and concentrated under reduced pressure. The resulting residue was recrystallized from CH_2Cl_2/hexane to yield **11** as a bright red crystalline solid (0.19 g, 80%): mp 180–181 °C (lit.[9a] mp 178–180 °C); ^{1}H NMR (CDCl$_3$) δ 6.5 (d, 1 H, H$_2$, $J_{1,2}$ = 10.5 Hz), 7.6–8.1 (m, 6 H, aromatic), 8.48 (d, 1 H, H$_1$, $J_{1,2}$ = 10.5 Hz).

Acknowledgments. The study was supported by National Cancer Institute Contract N01-CP-61041. We thank Dr. Stephen Hecht for his suggestions, Dr. Dhimant Desai for his assistance, and Beth Appel for final preparation of the manuscript.

Supplementary Material Available: The phase-sensitive COSY spectrum of 4-methoxybenzo[*c*]phenanthrene (2 pages). Ordering information is given on any current masthead page.

A General Approach to the Synthesis of Polyquinenes via the Weiss Reaction. 10. Transient Formation of *cis*-Tetracyclo[7.2.1.$0^{4,11}$.$0^{6,10}$]dodeca-3,5,7,9-tetraene and an Approach toward 10,11-Dimethyl-*cis*-tetracyclo[7.2.1.$0^{4,11}$.$0^{6,10}$]dodeca-3,5,7,9-tetraene

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This decade has witnessed much interest in the synthesis and reactions of polyquinanes[1] and polyquinenes.[2-7] In this connection polyquinenes **1** and **2** were studied earlier from a computational point of view.[8] According to ring current criteria, Jung[9] predicted that dicyclopenta[*cd*,*gh*]pentalene **1** would be aromatic; however, Binsch[10] proposed that **1** would behave as an antiaromatic species due to its second-order double-bond fixation. Nakajima et al. employed semiempirical SCF MO theory to arrive at the same conclusion.[11] Hess[8b] and Garret[12] have also studied the stability of systems such as **1** and **2**; moreover, MNDO calculations from our laboratory[13] and MM2 computations from Paquette et al.[14] have described the increase in strain energy in going from **2** to **1** as substantial (see also ref 15). In this respect **1** should behave as a highly reactive olefin with no sign of peripheral π delocalization[15] in contrast to the earlier hypothesis of Platt.[8a]

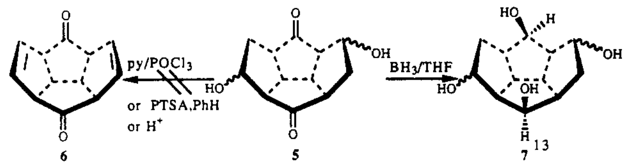

1


2

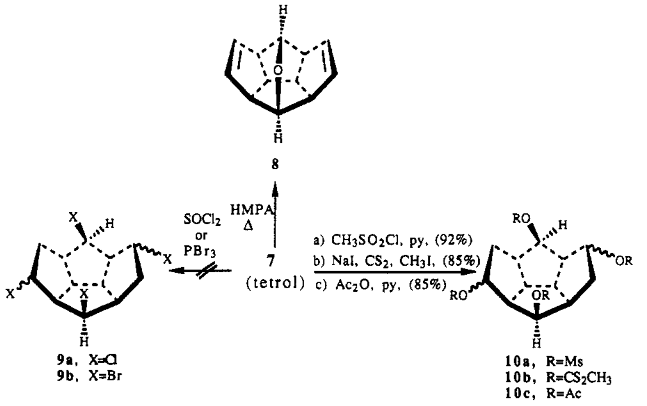

3a, R=H
4a, R=CH_3


3b, R=H
4b, R=CH_3

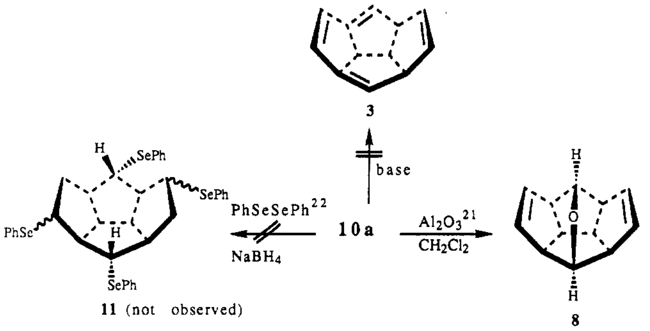
Scheme I



Scheme II



Scheme III



Since the previously reported difference in the heat of formation between tetraene **3a** and isomeric olefin **3b** was

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(1) Eaton, P. E. *Tetrahedron* **1979**, *35*, 2189. Paquette, L. A. *Top. Curr. Chem.* **1979**, *79*, 70; **1984**, *119*, 58. Paquette, L. A.; Doherty, A. M. *Polyquinane Chemistry, Synthesis and Reactions*; Springer Verlag: New York, 1987. Ramaiah, M. *Synthesis* **1984**, 529. Trost, B. M. *Chem. Soc. Rev.* **1982**, *11*, 141. Paquette, L. A. *Chem. Rev.* **1989**, *89*, 1051. Mehta, G.; Raja Reddy, K.; Nair, M. S. *Proc. Ind. Acad. Sci.* **1988**, 223.

