Synthetic Approach to Pentaleno[2,1-*b*:5,4-*b*']diindoles[1]

Kotha Sambasivarao, Sean Hollinshead, Desiree Grubisha, Frank Laib, Dennis Bennett, and James M. Cook*

Department of Chemistry, University of Wisconsin—Milwaukee, Milwaukee, Wisconsin 53201

Received January 5, 1990

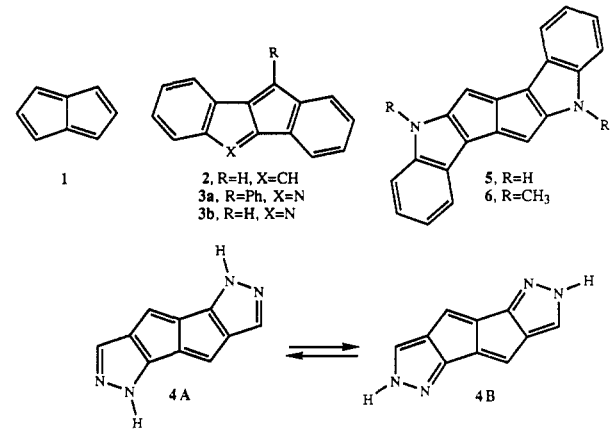
A combination of the Weiss reaction and the Fischer indole cyclization was employed to prepare the hexahydro-5,11-dihydropentaleno[2,1-*b*:5,4-*b*']diindoles **8** and **10**. These diindole perhydropentalenes were converted into a variety of 6,12-disubstituted derivatives (LH, Scheme I); numerous attempts were made to convert these intermediates into bis(indolo-substituted)pentalenes **5** or **6** via removal of the elements of LH. The elimination of one molecule of water from diphenylperhydropentalenediol **24** to provide triene **25** was successfully carried out, but further treatment yielded only the product of ring scission, the 2-phenylcyclopenta[*b*]indol-1-yl derivative **27a**. In the mass spectrum of the 6,12-substituted *exo,exo*-diesters **15** and **17** an intense peak (−2LH) corresponding to the mass for pentalene **6** was evident at 308 Da; however, all attempts to execute this cis(syn) elimination in the laboratory were unsuccessful. The 6,12-*exo,exo*-bis-sulfoxide and the corresponding bis-selenoxide derivative of **10** also failed to provide any of the desired pentalene **6**. As a final attempt the diphenyl diol **24** was treated with phenylselenol in the presence of zinc iodide; however, again ring scission took place to provide the diene **30** rather than the bis(phenylseleno)perhydropentalene **31**. The structure of **30** was elucidated by single-crystal X-ray analysis.

Introduction

Numerous attempts to isolate pentalene **1** by conventional synthetic methods over the last 60 years have been unsuccessful;[2] however, 1-methylpentalene was observed to dimerize at −140 °C.[3] The presence of bulky substituents in the pentalene framework appears to prevent dimerization. For example, the hexaphenyl,[4] bis(1,3-dimethylamino),[5] 1,3,5-tri-*tert*-butyl,[6] and benzoannulated pentalenes[7a] have been isolated and exhibit substantial stability. Dibenzopentalene **2** is a bronze-colored solid which readily polymerizes and behaves as a conjugated olefin. It absorbs four atoms of hydrogen in the presence of a catalyst and reacts vigorously with bromine via addition.[7a] A tetra-*tert*-butyl derivative of cyclopenta[*a,e*]pentalene has been prepared recently by Hafner.[7b] There have also been attempts to isolate pentalene by complexation with metal carbonyls.[8]

A group of pentalenes studied less extensively include those wherein one or two heteroatoms have been incorporated into the pentalene skeleton.[9,10] One example in this category is 10-phenyldibenzo[*b,f*-1]azapentalene **3a** synthesized several years ago by Eisch and Abraham.[10] All attempts to prepare the parent dibenzo[*b,f*-1]azapentalene **3b** have been unsuccessful; moreover, electron-transfer reactions appear to be the origin of dimers formed in this series rather than the intermediate azapentalene **3b**.[11] Numerous radical anions and trianions related to pentalenes have been studied extensively,[12] but formation of dications in this series has, to date, eluded experimentalists. There is only one report in which a pentalene is stabilized by heteroaromatic rings, the structure of which is represented by **4**.[13] LeGoff and Camp prepared the dipyrazolopentalene **4**, a heteroannulated analogue of dibenzopentalene, the stability of which is presumably enhanced by contribution from structures **4a** and **4b**. However, on the basis of the NMR spectrum of this material,[13] the molecule is better represented by **4b** rather than the pentalene **4a**. In connection with a program directed toward the synthesis of cyclopentapentalenes,[14] it was of interest to synthesize **5** or **6**, both of which are diindole analogues of dibenzopentalene **2**.

As illustrated in Scheme I, the bis(indolo-substituted)pentalene **5** or **6** could be envisaged to arise from the loss of two molecules of LH from a suitably substituted dihydropentalene **7**. Two independent pathways were devised, one of which (path A) centered on the previous



(1) Portions of this work were presented at the 197th American Chemical Society National Meeting, Dallas, Texas, April 9–14, 1989: Sambasivarao, K.; Cook, J. M., Functionalization of the *cis*-Bicyclo[3.3.0]octane-3,7-dione Unit and its Application to the Synthesis of Cyclopentapentalenes; Abstract ORGN-0194. Hollinshead, S.; Sambasivarao, K.; Cook, J. M. Studies Directed Toward the Synthesis of Diazapentalenes. Presented at the 22nd Great Lakes Regional Meeting, of the American Chemical Society, University of Minnesota-Duluth, Duluth, MN, May 31–June 2, 1989; Abstract No. 97.

(2) (a) Badger, G. M. *Aromatic Character and Aromaticity*; Cambridge University Press: New York, 1969. (b) Lloyd, D. *Non-Benzenoid Conjugated Carbocyclic Compounds*; Elsevier: New York, 1984; p 377. (c) Paquette, L. A. In *Topics in Current Chemistry*; Springer-Verlag: New York, 1984; Vol. 119, p 58. *Ibid.* 1979; Vol. 79, p 80. Paquette, L. A.; Doherty, A. M. In *Polyquinane Chemistry*; Springer-Verlag: New York, 1987; p 77.

(3) Block, R.; Marty, R. A.; de Mayo, P. *J. Am. Chem. Soc.* **1971**, *93*, 3071.

(4) LeGoff, E. *J. Am. Chem. Soc.* **1962**, *84*, 3975.

(5) Hafner, K.; Bangert, K. F.; Orfanos, V. *Angew. Chem., Int. Ed. Engl.* **1967**, *6*, 451.

(6) Hafner, K.; Süss, H. *Angew. Chem., Int. Ed. Engl.* **1973**, *12*, 575. Hafner, K.; Donges, R.; Goedecke, E.; Kaiser, R. *Angew. Chem.* **1973**, *85*, 362.

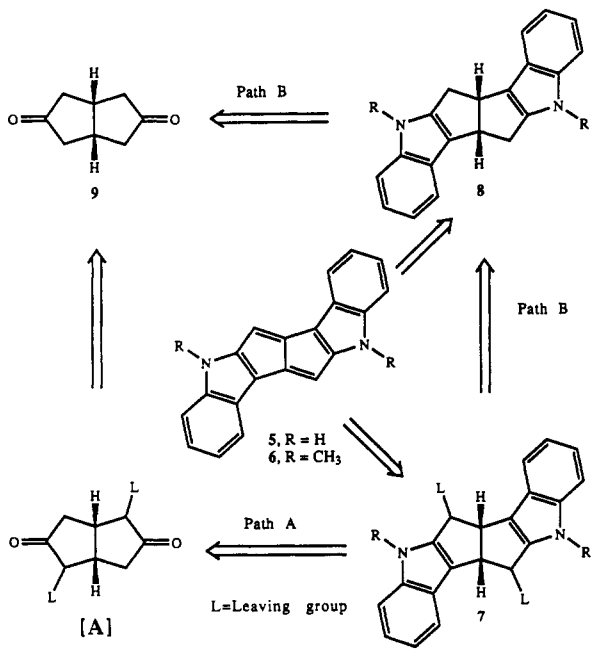
(7) (a) Blood, C. T.; Linstead, R. P. *J. Chem. Soc.*, **1952**, 2263. Bergmann, E. In *Non Benzenoid Aromatic Compounds*; Ginsberg, D., Ed.; Wiley Interscience: New York, 1959; p 149. LeGoff, E. *J. Am. Chem. Soc.* **1962**, *84*, 1505. Balaban, A.; Banciu, M.; Ciorba, V. In *Annulenes, Benzo-, Hetero-, Homoderivatives and Valence Isomers*; CRC Press: Boca Raton, FL, 1987, p 118. (b) Hafner, K.; Stowasser, B. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 466. Vogel, E.; Schmalstieg, L.; Weyer, H.-J.; Gleiter, R. *Chem. Lett.* **1987**, *33*. Donges, R.; Hafner, K.; Lindner, H. *Tetrahedron Lett.* **1976**, 1345.

(8) Knox, S. A. R.; Stone, F. G. A. *Acc. Chem. Res.* **1974**, *7*, 321 and references cited therein.

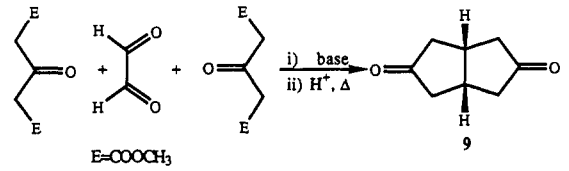
* To whom correspondence should be addressed.

