Mirror Image Synthesis of Left Ends of Ciguatoxin and Gambiertoxin 4b

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Three compounds related to the AB fragments of ciguatoxin and gambiertoxin 4b and two diastereomers (at the C-2 position) of the ABC fragment of ciguatoxin have been synthesized in enantiomeric form. The stereochemistry of the C-2 position was introduced selectively from the corresponding pentose derivative. Construction of the A ring with its side chain was completed by Nicholas type cyclization of an acetylene bis(cobalthexacarbonyl) complex followed by reductive decomplexation.

Ciguatoxin **1**, a polyether compound obtained from moray eel *Gymmothorax javanicus* as a principal toxin causing ciguatera poisoning,[1,2] originally produced by *Gambierdiscus toxicus*, is one of the most challenging targets for chemical synthesis.[3] During the earlier course of our synthetic studies directed toward ciguatoxin, we have established a series of methodologies: (i) to introduce a carbon chain as an alkynyl group onto the di- or tetrahydropyranyl ring of sugars at the C-1 position in α orientation,[4] (ii) to epimerize the alkynyl group into the β orientation via a bis(cobalthexacarbonyl) complex,[5] (iii) to open the dihydropyranyl ring to acyclic compounds, and (iv) to recyclize the oxepene ring with high stereoselectivity.[6] All of these reactions include cationic intermediates that are stabilized either by $\sigma-\pi$ conjugation with a silicon atom or by the Nicholas effect with the acetylene bis(cobalthexacarbonyl) complex.[7] Recently, we have developed an effective synthesis giving unsaturated medium-size (7, 8, 9, and 10 membered) ether rings based on the cyclization reaction with acetylene bis(cobalthexacarbonyl) complex followed by reductive decomplexation.[8] Here we report the application of such methodology to the synthesis of left end fragments of **1** and **2** (Figure 1).[3]

Our first synthetic plan includes construction of both diastereomers of A ring with its side chain (Figure 2).

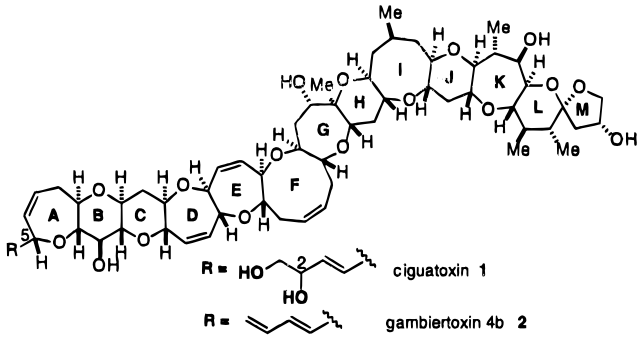

Figure 1.

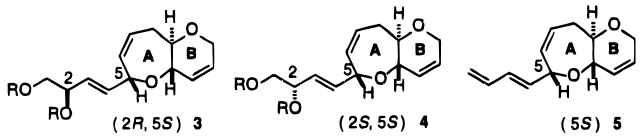

Figure 2.

Our retrosynthetic analysis of the target molecules **3** and **4** is shown in Scheme 1. The oxepene ring A in **6** would be derived through reductive decomplexation[8] from the corresponding cyclic acetylene−cobalt complex, which may be derived from *trans*-allylic cation **7**. This can be equilibrated from the *cis*-allylic cation **8** as an open chain intermediate from **9**. This disaccharide could be synthesized by combination of the oxocarbenium intermediate **10** and the silylacetylene **11**. Coupling between the silylacetylene **11** and either of the epimeric oxocarbenium ions **10** should give the 2*R* isomer; thus, the precursor is L-arabinal (**12**), since stereochemistry of the C-2 position corresponds to the C-4 position of pentoses. Similarly, D-xylal **13** should provide the 2*S* isomer by the coupling[9] with **11** in the presence of a Lewis acid.[4] Finally, acetylene **11** would be obtained from tri-*O*-acetyl-D-glucal **14**.

Synthesis of the (trimethylsilyl)acetylene **11** is shown in Scheme 2. The starting material, tri-*O*-acetyl-D-glucal, **14** was converted into the known diol **15**.[10] Selective

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(1) (a) Yasumoto, T.; Murata, M. *Chem. Rev.* **1993**, *93*, 1897. (b) Scheuer, P. J. *Tetrahedron* **1994**, *50*, 3.

(2) (a) Murata, M.; Lebrand, A. M.; Ishibashi, Y.; Yasumoto, T. *J. Am. Chem. Soc.* **1989**, *111*, 8929. (b) *Idem. Ibid.* **1990**, *112*, 4380. (c) Recently, absolute configuration of ciguatoxin was determined to be the enantiomer of **1** as described in Satake, M.; Morohashi, A.; Oguri, H.; Oishi, T.; Hirama, M.; Harada, N.; Yasumoto, T. *J. Am. Chem. Soc.* **1997**, *119*, 11325.

(3) Related synthetic studies on the AB fragment of ciguatoxin: (a) Suzuki, T.; Sato, O.; Hirama, M.; Yamamoto, Y.; Murata, M.; Yasumoto, T. *Tetrahedron Lett.* **1991**, *32*, 4505. (b) Oguri, H.; Hishiyama, S.; Oishi, T.; Hirama, M. *Synlett* **1995**, 1252. (c) Oka, T.; Fujiwara, K.; Murai, A. *Tetrahedron* **1998**, *54*, 21.

(4) (a) Ichikawa, Y.; Isobe, M.; Konobe, M.; Goto, T. *Carbohydr. Res.* **1987**, *171*, 193. (b) Tsukiyama, T.; Isobe, M. *Tetrahedron Lett.* **1992**, *33*, 7911.

(5) (a) Tanaka, S.; Tsukiyama, T.; Isobe, M. *Tetrahedron Lett.* **1993**, *34*, 5757. (b) Tanaka, S.; Isobe, M. *Tetrahedron* **1994**, *50*, 5633.

(6) (a) Tanaka, S.; Isobe, M. *Tetrahedron Lett.* **1994**, *35*, 7801. (b) Tanaka, S., Tatsuta, T., Yamashita, O.; Isobe, M. *Tetrahedron* **1994**, *50*, 12883.

(7) Nicholas, K. M. *Acc. Chem. Res.* **1987**, *20*, 207.

(8) (a) Isobe, M.; Yenjai, C.; Tanaka, S. *Synlett* **1994**, 916. (b) Yenjai, C.; Isobe, M. *Tetrahedron* **1998**, *54*, 2509.

(9) (a) Whistler, R. L. et al. *Methods in Carbohydrate Chemistry I*; Academic Press: New York, 1962; pp 84, 184. (b) Bredenkamp, M. W.; Holzapfel, C. W.; Toerien, F. *Synth. Commun.* **1992**, *22*, 2459.

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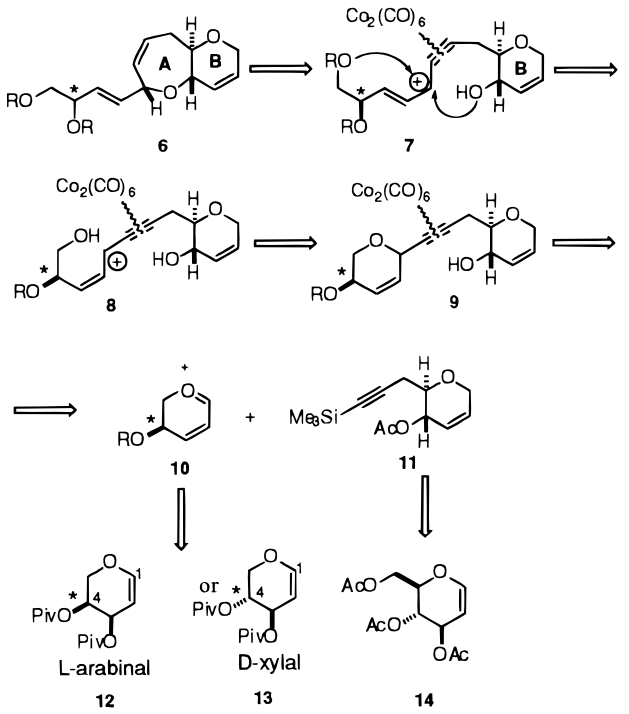
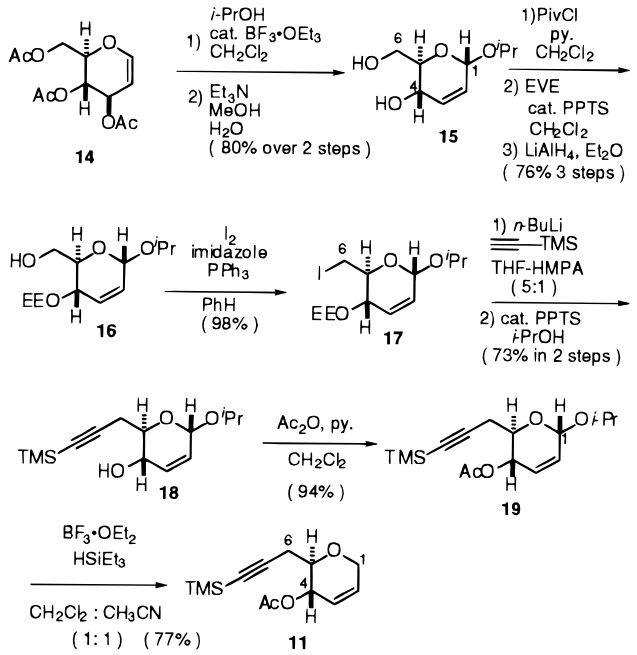
Scheme 1



Scheme 2

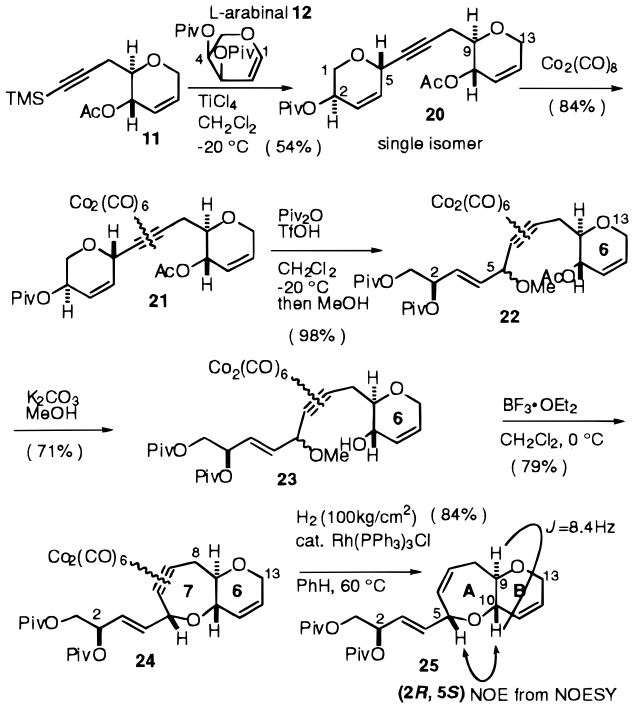


protections of the primary and secondary hydroxy groups of **15** as pivalate and ethoxy ethyl ether, respectively, were followed by LAH reduction to afford alcohol **16**. Iodination of the primary hydroxy group[11] and subsequent treatment with lithium acetylide followed by deprotection of ethoxy ethyl group gave the silylacetylene **18**. Reprotection of the C-4 hydroxyl group and reduction of the C-1 acetal with triethylsilane[12] afforded the (trimethylsilyl)acetylene **11**.

(10) (a) Isobe, M.; Ichikawa, Y.; Bai, D.-L.; Goto, T. *Tetrahedron Lett.* **1985**, *26*, 5203. (b) Isobe, M.; Ichikawa, Y.; Funabashi, Y.; Mio, S.; Goto, T. *Tetrahedron* **1986**, *42*, 2863.

(11) Classon, B.; Liu, Z.; Samuelsson, B. *J. Org. Chem.* **1988**, *53*, 6128.

Scheme 3



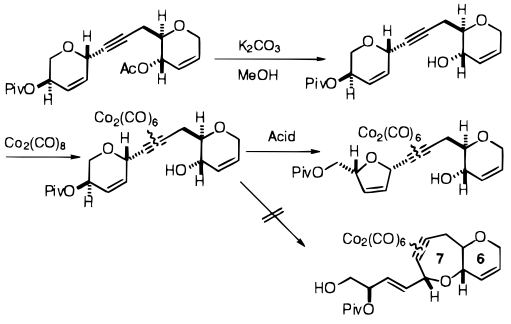
The synthesis of (2*R*,5*S*)-AB fragment **25** is shown in Scheme 3. Coupling of the silylacetylene **11** with arabinal dipivalate **12** afforded the disaccharide **20** with exclusive regio- and stereoselectivity. The disaccharide **20** was converted into the acetylene bis(cobalthexacarbonyl) complex **21** which was treated with pivalic anhydride and TfOH, followed by addition of MeOH to give the open chain product **22**.[6] Selective deacetylation gave **23**, which was then subjected to cationic cyclization to provide the *endo*-acetylene cobalt complex **24** as a single isomer. Decomplexation[8] of **24** by hydrogenation at 100 kg/cm^2 in the presence of Wilkinson catalyst afforded the AB-fragment **25**. The stereochemistry of **25** was confirmed by NMR studies; thus, 2 protons at δ 3.96 (H-10) and δ 4.75 (H-5) showed a cross-peak in its NOESY spectrum and $J_{9,10} = 8.4$ Hz indicating 2*R*, 5*S*-stereochemistry.[13,14]

The synthesis of (2*S*,5*S*)-AB fragment **27** was also achieved by employing the same strategy as above (Scheme 4). Coupling between silylacetylene **11** and D-xylal **13** led to the formation of the disaccharide **26** as a single isomer in this transformation.

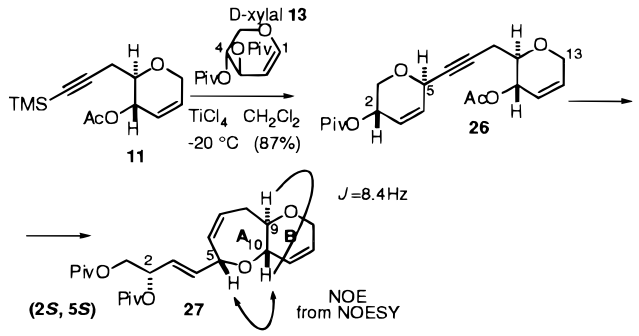
(12) Lewis, M. D.; Cha, J. K.; Kishi, Y. *J. Am. Chem. Soc.* **1982**, *104*, 4976.

(13) Hosokawa, S.; Isobe, M. *Synlett* **1995**, 1179.

(14) Related to this route, we examined direct formation of A ring from disaccharide as shown below. Unfortunately, however, this transformation was unsuccessful and only *exo*-cobalt complex was afforded.