(2) Polyunsaturated polyquinanes have been designated as polyquinenes. See: Venkatachalam, M.; Jawdosiuk, M.; Deshpande, M.; Cook, J. M. *Tetrahedron Lett.* **1985**, *26*, 2275. Nikon, A.; Silversmith, E. F. *Organic Chemistry. The Name Game. Modern Coined Terms and Their Origins*; Pergamon Press: New York, 1987; p 202.

(3) Butenschön, H.; de Meijere, A. *Tetrahedron* **1986**, *42*, 1721 and references cited therein. Lendvai, T.; Freidl, T.; Butenschön, H.; Clark, T.; de Meijere, A. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 719.

(4) Kuck, D.; Bogge, H. *J. Am. Chem. Soc.* **1986**, *108*, 8107. Kuck, D.; Schuster, A. *Angew. Chem., Int. Ed. Engl.* **1988**, *27*, 1192 and references cited therein.

(5) Stowasser, B.; Hafner, K. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 466.

(6) Gupta, A. K.; Lannoye, G. S.; Kubiak, G.; Schkeryantz, J.; Wehrli, S.; Cook, J. M. *J. Am. Chem. Soc.* **1989**, *111*, 2169.

(7) (a) Vogel, E.; Roth, H. D. *Angew. Chem., Int. Ed. Engl.* **1964**, *3*, 228. (b) Vogel, E.; Böll, W. A. *Ibid.* **1964**, *3*, 642. (c) *Chem. Eng. News* **1964**, *42* (Oct 5), 40. Vogel, E. *Pure Appl. Chem.* **1982**, *54*, 1015.

(8) (a) Zollinger, H.; Aromatic *Compounds* (volume 3) in Organic Chemistry, Series One, MTP International Review of Science (Ed. Hey, D. H.). Buttterworths, London, 1973, p 149. Platt, J. R. *J. Chem. Phys.* **1954**, *22*, 1448. (b) Hess, B. A., Jr.; Schaad, L. J. *J. Org. Chem.* **1971**, *36*, 3418. Hess, B. A., Jr.; Schaad, L. J. *J. Am. Chem. Soc.* **1971**, *93*, 305.

(9) Jung, D. E. *Tetrahedron* **1969**, *25*, 129.

(10) Binsch, G. *Aromaticity, Pseudo-Aromaticity, Anti-Aromaticity*, The Jerusalem Symposia on Quantum Chemistry and Biochemistry III, Bergmann, E. D., Pullman, P., Eds.; The Israel Academy of Sciences and Humanities: Jerusalem, 1971, p 25.

(11) Toyota, A.; Nakajima, T. *Tetrahedron* **1981**, *37*, 2575. Nakajima, T. *Molecular Orbitals in Chemistry, Physics and Biology*; Lowdin, P. O., Pullman, B., Eds.; Academic Press: New York, 1964; p 451. Nakajima, T. *Pure Appl. Chem.* **1971**, *28*, 219.

(12) Garrat, P. J.; Sargent, M. V. Nonbenzenoid Conjugated Hydrocarbons In *Advances in Organic Chemistry*; Taylor, E. C., Wynberg, H., Eds.; John Wiley and Sons: New York, 1969; Vol. 6.

(13) Lannoye, G.; Sambasivarao, K.; Wehrli, S.; Cook, J. M. *J. Org. Chem.* **1988**, *53*, 2327. Lannoye, G.; Cook, J. M. *Tetrahedron Lett.* **1987**, *23*, 4821. Professor Mehta has observed the formation of this ether under similar conditions. Mehta, G., private communication.

(14) Nakamura, K.; Vanucci, C. and Paquette, L. A. *J. Org. Chem.* **1988**, *53*, 2657.

(15) Glidewell, C.; Lloyd, D. *Chim. Scr.* **1988**, *28*, 385.

