HETEROCYCLES, Vol. 76, No. 1, 2008, pp. 667 - 678. © The Japan Institute of Heterocyclic Chemistry
Received, 25th March, 2008, Accepted, 28th April, 2008, Published online, 1st May, 2008. COM-08-S(N)60

# PREPARATION OF 1,3,3a,7a-TETRAHYDROISOTHIANAPHTHENE AND ITS APPLICATION TO TETRAHYDROTHIOPHENE-FUSED PORPHYRIN

**Yukiko Katsuyama,[a] Eita Yoshida,[a] Hiroki Uoyama,[a] Noboru Ono,[b] and Hidemitsu Uno[a]***

[a] Division of Synthesis and Analysis, Department of Molecular Science, Integrated Center for Sciences, Ehime University, Matsuyama 790-8577, uno@dpc.ehime-u.ac.jp [b] Department of Chemistry and Biology, Graduate School of Science and Engineering, Ehime University, Matsuyama 790-8577, Japan

**Abstract** –Dehydrobromination of 5,6-dibromoperhydroisothianaphthene with DBU gave a mixture of 1,3,3a,7a-tetrahydroisothianaphthene and 1,3,3a,4-tetrahydroisothianaphthene in a ratio of 5:1. The former compound acted as an s-*cis* diene in the Diels-Alder reaction with bis(phenylsulfonyl)ethylene to give an adduct, which was successively converted to tetrahydrothiphene-fused pyrroles and porphyrins.

*Dedicated to Professor Ryoji Noyori on the occasion of his 70$^{th}$ birthday*

## INTRODUCTION

Isothianaphthene (2-benzothiophene) is known as a reactive 10π-aromatic compound, which suffers easy oxidation and polymerization.[1] The carbon atoms adjacent to the sulfur on the thiophene ring are most reactive in both ionic and concerted reactions due to the large HOMO and LUMO coefficients.[2] Therefore, their application to organic synthesis is very limited: isothianaphthene *in-situ* generated from precursors reacted with an electrophile or dienophile to give a 1,3-substituted derivative, reactive positions of which are protected by the substituents or destroyed by breaking the thiophene aromaticity.[1] During our continuous study on the application of benzo[c] five-membered aromatic compounds and their precursors,[3] we required compounds having the isothianaphthene skeleton with no 1,3-substituent and reactive 4,7-positions, because they could be converted to useful isothianaphthene precursors.[4]

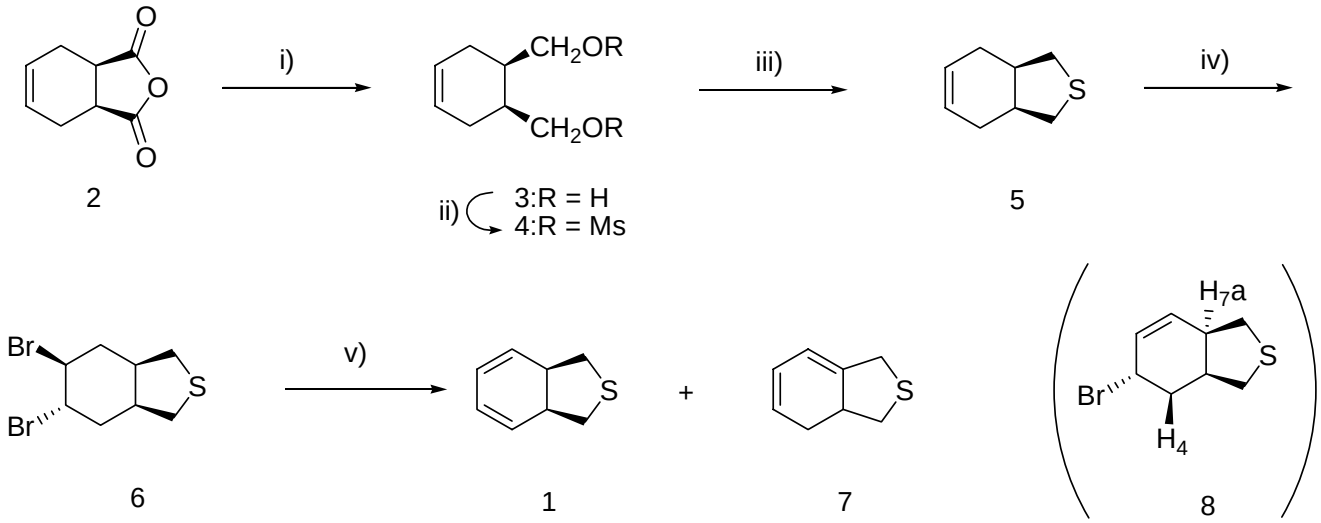
1,3,3a,7a-Tetrahydroisothianaphthene (**1**) seems to be a suitable candidate for this purpose, although the preparation has not been reported so far. In this paper, we discuss about the preparation and reaction of 1,3,3a,7a-tetrahydroisothianaphthene (**1**) and its conversion to a soluble precursor of tetrabenzoporphyrin (TBP).

Tetrabenzoporphyrins (TBPs) have attracted great attention as a practical material for an organic field-effect transistor (OFET), due to not only the stability in air compared to pentacene, a typical OFET material, but also the high mobility.[5] The fabrication of TBP-based devices, however, had been strictly limited to the vapor deposition method because TBP derivatives were essentially insoluble in any solvent. The solution processes such as spin- and dip-coating methods had not been applicable. Our solution process based on the FET active-layer formation on the insulating material by the retro-Diels-Alder reaction has been proven to be very effective for the OFET-device fabrication.[5] One drawback of this devices was low current capacity ascribed to the thickness of TBP layer. In order to solve this problem, we planned to prepare a variety of soluble TBP precursors having various kinds of functionalities, which were extruded in the retro Diels-Alder step.[6] We utilized 1,3,3a,7a-tetrahydroisothianaphthene (**1**) as the starting material for the preparation of such TBP precursors.