0022-3263/90/1955-3858$02.50/0

Scheme I. Retrosynthetic Analysis[15]



Scheme II

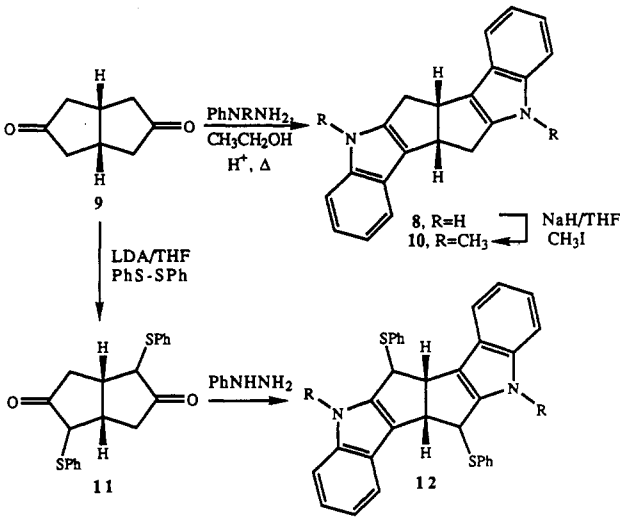


incorporation of the leaving groups into the *cis*-bicyclo[3.3.0]octane-3,7-dione unit ([A][13]) followed by two simultaneous regiospecific Fischer indole cyclizations to furnish **7**. Path B involves a regiospecific bis Fischer indolization with the readily available *cis*-bicyclo[3.3.0]octane-3,7-dione **9**[19] to provide **8**, followed by introduction of the two leaving groups in a stereospecific manner (see **7**).

Results and Discussion

The approach toward **5** or **6** began, as noted, with **9**, which is available on large scale from the Weiss reaction (Scheme II).[19] The 2,6-bis(phenylthio)-*cis*-bicyclo[3.3.0]octane-3,7-dione **11** was originally prepared by the method of Bertz;[20] however, it was found that **11** could be obtained in improved fashion by the method of Camp.[13] This involved treatment of **9** with LDA (10 M nBuLi was employed) at −78 °C after which the dianion was quenched

Scheme III



with diphenyl disulfide. The major product **11** of this process (Scheme III) was easily removed from undesirable byproducts by column chromatography and was identical with that reported by Bertz.[20] When **11** was heated with phenylhydrazine, under standard conditions of the Fischer indole cyclization,[16-18] a small amount of **12** was obtained, accompanied by several other compounds. The structure of **12** was confirmed by independent synthesis (see below). Separation of this diindole from the other components of the mixture (Scheme III) proved difficult and this approach was abandoned in favor of path B.

Analogous to previous work on the synthesis of diindoles,[17,18] **9** was reacted with phenylhydrazine in the presence of a catalytic amount of hydrochloric acid. The diindole **8** was isolated from this process in 20% yield as the sole identifiable material. The disposition of the two double bonds in **8** was established as anti and none of the syn,syn bicyclo[3.3.0]octanediene regioisomer was observed. This is in keeping with the preferred anti orientation of double bonds in the *cis*-bicyclo[3.3.0]octane system (see ref 21 for details). Numerous reaction conditions (H_2SO_4, HOAc, polyphosphoric acid) were employed, none of which served to increase the yield of **8**. The bis-tosylhydrazone of **9** was also prepared[16,17] and subjected

(9) Tanaka, S.; Satake, K.; Kiyomine, A.; Kumagai, T.; Mukai, T. *Angew. Chem., Int. Ed. Engl.* **1988**, *27*, 1061. Treibs, W. *Chimia* **1968**, *22*, 467. Treibs, W. *Chimia* **1972**, *26*, 627.

(10) Eisch, J. J.; Abraham, T. *Tetrahedron Lett.* **1976**, *20*, 1647.

(11) Abraham, T.; Curran, D. *Tetrahedron* **1982**, *38*, 1019. Abraham, T. *Monatsh. Chem.* **1982**, *113*, 1275. Abraham, T. *Monatsh. Chem.* **1989**, *120*, 117.

(12) Gerson, F.; Gescheidt, G. *Helv. Chim. Acta* **1988**, *71*, 1011. Katz, T. J.; Rosenberger, M. *J. Am. Chem. Soc.* **1962**, *84*, 865. Katz, T. J.; Rosenberger, M.; O'Hara, R. K. *J. Am. Chem. Soc.* **1964**, *86*, 249. Rabinovitz, M. In *Topics in Current Chemistry*; Springer-*Verlag*: New York, 1987; Vol 146, p 99.

(13) Camp, J. H. M. S. Thesis, Michigan State University, 1986.

(14) Lannoye, G.; Sambasivarao, K.; Wehrli, S.; Cook, J. M. *J. Org. Chem.* **1988**, *53*, 2327.

(15) Trombini, C. *da La Chimica and L'Industria* **1987**, 82. Corey, E. J.; Cheng, X.-M. *The Logic of Chemical Synthesis*; John Wiley: New York, 1989.

(16) Robinson, B. *Chem. Rev.* **1969**, *69*, 227. Robinson, B. *The Fischer Indole Synthesis*; Wiley-Interscience: New York, 1982. Crooks, P. A.; Robinson, B. *Chem. Ind.* **1967**, 547.

(17) Trudell, M. L.; Fukada, N.; Cook, J. M. *J. Org. Chem.* **1987**, *52*, 4293. Tan, Y.-C.; Trudell, M. L.; Cook, J. M. *Heterocycles* **1988**, *27*, 1607. Trudell, M. L.; Basile, A. S.; Shannon, H. E.; Skolnick, P.; Cook, J. M. *J. Med. Chem.* **1987**, *30*, 456.

(18) Bergman, J.; Pelcman, B. *J. Org. Chem.* **1989**, *54*, 826. Thummel, R. P.; Hegde, V. *J. Org. Chem.* **1989**, *54*, 1720. Berthel, S. J.; Gribble, G. W. *Abstracts of Papers*, 197th National Meeting American Chemical Society, Dallas, TX, Spring 1989; American Chemical Society: Washington, DC, 1989; Abstract No. 116. Gribble, G.; Fletcher, G.; Ketcha, D.; Rajopadhye, M. *J. Org. Chem.* **1989**, *54*, 3264.

(19) Weiss, U.; Edwards, J. M. *Tetrahedron Lett.* **1968**, 4885. Bertz, S. H.; Cook, J. M.; Gawish, A.; Weiss, U. *Org. Synth.* **1986**, *64*, 27.

(20) Bertz, S. H. *Tetrahedron Lett.* **1983**, *24*, 5577. Bertz, S. H. Ph.D. Thesis, Harvard University, 1978.

(21) Gawish, A.; Cook, J. M. Unpublished results. See also: Gupta, A. K.; Lannoye, G. S.; Kubiak, G.; Schkeryantz, J.; Wehrli, S.; Cook, J. M. *J. Am. Chem. Soc.* **1989**, *111*, 2169.

(22) Stork, G.; Brizzolara, A.; Landesman, H.; Szmuszkovicz, J.; Terrel, R. *J. Am. Chem. Soc.* **1963**, *85*, 207.

(23) For a similar observation on an enol ether of the *cis*-bicyclo[3.3.0]octane system, see: Camps, P. *Tetrahedron Lett.* **1974**, 4067.

(24) Barton, D. H. R.; Ollis, W. D. *Comprehensive Organic Chemistry*; Pergamon Press: New York, 1979.

(25) Greene, T. W. In *Protective Groups in Organic Synthesis*; Wiley-Interscience: New York, 1981.

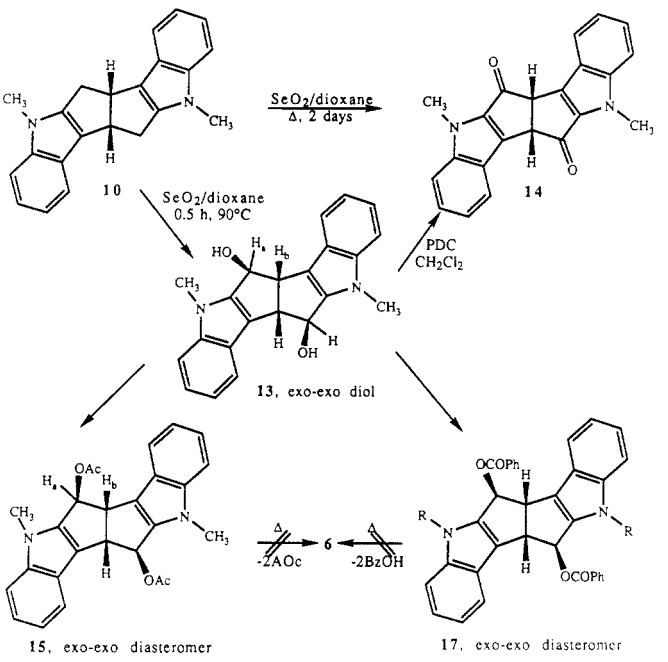
to Fischer indole cyclization; however, no increase in yield was realized. The structure of **8** was established on the basis of spectroscopic evidence. The molecule possesses a 2-fold axis of symmetry (C_2) which is in agreement with the 10-line ^{13}C NMR spectrum [δ 31.20 (t), 47.61 (d), 111.68 (d), 117.95 (d), 119.47 (d), 120.59 (d), 121.77 (s), 124.24 (s), 142.12 (s), 141.32 (s)] of the material with appropriate multiplicities. The mechanism of the Fischer indolization toward **8** involves two enehydrazine intermediates which simultaneously undergo [3,3] sigmatropic rearrangements, followed by losses of ammonia to generate the tetrahydropentalenodiindole **8**.[16-18] The disposition of the two bis-enehydrazines is anti, analogous to formation of the thermodynamically more stable bis-enamine of **9** reported earlier.[21] As mentioned, none of the syn,syn regioisomer was observed or isolated from this sequence.

