

Lewis Acid Catalyzed Ring-Opening Reactions of Sugar-Derived Semicyclic *N,O*-Acetals

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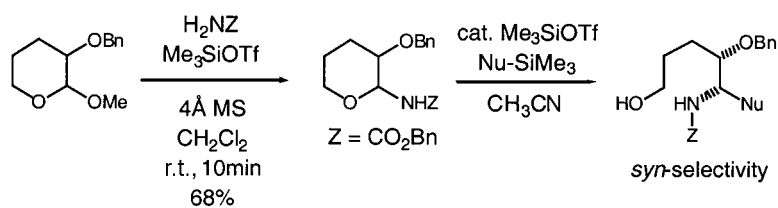
This paper is dedicated to Professor Dr. *Dieter Seebach* on the occasion of his 65th birthday

N-(Alkoxy carbonyl)-*N*-glycosides (polyoxygenated semicyclic *N,O*-acetals) were efficiently synthesized from regular acetyl or methyl glycosides (glucopyranoside, ribofuranoside, arabinofuranoside, and 2-deoxyribofuranoside) and a carbamate by treatment of trimethylsilyl trifluoromethanesulfonate and 4 Å molecular sieves. It was found that these *N*-glycosides underwent *Lewis* acid catalyzed ring-opening reactions with silylated nucleophiles to give ring-opened amino alcohols with good-to-high diastereoselectivity. The reactivity order, 2-deoxyribofuranoside > arabinofuranoside > ribofuranoside > glucopyranoside, was revealed. Ring-opening reductions were also investigated with silanes or diisobutylaluminum hydride. An appropriate reducing agent was found to be dependent on the *N*-glycosides used. A glycosidase inhibitor, (2*S*,3*R*,4*R*)-2-hydroxymethylpyrrolidine-3,4-diol (**7**) was synthesized by means of the reactions.

Introduction. – *N*-Glycosides (= semicyclic *N,O*-acetals with an exocyclic N-atom) are abundant in nature such as in nucleosides, *N*-glycopeptides, and glycolipids, and they play an important role in their biological activities [1]. Although they are often chemically synthesized *via* direct *N*-glycosylation of aza-nucleophiles (for example, azidotrimethylsilane), *N*-acylated aza-nucleophiles such as amides are less utilized due to their low nucleophilicity. *Kahne et al.* first reported that glycosyl sulfoxides serve as powerful glycosyl donors toward less reactive nucleophiles, including acetamide, in the presence of triflic anhydride [2]. However, the most common procedure for the synthesis of *N*-acylated-*N*-glycosides is acylation of glycosylamines [1c]. Meanwhile, we have recently found that direct *N*-glycosylation proceeded smoothly in the presence of trimethylsilyl trifluoromethanesulfonate (Me₃SiOTf) and 4-Å molecular sieves (4-Å MS), when simple monoxygenated glycosyl donors such as 2-methoxy-3-(benzyloxy)-tetrahydro-2*H*-pyran and carbamates as *N*-acylated aza-nucleophiles were used (*Scheme 1*) [3]. Moreover, the resulting *N*-(alkoxy carbonyl)-*N*-glycosides were found to undergo *Lewis* acid catalyzed ring-opening reactions with silylated nucleophiles (silyl enolates, allylsilanes, and trimethylsilyl isocyanide) to afford ring-opened products (1,4- or 1,5-amino alcohols) with high stereoselectivity. Along this line, we describe herein a further extension of the reactions to that of *sugar-derived* semicyclic *N,O*-acetals, which can afford polyoxygenated amino alcohols as useful intermediates for the synthesis of biologically important, polyoxygenated, N-containing compounds such as alkaloids. This report is the first systematic study of *Lewis* acid catalyzed ring-opening reactions of *N*-acyl-*N*-glycosides, while ring-opening alkylation or reduction of *N*-alkyl-*N*-glycosides including nucleosides with excess *Grignard* reagents or diisobu-

tylaluminium hydride [4]¹⁾ and a *Lewis* acid promoted ring-opening rearrangement of *N*-homoallyl-*N*-galactoside [6] or anomeric isomerization of nucleosides [7] or *N*-acyl-*N*-glycosides [8] have been reported.

Scheme 1. Preparation and Ring-Opening Reaction of Six-Membered Semicyclic *N,O*-Acetals



Results and Discussion. – At first, we investigated the feasibility of a series of the reactions with a glucose derivative (*Scheme 2*). Glucose-derived *N*-[(benzyloxy)carbonyl]-*N,O*-acetal **2a** was obtained in good yield from 1-*O*-acetyl-2,3,4,6-tetra-*O*-benzyl-*D*-glucose (**1a**) and benzyl carbamate (H_2NZ) according to the procedure that we described previously (see *Scheme 1*). Then, **2a** was subjected to the conditions of the Me_3SiOTf -catalyzed ring-opening reaction with the silyl enol ether **3B** derived from acetophenone. However, the desired ring-opened product **4aB** was obtained in low yield even after a prolonged reaction time, though good diastereoselectivity was observed. We speculated that the six-membered pyranose structure of **2a** might be stabilized due to the equatorial substituents at the positions C(2) to C(5) (*Fig. 1*). Thus, the assumed reactive intermediate, an acyclic *N*-acyliminium salt, could not be formed in sufficient amounts during the reaction²⁾³⁾.

Scheme 2. Preparation and Ring-Opening Reaction of *N*-Glucopyranoside **2a**

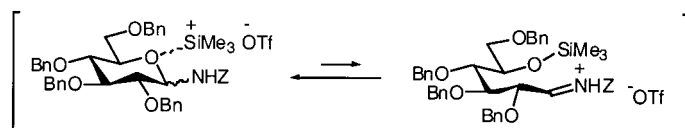
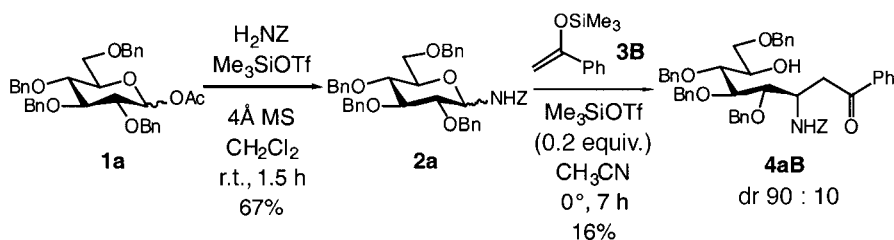
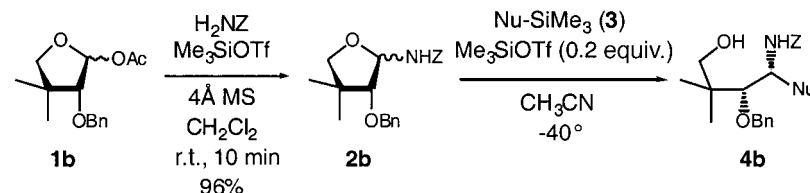


Fig. 1. Ring-opening of *N*-glucopyranoside **2a**

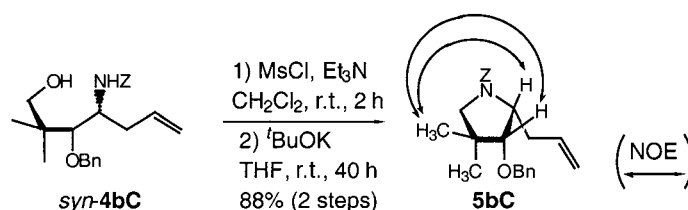
- 1) For ring-opening reactions of nucleosides by *Grignard* reagents or diisobutylaluminium hydride, see [5].
- 2) We have proposed the formation of an acyclic *N*-acyliminium ion as a reactive intermediate for the *Lewis* acid catalyzed ring-opening reactions, see [3c].
- 3) For a recent review on the chemistry of *N*-acyliminium ions, see [9].

Accordingly, we anticipated that *furanose*-derived *N,O*-acetals would be more reactive because the relatively high ring strain could be released by ring opening. Indeed, it was found that ring-opening reactions of (*R*)-pantolactone derivative **2b**, which was prepared in high yield from the corresponding 1-(acetyloxy)tetrahydrofuran **1b**, with silylated nucleophiles **3A–C** proceeded smoothly to give *syn*-amino alcohols **4bA–C** with good diastereoselectivity (Table 1). The configuration assignment of the allylation product **4bC** was made after conversion to pyrrolidine derivative **5bC** (Scheme 3). An NOE enhancement observed by NMR analysis of **5bC** (see *Exper. Part*) supported its 2,3-*cis* configuration, thus establishing the formation of the *syn*-product **4bC** as the major diastereoisomer. The relative configurations of other products were tentatively assigned by analogy. The stereochemistry of the reaction is consistent with our previous observation in reactions of six-membered *N,O*-acetals [3].

Table 1. Ring-Opening Reactions of a Pantolactone Derivative

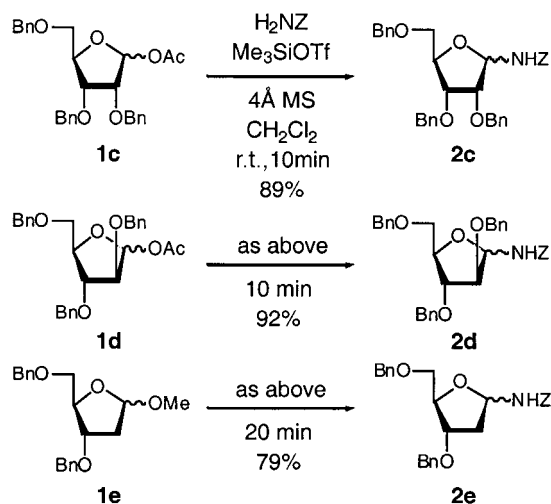


Nu-SiMe ₃ (3)	4b	Time/h	Yield/%	<i>syn/anti</i>
Me ₂ C=C(OSiMe ₃)(OMe) (3A)	4bA Nu = CMe ₂ CO ₂ Me	36	92	91 : 9
H ₂ C=C(OSiMe ₃)Ph (3B)	4bB Nu = CH ₂ COPh	16	94	90 : 10
H ₂ C=CHCH ₂ SiMe ₃ (3C)	4bC Nu = CH ₂ CH=CH ₂	20	72	89 : 11

Scheme 3. Configuration Assignment of Allylation Product *syn*-**4bC** by Conversion to **5bC**

Next, we set our investigation on the reactions of D-ribose, D-arabinose, and 2-deoxy-D-ribose derivatives. Formation of the corresponding *N,O*-acetals **2c–e** proceeded in high yields from regular furanosides **1c–e**, respectively (Scheme 4)⁴. Although use of the acetyloxy group as the leaving group is a key to obtain high yields of ribose and arabinose derivatives **2c** and **2d**, the methoxy group can be utilized for the *N*-glycosylation of the more reactive 2-deoxy-D-ribofuranoside **1e**.

