Experimental Section

All IR spectra were recorded on a Nicolet MX-1 FT-IR spectrometer. The ^1H NMR spectra were recorded in deuteriochloroform with 2% (v/v) tetramethylsilane as the internal reference on a Varian FT-80 or a Bruker AM300 spectrometer. Accurate mass measurements were obtained with Kratos MS50RF spectrometer in the electron-impact mode. Melting points were determined by using a Thomas-Hoover capillary apparatus and are uncorrected. All compounds gave satisfactory C, H, and N analyses (±0.4%) with the exception of **15**, which was analyzed with HRMS.

General Procedure for the Synthesis of Ester Derivatives 2a, 6a, and 9a. Sodium hydride (1.2 g, 50 mmol) is suspended in stirring benzene (100 mL) and treated portionwise with **5** (5.0 g, 33 mmol) at 65 °C. After the ensuing hydrogen evolution is complete, ethyl 2-bromopropionate is added and the reaction is refluxed for 48 h. The excess sodium hydride is destroyed with the dropwise addition of methanol, the reaction mixture is extracted with water, and the organic layer is dried ($MgSO_4$), filtered, and concentrated in vacuo to 5.1 g of solid. Recrystallization from ethyl ether affords 3 g (36%) of product, mp 54–56 °C. The yields for the analogous transformation in the synthesis of **9a** and **2a** were 64.9% (mp 105–107 °C) and 45% (mp 67–69 °C), respectively. Satisfactory analyses were reported (Ed.).

General Procedure for the Synthesis of Acid Derivatives 2b, 6b, and 9b. A suspension of **6a** (5.6 g, 22 mmol) in water (75 mL) is heated on a steam cone and slowly treated dropwise with a 50% sodium hydroxide solution until the ester dissolves. The solution is filtered, chilled, and treated dropwise with concentrated hydrochloric acid until the resulting precipitate formation is complete. The solid is recovered by filtration and recrystallized from ethanol–ethyl acetate (2:1), affording 1.5 g (30.6%), mp 202–203 °C. Yields for the acids corresponding to **9b** and **2b** are 98% (mp 207–210 °C) and 87% (mp 246–249 °C), respectively. Satisfactory analyses were reported (Ed.).

Dimethyl 7-Methylpyrrolo[1,2-*g*]thieno[2,3-*d*]pyridazine-8,9-dicarboxylate (7). A suspension of **6b** (1.0 g, 4.4 mmol) in a mixture of acetic anhydride (50 mL) and dimethyl acetylenedicarboxylate (0.76 g, 5.4 mmol) is slowly heated to 100 °C under nitrogen, with carbon dioxide evolution observed at 60 °C. The reaction mixture is concentrated in vacuo after heating for 1 h, the resultant solid is dissolved in chloroform and washed twice with water, and the organic layer is isolated, dried ($MgSO_4$), concentrated in vacuo, and recrystallized from a mixture of methanol–chloroform (2:1), affording 1.1 g (83%) of an off-white solid: mp 172–173 °C; IR 3090, 2950, 1705, 1520, 1435, 1260, 1220, 1200, 770, 705, 600, cm^{-1}; NMR δ 2.62 (s, 3 H), 3.93 (s, 3 H), 3.96 (s, 3 H), 7.32 (d, J = 5.3 Hz, 1 H), 7.47 (d, J = 5.3 Hz, 1 H), 8.47 (s, 1 H). Anal. Calcd for $C_{14}H_{12}N_2O_4S$: C, 55.25; H, 3.97; N, 9.20. Found: C, 54.91; H, 3.90; N, 9.06.

Dimethyl 2,7-Dimethylpyrrolo[1,2-*c*]thieno[3,2-*e*]pyrimidine-8,9-dicarboxylate (11). A suspension of **9b** (1.5 g, 6.3 mmol) in a mixture of acetic anhydride (50 mL) and dimethyl acetylenedicarboxylate (8.9 g, 63 mmol) is heated at 90 °C for 90 min under nitrogen. The reaction mixture is concentrated in vacuo to a dark solid, which is flash chromatographed in ethyl acetate–hexane (2:3), yielding 0.56 g (28%) of **11** and 0.52 g (25%) of **12**. Variable amounts of compound **10** were also formed in the reaction, but its yield seemed independent of the various reaction parameters. Compound **11**: mp 133–136 °C; IR 2960, 1700, 1610, 1560, 1510, 1445, 1320, 1210, 1085, 1045 cm^{-1}; NMR δ 2.56 (s, 3 H), 2.57 (s, 3 H), 3.87 (s, 3 H), 3.91 (s, 3 H), 7.73 (s, 1 H), 8.38 (s, 1 H). Anal. Calcd for $C_{15}H_{14}N_2O_4S$: C, 56.59; H, 4.43; N, 8.80. Found: C, 56.82; H, 4.51; N, 8.88.

