Chemistry of *O*-Silylated Ketene Acetals: A Mild and Convenient Synthesis of β-Lactam Antibiotics

Yasuyuki KITA,* Norio SHIBATA, Osamu TAMURA and Takashi MIKI

Faculty of Pharmaceutical Sciences, Osaka University, 1–6 Yamada-Oka, Suita, Osaka 565, Japan. *Received February 21, 1991*

β-Amido sulfoxides (1) reacted with *O*-silylated ketene acetal (16) in dry acetonitrile in the presence of a catalytic amount of zinc iodide to give the 4-phenylthioazetidin-2-ones (17). Oxidation of 17 with *m*-chloroperbenzoic acid gave the corresponding sulfoxides (18), which were treated with 16 to give the azetidin-2-one esters (20), known precursors of PS-5-type carbapenem antibiotics.

Keywords *O*-silylated ketene acetal; intramolecular Pummerer-type reaction; 4-phenylthioazetidin-2-one; PS-5

Since the discovery of non-classical β-lactam antibiotics such as thienamycin and PS-5, great efforts have been made to find new methodologies and reagents suitable for the preparation of these naturally occurring carbapenem antibiotics.[1] Recently we described[2] a biomimetic approach to penicillin synthesis from the Arnstein tripeptide analogue by using our silicon-induced Pummerer-type reaction.[3] In connection with this study, we have briefly communicated[4] an application of the method to a synthesis of carbapenem antibiotics involving PS-5 from readily obtained β-amido sulfoxides (**1**). We now give a full account of this work.

Several known (**1a**,[5] **1d**[6]) and unknown sulfoxides (**1b**, **c** and **1e—h**) were prepared by the following routes as outlined in Chart 1. Sulfoxides (**1a—f**) were prepared from the appropriate α,β-unsaturated amides or esters. Saponification of the ester (**2**) with potassium hydroxide in ethanol after addition of thiophenol to methyl acrylate gave the acid (**3**).[7] Condensation of **3** with amines was performed either by the use of a powerful dehydrating agent, (trimethylsilyl)ethoxyacetylene,[8] or *via* the acid chloride intermediate to give the corresponding β-amido sulfides (**4—6**), which were oxidized with sodium periodate ($NaIO_4$) to give the corresponding β-amido sulfoxides (**1a—c**). 2-Methyl-β-amido sulfoxides (**1d**, **e**) were prepared from 2-methyl acrylamide *via* β-amido sulfides (**7** and **8**). Addition of thiophenol to 2-methyl acrylamide produced **7**, which was oxidized with $NaIO_4$ to give **1d**. Treatment of **7** with benzyl bromide in the presence of sodium hydride followed by oxidation with $NaIO_4$ gave **1e**. Other 2-ethyl-β-amido sulfoxides (**1f—h**) were prepared from ketene silyl acetal (**9**) in 3 or 4 steps. Treatment of **9** with chlorothioanisole (**10**) in the presence of titanium tetrachloride ($TiCl_4$) in methylene chloride (CH_2Cl_2) gave the ester (**11**), which was hydrolyzed with sodium hydroxide in methanol to give the acid (**12**). Condensation of **11** with amines in the presence of trimethylaluminum[9] gave the amides (**13** and **14**), which were oxidized with $NaIO_4$ to give **1f**, and **g** in good overall yields. Condensation of the acid (**12**) with diphenylmethylamine using (trimethylsilyl)ethoxyacetylene gave the amide (**15**), which was oxidized with $NaIO_4$ to give **1h**. All these compounds gave proton nuclear magnetic resonance (^{1}H-NMR), infrared (IR), and analytical data consistent with the expected structures.

Treatment of the β-amido sulfoxides (**1a—h**) with 1-(dimethyl-*tert*-butylsiloxy)-1-methoxyethylene (**16**) caused an intramolecular Pummerer-type reaction to give the corresponding 4-phenylthioazetidin-2-ones (**17a—h**) (Table I). A typical procedure is as follows. An excess of **16** was added to a solution of **1a** and a catalytic amount of zinc iodide (ZnI_2) in dry acetonitrile at room temperature, and the mixture was stirred for 1 h. After removal of the solvent, the residue was purified by column chromatography to give **17a** in good yield.[10] The generality of this reaction is indicated by the finding that both *N*-substituted (**1b**, **1c**, **1e**, **1g**, and **1h**) and *N*-unsubstituted

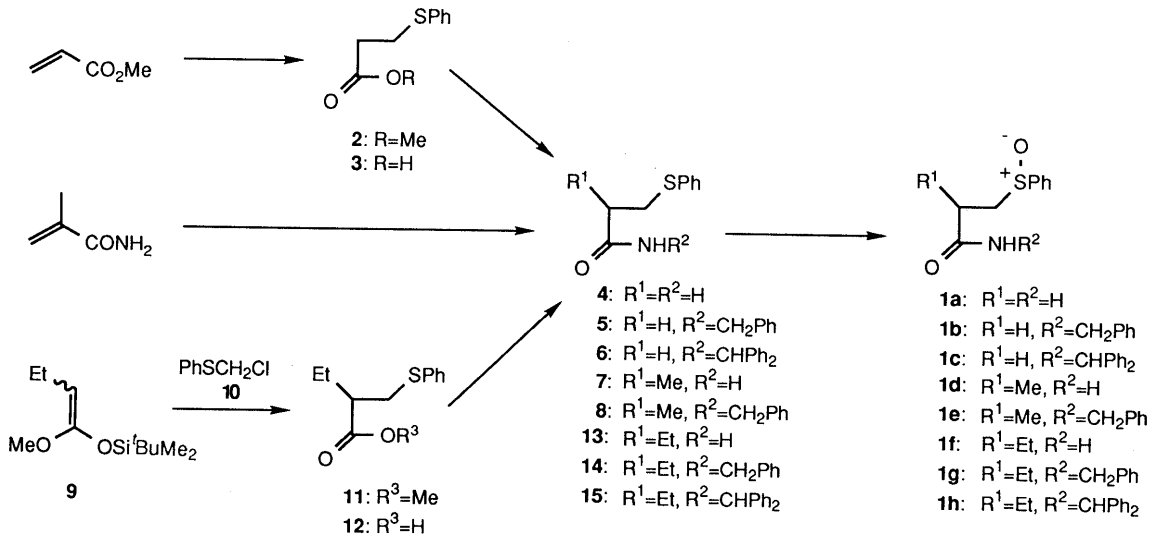
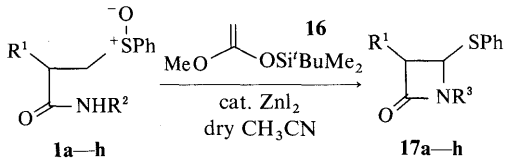


Chart 1

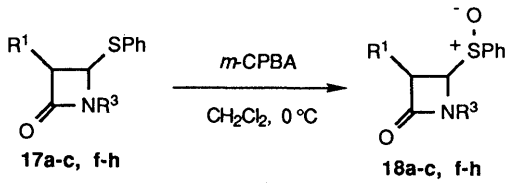
TABLE I. The Synthesis of β-Lactams (**17a—h**)



1a—h **17a—h**

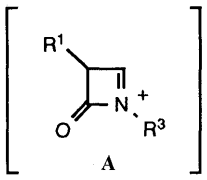
Run	Sulfoxide (**1**) R^1	R^2	Reaction conditions[a]	Product (**17**) R^3	Yield[b] (%)	Ratio[c] *cis* : *trans*
1	H	H **1a**	r.t. 1 h	$SiBuMe_2$ **17a**	88	
2	H	CH_2Ph **1b**	r.t. 6 h	CH_2Ph **17b**	73	
3	H	$CHPh_2$ **1c**	r.t. 3 h	$CHPh_2$ **17c**	93	
4	Me	H **1d**	r.t. 3 h	$BiBuMe_2$ **17d**	77	72 : 28
5	Me	CH_2Ph **1e**	r.t.—65 °C 5 h	CH_2Ph **17e**	77	71 : 29
6	Et	H **1f**	r.t.—50 °C 14 h	$SiBuMe_2$ **17f**	75	63 : 37
7	Et	CH_2Ph **1g**	r.t. 1 d	CH_2Ph **17g**	63	59 : 41
8	Et	$CHPh_2$ **1h**	r.t.—50 °C 6 h	$CHPh_2$ **17h**	78	44 : 56

a) The reactions were carried out on 0.05—0.2 mmol scale of sulfoxides with 2—5 eq of **16** in the presence of a catalytic amount (0.05—0.1 eq) of ZnI_2. *b*) Isolated yields (by column chromatography on silica gel) are given. *c*) The ratios were determined by 500 MHz ^{1}H-NMR and HPLC. r.t. = room temperature.



17a-c, f-h **18a-c, f-h**

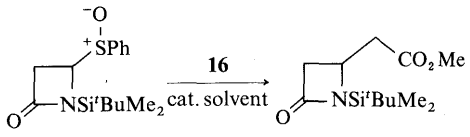
Chart 2



A

Fig. 1

TABLE II. Substitution Reaction of **18a**



18a **19a**

Entry	Catalyst	Solvent	Conditions	Yield (%)
1	ZnI_2	CH_3CN	r.t. 30 min	86
2	ZnI_2	CH_2Cl_2	r.t. 24 h	50
3	ZnI_2	THF	r.t. 4 h	60
4	$TiCl_4$, TMSOTf BF_3OEt_2, $SnCl_4$	CH_3CN	r.t. 15 min—18 h	Complex mixture
5	—	CH_3CN	r.t. 14 h—50 °C 3 d	0 (No reaction)

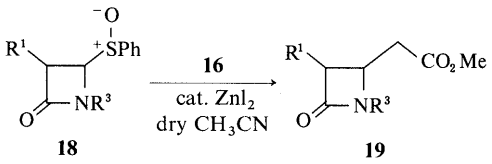
r.t: room temperature.

β-amido sulfides (**1a**, **1d**, and **1f**) reacted readily with **16** to give **17a—h** in high yields. These products were characterized on the basis of ^{1}H-NMR data and accurate mass spectra (MS); the *cis*/*trans* assignments (and ratios) for the 3,4-disubstituted azetidin-2-ones (**17d—h**) were made on the basis of 500 MHz ^{1}H-NMR spectrometric measurements and high performance liquid chromatography (HPLC) behavior.

