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# Total synthesis of sphingofungin E from D-glucose derivative

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**Abstract**—Total synthesis of sphingofungin E (**1**) from an already known D-glucose derivative **9** in a stereocontrolled manner is described. 

## 1. Introduction

The sphingofungins have been isolated by the Merck group as new antifungal natural products (Fig. 1).[1] These compounds have a unique mechanism for expression of their biological activities. Namely, they act as fungicides by inhibiting serine palmitoyl transferase, an enzyme essential in the biosynthesis of sphingolipids.[1a,c] The sphingofungins have four consecutive chiral centers and a *trans* olefinic group in their polar head moiety. In particular, sphingofungin E (**1**) and F (**2**) contain a quaternary center at the C-2 position. Their structures, especially the structure of sphingofungin E, are strikingly similar to myriocin (**3**), which has been reported as a potent immunosuppressive agent.[2] In conse-quence of many organic chemists having been interested in the structure of myriocin and its characteristic biological activity, myriocin and its related compounds have been successfully synthesized.[3] Concurrently with the synthetic studies of myriocin, several reports on total syntheses of sphingofungins have been published.[4–6] Especially, four groups including us have recently reported the total synthesis of sphingofungin E in a row.[5] Here we would like to describe in detail the total synthesis of sphingofungin E from an already known D-glucose derivative **9**.

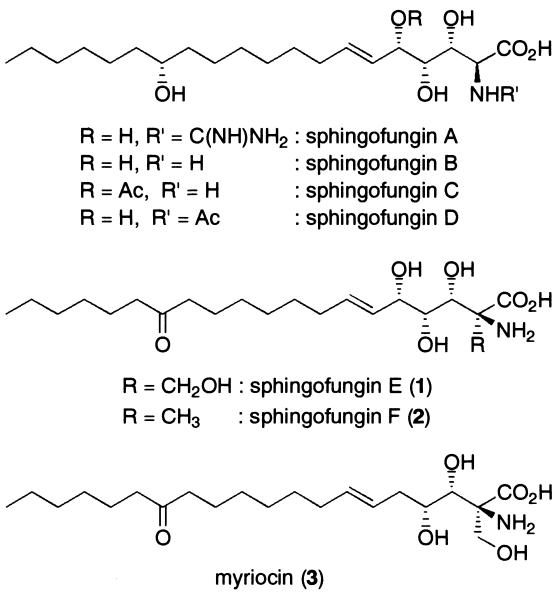


**Figure 1.** Structures of sphingofungins and myriocin.

Based on the retrosynthetic analysis depicted in Fig. 2, the molecule of **1** was divided into two fragments, the hydrophilic polar head group **5** and the lipophilic chain part **4**. We adopted the *B*-alkyl Suzuki–Miyaura cross-coupling reaction[7] for coupling these two fragments in a similar way to Trost's synthesis of sphingofungins E and F.[5c,6a] We thought that this method was the most suitable for conjoining a protected derivative of amino-polyol carboxylic acid **5** and a protected ketone derivative of **4** under moderate conditions to regulate the *E*-geometry of the alkenyl part. In further analysis, we envisioned that this protected derivative of **5** might be derived from a protected derivative of amino-polyol **6** having a C-2 tetra-substituted carbon and four contiguous chiral centers. Regarding this amino-polyol **6**, we focused particularly on the stereochemistry of the C-5 carbon, which has *S*-configuration. However, it should be understood that the C-5 diastereomeric isomer **7** of **6**, easily obtainable from lactone **8**, showed *R*-configuration on the C-5 carbon atom. Therefore, we had to convert the configuration on the C-5 carbon atom from *R* to *S*. A derivative of the lactone **8**, possessing C-2 branched mannosamine-like functional groups in its stereochemistry, had already been synthesized from D-glucose using a procedure via a spiro α-chloroepoxide[8] by Olesker et al.[9] A notable feature of this approach is that all of the functional groups of D-glucose are utilized for the synthesis, and the stereochemistry of the final product and synthetic intermediates are quite unambiguous.

*Keywords*: antifungals; D-glucose; sphingofungin E; Suzuki–Miyaura reaction; total synthesis.

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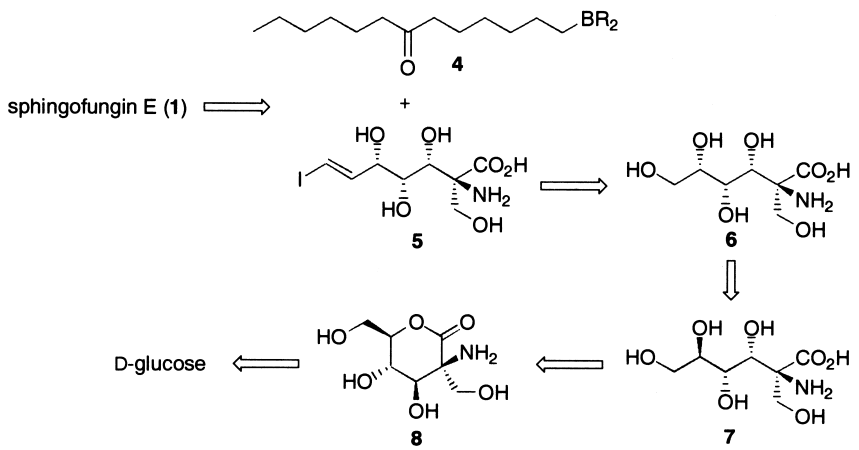



**Figure 2.** Retrosynthetic analysis of sphingofungin E.

## 2. Results and discussion

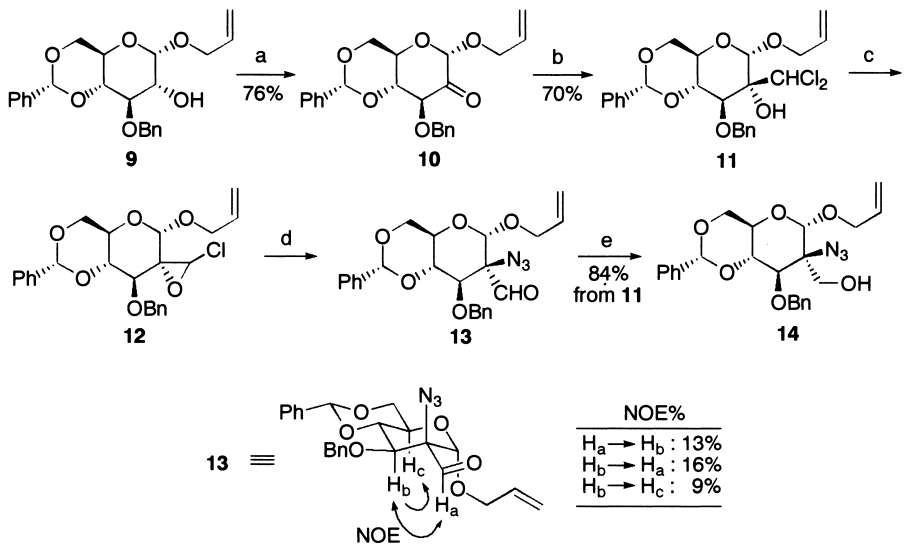
The first stage of the synthesis was stereoselective construction of the C-2 tetra-substituted carbon by using a spiro α-chloroepoxide method[8] (Scheme 1).

The protected D-glucose derivative **9**, which was easily prepared by a modification of the procedure reported by Fukase et al.,[10] could be converted to ketone **10** in 76% yield by Swern oxidation. Addition of dichloromethyllithium to the ketone moiety of **10** afforded C-2 dichloromethylated tertiary alcohol **11**, exclusively, in 70% yield without detection of the C-2 epimer, due to the steric hindrance of the anomeric axial allyloxy group. Treatment of a solution of **11** in dimethyl sulfoxide (DMSO) with 1,8-diazabicyclo[5.4.0]undec-7-en (DBU) gave a spiro α-chloroepoxide **12**,[11] which was then treated with $NaN_3$ in the presence of 15-crown-5 using hexamethylphosphoramide (HMPA) as a solvent to give azide-aldehyde **13** without yielding diastereo- or regioisomers. The aldehyde was immediately reduced with $NaBH_4$ to afford primary alcohol **14** in 84% yield in 3 steps.

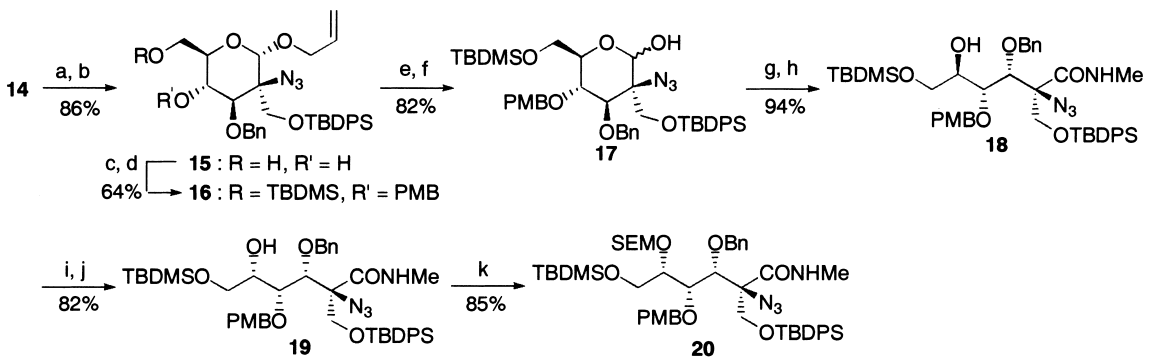
To determine the stereochemistry of the quaternary C-2 position, an NOE experiment of aldehyde **13** was conducted. Irradiation of the aldehyde proton ($H_a$) at $\delta$ 9.28 (singlet) induced enhancement of the C-3 proton ($H_b$) signal at $\delta$ 4.58 (d, $J$=9.8 Hz) by 13%. Additionally, irradiation of the $H_b$ signal induced enhancement of the $H_a$ signal and the C-5 proton ($H_c$) signal at $\delta$ 3.97 (dt, $J$=9.8, 3.9 Hz) by 16 and 9%, respectively. Based on these observations, the stereochemistry of the C-2 position was reasonably established.

The following steps from the primary alcohol **14** to acyclic amide **20** are depicted in Scheme 2.

Protection of the primary hydroxy group of **14** with *tert*-butyldiphenylsilyl chloride (TBDPS-Cl) and imidazole using *N*,*N*-dimethylformamide (DMF) as a solvent, and successive deprotection of the 4,6-*O*-benzylidene group with camphorsulfonic acid (CSA) in MeOH afforded diol **15** in 86% yield. The regioselective silylation at the C-6 hydroxy group of **15** with *tert*-butyldimethylsilyl chloride (TBDMS-Cl) and imidazole followed by the




**Scheme 1.** Construction of the C-2 tetra-substituted carbon and determination of its stereochemistry by NOE experiment. *Reagents and conditions*: (a) Swern oxidation, −78°C, 1 h; (b) $LiCHCl_2$, THF, −78°C, 30 min; (c) DBU, DMSO, 0°C, 3 h; (d) $NaN_3$, cat. 15-crown-5, HMPA, 70°C, 17 h; (e) $NaBH_4$, MeOH, 0°C, 1.5 h.




**Scheme 2.** *Reagents and conditions*: (a) TBDPS-Cl, imidazole, DMF, 60°C, 3 h; (b) cat. CSA, MeOH, rt, 26 h; (c) TBDMS-Cl, imidazole, DMF, 0°C, 2 h; (d) PMB-Cl, NaH, DMF, −23°C, 5 h; (e) $[Ir(C_8H_{12})(PMePh_2)_2]PF_6$, THF, rt, 2.5 h; (f) NBS, $H_2O$, THF, 0°C, 2 h; (g) Dess–Martin periodinane, $CH_2Cl_2$, rt, 2 h; (h) $H_2NMe$, MeOH, rt, 1.5 h; (i) Swern oxidation, −78°C, 1 h; (j) L-Selectride, THF, −78°C, 30 min; (k) SEM-Cl, $EtN(i\text{-}Pr)_2$, 1,2-dichloroethane, 60°C, 4 h.

*p*-methoxybenzyl (PMB) ether formation of the C-4 hydroxy group with PMB-Cl and NaH in DMF at −23°C for 5 h afforded **16** in 64% yield. The C-1 anomeric *O*-allyl group was deprotected by treatment with an Ir complex[12] and successive hydrolysis with *N*-bromosuccinimide (NBS) to give pyranose **17** in 82% yield. Compound **17** was oxidized to a lactone using Dess–Martin periodinane, and successively treated with methylamine in MeOH to afford stable amide **18** in 94% yield. In this lactone opening reaction, only mono-alkylamines as nucleophiles afforded stable amides. When ammonia or several di-alkylamines were used as nucleophiles, the corresponding acyclic amides could not be obtained as stable compounds.