With **8** in hand, attention turned to introduction of the required olefinic bonds by removal of two molecules of hydrogen (from **8**) to provide **5**. When **8** was subjected to a variety of reagents to effect dehydrogenation [S, Se, Pd, DDQ, SeO_2, or MnO_2], starting material was recovered. More vigorous conditions resulted only in products of decomposition and no evidence for the formation of the pentalene **5** was observed. At this juncture it was decided to remove the influence of the two indole N–H groups on the stability of **5** by conversion into the dimethyl tetrahydropentalene **10**. This was effected in 90% yield by treatment of **8** with sodium hydride and methyl iodide in tetrahydrofuran. The structure of **10** was entirely consistent with the observed spectroscopic data (see Experimental Section for details). A shorter route to **10** was developed by simply replacing phenylhydrazine with 1-methyl-1-phenylhydrazine in the Fischer indole cyclization. This gave **8** in greater than 50% yield. Since six new bonds, two protecting groups (CH_3), and four rings were appended to the dione **9** in a one-pot reaction,[26] no attempt to further improve the yield of **10** has been made. Again, when **10** was subjected to oxidation with a variety of dehydrogenating agents [Pd, S, Se, SO_2, MnO_2, $PdCl_2$, DDQ] similar to those attempted with **8**, no evidence for the formation of **6** was observed. This is not surprising in regard to the high reactivity and reported antiaromatic character of pentalenes.[2-8]

Attention now turned to functionalization of the bis(indolo-substituted)perhydropentalene nucleus **10** to provide intermediates related to **7** (Scheme I) which could either undergo E_2 elimination or cis-(syn) elimination. Initially, **10** was reacted with *N*-bromosuccinimide to functionalize the allylic positions of the molecule, but the results, while encouraging, were inconsistent. Since selenium dioxide (SeO_2) had been employed extensively in our laboratory to prepare 3-acylindoles,[27] the diindole **10** was heated with this reagent at 90 °C to provide the *exo,exo*-diol **13** (mp 229–230 °C) in 46% yield. A number of mono- and dioxygenated byproducts accompanied **13** in this process. Prolonged treatment of **10** with selenium dioxide in refluxing dioxane provided the diketone **14** in 56% yield after purification on silica gel.

The gross structure of **13** was established by ^{13}C NMR spectroscopy [(C_2), 10 lines] and mass spectroscopy [*m/e* 344 (28)]. The stereochemistry and disposition of the two hydroxyl groups were deduced from examination of the ^1H NMR spectrum of **13**. A singlet (2 H), which could be

Scheme IV



assigned to proton H_b, was located at δ 4.45 ppm, while a doublet which represented H_a was found at 5.22 ppm (2 H); this latter signal collapsed to a singlet on treatment of **13** with deuterium oxide. Examination of molecular models indicates that a slight distortion in the *cis*-bicyclo[3.3.0]octanedione skeleton results in a dihedral angle of approximately 90° between H_a and H_b in the *exo,exo*-diol **13**.[28] This results in the appearance of these two signals as singlets in the proton NMR spectrum of **13**.[29] In addition, attack of the reagent (SeO_2) from the convex face of the *cis*-bicyclo[3.3.0]octane system[14,21] would provide the *exo,exo*-diol **13** in agreement with the above assignment. The diol **13** was also oxidized with PDC in dichloromethane to provide the diketone **14** in 90% yield, which confirmed the intermediacy of **13** on the pathway to **14** during oxidation with SeO_2.

In order to attempt a syn elimination (pyrolysis), conversion of the diol **13** into the *exo,exo*-diacetate **15** or into the corresponding dibenzoate **17** was accomplished under standard conditions (Scheme IV). The structures of both diesters were confirmed by comparison of their ^1H and ^{13}C NMR spectra, respectively, with those of the *exo,exo*-diol **13**. In the ^1H NMR spectrum of both **15** and **17** the aliphatic methine protons (H_a, H_b) in the bicyclo[3.3.0]octane nucleus were observed as singlets which confirmed the exo,exo nature of the ester function. Attempts to effect the thermally induced (syn) elimination of the ester functions at temperatures ≥ mp (0.5 mmHg) from **15** or **17**, respectively, to provide pentalene **6** resulted in recovery of sublimed starting ester or tarry products of decomposition. However, pyrolysis of either diacetate **15** or the dibenzoate **17** in the mass spectrometer resulted in the observed loss of two molecules of acetic or benzoic acid, respectively, to provide an ion at 308 Da. This corresponds to the mass required for the desired pentalene **6** and served as the base peak (100%) in the spectrum of **15** and an intense peak (70%) in the spectrum of the dibenzoate **17**. This ion was neither present in the mass spectrum of diol **13** nor of **19**. Experiments designed to convert the diol **13** into the bis-dinitrobenzoate to provide better leaving

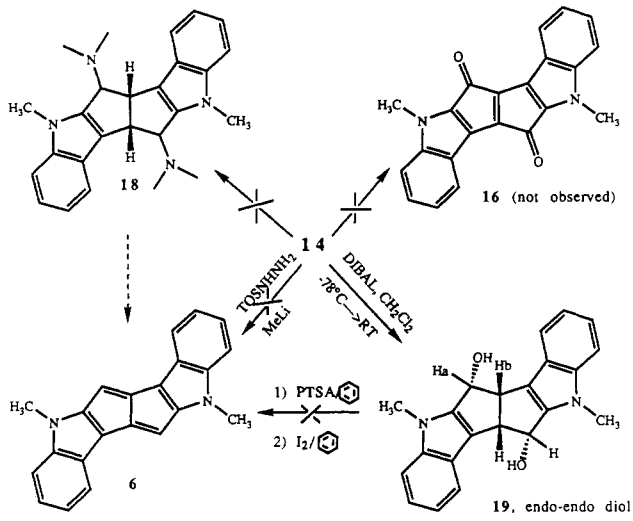
(26) For a description of this type of annulation reaction, see: Posner, G. H. *Chem. Rev.* **1986**, *86*, 831.

(27) Cain, M.; Campos, O.; Guzman, F.; Cook, J. M. *J. Am. Chem. Soc.* **1983**, *105*, 907. Compos, O.; DiPierro, M.; Cain, M.; Mantei, R.; Gawish, A.; Cook, J. M. *Heterocycles* **1980**, *14*, 975. Campos, O.; Cook, J. M. *Tetrahedron Lett.* **1979**, 1025.

(28) Karplus, M. *J. Chem. Phys.* **1959**, *30*, 11.

(29) Karplus, M.; Pople, J. A. *J. Chem. Phys.* **1963**, *38*, 2803.

Scheme V



groups for the syn elimination were unsuccessful and led only to products of decomposition or solvolysis.

The failure of the pyrolysis reactions prompted investigation of the 2,6-dioxo-*cis*-bicyclo[3.3.0]octane system, itself, as an intermediate toward **6**. Enones have been shown to be useful precursors for the synthesis of pentalene derivatives[30] (Scheme V); however, reaction of **14** with palladium(II) chloride (tBuOH/HCl) or *N*-bromosuccinimide in chloroform did not furnish the desired enone **16**. A similar result was obtained when **14** was heated with phenylselenic anhydride.

Attempts to prepare the tosylhydrazone of **14** under a variety of conditions were unsuccessful precluding an approach toward **6** via a Shapiro reaction,[31a] moreover heating **14** with formamide and formic acid, followed by formic acid and formaldehyde[5,31b] did not provide the desired bis(dimethylamino) derivative **18**. Treatment of dione **14**, however, with diisobutylaluminum hydride in methylene chloride furnished the *endo,endo*-diol **19** (mp 227–229° C) in 95% yield. The stereochemistry of diol **19** is opposite to that of diol **13**. The aliphatic methine protons (H_b and H_a) in **19** were observed as two complex multiplets at δ 4.59 and 5.33 ppm, respectively, the latter signal collapsed to a doublet of doublets on treatment of **19** with deuterium oxide. The dihedral angles between H_a, H_b, and H_c are all near 0°, consequently a complex coupling pattern was observed.[14,29] Moreover, W coupling between the protons attached to the hydroxy-substituted carbon atoms also complicated the spectrum. Because of the twist of the *cis*-bicyclo[3.3.0]octanediene system, H_a and H_d are not equivalent, although their chemical shifts are very similar. The *endo,endo*-diol **19** was heated in benzene in the presence of *p*-toluenesulfonic acid or in the presence of iodine; however, none of the desired **6** was observed.

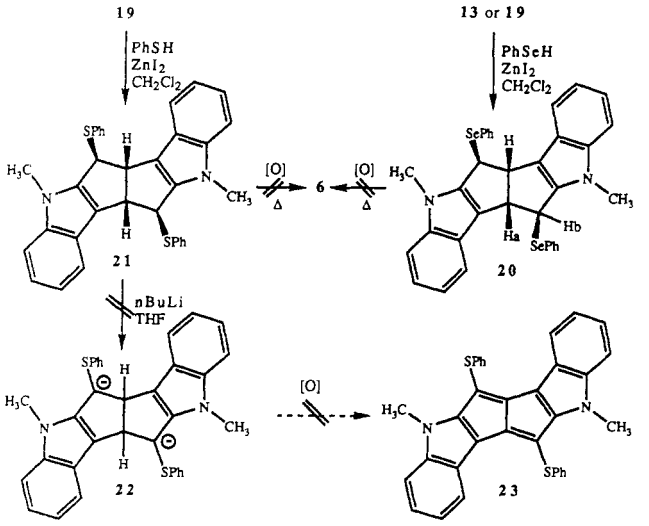
To find milder conditions for the introduction of the remaining two olefinic bonds into **10** (to generate **6**), we turned toward the preparation of **7** wherein L represented either an *exo*-phenylsulfoxo or *exo*-phenylselenoxyl function[33] targeted for a syn elimination. When the *endo,endo*-diol **19** was treated with *o*-nitrophenyl selenocyanide,[34] a mixture of products was formed which lacked C_2 symmetry. However, it had been reported by Clarembeau et al. that hydroxyl groups which are suitably activated, could be replaced by a phenylseleno function via an S_n1 process.[35] Consequently, *endo,endo*-diol **19** was stirred with benzeneselenol in dichloromethane in the presence of zinc iodide (Scheme V) at room temperature and provided the *exo,exo*-bis(phenylseleno)-*cis*-bicyclo[3.3.0]octane derivative **20** in 81% yield. Alternatively, **20** could be obtained by reaction of the *exo,exo*-diol **13** under the same conditions confirming the carbonium ion nature of the process. Because the quality of the bis(phenyl selenide) **20** from the former process was superior to that from the latter, reaction of **19** with benzeneselenol is preferred. The structure and stereochemistry of **20** was based primarily on ^1H and ^{13}C NMR spectroscopy. The symmetry inherent in **20** was apparent from the 15-line ^{13}C NMR spectrum [δ 30.60 (q), 43.78 (d), 58.19 (d), 109.84 (d), 118.60 (d), 119.38 (d), 121.04 (s), 121.32 (d), 123.09 (s), 128.33 (s), 128.56 (d), 129.02 (d), 136.79 (d), 142.36 (s), 142.49 (s)] of the material. Furthermore, in the proton spectrum of **20** the two signals (δ 4.25 and 4.75) which represent the aliphatic methine hydrogen atoms were observed as singlets, analogous to the signals observed for the *exo,exo*-diol **13**. Again, this is consistent with a dihedral angle of approximately 90° between protons H_a and H_b.