Although a number of methods have been developed[1)] for carbon–carbon bond formation at the C-4 position of azetidin-2-one, most of the methods start from 4-acetoxy and 4-chloroazetidin-2-ones and involve either strongly basic or acidic conditions or require low temperature. We found a versatile and practical method for carbon–carbon bond formation by using 4-phenylsulfinylazetidin-2-ones obtained from 4-phenylthioazetidin-2-ones. Oxidation of the sulfides (**17a**) with *m*-chloroperbenzoic acid (*m*-CPBA) in CH_2Cl_2 gave the sulfoxide (**18a**) (Chart 2), which was treated with **16** in the presence of a catalyst. Among various reaction conditions examined, the use of a catalytic amount of ZnI_2 in dry acetonitrile gave the best result (Table II). A typical experimental procedure is as follows for the formation of **19a** with **16**. A solution of **18a**, **16**, and a catalytic amount of ZnI_2 in dry acetonitrile was stirred at room temperature for 0.5 h. After usual work-up, a high yield of **19a** was obtained. Similarly, other 4-phenylsulfinylazetidin-2-ones (**18b**, **c** and **18f—h**) were reacted with **16** to give the corresponding azetidinone esters (**19b**, **c** and **19f—h**), which gave spectral and analytical data consistent with the expected structures. The reaction conditions and yields are summarized in Table III. In the case of 3-ethyl-4-phenylsulfinylazetidin-2-ones (**18f—h**), the *trans*-azetidin-2-one esters (**19f—h**) were produced selectively whether *cis*- or *trans*-azetidin-2-ones were used as the starting materials. Therefore, it is presumed that carbon–carbon bond formation in the reaction of 4-phenylsulfinylazetidin-2-ones with **16** proceeds *via* a nucleophilic attack of the ester enolate anion on the iminium intermediates (A) to give the *trans*-azetidin-2-one esters (**18f—h**) (Fig. 1). To our knowledge, this is the first example of the substitution of a sulfinyl group by an enol ester equivalent at the 4-position of azetidin-2-one.[11)]

Finally, our attention was focused on the synthesis of a carbapenem antibiotic, PS-5. The *trans*-azetidin-2-one methyl ester (**19f**) was transesterified[12)] with benzyl alcohol to give the *trans*-azetidin-2-one benzyl ester (**20**) in excellent yield. Desilylation of **20** with tetrabutylammonium fluoride (Bu_4 NF) and acetic acid (AcOH) in tetrahydrofuran (THF)

TABLE III. Carbon–Carbon Bond Formation at the C-4 Position of Azetidin-2-ones



18 19

Run	Sulfoxide (18)	R^1	R^3	Reaction conditions[a]	Product (19)	Yield[b] (%)	Ratio[c] *trans*:*cis*
1	**18a**	H	Si^tBuMe_2	r.t. 30 min	**19a**	86	
2	**18b**	H	CH_2Ph	r.t. 1 h	**19b**	52	
3	**18c**	H	$CHPh_2$	r.t. 10 min	**19c**	89	
4	**18f** (*cis*:*trans* = 63:37)	Et	Si^tBuMe_2	−20 °C 1 h	**19f**	79	94:6
5	**18f** (*cis*)	Et	Si^tBuMe_2	−20 °C 1 h	**19f**	73	95:5
6	**18f** (*trans*)	Et	Si^tBuMe_2	−20 °C 1 h	**19f**	77	95:5
7	**18g** (*cis*:*trans* = 59:41)	Et	CH_2Ph	−20 °C 10 min	**19g**	84	89:11
8	**18h** (*cis*:*trnas* = 44:56)	Et	$CHPh_2$	−20 °C 1 h	**19h**	80	91:9
9	**18i**	H	H	r.t. 30 min	**19a**[d]	68	

a) The reactions were carried out on 0.05—0.2 mmol scale of sulfoxides with 2—4 eq of **16** in the presence of a catalytic amount (0.05—0.1 eq) of ZnI_2. *b*) Isolated yields (by column chromatography on silica gel) are given. *c*) The ratios were determined by 500 MHz ^{1}H-NMR. *d*) The *N*-silylated compound (**19a**) was obtained.

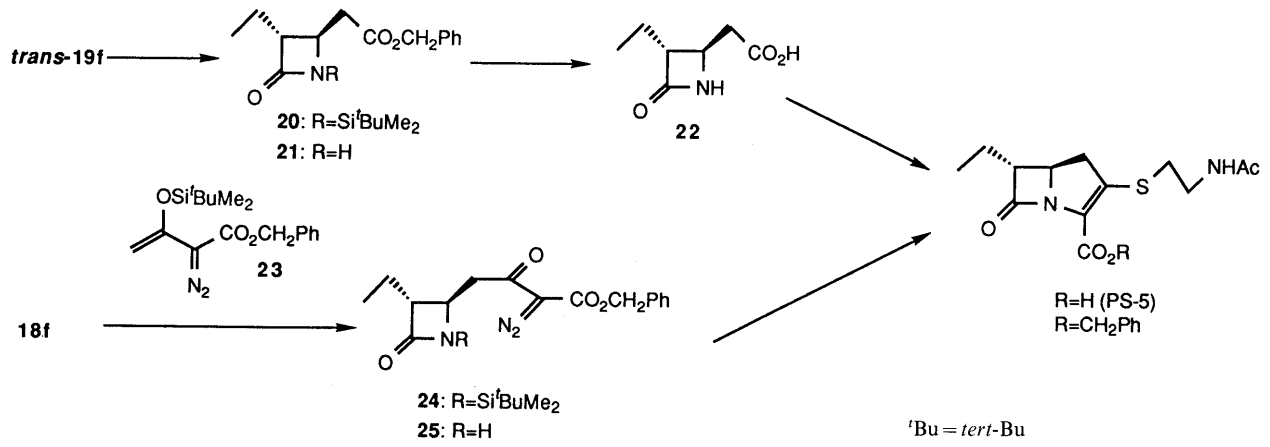


Chart 3

followed by reductive debenzylation on 10% palladium–carbon (Pd-C) in ethanol gave the known *trans*-4-carboxy-3-ethylazetidin-2-one (**22**)[13] (60% overall yield), which is the key intermediate to PS-5. Furthermore, 3-ethyl-4-sulfinylazetidin-2-one (**18f**, *cis*/*trans* = 59/41) was treated with the silyl enol ether (**23**) to give the *trans*-azetidin-2-one diazo ester (**24**) in 43% yield. The ester (**24**) was treated with Bu_4NF and AcOH in THF to give the known desilylated diazo ester (**25**)[13,14] (92%), which is also the key intermediate to PS-5·benzyl ester.

Experimental

All melting and boiling points are uncorrected. ^{1}H-NMR spectra were recorded on a Hitachi R-22 (90 MHz) or a JEOL JNM-GX 500 (500 MHz) spectrometer (with tetramethylsilane as an internal standard unless otherwise noted). IR absorption spectra were recorded on a JASCO HPIR-102 spectrophotometer. Low- and high-resolution MS were obtained with a JEOL JMS-D300 instrument, with a direct inlet system at 70 eV. For column chromatography, E. Merck silica gel (70—230 mesh ASTM) was used. For preparative thin layer chromatography (preparative TLC), E. Merck TLC plates precoated with Silica gel $60F_{254}$ (0.5 mm) were used.

***O*-Methyl-*O*-*tert*-butyldimethylsilyl Ketene Acetal (16)** The ketene acetal (**16**) was prepared by the reported method.[15]

Methyl 3-(Phenylthio)propionate (2) A mixture of methyl acrylate (4.3 g, 50 mmol), thiophenol (5.5 g, 50 mmol), and triethylamine (0.5 ml) was stirred at room temperature for 5 min, then at 50—60 °C for 1 h. The reaction mixture was evaporated *in vacuo*. The residue was distilled under reduced pressure to give **2** (9.2 g, 94%) as a colorless oil, bp 108—110 °C (2 mmHg) (lit.[16] 113—115 °C (2 mmHg)).

3-(Phenylthio)propionic Acid (3) A solution of **2** (7.6 g, 38.5 mmol) in ethanol (50 ml) was added to a solution of potassium hydroxide (6.47 g) in water (50 ml). The mixture was refluxed for 1 h, cooled to room temperature, acidified with 10% hydrochloric acid, and extracted with CH_2Cl_2 (50 ml × 5). The combined CH_2Cl_2 layer was dried over Na_2SO_4. Evaporation of the solvent and crystallization of the residue gave the acid **3** (4.7 g, 67%) as colorless crystals, mp 58—59 °C (hexane) (lit.[7] 58—60 °C). IR ν_{max} ($CHCl_3$) cm^{-1}: 3600—2200, 1710. ^{1}H-NMR ($CDCl_3$) δ: 2.63 (2H, t, J = 7 Hz, O=CCH_2–), 3.13 (2H, t, J = 7 Hz, –CH_2SPh), 7.17—7.34 (5H, m, SPh), 8.40—9.00 (1H, br, COOH). MS *m*/*z*: 182 (M^+).

3-(Phenylthio)propionamide (4) A solution of **3** (204.7 mg, 1.12 mmol) and a catalytic amount of dimethylformamide in thionyl chloride (2.7 g, 22.7 mmol) was refluxed for 1 h and concentrated *in vacuo*. After the residue was cooled at 0 °C, 28% aqueous ammonium hydroxide was added. The mixture was stirred for 1 h, acidified with concentrated hydrochloric acid, and extracted with CH_2Cl_2 (20 ml × 5). The combined organic layer was washed with saturated aqueous $NaHCO_3$ and brine, and dried over $MgSO_4$. Evaporation of the solvent *in vacuo* gave the residue, which was subjected to column chromatography on silica gel with AcOEt–hexane (1:3) to give **4** (127.3 mg, 63%) as colorless crystals, mp 119 °C (CH_2Cl_2–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3540, 3420, 1685. ^{1}H-NMR ($CDCl_3$) δ: 2.47 (2H, t, J = 7 Hz, O=CCH_2–), 3.14 (2H, t, J = 7 Hz, –CH_2SPh), 7.1—7.4 (5H, m, SPh). *Anal.* Calcd for $C_9H_{11}NOS$: C, 59.63; H, 6.13; N, 7.73; S, 17.69. Found: C, 59.26; H, 6.03; N, 7.60; S, 17.45.

***N*-Benzyl-3-(phenylthio)propionamide (5)** (Trimethylsilyl)ethoxyacetylene (65.3 mg, 0.460 mmol) was added to a stirred solution of **3** (56 mg,

0.308 mmol), benzylamine (34.9 mg, 0.326 mmol) and HgO (3 mg, 0.0138 mmol) in $(CH_2Cl)_2$ (2 ml) at room temperature. The mixture was stirred at 60 °C for 8 h and concentrated *in vacuo*. The residue was subjected to column chromatography on silica gel with CH_2Cl_2–Et_2O (20 : 1) to gave **5** (80 mg, 96%) as colorless crystals, mp 127 °C (CH_2Cl_2–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3440, 1665. ^{1}H-NMR ($CDCl_3$) δ: 2.51 (2H, t, J=7 Hz, O=CCH$_2$–), 3.26 (2H, t, J=7 Hz, –CH$_2$SPh), 4.41 (2H, d, J=6 Hz, –CH$_2$Ph), 5.8—6.0 (1H, br, NH), 7.27 (10H, m, ArH). MS m/z: 271 (M^+). *Anal.* Calcd for $C_{16}H_{17}NOS$: C, 70.80; H, 6.33; N, 5.16; S, 11.81. Found: C, 70.99; H, 6.37; N, 5.04; S, 11.60.

