Selective synthesis of *cis*-2-vinyl-3-alkylaziridines and 3-pyrrolines from common intermediates (*Z*)-4-*N*-arylsulfonylaminoalk-2-en-1-ols

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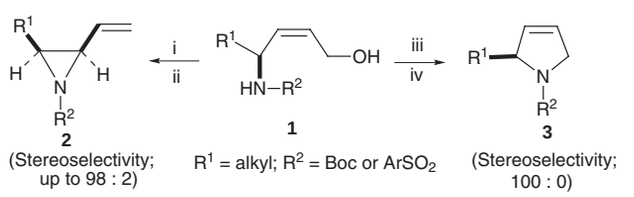
A simple method for the synthesis of both *cis*-2-vinylaziridines and 3-pyrrolines from common intermediate (*Z*)-4-(*N*-arylsulfonyl)amino-4-alkylbut-2-en-1-ols, is described. Palladium(0)-catalyzed reactions of methyl carbonates of the *N*-protected (*Z*)-4-amino-4-alkylbut-2-en-1-ols yield predominantly *cis*-3-alkyl-2-vinylaziridines. Alternatively, upon exposure to sodium hydride, methanesulfonates derived from *N*-protected (*Z*)-4-amino-4-alkylbut-2-en-1-ols give exclusively the corresponding 3-pyrrolines in high yields. A synthesis of biologically important (*S*)-3,4-dehydroproline is also presented.

In view of the important role played by chiral aziridines[1] as building blocks in the preparation of antibiotics,[2] dipeptide isosteres,[3] alkaloids,[4] azacycles,[5] allyl amines,[6] and amino allenes,[7] the development of versatile methodology for the synthesis of 2-(alk-1-enyl)aziridines in enantiomerically pure form has emerged as an important and challenging endeavor for synthetic chemists. On the other hand, chiral 3-pyrroline derivatives such as (*S*)-3,4-dehydroproline are of widespread interest because of their important biological activities.[8] In addition, chiral 3-pyrroline derivatives are known as useful intermediates for the synthesis of such compounds as amino acid analogues[9] and antibiotics.[10]

Recently, Olivo and coworkers reported that bicyclic compounds containing an aziridine-ring could be synthesized by exposure of some cyclic 4-aminobut-2-en-1-ol derivatives under Mitsunobu conditions.[11] It has been reported by Moreno-Mañas and coworkers that palladium(0)-catalyzed reactions of dicarbonates derived from (*Z*)- and (*E*)-but-2-ene-1,4-diol with certain amides yield medium and large unsaturated heterocycles instead of forming aziridines.[12] A previous report from our laboratories has demonstrated that (*E*)-4-(*N*-arylsulfonyl)amino-4-alkylbut-2-en-1-ols are useful intermediates for the stereoselective synthesis of *cis*-3-alkyl-2-alkenylaziridines by judicious selection of reaction conditions and substrate structures.[13] We have also reported that, whereas treatment of the mesylates (methanesulfonates) of *N*-protected (*E*)-2-alkyl-4-aminobut-2-en-1-ols with sodium hydride yields exclusively the corresponding *trans*-2-alkenyl-3-alkylaziridines, exposure of the corresponding methyl carbonates to $Pd(PPh_3)_4$ (5–20 mol%) affords predominantly the corresponding *cis*-isomers.[14]

Our present research is focused on the study of the influence of the (*Z*)-double bond geometry in the cyclization of methyl carbonates and mesylates of enantiomerically pure (*Z*)-4-amino-4-alkylbut-2-en-1-ols. As shown in Scheme 1, we anticipated that, whereas the palladium(0)-catalyzed reaction of methyl carbonates available by methoxycarbonylation of alcohols **1** would aid the production of the thermodynamically more stable *cis*-3-alkyl-2-alkenylaziridines **2**, the base-promoted reaction of mesylates obtainable by mesylation of **1** would produce 3-pyrroline derivatives **3**. In view of the considerable interest in regio- and stereoselective ring-closure, a detailed analysis of the (*Z*)-configurational influence on product distribution has been undertaken for palladium(0)-catalyzed and base-promoted cyclizations. This paper details the selective conversion of methyl carbonates and mesylates of chiral (*Z*)-4-aminobut-2-en-1-ol derivatives into *cis*-2-vinylaziridines **2** and 3-pyrrolines **3** (Scheme 1).[15]



Scheme 1 *Reagents:* i, $ClCO_2Me$–pyridine; ii, $Pd(PPh_3)_4$ (4 mol%) in THF; iii, MsCl–pyridine; iv, NaH in DMF.

Results and discussion

Preparation of the methyl carbonates and mesylates of (*Z*)-4-(*N*-arylsulfonylamino)but-2-en-1-ols

The starting (*Z*)-α,β-unsaturated esters (**4**–**8**) shown in Scheme 2 were readily prepared from the known chiral *N*-arylsulfonylamino aldehydes[13,16] by reacting with a phosphorus ylide developed by Ando.[17] Reduction of enoates (**4**–**8**) with DIBAL-H followed by methoxycarbonylation or mesylation afforded the requisite chiral methyl carbonates (**14**–**17**) or the mesylates (**18**–**22**) in good yields.

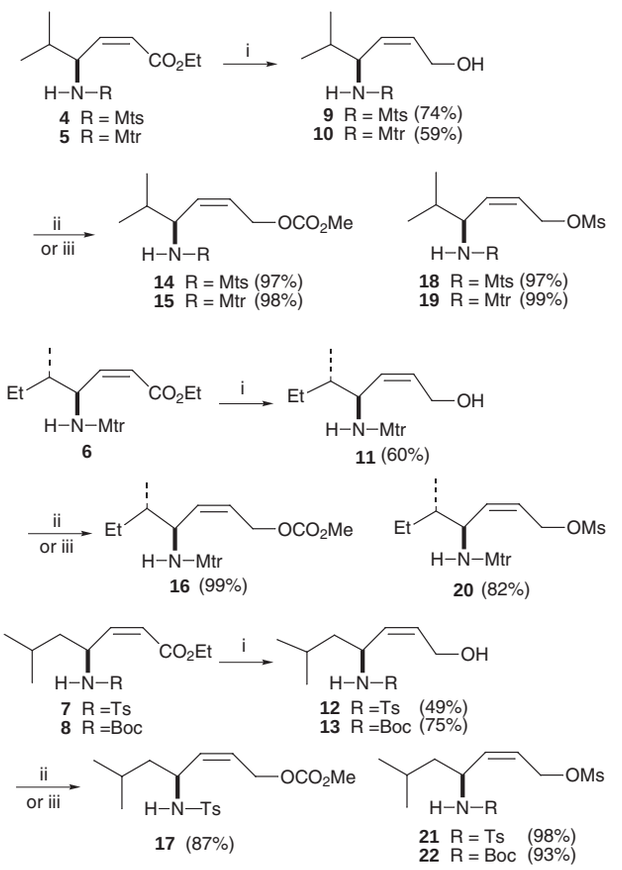
Palladium-catalyzed aziridination reactions of methyl carbonates of *N*-protected (*Z*)-4-aminobut-2-en-1-ol derivatives

We have previously shown that *cis*-3-alkyl-2-vinylaziridines like **H** are energetically more stable than the corresponding *trans*-isomers **G** (Scheme 3).[13,16,18] Accordingly, it was our expectation that the palladium(0)-catalyzed reaction of the (*Z*)-methyl carbonates of type **A** would aid the production of predominantly the thermodynamically more stable *cis*-2-vinylaziridines **H** *via* π-allyl palladium intermediates such as **B**, **C**, **D**, **E**, and **F** (Scheme 3).

Table 1 $Pd(PPh_3)_4$-catalyzed aziridination of allylic methyl carbonates **14**–**17**[a]

Entry	Substrate	$Pd(PPh_3)_4$ (mol%)	*T*/°C	*t*/min	*cis*:*trans*[b]	Yield (%)[c]
1	**14**	4	60	10	(**23**:**24**) = (94:6)	85
2	**15**	4	65	5	(**25**:**26**) = (97:3)	69
3	**16**	4	65	5	(**27**:**28**) = (97:3)	90
4	**17**	4	65	10	(**29**:**30**) = (94:6)	76

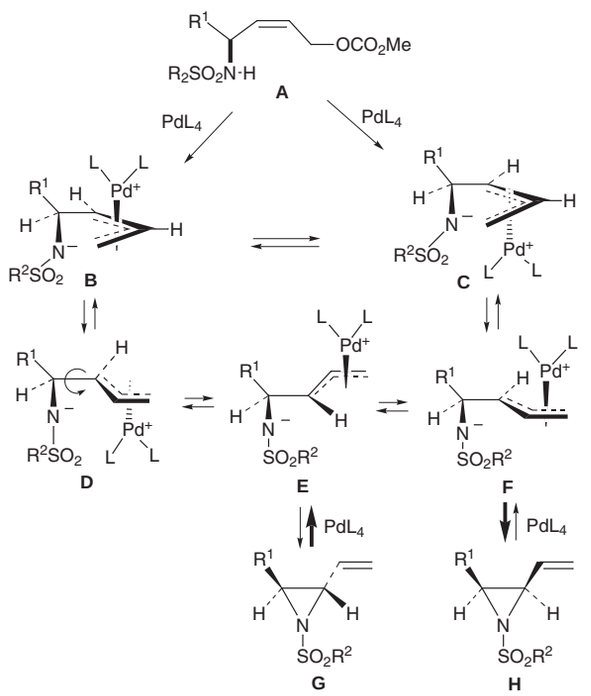
[a] All reactions were carried out in THF. [b] Ratios were determined by reverse phase HPLC ($MeOH:H_2O$ = 80–75:20–25 except for entry 4, $MeCN:H_2O$ = 1:1). [c] Combined isolated yields.



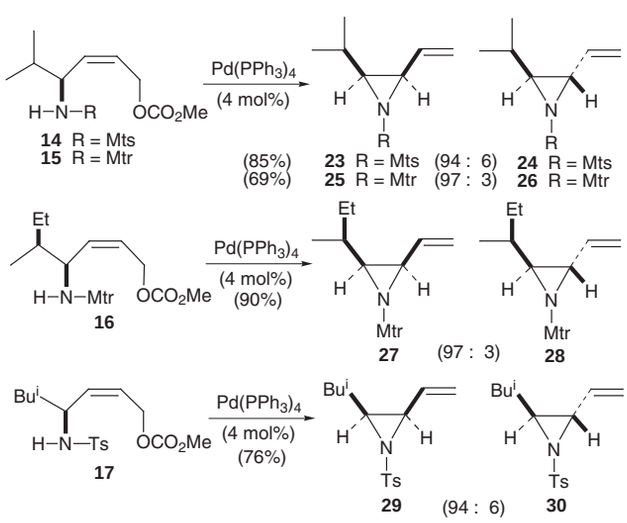
Scheme 2 *Reagents:* i, DlBAL-H; ii, $ClCO_2Me$–pyridine; iii, $MeSO_2Cl$–Et_3N.†

As one might expect, exposure of the carbonate **14** to 4 mol% of $Pd(PPh_3)_4$ in THF at 60 °C for 10 min afforded a separable equilibrated mixture of the known *cis*- and *trans*-3-isopropyl-2-vinylaziridines **23** and **24** in 85% combined yield with a ratio of 94:6 in favor of the 2,3-*cis*-isomer **23** (Scheme 4).[13,16,18] So far, THF appears to be the solvent of choice for this aziridination reaction. Quite similar results were obtained following treatment of the methyl carbonates **15**–**17** under these reaction conditions giving the corresponding *cis*-2-vinylaziridines **25**, **27**, and **29** as the major products. The stereoselection of the aziridination reaction of the methyl carbonates was at least 94:6 in favor of the thermodynamically more stable *cis*-aziridines (Scheme 4 and Table 1, entries 2–4). The product distribution of *cis*- and *trans*-aziridines, in combination with the relatively fast isomerization reaction rates of the 2-vinylaziridines recently reported,[16,18] provides convincing evidence that thermodynamic equilibration can be obtained under these reaction conditions.

