H_2O/CH_3OH as eluant at 5 mL per min (3.4 Kpsi). A mixture (6.4 mg) of **5** and **6** eluted as the major peak at 6.6 min, and a mixture (5.5 mg) of **7** and **8** eluted as a peak at about 10 min. Separation of **4** and **5** was carried out on the same Magnum 9 column (above), eluting with 0.1% TFA/35% H_2O/CH_3OH at 5 mL per min (3.3 Kpsi). Compound **5** (1.9 mg) eluted at about 32 min and **6** (2.8 mg) eluted at about 36 min. Separation of **7** and **8** was carried out on a Magnum 9 column, eluting with 0.1% TFA/20% H_2O/CH_3OH at 5 mL per min (3.7 Kpsi). Compound **7** eluted at 33 min and **8** eluted at 37 min.

Compound **5**: IR (CH_2Cl_2 film) 3600–3100 (OH), 3200–2300 (hydrogen-bonded OH), 1616 cm^{-1} (hydrogen-bonded carbonyl); UV (MeOH) λ_{max} (ϵ) 274 (48 754), 340 nm (5724); calcd for $C_{18}H_{24}O_6$ 336.1572, found M^+ m/z 336.1567; MS fragments, see Table I; ^1H NMR, see Table V, ^{13}C NMR, see Table II.

Compound **6**: IR (CH_2Cl_2 film) 3600–3100 (OH), 3200–2300 (hydrogen-bonded OH), 1615 cm^{-1} (hydrogen-bonded carbonyl); UV (MeOH) λ_{max} (ϵ) 274 (28 889), 338 nm (2660); calcd for $C_{18}H_{24}O_6$ 336.1572, found M^+ m/z 336.1564; MS fragments, see Table I; ^1H NMR, see Table V, ^{13}C NMR, see Table II.

Compound **7**: IR (CH_2Cl_2 film) 3600–3100 (OH), 3300–2400 (hydrogen-bonded OH), 1634 cm^{-1} (hydrogen-bonded carbonyl); UV (MeOH) λ_{max} (ϵ) 272 (28 860), 341 nm (2962); calcd for $C_{18}H_{22}O_5$ 318.1467, found M^+ m/z 318.1464; MS fragments, see Table I; ^1H NMR, see Table VI, ^{13}C NMR, see Table II.

Compound **8**: IR (CH_2Cl_2 film) 3600–3100 (OH), 1631 cm^{-1} (hydrogen-bonded carbonyl); UV (MeOH) λ_{max} (ϵ) 272 (10 089), 335 nm (2146); calcd for $C_{18}H_{22}O_5$ 318.1467, found M^+ m/z 318.1455; MS fragments, see Table I; ^1H NMR, see Table VI.

Acetylation of 2 and 3. A 15-mg mixture of **2** and **3** was dissolved in 2 mL of Ac_2O (Supelco, freshly opened ampule) and stirred at 110 °C under N_2 atmosphere for 24 h. The reaction mixture was concentrated under reduced pressure, stirred for 1 h at room temperature with aqueous Na_2CO_3 (4 mL, 10% w/v), and then extracted with Et_2O (3 × 4 mL). The Et_2O layer was washed with H_2O (4 mL), combined, dried over $MgSO_4$, filtered, and concentrated under reduced pressure to give 15 mg of a mixture of acetylated product. The mixture was separated by HPLC, using multiple injections of about 2 mg each on a Merck Lichrosorb column (7 μm, 10 mm × 250 mm) and elution with 0.2% H_2O/1% CH_3OH/CH_2Cl_2 at 3 mL/min (Consta Metric III Pump), monitored at 325 nm. Chromatography yielded major peaks at 7.0 min (9.2 mg), 15.9 min (3 mg), and 18.5 min (2.5 mg).

The major peak at 7.0 min was identified as the triacetylated product of compounds **2** and **3** on the basis of the following spectroscopic data: MS m/z 462 (M^+), 420 ($M - CH_2CO$), 360 ($420 - CH_3CO_2H$), 318 ($360 - CH_2CO$), 303 ($318 - CH_3$); ^1H NMR 0.94 (d, 6 H, $(CH_3)_2CH$), 1.55 (bs, 6 H, $(CH_3)_2COAc$), 1.98, 2.26, 2.28 (s, 9 H, OAc), 2.55 (s, 3 H, CH_3CO), 2.57, 2.78 (dd, 2 H, J = 6.7 Hz, H_{15a}, H_{15b}), 3.08 (ABX, 2 H, H_{7a}, H_{7b} J = 9.0, 14.5 Hz), 5.12 ppm (t, 1 H, J = 8.0 Hz, H-8); IR (CH_2Cl_2 film), 1777 (carbonyl aryl ester), 1738 (carbonyl aliphatic ester), 1695 cm^{-1} (aryl ketone); UV (MeOH) λ_{max} (ϵ) 241 (15 819), 307 nm (3935).

The peak at 15.7 min was identified as the diacetylated phenolic product of compounds **2** and **3** on the basis of the following spectroscopic data: m/z 420 (M^+); ^1H NMR 0.95 (d, 6 H, $(CH_3)_2CH$), 1.25, 1.36 (s, 6 H, $(CH_3)_2COH$), 2.24 (m, 1 H, H-16), 2.28, 2.25, (s, 6 H, OAc), 2.40, 2.78 (dd, 2 H, H_{15a}, H_{15b}), 2.41 (s, 3 H, CH_3CO), 3.08 (m, 2 H, H_{7a}, H7b), 4.80 ppm (t, 1 H, J = 9.3 Hz, H-8); IR (CH_2Cl_2 film), 1775 (carbonyl aryl ester), 1692 cm^{-1} (carbonyl aryl ketone); UV (MeOH) λ_{max} (ϵ) 241 (11 849), 305 nm (2718).

The peak at 18.5 min was identified as the diacetylated phenolic product of compounds **2** and **3**. The MS, ^1H NMR, IR, and UV data were similar to those for the peak at 15.7 min.

Single-Crystal X-ray Diffraction Analysis of Compound 2. Single-crystal X-ray diffraction analysis of **2** was carried out from three-dimensional intensity data collected on an Enraf-Nonius CAD-4 diffractometer [λ(Mo Kα) = 0.71073 Å] equipped with a graphite monochromator. Data were collected by a variable speed 2θ scan technique at 248 K. A total of 5583 data ($\pm h$, $+k$, $+l$) were collected ($2\theta \leq 60°$), of which 3623 were considered observed ($I \geq 3\sigma(I)$) after correction for Lorentz and polarization effects and after averaging symmetry equivalent reflections (R_{int} = 0.013). The molecule crystallizes as a hydrate from CH_3OH. Crystal data: triclinic, $P\bar{1}$, Z = 2, a = 9.852 (2), b = 11.563 (2), and c = 8.931 (2) Å, α = 107.51 (2)°, β = 110.54 (2)°, γ = 73.36 (2)°. The structure was solved by direct methods. Non-hydrogen atoms were refined with anisotropic vibrational parameters; all hydrogens were located from difference Fourier syntheses and were refined with isotropic temperature factors. Full matrix least-squares refinement (on F) converged to values of the standard crystallographic residuals, R = 0.043 and R_w = 0.055. An extinction coefficient refined to 1.24 (1) × 10^{-6}. The final difference Fourier map was featureless. Additional data have been deposited as supplementary material.

Acknowledgment. We thank Professor Sidney M. Hecht of the University of Virginia for supplying the plant material and also for helpful discussions during the course of the work.

Supplementary Material Available: Tables of fractional coordinates, thermal parameters, and interatomic distances and angles for compound **2** (3 pages). Ordering information is given on any current masthead page.

Formal Total Synthesis of 1β-Methylcarbapenem via a Novel Route to Deoxyamino Sugars[†,‡]

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Received June 27, 1988

Electrophilic amination of keto sugars provides an easy route to deoxyamino sugars. The usefulness of this procedure is demonstrated by the synthesis of lactone **5d**, a key intermediate for 1β-methylcarbapenem.

In carbohydrate transformations involving discrete electrophilic and nucleophilic partners, the sugar moiety usually functions in the former capacity.[1] However, nucleophilic displacements on sugar residues are comparatively difficult, owing to the inductive effect of the neighboring oxygen(s). This is exemplified in the preparation of deoxyamino sugars where the classical strategy involves displacement of a sulfonate ester with azide ion

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[‡]A preliminary account of this work has appeared: Udodong, U. E.; Fraser-Reid, B. *J. Org. Chem.* **1988**, *53*, 2131.

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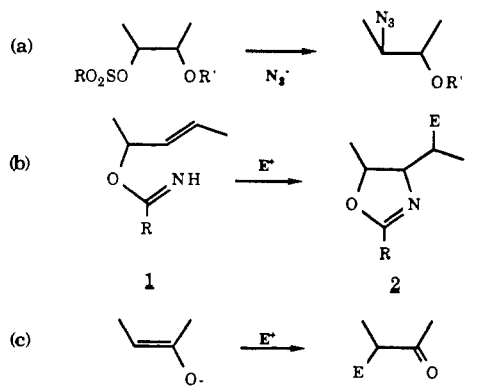
0022-3263/89/1954-2103$01.50/0

Scheme I



(Scheme I, eq a), the conditions for which are much more demanding than for simple alkyl sulfonates.[2] A strategy for avoiding this problem employs an electrophile-induced cyclization, **1** → **2** (eq b), the advantages of which have been amply demonstrated in our laboratory[3] and elsewhere.[4]

The role of the sugar moiety as a nucleophile (eq c) presents an intriguing, unexplored alternative to syntheses of modified sugars, particularly in view of the ready availability of suitable ketonic substrates.[5]

The foregoing concerns were brought into focus during attempts to develop a synthesis of lactone **5a**, a key intermediate for 1β-methylcarbapenem, **3a**.[6] The biological importance of this compound and of its analogue, thienamycin **3b**, has been well documented.[6,7] The seminal work of Merck scientists has demonstrated that "Melillo lactone" **5b** is a key intermediate for the synthesis of **3b**.[8] Accordingly, the methyl analogue **5a**, a demonstrated intermediate[6,9] for 1β-methylcarbapenem, **3a**, became our synthetic objective (Scheme II).

Lactone **5a** has equatorial substituents at C2, C3, and C4, and there is ample precedent for creating the first two by means of β-face hydrogenation of an exocyclic methylene group,[10] and by S_N2 displacement of a C3 axial sulfonate,[1d,11] respectively. By contrast, the C4 carboxyl group can be problematic, although earlier carbohydrate-based syntheses of Melillo lactone **5a** have developed multistep strategies for dealing with this stereocenter.[12]

In this paper, we report our studies related to compound **5a** during which novel strategies for installing deoxyamino substituents via electrophilic amination, and axial or equatorial C4 carboxyl synthons were developed.

The α-enone **8** seemed a promising precursor for lactone **5**, since it makes provisions for substitution at C2, C3, and C4. The attractiveness of this concept was enhanced by an updated version of the original synthesis,[13] which makes enone **8** available from methyl-α-D-glucopyranoside **6** in four steps (Scheme III, eq a). However, for certain transformations (vide infra), the *tert*-butyl glycoside **8c** was preferred, and its synthesis from the readily prepared enol acetate **9** was carried out as shown in Scheme III, eq b. Thus, the Ferrier rearrangement[14] afforded the glycosidated enol ester **10** in 87% yield. Prodigious experimentation showed that the optimum conditions for unmasking the α-enone involved treatment with triethylamine in ethylene glycol. This solvent offered the best compromise for dissolving the precursor and the resulting ketonic alcohol **8b**.

