buffer (pH 11.0) solution at 25 °C. The reciprocal of the difference absorbance around 260–280 nm was plotted against the reciprocal of the guest concentration. From the slope and the intercept, the association constant was obtained. The 1-adamantanecarboxylate concentration ranges from 1.0×10^{-4} M to 7.5×10^{-4} M. The association constants between β-cyclodextrin derivatives and methyl orange (5×10^{-5} M) or sodium *p*-nitrophenoxide (5×10^{-5} M) were also estimated by the difference spectra at 25 °C, where substituted β-cyclodextrin concentration range from 1.0×10^{-4} M to 1.0×10^{-3} M. The association constants in various pH were estimated in the same manner at 25 °C in Na_2CO_3–$NaHCO_3$ buffer (pH 8.0–11.5) solution. These spectral data were treated by the Benesi–Hildebrand method as previously reported.[4]

Reaction of Chloroacetaldehyde with Adenine Derivatives. The mixture of chloroacetaldehyde (1×10^{-2} M) with adenine derivatives (1×10^{-5} M) in phosphate buffer (pH 6.4) solution was incubated at 25 °C. The reaction was followed by a fluorescence measurement at 410 nm (at 13–60 h after the start of incubation).

Acknowledgment. We are grateful to Dr. K. Fujita (Fukuyama University) for the private communication of preparation, separation, and identification of **1a–c** and the valuable discussion.

Photochemistry of Polyhaloarenes. 4. Phototransformations of Perchloro-*o*-phenoxyphenol in Basic Media

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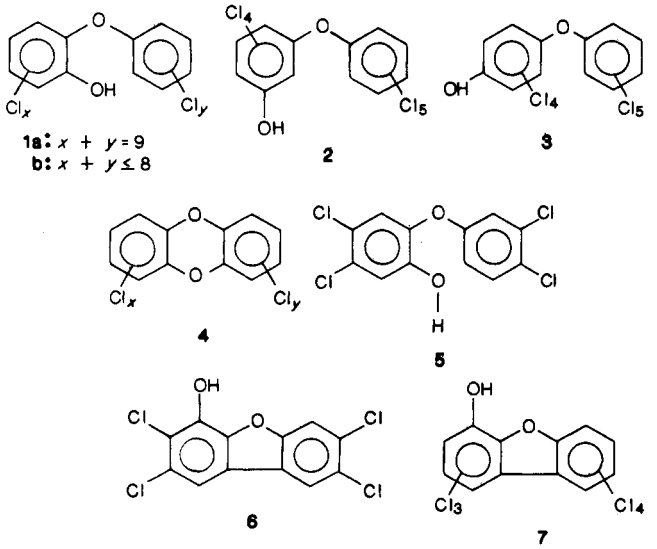
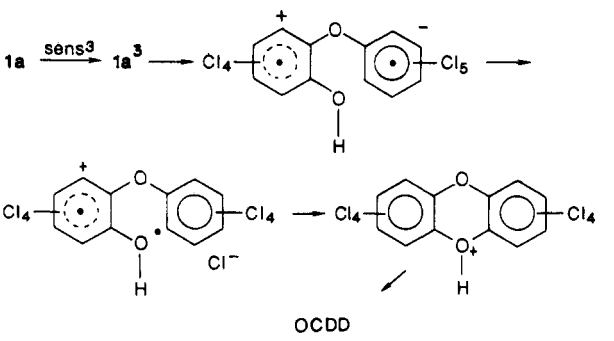
Irradiation of the sodium salt of the conjugate base of perchloro-*o*-phenoxyphenol (PreD$^-$Na$^+$) in methanol (300 nm) in the presence of sensitizer *m*-methoxyacetophenone generates ether cleavage products and mono- and di-dechlorination with no cyclization to OCDD. In the presence of sensitizer and excess triethylamine, irradiation of perchloro-*o*-phenoxyphenol leads to OCDD as a major product with ether cleavage and dechlorination products representing important reaction pathways. Photodecomposition of the conjugate base of perchloro-*o*-phenoxyphenol in methanol reveals a small amount of cyclization, while irradiation in methanol in the presence of a 10-fold excess of triethylamine increases the quantum yield for cyclization 17-fold. The photolytic transformations of the conjugate base of perchloro-*o*-phenoxyphenol in the presence of excess triethylamine are dependent upon solvent polarity with the quantum yield for cyclization increasing strongly in methanol or water/acetonitrile (70:30) relative to that in dibutyl ether. These results are interpreted in terms of electron transfer to PreD$^-$ to form a radical dianion.