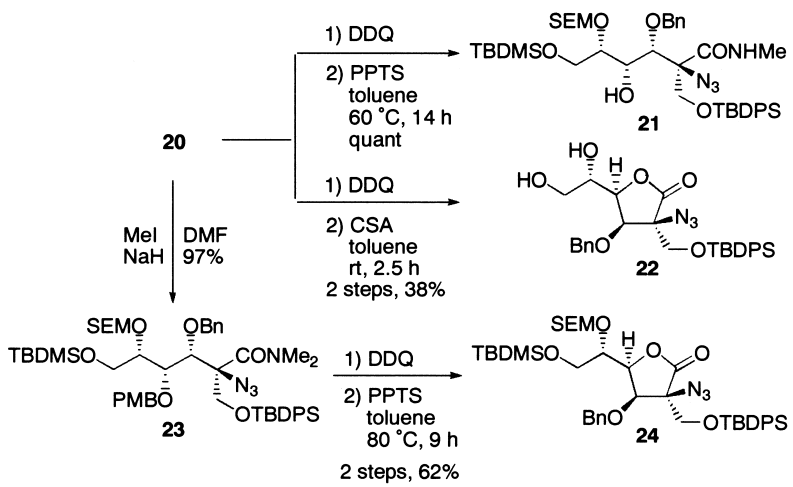
Since the configuration of the C-5 hydroxy group of **18** was opposite to that of natural sphingofungin E, we had to inverse the configuration from *R* to *S*. Therefore, compound **18** was oxidized by Swern oxidation to give a ketone, which was then reduced to alcohol **19** with lithium tri-*sec*-butylborohydride (L-Selectride). This hydride reduction was achieved in a 96:4 ratio diastereo-selectively. After purification by silica gel column chromatography, an inverted alcohol **19** was obtained in 82% yield in two steps. The C-5 hydroxy group of **19** was protected by treatment with 2-(trimethylsilyl)ethoxymethyl chloride (SEM-Cl) and diisopropylethylamine in dichloroethane to give SEM ether **20** in 85% yield.

Next, we carried out the cleavage of the amide bond via the formation of a five-membered lactone by the removal of the C-4 *O*-PMB group (Scheme 3).

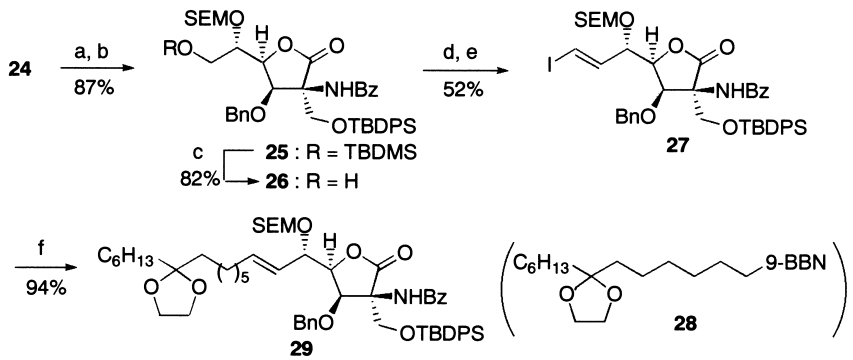
The deprotection of the C-4 *O*-PMB group by treatment of mono methyl amide **20** with 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) in $CH_2Cl_2$–$H_2O$ proceeded smoothly to give **21**, which did not lactonize even in the presence of pyridinium *p*-toluenesulfonate (PPTS) at 60°C for 14 h. However, compound **21** lactonized by treatment with 1 equiv. of CSA in toluene to give both C-5 *O*-SEM and C-6 *O*-TBDMS deprotected compound **22** in low yield. This lactone formation was achieved by activation of the amide bond by methylation to *N*,*N*-dimethyl amide from *N*-methylamide. Treatment of **20** with MeI in the presence of NaH as a base in DMF afforded *N*,*N*-dimethylamide **23** in 97% yield. After cleaving the PMB group, the reaction of **23** with PPTS in toluene at 80°C afforded desired lactone **24** in 62% yield without the undesired deprotection.

The next stage of the synthesis was installation of the lipophilic chain possessing an *E*-geometrical alkenyl part (Scheme 4).

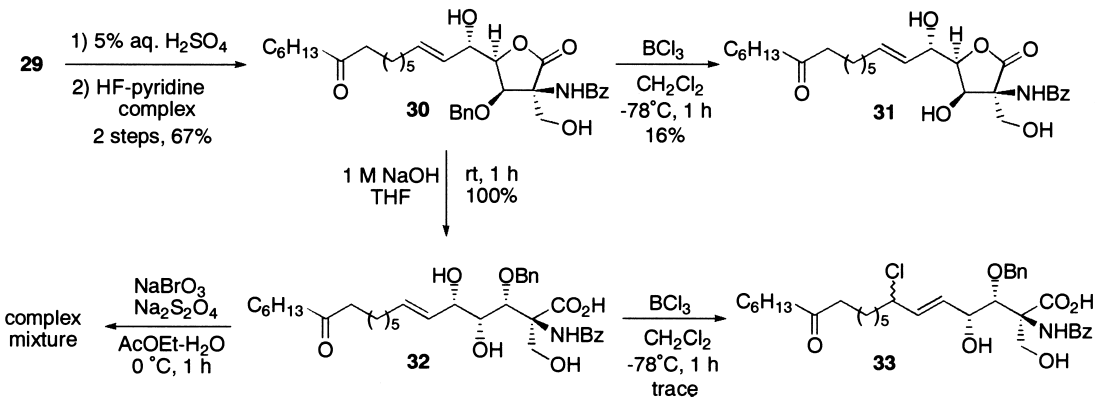
After the reduction of the azide group of **24** under hydrogen atmosphere using Pd on carbon as a catalyst in ethyl acetate,




**Scheme 3.** Lactone formation from amide **20**.




**Scheme 4.** *Reagents and conditions*: (a) Pd/C, $H_2$, AcOEt, rt, 14 h; (b) PhCOCl, $Et_3N$, $CH_2Cl_2$, rt, 2 h; (c) 5% aq. $H_2SO_4$, acetone, rt, 13 h; (d) Dess–Martin periodinane, $CH_2Cl_2$, rt, 1.5 h; (e) $CrCl_2$, $CHI_3$, THF, rt, 2 h; (f) **28**, $PdCl_2$(dppf), $Ph_3As$, $Cs_2CO_3$, THF–DMF, rt, 2 h.




**Scheme 5.** Deprotection of the C-3 *O*-benzyl group.

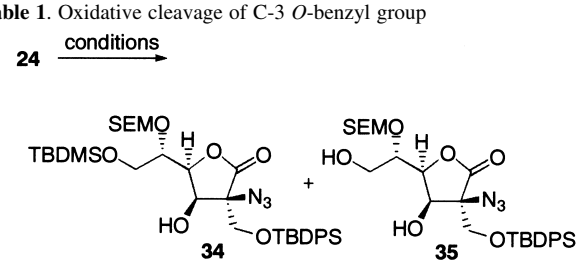
treatment of the resulting amine with benzoyl chloride and triethylamine afforded the benzoylamide **25** in 87% yield. Selective cleavage of the C-6 *O*-TBDMS group of **25** with 5% aqueous $H_2SO_4$ in acetone was accomplished to give alcohol **26** in 82% yield. Dess–Martin oxidation of the C-6 hydroxy group of **26** to an aldehyde, followed by iodo olefination[13] of the resulting aldehyde afforded iodoolefin **27** in 52% yield as a single geometrical isomer. *B*-alkyl Suzuki–Miyaura reaction[5c,6a,7] of vinyl iodide **27** and organoborane **28**[5c,6a] provided the desired alkene **29** in 94% yield. The coupling constant ($J$=15.6 Hz) between the two olefinic protons ($\delta$ 5.28 and 5.78) of compound **29** revealed the olefin geometry to be *E*-configuration.

Deprotection reactions of the benzyl group in the final stage of synthesis are shown in Scheme 5.

The C-14 ethylene acetal moiety of **29** was removed by hydrolysis with 5% aqueous $H_2SO_4$ in acetone. Treatment of the obtained ketone with an HF–pyridine complex in tetrahydrofuran (THF) cleaved both TBDPS and SEM ether to give keto diol **30** in 67% yield. Cleavage of the C-3 *O*-benzyl group proved to be very difficult in this stage. Treatment of lactone **30** with $BCl_3$ in $CH_2Cl_2$ to remove the benzyl group afforded desired triol **31** in only 16% yield. Furthermore, deprotection of the C-3 *O*-benzyl group of **32** with $BCl_3$ in $CH_2Cl_2$ after saponification of the lactone ring only afforded a trace amount of allyl chloride **33**, which was caused by $S_N2'$-type substitution reaction of the chloride anion. In contrast, it was stated by Kobayashi et al. in their report[4c] of the total synthesis of sphingofungin F that the C-4 *O*-benzyl group of a similar compound to **32** could be removed in good yield by using $BCl_3$ in $CH_2Cl_2$. This difference in reactivity between the C-3 and C-4 *O*-benzyl groups may be caused by the steric hindrance of the C-2 quaternary carbon. Additionally, oxidative deprotection of the C-3 *O*-benzyl group of **32** also did not work well. For instance, treatment of $NaBrO_3$ and $Na_2S_2O_4$ toward **32** in AcOEt–$H_2O$ afforded a complex mixture. The $^1$H NMR spectrum of this crude product showed no sign of the olefinic protons of **32**. Therefore, it was obvious that the double bond moiety of **32** could not be preserved under these reaction conditions.

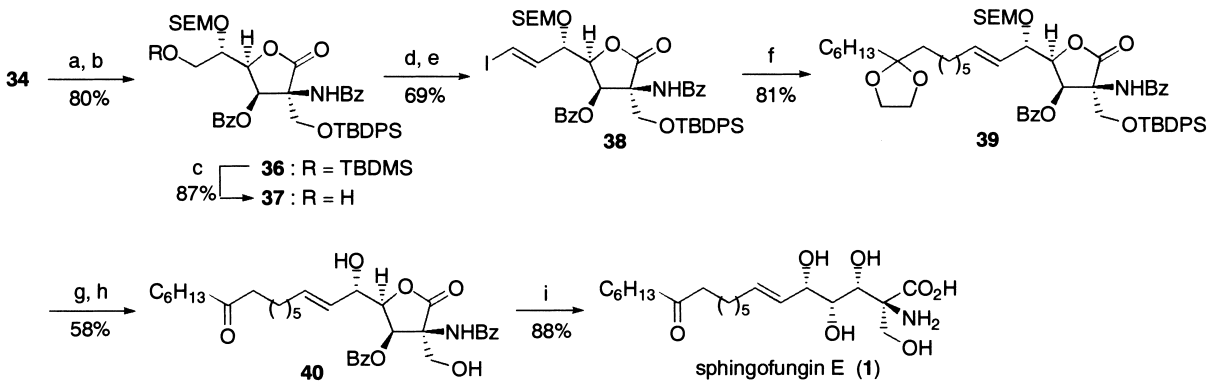
To avoid the difficulty of removing the C-3 *O*-benzyl group after introducing the lipophilic chain, we investigated

**Table 1**. Oxidative cleavage of C-3 *O*-benzyl group




| Entry | Conditions | Results (% yield[a]) |
|---|---|---|
| 1 | $RuCl_3$, $NaIO_4$ $CH_2Cl_2$, rt, 7 h | **34** (trace) |
| 2 | $NaBrO_3$, $Na_2S_2O_4$ AcOEt, rt, 2 h | **34** (45%), **35** (35%) |
| 3 | $NaBrO_3$, $NaHSO_3$ AcOEt, rt, 1 h | **34** (69%), **35** (trace) |

[a] Isolated yields.




**Scheme 6.** *Reagents and conditions*: (a) Pd/C, $H_2$, AcOEt, rt, 14 h; (b) PhCOCl, $Et_3N$, $CH_2Cl_2$, rt, 2 h; (c) 5% aq. $H_2SO_4$, acetone, rt, 13 h; (d) Dess–Martin periodinane, $CH_2Cl_2$, rt, 1.5 h; (e) $CrCl_2$, $CHI_3$, THF, rt, 2 h; (f) **28**, $PdCl_2$(dppf), $Ph_3As$, $Cs_2CO_3$, THF–DMF, rt, 2 h; (g) 5% aq. $H_2SO_4$, acetone, rt, 5 h; (h) HF–pyridine complex, THF, rt, 5.5 h; (i) NaOH, $H_2O$, dioxane, 70°C, 7.5 h, then neutralized with Amberlite IR-120.

oxidative cleavage[14] of the C-3 *O*-benzyl group using lactone **24** as a substrate (Table 1).

Treatment of **24** with a catalytic amount of $RuCl_3$ and excess $NaIO_4$ in $CH_2Cl_2$ afforded a trace amount of debenzylated product **34** (entry 1). The debenzylation proceeded smoothly by treatment of **24** with $NaBrO_3$ and $Na_2S_2O_4$ in AcOEt–$H_2O$, but undesired desilylation of the C-6 *O*-TBDMS group occured to give diol **35** (entry 2). Finally, treatment of **24** with $NaBrO_3$ and $NaHSO_3$ gave the desired debenzylated product **34** in 69% yield[15] (entry 3).