Our earlier studies on copper(I)-catalyzed additions[15] to **8a** suggested the retrosynthetic approach shown in Scheme IV as a means of tackling the C4 carboxyl synthon via the epimerization, **12** → **13**. However, a fortuitous observation, made during our studies on the addition of hydroxymethyl radicals to α-enones,[16-18] suggested a much simpler strategy. Thus, reaction of **8c** with $^{\bullet}CH_2OH$ gave the equatorial adduct **14a** as the principal product.

The difference in the stereochemical course of copper-mediated and radical additions to **8** is intriguing. Formation of **11** was expected, since cuprates usually promote axial addition. The mechanism of cuprate additions continues to be elusive,[19,20] but recently, Corey and Boaz advocated d orbital overlap with ψ_3^* of the enone,[21] as depicted in **16**, as a prelude to delivery of the alkyl substituent. Such complexation would be favored from the β face, since maximum overlap would be maintained as the system relaxes to the product **11**.

In the case of radical additions, where prior complexation is not a factor, the most favorable steric approach is from the α face, since the trajectory for β face addition lies across the ring.

Our recent work[16] has shown that the stereoselectivity of these radical additions is very sensitive to substitution at the γ-carbon. Thus, in **17a**, addition is entirely β face. With **17b**, it is 50:50, whereas with **17c** it is mainly α face. In view of the last result, addition to **8c** can be expected to be predominantly anti to the γ-substituent (i.e., CH_2OTBs)—as was indeed observed with the preponderant formation of **14a**.

With **14** in hand, a classical strategy for the C3 amino group (Scheme V) envisaged S_N2 displacement (**19** → **20**) with azide ion.[11] However, provisions for such an operation

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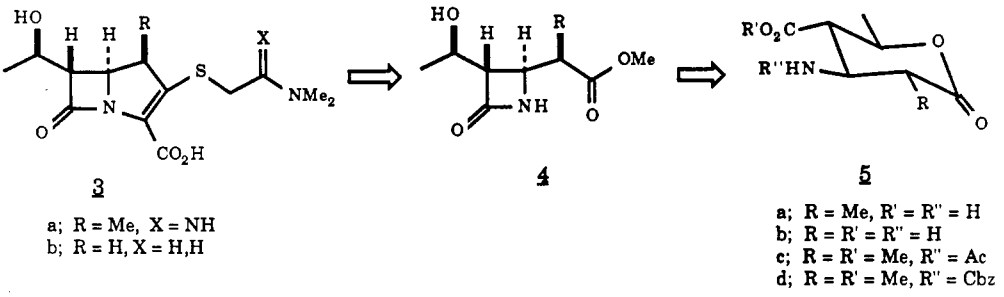
Scheme II



3

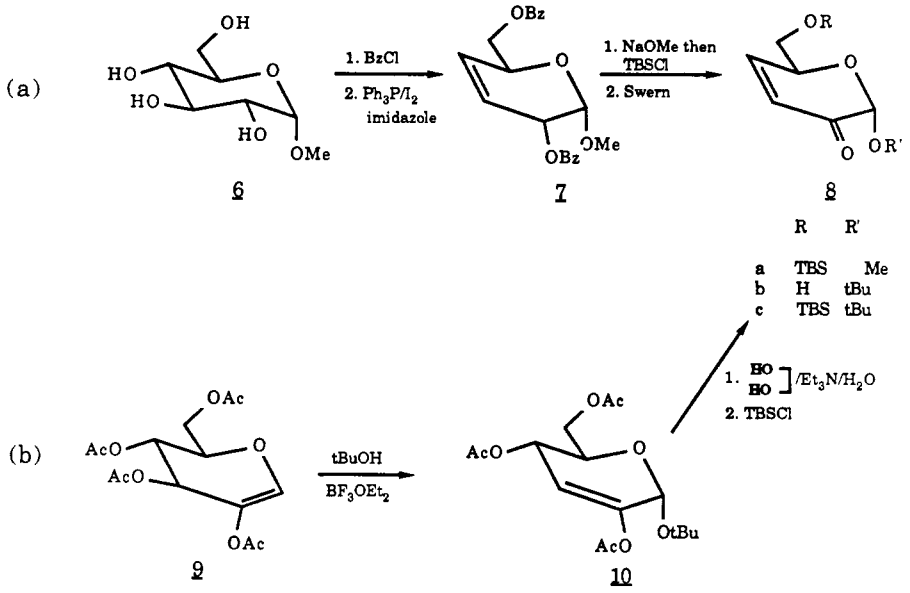
a; R = Me, X = NH
b; R = H, X = H,H

4

5

a; R = Me, R' = R'' = H
b; R = R' = R'' = H
c; R = R' = Me, R'' = Ac
d; R = R' = Me, R'' = Cbz

Scheme III



6

7

8

	R	R'
a	TBS	Me
b	H	tBu
c	TBS	tBu

9

10

would clearly demand several steps. By contrast, electrophilic amination should involve a single step (**14** → **21**), equatorial orientation being expected on the basis of thermodynamic control.

Of the several electrophilic amination protocols examined,[22] the one reported by Trimble and Vederas[23] proved best for our purposes. Nevertheless, the initial experiments were discouraging because deprotonation with a wide variety of bases caused either reduction of the carbonyl group to the equatorial alcohol or the production of intractable mixtures. However, potassium *tert*-butoxide had no undesirable effects, and quenching of the resulting potassium enolate with dibenzyl azodicarboxylate (DBAD) led to a single hydrazine adduct, **22**, in 94% isolated yield (Scheme VI). The proton NMR spectra of all compounds containing the (carbobenzyloxy)hydrazine moiety were assignable only after reductive cleavage and protection of the resulting amine as its acyl or Cbz derivative.

At this point, the C3 and C4 substituents had been introduced in a much simpler way than would have been possible using the classical strategy **14** → **18** → **19** → **20** outlined in Scheme V.

Since the hydrazino linkage would have to be cleaved reductively, it seemed judicious to establish the C2-CH_3 simultaneously. Therefore, a C2-methylene group was required. However, compound **22** failed to react with methylenetriphenylphosphorane at room temperature, and higher temperatures caused destruction. The Lombardo reagent, $ZnCH_2Br_2TiCl_4$,[24] also proved unavailing.

The epimeric hydroxymethyl silane mixture **23** was readily prepared. Although standard Peterson protocols[25] did not induce elimination, reaction with thionyl chloride in pyridine caused formation of the olefin **25a** and the vinyl silane **25b** in a 3:1 ratio. Protodesilylation[26] of the latter to the former could not be effected. Hydrogenation of **25a** over Raney nickel, followed by N-acetylation, then led to an inseparable mixture of **26a** and **27a** in a 3:1 ratio. The N-Cbz derivatives, **26b** and **27b**, could be obtained likewise as an inseparable mixture in a 5:1 ratio.

Interestingly, the disappointing ratio in the last reaction could be improved dramatically by conducting the hydrogenolysis and hydrogenation steps separately. Thus, when the hydrazine **23** was first converted to the acetamide **24** and then to the olefin **28a**, hydrogenation afforded **26a** and **27a** in a ratio greater than 10:1, as compared with a 3:1 mixture from **25a**.

With the asymmetric centers of 1β-methylcarbapenem properly incorporated into **26**, we were now in a position to elaborate this structure to the Melillo lactone analogue **5**. DIBAL treatment of a **26**/**27** mixture removed the pivaloyl protecting group and allowed chromatographic

(22) See for example: (a) Reed, J. N. Snieckus, V. *Tetrahedron Lett.* **1983**, *24* 3795. (b) Leffler, J. E.; Tsuno, Y. *J. Org. Chem.* **1963**, *28*, 902. (c) Colvin, E. W.; Kirby, G. W.; Wilson, A. C. *Tetrahedron Lett.* **1982**, *23*, 3835. (d) Baldwin, J. E.; Adlington, R. M.; Jones, R. H.; Schofield, C. J.; Zarocostas, C.; Greengrass, C. W. *J. Chem. Soc., Chem. Commun.* **1985**, 194.

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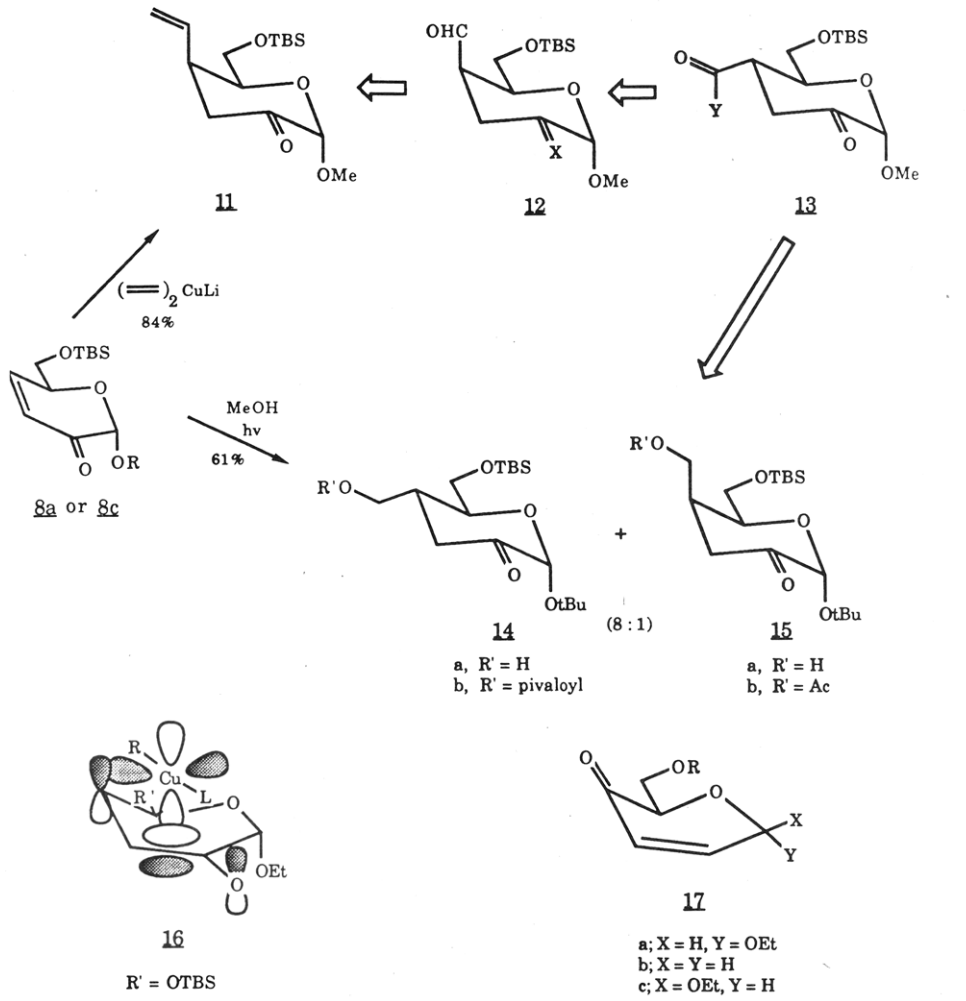
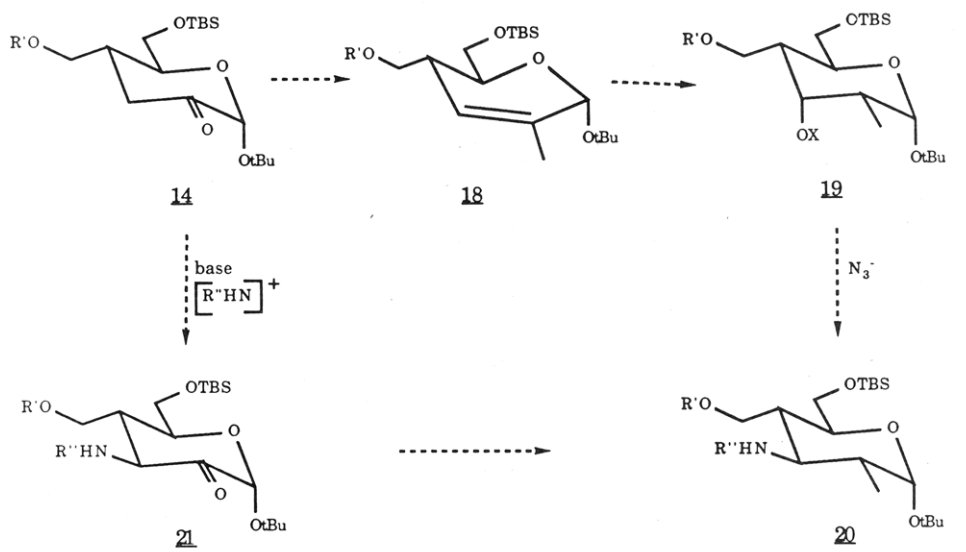
Scheme IV