***N*-(1,1-Diphenylmethyl)-3-(phenylthio)propionamide (6)** In a similar fashion, **3** (100.7 mg, 0.553 mmol) was treated with diphenylmethylamine (126.5 mg, 0.691 mmol), (trimethylsilyl)ethoxyacetylene (160.0 mg, 1.13 mmol) and HgO (6.7 mg, 0.0309 mmol) in $(CH_2Cl)_2$ (5 ml) at 60 °C for 6 d to give **6** (194.1 mg, quant.) as colorless crystals, mp 131—133 °C (CH_2Cl_2–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3445, 1665. ^{1}H-NMR ($CDCl_3$) δ: 2.50 (2H, t, J=7 Hz, O=CCH$_2$–), 3.20 (2H, t, J=7 Hz, –CH$_2$SPh), 6.20 (1H, br, NH), 6.22 (1H, s, –CHPh$_2$), 7.22 (15H, m, ArH). MS m/z: 347 (M^+), 238 (M^+ − SPh). Exact MS Calcd for $C_{22}H_{21}NOS$: 347.1344. Found: 347.1346.

2-Methyl-3-(phenylthio)propionamide (7) Thiophenol (1.29 g, 11.7 mmol) and triethylamine (47.4 mg, 0.468 mmol) were added to a solution of 2-methylacrylamide (1.0 g, 11.7 mmol) in MeOH (10 ml) at 0 °C. The mixture was stirred at room temperature for 1 d and evaporated *in vacuo*. The residue was diluted with CH_2Cl_2 (50 ml), washed with 5% sodium hydroxide, water, and brine. The organic layer was dried over $MgSO_4$ and evaporated *in vacuo* to give crude **7**, which was subjected to column chromatography on silica gel with $CHCl_3$–MeOH (20 : 1) to give pure **7** (1.49 g, 65%) as colorless crystals, mp 73 °C (CH_2Cl_2–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3540, 3500, 1680. ^{1}H-NMR ($CDCl_3$) δ: 1.28 (3H, d, J=7 Hz, –CH$_3$), 2.40—2.71 (1H, m, CH$_3$CH<), 2.96 (1H, dd, J=6, 13 Hz, –CHHSPh), 3.28 (1H, dd, J=7.5, 13 Hz, –CHHSPh), 5.7—6.4 (2H, br, NH$_2$), 7.18—7.40 (5H, m, SPh). MS m/z: 195 (M^+). *Anal.* Calcd for $C_{10}H_{13}NOS$: C, 61.50; H, 6.72; N, 7.17; S, 16.42. Found: C, 61.42; H, 6.70; N, 7.05; S, 16.23.

***N*-Benzyl-2-methyl-3-(phenylthio)propionamide (8)** Compound **7** (199 mg, 1.02 mmol) was added to a suspension of NaH (60%, 47 mg, 1.18 mmol) in dry THF (3 ml) at −25 °C under nitrogen. After stirring of this mixture for 20 min, benzyl bromide (0.13 ml, 1.09 mmol) was added. The reaction mixture was stirred for 30 min under the same conditions and at room temperature for 2 h, and saturated with aqueous NH_4Cl. The aqueous layer was extracted with CH_2Cl_2 (20 ml × 5). The combined organic layer was dried over $MgSO_4$ and evaporated *in vacuo*. The residue was subjected to column chromatography on silica gel with hexane–AcOEt (3 : 1) to give **8** (122 mg, 42%) as colorless crystals, mp 55—56 °C (CH_2Cl_2–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3450, 1665. ^{1}H-NMR ($CDCl_3$) δ: 1.28 (3H, d, J=7 Hz, –CH$_3$), 2.34—2.58 (1H, m, CH$_3$CH<), 3.00 (1H, dd, J=6, 13 Hz, –CHHSPh), 3.31 (1H, dd, J=8, 13 Hz, –CHHSPh), 4.44 (2H, d, J=6 Hz, –CH$_2$Ph), 6.02 (1H, br, NH), 7.37 (10H, m, SPh). MS m/z: 285 (M^+). Exact MS Calcd for $C_{17}H_{19}NOS$: 285.1185. Found: 285.1185.

Methyl 2-(Phenylthiomethyl)butanoate (11) The ketene silyl acetal (**9**) (2.23 g, 10.3 mmol) was added to a stirred solution of chlorothioanisole (**10**, 1.36 g, 8.56 mmol) and $TiCl_4$ (1.73 g, 9.12 mmol) in CH_2Cl_2 (18 ml) at −78 °C under nitrogen. The mixture was stirred under the same conditions for 4.5 h, then partitioned between CH_2Cl_2 (50 ml) and water. The aqueous layer was extracted with CH_2Cl_2 (50 ml × 4). The combined organic layer was washed with saturated aqueous $NaHCO_3$ and brine, dried over $MgSO_4$, and evaporated *in vacuo*. The residue was subjected to column chromatography on silica gel with hexane–ether (20 : 1) to give **11** (1.16 g, 60% from **10**) as a colorless oil, bp 90—95 °C (0.25 mmHg) (bath temperature). IR ν_{max} ($CHCl_3$) cm^{-1}: 1730. ^{1}H-NMR ($CDCl_3$) δ: 0.89 (3H, t, J=7 Hz, CH$_3$), 1.66 (2H, q, J=7 Hz, –CH$_2$CH$_3$), 2.56 (1H, m, –CHCH$_2$SPh), 2.99 (1H, dd, J=6, 13 Hz, –CHHSPh), 3.18 (1H, dd, J=8, 13 Hz, –CHHSPh), 3.67 (3H, s, –OCH$_3$), 7.12 (5H, m, SPh). MS m/z: 224 (M^+).

2-(Phenylthiomethyl)butanoic acid (12) A solution of sodium hydroxide (213 mg, 8.875 mmol) in water (2 ml) was added to a stirred solution of **11** (42.9 mg, 0.191 mmol) in methanol (2 ml). The mixture was refluxed for 1.5 h, poured into water (20 ml), acidified with 10% hydrochloric acid, and extracted with CH_2Cl_2 (20 ml × 4). The combined organic layer was washed with water, dried over $MgSO_4$, and evaporated *in vacuo*. The residue was subjected to column chromatography on silica gel with CH_2Cl_2–MeOH (10 : 1) to give **12** (25.8 mg, 64%) as a colorless oil, bp 80—85 °C (0.15 mmHg, bath temperature). IR ν_{max} ($CHCl_3$) cm^{-1}: 3600—2400, 1710. ^{1}H-NMR ($CDCl_3$) δ: 0.95 (3H, t, J=7 Hz, –CH$_3$), 1.75 (2H, quint, J=7 Hz, –CH$_2$CH$_3$), 2.56 (1H, m, –CHCH$_2$SPh), 2.98 (1H, dd, J=6, 14 Hz, CHHSPh), 3.18 (1H, dd, J=8, 14 Hz, –CHHSPh), 7.20—7.38 (5H, m, SPh), 9.67 (1H, br, COOH). MS m/z: 210 (M^+).

2-(Phenylthiomethyl)butanamide (13) A 1.0 M solution of trimethylaluminum in hexane (4.5 ml, 4.5 mmol) was added to a stirred suspension of ammonium chloride (238.5 mg, 4.46 mmol) in dry benzene (2 ml) at 0 °C under nitrogen. The mixture was stirred at 0 °C for 20 min and at room temperature for 45 min. Compound **11** (200.0 mg, 0.893 mmol) was added to the mixture, which was refluxed for 3 h and cooled to 0 °C. Then 5% hydrochloric acid was added to decompose excess trimethylaluminum, and the mixture was extracted with CH_2Cl_2 (20 ml × 5). The combined organic layer was washed with saturated aqueous $NaHCO_3$ and brine, dried over $MgSO_4$, and evaporated *in vacuo*. The residue was subjected to column chromatography on silica gel with CH_2Cl_2–MeOH (25 : 1) to give **13** (91.4 mg, 49%) as colorless crystals, mp 79—80 °C (CH_2Cl_2–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3540, 3420, 1680. ^{1}H-NMR ($CDCl_3$) δ: 0.93 (3H, t, J=7 Hz, –CH$_3$), 1.63 (2H, q, J=7 Hz, –CH$_2$CH$_3$), 2.27 (1H, m, –CHCH$_2$SPh). 2.97 (1H, dd, J=5.5, 12 Hz, –CHHSPh), 3.18 (1H, dd, J=8, 12 Hz, –CHHSPh), 5.45—6.10 (2H, br, NH$_2$), 7.11—7.33 (5H, m, SPh). MS m/z: 209 (M^+). Exact MS Calcd for $C_{11}H_{15}NOS$: 209.0874. Found: 209.0875.

***N*-Benzyl-2-(phenylthiomethyl)butanamide (14)** A 1.0 M solution of trimethylalumium in hexane (7.4 ml, 7.4 mmol) was added to a stirred solution of benzylamine (789.0 mg, 7.37 mmol) in dry benzene (2 ml) at −10 °C under nitrogren. The mixture was stirred at −10 °C for 20 min and at room temperature for 45 min. Compound **11** (509.0 mg, 2.27 mmol) was added, and the whole was refluxed for 2 h and cooled to 0 °C. Then 5% hydrochloric acid was added to decompose excess trimethylaluminum, and the solution was extracted with CH_2Cl_2 (30 ml × 4). The combined organic layer was washed with saturated aqueous $NaHCO_3$ and brine, dried over $MgSO_4$, and evaporated *in vacuo*. The residue was subjected to column chromatography on silica gel with AcOEt–hexane (4 : 1) to give **14** (556.0 mg, 82%) as colorless crystals, mp 87—88 °C (AcOEt–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3440, 1665. ^{1}H-NMR ($CDCl_3$) δ: 0.91 (3H, t, J=7 Hz, –CH$_3$), 1.61—1.83 2H, m, –CH$_2$CH$_3$), 2.14—2.33 (1H, m, –CHCH$_2$SPh), 3.07 (1H, dd, J=5.5, 13.5 Hz, –CHHSPh), 3.29 (1H, dd, J=8.5, 13.5 Hz, –CHHSPh), 4.49 (2H, d, J=6 Hz, –CH$_2$Ph), 5.87 (1H, br, NH), 7.26—7.38 (10H, m, ArH). MS m/z: 299 (M^+). *Anal.* Calcd for $C_{18}H_{21}NOS$: C, 72.20; H, 7.07; N, 4.08; S, 10.70. Found: C, 72.20; H, 7.03; N, 4.57; S, 10.68.