Our interest in the photochemical transformations of perchloro-*o*-, *m*-, and *p*-phenoxyphenol (**1a**, **2**, and **3**) is stimulated by the fact that these species are important contaminants in commercial pentachlorophenol,[1] absorb in the sunlight spectral range (near 300 nm), and possess the structural potential for conversion to polychlorodibenzodioxins **4**, which would include the highly toxic 2,3,7,8-tetrachlorodibenzo-*p*-dioxin substrate (TCDD),[2] mimics of TCDD (**5** and **6**),[3] and closely related analogues.



Scheme I



Our earlier studies[4,5] revealed that direct irradiation of perchloro-*o*-phenoxyphenol (**1a**) (300 nm, cyclohexane) results in (a) ether cleavage forming polychlorobenzenes, phenols and catechol and (b) reductive dechlorination generating polychloro-*o*-phenoxyphenols **1b**, while sensitized photodecomposition (acetone; *m*-methoxyacetophenone in cyclohexane) results in either predominant (83.6%) or substantial (32%) cyclization to polychlorodibenzodioxins **4** and hydroxyheptachlorodibenzofuran (**7**).

The cyclization pathway in acetone was enhanced by 85% in the presence of an electron-transfer reagent, triethylamine. Since the C–Cl bond energy should be about 95 kcal/mol,[6] while the triplet state energy is 72 kcal/mol

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Table I. Sensitized Photolysis of Predioxin Anion in Methanol

	sens[a]		sens, Et_3N[b]	
product	yield[c] (mol %)	quantum yield[d] × 10^3	yield[c] (mol %)	quantum yield[d] × 10^3
pentachlorophenol	10.7 ± 1.5	8.1 ± 0.9	14.9 ± 0.5	15.0 ± 0.5
2,3,4,5-tetrachlorophenol	10.3 ± 0.8	7.8 ± 0.8	8.6 ± 0.2	8.7 ± 0.2
8a,b	8.7 ± 0.2	5.9 ± 0.2		
9a,b	33.9 ± 0.2	25.8 ± 0.3		
9b,c			32.2 ± 0.9	32.5 ± 1.0
10	3.2 ± 0.2	2.6 ± 0.1		
OCDD			30.6 ± 0.5	31.0 ± 0.6

[a] Sodium salt of predioxin anion (PreD$^-$Na$^+$), 0.0073 M; *m*-methoxyacetophenone, 0.0375 M. [b] PreD$^-$Et$_3$NH$^+$, 0.01 M; *m*-methoxyacetophenone, 0.081 M; triethylamine, 0.04 M. [c] Average and range for two runs. [d] Quantum yields based on cyclopentanone actinometry.

Table II. Direct Photolysis of Predioxin Anion

	methanol[a]		methanol, Et_3N[b]	
product	yield[c] (mol %)	quantum yield[d] × 10^3	yield[c] (mol %)	quantum yield[d] × 10^3
pentachlorophenol	0.8 ± 0.0	0.7 ± 0.05	0.5 ± 0.1	0.4 ± 0.01
9b,c	1.1 ± 0.3	1.1 ± 0.3	1.6 ± 0.3	1.6 ± 0.06
9a			1.4 ± 0.3	1.4 ± 0.3
11a,b	1.2 ± 0.2	1.2 ± 0.08	12.5 ± 1.5	12.7 ± 1.6
OCDD	3.3 ± 0.6	3.3 ± 0.06	65.3 ± 0.2	66.0 ± 0.2

[a] PreD$^-$Na$^+$, 0.01 M. [b] PreD$^-$Et$_3$NH$^+$, 0.01 M; triethylamine, 0.1 M. [c] Average and range for two runs. [d] Quantum yields based on cyclopentanone actinometry.