Scheme V



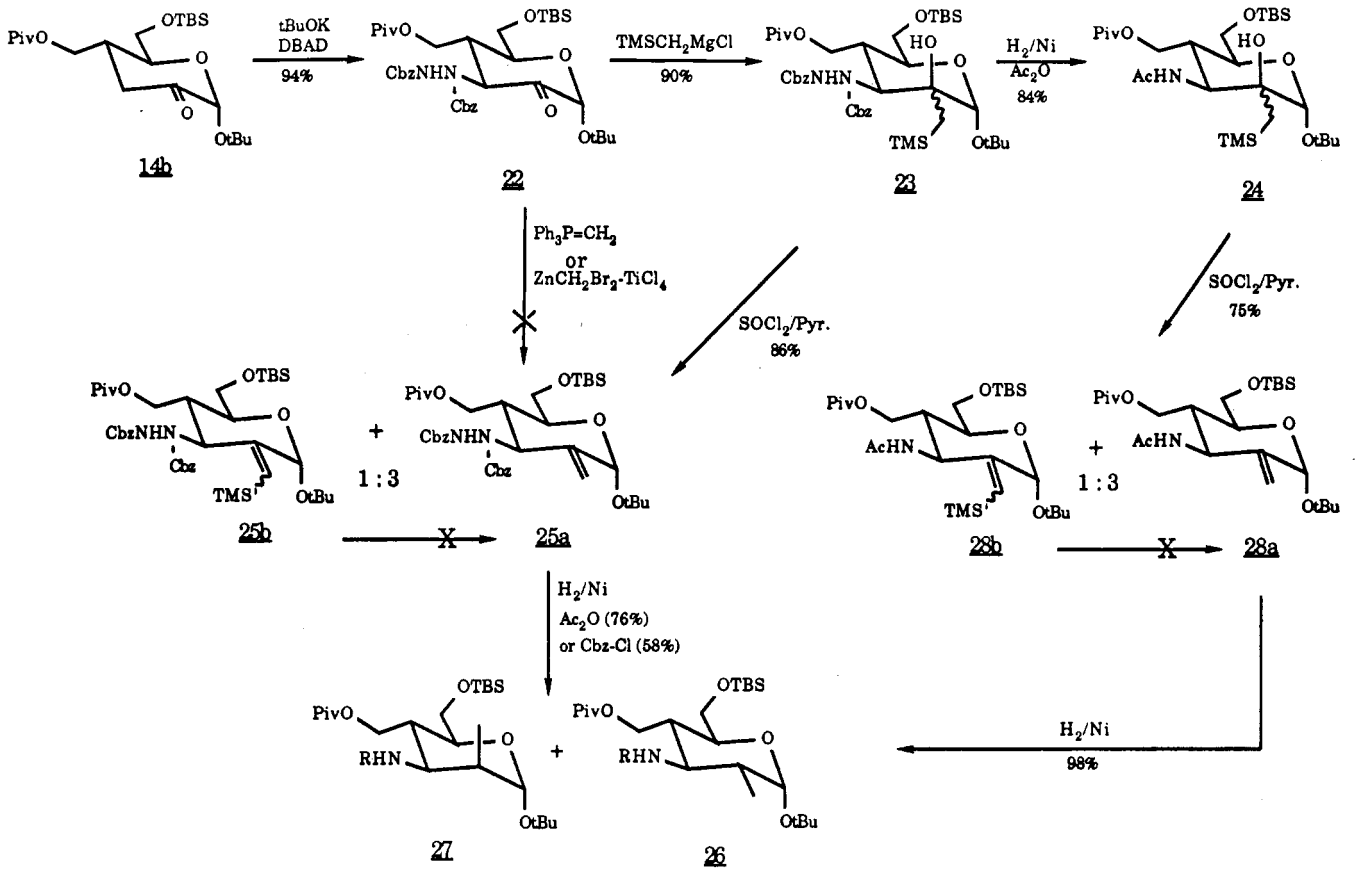
separation of the isomers. The resulting hydroxy compound, **30**, was then converted into **5** by the standard operations shown in Scheme VII. Attempted removal of the acetyl group from **5c** either by selective hydrolysis or with Meerwein's salt[27] was unrewarding. On the other hand, the Cbz analogue **5d** was obtained smoothly, and since the conversion of this compound into β-methylcarbapenem has already been demonstrated,[9a] our preparation of **5d** constitutes a formal total synthesis of the antibiotic.

Experimental Section

General Procedures. Melting points were determined in capillary tubes with a Büchi Model 510 melting point apparatus

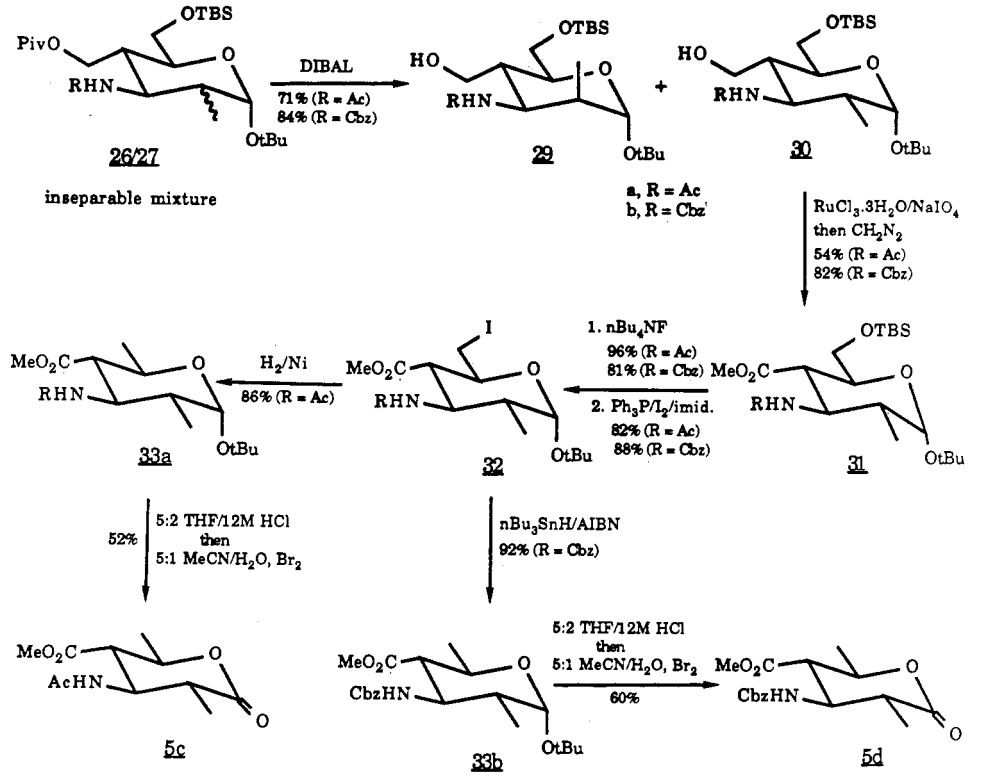
(27) Hanessian, S. *Tetrahedron Lett.* **1967**, 1549.

Scheme VI



a, R = Ac (1:3 from 25a, <1:10 from 28a)
b, R = Cbz (1:5)

Scheme VII



and are uncorrected. Elemental analyses were performed by M-H-W Laboratories (Phoenix, AZ). IR spectra were recorded on a Perkin-Elmer 298 instrument with sodium chloride plates for thin films of liquids, syrups, or solids in Nujol mulls. Optical rotations were determined at the sodium D line with a Perkin-Elmer 241 polarimeter. ^{1}H NMR spectra were recorded with a Varian XL-300 NMR spectrophotometer. The solvent used was $CDCl_3$ with internal tetramethylsilane or $CHCl_3$ as the standard.

The coupling constants were verified by homonuclear decoupling experiments. The progress of all reactions was monitored by thin-layer chromatography (TLC), which was performed on aluminum plates precoated with silica gel HF-254 (0.2-mm layers) containing a fluorescent indicator (Merck, 5539). Detection was by UV (254 nm), followed by charring with sulfuric acid spray, or with a solution of ammonium molybdate(VI) tetrahydrate (12.5 g), and cerium(IV) sulfate tetrahydrate (5.0 g) in 10% aqueous sulfuric acid (500 mL). Flash chromatography was performed with Kiesselgel 60 (230–400 mesh, Merck) silica gel.

1,5-Anhydro-2,3,4,6-tetra-*O*-acetyl-D-*arabino*-hex-1-enitol (9). Crude tetra-*O*-acetyl-α-D-glucopyranosyl bromide[28] (235.5 g, 0.61 mol) in 300 mL of dry acetonitrile containing n-Bu_4NBr (23.55 g, 0.073 mol) was cooled to 0 °C and treated dropwise over 2 h with diethylamine (177.4 mL, 1.71 mol) at 0 °C. After the addition, the resulting orange solution was stirred at 0 °C for 15 min and at room temperature for 1 h. The resulting black solution was then diluted with 300 mL of chloroform before being washed with 400 mL of cold saturated aqueous sodium bicarbonate. The chloroform solution was dried (Na_2SO_4) and concentrated at reduced pressure, and the residue (200 g) was flash chromatographed on silica gel (70:30 petroleum ether/EtOAc). The product was recrystallized from ether/petroleum ether to obtain a white solid (83 g, 41% yield): R_f 0.30 (70:30 petroleum ether/EtOAc); mp 61–62 °C; $[\alpha]^{22}_D$ −32.66° (*c* 1.24, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 2.05 (s, 3 H), 2.08 (s, 3 H), 2.09 (s, 6 H), 4.22 (dd, 1 H, J = 11.3, 2.8 Hz, H6), 4.37 (m, 1 H, H5), 4.42 (dd, 1 H, J = 11.3, 6.3 Hz, H6′), 5.22 (dd, 1 H, J = 5.6, 4.3 Hz, H4), 5.55 (d with long-range coupling to H5, 1 H, J = 4.3 Hz, H3), 6.72 (s, 1 H, H1). Anal. Calcd for $C_{14}H_{18}O_9$: C, 50.91; H, 5.49. Found: C, 51.00; H, 5.55.