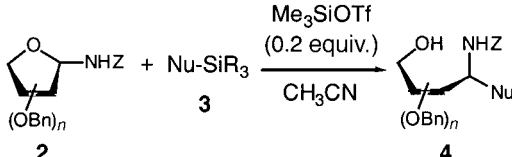
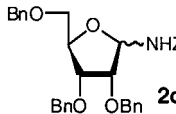
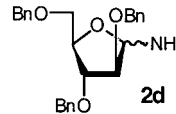
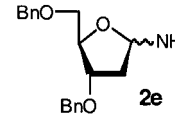
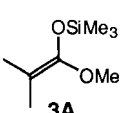
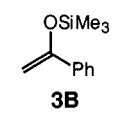
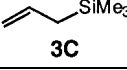
⁴) Semicyclic *N,O*-acetals **2** were obtained as anomeric mixtures (dr 5:5 to 8:2). We have observed that anomers can be interconverted in the presence of a *Lewis* acid, see [3c].

Scheme 4. Preparation of *N*-Furanosides

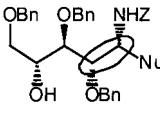
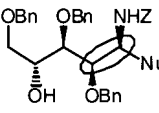
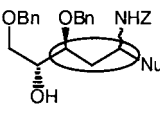
With furanose-derived *N,O*-acetals **2c–e** in hand, Me₃SiOTf-catalyzed ring-opening reactions with the silylated nucleophiles **3A–C** were next examined (Table 2). The reactions were carried out with a nucleophile (2 equiv.) and a catalytic amount of Me₃SiOTf (0.2 equiv.) in MeCN at low temperature depending on the reactivity of the nucleophile. In most reactions of ribose and arabinose derivatives **2c** and **2d**, good yields of *syn*-ring-opened products **4cA–B** and **4dA–C**, respectively, were obtained with high diastereoselectivity, while the reaction of deoxyribose derivative **2e** with acetophenone-derived silyl enol ether **3B** showed no diastereoselectivity. In contrast to the high yields obtained from the reactions of **2c** with silyl enolates **3A** and **3B**, no reaction of **2c** with allyltrimethylsilane (**3C**) was observed. The higher reactivity of arabinofuranoside **2d** than that of ribofuranoside **2c** might be attributed to the differences in ring strain or conformation caused by steric repulsion between substituents on the furan ring. The *syn*-configurations of products **4cA** and **4dC** were confirmed by ¹H-NMR analyses of the corresponding pyrrolidine derivatives **5cA** and **5dC** (Scheme 5).

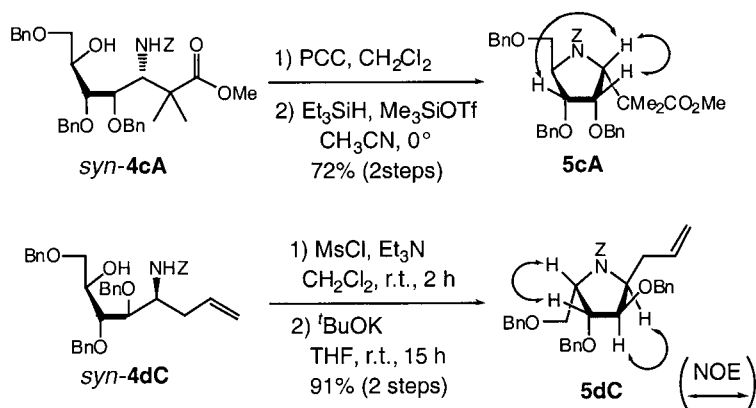
The stereochemistry can be rationalized by assuming the α - and β -(benzyloxy)-chelated transition states **TS _{α}** and **TS _{β}** , respectively, for acyclic *N*-acyliminium intermediates (Fig. 2). In **TS _{α}** , the diastereofaces of the iminium ion can be discriminated efficiently because of the close asymmetric environment created by the chiral C(α), and therefore, a nucleophile attacks preferentially from the side of the H-atom to give the *syn*-adduct (for the reactions of **2b–d**). On the other hand, in **TS _{β}** , the asymmetric environment created by the chiral C(β) is far from the reaction site leading to low selectivity (for the reaction of **2e**). In reactions of α,β -bis(benzyloxy)-substituted *N,O*-acetals such as **2c** and **2d**, chelation by both α - and β -(benzyloxy) groups might be also possible, though clear evidence in this respect has not been obtained yet.

Table 2. Ring-Opening Reactions of Furanose Derivatives

	$\text{Me}_3\text{SiOTf} \text{ (0.2 equiv.)}$ $\xrightarrow{\text{CH}_3\text{CN}}$		
			
 2c	 2d	 2e	
 3A	– 40°, 12 h 4cA (quant.) ^{a)} <i>syn/anti</i> 93:7	– 40°, 21 h 4dA (62%) ^{a)} <i>syn/anti</i> 91:9	–
 3B	– 40°, 16 h 4cB (70%) ^{a)} <i>syn/anti</i> 93:7	– 40°, 37 h 4dB (77%) ^{a)} <i>syn/anti</i> 93:7	– 40°, 9 h 4eB (80%) ^{a)} dr 50:50
 3C	0°, 23 h 4cC (0%) ^{a)}	– 30°, 39 h 4dC (64%) ^{a)} <i>syn/anti</i> 94:6	–

^{a)} Product **4**: **A** Nu = CMe₂CO₂Me; **B** Nu = CH₂COPh; **C** Nu = CH₂CH=CH₂.

 syn-4c	 syn-4d	 4e
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Scheme 5. Configuration Assignment of Ring-Opened Products **syn-4cA** and **syn-4dC**

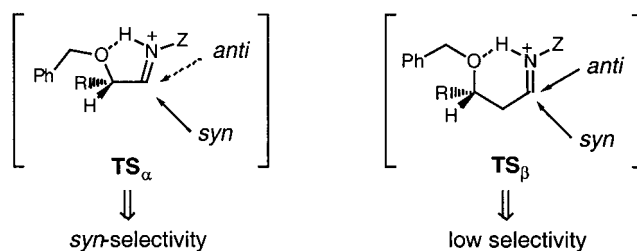
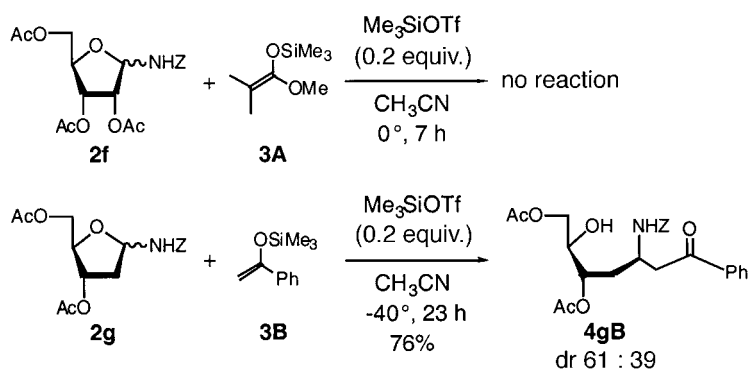


Fig. 2. Assumed transition states for the acyclic acyliminium intermediates

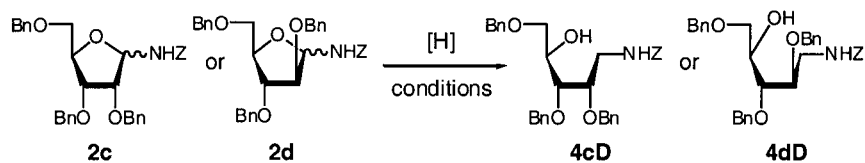
The choice of the protective groups at the OH groups of the sugars was also found to be important for the ring-opening reactions, *i.e.*, *O*-acetyl-protected ribose-derived *N,O*-acetal **2f** was unreactive under similar conditions, while the analogous deoxyribose derivative **2g** underwent the reaction with low selectivity (Scheme 6). An electron-withdrawing substituent at the α -position might retard the formation of the assumed *N*-acyliminium intermediate as proposed in glycosylation chemistry [10].

Scheme 6. Ring-Opening Reactions of *O*-Acetyl-Protected *N*-Furanosides

We next focused our attention on the ring-opening reduction of **2c** and **2d** (Table 3). At first, ribofuranoside **2c** was subjected to the conditions with triethylsilane as a reducing agent and Me_3SiOTf as a Lewis acid in MeCN (Entry 1). While **2c** remained unreacted under these conditions, use of chlorodimethylsilane improved the reaction dramatically to give amino alcohol **4cD** in good yield (Entries 2 and 3). Treatment of **2c** with diisobutylaluminium hydride (DIBAL) in THF [5] resulted in a low yield (Entry 4). On the other hand, arabinofuranoside **2d** reacted with triethylsilane to give **4dD** in moderate yield besides furan **6** (Entry 5). Other silanes such as chlorodimethylsilane and dimethylisopropylsilane were examined, but no remarkable improvement was observed (Entries 6–8). Meanwhile, treatment of **2d** with 3 equiv. of DIBAL in THF provided **4dD** in good yield (Entry 9).

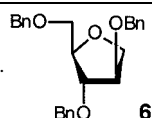
Finally, reduction product **4dD** was successfully transformed to the glycosidase inhibitor (2*S*,3*R*,4*R*)-2-(hydroxymethyl)pyrrolidine-3,4-diol (**7**) (Scheme 7)⁵⁾. That is, ring closure of **4dD** via mesylation followed by treatment with $t\text{BuOK}$ gave pyrrolidine

⁵⁾ For syntheses of **7**, see [11].