or less, the intermediacy of a radical anion, which would undergo C–Cl bond cleavage and then cyclization, is suggested.[7-15] Such a charge-transfer process in the absence of triethylamine might involve either an intramolecular or intermolecular electron transfer.[15-21] The sensitized (*m*-methoxyacetophenone) cyclization of phenoxyphenol **1a** exhibits a polar effect increasing from 0.6% cyclization in dibutyl ether to 47.9% in acetonitrile and is not increased with increasing concentration of phenoxyphenol **1a**. Focusing on the predominant cyclization to octachlorodibenzodioxin (OCDD) in neutral media, an intramolecular electron transfer in the triplet followed by chloride ion expulsion and cyclization to the conjugate acid of OCDD represents our present mechanistic picture (Scheme I). There is, however, an intriguing question as to the role of the triethylamine. Is the cyclization enhanced solely due to the formation of a phenoxide anion or is an intermolecular electron transfer from triethylamine to the predioxin anion the key? The purpose of the present study is to answer this question.

Scheme II

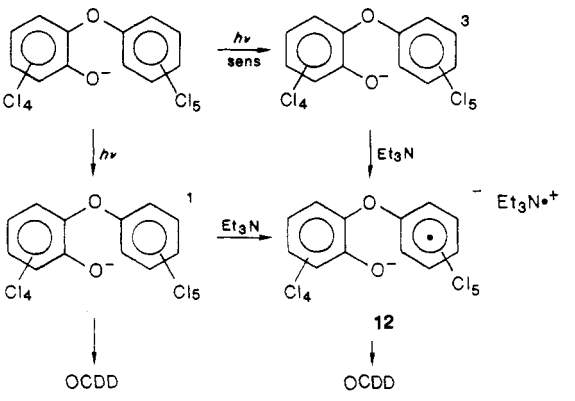
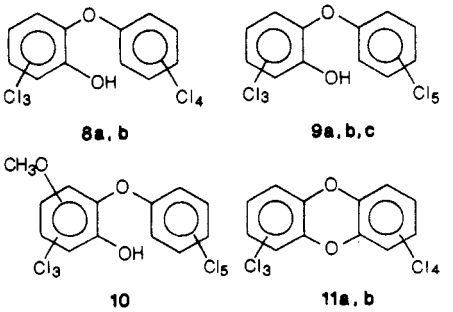


Table III. Photolysis of Predioxin Anion in the Presence of Triethylamine in Solvents of Differing Polarity

	quantum yield[a] × 10^3		
product	Bu_2O[b]	MeOH[b]	H_2O/CH_3CN[b]
pentachlorophenol	0.2 ± 0.0	0.4 ± 0.05	0.8 ± 0.2
9b,c	0.2 ± 0.0	1.6 ± 0.3	6.8 ± 0.6
9a		1.4 ± 0.3	4.1 ± 0.7
11a,b	0.1 ± 0.0	12.7 ± 1.6	3.7 ± 0.5
OCDD	4.7 ± 0.9	66.0 ± 0.2	33.3 ± 2.7

[a] Average and range for two runs; quantum yield based on cyclopentanone actinometry. [b] PreD$^-$Et$_3$NH$^+$ (0.01 M) and triethylamine (0.1 M) in dibutyl ether or methanol or H_2O/CH_3CN (70:30 v/v).

The sodium salt of predioxin **1a** (PreD$^-$Na$^+$) was prepared in methanol and irradiated (300 nm) in the presence of sensitizer *m*-methoxyacetophenone. Ether cleavage, forming pentachlorophenol and tetrachlorophenol, and dechlorination, leading to mono- and di-dechlorination (**9a,b** and **8a,b**), are the major reaction pathways with no



detectable cyclization to octachlorodibenzodioxin (OCDD). In the presence of sensitizer and excess triethylamine, however, cyclization is a major reaction pathway; ether cleavage and dechlorination remain as important processes (Table I). The presence of excess triethylamine clearly plays an important role in the chemistry of the triplet state. In order to determine if similar interactions prevail in the reactions of the singlet state, the sodium salt of perchlorophenoxyphenol (**1a**) was prepared and irradiated (300 nm) in methanol. A small amount of cyclization forming polychlorodibenzodioxin components (**11a,b** and