***N*-(1,1-Diphenylmethyl)-2-(phenylthiomethyl)butanamide (15)** (Trimethylsilyl)ethoxyacetylene (108.3 mg, 0.763 mmol) was added to a stirred solution of **12** (77.9 mg, 0.371 mmol), diphenylmethylamine (81.5 mg, 0.445 mmol) and HgO (6.4 mg, 0.0295 mmol) in $(CH_2Cl)_2$ (4 ml) at room temperature. The mixture was stirred at 60 °C for 7 d and concentrated *in vacuo*. The residue was subjected to column chromatography on silica gel with hexane–AcOEt (6 : 1) to give **15** (118.3 mg, 85%) as colorless crystals, mp 87—89 °C ($CHCl_3$–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3450, 1670. ^{1}H-NMR ($CDCl_3$) δ: 0.87 (3H, t, J=7 Hz, −CH$_3$), 1.66 (2H, q, J=7 Hz, –CH$_2$CH$_3$), 2.23 (1H, m, –CHCH$_2$SPh), 3.03 (1H, dd, J=5.5, 13 Hz, –CHHSPh), 3.15 (1H, dd, J=8.5, 13 Hz, –CHHSPh), 6.09 (1H, br d, J=8 Hz, NH), 6.27 (1H, d, J=8 Hz, –CHPh$_2$), 7.19—7.24 (15H, m, ArH). MS m/z: 375 (M^+). *Anal.* Calcd for $C_{24}H_{25}NOS$: C, 76.76; H, 6.71; N, 3.73; S, 8.54. Found: C, 76.51; H, 6.71; N, 3.75; S, 8.16.

General Procedure for the Preparation of β-Amido Sulfoxides (1a—h) $NaIO_4$ (1.5 mmol) was added to a stirred solution of a sulfide (**4**—**8** or **13**—**15**, 1 mmol) in MeOH (10 ml). The mixture was stirred at room temperature overnight and evaporated *in vacuo*. The residure was partitioned between CH_2Cl_2 (20 ml) and water (20 ml), and then the aqueous layer was extracted with CH_2Cl_2 (20 ml × 4). The combined organic layer was washed with brine, dried over $MgSO_4$, and concentrated *in vacuo*. The residue was subjected to column chromatography or preparative TLC on silica gel with CH_2Cl_2–MeOH, AcOEt to give the corresponding sulfoxide.

3-(Phenylsulfinyl)propionamide (1a) This (61.7 mg, 93%) was prepared from **4** (60.4 mg, 0.336 mmol) and $NaIO_4$ (117.5 mg, 0.549 mmol) in MeOH (3 ml) as colorless crystals, mp 135 °C (MeOH–Et_2O–hexane), (lit.[6] 129—130.5 °C). The IR and ^{1}H-NMR spectral data of **1a** were identical with those of lit.[6]

***N*-Benzyl-3-(phenylsulfinyl)propionamide (1b)** This (68.3 mg, quant.) was prepared from **5** (65 mg, 0.217 mmol) and $NaIO_4$ (70 mg, 0.327 mmol) in MeOH (3 ml) as colorless crystals, mp 94 °C (CH_2Cl_2–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3445, 1665, 1035. ^{1}H-NMR ($CDCl_3$) δ: 2.24—3.39 (4H, m, –CH$_2$CH$_2$S(O)Ph), 4.42 (2H, d, J=6 Hz, –CH$_2$Ph), 7.32 (5H, s,

$-CH_2Ph$), 7.58 (5H, s, –S(O)Ph). MS *m/z*: 287 (M^+). *Anal.* Calcd for $C_{16}H_{17}NO_2S$: C, 66.86; H, 5.97; N, 4.87; S, 11.6. Found: C, 66.56; H, 5.98; N, 4.73; S, 11.01.

***N*-(1,1-Diphenylmethyl)-3-(phenylsulfinyl)propionamide (1c)** This (48.2 mg, 86%) was prepared from **6** (53.6 mg, 0.154 mmol) and $NaIO_4$ (49.6 mg, 0.231 mmol) in MeOH (3 ml) as colorless crystals, mp 157—158 °C ($CHCl_3$–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3440, 1665, 1035. ^{1}H-NMR ($CDCl_3$) δ: 2.44—3.34 (4H, m, $-CH_2CH_2S(O)Ph$), 6.17 (1H, d, J=8 Hz, $CHPh_2$), 7.18 (10H, s, $CHPh_2$), 7.43 (5H, s, S(O)Ph). MS *m/z*: 363 (M^+). Exact MS Calcd for $C_{22}H_{21}NO_2S$: 363.1293. Found: 363.1313.

2-Methyl-3-(phenylsulfinyl)propionamide (1d) This (107.3 mg, 96%) was prepared from **7** (104 mg, 0.53 mmol) and $NaIO_4$ (145 mg, 0.68 mmol) in MeOH (5 ml) as colorless crystals, mp 99—105 °C (CH_2Cl_2–hexane) (lit.[6] 108—110 °C). IR ν_{max} (KBr) cm^{-1}: 3350, 3200, 1675, 1020. ^{1}H-NMR ($CDCl_3$) δ: 1.23, 1.44 (total 3H, each d, J=7 Hz, CH_3–), 2.5—3.9 (total 3H, m, $>CHCH_2SPh$), 6.04, 6.17, 6.78, 7.03 (total 2H, each brs, NH_2), 7.5 (5H, m, S(O)Ph). (The signals indicated this product to be a 1:1 mixture of geometrical isomers). MS *m/z*: 211 (M^+).

***N*-Benzyl-2-methyl-3-(phenylsulfinyl)propionamide (1e)** This (103 mg, 86%) was prepared from **8** (113 mg, 0.40 mmol) and $NaIO_4$ (110 mg, 0.514 mmol) in MeOH (2 ml) as colorless crystals, mp 112—122 °C (CH_2Cl_2–hexane). IR ν_{max}($CHCl_3$) cm^{-1}: 3450, 1665, 1040. ^{1}H-NMR ($CDCl_3$) δ: 1.23—1.42 (total 3H, each d, J=7 Hz, CH_3–), 2.78—3.40 (total 3H, m, $>CHCH_2SPh$), 4.28, 4.30 (1/2×2H, each d, J=5.5 Hz, $-CH_2Ph$), 4.49 (1/2×2H, d, J=5.5 Hz, $-CH_2Ph$), 6.70—6.95 (1H, br, NH), 7.20, 7.27 (total 5H, each s, CH_2Ph), 7.49 (5H, s, S(O)Ph). The signals indicated this product to be a 1:1 mixture of geometrical isomers). MS *m/z*: 301 (M^+). *Anal.* Calcd for $C_{17}H_{19}NO_2S$: C, 67.73 H, 6.37; N, 4.65; S, 10.64. Found: C, 67.65; H, 6.41; N, 4.52; S, 10.47.

2-(Phenylsulfinylmethyl)butanamide (1f) This (51.7 mg, quant.) was prepared from **13** (45.3 mg, 0.217 mmol) and $NaIO_4$ (69.6 mg, 0.325 mmol) in MeOH (3 ml) as colorless crystals, mp 120—128 °C (CH_2Cl_2–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3530, 3410, 1680, 1030. ^{1}H-NMR ($CDCl_3$) δ: 0.88, 1.00 (total 3H, each t, J=7.5 Hz, $-CH_2CH_3$), 1.6—2.0 (2H, m, $-CH_2CH_3$), 2.6—3.2 (total 3H, m, $>CHCH_2S(O)Ph$), 5.5—6.0 (2H, br, NH_2), 7.3—7.6 (5H, m, S(O)Ph). The signals indicated this product to be a mixture of geometrical isomers). MS *m/z*: 225 (M^+). Exact MS Calcd for $C_{11}H_{15}NO_2S$: 225.0824. Found: 225.0825.

***N*-Benzyl-2-(phenylsulfinylmethyl)butanamide (1g)** This (12 mg, 95%) was prepared from **14** (12 mg, 0.04 mmol) and $NaIO_4$ (20 mg, 0.093 mmol) in MeOH (1 ml) as colorless crystals, mp 125—130 °C (CH_2Cl_2–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3440, 1665, 1030. ^{1}H-NMR ($CDCl_3$) δ: 0.92, 1.00 (total 3H, each d, J=7 Hz, $-CH_2CH_3$), 1.7—2.1 (2H, m, $-CH_2CH_3$), 2.6—2.9 (1H, br, $EtCH<$), 2.9—3.3 (2H, m, $-CH_2SPh$), 4.32, 4.41, 4.59 4.61 (total 2H, each d, J=6 Hz, $-CH_2Ph$), 6.70 (1H, br, NH), 7.36—7.41 (5H, m, CH_2Ph), 7.60—7.64 (5H, s, S(O)Ph). (The signals indicated this product to be a mixture of geometrical isomers). MS *m/z*: 315 (M^+). Exact MS Calcd for $C_{18}H_{21}NO_2S$: 315.1290. Found: 315.1265.

***N*-(1,1-Diphenylmethyl)-2-(phenylsulfinylmethyl)butanamide (1h)** This (57.7 mg, 65%) was prepared from **15** (85.4 mg, 0.228 mmol) and $NaIO_4$ (73.1 mg, 0.342 mmol) in MeOH (3 ml) as colorless crystals, mp 175—176 °C ($CHCl_3$–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 3445, 1665, 1030. ^{1}H-NMR ($CDCl_3$) δ: 0.87, 0.97 (total 3H, t, J=7 Hz, $-CH_2CH_3$), 1.47—2.01 (2H, m, $-CH_2CH_3$), 2.54—3.33 (total 3H, m, $EtCH<$, $-CH_2S(O)Ph$), 6.14, 6.32 (total 1H, each d, J=8 Hz, $-CHPh_2$), 7.18, 7.24 (total 10H, each s, $CHCPh_2$), 7.38—7.42 (5H, m, S(O)Ph). (The signals indicated this product to be a mixture of geometrical isomers). MS *m/z*: 391 (M^+), 390 (M^+-1), 376 (M^+-Me).

General Procedure for the Reaction of β-Amido Sulfoxides (1a—h) with the Ketene Silyl Acetal (16) The ketene silyl acetal (**16**, 3—5 mmol) was added to a stirred solution of β-amido sulfoxide (**1**, 1 mmol) and ZnI_2 (0.05—0.1 mmol) in dry CH_3CN (10 ml) at room temperature under nitrogen. The mixture was stirred at the temperature and for the period indicated in Table I, then partitioned between CH_2Cl_2 (20 ml) and saturated aqueous $NaHCO_3$ (20 ml). The aqueous layer was extracted with CH_2Cl_2 (20 ml×4). The combined extract was washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was subjected to column chromatography or preparative TLC on silica gel with hexane–AcOEt to give the cyclized product.