***tert*-Butyl 2,4,6-Tri-*O*-acetyl-3-deoxy-α-D-*erythro*-hex-2-enopyranoside (10).** The enol acetate **9** (20.0 g, 60.55 mol) in 40 mL of dry methylene chloride containing 22.84 mL (242.2 mmol, 4 equiv) of dry tBuOH was treated dropwise at 0 °C with 3.72 mL (30.24 mmol, 0.5 equiv) of BF_3OEt_2. The reaction, which slowly went from light yellow to dark orange, was stirred at room temperature for 82 h or until most of the starting material was consumed, as indicated by TLC (65:35 petroleum ether/EtOAc). On diluting with 100 mL of methylene chloride and recooling to 0 °C, 50 mL of saturated aqueous sodium bicarbonate was added carefully, and the mixture was stirred for 5 min. The methylene chloride layer was decanted. The aqueous layer was extracted three times with methylene chloride. The combined organic solution was washed with saturated aqueous sodium chloride and dried over sodium sulfate. Flash chromatography of the concentrated residue (silica gel, 80:20 petroleum ether/EtOAc) gave 18.17 g (87% yield) of **10**: R_f 0.55 (80:20 petroleum ether/EtOAc); mp 64.65 °C (recrystallized from EtOH); $[\alpha]^{21}_D$ +79.48° (*c* 1.35, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 1.25 (s, 9 H), 2.04 (s, 3 H), 2.08 (s, 3 H), 2.14 (s, 3 H), 4.17 (m, 3 H, H5 + H6), 5.30 (s, 1 H, H1), 5.41 (m, 1 H, H4), 5.67 (d, 1 *H*, J = 2.1 Hz, H3). Anal. Calcd for $C_{16}H_{24}O_8$: C, 55.81; H, 7.02. Found: C, 56.03; H, 7.07.

***tert*-Butyl 3,4-Dideoxy-α-D-*glycero*-hex-3-enopyranosid-2-ulose (8b).** The triacetate **10** (6.0 g, 17.47 mmol) in 12 mL of MeOH was treated with 300 mL of 1:1:3 mixture of ethylene glycol/triethylamine/water and stirred at room temperature for 40 min. The resulting reddish orange solution was then extracted four times with 100 mL of methylene chloride. The combined organic solution was washed with saturated aqueous NaCl solution, dried (Na_2SO_4), and concentrated at reduced pressure. The residual oil was purified by flash chromatography on silica gel (60:40 petroleum ether/EtOAc) to obtain 1.4 g (40% yield) of the hydroxy enone as an unstable, yellow liquid: R_f 0.30 (70:30 petroleum ether/EtOAc); $[\alpha]^{19}_D$ +49.87° (*c* 1.55, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 1.21 (s, 12 H), 3.79 (m, 3 H, H6 + OH), 4.72 (m, 1 H, H5), 5.14 (s, 1 H, H1), 6.18 (br, dd, 1 H, J = 10.4, 2.4 Hz, H4), 6.98 (dd, 1 H, J = 10.5, 1.6 Hz, H3). Anal. Calcd for $C_{10}H_{16}O_4$: C, 59.98; H, 8.05. Found: C, 59.75; H, 7.89.

***tert*-Butyl 6-*O*-(*tert*-Butyldimethylsilyl)-3,4-dideoxy-α-D-*glycero*-hex-3-enopyranosid-2-ulose (8c).** To a solution of the alcohol **8b** (0.56 g, 2.81 mmol) in 5 mL of methylene chloride containing 0.9 mL (11.25 mmol, 4 equiv) of dry pyridine was added 0.55 g (3.65 mmol, 1.3 equiv) of *tert*-butyldimethylsilyl chloride. After being stirred for 19 h at room temperature, the reaction mixture was diluted with 10 mL of methylene chloride and washed with 5 mL of saturated aqueous sodium bicarbonate. The organic layer was removed. The aqueous layer was extracted three times with methylene chloride. The combined methylene chloride solution was washed with brine, dried over sodium sulfate, and concentrated in vacuo. Silica gel flash chromatography (96:4 petroleum ether/EtOAc) of the residual oil gave 0.63 g (72% yield) of **8c** as a colorless liquid: R_f 0.39 (96:4 petroleum ether/EtOAc); IR (neat) 1710, 1620 cm^{-1}; $[\alpha]^{19}_D$ −12.33° (*c* 1.40, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 0.10 (s, 6 H), 0.89 (s, 9 H), 1.29 (s, 9 H), 3.40 (dd, 1 H, J = 10.1, 7.0 Hz, H6), 3.82 (dd, 1 H, J = 10.0, 5.8 Hz, H6′), 4.60 (m, 1 H, H5), 5.10 (s, 1 H, H1), 6.14 (br dd, 1 H, J = 10.5, 2.4 Hz, H4), 7.10 (dd, 1 H, J = 10.5, 1.5 Hz, H3). Anal. Calcd for $C_{16}H_{30}O_4Si$: C, 61.10; H, 9.61. Found: C, 60.97; H, 9.52.

***tert*-Butyl 6-*O*-(*tert*-Butyldimethylsilyl)-3,4-dideoxy-4-*C*-(hydroxymethyl)-α-D-*erythro*-hexopyranosid-2-ulose (14a) and *tert*-Butyl 6-*O*-(*tert*-Butyldimethylsilyl)-3,4-dideoxy-4-*C*-(hydroxymethyl)-α-D-*threo*-hexopyranosid-2-ulose (15a).** A solution of the enone **8c** (1.0 g, 3.18 mmol) in 127 mL of absolute MeOH (freshly opened bottle used without purification) containing 193 mg (1.06 mmol, $^1/_3$ equiv) of benzophenone (recrystallized from absolute EtOH) was placed in a Pyrex tube (diameter = 16.5 cm, length = 19 cm). A condenser was attached, and the solution was degassed by bubbling argon through for 10 min. The reaction was positioned 10 cm from a 300-nm UV lamp (450-W Hanovia mercury lamp in a Pyrex sleeve contained in a water-cooled immersion well). The solution was irradiated for 60 min until most of the starting material was consumed, as indicated by TLC (70:30 CH_2Cl_2/petroleum ether). At the end of the reaction, the solution was allowed to cool before the solvent was evaporated off at reduced pressure. Flash chromatography (silica gel, 80:20 petroleum ether/EtOAc) of the residual oil gave 0.602 g of **14a** (R_f 0.55, 80:20 petroleum ether/EtOAc) and 0.222 g of a mixture of **15a** (R_f 0.33, 80:20 petroleum ether/EtOAc; 0.28, 90:10 CH_2Cl_2/EtOAc) and pinacole byproducts. This mixture was rechromatographed with 90:10 CH_2Cl_2/EtOAc to isolate 76 mg of pure **15a**. Total yield of **14a** + **15a** = 61.5%.

For compound **14a**: IR (neat) 3900 (br), 1735 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 0.10 (s, 3 H), 0.90 (s, 9 H), 1.29 (s, 9 H), 2.20 (m, 1 H, H4), 2.30 (dd, 1 H, J = 14.3, 4.3 Hz, H3 equatorial), 2.60 (dd, 1 H, J = 14.3, 12.8 Hz, H3 axial), 3.42 (dd, 1 H, J = 7.8, 5.3 Hz, OH), 3.52 (dd, 1 H, J = 11.6, 3.5 Hz, H4′[a]), 3.58 (dd, 1 H, J = 11.9, 5.9 Hz, H4[b]), 3.78 (dd, 1 H, J = 10.8, 7.0 Hz, H6), 3.82 (dd, 1 H, J = 10.8, 3.6 Hz, H6′), 4.10 (m, 1 H, H5), 4.88 (s, 1 H, H1); $[\alpha]^{20}_D$ +47.24° (*c* 1.45, $CHCl_3$); IR (neat) 3900 (br), 1735 cm^{-1}. Anal. Calcd for $C_{17}H_{34}O_5Si$: C, 58.92; H, 9.89. Found: C, 59.17; H, 9.66.

For compound **15a**: R_f 0.46 (90:10 petroleum ether/EtOAc); $[\alpha]^{20}_D$ +62.44° (*c* 1.19, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 0.10 (s, 6 H), 0.90 (s, 9 H), 1.30 (s, 9 H), 2.03 (s, 3 H), 2.50 (br, d, 1 H, J = 14.9 Hz, H3), 2.86 (dd, 1 H, J = 14.9, 6.1 Hz, H3′), 3.64 (dd, 1 H, J = 10.5, 6.8 Hz, H6), 3.74 (dd, 1 H, J = 10.6, 6.4 Hz, H6′), 4.06 (dd, 1 H, J = 11.4, 7.3 Hz, H4′[a]), 4.24 (dd, 1 H, J = 11.4, 5.3 Hz, H4′[b]), 4.58 (dt, 1 H, J = 6.5, 2.5 Hz, H5), 4.90 (s, 1 H, H1). Anal. Calcd for $C_{19}H_{36}O_6Si$: C, 58.70; H, 9.34. Found: H, 58.60; C, 9.23.

***tert*-Butyl 6-*O*-(*tert*-Butyldimethylsilyl)-3,4-dideoxy-4-*C*-[(trimethylacetoxy)methyl]-α-D-*erythro*-hexopyranosid-2-ulose (14b).** A solution of the keto alcohol **14a** (3.74 gm, 10.78 mmol) in 56 mL of methylene chloride containing pyridine (3.49 mL, 43.1 mmol, 4 equiv) was dropwise added pivaloyl chloride (1.59 mL, 12.94 mmol, 1.2 equiv) at 0 °C under argon. After the addition, the solution was stirred at room temperature for 12 h. The reaction was then quenched with saturated aqueous ammonium chloride (6 mL). The organic layer was separated, and the aqueous layer was extracted three times with methylene chloride. The combined organic solution was shaken with saturated aqueous sodium bicarbonate and brine. The dried (Na_2SO_4) solution was concentrated in vacuo. Flash chromatography (silica gel, 95:5 petroleum ether/EtOAc) of the residual matter gave 3.73 g (80% yield) of the pivalate as a colorless liquid: R_f 0.27 (95:5 petroleum ether/EtOAc); $[\alpha]^{20}_D$ +47.21° (*c* 1.04, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 0.05 (s, 6 H), 0.90 (s, 9 H), 1.20 (s, 9 H), 1.25 (s, 9 H), 2.40 (dd, 1 H, J = 13.6, 4.9 Hz, H3), 2.43–2.55 (m, 1 H,

(28) Lemieux, R. U. *Methods Carbohydr. Chem.* **1963**, *2*, 221.

H4), 2.74 (dd, 1 H, J = 13.8, 11.7 Hz, H3'), 3.79 (d, 2 H, J = 3.6 Hz, H6), 4.03 (dd, 1 H, J = 11.4, 3.7 Hz, H4'[a]), 4.12 (dd, 1 H, J = 11.4, 5.1 Hz, H4'[b]), 4.18 (td, 1 H, J = 9.7, 3.7 Hz, H5), 4.90 (s, 1 H, H1). Anal. Calcd for $C_{22}H_{42}O_6Si$: C, 61.36; H, 9.83. Found: C, 61.24; H, 9.82.