Dimethyl 4,8,8a,9-tetrahydro-2,6-dimethyl-4-oxopyrrolo[2,1-*b*]thieno[2,3-*d*]pyrimidine-7,8-dicarboxylate (12): mp 211–212 °C; IR 3230, 2955, 1735, 1710, 1630, 1505, 1475, 1390, 1310, 1260, 1200, 1185, 1175, 760 cm^{-1}; NMR δ 2.30 (d, J = 1.5 Hz, 3 H), 2.68 (d, J = 2.0 Hz, 3 H), 3.65 (s, 3 H), 3.73 (s, 3 H), 3.96 (dq, J = 9.0 Hz and J = 2.0 Hz, 1 H), 5.27 (d, J = 9.0 Hz, 1 H), 6.68 (q, J = 1.5 Hz, 1 H), 8.12 (br s, 1 H). Anal. Calcd for $C_{15}H_{16}N_2O_5S$: C, 53.56; H, 4.79; N, 8.33. Found: C, 53.30; H, 4.84; N, 8.31.

Dimethyl 7-Methylthieno[2,3-*g*]indolizine-8,9-dicarboxylate (4a). A suspension of **2b** (2.0 g, 8.9 mmol) is heated in a mixture of acetic anhydride (70 mL) and dimethyl acetylenedicarboxylate (7.6 g, 53 mmol) for 20 min under nitrogen. The reaction mixture is concentrated in vacuo and partitioned between chloroform and water, and the organic fraction is dried ($MgSO_4$), filtered, concentrated in vacuo, and flash chromatographed in ethyl acetate–hexane (2:3). The recovered product is recrystallized from ethyl acetate–hexane (1:1), yielding 1.3 g (46%) of a white solid: mp 136–138 °C; IR 3110, 2950, 1715, 1690, 1625, 1565, 1550, 1440, 1415, 1245, 1215, 1170, 740, 695 cm^{-1}; NMR 2.42 (s, 3 H), 3.90 (s, 6 H), 6.92 (d, J = 7.4 Hz, 1 H), 7.38 (m, 2 H), 8.28 (d, J = 5.5 Hz, 1 H). Anal. Calcd for $C_{15}H_{13}N_2O_4S$: C, 56.59; H, 4.43; N, 8.80. Found: C, 56.82; H, 4.51; N, 8.88.

Dimethyl 7-Phenylthieno[2,3-*g*]indolizine-8,9-dicarboxylate (4b). A solution of **3** (3.3 g, 12.2 mmol) in methylene chloride is treated dropwise with a mixture of trifluoromethanesulfonic acid (2 g, 13.4 mmol) in methylene chloride (40 mL) under nitrogen. After being stirred for 24 h, the yellow-orange solution is concentrated in vacuo, and the resulting solid is redissolved in anhydrous dimethylformamide (125 mL), treated with dimethyl acetylenedicarboxylate (1.7 g, 12.2 mmol) under nitrogen, and heated at 80 °C for 24 h. The reaction mixture is concentrated to dryness and partitioned between methylene chloride and water, and the organic layer is dried ($MgSO_4$), concentrated in vacuo, and flash chromatographed in ethyl acetate–hexane (3:7). The product is recovered as 0.75 g (17.4%) of a clear gold oil, which crystallizes in methanol, affording white crystals: mp 97–98 °C; IR 2950, 1730, 1700, 1620, 1600, 1555, 1507, 1480, 1415, 1340, 1245, 1210, 1160, 1065, 760, 700 cm^{-1}; NMR δ 3.74 (s, 3 H), 3.84 (s, 3 H), 7.46 (d, J = 7.5 Hz, 1 H), 7.56 (m, 5 H), 7.87 (d, J = 5.5 Hz, 1 H), 7.93 (d, J = 7.5 Hz, 1 H), 8.53 (d, J = 5.5 Hz, 1 H). Anal. Calcd for $C_{20}H_{15}NO_4S$: C, 65.74; H, 4.14; N, 3.83. Found: C, 65.78; H, 4.13; N, 3.83.