***N*-(*tert*-Butyldimethylsilyl)-4-(phenylthio)azetidin-2-one (17a)** This (134.8 mg, 0.406 mmol) was obtained from **1a** (102.5 mg, 0.520 mmol), **16** (293.5 mg, 1.56 mmol), and ZnI_2 (8.3 mg, 0.026 mmol) in CH_3CN (5 ml) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1740. ^{1}H-NMR ($CDCl_3$) δ: 0.31, 0.32 (total 6H, each s, Me_2Si), 1.00 (9H, s, *tert*-BuSi), 3.03 (1H, dd, J=2, 15 Hz, $-CHHCO$), 3.51 (1H, dd, J=5, 15 Hz, $-CHHCO$), 4.90 (1H, dd, J=2, 5 Hz, $>CHSPh$), 7.24—7.42 (5H, m, SPh). Exact MS Calcd for $C_{15}N_{23}NOSSi$: 293.1268. Found: 293.1243.

***N*-Benzyl-4-(phenylthio)azetidin-2-one (17b)** This (61.4 mg, 73%) was obtained from **1b** (90.0 mg, 0.314 mmol), **16** (300 mg, 0.60 mmol), and ZnI_2 (13 mg, 0.041 mmol) in CH_3CN (2 ml) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1750. ^{1}H-NMR ($CDCl_3$) δ: 2.89 (1H, dd, J=2, 15 Hz, $-CHHCO$), 3.32 (1H, dd, J=5, 15 Hz, $-CHHCO$), 4.13 4.79 (total 2H, each d, J=15 Hz, CH_2Ph), 4.83 (1H, dd, J=2, 5 Hz, $>CHSPh$), 7.16—7.42 (10H, m, ArH). Exact MS Calcd for $C_{16}H_{15}NOS$: 269.0875. Found: 269.0882.

***N*-(1,1-Diphenymethyl)-4-(phenylthio)azetidin-2-one (17c)** This (26.0 mg, 93%) was obtained from **1c** (29.4 mg, 0.08 mmol), **16** (48 mg, 0.255 mmol), and ZnI_2 (13 mg, 0.041 mmol) in CH_3CN (2 ml) as colorless crystals, mp 90 °C ($CHCl_3$–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 1775. ^{1}H-NMR ($CDCl_3$) δ: 2.94 (1H, dd, J=2.5, 15 Hz, $-CHHCO$), 3.28 (1H, dd, J=4.5, 15Hz, $-CHHCO$), 4.79 (1H, dd, J=2.5 H, 5 Hz, $>CHSPh$), 5.71 (1H, s, $CHPh_2$), 7.20, 7.22, 7.27 (15H, each s, ArH). Exact MS Calcd for $C_{22}H_{19}NOS$: 345.1187. Found: 345.1190.

***N*-(*tert*-Butyldimethylsilyl)-3-methyl-4-(phenylsulfinyl)azetidin-2-one-(17d)** This (66.7 mg, 77%, *cis*:*trans*=72:28) was obtained from **1d** (59.4 mg, 0.282 mmol), **16** (309.3 mg, 1.65 mmol), and ZnI_2 (9 mg, 0.028 mmol) in CH_3CN as a colorless oil; ^{1}H-NMR and HPLC showed *cis*:*trans*=72:28. The pure isomers (*cis*-**17d** and *trans*-**17d**) were isolated by column chromatography for characterization. *cis*-**17d**: a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1735. ^{1}H-NMR ($CDCl_3$) δ: 0.27 (6H, s, Me_2Si), 0.98 (9H, s, *tert*-Bu), 1.36 (3H, d, J=8 Hz, $CH_3C<$), 3.69 (1H, qd, J=8, 5 Hz, $>CHCO$), 5.04 (1H, d, J=5 Hz, $>CHSPh$), 7.24 (5H, m, –SPh). MS *m/z*: 307 (M^+). *trans*-**17d**: a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1735. ^{1}H-NMR ($CDCl_3$) δ: 0.29 (6H, s, Me_2Si), 0.98 (9H, s, *tert*-Bu), 1.27 (3H, d, J=8 Hz, $CH_3C<$), 3.19 (1H, qd, J=8, 2 Hz, $>CHCO$), 4.49 (1H, d, J=2 Hz, $>CHSPh$), 7.18—7.40 (5H, m, –SPh). MS *m/z*: 307 (M^+).

***N*-Benzyl-3-methyl-4-(phenylthio)azetidin-2-one (17e)** This (22.2 mg, 77%, *cis*:*trans*=71:29) was obtained from **1e** (31.0 mg, 0.103 mmol), **16** (24 mg, 0.128 mmol),, and ZnI_2 (6 mg, 0.0188 mmol) in CH_3CN (1 ml) as a colorless oil; ^{1}H-NMR and HPLC showed *cis*:*trans*=71:29. The pure isomers (*cis*-**17e** and *trans*-**17e**) were isolated by column chromatography for characterization. *cis*-**17e**: a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1745. ^{1}H-NMR ($CDCl_3$) δ: 1.44 (3H, d, J=8 Hz, $-CH_3C<$), 3.64 (1H qd, J=8, 5 Hz, $>CHCO$), 4.09, 4.78 (total 2H, each d, J=15 Hz, CH_2Ph), 5.03 (1H, d, J=5 Hz, $>CHSPh$), 7.09—7.40 (10H, m, ArH). Exact MS Calcd for $C_{17}H_{17}NOS$; 283.1029. Found: 283.1009. *trans*-**17e**: a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1745. ^{1}H-NMR ($CDCl_3$) δ: 1.33 (3H, d, J=8 Hz, $CH_3C<$), 3.02—3.28 (1H, m, $>CHCO$), 4.44 (1H, d, J=2 Hz, $>CHSPh$), 4.11, 4.88 (total 2H, each d, J=15 Hz, CH_2Ph), 7.19—7.42 (10H, m, ArH). Exact MS Calcd for $C_{17}H_{17}NOS$: 283.1030. Found: 283.1005.

***N*-(*tert*-Butyldimethylsilyl)-3-ethyl-4-(phenylthio)azetidin-2-one (17f, *cis*:*trans*=63:37)** This (159.3 mg, 75%, *cis*:*trans*=63:37) was obtained from **1f** (150.0 mg, 0.667 mmol), **16** (377.4 mg, 2.01 mmol), and ZnI_2 (10.0 mg, 0.0313 mmol) in CH_3CN (4 ml) as a colorless oil; ^{1}H-NMR and HPLC showed *cis*:*trans*=63:37. The pure isomers (*cis*-**17f** and *trans*-**17f**) were isolated by column chromatography for characterization.

(3*S**,4*S**)-*N*-(*tert*-Butyldimethylsilyl)-3-ethyl-4-(phenylthio)azetidin-2-one (*cis*-**17f**): a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1735, 1580. ^{1}H-NMR ($CDCl_3$) δ: 0.23, 0.26 (total 6H, each s, Me_2Si), 0.98 (9H, s, *tert*-BuSi), 1.07 (3H, t, J=7 Hz, $-CH_2CH_3$), 1.70—2.00 (2H, m, $-CH_2CH_3$), 3.47 (1H, td, J=7.5, 5 Hz, $>CHCO$), 5.03 (1H, d, J=5 Hz, $>CHSPh$), 7.13—7.31 (5H, m, SPh). Exact MS Calcd for $C_{17}H_{27}NOSSi$: 321.1583. Found: 321.1589.

(3*S**,4*R**)-*N*-(*tert*-Butyldimethylsilyl)-3-ethyl-4-(phenylthio)azetidin-2-one (*trans*-**17f**): a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1735, 1580. ^{1}H-NMR ($CDCl_3$) δ: 0.18 (6H, s, Me_2Si), 0.87 (3H, t, J=7 Hz, $-CH_2CH_3$), 0.99 (9H, s, *tert*-BuSi), 1.60—1.87 (2H, m, $-CH_2CH_3$), 3.13 (1H, td, J=7.5, 2 Hz, $>CHCO$), 4.56 (1H, d, J=2 Hz, $>CHSPh$), 7.20—7.37 (5H, m, SPh). Exact MS Calcd for $C_{17}H_{27}NOSSi$: 321.1579. Found: 321.1571.

***N*-Benzyl-3-ethyl-4-(phenylthio)azetidin-2-one (17g)** This (74.7 mg, 63%, *cis*:*trans*=59:41) was obtained from **1g** (125.8 mg, 0.399 mmol), **16** (384 mg, 2.04 mmol), and ZnI_2 (17.0 mg, 0.0533 mmol) in CH_3CN (2 ml) as a pale yellow oil; ^{1}H-NMR and HPLC showed *cis*:*trans*=59:41. The pure isomers (*cis*-**17g** and *trans*-**17g**) were isolated by column chromatography for characterization *cis*-**17g**: a pale yellow oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1745. ^{1}H-NMR ($CDCl_3$) δ: 1.11 (3H, t, J=7 Hz, $-CH_2CH_3$), 1.81 (2H, m, $-CH_2CH_3$), 3.34 (1H, dt, J=5, 7 Hz, $>CHCO$), 3.99, 4.68 (total 2H, each d, J=15 Hz, $-CH_2Ph$), 4.90 (1H, d, J=5 Hz, $>CHSPh$), 6.9—7.4 (10H, m, ArH). Exact MS Calcd for $C_{18}H_{19}NOS$: 297.1185. Found: 297.1179. *trans*-**17g**: colorless crystals, mp 45—46 °C

(CH_2Cl_2–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 1745. ^{1}H-NMR ($CDCl_3$) δ: 0.95 (3H, t, J=7 Hz, –CH_2CH_3), 1.6—2.0 (2H, m, –CH_2CH_3), 3.0 (1H, dt, J=2, 7Hz, >CHCO), 4.02, 4.73 (total 2H, each d, J=15 Hz, –CH_2Ph), 4.45 (1H, d, J=2 Hz, >CHSPh), 6.9—7.4 (10H, m, ArH). Exact MS Calcd for $C_{18}H_{19}NOS$: 297.1185. Found: 297.1177.