Scheme 4



The stereochemistry of **20** and **26** was determined from the coupling constant and NOE studies of their acetylene bis(cobalthexacarbonyl) complex **21** and **28**, respectively (Figure 3).[15]

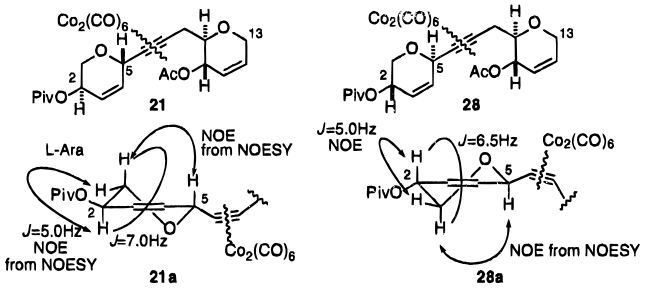


Figure 3.

Stereochemical course of the C-glycosylation is rationalized to give the *syn* products as shown in Figure 4; thus, three conformations (**30**, **31**, and **33**) of the cation intermediate **29** were considered to be destined to either *syn* or *anti* stereochemistry. On the basis of the cation intermediate **29**, the conformers **30** and **31**, which would afford the *anti*-isomer **32**, have steric repulsion between the ligands of cobalt complex and olefinic group. On the other hand, in the conformer **33** the bulky cobalt complex is outside of the side chain and has less steric repulsion; thus, **33** is ready to cyclize to obtain the *syn*-isomer **34**.[16]

We have also applied above methodology for the synthesis of (5*S*)-AB fragment of gambiertoxin 4b **5**. The difference between **5** and **25** locates on the side chain, so that it could be synthesized through *endo*-cobalt complex methodology. The synthetic route to **5** is shown in Scheme 5. Coupling between the lithium acetylide of **35** and the aldehyde **36**[17] under Yamaguchi's procedure[18] using $BF_3 \cdot Et_2O$ and deprotection of the ethoxy ethyl group afforded the diol **37**. This acetylene **37** was converted into the cobalt complex **38** which cyclized rapidly (0 °C, 20 min, 90%) to give *endo*-cobalt complex **39**. Finally, decomplexation accompanying dehalogenation with tri-*n*-butyltin hydride[19] yielded **5**, (5*S*)-AB fragment of gambiertoxin 4b, as a single stereoisomer. The stereochemistry of **5** was proved from NMR analysis of the two protons at δ 4.00

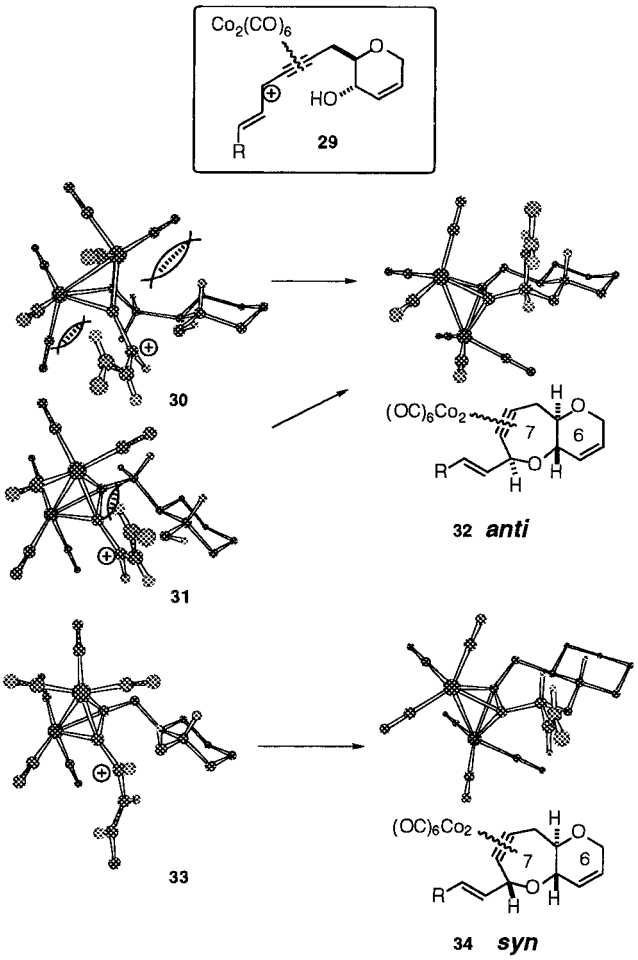
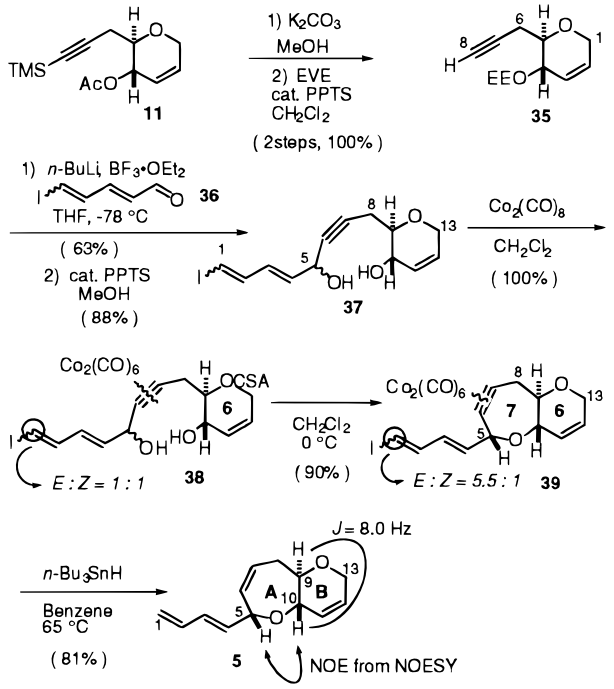


Figure 4.

(δ 4.63 (H-10) and δ 4.63 (H-5) showing a cross-peak in its NOESY spectrum as well as H-10 coupling with H-9 (8.0 Hz) indicating 5*S*-stereochemistry.

Scheme 5



(15) On this 1,4-*anti* stereoinduction: Hosokawa, S.; Isobe, M. *Tetrahedron Lett.* **1998**, *39*, 1917.
(16) On the cyclization to afford bicyclic ether with *endo*-acetylene bis(cobalthexacarbonyl) complex; Isobe, M.; Hosokawa, S.; Kira, K. *Chem. Lett.* **1996**, 473.
(17) Soullez, D.; Ple, G.; Duhamel, L.; Duhamel, P. *J. Chem. Soc., Chem. Commun.* **1995**, 563.
(18) Yamaguchi, M.; Hirao, I. *Tetrahedron Lett.* **1983**, *24*, 391.
(19) Hosokawa, S.; Isobe, M. *Tetrahedron Lett.* **1998**, *39*, 2609.

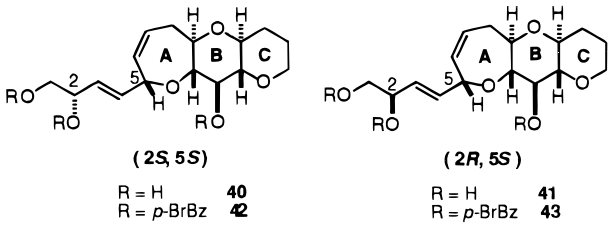
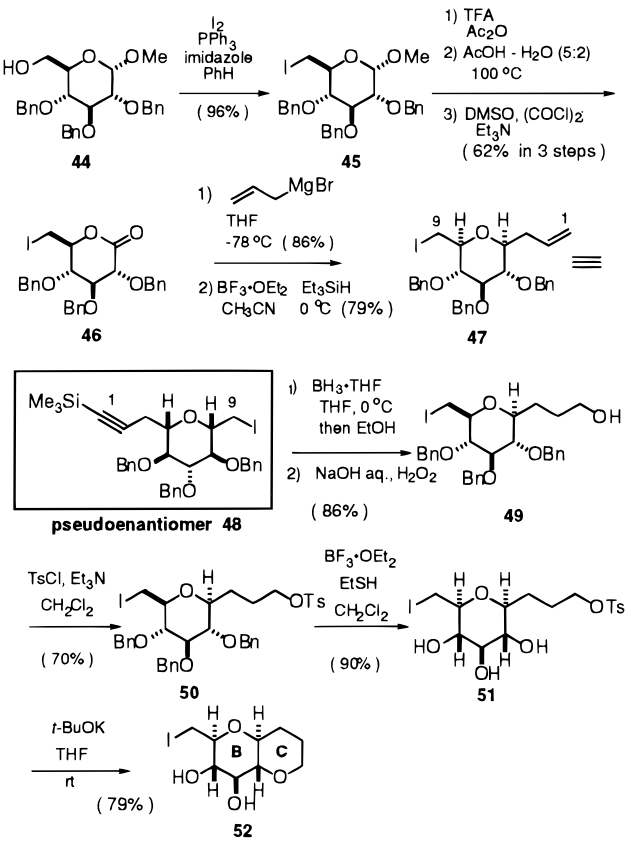


Figure 5.

On the basis of these results, we began to synthesize the ABC fragments of ciguatoxin to prove the absolute stereochemistry of ciguatoxin by comparing NMR and CD spectra of their *p*-bromobenzoate derivatives (Figure 5).[3]

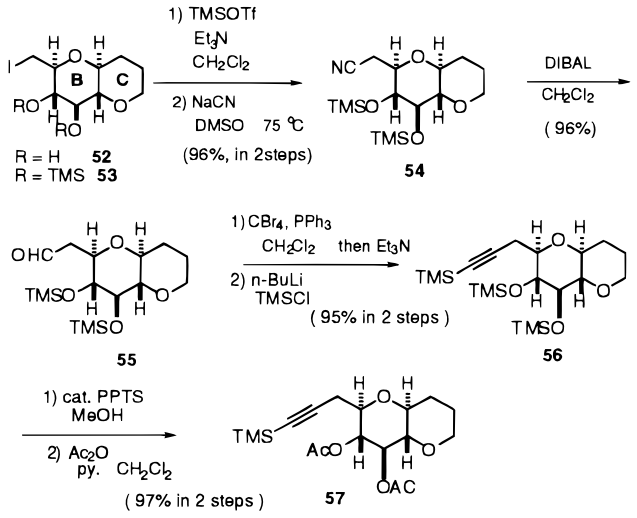
We started the synthesis from methyl 2, 3, 4-tri-*O*-benzyl-α-D-glucopyranoside **44**[20] as shown in Scheme 6.

Scheme 6



This primary alcohol **44** was converted to the corresponding iodide **45**. Its methyl acetal moiety was transformed to the lactone **46** by three-step sequence including acetolysis,[21] hydrolysis, and oxidation. Treatment of **46** with allylmagnesium bromide and then silyl hydride in the presence of Lewis acid produced the *β*-allyl-glycoside **47**.[22] At this point, **47** is *pseudo*-symmetrical product, thus the enantiomer of the BC ring could be synthesized in the form of **48** by an additional two-carbon extension at the C-9 to construct the C ring (illustrated as a silylacetylenic compound of the *pseudo*-enantiomer of **56** or **57**). Hydroxylation of the terminal olefin was achieved by hydroboration to give the primary alcohol **49**, which was tosylated to provide **50**. The benzyl protecting groups of **50** were removed[23] into the 2,3,4-triol **51** in high yield. Cyclization of the C-ring was facilitated with *t*-BuOK to afford the bicyclic compound **52**. Transformation of **52** to (trimethylsilyl)acetylene **57** is shown in Scheme 7. The

Scheme 7



two hydroxy groups were protected as TMS ethers using TMSOTf, which gave the best result since these survived even under the workup of DIBAL with 10% acetic acid at 0 °C. The direct substitution of this iodide **53** into (trimethylsilyl)acetylene **56** was unsuccessful; thus, we took alternative route to synthesize **56**. The iodine of **53** was replaced with cyanide to provide nitrile **54**, which was reduced with DIBAL to afford the aldehyde **55**. Aldehyde **55** was converted to (trimethylsilyl)acetylene **56** by Corey's protocol,[24] which was transformed into diacetate **57**. In this scheme, all steps were higher than 95% yield, and (trimethylsilyl)acetylene **57** was afforded in high yield.

The completion of (2*S*,5*S*)-ABC fragment is shown in Scheme 8. The (trimethylsilyl)acetylene **57** was coupled with D-xylal **13** to afford **58** stereoselectively (20:1) at the C-5 position. This acetylene **58** was converted into acetylene bis(cobalthexacarbonyl) complex **62**, and its stereochemistry of the C-5 position was determined (Figure 6). The left six-membered ring of **62** was opened via oxonium cation intermediate to obtain dipivalate **59**. Acetyl groups were removed, and the resulting diol was cyclized to give **60** as a single stereoisomer at the C-5 position. The cobalt complex **60** received the reductive decomplexation under high-pressure hydrogen atmosphere to afford tricyclic ether **61**, which was solvolyzed to give (2*S*,5*S*)-ABC fragment **40**.[25] (2*R*,5*S*)-ABC fragment **41** was prepared from L-arabinal using the same sequence as that shown for **40** (Schemes 8 and 9). The

(20) (a) Liptak, A.; Jodal, I.; Nanasi, P. *Carbohydr. Res.* **1975**, *44*, 1. (b) Hashimoto, H.; Asano, K.; Fujii, F.; Yoshimura, J. *Carbohydr. Res.* **1982**, *104*, 87.

(21) (a) Isobe. M.; Nishikawa, T.; Pikul, S.; Goto, T. *Tetrahedron Lett.* **1987**, *28*, 6485. (b) Angibeoud, P.; Utille, J.-P. *J. Chem. Soc. Parkin Trans. 1* **1990**, *5*, 1490. (c) Zottola, M.; Rao, B. V.; Fraser-Reid, B. *J. Chem. Soc., Chem. Commun.* **1991**, 969.

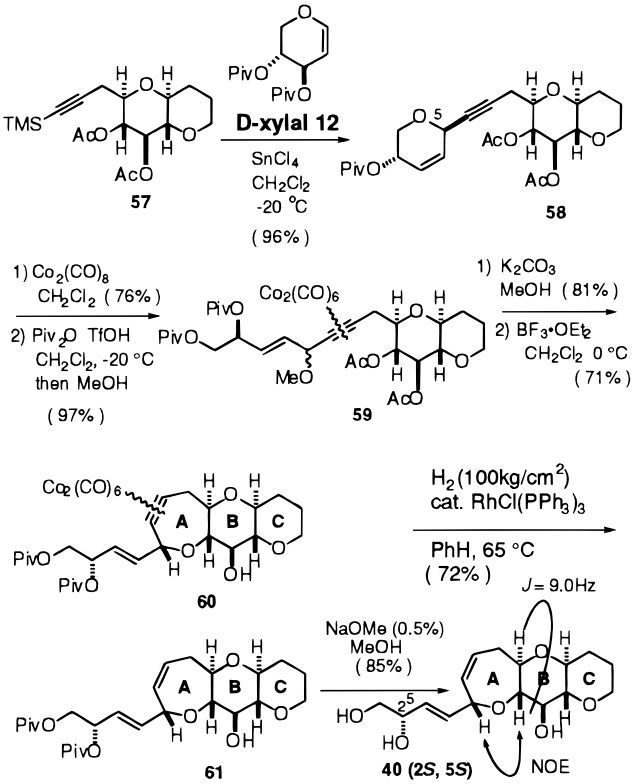
(22) Lewis, M. D.; Cha, J. K.; Kishi, Y. *J. Am. Chem. Soc.* **1982**, *104*, 4976.