Dimethyl 2-Methyl-1*H*-pyrrole-3,4-dicarboxylate (14) and 2,7-Dimethyldithieno[2,3-*b*:2′,3′-*f*][1,5]diazocine-4,9-(5*H*,10*H*)-dione (15). A solution of **12** (0.1 g, 0.29 mmol) and potassium carbonate (41 mg, 0.29 mmol) is refluxed for 5 h in dry acetonitrile (15 mL) under nitrogen. The light yellow solution is filtered and concentrated in vacuo to a yellow solid. Flash chromatography (2:3 EtOAc–hexane) of this material yields two products: compound **14** (49 mg, 86.2%) as a white solid, mp 159 °C (lit.[12] mp 159 °C), and compound **15** (16 mg, 20%) as a bright yellow solid, mp 209–210 °C: IR 3404, 3200, 1733, 1560, 1540, 1480, 760 cm^{-1}; NMR (DMSO-d_6) δ 2.22 (s, 3 H), 2.45 (s, 3 H), 6.64 (s, 1 H), 7.01 (s, 1 H), 7.87 (s, 2 H); HRMS molecular weight calcd for **15** ($C_{12}H_{10}N_2O_2S_2$) 278.0184, obsd 278.0190.

Registry No. **1**, 27685-92-3; **2a**, 118376-56-0; **2b**, 118376-65-1; **3**, 29389-86-4; **4a**, 118376-57-1; **4b**, 118376-64-0; **5**, 697-72-3; **6a**, 118376-58-2; **6b**, 118376-66-2; **7**, 118376-59-3; **8**, 108831-66-9; **9a**, 118376-60-6; **9b**, 118376-67-3; **10**, 118376-61-7; **11**, 118376-62-8; **12**, 118376-63-9; **14**, 90610-59-6; **15**, 118376-68-4; ethyl 2-bromopropionate, 535-11-5; dimethyl acetylenedicarboxylate, 762-42-5.

Supplementary Material Available: Full spectral data (IR, ^1H and ^{13}C NMR) for compounds **2a,b**, **6a,b**, **9a,b**, and **10** (2 pages). Ordering information is given on any current masthead page.

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(Benzyloxy)nitromethane: A New Reagent in Bicyclic β-Lactam Synthesis

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β-Lactams are outstanding antibiotics, and novel, concise chemistry for their elaboration is constantly being sought. The utility of nitroalkenes in carbapenam construction was

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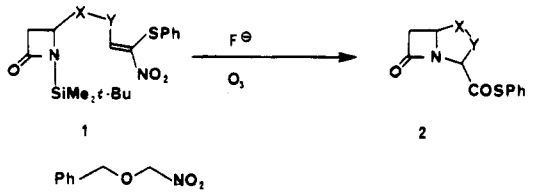
demonstrated by Shibuya,[1] and a 1,1-bis(alkylthio)nitroalkene intermediate was used in Hanessian's[2] penam synthesis. We recently reported[3] the use of (phenylthio)nitromethane for the construction of bicyclic β-lactams **2** from monocyclic precursors **1**. Unfortunately, selective hydrolysis of the phenylthio ester substituent of **2** to release the corresponding β-lactam carboxylic acid proved difficult in several cases. Benzyl esters have been widely used in β-lactam synthesis, since they are easily cleaved to produce the corresponding acids under mild, neutral conditions.[4] Thus, we sought to use (benzyloxy)nitromethane (**3**) in our β-lactam annulation chemistry. Such an approach should directly provide benzyl esters from nitroalkene precursors.