## RESULTS AND DISCUSSION

First, we attempted to prepare 1,3,3a,7a-tetrahydroisothianaphthene (**1**) starting from 1,2-dihydrophthalic anhydride, which was readily obtained by reduction of phthalic acid with sodium amalgam followed by dehydration with acetic anhydride.[7] Reduction of 1,2-dihydrophthalic anhydride with $LiAlH_4$, however, gave an intractable mixture. Therefore, we decided to make a detour to **1** as illustrated in Scheme 1. This route is essentially based on the synthesis of a 2,2-dioxo derivative of **1**.[8,9] Thus, commercially available cyclohex-4-ene-1,2-dicarboxylic anhydride (**2**) was reduced with $LiAlH_4$ in refluxing THF to give dihydroxy derivative **3** in a 75% yield.[8] The hydroxyl groups were converted to methanesulfonyl groups by addition of **3** to a solution of methanesulfonyl chloride in dry pyridine in an 87% yield. Obtained bis-mesylate **4** was treated with sodium sulfide nonahydrate in DMF at 80 °C to afford 1,3,3a,4,7,7a-hexahydroisothianaphthene (**5**) in a 91% yield. Bromination of **5** with a just equal molar ratio of $Br_2$ at -78 °C occurred cleanly to give dibromide **6** in a 77% yield. Double dehydrobromination of **6** with DBU at 80 °C gave a mixture of aimed **1** and regioisomer **7** in a ratio of 5:1 determined by $^1H$ NMR. From the NMR spectra, formation of other by-product was not observed. The isomers were separated by column chromatography to afford pure **1** and **7** in respective yields of 40 and 7%. This dehydrobromination of **6** *via* mono-bromide **8** must be kinetically controlled because the ratio of **1** to **7** did not change throughout the reaction in the GC monitoring, and no other diene by-product was formed. Moreover, the ratio was quite similar to that reported for the corresponding 2,2-dioxo derivative.[9] In

order to improve the selectivity of **1**, various conditions were examined and the results are listed in Table 1. When the reaction temperature was lowered, the selectivity increased although the longer reaction time was required (entries 1-3). Potassium *t*-butoxide was of no use in this dehydrobromination (entry 4). No reaction occurred under 50 °C, while complex mixture was formed at 50 °C. When equivalent amounts of the hindered strong bases such as *t*-butylimino-tri(pyrrolidino)phosphorane (BTPP)[10] and P4[11] were employed at 50 °C, no reaction occurred. When the reaction with BTPP was carried out at 120 °C, the selectivity was low (entry 5). In these cases with BTPP and P4, the first and second hydrogen abstractions from **6** and **8** would be disfavored by the steric hindrance. Therefore, the efficiency was lowered.

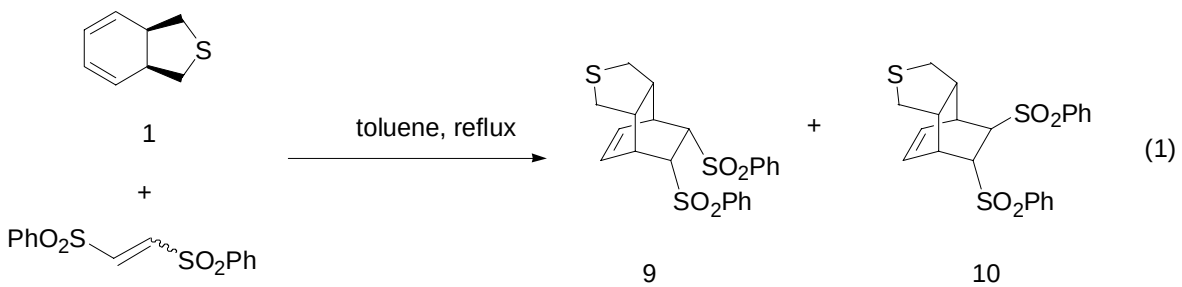



Scheme 1. *Reagents, conditions, and yields:* i) $LiAlH_4$, THF, reflux; 85%. ii) $MeSO_2Cl$, pyridine, 0 °C; 83%. iii) $Na_2S \cdot 9H_2O$, DMF, 80 °C; 91%. iv) $Br_2$, $CH_2Cl_2$, -78 °C; 77%. v) DBU, toluene.

Table 1. Dehydrobromination of **6**

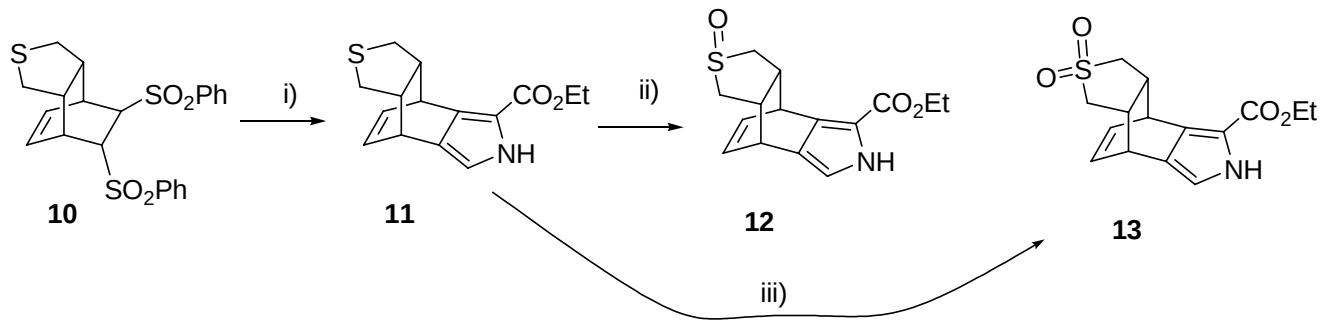
| Entry | Base | Conditions | Combined yield /% | Ratio of **1**/**7**[a)] |
|---|---|---|---|---|
| 1 | DBU | toluene, 80 °C, 15 h | 47 | 5/1 |
| 2 | DBU | toluene, 60 °C, 19 h | 51 | 8/1 |
| 3 | DBU | toluene, 50 °C, 100 h | 44 | 6/1 |
| 4 | *t*-BuOK | THF, 50 °C, 1.5 h | –[b)] | –[b)] |
| 5 | BTPP | toluene, reflux, 19 h | 67 | 2/1 |

a) The ratio was calculated by $^1$H NMR spectrum of the chromatographed sample. b) A complex mixture was formed.