Although several methods were available for selenoxide formation,[36] initially **20** was treated with *m*-chloroperbenzoic acid in dichloromethane. No evidence for either selenoxide or pentalene **6** formation was observed; these reactions either returned **20** or yielded tarry polymeric material. In an effort to isolate the bis-(phenyl selenoxide) intermediate, **20** was subjected to ozonolysis at low temperature. Thin-layer chromatography of the reaction solution indicated that **20** had been consumed; however, chromatography (silica gel) at low temperature yielded neither the bis-selenoxide nor pentalene **6**. Since the benzeneselenic acid which forms during the elimination process might effect decomposition of **6**, the milder methods of oxidation reported by Davis[37] were explored. When **20** was treated with the Davis reagent[37] in the presence of ethyl vinyl ether (benzeneselenic acid trap),[38] only tarry material or starting **20** were observed on workup.

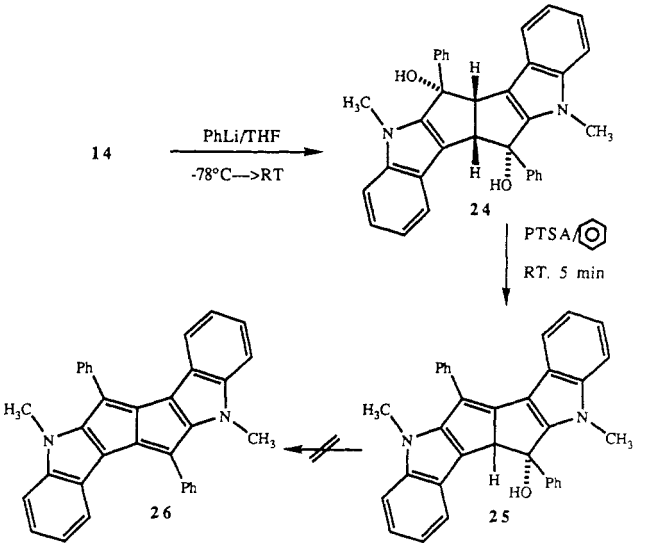
Since selenoxides are difficult to isolate and purify, attention turned to preparation of the corresponding bis-sulfoxide, although phenylselenoxides undergo syn elimination[36] at lower temperature than the corresponding bis-sulfoxides. The *endo,endo*-diol **19** was stirred with thiophenol in the presence of zinc iodide[39] to provide the *exo,exo*-bis(phenylthio)-*cis*-bicyclo[3.3.0]octane derivative **21** as a single diastereomer in 79% yield (mp 231–232 °C). The 15-line ^{13}C NMR spectrum of **21** was consistent with the structure as assigned (compare to **20**); moreover, the aliphatic methine protons (^1H NMR) of **21** appeared as singlets again confirming the exo,exo stereochemistry of

(30) Frank, W.; Gompper, R. *Tetrahedron Lett.* **1987**, *28*, 3083.
(31) (a) Shapiro, R. H. *Org. React.* **1976**, *23*, 405. (b) Chuen, C.; Fenton, S. *J. Org. Chem.* **1958**, *23*, 1538.
(32) Pizey, J. S. *Synthetic Reagents*; Ellis Horwood: Chichester, NY 1977; Vol. 3, p 262.
(33) Paulmier, C. *Selenium Reagents and Intermediates in Organic Synthesis*; Pergamon Press: New York, 1986. Liotta, D., Ed. *Organoselenium Chemistry*; John Wiley and Sons: New York, 1987.
(34) Grieco, P. A.; Gilman, S.; Nishizawa, M. *J. Org. Chem.* **1976**, *41*, 1485.
(35) Clarembeau, M.; Krief, A. *Tetrahedron Lett.* **1984**, *25*, 3625.
(36) Reich, H. J.; Wollowitz, S.; Trend, J. E.; Chow, F.; Wendelborn, D. F. *J. Org. Chem.* **1978**, *43*, 1697. Hori, T.; Sharpless, K. B. *Ibid.* **1978**, *43*, 1689.
(37) Davis, F. A.; Stringer, O. D.; Billmers, J. M. *Tetrahedron Lett.* **1983**, *24*, 1213. Davis, F. A.; Nadir, U. K. *Org. Prepn. & Proc. Int.* **1979**, 35. Vishwakarma, L. C.; Stringer, O. D.; Davis, F. A. *Org. Syn.* **1988**, *66*, 203.
(38) Eaton, P. E.; Andrews, G. D.; Krebs, E. P.; Kunai, A. *J. Org. Chem.* **1979**, *44*, 2824.
(39) Guindon, Y.; Frenette, R.; Fortin, K.; Rockach, J. *J. Org. Chem.* **1983**, *48*, 1357.

Scheme VI



Scheme VII



this material analogous to that in **13**. The bis(phenyl sulfide) **21** was oxidized to the bis-sulfoxide with *m*-chloroperbenzoic acid in 75% yield (mp 176–177 °C). The bis-sulfoxide was obtained as a mixture of diastereomers.

When the mixture of *exo,exo*-bis-sulfoxides was treated [benzene (reflux), toluene (reflux), xylene (reflux)] in the presence or absence of agents to trap the benzenesulfenic acid (K_2CO_3; py; Et_3N), no evidence for the formation of **6** was observed. At 78 °C only starting bis-sulfoxide was isolated; however, at temperatures greater than 100 °C only decomposition material was observed. Attempts to execute the syn elimination between 78 °C and 100 °C yielded both the bis-sulfoxide and products of decomposition; moreover, no ion corresponding to the desired pentalene (308 amu) was found in the mass spectrum of the bis-sulfoxide.

de Meijere has successfully employed a dianion approach for the preparation of acepentalenediide;[40] moreover, the generation of an anion followed by addition of an oxidizing agent can be employed to prepare alicyclic olefins. In this regard, the bis-(phenyl sulfide) **21** was stirred with excess *n*-butyllithium in tetrahydrofuran at −78 °C, after which the solution was allowed to warm to 0 °C and was quenched with deuterium oxide. Examination of the ^1H NMR spectrum and mass spectrum of recovered **21** indicated that no deuterium atoms had been incorporated into the molecule excluding the approach to pentalene **23** via oxidation of dianion **22** (Scheme VI).

As noted earlier, the presence of bulky substituents on the pentalene framework retards the dimerization of these reactive olefins.[5-7] Analogous to the work of Hafner,[7b] Brand,[41] and others, stabilization of the bis(indolo-substituted)pentalene **6** was pursued by placement of phenyl substituents at positions 6 and 12 of **10**. A successful route via this approach toward diphenyldibenzo[*a,e*]pentalene had been earlier reported.[41] As outlined in Scheme VII, the 6,12-dioxo bicyclooctane **14** was stirred with phenyllithium in THF (−78 °C → 25 °C) to provide the 6,12-diphenyl *endo,endo*-6,12-dihydroxy bicyclooctane derivative **24** (mp 232–233 °C) in 96% yield. This sequence not only gave the desired 6,12-*endo,endo*-diol, regiospecifically, but provided entry into the desired 6,12-diphenyl system with ease.[7,41] When diol **24** was stirred in benzene with *p*-toluenesulfonic acid (pTSA) in the presence of molecular sieves,[41] a red solid (mp 193–195 °C) was obtained (83% yield) whose structure was shown by spectroscopy to be the triene **25** (Scheme VII).