(Benzyloxy)nitromethane (**3**) was readily prepared by reaction of benzyl chloromethyl ether with silver nitrite (25%). The optically pure diastereoisomeric acetates **4** were prepared from L-aspartic acid according to the method of Weis et al.[5] Substitution of the 4-acetate group with 2-methyl-3-buten-2-ol[3] gave, after chromatography, the diastereoisomerically pure (3*R*,4*R*) ether **5** (50–70%). This was readily transformed into the β-nitro alcohols **7** (Scheme I). In contrast to (phenylthio)nitromethane derivatives, nitro alcohols **7** could not be dehydrated by reaction with methanesulfonyl chloride and diisopropylethylamine in dichloromethane. Instead, only the stable methanesulfonates were formed. Addition of the more basic DBU to the reaction mixture caused rapid elimination to produce the *Z*-nitroalkene **8** (81%). Both the rapid reaction of the (benzyloxy)nitromethane (**3**) anion with aldehyde **6** and the reluctance of the methanesulfonates of **7** to undergo elimination are noteworthy. pK_a measurements[6] of (phenylthio)nitromethane and (benzyloxy)nitromethane (**3**) gave values of 12.0 and 17.0, respectively. Deprotection and cyclization of the nitroalkene **8** with tetrabutylammonium fluoride in THF followed by ozonolysis in situ gave oxapenams **9** as a 1:1 mixture of diastereoisomers. Isomerization of the mixture with DBU in $CDCl_3$ at 55 °C gave only the exo disastereoisomer (52%). Assignment of the stereochemistry was based upon comparisons of ^1H NMR spectral data with known racemic oxapenam derivatives.[7]

Experimental Section

Melting points were determined on a Reichert hot stage apparatus and are uncorrected. Infrared spectra were recorded as KBr disks or films on a Sargent Welch SP3-100, a Perkin-Elmer 283, or a Nicolet 7199 FT instrument. ^1H NMR spectra were recorded on a Varian EM390A, a JEOL FX270, a Varian XL-400, or a Varian VXR-300 spectrometer with tetramethylsilane as internal standard. Mass spectra were recorded on a VG7070F or VG70-250SE mass spectrometer or were determined at the Midwest Center for Mass Spectrometry. Microanalyses were determined by Galbraith Laboratories, Knoxville, TN 37921, or by G. D. Searle and Co., Skokie, IL 60077. Samples for microanalyses that were oils were purified by flash chromatography, rotary evaporated, and subsequently further evaporated at ca. 0.1 mm.

Hexane, diethyl ether, and ethyl acetate were purified by distillation. THF was dried by distillation under nitrogen from sodium benzophenone ketyl. DMF, CH_2Cl_2, and Et_3N were freshly distilled from CaH_2. All reactions were carried out under dry nitrogen. Silica gel for chromatography refers to the Merck product Kieselgel 60 (art. 9385). Thin-layer chromatography was performed on Merck Kieselgel 60 F254 (art. 5715).

(Benzyloxy)nitromethane (3). Benzyl chloromethyl ether (4.21 mL, 30 mmol) was slowly added to a suspension of silver nitrite (4.66 g, 1 equiv) in dry THF and toluene (2:1, 50 mL) at −25 °C. Stirring was continued for 1 h at −25 °C and an additional 1 h at 0 °C. The mixture was filtered, and the solvent was evaporated in vacuo. Flash column chromatography [SiO_2, 4:1 hexanes/Et_2O] and bulb to bulb distillation at reduced pressure gave (benzyloxy)nitromethane (**3**) (1.25 g, 25%) as a pale yellow oil: R_f 0.84 (1:1 hexanes/Et_2O); IR (neat) ν_{max} 3040, 2950, 1560, 1375 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.38 (s, 5 H), 5.25 (s, 2 H), 4.84 (s, 2 H); ^{13}C NMR (75 MHz, $CDCL_3$) δ 134.9, 128.73, 128.67, 128.4, 95.8, 74.4; HRMS (EI) calcd for $C_8H_9NO_3$ 167.0583, found ($M^{\cdot+}$) 167.0582.

(3*R*,4*R*)-3-(Trimethylsilyl)-4-[(2-methyl-3-buten-2-yl)oxy]-2-azetidinone (5). A mixture of the diastereoisomeric acetates[6] (**4**) (2.01 g, 0.01 mol), 2-methyl-3-buten-2-ol (4.31 g, 5 equiv), and zinc acetate (1.1 g, 0.5 equiv) in dry benzene and hexane (4:1, 50 mL) was heated to reflux for 7.5 hours. Solvent was slowly removed (20 mL) via a Dean–Stark trap. The mixture was cooled, filtered, and evaporated in vacuo. Flash column chromatography [SiO_2, 1:1 hexanes/Et_2O] gave the title compound (**5**) (1.11 g, 49%): mp 118–120 °C (needles, hexane); $[\alpha]_D$ −2.3° (*c* 4.22, CH_2Cl_2); R_f 0.65 (Et_2O); IR (KBr) ν_{max} 3240, 3100, 1745, 1645, 1375, 1250, 1130, 1055, 840 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 6.19 (br s, 1 H, NH), 5.85 (dd, 1 H, *J* = 18, 10.8 Hz), 5.22 (d, 1 H, *J* = 4 Hz), 5.18 (d, 1 H, *J* = 1.6 Hz), 4.92 (d, 1 H, *J* = 1.6 Hz), 2.68 (d, 1 H, *J* = 1.6 Hz), 1.32 (s, 3 H),1.316 (s, 3 H), 0.13 (s, 9 H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.3, 143.3, 114.9, 75.3, 51.5, 26.7, 26.0, −2.6; mass spectrum (EI), *m/e* 228 (M^+ + H), 200, 188, 160, 144, 118, 70. Anal. Calcd for $C_{11}H_{21}NO_2Si$: C, 58.10; H, 9.31; N, 6.16. Found: C, 57.88; H, 9.23; N, 6.15.