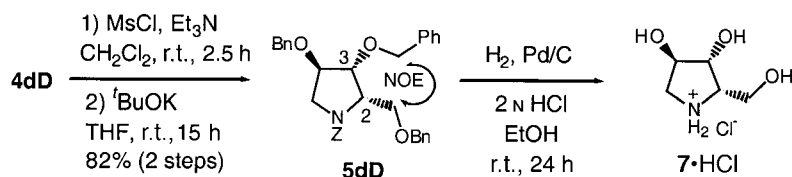
Table 3. Ring-Opening Reductions of **2c** and **2d**

Entry	2	Reagent	Conditions	Yield/%
1	2c	Et ₃ SiH (2.0 equiv.), Me ₃ SiOTf (0.2 equiv.)	MeCN, 0°, 1.5 h → r.t., 3 h	0
2		Me ₂ ClSiH (2.0 equiv.), Me ₃ SiOTf (0.2 equiv.)	MeCN, 0°, 6 h	67
3		Me ₂ ClSiH (2.0 equiv.), Me ₃ SiOTf (1.0 equiv.)	MeCN, 0°, 6 h	76
4		DIBALH (3.0 equiv.)	THF, -23°, 4 h	37
5	2d	Et ₃ SiH (2.0 equiv.), Me ₃ SiOTf (0.2 equiv.)	MeCN, 0°, 1.5 h → r.t., 3 h	52 ^{a)}
6		Me ₂ ClSiH (2.0 equiv.), Me ₃ SiOTf (0.2 equiv.)	MeCN, 0°, 11 h	37
7		Me ₂ ClSiH (2.0 equiv.), Me ₃ SiOTf (1.0 equiv.)	MeCN, 0°, 9 h	59
8		Me ₂ ⁱ PrSiH (2.0 equiv.), Me ₃ SiOTf (0.2 equiv.)	MeCN, 0°, 15 h	43
9		DIBALH (3.0 equiv.)	THF, -23°, 4 h	75

^{a)} Furan **6** was obtained in 38% yield.



5dD in high yield, and removal of all protective groups was achieved by hydrogenolysis over Pd/C with hydrochloric acid in EtOH providing the hydrochloride of **7** in high yield. Although this synthesis is one of the simple applications of our findings, diastereoselective syntheses of *C*-glycosides of imino sugars or polyoxygenated alkaloids utilizing the reactions are possible.

Scheme 7. Synthesis of Glycosidase Inhibitor **7**

In summary, we revealed that *N*-(alkoxycarbonyl)-*N*-glycosides (polyoxygenated five-membered semicyclic *N,O*-acetals) can be directly prepared from the corresponding regular glycosides with a carbamate, and that they undergo Me₃SiOTf-catalyzed ring-opening reactions with silylated nucleophiles to give ring-opened amino alcohols with good to high diastereoselectivity. The synthetic utility of this reaction was demonstrated by the synthesis of a glycosidase inhibitor, (2*S*,3*R*,4*R*)-2-(hydroxymethyl)pyrrolidine-3,4-diol (**7**).

This work was partially supported by CREST and SORST, Japan Science Technology Corporation (JST), and a Grant-in-Aid for Scientific Research from the Japan Society of the Promotion of Sciences (JSPS).

Experimental Part

1. *General.* CH₂Cl₂ was distilled from P₂O₅, then from CaH₂, and dried over molecular sieves 4-Å. MeCN was distilled from CaH₂ and dried over molecular sieves 4-Å. All other solvents and chemical compounds were purified by standard procedures. Column chromatography (CC): silica gel 60 (Merck). TLC: Wakogel B-5F. Optical rotations: Jasco P-1010 polarimeter; 10-cm cell. IR Spectra: Jasco FT/IR-610 infrared spectrometer in cm⁻¹; ¹H- and ¹³C-NMR Spectra: Jeol JNM-LA300 or JNM-LA400 spectrometer; in CDCl₃ unless otherwise noted; δ in ppm rel. to SiMe₄ as internal standard (δ (H) = 0) and CDCl₃ as internal standard (δ (C) = 77.0); *J* in Hz; dr = diastereoisomer ratio. MS: for high-resolution (HR) Jeol JMX-SX-102A spectrometer; for low-resolution (EI) Shimadzu GCMS-QP5050A spectrometer.

2. N-[(Benzoyloxy)carbonyl]-N-glycosides **2** (=semicyclic N,O-acetals with an exocyclic N-atom): *General Procedure:* To a suspension of a regular glycoside **1** (1.0 equiv.), benzyl carbamate (1.1 equiv.) and 4-Å-molecular-sieves powder (300 mg/1 mmol of glycoside) in CH₂Cl₂ (1.0M) was added dropwise trimethylsilyl trifluoromethanesulfonate (Me₃SiOTf; 1.0 equiv.) at r.t. The mixture was stirred for 10 to 20 min and then quenched with sat. aq. NaHCO₃ soln. After filtration through a Celite pad and extraction of the filtrate with AcOEt (3 ×), the combined org. phase was washed with brine, dried (MgSO₄), and evaporated, and the residue purified by CC (silica gel): **2**.

Benzyl (2,3,4,6-Tetra-O-benzyl-D-glucopyranosyl)carbamate (2a). From 1-O-acetyl-2,3,4,6-tetra-O-benzyl-D-glucopyranose (**1a**) in 67% yield. Colorless oil: α -D/ β -D 35:65. ¹H-NMR (400 MHz, CDCl₃): β -D-isomer: 7.35–7.21 (m, 23 H); 7.14–7.10 (m, 2 H); 5.15 (d, *J* = 12.2, 1 H); 5.11 (br.d, *J* = 10.0, 1 H); 5.06 (d, *J* = 12.2, 1 H); 4.90 (dd, *J* = 10.0, 8.6, 1 H); 4.89 (d, *J* = 10.9, 1 H); 4.85 (d, *J* = 10.9, 1 H); 4.79 (d, *J* = 11.0, 1 H); 4.76 (d, *J* = 11.3, 1 H); 4.67 (d, *J* = 11.3, 1 H); 4.59 (d, *J* = 12.2, 1 H); 4.50 (d, *J* = 11.0, 1 H); 4.46 (d, *J* = 12.2, 1 H); 3.76–3.65 (m, 4 H); 3.49 (br.d, *J* = 7.6, 1 H); 3.32 (br.t, *J* = 8.6, 1 H); α -D-isomer: 7.36–7.21 (m, 23 H); 7.14–7.09 (m, 2 H); 5.62 (t, *J* = 6.2, 1 H); 5.58 (br.d, *J* = 6.2, 1 H); 5.16 (d, *J* = 12.2, 1 H); 5.11 (d, *J* = 12.2, 1 H); 4.89 (d, *J* = 11.0, 1 H); 4.79 (d, *J* = 10.7, 1 H); 4.76 (d, *J* = 11.0, 1 H); 4.61 (d, *J* = 12.0, 1 H); 4.58 (s, 2 H); 4.50 (d, *J* = 10.7, 1 H); 4.45 (d, *J* = 12.2, 1 H); 3.82–3.56 (m, 6 H). ¹³C-NMR (100 MHz, CDCl₃, β -D-isomer 155.5; 138.3; 138.0; 137.8; 137.7; 136.1; 128.44; 128.38; 128.33; 128.31; 128.27; 128.12; 128.06; 127.95; 127.77; 127.69; 127.66; 85.9; 81.7; 80.2; 77.5; 76.2; 75.6; 74.9; 74.7; 73.5; 68.1; 67.0.

Benzyl [(3R)-3-(Benzoyloxy)tetrahydro-4,4-dimethylfuran-2-yl]carbamate (2b). From (3R)-3-(benzyloxy)-tetrahydro-4,4-dimethylfuran-2-yl acetate (**1b**)⁶ in 91% yield. Colorless oil. [α]_D²⁵ = +34.8 (*c* = 0.345, CHCl₃). IR (film): 3431, 3326, 3064, 3032, 2961, 2871, 1728, 1502, 1224, 1036, 736, 697. ¹H-NMR (300 MHz, CDCl₃; dr ca. 6:4): 7.37–7.22 (m, 10 H); 5.89 (br. d, *J* = 9.6, 0.6 H); 5.72 (br. dd, *J* = 9.6, 5.0, 0.6 H); 5.58 (br. d, *J* = 9.0, 0.4 H); 5.43 (br. dd, *J* = 9.0, 4.1, 0.4 H); 5.10 (s, 2 H); 4.66 (br. d, *J* = 11.7, 0.4 H); 4.57 (d, *J* = 11.5, 0.6 H); 4.53 (br. d, *J* = 11.7, 0.4 H); 4.51 (d, *J* = 11.5, 0.6 H); 3.69 (d, *J* = 8.1, 0.6 H); 3.64 (d, *J* = 8.4, 0.4 H); 3.58 (d, *J* = 8.4, 0.4 H); 3.50 (d, *J* = 5.0, 0.6 H); 3.45 (br. d, *J* = 4.1, 0.4 H); 3.39 (d, *J* = 8.1, 0.6 H); 1.11 (s, 1.2 H); 1.08 (s, 1.8 H); 1.06 (s, 1.8 H); 1.04 (s, 1.2 H). ¹³C-NMR (100 MHz, CDCl₃, dr ca. 6:4): 155.7; 155.3; 137.9; 137.2; 136.2; 136.0; 128.5; 128.4; 128.3; 128.2; 128.10; 128.06; 128.01; 127.9; 127.6; 127.4; 89.1; 87.2; 84.9; 82.7; 78.1; 76.7; 74.3; 72.2; 66.9; 66.8; 42.8; 41.6; 25.2; 24.4; 19.8; 19.5. Anal. calc. for C₂₁H₂₅NO₄: C 70.96, H 7.09, N 3.94; found: C 71.01, H 7.13, N 3.91.

Benzyl (2,3,5-Tri-O-benzyl-D-ribofuranosyl)carbamate (2c). From 2,3,5-tri-O-benzyl-D-ribofuranose 1-acetate (**1c**)⁷ in 89% yield. Colorless oil; dr ca. 7:3. [α]_D²⁵ = +61.2 (*c* = 2.295, CHCl₃). IR (film): 3417, 3063, 3031, 2925, 2866, 1732, 1505, 1455, 1353, 1239, 1027, 737, 698. ¹H-NMR (400 MHz, CDCl₃): major isomer: 7.32–7.12 (m, 20 H); 6.27 (br. d, *J* = 9.5, 1 H); 5.64 (dd, *J* = 9.5, 5.6, 1 H); 5.04 (s, 2 H); 4.58 (d, *J* = 12.2, 1 H); 4.50 (d, *J* = 12.2, 1 H); 4.48 (s, 2 H); 4.46 (d, *J* = 11.9, 1 H); 4.36 (d, *J* = 11.9, 1 H); 4.16 (ddd, *J* = 4.2, 3.5, 2.2, 1 H); 3.96 (t, *J* = 5.1, 1 H); 3.89 (dd, *J* = 5.1, 2.3, 1 H); 3.38 (dd, *J* = 10.5, 3.4, 1 H); 3.34 (dd, *J* = 10.5, 4.6, 1 H); minor isomer (selected signals): 5.47 (dd, *J* = 8.9, 5.2, 1 H); 5.03 (s, 2 H); 4.12 (m, 1 H); 3.76 (t, *J* = 11.1, 1 H); 3.54 (dd,

⁶) Acetate **1b** was prepared from (*R*)-pantolactone in 3 steps including benzylation of the OH group by benzyl trichloroacetimidate, reduction by diisobutylaluminium hydride, and acetylation by Ac₂O and a catalytic amount of *N,N*-dimethylpyridine-4-amine in Et₃N.