(23) (a) Fuji, K.; Ichikawa, K.; Node, M.; Fujita, E. *J. Org. Chem.* **1979**, *44*, 1661. (b) Daly, S. M.; Armstrong, R. W. *Tetrahedron Lett.* **1989**, *30*, 5713.

(24) (a) Corey, E. J.; Fuchs, P. L. *Tetrahedron Lett.* **1972**, *13*, 3769. (b) Jiang, B.; Ma, P. *Synth. Comm.* **1995**, *25*, 3641.

(25) Hosokawa, S.; Isobe, M. *Synlett* **1996**, 351.

Scheme 8



stereochemistry of **40** and **41** were proved by NMR analysis of two protons at δ 3.30 (H-10) and δ 4.58 (H-5)

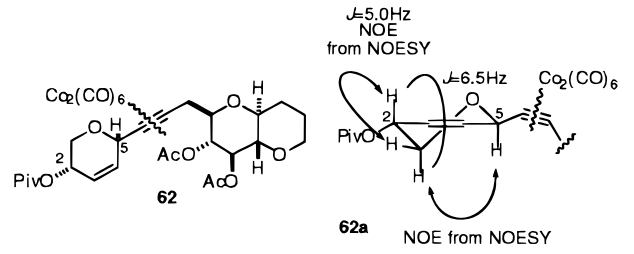
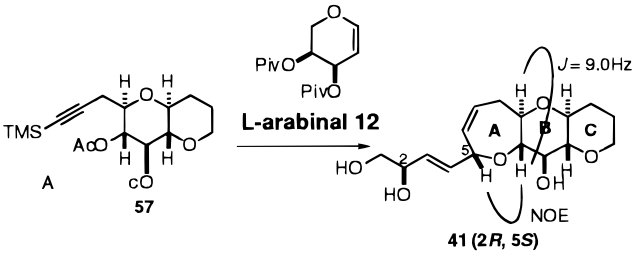


Figure 6.

showing cross-peak in its NOESY spectrum as well as H-10 coupling with H-9 (9.0 Hz) indicating 5*S*-stereochemistry.

Scheme 9



Next, we converted **40** and **41** into tris(*p*-bromobenzoyl) ester **42** and **43** (Figure 5), respectively, and took the NMR spectra and CD spectra of **42** and **43**. These isomers can be distinguished by ^{1}H NMR spectra with the difference in chemical shifts of *p*-bromobenzoyl groups and C-2 protons, although triols **40** and **41** and their 1,2-dipivalates did not show difference clearly. It means that a bulky group attached to the C-11 oxygen affects the configuration of the C-2 substituent. CD spectra of these isomers showed an opposite Cotton effect to the result of Hirama and Yasumoto[3] whose compounds are enantiomeric analogues of our compounds.

We have synthesized (2*R*,5*S*)- and (2*S*,5*S*)-AB fragments of ciguatoxin and (5*S*)-gambiertoxin 4b and two isomers of the ciguatoxin ABC fragment and compared NMR spectra and CD spectra of these tris(*p*-bromobenzoate) derivatives. In these syntheses, we have established an effective methodology for construction of the oxepene A ring with its side chains. The key steps were C-glycosidation of (trimethylsilyl)acetylene, ring opening of pyranoside with acetylene bis(cobalthexacarbonyl) complex, cationic cyclization (Nicholas reaction), and reductive decomplexation under a high-pressure hydrogen atmosphere. With this methodology, synthetic study toward ciguatoxin is in progress.

Experimental Section

General. All proton NMR spectra were measured in $CDCl_3$ solvent, and chemical shifts are reported as δ values in parts per million relative to tetramethylsilane (δ 0.00) or $CDCl_3$ (δ 7.26) as internal standard. Data are reported as follows: chemical shift (integrated intensity or assignment, multiplicity, coupling constants in hertz, assignment). All carbon NMR spectra were measured in $CDCl_3$ solvent, and chemical shifts are reported as δ values in parts per million relative to $CDCl_3$ (δ 77.0) as internal standard. The symbols (*) represent interchangeable assignments. Infrared spectra are reported in wavenumber (cm^{-1}). Analytical thin-layer chromatography (TLC) was conducted on precoated TLC plates (layer thickness 0.25 mm); preparative layer chromatography (PLC) (layer thickness 0.5 mm or 2.0 mm). Tetrahydrofuran (THF) was distilled from potassium metal in the presence of potassium benzophenone ketyl as an inductor. Dichloromethane was dried over molecular sieves 4A (nacalai tesque) and used without distillation. Pyridine and triethylamine were dried over KOH pellets and used without distillation.

Di-*O*-pivaloyl-L-arabinal (12). To a solution of di-*O*-triacetyl-L-arabinal (1.03 g, 5.15 mmol) in 20 mL of MeOH was added 20 μL of NaOMe (28% in MeOH). After stirring for 3 h at room temperature, the reaction mixture was concentrated in vacuo, and the resulting residue was dissolved into CH_2Cl_2 (20 mL). To this solution were added triethylamine (10 mL, 72.1 mmol), pivaloyl chloride (3.2 mL, 25.8 mmol), and DMAP (20 mg). After stirring overnight at room temperature, the reaction mixture was concentrated in vacuo. The resulting residue was purified by silica gel column chromatography (ether/hexane = 1:2) gave dipivalate **12** as colorless oil (1.26 g, 4.44 mmol, 86%). $[\alpha]^{26}_D$ −208.1 (*c* 0.81, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.19 (9H, s, OPiv), 1.21 (9H, s, OPiv), 3.96 (1H, dd, J = 10.5, 9.5 Hz, H-5a), 4.02 (1H, ddd, J = 10.5, 4.5, 1.5 Hz, H-5b), 4.87 (1H, dd, J = 6, 5 Hz, H-2), 5.15 (1H, dt, J = 9.5, 4 Hz, H-4), 5.37 (1H, brt, J = 5 Hz, H-3), 6.48 (1H, d, J = 6 Hz, H-1); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 26.98, 27.04, 38.6, 38.7, 62.6, 62.7, 66.1, 97.6, 147.4, 177.1, 177.3; IR (KBr) 2977, 1733, 1644, 1481, 1281, 1264, 1158, 1086 cm^{-1}. Anal. Calcd for $C_{15}H_{24}O_5$: C, 63.36; H, 8.51. Found: C, 63.37; H, 8.38.

Di-*O*-pivaloyl-D-xylal (13). Di-*O*-pivaloyl-D-xylal **13** was prepared as **12** in 86%. Mp 35−35.5 °C; $[\alpha]^{27}_D$ −250.1 (*c* 0.82, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.19 (18H, s × 2, OPiv), 3.95 (1H, dd, J = 12, 2 Hz, H-5a), 4.17 (1H, ddd, J = 12, 3.5, 1.5 Hz, H-5b), 4.88−4.98 (3H, m, H-2, H-3 and H-4), 6.57 (1H, d, J = 5.5 Hz, H-1); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 26.8, 26.9, 38.4, 63.4, 63.5, 66.8, 97.4, 147.7, 177.1, 177.2; IR (KBr) 2974, 1734, 1645, 1481, 1275, 1251, 1148, 1095 cm^{-1}; EI-MS *m*/*z* 284 (M^+), 183 ($M - OPiv^+$). Anal. Calcd for $C_{15}H_{24}O_5$: C, 63.36; H, 8.51. Found: C, 63.30; H, 8.68.

(2*S,5*S**,6*R**)-5-(1′-Ethoxyethoxy)-6-(hydroxymethyl)-2-(isopropyloxy)-5,6-dihydro-2*H*-pyran (16).** To a solution of the diol **15** (23.4 g, 124 mmol) in CH_2Cl_2 (400 mL) were successively added pyridine (34 mL, 420 mmol) and PivCl (16

mL, 130 mmol) at 0 °C. After stirring at 0 °C for 30 min, the reaction mixture was quenched with H_2O and extracted with ether (×3). The extracts were washed with aq 1.0 N HCl, H_2O, and brine, dried over Na_2SO_4, and concentrated under reduced pressure. The crude oil was dissolved in 500 mL of CH_2Cl_2. To this solution were added EVE (26 mL, 272 mmol) and PPTS (500 mg, 1.99 mmol). After stirring at room temperature overnight, the reaction was quenched with sat. $NaHCO_3$ and extracted with CH_2Cl_2 (×2). The extracts were dried over Na_2SO_4 and concentrated under reduced pressure. The resulting crude oil was dissolved in 500 mL of Et_2O. To this solution was added LAH (5.05 g, 133 mmol) in small portions at 0 °C. After stirring at 0 °C for 5 min, to the reaction mixture were successively added AcOEt, sat. NH_4Cl, and aq 3 N HCl and then extracted with ether (×3). The extracts were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. Purification of the residue with silica gel column chromatography (ether/hexane = 50:50) gave the colorless oil **16** (24.6 g, 76%, in three steps). ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.14−1.25 (9H, m, OCH(CH_3)$_2$, OCH(CH_3)OCH$_2CH_3$), 1.32 (3H, d, J = 5.2 Hz, OCH(CH_3)OCH$_2$CH$_3$), 1.94, 2.33 (total 1H, each m, OH), 3.45−3.71 (2H, m, H-6), 3.71−3.87 (3H, m, H-5, OCH(CH$_3$)OCH_2CH$_3$), 3.90−4.01 (1H, m, OCH(CH$_3$)$_2$), 4.18,4.28 (total 1H, each m, H-4), 4.78,4.81 (total 1H, each q, J = 5.2 Hz, OCH(CH$_3$)OCH$_2$CH$_3$), 5.08 (1H, m, H-1), 5.66−5.73 (1H, m, H-3), 5.97 (d, J = 10.2 Hz, H-2), [6.04 (d, J = 10.3 Hz, H-2)]; IR (KBr) 3464(br), 2976, 2920, 1465, 1453, 1379, 1309, 1131, 1031, 934 cm^{-1}. Anal. Calcd for $C_{13}H_{24}O_5$: C, 59.98; H, 9.29. Found: C, 59.90; H, 9.07.

(2*S,5*S**,6*R**)-5-(1′-Ethoxyethoxy)-6-(iodomethyl)-2-(isopropyloxy)-5,6-dihydro-2*H*-pyran (17).** To a solution of the alcohol **16** (215 mg, 826 μmol) in PhH (5 mL) were successively added imidazole (140 mg, 2.06 mmol), PPh_3 (540 mg, 2.06 mmol), and iodine (251 mg, 1.98 mmol). After stirring at room temperature for 30 min, the reaction mixture was quenched with sat. Na_2SO_3 and extracted with ether (×3). The extracts were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. Purification of the residue with silica gel column chromatography (ether/hexane = 10:90) gave colorless oil **17** (298 mg, 98%). ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.15−1.62 (12H, m, OCH(CH_3)$_2$, OCH(CH_3)OCH$_2CH_3$), 3.31−3.38 (1H, m, H-6), 3.44−3.72 (4H, m, H-5, H-6, OCH(CH$_3$)OCH_2-CH$_3$), 3.96, 4.06 (total 1H, each m, H-4), 4.11 (1H, m, OCH(CH$_3$)$_2$), 4.80, 4.85, (total 1H, each q, J = 5.3 Hz, OCH(CH$_3$)OCH$_2$CH$_3$), 5.10 (1H, brs, H-1), 5.65−5.75 (1H, m, H-3), 5.94 (d, J = 12.0 Hz, H-2), [5.99 (d, J = 10.5 Hz, H-2)]; IR (KBr) 2973, 2900, 1735, 1653, 1446, 1382, 1301, 1124, 1025, 943 cm^{-1}. Anal. Calcd for $C_{13}H_{23}O_4I$: C, 42.18; H, 6.26. Found: C, 42.11; H, 6.21.

(2*S,5*S**,6*R**)-5-Hydroxy-6-(3-(trimethylsilyl)-2-propynyl)-2-(isopropyloxy)-5,6-dihydro-2*H*-pyran (18).** To a solution of 220 μL of (trimethylsilyl)acetylene (1.56 mmol) in 4.0 mL of THF was added 770 μL (1.23 mmol) of *n*-BuLi (1.6 M in hexane) at −78 °C. The resulting colorless solution was warmed to 0 °C and stirred for 30 min. To this solution were successively added a solution of iodide **17** (397 mg, 1.02 mmol) in 4.0 mL of THF via cannula and 2.0 mL of HMPA at 0 °C. After stirring for 30 min at 0 °C, the reaction mixture was poured into a cold sat. NH_4Cl and extracted with ether (×3). The extracts were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. Purification of the residue with silica gel column chromatography (ether/hexane = 10:90) gave colorless oil, ethoxyethyl ether of **17′** (267 mg, 740 mmol, 73%). Because of its instability, this compound was subjected to the next reaction right away. To a solution of the ethoxy ether (267 mg, 740 mmol) in 6.0 mL of *i*-PrOH was added PPTS (23.0 mg, 0.09 mmol). The resulted solution was stirred for 1 h at room temperature and concentrated. The crude oil was purified by silica gel column chromatography (ether/hexane = 40:60) to give allyl alcohol **18** (201 mg, 100%). $[\alpha]^{25}_D$ +66.7 (*c* 0.39, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.16 (9H, s, TMS), 1.18, 1.26 (each 3H, each d, J = 6.2 Hz, −CH(CH_3)$_2$), 1.95 (1H, brd, J = 7.0 Hz, OH), 2.54 (1H, ddd, J = 17, 3, 2 Hz, H-6a), 2.70 (1H, dd, J = 17, 5 Hz, H-6b), 3.80 (1H, ddd, J = 9, 7.3, 5 Hz, H-5), 3.98−4.12 (2H, m, H-4, OCH(CH$_3$)$_2$), 5.06 (1H, m, H-1), 5.74 (1H, ddd, J = 10, 3, 2 Hz, H-3*), 5.90 (1H, m, H-2*); IR (KBr) 3433 (br), 2967, 2901, 2180, 1383, 1314, 1250, 1031, 839 cm^{-1}; MS(EI) m/z = 268 (M$^+$). Anal. Calcd for $C_{14}H_{24}O_3Si$: C, 61.90; H, 8.44. Found: C, 61.77; H, 8.61.

(2*S,5*S**,6*R**)-5-Acetoxy-6-(3-(trimethylsilyl)-2-propynyl)-2-(isopropyloxy)-5,6-dihydro-2*H*-pyran (19).** To the solution of allyl alcohol **18** (201 mg, 750 μmol) in 6.0 mL of CH_2Cl_2 were successively added pyridine (600 μL, 7.42 mmol), Ac_2O (200 μL, 1.99 mmol), and DMAP (50 mg, 0.41 mmol). After stirring for 3 h, to the reaction mixture was added H_2O. The resulting mixture was extracted with CH_2Cl_2 (×2). The extracts were dried over Na_2SO_4 and concentrated under reduced pressure. The crude residue was purified by silica gel column chromatography (ether/hexane = 30:70) to give **19** (228 mg, 94%). $[\alpha]^{25}_D$ +88.1 (*c* 0.99, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.15 (9H, s, TMS), 1.18, 1.28 (each 3H, each d, J = 6.3 Hz, OCH(CH_3)$_2$), 2.08 (3H, s, OAc), 2.44 (1H, dd, J = 17.6, 8.6 Hz, H-6a), 2.58 (1H, dd, J = 17.6, 3.4 Hz, H-6b), 4.08 (1H, dt, J = 8.6, 3.4 Hz, H-5), 4.11 (1H, m, OCH(CH$_3$)$_2$), 5.14 (2H, m, H-1, H-4), 5.82 (2H, m, H-2, H-3); IR (KBr) 2971, 2181, 1744, 1373, 1236, 1034, 844 cm^{-1}. Anal. Calcd for $C_{16}H_{26}O_4Si$: C, 61.90; H, 8.44. Found: C, 61.74; H, 8.45.