The synthesis of sphingofungin E was achieved by applying the above mentioned procedure (Scheme 6).

Namely, reduction of the azide group of **34** under hydrogen using Pd on carbon in ethyl acetate, followed by treatment with 3 equiv. of benzoyl chloride and excess triethylamine, afforded the *O*-benzoylated benzoylamide **36** in 80% yield. Selective cleavage of the C-6 *O*-TBDMS group of **36** by treatment with 5% aqueous $H_2SO_4$ in acetone was accomplished to give alcohol **37** in 87% yield. Dess–Martin periodinane oxidation of the C-6 hydroxy group of **37** to an aldehyde, followed by iodo olefination of the resulting aldehyde afforded *E*-iodoolefin **38** exclusively in 69% yield. Suzuki–Miyaura cross-coupling reaction of vinyl iodide **38** and organoborane **28** provided the desired *E*-alkene **39** in 81% yield. Deprotection reaction to convert **39** to **1** was carried out as follows. The C-14 ethylene acetal of **39** was removed by hydrolysis with 5% aqueous $H_2SO_4$ in acetone. Treatment of the obtained ketone with an HF–pyridine complex in THF cleaved both TBDPS and SEM ether to give keto diol **40** in 58% yield. Finally, the lactone ring, benzamide and benzoyl ester groups of **40** were saponified in the presence of NaOH in dioxane–$H_2O$, then neutralization with Amberlite IR-120 ion-exchange resin afforded sphingofungin E (**1**) in 88% yield. The spectral data of the obtained synthetic sample closely agreed with those of both natural sphingofungin E reported by the Merck group[1c] and synthetic sphingofungin E reported by Trost,[5c] Lin[5a] and Chida.[5d]

## 3. Conclusion

In summary, total synthesis of sphingofungin E has been accomplished from the known D-glucose derivative **9** in 29 steps in 1.1% overall yield. In our synthesis, it is noteworthy that all of the functional groups of D-glucose were utilized effectively for the synthesis. Moreover, the target product was solely obtained in fairly good yield in each step.

## 4. Experimental

### 4.1. General procedures

Infrared spectra were recorded on a Jasco FT-IR610 spectrophotometer. High-resolution mass (HRMS) spectroscopy was carried out with a JEOL JMS-700V mass spectrometer. $^1$H NMR spectra were recorded on a Varian (500 MHz) instrument with tetramethylsilane as an internal reference. $^{13}$C NMR spectra were recorded on a Varian (500 MHz) at 125 MHz or a JEOL JNM-GSX400 at 100 MHz. Separation of the compounds by column chromatography was carried out with Silica Gel 60 (Merck, 230–400 mesh ASTM) or Silica Gel 60 N (Kanto, spherical, neutral). All reactions were carried out under positive pressure of $N_2$ unless otherwise noted. Tetrahydrofuran was distilled immediately before use from sodium benzophenone ketyl.

**4.1.1. Allyl 3-*O*-benzyl-4,6-*O*-benzylidene-α-D-*arabino*-hexopyranosid-2-ulose (10).** To a solution of oxalyl chloride (13.1 ml, 151 mmol) in $CH_2Cl_2$ (100 ml) was slowly added a solution of DMSO (21.4 ml, 301 mmol) in $CH_2Cl_2$ (50 ml) at −78°C. After stirring for 10 min, to the mixture was added a solution of **9** (30.0 g, 75.3 mmol) in $CH_2Cl_2$ (100 ml), and the mixture was stirred for 1 h at −78°C. To the resulting solution was slowly added $Et_3N$ (83.4 ml, 602 mmol), and the mixture was stirred for 1 h at 0°C. After the addition of water (200 ml), the reaction mixture was poured into water and extracted with ether. The organic layer was washed with brine, dried over anhydrous $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give 39.7 g of a crude product. Recrystallization from hexane–AcOEt gave ketone **10** (22.6 g, 76%) as a white crystalline solid, mp 77–79°C. $[\alpha]_D^{24}$=+28.7 (*c* 1.2, $CHCl_3$). IR (KBr) 1753 cm$^{-1}$. $^1$H NMR ($CDCl_3$) $\delta$ 3.80 (t, 1H, *J*=6.8 Hz), 3.88 (t, 1H, *J*=9.8 Hz), 4.09 (dd, 1H, *J*=4.9, 12.7 Hz), 4.20–4.27 (m, 2H), 4.37 (dd, 1H, *J*=4.9, 9.8 Hz), 4.56 (d, 1H, *J*=10.7 Hz), 4.72 (d, 1H, *J*=12.7 Hz), 4.91 (d,

1H, $J$=12.7 Hz), 4.93 (d, 1H, $J$=12.7 Hz), 5.26 (d, 1H, $J$=11.7 Hz), 5.31 (d, 1H, $J$=15.6 Hz), 5.56 (s, 1H), 5.89 (ddt, 1H, $J$=15.6, 11.7, 5.9 Hz), 7.27–7.34 (m, 3H), 7.36–7.45 (m, 5H), 7.48–7.53 (m, 2H). $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 63.40, 68.68, 69.17, 73.51, 80.74, 82.41, 99.98, 101.13, 118.86, 126.13 (2C), 127.82 (2C), 128.24 (2C), 128.36 (2C), 129.12, 132.67, 136.89, 137.49, 197.34. HRMS (FAB, positive-ion), calcd for $C_{23}H_{25}O_6$: $(M+H)^+$ 397.1651; found: 397.1646.

**4.1.2. Allyl 3-*O*-benzyl-4,6-*O*-benzylidene-2-*C*-dichloromethyl-α-D-glucopyranoside (11).** To a solution of $CH_2Cl_2$ (4.1 ml, 63.8 mmol) in THF (50 ml) was slowly added a 1.54 M solution of *n*-BuLi in hexane (37.6 ml, 57.9 mmol) at −78°C. After stirring for 10 min, to the reaction mixture was slowly added a solution of **10** (7.70 g, 19.3 mmol) in THF (20 ml) via cannula at −78°C. After stirring for 30 min, to the reaction mixture were slowly added MeOH (3 ml) and sat. $NH_4Cl$ (10 ml). The resulting mixture was poured into water and extracted with ether. The organic layer was washed with brine, dried over anhydrous $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude mixture, which was purified by silica gel column chromatography. Elution with EtOAc–hexane (1:9) afforded **11** (7.5 g, 80%) as a colorless oil. $[\alpha]_D^{24}$=+42.7 ($c$ 1.1, $CHCl_3$). IR (neat) 3528 cm$^{-1}$. $^1$H NMR ($CDCl_3$) $\delta$ 3.52 (s, 1H), 3.82 (t, 1H, $J$=10.3 Hz), 3.94 (dt, 1H, $J$=9.8, 4.9 Hz), 4.08 (d, 1H, $J$=9.8 Hz), 4.13 (dd, 1H, $J$=4.9, 10.7 Hz), 4.25–4.32 (m, 2H), 4.34 (d, 1H, $J$=9.8 Hz), 4.85 (d, 1H, $J$=11.7 Hz), 4.92 (d, 1H, $J$=11.7 Hz), 5.28 (s, 1H), 5.29 (d, 1H, $J$=12.7 Hz), 5.35 (d, 1H, $J$=16.6 Hz), 5.61 (s, 1H), 5.94 (ddt, 1H, $J$=4.9, 12.7, 16.6 Hz), 6.25 (s, 1H), 7.28–7.33 (m, 4H), 7.37–7.40 (m, 4H), 7.46–7.48 (m, 2H). $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 63.05, 68.76, 69.10, 73.14, 75.77, 78.00, 79.50, 82.45, 97.06, 101.30, 119.01, 126.02 (2C), 127.69, 127.83 (2C), 128.19 (2C), 128.26 (2C), 128.93, 132.64, 137.28, 138.04. HRMS (FAB, positive-ion), calcd for $C_{24}H_{27}Cl_2O_6$: $(M+H)^+$ 481.1185; found: 481.1188.

**4.1.3. Allyl 2-azido-3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-2-*C*-formyl-α-D-mannopyranoside (13) and allyl 2-azido-3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-2-*C*-hydroxymethyl-α-D-mannopyranoside (14).** To a solution of alcohol **11** 8.9 g (80.8 mmol) in DMSO (100 ml) was added DBU (13.3 ml, 88.9 mmol) at 0°C. After stirring for 3 h at room temperature, to this reaction mixture was added water (10 ml). The resulting mixture was poured into water and extracted with ether. The combined organic layer was washed with brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give 34.3 g of residue. This residue was dissolved in HMPA (150 ml) to which were added $NaN_3$ (52.5 g, 808 mmol) and 15-crown-5 (3.2 ml, 16.2 mmol), and the mixture was stirred for 17 h at 70°C. The resulting mixture was poured into water (200 ml) and extracted with ether. The combined organic layer was washed with brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give 37.3 g of a crude product. A small amount of this crude product of the aldehyde **13** was purified by silica gel column chromatography for an NOE experiment. Elution with EtOAc–hexane (1:9) afforded aldehyde **13** as a colorless oil.

The residual crude product of aldehyde **13** was dissolved in MeOH (100 ml). To this solution was added $NaBH_4$ (3.1 g, 80.9 mmol) at 0°C. After stirring for 1.5 h at 0°C, to the reaction mixture was quenched with water (20 ml). The resulting mixture was evaporated in vacuo to remove MeOH, and diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give 35.9 g of a crude product, which was purified by silica gel column chromatography. Elution with EtOAc–hexane (1:9 then 2:8) afforded **14** (30.7 g, 84%) as a colorless oil. Physical data of **13**: $[\alpha]_D^{24}$=+74.0 ($c$ 1.4, $CHCl_3$). IR (neat) 2136, 1735 cm$^{-1}$. $^1$H NMR ($CDCl_3$) $\delta$ 3.88 (t, 1H, $J$=9.8 Hz), 3.93 (dd, 1H, $J$=6.8, 13.6 Hz), 3.97 (dt, 1H, $J$=9.8, 3.9 Hz), 4.15 (dd, 1H, $J$=5.9, 13.6 Hz),4.24 (t, 1H, $J$=9.8 Hz), 4.58 (d, 1H, $J$=9.8 Hz), 4.66 (s, 1H), 4.72 (d, 1H, $J$=11.7 Hz), 4.96 (d, 1H, $J$=12.7 Hz), 5.19–5.24 (m, 2H), 5.66 (s, 1H), 5.73–5.82 (m, 1H), 7.23–7.35 (m, 5H), 7.36–7.43 (m, 3H), 7.51 (dd, 2H, $J$=2.0, 7.8 Hz), 9.28 (s, 1H). $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 64.05, 68.51, 68.64, 73.92, 74.68, 74.95, 80.47, 99.02, 101.79, 118.86, 125.99, 127.99 (2C), 128.09 (2C), 128.35 (2C), 128.50 (2C), 129.13, 132.30, 137.18, 137.40, 195.93. HRMS (FAB, positive-ion), calcd for $C_{24}H_{26}N_3O_6$: $(M+H)^+$ 452.1821; found: 452.1814. Physical data of **14**: $[\alpha]_D^{24}$=+50.6 ($c$ 1.0, $CHCl_3$). IR (neat) 3515, 2125 cm$^{-1}$. $^1$H NMR ($CDCl_3$) $\delta$ 2.50 (t, 1H, $J$= 6.8 Hz), 3.84–3.90 (m, 2H), 3.92 (d, 2H, $J$=6.8 Hz), 4.03 (dd, 1H, $J$=5.9, 12.7 Hz), 3.98–4.31 (m, 4H), 4.72 (s, 1H), 4.73 (d, 1H, $J$=12.7 Hz), 4.98 (d, 1H, $J$=11.7 Hz), 5.28 (d, 1H, $J$=11.7 Hz), 5.32 (d, 1H, $J$=15.6 Hz), 5.65 (s, 1H), 5.89 (ddt, 1H, $J$=15.6, 11.7, 6.8 Hz), 7.27–7.41 (m, 8H), 7.45–7.50 (m, 2H). $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 62.83, 63.94, 68.03, 68.61, 68.70, 75.29, 76.53, 80.50, 100.12, 101.62, 119.06, 126.00, 127.76 (2C), 127.99 (2C), 128.26 (2C), 128.37 (2C), 128.99, 132.63, 137.34, 138.01. HRMS (FAB, positive-ion), calcd for $C_{24}H_{28}N_3O_6$: $(M+H)^+$ 454.1978; found: 454.1956.