† Abbreviations used in the schemes of this paper: Mts = 2,4,6-trimethylphenylsulfonyl; Mtr = 4-methoxy-2,3,6-trimethylphenylsulfonyl; Ts = *p*-tolylsulfonyl; Boc = *tert*-butoxycarbonyl; TBS = *tert*-butyl(dimethyl)silyl.



Scheme 3 R^1 = alkyl; R^2 = aryl.

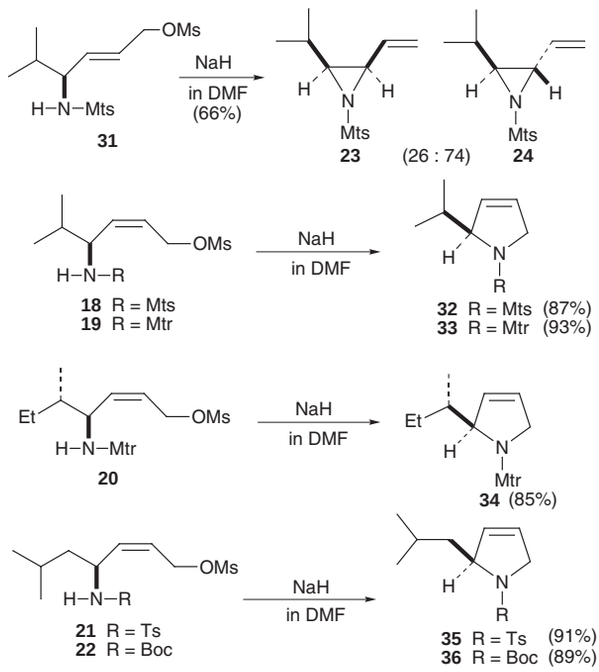


Scheme 4

Base-promoted five-membered ring cyclization reactions of mesylates of (*Z*)-*N*-protected 4-aminobuten-1-ol derivatives

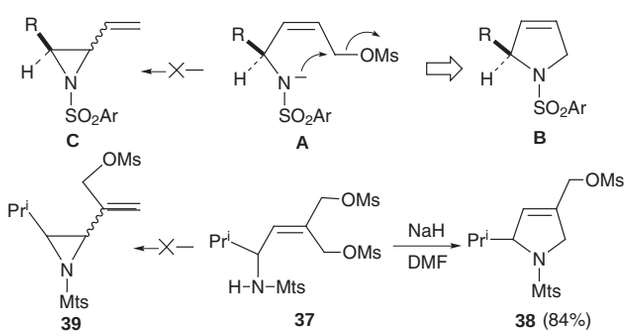
We have recently demonstrated that the treatment of the mesylates derived from (*E*)-*N*-protected 4-aminobuten-1-ol derivatives with NaH in DMF gave a mixture of *cis*- and *trans*-2-vinylaziridines in variable ratios depending upon the substrate structure (Scheme 5).[13] For example, exposure of the mesylate **31** to NaH in DMF led to the isolation of two aziridines **23** and **24** in a ratio of 26:74 favoring the thermo-

dynamically less stable *trans*-2-vinylaziridine.[13] On the other hand, treatment of (*Z*)-mesylates **18**–**22** with NaH yielded exclusively the corresponding 3-pyrrolines **32**–**36** in high yields (Scheme 5).



Scheme 5

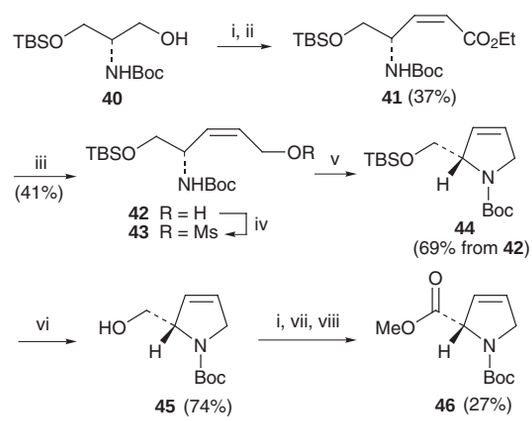
In the case of the (*Z*)-mesylates **18**–**22**, although the actual basis for the preference of 5-membered ring cyclizations over aziridines is not clear, the proximity of the nitrogen anionic species **A** to the mesyloxymethyl group may accelerate the five-membered ring closure to give exclusively the 3-pyrroline derivatives **B** (Scheme 6). This assumption was partially supported by the following experiment. Exposure of racemic bis-(mesylate) **37** to NaH in DMF led to only 3-pyrroline derivative **38** in good yield. No evidence for the presence of aziridines of type **39** was detected by HPLC analysis of the crude reaction product.



Scheme 6

Application to the synthesis of biologically important (*S*)-3,4-dehydroproline

To demonstrate the utility of the five-membered ring cyclization decribed above, we have used this chemistry for the synthesis of the biologically important (*S*)-3,4-dehydroproline **46** (Scheme 7). The *N*,*O*-diprotected amino alcohol **40** can be synthesized from (*R*)-serine following the known protocol.[19] Swern oxidation of **40** followed by (*Z*)-selective Wittig olefination reaction[17] gave (*Z*)-α,β-unsaturated ester **41** along with a small amount of the corresponding (*E*)-isomer. Successive treatment of the ester **41** with DIBAL-H and MsCl in the presence of Et_3N afforded the methylsulfonate **43**. The mesylate **43** was found to be rather labile towards chromatographic purification on silica gel. Consequently, without purification, crude mesylate **43** was treated with NaH in DMF to yield 3,4-dehydroprolinol derivative **44** in good yield. Following a standard sequence of reactions, the compound **44** was converted into (*S*)-*N*-Boc-3,4-dehydroproline methyl ester **46** *via* (*S*)-*N*-Boc-prolinol **45** (Scheme 7).



Scheme 7 *Reagents:* i, $(COCl)_2$–DMSO, Et_2NPr^i; ii, $(PhO)^2P(O)$–CH_2CO_2Et-LiCl–Et_2NPr^i; iii, DIBAL; iv, $MeSO_2Cl$–ET_3N; v, NaH in DMF; vi, Bu^n_4NF; vii, $NaClO_2$–NaH_2PO_4; viii, diazomethane.

In summary, it has been shown herein that both *cis*-2-vinyl-3-alkylaziridines and 3-pyrrolines can be synthesized from common *N*-protected (*Z*)-4-alkyl-4-aminobut-2-en-1-ols. Whereas palladium-catalyzed reactions of the methyl carbonates of the amino alcohols afford mixtures of *cis*- and *trans*-3-alkyl-2-vinylaziridines in which the *cis*-isomers predominate over *trans*-stereoisomers, base-promoted reactions of the methanesulfonates of the *N*-protected (*Z*)-amino alcohols yield exclusively 3-pyrroline derivatives. A simple synthesis of biologically important 3,4-dehydroproline is also described.

Experimental

General methods

The instrumentation has already been described.[12b,c] All reactions were carried out under a positive pressure of argon. All glassware and syringes were dried in an electric oven at 100 °C prior to use. All melting points are uncorrected. ^1H NMR spectra were recorded using a JEOL EX-270 (270 MHz) or Bruker AC-300 (300 MHz) spectrometer in $CDCl_3$. Chemical shifts are reported in parts per million downfield from internal Me_4Si. *J* Values are given in Hz. For flash chromatography, silica gel 60 H (silica gel for thin-layer chromatography, Merck) or silica gel 60 (finer than 230 mesh, Merck) was employed. For the determination of optical purity, a Chiralcel OD (DAICEL, 4.6 × 260 mm) was used. For reverse-phase HPLC, μ-Bondasphere-C-18 (3.9 × 150 mm column, Waters) was employed (28 °C).

General procedure for preparation of (*Z*)-enoates (4–8). Synthesis of ethyl (4*S*,2*Z*)-5-methyl-4-[*N*-(2,4,6-trimethylphenylsulfonyl)amino]hex-2-enoate (4)

To a stirred solution of ethyl diphenylphosphonoacetate (5.61 g, 17.5 mmol) in anhydrous THF (25 cm^3) was added NaH (504 mg, 21 mmol) at −78 °C and the mixture was stirred at this temperature for 15 min. A solution of (*S*)-valinal (4.96 g, 17.5 mmol) in anhydrous THF (10 cm^3) was added to the above reagent at −78 °C under stirring, and the stirring was continued for 1 h with warming to 0 °C. A saturated NH_4Cl (10 cm^3) was added to the mixture and the whole was extracted with Et_2O. The extract was washed successively with water and brine, and dried over $MgSO_4$. Usual workup followed by flash

chromatography over silica gel with *n*-hexane–EtOAc (5:1) gave the title compound **4** (3.67 g, 59%). Further elution gave the (*E*)-isomer of **4** (1.66 g, 27%). Compound **4**: colorless crystals, mp 102 °C [from *n*-hexane–Et_2O (4:1)] (Found: C, 60.9; H, 7.7; N, 3.8. $C_{18}H_{27}NO_4S$ requires C, 61.2; H, 7.7; N, 4.0%); $[\alpha]_D^{28}$ +56.9 (*c* 1.23, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.85 (3 H, d, *J* 6.8, CMe), 0.90 (3 H, d, *J* 7.0, CMe), 1.26 (3 H, t, *J* 7.3, CMe), 1.83 (1 H, m, 5-H), 2.28 (3 H, s, CMe), 2.60 (6 H, s, 2 × CMe), 4.09 (1 H, q, *J* 7.3, OCH_2), 4.67 (1 H, m, 4-H), 4.98 (1 H, m, NH), 5.60 (1 H, dd, *J* 11.6 and 1.1, 2-H), 5.92 (1 H, dd, *J* 11.6 and 9.2, 3-H), 6.91 (2 H, m, Ph); δ_C(67.8 MHz; $CDCl_3$) 14.3, 18.0, 19.0, 21.1, 23.2, 33.3, 56.0, 60.4, 88.9, 120.5, 132.0, 134.2, 139.3, 142.2, 148.2, 165.7. (4*S*,2*E*) Isomer of (**4**): colorless oil [Found (FAB): $(M + H)^+$, 354.1745. $C_{18}H_{28}NO_4S$ requires *M* + H, 354.1739]; $[\alpha]_D^{28}$ −34.9 (*c* 1.26, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.82 (3 H, d, *J* 6.8, CMe), 0.90 (3 H, d, *J* 7.0, CMe), 1.25 (3 H, t, *J* 7.0, CMe), 1.80 (1 H, m, 5-H), 2.27 (3 H, s, CMe), 2.62 (6 H, s, 2 × CMe), 3.66 (1 H, m, 4-H), 4.11 (2 H, q, *J* 7.0, OCH_2), 4.73 (1 H, d, *J* 8.4, NH), 5.60 (1 H, dd, *J* 15.9 and 1.4, 2-H), 6.53 (1 H, dd, *J* 15.9 and 7.6, 3-H), 6.92 (2 H, m, Ph); *m*/*z* (FAB, LRMS) 354 (MH^+), 119 (base peak).