(2*R,3*S**)-3-Acetoxy-2-(3-(trimethylsilyl)-2-propynyl)-5,6-dihydro-2*H*-pyran (11).** To the solution of allyl acetate **19** (228 mg, 735 μmol) in 2.5 mL of CH_2Cl_2 and 2.5 mL of CH_3CN were successively added triethylsilane (590 μL, 3.69 mmol) and BF_3·OEt_2 (135 μL, 1.47 mmol). After stirring for 2 h, the reaction mixture was poured into a cooled sat. $NaHCO_3$. The resulting mixture was extracted with CH_2Cl_2 (×2). The extracts were dried over Na_2SO_4 and concentrated under reduced pressure. The crude residue was purified by silica gel column chromatography (ether/hexane = 30:70) to give **11** (142 mg, 77%). $[\alpha]^{25}_D$ +0.8 (*c* 0.77, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.13 (9H, s, TMS), 2.06 (3H, s, Ac), 2.48 (1H, dd, J = 17, 6.5 Hz, H-6a), 2.56 (1H, dd, J = 17, 5 Hz, H-6b), 3.66 (1H, td, J = 7, 5 Hz, H-5), 4.19 (2H, m, H-1), 5.18 (1H, dddd, J = 7, 4, 2.5, 2 Hz, H-4), 5.73 (1H, dq, J = 10.5, 2.5 Hz, H-3), 5.91 (1H, dq, J = 10.5, 2 Hz, H-2); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 0.00, 21.43, 23.45, 64.58, 68.11, 74.00, 85.48, 102.21, 123.88, 129.61, 170.28; IR (KBr) 3048, 2962, 2830, 1741, 1417, 1374, 1236, 1043 cm^{-1}. Anal. Calcd for $C_{13}H_{20}O_3Si$: C, 61.87; H, 7.99. Found: C, 61.67; H, 8.04.

Disaccharide 20. To a mixture of silylacetylene **11** (47.7 mg, 189 μmol) and arabinal **12** (68.4 mg, 241 μmol) in 1.5 mL of CH_2Cl_2 was added $TiCl_4$ (25 μL, 228 μmol) at −20 °C. After stirring for 30 min at −20 °C, the reaction mixture was poured into a cold mixture of sat. $NaHCO_3$ aq. and sat. aq NaK(CH(OH)COO)$_2$. The resulting mixture was extracted with Et_2O (×2). The extracts were washed with brine, dried over Na_2SO_4, and concentrated. The crude mixture was purified by silica gel column chromatography (ether/hexane = 50:50) to give **20** (37.0 mg, 54%). $[\alpha]^{28}_D$ +10.3 (*c* 0.70, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.19 (9H, s, Piv), 2.07 (3H, s, Ac), 2.50 (1H, ddd, J = 17, 7, 2 Hz, H-8a), 2.59 (1H, ddd, J = 17, 5, 2 Hz, H-8b), 3.67 (1H, td, J = 7, 5 Hz, H-9), 3.76 (1H, ddd, J = 13, 2, 1 Hz, H-1a), 4.18 (1H, dd, J = 13, 3.5 Hz, H-1b), 4.21 (2H, m, H-13), 4.92 (1H, m, H-5), 5.01 (1H, m, H-2), 5.19 (1H, m, H-10), 5.74 (1H, dq, J = 10.5, 2.5 Hz, H-3*), 5.87(1H, dddd, J = 10, 4.5, 2.5, 1 Hz, H-11*), 5.93 (1H, dq, J = 10.5, 2.0 Hz, H-4*), 6.02 (1H, ddd, J = 10, 4.5, 1 Hz, H-12*); IR (KBr) 2972, 2871, 2222, 1732, 1719, 1482, 1370, 1278, 1236, 1156 cm^{-1}; MS(EI) m/z 362 (M$^+$). Anal. Calcd for $C_{20}H_{26}O_6$: C, 66.28; H, 7.23. Found: C, 66.22; H, 7.37.

Acetylenecobalthexacarbonyl Complex 21. To a solution of acetylene **20** (44.5 mg, 141 μmol) in 2.0 mL of CH_2Cl_2 was added a solution of $Co_2(CO)_8$ (61.4 mg, 174 μmol) in 0.75 mL of CH_2Cl_2 at room temperature. After stirring for 2 h, the solvent was removed in vacuo. The residue was purified by silica gel column chromatography (ether/hexane = 40:60) to give a dark red oil **21** (71.5 mg, 84%). $[\alpha]^{28}_D$ +168.5 (*c* 0.10, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.21 (9H, s, Piv), 2.11 (3H, s, Ac), 2.98 (1H, dd, J = 16.5, 10 Hz, H-8a), 3.11 (1H, dd, J = 16.5, 2.5 Hz, H-8b), 3.58−3.66 (1H, m, H-9), 3.67 (1H, dd, J = 11.5, 7 Hz, H-1a), 4.16 (2H, m, H-13), 4.28(1H, dd, J =

11.5, 5 Hz, H-1b), 5.23, 5.25, 5.33 (each 1H, each m, H-2*, H-5*, H-10*), 5.75 (1H, m, H-3*), 5.89 (1H, dt, J = 10.5, 2.0 Hz, H-11*), 5.96 (1H, dq, J = 10.5, 2.0 Hz, H-12*), 6.04 (1H, m, H-4*); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 20.90, 27.00, 36.62, 38.66, 64.13, 65.27, 68.95, 73.99, 76.63, 92.69, 96.91, 124.45, 125.37, 129.52, 132.09, 170.60, 178.06, 199.77 (br); IR (KBr) 2975, 2934, 2874, 2092, 2053, 2013, 1734, 1481, 1372, 1278, 1234, 1153, 1091, 1032 cm^{-1}; MS(FAB) m/z 649 (M + H$^+$), 592 (M − 2×CO), 564 (M − 3xCO), 536 (M − 4×CO), 508 (M − 5×CO), 480 (M − 6×CO); HRMS(FAB) calcd for $C_{22}H_{26}O_8Co_2$, 536.0291, found 536.0278.

Acetylenecobalthexacarbonyl Complex 22. To a solution of Piv_2O (100 μL, 493 μmol) in 0.75 mL of CH_2Cl_2 was added TfOH (25 μL, 283 μmol) at −20 °C under N_2. After stirring for 20 min at −20 °C, to this mixture was added a solution of cobalt complex **21** (33.0 mg, 51.1 μmol) in 1.5 mL of CH_2Cl_2 via cannula. After stirring for 1 h at −20 °C, to the resulting dark red solution was added 300 μL of MeOH. The reaction mixture was poured into a cooled sat. $NaHCO_3$ aq. and extracted with CH_2Cl_2 (×2). The extracts were dried over Na_2SO_4, concentrated in vacuo, and purified by silica gel column chromatography (ether/hexane = 40:60) to give dark red oil **22** (38.0 mg, 98%). ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.19, 1.20 (total 18H, each s, Piv), 2.09 (3H, s, Ac), 2.84−3.07 (2H, m, H-8), 3.57−3.69 (1H, m, H-9), 4.04 (dd, J = 11.5, 7.5 H-1a), 4.17 (2H, m, H-13), 4.27 (dd, J = 11.5, 3.5 Hz, H-1b), [4.31 (dd, J = 11.5, 3.5 Hz, H-1b)], 4.75 (1H, m, H-5), 5.20 (1H, m, H-10), 5.57 (1H, m, H-2), 5.73−6.00 (4H, m, H-3, H-4, H-11, H-12); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 20.90, 26.92, 27.01, 27.04, 36.23, 36.34, 38.65, 38.71, 56.76, 56.99, 62.48, 62.71, 64.41, 68.86, 70.47, 71.91, 71.99, 76.63, 80.25, 80.50, 89.58, 89.79, 95.65, 95.88, 124.31, 129.46, 129.68, 131.25, 131.68, 131.89, 132.29, 170.61, 177.20, 177.53, 177.99, 199.51 (br); IR (KBr) 2973, 2940, 2881, 2090, 2053, 2024, 1733, 1482, 1372, 1282, 1233, 1140 cm^{-1}; MS(FAB) m/z 732.8 (M + H − MeOH), 679.8 (M − 3×CO); HRMS(FAB) calcd for $C_{31}H_{25}O_{13}Co_2$ 733.0741, found 733.0704.

Acetylenecobalthexacarbonyl Complex 23. To a solution of cobalt complex **22** (152 mg, 199 μmol) in 1.5 mL of MeOH was added K_2CO_3 (21.0 mg, 152 μmol) at 0 °C. After warming up to room temperature, the reaction mixture was stirred for 30 min. The resulting mixture was quenched with sat. NH_4Cl aq. and extracted with Et_2O (×2). The extracts were washed with brine, dried over Na_2SO_4, concentrated in vacuo, and purified by silica gel column chromatography (ether/hexane = 50:50) to give a dark red oil **23** (125 mg, 87%). ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.19, 1.20, 1.21 (total 18H, each s, Piv), 2.15−2.30 (1H, m, −OH), 2.81 (dd, J = 15, 10 Hz, H-8a), 2.94 [(dd, J = 15, 10 Hz, H-8a)], 3.30−3.40 (2H, m, H-8b, H-9), 3.41, 3.42 (total 3H, each s, OMe), 4.00−4.15 (4H, m, H-1a, H-10, H-13), 4.26 (dd, J = 11.5, 3.5 Hz, H-1b), [4.29(dd, J = 11.5, 3.0 Hz, H-1b)], 4.75 (1H, m, H-5), 5.51 (1H, m, H-2), 5.71−5.92 (4H, m, H-3, H-4, H-11, H-12); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 26.96, 27.01, 27.04, 36.76, 38.72, 56.83, 56.94, 62.56, 62.82, 64.51, 65.78, 67.41, 71.94, 72.07, 79.92, 79.98, 80.33, 80.51, 89.39, 96.43, 128.23, 130.84, 131.77, 132.08, 132.14, 177.41, 177.63, 178.22, 199.62 (br); IR (KBr) 3482 (br), 2974, 2939, 2873, 2090, 2051, 2022, 1734, 1482, 1287, 1165, 1146, 1029 cm^{-1}; MS(FAB) m/z 691.1 (M + H − MeOH), 638.1 (M − 3×CO); HRMS(FAB) calcd for $C_{29}H_{33}O_{12}Co_2$ 691.0635, found 691.0618.

***endo*-Acetylenecobalthexacarbonyl Cyclic Ether 24.** To a solution of cobalt complex **23** (6.5 mg, 9.02 μmol) in 1.3 mL of CH_2Cl_2 was added BF_3·OEt_2 (0.1 M in 1,2-dichloromethane, 70 μL, 7.58 μmol) at 0 °C. After stirring for 40 min at 0 °C, the reaction mixture was quenched by sat. aq NH_4Cl and extracted with Et_2O (×1). The extracts were washed with brine, dried over Na_2SO_4, concentrated in vacuo, and purified by silica gel column chromatography (ether/hexane = 25:75) to give a dark red oil **24** (4.9 mg, 79%). $[\alpha]^{29}_D$ −309.0 (*c* 0.11, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.18, 1.21 (each, 9H, each s, Piv), 2.86−2.99 (1H, m, H-8a), 3.45−3.58 (2H, m, H-8b, H-9), 3.99−4.08 (1H, m, H-10), 4.04 (1H, dd, J = 11.5, 7.5 Hz, H-1a), 4.14 (2H, m, H-13), 4.29 (1H, dd, J = 11.5, 3 Hz, H-1b), 5.13 (1H, d, J = 4 Hz, H-5), 5.61 (1H, m, H-2), 5.76 (1H, m, H-11*), 5.87 (1H, dd, J = 16, 5 Hz, H-3), 5.89−5.96 (1H, m, H-12*), 5.94 (1H, dd, J = 16, 4 Hz, H-4); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 27.00, 27.03, 31.49, 38.72, 38.75, 64.97, 64.99, 70.82, 75.38, 78.88, 80.97, 91.95, 100.22, 124.97, 127.05, 128.31, 132.15, 177.25, 178.09, 199.04 (br); IR (KBr) 2975, 2935, 2972, 2841, 2094, 2051, 2026, 1735, 1577, 1481, 1280, 1146 cm^{-1}; MS(FAB) m/z 691.2 (M + H), 606.2 (M − 3×CO), 578 (M − 4×CO); HRMS(FAB) calcd for $C_{29}H_{33}O_{12}Co_2$ 691.0635, found 691.0621.

(2*R*,5*S*)-AB Segment 25. To a solution of *endo*-acetylenecobalt complex **24** (5.3 mg, 7.36 μmol) in 1.0 mL of PhH was added Wilkinson catalyst (0.7 mg, 0.76 μmol). After stirring for 5 h at 60 °C under 100 kg/cm^2, the reaction mixture was filtered, concentrated in vacuo, and purified by silica gel column chromatography (ether/hexane = 30:70) to give **25** (2.5 mg, 84%). Mp 96−96.5 °C; $[\alpha]^{26}_D$ −54.6 (*c* 0.75, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.18, 1.21 (each 9H, each s, Piv), 2.38 (1H, ddq, J = 15.9, 10.6, 3 Hz, H-8a), 2.59 (1H, ddd, J = 15.9, 8, 3.9 Hz, H-8b), 3.24 (1H, ddd, J = 10.6, 8.9, 3.9 Hz, H-9), 3.98 (1H, m, H-10), 4.08 (1H, dd, J = 11.8, 7.2 Hz, H-1a), 4.15 (2H, m, H-13), 4.25 (1H, dd, J = 11.8, 3.5 Hz, H-1b), 4.58 (1H, m, H-4), 5.54 (1H, m, H-2), 5.66−5.91 (5H, m, H-3, H-6, H-7, H-11, H-12), 5.86 (1H, dd, J = 15.5, 4.8 Hz, H-4); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 27.08, 34.63, 38.77, 64.86, 65.52, 70.93, 74.65, 79.39, 124.98, 127.76, 134.29, 177.44, 178.14; IR (KBr) 2975, 1735, 1482, 1280, 1142, 1106 cm^{-1}; MS(EI) m/z 406 (M$^+$), 304 (M$^+$ − PivOH). Anal. Calcd for $C_{23}H_{34}O_6$: C, 67.98; H,8.37. Found: C, 67.99; H, 8.60.

