General Approach to the Synthesis of Polyquinenes. 8.[1a] Synthesis of Triquinacene, 1,10-Dimethyltriquinacene, and 1,10-Cyclohexanotriquinacene[1b]

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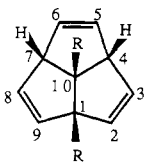
Abstract: The synthesis of tricyclo[5.2.1.$0^{4,10}$]deca-2,5,8-triene (**1**), 1,10-dimethyltricyclo[5.2.1.$0^{4,10}$]deca-2,5,8-triene (**3**), and tetracyclo[5.5.2.$0^{1,8}$.$0^{4,8}$]tetradeca-2,5,13-triene (**4**) has been accomplished via the reaction of 1,2-dicarbonyl compounds with di-*tert*-butyl 3-oxoglutarate (Weiss reaction). Condensation of glyoxal **5a** with di-*tert*-butyl 3-oxoglutarate (**6b**) gave the tetra-*tert*-butyl *cis*-dioxobicyclo[3.3.0]octane-2,4,6,8-tetracarboxylate **7b** in 93% yield. This bisenol **7b** was converted into the bisenol ether **9b** regiospecifically (90% yield). This transformation was followed by monoalkylation (KH, allyl iodide; −58 °C) and hydrolysis to generate 2-allyl-*cis*-bicyclo[3.3.0]octane-3,7-dione in 90% overall yield from **9b**. The mixture of epimeric 2-allyl-3,7-diones **11a,b** was transformed (O_3; DMS) into the mixture of epimeric aldehydes **12a,b**. This process was followed by aldol cyclization (2 N HCl, THF) to provide the diastereomeric mixture of *endo*- (**13a**) and *exo*- (**13b**) triquinane monols in 85% yield. Reduction of **13a,b** with borane–THF (0 °C) generated the stereoisomeric mixture of triols **14a,b** which were subjected to an HMPA-mediated dehydration sequence to provide triquinacene (**1**), accompanied by small amounts of isotriquinacene. The mixture of trienes were converted into pure **1** by exposure to *p*-TSA in methylene chloride–pentane. Substitution of biacetyl (**5b**) for glyoxal **5a** in the Weiss reaction, followed by the analogous steps detailed in the synthesis of **1**, provided 1,10-dimethyltriquinacene (**3**). In addition, the synthesis of 1,10-cyclohexanotriquinacene (**4**), another centro-substituted triquinacene, has been accomplished by substitution of cyclohexane-1,2-dione (**23**) for **5a** in the condensation, followed by the same sequence of reactions presented above for **1** and **3**.

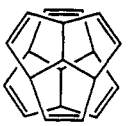
The synthesis and chemistry of triquinacene (**1**) have been a topic of continuous interest since the molecule was first prepared by Woodward et al. in 1964.[2] A number of groups have devised routes to this triquinane[1b,3] as part of an approach toward dodecahedrane;[4] moreover, de Meijere has detailed attempts to prepare the strained polyquinene acepentalene from **1** and has reported the preparation of dihydroacepentalenediide.[5]

Recently Serratosa et al.[6] have proposed an "aldol approach" to the synthesis of dodecahedrane related to the pericyclic route **2** originally proposed for this molecule by Woodward,[2] Müller,[7]

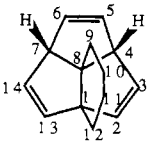


1, R=H

3, R=CH_3



2



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and Jacobson.[3,8] Difficulties encountered in the reaction of the two triquinacene units of **2** in the desired fashion via their concave rather than convex faces have hampered previous attempts to execute this convergent, reflexive synthesis[9] via the pericyclic approach. Presumably this will pose difficulties in the related aldol approach.[6]

In keeping with our interest in the preparation of polyquinenes[1b,10] via the Weiss reaction,[11] we wish to report the successful execution of a general approach for synthesis of triquinacene (**1**),[1b] and the centro-substituted triquinacenes 1,10-dimethyltriquinacene (**3**) and 1,10-cyclohexanotriquinacene (**4**). Of particular interest in regard to the present work is the unique topography of the tetracycle **4**. This molecule has embodied in its [4.3.3]propellane molecular structure[12] a six-membered ring which shields the convex face of the triquinane skeleton. This type of centro-substituted triquinacene may prove to be useful in the pericyclic[2] and aldol[6] approaches to the spherically shaped dodecahedrane.

The initial route to triquinacene (**1**) via the Weiss reaction (Scheme I) involved the monoalkylation of the highly symmetrical *cis*-bicyclo[3.3.0]octane-3,7-dione, which could at best be accomplished in only 45% yield.[13] Although symmetry in synthesis is often desirable, it is sometimes a complicating factor. Numerous attempts to differentiate between the carbonyl groups in the two five-membered rings of *cis*-bicyclo[3.3.0]octane-3,7-dione have been reported.[14] These methods have involved multistep synthesis,

(1) (a) This paper is dedicated to Dr. Ulrich Weiss on the occasion of his 80th birthday. (b) Portions of this work have been reported previously in preliminary form, See: Gupta, A. K.; Weiss, U.; Cook, J. M. *Tetrahedron Lett.* **1988**, *29*, 2535. Bertz, S. H.; Lannoye, G. S.; Cook, J. M. *Tetrahedron Lett.* **1985**, *26*, 4695.

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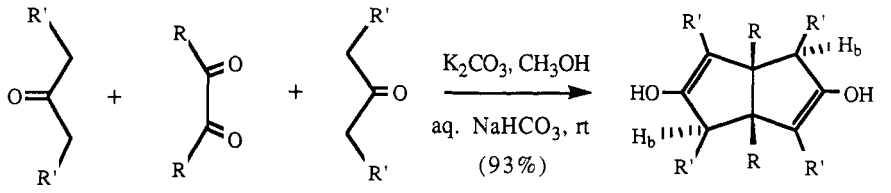
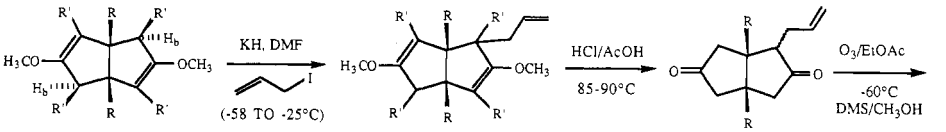
Scheme I



6a, R'=CO_2Me **5a**, R=H **6a**, R'=CO_2Me **7a**, R=H, R'=CO_2Me
6b, R'=CO_2tBu **5b**, R=Me **6b**, R'=CO_2tBu **7b**, R=H, R'=CO_2tBu
8, R=Me, R'=CO_2tBu