Ethyl (4*S*,2*Z*)-4-[*N*-(4-methoxy-2,3,6-trimethylphenylsulfonyl)amino]-5-methylhex-2-enoate (5). Colorless crystals, mp 93 °C [from *n*-hexane–Et_2O (2:1)] (Found: C, 59.25; H, 7.5; N, 3.7. $C_{19}H_{29}NO_5S$ requires C, 59.5; H, 7.6; N, 3.65%); $[\alpha]_D^{23}$ +47.7 (*c* 0.786, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.85 (3 H, d, *J* 6.8, CMe), 0.90 (3 H, d, *J* 6.8, CMe), 1.25 (3 H, t, *J* 7.0, CMe), 1.83 (1 H, m, 5-H), 2.13 (3 H, s, CMe), 2.56 (3 H, s, CMe), 2.62 (3 H, s, CMe), 3.84 (3 H, s, OMe), 4.08 (2 H, q, *J* 7.0, OCH_2), 4.66 (1 H, dddd, *J* 9.2, 8.6, 5.9 and 1.1, 4-H), 4.91 (1 H, d, *J* 8.6, NH), 5.61 (1 H, dd, *J* 11.9 and 1.1, 2-H), 5.92 (1 H, dd, *J* 11.9 and 9.1, 3-H), 6.53 (1 H, s, Ph). (4*S*,2*E*) Isomer of (**5**): colorless oil [Found (FAB): $(M + H)^+$, 384.1839. $C_{19}H_{30}NO_5S$ requires *M* + H, 384.1844]; $[\alpha]_D^{23}$ −48.4 (*c* 1.01, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.83 (3 H, d, *J* 6.8, CMe), 0.91 (3 H, d, *J* 7.0, CMe), 1.24 (3 H, t, *J* 7.0, CMe), 1.80 (1 H, m, 5-H), 2.11 (3 H, s, CMe), 2.56 (3 H, s, CMe), 2.65 (3 H, s, CMe), 3.61 (1 H, m, 4-H), 3.84 (3 H, s, OMe), 4.09 (2 H, q, *J* 7.0, OCH_2), 4.67 (1 H, d, *J* 8.1, NH), 5.50 (1 H, d, *J* 15.7, 2-H), 6.47 (1 H, dd, *J* 15.7 and 8.1, 3-H), 6.55 (1 H, s, Ph); *m*/*z* (FAB, LRMS) 384 (MH^+), 213 (base peak).

Ethyl (4*S*,5*S*,2*Z*)-5-methyl-4-[*N*-(4-methoxy-2,3,6-trimethylphenylsulfonyl)amino]hept-2-enoate (6). Colorless oil [Found (FAB): $(M + H)^+$, 398.2006. $C_{20}H_{32}NO_5S$ requires *M* + H, 398.2001]; $[\alpha]_D^{25}$ +49.2 (*c* 0.895, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.826 (3 H, d, *J* 6.8, CMe), 0.830 (3 H, t, *J* 7.3, CMe), 1.11 (1 H, m, 6-C*H*H), 1.25 (3 H, t, *J* 6.8, CMe), 1.45–1.64 (2 H, m, 6-CH*H* and 5-H), 2.13 (3 H, s, CMe), 2.56 (3 H, s, CMe), 2.62 (3 H, s, CMe), 3.84 (3 H, s, OMe), 4.08 (2 H, q, *J* 6.8, OCH_2), 4.73 (1 H, ddd, *J* 9.2, 8.4 and 5.9, 4-H), 4.94 (1 H, d, *J* 8.4, NH), 5.59 (1 H, dd, *J* 11.9, 0.8, 2-H), 5.92 (1 H, dd, *J* 11.9, 9.2, 3-H), 6.53 (1 H, s, Ph); *m*/*z* (FAB, LRMS) 398 (MH^+, base peak). (4*S*,5*S*,2*E*) Isomer of (**6**): colorless oil [Found (FAB): $(M + H)^+$, 398.1999. $C_{20}H_{32}NO_5S$ requires *M* + H, 398.2001]; $[\alpha]_D^{25}$ −36.7 (*c* 1.35, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.88 (3 H, d, *J* 6.8, CMe), 0.85 (3 H, t, *J* 7.6, CMe), 1.11 (1 H, m, 6-C*H*H), 1.24 (3 H, t, *J* 7.0, CMe), 1.36–1.61 (2 H, m, 6-CH*H* and 5-H), 2.12 (3 H, s, CMe), 2.56 (3 H, s, CMe), 2.65 (3 H, s, CMe), 3.73 (1 H, m, 4-H), 3.84 (3 H, s, OMe), 4.09 (2 H, q, *J* 7.0, OCH_2), 4.65 (1 H, d, *J* 7.8, NH), 5.52 (1 H, dd, *J* 15.9 and 1.4, 2-H), 6.48 (1 H, dd, *J* 15.9 and 7.8, 3-H), 6.55 (1 H, s, Ph); *m*/*z* (FAB, LRMS) 398 (MH^+), 213 (base peak).

Ethyl (4*S*,2*Z*)-6-methyl-4-[*N*-(4-methylphenylsulfonyl)amino]hept-2-enoate (7). Colorless crystals, mp 60 °C [from *n*-hexane–Et_2O (4:1)] (Found: C, 60.0; H, 7.6; N, 4.0. $C_{17}H_{25}NO_4S$ requires C, 60.15; H, 7.4; N, 4.1%); $[\alpha]_D^{27}$ +15.6 (*c* 1.21, $CHCl_3$); δ_H(300 MHz; $CDCl_3$) 0.77 (3 H, d, *J* 6.5, CMe), 0.86 (3 H, d, *J* 6.6, CMe), 1.25 (1 H, ddd, *J* 13.8, 8.8 and 5.0, 5-C*H*H), 1.29 (3 H, t, *J* 7.1, CMe), 1.41 (1 H, ddd, *J* 13.8, 9.1 and 5.1, 5-CH*H*), 1.62 (1 H, m, 6-H), 2.41 (3 H, s, CMe), 4.16 (2 H, q, *J* 7.1, OCH_2), 4.91 (1 H, m, 4-H), 5.01 (1 H, d, *J* 7.8, NH), 5.56 (1 H, dd, *J* 11.7 and 0.9, 2-H), 5.91 (1 H, dd, *J* 11.7 and 8.6, 3 H), 7.23–7.27 (2 H, m, Ph), 7.69–7.73 (2 H, m, Ph). (4*S*,2*E*) Isomer of (**7**): colorless oil [Found (FAB): $(M + H)^+$, 340.1586. $C_{17}H_{26}NO_4S$ requires *M* + H, 340.1583]; $[\alpha]_D^{27}$ −44.3 (*c* 1.17, $CHCl_3$); δ_H(300 MHz; $CDCl_3$) 0.78 (3 H, d, *J* 6.5, CMe), 0.84 (3 H, d, *J* 6.6, CMe), 1.25 (3 H, t, *J* 7.1, CMe), 1.30–1.37 (2 H, m, 5-CH_2), 1.59 (1 H, m, 6-H), 2.41 (3 H, s, CMe), 3.96 (1 H, m, 4-H), 4.12 (2 H, q, *J* 7.1, OCH_2), 4.59 (1 H, d, *J* 7.9, NH), 5.72 (1 H, dd, *J* 15.6 and 1.2, 2-H), 6.54 (1 H, dd, *J* 15.6 and 6.8, 3-H), 7.26–7.29 (2 H, m, Ph), 7.70–7.74 (2 H, m, Ph); *m*/*z* (FAB, LRMS) 340 (MH^+), 169 (base peak).

Ethyl (4*S*,2*Z*)-4-[*N*-(*tert*-butoxycarbonyl)amino]-6-methyl-2-heptenoate (8). Colorless oil [Found (FAB): $(M + H)^+$, 286.2022. $C_{15}H_{28}NO_4$ requires *M* + H, 286.2018]; $[\alpha]_D^{26}$ +68.3 (*c* 1.34, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.94 (3 H, d, *J* 6.8, CMe), 0.98 (3 H, d, *J* 6.8, CMe), 1.29 (3 H, t, *J* 7.3, CMe), 1.35–1.47 (2 H, m, 5-CH_2), 1.42 (9 H, s, CMe_3), 1.67 (1 H, m, 6-H), 4.19 (2 H, q, *J* 7.3, OCH_2), 4.76 (1 H, m, 4-H), 5.15 (1 H, m, NH), 5.75 (1 H, d, *J* 11.6, 2-H), 6.08 (1 H, br, 3-H); *m*/*z* (FAB, LRMS) 286 (MH^+), 230 (base peak). (4*S*,2*E*) Isomer of (**8**): colorless oil [Found (FAB): $(M + H)^+$, 286.2010. $C_{15}H_{28}NO_4$ requires *M* + H, 286.2018]; $[\alpha]_D^{26}$ −17.3 (*c* 0.509, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.94 (6 H, d, *J* 6.8, 2 × CMe), 1.29 (3 H, t, *J* 7.0, CMe), 1.36–1.43 (2 H, m, 5-CH_2), 1.46 (9 H, s, CMe_3), 1.68 (1 H, m, 6-H), 4.19 (2 H, q, *J* 7.0, OCH_2), 4.34 (1 H, m, 4-H), 4.44 (1 H, m, NH), 5.92 (1 H, d, *J* 15.4, 2-H), 6.83 (1 H, dd, *J* 15.4 and 5.4, 1 H); *m*/*z* (FAB, LRMS) 286 (MH^+), 140 (base peak).

General procedure for preparation of allylic alcohols. (4*S*,2*Z*)-5-Methyl-4-[*N*-(2,4,6-trimethylphenylsulfonyl)amino]hex-2-en-1-ol (9)

DIBAL-H (1.0 M solution in toluene; 34.7 cm^3, 34.7 mmol) was added dropwise to a stirred solution of the enoate **4** (3.5 g, 9.9 mmol) in toluene (25 cm^3) and at −78 °C under argon. The stirring was continued for 2 h with warming to 0 °C. A saturated NH_4Cl solution (30 cm^3) was added with vigorous stirring. The mixture was made acidic with saturated aqueous citric acid and extracted with a mixed solvent of Et_2O–EtOAc (2:1). The extract was washed with water and dried over $MgSO_4$. The usual workup followed by recrystallization from Et_2O gave the alcohol **9** (2.29 g, 74%) as colorless needles, mp 83 °C [from *n*-hexane–Et_2O (1:2)] (Found: C, 61.5; H, 8.05; N, 4.5. $C_{16}H_{25}NO_3S$ requires C, 61.7; H, 8.1; N, 4.5%); $[\alpha]_D^{28}$ ±0.15 (*c* 1.29, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.81 (3 H, d, *J* 7.0, CMe), 0.83 (3 H, d, *J* 7.3, CMe), 1.66 (1 H, m, 5-H), 2.30 (3 H, s, CMe), 2.64 (6 H, s, 2 × CMe), 3.78–3.90 (2 H, m, OC*H*H and 4-H), 4.03 (1 H, m, OCH*H*), 4.71 (1 H, d, *J* 7.8, NH), 5.24 (1 H, dddd, *J* 11.1, 10.3, 1.4 and 1.4, 3-H), 5.59 (1 H, dddd, *J* 11.1, 8.1, 5.9 and 0.8, 2-H), 6.95 (2 H, m, Ph); δ_C(67.8 MHz; $CDCl_3$) 18.2, 18.8, 21.1, 23.2, 33.2, 56.1, 58.4, 129.7, 131.1, 132.1, 134.9, 139.1, 142.4.