0022-3263/90/1955-4480$02.50/0

Scheme IV[a]

$$\underset{\text{(not isolated)}}{3^{*}} \xleftarrow[\substack{\text{pyrolysis}\\ \text{or HMPA, }\Delta\,^{a}\\ 215\text{-}220^{\circ}\text{C}}]{\Delta} \textbf{10b}\ \text{(tetraxanthate)} \xrightarrow[\substack{\text{or PhOPh, }\Delta\\ 220\text{-}230^{\circ}\text{C}\\ \text{DPIBF}\\ \text{(see Table)}}]{\substack{\text{xylene, }\Delta\\ \text{DPIBF}}} \substack{\text{No adduct}\\ \text{with 3}}$$

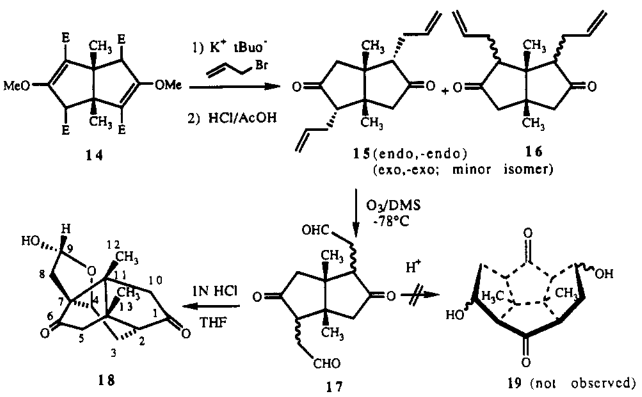
[a] X. Fu, A. K. Gupta, J. M. Cook, unpublished results. *The molecular ion of tetraene 3 was observed as the parent peak (100%) in the mass spectrum of **10b** hence the four xanthates were eliminated.

approximately 1 kcal/mol,[13] a route to either of these olefins was considered a viable approach toward *cis*-tetracyclo[7.2.1.0^{4,11}.0^{6,10}]dodeca-1,3,5,7,9(12)-pentaene, **2**. Outlined below are efforts directed toward the synthesis of either **3** or **4** which ultimately resulted in the synthesis and observation of the tetraene as a transient intermediate. The synthesis began with 2,6-diallyl-*cis*-bicyclo[3.3.0]octane-3,7-dione available from the Weiss reaction.[16] This was converted into the diol **5** by published methods.[13] All attempts to convert the diol **5** into the known diene dione **6**[17] (Scheme I) under conditions of dehydration were unsuccessful (see table, supplementary material). Either products of retro-aldol reactions[18] or unidentified oligomers which contained ether linkages were obtained.

At this stage the diketo diol **5** was treated with an electrophilic reducing agent (BH_3–THF)[19] to provide the tetrol **7** in greater than 90% yield. The stereochemistry of the hydroxy groups was established as indicated earlier[13] and the mixture (9:1) of isomeric tetrols was employed as described below. When the tetrol **7** was heated in HMPA, analogous to the conditions employed for the synthesis of various triquinacenes,[6] only the tetracyclic ether **8** was isolated.[13] In an effort to convert **7** into appropriately substituted precursors of tetraene **3**, tetrol **7** was treated with $SOCl_2$ or PBr_3, under a variety of conditions, but neither **9a** nor **9b** was observed (Scheme II), respectively. The tetrol (**7**) could, however, be converted into the tetramesylate **10a** (92%), tetraxanthate **10b** (85%), or tetraacetate **10c** (85%) under standard conditions, as illustrated in Scheme II.

Although the starting 2,6-diallyl dione could be prepared on 15–20-g scale, an improved synthesis of this material was developed via a Claisen rearrangement,[20] and efforts were redoubled toward **3**. The tetramesylate **10a** was treated with a variety of bases under conditions of E_2 elimination; however, only polymeric material was obtained. Moreover, stirring **10a** with alumina, analogous to the conditions of Deslongchamps (Scheme III),[21] gave only the tetracyclic ether **8**, albeit in only moderate yield. All efforts to convert **10a** into the tetraphenylseleno derivative **11** under the conditions of Jones et al.[22] were also not successful. Attempted pyrolysis of the tetraacetate **10c** under high vacuum in the presence or absence of diphenylisobenzofuran (DPIBF)[23] or to trap the tetraene **3** under conditions of E_2 elimination[24] were likewise unsuccessful.

Scheme V

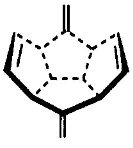


As a final resort the pyrolysis of the tetraxanthate **10b** was pursued under a variety of conditions. Pyrolysis under high vacuum with or without the addition of DPIBF gave only black polymeric material; however, pyrolysis of tetraxanthate **10b** in the mass spectrometer gave a parent peak at 154 Da in agreement with the molecular formula for **3**.[25]

Although the four xanthate groups have been removed, neither a trace of **3** nor a suitable Diels–Alder adduct with DPIBF have been isolated. The inability to trap or isolate **3** may be due to the ability of **3** to self-condense into polymeric material or to react with oxygen or moisture in the air. Although most of the reactions in the table (supplementary material) were run under an inert atmosphere, it is known that diene **12** is highly sensitive to air.[26] In contrast it was reported that tetraene **13** could be handled with relative ease.[27]

Although the discrepancy between the reactivity of **12** and the stability of **13** is not readily understood, it was felt that synthesis of a tetraene (see **3b** or **4b**) in which the convex faces were hindered to attack or prohibited from self-condensation[28] might provide a means by which to isolate a pentaene related to **2**.