(2*S*,5*S*)-AB Segment 27. (2*S*,5*S*)-AB Fragment **27** was derived from **11** and D-xylal **13** as **25**. $[\alpha]^{26}_D$ −17.2 (*c* 0.47, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.18, 1.21 (each 9H, each s, Piv), 2.38 (1H, ddq, J = 16, 10.5, 3 Hz, H-8a), 2.59 (1H, ddd, J = 16, 8, 3.6 Hz, H-8b), 3.24 (1H, ddd, J = 10.5, 8.4, 3.6 Hz, H-9), 3.98 (1H, m, H-10), 4.08 (1H, dd, J = 11.8, 7 Hz, H-1a), 4.15 (2H, m, H-13), 4.24 (1H, dd, J = 11.8, 3.5 Hz, H-1b), 4.59 (1H, m, H-5), 5.54 (1H, ddd, J = 7, 6.5, 3.5 Hz, H-2), 5.65−5.88 (5H, m, H-3, H-6, H-7, H-11, H-12), 5.88 (1H, dd, J = 15.5, 4.8 Hz, H-4); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 27.06, 34.63, 38.71, 38.77, 64.79, 65.49, 71.03, 74.65, 77.54, 79.29, 125.03, 127.71, 127.82, 134.24, 134.78, 177.44, 178.12; IR (KBr) 2967, 1729, 1482, 1286, 1146, 1020 cm^{-1}; MS(EI) m/z 406 (M$^+$), 304 (M$^+$ − PivOH); EI HRMS calcd for $C_{23}H_{34}O_6$ 406.2355, found 406.2340.

(2*R,3*S**)-3-(1′-Ethoxyethoxy)-2-(2-propynyl)-2, 3-dihydro-6*H*-pyran (35).** To a solution of allyl acetate **11** (142 mg, 563 μmol) in 4.0 mL of MeOH was added K_2CO_3 (190 mg, 1.37 mmol). After stirring for 2 h, to the reaction mixture was added sat. NH_4Cl at 0 °C. The resulting mixture was extracted with Et_2O (×2). The extracts was washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. The crude residue was purified by silica gel column chromatography (ether/hexane = 65:35) to give allyl alcohol (78 mg, 100%). $[\alpha]^{25}_D$ +0.3 (*c* 1.94, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.90 (1H, d, J = 6.6 Hz, −OH), 2.08 (1H, t, J = 2.7 Hz, H-8), 2.60 (1H, ddd, J = 16.9, 6.1, 2.7 Hz, H-6a), 2.67 (1H, ddd, J = 2.7, 5.2, 16.9 Hz, H-6b), 3.45 (1H, ddd, J = 7.6, 6.1, 5.2 Hz, H-5), 4.19 (3H, m, H-1, H-4), 5.84 (2H, m, H-2, H-3); IR (KBr) 3407 (br), 3041, 2889, 1653, 1636, 1541, 1419, 1375, 1127, 1084, 1032 cm^{-1}. Anal. Calcd for $C_8H_{10}O_2$: C, 69.53; H, 7.30. Found: C, 69.52; H, 7.50.

To the solution of this allyl alcohol (236 mg, 1.71 mmol) in 5.0 mL of CH_2Cl_2 was successively added EVE (350 μL, 3.66 mmol) and PPTS (31 mg, 0.12 mmol). After stirring for 6 h, to the reaction mixture was added sat. $NaHCO_3$. The resulting mixture was extracted with CH_2Cl_2 (×2). The extracts were dried over Na_2SO_4 and concentrated under reduced pressure. The crude residue was purified by silica gel column chromatography (ether/hexane = 17:83) to give **35** (364 mg, 100%). ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.22 (3H, t, J = 6.9 Hz, OCH(CH_3)OCH$_2$*CH*$_3$), 1.34, 1.35 (total 3H, each d, J = 5.2 Hz, OCH(*CH*$_3$)OCH$_2$CH$_3$), 2.04, 2.06 (total 1H, each t, J = 2.5Hz, H-8), 2.52−2.76 (2H, m, H-6), 3.53 (2H, m, OCH(CH$_3$)OC*H*$_2$CH$_3$), 3.67 (1H, m, H-5), 4.14 (1H, m, H-4), 4.21 (2H, m, H-1), 4.81, 4.87 (total 1H, each q, J = 5.2 Hz, OC*H*(CH$_3$)OCH$_2$CH$_3$), 5.86 (2H, m, H-2, H-3); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 15.1, 20.3,

20.5, 21.7, 60.6, 60.9, 65.28, 65.31, 68.4, 69.7, 70.1, 71.1, 74.8, 74.9, 80.4, 80.7, 98.3, 100.8, 125.8, 127.1, 127.6, 128.0; IR (KBr) 2980, 2931, 2913, 2887, 1717, 1653, 1541, 1508, 1457, 1390, 1128, 1083, 1053, 1034 cm^{-1}. Anal. Calcd for $C_{12}H_{18}O_2$: C, 68.54; H, 8.63. Found: C, 68.42; H, 8.83.

(2*R,3*S**)-3-(1′-Ethoxyethoxy)-2-(5-hydroxy-1-iodoocta-1,3-dien-6-ynyl)-2,3-dihydro-6*H*-pyran (37).** To the solution of acetylene **35** (72.1 mg, 343 μmol) in THF (2.0 mL) was added *n*-BuLi (1.6 M in hexane, 260 μL, 412 μmol) at −78 °C under N_2. After stirring at 0 °C for 30 min, this reaction mixture was recooled to −78 °C. At this temperature, to this solution was added BF_3·OEt_2 (0.54 M in THF, 630 μL, 378 μmol). After stirring for 10 min, aldehyde **36** (107 mg, 515 μmol) in THF (2.0 mL) was added. After additional stirring for 20 min, the reaction mixture was poured into a cooled sat. $NaHCO_3$ and extracted by ether (×3). The extracts were washed with brine and dried over Na_2SO_4. Evaporation, concentration, and purification by silica gel column chromatography gave colorless adduct (92.0 mg, 220 μmol, 63%) which received next reaction immediately because of instability. The adduct was dissolved in MeOH (5.0 mL), and to the resulting solution was added PPTS (3.0 mg). After stirring for 1 h, to this reaction mixture was added sat. $NaHCO_3$ at 0 °C. Extraction with ether (×3) and evaporation gave crude residue which was purified by silica gel column chromatography (ethyl acetate/hexane = 1:1) to afford colorless oil **37** (65.6 mg, 190 μmol, 88%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.65−2.74 (2H, m, H-8), 3.40−3.50 (1H, m, H-9), 4.11−4.20 (3H, m, H-10, H-13), 4.90, 4.98 (total 1H, each m, H-5), 5.76−5.91 (2H, m, H-11, H-12), 6.02−6.10, 6.29−6.47, 6.55−6.65 (total 3H, each m, H-2, H-3, H-4), 6.76, 6.78, 7.04, 7.07 (total 1H, each d, J = 11 Hz, 10 Hz, 14 Hz, 14.5 Hz, respectively, H-1); IR (KBr) 3375 (br), 2882, 2843, 2219, 1669, 1613, 1417, 1259, 1120, 1079, 1029, 977, 810, 696 cm^{-1}. Anal. Calcd for $C_{13}H_{15}O_3I$: C, 45.11; H, 4.37. Found: C, 45.11; H, 4.47.

Acetylene Biscobalthexacarbonyl Complex 38. To the solution of acetylene **37** (26.6 mg, 76.8 μmol) in CH_2Cl_2 (1.0 mL) was added a solution of $Co_2(CO)_8$ (50 mg, 146 μmol) in CH_2Cl_2 (1.0 mL) at 0 °C. After stirring for 1 h at room temperature, the reaction mixture was concentrated in vacuo. Purification by silica gel column chromatography (ethyl acetate/hexane = 1:2) gave a dark red oil **38** (48.5 mg, 76.7 μmol, 100%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.95−3.17 (1H, m, H-9), 3.22−3.45, 3.45−3.66 (each 1H, each m, H-8), 3.95−4.30 (3H, m, H-10, H-13), 5.26−5.36 (1H, m, H-5), 5.76−5.94 (2H, m, H-11, H-12), 5.36−5.48, 6.03−6.17, 6.27−6.47, 6.48−6.65, 6.69−6.82, 6.93−7.14 (total 4H, each m, H-1, H-2, H-3, H-4). All peaks are broadened, due to the paramagnetic susceptibility of cobalt; IR (KBr) 3402 (br), 2930, 2889, 2854, 2091, 2049, 2017, 1602, 1117, 1078, 1027, 979, 701, 518 cm^{-1}; MS(FAB) *m*/*z* 631 (M − H), 615 (M + H − H_2O), 604 (M − CO), 576 (M − 2×CO), 548 (M − 3×CO), 492 (M − 5×CO), 464 (M − 6×CO); HRMS(FAB) calcd for $C_{19}H_{14}O_9Co_2$ 630.8479, found 630.8330.

Cyclic Acetylenecobalthexacarbonyl Complex 39. To the solution of cobalt complex **38** (29.2 mg, 46.2 μmol) in 30 mL of CH_2Cl_2 (degassed ×3) was added CSA (21.4 mg, 92.4 μmol) at 0 °C. After stirring for 40 min at 0 °C, the reaction mixture was poured on silica gel column. Purification by column chromatography (ether/hexane = 1:4) gave a dark red oil **39** (25.5 mg, 41.5 μmol, 90%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.86−3.00 (1H, m, H-9), 3.44−3.62 (2H, m, H-8), 3.98−4.20 (3H, m, H-10, H-13), 5.05−5.23 (1H, m, H-5), 5.70−5.98 (3H, m, H-4*, H-11, H-12), 6.27−6.48, 6.49−6.65, 6.72−6.86, 6.96−7.13 (total 3H, each m, H-1*, H-2*, H-3*). All peaks are broadened, due to the paramagnetic susceptibility of cobalt. ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 38.8, 65.0, 75.5, 75.7, 79.0, 80.3, 81.2, 127.0, 128.5, 130.4, 130.9, 132.5, 136.5, 144.3196.8−199.8 (br); IR (KBr) 2934, 2858, 2093, 2051, 2034, 1732, 1579, 1264, 1120, 1089, 1053, 1012, 982, 646, 515 cm^{-1}; MS(FAB) *m*/*z* 615 (M + H), 586 (M − CO), 576 (M − 2×CO), 558 (M − 2×CO), 530 (M − 3×CO), 502 (M − 4×CO), 474 (M − 5×CO), 446 (M − 6×CO); HRMS(FAB) calcd for $C_{18}H_{13}O_7Co_2$ 585.8371, found 585.8355.

(5*S*)-Gambiertoxin AB Segment 5. The mixture of cobalt complex **39** (76.5 mg, 126 μmol) and tributyltin hydride (400 μL, 1.51 mmol) in benzene (3.5 mL) was degassed (×3) and stirred at 65 °C. After 1 h, the reaction mixture was cooled and concentrated in vacuo. The residue was purified by silica gel column chromatography to afford colorless oil **5** (20.5 mg, 10.0 μmol, 81%). $[\alpha]^{29}_D$ −9.2 (*c* 0.45, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.38 (1H, ddq, J = 16, 10.5, 3 Hz, H-8a), 2.61 (1H, ddd, J = 16, 8, 3.5 Hz, H-8b), 3.27 (1H, ddd, J = 10.5, 8, 3.5 Hz, H-9), 4.00 (1H, dt, J = 8, 3 Hz, H-10), 4.08−4.25 (2H, m, H-13), 4,63 (1H, m, H-5), 5.10−5.15 (1H, m, H-1a), 5.19−5.26 (1H, m, H-1b), 5.65−5.90 (5H, m, H-4*, H-6, H-7, H-11, H-12), 6.28−6.40 (2H, m, H-2, H-3*); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 34.5, 65.5, 74.8, 78.2, 79.1, 117.8, 127.3, 127.7, 127.9, 131.5, 133.9, 134.5, 136.5; IR (KBr) 2931, 2858, 1733, 1288, 1139, 1108, 1072, 1020, 902, 676 cm^{-1}. Anal. Calcd for $C_{13}H_{16}O_2$: C,76.44; H, 7.89. Found: C, 76.56; H, 7.62.

Methyl 6-Deoxyiodo-tri-*O*-benzyl-D-glucopyranoside (45). To a solution of the alcohol **44** (770 mg, 1.66 mmol) in PhH (18 mL) were successively added imidazole (282 mg, 415 mmol), PPh_3 (1,08 g, 415 mmol), and iodine (841 mg, 3.32 mmol). After stirring at room temperature for 3 h, the reaction mixture was quenched with sat. Na_2SO_3 and extracted with ether (×3). The extracts were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. Purification of the residue by silica gel column chromatography (ether/hexane = 30: 70) gave colorless oil **45** (910 mg, 96%). $[\alpha]^{28}_D$ +34.1 (*c* 2.33, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.29 (1H, dd, J = 11, 6.5 Hz, H-6a), 3.34 (1H, t, J = 9.0 Hz, H-4), 3.42 (3H, s, OMe), 3.41−3.48 (1H, m, H-5), 3.45 (1H, t, J = 9.5 Hz, H-3), 3.47 (1H, dd, J = 11, 2.5 Hz, H-6b), 3.54 (1H, dd, J = 9.5, 3.4 Hz, H-2), 4.02 (1H, dd, J = 9.5, 9 Hz, H-3), 4.61 (1H, d, J = 3.4 Hz, H-1), 4.66 (1H, d, J = 11.8 Hz, CH_2Ph), 4.68 (1H, d, J = 10.6 Hz, CH_2Ph), 4.81 (1H, d, J = 11.8 Hz, CH_2-Ph), 4.81 (1H, d, J = 10.8 Hz, CH_2Ph), 4.94 (1H, d, J = 10.8 Hz, CH_2Ph), 4.99 (1H, d, J = 10.6 Hz, CH_2Ph), 7.30−7.39 (15H, m, *Ph*); IR (KBr) 3063, 3030, 2906, 1952, 1497, 1455, 1360, 1198, 1089(br), 738, 696. Anal. Calcd for $C_{28}H_{31}O_5I$: C, 58.52; H, 5.44. Found: C, 58.51; H, 5.46.

6-Deoxyiodo-tri-*O*-benzyl-1,5-D-gluconolactone (46). To a solution of **45** (75.8 g, 146 mmol) in 1.00 L of acetic anhydride was added 100 mL of TFA at 0 °C. After removal of the ice−water bath, the reaction mixture was stirred for 1 day at room temperature. The resulting mixture was poured into cooled aq $NaHCO_3$ and extracted with Et_2O (×3). The extracts were washed with H_2O (×2), aq $NaHCO_3$ (×1), and brine, dried over Na_2SO_4, and concentrated under reduced pressure. The crude oil was suspended in 1.20 L of AcOH and 0.50 L of H_2O. The suspension was turned to clear solution at 100 °C. After stirring for 1 day at 100 °C, the reaction mixture was extracted with ether−hexane (1:1) (×3). The extracts were washed with H_2O (×2), $NaHCO_3$ aq. (×1), brine, dried over Na_2SO_4, and concentrated under reduced pressure. The crude oil was dissolved in 300 mL of CH_2Cl_2. In another three-necked flask, to a solution of $(COCl)_2$ (16.0 mL, 222 mmol) in 300 mL of CH_2Cl_2 was dropwise added a solution of DMSO (26 mL, 444 mmol) in 400 mL of CH_2Cl_2 at −78 °C. After stirring for 20 min, to this mixture was dropwise added a solution of crude substrate at −78 °C. After stirring for 30 min, triethylamine (67 mL, 555 mmol) was dropwise added to this mixture at −78 °C. After raising the temperature to 0 °C, the resulting mixture was poured into H_2O and extracted with CH_2Cl_2 (×3). The extracts were dried over Na_2SO_4 and concentrated under reduced pressure. The residue was purified by silica gel column chromatography (ether/hexane = 25:75) to give colorless oil **46** (46.0 g, 62% in three steps). $[\alpha]^{28}_D$ +73.6 (*c* 0.73, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.44 (1H, dd, J = 11, 4 Hz, H-6a), 3.53 (1H, dd, J = 11, 3.6 Hz, H-6b), 3.76 (1H, dd, J = 9, 6.2 Hz, H-4), 3.97 (1H, dd, J = 6.2, 5.5 Hz, H-3), 4.13 (1H, d, J = 5.5 Hz, H-2), 4.18 (1H, td, J = 9, 4 Hz, H-5), 4.53 (1H, d, J = 11.5 Hz, CH_2Ph), 4.62 (1H, d, J = 11.0 Hz, CH_2Ph), 4.64 (1H, d, J = 11.5 Hz, CH_2Ph), 4.68 (1H, d, J = 11.0 Hz, CH_2Ph), 4.74 (1H, d, J = 11.5 Hz, CH_2Ph), 4.96 (1H, d, J = 11.5 Hz, CH_2Ph), 7.24−7.41 (15H, m, *Ph*); IR (KBr) 3064, 3032, 2933, 2879, 1760, 1498, 1456, 1365, 1214, 1117, 1090, 1070, 738, 698 cm^{-1}. Anal. Calcd for $C_{27}H_{27}O_5I$: C, 58.08; H, 4.87. Found: C, 58.20; H, 4.74.