***tert*-Butyl 6-*O*-(*tert*-Butyldimethylsilyl)-3-(*N*,*N*'-dicarbobenzyloxyhydrazino)-3,4-dideoxy-4-*C*-[(trimethylacetoxy)methyl]-α-D-*arabino*-hexopyranosid-2-ulose (22).** Potassium *tert*-butoxide was prepared as described in *Organic Syntheses* (1963, Collect. Vol. IV, p 132). Thus, dry *t*-BuOH (16 mL) was treated with 36 mg (9.21 mmol) of potassium (cut and weighed in hexanes). The mixture was heated to a gentle reflux under argon until all the potassium dissolved (2 h). Dry THF (16 mL) was then added to give a 0.288 M solution of *t*-BuOK.

A solution of the ketone **14b** (1.38 g, 3.20 mmol) in 50 mL of dry THF was cooled under argon to −78 °C and dropwise treated with 12.8 mL (1.15 equiv) of the *t*-BuOK solution. The reaction was allowed to warm to 0 °C over 20 min. After the resulting yellow solution was recooled to −78 °C, DBAD (1.11 g, 3.72 mmol, 1.16 equiv) dissolved in 1 mL of THF was added over 1 min while the temperature was maintained at −78 °C. An orange solution resulted. Stirring was continued at the same temperature for 10 min. The reaction was then quenched with 5 mL of saturated aqueous ammonium chloride and allowed to warm to room temperature. Ether (30 mL) was added. The organic phase was separated. The aqueous phase was extracted three times with ether. The combined organic solution was washed with brine, dried (Na_2SO_4), and concentrated at reduced pressure. The residual oil was flash chromatographed on silica gel (90:10 petroleum ether/EtOAc) to obtain 2.2 g (94% yield) of **22** (white solid): R_f 0.24 (95:5 petroleum ether/EtOAc); $[\alpha]^{20}_D$ +41.37° (c 1.09, $CHCl_3$). Anal. Calcd for $C_{38}H_{56}N_2O_{10}Si$: C, 62.61; H, 7.74; N, 3.84. Found: C, 62.50; H, 7.71; N, 3.86.

***tert*-Butyl 3-Acetamido-6-*O*-(*tert*-butyldimethylsilyl)-3,4-dideoxy-4-*C*-[(trimethylacetoxy)methyl]-α-D-*arabino*-hexopyranosid-2-ulose (21, R'' = Ac, R' = pivaloyl).** The keto hydrazine **22** (200 mg, 0.27 mmol) in 10 mL of absolute MeOH containing 0.1 mL of HOAc was hydrogenated overnight over Raney nickel at normal pressure. Afterwards, the mixture was filtered through Celite to remove the catalyst. The filtrate was concentrate in vacuo to remove MeOH and HOAc. The crude amine was stirred for 2 h in MeOH containing excess (0.5 mL) acetic anhydride. The reaction was then concentrated at reduced pressure and filtered through a bit of silica gel (using 1:1 methylene chloride/EtOAc) to remove any solid matter. Flash chromatography of the reconcentrated filtrate on silica gel (80:20 methylene chloride/acetone) gave 116.7 mg (86% yield) of the acetamido alcohol as a 1:1.8 (axial/equatorial) mixture at C-2.

For the equatorial hydroxy compound: R_f 0.23 (80:20 methylene chloride/acetone); ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.05 (s, 6 H), 0.89 (s, 9 H), 1.19 (s, 9 H), 1.28 (s, 9 H), 1.78 (m, 1 H, H4), 2.02 (s, 1 H), 3.40 (dd, 1 H, J = 10.4, 3.7 Hz, H2), 3.69–3.80 (m, 3 H, H6 + OH), 3.94–4.10 (m, 1 H, H5), 4.10 (dd, 1 H, J = 11.8, 3.9 Hz, H4'[α]), 4.17 (dd, 1 H, J = 11.8, 2.0 Hz, H4'[b]), 4.30 (m, 1 H, H3), 5.12 (d, 1 H, J = 3.8 Hz, H1), 5.42 (d, 1 H, J = 9.2 Hz, NH). Anal. Calcd for $C_{24}H_{47}NO_7Si$: C, 58.86; H, 9.67; N, 2.86. Found: C, 58.85; H, 9.59; N, 2.80.

For the axial hydroxy compound: R_f 0.36 (80:20 methylene chloride/acetone); ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.07 (s, 6 H), 0.90 (s, 9 H), 1.20 (s, 9 H), 1.23 (s, 9 H), 1.21 (m, 1 H, H4), 2.01 (s, 3 H), 3.50 (m, 1 H, H2), 3.69–3.78 (m, 3 H, H6 + OH), 3.97 (dd, 1 H, J = 11.9, 3.4 Hz, H4'[a]), 4.04 (td, 1 H, J = 10.8, 3.1 Hz, H5), 4.16 (dd, 1 H, J = 11.8, 2.2 Hz, H4'[b]), 4.48 (m, 1 H, H3), 5.04 (d, 1 H, J = 2.1 Hz, H1), 5.90 (d, 1 H, J = 9.7 Hz, NH). Anal. Calcd for $C_{24}H_{47}NO_7Si$: C, 58.86; H, 9.67; N, 2.86. Found: C, 58.64; H, 9.46; N, 2.90.

The acetamido alcohol (80.7 mg, 0.16 mmol) in 1 mL of methylene chloride was added to a mixture of PDC (186 mg, 3 equiv) and acetic anhydride[29] (0.013 mL, 2 equiv) in 2 mL of methylene chloride under argon. The mixture was heated under reflux for 1 h. Ether (6 mL) was then added. The mixture was filtered through Florisil. The filtrate was concentrated in vacuo. The residual oil was flash chromatographed on silica gel (80:20 petroleum ether/acetone) to obtain 49.9 mg (62% yield) of the ketone **21** (R'' = Ac, R' = pivaloyl): R_f 0.28 (80:20 petroleum ether/acetone, streaks); ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.05 (s, 6 H), 0.89 (s, 9 H), 1.25 (s, 9 H), 1.28 (s, 9 H), 2.06 (s, 3 H), 2.17 (tt, 1 H, J = 11.0, 2.7 Hz, H4), 3.80 (m, 2 H, H6), 4.02 (dd, 1 H, J = 11.9, 2.8 Hz, H4'[a]), 4.16 (dd, 1 H, J = 11.9, 2.4 Hz, H4'[b]), 4.48 (td, 1 H, J = 10.2, 3.1 Hz, H5), 5.11 (s, 1 H, H1), 5.28 (dd, 1 H, J = 11.9, 8.6 Hz, H3), 5.90 (d, 1 H, J = 8.7 Hz, NH). Anal. Calcd for $C_{24}H_{45}NO_7Si$: C, 59.11; H, 9.30; N, 2.87. Found: C, 57.32; H, 8.64; N, 2.79.

***tert*-Butyl 6-*O*-(*tert*-Butyldimethylsilyl)-3-(*N*,*N*'-dicarbobenzyloxyhydrazino)-3,4-dideoxy-4-*C*-[(trimethylacetoxy)methyl]-2-*C*-[(trimethylsilyl)methyl]-α-D-manno- and -glucopyranoside (23).** The keto hydrazine **22** (1.13 g, 1.55 mmol) in 22 mL of anhydrous ether was cooled under argon to 0 °C. [(Trimethylsilyl)methyl]magnesium chloride (7.0 mL of a 1 M ether solution, 4.5 equiv) was added dropwise over 5 min. The resulting slightly yellow solution was then stirred at room temperature for 6 h. The reaction was quenched with 20 mL of saturated aqueous ammonium chloride and diluted with 10 mL of ether. The organic layer was separated. The aqueous layer was extracted three times with ether. The combined ether solution was washed with saturated aqueous sodium chloride solution, dried over sodium sulfate, and concentrated at reduced pressure. The residual semisolid was then flash chromatographed on silica gel (98:2 methylene chloride/EtOAc) to isolate 1.15 g (90% yield) of the two upper running spots (R_f 0.29 and 0.41, 98:2 CH_2Cl_2/EtOAc; R_f 0.34 and 0.47, 90:10 petroleum ether/EtOAc).

***tert*-Butyl 3-Acetamido-6-*O*-(*tert*-butyldimethylsilyl)-3,4-dideoxy-4-*C*-[(trimethylacetoxy)methyl]-2-*C*-[(trimethylsilyl)methyl]-α-D-manno- and -glucopyranoside (24).** A solution of **23** (2.15 g, 2.63 mmol) in 10 mL of absolute MeOH containing three drops of acetic acid as hydrogenated for 12 h over Raney nickel. The catalyst was then filtered off. The crude product was concentrated to complete dryness in vacuo. This was taken up in 5 mL of MeOH and stirred for 2 h with excess (0.5 mL) acetic anhydride. The reaction was then concentrated at reduced pressure. The residual matter was flash chromatographed on silica gel (70:30 petroleum ether/EtOAc) to obtain 1.27 g (84% yield) of pure **24**: R_f 0.44 (65:35 petroleum ether/EtOAc); ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.04 (s, 3 H), 0.06 (s, 3 H), 0.09 (s, 9 H), 0.70 (d, 1 H, J = 14.6 Hz, TMS-CH), 0.90 (s, 9 H), 1.05 (dd, 1 H, J = 14.6, 2.4 Hz, TMS-CH), 1.22 (s, 9 H), 1.28 (s, 9 H), 2.04 (s, 3 H), 3.75 (m, 3 H, H6 + OH), 3.98 (m, 2 H, H4'), 4.12 (dd, 1 H, J = 11.9, 1.9 Hz, H5), 4.44 (dd, 1 H, J = 12.0, 10.1 Hz, H3), 4.72 (s, 1 H, H1), 5.42 (d, 1 H, J = 9.9 Hz, NH). Anal. Calcd for $C_{28}H_{57}NO_7Si_2$: C, 58.39; H, 9.98; N, 2.43. Found: C, 58.51; N, 9.87; N, 2.48.

***tert*-Butyl 3-Acetamido-6-*O*-(*tert*-butyldimethylsilyl)-2,3,4-trideoxy-4-*C*-[(trimethylacetoxy)methyl]-2-*C*-methylene-α-D-*arabino*-hexopyranoside (28a) and *tert*-Butyl 3-Acetamido-6-*O*-(*tert*-butyldimethylsilyl)-2,3,4-trideoxy-4-*C*-[(trimethylacetoxy)methyl]-2-*C*-[(trimethylsilyl)methylene]-α-D-*arabino*-hexopyranoside (28b).** A solution of **24** (13.2 mg, 0.023 mmol) in 1 mL of dry pyridine was cooled to 0 °C under argon. Thionyl chloride (3 equiv) was added. The resulting yellow solution was stirred at 0 °C for 15 min. The reaction was then quenched with 0.5 mL of saturated aqueous sodium bicarbonate. Solvent was removed at reduced pressure. The residue was diluted with methylene chloride (5 mL) and water (2 mL). The organic layer was removed, and the aqueous layer was extracted three times with methylene chloride. The combined organic solution was washed with brine, dried over sodium sulfate, and concentrated at reduced pressure. The crude olefin was purified by flash chromatography on silica gel, eluting first with 80:20 petroleum ether/EtOAc to isolate 2.4 mg (19% yield) of **28b** and then with 65:35 petroleum ether/EtOAc to isolate 6.3 mg (57% yield) of **28a**.