***N*-(1,1-Diphenymethyl)-3-ethyl-4-(phenylthio)azetidin-2-one (17h)** This (38.3 mg, 78%, *cis*:*trans*=44:56) was obtained from **1h** (51.4 mg, 0.131 mmol), **16** (124.3 mg, 0.661 mmol), and ZnI_2 (3.8 mg, 0.012 mmol) in CH_3CN (3 ml) as a pale yellow oil; ^{1}H-NMR and HPLC showed *cis*:*trans*=44:56. The pure isomers (*cis*-**17h** and *trans*-**17h**) were isolated by column chromatography for characterization. *cis*-**17h**: a yellow oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1745 ^{1}H-NMR ($CDCl_3$) δ: 1.10 (3H, t, J=7 Hz, –CH_2CH_3), 1.9 (2H, m, –CH_2CH_3), 3.32 (1H, td, J=7, 4.5, >CHCO), 4.92 (1H, d, J=4.5 Hz, >CHSPh), 5.76 (1H, s, $CHPh_2$), 7.0—7.4 (15H, m, ArH). Exact MS Calcd for $C_{24}H_{23}NOS-SPh$: 264.1388. Found: 264.1393. *trans*-**17h**: colorless crystals, mp 83—84 °C (CH_2Cl_2–hexane). IR ν_{max} ($CHCl_3$) cm^{-1}: 1745. ^{1}H-NMR ($CDCl_3$) δ: 0.90 (3H, t, J=7 Hz, –CH_2CH_3), 1.5—1.9 (2H, m, –CH_2CH_3), 3.09 (1H, td, J=7, 2 Hz, >CHCO), 4.48 (1H, d, J=2 Hz, >CHSPh), 5.71 (1H, s, $CHPh_2$), 7.0—7.4 (15 H, m, ArH). Exact MS Calcd for $C_{24}H_{23}NOS-SPh$: 264.1389. Found: 264.1389.

General Procedure for the Preparation of 4-Phenylsulfinylazetidin-2-one (18a—c, f—h) *m*-CPBA (80%, 1 mmol) was added to a stirred solution of 4-phenylthioazetidin-2-one (**18a**—**c** or **18f**—**h**, 1 mmol) in CH_2Cl_2 (3 ml) at 0 °C for 30 min. The reaction mixture was diluted with CH_2Cl_2 (50 ml) and washed with saturated aqueous $NaHCO_3$ (30 ml). The aqueous layer was extracted with CH_2Cl_2 (20 ml × 4). The combined organic extract was washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was subjected to column chromatography or preparative TLC on silica gel with hexane–AcOEt to give the corresponding sulfoxide.

***N*-(*tert*-Butyldimethylsilyl)-4-(phenylsulfinyl)azetidin-2-one (18a)** This (24.7 mg, quant.) was obtained from **17a** (23.3 mg, 0.0795 mmol), *m*-CPBA (80%, 17.1 mg, 0.0795 mmol) in CH_2Cl_2 (3 ml) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1760, 1045. ^{1}H-NMR ($CDCl_3$) δ: 0.38, 0.40, 0.42, 0.43 (total 6H, each s, Me_2Si), 1.06 (9H, s, *tert*-BuSi), 2.70 (1/2 × 1H, dd, J=5, 15.5 Hz, –CHHCO), 2.79 (1/2 × 1H, dd, J=3, 16.5 Hz, –CHHCO), 3.10 (1/2 × 1H, dd, J=5.5, 16.5 Hz, >CHHCO), 3.60 (1/2 × 1H, dd, J=2, 15.5 Hz, –CHHCO), 4.29 (1/2 × 1H, dd, J=2, 5 Hz, >CHSPh), 4.43 (1/2 × 1H, dd, J=2, 5.5 Hz, >CHSPh), 7.49—7.67 (5H, m, SPh). Exact MS Calcd for $C_{15}H_{23}NO_2SSi-tert$-Bu: 252.0512. Found: 252.0511.

***N*-Benzyl-4-(phenylsulfinyl)azetidin-2-one (18b)** This (45.9 mg, 93%) was obtained from **17b** (46.9 mg, 0.174 mmol), *m*-CPBA (80%, 37.6 mg, 0.174 mmol) in CH_2Cl_2 (3 ml) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1765, 1445, 1375, 1085, 1040. ^{1}H-NMR ($CDCl_3$) δ: 2.65 (1H, dd, J=5, 15 Hz, –CHHCO), 3.42 (1H, dd, J=2, 15 Hz, –CHHCO), 4.17 (1H, dd, J=2, 5 Hz, >CHSPh), 4.29, 4.76 (total 2H, each d, J=15 Hz, CH_2Ph), 7.22—7.56 (10H, m, ArH). Exact MS Calcd for $C_{16}H_{15}NO_2S-S(O)$Ph: 160.0760. Found: 160.0757.

***N*-(1,1-Diphenymethyl)-4-(phenylsulfinyl)azetidin-2-one (18c)** This (16.2 mg, 67%) was obtained from **17c** (23.1 mg, 0.067 mmol), *m*-CPBA (80%, 15.1 mg, 0.0704 mmol) in CH_2Cl_2 (1 ml) as colorless crystals. IR ν_{max} ($CHCl_3$) cm^{-1}: 1760, 1050. ^{1}H-NMR ($CDCl_3$) δ: 2.63 (68/100 × 1H, dd, J=5, 15 Hz, –CHHCO), 2.99 (32/100 × 2H, d, J=4 Hz, –CH_2CO), 3.63 (68/100 × 1H, dd, J=2, 15 Hz, –CHHCO), 4.13 (1H, dd, J=2.5, 5 Hz, >CHSPh), 4.53 (32/100 × 1H, t, J=5 Hz, >CHSPh), 5.68 (32/100 × 1H, s, $CHPh_2$), 6.18 (68/100 × 1H, s, $CHPh_2$), 7.40 (15H, each s, ArH). Exact MS Calcd for $C_{22}H_{19}NO_2S-S(O)$Ph: 236.1017. Found: 236.1073.

***N*-(*tert*-Butyldimethylsilyl)-3-ethyl-4-(phenylsulfinyl)azetidin-2-one (18f, *cis*:*trans*=63:37)** This (21.3 mg, 85%, *cis*:*trans*=63:37) was obtained from **17f** (*cis*:*trans*=63:37, 24 mg, 0.0748 mmol), *m*-CPBA (80%, 16.1 mg, 0.0748 mmol) in CH_2Cl_2 (2 ml) as a colorless oil.

(3*S,4*S**)-*N*-(*tert*-Butyldimethylsilyl)-3-ethyl-4-(phenylsulfinyl)azetidin-2-one (*cis*-18f)** This (*cis*, 11.7 mg, 81%) was obtained from *cis*-**17f** (13.7 mg, 0.0427 mmol), *m*-CPBA (80%, 9.6 mg, 0.0448 mmol) in CH_2Cl_2 (1.5 ml) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1750, 1030. ^{1}H-NMR ($CDCl_3$) δ: 0.22, 0.29 (total 1/3 × 6H each, s, Me_2Si), 0.26, 0.31 (total 2/3 × 6H each, s, Me_2Si), 0.82 (3H, t, J=7 Hz, –CH_2CH_3), 1.02 (1/3 × 9H, s, *tert*-BuSi), 1.04 (2/3 × 9H, s, *tert*-BuSi), 1.27—1.78 (2/3 × 2H, m, –CH_2CH_3), 2.18—2.51 (1/3 × 2H, m, –CH_2CH_3), 3.24—4.73 (total 1H, m, >CHCO), 4.42 (2/3 × 1H, d, J=5.5 Hz, >CHSPh), 4.62 (1/3 × 1H, d, J=5.5 Hz, >CHSPh), 7.44—7.62 (5H, m, S(O)Ph). MS *m*/*z*: 322 (M^+ – Me), 280 (M^+ – *tert*-Bu). Exact MS Calcd for $C_{17}H_{27}NO_2SSi-tert$-Bu: 280.0824. Found: 280.0819.

(3*S,4*R**)-*N*-(*tert*-Butyldimethylsilyl)-3-ethyl-4-(phenylsulfinyl)azetidin-2-one (*trans*-18f)** This (*trans*, 5.7 mg, 99%) was obtained from *trans*-**17f** (5.5 mg, 0.0171 mmol), *m*-CPBA (80%, 3.7 mg, 0.0171 mmol) in CH_2Cl_2 (1 ml) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1750, 1030. ^{1}H-NMR ($CDCl_3$) δ: 0.33, 0.38. 0.40 (total 6H, each s, Me_2Si), 0.53—0.71 (total 3H, m, –CH_2CH_3), 1.04 (9H, s, *tert*-BuSi), 1.18—1.49 (2H, m, –CH_2CH_3), 2.91 (1/2 × 1H, td, J=7, 2 Hz, >CHCO), 3.69 (1/2 × 1H, td, J=7, 2 Hz, >CHCO), 4.00 (1/2 × 1H, d, J=2 Hz, >CHSPh), 4.13 (1/2 × 1H, d, J=2 Hz, >CHSPh), 7.47—7.62 (5H, m, S(O)Ph). MS *m*/*z*: 322 (M^+ – Me), 280 (M^+ – *tert*-Bu). Exact MS Calcd for $C_{17}H_{27}NO_2SSi-tert$-Bu: 280.0828. Found: 280.0838.

***N*-Benzyl-3-ethyl-4-(phenylsulfinyl)azetidin-2-one (18g)** This (7.6 mg, 53%, *cis*:*trans*=59:41) was obtained from **17g** (13.6 mg, 0.0458 mmol), *m*-CPBA (80%, 9.9 mg, 0.0458 mmol) in CH_2Cl_2 (1 ml) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1755, 1035. ^{1}H-NMR ($CDCl_3$) δ: 1.18—1.33 (total 3H, m, –CH_2CH_3), 2.07—2.33 (total 2H, m, –CH_2CH_3), 2.98 (59/100 × 1H, d, J=15.5 Hz, –CHHPh), 3.4—3.8 (59/100 × 1H, dt, J=4.5, 8 Hz, >CHCO), 3.8—4.0 (41/100 × 1H, m, >CHCO), 4.27—4.56 (59/100 × 2H, m, >CHSPh, –CHHPh, 41/100 × 1H, m, –CHHPh), 4.83 (41/100 × 1H, d, J=14.5 Hz, –CHHPh), 6.5—6.8, 7.1—7.4 (total 5H, m, CH_2Ph), 7.5—7.8 (5H, m, S(O)Ph). MS *m*/*z*: 313 (M^+), 312 (M^+ – 1), 188 (M^+ – S(O)Ph).