⁷) Regular glycosides were prepared from the corresponding sugars according to conventional methods including *a*) methyl glycoside formation by treatment with a catalytic amount of acetyl chloride in MeOH, *b*) benzylation of OH groups by NaH and benzyl bromide in DMF, *c*) hydrolysis of the methyl glycoside with 1N HCl in refluxing dioxane, and *d*) acetylation of the anomeric OH group by Ac₂O and a catalytic amount of *N,N*-dimethylpyridin-4-amine in Et₃N, see [12].

$J = 11.1, 4.6, 1 \text{ H}$). $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 ; major isomer: 155.9; 137.8; 137.6; 137.3; 136.3; 128.41; 128.38; 128.35; 128.1; 128.0; 127.9; 127.82; 128.78; 127.7; 127.6; 127.5; 127.4; 81.2; 81.1; 77.8; 76.5; 73.5; 72.48; 72.45; 70.0; 66.7. Anal. calc. for $\text{C}_{34}\text{H}_{35}\text{NO}_6$: C 73.76, H 6.37, N 2.53; found: C 73.44, H 6.34, N 2.51.

Benzyl (2,3,5-Tri-*O*-benzyl-*D*-arabinofuranosyl)carbamate (2d). From 2,3,5-tri-*O*-benzyl-*D*-arabinofuranose 1-acetate (**1d**)⁷ in 92% yield. Colorless oil. $[\alpha]_{\text{D}}^{25} = +2.2$ ($c = 0.825$, CHCl_3). IR (film): 3411, 3339, 3087, 3062, 3031, 2922, 2864, 1728, 1509, 1498, 1454, 1215, 1091, 1048, 1028, 738, 697, 459. $^1\text{H-NMR}$ (400 MHz, CDCl_3 , dr ca. 1:1): 7.38–7.18 (*m*, 20 H); 5.92 (br. *d*, $J = 10.2, 0.5 \text{ H}$); 5.87 (br. *d*, $J = 10.2, 0.5 \text{ H}$); 5.75 (br. *d*, $J = 10.2, 0.5 \text{ H}$); 5.71 (br. *dd*, $J = 9.9, 5.5, 0.5 \text{ H}$); 5.13 (*d*, $J = 12.2, 0.5 \text{ H}$); 5.10 (*s*, 1 H); 5.08 (*d*, $J = 12.2, 0.5 \text{ H}$); 4.57–4.39 (*m*, 6 H); 4.34 (*ddd*, $J = 7.6, 5.4, 1.7, 0.5 \text{ H}$); 4.07–3.93 (*m*, 2 H); 3.89 (*s*, 0.5 H); 3.59 (*dd*, $J = 9.8, 5.4, 0.5 \text{ H}$); 3.53 (*d*, $J = 3.9, 1 \text{ H}$); 3.48 (*dd*, $J = 9.8, 8.3, 0.5 \text{ H}$). $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , dr ca. 1:1): 155.3; 155.0; 137.9; 137.7; 137.5; 137.0; 136.9; 136.05; 136.02; 136.00; 135.97; 128.38; 128.36; 128.32; 128.30; 128.22; 128.19; 128.08; 128.04; 127.99; 127.93; 127.84; 127.81; 127.74; 127.71; 127.63; 127.58; 127.54; 127.51; 85.5; 84.9; 82.5; 82.2; 81.93; 81.85; 81.2; 80.1; 73.2; 73.1; 72.0; 71.6; 71.5; 71.3; 69.9; 69.7; 66.8. Anal. calc. for $\text{C}_{34}\text{H}_{35}\text{NO}_6$: C 73.76, H 6.37, N 2.53; found: C 73.67, H 6.36, N 2.50.

Benzyl (3,5-di-*O*-benzyl-2-deoxy-*D*-ribofuranosyl)carbamate (2e). From methyl 3,5-di-*O*-benzyl-2-deoxy-*D*-ribofuranoside (**1e**)⁷ in 79% yield. Colorless oil. $[\alpha]_{\text{D}}^{25} = +21.1$ ($c = 0.435$, CHCl_3). IR (film): 3409, 3328, 3060, 3032, 2920, 2863, 1727, 1504, 1452, 1357, 1247, 1212, 1078, 741, 697. $^1\text{H-NMR}$ (300 MHz, CDCl_3 ; dr ca. 8:2): 7.40–7.20 (*m*, 15 H); 6.11 (br. *d*, $J = 10.1, 0.8 \text{ H}$); 5.95 (br. *d*, $J = 10.1, 0.8 \text{ H}$); 5.81 (br. *dd*, $J = 9.8, 7.1, 0.8 \text{ H}$); 5.65 (br. *d*, $J = 10.1, 0.8 \text{ H}$); 5.12 (*d*, $J = 12.2, 0.8 \text{ H}$); 5.08 (*s*, 0.4 H); 5.06 (*d*, $J = 12.2, 0.8 \text{ H}$); 4.54 (*d*, $J = 12.1, 0.8 \text{ H}$); 4.48–4.43 (*m*, 3.2 H); 4.35 (*dd*, $J = 5.5, 4.5, 0.8 \text{ H}$); 4.28–4.20 (*m*, 0.4 H); 4.07 (*d*, $J = 5.5, 0.8 \text{ H}$); 3.56 (*dd*, $J = 10.1, 3.1, 0.2 \text{ H}$); 3.45 (*dd*, $J = 10.1, 3.8, 1.0 \text{ H}$); 3.32 (*dd*, $J = 10.1, 6.0, 0.8 \text{ H}$); 2.27 (*ddd*, $J = 13.6, 6.2, 2.7, 0.2 \text{ H}$); 2.18 (apparent *dt*, $J = 13.7, 6.5, 0.8 \text{ H}$); 1.95 (*d*, $J = 13.7, 0.8 \text{ H}$); 1.89 (*m*, 0.2 H). $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 ; dr ca. 8:2): 155.3; 137.8; 137.7; 137.4; 136.19; 136.14; 128.36; 128.32; 128.28; 128.24; 128.06; 128.01; 127.9; 127.7; 127.59; 127.53; 127.48; 127.42; 83.0; 82.9; 82.5; 82.4; 80.2; 79.7; 73.5; 73.3; 70.95; 70.91; 70.3; 66.6; 66.5; 38.5; 37.0. Anal. calc. for $\text{C}_{27}\text{H}_{29}\text{NO}_5$: C 72.46, H 6.53, N 3.13; found: C 72.23, H 6.61, N 3.08.

3. *Me₃SiOTf-Catalyzed Ring-Opening Reactions of N-Glycosides 2: General Procedure*. To a soln. of an *N*-glycoside **2** (1 equiv.) and a nucleophile **3** (2 equiv.) in MeCN (0.1M) was added dropwise Me_3SiOTf (0.2 equiv.) at the appropriate temp. After being stirred at that temp. for the time indicated in the schemes or tables, the mixture was quenched with sat. aq. NaHCO_3 soln. and extracted with AcOEt ($2 \times$). The combined org. phase was washed with brine, dried (MgSO_4), and evaporated and the residue purified by prep. TLC to give a ring-opened product **4**. The dr of **4** were determined by $^1\text{H-NMR}$ analyses.

Benzyl [(2*S*,3*R*,4*R*,5*R*)-2,3,4,6-Tetrakis(benzyloxy)-5-hydroxy-1-(2-oxo-2-phenylethyl)hexyl]carbamate (4aB). Yield 16%. Colorless oil; dr 90:10. $^1\text{H-NMR}$ (300 MHz, CDCl_3): major isomer: 7.72 (*d*, $J = 7.5, 2 \text{ H}$); 7.52 (*t*, $J = 7.5, 2 \text{ H}$); 7.46–7.10 (*m*, 26 H); 5.30 (br. *d*, $J = 9.7, 1 \text{ H}$); 5.09 (*s*, 2 H); 4.82 (*d*, $J = 11.5, 1 \text{ H}$); 4.74 (*d*, $J = 11.2, 1 \text{ H}$); 4.68–4.42 (*m*, 6 H); 4.35 (*m*, 1 H); 4.05 (*m*, 1 H); 3.91 (*s*, 2 H); 3.81 (*m*, 1 H); 3.70–3.57 (*m*, 2 H); 3.08 (*dd*, $J = 17.0, 5.1, 1 \text{ H}$); 2.82 (br. *s*, 1 H); 2.78 (*dd*, $J = 17.0, 7.9, 1 \text{ H}$); minor isomer (selected signal): 5.83 (*d*, $J = 7.1, 1 \text{ H}$). $^{13}\text{C-NMR}$ (100 MHz, CDCl_3 , major isomer): 197.5; 156.0; 138.3; 138.1; 136.53; 136.46; 133.1; 128.5; 128.44; 128.40; 128.37; 128.30; 128.29; 128.26; 128.16; 128.05; 127.9; 127.74; 127.67; 127.63; 127.56; 79.4; 78.8; 77.5; 77.2; 74.9; 73.4; 71.2; 70.4; 66.9; 48.7; 41.3; 29.7.

Methyl (4*R*)-4-(Benzyloxy)-3-[(benzyloxy)carbonylamino]-6-hydroxy-2,2,5,5-tetramethylhexanoate (4bA). Yield 92%. Colorless oil; *syn/anti* 91:9. $[\alpha]_{\text{D}}^{25} = +54.0$ ($c = 0.455$, CHCl_3). IR (film) 3447, 3089, 3064, 3032, 2952, 2878, 1725, 1507, 1456, 1319, 1265, 1219, 1146, 1056, 735, 697. $^1\text{H-NMR}$ (300 MHz, CDCl_3): *syn*-isomer: 7.36–7.25 (*m*, 10 H); 5.63 (*d*, $J = 9.0, 1 \text{ H}$); 5.11 (*s*, 2 H); 4.77 (*d*, $J = 11.3, 1 \text{ H}$); 4.54 (*d*, $J = 11.3, 1 \text{ H}$); 4.12 (*d*, $J = 9.9, 1 \text{ H}$); 3.59 (*s*, 3 H); 3.51 (*s*, 1 H); 3.51 (*d*, $J = 11.3, 1 \text{ H}$); 3.36 (*d*, $J = 11.3, 1 \text{ H}$); 2.04 (br. *s*, 1 H); 1.25 (*s*, 3 H); 1.20 (*s*, 3 H); 0.98 (*s*, 3 H); 0.911 (*s*, 3 H); (*anti*-isomer (selected signals): 5.41 (*d*, $J = 10.3, 1 \text{ H}$); 5.21 (*d*, $J = 12.5, 1 \text{ H}$); 5.14 (*d*, $J = 12.5, 1 \text{ H}$); 4.08 (*d*, $J = 11.0, 1 \text{ H}$); 3.44 (*d*, $J = 11.4, 1 \text{ H}$); 3.30 (*d*, $J = 11.4, 1 \text{ H}$). $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , *syn*-isomer): 177.2; 156.4; 138.1; 136.7; 128.44; 128.41; 128.2; 127.6; 127.0; 81.3; 74.4; 69.6; 66.8; 55.9; 52.0; 47.4; 41.4; 24.3; 21.8; 21.6; 21.3. Anal. calc. for $\text{C}_{26}\text{H}_{35}\text{NO}_6 \cdot 0.15 \text{ H}_2\text{O}$: C 67.84, H 7.73, N 3.04; found: C 67.81, H 7.56, N 3.04.