12


13

Close examination of the structure of **3** indicated that substitution of methyl for hydrogen at positions 10 and 11 (see **4a**, **4b**) would not only retard self-condensation but would also provide a probe with which to monitor any

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

[17] Paquette, L. A.; Nakamura, K.; Fischer, J. W. *Tetrahedron Lett.* **1985**, 4051. Paquette, L. A.; Nakamura, K.; Engel, P. *Chem. Ber.* **1986**, *119*, 3782. Mehta, G.; Nair, M. S. *J. Chem. Soc., Chem. Commun.* **1985**, 629; *J. Am. Chem. Soc.* **1985**, *107*, 7519.

[18] Han, C. H.; Takahashi, K.; Cook, J. M.; Weiss, U.; Silverton, J. R. *J. Am. Chem. Soc.* **1982**, *104*, 318.

[19] Venkatachalam, M.; Deshpande, M. N.; Jawdosiuk, M.; Kubiak, G.; Wehrli, S. and Cook, J. M. *Tetrahedron* **1986**, *42*, 1597.

[20] The details of these experiments will be published elsewhere. Rao, K. S.; and Cook, J. M. *Organic Preparations and Procedures*, in press.

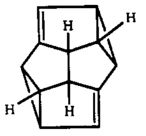
[21] Deslongchamps, P.; Soucy, P. *Tetrahedron* **1981**, *37*, 385.

[22] Jones, D. N.; Mundy, D. and Whitehouse, R. D. *Chem. Commun.* **1970**, 86. Clive, D. J. *Aldrich Chim. Acta* **1978**, *11*, 43.

[23] For a recent reference for use of this diene, see: Chenier, P. J.; Southand, D. A. *J. Org. Chem.* **1989**, *54*, 3519 and references cited therein.

[24] Paquette, L. A. *Top. Curr. Chem.* **1979**, *79*, 118.

[25] At present, formation of the biscyclopropyl derivative (i) in the mass spectrometer cannot be ruled out; however, construction of its framework with molecular models indicates prohibitive strain in relation to **3**.



i

[26] Fukunaga, T.; Clement, R. A. *J. Org. Chem.* **1977**, *42*, 270.

[27] Paquette, L. A.; Wyvratt, M. J. *J. Am. Chem. Soc.* **1974**, *96*, 4671.

[28] Hafner, K.; Süss, H. U. *Angew. Chem., Int. Ed. Engl.* **1973**, *12*, 575. Donges, R.; Hafner, K.; Lindner, H. *Tetrahedron Lett.* **1976**, 1345.

anisotropy due to π delocalization in **2** (R = CH_3). By taking advantage of the Weiss reaction, the two requisite methyl functions can be installed by replacing glyoxal with biacetyl with minimal departure from the previous route. The known bisenol ether **14**[6] was alkylated with allyl bromide in THF in the presence of potassium *tert*-butoxide (Scheme V).