***N*-(1,1-Diphenymethyl)-3-ethyl-4-(phenylsufinyl)azetidin-2-one (18h)** This (33.9 mg, 78%, *cis*:*trans*=44:56) was obtained from **17h** (41.9 mg, 0.112 mmol), *m*-CPBA (80%, 24.2 mmol, 0.112 mmol) in CH_2Cl_2 (1 ml) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1760, 1045. ^{1}H-NMR ($CDCl_3$) δ: 0.41, 0.59 (56/100 × 3H, t, J=7 Hz, –CH_2CH_3), 1.15—1.55 (56/100 × 2H, m, –CH_2CH_3, 44/100 × 3H, m, –CH_2CH_3), 1.98—2.51 (44/100 × 2H, br, –CH_2CH_3), 3.04, 3.68 (56/100 × 1H, td, J=7, 2Hz, >CHCO), 3.35–3.58 (44/100 × 1H, m, >CHCO), 3.71, 4.12 (56/100 × 1H, d, J=2 Hz, >CHSPh), 4.41, 4.47 (44/100 × 1H, d, J=5 Hz, >CHSPh), 4.60, 5.27 (44/100 × 1H, s, $CHPh_2$), 5.70, 6.12 (56/100 × 1H, s, $CHPh_2$), 6.98—7.53 (15H, m, ArH). Exact MS Calcd for $C_{24}H_{23}NO_2S-SPh$: 264.1388. Found: 264.1399.

General Procedure for the Reaction of 4-Phenylsulfinylazetidin-2-ones (18a—c, f—h) with the Ketene Silyl Acetal (16) The ketene silyl acetal (**16**, 2—4 mmol) was added to a stirred solution of 4-phenylsulfinylazetidin-2-one (**18**, 1 mmol) and ZnI_2 (0.05—0.1 mmol) in dry CH_3CN (10 ml) under nitrogen. The mixture was stirred at the temperature and for the period indicated in Table III, then partitioned between CH_2Cl_2 (20 ml) and saturated aqueous $NaHCO_3$ (20 ml). The aqueous layer was extracted with CH_2Cl_2 (20 ml × 4). The combined extract was washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was subjected to column chromatography or preparative TLC on silica gel with hexane–AcOEt to give the ester.

***N*-(*tert*-Butyldimethylsilyl)-4-(methoxycarbonylmethyl)azetidin-2-one (19a)**: i) This (7.3 mg, 86%) was obtained from **18a** (10.3 mg, 0.033 mmol), **16** (23.3 mg, 0.124 mmol), and ZnI_2 (1.1 mg, 0.0033 mmol) in CH_3CN (0.5 ml) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1730. ^{1}H-NMR ($CDCl_3$) δ: 0.22, 0.25 (total 6H, each s, Me_2Si), 0.96 (9H, s, *tert*-BuSi), 2.49 (1H, dd, J=9.8, 15.9 Hz, –CHHCO$_2$Me), 2.77 (1H, dd, J=2.5, 15.9 Hz, –CHHCO), 2.87 (1H, dd, J=3.7, 15.9 Hz, –CHHCO$_2$Me), 3.30 (1H, dd, J=5.5, 15.9 Hz, –CHHCO), 3.70 (3H, s, OMe), 3.89 (1H, m, >CHCH$_2$). MS *m*/*z*: 243 (M^+ – Me), 200 (M^+ – *tert*-Bu). Exact MS Calcd for $C_{12}H_{23}NO_3Si-tert$-Bu: 200.0740. Found: 200.0737. ii) This (7.2 mg, 50%) was obtained from **18a** (17.4 mg, 0.0563 mmol), **16** (21.2 mg, 0.113 mmol), and ZnI_2 (1.8 mg, 0.0056 mmol) in CH_2Cl_2 (1 ml) as a colorless oil. iii) This (7.3 mg, 60%) was obtained from **18a** (14.7 mg, 0.0563 mmol), and **16** (17.9 mg, 0.0952 mmol), and ZnI_2 (1.5 mg, 0.0048 mmol) in THF (1 ml) as a colorless oil. iv) This (14.3 mg, 68%) was obtained from **18i** (16.0 mg, 0.0821 mmol), **16** (38.6 mg, 0.205 mmol), and ZnI_2 (2.6 mg, 0.00821 mmol) in CH_3CN (1 ml) as a colorless oil.

***N*-Benzyl-4-(methoxycarbonylmethyl)azetidin-2-one (19b)** This (6.7 mg, 52%) was obtained from **18b** (16.0 mg, 0.056 mmol), **16** (34 mg, 0.18 mmol), and ZnI_2 (5 mg, 0.0157 mmol) in CH_3CN (1 ml) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1740, 1440, 1400. ^{1}H-NMR ($CDCl_3$) δ: 2.50 (2H, dd, J=2, 6.5 Hz, –CH_2CO_2Me), 2.67 (1H, dd, J=2, 14.5 Hz, –CHHCO), 3.11 (1H, dd, J=5, 14.5 Hz, –CHHCO), 3.56 (3H, s, –OMe), 3.76—4.02 (1H, m, >CHCH$_2$CO$_2$), 4.20, 4.45 (2H, AB-q, J=15 Hz, –CH_2Ph), 7.22 (5H, s, ArH). Exact MS Calcd for $C_{13}H_{15}NO_3$: 233.1047. Found: 233.1047.

***N*-(1,1-Diphenymethyl)-4-(methoxycarbonylmethyl)azetidin-2-one (19c)** This (9.1 mg, 89%) was obtained from **18c** (12.0 mg, 0.0294 mmol), **16** (12.5 mg, 0.0664 mmol), and ZnI_2 (1.1 mg, 0.00332 mmol) in CH_3CN (0.5 ml) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1745. ^{1}H-NMR ($CDCl_3$) δ: 2.35 (1H, d, J=1.2 Hz, –CHHCO$_2$Me), 2.44 (1H, s, –CHHCO$_2$Me), 2.74 (1H, dd, J=2.4, 14.2 Hz, –CHHCO), 3.22 (1H, dd, J=5.0, 14.2 Hz, –CHHCO), 3.60 (3H, s, –OMe), 4.00 (1H, m, >CHCH$_2$CO$_2$), 5.95 (1H,

s, CHPh$_2$), 7.27 (10H, m, ArH). Exact MS Calcd for $C_{19}H_{19}NO_3$: 309.1363. Found: 309.1355.

***N*-(*tert*-Butyldimethylsilyl)-3-ethyl-4-(methoxycarbonylmethyl)azetidin-2-one (19f)** i) This (9.1 mg, 79%) was obtained from **18f** (*cis*:*trans* = 63:37, 13.6 mg, 0.0404 mmol), **16** (15.2 mg, 0.0808 mmol), and ZnI_2 (1.3 mg, 0.0040 mmol) in CH_3CN (1 ml) as a colorless oil; ^{1}H-NMR showed *trans*:*cis* = 94:6. The pure isomers (*trans*-**19f** and *cis*-**19f**) were isolated by column chromatography for characterization. ii) This (12.9 mg, 73%) was obtained from *cis*-**18f** (21.0 mg, 0.0623 mmol), **16** (23.4 mg, 0.125 mmol), and ZnI_2 (2.0 mg, 0.0062 mmol) in CH_3CN (1 ml) as a colorless oil; ^{1}H-NMR showed *trans*:*cis* = 95:5. iii) This (13.2 mg, 77%) was obtained from *trans*-**18f** (20.2 mg, 0.0599 mmol), **16** (22.6 mg, 0.120 mmol), and ZnI_2 (1.9 mg, 0.0060 mmol) in CH_3CN (1 ml) as a colorless oil; ^{1}H-NMR showed *trans*:*cis* = 95:5.

(3*R**,4*R**)-*N*-(*tert*-Butyldimethylsilyl)-3-ethyl-4-(methoxycarbonylmethyl)azetidin-2-one (*trans*-**19f**): IR ν_{max} ($CHCl_3$) cm^{-1}: 1730. ^{1}H-NMR ($CDCl_3$) δ: 0.20, 0.25 (total 6H, each s, Me_2Si), 0.96 (9H, s, *tert*-BuSi), 1.00 (3H, t, J = 7.2 Hz, $-CH_2CH_3$), 1.75 (2H, m, $-CH_2CH_3$), 2.50 (1H, dd, J = 9.8, 15.5 Hz, $-CHHCO_2Me$), 2.84 (1H, dd, J = 4.3, 15.5 Hz, $-CHHCO_2Me$), 2.88 (1H, ddd, J = 2.4, 6.0, 7.0 Hz, $>CHCO$), 3.59 (1H, ddd, J = 2.4, 4.3, 9.8 Hz, $>CHCH_2CO_2$), 3.70 (3H, s, OMe). Exact MS Calcd for $C_{14}H_{27}NO_3Si-tert$-Bu: 228.1053. Found: 228.1041.

(3*R**,4*S**)-*N*-(*tert*-Butyldimethylsilyl)-3-ethyl-4-(methoxycarbonylmethyl)azetidin-2-one (*cis*-**19f**): IR ν_{max} ($CHCl_3$) cm^{-1}: 1730. ^{1}H-NMR ($CDCl_3$) δ: 0.20, 0.23 (total 6H, each s, Me_2Si), 0.95 (9H, s, *tert*-BuSi), 1.06 (3H, t, J = 7.2 Hz, $-CH_2CH_3$), 1.65—1.81 (2H, m, $-CH_2CH_3$), 2.58 (1H, dd, J = 9.8, 16.5 Hz, $-CHHCO_2Me$), 2.70 (1H, dd, J = 5.5, 16.5 Hz, $-CHHCO_2Me$), 3.28 (1H, ddd, J = 5.5, 5.9, 10.5 Hz, $>CHCO$), 3.70 (3H, s, OMe), 4.09 (1H, ddd, J = 4.3, 5.5, 9.8 Hz, $>CHCH_2CO_2$). MS *m/z*: 228 ($M^+ - tert$-Bu).

***N*-Benzyl-3-ethyl-4-(methoxycarbonylmethyl)azetidin-2-one (19g)** This (4.8 mg, 84%) was obtained from **18g** (6.9 mg, 0.0220 mmol), **16** (8.3 mg, 0.0441 mmol), and ZnI_2 (0.7 mg, 0.0022 mmol) in CH_3CN (0.5 ml) as a colorless oil; ^{1}H-NMR showed *trans*:*cis* = 89:11. IR ν_{max} ($CHCl_3$) cm^{-1}: 1725, 1440, 1400. ^{1}H-NMR ($CDCl_3$) δ: 0.98 (89/100 × 3H, t, J = 7.3 Hz, $-CH_2CH_3$), 1.08 (11/100 × 3H, t, J = 7.3 Hz, $-CH_2CH_3$), 1.65—1.84 (2H, m, $-CH_2CH_3$), 2.47 (11/100 × 2H, d, J = 6.7 Hz, $-CH_2CO_2Me$), 2.48 (89/100 × 1H, dd, J = 15.9, 7.3 Hz, $-CHHCO_2Me$), 2.58 (89/100 × 1H, dd, J = 15.9, 6.1 Hz, $-CHHCO_2Me$), 2.85 (89/100 × 1H, ddd, J = 1.8, 7.0, 8.0 Hz, $>CHCH_2CO_2$), 3.19 (11/100 × 1H, ddd, J = 5.5, 6.9, 9.0 Hz, $>CHCH_2CO_2$), 3.55 (89/100 × 1H, ddd, J = 1.8, 6.1, 7.3 Hz, $>CHCO$), 3.58 (11/100 × 3H, s, –OMe), 3.61 (89/100 × 3H, s, –OMe), 4.03 (11/100 × 1H, dt, J = 5.5, 6.7 Hz, $>CHCO$), 4.17, 4.55 (89/100 × 2H, each d, J = 15.3 Hz, $-CH_2Ph$), 4.25, 4.55 (11/100 × 2H, each d, J = 15.3 Hz, $-CH_2Ph$), 7.24—7.35 (10H, m, ArH). Exact MS Calcd for $C_{15}H_{19}NO_3$: 261.1362. Found: 261.1362.