(4*R*)-4-[(2-Methyl-3-buten-2-yl)oxy]-2-azetidinone. To a solution of (4*R*,3*R*)-3-(trimethylsilyl)-4-[(2-methyl-3-buten-2-yl)oxy]-2-azetidenone (0.41 g) in methanol (13 mL) was added pH 7.0 phosphate buffer (2 mL) and KF (0.116 g, 1.1 equiv). The suspension was stirred at room temperature for 4 h, and then it was diluted with water (25 mL) and extracted with CH_2Cl_2 (3 × 25 mL). The combined extracts were dried ($MgSO_4$) and evaporated in vacuo. Flash column chromatography [SiO_2, Et_2O] gave the title compound (0.211 g, 76%): mp 58–59 °C (hexanes); $[\alpha]_D$ +47.2° (*c* 1.13, $CHCl_3$); R_f 0.35 (Et_2O); IR (KBr) ν_{max} 3350, 2950, 1765, 1385, 1075 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 6.3 (br s, 1 H, NH), 5.86 (dd, 1 H, *J* = 10.8, 17.6 Hz), 5.21 (d, 1 H, *J* = 5.2 Hz), 5.18 (s, 1 H), 5.13 (d, 1 H, *J* = 2.8 Hz), 3.11 (dt, 1 H, *J* = 14.8, 3.6, 2.8 Hz), 2.85 (d, 1 H, *J* = 15.2 Hz), 1.33 (s, 3 H), 1.32 (s, 3 H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 167.03, 143.0, 114.9, 90.2, 73.1, 47.0, 26.5, 26.0; mass spectrum (CI), *m/e* 156.1 (M^+ + H), 128.0. Anal. Calcd for $C_8H_{13}NO_2$: C, 61.91; H, 8.44; N, 9.00. Found: C, 61.65; H, 8.40; N, 8.96.

(4*R*)-*N*-(*tert*-Butyldimethylsilyl)-4-[(2-methyl-3-buten-2-yl)oxy]-2-azetidinone. To a stirred solution of *tert*-butyldimethylsilyl chloride (0.28 g, 1.5 equiv), (dimethylamino)pyridine (0.01 equiv), and diisopropylethylamine (0.32 g, 2 equiv) in DMF (10 mL) was added (4*R*)-4-[(2-methyl-3-buten-2-yl)oxy]-2-azetidinone (0.19 g). The solution was stirred at room temperature for 4 h, and then it was diluted with Et_2O (50 mL) and washed with water (3 × 25 mL). The Et_2O was dried and evaporated in

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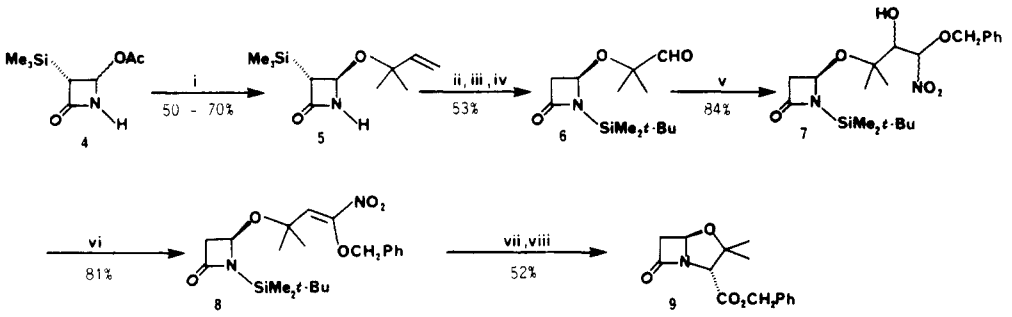
Scheme I[a]