(2*S,3*S**,4*R**,5*S**,6*S**)-6-(Iodomethyl)-2-(2-propenyl)-3,4,5-tris(benzyloxy)tetrahydropyran (47).** To a solution of **46** (37.0 g, 66.3 mmol) in 1.00 L of Et_2O was added a solution of allylmagnesium bromide (1.0 M in ether, 80 mL, 80 mmol) at −78 °C. After stirring for 30 min, the reaction mixture was poured into a solution of cold sat. aq NH_4Cl and extracted with Et_2O (×3). The extracts were washed with brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was dissolved in 800 mL of CH_3CN. To this solution were added triethylsilane (21 mL, 131 mmol) and BF_3·OEt_2 (7.1 mL, 77.2 mmol) at 0 °C. After stirring for 30 min, the reaction mixture was poured into cooled sat. aq $NaHCO_3$ and extracted with Et_2O (×3). The extracts were washed with brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by silica gel column chromatography (ether/hexane = 25:75) to give **47** (28.0 g, 72% in two steps). Mp 79.5−80 °C; $[\alpha]^{30}_D$ +23.3 (*c* 2.04, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.31 (1H, td, *J* = 15, 7 Hz, H-3a), 2.58 (1H, dddt, *J* = 15, 6.5, 3, 1.5 Hz, H-3b), 3.03 (1H, ddd, *J* = 9.5, 6, 3 Hz, H-4), 3.29−3.45 (3H, m, H-5, H-8, H-9a), 3.41 (1H, t, *J* = 9.5 Hz, H-7), 3.49 (1H, dd, *J* = 11, 3 Hz, H-9b), 3.73 (1H, t, *J* = 9.5 Hz, H-6), 4.66 (1H, d, *J* = 10.7 Hz, C*H*$_2$Ph), 4.74 (1H, d, *J* = 10.6 Hz, C*H*$_2$Ph), 4.88 (1H, d, *J* = 10.7 Hz, C*H*$_2$Ph), 4.90 (1H, m, C*H*$_2$Ph), 4.93 (1H, d, *J* = 10.6 Hz, C*H*$_2$Ph), 5.07−5.15 (2H, m, H-1), 7.26−7.37 (15H, m, *Ph*); IR (KBr) 3031, 2904, 2864, 1497, 1455, 1361, 1210, 1065(br), 915, 735, 697. Anal. Calcd for $C_{30}H_{33}O_4I$: C, 61.63; H, 5.69. Found: C, 61.62; H, 5.48.

(2*S,3*S**,4*R**,5*S**,6*S**)-2-(3-Hydroxypropyl)-5-(iodomethyl)-3,4,5-tris(benzyloxy)tetrahydropyran (49).** To a solution of **47** (337 mg, 577 μmol) in 7.0 mL of THF was added a solution of diborane (1.0 M in THF, 1.0 mL, 1.00 mmol) at 0 °C. After stirring for 1 h, to the reaction mixture was successively added 1.0 mL of EtOH, 2.0 mL of 2.5 N aq NaOH, and 2.0 mL of 30% aq H_2O_2. After stirring for 30 min, the reaction mixture was poured into cooled sat. aq Na_2SO_3 and extracted with Et_2O (×3). The extracts was washed with brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by silica gel column chromatography (ether/hexane = 70:30) to give **49** (298 mg, 86%). Mp 118−118.5 °C; $[\alpha]^{27}_D$ +11.6 (*c* 0.48, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.48 (1H, m, H-3a), 1.67−1.79 (2H, m, H-2), 1.90−2.01 (1H, m, H-3b), 3.08 (1H, ddd, *J* = 9, 6, 2.5 Hz, H-4), 3.28 (1H, dd, *J* = 10.6, 6 Hz, H-9a), 3.26−3.36 (1H, m, H-7), 3.39 (1H, t, *J* = 9 Hz, H-5), 3.48 (1H, dd, *J* = 10.6, 2.5 Hz, H-9b), 3.67 (2H, q, *J* = 6 Hz, H-1), 3.73 (1H, t, *J* = 9 Hz, H-6), 4.66, 4.73, 4.90, 4.91 (each 1H, each d, *J* = 10.6 Hz, C*H*$_2$Ph), 4.88, 4.92 (each 1H, each d, *J* = 10.8 Hz, C*H*$_2$Ph), 7.26−7.38 (15H, m, *Ph*); IR (KBr) 3389 (br), 3033, 3013, 2859, 1454, 1356, 1130, 1059 cm^{-1}. Anal. Calcd for $C_{30}H_{35}O_5I$: C, 59.79; H, 5.86. Found: C, 59,76; H, 5.91.

(2*S,3*S**,4*R**,5*S**,6*S**)-2-(3-*p*-Toluenesulfonyl)-5-(iodomethyl)-3,4,5-trihydroxytetrahydropyran (51).** To a solution of **49** (116 mg, 193 μmol) in 4.0 mL of CH_2Cl_2 were added pyridine (200 μL, 2.48 mmol) and TsCl (108 mg, 568 μmol) at 0 °C. After stirring for 1 day at room temperature, the reaction mixture was poured into cooled sat. aq $NaHCO_3$ and extracted with Et_2O (×3). The extracts was washed with brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by silica gel column chromatography (ether/hexane = 25:75) to give tosylate **50** (98.0 mg, 67%). Mp 105−105.5 °C; $[\alpha]^{27}_D$ +9.5 (*c* 0.27, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$), δ 1.40−1.47 (1H, m, H-3a), 1.68−1.78 (1H, m, H-3b), 1.82−1.91 (2H, m, H-2), 2.42 (3H, s, ArC*H*$_3$), 2.99 (1H, m, H-4), 3.15−3.22 (3H, m, H-5, H-8, H-9a), 3.32 (1H, t, *J* = 9.0 Hz, H-7), 3.42 (1H, dd, *J* = 10.3, 2.5 Hz, H-9b), 3.66 (1H, m, H-6), 4.06 (2H, m, H-1), 4.59, 4.70, 4.85, 4.91 (each 1H, each d, *J* = 10.5 Hz, C*H*$_2$Ph), 4.87, 4.90 (each 1H, each d, *J* = 11.0 Hz, C*H*$_2$-Ph), 7.26−7.36 (17H, m, CH_2*Ph*, $C_6H_4CH_3$), 7.78 (2H, d, *J* = 8.0 Hz, $C_6H_4CH_3$). Anal. Calcd for $C_{37}H_{41}O_7IS$: C, 58.73; H, 5.46. Found: C, 58.56; H, 5.50.

To a solution of the tosylate **50** (135 mg, 174 μmol) in 4.0 mL of CH_2Cl_2 were added EtSH (250 μL, 3.31 mmol) and BF_3·OEt_2 (250 μL, 2.61 mmol) at −78 °C. After being stirred overnight at room temperature, the reaction mixture was poured into cooled sat. aq $NaHCO_3$ and extracted with Et_2O (×3). The extracts were washed with brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by silica gel column chromatography (ethyl acetate/hexane = 75:25) to give **51** (78.4 mg, 90%). $[\alpha]^{28}_D$ +6.1 (*c* 0.77, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.45−1.57 (1H, m, H-3a), 1.72−1.89 (1H, m, H-3b), 1.89−2.03 (2H, m, H-2), 2.45 (3H, s, ArC*H*$_3$), 3.06 (1H, m, H-4), 3,18−3.27 (2H, m, H-5, H-9a), 3.29 (1H, t, *J* = 9.0 Hz, H-7), 3.47−3.55 (2H, m, H-6, H-9b), 4.03−4.17 (2H, m, H-1), 7.36 (2H, d, *J* = 8.4 Hz, $C_6H_4CH_3$), 7.79 (2H, d, *J* = 8.4 Hz, $C_6H_4CH_3$); IR (KBr) 3341 (br), 2964, 2923, 2904, 2854, 1597, 1351, 1174, 1093, 946 cm^{-1}. Anal. Calcd for $C_{16}H_{23}O_7IS$: C, 39.52; H, 4.77. Found: C, 39.39; H, 4.83.

(2*S,3*S**,4*R**,4a*S**,8a*S**)-3,4-Dihydroxy-2-(iodomethyl)-1,4-dioxabicyclo[4.0.4]octane (52).** To a solution of **51** (217 mg, 446 μmol) in 16.0 mL of THF was added t-BuOK (55.3 mg, 491 μmol) at 0 °C. After raising the temperature to room temperature, the reaction mixture was stirred for 30 min at room temperature. The resulting pale green suspension was quenched with sat. aq NH_4Cl and extracted by AcOEt (×3). The extracts were washed with brine, dried over Na_2SO_4, concentrated in vacuo, and purified by silica gel column chromatography (methanol/dichloromethane = 1:6) to give **52** (111 mg, 79%). Mp 165−165.5 °C; $[\alpha]^{27}_D$ +36.4 (*c* 0.17, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$)δ 1.43−1.58 (1H, m, H-3a), 1.60−1.70 (2H, m, H-2), 2.13 (1H, m, H-3b), 2.94 (1H, t, *J* = 9 Hz, H-5), 3.08 (1H, ddd, *J* = 9, 5.6, 2.5 Hz, H-8), 3.20 (1H, ddd, *J* = 10.5, 9, 4.4 Hz, H-4), 3.37 (1H, m, H-1a), 3.38 (1H, dd, *J* = 10.5, 5.6 Hz, H-9a), 3.44 (1H, t, *J* = 9 Hz, H-7), 3.56 (1H, dd, *J* = 10.5, 2.5 Hz, H-9b), 3.62 (1H, t, *J* = 9 Hz, H-6), 3.97 (1H, m, H-1b); IR (KBr) 3415 (br), 2948, 2867, 1435, 1360, 1319, 1128, 1091, 1064 cm^{-1}; EI-MS *m*/*z* 314 (M^+), 187 (M^+ − I). Anal. Calcd for $C_9H_{15}O_4I$: C, 34.41; H, 4.81. Found: C, 34.50; H, 4.79.

(2*R,3*S**,4*R**,4a*S**,8a*S**)-3,4-Bis(trimethylsilyloxy)-2-(cyanomethyl)-1,4-dioxabicyclo[4.0.4]octane (54).** To a solution of **52** (100 mg, 318 μmol) in 3.0 mL of CH_2Cl_2 were added Et_3N (270 μL, 955 μmol) and TMSOTf (185 μL, 955 μmol) at 0 °C. After stirring for 1 h, the reaction mixture was poured into cooled sat. aq $NaHCO_3$ and extracted with Et_2O (×3). The extracts were washed with brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was dissolved in 4.5 mL of DMSO, and NaCN (20.3 mg, 417 μmol) was added. After the temperature was raised to 75 °C, the reaction mixture was stirred for 30 min. After being cooled to room temperature, the reaction mixture was diluted with H_2O and extracted with Et_2O (×2). The extracts were washed with H_2O (×2) and brine, dried over Na_2SO_4, concentrated in vacuo, and purified by silica gel column chromatography (ether/hexane = 25:75) to give **54** (96% in two steps). Mp 94−94.5 °C; $[\alpha]^{28}_D$ +29.4 (*c* 0.22, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.04 (9H, s, *TMS*), 0.09 (9H, s, *TMS*), 1.40−1.54 (1H, m, H-3a), 1.65−1.75 (2H, m, H-2), 2.05−2.15 (1H, m, H-3b), 2.57 (1H, dd, *J* = 17, 5.5 Hz, H-9a), 2.74 (1H, dd, *J* = 17, 3 Hz, H-9b), 2.82 (1H, t, *J* = 9.0 Hz, H-5), 3.10 (1H, ddd, *J* = 11, 9.5, 4.5 Hz, H-4), 3.28 (1H, ddd, *J* = 11.5, 9, 6.3 Hz, H-1a), 3.37−3.52 (3H, m, H-7, H-8, H-6), 3.90 (1H, m, H-1b); IR (KBr) 2957, 2896, 1415, 1381, 1251, 1152, 1098, 1078, 884, 842, 759 cm^{-1}. Anal. Calcd for $C_{16}H_{31}O_4NSi_2$: N, 3.92; C, 53.75; H, 8.75. Found: N, 3.70; C, 53.75; H, 9.04.

(2*S,3*S**,4*R**,4a*S**,8a*S**)-3,4-Bis(trimethylsilyloxy)-2-(formylmethyl)-1,4-dioxabicyclo[4.0.4]octane (55).** To a solution of **54** (100 mg, 280 μmol) in 3.0 mL of CH_2Cl_2 was added a solution of DIBAL (1.0 M in hexane, 310 μL, 310 μmol) at −78 °C. After stirring for 1.5 h at −78∼−20 °C, to the reaction mixture was added 10% aq AcOH, and it was extracted with ether:hexane (1:1) (×2). The extracts were washed with H_2O, sat. aq $NaHCO_3$, and brine, dried over Na_2SO_4, concentrated in vacuo, and purified by silica gel column chromatography (ether/hexane = 33:67) to give aldehyde **55** (97.3 mg, 96%). $[\alpha]^{28}_D$ +14.2 (*c* 0.31, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.14, 0.15 (each 9H, each s, *TMS*), 1.32−1.46 (1H, m, H-3), 1.64−1.74 (2H, m, H-2), 2.00−2.09 (1H, m, H-3), 2.46 (1H, ddd, *J* = 16.5, 9, 3.5 Hz, H-9a), 2.73 (1H, ddd, *J* = 16.5, 3.5, 1.5 Hz, H-9b), 2.78 (1H, ddd, *J* = 11, 9, 4.5 Hz, H-4), 3.21−3,30 (1H, m, H-1a), 3.33 (1H, dd, *J* = 9, 8 Hz, H-6), 3.50

(1H, t, J = 9 Hz, H-7), 3.75 (1H, td, J = 9, 3.5 Hz, H-8), 3.89 (1H, m, H-1b), 9.76 (1H, dd, J = 3.5, 1.5 Hz, *CHO*); IR (KBr) 2954, 2944, 2893, 2852, 2734, 1731, 1250, 1153, 1101, 1093, 851, 842 cm^{-1}. Anal. Calcd for $C_{16}H_{32}O_5Si_2$: C, 53.29; H, 8.94. Found: C, 53.28; H, 9.10.