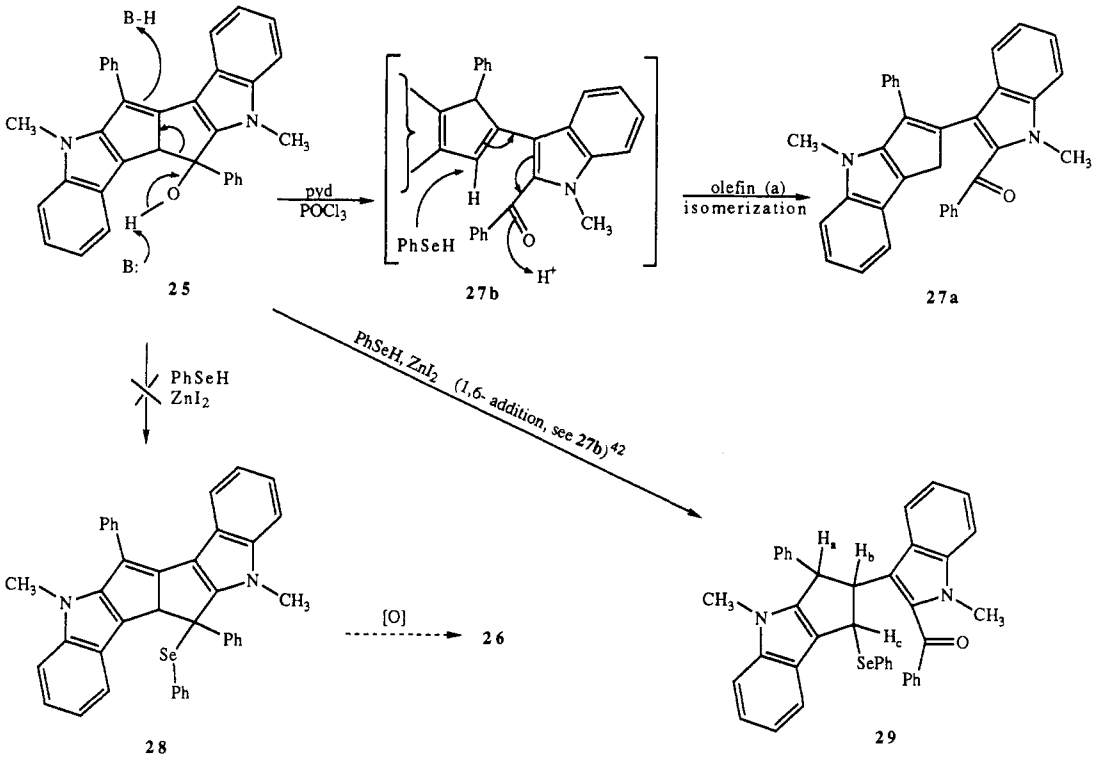
Examination of the IR spectrum of **25** indicated the presence of a hydroxyl band (3438 cm^{-1}), while a one proton singlet at δ 4.45 ppm was observed in the ^1H NMR spectrum of this triene consonant with the single aliphatic methine proton in **25**. The structure was confirmed on comparison of the ^1H and ^{13}C NMR spectra, as well as the mass spectrum, to those of diol **24**.

Removal of water from triene **25** to provide pentalene **26** was attempted under a variety of conditions including PTSA/benzene (reflux), TFA (room temperature), Martins reagent (−20 → room temperature), Amberlite resin CH_2Cl_2), etc. These reactions resulted in intractable mixtures with no evidence for the formation of bis(indolo-substituted) diphenylpentalene **26**. Dehydration of **24** with $POCl_3$, in pyridine effected ring scission of the bicyclooctanediene framework to furnish the phenyl ketone **27a** which presumably arose via intermediate triene **27b**, as illustrated in Scheme VIII. Independent evidence for this mechanism was obtained for treatment of triene **25** with $POCl_3$/py or simply with base, provided the phenyl ketone **27a** in good yield. Ring scission to provide **27b**, followed by olefin isomerization, would account for the formation of phenyl ketone **27a**. The carbonyl group of **27a** was clearly evident in the IR (1640 cm^{-1}) and ^{13}C NMR (δ 190 ppm) spectra of this material (see Experimental Section for details). Since the triene **25** underwent ring fragmentation in the presence of base or decomposition on exposure to acid, it was decided to convert triene **25** into the phenylseleno-substituted triene **28**, a syn elimination of the corresponding selenoxide would presumably provide (indolo-substituted) diphenylpentalene **26**. When **25** was reacted with benzeneselenol in the presence of zinc iodide[35] again a ring-cleaved material was obtained whose structure has been proposed as **29**. None of the desired phenylseleno triene **28** was observed or isolated. The structure of phenyl ketone **29** was confirmed by spectroscopy. The carbonyl group in the IR spectrum of **29** was observed at 1650 cm^{-1}, which was confirmed by a signal at 190 ppm (δ) in the ^{13}C NMR spectrum of the material, analogous to the signal observed in the spectrum of **27a**. In the ^1H NMR spectrum of **29** the three aliphatic protons were observed as an AMX system further complicated by long-range coupling be-

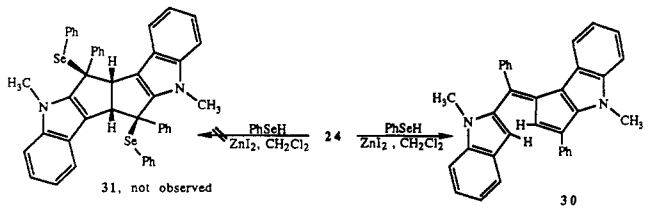
(40) Butenschön, H.; de Meijere, A. *Tetrahedron* **1986**, *42*, 1721. Lendvai, T.; Friedl, T.; Butenschön, H.; Clark, T.; de Meijere, A. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 719.

(41) Brand, K. *Chem. Ber.* **1912**, *45*, 3071. Brand, K.; Gabel, W.; Ott, H. *Chem. Ber.* **1936**, *69*, 2504. Brand, K.; Ludwig, H. *Chem. Ber.* **1920**, *53*, 809. Blood, C. T.; Linstead, R. P. *J. Chem. Soc.* **1952**, *2255*. Brand, K. *Chem. Ber.* **1936**, *69*, 2504.

Scheme VIII



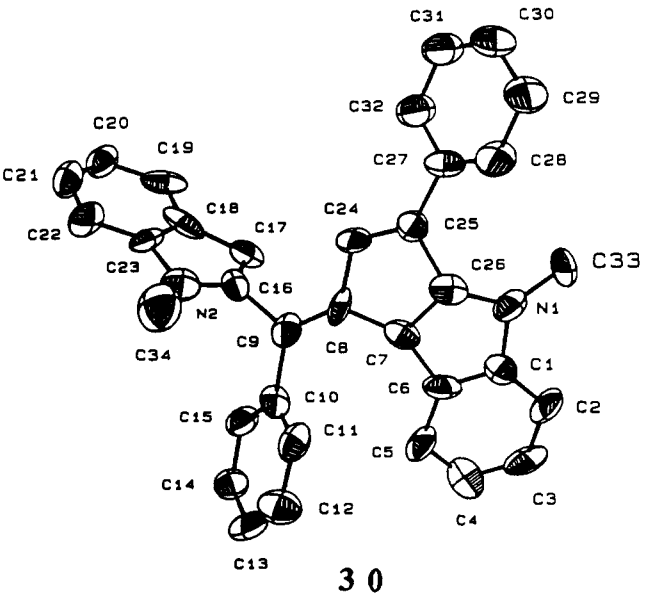
Scheme IX



tween H_a and H_c; the corresponding carbon signals were observed as doublets in the off-resonance coupled ^{13}C NMR spectrum of **29**. The origin of **29** is not clear, for 1,6-addition of phenylselenol (ZnI_2) to the vinylogous α,β-unsaturated carbonyl intermediate **27b**[42a] followed by tautomerization to regenerate the aromatic indole unit, would provide **29**, as shown in Scheme VIII. On the other hand, addition of the elements of phenylselenol across the vinylic double bond[42b] via a free-radical mechanism would also provide **29**.

As a final attempt (Scheme IX) the diphenyl diol **24** was treated with phenylselenol in the presence of zinc iodide;[35] however, again ring scission took place to provide the diene **30** rather than the bis(phenylseleno)perhydropentalene **31**. Due to the unique anisotropy in **30**, the ^1H NMR spectrum of this red material was complicated. For example, aromatic multiplets appeared at high field [δ 5.73 (d) and 6.72 (t)] and were coupled to aromatic signals at δ 7.02 (t) and 7.60, respectively. For this reason the structure of **30** was unambiguously assigned by single-crystal X-ray analysis (see Figure 1 and supplementary material for details).

In summary, a combination of the Weiss reaction[14,19] and the Fischer indole cyclization[16-18] was employed to execute a facile preparation of the hexahydro-5,11-dihydro-



30

Figure 1. ORTEP representation of **30** (see supplementary material for details of the crystal structure).

pentaleno[2,1-*b*:5,4-*b*']diindoles 8 and **10**. These diindole perhydropentalenes were converted into a variety of 6,12-disubstituted derivatives (LH, Scheme I). Numerous attempts were made to convert these intermediates into bis(indolo-substituted)pentalenes such as **5** or **6**. The elimination of one molecule of water from **24** to provide triene **25** was successfully carried out, but further treatment yielded only the 2-phenylcyclopenta[*b*]indol-1-yl derivative **27a**. All attempts to effect the elimination of two molecules of LH (see 7) via an E_2 elimination or cis (syn) elimination to provide pentalenes **5** or **6** yielded only products of decomposition or of ring scission (see for example **27a**, **29**, and **30**). However, in the mass spectrum of the *exo,exo*-diesters **15** and **17**, an intense peak corresponding to the ion for pentalene **6** was clearly evident at

(42) (a) Monahan, R.; Brown, D.; Waykole, L.; Liotta, D. In *Organoselenium Chemistry*; Liotta, E., Ed.; Wiley Interscience: New York, 1987; Chapter 4, p 226. Anciaux, A.; Eman, A.; Dumont, N.; Krief, A. *Tetrahedron Lett.* **1975**, 1617. (b) Perkins, M. J.; Smith, B. V.; Turner, E. S. *J. Chem. Soc., Chem. Commun.* **1980**, 977.

308 Da and may have arisen from the desired syn elimination on heating. A similar ion (460 amu) was not observed in the spectrum of the diphenyl diol **24** or the diphenyl monol **25** under conditions of EI or CI mass spectroscopy. Since diphenyldibenzopentalene has been prepared and isolated,[41] whereas the corresponding diindole analogue **26** has alluded synthesis (to date) under the analogous conditions, the diindole units in **5** or **6** clearly do not provide the same stabilization as the benzene rings present in dibenzopentalenes.[7,41] Whether this difference is due to lack of stabilization from a thermodynamic standpoint or is kinetic in origin wherein the indole unit provides an additional pathway for decomposition is not known at this time.

Experimental Section

Melting points were taken on a Thomas-Hoover melting point apparatus; they are uncorrected. Microanalyses were performed on an F and M Scientific Corp. model 185 carbon, hydrogen, and nitrogen analyzer; some analyses were carried out at the National Institutes of Health, Bethesda, MD. High-resolution nuclear magnetic resonance spectra were run on a Bruker 250-MHz multiple-probe instrument or on a 500-MHz GE-9 spectrometer. The low-resolution chemical-ionization (CI) mass spectra were obtained on a Hewlett-Packard 5985 gas chromatograph–mass spectrometer, while high-resolution spectra were recorded on an AEI MS-902 mass spectrometer. Infrared spectra were taken on a Mattson Instruments Polaris FTIR spectrophotometer.