(4*S*,2*Z*)-4-[*N*-(4-Methoxy-2,3,6-trimethylphenylsulfonyl)amino]-5-methylhex-2-en-1-ol (10). By a procedure identical with that described for the preparation of the alcohol **9** from **4**, the enoate **5** (1.25 g, 3.26 mmol) was converted into the alcohol **10** (659 mg, 59%) as colorless crystals, mp 92 °C [from *n*-hexane–Et_2O (1:2)] (Found: C, 59.6; H, 7.8; N, 4.1. $C_{17}H_{27}NO_4S$ requires C, 59.8; H, 8.0; N, 4.1%); $[\alpha]_D^{22}$ +2.74 (*c* 0.972, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.81 (3 H, d, *J* 7.3, CMe), 0.84 (3 H, d, *J* 7.3, CMe), 1.60–1.72 (2 H, m, 5-H and OH), 2.15 (3 H, s, CMe), 2.56 (3 H, s, CMe), 2.68 (3 H, s, CMe), 3.77–3.92 (2 H, m, OC*H*H and 4-H), 3.85 (3 H, s, OMe), 4.04 (1 H, dddd, *J* 12.2, 8.1, 4.3 and 1.4, OCH*H*), 4.56 (1 H, m, NH),

5.23 (1 H, dddd, *J* 11.1, 10.0, 1.4 and 0.8, 3-H), 5.60 (1 H, dddd, *J* 11.1, 8.1, 6.5 and 0.8, 2-H), 6.58 (1 H, s, Ph).

(4*S*,5*S*,2*Z*)-5-Methyl-4-[*N*-(4-methoxy-2,3,6-trimethylphenylsulfonyl)amino]hept-2-en-1-ol (11). By a procedure identical with that described for the preparation of the alcohol **9** from **4**, enoate **6** (1.78 g, 4.48 mmol) was converted into the title compound **11** (953 mg, 60%) as colorless crystals, mp 96 °C [from *n*-hexane–Et_2O–$CHCl_3$ (5:10:1)] (Found: C, 61.0; H, 8.2; N, 4.0. $C_{18}H_{29}NO_4S$ requires C, 60.8; H, 8.2; N, 3.9%); $[\alpha]_D^{20}$ +4.22 (*c* 1.61, $CHCl_3$); δ_H(600 MHz; $CDCl_3$) 0.80 (3 H, d, *J* 7.1, CMe), 0.81 (3 H, t, *J* 7.8, CMe), 1.02 (1 H, m, 6-C*H*H), 1.35 (1 H, m, 6-CH*H*), 1.43 (1 H, m, 5-H), 1.60 (1 H, m, OH), 2.15 (3 H, s, CMe), 2.57 (3 H, s, CMe), 2.68 (3 H, s, CMe), 3.85 (1 H, m, OC*H*H), 3.85 (3 H, s, OMe), 3.95 (1 H, ddd, *J* 9.1, 6.2 and 6.2, 4-H), 4.02 (1 H, dddd, *J* 12.8, 7.7, 4.1 and 1.1, OCH*H*), 4.53 (1 H, m, NH), 5.24 (1 H, dd, *J* 10.7 and 9.1, 3-H), 5.59 (1 H, ddd, *J* 10.7, 7.7 and 6.0, 2-H), 6.58 (1 H, s, Ph).

(4*S*,2*Z*)-6-Methyl-4-[*N*-(4-methylphenylsulfonyl)amino]hept-2-en-1-ol (12). By a procedure identical with that described for the preparation of the alcohol **9** from **4**, enoate **7** (1.02 g, 3 mmol) was converted into the title compound **12** (440 mg, 49%) as colorless needles, mp 96 °C [from *n*-hexane–Et_2O (1:3)] (Found: C, 60.3; H, 7.7; N, 4.7. $C_{15}H_{23}NO_3S$ requires C, 60.6; H, 7.8; N, 4.7%); $[\alpha]_D^{24}$ −4.74 (*c* 1.07, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.76 (3 H, *J* 6.5, CMe), 0.79 (3 H, d, *J* 6.5, CMe), 1.16–1.38 (2 H, m, 5-CH_2), 1.48 (1 H, m, 6-H), 2.00 (1 H, dd, *J* 8.4 and 4.3, OH), 2.43 (3 H, s, CMe), 3.97 (1 H, m, OC*H*H), 4.12–4.26 (2 H, m, OCH*H* and 4-H), 4.52 (1 H, m, NH), 5.18 (1 H, dd, *J* 11.1 and 10.0, 3-H), 5.60 (1 H, ddd, *J* 11.1, 8.1 and 5.9, 2-H), 7.29–7.32 (2 H, m, Ph), 7.73–7.77 (2 H, m, Ph).

(4*S*,2*Z*)-4-[*N*-(*tert*-Butyloxycarbonyl)amino]-6-methylhept-2-en-1-ol (13). By a procedure identical with that described for the preparation of the alcohol **9** from **4**, enoate **8** (750 mg, 2.63 mmol) was converted into the title compound **13** (480 mg, 75%) as a colorless oil [Found (FAB): $(M + H)^+$, 244.1911. $C_{13}H_{26}NO_3$ requires *M* + H, 244.1913]; $[\alpha]_D^{25}$ −7.82 (*c* 0.742, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.90 (3 H, d, *J* 6.2, CMe), 0.92 (3 H, d, *J* 6.5, CMe), 1.18–1.42 (2 H, m, 5-CH_2), 1.42 (9 H, s, CMe_3), 1.59 (1 H, m, 6-H), 3.67 (1 H, d, *J* 7.6, OH), 3.89 (1 H, m, 4-H), 4.40–4.53 (3 H, m, NH and OCH_2), 5.21 (1 H, dd, *J* 10.5 and 10.3, 3-H), 5.82 (1 H, ddd, *J* 10.5, 10.5 and 6.2, 2-H); *m*/*z* (FAB, LRMS) 244 (MH^+), 188 (base peak).

General procedure for preparation of methyl carbonates. (4*S*,2*Z*)-*O*-Methoxycarbonyl-5-methyl-4-[*N*-(2,4,6-trimethylphenylsulfonyl)amino]hex-2-en-1-ol (14)

To a stirred mixture of the alcohol **9** (200 mg, 0.642 mmol), pyridine (0.52 cm^3, 6.42 mmol), $CHCl_3$ (3 cm^3) and THF (3 cm^3) at −78 °C was added dropwise methyl chloroformate (0.075 cm^3, 0.963 mmol), and the mixture was stirred with warming to 0 °C. After 1 h, 5% aqueous $NaHCO_3$ (1 cm^3) was added to the mixture with vigorous stirring. The whole was extracted with a mixed solvent of Et_2O–EtOAc (3:1), and the extract was washed successively with 5% aqueous citric acid, water, 5% aqueous $NaHCO_3$, and water, and dried over $MgSO_4$. Usual workup followed by flash chromatography over silica gel with *n*-hexane–EtOAc (3:1) gave the title compound **14** (230 mg, 97%) as colorless needles, mp 98 °C [from *n*-hexane–Et_2O (3:1)] [Found (FAB): $(M + H)^+$, 370.1685. $C_{18}H_{28}NO_5S$ requires *M* + H, 370.1688]; $[\alpha]_D^{29}$ +82.8 (*c* 1.11, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.85 (3 H, d, *J* 7.0, CMe), 0.89 (3 H, d, *J* 6.8, CMe), 1.74 (1 H, m, 5-H), 2.29 (3 H, s, CMe), 2.62 (6 H, s, 2 × CMe), 3.75 (1 H, m, 4-H), 3.77 (3 H, s, OMe), 4.24 (1 H, ddd, *J* 13.2, 6.2 and 0.8, OC*H*H), 4.43 (1 H, ddd, *J* 13.2, 6.2 and 1.4, OCH*H*), 4.59 (1 H, m, NH), 5.29 (1 H, dddd, *J* 11.3, 10.0, 1.4, 0.8 and 3-H), 5.46 (1 H, ddd, *J* 11.3, 6.2 and 6.2, 2-H), 6.93 (2 H, m, Ph); δ_C(67.8 MHz; $CDCl_3$) 18.1, 18.7, 21.1, 23.1, 33.3, 55.0, 56.3, 63.4, 126.0, 131.7, 132.1, 134.7, 139.0, 142.4, 155.6; *m*/*z* (FAB, LRMS) 370 (MH^+), 119 (base peak).

(4*S*,2*Z*)-4-[*N*-(4-Methoxy-2,3,6-trimethylphenylsulfonyl)-amino]-*O*-methoxycarbonyl-5-methylhex-2-en-1-ol (15). By a procedure identical with that described for the preparation of the carbonate **14** from **9**, the alcohol **10** (419 mg, 1.23 mmol) was converted into the title compound **15** (480 mg, 98%) as a colorless oil [Found (FAB): $(M + H)^+$, 400.1800. $C_{19}H_{30}NO_6S$ requires *M* + H, 400.1794]; $[\alpha]_D^{24}$ +83.3 (*c* 0.858, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.85 (3 H, d, *J* 7.0, CMe), 0.89 (3 H, d, *J* 7.0, CMe), 1.74 (1 H, m, 5-H), 2.14 (3 H, s, CMe), 2.56 (3 H, s, CMe), 2.65 (3 H, s, CMe), 3.72 (1 H, ddd, *J* 10.0, 6.8 and 6.5, 4-H), 3.77 (3 H, s, OMe), 3.85 (3 H, s, OMe), 4.19 (1 H, ddd, *J* 13.0, 6.8 and 1.1, OC*H*H), 4.41 (1 H, ddd, *J* 13.0, 6.8 and 1.4, OCH*H*), 4.55 (1 H, d, *J* 6.5, NH), 5.28 (1 H, dddd, *J* 11.1, 10.0, 1.4 and 1.4, 3-H), 5.44 (1 H, ddd, *J* 11.1, 6.8 and 6.8, 2-H), 6.57 (1 H, s, Ph); *m*/*z* (FAB, LRMS) 400 (MH^+), 213 (base peak).

(4*S*,5*S*,2*Z*)-*O*-Methoxycarbonyl-5-methyl-4-[*N*-(4-methoxy-2,3,6-trimethylphenylsulfonyl)amino]hept-2-en-1-ol (16). By a procedure identical with that described for the preparation of the carbonate **14** from **9**, the alcohol **11** (342 mg, 0.962 mmol) was converted into the title compound **16** (395 mg, 99%) as a colorless oil [Found (FAB): $(M + H)^+$, 414.1953. $C_{20}H_{32}NO_6S$ requires *M* + H, 414.1950]; $[\alpha]_D^{22}$ +73.8 (*c* 0.569, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.83 (3 H, d, *J* 7.0, CMe), 0.84 (3 H, t, *J* 7.6, CMe), 1.06 (1 H, m, 6-C*H*H), 1.41 (1 H, m, 6-CH*H*), 1.52 (1 H, m, 5-H), 2.14 (3 H, s, CMe), 2.55 (3 H, s, CMe), 2.66 (3 H, s, CMe), 3.77 (3 H, s, OMe), 3.81 (1 H, m, 4-H), 3.85 (3 H, s, OMe), 4.17 (1 H, ddd, *J* 13.0, 6.2 and 1.4, OC*H*H), 4.40 (1 H, ddd, *J* 13.0, 6.8 and 1.4, OCH*H*), 4.54 (1 H, d, *J* 7.3, NH), 5.29 (1 H, dddd, *J* 11.6, 10.3, 1.4 and 1.4, 3-H), 5.44 (1 H, ddd, *J* 11.6, 6.8 and 6.2, 2-H), 6.57 (1 H, s, Ph); *m*/*z* (FAB, LRMS) 414 (MH^+), 213 (base peak).