Benzyl [(2*R*)-2-(Benzyloxy)-4-hydroxy-3,3-dimethyl-1-(2-oxo-2-phenylethyl)butyl]carbamate (4bB). Yield 94%. Colorless oil; *syn/anti* 90:10. $[\alpha]_{\text{D}}^{25} = +4.3$ ($c = 0.645$, CHCl_3). IR (film): 393, 2923, 2878, 1712, 1598, 1497, 1450, 1294, 1216, 1057, 914, 736, 698. $^1\text{H-NMR}$ (400 MHz, CDCl_3 ; *syn*-isomer): 7.83 (*d*, $J = 7.6, 2 \text{ H}$); 7.56 (*t*, $J = 7.6, 1 \text{ H}$); 7.42 (*t*, $J = 7.6, 2 \text{ H}$); 7.40–7.15 (*m*, 10 H); 5.56 (*d*, $J = 8.3, 1 \text{ H}$); 5.08 (*s*, 2 H); 4.76 (*d*, $J = 11.7, 1 \text{ H}$); 4.49 (*d*, $J = 11.7, 1 \text{ H}$); 4.47 (*m*, 1 H); 3.60 (*s*, 2 H); 3.43 (*dd*, $J = 11.2, 8.3, 1 \text{ H}$); 3.21 (*dd*, $J = 17.6, 3.2, 1 \text{ H}$); 3.14 (*m*, 1 H); 2.90 (*dd*, $J = 17.6, 10.5, 1 \text{ H}$); 1.05 (*s*, 3 H); 0.92 (*s*, 3 H). $^{13}\text{C-NMR}$ (100 MHz, CDCl_3 ; *syn*-

isomer): 199.3; 155.3; 138.0; 136.4; 136.1; 133.5; 128.5; 128.4; 128.1; 128.04; 128.00; 82.7; 76.4; 70.2; 66.7; 46.7; 43.4; 41.1; 22.2; 20.6. Anal. calc. for $C_{29}H_{33}NO_5$: C 73.24, H 6.99, N 2.95; found: C 73.00, H 7.11, N 2.83.

Benzyl [1-(1R)-1-(Benzyloxy)-3-hydroxy-2,2-dimethylpropyl]but-3-enyl]carbamate (4bC). Yield 72%. Colorless oil; *syn/anti* 89:11. $[\alpha]_D^{25} = +21.3$ ($c = 0.200$, $CHCl_3$). IR (film): 3439, 3065, 3032, 2962, 2875, 1702, 1499, 1331, 1214, 1053, 1027, 914, 736, 697. 1H -NMR (400 MHz, $CDCl_3$): *syn*-isomer: 7.37–7.24 (*m*, 10 H); 5.78 (*m*, 1 H); 5.34 (*d*, $J = 9.0$, 1 H); 5.18–5.00 (*m*, 4 H); 4.73 (*d*, $J = 11.0$, 1 H); 4.64 (*d*, $J = 11.0$, 1 H); 3.98 (apparent *q*, $J = 8.0$, 1 H); 3.56 (*d*, $J = 10.4$, 1 H); 3.49 (*s*, 1 H); 3.29 (*d*, $J = 10.4$, 1 H); 2.38 (*m*, 1 H); 2.26 (*m*, 1 H); 2.16 (*br.*, 1 H); 1.00 (*s*, 3 H); 0.88 (*s*, 3 H); *anti*-isomer (selected signal): 3.88 (*m*, 1 H). ^{13}C -NMR (100 MHz; $CDCl_3$, *syn*-isomer): 155.7; 138.0; 136.6; 134.7; 128.5; 128.4; 128.0; 127.9; 127.6; 118.0; 83.7; 76.2; 69.9; 66.6; 50.4; 40.4; 40.2; 22.6; 20.8. Anal. calc. for $C_{24}H_{31}NO_4$: C 72.52, H 7.86, N 3.52; found: C 72.26, H 7.88, N 3.47.

Methyl (4S,5R,6R)-4,5,7-Tris(benzyloxy)-3-[(benzyloxy)carbonyl]amino]-6-hydroxy-2,2-dimethylheptanoate (4cA). Yield quant. Colorless oil; *syn/anti* 93:7. $[\alpha]_D^{25} = +40.5$ ($c = 0.135$, $CHCl_3$). IR (film): 3447, 3063, 3031, 1725, 1507, 1454, 1218, 1067, 1028, 736, 697. 1H -NMR (400 MHz, $CDCl_3$): *syn*-isomer: 7.38–7.12 (*m*, 20 H); 5.65 (*d*, $J = 9.9$, 1 H); 5.03 (*d*, $J = 12.2$, 1 H); 4.73 (*d*, $J = 11.8$, 1 H); 4.68 (*d*, $J = 11.1$, 1 H); 4.57 (*d*, $J = 12.2$, 1 H); 4.51 (*d*, $J = 12.0$, 1 H); 4.45 (*d*, $J = 12.0$, 1 H); 4.45 (*d*, $J = 11.8$, 1 H); 4.38 (*d*, $J = 11.1$, 1 H); 4.29 (*d*, $J = 9.9$, 1 H); 3.96 (*dddd*, $J = 8.3, 5.5, 5.4, 3.0$, 1 H); 3.91 (*d*, $J = 2.2$, 1 H); 3.81 (*dd*, $J = 8.3, 2.2, 1$ H); 3.68 (*dd*, $J = 9.6, 3.0$, 1 H); 3.58 (*dd*, $J = 9.6, 5.5$, 1 H); 3.49 (*s*, 3 H); 2.75 (*d*, $J = 5.4$, 1 H); 1.25 (*s*, 3 H); *anti*-isomer (selected signals): 5.51 (*d*, $J = 10.2$, 1 H); 2.60 (*d*, $J = 5.4$, 1 H). ^{13}C -NMR (100 MHz, $CDCl_3$; *syn*-isomer): 177.1; 156.4; 138.5; 137.8; 137.5; 136.5; 128.37; 128.33; 128.2; 128.1; 128.0; 127.9; 127.74; 127.72; 127.4; 127.3; 78.3; 77.8; 74.0; 73.3; 71.7; 71.1; 69.6; 66.6; 55.8; 51.9; 46.6; 23.9; 21.4. Anal. calc. for $C_{39}H_{45}NO_8 \cdot 0.23 H_2O$: C 70.98, H 6.94, N 2.12; found: C 70.98, H 7.07, N 2.12.

Benzyl [(2S,3R,4R)-2,3,5-Tris(benzyloxy)-4-hydroxy-1-(2-oxo-2-phenylethyl)pentyl]carbamate (4cB). Yield 70%. Colorless oil; *syn/anti* 93:7. $[\alpha]_D^{25} = +12.1$ ($c = 0.105$, $CHCl_3$). IR (film): 3430, 3063, 3031, 2918, 2870, 1717, 1684, 1507, 1497, 1454, 1215, 1090, 1071, 1027, 738, 697. 1H -NMR (400 MHz, $CDCl_3$): *syn*-isomer: 7.84 (*d*, $J = 7.3$, 2 H); 7.54 (*tt*, $J = 7.3, 1.2$, 1 H); 7.41 (*t*, $J = 7.3$, 2 H); 7.36–7.14 (*m*, 20 H); 5.62 (*br. d*, $J = 8.6$, 1 H); 5.04 (*d*, $J = 12.2$, 1 H); 4.88 (*d*, $J = 12.2, 1$ H); 4.70 (*d*, $J = 11.1$, 1 H); 4.66 (*d*, $J = 11.5$, 1 H); 4.72–4.59 (*m*, 1 H, overlapped), 4.56 (*d*, $J = 11.1$, 1 H); 4.55 (*d*, $J = 12.0$, 1 H); 4.50 (*d*, $J = 12.0$, 1 H); 4.47 (*d*, $J = 11.5$, 1 H); 4.12 (*m*, 1 H); 3.89 (*dd*, $J = 4.6, 1.8$, 1 H); 3.84 (*dd*, $J = 6.3, 4.6$, 1 H); 3.67 (*dd*, $J = 9.8, 3.4$, 1 H); 3.63 (*dd*, $J = 9.8, 5.4$, 1 H); 3.26 (*dd*, $J = 16.5, 4.6$, 1 H); 3.10 (*br. s*, 1 H); 3.06 (*dd*, $J = 16.5, 9.0$, 1 H); *anti*-isomer (selected signals): 7.78 (*d*, $J = 8.0$, 1 H); 6.03 (*br. d*, $J = 9.0$, 1 H). ^{13}C -NMR (100 MHz, $CDCl_3$; *syn*-isomer): 198.8; 155.8; 138.1; 138.0; 137.4; 136.52; 136.42; 133.3; 128.5; 128.44; 128.42; 128.40; 128.38; 128.29; 128.26; 128.22; 128.12; 128.03; 128.00; 127.95; 127.88; 127.78; 127.69; 127.56; 79.2; 78.3; 74.0; 73.4; 73.1; 71.1; 70.8; 66.6; 47.9; 41.6. Anal. calc. for $C_{42}H_{43}NO_7 \cdot 0.2 H_2O$: C 74.47, H 6.46, N 2.07; found: C 74.46, H 6.49, N 2.12.