Next, we examined the reactivity of **1** as a diene in the Diels-Alder reaction (Eq 1). *Cis*-bis(phenylsulfonyl)ethylene was chosen as a dienophile because it was reported to have a moderate reactivity toward dienes[12] and the adduct could be utilized for preparation of a pyrrole. Isomerization of *cis*-bis(phenylsulfonyl)ethylene was reported to isomerizes the trans isomer which was the more reactive dienophile when a high temperature and prolonged reaction time were employed.[12] The Diels-Alder reaction of **1** with *cis*-bis(phenylsulfonyl)ethylene was conducted under toluene reflux. The Diels-Alder reaction proceeded slowly and the starting diene disappeared after 5 days. From the $^1$H-NMR spectrum of the mixture, two products were formed. Separation of the mixture by column chromatography on silica gel gave *anti-cis* adduct **9** and *anti-trans*-adduct **10** in respective yields of 47 and 16%. The stereochemistries of **9** and **10** were unambiguously determined by COSY and differential NOE experiments. As the Diels-Alder reaction of 1,3-cyclohexadiene with *cis*-bis(phenylsulfonyl)- ethylene was reported to give only a *cis* adduct, 1,3,3a,7a-tetrahydroisothianaphthene (**1**) was a less reactive diene than 1,3-cyclohexadiene probably due to the distorted nature of the diene part by *cis*-fused tetrahydrothiophene ring. On the other hand, the reaction of **1** with *trans*-bis(phenylsulfonyl)ethylene finished more rapidly within 17 h to give only *anti-trans*-adduct **10** in a 63 % yield.

The modified Barton-Zard reaction of **10** with ethyl isocyanoacetate gave pyrrole **11** in a 87% yield (Scheme 2).[13] Oxidation of **11** with one and two equivalents of mCPBA gave sulfoxide **12** and sulfone **13** in respective yields of 73 and 91%. Among the pyrrole derivatives, sulfone **13** gave good single crystals for X-ray analysis.[14] The Ortep drawings of **13** with some plane angles and bond lengths are shown in Figure 1. The angle between the pyrrole and olefin planes [124.4(2)º + 3.3(1)º = 127.7(2)º] was quite widened by comparison with the simple ethylene-bridged isoindole [122.3(3)º].[15] In concert with this widening, the bond lengths between the bridge-head and sp$^3$-hybridized bridge carbons were elongated to be 1.563(3) and 1.557(3) Å from the values [1.528(8) and 1.547(6) Å] observed in the simple ethylene-bridged isoindole. These differences would be probably due to the steric interaction between the bulky sulfolane-bridging moiety and the double bond.




Scheme 2. *Reagents, conditions, and yields:* i) $CNCH_2CO_2Et$, *t*-BuOK, THF, rt; 87%. ii) *m*-CPBA (1 eq), $CH_2Cl_2$, 0 ºC; 73%. iii) *m*-CPBA (2 eq), $CH_2Cl_2$, 0 ºC; 91%.

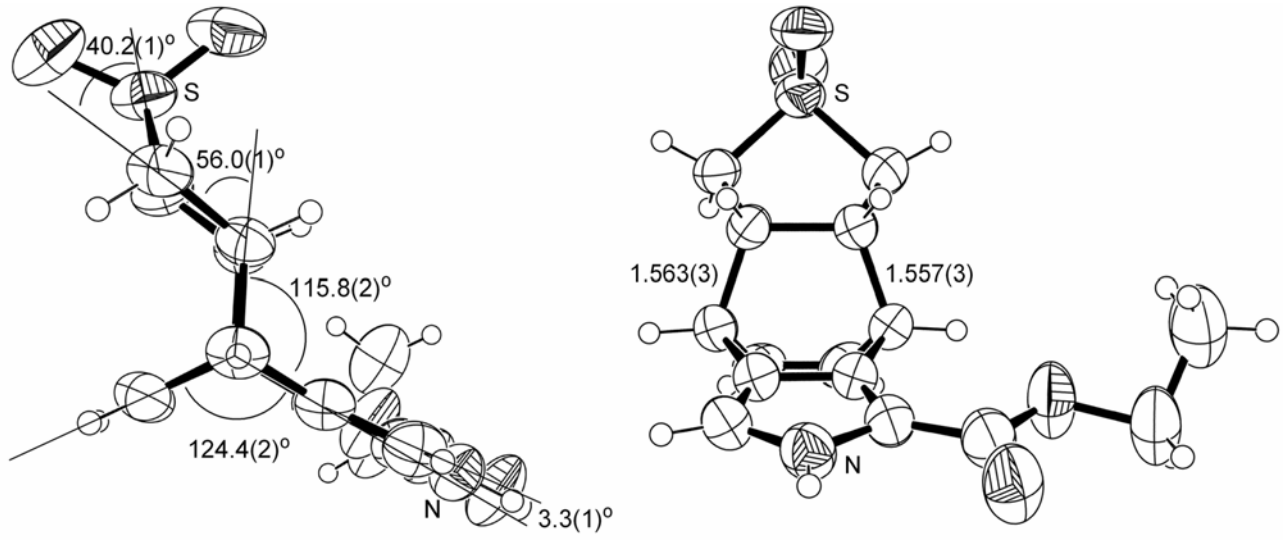
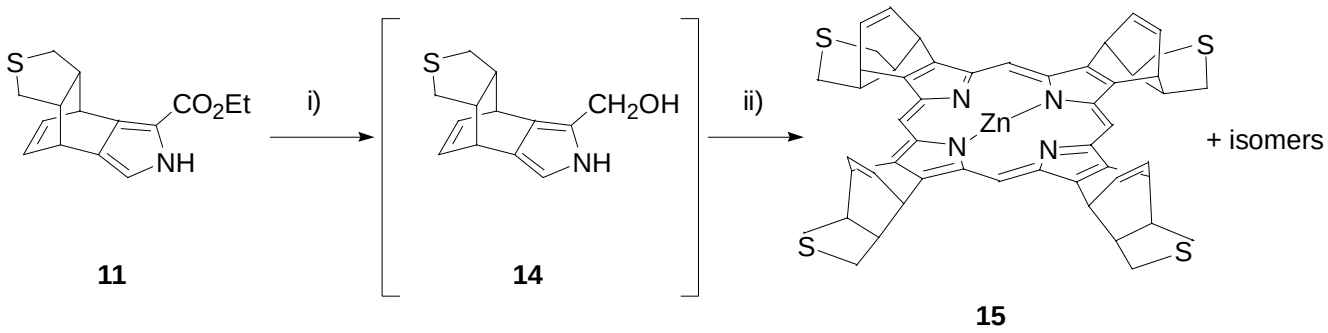



Figure 1. Ortep drawings of **13** with plane angles (left) and bond lengths (right). Disordered atoms with the smaller occupancy are omitted for clarity.




Scheme 3. *Reagents and conditions*: i) $LiAlH_4$, THF, 0 ºC, in the dark; ii) *p*-TSA, $CHCl_3$, rt; chloranil, $CHCl_3$, rt.