***N*-(1,1-Diphenymethyl)-3-ethyl-4-(methoxycarbonylmethyl)azetidin-2-one (19h)** This (21.0 mg, 80%) was obtained from **18h** (30.3 mg, 0.779 mmol), **16** (29.3 mg, 0.156 mmol), and ZnI_2 (2.4 mg, 0.0078 mmol) in CH_3CN (0.8 ml) as a colorless oil; ^{1}H-NMR showed *trans*:*cis* = 91:9. IR ν_{max} ($CHCl_3$) cm^{-1}: 1735, 1495, 1440, 1380. ^{1}H-NMR ($CDCl_3$) δ: 0.97 (91/100 × 3H, t, J = 7.3 Hz, $-CH_2CH_3$), 1.09 (9/100 × 3H, t, J = 7.3 Hz, $-CH_2CH_3$), 1.75 (2H, m, $-CH_2CH_3$), 2.345 (9/100 × 1H, dd, J = 5.5, 17 Hz, $-CHHCO_2Me$), 2.38 (91/100 × 1H, dd, J = 8.5, 15.9 Hz, $-CHHCO_2Me$), 2.44 (91/100 × 1H, dd, J = 5.5, 15.9 Hz, $-CHHCO_2Me$), 2.46 (9/100 × 1H, dd, J = 8, 17 Hz, $-CHHCO_2Me$), 2.85 (91/100 × 1H, dt, J = 1.8, 7.3 Hz, $>CHCO$), 3.20 (9/100 × 1H, ddd, J = 5.5, 6.1, 9.8 Hz, $>CHCO$), 3.57 (9/100 × 3H, s, –OMe), 3.59 (91/100 × 3H, s, –OMe), 3.66 (91/100 × 1H, ddd, J = 1.8, 5.5, 8.5 Hz, $>CHCH_2CO$), 4.15 (9/100 × 1H, dt, J = 9.8, 5.5 Hz, $>CHCH_2CO$), 5.92 (9/100 × 1H, s, $-CHPh_2$), 5.95 (91/100 × 1H, s, $CHPh_2$), 7.24—7.40 (10H, m, ArH). Exact MS Calcd for $C_{21}H_{23}NO_3$: 337.1676. Found: 337.1671.

(3*R,4*R**)-4-(Benzyloxycarbonylmethyl)-*N*-(*tert*-butyldimethylsilyl)-3-ethylazetidin-2-one (20)** Titanium tetraisopropoxide (11.1 mg, 0.0389 mmol) was added to a stirred solution of *trans*-**19f** (11.1 mg, 0.0389 mmol) in benzyl alcohol (0.5 ml) at room temperature. The mixture was stirred at 80 °C for 2 h and then 1 N hydrochloric acid was added. The aqueous layer was extracted with ether (20 ml × 5) and the combined organic layer was washed with saturated aqueous $NaHCO_3$ (20 ml) and brine (30 ml), dried over $MgSO_4$, and concentrated under reduced pressure. The residue was subjected to column chromatography on silica gel with hexane–AcOEt (5:1) to give **21** (13.8 mg, 98%) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 1730. ^{1}H-NMR ($CDCl_3$) δ: 0.18, 0.22 (total 6H, each s, Me_2Si), 0.91 (9H, s, *tert*-BuSi), 1.00 (3H, t, J = 8 Hz, $-CH_2CH_3$), 1.51—1.84 (2H, m, $-CH_2CH_3$), 2.47 (1H, dd, J = 9.5, 15 Hz, $-CHHCO_2Me$), 2.76—2.98 (2H, m, $-CHHCO_2Me$, $>CHCO$), 3.58 (1H, ddd, J = 2.5, 4, 9.5 Hz, $>CHCH_2CO_2$), 5.09 (2H, s, $-CH_2Ph$), 7.33 (5H, s, Ph). Exact MS Calcd for $C_{16}H_{22}NO_3Si-tert$-Bu: 304.1369. Found: 304.1371.

(3*R,4*R**)-4-(Benzyloxycarbonylmethyl)-3-ethylazetidin-2-one (21)** A solution of $Bu_4NF \cdot 3H_2O$ (14.8 mg, 0.0470 mmol) and AcOH (4.8 mg, 0.0754 mmol) in THF (0.5 ml) was added dropwise to a stirred solution of **20** (13.6 mg, 0.0377 mmol) in THF (1 ml) at 0 °C. The mixture was stirred at 0 °C for 30 min, diluted with CH_2Cl_2 (50 ml), washed with water (20 ml) and brine (20 ml), dried over $MgSO_4$, and concentrated *in vacuo*. The residue was subjected to column chromatography on silica gel with CH_2Cl_2–MeOH (20:1) to give **21** (7.9 mg, 8.5%) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 3420, 1755. ^{1}H-NMR ($CDCl_3$) δ: 0.99 (3H, t, J = 7.5, $-CH_2CH_3$), 1.76 (2H, m, $-CH_2CH_3$), 2.64—2.82 (total 3H, m, $-CH_2CO_2$, $>CHCO$), 3.67 (1H, m, $-CHCH_2CO_2$), 5.11 (2H, s, $-CH_2Ph$), 5.96—6.11 (1H, br, NH), 7.31 (5H, s, Ph). Exact MS Calcd for $C_{14}H_{17}NO_3$: 247.1209. Found: 247.1224.

(3*R,4*R**)-4-Carboxymethyl-3-ethylazetidin-2-one (22)** A 10% Pd–C catalyst (4.2 mg) was added to a stirred solution of **21** (7.4 mg, 0.030 mmol) in ethanol (1 ml) at room temperature. The apparatus was filled with hydrogen and the mixture was stirred at room temperature for 10 min. Pd–C was removed by filtration and the solvent was removed *in vacuo* to give the acid, which was purified by recrystallization to give **22** (3.3 mg, 70%) as colorless crystals, mp 105—108 °C (CH_2Cl_2–C_6H_6) (lit.[12] 105—108 °C (CH_2Cl_2–C_6H_6)). IR ν_{max} ($CHCl_3$) cm^{-1}: 3420, 2280—3600, 1730. ^{1}H-NMR ($CDCl_3$) δ: 1.03 (3H, t, J = 7.3 Hz, $-CH_2CH_3$), 1.73, 1.82 (each 1H, each quint, t, J = 7.3, 14.7 Hz $-CH_2CH_3$), 2.61 (1H, dd, J = 9.8, 16.5 Hz, $-CHHCO_2H$), 2.79 (1H, dd, J = 4.3, 16.5 Hz, $-CHHCO_2H$), 2.80—2.83 (1H, m, $>CHCO$), 3.65 (1H ddd, J = 1.8, 4.3, 9.8 Hz, $>CHCH_2CO_2H$), 6.53 (1H, br, NH). MS *m/z*: 158 (MH*).

(3*R,4*R**)-4-(3-Benzyloxycarbonyl-3-diazo-2-oxopropyl)-*N*-(*tert*-butyldimethylsilyl)-3-ethylazetidin-2-one (24)** The silyl enol ether (**23**, 103.8 mg, 0.3125 mmol) was added to a stirred solution of 4-phenylsulfinylazetidin-2-one (**18f**, 42.0 mg, 0.125 mmol) and ZnI_2 (4.0 mg, 0.0125 mmol) in dry CH_3CN (1 ml) under nitrogen. The mixture was stirred at room temperature for 15 min, then partitioned between CH_2Cl_2 (20 ml) and saturated aqueous $NaHCO_3$ (20 ml). The aqueous layer was extracted with CH_2Cl_2 (20 ml × 4). The combined extract was washed with brine, dried over $MgSO_4$ and concentrated under reduced pressure. The residue was subjected to preparative TLC on silica gel with hexane–AcOEt to give the ester **24** (21.6 mg, 40%) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 2150, 1275, 1645. ^{1}H-NMR ($CDCl_3$) δ: 0.24, 0.25 (total 6H, each s, Me_2Si), 0.97 (9H, s, *tert*-BuSi), 0.99 (3H, t, J = 7.3 Hz, $-CH_2CH_3$), 1.77 (2H, m, $-CH_2CH_3$), 2.81 (1H, dt, J = 1.8, 6.7 Hz, 3-H), 3.02 (1H, dd, J = 9.8, 17.1 Hz, $-CHHC=O$), 3.45 (1H, dd, J = 3.7, 17.1 Hz, $-CHHC=O$), 3.65 (1H, m, 4-H), 5.28, 5.29 (total 2H, each s, $-CH_2Ph$), 7.38 (5H, m, Ph). Exact MS Calcd for $C_{22}H_{31}N_3O_4Si-tert$-Bu: 372.1378. Found: 372.1378.

(3*R,4*R**)-4-(3-Benzyloxycarbonyl-3-diazo-2-oxopropyl)-3-ethylazetidin-2-one (25)**[13,14] A solution of $Bu_4NF \cdot 3H_2O$ (18.4 mg, 0.0585 mmol) and AcOH (7.0 mg, 0.117 mmol) in THF (1 ml) was added dropwise to a stirred solution of **24** (25.1 mg, 0.0585 mmol) in THF (0.5 ml) at 0 °C. The mixture was stirred at the same temperature for 30 min, diluted with CH_2Cl_2 (50 ml), washed with water (20 ml) and brine (20 ml), dried over Na_2SO_4, and concentrated *in vacuo*. The residue was subjected to column chromatography on silica gel with hexane–AcOEt (3:2) to give **25** (17.0 mg, 93%) as a colorless oil. IR ν_{max} ($CHCl_3$) cm^{-1}: 3460, 2180, 1760, 1720, 1645. ^{1}H-NMR ($CDCl_3$) δ: 1.00 (3H, t, J = 7 Hz, $-CH_2CH_3$), 1.73 (2H, m, $-CH_2CH_3$), 2.75 (1H, m, 3-H), 3.00 (1H, dd, J = 8, 18 Hz, $-CHHC=O$), 3.41 (1H, dd, J = 4, 18 Hz, $-CHHC=O$), 3.68 (1H, m, 4-H), 5.26 (2H, s, $-CH_2Ph$), 6.08 (1H, br s, NH), 7.41 (5H, s, Ph).

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