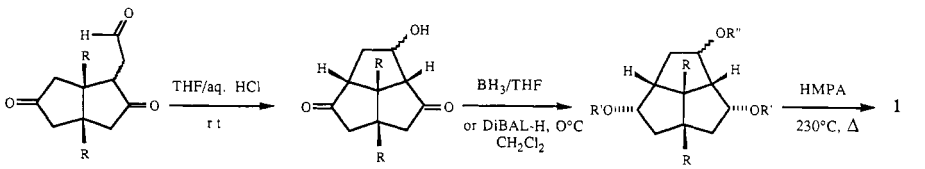
Scheme II



9a, R=H(Ha), R'=CO_2Me
9b, R=H(Ha), R'=CO_2tBu
16, R=CH_3, R'=CO_2tBu

10, R=H, R'=CO_2tBu
17, R=CH_3, R'=CO_2tBu

11a, R=H (-$CH_2CH=CH_2$, *exo*)
11b, R=H (-$CH_2CH=CH_2$, *endo*)
18a, R=CH_3 (-$CH_2CH=CH_2$, *exo*)
18b, R=CH_3 (-$CH_2CH=CH_2$, *endo*)



12a, R=H, (-CHO, *exo*)
12b, R=H, (-CHO, *endo*)
19a, R=CH_3 (-CHO, *exo*)
19b, R=CH_3 (-CHO, *endo*)

13a, R=H, (-OH, *endo*)
13b, R=H, (-OH, *exo*)
20a, R=CH_3 (-OH, *exo*)
20b, R=CH_3 (-OH, *endo*)

14a, R=R'=H, R"=H (*endo*)
14b, R=R'=H, R"=H (*exo*)
15, R=H, R'=R"=SO_2Me
21, R=CH_3, R'=R"=H (*exo* and *endo*)

protection–deprotection sequences accompanied by several recycle passes, or alkylation reactions the yields of which have been only moderate.[13,14] Since the alkylation step was crucial to the successful synthesis of **1** from glyoxal **5a** and dimethyl 3-oxoglutarate (**6a**), another approach was investigated. The Weiss reaction between **5a** and **6a** gave the 1:2 adduct **7a** as the bisenol tautomer in high yield. The anti disposition of the two enolic double bonds in **7a** has been previously established by Camps in a different series[15] and confirmed in our laboratory.[10] Treatment of the bisenol tetraester **7a** with diazomethane provided in 93% yield the bisenol ether **9a**, a molecule in which four reactive atoms were now protected from alkylation. Attempts to monoalkylate **9a** at low temperatures with allyl iodide were successful but hydrolysis of the methyl ester groups in the allylated material resulted in the isolation of a number of products of incomplete hydrolysis.[13] Evidently, attack of the electrophile occurred, as expected, from the convex face of **9a** and forced the methyl ester into the sterically congested cavity of the V-shaped molecule, which retards the rate of hydrolysis of this ester function.[13] However, the versatility of the reaction of **5** and **6** could be exploited by substituting the *tert*-butyl ester functions of **6b** (R' = CO_2tBu) for those of the methyl ester analogue **6a**. This replacement, moreover, had profound effects on the regioselectivity of the monoalkylation process (see below) and provided a simple means by which to alter the symmetry of the *cis*-bicyclo[3.3.0]octane-3,7-dione unit (see ref 16 for details). When glyoxal **5a** was stirred with di-*tert*-butyl 3-oxoglutarate (**6b**) in alkaline solution, a 93% yield of tetra-*tert*-butyl *cis*-3,7-dioxobicyclo[3.3.0]octane-2,4,6,8-tetracarboxylate (**7b**) was realized. Treatment of tetraester **7b** with diazomethane resulted in the clean formation of bisenol ether **9b** and in greater than 90% yield. The symmetry (C_2) of the bisenol ether **9b** (Scheme II) was confirmed by ^{13}C NMR spectroscopy; 10 lines were observed in the carbon spectrum, which corresponded to 20 carbon atoms. The stereochemistry of the tetra-*tert*-butyl ester functions in **7b** as well as the stereochemistry and anti disposition of the double bonds in **9b** were assigned on comparison of the proton and ^{13}C NMR spectra of these molecules to that reported for tetraethyl *cis*-3,7-dioxobicyclo[3.3.0]octane-2,4,6,8-tetracarboxylate by Camps.[15] The coupling constants observed in the proton spectrum for H_a and H_b (Schemes I and II) in **7b** (J_{ab} = 2.1 Hz) and in **9b** (J_{ab} = 1.8 Hz) are in agreement with the exo stereochemistry assigned to the two ester functions located at C(2) and C(6). The two methine protons (H_a, H_b) must lie on opposite faces (trans coupling) of the molecule;[17] consequently, the two ester groups must be located on the exo faces of **7b** and **9b**, respectively. The stereochemistries of **7a** and **9a** were confirmed in similar fashion and the coupling constants were also correlated with the related tetramethyl esters reported in ref 10.

From the outset it was decided to employ an allyl group as a masked acetaldehyde equivalent because the allyl group would be stable under conditions of hydrolysis and could be converted into an aldehyde at a latter stage in the synthesis. Monoalkylation of the tetramethyl tetraester **9a** (Scheme II) with allyl iodide and potassium hydride at low temperature (−58 °C) gave a mixture of monoalkylated and dialkylated material.[13] In contrast, however, monoalkylation of the tetra-*tert*-butyl tetraester **9b** under the analogous conditions gave the desired monoalkylated derivative **10** with high regioselectivity in 90% yield. A detailed study of the influence of temperature and stoichiometry on the alkylation of **9a** and **9b** has been carried out.[13] In brief, the large *tert*-butyl ester groups retard the rate of addition of electrophiles to the anion of **9b** and provide a wider reaction window in regard to temperature than was observed in the alkylation of the tetramethyl ester

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9a. This permits the use of low temperatures in the alkylation of **9b** to prevent the addition of a second electrophile. This observation has far-reaching implications with regard to chemistry in this area, for the symmetry of the *cis*-bicyclo[3.3.0]octane-3,7-dione unit has effectively been altered. The consequences of this observation will be reported elsewhere.[16] The tetra-*tert*-butyl ester functions are, therefore, extremely important in directing the reaction toward mono- rather than dialkylation. Thus, **9b** was monoalkylated (−60 to −40 °C) with potassium hydride–allyl iodide to provide **10**, and the product was hydrolyzed to generate the monoallyl 3,7-dione **11** in 90% overall yield from **9b**. The monoallyl derivative was isolated as a mixture of exo (**11a**) and endo (**11b**) stereoisomers in a ratio of 3:1 (^{13}C NMR),[13] accompanied by less than 2% of the dialkylated 3,7-dione.

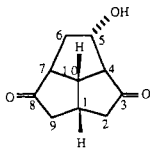
When the mixture of epimeric 2-allyl derivatives **11a,b** was subjected to oxidation with OsO_4–$NaIO_4$[18] on small scale, an 80–85% yield of a stereoisomeric mixture of the corresponding aldehydes **12a,b** was realized, as illustrated in Scheme II. As expected, the ratio (3:1) of the two aldehydes was similar to that of the mixture of epimeric 2-allyl derivatives with the exo isomer predominating. This was determined by integration of the ^{13}C and ^{1}H NMR spectra of the mixture [^{13}C NMR 199.5, 199.8 ppm (aldehyde); ^{1}H δ 9.80, 9.35 ppm]. The scale-up of the OsO_4-mediated oxidation of **11** proved troublesome, for yields decreased. For this reason the 2-allyl dione **11a,b** was stirred with ozone at −60 °C in ethyl acetate, followed by addition of dimethyl sulfide (DMS),[19] to provide aldehydes **12a,b** on a large scale in 81% yield.