(4*S*,2*Z*)-*O*-Methoxycarbonyl-6-methyl-4-[*N*-(4-methylphenylsulfonyl)amino]hept-2-en-1-ol (17). By a procedure identical with that described for the preparation of the carbonate **14** from **9**, the alcohol **12** (149 mg, 0.5 mmol) was converted into the title compound **17** (155 mg, 87%) as a colorless oil [Found (FAB): $(M + H)^+$, 356.1536. $C_{17}H_{26}NO_5S$ requires *M* + H, 356.1531]; $[\alpha]_D^{21}$ +74.7 (*c* 1.04, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.81 (3 H, d, *J* 6.2, CMe), 0.83 (3 H, d, *J* 6.8, CMe), 1.23 (1 H, ddd, *J* 14.3, 7.3 and 7.3, 5-C*H*H), 1.41 (1 H, ddd, *J* 14.3, 7.6 and 5.9, 5-CH*H*), 1.56 (1 H, m, 6-H), 2.42 (3 H, s, CMe), 3.79 (3 H, s, OMe), 4.08 (1 H, dddd, *J* 9.5, 7.6, 7.3 and 7.0, 4-H), 4.49 (1 H, ddd, *J* 12.7, 6.2 and 1.4, OC*H*H), 4.59 (1 H, ddd, *J* 12.7, 6.8 and 1.4, OCH*H*), 4.62 (1 H, m, NH), 5.26 (1 H, dddd, *J* 11.3, 9.5, 1.4 and 1.4, 3-H), 5.43 (1 H, ddd, *J* 11.3, 6.8 and 6.2, 2-H), 7.26–7.30 (2 H, m, Ph), 7.71–7.75 (2 H, m, Ph); *m*/*z* (FAB, LRMS) 356 (MH^+), 280 (base peak).

General procedure for preparation of allylic methanesulfonates. (4*S*,2*Z*)-*O*-Methylsulfonyl-5-methyl-4-[(2,4,6-trimethylphenylsulfonyl)amino]hex-2-en-1-ol (18)

To a stirred mixture of the alcohol **9** (311 mg, 1 mmol), Et_3N (1.38 cm^3, 10 mmol) and THF (12 cm^3) was added dropwise methanesulfonyl chloride (0.387 cm^3, 5 mmol) at 0 °C. The stirring was continued for 0.5 h at 0 °C followed by quenching with 1.5 cm^3 of saturated aqueous $NaHCO_3$ with vigorous stirring. The whole was extracted with Et_2O and the extract was washed successively with 5% aqueous citric acid, water, 5% aqueous $NaHCO_3$, and water, and dried over $MgSO_4$. Usual workup followed by flash chromatography over silica gel with *n*-hexane–EtOAc (5:3) gave the title compound **18** (378 mg, 97%) as a colorless oil [Found: (FAB): $(M + H)^+$, 390.1398.

$C_{17}H_{28}NO_5S_2$ requires M + H, 390.1409]; $[\alpha]_D^{28}$ +59.2 (*c* 0.843, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.84 (3 H, d, *J* 6.8, CMe), 0.87 (3 H, d, *J* 7.0, CMe), 1.72 (1 H, m, 5-H), 2.30 (3 H, s, CMe), 2.62 (6 H, s, 2 × CMe), 3.00 (3 H, s, SO_2Me), 3.77 (1 H, dd, *J* 9.2 and 6.2, 4-H), 4.47 (1 H, ddd, *J* 11.9, 6.2 and 1.1 OC*H*H), 4.60 (1 H, ddd, *J* 11.9, 7.0 and 1.4, OCH*H*), 4.64 (1 H, br s, NH), 5.43 (1 H, dddd, *J* 11.1, 9.2, 1.4 and 1.1, 3-H), 5.55 (1 H, ddd, *J* 11.1, 7.0 and 6.2, 2-H), 6.95 (2 H, m, Ph); *m*/*z* (FAB, LRMS) 390 (MH^+), 294 (base peak).

(4*S*,2*Z*)-*O*-Methylsulfonyl-4-[*N*-(4-methoxy-2,3,6-trimethylphenylsulfonyl)amino]-5-methylhex-2-en-1-ol (19). By a procedure identical with that described for the preparation of the mesylate **18** from **9**, the alcohol **10** (120 mg, 0.351 mmol) was converted into the title compound **19** (146 mg, 99%) as a colorless oil [Found (FAB): $(M + H)^+$, 420.1501. $C_{18}H_{30}NO_6S_2$ requires M + H, 420.1514]; $[\alpha]_D^{23}$ +65.4 (*c* 0.208, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.85 (3 H, d, *J* 7.0, CMe), 0.88 (3 H, d, *J* 6.5, CMe), 1.72 (1 H, m, 5-H), 2.14 (3 H, s, CMe), 2.56 (3 H, s, CMe), 2.65 (3 H, s, CMe), 2.99 (3 H, s, SO_2Me), 3.74 (1 H, dd, *J* 9.5 and 5.9, 4-H), 3.86 (3 H, s, OMe), 4.42 (1 H, ddd, *J* 11.9, 6.5 and 0.8, OC*H*H), 4.57 (1 H, ddd, *J* 11.9, 6.8 and 1.1, OCH*H*), 5.41 (1 H, dddd, *J* 11.1, 9.5, 0.8 and 0.8, 3-H), 5.52 (1 H, ddd, *J* 11.1, 6.8 and 6.5, 2-H), 6.59 (1 H, s, Ph); *m*/*z* (FAB, LRMS) 420 (MH^+), 213 (base peak).

(4*S*,5*S*,2*Z*)-*O*-Methylsulfonyl-5-methyl-4-[*N*-(4-methoxy-2,3,6-trimethylphenylsulfonyl)amino]hept-2-en-1-ol (20). By a procedure identical with that described for the preparation of the mesylate **18** from **9**, the alcohol **11** (249 mg, 0.70 mmol) was converted into the title compound **20** (248 mg, 82%) as a colorless oil [Found (FAB): $(M + H)^+$, 434.1662. $C_{19}H_{32}NO_6S_2$ requires M + H, 434.1671]; $[\alpha]_D^{20}$ +60.7 (*c* 0.537, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.82 (3 H, d, *J* 7.3, CMe), 0.84 (3 H, d, *J* 7.3, CMe), 1.05 (1 H, m, 6-C*H*H), 1.30–1.55 (2 H, m, 6-CH*H* and 5-H), 2.15 (3 H, s, CMe), 2.56 (3 H, s, CMe), 2.66 (3 H, s, CMe), 2.99 (3 H, s, SO_2Me), 3.81–3.91 (2 H, m, 4-H and NH), 3.86 (3 H, s, OMe), 4.40 (1 H, dd, *J* 12.2 and 5.9, OC*H*H), 4.55 (1 H, dd, *J* 12.2 and 6.2, OCH*H*), 5.42 (1 H, dddd, *J* 11.1, 9.7, 1.4 and 1.4, 3-H), 5.52 (1 H, ddd, *J* 11.1, 6.2 and 5.9, 2-H), 6.59 (1 H, s, Ph); *m*/*z* (FAB, LRMS) 434 (MH^+), 213 (base peak).

(4*S*,2*Z*)-*O*-Methylsulfonyl-6-methyl-4-[*N*-(4-methylphenylsulfonyl)amino]hept-2-en-1-ol (21). By a procedure identical with that described for the preparation of the mesylate **18** from **9**, the alcohol **12** (150 mg, 0.504 mmol) was converted into the title compound **21** (185 mg, 98%) as a colorless oil [Found (FAB): $(M + H)^+$, 376.1248. $C_{16}H_{26}NO_5S_2$ requires M + H, 376.1252]; $[\alpha]_D^{23}$ +45.5 (*c* 0.176, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.77 (3 H, d, *J* 6.2, CMe), 0.81 (3 H, d, *J* 6.8, CMe), 1.22 (1 H, ddd, *J* 14.3, 7.3 and 7.3, 5-C*H*H), 1.36 (1 H, ddd, *J* 14.3, 7.8 and 7.8, 5-CH*H*), 1.50 (1 H, m, 6-H), 2.43 (3 H, s, CMe), 3.05 (3 H, s, SO_2Me), 4.10 (1 H, m, 4-H), 4.70 (1 H, ddd, *J* 12.4, 7.0 and 1.1, OC*H*H), 4.74 (1 H, ddd, *J* 12.4, 7.0 and 1.1, OCH*H*), 5.40 (1 H, dddd, *J* 11.1, 9.5, 1.4 and 1.4, 3-H), 5.52 (1 H, ddd, *J* 11.1, 7.0 and 7.0, 2-H), 7.29–7.32 (2 H, m, Ph), 7.71–7.75 (2 H, m, Ph); *m*/*z* (FAB, LRMS) 376 (MH^+), 280 (base peak).

(4*S*,2*Z*)-4-[*N*-(*tert*-Butoxycarbonyl)amino]-*O*-methylsulfonyl-6-methylhept-2-en-1-ol (22). By a procedure identical with that described for the preparation of the mesylate **18** from **9**, the alcohol **13** (150 mg, 0.617 mmol) was converted into the mesylate **22** (185 mg, 93%) as a colorless oil [Found (FAB): $(M + H)^+$, 322.1691. $C_{14}H_{28}NO_5S$ requires M + H, 322.1688]; $[\alpha]_D^{26}$ +64.8 (*c* 0.886, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.91 (3 H, d, *J* 6.2, CMe), 0.94 (3 H, d, *J* 5.9, CMe), 1.18–1.47 (2 H, m, 5-CH_2), 1.42 (9 H, s, CMe_3), 1.62 (1 H, m, 6-H), 3.05 (3 H, s, SO_2Me), 4.35 (1 H, m, 4-H), 4.42 (1 H, br, NH), 4.90–5.02 (2 H, m, OCH_2), 5.48 (1 H, dd, *J* 11.3 and 9.7, 3-H), 5.65 (1 H, ddd, *J* 11.3, 6.5 and 6.5, 2-H); *m*/*z* (FAB, LRMS) 322 (MH^+), 170 (base peak).