For compound **28b**: R_f 0.52 (65:25 petroleum ether/EtOAc); $[\alpha]^{20}_D$ +31.50° (c 1.06, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.03 (s, 6 H), 0.16 (s, 9 H), 0.85 (s, 9 H), 1.22 (s, 9 H), 1.30 (s, 9 H), 1.75 (m, 1 H, H4), 2.10 (s, 3 H), 3.75 (m, 2 H, H6), 4.00 (dd, 1 H, J = 11.8, 4.2 Hz, H4'[a]), 4.21 (m, 2 H, H4'[b] + H5), 5.10 (m, 1 H, H3), 5.22 (d, 1 H, J = 2.0 Hz, vinyl H), 5.36 (d, 1 H, J = 9.6 Hz, NH), 5.65 (s, 1 H, H1). Anal. Calcd for $C_{28}H_{55}NO_6Si_2$: C, 60.28; H, 9.94; N, 2.51. Found: C, 60.47; H, 10.14; N, 2.24.

(29) Anderson, F.; Samuelsson, B. *Carbohydr. Res.* **1984**, *129*, C1–C3.

For compound **28a**: R_f 0.30 (65:35 petroleum ether/EtOAc); $[\alpha]^{20}_D$ +69.43° (*c* 1.23, $CHCl_3$); ^1H NMR (300 Hz, $CDCl_3$) δ 0.05 (s, 6 H), 0.86 (s, 9 H), 1.20 (s, 9 H), 1.25 (s, 9 H), 1.85 (m, 1 H, H4), 2.05 (s, 3 H), 3.70 (dd, 1 H, *J* = 11.2, 4.4 Hz, H6), 3.78 (dd, 1 H, *J* = 11.2, 2.6 Hz, H6'), 3.98 (dd, 1 H, *J* = 11.6, 4.4 Hz, H4'[a]), 4.07 (m, 1 H, H5), 4.16 (dd, 1 H, *J* = 11.6, 3.5 Hz, H4'[b]), 4.90 (s, 1 H, vinyl H), 4.93 (m, 1 H, H3), 4.96 (s, 1 H, vinyl H), 5.43 (s, 1 H, H1), 5.57 (d, 1 H, *J* = 9.6 Hz, NH). Anal. Calcd for $C_{25}H_{47}NO_6Si$: C, 61.82; H, 9.75; N, 2.88. Found: C, 61.63; H, 9.54; N, 2.76.

***tert*-Butyl 6-*O*-(*tert*-Butyldimethylsilyl)-3-(*N*,*N*'-dicarbobenzyloxyhydrazino)-2,3,4-trideoxy-4-*C*-[(trimethylacetoxy)methyl]-2-*C*-methylene-α-D-*arabino*-hexopyranoside (25a) and *tert*-Butyl 6-*O*-(*tert*-Butyldimethylsilyl)-3-(*N*,*N*'-dicarbobenzyloxyhydrazino)-2,3,4-trideoxy-4-*C*-[(trimethylacetoxy)methyl]-2-*C*-[(trimethylsilyl)methylene]-α-D-*arabino*-hexopyranoside (25b).** The alcohol **23** (330 mg, 0.40 mmol) in 22 mL of dry pyridine was cooled to 0 °C under argon. To this solution was dropwise added thionyl chloride (0.09 mL, 3 equiv). The reaction was stirred at 0 °C for 15 min. The cooling bath was removed, and stirring was continued for an additional 10 min. Cold saturated aqueous sodium bicarbonate was then added to the resulting yellow solution until there was no more evolution of gas bubbles. Azeotropic evaporation with toluene gave a residue, which was diluted with methylene chloride and water. After separating the organic phase, the aqueous layer was extracted three times with methylene chloride. The organic solution was washed with brine, dried over sodium sulfate, and concentrated at reduced pressure. Flash chromatography of the crude product on silica gel (90:10 petroleum ether/EtOAc) gave 69.5 mg of **25b** (R_f 0.39) and 190.2 mg of **25a** (R_f 0.24). Total yield = 86%.

***tert*-Butyl 3-Acetamido-6-*O*-(*tert*-butyldimethylsilyl)-2,3,4-trideoxy-4-*C*-(hydroxymethyl)-2-*C*-methyl-α-D-mannopyranoside (29a) and *tert*-Butyl 3-Acetamido-6-*O*-(*tert*-butyldimethylsilyl)-2,3,4-trideoxy-4-*C*-(hydroxymethyl)-2-*C*-methyl-α-D-glucopyranoside (30a). (a) From 28a.** A solution of **28a** (294.2 mg, 0.60 mmol) in 5 mL of MeOH was hydrogenated over Raney nickel for 1.5 h. The catalyst was then filtered off. The filtrate was concentrate and dried in vacuo. The resulting crude **26a**/**27a** (289.6 mg, 98% yield) inseparable mixture (R_f 0.33, CH_2Cl_2/EtOAc) was dissolved in 20 mL of dry methylene chloride. After the mixture was cooled under argon to −78 °C, DIBAL (2.37 mL of a 1 M hexanes solution, 4 equiv) was dropwise added over 5 min. The reaction was stirred for 10 min at −78 °C before being quenched with 1 mL of MeOH. The cooling bath was removed. The mixture was stirred at room temperature for 0.5 h with 6 L of saturated aqueous sodium potassium tartrate. Afterwards, a few drops of water was added to dissolved any suspended solid. The organic solution was decanted. The aqueous layer was extracted three times with chloroform. The combined organic solution was dried over sodium sulfate and then concentrated at reduced pressure. The residue was chromatographed on silica gel, eluting first with 90:10 CH_2Cl_2/acetone and then with 85:15 CH_2Cl_2/acetone to isolate 171.14 mg of **30a** and 9.96 mg of **29a** (70% yield from **28a**).

For compound **30a**: R_f 0.46 (80:20 methylene chloride/acetone); $[\alpha]^{20}_D$ +115.51° (*c* 1.07, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 0.07 (s, 6 H), 0.87 (s, 12 H, Si-*t*-Bu + C2-Me), 1.22 (s, 9 H), 1.44 (m, 1 H, H4), 1.69 (m, 1 H, H2), 2.06 (s, 3 H), 3.49–3.64 (m, 2 H, H4'), 3.73 (dd, 1 H, *J* = 11.4, 3.1 Hz, H6), 3.86–3.94 (m, 2 H, H6' + OH), 4.05–4.16 (m, 2 H, H3 + H5), 4.98 (d, 1 H, *J* = 3.4 Hz, H1), 5.60 (d, 1 H, *J* = 9.2 Hz, NH; ^1H NMR of **30a** + D_2O (300 MHz, $CDCl_3$) δ 0.07 (s, 6 H), 0.87 (s, 12 H), 1.20 (s, 9 H), 1.40 (m, 1 H, H4), 1.68 (m, 1 H, H2), 2.05 (s, 3 H), 3.51 (dd, 1 H, *J* = 12.9, 3.7 Hz, H4'[a]), 3.59 (dd, 1 H, *J* = 12.9, 1.7 Hz, H4'[b]), 3.72 (dd, 1 H, *J* = 11.3, 3.2 Hz, H6), 3.89 (dd, 1 H, *J* = 11.3, 3.4 Hz, H6'), 4.04–4.14 (overlapping dd and q, 2 H, H3 + H5), 4.97 (d, 1 H, *J* = 3.4 Hz, H1), 5.18 (d, 1 H, *J* = 10.0 Hz, NH). Anal. Calcd for $C_{20}H_{41}NO_5Si$: C, 59.51; H, 10.24; N, 3.47. Found: C, 59.60; H, 10.24; N, 3.68.

(b) From 25a. The compound **25a** (290 mg, 0.39 mmol) in 10 mL of MeOH containing 3 drops of acetic acid was hydrogenated over Raney nickel for 8 h. The catalyst was then filtered off. The concentrated and dried crude product was taken up in 5 mL of MeOH and stirred with excess (0.5 mL) of acetic anhydride. After 2 h, the reaction was concentrated to complete dryness at reduced pressure to give 148.3 mg of **26a**/**27a** (76% yield). This in 5 mL of dry methylene chloride was cooled to −78 °C under argon and dropwise treated with DIBAL (1.2 mL of a 1 M hexanes solution, 4 equiv). The solution was stirred for 10 min at −78 °C before being quenched with 0.5 mL of MeOH. Extractive workup and flash chromatography as before gave 63.33 mg (52% yield) of **30a** and 19.86 mg (16% yield) of **29a**. Total yield = 52% from **25a**.

***tert*-Butyl 6-*O*-(*tert*-Butyldimethylsilyl)-4-(carbobenzyloxyamino)-2,3,4-trideoxy-4-*C*-(hydroxymethyl)-2-*C*-methyl-α-D-mannopyranoside (29b) and *tert*-Butyl 6-*O*-(*tert*-Butyldimethylsilyl)-4-(carbobenzyloxyamino)-2,3,4-trideoxy-4-*C*-(hydroxymethyl)-2-*C*-methyl-α-D-glucopyranoside (30b).** The hydrazino olefin **25a** (185 mg, 0.25 mmol) in 3 mL of MeOH containing three drops of AcOH was hydrogenated over Raney nickel for 6 h or until no more starting material could be seen by TLC (85:15 petroleum ether/EtOAc). The catalyst was then removed by filtration through Celite. The filtrate was concentrated to complete dryness at reduced pressure to give 103.7 mg. The crude amine (98.7 mg) in 5 mL of absolute MeOH containing 0.077 mL (2.5 equiv) of triethylamine was cooled to 0 °C under argon and dropwise treated with 0.063 mL (2 equiv) of benzyl chloroformate. After 1.5 h of stirring at 0 °C, solvent was removed at reduced pressure. The residual oil was flash chromatographed on silica gel, eluting first with 95:5 petroleum ether/EtOAc to remove excess benzyl chloroformate and then with 90:10 petroleum ether/EtOAc to isolate 85.3 mg of **26b**/**27b** as an inseparable mixture (R_f 0.34, 90:19 petroleum ether/EtOAc).

This pivalate in 4 mL of methylene chloride was cooled to −78 °C under argon and treated dropwise with 0.59 mL (4 equiv) of DIBAL (1 M solution in hexanes). After 10 min, the reaction was quenched with MeOH and worked up as before. The crude product was flash chromatographed on silica gel, eluting first with 90:10 petroleum ether/EtOAc to isolate 50.8 mg (70% yield) of **30b** and then with 80:20 petroleum ether/EtOAc to isolate 10.2 mg (14% yield) of **29b**. Total yield = 84%, 51% from **25a**.

For compound **30b**: R_f 0.43 (85:15 petroleum ether/EtOAc); $[\alpha]^{19}_D$ +79.26° (*c* 0.82, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 0.07 (s, 6 H), 0.90 (overlapping s and d, 12 H, Si-*t*-Bu + C2-Me), 1.23 (s, 9 H), 1.45 (m, 1 H, H4), 1.65 (m, 1 H, H2), 3.62 (m, 3 H, H4' + OH), 3.75 (dd, 1 H, *J* = 11.2, 3.6 Hz, H6), 3.76–3.85 (m, 1 H, H3 overlaps with H6'), 3.86 (dd, 1 H, *J* = 11.2, 3.4 Hz, H6'), 4.07 (td, 1 H, *J* = 10.2, 3.4 Hz, H5), 4.45 (d, 1 H, *J* = 9.9 Hz, NH), 4.96 (d, 1 H, *J* = 3.1 Hz, H1), 5.13 (dd, 2 H, *J* = 18.8, 12.2 Hz, Cbz-CH_2), 7.35 (m, 5 H, aromatic). Anal. Calcd for $C_{26}H_{45}NO_6Si$: C, 62.99; H, 9.15; N, 2.83. Found: C, 63.11; H, 8.99; N, 2.76.