Examination of the geometry of both stereoisomeric diketo dialdehydes **12a,b** indicated that only the endo isomer (**12a**) could cyclize to provide the desired triquinacene ring system. It was, therefore, decided to adopt reaction conditions which would permit equilibration of the exo isomer (**12b**) into the desired endo (**12a**) stereoisomer. Once the endo isomer **12a** cyclized, it was felt that triquinacene **13** would not reopen readily in acidic solution due to the stability of the newly formed C–C single bond. The thermodynamic equilibrium (3:1) between the exo (**12a**) and endo (**12b**) isomers could reestablish and this process would continue until **12** was completely converted into the tricyclic system **13** (Scheme II). In fact, the conversion of **12a,b** into **13** in THF in the presence of aqueous HCl (2 N) took 1 week to go to completion but occurred in greater than 85% yield.

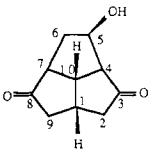
The molecular structures of the two tricyclic alcohols **13a** and **13b** were confirmed by NMR spectroscopy (1D, 2D, ^{1}H, and ^{13}C NMR). From the mixture (approximate ratio 1:1), the endo isomer **13a** solidified and was recrystallized from a mixture of chloroform–hexane. The exo isomer (**13b**) was obtained in only 80% purity. A systematic analysis of NMR data for both alcohols led to the assignments and coupling constants depicted in Table I. The coupling constant (10 Hz) between H(10) and each of the junction protons H(1), H(4), and H(7) in both **13a,b** corresponds to a dihedral angle of (or near) 0° and confirms the endo mode of cyclization. The solution to the assignment of the stereochemistry of the hydroxyl group at C(5) was obtained from the coupling constants of the two protons at C(6) in monol **13a**. In addition to the geminal coupling (13 Hz) for the protons at C(6) (δ 2.27 ppm), only small couplings with H(7) and H(5) of 1.5 and 2 Hz, respectively (Table I), were observed, indicating that the corresponding dihedral angles are close to 90°. Examination of molecular models indicates this situation can only occur for the endo proton H(6) when the hydroxy group is also endo. This configuration is consistent with the 6-Hz coupling constant between H(5) and H(4), dihedral angle of 20°. In the exo epimer **13b**, a long-range coupling constant (four bonds) between H(4) and one of the protons at H(6) of 1.5 Hz can be employed to identify the H(6) exo proton at δ 1.985. The coupling constants of both protons at H(6) and H(5) are consistent with the exo configuration for the hydroxyl function in **13b** (Table I). In addition, H(5) is more deshielded in the endo isomer **13a** than in the exo diastereomer (δ 4.49 ppm vs δ 4.27 ppm), and in **13a** proton H(6) endo is more deshielded than H(6) exo (δ 2.27 ppm and 2.07 ppm), respectively. In contrast, the shifts are reversed in the exo isomer **13b** [that is, H(6) exo δ 1.98 ppm, H(6) endo δ 1.62 ppm]. Nuclear Overhauser measurements which were performed on both alcohols **13a** and **13b** yielded the following information: Upon saturation of H(5) in **13a**, the signal for H(4) underwent an enhancement of 22% and the resonance for H(6) exo underwent one of **5%**. In contrast, irradiation of H(5) in **13b** caused an enhancement of H(4) by only 5% and of H(6) endo by 7%. The strong NOE of 22% observed for **13a** confirms the close proximity of H(5) and H(4) and the endo configuration for the hydroxyl group in this diastereomer. The assignments for **13a** and **13b** in the C-13 spectra (Table II) were based on the proton assignments (2D ^{1}H–^{13}C correlated spectra). Carbon atom C(5) is notably more deshielded in the exo isomer **13b** than in the endo epimer, as illustrated in Table II.

Several other methods were attempted to effect cyclization of the aldehydes **12a,b** to the tricyclic diketo alcohols **13a,b**, including acetic acid–acetic anhydride; trifluoroacetic acid; THF, HCl(g); THF, HBr(g). These reactions, however, furnished a complicated mixture of tricyclic compounds (see the supplementary material for details).

Table I. Proton Assignments and Chemical Shifts of the Two Triquinane Monols Endo (**13a**) and Exo (**13b**)



13a



13b

	13a		13b	
proton	chemical shift, δ	*J* value, Hz	chemical shift, δ	*J* value, Hz
H(5)	4.49	J_{5-4} = 6 J_{5-6exo} = 4 $J_{5-6endo}$ = 2	4.24	J_{5-4} = 1.5 J_{5-6exo} = 3 $J_{5-6endo}$ = 4.5
H(10)	3.58	J_{10-4} = 10 J_{10-7} = 10 J_{10-1} = 10	3.60	J_{10-4} = 9 J_{10-7} = 10 J_{10-1} = 10
H(1)	3.15	J_{1-10} = 10 J_{1-2exo} = 10 J_{1-9exo} = 11 $J_{1-2endo}$ = 4 $J_{1-9endo}$ = 7.5	2.96	J_{1-10} = 10 J_{1-2exo} = 10 J_{1-9exo} = 9.5 $J_{1-2endo}$ = 7 $J_{1-9endo}$ = 3.5
H(4)	2.92	J_{4-5} = 6 J_{4-10} = 10 J_{4-2exo} = 2 J_{4-7} < 1	2.77	J_{4-5} = 1.5 J_{4-10} = 9 J_{4-2exo} = 2 J_{4-6exo} = 1.5
H(7)	2.84	J_{7-10} = 10 J_{7-6exo} = 10 $J_{7-6endo}$ = 1.5 J_{7-9exo} = 2 J_{7-4} < 1	3.00	J_{7-10} = 10 J_{7-6exo} = 9 $J_{7-6endo}$ = 9 J_{7-9exo} = 2
H(2) exo	2.69	J_{gem} = 19.5 J_{2exo-1} = 10 J_{2exo-4} = 2	2.58	J_{gem} = 19.5 J_{2exo-1} = 10 J_{2exo-4} = 2
H(9) exo	2.66	J_{gem} = 19.5 J_{9exo-1} = 11 J_{9exo-7} = 1.5	2.64	J_{gem} = 18.5 J_{9exo-1} = 9.5 J_{9exo-7} = 2
H(9) endo	2.42	J_{gem} = 19.5 $J_{9endo-1}$ = 7.5	2.13	J_{gem} = 18.5 $J_{9endo-1}$ = 3.5
H(2) endo	2.32	J_{gem} = 19.5 $J_{2endo-1}$ = 4	1.93	J_{gem} = 19.5 $J_{2endo-1}$ = 7
H(6) endo	2.27	J_{gem} = 13 $J_{6endo-7}$ = 1.5 $J_{6endo-5}$ = 2	1.62	J_{gem} = 13.5 $J_{6endo-7}$ = 9 $J_{6endo-5}$ = 4.5
H(6) exo	2.08	J_{gem} = 13.5 J_{6exo-7} = 10 J_{6exo-5} = 4	1.99	J_{gem} = 13.5 J_{6exo-7} = 9 J_{6exo-5} = 3 J_{6exo-4} = 1.5