Analytical TLC plates used were E. Merck Brinkmann UV-active silica gel or alumina on plastic. Flash chromatography was performed according to the method of Still with 4–63 μm silica gel.[43] Solvents were purified and dried as reported.[14] Unless otherwise stated, all chemicals were purchased from Aldrich Chemical Co.

***cis*-5,6,6a,11,12,12a-Hexahydro-5,11-dihydropentaleno[2,1-*b*:5,4-*b*']diindole (8).** Bicyclo[3.3.0]octane-3,7-dione **9** (4.08 g, 30 mmol) was dissolved in absolute ethanol (100 mL), and excess phenylhydrazine (9 mL) as well as concentrated hydrochloric acid (4.5 drops) was added to the solution. The mixture was heated for 45 min, after which ethanolic hydrogen chloride (100 mL, saturated) and ethanol (100 mL) were added and the solution was held at reflux for 72 h. The solvent was removed under reduced pressure and the crude oil which remained was chromatographed on silica gel to provide **8** (1.8 g) in 20% yield. All attempts to increase the yield of this sequence were unsuccessful. **8**: mp 256–8 °C (sublimes at 235 °C at 0.5 mmHg); IR (KBr) 3402 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.05 (1 H, t), 3.10 (1 H, t) 3.28 (1 H, dd), 3.38 (1 H, dd), 4.54 (2 H, m), 7.00–7.35 (6 H, multiplet), 7.58 (2 H, m) 7.70 (2 H, s); ^{13}C NMR (62.8 MHz, $CDCl_3$) δ 31.20 (t), 47.61 (d), 111.68 (d), 117.95 (d), 119.47 (d), 120.59 (d), 121.77 (s), 124.24 (s), 141.32 (s), 142.12 (s); mass spectrum (CI, CH_4), relative intensity (*m/e*) 285 (M + 1). Anal. Calcd for $C_{20}H_{16}N_2$: C, 84.47; H, 5.68; N, 9.68. Found: C, 84.21; H, 5.74; N, 9.68.

Method A. *cis*-5,6,6a,11,12,12a-Hexahydro-5,11-dimethylpentaleno[2,1-*b*:5,4-*b*']diindole (10). Sodium hydride (347 mg, 60% dispersion in oil, 10.3 mmol) was added to a solution of diindole **8** (0.98 g, 3.4 mmol) in dry DMF (20 mL), followed by addition of iodomethane (1.46 g, 0.64 mL, 10.3 mmol). The mixture was stirred at ambient temperature for 24 h, after which time the solvent was removed under reduced pressure and the residue partitioned between ethyl acetate and water. The organic layer was separated, washed with brine (20 mL × 1), dried (Na_2SO_4), and evaporated in vacuo to yield a solid (954 mg, 90%). This material was purified by crystallization ($EtOAc/CH_3OH$). An analytical sample of **10** was obtained by sublimation at 210 °C (0.5 mmHg): mp 228–3 °C; IR (KBr) 2917, 2846, 1623, 1475, 737 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.08 (1 H, t), 3.32 (1 H, dd), 3.40 (1 H, dd), 3.60 (6 H, s), 4.70 (2 H, m), 7.05–7.30 (6 H, m), 7.55 (2 H, m); ^{13}C NMR (62.8 MHz, $CDCl_3$) δ 30.50 (t), 30.60 (q), 48.20 (d), 110.30 (d), 120.32 (d), 120.70 (d), 124.52 (s), 142.48 (s), 145.59 (s); mass spectrum (EI), *m/e* 312 (100, M^+), 297 (53.2); Anal. Calcd for $C_{22}H_{20}N_2$: C, 84.57; H, 6.46; N, 8.97. Found: C, 84.37; H, 6.37; N, 9.08.

Method B. To *cis*-bicyclo[3.3.0]octane-3,7-dione **9** (13.4 g, 97.10 mmol) in absolute ethanol (1 L) was added 1-methyl-1-phenylhydrazine (25.0 g, 205 mmol), and then concentrated aqueous HCl (60 mL) was added. The reaction mixture was slowly brought to reflux temperature and during the first 2 h, the mixture turned blood-red. The heating was continued for 24 h, followed by cooling. The solvent was removed very carefully under reduced pressure, and the residue was dissolved in $CHCl_3$ (100 mL), and then silica gel (30 g) was added. The chloroform was removed to give a pink solid which was charged to the top of a silica gel (150 g) column and eluted with EtOAc–hexane (1:19) to give **10** (15 g, 49.5%). The physical and spectral properties of this material were identical with those reported above in method A.

(6α,6aα,12α,12aα)-5,6,6a,11,12,12a-Hexahydro-5,11-dimethylpentaleno[2,1-*b*:5,4-*b*']diindole-6,12-diol (13). To diindole **10** (0.5 g, 1.6 mmol) in anhydrous dioxane (50 mL) was added SeO_2 (0.36 g, 3.2 mmol). The flask was plunged into an oil bath at 100 °C and heated for 30 min. The reaction was carefully monitored by TLC. Upon cooling the residue was filtered through Celite, and the filtrate was evaporated in vacuo. Chromatography of the crude oil on silica gel (20 g) with $CHCl_3$–EtOAc (1:1, gradient elution) afforded the title compound **13** (254 mg, 46%) accompanied by minor amounts of components at various oxidation levels which were not fully characterized. **10**: mp 229–30 °C dec; IR (KBr) 3402 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.55 (6 H, s), 4.45 (2 H, s), 5.22 (2 H, d, J = 7.5 Hz collapses into singlet on addition of D_2O), 6.91–7.21 (6 H, m), 7.61 (2 H, d, J = 7.5 Hz); ^{13}C NMR (62.8 MHz, $CDCl_3$ + DMSO-d_6) δ 30.01 (q), 58.51 (d), 71.52 (d), 109.01 (d), 119.51 (d), 119.98 (s), 121.11 (d), 123.01 (s), 142.10 (s), 144.82 (s); mass spectrum (EI), *m/e* 344 (28.5), 326 (34.2); high-resolution mass spectrum calcd for $C_{22}H_{20}N_2O_2$ 344.1525, found 344.1524.

Method A. *cis*-5,6a,11,12a-Tetrahydro-5,11-dimethylpentaleno[2,1-*b*:5,4-*b*']diindole-6,12-dione (14). To 6.0 g (19.2 mmol) of diindole **10** in anhydrous dioxane (600 mL) was added selenium dioxide (4.5 g, 45 mmol), and the reaction mixture was held at reflux for 48 h. The reaction solution was cooled and filtered through Celite, and the solvent was removed in vacuo. The residue was charged onto silica gel (100 g). Elution of the column with a mixture of $CHCl_3$–CCl_4 (1:1) gave dione **14** (3.5 g, 53.6%) as a white solid: mp 303–304 °C; IR (KBr) 1681, 1617 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.82 (6 H, s), 4.76 (2 H, s), 7.05–7.45 (6 H, m), 8.12 (2 H, d, J = 7.6 Hz); ^{13}C NMR (62.8 MHz, $CDCl_3$) δ 30.16 (q), 53.95 (d), 110.96 (d), 121.25 (d), 123.07 (s), 123.31 (d), 127.48 (d), 135.48 (s), 139.99 (s), 144.91 (s), 189.70 (s); mass spectrum (EI), *m/e* 340 (100), 312 (59), 297 (73); high-resolution mass spectrum calcd for $C_{22}H_{16}N_2O_2$ 340.1212, found 340.1202. Anal. Calcd for $C_{22}H_{16}N_2O_2$: C, 77.63; H, 4.74; N, 8.23. Found: C, 77.39; H, 4.67; N, 8.37.

Method B. To a solution of *exo,exo*-diol **13** (10 mg, 0.029 mmol) in dry dichloromethane (10 mL) was added pyridinium dichromate (24 mg, 0.064 mmol), and the reaction mixture was stirred for 3 days at room temperature. Dry ether (15 mL) was then added, and the solution filtered after which the solvent was removed in vacuo. The diketone **14** was purified on silica gel (5 g) with $CHCl_3$ as the eluent (yield 90%). This material was identical in all respects with the material prepared by method A.

(6α,6aα,12α,12aβ)-5,6,6a,11,12,12a-Hexahydro-5,11-dimethylpentaleno[2,1-*b*:5,4-*b*']diindole-6,12-diol (19). To a cooled solution of diketone **14** (280 mg, 0.82 mmol) in dry dichloromethane (20 mL) at −78 °C was added DIBAL (0.86 mL, 1.5 M solution in THF, 1.2 mmol), and the reaction mixture was slowly allowed to warm to room temperature. Stirring was continued for 2 h. The reaction mixture was quenched with a saturated solution of aqueous NH_4Cl followed by H_2SO_4 (1 M) after which it was extracted with additional CH_2Cl_2 (50 mL). The organic layer was washed with H_2SO_4 (1 M) and dried (Na_2SO_4), and the solvent was removed in vacuo, to yield the *endo,endo*-diol **19** (270 mg, 95%) as a white solid: mp 227–29 °C dec; IR (KBr) 3451 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.76 (6 H, s), 4.59 (2 H, m), 5.53 (2 H, collapsed to dd on D_2O exchange, J = 2.5 and 5.7 Hz), 7.03–7.36 (6 H, m), 7.69 (2 H, d, J = 7.9 Hz); ^{13}C NMR (62.8 MHz, $CDCl_3$) δ 30.24 (q), 52.60 (d), 69.89 (d), 109.87 (d), 114.28

(43) Still, C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

(s), 119.97 (d), 120.46 (d), 122.04 (d), 124.49 (s), 142.71 (s); mass spectrum (EI) *m/e* 344 (28), 326 (34.5); high-resolution mass spectrum calcd for $C_{22}H_{20}N_2O_2$ 344.1525, found 344.1523.