Benzyl [(2S,3R,4R)-2,3,5-Tris(benzyloxy)-4-hydroxypentyl]carbamate (4cD). Yield 76%. Colorless oil. 1H -NMR (300 MHz, $(D_6)DMSO, 80^\circ$): 7.36–7.21 (*m*, 20 H); 6.74 (*br. s*, 1 H); 5.03 (*s*, 2 H); 4.66 (*d*, $J = 11.3$, 1 H); 4.58 (*d*, $J = 11.7$, 1 H); 4.57 (*d*, $J = 11.3$, 1 H); 4.53 (*d*, $J = 11.7$, 1 H); 4.50 (*d*, $J = 12.4$, 1 H); 4.46 (*d*, $J = 12.4$, 1 H); 3.91–3.81 (*m*, 2 H); 3.69 (*dd*, $J = 6.2, 3.6$, 1 H); 3.61 (*dd*, $J = 10.1, 3.6$, 1 H); 3.52 (*dd*, $J = 10.1, 6.0$, 1 H); 3.46 (*ddd*, $J = 14.1, 5.5, 4.2$, 1 H); 3.33 (*ddd*, $J = 14.1, 6.4, 6.4$, 1 H). ^{13}C -NMR (75 MHz, $(D_6)DMSO, 80^\circ$): 155.8; 138.43; 138.36; 138.28; 137.0; 127.8; 127.66; 127.63; 127.61; 127.17; 127.13; 127.08; 127.05; 127.01; 126.80; 126.75; 79.9; 78.0; 72.5; 72.1; 71.8; 71.0; 69.3; 64.9; 40.8. Anal. calc. for $C_{34}H_{37}NO_6 \cdot 0.28 H_2O$: C 72.83, H 6.75, N 2.49; found: C 72.83, H 6.67, N 2.45.

Methyl (4R,5R,6R)-4,5,7-Tris(benzyloxy)-3-[(benzyloxy)carbonyl]amino]-6-hydroxy-2,2-dimethylheptanoate (4dA). Yield 62%. Colorless oil; *syn/anti* 91:9. $[\alpha]_D^{25} = -33.4$ ($c = 0.050$, $CHCl_3$). IR (film): 3443, 3063, 3031, 2950, 2869, 1719, 1507, 1454, 1250, 1217, 1148, 1100, 1052, 1028, 735, 697. 1H -NMR (400 MHz, $CDCl_3$); *syn*-isomer: 7.38–7.10 (*m*, 20 H); 5.86 (*d*, $J = 10.5$, 1 H); 5.14 (*d*, $J = 12.4$, 1 H); 5.10 (*d*, $J = 12.4$, 1 H); 4.90 (*d*, $J = 10.7, 1$ H); 4.65 (*d*, $J = 11.0$, 1 H); 4.56 (*d*, $J = 12.0$, 1 H); 4.50 (*d*, $J = 12.0$, 1 H); 4.45 (*d*, $J = 11.0$, 1 H); 4.34 (*d*, $J = 10.7, 1$ H); 4.04 (*d*, $J = 10.7, 1$ H); 3.93 (*m*, 1 H); 3.89 (*d*, $J = 7.0$, 1 H); 3.72–3.56 (*m*, 3 H); 3.30 (*s*, 3 H); 2.82 (*d*, $J = 5.4$, 1 H); 1.23 (*s*, 3 H); 1.21 (*s*, 3 H); *anti*-isomer (selected signals): 5.54 (*d*, $J = 11.0$, 1 H); 2.41 (*d*, $J = 4.6$, 1 H). ^{13}C -NMR (100 MHz, $CDCl_3$, *syn*-isomer): 176.4; 156.8; 138.10; 138.05; 137.99; 137.8; 136.5; 128.5; 128.3; 128.23; 128.17; 128.11; 128.07; 127.9; 127.8; 127.61; 127.58; 127.4; 78.7; 77.8; 74.5; 73.9; 72.2; 70.9; 70.8; 66.9; 59.1; 51.7; 45.2; 23.7; 23.4. Anal. calc. for $C_{39}H_{45}NO_8$: C 71.43, H 6.92, N 2.14; found: C 71.16, H 7.03, N 2.09.

Benzyl [(2R,3R,4R)-2,3,5-Tris(benzyloxy)-4-hydroxy-1-(2-oxo-2-phenylethyl)pentyl]carbamate (4dB). Yield 77%. Colorless oil; *syn/anti* 93:7. $[\alpha]_D^{25} = +7.6$ ($c = 0.880$, $CHCl_3$). IR (film): 3437, 3063, 3031, 2909, 2868, 1716, 1683, 1597, 1497, 1454, 1215, 1071, 1027, 737, 698. 1H -NMR (400 MHz, $CDCl_3$); *syn*-isomer: 7.81 (*d*, $J = 7.3$, 2 H); 7.53 (*tt*, $J = 7.3, 1.2$, 1 H); 7.40 (*t*, $J = 7.3$, 2 H); 7.36–7.13 (*m*, 20 H); 5.50 (*br. d*, $J = 9.0$, 1 H); 5.09

(*d, J* = 12.2, 1 H); 5.02 (*d, J* = 12.2, 1 H); 4.79 (*d, J* = 11.2, 1 H); 4.66 (*d, J* = 11.2, 1 H); 4.57 (*d, J* = 11.2, 1 H); 4.56 (*d, J* = 11.9, 1 H); 4.51 (*d, J* = 11.2, 1 H); 4.50 (*d, J* = 11.9, 1 H); 4.56–4.46 (*m*, 1 H, overlapped), 4.05 (*m*, 1 H); 3.92 (*dd, J* = 6.3, 2.3, 1 H); 3.75 (*t, J* = 6.3, 1 H); 3.72 (*dd, J* = 9.6, 3.6, 1 H); 3.67 (*dd, J* = 9.6, 6.0, 1 H); 3.23 (*dd, J* = 16.9, 4.5, 1 H); 3.01 (*dd, J* = 16.9, 8.6, 1 H); 2.86 (*br. d, J* = 5.1, 1 H); *anti*-isomer (selected signals): 6.00 (*br. d, J* = 8.3, 1 H); 3.60 (*dd, J* = 9.6, 5.4, 1 H); 3.57 (*dd, J* = 9.6, 4.6, 1 H); 3.41 (*dd, J* = 17.5, 5.1, 1 H); 2.97 (*dd, J* = 17.5, 6.8, 1 H). ¹³C-NMR (100 MHz, CDCl₃; *syn*-isomer): 198.2; 155.9; 138.2; 138.0; 137.8; 136.45; 136.37; 133.2; 128.5; 128.41; 128.36; 128.35; 128.30; 128.12; 128.08; 127.92; 127.87; 127.84; 127.65; 127.60; 80.2; 78.8; 75.0; 74.4; 73.3; 71.1; 70.7; 66.8; 49.2; 41.3. Anal. calc. for C₄₂H₄₃NO₇: C 74.87, H 6.43, N 2.08; found: C 74.58, H 6.53, N 2.11.

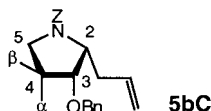
Benzyl [1-[(1*R*,2*R*,3*R*)-1,2,4-*Tris*(benzyloxy)-3-hydroxybutyl]but-3-enyl]carbamate (**4dC**). Yield 64%. Colorless oil; *syn*:anti 94:6. [α]_D²⁵ = +10.2 (*c* = 0.275, CHCl₃). IR (film): 3438, 3064, 3031, 2916, 2865, 1718, 1497, 1454, 1213, 1092, 1028, 736, 698. ¹H-NMR (300 MHz, CDCl₃): *syn*-isomer: 7.36–7.19 (*m*, 20 H); 5.66 (*ddt, J* = 17.1, 10.1, 7.1, 1 H); 5.23 (*d, J* = 9.5, 1 H); 5.10 (*d, J* = 12.2, 1 H); 5.02 (*d, J* = 12.2, 1 H); 4.99 (*br. d, J* = 10.1, 1 H); 4.95 (*br. d, J* = 17.1, 1 H); 4.82 (*d, J* = 11.0, 1 H); 4.68 (*d, J* = 11.2, 1 H); 4.56 (*d, J* = 12.1, 1 H); 4.54 (*d, J* = 11.0, 1 H); 4.51 (*d, J* = 12.1, 1 H); 4.49 (*d, J* = 11.2, 1 H); 4.07–4.01 (*m*, 2 H); 3.70–3.58 (*m*, 4 H); 2.73 (*d, J* = 5.9, 1 H); 2.39–2.15 (*m*, 2 H); *anti*-isomer (selected signals): 5.92 (*d, J* = 9.7, 1 H); 3.10 (*d, J* = 6.8, 1 H). ¹³C-NMR (75 MHz, CDCl₃; *syn*-isomer): 156.2; 138.3; 138.04; 137.97; 136.5; 134.6; 128.5; 128.4; 128.3; 128.1; 127.9; 127.8; 127.7; 127.6; 117.7; 80.0; 79.7; 74.9; 74.6; 73.3; 71.3; 70.7; 66.7; 51.9; 38.0. Anal. calc. for C₃₇H₄₁NO₆: C 74.60, H 6.94, N 2.35; found: C 74.30, H 6.95, N 2.35.

Benzyl [(2*R*,3*R*,4*R*)-2,3,5-*Tris*(benzyloxy)-4-hydroxypentyl]carbamate (**4dD**). Yield 75%. Colorless oil. [α]_D²⁵ = –2.4 (*c* = 0.655, CHCl₃). IR (film): 3426, 3350, 3063, 3031, 2925, 2868, 1718, 1514, 1497, 1454, 1399, 1337, 1253, 1069, 1028, 737, 698. ¹H-NMR (300 MHz, CDCl₃): 7.38–7.25 (*m*, 20 H); 5.05 (*s*, 2 H); 4.85 (*br. t, J* = 5.8, 1 H); 4.60 (*d, J* = 11.4, 1 H); 4.58 (*d, J* = 11.4, 1 H); 4.54 (*d, J* = 11.4, 1 H); 4.53 (*d, J* = 11.4, 1 H); 4.52 (*s*, 2 H); 3.99 (*ddt, J* = 7.1, 6.0, 4.6, 1 H); 3.78 (*ddd, J* = 5.5, 5.3, 3.5, 1 H); 3.63 (*d, J* = 4.6, 2 H); 3.61 (*dd, J* = 7.1, 3.5, 1 H); 3.50 (*ddd, J* = 14.3, 5.8, 5.5, 1 H); 3.31 (*ddd, J* = 14.3, 5.8, 5.3, 1 H); 2.83 (*d, J* = 6.0, 1 H). ¹³C-NMR (75 MHz, CDCl₃): 156.4; 137.8; 137.6; 136.6; 128.5; 128.4; 128.3; 128.00; 127.96; 127.82; 127.8; 78.0; 77.1; 73.5; 73.4; 72.6; 70.9; 70.3; 66.5; 40.9. Anal. calc. for C₃₄H₃₇NO₆·0.28 H₂O: C 72.83, H 6.75, N 2.49; found: C 72.83, H 6.67, N 2.45.