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Table II. ^{13}C NMR Chemical Shifts (δ) for the Triquinanols

carbon	13a	13b	20a[a]	carbon	29[b]
C(8)	223.02	220.51[c]	218.99[c]	C(14)	219.88[c]
C(3)	219.93	219.09[c]	217.63[c]	C(3)	217.69[c]
C(5)	74.74	77.94	78.69	C(5)	73.77
C(4)	58.88	62.28	68.92	C(4)	66.13
C(7)	52.56	50.75	59.55	C(7)	56.70
C(2)	48.74	46.34	53.25	C(2)	53.16
C(10)	47.54	46.54	57.31	C(8)	56.74
C(9)	45.28	45.73	59.92	C(13)	51.82
C(6)	43.63	38.70	39.12	C(6)	40.96
C(1)	31.66	31.50	42.71	C(1)	42.13

[a] 10-CH_3 and 5-CH_3: δ 23.46 and 23.29 ppm. [b] C(9)–C(12): δ 34.73 and 34.30 ppm. C(10)–C(11): δ 22.78 and 21.36 ppm. [c] These assignments could be reversed.

Reduction of the two carbonyl groups present in **13a,b** under alkaline conditions ($NaBH_4$, CH_3OH) resulted in a retro-aldol reaction to generate **12**, followed by reduction of the three carbonyl groups to provide the ring-opened triol. In contrast, Lewis acid mediated reduction of **13** with borane–THF resulted in the formation of the desired triols **14a,b**, isolated as a mixture of stereoisomers in 93% yield. Examination of the mass spectrum of the mixture of triols represented by **14** confirmed the presence of a weak parent ion at 184 amu; moreover, this ion rapidly lost three molecules of water to generate the base peak at 130 amu. Examination of the ^{13}C NMR spectrum of **14** confirmed the presence of two stereoisomers represented by **14a,b**, the chemical shifts of which were determined from two-dimensional NMR spectroscopy and a DEPT NMR experiment. Due to the shape of the triquinane ring system, the hydride atom approaches the keto functionality of the *endo*-**13a** and *exo*-**13b** alcohols from the convex face. Consequently, the two new hydroxyl groups generated in this one-step sequence possess the endo configuration as illustrated in Scheme II. In both cases, the stereochemistry of the third hydroxyl group (from **13a,b**) which formed via the intramolecular aldol condensation was retained. The stereochemistry at each chiral center of the triols is unimportant if an approach can be found to remove both (endo or exo) hydroxyl groups indiscriminately.

A variety of methods is available to convert the hydroxyl groups of **14** into double bonds; however, secondary hydroxyl groups are smoothly eliminated on heating the corresponding polyhydroxy compounds in HMPA.[10,20,21] The mixture of triols **14a,b** was heated in refluxing HMPA for 48 h to furnish an 80% yield of triquinacene **1**, accompanied by 8% of isotriquinacene.[22] [Note: care must be taken to employ a cold finger condensor (dry ice–acetone) in this process to prohibit loss of volatile polyquinenes.] Since isotriquinacene, the bridgehead olefinic isomer, is approximately 5–7 kcal higher in energy[23] (MM2) as compared to **1**, the mixture can be converted into **1** by stirring in CH_2Cl_2–pentane in the presence of *p*-toluenesulfonic acid.[10,24] The disappearance of isotriquinacene can be followed by capillary gas chromatography until the purity of **1** is greater than 99%, negating the need for careful distillation. Triquinacene triol **14** was also converted into the trimesylate **15**, and the mesyl groups were eliminated, according to the procedure (Al_2O_3) of Deslongchamps[21] to provide **1** (80%), accompanied by less than 2% of isotriquinacene (see the supplementary material for details). The spectral and physical properties of **1** were identical with those reported in the literature.[2,3] In summary, **1** can be prepared from glyoxal **5** and di-*tert*-butyl 3-oxoglutarate in seven steps, the yields of which range from 80% to 93% and the sequence can be scaled up with ease.

The versatility of the Weiss reaction for the construction of polyquinenes stimulated interest in the synthesis of 1,10-dimethyltriquinacene (**3**). At the outset this synthesis might appear difficult, for the methyl group at carbon-1 is located on a nonactivated position of the triquinacene framework. Moreover, the second methyl group (C-10) is cojoined at an activated position while two other activated carbon atoms remain encased in **3**. Dissection of **3** in a retrosynthetic sense, however, provided a simple approach related to that employed for the preparation of **1** (Schemes I and II). When glyoxal **5a** was replaced by biacetyl **5b** in the Weiss reaction and stirred with di-*tert*-butyl 3-oxoglutarate (**6b**), a 93% yield of the 1,5-dimethyl-*cis*-bicyclo[3.3.0]octane-3,7-dione tetraester **8** was realized. The bisenol **8** was converted into the required bisenol ether **16** in excellent yield upon treatment with ethereal diazomethane. Eleven lines were observed in the ^{13}C NMR spectrum of **8**, which corresponded to 22 carbon atoms, while 12 lines were found in the spectrum of the bisenol ether **16**. The stereochemistry of **8** and **16** was assigned on comparison of their proton and ^{13}C NMR spectra to those previously reported for tetra-*tert*-butyl ester derivatives **7b** and **9b** (see above).[10,15]

Alkylation of **16** at −25 °C with allyl iodide–KH, followed by hydrolysis and decarboxylation gave 2-allyl-1,5-dimethyl-*cis*-bicyclo[3.3.0]octane-3,7-dione **18a,b** as a mixture of epimers (exo/endo, 2:3) in excellent yield. It was necessary to effect alkylation of **16** at warmer temperatures in comparison to the alkylation of **9b** in order to maximize the yield of **18**. Presumably, the 1,5-dimethyl functions in **16** retard the attack by electrophiles at positions 2 and 6. The ratio of diastereomers in **18** was determined from proton and ^{13}C NMR spectroscopy. Conversion of the allyl group of **18a,b** into the corresponding exo (**19a**) and endo (**19b**) aldehydes was accomplished via ozonolysis according to published procedures,[13] again in yields greater than 90%. Because of the interaction between the methyl groups located at positions 1 and 5 of **19** and the aldehyde function at C(2), the endo isomer **19b** predominated in the mixture in a ratio of 3:2. Aldol cyclization of the mixture of aldehydes **19a,b** was carried out in THF in the presence of 4% aqueous HCl to provide the epimeric mixture of diketo alcohols represented by **20a,b**. The cyclization was complete in 72 h, whereas condensation of **12** to provide **13** had taken much longer as a consequence of the preferred exo stereochemistry in the case of **12a,b**. The mixture of epimeric alcohols **20a** and **20b** was isolated in 70% yield, accompanied by another diketo alcohol (12%), whose carbon skeleton is felt to be derived by aldolization of **19** in a transannular fashion (see ref 25 for details). The stereochemistry of the major alcohol **20a** was established as exo on the basis of comparison of the proton and carbon-13 NMR spectra of **20a** to that of **13a** and **13b** (see Tables I and III). In particular, the chemical shifts and coupling constants of the protons designated as H(5) and H(6) as well as the chemical shift (δ 78.69 ppm, Table II) of the carbon atom at C(5) are characteristic of an exo alcohol in this series.