(6α,6aα,12α,12aα)-5,6,6a,11,12,12a-Hexahydro-5,11-dimethylpentaleno[2,1-*b*:5,4-*b'*]diindole-6,12-diyl Diacetate (15). Acetic anhydride (325 mg, 3.45 mmol) was added dropwise to a stirred solution of the *exo,exo*-diol **13** (540 mg, 1.57 mmol) in anhydrous dichloromethane which contained freshly distilled triethylamine (0.48 g, 4.70 mmol) and a trace of (dimethylamino)pyridine. After 20 h, solid $NaHCO_3$ was added, followed by aqueous $NaHCO_3$, and then the mixture was extracted with CH_2Cl_2 (3 × 100 mL). The organic layer was separated, washed with aqueous $NaHCO_3$ solution, and dried (Na_2SO_4), and the solvent was removed under reduced pressure. Chromatography of the crude solid on silica gel (CH_2Cl_2, eluent) afforded the *exo,exo*-diacetate **15** (520 mg, 77%). It was recrystallized from dichloromethane–diethyl ether: mp >400 °C (darkening, 200 °C); IR (KBr) 1735 cm^{-1}; ^1H NMR (250 HMz, $CDCl_3$) δ 2.25 (6 H, s), 3.61 (6 H, s), 4.51 (2 H, s), 6.47 (2 H, s), 7.18–7.33 (6 H, m), 8.11 (2 H, d, *J* = 7.1 Hz); ^{13}C NMR (62.8 MHz, $CDCl_3$) δ 21.34 (q), 30.63 (q), 56.44 (d), 74.12 (d), 110.05 (d), 119.93 (d), 120.61 (d), 122.22 (s), 122.57 (d), 123.34 (s), 140.13 (s), 142.63 (s), 171.09 (s). Mass spectrum (EI), *m/e* 428 (M^+, 65), 369 (25), 368 (26), 309 (60), 308 (100), 297 (65); high-resolution mass spectrum calcd for $C_{26}H_{24}N_2O_4$ 428.1736, found 428.1725. Anal. Calcd for $C_{26}H_{24}N_2O_4$: C, 72.88; H, 5.65; N, 6.54. Found: C, 73.12; H, 5.70; N, 6.61.

(6α,6aα,12α,12aα)-5,6,6a,11,12,12a-Hexahydro-5,11-dimethylpentaleno[2,1-*b*:5,4-*b'*]diindole-6,12-diyl Dibenzoate (17). The *exo,exo*-diol **13** (0.60 g, 1.74 mmol), benzoyl chloride (0.51 g, 3.66 mmol), triethylamine (371 mg, 3.66 mmol), and a trace of (dimethylamino)pyridine were stirred together in anhydrous CH_2Cl_2 for 18 h after which time the solvent was removed in vacuo. The residue was charged onto a column of silica gel (10 g). Elution with a $CHCl_3$–hexane mixture (3:1) gave the *exo,exo*-dibenzoate **17** (0.94 g, 98%). This diester was recrystallized from a dichloromethane–methanol mixture: mp 238–239 °C; IR (KBr) 1735 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.67 (6 H, s), 4.71 (2 H, s), 6.72 (2 H, s), 7.11–8.35 (18 H, m); mass spectrum (EI), 552 (M^+, 2), 430 (5), 309 (40), 308 (70), 105 (100); high-resolution mass spectrum calcd for $C_{36}H_{28}N_2O_4$ 552.2049, found 552.2007. Anal. Calcd for $C_{36}H_{28}N_2O_4$: C, 78.24; H, 5.11; N, 5.07. Found: C, 77.88; H, 5.04; N, 5.02.

(6α,6aα,12α,12aα)-5,6,6a,11,12,12a-Hexahydro-5,11-dimethyl-6,12-bis(phenylthio)pentaleno[2,1-*b*:5,4-*b'*]diindole (21). To *endo,endo*-diol **19** (5.5 mg, 1.56 mmol) in dry CH_2Cl_2 (60 mL) were added thiophenol (500 mg, 4.5 mmol) and ZnI_2 (643 mg, 2.0 mmol), and then the reaction mixture was stirred for 3.5 h at room temperature. The organic layer was then washed with H_2O (100 mL), aqueous NaOH solution (1 N, 100 mL), and brine and dried ($MgSO_4$). The solvent was removed in vacuo to give **21** (750 mg, 79%). TLC and ^1H NMR of this material indicated the product was homogeneous. It was further purified by crystallization from acetone: mp 231–32 °C; IR (KBr) 3047, 2921 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.63 (6 H, s), 4.38 (2 H, s), 4.65 (2 H, s), 6.95–7.50 (18, m); ^{13}C NMR (62.8 MHz, $CDCl_3$) δ 30.58 (q), 51.05 (d), 57.46 (d), 109.93 (d), 118.76 (d), 119.39 (d), 120.92 (d), 121.44 (s), 123.10 (s), 128.47 (d), 129.04 (d), 133.54 (s), 134.99 (d), 141.65 (s), 142.38 (s). Anal. Calcd for $C_{34}H_{28}N_2S_2$: C, 77.25; H, 5.30; N, 5.30. Found: C, 76.96; H, 5.37, N, 5.14.

(6α,6aα,12α,12aα)-5,6,6a,11,12,12a-Hexahydro-5,11-dimethyl-6,12-bis(phenylseleno)pentaleno[2,1-*b*:5,4-*b'*]diindole (20). Method A. To the *endo,endo*-diol **19** (120 mg, 0.34 mmol) in dry CH_2Cl_2 (20 mL) were added zinc iodide (150 mg, 0.47 mmol) and benzeneselenol (145 mg, 0.92 mmol), and the reaction mixture was stirred at room temperature for 1 h. The solution was diluted with CH_2Cl_2 (20 mL), washed with H_2O (100 mL), aqueous NaOH (1 N, 50 mL × 2), and brine, and dried ($MgSO_4$). The solvent was removed under reduced pressure to give **20** (176 mg, 81%). The solid was purified by passing it through a short column of silica gel (10 g): mp 203–204 °C; IR (KBr) 3050, 2917 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.61 (6 H, s), 4.25 (2 H, s), 4.75 (2 H, s), 6.90–7.55 (18 H, m); ^{13}C NMR (62.8 MHz, $CDCl_3$) δ 30.60 (q), 43.78 (d), 58.19 (d), 109.84 (d), 118.60 (d), 119.38 (d), 121.04 (s), 121.32 (d), 123.09 (s), 128.33 (s), 128.56 (d), 129.02 (d), 136.79 (d), 142.36 (s), 142.49 (s).

Method B. To the *exo,exo*-diol **13** (178 mg, 0.51 mmol) in dry CH_2Cl_2 (30 mL) were added zinc iodide (170 mg, 0.53 mmol) and benzeneselenol (166 mg, 1.05 mmol), and then the reaction mixture was stirred at room temperature for 1 h. It was diluted then with CH_2Cl_2 (30 mL), washed with H_2O (100 mL), aqueous NaOH (1 N, 50 mL × 2), and brine, and dried ($MgSO_4$). The solvent was removed in vacuo to give **20** (220 mg, 68%). The properties of this material were identical with those of the material obtained by method A in the previous experiment.

Attempted Preparation of 5,11-Dihydro-5,11-dimethylpentaleno[2,1-*b*:5,4-*b'*]diindole by Elimination of the Bis-Sulfoxide Moieties. To a stirred solution of disulfide **21** (300 mg, 0.57 mmol) in dry CH_2Cl_2 (30 mL) at 10 °C was added 80% MCPBA (300 mg, 1.4 mmol) and the stirring continued for 45 min. The reaction mixture was then diluted with water (50 mL), washed with aqueous $NaHCO_3$ (50 mL × 2) and brine, and dried. Removal of solvent gave the disulfoxide as the crude product. It was further purified by crystallization from ethanol (240 mg, 75%). TLC indicates it was a mixture of at least two isomeric sulfoxides: mp 176–177 °C dec; IR (KBr) 3057, 2938, 1482, 1384, 1307, 1046, 744 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.45–4.10 (8 H, series of overlapping singlets and multiplets), 4.70 (2 H, complex m), 6.70–7.80 (18 H, m). Anal. Calcd for $C_{34}H_{28}N_2S_2O_2$: C, 72.85; H, 5.00; N, 5.00. Found: C, 72.07; H, 5.03, N, 4.74. The sulfoxide was heated at different temperatures [benzene (reflux), toluene (reflux), xylene (reflux)] in the presence of various agents to trap phenylsulfenic acid (triethyl amine, pyridine, potassium carbonate). No evidence for **6** was observed.

(6α,6aβ,12α,12aβ)-5,6,6a,11,12,12a-Hexahydro-5,11-dimethyl-6,12-diphenylpentaleno[2,1-*b*:5,4-*b'*]diindole-6,12-diol (24). Phenyllithium (5 mL of 2.0 M solution, 10.3 mmol)[41] was added to a solution of diketone **14** (500 mg, 1.47 mmol) in anhydrous THF (30 mL) at −78 °C, and then the reaction mixture was slowly brought to room temperature. After the reaction stirred at room temperature for 4 h, examination by TLC indicated the presence of some starting material. Again the reaction mixture was cooled to −78 °C and a solution of phenyllithium (5 mL of 2.0 M solution) was added, and the reaction mixture was slowly brought to room temperature. The solution was stirred for 2 days. The reaction mixture was quenched with aqueous saturated NH_4Cl solution (100 mL) and then extracted with EtOAc (75 mL × 3). The organic layer was washed with brine (50 mL) and dried ($MgSO_4$). Removal of the solvent in vacuo gave the crude solid which was charged to a column of silica gel (50 g). Elution with hexane removed nonpolar products of high retention time. Further elution of the column with an EtOAc–hexane mixture (1:19) gave *endo,endo*-diol **24** (702 mg, 96%). It was recrystallilzed from EtOAc–hexane (3:7): mp 232–233 °C; IR (KBr) 3507–3458 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.41 (6 H, s), 4.18 (2 H, s), 7.10–7.47 (16 H, m), 7.66 (2 H, d, *J* = 7.5 Hz); ^{13}C NMR (62.8 MHz, $CDCl_3$): δ 29.96 (q), 64.33 (d), 79.95 (s), 110.10 (d), 115.47 (s), 120.17 (d), 120.86 (d), 122.28 (d), 124.27 (s), 125.18 (d), 127.24 (d), 128.69 (d), 142.42 (s), 146.01 (s), 148.76 (s); mass spectrum (CI), *m/e* 497 (M + 1, 40), 479 (100); (EI) 496 (M^+, 3), 478 (100), 449 (8), 373 (20), 261 (25), 248 (90). Anal. Calcd for $C_{34}H_{28}N_2O_2$: C, 82.33; H, 5.68; N, 5.64. Found: C, 81.96; H, 6.15; N, 5.50.