For compound **29b**: R_f 0.25 (85:15 petroleum ether/EtOAc); ^1H NMR (300 MHz, $CDCl_3$) δ 0.06 (s, 6 H), 0.89 (s, 9 H), 0.97 (d, 3 H, *J* = 7.1 Hz, C2-Me), 1.22 (s, 9 H), 1.75 (m, 1 H, H4), 1.90 (m, 1 H, H2), 3.52–3.64 (m, 2 H, H4' + OH), 3.71 (dd, 1 H, *J* = 11.2, 3.8 Hz, H6), 3.84 (dd, 1 H, *J* = 11.2, 3.4 Hz, H6'), 4.01 (td, 1 H, *J* = 10.1, 3.5 Hz, H5), 4.27 (dt, 1 H, *J* = 10.4, 4.4 Hz, H3), 4.83 (d, 1 H, overlaps with H1, NH), 4.85 (d, 1 H, *J* = 1.9 Hz, H1), 5.12 (dd, 2 H, *J* = 16.0, 12.1 Hz, Cbz-CH_2), 7.36 (m, 5 H, aromatic).

***tert*-Butyl 3-Acetamido-6-*O*-(*tert*-butyldimethylsilyl)-4-*C*-carbomethoxy-2,3,4-trideoxy-2-*C*-methyl-α-D-glucopyranoside (31a).** The alcohol **30a** (251.4 mg, 0.62 mmole) was dissolved in acetonitrile (2 mL) and CCl_4 (2 mL).[30] Water (3 mL) was added, followed by $NaIO_4$ (532.87 mg, 4.1 equiv). After the mixture was stirred to complete dissolutioning of the periodate, a catalytic amount of $RuCl_3 \cdot 3H_2O$ was added whereupon the colorless solution immediately turned dark. TLC (80:20 methylene chloride/acetone) in 10 min showed complete consumption of the starting material. The mixture was then diluted with methylene chloride. The organic layer was separated. The aqueous layer was extracted three times with methylene chloride. The combined organic solution was dried (Na_2SO_4). The concentrated black residue was taken up in ether and filtered through Celite. The filtrate was concentrated to complete dryness at reduced pressure and then treated with an ether solution of diazomethane. The solvent was then blown off with argon. The residual matter was flash chromatographed on silica gel, eluting first with 95:5 methylene chloride/acetone to remove colored impurities and then

(30) Carlsen, P. H. J.; Katsuki, T.; Martin, V. S.; Sharpless, K. B. *J. Org. Chem.* **1981**, *46*, 3936.

with 90:10 methylene chloride/acetone to collect 143.8 mg (54% yield) of the ester. This yield was not optimized; the acid seemed to be soluble in water and may have been lost during the extraction (for example, see the preparation of **31b**): R_f 0.33 (90:10 methylene chloride/acetone); $[\alpha]^{20}_D$ +116.19° (*c* 0.84, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 0.04 (s, 6 H), 0.87 (overlapping s and d, 12 H, Si-*t*-Bu + C2-Me), 1.25 (s, 9 H), 1.63 (m, 1 H, H2), 1.95 (s, 3 H), 2.36 (t, 1 H, *J* = 10.8 Hz, H4), 3.56 (dd, 1 H, *J* = 10.9, 3.8 Hz, H6), 3.65 (s, 3 H), 3.66 (dd, 1 H, *J* = 10.9, 4.8 Hz, H6′), 4.27 (dd, 1 H, *J* = 10.4, 4.4 Hz, H5), 4.32 (unresolved ddd resembling a quartet, H3), 4.98 (d, 1 H, *J* = 3.4 Hz, H1), 5.10 (d, 1 H, *J* = 9.9 Hz, NH). Anal. Calcd for $C_{21}H_{41}NO_6Si$: C, 58.43; H, 9.57; N, 3.24. Found C, 58.65; H, 9.56; N, 3.16.

***tert*-Butyl 6-*O*-(*tert*-Butyldimethylsilyl)-3-(carbobenzyloxyamino)-4-*C*-carbomethoxy-2,3,4-trideoxy-2-*C*-methyl-α-D-glucopyranoside (31b).** To the alcohol **30b** (43.7 mg, 0.088 mmol) in 1.75 mL of 1:1:1.5 CH_3CN/CCl_4/water was added $NaIO_4$ (77.30 mg, 4.1 equiv). The mixture was stirred to dissolve the periodate. A catalytic amount of $RuCl_3 \cdot 3H_2O$ was then added. After 15 min of stirring, methylene chloride was added. The organic layer was decanted. The aqueous layer was extracted three times with methylene chloride. The aqueous solution was then concentrated at reduced pressure, and the solid residue was washed with methylene chloride. The combined methylene chloride solution was dried over sodium sulfate and concentrated in vacuo to complete dryness. The resulting black residue was treated with diazomethane solution in ether. After 10 min, solvent was blown off with argon. The crude ester was flash chromatographed on silica gel, eluting with 90:10 petroleum ether/EtOAc to isolate 37.7 mg (82% yield) of the ester **31b**: R_f 0.29 (90:10 petroleum ether/EtOAc); $[\alpha]^{20}_D$ +61.68° (*c* 0.89, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 0.03 (s, 6 H), 0.85 (overlapping s and d, 12 H, Si-*t*-Bu + C2-Me), 1.23 (s, 9 H), 1.66 (m, 1 H, H2), 2.42 (t, 1 H, *J* = 10.9 Hz, H4), 3.55 (s, 3 H), 3.59 (dd, 1 H, *J* = 10.9, 3.9 Hz, H6), 3.63 (dd, 1 H, *J* = 10.9, 5.0 Hz, H6′), 4.04 (unresolved ddd resembling a quartet, H3), 4.25 (td, 1 H, *J* = 10.4, 4.5 Hz, H5), 4.50 (d, 1 H, *J* = 9.7 Hz, NH), 4.97 (d, 1 H, *J* = 3.2 Hz, H1), 5.06 (dd, 2 H, *J* = 14.3, 12.4 Hz, Cbz-CH_2), 7.33 (m, 5 H, aromatic).

***tert*-Butyl 3-Acetamido-4-*C*-carbomethoxy-2,3,4,6-tetradeoxy-6-iodo-2-*C*-methyl-α-D-glucopyranoside (32a).** The compound **31a** (21.0 mg, 0.048 mmol) in 1 mL of dry THF was cooled to 0 °C under argon and treated with *n*-Bu_4NF (0.10 mL of a 1.1 M THF solution, 2.2 equiv). The reaction was stirred for 70 min at room temperature before concentrating in vacuo. Flash chromatography of the residue on silica gel (70:30 CH_2Cl_2/acetone) gave 14.9 mg (96% yield) of the free C6-alcohol: R_f 0.31 (70:39 CH_2Cl_2/acetone); $[\alpha]^{19}_D$ +124.41° (*c* 0.68, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 0.89 (d, 3 H, *J* = 6.8 Hz, C2-Me), 1.25 (s, 9 H, O-*t*-BU), 1.69 (m, 2 H, H2 + OH), 1.96 (s, 3 H, Ac), 2.51 (t, 1 H, *J* = 10.9 Hz, H4), 3.54 (dd, 1 H, *J* = 11.9, 4.8 Hz, H6), 3.64 (dd, 1 H, *J* = 11.7, 2.8 Hz, H6′), 3.68 (s, 3 H, CO_2Me), 4.30 (td, 1 H, *J* = 10.8, 4.0 Hz, H5), 4.34 (unresolved ddd resembling a quartet, 1 H, overlaps with H5, H3), 5.02 (d, 1 H, *J* = 3.4 Hz, H1), 5.23 (d, 1 H, *J* = 9.6 Hz, NH).

The alcohol (14.0 mg, 0.044 mmol) in 1 mL of 1:1 THF/benzene was treated under argon with imidazole (15.91 mg, 5.3 equiv) and triphenylphosphine (37.02 mg, 3.2 equiv), followed by iodine (33.58 mg, 3 equiv).[31] The reaction was stirred at room temperature for 3.5 h. After diluting with methylene chloride, the mixture was shaken with aqueous sodium thiosulfate to remove the yellow iodine color. The methylene chloride layer was removed, and the aqueous layer was extracted three times with methylene chloride. The combined organic solution was washed with brine, dried (Na_2SO_4), and concentrated at reduced pressure. Flash chromatography of the residual matter on silica gel (80:20 petroleum ether/acetone) gave 15.5 mg (82% yield) of the iodide **32a**: R_f 0.40 (75:25 petroleum ether/acetone), 0.45 (85:15 CH_2Cl_2/acetone); $[\alpha]^{19}_D$ +109.2° (*c* 0.75, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 0.87 (d, 3 H, *J* = 6.8 Hz), 1.24 (s, 9 H), 1.67 (m, 1 H, H2), 1.96 (s, 3 H), 2.38 (t, 1 H, *J* = 10.7 Hz, H4), 3.15 (dd, 1 H, *J* = 10.9, 5.7 Hz, H6), 3.28 (dd, 1 H, *J* = 10.9, 2.7 Hz, H6′), 3.69 (s, 3 H), 3.99 (ddd, 1 H, *J* = 10.1, 5.6, 2.8 Hz, H5), 4.36 (unresolved ddd resembling a quartet, 1 H, H3), 5.02 (d, 1 H, *J* = 3.4 Hz, H1), 5.14 (d, 1 H, *J* = 9.3 Hz, NH).

***tert*-Butyl 3-(Carbobenzyloxyamino)-4-*C*-carbomethoxy-2,3,4,6-tetradeoxy-6-iodo-2-*C*-methyl-α-D-glucopyranoside (32b).** A solution of **31b** (37.7 mg, 0.072 mmol) in 1.8 mL of dry THF was cooled under argon to 0 °C and treated dropwise with *n*-Bu_4NF (0.14 mL of a 1.1 M solution in THF, 2.2 equiv). After 1 h of stirring at 0 °C, the solvent was removed at reduced pressure. Flash chromatography of the residual oil on silica gel (75:25 petroleum ether/acetone) gave 23.9 mg (81% yield) of pure C6-alcohol: R_f 0.28 (75:25 petroleum ether/acetone); ^1H NMR (300 MHz, $CDCl_3$) δ 0.91 (d, 3 H, *J* = 6.8 Hz), 1.24 (s, 9 H), 1.75 (m, 1 H, H2), 1.85 (m, 1 H, OH), 2.57 (t, 1 H, *J* = 10.9 Hz, H4), 3.47–3.66 (m, 2 H, H6), 3.57 (s, 3 H), 4.06 (unresolved ddd resembling a quartet, 1 H, H3), 4.28 (td, 1 H, *J* = 10.7, 4.0 Hz, H5), 4.58 (d, 1 H, *J* = 9.7 Hz, NH), 5.01 (d, 1 H, *J* = 3.2 Hz, H1), 5.07 (dd, 2 H, *J* = 14.0, 12.4 Hz, Cbz-CH_2), 7.34 (m, 5 H, aromatic).