[a] Reagents: (i) $Me_2C(OH)CH{=}CH_2$, $Zn(OAc)_2{\cdot}2H_2O$, PhH, Δ; (ii) KF, MeOH, pH 7.0 buffer; (iii) *t*-$BuMe_2SiCl$, EtN^iPr_2, DMF; (iv) O_3, CH_2Cl_2, −78 °C; Me_2S; (v) $PhCH_2OCH_2NO_2$ (**3**), *t*-BuOH, THF, *t*-BuOK (10 mol %); (vi) MsCl, Et_3N, CH_2Cl_2; DBU; (vii) *n*-Bu_4NF, THF, −55 °C; CH_2Cl_2, O_3, −78 °C; (viii) DBU, $CDCl_3$, 55 °C.

vacuo. Flash column chromatography [SiO_2, 1:1 Et_2O/hexanes] gave the title compound (0.33 g, 100%): oil; $[\alpha]_D$ −92.2° (*c* 1.28, $CHCl_3$); R_f 0.73 (Et_2O); IR (neat) ν_{max} 2945, 2860, 1755, 1310, 1180, 1065 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.87 (dd, 1 H, *J* = 10.5, 17.7 Hz), 5.18 (dd, 2 H, *J* = 3, 14.4 Hz), 4.95 (dd, 1 H, *J* = 3.3, 1.5 Hz), 3.12 (dd, 1 H, *J* = 3, 15.3 Hz), 2.85 (dd, 1 H, *J* = 1.5, 15.3 Hz), 1.31 (s, 3 H), 1.29 (s, 3 H), 0.96 (s, 9 H), 0.26 (s, 3 H), 0.21 (s, 3 H); mass spectrum (CI), *m/e* 270.2 (M^+ + H), 202.1, 170.1, 143.1. Anal. Calcd for $C_{14}H_{27}NO_2Si$: C, 62.40; H, 10.10; N, 5.20. Found: C, 62.02; H, 10.25; N, 5.03.

(4*R*)-*N*-(*tert*-Butyldimethylsilyl)-4-[(2-methyl-3-oxo-2-propyl)oxy]-2-azetidinone (6). Ozone was bubbled through a solution of (4*R*)-*N*-(*tert*-butyldimethylsilyl)-4-[(2-methyl-3-buten-2-yl)oxy]-2-azetidinone (0.33 g) in dichloromethane (20 mL) at −78 °C until a blue/purple color persisted. The solution was purged with nitrogen, and dimethyl sulfide (1 mL) was added. The mixure was warmed to room temperature and stirred for 20 h, and then the solvent was evaporated in vacuo. Flash column chromatography [SiO_2, 1:1 hexanes/Et_2O] gave the compound **6** (0.23 g, 70%): oil; $[\alpha]_D$ −123.6° (*c* 1.12, $CHCl_3$); R_f 0.66 (Et_2O); IR (neat) ν_{max} 2940, 2870, 1760, 1440, 1315, 1080, 825 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 9.59 (s, 1H), 5.01 (dd, 1 H, *J* = 1.2, 3.2 Hz), 3.21 (dd, 1 H, *J* = 3.2, 15.2 Hz), 2.86 (dd, 1 H, *J* = 0.8, 15.2 Hz), 1.33 (s, 3 H), 1.31 (s, 3 H), 0.97 (s, 9 H), 0.29 (s, 3 H), 0.25 (s, 3 H); HRMS (CI) calcd for $C_{13}H_{25}NO_3Si$ 272.1682, found (M^+) 272.1717.

(4*R*)-*N*-(*tert*-Butyldimethylsilyl)-4-[[2-methyl-4-nitro-4-(benzyloxy)-3(*Z*)-buten-2-yl]oxy]-2-azetidinone (8). To a solution of (benzyloxy)nitromethane (**3**) (0.17 g, 1.2 equiv) in *tert*-butyl alcohol and THF (1:1, 10 mL) at 0 °C was added potassium *tert* butoxide (1.0 M in *t*-BuOH; 0.085 mL, 0.1 equiv). After 15 min, the β-lactam aldehyde (**6**) in THF (1 mL) was added, and the stirring was continued for a further 3 h. The solution was diluted with pH 7.0 phosphate buffer (50 mL) and extracted with Et_2O (3 × 25 mL). The combined extracts were dried and evaporated in vacuo. Flash column chromatography [SiO_2, 1:1 hexanes/Et_2O] gave a diastereoisomeric mixture of nitro alcohols **7** (0.311 g, 84%).