**4.1.4. Allyl 2-azido-3-*O*-benzyl-2-*C*-(*tert*-butyldiphenylsilyloxymethyl)-2-deoxy-α-D-mannopyranoside (15).** To a solution of alcohol **14** (13.5 g, 29.8 mmol) and imidazole (6.1 g, 89.3 mmol) in DMF (30 ml) was added TBDPS-Cl (8.5 ml, 32.8 mmol), and this solution was stirred for 14 h at room temperature. After further stirring for 3 h at 60°C, to this reaction mixture was added sat. $NaHCO_3$ (10 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a residue. This residue was dissolved in MeOH (40 ml) and THF (25 ml), and to this solution was added CSA (1.0 g). After stirring for 26 h at room temperature, to this reaction mixture was added $Et_3N$ (10 ml). After evaporation of this mixture in vacuo, the reaction mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give 25.0 g of a crude product, which was purified by silica gel column chromatography. Elution with EtOAc–hexane (3:7 then 4:6) afforded **15** (15.8 g, 86%) as a white crystalline solid, mp 107–109°C. $[\alpha]_D^{24}$=+23.8 ($c$ 1.6, $CHCl_3$). IR (KBr) 3411, 2128 cm$^{-1}$. $^1$H NMR ($CDCl_3$) $\delta$ 1.06 (s, 9H), 2.58 (brs, 1H), 3.13 (d, 1H, $J$=3.9 Hz), 3.56 (d, 1H, $J$=8.8 Hz), 3.63 (dt, 1H, $J$=9.8, 3.9 Hz), 3.80–3.88 (m, 3H), 3.93–4.00 (m, 2H), 4.04 (dt, 1H, $J$=4.9, 9.8 Hz), 4.22 (dd, 1H, $J$=5.9, 12.7 Hz), 4.41 (d, 1H, $J$=11.7 Hz), 4.65 (d, 1H, $J$=11.7 Hz),

5.07 (s, 1H), 5.19 (d, 1H, $J$=10.7 Hz), 5.26 (d, 1H, $J$=18.6 Hz), 5.86 (ddt, 1H, $J$=10.7, 18.6, 4.9 Hz), 7.03–7.08 (m, 2H), 7.10–7.14 (m, 3H), 7.35–7.41 (m, 4H), 7.41–7.47 (m, 2H), 7.62 (d, 2H, $J$=6.8 Hz), 7.69 (d, 2H, $J$=6.8 Hz). $^{13}$C NMR (125 MHz, $CDCl_3$) $\delta$ 19.11, 26.65 (3C), 62.25, 64.28, 68.56, 69.00, 69.63, 72.00, 75.75, 80.13, 97.13, 117.47, 127.66 (2C), 127.74 (2C), 127.78, 127.85 (2C), 128.30 (2C), 129.66, 129.84, 132.25, 132.77, 133.29, 135.47 (2C), 135.68 (2C), 137.38. HRMS (FAB, positive-ion), calcd for $C_{33}H_{41}N_3O_6SiNa$: $(M+Na)^+$ 626.2662; found: 626.2664.

**4.1.5. Allyl 2-azido-3-*O*-benzyl-6-*O*-(*tert*-butyldimethylsilyl)-2-*C*-(*tert*-butyldiphenylsilyloxymethyl)-2-deoxy-4-*O*-(*p*-methoxybenzyl)-α-D-mannopyranoside (16).** To a solution of diol **15** (15.6 g, 25.8 mmol) and imidazole (5.3 g, 77.5 mmol) in DMF (30 ml) was added TBDMS-Cl (4.1 g, 27.1 mmol). After stirring for 2 h at 0°C, to this reaction mixture was added sat. $NaHCO_3$ (10 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give 18.5 g of a residue. This residue was dissolved in DMF (30 ml). PMB-Cl (7.0 ml, 51.6 mmol) was added to this solution. After cooling the solution to −23°C, to this mixture was slowly added 55 wt% NaH (1.2 g, 28.4 mmol). After stirring for 5 h, the reaction mixture was quenched with 1 M aq. NaOH (10 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give 26.2 g of a crude product, which was dissolved in THF (25 ml). To this solution were added 1 M aq. NaOH (20 ml) and 15-crown-5 (0.5 ml) to convert excess PMB-Cl to PMB-OH. After observance of the disappearance of PMB-Cl by TLC monitoring, the reaction mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with EtOAc–hexane (3:97 then 1:19) afforded **16** (13.9 g, 64%) as a colorless oil. $[\alpha]_D^{24}$=+34.5 ($c$ 0.64, $CHCl_3$). IR (neat) 2124 cm$^{-1}$. $^1$H NMR ($CDCl_3$) $\delta$ 0.09 (s, 3H), 0.11 (s, 3H), 0.93 (s, 9H), 1.03 (s, 9H), 3.59–3.66 (m, 2H), 3.69 (d, 1H, $J$=10.3 Hz), 3.76–3.90 (m, 6H, involving a singlet at $\delta$ 3.79), 4.23 (dd, 1H, $J$=5.1, 12.4 Hz), 4.31 (d, 1H, $J$=11.0 Hz), 4.59 (d, 1H, $J$=12.4 Hz), 4.73 (d, 2H, $J$=11.0 Hz), 5.14 (s, 1H), 5.18 (dd, 1H, $J$=1.5, 10.3 Hz), 5.23 (dd, 1H, $J$=1.5, 16.8 Hz), 5.86 (ddt, 1H, $J$=10.3, 16.8, 5.1 Hz), 6.86 (d, 2H, $J$=8.8 Hz), 6.98–7.10 (m, 5H), 7.22 (d, 2H, $J$=8.1 Hz), 7.33–7.50 (m, 6H), 7.58–7.63 (m, 2H), 7.66–7.72 (m, 2H). $^{13}$C NMR (125 MHz, $CDCl_3$) $\delta$ −5.35, −5.22, 18.23, 19.05, 25.83 (3C), 26.60 (3C), 55.20, 62.09, 65.11, 68.18, 69.77, 72.91, 74.88, 75.66, 76.33, 79.31, 96.35, 113.87 (2C), 117.07, 127.64 (2C), 127.73, 127.75 (2C), 128.18 (2C), 129.58 (2C), 129.63 (2C), 129.75, 130.40, 132.35, 132.76, 133.50, 135.49 (2C), 135.66 (2C), 137.29, 159.30. HRMS (FAB, positive-ion), calcd for $C_{47}H_{63}N_3O_7Si_2Na$: $(M+Na)^+$ 860.4102; found: 860.4108.

**4.1.6. 2-Azido 3-*O*-benzyl-6-*O*-(*tert*-butyldimethylsilyl)-2-*C*-(*tert*-butyldiphenylsilyloxymethyl)-2-deoxy-4-*O*-(*p*-methoxybenzyl)-α-D-mannopyranoside (17).** A solution of $[Ir(C_8H_{12})(MePPh_2)_2]PF_6$ (0.2 g, 0.24 mmol) in THF (10 ml) was placed in a two-necked flask and the air was replaced with a hydrogen atmosphere. After stirring for 5 min, the color of the solution turned to colorless from red, then the hydrogen was replaced with nitrogen. To the reaction mixture was added a solution of **16** (10.6 g, 12.6 mmol) in THF (12 ml) via cannula, and this solution was stirred for 2.5 h at room temperature. Evaporation of the reaction mixture in vacuo afforded a residue, which was dissolved in THF (15 ml) and $H_2O$ (5 ml). To this solution was added NBS (2.7 g, 15.1 mmol) at 0°C, and the mixture was stirred for 2 h. The reaction mixture was quenched with sat. $NaHCO_3$ (5 ml) and sat. $Na_2S_2O_3$ (5 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (7:93 then 1:9) afforded **17** (8.26 g, 82%) as a colorless oil. $[\alpha]_D^{24}$=+12.6 ($c$ 1.2, $CHCl_3$). IR (neat) 3428, 2120 cm$^{-1}$. $^1$H NMR ($CDCl_3$) $\delta$ 0.08 (s, 3H), 0.11 (s, 3H), 0.92 (s, 9H), 1.04 (s, 9H), 2.72 (d, 1H, $J$=2.9 Hz), 3.69 (d, 1H, $J$=8.8 Hz), 3.71 (d, 1H, $J$=9.8 Hz), 3.76–3.82 (m, 4H, involving a singlet at $\delta$ 3.78), 3.82–3.94 (m, 3H), 4.00 (t, 1H, $J$=8.8 Hz), 5.40 (d, 1H, $J$=3.9 Hz), 6.85 (d, 2H, $J$=8.8 Hz), 7.03–7.08 (m, 2H), 7.09–7.14 (m, 3H), 7.19–7.24 (m, 2H), 7.34–7.48 (m, 6H), 7.63 (d, 2H, $J$=6.8 Hz), 7.67 (d, 2H, $J$=7.8 Hz). $^{13}$C NMR (125 MHz, $CDCl_3$) $\delta$ −5.34, −5.17, 18.36, 19.15, 25.91 (3C), 26.71 (3C), 55.22, 62.46, 65.09, 69.55, 72.94, 74.79, 75.59, 76.36, 78.76, 92.23, 113.86 (2C), 127.69 (2C), 127.71, 127.75 (2C), 128.05 (2C), 128.23 (2C), 129.60 (2C), 129.72, 129.79, 130.44, 132.49, 132.75, 135.58 (2C), 135.63 (2C), 137.41, 159.25. HRMS (FAB, positive-ion), calcd for $C_{44}H_{58}N_3O_7Si_2$: $(M-H)^+$ 796.3813; found: 796.3824.

**4.1.7. (2*S*,3*R*,4*S*,5*R*)-*N*-Methyl-2-azido-3-benzyloxy-6-(*tert*-butyldimethylsilyloxy)-2-(*tert*-butyldiphenylsilyloxymethyl)-4-(*p*-methoxybenzyloxy)hexanoamide (18).** To a solution of **17** (1.87 g, 2.3 mmol) in $CH_2Cl_2$ (5 ml) was added Dess–Martin periodinane (1.50 g, 3.5 mmol) at 0°C and this solution was stirred for 5 min. After further stirring for 2 h at room temperature, to this reaction mixture were slowly added sat. $NaHCO_3$ (5 ml) and sat. $Na_2S_2O_3$ (5 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give 1.80 g of a residue, which was dissolved in MeOH (5 ml). To this solution was added 40% solution of $MeNH_2$ in MeOH (5 ml). After stirring for 1.5 h at room temperature, the solvent of the reaction mixture was removed in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (1:9 then 3:17) afforded **18** (1.85 g, 94%) as a white solid, mp 85–87°C. $[\alpha]_D^{24}$=+35.3 ($c$ 1.0, $CHCl_3$). IR (KBr) 3317, 2130, 1650 cm$^{-1}$. $^1$H NMR ($CDCl_3$) $\delta$ 0.06 (s, 3H), 0.07 (s, 3H), 0.90 (s, 9H), 1.03 (s, 9H), 2.68 (d, 1H, $J$=6.6 Hz), 2.79 (d, 3H, $J$=5.1 Hz), 3.57 (dd, 1H, $J$=2.2, 8.1 Hz), 3.66–3.75 (m, 3H), 3.79 (s, 3H), 4.09 (s, 2H), 4.37–4.45 (m, 3H), 4.63 (d, 1H, $J$=10.3 Hz), 4.78 (d, 1H, $J$=11.0 Hz), 6.81–6.89 (m, 3H), 7.09–7.26 (m, 7H), 7.34–7.47 (m, 6H), 7.61 (dd, 2H, $J$=1.5, 7.3 Hz), 7.66 (dd, 2H, $J$=1.5, 8.1 Hz). $^{13}$C NMR (125 MHz, $CDCl_3$) $\delta$ −5.37, −5.35, 18.22, 19.16, 25.87 (3C), 26.59 (3C), 55.18, 63.39, 65.73, 71.56, 73.57, 74.28, 75.33, 77.91, 79.69, 113.64 (2C), 127.53, 127.63 (2C),

127.74 (4C), 128.07, 128.19 (2C), 129.42 (2C), 129.75, 129.84, 130.53, 132.46, 132.59, 135.51 (2C), 135.56 (2C), 137.59, 159.10, 169.26. HRMS (FAB, positive-ion), calcd for $C_{45}H_{63}N_4O_7Si_2$: $(M+H)^+$ 827.4235; found: 827.4232.