Porphyrin synthesis was carried by using the tetrahydrothiophene-fused pyrrole **11**. Reduction of pyrrole **11** with $LiAlH_4$ gave rather unstable hydroxymethylpyrrole **14**, which was then treated successively with pTSA and chloranil without isolation. Zinc porphyrin **15** was obtained in a 7% yield as a mixture of stereoisomers. From the UV-vis spectrum of **15**, a very strong Soret band appeared at 405 nm. In addition to the Q-band absorptions at the usual region (531 and 565 nm),[16] an additional absorption was observed at 615 nm (Figure 2). As zinc porphyrins usually have two strong absorptions at the Q-band region, this spectrum is quite interesting. The isomeric mixture of porphyrin **15** was readily soluble in common solvents such as chloroform, toluene, acetone, and etc. The porphyrin **15** was converted to tetrabenzoporphyrin by heating at 200 ºC in a solid or film. Further study using the porphyrin as the organic FET material is under way.

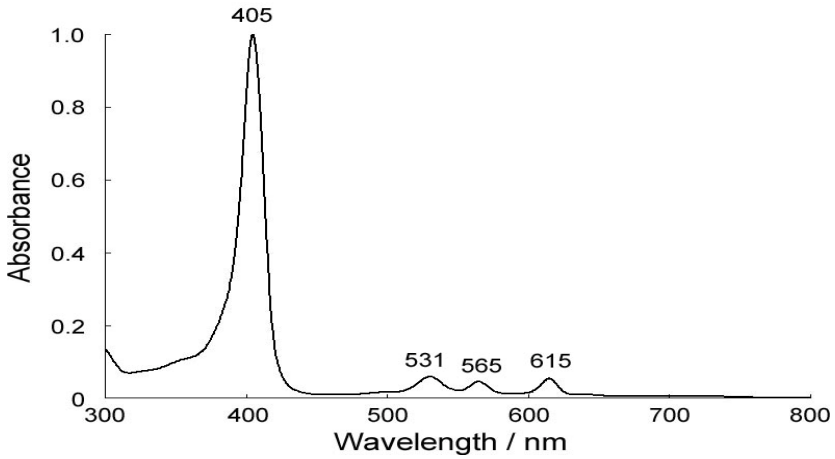



Figure 2. UV-vis spectrum of **15** in $CHCl_3$

In conclusion, dehydrobromination of 5,6-dibromoperhydroisothianaphthene with DDQ gave 1,3,3a,7a-tetrahydroisothianaphthene. 1,3,3a,7a-Tetrahydroisothianaphthene was an less reactive s-*cis* diene than 1,3-cyclohexadiene in the Diels-Alder reaction. The reaction of 1,3,3a,7a-tetrahydroisothianaphthene with *cis*-bis(phenylsulfonyl)ethylene occurred very slowly even at a high temperature to give a mixture of adducts accompanied with the olefin isomerization. The adducts were converted to pyrroles and porphyrin.

## EXPERIMENTAL

### General

Melting points were measured on a Yanagimoto micromelting point apparatus and are uncorrected. NMR spectra were obtained with a JEOL GSX-270, AL-400 or EX-400 spectrometer at the ambient temperature by using $CDCl_3$ as a solvent and tetramethylsilane as an internal standard for $^1H$ and $^{13}C$. IR spectra were measured with a Horiba FT-720 infrared spectrophotometer. Mass spectra (EI, 70 eV; FAB, glycerin) were measured with a JEOL JMS-700. Elemental analyses were performed with a Yanaco MT-5 elemental analyzer. The X-ray measurement was done with Rigaku AFC7R (10 kW). Dehydrated tetrahydrofuran and dichloromethane were purchased from Kanto Chemical Co. and used without further purification. Potassium *tert*-butoxide was sublimed at 200 °C under a reduced pressure (*ca.* 13 Pa) and dissolved in dry THF (1.0 mol $L^{-1}$). Toluene and pyridine was distilled from $CaH_2$ under nitrogen and stored on molecular sieves 4A. DBU and DMF was distilled under reduced pressure (ca. 2000 Pa) and then stored over molecular sieves 13A. Other commercially available materials were used without further purification.

### 1,3,3a,4,7,7a-Hexahydroisothianaphthene (5)[8]

Commercially available tetrahydrophthalic anhydride (**2**; 19.78 g. 0.13 mol) was placed in the dropping funnel and then suspended with dry THF (100 mL). The suspension of **1** was slowly added to the vigorously-stirred suspension of $LiAlH_4$ (17.02 g, 0.45 mol) in dry THF (250 mL) for 40 min with cooling by the ice-water bath. After the addition, the mixture was allowed to warm up to rt. The mixture was then heated to reflux overnight. The mixture was cooled to rt and then slowly poured into a mixture of ice (200 g) and 10% aqueous HCl solution (400 mL). Sodium chloride (100 g) and Celite (30 g) were added to the white suspension and the mixture was stirred for 10 min. The suspension was then filtered through a Celite pad, which was thoroughly washed with EtOAc (500 mL). The filtrate was separated and the aqueous phase was extracted with EtOAc (3 x 200 mL). The combined organic phase was washed with saturated aqueous $NaHCO_3$ solution (300 mL) and brine (300 mL), dried over $MgSO_4$, and concentrated *in vacuo* to leave yellow oil. The oil was distilled through a 20-cm Vigreux column under reduced pressure (ca. 100 Pa). Distillate between 110-130 °C (Lit. 130-137 °C/133-200 Pa)[8] was collected to give 15.77 g (85%) of 4-cyclohexene-1,2-bismethanol (**3**) as colorless oil; $^1$H NMR δ 2.0-2.2 (6H, m), 3.26 (2H, br), 3.61 (2H, dd, *J* = 16.5 and 5.0 Hz), 3.68 (2H, dd, *J* = 16.5 and 8.0 Hz), and 5.61 (2H, s); $^{13}$C NMR δ 25.9, 34.0, 37.3, 69.9, and 124.8.

