3.72 (1 H, dd, *J* 9.7 and 2.2, C*H*OH), 3.25–3.10 (1 H, br s, OH), 2.61 (1 H, double AB quartet, *J* 16.4 and 4.4, CH_AH$_B$), 2.67 (1 H, double AB quartet, *J* 16.4 and 10.9, CH$_A$$H_B$), 2.22 (3 H, s, MeCO), 1.26 (3 H, s, Me) and 1.20 (3 H, s, Me); δ_C(51 MHz; $CDCl_3$) 208.6, 137.4, 130.9, 129.1, 128.6, 72.1, 53.0, 44.6, 30.6, 24.5 and 23.9; *m*/*z* 238.1 (100%, M), 220.1 (30, M − H_2O) and 151.1 (70, C_3H_6SPh).

5-Methyl-5-phenylsulfanylhexan-2,4-diols 77 and 78

In the same way as diol **16**, ketone **76** (0.1 g, 0.42 mmol) gave, after column chromatography eluting with light petroleum–ether (1 : 1), the *diol* **77** (62 mg, 61%) as an oil, R_f (light petroleum–ether 1 : 1) 0.2; ν_{max} (film, $CDCl_3$)/cm^{-1} 3500–3300 (OH); δ_H(200 MHz; $CDCl_3$) 7.54–7.25 (5 H, m, SPh), 4.03–3.87 (1 H, m, C*H*Me), 3.87–3.50 (2 H, br s, 2 × OH), 3.54 (1 H, dd, *J* 9.8 and 2.9, C*H*OH), 1.68–1.39 (2 H, m, CH_2), 1.27 (3 H, s, Me), 1.18 (3 H, s, Me) and 1.16 (3 H, d, *J* 6.0, *Me*CH); δ_C(51 MHz; $CDCl_3$) 137.4, 130.1, 129.2, 128.8, 76.0, 66.4, 54.7, 38.1, 25.4, 23.6 and 21.9; *m*/*z* 240.1 (35%, M), 151.1 (100, C_3H_6SPh), 110.0 (60, PhSH) and 71.1 (45, C_4H_7O) (Found: M$^+$, 240.1178. $C_{13}H_{20}O_2S$ requires *M*, 240.1183) and the *diol* **78** (31 mg, 30%) as an oil, R_f (light petroleum–ether 1 : 1) 0.1; ν_{max} (film, $CDCl_3$)/cm^{-1} 3450–3300 (OH); δ_H(200 MHz; $CDCl_3$) 7.58–7.34 (5 H, m, SPh), 4.20–4.05 (1 H, m, C*H*Me), 3.67 (1 H, dd, *J* 9.8 and 3.0, C*H*OH), 3.29–3.17 (1 H, br s, OH), 2.55–2.20 (1 H, br s, OH), 1.74–1.45 (2 H, m, CH_2), 1.24 (3 H, s, Me), 1.22 (3 H, d, *J* 6.4, *Me*CH) and 1.18 (3 H, s, Me); δ_C(51 MHz; $CDCl_3$) 137.4, 130.1, 129.2, 128.7, 71.7, 65.5, 55.1, 38.2, 25.6, 23.3 and 22.4; *m*/*z* 240.1 (5%, M), 151.1 (100, C_3H_6SPh), 110.0 (65, PhSH) and 71.1 (50, C_4H_7O) (Found: M$^+$, 240.1185. $C_{13}H_{20}O_2S$ requires *M*, 240.1183).

(3*R,5*R**)-3-Phenylsulfanyl-2,2,5-trimethyltetrahydrofuran 79**

In the same way as oxetane **3** (Table 1, entry 3), diol **77** (40 mg, 0.16 mmol) gave, after column chromatography eluting with light petroleum–ether (9 : 1), the *THF* **79** (37 mg, 99%), R_f (light petroleum–ether 9 : 1) 0.25; ν_{max}($CHCl_3$)/cm^{-1} 1550 (SPh); δ_H(500 MHz; $CDCl_3$) 7.45–7.20 (5 H, m, SPh), 4.05 (1 H, d quintet, *J* 9.9 and 6.0, C*H*Me), 3.47 (1 H, dd, *J* 11.1 and 6.8, C*H*SPh), 2.45 (1 H, quintet, *J* 5.6, CH_AH$_B$), 1.74 (1 H, ddd, *J* 9.9, 6.5 and 5.5, CH$_A$$H_B$), 1.27 (6 H, s, 2 Me) and 1.26 (3 H, d, *J* 6.1, CH*Me*); δ_C(101 MHz; $CDCl_3$) 135.9, 131.3, 129.0, 126.9, 82.3, 72.1, 56.3, 42.3, 28.1, 25.6 and 22.1; *m*/*z* 207.1 (55%, M − Me), 164.1 (15, M − C_3H_6O) and 110.0 (20, PhSH) [Found: (M − Me)$^+$, 207.0842. $C_{12}H_{15}OS$ requires *M* − Me, 207.0430].