Treatment of **20a,b** with diisobutylaluminum hydride gave a mixture of epimeric triols **21** in 66% yield. The mixture of triols was then heated in HMPA at 230 °C for 24 h analogous to the conditions employed for the conversion of **14** into **1**. Careful extraction of the HMPA solution with pentane–water, followed by distillation at low temperature, yielded 1,10-dimethyltri-

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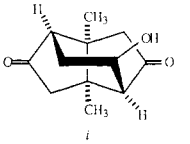
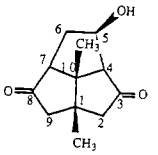
(24) Smith, A. B., III; Jerris, P. J. *J. Org. Chem.* **1982**, *47*, 1845.

(25) The structure of the byproduct i is felt to be that represented below as determined by 2D COSY NMR (250 MHz) and double irradiation experiments. Kubiak, G.; Wehrli, S.; Cook, J. M., unpublished results.

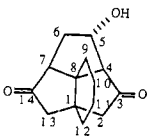


i

Table III. Proton Chemical Shifts and Coupling Constants of the Monols **20a** and **29**



20a[a]



29[b]

	20a[a]			**29**[b]	
proton	chemical shift, δ	J value, Hz	proton	chemical shift, δ	J value, Hz
H(5)	4.39	$J_{5-4} = 6$ $J_{5-6exo} = 4$ $J_{5-6endo} = 4.5$	H(5)	4.50	$J_{5-4} = 6.5$ $J_{5-6exo} = 4.5$ $J_{5-6endo} = 5$
H(4)	2.53	$J_{4-5} = 4$ $J_{4-2exo} = 2$ $J_{4-6exo} = 1$	H(4)[c]	2.69	$J_{4-5} = 7$ $H_{4-2exo} = 2$ $J_{4-7} < 1$
H(7)	2.81	$J_{7-6} = 9$ $J_{7-6endo} = 7.5$ $J_{7-9exo} = 2$ $J_{7-4} < 1$	H(7)	2.50	$J_{7-6exo} = 9$ $J_{7-6endo} = 4.5$ $J_{7-13exo} = 2$ $J_{7-4} < 1$
H(2) exo	2.41	$J_{gem} = 18$ $J_{2exo-4} = 2$	H(2) exo[c]	2.68	$J_{gem} = 18$ $J_{2exo-4} = 2$
H(9) exo	2.56	$J_{gem} = 17.5$ $J_{9exo-7} = 2$	H(13) exo	2.40	$J_{gem} = 18$ $J_{13exo-7} = 2$
H(9) endo	2.38	$J_{gem} = 17.5$	H(13) endo	2.68	$J_{gem} = 18$
H(2) endo	2.27	$J_{gem} = 18$	H(2) endo[c]	2.28	$J_{gem} = 18$
H(6) endo	1.90	$J_{6gem} = 14$ $J_{6endo-7} = 7.5$ $J_{6endo-5} = 4.5$	H(6) endo	2.03	$J_{gem} = 14$ $J_{6endo-7} = 4.5$ $J_{6endo-5} = 4.5$
H(6) exo	2.23	$J_{gem} = 14$ $J_{6exo-7} = 9$ $J_{6exo-5} = 4$ $J_{6exo-4} = 1$	H(6) exo	2.30	$J_{gem} = 14$ $J_{6exo-7} = 9$ $J_{6exo-5} = 5$

[a] 11- and 12-CH_3 are δ 1.22 and 1.48 ppm. [b] 9-, 10-, 11-, and 12-CH_3 from δ 1.4 to 1.6 ppm. [c] Coupling constants measured from the spectrum in CD_3OD.

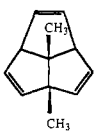
quinacene (**3**) (GC retention time, 5.7 min), accompanied by an olefinic isomer represented by either **22a** or **22b** (GC retention time, 6.5 min) in a ratio of 83:17. Again, the relative stabilities of **3** and its olefinic isomers **22a,b** were assessed via a variety of computational methods.[26] As illustrated in Table IV, both bridgehead isomers **22a,b** of **3** are higher in energy than **3**, consequently the mixture of dimethyltriquinacenes was stirred in the presence of *p*-toluenesulfonic acid in pentane–CH_2Cl_2.

After 3 h the olefinic isomer (retention time, 6.5 min) had disappeared and 1,10-dimethyltriquinacene (**3**) was isolated in pure form. The structure of **3** was determined upon examination of the proton and carbon NMR spectra of this triene. As expected from the symmetry (C_s) of **3**, six resonance signals were observed in the proton spectrum. Two of these represented the protons located on the angular methyl functions of **3** (δ 1.15, 1.24 ppm), while the two bridgehead methine protons were observed as a singlet at δ 3.20 ppm. The signals for the vinyl protons which remained were observed as follows: δ 5.48 (2 H, dd, J = 5.75 and 1.4 Hz), 5.51 (2 H, dd, J = 5.75 and 1.9 Hz), and 5.59 (2 H, s) ppm in complete agreement with the structure of **3**. Examination of **3** by carbon NMR and high-resolution mass spectroscopy confirmed the structure as 1,10-dimethyltriquinacene.

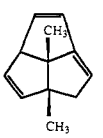
As pointed out earlier, the pericyclic approach **2** to dodecahedrane has been hampered by the propensity of **1** to undergo reaction via the convex faces of the molecules rather than reaction between the desired concave faces. For this reason a short synthesis of the centro-substituted triquinacene **4** was investigated. The construction of the [4.3.3]propellane framework contained in **4** began with the condensation of 2 equiv of di-*tert*-butyl 3-oxoglutarate (**6b**) with cyclohexane-1,3-dione (**23**) in an alkaline medium in similar fashion to the preparation of [*n*.3.3]propellanes

(26) Wertz, D. H.; Allinger, N. L. *Tetrahedron* **1974**, *30*, 1579 (Program QCPE 400). Allinger, N. L. *J. Am. Chem. Soc.* **1977**, *99*, 8127 (Program QCPE 395). Molecular Mechanics Package (MS-DOS computers) by Gajewski, J. J.; Gilbert, K. E. Serena Software, Box 3076, Bloomington, IN 47402, reviewed in *J. Am. Chem. Soc.* **1986**, *108*, 5042.

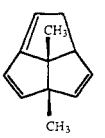
Table IV. Relative Energy Differences between Dimethyltriquinacene **3** and **22a,b**



3



22a



22b

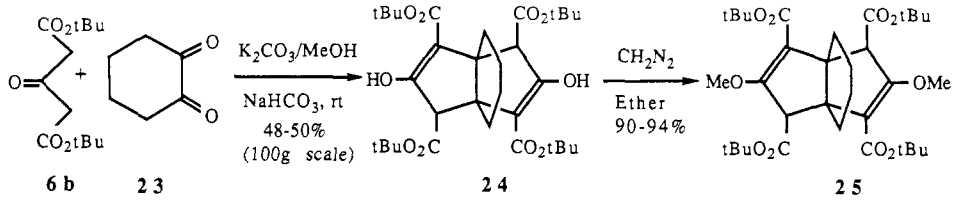
	ΔE relative to **3**, kcal/mol	
method[a]	**22a**	**22b**
MMPMI	7.6	8.0
MMPI	9.4	9.5
MM2	16.8	17.0

[a] All three computational methods place the two bridgehead isomers considerably higher in energy than the symmetrical isomer and nearly isoelectronic between the pair. The MM2 force field does not take into account stabilization of the bridgehead isomers through conjugation of the double bonds, consequently the relative energy difference between **3** and the two bridgehead isomers **22a,b** is probably slightly smaller.