**4.1.8. (2*S*,3*R*,4*S*,5*S*)-*N*-Methyl-2-azido-3-benzyloxy-6-(*tert*-butyldimethylsilyloxy)-2-(*tert*-butyldiphenylsilyloxymethyl)-5-hydroxy-4-(*p*-methoxybenzyloxy)hexanoamide (19).** To a solution of oxalyl chloride (0.36 ml, 4.1 mmol) in $CH_2Cl_2$ (5 ml) was slowly added DMSO (0.58 ml, 8.2 mmol) at −78°C. After stirring for 10 min, to this mixture was added a solution of **18** (1.68 g, 2.03 mmol) in $CH_2Cl_2$ (5 ml) via cannula and the mixture was stirred for 1 h at −78°C. To this resulting mixture was slowly added $Et_3N$ (2.3 ml, 16.4 mmol), and this mixture was stirred for 30 min at 0°C. The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give 1.83 g of residue, which was dissolved in THF (5 ml) and slowly transferred into a 1.0 M solution of L-Selectride in THF (6.0 ml, 6.0 mmol) via cannula at −78°C. After stirring for 30 min, to this reaction mixture were added 1 M aq. NaOH (2 ml) and 40% aq. $H_2O_2$ (2 ml). After stirring for 30 min at room temperature, the resulting mixture was quenched with sat. $Na_2S_2O_3$ (1 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (1:9 then 3:17) afforded **19** (1.38 g, 82%) as a colorless oil. $[\alpha]_D^{24}$=+12.8 (*c* 0.50, $CHCl_3$). IR (neat) 3433, 2128, 1737, 1677 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.04 (s, 6H), 0.89 (s, 9H), 1.03 (s, 9H), 2.54 (br, d, 1H, *J*=5.9 Hz), 2.82 (d, 3H, *J*=4.9 Hz), 3.41–3.47 (m, 1H), 3.49 (t, 1H, *J*=7.8 Hz), 3.59 (dd, 1H, *J*=5.9, 9.8 Hz), 3.76–3.85 (m, 4H, involving a singlet at $\delta$ 3.78), 4.06 (d, 1H, *J*=9.8 Hz), 4.17 (d, 1H, *J*=10.7 Hz), 4.27 (d, 1H, *J*=6.8 Hz), 4.34 (d, 1H, *J*=11.7 Hz), 4.48 (d, 1H, *J*=10.7 Hz), 4.74 (d, 1H, *J*=10.7 Hz), 4.79 (d, 1H, *J*=11.7 Hz), 6.77–6.85 (m, 3H), 7.01–7.07 (m, 2H), 7.14–7.22 (m, 3H), 7.35–7.48 (m, 6H), 7.59 (d, 2H, *J*=6.8 Hz), 7.66 (d, 2H, *J*=6.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ −5.48, −5.42, 18.08, 19.08, 25.80 (3C), 26.33, 26.52 (3C), 55.08 (2C), 63.57, 65.56, 71.58, 74.37, 74.56, 76.90, 80.57, 113.53 (2C), 127.36, 127.42 (2C), 127.70 (2C), 127.71 (2C), 128.11 (2C), 129.72, 129.78 (2C), 129.84, 130.45, 132.26, 132.41, 135.42 (2C), 135.51 (2C), 137.58, 159.09, 169.24. HRMS (FAB, positive-ion), calcd for $C_{45}H_{63}N_4O_7Si_2$: $(M+H)^+$ 827.4235; found: 827.4239.

**4.1.9. (2*S*,3*R*,4*S*,5*S*)-*N*-Methyl-2-azido-3-benzyloxy-6-(*tert*-butyldimethylsilyloxy)-2-(*tert*-butyldiphenylsilyloxymethyl)-4-(*p*-methoxybenzyloxy)-5-[2-(trimethylsilyl)ethoxymethoxy]hexanoamide (20).** To a solution of **19** (1.33 g, 1.61 mmol) in dichloroethane (5 ml) were added EtN(*i*-Pr)$_2$ (1.3 ml, 8.0 mmol) and SEM-Cl (0.85 ml, 4.8 mmol). After stirring for 4 h at 60°C, the reaction mixture was quenched with sat. $NaHCO_3$ (2 ml). This mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (1:9) afforded **20** (1.31 g, 85%) as a colorless oil. $[\alpha]_D^{24}$=−1.5 (*c* 0.6, $CHCl_3$). IR (neat) 3438, 2127, 1681, 1515, 1250 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.00 (s, 9H), 0.06 (s, 3H), 0.07 (s, 3H), 0.87 (m, 11H, involving a singlet at $\delta$ 0.93), 0.17 (s, 9H), 2.86 (d, 3H, *J*=4.8 Hz), 3.42 (br, t, 1H, *J*=7.8 Hz), 3.54 (dt, 1H, *J*=5.9, 10.3 Hz), 3.70–3.79 (m, 4H), 3.81 (s, 3H), 3.90 (dd, 1H, *J*=1.8, 6.6 Hz), 4.15 (d, 1H, *J*=10.5 Hz), 4.18 (d, 1H, *J*=6.6 Hz), 4.25 (d, 1H, *J*=10.5 Hz), 4.37 (d, 1H, *J*=11.7 Hz), 4.50 (d, 1H, *J*=10.5 Hz), 4.75–4.84 (m, 3H), 4.88 (d, 1H, *J*=11.7 Hz), 6.81 (d, 2H, *J*=8.5 Hz), 6.84 (q, 1H, *J*=4.8 Hz), 7.05–7.11 (m, 2H), 7.17–7.26 (m, 5H), 7.41–7.52 (m, 6H), 7.65 (d, 2H, *J*=7.1 Hz), 7.72 (d, 2H, *J*=7.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ −5.49, −5.46, −1.44 (3C), 18.11 (2C), 19.19, 25.86 (3C), 26.41, 26.59 (3C), 55.17, 61.94, 65.40, 65.72, 74.25, 74.72, 75.00, 76.10, 79.49, 79.70, 96.39, 113.49 (2C), 127.23, 127.46 (2C), 127.73 (2C), 127.75 (2C), 128.07 (2C), 129.71, 129.85, 130.07 (2C), 130.82, 132.51, 132.69, 135.55 (2C), 135.60 (2C), 138.14, 159.05, 168.58. HRMS (FAB, positive-ion), calcd for $C_{51}H_{76}N_4O_8Si_3Na$: $(M+Na)^+$ 979.4869; found: 979.4861.

**4.1.10. Physical data of (2*S*,3*R*,4*S*,5*S*)-*N*-methyl-2-azido-3-benzyloxy-6-(*tert*-butyldimethylsilyloxy)-2-(*tert*-butyldiphenylsilyloxymethyl)-4-hydroxy-5-[2-(trimethylsilyl)ethoxymethoxy]hexanoamide (21).** $[\alpha]_D^{24}$=−11.2 (*c* 1.1, $CHCl_3$). IR (neat) 3539, 3435, 3370, 2127, 1681 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.00 (s, 3H), 0.02 (s, 3H), 0.89 (s, 9H), 1.04 (s, 9H), 2.84 (d, 3H, *J*=5.1 Hz), 3.02 (d, 1H, *J*=5.9 Hz), 3.44–3.49 (m, 1H), 3.55 (ddd, 1H, *J*=6.6, 9.5, 10.3 Hz), 3.69 (ddd, 1H, *J*=6.6, 9.5, 10.3 Hz), 3.72–3.83 (m, 3H), 4.08 (d, 1H, *J*=10.3 Hz), 4.12 (d, 1H, *J*=3.7 Hz), 4.17 (d, 1H, *J*=10.3 Hz), 4.37 (d, 1H, *J*=11.0 Hz), 4.74 (d, 1H, *J*=11.0 Hz), 4.80 (s, 2H), 6.86 (q, 1H, *J*=5.1 Hz), 7.08–7.12 (m, 2H), 7.20–7.24 (m, 3H), 7.37–7.48 (m, 6H), 7.63 (d, 2H, *J*=6.8 Hz), 7.67 (d, 2H, *J*=6.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ −5.44 (2C), −1.46 (3C), 15.24, 18.11, 18.23, 19.19, 25.88 (3C), 26.34, 26.62 (3C), 63.45, 65.08, 65.81, 70.09, 75.33, 75.66, 78.63, 79.55, 95.19, 127.57 (2C), 127.78 (2C), 127.80 (2C), 128.35 (2C), 129.80, 129.91, 132.41, 132.53, 135.59 (2C), 135.61 (2C), 137.53, 169.00. HRMS (FAB, positive-ion), calcd for $C_{43}H_{69}N_4O_7Si_3$: $(M+H)^+$ 837.4474; found: 837.4476.

**4.1.11. Physical data of (1′*S*,3*S*,4*R*,5*S*)-3-azido-4-benzyloxy-3-(*tert*-butyldiphenylsilyloxymethyl)-5-(1′,2′-dihydroxyethyl)-2-oxo-tetrahydrofuran (22).** $^1H$ NMR ($CDCl_3$) $\delta$ 1.12 (s, 9H), 1.96 (br, 1H), 2.88 (br, 1H), 3.67 (t, 2H, *J*=5.4 Hz), 3.84 (d, 1H, *J*=10.3 Hz), 4.00 (d, 1H, *J*=10.3 Hz), 4.08–4.13 (m, 1H), 4.40 (d, 1H, *J*=5.6 Hz), 4.47 (d, 1H, *J*=11.0 Hz), 4.60 (t, 1H, *J*=4.7 Hz), 4.93 (d, 1H, *J*=11.0 Hz), 7.28–7.34 (m, 5H), 7.38–7.55 (m, 6H), 7.63–7.70 (m, 4H). MS (FAB, positive-ion) *m/z*, 584 $(M+Na)^+$; 600 $(M+K)^+$.

**4.1.12. (2*S*,3*R*,4*S*,5*S*)-*N*,*N*-Dimethyl-2-azido-3-benzyloxy-6-(*tert*-butyldimethylsilyloxy)-2-(*tert*-butyldiphenylsilyloxymethyl)-4-(*p*-methoxybenzyloxy)-5-[2-(trimethylsilyl)ethoxymethoxy]hexanoamide (23).** To a solution of **20** (1.56 g, 1.63 mmol) in DMF (3 ml) were added MeI (0.30 ml, 4.8 mmol) and 55 wt% of NaH (87 mg, 2.0 mmol) at 0°C. After stirring for 1.5 h, the reaction mixture was quenched with sat. $NH_4Cl$ (2 ml). The resulting

mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give 1.62 g of a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (1:19) afforded **23** (1.50 g, 97%) as a colorless oil. $[\alpha]_D^{24}=-10.2$ (*c* 0.5, $CHCl_3$). IR (neat) 2111, 1633, 1616 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.00 (s, 9H), 0.05 (s, 6H), 0.91 (s, 9H), 1.10 (s, 9H), 2.93 (brs, 3H), 3.36 (brs, 3H), 3.55 (dt, 1H, *J*=6.0, 9.8 Hz), 3.64 (dt, 1H, *J*=2.6, 9.8 Hz), 3.69–3.83 (m, 6H, involving a singlet at $\delta$ 3.79), 3.90 (dd, 1H, *J*=2.5, 5.5 Hz), 4.21 (d, 1H, *J*=10.6 Hz), 4.28 (d, 1H, *J*=10.6 Hz), 4.33 (d, 1H, *J*=5.5 Hz), 4.48 (d, 1H, *J*=11.6 Hz), 4.51 (d, 1H, *J*=10.6 Hz), 4.75 (d, 1H, *J*=10.6 Hz), 4.82 (s, 2H), 4.86 (d, 1H, *J*=11.6 Hz), 6.81 (d, 2H, *J*=8.6 Hz), 7.13–7.18 (m, 2H), 7.19–7.28 (m, 5H), 7.36–7.50 (m, 6H), 7.67 (d, 2H, *J*=6.5 Hz), 7.73 (d, 2H, *J*=6.7 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ −5.51, −5.47, −1.46 (3C), 18.08, 18.09, 19.11, 25.84 (3C), 26.71 (3C), 38.78, 55.10 (2C), 62.42, 65.36, 67.46, 74.03, 75.03, 76.45, 79.55, 80.18, 96.14, 113.42 (2C), 127.14, 127.55 (2C), 127.71 (2C), 127.74 (2C), 128.02 (2C), 129.70, 129.79 (2C), 129.84, 131.01, 132.48, 132.58, 135.55 (2C), 135.61 (2C), 138.33, 158.92, 168.40. HRMS (FAB, positive-ion), calcd for $C_{52}H_{78}N_4O_8Si_3K$: $(M+K)^+$ 1009.4765; found: 1009.4763.

**4.1.13. (1′*S*,3*S*,4*R*,5*S*)-3-Azido-4-benzyloxy-5-[2′-(*tert*-butyldimethylsilyloxy)-1′-[2-(trimethylsilyl)ethoxymethoxy]ethyl]-3-(*tert*-butyldiphenylsilyloxymethyl)-2-oxo-tetrahydrofuran (24).** To a solution of **23** (1.49 g, 1.53 mmol) in $CH_2Cl_2$ (3 ml) was added $H_2O$ (0.5 ml) and DDQ (0.42 g, 1.84 mmol) at 0°C. After stirring for 3 h at room temperature, to this reaction mixture was added 1 M aq. NaOH (5 ml). This mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give 1.44 g of a crude alcohol, which was dissolved in toluene (5 ml), and PPTS (0.78 g, 3.1 mmol) was added to this solution. After stirring for 24 h at 70°C, the reaction mixture was quenched with sat. $NaHCO_3$ (2 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (1:19) afforded **24** (0.83 g, 62%) as a colorless oil. $[\alpha]_D^{24}=-6.4$ (*c* 0.6, $CHCl_3$). IR (neat) 2120, 1785 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.01 (s, 12H), 0.04 (s, 3H), 0.84–1.00 (m, 11H, involving a singlet at $\delta$ 0.87), 1.07 (s, 9H), 3.57 (dt, 1H, *J*=15.6, 5.9 Hz), 3.64–3.77 (m, 4H), 3.88 (d, 1H, *J*=8.8 Hz), 3.96 (dd, 1H, *J*=4.9, 10.7 Hz), 4.41 (d, 1H, *J*=10.7 Hz), 4.45 (d, 1H, *J*=5.9 Hz), 4.70 (d, 1H, *J*=6.8 Hz), 4.75 (d, 1H, *J*=6.8 Hz), 4.85 (d, 1H, *J*=4.9 Hz), 4.86 (d, 1H, *J*=5.9 Hz), 7.28–7.38 (m, 5H), 7.38–7.50 (m, 6H), 7.60–7.70 (m, 4H). $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ −5.49, −5.40, −1.46, 17.99, 18.26, 19.18, 25.89 (3C), 26.70 (3C), 55.51, 62.31, 65.33, 65.58, 69.82, 74.33, 75.65, 77.82, 80.14, 95.03, 114.27, 127.93 (2C), 127.94 (2C), 128.00 (2C), 128.22, 128.55 (2C), 130.14, 131.75, 131.92, 131.97, 135.56 (2C), 135.57 (2C), 136.54, 171.69. HRMS (FAB, positive-ion), calcd for $C_{42}H_{63}N_3O_7Si_3Na$: $(M+Na)^+$ 828.3872; found: 828.3859.