Benzyl [(3*S*,4*R*)-3,5-*bis*(benzyloxy)-4-hydroxy-1-(2-oxo-2-phenylethyl)pentyl]carbamate (**4eB**). Yield 80%. Colorless oil; dr 50:50. [α]_D²⁵ = +0.6 (*c* = 0.785, CHCl₃). IR (film): 3416, 3063, 3031, 2915, 2867, 1716, 1678, 1597, 1580, 1497, 1453, 1253, 1216, 1094, 1071, 1027, 752, 698. ¹H-NMR (400 MHz, CDCl₃, dr 50:50): 7.90 (*d, J* = 7.3, 1 H); 7.88 (*d, J* = 7.3, 1 H); 7.54 (*tt, J* = 7.3, 1.2, 0.5 H); 7.53 (*tt, J* = 7.3, 1.2, 0.5 H); 7.42 (*t, J* = 7.3, 1 H); 7.40 (*t, J* = 7.3, 1 H); 7.36–7.18 (*m*, 15 H); 5.80 (*br. d, J* = 8.0, 0.5 H); 5.64 (*br. d, J* = 8.3, 0.5 H); 5.05 (*s*, 2 H); 4.57 (*d, J* = 11.0, 0.5 H); 4.53 (*d, J* = 11.0, 0.5 H); 4.51 (*s*, 1 H); 4.50 (*s*, 1 H); 4.46 (*s*, 1 H); 4.42–4.26 (*m*, 1 H); 3.99–3.89 (*m*, 1 H); 3.65 (*ddd, J* = 9.5, 4.6, 2.4, 0.5 H); 3.62–3.52 (*m*, 2.5 H); 3.40 (*br. d, J* = 17.0, 1 H); 3.09 (*dd, J* = 17.1, 6.6, 0.5 H); 3.01 (*dd, J* = 17.1, 6.6, 0.5 H); 2.89 (*m*, 0.5 H); 2.62 (*m*, 0.5 H); 2.07–1.85 (*m*, 1.5 H); 1.76 (*ddd, J* = 14.9, 9.6, 3.3, 0.5 H). ¹³C-NMR (100 MHz, CDCl₃, dr 50:50): 198.90; 198.85; 155.9; 155.8; 137.9; 137.81; 137.77; 137.72; 136.67; 136.66; 136.5; 136.4; 133.2; 128.55; 128.54; 128.40; 128.38; 128.35; 128.31; 128.09; 128.05; 128.03; 127.95; 127.93; 127.87; 127.80; 127.78; 127.75; 127.73; 127.70; 127.68; 77.2; 76.8; 73.4; 73.3; 72.6; 71.6; 71.5; 70.9; 70.8; 66.5; 66.4; 46.1; 46.6; 42.9; 42.5; 34.4; 33.8. Anal. calc. for C₃₅H₃₇NO₆: C 74.05, H 6.57, N 2.47; found: C 73.84, H 6.80, N 2.42.

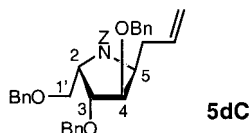
4. Cyclization via the Mesylation/*t*BuOK-Treatment Sequence. General Procedure [13]. To a soln. of **4** (1.0 equiv.) and Et₃N (2.2 equiv.) in CH₂Cl₂ (0.1M) was added dropwise methanesulfonyl chloride (2.0 equiv.) at r.t. The mixture was stirred at r.t. for 2–2.5 h. After dilution with AcOEt, the org. layer was washed with brine, dried (MgSO₄) and evaporated. The residue was diluted with dry THF (0.1M) and treated with *t*BuOK (2.0 equiv.) at r.t. The mixture was stirred at r.t. for 15 h, quenched with sat. aq. NH₄Cl soln., and extracted with AcOEt (3 ×). The combined org. phase was dried (MgSO₄) and evaporated and the residue purified by prep. TLC (hexane/AcOEt 2:1): **5**.

(2*R*,3*R*)-2-*Allyl*-3-(benzyloxy)-1-[(benzyloxy)carbonyl]-4,4-dimethylpyrrolidine (**5bC**). From **4bC** in 88% yield. Colorless oil; single isomer. ¹H-NMR (300 MHz, (D₆)DMSO, 50°): 7.35–7.24 (*m*, 2 Ph); 5.78 (*br. m, CH=CH₂*); 5.09 (*d, J* = 12.8, 1 H, PhCH₂OCO); 5.03 (*d, J* = 12.8, 1 H; PhCH₂OCO); 4.95 (*br. d, J* = 9.7, CH=CH₂); 4.58 (*d, J* = 11.5, 1 H, PhCH₂O–C(3)); 4.51 (*d, J* = 11.5, 1 H, PhCH₂O–C(3)); 3.99 (*br. dt, J* = 5.7, 6.8 1 H; H–C(2)); 3.62 (*d, J* = 5.7, H–C(3)); 3.24 (*br. d, J* = 10.2, H_β–C(5)); 3.07 (*d, J* = 10.2, H_α–C(5)); 2.67–2.40 (*m, CH₂CH=CH₂*); 1.07 (*s, Me_α–C(4)*); 0.93 (*s, Me_β–C(4)*). NOE: see Table 4. ¹³C-NMR (75 MHz, (D₆)DMSO, 50°): 154.5; 138.1; 136.9; 135.9; 128.1; 128.0; 127.5; 127.24; 127.21; 115.9; 85.1; 73.4; 65.7; 60.3; 56.7; 54.6; 30.4; 25.0; 20.1.

Table 4. ¹H-NOE Enhancements of **5bC**

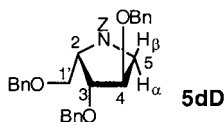
Irradiated H	Enhancements/%
H–C(2)	H–C(3) (7.9), Me _β (3.6)
H–C(3)	H–C(2) (7.8), Me _α (3.4), Me _β (3.2), PhCH ₂ O–C(3) (6.9)
Me _α	H–C(3) (1.0), H _α –C(5) (1.6), PhCH ₂ O–C(3) (1.1), Me _β (2.5)
Me _β	H–C(2) (1.4), H–C(3) (2.4), H _β –C(5) (2.6), Me _α (2.0)
H _α –C(5)	Me _α (3.2)
H _β –C(5)	Me _β (1.9)

(2*S*,3*R*,4*R*,5*S*)-5-Allyl-3,4-bis(benzyloxy)-1-[(benzyloxy)carbonyl]-2-[(benzyloxy)methyl]pyrrolidine (**5dC**). From **4dC** in 91% yield. Colorless oil; single isomer. ¹H-NMR (300 MHz, (D₆)DMSO, 80°): 7.36–7.16 (*m*, 20 H, 4 Ph); 5.77 (*m*, CH=CH₂); 5.07 (*s*, PhCH₂OCO); 4.96–4.82 (*m*, CH=CH₂), 4.66 (*d*, *J* = 11.9, 1 H, PhCH₂O–C(4)); 4.60 (*d*, *J* = 11.9, 1 H, PhCH₂O–C(4)); 4.60 (*s*, 2 H, PhCH₂OCH₂); 4.40–4.32 (*m*, H–C(3), PhCH₂O–C(3)); 4.18 (*dd*, *J* = 8.8, 7.9, H–C(4)); 4.07–3.96 (*m*, H–C(2), H–C(5)); 3.76 (*br. s*, 1 H; PhCH₂OCH₂); 3.52 (*br. d*, *J* = 9.2, 1 H; PhCH₂OCH₂); 2.54 (*m*, 1 H; PhCH₂OCH₂); 2.25 (*m*, 1 H; CH₂CH=CH₂). NOE: see Table 5. ¹³C-NMR (75 MHz, (D₆)DMSO, 80°): 153.4; 138.2; 138.1; 136.4; 135.4; 127.9; 127.77; 127.72; 127.44; 127.37; 127.04; 126.99; 126.94; 126.79; 126.70; 116.6; 80.25; 80.11; 72.2; 71.99; 71.96; 65.7; 55.8; 55.7; 30.1.

Table 5. ¹H-NOE Enhancements of **5dC**

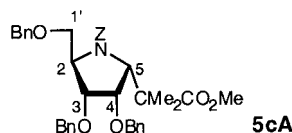
Irradiated H	Enhancements/%
H–C(2), H–C(5)	H–C(3) and/or PhCH ₂ O–C(3) (2.8), H–C(4) (1.7), H _b –C(1') (1.9)
H–C(3), PhCH ₂ O–C(3)	H–C(2) (4.1), H–C(4) (1.3), H _a –C(1') (0.9), PhCH ₂ OCH ₂ (1.7)
H–C(4)	H–C(3) (2.1), H–C(5) (7.0), PhCH ₂ O–C(4) (4.8)
H _a –C(1')	H–C(3) and/or PhCH ₂ O–C(3) (9.0), H _b –C(1') (10.3)
H _b –C(1')	H–C(3) and/or PhCH ₂ O–C(3) (6.0)
PhCH ₂ O–C(4), PhCH ₂ OCH ₂	H–C(2) or H–C(5) (1.2), H–C(3) and/or PhCH ₂ O–C(3) (4.0), H–C(4) (0.7)

(2*S*,3*R*,4*R*)-3,4-Bis(benzyloxy)-1-[(benzyloxy)carbonyl]-2-[(benzyloxy)methyl]pyrrolidine (**5dD**). From **4dD** in 82% yield. Colorless oil. [α]_D²⁵ = –7.7 (*c* = 0.430, CHCl₃). IR (film): 3063, 3031, 2931, 2867, 1702, 1496, 1454, 1414, 1356, 1207, 1095, 1027, 913, 735, 697. ¹H-NMR (300 MHz, (D₆)DMSO, 50°): 7.37–7.19 (*m*, 4 Ph); 5.08 (*d*, *J* = 12.9, 1 H, PhCH₂OCO); 5.03 (*d*, *J* = 12.9, 1 H, PhCH₂OCO); 4.61 (*s*, PhCH₂O–C(3)); 4.56 (*d*, *J* = 12.2, 1 H, PhCH₂O–C(4)); 4.51 (*d*, *J* = 12.2, 1 H, PhCH₂O–C(4)); 4.42 (*s*, PhCH₂OCH₂); 4.23 (*ddd*, *J* = 6.4, 6.4, 4.5, H–C(4)); 4.18–4.09 (*m*, H–C(2), H–C(3)); 3.72–3.63 (*m*, PhCH₂OCH₂); 3.56 (*dd*, *J* = 11.3, 6.4, H_a–C(5)); 3.34 (*dd*, *J* = 11.3, 4.5, H_β–C(5)). NOE: see Table 6. ¹³C-NMR (125 MHz, (D₆)DMSO, 80°): 154.0; 138.1; 137.92; 137.86; 136.5; 127.9; 127.77; 127.71; 127.3; 127.11; 127.09; 127.04; 127.02; 126.99; 126.81; 126.76; 81.2; 79.0; 72.2; 71.7; 70.6; 66.3; 65.7; 57.4; 49.1. Anal. calc. for C₃₄H₃₅NO₅: C 75.95, H 6.56, N 2.61; found: C 76.04, H 6.74, N 2.53.