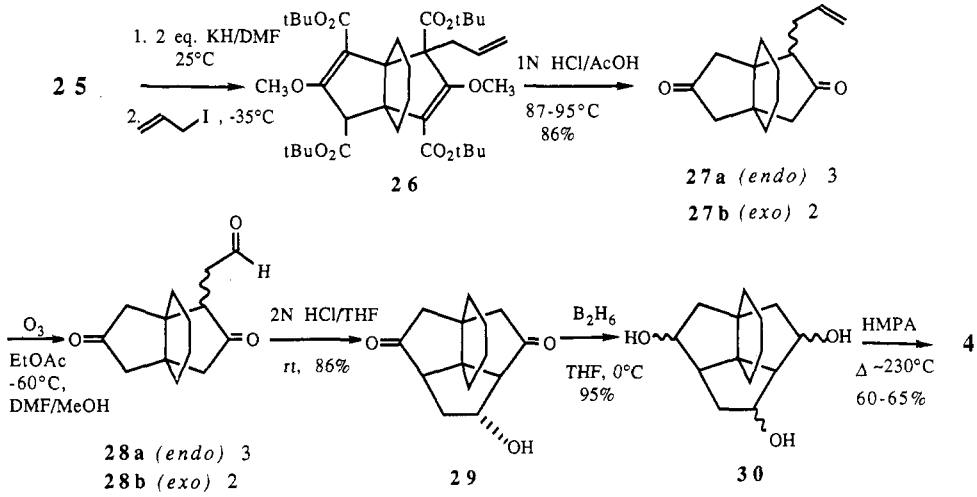
reported earlier (Scheme III).[27] Although the tetra-*tert*-butyl dioxopropellanetetracarboxylate **24** was isolated in only 50% yield, the reaction can be scaled up above the 100-g level; additional quantities of **24** remained in the mother liquor. The tetraester **24** exists in solution entirely as the bisenol tautomer and was isolated as a single symmetrical stereoisomer. The ^1H NMR spectrum of **24** contained a single resonance signal at δ 1.26 ppm, which represented the four bridgehead methylene groups. The 12 methyl groups of the 4 *tert*-butyl ester functions appeared as two singlets at δ 1.50 (18 H) and 1.55 (18 H) ppm, while the methine protons of carbon atoms 2 and 6 were observed as a singlet in the spectrum at δ 3.77 ppm. The two enolic hydrogen atoms were found to resonate downfield at δ 10.90 ppm while the C_2

(27) Weber, R. W.; Cook, J. M. *Can. J. Chem.* **1978**, *56*, 189.

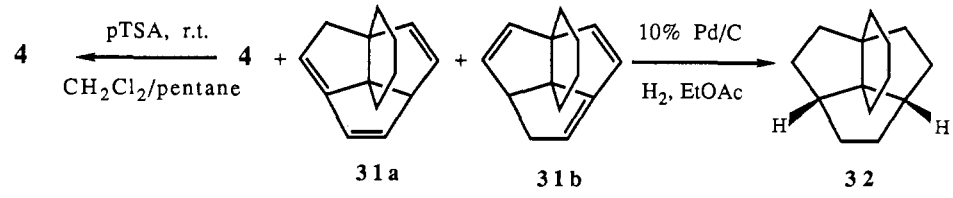
Scheme III



Scheme IV



Scheme V



symmetry of **24** was evident on examination of its 12-line ^{13}C NMR spectrum.

In order to protect the enolic hydroxyl functions of the bisenol **24**, it was converted into the bisenol ether **25** on treatment with ethereal diazomethane. The C_2 symmetry of **25** was evident from the 13-line ^{13}C NMR spectrum of the material. The methyl groups of the enol ether functions appeared in the carbon-13 spectrum as a singlet at δ 57.23 ppm and were also observed as a single resonance line (δ 3.70 ppm) in the ^1H NMR of **25**. The anti disposition of the double bonds in **25** was, therefore, assigned on the basis of the symmetry observed in both the ^1H and ^{13}C NMR spectrum of **25**, in agreement with the assignments for **7b** and **9b** (Scheme II).

The bisenol ether **25** was stirred at 25 °C with 2.2 equiv of potassium hydride in DMF for 1 h, followed by addition of allyl iodide (2.2 equiv) at −35 °C. Hydrolysis and decarboxylation of the intermediate tetraester **26** furnished the desired monoallyl[4.3.3]propellanedione **27** in 86% overall yield from **2**. Regiospecific monoalkylation had been effected in high yield. The monoallyl derivative **27** was isolated as a mixture of endo (**27a**) and exo (**27b**) stereoisomers in a ratio of 3:2 (GC and ^{13}C NMR). Conversion of the allyl group of **27** into the aldehyde function of **28** was accomplished by ozonolysis in 93% yield, according to published procedures.[10] Aldol cyclization of **28a,b** to provide triquinane **29** was executed under conditions of tautomeric equilibrium (2 N HCl–THF) to permit the exo stereoisomer **28b** to epimerize to the endo diastereomer **28a**.[10] Since the endo stereoisomer **28a** was the thermodynamically more stable epimer, the cyclization to **29** occurred rapidly and in 86% yield.

The stereochemistry of the endo triquinane monol **29**, the only epimer isolated from this process, was established principally on the basis of the ^{13}C NMR spectroscopy. Compare, for example, the chemical shifts of the C(5) carbon atom in **29** (δ 73.77 ppm) to that in the endo hydroxytriquinane **13a** (δ 74.74 ppm), both of which are upfield from the corresponding signal in either of the exo isomers **13b** or **20a** (see Table II). In addition, since the proton spectrum of **13a** (endo) differed somewhat from that of **29** (endo), an NOE experiment was carried out. Upon irradiation of the proton at C(5) in **29**, the signal for the junction proton H(4) increased (10%) and the analogous signal for H(6) exo also was enhanced (5%). These results are consistent with the configuration of the hydroxyl group (endo) as illustrated in **29** (Scheme IV).