**4.1.14. (1′*S*,3*S*,4*R*,5*S*)-3-Benzamido-4-benzyloxy-5-[2′-(*tert*-butyldimethylsilyloxy)-1′-[2-(trimethylsilyl)ethoxymethoxy]ethyl]-3-(*tert*-butyldiphenylsilyloxymethyl)-2-oxo-tetrahydrofuran (25).** To a solution of **24** (0.22 g, 0.27 mmol) in AcOEt (1 ml) was added 10% Pd–C (0.22 g) and the air was replaced with hydrogen. After stirring for 3 h at room temperature, the reaction mixture was filtered through Celite. The filtrate was evaporated in vacuo to give a crude amine, which was dissolved in $CH_2Cl_2$ (1 ml). To this solution were added DMAP (10 mg), $Et_3N$ (0.11 ml, 0.82 mmol) and PhCOCl (63 μl, 0.55 mol). After stirring for 1 h at room temperature, the reaction mixture was quenched with sat. $NaHCO_3$ (0.5 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (1:19) afforded **25** (0.21 g, 87%) as a colorless oil. $[\alpha]_D^{24}=+32.5$ (*c* 0.5, $CHCl_3$). IR (neat) 3422, 3352, 1783, 1668 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.00 (s, 6H), 0.01 (s, 3H), 0.83–0.98 (m, 11H, involving a singlet at $\delta$ 0.84), 1.01 (s, 9H), 3.65 (t, 2H, *J*=8.3 Hz), 3.69 (dd, 1H, *J*=3.9, 11.1 Hz), 3.75 (dd, 1H, *J*=3.1, 11.1 Hz), 4.06–4.09 (m, 1H), 4.29 (d, 1H, *J*=10.0 Hz), 4.34 (d, 1H, *J*=10.0 Hz), 4.49 (d, 1H, *J*=11.3 Hz), 4.62 (d, 1H, *J*=4.3 Hz), 4.66 (d, 1H, *J*=11.3 Hz), 4.73 (d, 1H, *J*=6.9 Hz), 4.77 (d, 1H, *J*=6.9 Hz), 4.93 (dd, 1H, *J*=4.3, 7.5 Hz), 6.77 (broad s, 1H), 7.06–7.12 (m, 2H), 7.12–7.18 (m, 3H), 7.27–7.49 (m, 9H), 7.56–7.60 (m, 2H), 7.61 (d, 2H, *J*=6.7 Hz), 7.66 (d, 2H, *J*=7.2 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ −5.49, −5.41, −1.42 (3C), 17.95, 18.20, 19.16, 25.86 (3C), 26.66 (3C), 62.87, 64.07, 65.35, 66.59, 74.40, 76.07, 79.74, 82.43, 94.97, 127.01 (2C), 127.52 (2C), 127.70, 127.74 (2C), 127.85 (2C), 128.24 (2C), 128.51 (2C), 129.88, 129.92, 131.87, 132.02, 132.02, 132.43, 133.56, 135.49 (2C), 135.61 (2C), 137.23, 167.61, 174.20. HRMS (FAB, positive-ion), calcd for $C_{49}H_{70}NO_8Si_3$: $(M+H)^+$ 884.4409; found: 884.4398.

**4.1.15. (1′*S*,3*S*,4*R*,5*S*)-3-Benzamido-4-benzyloxy-3-(*tert*-butyldiphenylsilyloxymethyl)-5-[2′-hydroxy-1′-[2-(trimethylsilyl)ethoxymethoxy]ethyl]-2-oxo-tetrahydrofuran (26).** To a solution of **25** (0.21 g, 0.24 mmol) in acetone (1.2 ml) was added 5% aq. $H_2SO_4$ (0.2 ml). After stirring for 3 h at room temperature, the reaction mixture was quenched with sat. $NaHCO_3$ (0.5 ml). The resulting mixture was evaporated in vacuo, and diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (3:17) afforded **26** (0.15 g, 82%) as a colorless oil. $[\alpha]_D^{24}=+30.3$ (*c* 0.6, $CHCl_3$). IR (neat) 3426, 1784, 1667 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.01 (s, 9H), 0.86–1.00 (m, 2H), 1.02 (s, 9H), 2.78 (broad s, 1H), 3.46–3.52 (m, 1H), 3.58–3.70 (m, 2H), 3.74 (dt, 1H, *J*=11.0, 6.0 Hz), 4.08–4.11 (m, 1H), 4.26 (d, 1H, *J*=10.3 Hz), 4.29 (d, 1H, *J*=10.3 Hz), 4.48 (d, 1H, *J*=11.1 Hz), 4.58 (d, 1H, *J*=4.1 Hz), 4.63 (d, 1H, *J*=11.1 Hz), 4.77 (d, 1H, *J*=7.0 Hz), 4.81 (d, 1H, *J*=7.0 Hz), 4.83 (dd, 1H, *J*=4.1, 8.5 Hz), 6.72 (brs, 1H), 7.05–7.09 (m, 2H), 7.12–7.18 (m, 3H), 7.30–7.50 (m, 9H), 7.58 (d, 2H, *J*=7.9 Hz), 7.62 (d, 2H, *J*=7.9 Hz), 7.67 (d, 2H, *J*=7.1 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ −1.47 (3C), 18.05, 19.15, 26.66 (3C), 62.04, 64.29, 65.92, 66.56, 74.64, 78.53, 79.55,

81.89, 95.57, 127.00 (2C), 127.77 (2C), 127.82 (2C), 128.87, 127.93 (2C), 128.29 (2C), 128.55 (2C), 123.00, 130.04, 131.89, 131.96, 132.24, 133.37, 135.52 (2C), 135.59 (2C), 136.87, 167.53, 174.14. HRMS (FAB, positive-ion), calcd for $C_{43}H_{56}NO_8Si_2$: $(M+H)^+$ 770.3544; found: 770.3542.

**4.1.16. (2′*E*,1′*S*,3*S*,4*R*,5*R*)-3-Benzamido-4-benzyloxy-3-(*tert*-butyldiphenylsilyloxymethyl)-5-[3′-iodo-1′-[2-(trimethylsilyl)ethoxymethoxy]prop-2′-en-1′-yl]-2-oxotetrahydrofuran (27).** To a solution of **26** (80 mg, 0.10 mmol) in $CH_2Cl_2$ was added Dess–Martin periodinane (89 mg, 0.21 mmol) at 0°C. After stirring for 1.5 h at room temperature, the reaction mixture was quenched with sat. $NaHCO_3$ (0.2 ml) and sat. $Na_2S_2O_3$ (0.2 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a residue, which was dissolved in THF (1 ml). To this solution was added $CHI_3$ (0.12 g, 0.31 mmol). To a suspension of $CrCl_2$ (77 mg, 0.63 mmol) in THF (0.6 ml) was added this solution via cannula at 0°C. After stirring for 1 h, the reaction mixture was further stirred for 2 h at room temperature and quenched with $H_2O$ (1 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (0:10 then 1:9) afforded **27** (48 mg, 52%) as a colorless oil. $[\alpha]_D^{24}$=+29.6 (*c* 0.7, $CHCl_3$). IR (neat) 3420, 3318, 1783, 1667 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.02 (s, 9H), 0.83–0.96 (m, 2H), 1.02 (s, 9H), 3.54 (dt, 1H, *J*=10.7, 6.8 Hz), 3.70 (dt, 1H, *J*=10.7, 5.9 Hz), 4.27 (s, 2H), 4.34 (d, 1H, *J*=10.7 Hz), 4.45–4.47 (m, 2H), 4.60–4.65 (m, 2H), 4.67 (d, 1H, *J*=6.8 Hz), 4.69 (d, 1H, *J*=6.8 Hz), 6.31–6.40 (m, 2H, involving a doublet at $\delta$ 6.37, *J*=13.6 Hz), 6.75 (s, 1H), 7.04–7.10 (m, 2H), 7.14–7.19 (m, 3H), 7.29–7.50 (m, 9H), 7.56 (d, 2H, *J*=6.8 Hz), 7.61 (d, 2H, *J*=6.8 Hz), 7.66 (d, 2H, *J*=7.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ −1.39 (3C), 17.89, 19.16, 26.70 (3C), 64.19, 65.43, 66.64, 74.69, 76.18, 79.50, 83.35, 83.38, 93.08, 127.04 (2C), 127.41 (2C), 127.79, 127.85 (2C), 127.99, 128.11 (2C), 128.33 (2C), 128.58 (2C), 130.04, 130.11, 131.94, 132.02, 132.27, 133.28, 135.55 (2C), 135.62 (2C), 137.07, 140.37, 167.56, 174.00. HRMS (FAB, positive-ion), calcd for $C_{44}H_{55}INO_7Si_2$: $(M+H)^+$ 892.2562; found: 892.2568.

**4.1.17. (2′*E*,1′*S*,3*S*,4*R*,5*R*)-3-Benzamido-4-benzyloxy-3-(*tert*-butyldiphenylsilyloxymethyl)-5-[10′,10′-ethylenedioxy-1′-[2-(trimethylsilyl)ethoxymethoxy]hexadec-2′-en-1′-yl]-2-oxo-tetrahydrofuran (29).** To a solution of 7,7-ethylenedioxy-1-tridecene (91 mg, 0.38 mmol) in THF (0.1 ml) was added 0.5 M solution of 9-borabicyclo[3.3.1]-nonane (9-BBN) in THF (0.38 ml, 0.19 mmol). After stirring for 2 h at room temperature, the reaction mixture was treated with distilled water (22 μl) and stirred for 10 min. This reaction mixture was added to a solution of **27** (56 mg, 0.06 mmol), $Ph_3As$ (1.8 mg, 0.006 mmol) and $Cs_2CO_3$ (0.20 g, 0.63 mmol) in DMF (0.1 ml) via cannula, which was washed with DMF (0.4 ml). After cooling to 0°C, to this mixture was added [1,1′-bis(diphenylphosphino)-ferrocene]dichloropalladium ($PdCl_2$(dppf)) (5.0 mg, 0.006 mmol) and the mixture was stirred for 1 h. After further stirring for 1 h at room temperature, to the reaction mixture was added $H_2O$ (0.5 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (0:10 then 1:9) afforded **29** (60 mg, 94%) as a colorless oil. $[\alpha]_D^{24}$=+50.9 (*c* 0.3, $CHCl_3$). IR (neat) 3423, 1787, 1668 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.02 (s, 9H), 0.88 (t, 3H, *J*=6.8 Hz), 0.88–0.96 (m, 2H), 1.02 (s, 9H), 1.20–1.38 (m, 16H), 1.53–1.62 (m, 4H), 2.00 (q, 2H, *J*=7.8 Hz), 3.54 (dt, 1H, *J*=5.9, 9.8 Hz), 3.79 (dt, 1H, *J*=6.8, 9.8 Hz), 3.92 (s, 4H), 4.26 (d, 1H, *J*=9.8 Hz), 4.36 (d, 1H, *J*=10.7 Hz), 4.44 (d, 1H, *J*=10.7 Hz), 4.48 (d, 1H, *J*=2.9 Hz), 4.52 (t, 1H, *J*=8.3 Hz), 4.60 (d, 1H, *J*=11.7 Hz), 4.66 (dd, 1H, *J*=2.9, 7.8 Hz), 4.69 (d, 1H, *J*=6.8 Hz), 4.73 (d, 1H, *J*=6.8 Hz), 5.28 (dd, 1H, *J*=7.8, 15.6 Hz), 5.78 (dt, 1H, *J*=6.8, 15.6 Hz), 6.80 (s, 1H), 7.04–7.10 (m, 2H), 7.13–7.18 (m, 3H), 7.30–7.51 (m, 9H), 7.58 (d, 2H, *J*=7.8 Hz), 7.63 (d, 2H, *J*=7.8 Hz), 7.66 (d, 2H, *J*=7.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ −1.38 (3C), 14.09, 17.92, 19.19, 22.61, 23.78, 23.81, 26.67 (3C), 28.96, 29.33, 29.61, 29.76, 31.84, 32.54, 37.14, 37.17, 63.73, 64.88 (2C), 65.15, 66.88, 74.18, 74.38, 79.73, 84.65, 92.00, 111.81, 123.80, 127.06 (2C), 127.18 (2C), 127.50, 127.78 (2C), 127.91 (2C), 128.16 (2C), 128.53 (2C),129.91, 129.99, 131.90, 132.12, 132.43, 133.52, 135.58 (2C), 135.64 (2C), 137.50, 138.62, 167.63, 174.32. HRMS (FAB, positive-ion), calcd for $C_{59}H_{83}NO_9Si_2Na$: $(M+Na)^+$ 1028.5504; found: 1028.5482.