The diol **1** (17.02 g, 119.7 mmol) in dry pyridine (48 mL) was slowly added to a solution of methanesulfonyl chloride (27.6 mL, 357 mmol) in dry pyridine (118 mL) over 45 min. After the addition, the mixture was allowed to warm up to rt. After being stirred for 2.5 h, the mixture was slowly poured into a mixture of ice (50 g), NaCl (50 g), and a saturated aqueous $NaHCO_3$ solution (100 mL). The mixture was extracted with $CHCl_3$ (3 x 150 mL). The organic extract was washed with brine, dried over $MgSO_4$, and concentrated to leave viscous oil. The oil was treated with a small amount of ether and solidification occurred. The powdery solid was triturated with hexane to give 29.61 g (83%) of bismethanesulfonate **4** as white powder: $^1$H NMR δ 1.99 (2H, dd, *J* = 17.1 and 6.1 Hz), 2.22 (2H, dd, *J* = 17.1 and 4.9 Hz), 2.43 (2H, m), 3.04 (6H, m), 4.17 (2H, dd, *J* = 10.0 and 7.1 Hz), 4.29 (2H, dd, *J* = 10.0 and 7.1 Hz), and 5.67 (2H, br-s).

Bismethanesulfonate **4** (29.60 g, 99.2 mmol) and sodium sulfide nonahydrate (35.74 g, 178.7 mmol) in dry DMF (100 mL) was heated at 80 °C with stirring for 17 h. After being cooled to rt, the mixture was quenched with water (500 mL). The mixture was extracted with $Et_2O$ (5 x 100 mL). The ethereal extract was washed with water (3 x 150 mL) and brine (200 mL), dried over $MgSO_4$, and concentrated. The residual oil was distilled under a reduced pressure (ca. 3.2 kPa) and distillate between 104-112 °C were collected to give 12.70 g (90.5 mmol, 91%) of the title compound as pale yellow oil: bp 104-112 °C (3.2 kPa); $^1$H NMR δ 2.16 (4H, m), 2.42 (2H, m), 2.65 (2H, dd, *J* = 9.8 and 5.9 Hz), 2.92 (2H, dd, *J* = 9.8 and 5.9 Hz), and 5.62 (2H, m); IR (neat) $\nu_{max}$ 3021, 2902, 1654, and 660 cm$^{-1}$; GC-EI-MS *m/z* 140 ($M^+$), 124, 93, 82, and 79; Anal. Calcd for $C_8H_{12}S$: C, 68.51; H, 8.62. Found: C, 69.30; H, 8.88%.

**5,6-Dibromo-1,3,3a,4,5,6,7,7a-octahydroisothianaphthene (6)**

To a stirred solution of hexahydroisothianaphthene **5** (2.805 g, 20.0 mmol) in dry $CH_2Cl_2$ (40 mL) was added bromine (3.196 g, 1.02 mL, 20 mmol) at -78 ºC over 5 min. After the addition, the mixture was allowed to warm up to rt. The reaction was quenched with 10% aqueous $NaHSO_3$ solution (20 mL) and brine (20 mL). The mixture was extracted with $CHCl_3$ (3 x 100 mL). The organic extract was washed with brine (50 mL), dried over $MgSO_4$, and concentrated to leave brown solid. The solid was recrystallized from $CHCl_3$/$Et_2O$/hexane to give 4.62 g (15.4 mmol, 77%) of the title compound as white solid; mp 95-97 °C; $^1$H NMR δ 2.1-2.6 (6H, m); 2.79 (2H, m), 2.90 (1H, dd, $J$ = 10.5 and 7.2 Hz), 3.03 (1H, dd, $J$ = 10.7 and 5.8 Hz), 4.15 (1H, ddd, $J$ = 10.5, 9.1, and 4.5 Hz), and 4.32 (1H, ddd, $J$ = 10.5, 9.5, and 4.0 Hz); IR (KBr) $\nu_{max}$ 2925, 1446, 778, and 683 cm$^{-1}$; EI-MS *m/z* 302, 300, 298, 221, 219, 139, and 105; Anal. Calcd for $C_8H_{12}Br_2S$: C, 32.02; H, 4.03. Found: C, 31.95; H, 3.84%.

**1,3,3a,7a-Tetrahydroisothianaphthene (1) and 1,3,3a,4-Tetrahydroisothianaphthene (7)**

5,6-Dibromo-1,3,3a,4,5,6,7,7a-octahydroisothianaphthene (**6**; 3.00 g, 10.0 mmol) and distilled DBU (3.14 mL, 21.0 mmol) in dry toluene (40 mL) was heated at 80 °C. After 15 h, the mixture was cooled to rt and water (32 mL) was added. The mixture was separated and the aqueous phase was extracted with toluene (4 x 40 mL). The toluene extract was washed with a 5% aqueous HCl solution (32 mL) and brine (40 mL), dried over $Na_2SO_4$, and concentrated. $^1$H-NMR analysis revealed the existence of the title compounds in a ratio of **1**:**7** = 5:1. This mixture was used for the following reactions without purification. Separation of the isomers **1** and **7** was done by column chromatography. The residual oil was chromatographed on silica gel (2% $Et_2O$/hexane) to give 550 mg (40%) of **1** and 96 mg (7%) of **7**. **1**: colorless oil; $R_f$ 0.65 (10% $Et_2O$/hexane); $^1$H NMR δ 2.87 (2H, m, H$^1$ and H$^3$), 2.92 (2H, m, H$^1$ and H$^3$), 3.14 (2H, m, H$^{3a}$ and H$^{7a}$), 5.73 (2H, m, H$^4$ and H$^7$), and 5.91 (2H, m, H$^5$ and H$^6$); $^{13}$C NMR δ 37.8 (C1 and C3), 41.9 (C3a and C7a), 123.7 (C4 and C7), and 128.7 (C5 and C7); IR (neat) $\nu_{max}$ 1456, 1437, 1259, 1220, 1193, and 1003 cm$^{-1}$; GC-EI-MS *m/z* 138 (M$^+$), 123, 92, and 91; HRMS (EI) Calcd for $C_8H_{10}S$: 138.0503; found 138.0502. **7**: colorless oil; $R_f$ 0.75 (10% $Et_2O$/hexane); $^1$H NMR δ 2.01 (1H, br-t, $J$ = 17.0 Hz, H$^4$), 2.42 (1H, ddd, $J$ = 17.0, 8.3, and 6.4 Hz, H$^4$), 2.65 (1H, t, $J$ = 10.5 Hz, H$^3$), 2.87 (1H, m, H$^{3a}$), 3.11 (1H, t, $J$ = 10.5 and 7.3 Hz, H$^3$), 3.65 (2H, s, H$^1$), 5.70 (1H, m, H$^6$), 5.82 (1H, m, H$^7$), and 5.94 (1H, m, H$^5$); $^{13}$C NMR δ 29.3 (C3), 35.0 (C1), 38.5 (C4), 42.9 (C3a), 117.1 (C5), 123.7 (C6), 124.9 (C7), and 143.1 (C7a).