The mixture of diallyl tetraesters was neither separated nor characterized, but rather the crude product was hydrolyzed and decarboxylated (HOAc/aqueous HCl/Δ). Analysis of the reaction mixture by capillary GC indicated that this material consisted of three components all of which were shown to be isomeric bis-allylated *cis*-bicyclo[3.3.0]octane-3,7-diones. The isomers were separated by flash chromatography and purified by fractional crystallization of the major isomer (45%); the ^1H and ^{13}C NMR spectra of the major isomer were consistent with either of the two symmetrical 2,6-regioisomers represented by **15**. This is a consequence of the C_2 symmetry of either of these stereoisomers. This material on crystallization gave the endo-endo stereoisomer **15**, the mother liquor of which contained a small amount of the exo-exo diastereomer (see ref 29 for details). The second isomer was obtained in 30% yield and was assigned as the 2,8-diallyl regioisomer **16** while the third component was not obtained in sufficient purity to permit unequivocal spectral characterization. Since the 2,6-*endo*-*endo*-diallyl-1,5-dimethyl-*cis*-bicyclo[3.3.0]octane-3,7-dione (**15**) could now be synthesized on a preparative scale, attention turned to transformation of it into the 10,11-dimethyl-2,7-dihydroxy-*cis*-tetracyclo[7.2.1.$0^{4,11}$.$0^{6,10}$]dodecane-5,12-dione, **19**. Conversion of **15** into a mixture of stereoisomeric exo/endo bisaldehydes represented by **17** was accomplished via ozonolysis at −60 °C in 98% yield. The structure of **17** was based on examination of the ^1H NMR and ^{13}C NMR spectra of the material [^{13}C δ 199.16 (aldehyde), ^1H δ 9.82]. It was anticipated that the endo-endo diastereomer would predominate based on previous results in this series.[29] The bisaldolization of **17** was effected under acidic conditions at high dilution to promote intramolecular reaction in similar fashion to the synthesis of diketo diol **5**. Unfortunately, bisaldehyde **17** cyclized to provide the transannular product **18** rather than the desired 10,11-dimethyl diketo diol **19**. This type of transannular cyclization has been previously observed by Pattenden[30] and Paquette[31] and during the synthesis of 1,10-dimethyl triquinacene.[6] In the latter case, evidence from X-ray crystallography indicated that methyl–methyl repulsion in the 1,5-dimethyl-*cis*-bicyclo[3.3.0]octane-3,7-dione skeleton causes a twist of the two cyclopentanoid units,[29] the result of which favors transannular cyclization. It is important to reiterate that aldol cyclization of the parent system (R = H) gave the desired bis-aldol **5** as the major product with only minor contamination from products of transannular cyclization.[32] All attempts to effect equilibration of **18** into **19** under acidic or alkaline conditions were unsuccessful. A systematic analysis of the ^{13}C NMR spectrum of **18** led to the assignment of two carbonyl signals (δ 231.26, 226.44), three quaternary carbon atoms (δ 68.17, 47.85, 46.17), three methine (CH's) signals (δ 99.24, 75.00, 57.21), four methylene (CH_2's) signals (δ 43.59, 42.71, 34.94, 28.14), and two signals which represent methyl functions (δ 19.14, 17.11). The carbon signal at δ 99.24 indicated the possibility of a carbon atom attached to two oxygen units. Examination of molecular models indicates that this situation can only occur if the cyclization of the diketo aldehyde **17** occurs in a transannular fashion. Since both methylene protons at CH_2-5 and CH_2-10 show geminal coupling (19 Hz) and almost no coupling with adjacent methyl groups, this indicates there is no cyclization at the CH_2-5 or CH_2-10 positions. Since the two junction protons (H-4 and H-2) couple with the protons of the methylene group (CH_2-3, J = 13, 4 Hz), the cyclization must occur between positions labeled CH_2-2 and CH_2-4 in **18**. The structure of **18** was further confirmed by 2D COSY and NOESY experiments.

According to MNDO calculations, the increase in heat of formation in going from **3** to **2** is approximately 70 kcal/mol; moreover, the increase in going from **2** to **1** is even greater.[13] In addition, the increase in strain energy between tetraene **3** and pentaene **2** is 51.5 kcal/mol and would be expected to be larger for cyclopentapentalene **1**.[13] Observation of the tetraene **3** under high vacuum in the mass spectrometer but failure to isolate or trap the compound illustrates the instability of this highly reactive olefinic system reminescent of the properties of diene **12**.[26] This reactivity presumably would occur with either **2** or **3** in the presence of radicals or carbenium ions precluding a route toward **1** by either of these approaches, albeit the dianion chemistry pioneered by de Meijere toward aceapentalene[3] might circumvent some of these difficulties. Even if Π delocalization in 10π annulene **2** were to occur, the resonance energy ($\ll$36 kcal/mol) gained from this overlap would not be enough to offset the increase in energy in going from **3** to **2** (70 kcal/mol). The preparation of **3** has also alluded Paquette et al.,[14] as well as Prinzbach in a related system.[33] Although the reactivity of **3** does not bear directly on the stability of **1**, examination of energy considerations via MNDO[13] and the character of **3** described herein support the contention by Binsch,[10] Nakajima,[11] and Glidewell et al.[15] that **1** and **2** should behave as highly reactive olefins rather than the delocalized π systems of Platt[8a] and Jung.[9]

Experimental Section

The experimental details are identical with those reported earlier.[6] All chemicals, unless otherwise specified, were purchased from Aldrich Chemical Co.