(2*S,3*S**,4*R**,4a*S**,8a*S**)-3,4-bis(trimethylsilyloxy)-2-(3-(trimethylsilyl)-2-propynyl)-1,4-dioxabicyclo[4.0.4]octane (56).** To a solution of CBr_4 (2.23 g, 6.72 mmol) in 10 mL of CH_2Cl_2 was added a solution of PPh_3 (3.53 g, 13.5 mmol) in 10 mL of CH_2Cl_2 at 0 °C via cannula. After stirring for 5 min, a solution of aldehyde **55** (605 mg, 1.68 mmol) in 10 mL of CH_2Cl_2 was added to this reaction mixture at 0 °C via cannula. After stirring for 30 min, to the reaction mixture was added Et_3N (2.4 mL, 16.8 mmol), and the resulting orange mixture was poured into cooled sat. aq $NaHCO_3$ and extracted with CH_2Cl_2 (×2). The extracts were dried over Na_2SO_4, concentrated in vacuo, and purified by short silica gel column chromatography (ether/hexane = 33:67) to give a colorless oil, which was used to next reaction right away. To a solution of colorless dibromide in 24 mL of THF was added a solution of *n*-BuLi (1.6M in hexane, 2.3 mL, 1.44 mmol) at −78 °C. After stirring for 30 min at −78 °C, to the resulting dark green solution was added TMSCl (640 μL, 5.04 mmol). After stirring for 20 min at −78 °C, into this solution was poured a cooled aq $NaHCO_3$, and it was extracted with Et_2O:hexane = 1:1 (×2). The extracts were washed with brine, dried over Na_2SO_4, concentrated in vacuo, and purified by silica gel column chromatography (ether/hexane = 15:85) to give **56** (589 mg, 95% in two steps). Mp 63−63.5 °C; $[\alpha]^{28}_D$ +26.3 (*c* 0.48, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.14, 0.15, 0.19 (each 9H, each s, *TMS*), 1.41−1.53 (1H, m, H-3), 1.64−1.74 (2H, m, H-2), 2.05−2.13 (1H, m, H-3), 2.53 (1H, dd, J = 17.5, 5 Hz, H-9a), 2.63 (1H, dd, J = 17.5, 3.5 Hz, H-9b), 2.79 (1H, t, J = 9.5 Hz, H-5), 3.07 (1H, ddd, J = 11, 9.5, 4.5 Hz, H-4), 3.32−3.23 (2H, m, H-1a, H-8), 3.46 (1H, t, J = 8.5 Hz, H-7), 3.57 (1H, dd, J = 9.5, 8.5 Hz, H-6), 3.88 (1H, m, H-1b); IR (KBr) 2950, 2900, 2859, 2176, 1249, 1151, 1079, 850, 838 cm^{-1}. Anal. Calcd for $C_{20}H_{40}O_4Si_3$: C, 56.02; H, 9.40. Found: C, 56.09; H, 9.66.

(2*S,3*S**,4*R**,4a*S**,8a*S**)-3,4-Diacetoxy-2-(3-(trimethylsilyl)-2-propynyl)-1,4-dioxabicyclo[4.0.4]octane (57).** To a solution of **56** (693 mg, 1.62 mmol) in 25 mL of MeOH was added PPTS (6.0 mg, 23.9 μmol). After stirring for 1 h at room temperature, the reaction mixture was concentrated in vacuo, and the residue was dissolved in 25 mL of CH_2Cl_2. To this solution were added Ac_2O (3.0 mL, 29.9 mmol), pyridine (6.0 mL, 74.2 mmol), and DMAP (10 mg, 81.9 μmol). After stirring for 1.5 h at room temperature, to this reaction mixture was added H_2O, and it was extracted with Et_2O. The extracts were washed with sat. aq $CuSO_4$, H_2O, and brine and dried over Na_2SO_4. Evaporation and concentration gave crude oil which was purified by silica gel column chromatography (ether/hexane = 40:60) to give **57** (577 mg, 97%). Mp 79.5−80 °C; $[\alpha]^{26}_D$ +32.9 (*c* 4.68, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.15 (9H, s, *TMS*), 1.44−1.57 (1H, m, H-3a), 1.68−1.77 (2H, m, H-2), 2.03 (3H, s, *Ac*), 2.06 (3H, s, *Ac*), 2.11−2.19 (1H, m, H-3b), 2.48 (1H, dd, J = 17, 6 Hz, H-9a), 2.50 (1H, dd, J = 17, 5 Hz, H-9b), 3.08 (1H, t, J = 9.5 Hz, H-5), 3.23 (1H, ddd, J = 11, 9.5, 4.5 Hz, H-4), 3.28−3.37 (1H, m, H-1a), 3.58 (1H, ddd, J = 9.5, 6, 5 Hz, H-8), 3.94 (1H, m, H-1b), 4.92 (1H, t, J = 9.5 Hz, H-7), 5.12 (1H, t, J = 9.5 Hz, H-6); ^{13}C NMR (67.9 MHz, $CDCl_3$) δ 20.83, 20.92, 23.81, 24.87, 27.08, 28.91, 67.78, 72.43, 73.89, 75.38, 76.14, 79.32, 86.74, 101.71, 169.77, 179,64; IR (KBr) 2957, 2868, 2180, 1749 (br), 1363, 1242 (br), 1104, 1040, 840, 762 cm^{-1}. Anal. Calcd for $C_{18}H_{28}O_6Si$: C, 58.67; H, 7.66. Found: C, 58.53; H, 7.72.

Acetylene 58. To a solution of **57** (577 mg, 1.57 mmol) and di-*O*-pivaloyl-D-xylal (668 mg, 2.36 mmol) in 25 mL of CH_2Cl_2 was added $SnCl_4$ (265 μL, 2.28 mmol) at −20 °C. After stirring for 30 min at −20 °C, another di-O-pivaloyl-D-xylal (446 mg, 1.57 mmol) was added. After additional 30 min at −20 °C, the reaction mixture was poured into cooled sat. aq $NaHCO_3$ and sat. aq $NaK(CH(OH)COO)_2$ (1:1) and extracted with CH_2Cl_2 (×3). The extracts were dried over Na_2SO_4, concentrated in vacuo, and purified by silica gel column chromatography (ether/hexane = 60:40) to give a colorless oil **58** (723 mg, 96%). $[\alpha]^{28}_D$ +158.1 (*c* 0.69, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.21 (9H, s, *Piv*), 1.46−1.56 (1H, m, H-14a), 1.68−1.76 (2H, m, H-15), 2.04, 2.06 (each 3H, each s, *Ac*), 2.01−2.17 (1H, m, H-14b), 2.45 (1H, ddd, J = 12.5, 6.4, 2.4 Hz, H-8a), 2.53 (1H, ddd, J = 12.5, 5, 2.5 Hz, H-8b), 3.08 (1H, t, J = 9.5 Hz, H-12), 3.22 (1H, ddd, J = 11, 9.5, 4.5 Hz, H-13), 3.28−3.37 (1H, m, H-16a), 3.58 (1H, ddd, J = 10, 6, 4.5 Hz, H-9), 3.79 (1H, m, H-1a), 3.94 (1H, m, H-16b), 4.19 (1H, dd, J = 13.5, 3.5 Hz, H-1b), 4.90 (1H, m, H-5), 4.93 (1H, t, J = 9.5 Hz, H-10), 5.02 (1H, m, H-2), 5.12 (1H, t, J = 9.5 Hz, H-11), 5.89 (1H, m, H-4*), 6.01 (1H, dd, J = 10.5, 3.6 Hz, H-3*); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 20.75, 20.92, 22.64, 24.87, 27.10, 28.97, 38.74, 63.13, 63.68, 64.28, 67.80, 72.20, 73.87, 75.38, 75.87, 77.91, 79.26, 82.14, 122.55, 132.09, 169.79, 170.62, 178.24; IR (KBr) 2968, 2946, 2864, 1751, 1725, 1368, 1243, 1159, 1098, 1051, 945, 736 cm^{-1}. Anal. Calcd for $C_{25}H_{34}O_9$: C, 62.75; H, 7.16. Found: C, 62.76; H, 7.31.

Acetylenecobalthexacarbonyl Complex 62. To a solution of **58** (42.7 mg, 89.2 μmol) in 2.0 mL of CH_2Cl_2 was added a solution of $Co_2(CO)_8$ (136 mg, 398 μmol) in 1.5 mL of CH_2Cl_2 via cannula. After being stirred for 30 min at room temperature, the reaction mixture was concentrated in vacuo and purified by silica gel column chromatography (ether/hexane = 40:60) to give dark red oil **62** (52.0 mg, 76%). This compound was labile and was used to next reaction right away. $[\alpha]^{30}_D$ +85.9 (*c* 0.10, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.21 (9H, s, *Piv*), 1.44−1.52 (1H, m, H-14a), 1.66−1.75 (2H, m, H-15), 2.06, 2.08 (each 3H, each s, *Ac*), 2.09−2.16 (1H, m, H-14b), 2.89 (1H, J = 16.5, 3.5 Hz, H-8a), 2.95 (1H, dd, J = 16.5, 8 Hz, H-8b), 3.12 (1H, t, J = 9.5 Hz, H-12), 3.19 (1H, dt, J = 9.5, 4.5 Hz, H-13), 3.28−3.37 (1H, m, H-16a), 3.58 (1H, ddd, J = 9.5, 8, 3.5 Hz, H-9), 3.64 (1H, dd, J = 11.5, 7 Hz, H-1a), 3.94 (1H, m, H-16b), 4.24 (1H, dd, J = 11.5, 5 Hz, H-1b), 4.94 (1H, t, J = 9.5 Hz, H-10), 5.16 (1H, t, J = 9.5 Hz, H-11), 5.25 (1H, m, H-2), 5.29 (1H, dd, J = 4, 2 Hz, H-5), 5.90 (1H, dt, J = 10.5, 2 Hz, H-4), 6.02 (1H, ddd, J = 10.5, 2, 1.5 Hz, H-3); ^{13}C NMR (67.9 MHz, $CDCl_3$) δ 20.70, 20.93, 24.87, 27.13, 28.77, 35.33, 38.78, 64.11, 65.41, 67.83, 72.47, 73.62, 73.87, 75.13, 78.81, 79.15, 92.72, 96.17, 125.48, 132.16, 170.20, 178.06, 199.42 (br); IR (KBr) 2959, 2947, 2862, 2092, 2052, 2018, 1754, 1732, 1365, 1239, 1155, 1093, 522 cm^{-1}; FAB-MS m/z 765 (M + H), 708 (M − 2×CO), 680 (M − 3×CO), 652 (M − 4×CO), 596 (M − 6×CO); HR-FAB-MS calcd for $C_{29}H_{34}O_{13}Co_2$ 708.0663, found 708.0641.

5-Methyl Ether 59. To a solution of pivalic anhydride (105 μL, 523 μmol) in 3.0 mL of CH_2Cl_2 was added TfOH (25 μL, 262 μmol) at −20 °C. After stirring for 30 min at −20 °C, to the mixture was added a solution of cobalt complex **62** (39.9 mg, 52.3 μmol) in 2.0 mL of CH_2Cl_2 via cannula. After stirring for 30 min at −20 °C, to the reaction mixture was added MeOH (200 μL), and the resulting dark red solution was poured into cooled sat. aq $NaHCO_3$ and extracted with Et_2O (×2). The extracts were washed with brine, dried over Na_2SO_4, concentration in vacuo, and purified by silica gel column chromatography (ether/hexane = 40:60) to give a dark red oil **59** (44.8 mg, 97%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.19, 1.20, 1.21, 1.22 (total 18H, each s, *Piv*), 1.44−1.56 (1H, m, H-14a), 1.70 (2H, m, H-15), 2.05, 2.06 (each 3H, each s, *Ac*), 2.07 (6H, s, Acx2), 2.09−2.16 (1H, m, H-14b), 3.11 (1H, t, J = 9 Hz, H-12), 3.20 (1H, m, H-13), 3.27−3.36 (1H, m, H-16a), 3.38, 3.42 (total 3H, each s, *OMe*), 3.57 (1H, m, H-9), 3.95 (1H, m, H-16b), 4.04 (1H, ddd, J = 12, 7.5, 5 Hz, H-1a), 4.29 (1H, ddd, J = 12, 6, 3.5 Hz, H-1b), 4.74 (1H, m, H-5), 4.92, 4.93 (1H, each t, J = 9.5 Hz, H-10), 5.16 (1H, t, J = 9.5 Hz, H-11), 5.58 (1H, m, H-2), 5.79 (2H, m, H-3, H-4); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 20.6, 20.8, 24.8, 26.97, 27.01, 27.02, 28.9, 35.2, 35.7, 38.67, 38.73, 38.8, 57.15, 57.21, 64.7, 67.8, 70.51, 70.54, 72.5, 73.8, 73.9, 75.0, 76.4, 87.7, 79.2, 81.1, 81.4, 92.4, 93.1, 97.2, 97.9, 126.5, 127.3, 132.9, 133.2, 170.20, 170.23, 170.7, 177.2, 178.1, 199.7(br); IR (KBr) 2977, 2939, 2912, 2865, 2092, 2053, 2029, 1751, 1735, 1482, 1367, 1284, 1241, 1141, 520 cm^{-1}; MS(FAB) m/z 849 (M + H − MeOH), 796 (M − 3×CO), 768 (M − 4×CO), 712 (M − 6×CO); HRMS(FAB) calcd for $C_{36}H_{43}O_{16}Co_2$ 849.1214, found 849.1214.