**(3aS*,4R*,7S*,7aR*,8S*,9R*)-8,9-Bis(phenylsulfonyl)-1,3,3$^a$,4,7,7$^a$-hexahydro-4,7-ethano-2-benzothiophene (9) and (3aS*,4R*,7S*,7aR*,8R*,9R*)-8,9-Bis(phenylsulfonyl)-1,3,3$^a$,4,7,7$^a$-hexahydro-4,7-ethano-2-benzothiophene (10)**

**Reaction with *cis*-bis(phenylsulfonyl)ethylene:** 1,3,3a,7a-Tetrahydroisothianaphthene (**1**; 550 mg, 3.98

mmol) and *cis*-bis(phenylsulfonyl)ethylene (1.233 g, 4.00 mmol) in dry toluene (8 mL) were heated to reflux and the reaction was monitored by TLC. After 52 h, the starting material disappeared. The mixture was cooled to rt and then concentrated. The residual solid was chromatographed on silica gel (40-70% EtOAc/hexane) to give 835 mg (47%) of **9** and 290 mg (16%) of **10**. **9**: colorless crystals; mp 256-259 ºC; $R_f$ 0.55 (50% EtOAc/$CHCl_3$); $^1$H NMR δ 2.45 (2H, m, $H^{3a}$ and $H^{7a}$), 2.76 (4H, m, $H^1$ and $H^3$), 3.20 (2H, $H^4$ and $H^7$), 3.93 (2H, m, $H^8$ and $H^9$), 6.43 (2H, m, $H^5$ and $H^6$), 7.56 (4H, m, meta), 7.65 (2H, m, para), and 7.99 (4H, m, ortho); $^{13}$C NMR δ 37.2 (C1 and C3), 37.4 (C3a and C7a), 49.0 (C4 and C7), 69.6 (C8 and C9), 128.8 (Ar), 128.9 (Ar), 132.5 (C5 and C6),* 133.6 (Ar),* and 140.8 (Ar); IR (KBr) $\nu_{max}$ 1446, 1300, 1146, and 1084 cm$^{-1}$; MS *m/z* 446 ($M^+$), 306, 105, 163, and 125. Anal. Calcd for $C_{22}H_{22}O_4S_3$: C, 59.17; H, 5.14. Found: C, 58.87; H, 4.97%. **10**: colorless crystals, mp 112-114 ºC; $R_f$ 0.85 (50% EtOAc/$CHCl_3$); $^1$H NMR δ 2.3-2.45 (2H, m, $H^1$ and $H^3$), 2.71 (1H, m, $H^{3a}$), 2.7-2.85 (2H, m, $H^1$ and $H^3$), 3.08 (1H, m, $H^4$), 3.28 (1H, m, $H^7$), 3.44 (1H, m, $H^{7a}$), 3.80 (1H, dd, $J$ = 5.6 and 2.7 Hz, $H^9$), 4.00 (1H, dd, $J$ = 5.6 and 2.0 Hz, $H^8$), 6.23 (2H, m, $H^5$ and $H^6$), 7.57 (2H, m, Ar), 7.61 (1H, m, Ar), 7.68 (2H, m, Ar), 7.71 (1H, m, Ar), 7.77 (2H, m, Ar), and 7.94 (2H, m, Ar); $^{13}$C NMR δ 35.6, 36.7 (C1 and C3), 37.3, 37.3 (C3a and C7a), 43.4, 47.4 (C4 and C7), 63.4, 65.7 (C8 and C9), 128.4 (2C, Ar), 129.1 (Ar), 129.2 (Ar), 132.3, 133.8, 133.9, 134.0 (C5, C6, and 2Ar), 138.4 (Ar), and 139.0 (Ar); IR (KBr) $\nu_{max}$ 1446, 1308, 1142, and 1084 cm$^{-1}$; EI-MS *m/z* 446 ($M^+$), 304, 219, and 125. Anal. Calcd for $C_{22}H_{22}O_4S_3$: C, 59.17; H, 5.14. Found: C, 59.57; H, 5.26%.

**Reaction with *trans*-bis(phenylsulfonyl)ethylene:** 1,3,3a,7a-Tetrahydroisothianaphthene (**1**; 799 mg, 5.78 mmol) contaminated with **7** (**1**:**7** = 5:1) and *trans*-bis(phenylsulfonyl)ethylene (1.62 g, 5.25 mmol) in dry toluene (12 mL) were heated to reflux and the reaction was monitored by TLC. After 17 h, the starting material disappeared. The mixture was cooled to rt and then concentrated. The residual solid was triturated with hexane and the precipitates were collected to yield 1.108 g (43%) of **10**. Another crop (0.515 g, 20%) was obtained by the column chromatography.

**Ethyl (4R*,4aS*,7aR*,8S*)-4,4a,5,7,7a,8-hexahydro-4,8-etheno-2*H*-thieno[3,4-*f*]isoindole-2-carboxylate (11)**

To ethyl isocyanoacetate (0.57 mL, 5.14 mmol) was added a 1.0 M solution of *t*-BuOK in THF (10.3 mmol, 10.3 mL) at 0 ºC. To the mixture was slowly added disulfone **10** (1.91 g, 4.28 mmol) in dry THF (43 mL). After the addition, the bath was removed and the mixture was stirred for 2 h. A 5% aqueous HCl solution (40 mL) was added and the mixture was extracted with EtOAc (4 x 50 mL). The organic extract was washed with a saturated aqueous $NaHCO_3$ solution and brine, dried over $Na_2SO_4$, and concentrated to leave a brown solid. The solid was recrystallized from $CH_2Cl_2$/$Et_2O$/hexane to afford 1.03 g (87%) of **11** as amber needles: mp 171-172 ºC; $R_f$ 0.75 (20% EtOAc/$CHCl_3$); $^1$H NMR δ 1.37 (3H, t, $J$ = 7.0 Hz, $OCH_2CH_3$), 2.6-2.9 (6H, m, $H^{4a}$, $H^5$, $H^7$, and $H^{7a}$), 3.72 (1H, m, $H^4$), 4.22 (1H, m, $H^8$), 4.31

(2H, q, $J$ = 7.0 Hz, OC$H_2$CH$_3$), 6.55 (1H, d, $J$ = 3.4 Hz, H$^3$), 6.56 (2H, m, H$^9$ and H$^{10}$), and 8.30 (1H, br, NH); $^{13}$C NMR δ 14.5 (OCH$_2$*C*H$_3$), 36.5 (C5 and C7), 37.4, 37.5 (C4a and C7a), 53.5, 54.5 (C4 and C8), 60.0 (O*C*H$_2$CH$_3$), 113.4 (C3), 114.8 (C1), 131.8 (C3a), 136.4 (C9 or C10), 136.6 (C8a), 137.2 (C9 or C10), and 161.3 ($CO_2$); IR (KBr) $\nu_{max}$ 3315, 1668, 1427, 1141, 1097, and 692 cm$^{-1}$; EI-MS *m/z* 275 (M$^+$), 190, 189, 161, and 143. Anal. Calcd for $C_{15}H_{17}NO_2S$: C, 65.43; H, 6.22; N, 5.09. Found: C, 65.07; H, 6.17; N, 5.05%.