General procedure for aziridination reaction of (*Z*)-allylic carbonates (14) with tetrakis(triphenylphosphine)palladium(0). Synthesis of (2*R*,3*S*)-3-isopropyl-*N*-(2,4,6-trimethylphenylsulfonyl)-2-vinylaziridine (23) and the (2*S*,3*S*)-isomer (24)

A stirred mixture of the allylic carbonate **14** (288 mg, 0.80 mmol) and $Pd(PPh_3)_4$ (36 mg, 0.032 mmol, 4 mol%) in dry THF (5 cm^3) was heated at 60 °C for 5 min. The mixture was concentrated under reduced pressure to leave an oil, which was flash chromatographed on silica gel with *n*-hexane–EtOAc (10 : 1) to give a 94 : 6 mixture of the vinylaziridines **23** and **24** (166 mg, 73%). The mixture was flash chromatographed over silica gel. Elution with *n*-hexane–EtOAc (15 : 1) gave 156 mg (69%) of **23** and further elution yielded 10 mg (4%) of **24**. Compound **23**: colorless prisms, mp 46 °C (from cold *n*-hexane) (Found: C, 65.2; H, 7.95; N, 4.8. $C_{16}H_{23}NO_2S$ requires C, 65.5; H, 7.9; N, 4.8%); $[\alpha]_D^{23}$ −11.6 (*c* 1.01, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.78 (3 H, d, *J* 6.8, CMe), 0.88 (3 H, d, *J* 7.0, CMe), 1.43 (1 H, m, Me_2CH), 2.30 (3 H, s, CMe), 2.56 (1 H, dd, *J* 10.3 and 7.6, 3-H), 2.70 (6 H, s, 2 × CMe), 3.41 (1 H, dd, *J* 7.6 and 6.8, 2-H), 5.27 (1 H, dd, *J* 10.3 and 1.1, CH=C*H*H), 5.41 (1 H, dd, *J* 17.1 and 1.1, CH=CH*H*), 5.64 (1 H, dd, *J* 17.1, 10.3 and 6.8, C*H*=CH_2), 6.95 (2 H, s, Ph); δ_C(67.8 MHz; $CDCl_3$) 19.1, 20.7, 21.2, 23.3, 26.9, 44.9, 51.4, 121.0, 130.4, 131.9, 133.0, 140.1, 143.0. Compound **24**: colorless prisms, mp 67 °C (from *n*-hexane) (Found: C, 65.5; H, 7.95; N, 4.7. $C_{16}H_{23}NO_2S$ requires C, 65.5; H, 7.9; N, 4.8%); $[\alpha]_D^{24}$ −89.7 (*c* 0.609, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.70 (3 H, d, *J* 6.5, CMe), 0.87 (3 H, d, *J* 7.0, CMe), 1.51 (1 H, m, Me_2CH), 2.29 (3 H, s, CMe), 2.70 (6 H, s, 2 × CMe), 2.80 (1 H, dd, *J* 7.3 and 4.3, 3-H), 3.11 (1 H, dd, *J* 9.5 and 4.3, 2-H), 5.35 (1 H, dd, *J* 10.3 and 1.4, CH=C*H*H), 5.50 (1 H, dd, *J* 17.3 and 1.4, CH=CH*H*), 6.17 (1 H, ddd, *J* 17.3, 10.3 and 9.5, C*H*=CH_2), 6.93 (s, 2 H); δ_C(67.8 MHz; $CDCl_3$) 19.4, 21.2, 23.2, 30.3, 51.0, 53.7, 121.4, 131.8, 132.5, 134.5, 139.9, 142.7.

(2*R*,3*S*)-3-Isopropyl-*N*-(4-methoxy-2,3,6-trimethylphenylsulfonyl)-2-vinylaziridine (25) and the (2*S*,3*S*)-isomer (26). The allylic carbonate **25** (408 mg, 1.02 mmol) was converted into a 97 : 3 mixture of the vinylaziridines **25** and **26** (226 mg, 69%) by treatment with 4 mol% $Pd(PPh_3)_4$ in THF at 65 °C for 5 min. The mixture was flash chromatographed over silica gel. Elution with *n*-hexane–EtOAc (20 : 1) gave 219 mg (67%) of **25** and further elution yielded 7 mg (2%) of **26**. Compound **25**: colorless oil [Found (FAB): $(M + H)^+$, 324.1640. $C_{17}H_{26}NO_3S$ requires M + H, 324.1633]; $[\alpha]_D^{17}$ −4.37 (*c* 0.183, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.80 (3 H, d, *J* 6.8, CMe), 0.88 (3 H, d, *J* 7.0, CMe), 1.44 (1 H, m, Me_2CH), 2.15 (3 H, s, CMe), 2.56 (1 H, dd, *J* 9.7 and 7.0, 3-H), 2.68 (3 H, s, CMe), 2.70 (3 H, s, CMe), 3.40 (1 H, dd, *J* 7.0 and 6.8, 2-H), 3.85 (3 H, s, OMe), 5.27 (1 H, ddd, *J* 10.3, 1.6 and 0.8, CH=C*H*H), 5.41 (1 H, ddd, *J* 17.3, 1.6 and 0.5, CH=CH*H*), 5.65 (1 H, ddd, *J* 17.3, 10.3 and 6.8, C*H*=CH_2), 6.56 (1 H, s, Ph); *m*/*z* (FAB, LRMS) 324 (MH^+), 110 (base peak). Compound **26**: colorless crystals, mp 97 °C (from *n*-hexane) (Found: C, 62.9; H, 7.8; N, 4.3. $C_{17}H_{25}NO_3S$ requires C, 63.1; H, 7.8; N, 4.3%); $[\alpha]_D^{19}$ −79.6 (*c* 1.40, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.73 (3 H, d, *J* 7.0, CMe), 0.88 (3 H, d, *J* 7.0, CMe), 1.52 (1 H, m, Me_2CH), 2.15 (3 H, s, CMe), 2.69 (6 H, s, 2 × CMe), 2.81 (1 H, dd, *J* 7.6 and 4.1, 3-H), 3.10 (1 H, dd, *J* 9.7 and 4.1, 2-H), 3.85 (3 H, s, OMe), 5.33 (1 H, dd, *J* 10.3 and 1.1, CH=C*H*H), 5.48 (1 H, dd, *J* 17.3 and 1.4, CH=CH*H*), 6.18 (1 H, ddd, *J* 17.3, 10.3 and 9.7, C*H*=CH_2), 6.55 (1 H, s, Ph).

(3*R*,4*S*,5*S*)-5-Methyl-3,4-epimino-*N*-(4-methoxy-2,3,6-trimethylphenylsulfonyl)hept-1-ene (27) and the (3*S*,4*S*,5*S*)-isomer (28). The allylic carbonate **16** (480 mg, 1.16 mmol) was converted into a 97 : 3 mixture of the vinylaziridines **27** and **28** (303 mg, 77%) by treatment with 2 mol% $Pd(PPh_3)_4$ in THF at 65 °C for 5 min. The mixture was flash chromatographed over silica gel. Elution with *n*-hexane–EtOAc (30 : 1) gave 294 mg (75%) of

27 and further elution yielded 9 mg (2%) of **28**. Compound **27**: colorless oil [Found (FAB): $(M + H)^+$, 338.1794. $C_{18}H_{28}NO_3S$ requires M + H, 338.1789]; $[\alpha]_D^{24}$ +1.44 (*c* 1.25, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.79 (3 H, t, *J* 7.6, CMe), 0.85 (3 H, d, *J* 7.0, CMe), 1.04–1.45 (3 H, m, CH_2 and CH_2CH), 2.15 (3 H, s, CMe), 2.67 (1 H, dd, *J* 9.7 and 7.0, 4-H), 2.68 (3 H, s, CMe), 2.69 (3 H, s, CMe), 3.35 (1 H, dd, *J* 7.0 and 7.0, 3-H), 3.85 (3 H, s, OMe), 5.26 (1 H, d, *J* 10.0, CH=CHH), 5.38 (1 H, d, *J* 17.0, CH=CHH), 5.64 (1 H, ddd, *J* 17.0, 10.0 and 7.0, $CH=CH_2$), 6.56 (1 H, s, Ph); *m*/*z* (FAB, LRMS) 338 (MH^+), 124 (base peak). Compound **28**: colorless prisms, mp 72 °C (from *n*-hexane) (Found: C, 63.9; H, 8.1; N, 4.1. $C_{18}H_{27}NO_3S$ requires C, 64.1; H, 8.1; N, 4.15%); $[\alpha]_D^{24}$ −51.9 (*c* 0.486, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.75 (3 H, t, *J* 7.3, CMe), 0.86 (3 H, d, *J* 6.8, CMe), 1.06 (1 H, m, CHH), 1.19–1.38 (2 H, m, CH and CH_2CH), 2.15 (3 H, s, CMe), 2.68 (6 H, s, 2 × CMe), 2.87 (1 H, dd, *J* 7.3 and 4.3, 3-H), 3.07 (1 H, dd, *J* 9.5 and 4.3, 2-H), 3.85 (3 H, s, OMe), 5.32 (1 H, d, *J* 10.3, CH=CHH), 5.47 (1 H, d, *J* 17.3, CH=CH), 6.18 (1 H, ddd, *J* 17.3, 10.3 and 9.5, $CH=CH_2$), 6.55 (1 H, s, Ph).

(2*R*,3*S*)-*N*-(4-Methylphenylsulfonyl)-3-(2-methylpropyl)-2-vinylaziridine (29) and the (2*S*,3*S*)-isomer (30). The allylic carbonate **17** (225 mg, 0.633 mmol) was converted into a 94:6 mixture of the vinylaziridines **29** and **30** (131 mg, 74%) by treatment with 4 mol% of $Pd(PPh_3)_4$ in THF at 65 °C for 10 min. The mixture was flash chromatographed over silica gel. Elution with *n*-hexane–EtOAc (10:1) gave 123 mg (70%) of **29** and further elution yielded 8 mg (4%) of **30**. Compound **29**: colorless oil [Found (FAB): $(M + H)^+$, 280.1380. $C_{15}H_{22}NO_2S$ requires M + H, 280.1371]; $[\alpha]_D^{23}$ −6.28 (*c* 0.605, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.88 (3 H, d, *J* 6.5, CMe), 0.89 (3 H, d, *J* 6.8, CMe), 1.30 (1 H, ddd, *J* 14.0, 7.8 and 6.2, CHH), 1.39 (1 H, ddd, *J* 14.0, 7.0 and 5.7, CHH), 1.60 (1 H, m, Me_2CH), 2.44 (3 H, s, CMe), 2.97 (1 H, ddd, *J* 7.8, 7.3 and 7.0, 3-H), 3.33 (1 H, dd, *J* 7.3 and 7.3, 2-H), 5.26 (1 H, ddd, *J* 10.3, 1.1 and 1.1, CH=CHH), 5.38 (1 H, ddd, *J* 17.3, 1.1 and 1.1, CH=CHH), 5.59 (1 H, ddd, *J* 17.3, 10.3 and 7.3, $CH=CH_2$), 7.31–7.34 (2 H, m, Ph), 7.80–7.84 (2 H, m, Ph); *m*/*z* (FAB, LRMS) 280 (MH^+), 124 (base peak). Compound **30**: colorless crystals, mp 59 °C (from *n*-hexane) (Found: C, 64.3; H, 7.6; N, 5.0. $C_{15}H_{21}NO_2S$ requires C, 64.5; H, 7.6; N, 5.0%); $[\alpha]_D^{23}$ −72.3 (*c* 0.411, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.88 (1 H, d, *J* 6.2, CMe), 0.90 (1 H, d, *J* 6.2, CMe), 1.39 (1 H, m, Me_2CH), 1.58–1.68 (2 H, m, CH_2), 2.43 (3 H, s, CMe), 2.95 (1 H, m, 3-H), 3.08 (1 H, dd, *J* 8.9 and 4.3, 2-H), 5.34 (1 H, d, *J* 10.3, CH=CHH), 5.47 (1 H, d, *J* 16.7, CH=CHH), 6.02 (1 H, ddd, *J* 16.7, 10.3 and 8.9, $CH=CH_2$), 7.29–7.32 (2 H, m, Ph), 7.81–7.84 (2 H, m, Ph).