When **29** was stirred in borane–THF (1 N) at 0 °C for 24 h, a mixture of stereoisomeric triols **30** was isolated in 95% yield (Scheme IV). These triols **30** were not separated but were heated in HMPA at 230–240 °C for 20 h under conditions analogous to those employed for the conversion of other polyols into polyquinenes.[10,11] Careful extraction of the HMPA solution with pentane–water, followed by distillation of the pentane layer through a column packed with glass beads furnished the propellane triquinacene **4** in 60–65% yield, accompanied by two minor olefinic isomers **31a** and **31b** (GC ratio 90:4:6). When the mixture of propellane triquinacenes **4**, **31a,b** was stirred in the presence of *p*-toluenesulfonic acid, the minor isomers **31a,b** disappeared and **4** was isolated in pure form (GC retention time, 8.2 min). As expected from the C_2 symmetry of **4**, 10 lines were observed in the ^{13}C NMR spectrum of this triene and 5 resonance signals were found in the proton NMR at δ 5.54 (2 H, dd, J = 6.0, 2.8 Hz), 5.53 (2 H, s), 5.40 (2 H, dd, J = 6.0, 1.7 Hz), 3.27 (2 H, t, J = 2.8, 1.7 Hz), and 1.48 (8 H, br s) ppm, respectively. This triene **4** is much easier to isolate from this process, since it has a much higher boiling point (63 °C/10 mmHg) than **1**. In addition, the mixture of olefinic isomers **4**, **31a,b** was converted into the parent hydrocarbon **32** upon catalytic hydrogenation, indicating that **31a**

and **31b** were indeed olefinic isomers of **4**.

Conclusion

In summary, the synthesis of triquinacenes **1**,[1b] **3**, and **4**[1b] have been accomplished via the Weiss reaction including the synthesis of the first two centro-substituted triquinacenes.[12] Since all of the steps outlined in Schemes I–V can be scaled up with ease, it is felt this general route can be employed for the preparation of multigram quantities of these trienes. Replacement of glyoxal **5a** with other 1,2-dicarbonyl compounds provides a simple entry into 1,10-disubstituted triquinacenes. Moreover, regiospecific alteration of the symmetry of the *cis*-bicyclo[3.3.0]octane-3,7-dione unit by the monoalkylation sequence detailed herein has enhanced the versatility of the Weiss reaction for the construction of polyquinenes of complex structure, including molecules amenable for the Woodward pericyclic[2] and Serratosa "aldol"[6] approaches to dodecahedrane. Although triquinacenes have occupied a pivotal position in the development of polyquinane chemistry,[28] to our knowledge no previous route to these topologically interesting centro-substituted molecules has been reported. Further work in this area is under way and will be reported in due course.

Experimental Section

The details of the general experimental are contained in the supplementary material. Tetra-*tert*-butyl *cis*-3,8-dihydroxybicyclo[3.3.0]octa-2,6-diene-2,4,6,8-tetracarboxylate (**7b**), tetramethyl 3,7-dimethoxy-*cis*-bicyclo[3.3.0]octa-2,6-diene-2,4,6,8-tetracarboxylate (**9a**), and tetra-*tert*-butyl-3,7-dimethoxy-*cis*-bicyclo[3.3.0]octa-2,6-diene-2,4,6,8-tetracarboxylate (**9b**) were prepared according to our published procedures.[10,11] Unless otherwise stated, all other starting materials were purchased from Aldrich Chemical Co., Milwaukee, WI.

Di-*tert*-butyl 3-Oxoglutarate (6b). The 3-oxoglutaric acid (75.0 g, 0.513 mol) was placed into a cold (−60 °C, hexane–dry ice bath) Parr hydrogenation pressure bottle. Freshly condensed isobutylene (250 mL), anhydrous ether (60 mL), and concentrated sulfuric acid (5 mL) were added to the slurry. The bottle was tightly capped with a rubber stopper secured by wire and placed on a shaker (parr hydrogenation apparatus) for 4 days or until all of the solid material (3-oxoglutaric acid) had dissolved. The bottle was then cooled to −58 °C and uncapped. The contents were poured into a well-stirred, chilled solution of aqueous sodium bicarbonate solution (300 mL, 10%) in a 2-L beaker. The solid which formed was filtered from the medium, washed with water (3 × 50 mL), and dried under vacuum to provide 110 g (83%) of white solid. The crude material was crystallized from a mixture of hexane–ethyl acetate to provide pure di-*tert*-butyl ester **6b** (95.0 g, 0.368 mol, 72%). The reaction was repeated on scales ranging from 25 to 90 g with yields in the 60–85% range. **6b**: mp 60–61 °C (lit.[31] mp 58–60 °C); ^{1}H NMR (60 MHz, $CDCl_3$) δ 1.32 (18 H, s), 3.20 (4 H, s); ^{13}C NMR (20 MHz, $CDCl_3$) δ 27.5, 49.7, 81.5, 165.5, 195.6.

2-Allyl-*cis*-bicyclo[3.3.0]octane-3,7-dione (11a,b). The tetra-*tert*-butyl ester **9b** (31.8 g, 56.2 mmol) was dissolved in dry DMF (200.0 mL). This solution was slowly added to a three-necked round-bottom flask which contained KH (7.3 g, 182.5 mmol). The reaction mixture was maintained under a dry, inert atmosphere (Ar) and kept at a temperature of −25 °C (CCl_4–dry ice bath). After the tetraester **9b** was added to the KH slurry, the temperature was lowered to −58 °C (hexane–dry ice bath) for 1.0 h. An overhead stirrer was necessary to keep the solution from solidifying. A large excess of allyl iodide (17.0 mL, 185.9 mmol) was added to the reaction mixture with a syringe and the temperature was maintained at −58 °C for 5.0 h. The reaction was quenched by adding an excess of aqueous HCl (250.0 mL, 1.0 N) to the mixture at −58 °C. The solution was permitted to warm to room temperature. Water (2.0 L) was added and the reaction mixture was extracted with ether (3 × 150 mL). The organic layers were combined, and the solvent was removed under reduced pressure. The oil **10** which resulted was suitable for decarboxylation. Decarboxylation was accomplished by heating **10** in a mixture of glacial acetic acid and aqueous HCl (1.0 N) at reflux for 1.5 h. The solution was then cooled to room temperature, diluted with water, and washed with $CHCl_3$ (3 × 75 mL). The organic layers were combined, washed with aqueous sodium bicarbonate (10% w/w), and then dried ($MgSO_4$). The solvent was removed under reduced pressure to provide a light orange oil (9.86 g). It was purified by column chromatography using ethyl acetate–hexane (20:80) to give 8.9 g of pure monoallyl derivative **11a,b** (90%): bp 120 °C (0.1 mmHg); IR (neat) 2920, 1720, 1630, 1390, 1130, 900 cm^{-1}; ^{1}H NMR (60 mHz, $CDCl_3$) δ 1.9–2.8 (8 H, m), 2.9–3.4 (3 H, m), 4.9 (1 H, m), 5.1 (1 H, m), 5.5 (1 H, m). **11a**: ^{13}C NMR (62.8 mHz, $CDCl_3$) δ 33.52 (t, carbon α to the alkene), 34.07, 41.75, (d, bridgehead carbon), 43.35 (t), 43.39 (t), 43.76 (t), 53.43 (d, carbon α to the ketone), 117.69 (t), 134.65 (d), 217.89 (s), 218.28 (s). **11b**: ^{13}C NMR (62.8 mHz, $CDCl_3$) δ 30.72 (t), 33.83 (d), 40.59 (d, bridgehead carbons), 41.82 (t), 43.35 (t), 44.09 (t), 53.69 (d, carbon α to the ketone), 116.17 (t), 135.55 (d), 217.06 (s), 217.15 (s); mass spectrum (CI, CH_4), *m/e* (relative intensity) 179 (M + 1, 100), 137 (9.1). Anal. Calcd for $C_{11}H_{14}O_2$: C, 74.13; H, 7.92. Found: C, 74.19; H, 7.86.