Monodehydration of (6α,6aβ,12α,12aβ)-5,6,6a,11,12,12a-Hexahydro-5,11-dimethyl-6,12-diphenylpentaleno[2,1-*b*:5,4-*b'*]diindole-6,12-diol (24) To Provide Triene (25). The diol **24** (550 mg, 1.1 mmol) was stirred at room temperature in anhydrous benzene (100 mL) which contained dry PTSA (220 mg, 1.28 mmol) and 4-Å molecular sieves (10 g). After 5 min, water was added to the dark red solution, and the mixture was washed with an aqueous $NaHCO_3$ solution (100 mL) and brine and dried ($MgSO_4$). The solvent was removed in vacuo to give a red solid (505 mg, 96%). Examination of the TLC indicated the presence of only one component **25**: mp 193–195 °C; IR (KBr) 3438, 1631 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.37 (3 H, s), 3.60 (3 H, s), 4.45 (1 H, s), 6.91–7.85 (17 H, m), 7.95 (1 H, d, *J* = 9.5); ^{13}C NMR (62.8 MHz, $CDCl_3$) δ 31.10 (q), 31.90 (q), 73.40 (d), 77.03 (s), 109.73 (s), 110.50 (d), 110.73 (d), 118.61 (s), 119.13 (d), 120.54 (d), 120.95 (d), 121.18 (d), 121.59 (s), 122.71 (d), 123.20 (d), 123.40 (s), 125.52 (s), 126.29 (d), 128.26 (d), 128.49 (d), 129.07 (d), 129.63 (d), 130.40 (d), 136.17 (s), 142.03 (s), 142.25 (s), 144.60 (s), 151.14 (s), 154.85 (s), 156.81 (s); mass spectrum (CI), *m/e* 479 (M + 1, 100); (EI) 478 (M^+, 100), 463 (2), 449 (18), 373 (30), 357 (18); UV–vis λ_{max}

465 (1.680), 3.22 (2.458), 305 (2.012) shoulder; c (147 μM) $CHCl_3$; high-resolution mass spectrum calcd for $C_{34}H_{26}ON_2$ 478.2045, found 478.2037.

[3-(1,4-Dihydro-4-methyl-2-phenylcyclopent[*b*]indol-1-yl)-1-methyl-1*H*-indol-2-yl]phenylmethanone (27a). Freshly distilled $POCl_3$ (64 mg, 0.42 mmol) was added to a stirred solution of the alcohol **25** (26 mg, 0.052 mmol) in anhydrous benzene (20 mL) and pyridine (83 mg, 1.05 mmol). The mixture was heated at reflux for 3 h after which it was cooled. Water (cold) was then added very slowly, and the solution was extracted with toluene (30 mL). The organic layer was dried (Na_2SO_4) and the solvent removed in vacuo to provide an oil which was chromatographed on silica gel (3:1 $CHCl_3$–CCl_4, gradient elution). The main component **27a** (20 mg, 75%) was isolated as a red oil **27a**: IR ($CHCl_3$) 1640 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 3.43 (3 H, s), 3.72 (3 H, s), 3.76 (2 H, s), 6.72–7.80 (18 H, m); ^{13}C NMR (135.6 MHz, $CDCl_3$) δ 31.84 (q), 32.30 (q), 37.22 (t), 110.44 (d), 110.82 (d), 118.51 (s), 118.77 (d), 120.07 (s), 120.17 (d), 120.81 (d), 121.35 (d), 122.46 (d), 124.33 (s), 125.43 (d), 127.86 (s), 128.09 (d), 128.45 (d), 128.78 (d), 130.55 (d), 130.83 (d), 133.69 (d), 134.66 (s), 137.39 (s), 138.49 (s), 138.60 (s), 139.30 (s), 141.96 (s), 190.00 (s); high-resolution mass spectrum calcd for $C_{34}H_{26}N_2O$ 478.2045, found 478.2024.

[1-Methyl-3-(1,2,3,4-tetrahydro-4-methyl-3-phenyl-1-(phenylseleno)cyclopent[*b*]indol-2-yl)-1*H*-indol-2-yl]-phenylmethanone (29). To a stirred solution of alcohol **25** (520 mg, 1.11 mmol) in dry CH_2Cl_2 (60 mL) was added zinc iodide (420 mg, 1.07 mmol), followed by benzeneselenol (200 mg, 1.27 mmol), and then the mixture was stirred for 1 h at room temperature. The reaction solution was diluted with H_2O (50 mL), washed with an aqueous NaOH solution (1 N, 50 mL) and brine and dried ($MgSO_4$). Removal of solvent under reduced pressure gave a crude oil. It was charged onto a column of silica gel (50 g). Elution with hexane removed the minor aromatic impurity; continued elution gave **29** (250 mg, 31%) as an oil. **29**: IR (neat) 3057, 2931, 1650, 1475, 1257, 962, 744 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.14 (3 H, s), 3.71 (3 H, s), 4.05 (1 H, t, J = 5.4 Hz), 4.80 (1 H, dd, J = 1.1, 4.3 Hz), 5.01 (1 H, dd, J = 1.1, 4.1 Hz), 6.33 (1 H, d, J = 7.5 Hz), 6.89–7.69 (22 H, m); ^{13}C NMR (62.8 MHz, $CDCl_3$) δ 30.30 (q), 31.82 (q), 49.64 (q), 53.17 (d), 60.61 (d) (multiplicities assigned only for these signals because the others overlapped), 109.58, 109.87, 110.18, 110.45, 118.95, 119.68, 119.79, 120.36, 120.78, 121.33, 121.41, 123.63, 124.77, 125.66, 126.88, 127.38, 127.93, 128.67, 128.39, 128.57, 128.76, 129.95, 130.19, 132.85, 136.45, 136.68, 142.32, 142.68, 145.48, 190.16.

Reaction of Benzeneselenol with (6α,6aβ,12α,12aβ)-5,6,6a,11,12,12a-Hexahydro-5,11-dimethyl-6,12-diphenylpentaleno[2,1-*b*:5,4-*b*']diindole-6,12-diol in the Presence of Zinc Iodide To Provide 30. The diol **24** (332 mg, 0.67 mmol) in dry CH_2Cl_2 (50 mL) was treated with benzeneselenol (450 mg, 1.35 mmol) in the presence of ZnI_2 (380 mg, 1.19 mmol) at room temperature for 40 min. The reaction mixture was then diluted with H_2O (50 mL), and the organic layer was separated, washed with an aqueous NaOH solution (1 N) and brine, and dried ($MgSO_4$). Removal of solvent in vacuo gave an oil. It was charged onto a column of silica gel (50 g). Elution with hexane removed minor aromatic impurities. Further elution of the column with EtOAc–hexane (1:19) gave **30** (100 mg, 32%). The best way to crystallize **30** is to let the chromatographic fractions stand at room temperature overnight. **30**: mp 184–185 °C; IR (KBr) 3050 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 3.32 (3 H, s), 3.68 (3 H, s), 5.73 (1 H, d, J = 8.2 Hz); 6.34 (1 H, s), 6.64 (1 H, s), 6.72 (1 H, t, J = 8 Hz), 7.02 (1 H, t, J = 7.3 Hz), 7.12–7.60 (14 H, m), 7.66 (1 H, d, J = 7.7 Hz); ^{13}C NMR (62.8 MHz, $CDCl_3$) δ 31.46 (q), 31.88 (q), 109.57 (d), 109.86 (d), 110.10 (d), 114.5 (s), 120.01 (d), 120.29 (d), 120.48 (d), 121.05 (d), 122.63 (d), 123.36 (s), 127.81 (s), 121.91 (d), 128.21 (d), 128.54 (d), 128.74 (d), 129.04 (d), 131.67 (d), 131.92 (d), 135.03 (s), 135.51 (s), 136.68 (s), 137.59 (s), 139.38 (s), 140.36 (s), 141.56 (s), 142.35 (s). Some of the carbon atoms overlap in the aromatic region; mass spectrum (EI), m/e, 462 (100, M^+) 463 (M + 1, 38.9); UV–vis λ_{max} 426 (1.105), 296 (2.173); c (42 μM) $CHCl_3$. Anal. Calcd for $C_{34}H_{26}N_2$: C, 88.31, H, 5.62, N, 6.06. Found: C, 87.82; H, 5.77; N, 5.99.

Acknowledgment. We thank the National Science Foundation (Grant No. CHE-8604443) and the donors of the Petroleum Research Fund, administered by the American Chemical Society, for support of this work. The technical assistance of Dr. David Nettesheim, Noel Whittaker, and Keith Krumnow is gratefully acknowledged. The 500-MHz NMR was purchased with funds from NIH (BRSG) and NSF instrumentation programs. A special thanks to Anju Gupta and Liesl Schindler for preparation of this manuscript are in order.

Supplementary Material Available: Details of the structure determination, tables of fractional coordinates and anisotropic temperature factors, bond lengths, and bond angles (7 pages); structure factors for **30** (6 pages). Ordering information is given on any current masthead page.