General procedure for base-promoted cyclization of allylic mesylates (18). (2*S*)-2-Isopropyl-*N*-(2,4,6-trimethylphenylsulfonyl)-3-pyrroline (32)

To a stirred suspension of NaH (11.6 mg, 0.482 mmol) in DMF (1 cm^3) under argon was added a solution of the allylic mesylate **18** (125 mg, 0.321 mmol) in DMF (1 cm^3) at 0 °C. After 0.5 h, 1 cm^3 of a saturated NH_4Cl solution was added to the mixture. The whole was extracted with Et_2O and the extract was washed with water, and dried over $MgSO_4$. Usual workup followed by flash chromatography over silica gel with *n*-hexane–EtOAc (10:1) gave the title compound **32** (82 mg, 87%) as colorless crystals, mp 74 °C [from *n*-hexane–Et_2O (10:1)] (Found: C, 65.4; H, 7.9; N, 4.6. $C_{16}H_{23}NO_2S$ requires C, 65.5; H, 7.9; N, 4.8%); $[\alpha]_D^{27}$ +123 (*c* 0.892, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.71 (3 H, d, *J* 6.5, CMe), 0.85 (3 H, d, *J* 7.0, CMe), 1.84 (1 H, m, Me_2CH), 2.30 (3 H, s, CMe), 2.65 (6 H, s, 2 × CMe), 3.84 (1 H, dddd, *J* 14.6, 5.7, 2.1 and 2.1, 5-CHH), 4.26 (1 H, dddd, *J* 14.6, 2.1, 2.1 and 2.1, 5-CHH), 4.65 (1 H, m, 2-H), 5.68 (1 H, dddd, *J* 6.5, 2.1, 2.1 and 2.1, CH=CH), 5.81 (1 H, dddd, *J* 6.5, 2.1, 2.1 and 2.1, CH=CH), 6.85 (2 H, s, Ph); δ_C(67.8 MHz; $CDCl_3$) 16.0, 19.4, 21.1, 23.0, 32.2, 55.4, 71.8, 126.4, 126.7, 132.1, 133.4, 140.4, 142.7.

(2*S*)-2-Isopropyl-*N*-(4-methoxy-2,3,6-trimethylphenylsulfonyl)-3-pyrroline (33). The methanesulfonate **19** (130 mg, 0.31 mmol) was converted into the title compound **33** (93 mg, 93%) as colorless crystals, mp 83 °C (from *n*-hexane) (Found: C, 63.0; H, 7.8; N, 4.4. $C_{17}H_{25}NO_3S$ requires C, 63.1; H, 7.8; N, 4.3%); $[\alpha]_D^{23}$ +122 (*c* 0.753, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.71 (3 H, d, *J* 7.0, CMe), 0.85 (3 H, d, *J* 7.0, CMe), 1.84 (1 H, m, Me_2CH), 2.15 (3 H, s, CMe), 2.59 (3 H, s, CMe), 2.70 (3 H, s, CMe), 3.81 (1 H, dddd, *J* 14.6, 5.7, 2.1 and 2.1, 5-CHH), 3.86 (3 H, s, OMe), 4.26 (1 H, dddd, *J* 14.6, 2.1, 2.1 and 2.1, 5-CHH), 4.66 (1 H, m, 2-H), 5.68 (1 H, dddd, *J* 6.2, 2.1, 2.1 and 2.1, CH=CH), 5.81 (1 H, dddd, *J* 6.2, 2.1, 2.1 and 2.1, CH=CH), 6.58 (1 H, s, Ph).

(2*S*,1′*R*)-2-(1-Methylpropyl)-*N*-(4-methoxy-2,3,6-trimethylphenylsulfonyl)-3-pyrroline (34). The mesylate **20** (200 mg, 0.461 mmol) was converted into the title compound **34** (132 mg, 85%) as a colorless oil [Found (FAB): $(M + H)^+$, 338.1795. $C_{18}H_{27}NO_3S$ requires M + H, 338.1790]; $[\alpha]_D^{19}$ +122 (*c* 0.242, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.68 (3 H, d, *J* 7.0, CMe), 0.83 (3 H, t, *J* 7.3, CMe), 1.08 (1 H, m, 2′-CHH), 1.27 (1 H, m, 2′-CHH), 1.47 (1 H, m, 1′-H), 2.15 (3 H, s, CMe), 2.59 (3 H, s, CMe), 2.70 (3 H, s, CMe), 3.83 (1 H, dddd, *J* 14.6, 5.7, 2.2 and 2.2, 5-CHH), 3.86 (3 H, s, OMe), 4.30 (1 H, dddd, *J* 14.6, 2.2, 2.2 and 2.2, 5-CHH), 4.73 (1 H, m, 2-H), 5.63 (1 H, dddd, *J* 6.2, 2.2, 2.2 and 2.2, CH=CH), 5.80 (1 H, dddd, *J* 6.2, 2.2, 2.2 and 2.2, CH=CH), 6.58 (1 H, s, Ph); *m*/*z* (FAB, LRMS) 338 (MH^+, base peak).

(2*S*)-2-Isobutyl-*N*-(4-methylphenylsulfonyl)-3-pyrroline (35). The mesylate **21** (155 mg, 0.413 mmol) was converted into the title compound **35** (105 mg, 91%) as colorless crystals, mp 84 °C [from *n*-hexane–Et_2O (2:1)] (Found: C, 64.2; H, 7.7; N, 4.9. $C_{15}H_{21}NO_2S$ requires C, 64.5; H, 7.6; N, 5.0%); $[\alpha]_D^{25}$ +210 (*c* 0.950, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.96 (6 H, d, *J* 6.8, 2 × CMe), 1.51 (1 H, m, Me_2CH), 1.65–1.84 (2 H, m, 1′-CH_2), 2.42 (3 H, s, CMe), 4.04–4.20 (2 H, m, 5-CH_2), 4.44 (1 H, m, 2-H), 5.57 (1 H, dddd, *J* 6.2, 1.9, 1.9 and 1.9, CH=CH), 5.63 (1 H, dddd, *J* 6.2, 1.9, 1.9 and 1.9, CH=CH), 7.28–7.31 (2 H, m, Ph), 7.68–7.71 (2 H, m, Ph).

(2*S*)-*N*-(*tert*-Butoxycarbonyl)-2-isobutyl-3-pyrroline (36). The mesylate **22** (158 mg, 0.492 mmol) was converted into the title compound **36** (99 mg, 89%) as a colorless oil [Found (CI): $(M + H)^+$, 226.1813. $C_{13}H_{24}NO_2$ requires M + H, 226.1807]; $[\alpha]_D^{27}$ +186 (*c* 0.888, $CHCl_3$); δ_H(300 MHz; $CDCl_3$; 328 K) 0.91 (3 H, d, *J* 6.5, CMe), 0.94 (3 H, d, *J* 6.5, CMe), 1.41 (1 H, m, 1′-CHH), 1.48 (9 H, s, CMe_3), 1.65 (1 H, m, Me_2CH), 1.73 (1 H, m, 1′-CHH), 4.00 (1 H, dddd, *J* 15.6, 5.3, 1.8 and 1.8, 5-CHH), 4.18 (1 H, m, 5-CHH), 4.51 (1 H, br s, 2-H), 5.72 (1 H, m, CH=CH), 5.79 (1 H, m, CH=CH); *m*/*z* (CI, LRMS) 226 (MH^+), 170 (base peak).

(±)-*O*,*O*-Bis(methylsulfonyl)-2-hydroxymethyl-5-methyl-4-[*N*-(2,4,6-trimethylphenylsulfonyl)amino]hex-2-en-1-ol (37). The title dimesylate **37** was obtained *via* a sequence of reactions starting from racemic valinol. Compound **37**: colorless oil [Found (FAB): $(M + H)^+$, 498.1294. $C_{19}H_{32}NO_8S_3$ requires M + H, 498.1290]; δ_H(270 MHz; $CDCl_3$) 0.83 (3 H, d, *J* 7.0, CMe), 0.87 (3 H, d, *J* 7.0, CMe), 1.73 (1 H, m, 5-H), 2.31 (3 H, s, CMe), 2.61 (6 H, s, 2 × CMe), 3.04 (3 H, s, SO_2Me), 3.05 (3 H, s, SO_2Me), 3.82 (1 H, ddd, *J* 10.3, 7.8 and 7.0, 4-H), 4.51 (1 H, d, *J* 11.9, OCHH), 4.55 (1 H, d, *J* 11.1, OCHH), 4.56 (1 H, d, *J* 11.1, OCHH), 4.73 (1 H, d, *J* 11.9, OCHH), 4.97 (1 H, d, *J* 7.8, NH), 5.64 (1 H, d, *J* 10.3, 3-H), 6.96 (2 H, s, Ph); *m*/*z* (FAB, LRMS) 498 (MH^+), 97 (base peak).

(±)-2-Isopropyl-4-(methanesulfonyloxymethyl)-*N*-(2,4,6-trimethylphenylsulfonyl)-3-pyrroline (38). The dimesylate **37** (95 mg, 0.191 mmol) was converted into the title compound **38** (64 mg, 84%) as a colorless oil [Found (FAB): $(M + H)^+$, 402.1419. $C_{18}H_{28}NO_5S_2$ requires M + H, 402.1409]; δ_H(300 MHz; $CDCl_3$) 0.72 (3 H, d, J 6.8, CMe), 0.86 (3 H, d, J 7.0, CMe), 1.84 (1 H, m, Me_2CH), 2.31 (3 H, s, CMe), 2.65 (6 H, s, 2 × CMe), 3.02 (3 H, s, SO_2Me), 3.86 (1 H, ddddd, J 14.2, 5.4, 2.1, 1.1 and 1.1, 5-C*H*H), 4.31 (1 H, m, 5-CH*H*), 4.70 (1 H, m, 2-H), 4.74–4.85 (2 H, m, OCH_2), 5.83 (1 H, m, 3-H), 6.96 (2 H, s, Ph); *m*/*z* (FAB, LRMS) 402 (MH^+), 119 (base peak).