Table 6. ¹H-NOE Enhancements of **5dD**

Irradiated H	Enhancements/%
H–C(2), H–C(3)	CH ₂ (1') (5.2), PhCH ₂ O–C(3) (3.2)
H–C(4)	H _α –C(5) (8.1), PhCH ₂ O–C(4) (4.6), PhCH ₂ O–C(3) (4.6)
H _α –C(5)	H _β –C(5) (24.7), H–C(4) (7.8)
H _β –C(5)	H _α –C(5) (18.0), H–C(4) (1.8), PhCH ₂ O–C(4) (1.2)
CH ₂ (1')	H–C(2) (5.3), PhCH ₂ O–C(3) (1.8), PhCH ₂ OCH ₂ (3.9)
PhCH ₂ O–C(3)	H–C(3) (4.0), H–C(4) (0.9)
PhCH ₂ O–C(4)	H–C(3) (1.2), H–C(4) (4.0)
PhCH ₂ OCH ₂	CH ₂ (1') (2.0)

5. (2*R*,3*R*,4*S*,5*R*)-3,4-Bis(benzyloxy)-1-[(benzyloxy)carbonyl]-2-[(benzyloxy)methyl]-5-[(1-methoxycarbonyl)-1-methylethyl]pyrrolidine (**5cA**). To a suspension of **4cA** (21.9 mg, 0.033 mmol) and 4-Å molecular sieves powder (activated in a domestic microwave oven; 43 mg) in CH₂Cl₂ (0.66 ml) was added pyridinium chlorochromate (21.3 mg, 3 equiv.) at r.t. After being stirred at r.t. for 2 h, *Celite* and AcOEt were added to the mixture. The resulting suspension was filtered through a short column (silica gel, washing with AcOEt), and the filtrate evaporated. The residue was dissolved in dry MeCN (2 ml) and treated with Et₃SiH (19 μl, 3 equiv.) and Me₃SiOTf (18 μl, 3 equiv.) at 0°. After 20 min, the mixture was quenched with sat. aq. NaHCO₃ soln. and extracted with AcOEt (3 ×). The combined org. phase was washed with brine, dried (MgSO₄), and evaporated, and the residue purified by prep. TLC (hexane/AcOEt 3:1) to give **5cA** (15.8 mg, 72%). Colorless oil; single isomer. ¹H-NMR (300 MHz, (D₆)DMSO, 80°): 7.36–7.17 (*m*, 20 H, 4 Ph); 5.11 (*d*, *J* = 12.5, 1 H, PhCH₂OCO); 4.87 (*d*, *J* = 12.5, 1 H, PhCH₂OCO); 4.66 (*d*, *J* = 11.5, 1 H, PhCH₂O–C(4)); 4.64 (*d*, *J* = 6.7, H–C(5)); 4.60 (*d*, *J* = 11.8, 1 H, PhCH₂O–C(3)); 4.55 (*d*, *J* = 11.8, 1 H, PhCH₂O–C(3)); 4.45 (*d*, *J* = 11.5, 1 H, PhCH₂O–C(4)); 4.32 (*dd*, *J* = 6.7, 5.1, H–C(4)); 4.29 (*s*, PhCH₂OCH₂); 4.07 (*dd*, *J* = 5.1, 4.2, H–C(3)); 3.93–3.83 (*m*, H–C(2), H_α–C(1')); 3.46 (*dd*, *J* = 9.2, 1.2, H_β–C(1')); 3.41 (*s*, MeO); 1.21 (*s*, Me_a of CMe₂CO₂Me); 1.13 (*s*, Me_b of CMe₂CO₂Me). NOE: see Table 7. ¹³C-NMR (75 MHz, (D₆)DMSO, 80°): 176.3; 154.5; 137.9; 137.8; 136.2; 127.9; 127.8; 127.75; 127.68; 127.5; 127.4; 127.2; 127.04; 126.99; 126.95; 126.88; 79.0; 76.6; 71.99; 71.93; 71.6; 67.1; 65.6; 63.4; 62.2; 50.7; 44.9; 24.1; 22.5.

Table 7. ¹H-NOE Enhancements of **5cA**

Irradiated	Enhancements/%
H–C(3)	H–C(4) (7.2), H–C(5) (3.9), PhCH ₂ O–C(3) (5.8)
H–C(2), H _α –C(1')	H _β –C(1') (14.2), PhCH ₂ OCH ₂ (2.3)
H–C(4)	H–C(3) (6.6), H–C(5) (9.8)
H–C(5)	H–C(4) (5.2)
H _β –C(1')	H–C(2) and/or H _α –C(1') (21.0), PhCH ₂ OCH ₂ (3.0)
Me _a of CMe ₂ CO ₂ Me	H–C(4) (1.1), H–C(5) (1.1), PhCH ₂ O–C(4) (1.3)
Me _b of CMe ₂ CO ₂ Me	H–C(5) (1.7)

6. (2*S*,3*R*,4*R*)-2-(Hydroxymethyl)pyrrolidine-3,4-diol Hydrochloride (**7**·HCl). A suspension of **5dD** (36.8 mg), 10% Pd/C (20 mg), and 2*N* HCl (0.5 ml) in EtOH (1.5 ml) was stirred under 1 atm of H₂ at r.t. for

24 h. After removal of H₂, the mixture was filtered through a *Celite* pad with EtOH. Evaporation of the filtrate gave almost pure 7·HCl (13.8 mg). $[\alpha]_D^{25} = -3.4$ ($c = 0.070$, H₂O). ¹H-NMR (300 MHz, D₂O; dioxane (δ 3.70) as internal standard): 4.29 (br. *d*, $J = 4.4$, 1 H); 4.23 (br. *s*, 1 H); 3.98–3.76 (*m*, 3 H); 3.57 (*dd*, $J = 13.0, 4.7$, 1 H); 3.21 (*d*, $J = 13.0$, 1 H). ¹³C-NMR (75 MHz, D₂O; dioxane (δ 67.40) as internal standard): 75.15; 63.84; 58.08; 51.35.

REFERENCES

- [1] a) O. Lockhoff, *Angew. Chem., Int. Ed.* **1991**, *30*, 1611; b) G. Arsequell, G. Valencia, *Tetrahedron: Asymmetry* **1999**, *10*, 3045; c) F. Schweizer, *Angew. Chem., Int. Ed.* **2002**, *41*, 230.
- [2] D. Kahne, S. Walker, Y. Cheng, D. Van Engen, *J. Am. Chem. Soc.* **1989**, *111*, 6881.
- [3] a) M. Sugiura, S. Kobayashi, *Org. Lett.* **2001**, *3*, 477; b) M. Sugiura, H. Hagio, R. Hirabayashi, S. Kobayashi, *Synlett* **2001**, 1225; c) M. Sugiura, H. Hagio, R. Hirabayashi, S. Kobayashi, *J. Am. Chem. Soc.* **2001**, *123*, 12510.
- [4] M. Nagai, J. J. Gaudino, C. S. Wilcox, *Synthesis* **1992**, 163; L. Lay, F. Nicotra, A. Paganini, C. Pangrazio, L. Panza, *Tetrahedron Lett.* **1993**, *34*, 4555; L. Cipolla, L. Lay, F. Nicotra, C. Pangrazio, L. Panza, *Tetrahedron* **1995**, *51*, 4679; L. Cipolla, B. La Ferla, F. Peri, F. Nicotra, *Chem. Commun.* **2000**, 1289; M. Bortolussi, C. Cinquin, R. Bloch, *Tetrahedron Lett.* **1996**, *37*, 8729.
- [5] M. Kawana, *Chem. Lett.* **1981**, 1541; K. Hirota, Y. Monguchi, Y. Kitade, H. Sajiki, *Tetrahedron* **1997**, *53*, 16683.
- [6] S. Deloisy, H. Kunz, *Tetrahedron Lett.* **1998**, *39*, 791.
- [7] T. Yamaguchi, M. Saneyoshi, *Chem. Pharm. Bull.* **1984**, *32*, 1441.
- [8] O. Lockhoff, P. Stadler, *Carbohydr. Res.* **1998**, *314*, 13.
- [9] W. N. Speckamp, M. J. Moolenaar, *Tetrahedron* **2000**, *56*, 3817.
- [10] D. R. Mootoo, P. Konradsson, U. Uododong, B. Fraser-Reid, *J. Am. Chem. Soc.* **1988**, *110*, 5583; B. Fraser-Reid, Z. Wu, U. E. Uododong, H. Ottoson, *J. Org. Chem.* **1990**, *55*, 6068; B. G. Wilson, B. Fraser-Reid, *J. Org. Chem.* **1995**, *60*, 317.
- [11] E. J. Reist, L. V. Fisher, L. Goodman, *J. Org. Chem.* **1967**, *32*, 2541; J. Fukuzawa, S. Okuda, K. Saito, S. Hatanaka, *Phytochemistry* **1985**, *24*, 593; R. J. Nash, E. A. Bell, J. M. Williams, *Phytochemistry* **1985**, *24*, 1620; N. Ikota, *Chem. Pharm. Bull.* **1989**, *37*, 3057; J. G. Buchanan, K. W. Lumbard, R. J. Sturgeon, D. K. Thompson, R. H. Wightman, *J. Chem. Soc. Perkin Trans. 1* **1990**, 699; Q. Meng, M. Hesse, *Helv. Chim. Acta* **1991**, *74*, 445; P. A. M. van der Klein, W. Filemon, H. J. G. Broxterman, G. A. van der Marel, J. H. van Boom, *Synth. Commun.* **1992**, *22*, 1763; M. Nakata, T. Tamai, T. Kamio, M. Kinoshita, K. Tatsuta, *Bull. Chem. Soc. Jpn.* **1994**, *67*, 3057; Y. Huang, D. R. Dalton, P. J. Carroll, *J. Org. Chem.* **1997**, *62*, 372; J. H. Kim, M. S. Yang, W. S. Lee, K. H. Park, *J. Chem. Soc. Perkin Trans. 1* **1998**, 2877.
- [12] O. R. Martin, *Carbohydr. Res.* **1987**, *171*, 211; P. A. M. van der Klein, A. E. J. de Nooy, G. A. van der Marel, J. H. van Boom, *Synthesis* **1991**, 347; F. Vandenriessche, R. Snoeck, G. Janssen, J. Hoogmartens, A. Van Aerschot, E. De Clercq, P. Herdewijn, *J. Med. Chem.* **1992**, *35*, 1458; N. Hossain, H. van Halbeek, E. De Clercq, P. Herdewijn, *Tetrahedron* **1998**, *54*, 2209.
- [13] T. A. Johnson, M. D. Curtis, P. Beak, *J. Am. Chem. Soc.* **2001**, *123*, 1004.

Received June 6, 2002