The alcohol (23.9 mg 0.058 mmol) in 1.2 mL of 1:3 THF/benzene was treated under argon with imidazole (21.06 mg, 5.3 equiv) and triphenylphosphine (48.99 mg, 3.2 equiv), followed by iodine (44.44 mg, 3 equiv). The mixture was stirred for 1 h at room temperature before diluting with methylene chloride. The mixture was then washed with aqueous sodium thiosulfate to remove excess iodine. The organic solution was decanted, and the aqueous layer was extracted three times with methylene chloride. The combined organic solution was shaken with brine, dried (Na_2SO_4), and concentrated at reduced pressure. Flash chromatography of the residual solid on silica gel (85:15 petroleum ether/acetone) gave 26.7 mg (88% yield) of **32b**: R_f 0.35 (85:15 petroleum ether/acetone); ^1H NMR (300 MHz, $CDCl_3$) δ 0.90 (d, 3 H, *J* = 6.6 Hz), 2.44 (t, 1 H, *J* = 10.6 Hz, H4), 3.14 (dd, 1 H, *J* = 10.9, 6.0 Hz, H6), 3.26 (dd, 1 H, *J* = 10.9, 2.7 Hz, H6′), 3.96–4.30 (m, 2 H, H3 + H5), 4.55 (d, 1 H, *J* = 9.5 Hz, NH), 5.02 (d, 1 H, *J* = 3.3 Hz, H1), 5.07 (dd, 2 H, *J* = 19.0, 12.4 Hz, Cbz-CH_2), 7.36 (m, 5 H, aromatic).

***tert*-Butyl 3-Acetamido-4-*C*-carbomethoxy-2,3,4,6-tetradeoxy-2-*C*-methyl-α-D-glucopyranoside (33a).** The iodide **32a** (52.0 mg, 0.121 mmol) in 5 mL of dry EtOAc containing Et_3N (0.034 mL, 2 equiv) was hydrogenated over Raney nickel for 1.5 h. The catalyst was then filtered off. The filtrate was concentrated at reduced pressure. The residual oil was flash chromatographed on silica gel (75:25 petroleum ether/acetone) to obtain 31.6 mg (86% yield) of **33a**: R_f 0.37 (75:25 petroleum ether/acetone), 0.29 (85:15 methylene chloride/acetone); $[\alpha]^{20}_D$ +137.96° (*c* 0.59, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 0.87 (d, 3 H, *J* = 6.8 Hz, C2-Me), 1.11 (d, 3 H, *J* = 6.3 Hz, C5-Me), 1.25 (s, 9H, O-*t*-Bu), 1.65 (m, 1 H, H2), 1.95 (s, 3 H, Ac), 2.19 (t, 1 H, *J* = 10.7 Hz, H4), 3.67 (s, 3 H, CO_2Me), 4.30 (m, 2 H, H3 + H5), 4.94 (d, 1 H, *J* = 3.4 Hz, H1), 5.11 (d, 1 H, *J* = 9.8 Hz, NH). Anal. Calcd for $C_{15}H_{27}NO_5$: C, 59.78; H, 9.03; N, 4.65. Found: C, 59.76; H, 9.14; N, 4.56.

***tert*-Butyl 3-(Carbobenzyloxyamino)-4-*C*-carbomethoxy-2,3,4,6-tetradeoxy-2-*C*-methyl-α-D-glycopyranoside (33b).** The iodide **32b** (16.2 mg, 0.031 mmol) in 1 mL of dry benzene was treated with *n*-Bu_3SnH (0.017 mL, 2 eq) under argon. The solution was heated to reflux and then treated with a catalytic amount of AIBN. After 10 min of refluxing, the reaction was allowed to cool to room temperature. The solvent was then removed at reduced pressure. The residual oil was flash chromatographed on silica gel (97:3 methylene chloride/acetone) to isolate 11.3 mg (92% yield) of pure **33b**: R_f 0.28 (98:2 methylene chloride/acetone); $[\alpha]^{19}_D$ +82.45° (*c* 0.61, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 0.88 (d, 3 H, *J* = 6.8 Hz, C2-Me), 1.10 (d, 3 H, *J* = 6.2 Hz, C5-Me), 1.24 (s, 9 H), 1.70 (m, 1 H, H2), 2.26 (t, 1 H, *J* = 10.9 Hz, H4), 3.60 (s, 3 H), 4.00 (unresolved ddd resembling a quartet, 1 H, H3), 4.27 (m, 1 H, H5), 4.52 (d, 1 H, *J* = 9.3 Hz, NH), 4.93 (d, 1 H, *J* = 3.2 Hz, H1), 5.06 (s, 2 H, Cbz-CH_2), 7.34 (m, 5 H, aromatic).

3-Acetamido-4-*C*-carbomethoxy-2,3,4,6-tetradeoxy-2-*C*-methyl-D-glucono-1,5-lactone (5c). The compound **33a** (8.4 mg, 0.027 mmol) in 0.5 mL of THF was stirred with 0.2 mL of 12 M HCl for 12 h. Afterwards, two drops of water was added. The solution was then neutralized with solid sodium bicarbonate until there was no more evolution of gas bubbles. The mixture was filtered, the solid being washed with acetone. The filtrate was

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concentrated at reduced pressure. The residual solid was extracted with acetone. The extract was concentrated to give 6.4 mg (94% yield) of the lactol. This (5.0 mg) in 0.5 mL of MeCN and 0.1 mL of water was treated with excess bromine (three drops). Calcium carbonate (10 mg) was then added immediately. After 1 h of stirring at room temperature, the mixture was filtered through Celite, washing with MeCN. The filtrate was concentrated at reduced pressure. The residual oil was flash chromatographed on silica gel, eluting first with 90:10 methylene chloride/acetone to remove yellow impurities and then with 65:35 methylene chloride/acetone to collect 2.6 mg (52% yield) of the lactone **5c**: R_F 0.49 (65:35 methylene chloride/acetone); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.37 (d, 3 H, J = 7.1 Hz, C2-Me), 1.39 (d, 3 H, J = 6.2 Hz, C5-Me), 2.00 (s, 3 H, Ac), 2.62 (m, 1 H, H2), 2.78 (t, 1 H, J = 10.6 Hz, H4), 3.73 (s, 3 H, CO_2Me), 4.25 (ddd, J = 10.97, 10.97, 9.04 Hz, H3), 4.57 (m, 1 H, H5), 5.54 (d, 1 H, J = 8.1 Hz, NH).

3-(Carbobenzyloxyamino)-4-*C*-carbomethoxy-2,3,4,6-tetradeoxy-2-*C*-methyl-D-glucono-1,5-lactone (5d). The compound **33b** (11.3 mg, 0.02 mmol) in 0.5 mL of THF was stirred with 0.2 mL of 12 M HCl for 13 h. The reaction was then diluted with two drops of water and neutralized with solid sodium bicarbonate. The mixture was filtered, washing with THF. The filtrate was concentrated at reduced pressure to give a solid, which was extracted with THF. The THF solution was concentrated at reduced pressure to give the crude lactol. This was taken up in 0.5 mL of MeCN and 0.1 mL of water. Three drops of bromine was added, followed by 10 mg of calcium carbonate. The mixture was stirred for 1.5 h at room temperature before filtering through Celite and washing with MeCN. The filtrate was concentrated at reduced pressure, and the residue was flash chromatographed on silica gel (75:25 petroleum ether/acetone). The product was rechromatographed with methylene chloride/EtOAc (90:10) to obtain 5.8 mg (60% yield from **33b**) of the lactone **5d**: R_f 0.33 (75:25 petroleum ether/acetone), 0.25 (CH_2Cl_2/EtOAc); $[\alpha]^{20}_D$ +20.17° (c 0.58, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.36 (d, 3 H, J = 6.1 Hz, C2-Me, overlaps with C5-Me), 1.38 (d, 3 H, J = 6.9 Hz, C5-Me), 2.65 (m, 1 H, H2), 2.82 (t, 1 H, J = 10.9 Hz, H4), 3.63 (s, 3 H, CO_2Me), 3.92 (ddd, 1 H, J = 11.11, 11.11, 8.9 Hz, H3), 4.52 (m, 1 H, H5), 4.88 (d, 1 H, J = 8.5 Hz, NH), 5.08 (s, 2 H, Cbz-CH_2), 7.34 (m, 5 H, aromatic).

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Intramolecular Cycloadditions of Alkenes to Oxyallyl Zwitterions Generated from Photorearrangements of 2,5-Cyclohexadien-1-ones

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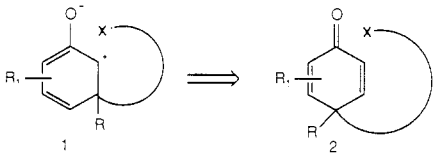
Photorearrangements of 2,5-cyclohexadien-1-ones containing a 3′-alkenyl substituent at C(4) provide intermediate alkenyl-substituted oxyallyl zwitterions **21** from which 5 + 2 cycloadditions give bridged cyclohexenones **22** and **23**. The occurrence of 3 + 2 cycloadditions to give dienol ethers **24** and bridged cyclopentanones **25** also is described.

We have reported that oxyallyl zwitterions **1** generated as transient intermediates from 2,5-cyclohexadien-1-ones **2** by two successive photorearrangements undergo intramolecular cycloaddition with tethered furans and alkyl azide substituents.[1] In these cycloadditions, the zwitterionophile X behaves as a four-electron component.

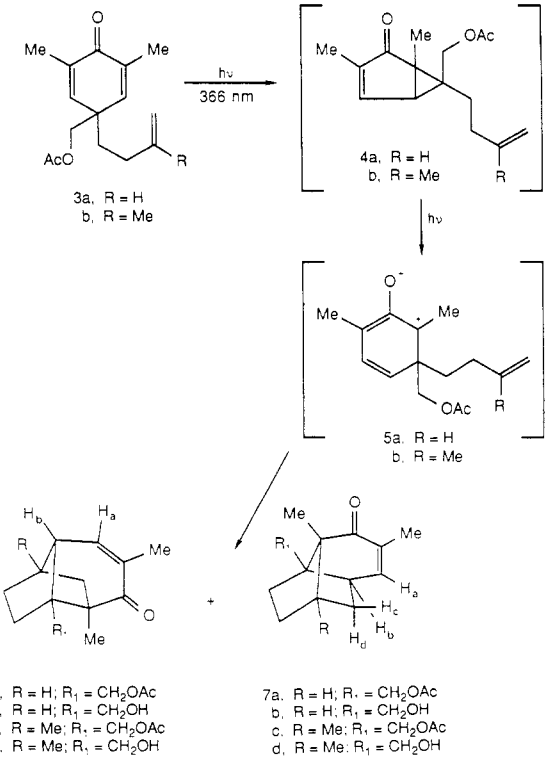


Herein, we report the complementary intramolecular cycloadditions of photogenerated zwitterions to alkene substituents (X = CR=CR_2).[2] These new tandem photorearrangement–cycloaddition processes are expected to have utility in carbocyclic and heterocyclic ring constructions.

Results and Discussion

As a result of previous work,[1,3] it was recognized that the group R in zwitterion **1** probably had to have a relatively low migration tendency to allow the cycloaddition process to be competitive with rearrangement to a phenol. Consequently, 4-(acetoxymethyl)-4-(3′-butenyl)-2,6-dimethyl-2,5-cyclohexadien-1-one (**3a**) was selected for initial study (Scheme I). Irradiation of a solution of **3a** in

Scheme I



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