2,5,7,12-Tetrakis(mesyloxy)tetracyclo[7.2.1.$0^{4,11}$.$0^{6,10}$]dodecane (10a). A solution of dry tetrol **7** (0.450 g, 2 mmol) in pyridine (20 mL) was cooled to 0 °C, and methanesulfonyl chloride (1.7 g, 15 mmol) was added. The solution was stirred for 2 days at room temperature, after which it was poured into cold aqueous HCl (10%). The product was extracted from the aqueous layer into chloroform (4 × 25 mL), and the combined organic layers were dried ($MgSO_4$) and concentrated. The crude oil was chromatographed on silica gel (eluent 25% EtOAc in hexane) to give the tetramesylate **10a** (1.0 g, 92%) as a white solid: mp 169–170 °C (from ethyl acetate/hexane); IR (KBr) 1350, 1175 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 1.80–2.50 (m, 4 H), 3.00 (s, 6 H), 3.20 (s, 6 H), 2.70–4.20 (m, 6 H), 5.30 (m, 4 H); ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 84.68, 80.92, 55.60, 49.67, 47.24, 38.60, 38.40, 36.25; mass spectrum (EI, 15 eV), *m/e* (relative intensity) 346 (M − $2CH_3SO_3H$, trace), 267 (80), 250 (40), 171 (100). Anal. Calcd for $C_{16}H_{26}O_{12}S_4$: C, 35.67; H, 4.86. Found: C, 35.14; H, 4.68.

2,5,7,12-Tetrakis(xanthyloxy)tetracyclo[7.2.1.$0^{4,11}$.$0^{6,10}$]dodecane (10b). To a magnetically stirred suspension of sodium hydride (0.480 g, 20 mmol) in carbon disulfide (50 mL) was added a solution of tetrol **7** (0.450 g, 2 mmol) in THF (20 mL). After the mixture was stirred for 24 h at room temperature, methyl

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(29) Kubiak, G. Ph.D. Thesis, University of Wisconsin—Milwaukee, Milwaukee, WI, 1989.

(30) Cooper, K.; Pattenden, G. *J. Chem. Soc., Perkin, Trans. 1* **1984**, 799.

(31) Paquette, L. A.; Lau, C. J. *Synth. Commun.* **1986**, *16*, 103.

(32) Lannoye, G. Ph.D. Thesis, University of Wisconsin—Milwaukee, Milwaukee, WI, 1987.

(33) Sedelmeier, G.; Fessner, W. D.; Pinkos, R.; Grund, C.; Murty, B.; Hunkley, D.; Rihs, G.; Fritz, H.; Krüger, C.; Prinzbach, H. *Chem. Ber.* **1986**, *119*, 3442.

iodide (2.8 g, 20 mmol) was added via syringe. The reaction mixture was stirred for 48 h, diluted with ether (100 mL), and washed with water and brine. The solvent was removed under reduced pressure. Chromatography of the residue on silica gel (eluent 10% ethyl acetate/hexane) afforded tetraxanthate **10b** (1.0 g, 85%) as a yellow viscous oil: IR (neat) 1700, 1412, 1201 cm^{-1}; ^{1}H NMR (250 MHz, $CDCl_3$) δ 1.30–2.00 (m, 4 H), 2.45 (s, 6 H), 2.55 (s, 6 H), 2.70 (bs, 6 H), 3.50–3.80 (m, 4 H); ^{13}C NMR (62.86 MHz, $CDCl_3$) (major isomer) δ 216.00, 215.00, 87.56, 84.86, 60.45, 49.72, 46.25, 34.66, 19.10, 14.28; mass spectrum (CI, CH_4), *m/e* (relative intensity) 155 ($M^+ + 1 - 4CH_3CS_2OH$, 100); (EI, 15 eV) *m/e* (relative intensity) 479 ($M^+ - CH_3CS_2OH$, trace), 371 (23.2), 370 ($M^+ - 2CH_3CS_2OH$, 21.2), 295 (28.3), 262 ($M^+ - 3CH_3CS_2OH$, 19.3), 187 (32.8), 155 ($M^+ - 4CH_3CS_2OH + 1$, 100), 154 ($M - 4CH_3CS_2OH$, 14.8); high-resolution mass spectrum calcd for $C_{20}H_{26}O_4S_8$ 585.9597, found 585.9579.

2,5,7,12-Tetrakis(acetyloxy)tetracyclo[7.2.1.0^{4,11}.0^{6,10}]dodecane (10c). To a stirred solution of tetrol 7 (0.420 g, 1.8 mmol) in dry pyridine (20 mL) was added acetic anhydride (5 mL) and a catalytic amount of DMAP (20 mg). The reaction mixture was stirred at room temperature for 20 h and poured into crushed ice (50 g). The tetraacetate was extracted from the aqueous layer into ether (4 × 250 mL), and the combined organic layers were washed with saturated $CuSO_4$ solution (2 × 50 mL) and brine (50 mL) and dried ($MgSO_4$). The solvent was removed under reduced pressure, and the residue was purified on a short column of silica gel (elution with ether) to give tetraacetate **10c** (0.60 g, 85%): IR (neat) 2900 (br), 1725 cm^{-1}; ^{1}H NMR (250 MHz, $CDCl_3$) δ 1.30–2.20 (m, 4 H), 2.05 (s, 6 H), 2.15 (s, 6 H), 2.80–4.20 (m, 6 H), 5.10–5.35 (m, 4 H); ^{13}C NMR (62.86, $CDCl_3$) (major isomer) δ 170.45, 170.25, 79.06, 78.57, 54.13, 50.69, 48.23, 35.01, 21.11, 20.79; mass spectrum (EI, 15 eV), *m/e* (relative intensity) 351 ($M^+ - COCH_3$, 2.7), 334 ($M^+ - CH_3COOH$, 1.3), 292 (34.3), 274 (40), 232 (100), 214 (35.2), 190 (99.2), 172 (75); high-resolution mass spectrum calcd for $C_{13}H_{23}O_7$ 351.1435 ($M^+ - COCH_3$), found 351.1451.