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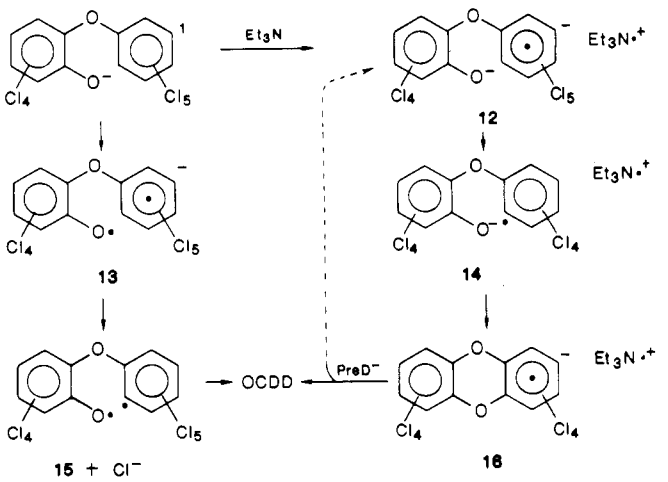
Scheme III



OCDD) is revealed (Table II). In sharp contrast, the quantum yield for cyclization increases more than 17-fold when the irradiation of the predioxin anion (0.01 M) is carried out in the presence of triethylamine (0.1 M) forming octachlorodibenzodioxin and daughter products (Table II).

Since it is likely that the predioxin anion is twisted with essentially two independent π systems, reminiscent of phenyl-β-naphthylamine derivatives[19] and diphenylcarbene,[22] a low-lying π^* orbital should exist[23] and formation of the same radical dianion (**12**) by electron transfer to either triplet or singlet predioxin anion seems to be a reasonable hypothesis (Scheme II). If radical dianion **12** is indeed the key to facile cyclization, the charge creation that is brought about by electron transfer to either triplet or singlet should be reflected in a strong dependence upon solvent polarity.

In order to test this anticipated feature, the triethylammonium salt of predioxin (**1a**) was prepared and irradiated in the presence of a 10-fold excess of triethylamine in solvents of differing polarity. While there is some cyclization in a solvent of low polarity, dibutyl ether (E_T = 33 kcal/mol),[24] solvents of high polarity such as methanol (E_T = 56 kcal/mol) and H_2O/CH_3CN (70:30) (E_T = 58 kcal/mol) clearly enhance the quantum yield for cyclization (Table III), which supports the electron-transfer steps suggested in Scheme II. An intramolecular electron transfer in either singlet or triplet from the left side ring to the right side ring would involve charge dispersion and would be inhibited by an increase in solvent polarity. Focusing our attention on the singlet predioxin anion, the results of Table II allow one to conclude that an external electron donor is not required for cyclization. In the presence of an external electron donor, there may, in fact, be a competition between intramolecular and intermolecular electron transfer that is controlled by the polarity of the solvent. In Scheme III such a mechanistic picture is illustrated. In highly polar solvents electron transfer forming radical dianion **12** is dominant. Chloride ion is expelled to form radical anion **14**, which undergoes cyclization producing OCDD radical anion **16**, which can undergo back electron transfer with the triethylamine radical cation or transfer an electron to the predioxin anion forming in either case OCDD product. If electron transfer from **16** to $PreD^-$ occurs, the process is an intramolecular $S_{RN}1$ mechanism.[25] In the past, phenoxide anions have not been observed to participate in $S_{RN}1$ mechanisms,[25] so, if such a process is operative in this case it is due to the advantage of intramolecularity and the low-lying π^* molecular orbital available on a polychloroarene substrate. While the quantum yields do not provide evidence for a chain process, short chains cannot be ruled out. In solvents of low polarity or in the absence of an external electron-transfer agent, intramolecular electron-transfer-generating diradical anion **13** may predominate. Species **13** upon chloride ion expulsion forms diradical **15**, which leads directly to OCDD product.

Experimental Section

General Methods. The solvents that were used in the photolysis experiments were purified by distillation using standard procedures. Cyclopentanone and triethylamine were freshly distilled prior to their use. *m*-Methoxyacetophenone was used as obtained (Aldrich Co., 99%).