***endo*-Acetylenecobalthexacarbonyl Cyclic Ether 60.** To a solution of **59** (930 mg, 1.06 mmol) in 40 mL of degassed MeOH was added K_2CO_3 (176 mg, 1.27 mmol). After being stirred for 45 min at room temperature, the reaction mixture was poured into cooled sat. aq NH_4Cl and extracted with AcOEt (×2). The extracts were washed with brine, dried over Na_2SO_4, concentrated, and purified by silica gel column chromatography (ethyl acetate/hexane = 50:50) to give a dark red diol **59′** (685 mg, 81%). To a solution of **59′** (21.3 mg, 26.7 μmol) in degassed 26.0 mL of CH_2Cl_2 was added a solution of BF_3·OEt_2 (0.27 M in 1,2-dichloromethane, 100 μL, 27.2 μmol) at 0 °C. After being stirred for 20 min at 0 °C, the reaction mixture was poured into cooled sat. aq $NaHCO_3$ and extracted with AcOEt (×2). The extracts were washed with brine, dried over Na_2SO_4, concentrated, and purified by silica gel column chromatography (ether/hexane = 30:70) to give a dark red oil **60** (14.5 mg, 71%). **59′**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.19, 1,20 (9H, each s, *Piv*), 1.21 (9H, brs, *Piv*), 1.40−1.53 (1H, m, H-14a), 1.69 (2H, m, H-15), 2.02−2.12 (1H, m, H-14b), 2.60−2.86 (2H, m, H-8), 2.94 (1h, t, J = 9 Hz, H-12), 3.04−3.14(1H, m, H-13), 3.32−3.45 (3H, m, H-10, H-11, H-16a), 3.39, 3.43 (total 3H, each s, *OMe*), 3.59 (1H, m, H-9), 3.96 (1H, m, H-16b), 4.06 (1H, ddd, J = 12, 8, 3 Hz, H-1a), 4.29 (1H, dd, J = 12, 3.5 Hz, H-1b), 4.78 (1H, m, H-5), 5,56 (1H, m, H-2), 5.80 (2H, m, H-3, H-4); ^{13}C NMR (75.4 MHz, $CDCl_3$), δ 25.0, 26.98, 27.01, 27.03, 28.79, 28.84, 28.86, 35.7, 36.0, 38.70, 38.72, 38.77, 38.79, 57.1, 57.2, 64.8, 64.9, 67.8, 70.6, 70.8, 74.6, 76.1, 76.5, 80.2, 80.3, 81.2, 81.4, 81.7, 93.6, 93.9, 96.7, 97.6, 126.3, 127.2, 133.2, 177.4, 177.5, 178.20, 178.23, 178.3, 199.9(br); IR (KBr) 3467 (br), 2968, 2948, 2881, 2870, 2090, 2048, 2027, 1739, 1733, 1482, 1280, 1163, 1153, 1084 cm^{-1}; MS(FAB) *m*/*z* 765 (M + H − MeOH), 712 (M − 3×CO), 684 (M − 4×CO), 656 (M − 5×CO), 628 (M − 6×CO); HRMS(FAB) calcd for $C_{32}H_{39}O_{14}Co_2$ 765.1003, found 765.1003. **60**: $[\alpha]^{29}_D$ −266 (*c* 0.12, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.18, 1.20 (each 9H, each s, O*Piv*), 1.40−1.53 (1H, m, H-14a), 1.72 (2H, m, H-15), 2.04−2.11 (1H, m, H-14b), 2.87 (1H, bs, -*OH*), 2.91 (1H, dd, J = 16, 10 Hz, H-8a), 3.05 (1H, t, J = 9 Hz, H-12), 3.13 (1H, td, J = 9, 4 Hz, H-13), 3.38 (1H, m, H-16a), 3.41 (1H, t, J = 9 Hz, H-10), 3.47 (1H, ddd, J = 10, 9, 4 Hz, H-9), 3.51 (1H, m, H-16a), 3.60 (1H, dd, J = 16, 4 Hz, H-8b), 3.68 (1H, t, J = 9 Hz, H-11), 4.00 (1H, m, H-16b), 4.12 (1H, dd, J = 11.6, 7 Hz, H-1a), 4.27 (1H, dd, J = 11.6, 3.5 Hz, H-1b), 5.07 (1H, d, J = 4.7 Hz, H-5), 5,63 (1H, m, H-2), 5.88 (1H, dd, J = 16, 5 Hz, H-3), 5.92 (1H, dd, J = 16, 4.7 Hz, H-4); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 24.9, 26.95, 27.04, 28.9, 38.67, 38.72, 38.8, 54.7, 67.6, 70.7, 74.3, 74.7, 75.8, 76.4, 80.0, 81.37, 87.6, 91.7, 99.8, 125.8, 131.9, 198.9(br); IR (KBr) 3503(br), 2958, 2932, 2873, 2093, 2054, 2025, 1733, 1482, 1282, 1146, 1097, 519 cm^{-1}; MS(FAB) *m*/*z* 765 (M + H), 680 (M − 3×CO), 653 (M + H − 4×CO), 624 (M − 5×CO), 596 (M − 6×CO); HRMS(FAB) calcd for $C_{26}H_{38}O_8Co_2$, 596.1230, found 596.1224.

(2*S*,5*S*)-ABC Segment Dipivalate 61. To a solution of **60** (10.2 mg, 13.3 μmol) in 2.0 mL of benzene was added Wilkinson catalyst (0.6 mg, 0.67 μmol). After stirring for 5 h at 65−70 °C under 100 kg/cm^2 hydrogen atmosphere, the pressure was reduced to ambient pressure, and the temperature was turned into room temperature. The resulting mixture was filtered, concentrated, and purified by silica gel column chromatography (ether/hexane = 30:70) to give **61** (4.6 mg, 72%). Mp 88.5−89 °C; $[\alpha]^{26}_D$ −17.2 (*c* 0.47, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.19 (9H, s, *Piv*), 1.21 (9H, s, *Piv*), 1.45 (1H, m, H-14a), 1.72 (2H, m, H-15), 2.07 (1H, m, H-14b), 2.40 (1H, m, H-8a), 2.62 (1H, ddd, J = 4, 8.5, 16.0 Hz, H-8b), 2.78 (1H, brs, −OH), 3.03 (1H, t, J = 9.0 Hz, H-12), 3.13 (1H, ddd, J = 11, 9, 6.5 Hz, H-13), 3.24 (1H, ddd, J = 9, 8.5, 4 Hz, H-9), 3.37 (1H, t, J = 9 Hz, H-10), 3.43 (1H, m, H-16a), 3.67 (1H, t, J = 9 Hz, H-11), 4.00 (1H, m, H-16b), 4.12 (1H, dd, J = 6.5, 12 Hz, H-1a), 4.27 (1H, dd, J = 4.0, 12 Hz, H-1b), 4.55 (1H, m, H-5), 5.52 (1H, m, H-2), 5.73 (1H, ddd, J = 15.5, 6, 1.5 Hz, H-3), 5.75 (1H, m, H-7), 5.84 (1H, m, H-6), 5.89 (1H, ddd, J = 15.5, 6, 1 Hz, H-4); IR (KBr) 3470, 2971, 2871, 1732, 1482, 1281, 1144, 1098, 1040 cm^{-1}. Anal. Calcd for $C_{26}H_{40}O_8$: C, 64.98; H, 8.39. Found: C, 64.97; H, 8.41.

(2*S*,5*S*)-ABC Segment 40. To the solution of dipivalate **61** (9.4 mg, 19.6 μmol) in MeOH (1.5 mL) was added NaOMe (28% in MeOH, 30 μL). After being stirred for 4 h at room temperature, the reaction was quenched by AcOH (10% in MeOH, 50 μL) at 0 °C. The resulting mixture was concentrated in vacuo. The residue was purified by silica gel column chromatography to obtain (2*S*,5*S*)-ABC segment **40** (5.2 mg, 85%). Mp 144.5−145 °C; $[\alpha]^{28}_D$ −52.7 (*c* 0.045, MeOH); ^{1}H NMR (400 MHz, CD_3OD) δ 1.38−1.47 (1H, m, H-14a), 1.65−1.72 (2H, m, H-15), 2.01−2.05 (1H, m, H-14b), 2.33−2.41 (1H, m, H-8a), 2.55−2.61 (1H, m, H-8b), 2.89 (1H, t, J = 9 Hz, H-12), 3.09 (1H, ddd, J = 11, 9, 4.5 Hz, H-13), 3.21 (1H, td, J = 9, 4 Hz, H-9), 3.30 (1H, t, J = 9 Hz, H-10), 3.32−3.39 (1H, m, H-16a), 3.47 (1H, dd, J = 11, 6 Hz, H-1a), 3.51 (1H, dd, J = 11, 5 Hz, H-1b), 3.51 (1H, t, J = 9 Hz, H-11), 3.89−2.94 (1H, m, H-16b), 4.08−4.13 (1H, m, H-2), 4.55−4.58 (1H, m, H-5), 5.75−5.82 (3H, m, H-3*, 6, 7), 5.85 (1H, dd, J = 15.5, 5 Hz, H-4*); IR (KBr) 3356, 3195, 1101, 1042 cm^{-1}. Anal. Calcd for $C_{16}H_{24}O_6$: C, 61.52; H, 7.74. Found: C, 61.51; H, 7.72.

(2*R*,5*S*)-ABC Segment 41. (2*R*,5*S*)-ABC segment **41** was prepared as (2*S*,5*S*)-ABC segment **40**. Mp 167.5−168 °C; $[\alpha]^{28}_D$ −45.4 (*c* 0.045, MeOH); ^{1}H NMR (400 MHz, CD_3OD) δ 1.39−1.47 (1H, m, H-14a), 1.65−1.72 (2H, m, H-15), 2.00−2.05 (1H, m, H-14b), 2.33−2.41 (1H, m, H-8a), 2.54−2.62 (1H, m, H-8b), 2.89 (1H, t, J = 9 Hz, H-12), 3.09 (1H, ddd, J = 11, 9, 4.5 Hz, H-13), 3.21 (1H, td, J = 9, 4 Hz, H-9), 3.31 (1H, t, J = 9 Hz, H-10), 3.35−3.39 (1H, m, H-16a), 3.46 (1H, dd, J = 11, 4 Hz, H-1a), 3.50 (1H, dd, J = 11, 5.5 Hz, H-1b), 3.50 (1H, t, J = 9 Hz, H-11), 3.89−2.94 (1H, m, H-16b), 4.09−4.14 (1H, m, H-2), 4.55−4.58 (1H, m, H-5), 5.77−5.82 (2H, m, H-6, 7), 5.81 (1H, dd, J = 15.5, 5 Hz, H-3*), 5.86 (1H, dd, J = 15.5, 4.5 Hz, H-4*); IR (KBr) 3314 (br), 3232, 1098, 1047 cm^{-1}. Anal. Calcd for $C_{16}H_{24}O_6$: C, 61.52; H, 7.74. Found: C, 61.51; H, 7.72.

(2*S*,5*S*)-Tris(*p*-bromobenzoyl)-ABC Segment 42. To the solution of (2*S*,5*S*)-ABC fragment **40** (2.8 mg, 8.96 μmol) in the mixture of CH_2Cl_2 (1.0 mL) and triethylamine (50 μL) was added *p*-bromobenzoyl chloride (9.4 mg, 45.7 μmol) at 0 °C. After being stirred overnight at room temperature, to this reaction mixture was added sat. $NaHCO_3$, and it was extracted with Et_2O (×2). The extracts were washed with brine and dried over Na_2SO_4. Evaporation and concentration gave a crude oil which was purified by silica gel column chromatography (ether/hexane = 40:60) to obtain (2*S*,5*S*)-tris(*p*-bromobenzoyl)-ABC segment **42** (2.9 mg, 3.34 μmol, 37%). Mp 174.5−175 °C; $[\alpha]^{27}_D$ −33.1 (*c* 0.42, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.50 (1H, ddd, J = 12, 11, 5 Hz, H-14a), 1.67−1.81 (2H, m, H-15), 2.14 (1H, m, H-14b), 2.44 (1H, ddtd, J = 15.5, 10, 3, 2 Hz, H-8a), 2.68 (1H, ddd, J = 15.5, 8.5, 3.5 Hz, H-8b), 3.19 (1H, t, J = 9 Hz, H-12), 3.27 (1H, ddd, J = 10.5, 9, 4.5 Hz, H-13), 3.31 (1H, dd, J = 11.5, 4 Hz, H-16a) 3.41 (1H, ddd, J = 10, 9, 3.5 Hz, H-9), 3.58 (1H, t. J = 9 Hz, H-10), 3.92 (1H, m, H-16b), 4.22 (1H, dd, J = 11.5, 7 Hz, H-1a), 4.33 (1H, dd, J = 11.5, 3.5 Hz, H-1b), 4.55 (1H, m, H-5), 5.42 (1H, t, J = 9 Hz, H-11), 5.69−5.90 (5H, m, H-2, H-3, H-4, H-6, H-7), 7.38, 7.55, 7.56, 7.68, 7.817, 7.822 (each 2H, each d, each J = 8.5 Hz, *O-p*-Br*Bz*); ^{13}C NMR (75.4 MHz, $CDCl_3$), δ 29.1, 29.6, 34.1, 65.5, 67.7, 72.5, 75.0, 75.6, 79.7, 85.6. 123.5, 128.0. 128.7, 129.3, 131.1, 131.3, 131.6, 131.85, 131.90, 134.8, 135.2, 164.9, 165.4, 165.6; IR (KBr) 2952, 2867, 1724, 1590, 1484, 1399, 1267, 1174, 1101, 1013, 847, 754 cm^{-1}. Anal. Calcd for $C_{37}H_{31}O_9Br_3$: C, 51.59; H, 3.86. Found: C, 51.50; H, 3.85.

(2*R*,5*S*)-Tris(*p*-bromobenzoyl)-ABC Fragment 43. (2*R*,-5*S*)-tris(*p*-bromobenzoyl)-ABC **43** segment was prepared as (2*S*,5*S*)-tris(*p*-bromobenzoyl)-ABC segment **42.** Mp 104.5−105 °C; $[\alpha]^{27}_D$ −79.9 (*c* 0.50, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.50 (1H, ddd, J = 12, 11, 5 Hz, H-14a), 1.67−1.81 (2H, m, H-15), 2.13 (1H, m, H-14b), 2.43 (1H, ddq, J = 16, 10, 3 Hz, H-8a), 2.68 (1H, ddd, J = 16, 8.5, 1.5 Hz, H-8b), 3.20 (1H, t, J = 9 Hz, H-12), 3.27 (1H, ddd, J = 10.5, 9, 4 Hz, H-13), 3.31 (1H, td, J = 11, 3.5 Hz, H-16a), 3.41 (1H, ddd, J = 10, 9, 3.5 Hz, H-9), 3.59 (1H, t, J = 9 Hz, H-10), 3.94 (1H, m, H-16b), 4.10 (1H, dd, J = 10.5, 7 Hz, H-1a), 4.18 (1H, dd, J = 10.5, 3.5 Hz, H-1b), 4.51 (1H, m, H-5), 5.42 (1H, t, J = 9 Hz, H-11), 5.65−5.88 (5H, m, H-2, H-3, H-4, H-6, H-7), 7.54 (2H, d, J =

8.5 Hz, *O-p*-Br*Bz*), 7.55 (4H, d, J = 8.5 Hz, *O-p*-Br*Bz*), 7.55 (4H, d, J = 8.5 Hz, *O-p*-Br*Bz*), 7.99, 7.81, 7.90 (each 2H, each d, each J = 8.5 Hz, *O-p*-Br*Bz*); ^{13}C NMR (75.4 MHz, $CDCl_3$), δ 29.1, 29.6, 34.1, 65.1, 67.7, 71.9, 75.0, 75.2, 75.6, 76.8, 79.7, 85.6, 123.6, 127.8, 128.2, 128.4, 129.3, 131.2, 131.8, 134.7, 135.0, 164.9, 165.3, 165.6; IR (KBr) 2951, 2855, 1725, 1591, 1484, 1399, 1267, 1174, 1013, 847, 754 cm^{-1}. Anal. Calcd for $C_{37}H_{31}O_9Br_3$: C, 51.59; H, 3.86. Found: C, 51.56; H, 3.93.

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Supporting Information Available: ^{1}H NMR of spectra of compounds **5, 11**−**13, 17, 20**−**25, 27, 35, 37, 40**−**43, 45**−**47, 49**−**52, 54**−**61**, the diastereomer of **61** at C-2 position, **62**; CD spectra of compounds **42** and **43** (38 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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