**Ethyl (4R*,4aS*,6R*,7aR*,8S*)-4,4a,5,7,7a,8-hexahydro-6-oxo-4,8-etheno-2*H*-thieno[3,4-*f*]iso-indole-2- carboxylate (12)**

Pyrrole **11** (280 mg, 1.02 mmol) was dissolved in $CH_2Cl_2$ (10 mL). To the solution was added mCPBA (80%, 240 mg, 1.10 mmol) at 0 ºC. After the mixture was stirred at rt for 2 h, the mixture was diluted with EtOAc (20 mL). The mixture was washed with a 5% aqueous $NaHSO_3$ solution (30 mL) and saturated aqueous $NaHCO_3$ solution (5 x 30 mL). After concentration, the residue was chromatographed on silica gel (20-100% EtAc/$CHCl_3$) to give 232 mg (73%) of the title sulfoxide as colorless crystals; $R_f$ 0.05 (20% EtOAc/$CHCl_3$); $^1$H NMR δ 1.37 (3H, t, $J$ = 7.0 Hz, OCH$_2$C*H*$_3$), 2.18 (2H, m, H$^5$ and H$^7$), 3.1-3.3 (4H, m, H$^{4a}$, H$^5$, H$^7$, and H$^{7a}$), 3.86 (1H, m, H$^4$), 4.32 (2H, q, $J$ = 7.0 Hz, OC$H_2$CH$_3$), 4.34 (1H, m, H$^8$), 6.61 (2H, m, H$^3$, H$^9$, and H$^{10}$), and 8.46 (1H, br, NH); $^{13}$C NMR δ 14.5 (OCH$_2$*C*H$_3$), 36.6, 36.9 (C4a and C7a), 47.2, 47.9 (C5 and C7), 55.9 (C4 and C8), 60.1 (O*C*H$_2$CH$_3$), 113.6 (C3), 115.0 (C1), 130.8 (C3a), 135.6 (C9 or C10), 135.7 (C8a), 136.3 (C9 or C10), and 161.2 ($CO_2$); IR (KBr) $\nu_{max}$ 3172, 1691, 1291, and 1040 cm$^{-1}$; EI-MS *m/z* 291 (M$^+$), 189, 143, and 115. Anal. Calcd for $C_{15}H_{17}NO_3S$+1/2$H_2O$: C, 59.98; H, 6.00; N, 4.66. Found: C, 60.16; H, 5.84; N, 4.66%.

**Ethyl (4R*,4aS*,6R*,7aR*,8S*)-4,4a,5,7,7a,8-hexahydro-6,6-dioxo-4,8-etheno-2*H*-thieno[3,4-*f*]iso-indole-2- carboxylate (13)**

Pyrrole **11** (1.02g, 3.70 mmol) was dissolved in $CH_2Cl_2$ (45 mL). To the solution was added mCPBA (70%, 1.82 g, 7.38 mmol) at 0 ºC. After the mixture was stirred at room temperature for 2 h, the mixture was diluted with EtOAc (80 mL). The mixture was washed with a 5% aqueous $NaHSO_3$ solution (50 mL) and saturated aqueous $NaHCO_3$ solution (5 x 60 mL). After concentration, the residual solid was recrystallized from EtOAc/hexane to give 650 mg (58%) of the title compound as colorless crystals. Another crop (382 mg, 33%) was obtained by colum chromatograph of the mother liquor on silica gel (0-5% EtOAc/$CHCl_3$). Combined yield: 91%; colorless crystals: mp 193-194 ºC; $R_f$ 0.15 (5% EtOAc/$CHCl_3$); $^1$H NMR δ 1.35 (3H, t, $J$ = 7.3 Hz, OCH$_2$C*H*$_3$), 2.63 (4H, m, H$^{4a}$, H$^5$, H$^7$, and H$^{7a}$), 3.23 (2H, m, H$^5$ and H$^7$), 3.88 (1H, m, H$^4$), 4.30 (2H, m, OC$H_2$CH$_3$), 4.37 (1H, m, H$^8$), 6.61 (2H, m, H$^3$, H$^9$, and H$^{10}$), and 8.95 (1H, br, NH); $^{13}$C NMR δ 14.2 (OCH$_2$*C*H$_3$), 37.0, 37.3 (C4a and C7a), 39.8, 40.5 (C5 and C7), 56.4, 56.4 (C4 and C8), 60.4 (O*C*H$_2$CH$_3$), 113.5 (C3), 115.0 (C1), 129.9 (C3a), 134.5 (C8a),

135.9, 136.6 (C9 and C10), and 161.2 ($CO_2$); IR (KBr) $\nu_{max}$ 3382, 1695, 1299, and 1143 $cm^{-1}$; EI-MS *m/z* 307 ($M^+$), 189, 143, and 115. Anal. Calcd for $C_{15}H_{17}NO_4S$: C, 58.61; H, 5.57; N, 4.56. Found: C, 58.65; H, 5.60; N, 4.57%.

*Crystallographical data for* **13**: $C_{15}H_{17}NO_4S$; FW = 307.36, colorless prisms, 0.55 x 0.2 x 0.15 mm, *orthorhombic*, *Pbca* (#61), $Z = 8$ in a cell of dimensions $a = 14.075(7)$ Å, $b = 10.754(5)$ Å, $c = 19.460(9)$ Å, $V = 2946(2)$ $Å^3$, $D_{calc} = 1.386$ $g \cdot cm^{-3}$, *Mo Kα*, $F(000) = 1296$, $T = 288$, 3314 unique reflections, 2798 with $F^2 > 2\sigma(F^2)$. The final $R_1 = 0.073$, $wR_2$ *(all)* = 0.2131, goodness-of-fit = 1.171 for 209 parameters refined on $F^2$, CCDC No. 680272.