The nitro alcohols **7** (0.362 g) were dissolved in dichloromethane (20 mL), and dimethylaminopyridine (0.05 equiv) was added. The solution was cooled to −78 °C, and then methanesulfonyl chloride (0.189 g, 2 equiv) and diisopropylethylamine (0.319 g, 2 equiv) were added simultaneously. The solution was warmed to room temperature and stirred for 19 h. 1,8-Diazabicyclo[5.4.0]undec-7-ene (0.5 g, 4 equiv) was added, and the solution was stirred for a further 1 h. The solution was washed with water (10 mL), dilute hydrochloric acid (2 M, 10 mL), and aqueous sodium bicarbonate (saturated, 10 mL), dried, and evaporated in vacuo. Flash column chromatography [SiO_2, 1:1 hexanes/Et_2O] gave the title compound (**8**) (0.282 g, 81%) as an oil: $[\alpha]_D$ −53.4° (*c* 1.06, $CHCl_3$); R_f 0.6 (3:1 hexanes/Et_2O); IR (neat) ν_{max} 2940, 2870, 1760, 1685, 1545, 1075 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.41 (br s, 5 H), 6.54 (s, 1 H), 5.01 (s, 2 H), 4.77 (dd, 1 H, *J* = 3.3, 1.2 Hz), 3.08 (dd, 1 H, *J* = 3.3, 15.3 Hz), 2.78 (dd, 1 H, *J* = 0.9, 15.3 Hz), 1.35 (s, 3 H), 1.34 (s, 3 H), 0.95 (s, 9 H), 0.26 (s, 3 H), 0.21 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.4, 154.4, 133.8, 129.4, 129.2, 128.8, 121.2, 76.2, 75.3, 74.4, 49.4, 27.7, 26.0, 25.8, 18.1; mass spectrum (CI), *m/e* 382.2, 292.1, 274.1, 184.1, 142.1, 115.0.

(2*R*,5*R*)-3,3-Dimethyl-2-[(benzyloxy)carbonyl]-4-oxa-1-azabicyclo[3.2.0]heptan-7-one (9). To solution of the β-lactam nitroalkene **8** (0.28 g, 0.67 mmol) in THF (2 mL) at −55 °C was added tetrabutylammonium fluoride (1.0 M in THF, 0.67 mL, 1 equiv). After 10 min the solution was diluted with dichloromethane (20 mL) and cooled to −78 °C, and ozone was bubbled through. The solution was purged with nitrogen and then washed with water (10 mL) and dried, and evaporated in vacuo to give a 1:1 mixture of diastereoisomeric oxapenams. The mixture was dissolved in $CDCl_3$ (2 mL), and 1,8-diazabicyclo[5.4.0]undec-7-ene (0.02 mL, 2 equiv) was added. The solution was heated to 55 °C for 8 h. Flash column chromatography [SiO_2, 3:1 hexanes/Et_2O] gave the title compound (**9**) (0.093 g, 52%): oil; $[\alpha]_D$ +134° (*c* 1.06, $CHCl_3$); R_f 0.33 (1:1 hexanes/Et_2O); IR (neat) ν_{max} 2995, 1790, 1755, 1165, 700 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.37 (s, 5 H), 5.42 (d, 1 H, *J* = 2.7 Hz), 5.10 (s, 2 H), 4.28 (s, 1 H), 3.32 (dd, 1 H, *J* = 2.7, 16.2 Hz), 2.88 (d, 1 H, *J* = 16.2 Hz), 1.51 (s, 3 H), 1.19 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 176.7, 168.3, 134.8, 128.7, 90.3, 84.1, 68.6, 67.3, 45.0, 28.8, 22.5; mass spectrum (EI), 276 (M^+ + H), 247, 234, 200, 98, 91; HRMS (EI) calcd for $C_{15}H_{17}NO_4$ 275.1157, found ($M^{\cdot+}$) 275.1163.

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Preparation of Optically Active 2-Thienylcarbinols by Kinetic Resolution Using the Sharpless Reagent

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After the discovery of the Sharpless asymmetric epoxidation[2] and kinetic resolution of allylic alcohols,[2b,3] the kinetic resolution of various other types of substrates having a hydroxyl group at the chiral center and a prox-

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