(3*R,5*S**)-3-Phenylsulfanyl-2,2,5-trimethyltetrahydrofuran 80**

In the same way as oxetane **3** (Table 1, entry 3), diol **78** (40 mg, 0.16 mmol) gave, after column chromatography eluting with light petroleum–ether (9 : 1), the *THF* **80** (37 mg, 99%), R_f (light petroleum–ether 9 : 1) 0.25; $\nu_{max}(CHCl_3)/cm^{-1}$ 1550 (SPh); δ_H(500 MHz; $CDCl_3$) 7.42–7.20 (5 H, m, SPh), 4.21 (1 H, sextet, *J* 6.1, C*H*Me), 3.44 (1 H, t, *J* 8.6, C*H*SPh), 2.18 (1 H, dt, *J* 13.1 and 8.2, CH_AH_B), 2.08 (1 H, ddd, *J* 13.0, 8.5 and 5.4, CH_AH_B), 1.28 (3 H, s, Me), 1.26 (3 H, s, Me) and 1.22 (3 H, d, *J* 6.2, CH*Me*); δ_C(101 MHz; $CDCl_3$) 136.0, 131.0, 129.0, 126.7, 82.9, 71.3, 54.8, 41.1, 28.3, 22.5 and 22.4; *m*/*z* 222.1 (100%, M), 164.1 (15, M − C_3H_6O) and 110.0 (20, PhSH) (Found: M^+, 222.1078. $C_{13}H_{18}OS$ requires *M*, 222.1078).

Acknowledgements

We thank the EPSRC, Zeneca and GlaxoWelcome for CASE studentships. We thank Dr Brian Looker (GW) and Dr Ray Jones (Zeneca) for considerable contributions, both intellectual and material.