Ethyl (4*S*,2*Z*)-5-(*tert*-butyldimethylsilyloxy)-4-[*N*-(*tert*-butoxycarbonyl)amino]pent-2-enoate (41)

To a stirred solution of oxalyl chloride (4.11 cm³, 42.9 mmol) in a mixed solvent of $CHCl_3$ (30 cm³) and *n*-hexane (30 cm³) at −78 °C under argon was added dropwise a solution of DMSO (11.7 cm³, 165 mmol) in $CHCl_3$ (10 cm³). After 30 min, a solution of the alcohol **40** (10 g, 33.3 mmol) in $CHCl_3$ (10 cm³) was added to the above reagent at −78 °C, and the mixture was stirred for 1 h. Diisopropylethylamine (40.3 cm³, 231 mmol) was added to the above solution at −78 °C and the mixture was stirred for 30 min at this temperature. A suspension of LiCl (1.32 g, 36.3 mmol) and ethyl diphenylphosphonoacetate (11.6 g, 36.3 mmol) in MeCN (70 cm³) was added to the above mixture at −78 °C. The mixture was stirred for 2 h at this temperature and an additional 1.5 h at −20 °C. The mixture was made acidic with saturated citric acid and concentrated under reduced pressure to leave a residual oil, which was extracted with Et_2O. The extract was washed successively with water, 5% $NaHCO_3$, and water, and dried over $MgSO_4$. Usual workup followed by flash chromatography over silica gel with *n*-hexane–EtOAc (15:1) gave, in order of elution, the (*Z*)-enoate **41** (4.57 g, 37%), and its (*E*)-isomer (1.06 g, 9%). Compound **41**: colorless oil [Found (FAB): $(M + H)^+$, 374.2368. $C_{18}H_{36}NO_5Si$ requires M + H, 374.2363]; $[\alpha]_D^{21}$ −13.3 (*c* 0.513, $CHCl_3$); δ_H(300 MHz; $CDCl_3$) 0.03 (3 H, s, SiMe), 0.05 (3 H, s, SiMe), 0.88 (9 H, s, $SiCMe_3$), 1.27 (3 H, t, J 7.1, CMe), 1.42 (9 H, s, $OCMe_3$), 3.75 (1 H, m, 5-C*H*H), 3.81 (1 H, dd, J 10.0 and 3.6, 5-CH*H*), 4.16 (2 H, q, J 7.1, OCH_2), 5.13–5.23 (2 H, m, 4-H and NH), 5.83 (1 H, d, J 11.6, 2-H), 6.15 (1 H, dd, J 11.6 and 8.1, 3-H); *m*/*z* (FAB, LRMS) 374 (MH^+), 274 (base peak). (*E*)-Isomer of **41**: colorless oil [Found (FAB): $(M + H)^+$, 374.2357. $C_{18}H_{36}NO_5Si$ requires M + H, 374.2363]; $[\alpha]_D^{22}$ −1.62 (*c* 0.782, $CHCl_3$); δ_H(300 MHz; $CDCl_3$) 0.04 (3 H, s, SiMe), 0.05 (3 H, s, SiMe), 0.88 (9 H, s, $SiCMe_3$), 1.28 (3 H, t, J 7.1, CMe), 1.45 (9 H, s, $OCMe_3$), 3.69 (1 H, dd, J 10.1 and 4.0, 5-C*H*H), 3.72 (1 H, dd, J 10.1 and 4.4, 5-CH*H*), 4.19 (2 H, q, J 7.1, OCH_2), 4.35 (1 H, br s, 4-H), 4.91 (1 H, br s, NH), 5.96 (1 H, dd, J 15.7 and 1.7, 2-H), 6.89 (1 H, dd, J 15.7 and 5.2, 3-H); *m*/*z* (FAB, LRMS), 374 (MH^+), 260 (base peak).

(4*S*,2*Z*)-5-(*tert*-Butyldimethylsilyloxy)-4-[*N*-(*tert*-butoxycarbonyl)amino]pent-2-en-1-ol (42). By a procedure identical with that described for the preparation of the alcohol **9** from **4**, enoate **41** (4.4 g, 11.7 mmol) was converted into the title compound **42** (1.86 g, 41%) as a colorless oil [Found (FAB): $(M + H)^+$, 332.2252. $C_{16}H_{34}NO_4Si$ requires M + H, 332.2257]; $[\alpha]_D^{22}$ +7.18 (*c* 0.891, $CHCl_3$); δ_H(270 MHz; $CDCl_3$) 0.07 (6 H, s, 2 × SiMe), 0.91 (9 H, s, $SiCMe_3$), 1.44 (9 H, s, $OCMe_3$), 3.54 (1 H, br s, OH), 3.60 (1 H, dd, J 10.0 and 4.1, 5-C*H*H), 3.69 (1 H, dd, J 10.0 and 4.3, 5-CH*H*), 3.98 (1 H, ddd, J 12.4, 6.2 and 5.4, 1-C*H*H), 4.37 (1 H, ddd, J 12.4, 8.4 and 3.8, 1-CH*H*), 4.51 (1 H, m, 4-H), 5.06 (1 H, m, NH), 5.52 (1 H, dd, J 10.5 and 9.7, 3-H), 5.84 (1 H, ddd, J 10.5, 8.4 and 6.2, 2-H); *m*/*z* (FAB, LRMS) 332 (MH^+), 232 (base peak).

(2*S*)-2-(*tert*-Butyldimethylsilyloxy)-*N*-(*tert*-butoxycarbonyl)-3-pyrroline (44)

To a stirred mixture of the alcohol **42** (1.5 g, 4.53 mmol), Et_3N (6.27 cm³, 45.3 mmol), and THF (30 cm³) was added dropwise methanesulfonyl chloride (1.75 cm³, 22.7 mmol) at −78 °C. The stirring was continued for 45 min with warming to 0 °C followed by quenching with 6 cm³ of saturated aqueous $NaHCO_3$ with vigorous stirring. The mixture was concentrated under reduced pressure below 25 °C to leave a residual oil, which was extracted with a mixed solvent of Et_2O–EtOAc (3:1). The extract was washed successively with 5% aqueous citric acid, water, 5% aqueous $NaHCO_3$, and water, and dried over $MgSO_4$. Usual workup gave a crude mesylate. To a stirred suspension of NaH (163 mg, 6.80 mmol) in DMF (6 cm³) under argon was added a solution of the crude mesylate in DMF (6 cm³) at 0 °C. After 45 min, the mixture was poured into ice-water (20 cm³) saturated with NH_4Cl. The whole was extracted with Et_2O and the extract was washed with water, and dried over $MgSO_4$. Usual workup followed by flash chromatography over silica gel with *n*-hexane–EtOAc (20:1) gave the title compound **44** (985 mg, 69%) as a colorless oil [Found (FAB): $(M + H)^+$, 314.2156. $C_{16}H_{32}NO_3Si$ requires M + H, 314.2152; $[\alpha]_D^{22}$ −159 (*c* 1.03, $CHCl_3$); δ_H(300 MHz; $CDCl_3$; 328 K) 0.02 (3 H, s, SiMe), 0.03 (3 H, s, SiMe), 0.88 (9 H, s, $SiCMe_3$), 1.48 (9 H, s, $OCMe_3$), 3.65 (1 H, m, 5-C*H*H), 3.86 (1 H, dd, J 9.6 and 3.2, 5-CH*H*), 3.99 (1 H, dd, J 15.2 and 5.2, OC*H*H), 4.16 (1 H, m, OCH*H*), 4.49 (1 H, br s, 2-H), 5.78–5.82 (2 H, m, 3-H and 4-H); *m*/*z* (FAB, LRMS) 314 (MH^+), 258 (base peak).

(2*S*)-*N*-(*tert*-Butoxycarbonyl)-2-hydroxymethyl-3-pyrroline (45)

To a stirred solution of **44** (962 mg, 3.07 mmol) in THF (10 cm³) was added dropwise tetrabutylammonium fluoride (1.0 M in THF; 3.38 cm³, 3.38 mmol) at 0 °C and the mixture was stirred for 2.5 h at this temperature. The mixture was made acidic with a saturated aqueous citric acid and the whole was extracted with a mixed solvent of Et_2O–EtOAc (1:1). The extract was washed successively with 5% aqueous $NaHCO_3$ and water, and dried over $MgSO_4$. Usual workup followed by flash chromatography over silica gel with *n*-hexane–EtOAc (3:2) gave the title compound **45** (454 mg, 74%) as a colorless oil [Found (FAB): $(M + H)^+$, 200.1281. $C_{10}H_{18}NO_3$ requires M + H, 200.1287]; $[\alpha]_D^{22}$ −125 (*c* 0.712, $CHCl_3$); δ_H(300 MHz; $CDCl_3$; 328 K) 1.49 (9 H, s, CMe_3), 1.53 (1 H, m, OH), 3.59 (1 H, dd, J 11.2 and 6.2, OC*H*H), 3.76 (1 H, m, OCH*H*), 4.07 (1 H, dddd, J 15.7, 5.5, 2.0 and 2.0, 5-C*H*H), 4.19 (1 H, m, 5-CH*H*), 4.68 (1 H, br s, 2-H), 5.64 (1 H, m, C*H*=CH), 5.82 (1 H, m, CH=C*H*); *m*/*z* (FAB, LRMS) 200 (MH^+), 144 (base peak).

(2*S*)-*N*-(*tert*-Butoxycarbonyl)-2-methoxycarbonyl-3-pyrroline (46)

To a stirred solution of oxalyl chloride (0.096 cm³, 1 mmol) in a mixed solvent of $CHCl_3$ (0.5 cm³) and *n*-hexane (0.5 cm³) at −78 °C under argon was added dropwise a solution of DMSO (0.178 cm³, 2.5 mmol) in $CHCl_3$ (0.15 cm³). After 30 min, a solution of the alcohol **45** (100 mg, 0.5 mmol) in $CHCl_3$ (0.15 cm³) was added to the above reagent at −78 °C, and the mixture was stirred for 1 h. Diisopropylethylamine (0.613 cm³, 3.5 mmol) was added to the above solution at −78 °C and the mixture was stirred for 30 min with warming to 0 °C. The mixture was made acidic with a saturated aqueous citric acid and the whole was extracted with Et_2O. The extract was washed successively with water, 5% aqueous $NaHCO_3$, and water, and dried over $MgSO_4$. Concentration under reduced pressure gave a crude aldehyde. To a stirred mixture of the crude aldehyde, 2-methylbut-2-ene (0.126 cm³, 1.5 mmol), and sodium dihydrogenphosphate dihydrate (78.3 mg, 0.5 mmol) in a mixed solvent of *t*-BuOH (3.6 cm³) and H_2O (1 cm³) was added sodium chlorite (191 mg, 1.25 mmol) portionwise at room temperature and the mixture was stirred for 2 h. The mixture was quenched with a saturated $NaHSO_3$ (1 cm³) and made acidic with 18% HCl. The whole was extracted with $CHCl_3$ (three times),

and the extract was dried over $MgSO_4$. Concentration under reduced pressure gave crude *N*-*tert*-butoxycarbonyl (*S*)-dehydroproline. To a stirred solution of the crude *N*-*tert*-butoxycarbonyl (*S*)-dehydroproline in Et_2O (1 mL) was added diazomethane (*ca*. 10 mmol) in Et_2O (3 mL) at 0 °C and the mixture was stirred for 30 min at this temperature. An excess amount of acetic acid was added to the mixture and the whole was extracted with a mixed solvent of Et_2O–EtOAc (2:1). The extract was washed successively with water, 5% aqueous $NaHCO_3$, and water, and dried over $MgSO_4$. Usual workup followed by flash chromatography over silica gel with *n*-hexane–EtOAc (5:1) gave the title compound **46** (31 mg, 27%) as a colorless oil [Found (FAB): $(M + H)^+$, 228.1242. $C_{11}H_{18}NO_4$ requires *M* + H, 228.1236]; $[a]_D^{21}$ −221 (*c* 0.610, $CHCl_3$); δ_H(300 MHz; $CDCl_3$; 328 K) 1.43 (9 H, s, $OCMe_3$), 3.74 (3 H, s, OMe), 4.15–4.33 (2 H, m, 5-CH_2), 4.98 (1 H, m, 2-H), 5.72 (1 H, m, C*H*=CH), 5.96 (1 H, m, CH=C*H*); *m*/*z* (FAB, LRMS) 228 (MH^+), 172 (base peak).

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