The photolysis of perchloro-*o*-phenoxyphenol (**1a**) was carried out in a Rayonet merry-go-round reactor (The Southern New England Co.) equipped with eight 3000-Å Rull lamps. A continuous stream of air was passed into the reactor chamber and the measured temperature of the latter during photolysis was 40 °C. The photolysis samples were placed in quartz tubes (170 mm × 15 mm) attached with Pyrex glass sliding stoppers, degassed through 3 or 4 freeze–pump–thaw cycles, sealed in vacuum, and irradiated in the photoreactor at 300 nm for 3 h. The product quantum yields were measured using cyclopentanone as the actinometer. The cyclopentanone solution was prepared in the same solvent as the one used in the predioxin photolysis in each case. *m*-Methoxyacetophenone was employed as the sensitizer.

The photoproducts were identified by comparing their GLC retention times with those of known standards and by mass spectrometry. GLC analysis of the photolysates was carried out on a Varian 3700 gas chromatograph equipped with a flame ionization detector. A 60-ft 7% OV-101 on Chromosorb-P (60/80 mesh) column was employed. Analyses were carried out by using a starting temperature of 120 °C (5-min hold, rate of increase 5°/min, and a maximum temperature of 290 °C), an injection port temperature of 250 °C, a detector temperature of 300 °C, and a helium flow of 60 mL/min.

Mass spectral analyses of the photolysis samples were carried out at 70 eV on a Finnigan 4023 mass spectrometer equipped with a Finnigan 9610 gas chromatograph. Ultraviolet spectral measurements were made on a Varian Cary 118. Owing to the general difficulty encountered in the GLC analysis of free hydroxy compounds, the photolysis mixtures in each case were treated with an etherial solution of diazomethane at 0 °C in order to convert the free hydroxy compounds to their corresponding methyl ethers; thus, the product components were identified as their corresponding methyl ether derivatives. The yields (mol %) were determined on the basis of dodecane as an internal standard.

Sensitized Photolysis of Predioxin Anion in Absolute Methanol. A 25.0-mL solution of predioxin (**1a**) (93.8 mg, 0.189 mmol) and dodecane (37.5 mg, 0.221 mmol) was prepared in methanol. The solution was 0.00756 M with respect to predioxin. To a 4.0-mL sample of the predioxin solution placed in a quartz tube was added a micro drop of phenolphthalein indicator followed by dropwise addition of a methanolic solution of sodium methoxide (0.213 M) until the solution was neutralized. To this solution was now added *m*-methoxyacetophenone (0.0225 g, 0.15 mmol), and the solution was degassed, sealed in vacuum, and irradiated for 3 h. The photolysis was carried out in duplicate. Quantum yields were determined using cyclopentanone actinometry; two 4.0-mL samples of 2.0 M cyclopentanone in absolute methanol were employed.

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Sensitized Photolysis of Predioxin Anion in Methanol in the Presence of Excess Triethylamine. A 10.0-mL methanolic solution of predioxin (0.0496 g, 0.10 mmol), *m*-methoxyacetophenone (0.122 g, 0.81 mmol), and dodecane (26.2 mg, 0.154 mmol) was prepared. To two 4.0-mL samples of the solution was added 1 equiv of triethylamine in order to convert predioxin to its anion. Then, to each sample was added 16.0 mg (0.16 mmol) of triethylamine. The mole ratio of predioxin anion to triethylamine was 1:4. The samples were degassed and irradiated according to the general procedure. Quantum yields were measured using cyclopentanone actinometry. A 10.0-mL methanolic solution of cyclopentanone (2.121 g, 25.2 mmol) and dodecane (0.138 g, 0.809 mmol) was prepared. Two 4.0-mL samples were degassed and irradiated simultaneously with the predioxin samples.

Direct Photolysis of Predioxin Anion in Absolute Methanol. A 10.0-mL solution of predioxin (0.0495 g, 0.998 mmol) and dodecane (0.0749 g, 0.4397 mmol) was prepared in methanol, providing a 0.01 M solution of predioxin. Two 4.0-mL samples were placed in two separate quartz tubes, and to each a micro drop of phenolphthalein indicator was added and the solution neutralized with methoxide (1.0 M). The solutions were then degassed, sealed in vacuum, and irradiated for 3 h. Quantum yields were determined using cyclopentanone actinometry; two 4.0-mL samples of 2.0 M cyclopentanone in absolute methanol were used.