**4.1.18. (2′*E*,1′*S*,3*S*,4*R*,5*R*)-3-Benzamido-4-benzyloxy-3-hydroxymethyl-5-(1′-hydroxy-10′-oxo-hexadec-2′-en-1′-yl)-2-oxo-tetrahydrofuran (30).** To a solution of **29** (16 mg, 0.016 mmol) in acetone (0.3 ml) was added 5% aq. $H_2SO_4$ (40 μl). After stirring for 5 h at room temperature, the reaction mixture was quenched with sat. $NaHCO_3$ (0.1 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a residue, which was dissolved in THF (0.2 ml). To this solution was added HF–Py complex (0.1 ml). The mixture was stirred for 5 h at room temperature and quenched with sat. $NaHCO_3$ (0.5 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with MeOH–$CHCl_3$ (0:10 then 1:19) afforded **30** (6.3 mg, 67%) as a colorless oil. $[\alpha]_D^{24}$=+34.5 (*c* 0.2, $CHCl_3$). IR (neat) 3364, 1777, 1710, 1656 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.89 (t, 3H, *J*=6.8 Hz), 1.22–1.42 (m, 12H), 1.49–1.62 (m, 4H), 2.01–2.06 (m, 2H), 2.38 (t, 4H, *J*=7.8 Hz), 2.69 (brs, 1H), 3.87 (t, 1H, *J*=11.7 Hz), 4.19 (d, 1H, *J*=12.7 Hz), 4.46–4.62 (m, 4H), 4.85 (d, 1H, *J*=3.8 Hz), 5.23 (d, 1H, *J*=9.8 Hz), 5.50 (dd, 1H, *J*=15.6, 6.8 Hz), 5.85 (dt, 1H, *J*=15.6, 6.8 Hz), 7.07 (s, 1H), 7.08–7.14 (m, 2H), 7.18–7.25 (m, 3H), 7.43 (t, 2H, *J*=7.8 Hz), 7.56 (t, 1H, *J*=6.8 Hz), 7.75 (d, 2H, *J*=6.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ 14.02, 22.49, 23.76, 23.85, 28.62, 28.91, 28.93, 28.99, 31.60, 32.28, 42.70, 42.83, 65.74, 68.20, 70.64, 74.74, 78.00, 84.15, 126.07, 127.25 (2C), 127.81 (2C), 128.21, 128.51 (2C), 128.84 (2C), 132.61, 132.78, 136.50, 136.52, 169.75,

173.73, 211.66. HRMS (FAB, positive-ion), calcd for $C_{35}H_{47}NO_7Na$: $(M+Na)^+$ 616.3250; found: 616.3238.

**4.1.19. (2′*E*,1′*S*,3*S*,4*R*,5*R*)-3-Benzamido-4-hydroxy-3-hydroxymethyl-5-(1′-hydroxy-10′-oxo-hexadec-2′-en-1′-yl)-2-oxo-tetrahydrofuran (31).** To a solution of **30** (5.8 mg, 0.01 mmol) in $CH_2Cl_2$ (0.1 ml) was slowly added 1.0 M $BCl_3$ solution in $CH_2Cl_2$ (20 μl, 0.02 mmol) at −78°C. After stirring for 1 h, the reaction mixture was quenched with sat. $NaHCO_3$ (0.1 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by thin layer chromatography on silica gel (Silica gel 60 F254, 0.5 mm, Merck). Development with MeOH–$CHCl_3$ (1:9) ($R_f$=0.223) afforded **31** (0.8 mg, 16%) as a white powder. $[\alpha]_D^{24}$=+24.5 (*c* 0.5, $CHCl_3$). IR (KBr) 3604, 3418, 1782, 1705, 1652 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) δ 0.87 (t, 3H, *J*=6.8 Hz), 1.20–1.36 (m, 6H), 1.37–1.66 (m, 8H), 2.05–2.15 (m, 2H), 2.35 (dt, 2H, *J*=2.0, 6.8 Hz), 2.39 (t, 2H, *J*=7.8 Hz), 2.69 (brs, 1H), 3.93–4.12 (m, 3H, involving a doublet at δ 4.06, *J*=10.7 Hz), 4.57 (dd, 1H, *J*=5.9, 3.9 Hz), 4.66 (t, 1H, *J*=5.9 Hz), 4.92 (brs, 1H), 5.61 (dd, 1H, *J*=6.8, 15.6 Hz), 5.93 (dt, 1H, *J*=15.6, 6.8 Hz), 7.00 (s, 1H), 7.47 (t, 2H, *J*=7.8 Hz), 7.57 (t, 1H, *J*=6.8 Hz), 7.82 (d, 2H, *J*=8.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) δ 14.02, 22.47, 23.76, 23.78, 25.97, 28.20, 28.37, 28.68, 28.88, 31.56, 31.91, 42.65, 42.77, 64.44, 67.77, 70.96, 72.34, 84.67, 126.34, 127.35 (2C), 128.80 (2C), 132.44, 132.67, 135.60, 169.52, 173.93, 212.92. HRMS (FAB, positive-ion), calcd for $C_{28}H_{42}NO_7$: $(M+H)^+$ 504.2961; found: 504.2962.

**4.1.20. (1′*S*,3*S*,4*R*,5*S*)-3-Azido-5-[2′-(*tert*-butyldimethylsilyloxy)-1′-[2-(trimethylsilyl)ethoxymethoxy]ethyl]-3-(*tert*-butyldiphenylsilyloxymethyl)-4-hydroxy-2-oxo-tetrahydrofuran (34).** To a solution of **24** (0.44 g, 0.55 mmol) and $NaBrO_3$ (0.25 g, 1.64 mmol) in AcOEt (2 ml) and $H_2O$ (1 ml) was slowly added 1.64 M $NaHSO_3$ solution in $H_2O$ (1.0 ml, 1.64 mmol) at 0°C and the mixture was stirred for 10 min. After further stirring for 1 h at room temperature, the reaction mixture was quenched with sat. $Na_2S_2O_3$ (0.5 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (1:19) afforded **34** (0.83 g, 61%) as a colorless oil. $[\alpha]_D^{24}$=+14.3 (*c* 1.5, $CHCl_3$). IR (neat) 3426, 2126, 1786 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) δ 0.03 (s, 9H), 0.12 (s, 6H), 0.88–1.03 (m, 11H, involving a singlet at δ 0.91), 1.06 (s, 9H), 3.03–3.72 (m, 3H), 3.80 (d, 1H, *J*=10.7 Hz), 3.85–3.92 (m, 3H, involving a doublet at δ 3.87, *J*=10.7 Hz), 4.09 (dt, 1H, *J*=3.9, 7.8 Hz), 4.48 (dd, 1H, *J*=3.9, 6.8 Hz), 4.54 (t, 1H, *J*=4.9 Hz), 4.77 (d, 1H, *J*=6.8 Hz), 4.81 (d, 1H, *J*=6.8 Hz), 7.38–7.49 (m, 3H), 7.61–7.66 (m, 2H). $^{13}C$ NMR (125 MHz, $CDCl_3$) δ −5.64, −5.62, −1.46 (3C), 18.07, 18.23, 19.18, 25.80 (3C), 26.66 (3C), 62.91, 65.12, 65.84, 69.75, 71.73, 75.31, 83.23, 95.23, 127.98 (2C), 127.99 (2C), 130.18, 130.19, 131.75, 131.91, 135.50 (2C), 135.55 (2C), 171.72. HRMS (FAB, positive-ion), calcd for $C_{35}H_{57}N_3O_7Si_3Na$: $(M+Na)^+$ 738.3402; found: 738.3400.

**4.1.21. (1′*S*,3*S*,4*R*,5*S*)-3-Benzamido-4-benzoyloxy-5-[2′-(*tert*-butyldimethylsilyloxy)-1′-[2-(trimethylsilyl)ethoxymethoxy]ethyl]-3-(*tert*-butyldiphenylsilyloxymethyl)-2-oxo-tetrahydrofuran (36).** To a solution of **34** (0.24 g, 0.34 mmol) in AcOEt (1 ml) was added 10% Pd–C (0.20 g) and air was replaced with a hydrogen. After stirring for 14 h at room temperature, the reaction mixture was filtered through Celite. The filtrate was evaporated in vacuo to give a residue, which was dissolved in $CH_2Cl_2$ (1 ml). To this solution were added DMAP (10 mg), $Et_3N$ (0.19 ml, 1.36 mmol) and PhCOCl (0.11 ml, 1.02 mmol). After stirring for 2 h at room temperature, the reaction mixture was quenched with sat. $NaHCO_3$ (0.5 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (1:19 then 3:17) afforded **36** (0.24 g, 80%) as a colorless oil. $[\alpha]_D^{24}$=+28.8 (*c* 1.5, $CHCl_3$). IR (neat) 3432, 3347, 1788, 1726, 1673 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) δ 0.00 (s, 6H), 0.04 (s, 9H), 0.85 (s, 9H), 0.88–1.06 (m, 2H), 1.12 (s, 9H), 3.69 (dt, 1H, *J*=5.9, 9.8 Hz), 3.77 (dt, 1H, *J*=5.9, 9.8 Hz), 3.80–3.88 (m, 2H), 4.11 (d, 1H, *J*=9.8 Hz), 4.21–4.26 (m, 1H), 4.27 (d, 1H, *J*=9.8 Hz), 4.86 (d, 1H, *J*=6.8 Hz), 4.93 (d, 1H, *J*=6.8 Hz), 5.14 (dd, 1H, *J*=5.9, 8.8 Hz), 6.25 (d, 1H, *J*=5.9 Hz), 6.32 (s, 1H), 7.18 (t, 2H, *J*=7.8 Hz), 7.27–7.51 (m, 12H), 7.67 (d, 2H, *J*=6.8 Hz), 7.71–7.72 (m, 2H), 7.90 (d, 2H, *J*=7.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) −5.63, −5.59, −1.44 (3C), 17.95, 18.24, 19.19, 25.85 (3C), 26.71 (3C), 63.60, 64.35, 65.40, 65.51, 72.49, 76.35, 80.21, 95.49, 126.77 (2C), 127.92 (2C), 127.99 (2C), 128.14 (2C), 128.29 (2C), 128.57, 129.78 (2C), 130.09, 130.11, 131.43, 131.60, 131.96, 132.72, 133.38, 135.48 (2C), 135.65 (2C), 165.18, 166.48, 172.73. HRMS (FAB, positive-ion), calcd for $C_{49}H_{68}NO_9Si_3Na$: $(M+H)^+$ 920.4021; found: 920.4019.

**4.1.22. (1′*S*,3*S*,4*R*,5*S*)-3-Benzamido-4-benzoyloxy-3-(*tert*-butyldiphenylsilyloxymethyl)-5-[2′-hydroxy-1′-[2-(trimethylsilyl)ethoxymethoxy]ethyl]-2-oxo-tetrahydrofuran (37).** To a solution of **36** (0.22 g, 0.24 mmol) in acetone (1 ml) was added 5% aq. $H_2SO_4$ (0.2 ml). After stirring for 13 h at room temperature, the reaction mixture was quenched with sat. $NaHCO_3$ (0.5 ml). The resulting mixture was evaporated in vacuo and diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (2:8 then 1:3) afforded **37** (0.16 g, 87%) as a colorless oil. $[\alpha]_D^{24}$=+31.0 (*c* 0.8, $CHCl_3$). IR (neat) 3430, 1789, 1726, 1672 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) δ 0.02 (s, 9H), 0.86–1.13 (m, 2H), 1.11 (s, 9H), 2.87 (br, 1H), 3.64 (dt, 1H, *J*=10.7, 5.9 Hz), 3.80 (dt, 1H, *J*=10.7, 5.9 Hz), 4.07 (d, 1H, *J*=9.8 Hz), 4.20–4.26 (m, 1H), 4.28 (d, 1H, *J*=9.8 Hz), 4.87 (d, 1H, *J*=6.8 Hz), 4.90 (d, 1H, *J*=6.8 Hz), 4.99 (dd, 1H, *J*=8.8, 5.9 Hz), 6.18 (d, 1H, *J*=5.9 Hz), 6.27 (s, 1H), 7.18 (t, 2H, *J*=7.8 Hz), 7.28 (t, 3H, *J*=7.3 Hz), 7.31–7.50 (m, 9H), 7.66 (d, 2H, *J*=6.8 Hz), 7.70 (d, 2H, *J*=6.8 Hz), 7.88 (d, 2H, *J*=7.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) −1.50 (3C), 18.03, 19.18, 26.69 (3C), 62.61, 64.14, 65.66, 65.99, 72.40, 78.43, 79.48, 95.90, 126.75 (2C), 127.98 (2C), 128.05 (2C), 128.21 (2C), 128.29, 128.36 (2C), 129.78 (2C), 130.19,

130.20, 131.38, 131.72, 131.83, 132.57, 133.54, 135.50 (2C), 135.66 (2C), 165.30, 166.60, 172.85. HRMS (FAB, positive-ion), calcd for $C_{43}H_{53}NO_9Si_2K$: $(M+K)^+$ 822.2896; found: 822.2893.