**Preparation of porphyrin 15**

A 1.0-M $LiALH_4$ solution of dry THF (4.0 mL, 1.0 mmol) was placed in a round-bottomed flask equipped with a magnetic stirring bar and a rubber serum cap with a nitrogen balloon. The vessel was thoroughly wrapped with an aluminum foil. To the $LiAlH_4$ solution was slowly added a solution of pyrrolecarboxylate **11** (136 mg, 0.494 mmol) in dry THF (15 mL) by syringe at 0 °C over 30 min. After the addition, the reaction mixture was allowed to warm up to rt and stirred overnight. After the disappearance of **11** was checked by TLC, the mixture was quenched by addition with water (20 mL), and the mixture was extracted with EtOAc (3 x 20 mL). The organic extract was washed with brine and dried over $Na_2SO_4$, and concentrated *in vacuo.* This crude mixture was diluted with $CH_2Cl_2$ (150 mL) under nitrogen. *p*-Toluenesulfonic acid monohydrate (20 mg, 0.05 mmol) was added and the mixture was stirred at rt for 12 h in the dark. Then, *p*-chloranil (159 mg, 0.61 mmol) and $Zn(OAc)_2 \cdot 2H_2O$ (220 mg, 1.00 mM) were added and the mixture was stirred for additional 24 h. The reaction mixture was washed with a saturated aqueous $NaHCO_3$ solution (100 mL), water (100 mL), and brine (100 mL), dried over $Na_2SO_4$, passed through a short column of silica gel, and concentrated *in vacuo*. The residue was recrystallized from $CHCl_3$/MeOH to give 8.0 mg (7%) of the title compound as a mixture of diastereomers. Purple powdery solid: $R_f = 0.15$ ($CHCl_3$); $^1H$ NMR δ 2.53-3.13 (24H, m), 5.28-5.38 (8H, m), 7.07-7.14 (8H, m), and 10.13-10.21 (4H, m); UV-vis ($CHCl_3$) $\lambda_{max}$ [relative intensity] 405 [1.000], 531 [0.056], 565 [0.045], and 615 [0.051]; MALDI-TOF MS: m/z = 921 [$M^+$ ($^{68}Zn$) + 1].

**ACKNOWLEDGEMENTS**

This work was partially supported by Grant-in-Aid for Scientific Research B (17350022) from Ministry of Education, Culture, Sports, Science and Technology of Japan.

**REFERENCES AND NOTES**

1. T. L. Gilchrist and S. J. Higgins, "*Benzo[c]thiophenes,*" in "*Hetarenes and Related Ring Systems,*

*Fused Five-Membered Hetarenes with One Heteroatom*," ed. by E. J. Thomas, in a series of "*Science of Synthesis*," George Thieme Verlag, Stuttgart, 2000, **10.5**, 185.

2. G. M. Brooke and S. D. Mawson, *J. Chem. Soc., Perkin Trans. 1*, 1990, 1919; G. M. Brooke and J. A. K. J. Ferguson, *J. Fluorine Chem.*, 1988, **41**, 263.
3. A recent report, see: H. Uno, Y. Shimizu, H. Uoyama, Y. Tanaka, T. Okujima, and N. Ono, *Eur. J. Org. Chem.*, 2008, 87.
4. H. Uno, K. Nakamoto, K. Kuroki, A. Fujimoto, and N. Ono, *Chem. Eur. J.*, 2007, **13**, 5773; Y. Shimizu, Z. Shen, T. Okujima, H. Uno, and N. Ono, *Chem. Commun*., 2004, 374; Y. Simizu, Z. Shen, S. Ito, H. Uno, J. Daub, and N. Ono, *Tetrahedron Lett*., 2002, **43**, 8485.
5. P. B. Shea, J. Kanicki, L. R. Pattison, P. Petroff, M. Kawano, H. Yamada, and N. Ono, *J. Appl. Phys.*, 2006, **100**, 034502; S. Aramaki, Y Sakai, and N. Ono, *Appl. Phys. Lett.*, 2004, **84**, 2085.
6. T. Okujima, Y. Hashimoto, G. Jin, H. Yamada, H. Uno, and N. Ono, *Tetrahedron*, 2008, **64**, 2405.
7. R. N. McDonald and C. E. Reineke, *Org. Synth. Col. Vol.*, 1988, **6**, 461.
8. B. P. Mundy and J. J. Theodore, *J. Am. Chem. Soc.*, 1980, **102**, 2005.
9. R. A. Aitken, J. I. G. Cadogan, I. Gosney, and S. F. Newlands, *J. Chem. Soc., Perkin Trans. 1*, 1994, 2301.
10. T. Murashima, R. Tamai, K. Fujita, H. Uno, and N. Ono, *Tetrahedron Lett.*, 1996, **37**, 8391.
11. T. Imahori, YAKUGAKU ZASSHI, 2004, **124**, 509.
12. S. Cossu, O. De Lucchi, and F. Dilillo, *Gazz., Chim. Ital*., 1989, **119**, 519; O. De Lucchi, V. Lucchini, L. Pasquato, and G. Modena, *J. Org. Chem*., 1984, **49**, 596.
13. H. Ono, *Heterocycles*, 2008, **75**, 243.
14. X-ray data were processed by CrystalStructure Ver. 3.8.2. Structures were solved by SIR-97 and then refined by SHELXL-97. CrystalStructure Ver. 3.8.2: Rigaku (3-9-12 Akishima, Tokyo, Japan) and Rigaku/MSC (9009 New Trails Dr., The Woodlands, TX 77381 USA), (2006). SIR-97: Istituto di Gristallografia, Italy; A. Altomare, M. C. Burla, M. Camalli, G. Cascarano, C. Giacovazzo, A. Guagliardi, A. G. G. Moliterni, G. Polidori, and R. Spagna, *J. Appl. Cryst*., 1999, **32**, 115. SHELXL-97: University of Göttingen, Göttingen, Germany; G. Sheldrick and T. Schneider, *Methods Enzymol.*, 1997, **277**, 319.
15. H. Uno, S. Ito, M. Wada, H. Watanabe, M. Nagai, A. Hayashi, T. Murashima, and N. Ono, *J. Chem. Soc., Perkin Trans. 1*, 2000, 4347.
16. K. M. Smith, "*Porphyrins and Metalloporphyrins,*" Elsevier, Amsterdam, 1975.