Photolysis of Predioxin Anion in Solvents of Different Polarity in the Presence of Excess Triethylamine. Stock solutions (10.0 mL) containing 0.01 M predioxin were prepared in absolute methanol, dibutyl ether (distilled from calcium hydride just before use), and H_2O/CH_3CN (70:30). Two 4.0-mL samples of each of the stock solutions were transferred into separate quartz tubes and 1 microdrop of phenolphthalein indicator was added to each tube. Triethylamine was added drop by drop with a micro syringe until neutralization was achieved. At this point triethylamine (0.041 g, 0.40 mmol) and dodecane (50 μL, 0.22 mmol) were added, and the samples were degassed, sealed in vacuum, and irradiated for 3 h. Cyclopentanone actinometry was employed, using 2.0 M solutions of cyclopentanone in dibutyl ether to measure quantum yields in the dibutyl ether runs and 2.0 M solutions of cyclopentanone in methanol to measure quantum yields in the methanol and H_2O/CH_3CN runs. Methanol solvent was used in the latter two solvent systems due to a solubility problem with cyclopentanone in H_2O/CH_3CN; however, the refractive index for these two solvent systems is very close (methanol n^{20}_D 1.329, H_2O/CH_3CN n^{20}_D 1.336).

Acknowledgment. We express our appreciation to the National Institute of Environmental Health Sciences (ES0040) for the support of this work.

Registry No. **1a**, 35245-80-8; **1a**·Na, 104156-80-1; **4b**, 3268-87-9; **8a**, 104156-81-2; **9a**, 104156-82-3; **10**, 104156-83-4; **11a**, 35822-46-9; **11b**, 58200-70-7; 3'-$H_3COC_6H_4COCH_3$, 586-37-8; 2,3,4,5-tetrachlorophenol, 4901-51-3; pentachlorophenol, 87-86-5.

Novel Potentiators of β-Lactam Antibiotics. Structures of SQ 28504 and SQ 28546

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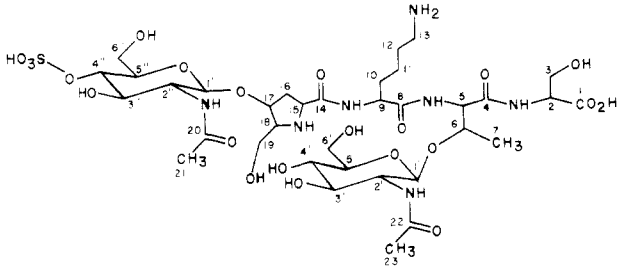
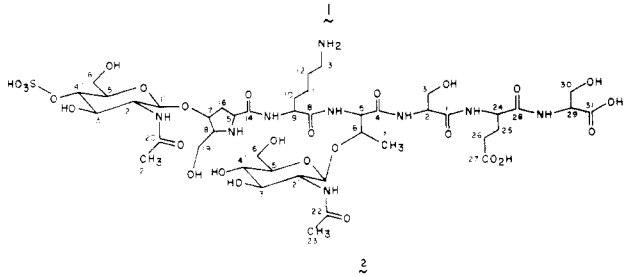
The structures of two novel potentiators of β-lactam antibiotics, namely, SQ 28504 (**1**) and SQ 28546 (**2**), are presented. The structure elucidations of these O-sulfated glycopeptides are based on NMR and FAB mass spectral data. Thermospray mass and MS/MS spectra were obtained of hydrolysates formed by treatment with carboxypeptidases and aided in the deduction of structures **1** and **2**.

The isolation and biological properties of two novel O-sulfated glycopeptides SQ 28504 (**1**) and SQ 28546 (**2**) have been reported.[1] These bacterial metabolites are found in the culture broth of *Chromobacterium violaceum*



1



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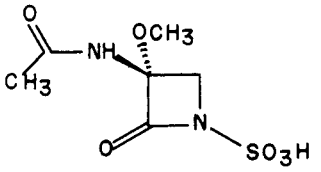

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and are coproduced with the monobactam[2] SQ 26180 (**3**). SQ 28504 and SQ 28546 potentiate the activity of β-lactam antibiotics against gram-negative organisms, inducing morphological changes. Bulge formation in the elongated cells is observed and culture growth is inhibited. These changes are similar to those reported for the bulgecins,[3,4] O-sulfated glycopeptides coproduced with the monobactam sulfacezin.[5] In the present paper, the structure elucidation of SQ 28504 and SQ 28546 based upon NMR and mass spectral data is discussed in detail. The unique assembly

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