References

1 K. C. Nicolaou and R. K. Guy, *Angew. Chem., Int. Ed. Eng.*, 1995, **34**, 2079.
2 T. Suzuki and E. Kurosawa, *Chem. Lett.*, 1979, 301.
3 F. A. Macías, J. M. G. Molinillo and G. M. Massanet, *Tetrahedron*, 1993, **49**, 2499.
4 Y. Kawahata, S. Takatsuto, N. Ikekawa, M. Murata and S. Omura, *Chem. Pharm. Bull.*, 1986, **34**, 3102.
5 D. W. Norbeck and J. B. Kramer, *J. Am. Chem. Soc.*, 1988, **110**, 7217.
6 (*a*) T. Bach, K. Kather and O. Krämer, *J. Org. Chem.*, 1998, **63**, 1910; (*b*) T. Bach, F. Eilers and K. Kather, *Liebigs Ann./Recl.*, 1997, 1529; (*c*) H. Xianming and R. M. Kellogg, *Tetrahedron: Asymmetry*, 1995, **6**, 1399; (*d*) P. Crotti, L. Favero, F. Macchia and M. Pineschi, *Tetrahedron Lett.*, 1994, **35**, 7089; (*e*) D. R. Morton and R. A. Morge, *J. Org. Chem.*, 1978, **43**, 2093; (*f*) A. Bochki, L. R. Falvello, F. Foubelo and M. Yus, *Tetrahedron: Asymmetry*, 1997, **8**, 2633.
7 (*a*) R. J. Lindeman, in *Comprehensive Heterocyclic Chemistry II*, eds. A. R. Katritzky and C. W. Rees, Pergamon, Oxford, 1996, 1B, p. 721; (*b*) J. A. Porco and S. L. Schreiber, in *Comprehensive Organic Chemistry*, eds. B. M. Trost and I. Fleming, Pergamon, Oxford, 1991, 5, p. 151; (*c*) S. Searles, in *Comprehensive Heterocyclic Chemistry*, eds. A. R. Katritzky and C. W. Rees, Pergamon, Oxford, 1984, 7, p. 363.
8 (*a*) H. Xianming and R. M. Kellogg, *Synthesis*, 1995, 533; (*b*) K. L. Thompson, M. N. Chang, Y.-C. P. Chiang, S. S. Yang, J. C. Chabala, B. H. Arison, M. D. Greenspan, D. P. Hanf and J. Yudkovitz, *Tetrahedron Lett.*, 1991, **32**, 3337.
9 H.-C. Tsui and L. A. Paquette, *J. Org. Chem.*, 1998, **63**, 9968.
10 T. Bach, *Synthesis*, 1998, 683.
11 D. Craig and V. R. N. Munasinghe, *J. Chem. Soc., Chem. Commun.*, 1993, 901.
12 P. Rollin, *Tetrahedron Lett.*, 1986, **27**, 4169; P. Rollin, *Synth. Commun.*, 1986, **16**, 611.
13 V. K. Aggarwal, I. Coldham, S. A. McIntyre and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 1991, 451.
14 J. Eames and S. Warren, *Tetrahedron Lett.*, 1996, **37**, 3525.
15 (*a*) C. H. Heathcock in *Modern Synthetic Methods*, VCH, Switzerland, 1992, p. 1–102; (*b*) C. H. Heathcock in *Comprehensive Organic Synthesis*, eds. B. M. Trost and I. Fleming, Pergamon, Oxford, 1991, 2, p. 181; (*c*) B. M. Kim, S. F. Williams and S. Masamune in *Comprehensive Organic Synthesis*, eds. B. M. Trost and I. Fleming, Pergamon, Oxford, 1991, 2, p. 239.
16 J. G. Verkade and L. D. Quin, in *Methods in Stereochemical Analysis 8: Phosphorus 31 NMR Spectroscopy in Stereochemical Analysis*, VCH, Deerfield Beach, 1987, p. 271; and references therein.
17 A. J. Kirby, *Adv. Phys. Org. Chem.*, 1980, p. 208.
18 (*a*) T. Sato, H. Okazaki, J. Otera and H. Nozaki, *J. Am. Chem. Soc.*, 1988, **110**, 5209; (*b*) A. de Groot and B. J. M. Jansen, *Synthesis*, 1985, 434; A. de Groot and B. J. M. Jansen, *Tetrahedron Lett.*, 1981, **22**, 887.
19 C. H. Heathcock, M. C. Pirrung, S. H. Montgomery and J. Lampe, *Tetrahedron*, 1981, **37**, 4087.
20 S. Masamune, W. Choy, J. S. Peterson and L. R. Sita, *Angew. Chem., Int. Ed. Engl.*, 1985, **24**, 1.
21 J. Eames, M. de las Heras, R. V. H. Jones and S. Warren, *Tetrahedron Lett.*, 1996, **37**, 1117.
22 P. G. Jones, *Chem. Br.*, 1981, **17**, 222.
23 P. Canbère and P. Coutrot, in *Comprehensive Organic Synthesis*, eds. B. M. Trost and I. Fleming, Pergamon, Oxford, 1991, 8, 835.
24 A. R. Maguire, in *Comprehensive Organic Functional Group Transformations*, eds. A. R. Katritzky, O. Meth-Cohn and C. W. Rees, Pergamon, Oxford, 1995, 1, 859.
25 V. K. Aggarwal, I. Coldham, S. McIntyre and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 1991, 451.
26 K. Chibale and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 1996, 1935.
27 K. Chibale and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 1995, 2411.
28 S. H. Montgomery, M. C. Pirrung and C. H. Heathcock, *Org. Synth.*, 1985, **63**, 99.
29 R. O. Duthaler, P. Herald, S. Wyler-Helfer and M. Rudiker, *Helv. Chim. Acta*, 1990, **73**, 659.
30 A. Balsamo, G. Ceccarelli, P. Crotti and F. Macchia, *J. Org. Chem.*, 1975, **40**, 473.
31 T. Harada, S. Tanaka and A. Oku, *Tetrahedron*, 1992, **48**, 8621.
32 H. Sacha, D. Waldmuller and M. Braun, *Chem. Ber.*, 1994, **127**, 1959.
33 W. R. Roush, K. Ando, D. B. Powers, A. D. Palkowitz and R. L. Halterman, *J. Am. Chem. Soc.*, 1990, **112**, 6339.
34 K. Inomata, T. Kawahara and T. Mukaiyama, *Chem. Lett.*, 1974, 245.
35 C. R. Sarko, S. E. Collibee, A. L. Knorr and M. DiMare, *J. Org. Chem.*, 1996, **61**, 868.
36 T. Sugita, N. Nishio and K. Ichikawa, *Bull. Chem. Soc. Jpn.*, 1982, **55**, 1677.
37 V. K. Aggarwal, J. Eames, M.-J. Villa, S. McIntyre, F. H. Sansbury and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 2000, 533.
38 P. Picard, D. Leclerq, J. P. Bats and J. Moulines, *Synthesis*, 1981, 550.