**4.1.23. (2′*E*,1′*S*,3*S*,4*R*,5*R*)-3-Benzamido-4-benzoyloxy-3-(*tert*-butyldiphenylsilyloxymethyl)-5-[3′-iodo-1′-[2-(trimethylsilyl)ethoxymethoxy]prop-2′-en-1′-yl]-2-oxotetrahydrofuran (38).** To a solution of **37** (0.157 g, 0.20 mmol) in $CH_2Cl_2$ (0.5 ml) was added Dess–Martin periodinane (0.21 g, 0.50 mmol) at 0°C. After stirring for 1.5 h at room temperature, the reaction mixture was quenched with sat. $NaHCO_3$ (0.5 ml) and sat. $Na_2S_2O_3$ (0.5 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a residue, which was dissolved in THF (1 ml). To this solution was added $CHI_3$ (0.24 g, 0.60 mmol). To a suspension of $CrCl_2$ (0.15 g, 1.2 mmol) in THF (1.2 ml) was added this solution via cannula at 0 °C. After stirring for 1 h, the reaction mixture was further stirred for 2 h at room temperature, and quenched with $H_2O$ (1 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (0:10 then 3:17) afforded **38** (0.12 g, 80%) as a colorless oil. $[\alpha]_D^{24}$=+17.8 (*c* 0.7, $CHCl_3$). IR (neat) 3431, 3386, 1792, 1729, 1675 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.00 (s, 9H), 0.84–1.00 (m, 2H), 1.09 (s, 9H), 3.58 (dt, 1H, *J*=9.8, 5.9 Hz), 3.72 (dt, 1H, *J*=9.8, 5.9 Hz), 4.00 (d, 1H, *J*=9.8 Hz), 4.21 (d, 1H, *J*=9.8 Hz), 4.56 (dd, 1H, *J*=5.9, 8.8 Hz), 4.62 (dd, 1H, *J*=5.9, 8.8 Hz), 4.70 (d, 1H, *J*=6.8 Hz), 4.78 (d, 1H, *J*=6.8 Hz), 6.02 (d, 1H, *J*=4.9 Hz), 6.29–6.38 (m, 3H), 7.17 (t, 2H, *J*=7.8 Hz), 7.20–7.34 (m, 4H), 7.34–7.48 (m, 8H), 7.66 (d, 4H, *J*=6.8 Hz), 7.85 (d, 2H, *J*=7.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) −1.40 (3C), 17.89, 19.18, 26.79 (3C), 63.96, 65.43, 65.52, 71.31, 76.29, 80.89, 83.18, 93.34, 126.81 (2C), 128.07 (2C), 128.11 (2C), 128.29 (2C), 128.39 (2C), 128.44, 129.85 (2C), 130.27, 130.34, 131.39, 131.75, 131.81, 132.70, 133.50, 135.52 (2C), 135.79 (2C), 140.01, 164.83, 166.41, 172.21. HRMS (FAB, positive-ion), calcd for $C_{44}H_{52}INO_8Si_2$ K: $(M+K)^+$ 944.1913; found: 944.1901.

**4.1.24. (2′*E*,1′*S*,3*S*,4*R*,5*R*)-3-Benzamido-4-benzoyloxy-3-(*tert*-butyldiphenylsilyloxymethyl)-5-[10′,10′-ethylenedioxy-1′-[2-(trimethylsilyl)ethoxymethoxy]hexadec-2′-en-1′-yl]-2-oxo-tetrahydrofuran (39).** To a solution of 7,7-ethylenedioxo-1-tridecene (0.10 g, 0.42 mmol) in THF (0.1 ml) was added 0.5 M 9-BBN solution in THF (0.42 ml, 0.21 mmol). After stirring for 2 h at room temperature, the reaction mixture was treated with distilled water (25 μl) and stirred for 10 min. This solution was added to a solution of **38** (64 mg, 0.07 mmol), $Ph_3As$ (2.1 mg, 0.007 mmol) and $Cs_2CO_3$ (0.23 g, 0.70 mmol) in DMF (0.5 ml) via cannula. After cooling at 0 °C, to the mixture was added $PdCl_2$(dppf) (5.7 mg, 0.007 mmol) and this mixture was stirred for 1 h. After further stirring for 1 h at room temperature, to the reaction mixture was added $H_2O$ (0.5 ml). The resulting mixture was diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with AcOEt–hexane (0:10 then 1:9) afforded **39** (58 mg, 81%) as a colorless oil. $[\alpha]_D^{24}$=+43.5 (*c* 0.7, $CHCl_3$). IR (neat) 3433, 3348, 1790, 1726, 1676 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.04 (s, 9H), 0.88 (t, 3H, *J*=6.8 Hz), 0.90–1.05 (m, 2H), 1.06–1.20 (m, 12H), 1.52–1.62 (m, 4H), 1.79–1.90 (m, 2H), 3.60 (dt, *J*=9.8, 5.9 Hz), 3.83 (dt, 1H, *J*=10.7, 5.9 Hz), 3.91 (s, 4H), 4.06 (d, 1H, *J*=10.7 Hz), 4.23 (d, 1H, *J*=10.7 Hz), 4.53 (t, 1H, *J*=8.8 Hz), 4.70 (dd, 1H, *J*=4.9, 8.8 Hz), 4.74 (d, 1H, *J*=7.8 Hz), 4.76 (d, 1H, *J*=2.8 Hz), 5.18 (dd, 1H, *J*=8.8, 15.6 Hz), 5.56 (dt, 1H, *J*=6.8, 15.6 Hz), 6.08 (d, 1H, *J*=5.9 Hz), 6.38 (s, 1H), 7.19 (t, 2H, *J*=7.8 Hz), 7.27–7.35 (m, 3H), 7.38–7.50 (m, 9H), 7.69 (t, 4H, *J*=6.8 Hz), 7.89 (d, 2H, *J*=7.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) $\delta$ −1.38 (3C), 14.07, 17.92, 19.21, 22.58, 23.72, 23.79, 26.79 (3C), 28.59, 29.21, 29.59, 29.72, 31.82, 32.34, 37.14, 37.15, 40.10, 40.13, 64.43, 64.85 (2C), 65.21, 74.72, 82.24, 92.08, 111.81, 123.23, 126.80 (2C), 128.00 (2C), 128.07 (2C), 128.26 (2C), 128.30 (2C), 128.82, 129.83 (2C), 130.21, 130.25, 131.56, 131.61, 131.94, 133.04, 133.30, 135.57 (2C), 135.77 (2C), 138.88, 164.54, 166.34, 172.58. HRMS (FAB, positive-ion), calcd for $C_{59}H_{81}NO_{10}Si_2K$: $(M+K)^+$ 1058.5036; found: 1058.5015.

**4.1.25. (2′*E*,1′*S*,3*S*,4*R*,5*R*)-3-Benzamido-4-benzoyloxy-3-hydroxymethyl-5-(1′-hydroxy-10′-oxo-hexadec-2′-en-1′-yl)-2-oxo-tetrahydrofuran (40).** To a solution of **39** (34.1 mg, 0.033 mmol) in acetone (0.5 ml) was added 5% aq. $H_2SO_4$ (0.1 ml). After stirring for 5 h at room temperature, the reaction mixture was quenched with sat. $NaHCO_3$ (0.1 ml) and diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a residue, which was dissolved in THF (0.2 ml). To this solution was added HF–pyridine complex (60 μl) and the mixture was stirred for 5.5 h at room temperature. The reaction mixture was quenched with sat. $NaHCO_3$ (0.5 ml) and diluted with ether, which was washed with water and brine, dried over $MgSO_4$ and filtered. The filtrate was evaporated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with MeOH–$CHCl_3$ (0:10 then 1:19) afforded **40** (11.5 mg, 58%) as a colorless oil. $[\alpha]_D^{24}$=+27.7 (*c* 0.4, $CHCl_3$). IR (neat) 3961, 3605, 3423, 1787, 1737, 1711, 1667 $cm^{-1}$. $^1H$ NMR ($CDCl_3$) $\delta$ 0.88 (t, 3H, *J*=6.8 Hz), 1.12–1.22 (m, 12H), 1.24–1.34 (m, 4H), 1.45–1.59 (m, 4H), 1.88–1.94 (m, 2H), 2.36 (t, 2H, *J*=7.8 Hz), 2.38 (t, 2H, *J*=7.8 Hz), 4.09 (d, 1H, *J*=11.7 Hz), 4.18 (d, 1H, *J*=11.7 Hz), 4.68 (t, 1H, *J*=6.2 Hz), 4.84 (t, 1H, *J*=5.9 Hz), 5.49 (dd, 1H, *J*=6.8, 15.6 Hz), 5.72 (dt, 1H, *J*=6.8, 15.6 Hz), 6.11 (d, 1H, *J*=5.9 Hz), 6.81 (s, 1H), 7.24 (t, 2H, *J*=7.8 Hz), 7.33 (t, 2H, *J*=7.8 Hz), 7.38 (t, 1H, *J*=7.8 Hz), 7.50 (t, 1H, *J*=7.8 Hz), 7.51 (d, 2H, *J*=7.8 Hz), 7.89 (d, 2H, *J*=7.8 Hz). $^{13}C$ NMR (125 MHz, $CDCl_3$) 14.02, 22.48, 23.71, 23.83, 28.29, 28.67, 28.87, 28.91, 31.58, 32.05, 42.70, 42.82, 64.88, 65.13, 70.68, 71.54, 82.69, 125.94, 127.04 (2C), 128.25, 128.45 (2C), 128.55 (2C), 129.80 (2C), 132.17, 132.35, 133.82, 136.45, 165.22, 168.29, 172.82, 212.16. HRMS (FAB, positive-ion), calcd for $C_{35}H_{46}NO_8$: $(M+H)^+$ 608.3223; found: 608.3240.

**4.1.26. (6*E*,2*S*,3*R*,4*R*,5*S*)-2-Amino-2-hydroxymethyl-14-oxo-3,4,5-trihydroxyeicos-6-enoic acid (1) (sphingofungin E).** To a solution of diol **40** (11.0 mg, 0.018 mmol) in dioxane (0.2 ml) and $H_2O$ (0.2 ml) was added NaOH

(2.2 mg, 0.055 mmol). After stirring for 7.5 h at 70°C, the reaction mixture was cooled to room temperature and acidic resin (IR-120) was added to neutralize the pH of the solution. The resulting mixture was filtered through Celite and the filtrate was concentrated in vacuo to give a crude product, which was purified by silica gel column chromatography. Elution with $CHCl_3$–MeOH–$H_2O$ (9:1:0 then 8:2:1) afforded **1** (6.7 mg, 88%) as a white powder, mp 145–147°C. $[\alpha]_D^{24}=-5.43$ (*c* 0.5, $CH_3OH$). IR (KBr) 3532, 3198, 2928, 2855, 1711, 1637 $cm^{-1}$. $^1H$ NMR ($CD_3OD$) $\delta$ 0.90 (t, 3H, *J*=6.8 Hz), 1.26–1.44 (m, 12H), 1.49–1.58 (m, 4H), 2.05 (q, 2H, *J*=6.8 Hz), 2.44 (t, 2H, *J*=7.3 Hz), 2.45 (t, 2H, *J*=7.3 Hz), 3.64 (d, 1H, *J*=6.9 Hz), 3.85 (d, 1H, *J*=11.7 Hz), 3.94–4.00 (m, 2H, involving a doublet at $\delta$ 3.97 *J*=11.7 Hz), 4.11 (t, 1H, *J*=7.3 Hz), 5.45 (dd, 1H, *J*=7.8, 15.6 Hz), 5.77 (dt, 1H, *J*=15.6, 6.8 Hz). $^{13}C$ NMR (125 MHz, $CD_3OD$) 14.37, 23.58, 24.84, 24.86, 29.99, 30.01, 30.14, 30.16, 32.81, 33.42, 43.45, 43.48, 64.95, 70.03, 71.11, 75.52, 76.27, 130.14, 135.70, 173.42, 214.34. HRMS (FAB, positive-ion), calcd for $C_{21}H_{40}NO_7$: $(M+H)^+$ 418.2805; found: 418.2806.

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