Tetra-*tert*-butyl 2,6-Di(3-propenyl)-3,7-dimethoxy-1,5-dimethyl-*cis*-bicyclo[3.3.0]octa-3,7-diene-2,4,6,8-tetracarboxylate. In a 500-mL round-bottom flask which had been flame dried, KO-*t*-Bu (2.36 g, 21 mmol) was dissolved in dry THF (50 mL) and stirred under argon. The bis enol-ether **14** (5.0 g, 8.4 mmol) was dissolved in dry THF (50 mL) and was added to the *tert*-butoxide solution through a double-edged needle. The mixture immediately took on a yellow color which gradually darkened to red-orange. The solution was stirred at room temperature for 1 h after which allyl iodide (5.0 g, 29 mmol) was added via a syringe. After the mixture was stirred for 45 min, the reaction was observed by TLC (silica gel, 50% EtOAc/hexane). Analysis of the TLC indicated that the alkylation was incomplete for starting **14** remained. Two more additions of potassium *tert*-butoxide (2.0 g) followed by injections of allyl iodide (4.0 g) were required to force the dialkylation to completion. The solvent was removed under reduced pressure (rotary evaporator), and the residue was taken up in EtOAc (100 mL) and H_2O (50 mL). The layers were separated, after which the organic layer was washed with aqueous HCl (2 × 50 mL) and brine (2 × 50 mL). The organic solution was dried ($MgSO_4$), after which it was concentrated by rotary evaporation and dried under vacuum to provide a dark viscous oil (5.50 g, >98%). This material was used in the next step without further purification.

2,6-Di(3-propenyl)-1,5-dimethyl-*cis*-bicyclo[3.3.0]octane-3,7-dione (15). The mixture of diallyl tetraesters (5.50 g) from the previous experiment was dissolved in a mixture of glacial acetic acid (50 mL) and aqueous HCl (50 mL) and heated to reflux. The solution was maintained at reflux for 3 h, after which it was cooled to 0 °C. The reaction mixture was diluted with water (200 mL) and extracted with $CHCl_3$ (3 × 50 mL). The combined chloroform layers were washed with water (2 × 50 mL, aqueous $NaHCO_3$ (2 × 50 mL), and brine (50 mL). The solution was dried ($MgSO_4$) and concentrated by rotary evaporation to furnish a dark viscous oil (2.0 g, 98%). Analysis of this material by capillary GC indicated it consisted of three components: retention time 9.30 min (30%) **16**, 9.96 min (45%) **15**, and 10.04 min (12%). The mixture was further purified on silica gel by flash column chromatography (eluent, EtOAc 20%/hexane) to provide two major isomers.

Isomer I (2,6-diallyl dione), 15: mp 79–80 °C; IR (KBr) 1735 cm^{-1}; ^{1}H NMR (250 MHz, $CDCl_3$) δ 1.18 (6 H, s), 1.84–2.40 (10 H, m), 5.0 (4 H, m), 5.85 (2 H, m); ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 216.48, 136.73, 116.26, 56.19, 47.52, 45.95, 31.01, 21.62; GC mass spectrum, *m/e* (relative intensity) 246 (M^+, 2.3), 231 (1.2), 218 (2.7), 150 (12.5), 149 (10.2), 96 (62.5), 95 (100). Anal. Calcd for $C_{16}H_{22}O_2$: C, 78.02; H, 8.99. Found: C, 77.99; H, 8.90.

Isomer II (2,8-diallyl dione), 16: yellow oil; IR (neat) 1725, 1635 cm^{-1}; ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 217.03, 137.01, 115.99, 58.26, 54.77, 50.19, 41.62, 30.97, 16.04; GC mass spectrum, *m/e* (relative intensity), 246 (M^+, 2.1), 231 (2.3), 218 (1.9), 150 (14.2), 149 (12.3), 107 (33.3), 96 (95.8), 79 (100); high-resolution mass spectrum calcd for $C_{16}H_{22}O_2$ 246.1620, found 246.1609.

2,6-Bis(1-oxo-2-ethyl)-1,5-dimethyl-*cis*-bicyclo[3.3.0]octane-3,7-dione (17). The 2,6-diallyl dione **15** (1.7 g, 6.9 mmol) was dissolved in dry ethyl acetate (200 mL) in a 500-mL three-necked flask equipped with a magnetic stirrer and low-temperature thermometer. The flask was placed in a dry ice/acetone cooling bath, and the temperature was allowed to drop to ca. −60 °C. Ozone was generated (O_3 flow 3.5 lpm; 114 VAC, pressure; 5.9 psi) and bubbled through the cold solution until a light blue color was observed. The excess O_3 was purged from the medium with argon. Dry CH_3OH (50 mL) and dimethyl sulfide (50 mL) were added to the reaction mixture, and the temperature was allowed to raise to 25 °C. After the reaction mixture was stirred for 48 h the solvent was removed under reduced pressure to provide an oil. The residue was taken up in fresh EtOAc and dried ($MgSO_4$). The solvent was removed under reduced pressure to provide a viscous oil (1.8 g). This material was purified by elution through a short column (silica gel) with EtOAc (eluent) to afford diketo dialdehyde **17** (1.7 g, 98%) as a colorless oil: IR (neat) 1735, 1710 cm^{-1}; ^{1}H NMR (DMSO-d_6, 250 MHz) δ 1.24 (s, 6 H), 1.90–3.10 (m, 10 H), 9.82 (s, 2 H); ^{13}C NMR (62.86 MHz, $CDCl_3$) major isomer δ 214.01, 199.16, 51.44, 51.44, 40.60, 20.92; mass spectrum (CI, CH_4), *m/e* (relative intensity) 251 (M + 1, 18.5), 233 (100), 215 (23.6), 187 (52.4); high-resolution mass spectrum calcd for $C_{14}H_{18}O_4$ 250.1205, found 250.1215.

Cyclization of 2,6-Bis(1-oxo-2-ethyl)-1,5-dimethyl-*cis*-bicyclo[3.3.0]octane-3,7-dione (17) To Provide Transannular Product 18. The diketo dialdehyde **17** (1.5 g, 6 mmol) was dissolved in THF (500 mL), and aqueous HCl (7.5 mL of a 2.0 N solution) was added to the reaction mixture, after which it was stirred for 7 days at room temperature under Ar. The reaction was monitored (via partial workup) by ^{1}H NMR spectroscopy. The solution was neutralized with solid $NaHCO_3$, and the inorganic material was filtered from the medium. The THF was removed under reduced pressure to provide an aqueous layer, which contained the crude material. The aqueous layer was diluted with water (50 mL) and extracted with ethyl acetate (continuous extraction) for 4 days. The solvent was dried ($MgSO_4$) and then removed under reduced pressure to provide a solid (1.25 g). This material was purified by flash chromatography on silica gel (eluent, 10% MeOH in EtOAc) to provide white crystalline **18** (1.0 g, 66%): mp 161–162 °C; IR (KBr) 3450, 1725 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.01 (3 H, s), 1.14 (3 H, s), 1.51 (1 H, dd, J = 13, 4.5 Hz), 1.72 (1 H, ddd, J = 13, 13, 3.5 Hz), 2.08 (1 H, dddd, J = 13, 6, 3.5 Hz), 2.27 (1 H, dd, J = 13, 6 Hz), 2.28 (1 H, d, J = 19 Hz), 2.34 (1 H, d, J = 19 Hz), 2.35 (1 H, bs), 2.45 (1 H, d, J = 19 Hz), 2.49 (1 H, d, J = 19 Hz), 3.95 (1 H, dd, J = 13, 6 Hz), 5.62 (1 H, t, J = 6, 4.5 Hz); ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 231.26, 226.44, 99.24, 75.00, 68.17, 57.21, 47.85, 46.17, 43.59, 42.71, 34.94, 28.84, 19.14, 17.11; mass spectrum (CI, CH_4), *m/e* (relative intensity) 251 (M + 1, 15.3), 233 (100); (EI, 15 ev), *m/e* (relative intensity) 250 (M^+, 48.6), 232 (M − 18, 100), 214 (9.1), 204 (43.1), 152 (32.5). Anal. Calcd for $C_{14}H_{18}O_4$: C, 67.16; H, 7.24. Found: C, 67.08; H, 7.22.

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Supplementary Material Available: Table summarizing reactions attempted toward the synthesis of tetraene 3 and NMR spectra for compounds **10a–c** and **18** (11 pages). Ordering information is given on any current masthead page.