2-(2-Oxoethyl)-*cis*-bicyclo[3.3.0]octane-3,7-dione (12a,b). The monoallyl derivatives **11a,b** (3.16 g, 17.75 mmol) were dissolved in a mixture of dioxane and water (65:45, 80 mL). The reaction vessel was wrapped with aluminum foil to prevent light from entering the solution. A catalytic amount of solid OsO_4 (5 mg) was added to the mixture. The reaction slurry was permitted to stir for 45 min, whereupon the solution took on a dark brownish-purple color. Small quantities of solid $NaIO_4$ (10.0 g, 46.7 mmol) were added to the mixture over a 4-h period. After the reaction was completed, the mixture was filtered in order to remove solid inorganic salts. The salts were washed with ethyl acetate. The aqueous layer was extracted repeatedly with fresh ethyl acetate. The ethyl acetate washes were combined and percolated through a column (alumina) to remove residual OsO_4. The solvent was removed under reduced pressure to provide a light yellow oil (2.54 g, 14.1 mmol, 79.5%). The residue contained a mixture of the two aldehydic epimers **12a,b**. According to analysis by TLC (SiO_2, 9:1, ethyl acetate–ethanol), the two tricyclic aldol products **13a,b** were also present. **12a,b**: IR (neat) 2928, 2770, 1715, 1410, 1170 cm^{-1}; ^{1}H NMR (60 MHz, $CDCl_3$) δ 1.8–2.6 (8 H, m), 2.7–2.9 (3 H, m), 9.8 (1 H, 2 s); ^{13}C NMR (20 MHz, $CDCl_3$) (major isomer) δ 33.6, 41.6, 42.2, 42.3, 42.5, 42.8, 46.8, 199.5, 217.3, 217.7; mass spectrum (EI, 15 eV), *m/e* (relative intensity) 180 (M^+, 7.5), 152 (12.0), 137 (100).

Preparation of 2-(2-Oxoethyl)-*cis*-bicyclo[3.3.0]octane-3,7-dione (12a,b) via Ozonolysis in Ethyl Acetate. The monoallyl derivatives **11a,b** (5.632 g, 31.6 mmol) were dissolved in dry ethyl acetate (500 mL). The reaction mixture was cooled to −58 °C (hexane–dry ice bath). Ozone was bubbled through the solution until a light blue color appeared. The excess O_3 was purged from the solution with dry nitrogen. While the reaction mixture was allowed to stir at −58 °C, dimethyl sulfide (50 mL) and methanol (50 mL) were added to the mixture with a syringe. The solution was permitted to stir for 12 h during which time the temperature was allowed to rise to 27 °C. The solvent was removed under reduced pressure and the crude aldehyde **12a,b** was purified by passing it through a short silica gel column with ethyl acetate to afford 4.6 g of a colorless oil (81%). The IR, MS, and C-13 NMR data for the crude **12a,b** were identical with those obtained on **12a,b** prepared above.

5-Hydroxytricyclo[5.2.1.0^{4,10}]decane-3,8-dione (13a,b). The mixture of monoaldehydes **12a,b** (10.92 g, 60.7 mmol) was dissolved in THF (1.0 L) and aqueous HCl (70.0 mL, 1.0 N) was added to the solution. The mixture was stirred for 1 week and maintained under an inert atmosphere (Ar). Solid $NaHCO_3$ was then added to the mixture and the slurry was allowed to stir for 1 h. The solid $NaHCO_3$ was filtered from the medium and discarded. The solvent from the filtrate was removed under reduced pressure to provide an oil which appeared to be light orange. Water was removed from the oil by azeotropic distillation with benzene. The benzene was removed under reduced pressure to provide an oil (9.38 g, 52.1 mmol, 85.9%). The oil was found to be a mixture (50:50) of two epimeric alcohols (C-13 NMR spectrum). Analysis of the oil by thin-layer chromatography (SiO_2, CH_3OH–CH_2Cl_2, 10:90) indicated the presence of two components with R_fs of 0.27 and 0.23. From the mixture of epimers, the endo isomer **13a** solidified and was recrystallized from a mixture of chloroform–hexane. **13a** (endo isomer: R_f 0.27, SiO_2 with 10:90, CH_3OH–ethyl acetate): mp 164–165 °C; IR (KBr) 3400, 3000, 1735 (sh), 1725, 1410 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.49 (1 H, ddd, J = 6, 4, 2 Hz), 3.58 (1 H, ddd, J = 10), 3.15 (1 H, dddd, J = 10, 11, 4, 7.5 Hz), 2.92 (1 H, dddd, J = 6, 10, 2, <1 Hz), 2.84 (1 H, dddd, J = 10, 1.5, 2, 1 Hz), 2.69 (1 H, ddd, J = 19.5, 10, 2 Hz), 2.66 (1 H, ddd, J = 19.5, 11, 1.5 Hz), 2.42 (1 H, dd, J = 19.5, 7.5 Hz), 2.32 (1 H, dd, J = 19.5, 4 Hz), 2.27 (1 H, ddd, J = 13, 1.5, 2 Hz), 2.08 (1 H, ddd, J = 13, 10, 4 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 223.02, 219.93, 74.74, 58.88, 52.56, 48.74, 47.54, 45.28, 43.63, 31.66; mass spectrum (CI, CH_4), *m/e* (relative intensity) 181 (M + 1, 51.4), 163 (100). Anal. Calcd for

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(31) Di-*tert*-butyl 3-oxoglutarate (27,081-4); mp 58–60 °C; Aldrich Chemical Co. Catalog Handbook of Fine Chemicals, 1986–1987; p 430.

$C_{10}H_{12}O_3$: C, 66.65; H, 6.71. Found: C, 66.40; H, 6.78. **13b** (exo isomer; R_f 0.23, SiO_2, 10:90, CH_3OH–ethyl acetate): IR (neat) 3480, 3040, 1730, 1705 (sh), 1442, 1335, 1070 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 4.24 (1 H, ddd, J = 1.5, 3, 4.5 Hz), 3.60 (1 H, ddd, J = 9, 10 Hz), 2.96 (1 H, dddd, 10, 9.5, 7, 3.5 Hz), 2.77 (1 H, dddd, J = 1.5, 9, 2, 1.5 Hz), 3.00 (1 H, dddd, J = 10, 9, 2 Hz), 2.58 (1 H, ddd, J = 19.5, 10, 2 Hz), 2.64 (1 H, ddd, J = 18.5, 9.5, 2 Hz), 2.13 (1 H, dd, J = 18.5, 3.5 Hz), 1.93 (1 H, dd, J = 19.5, 7 Hz), 1.62 (1 H, ddd, J = 13.5, 9, 4.5 Hz), 1.99 (1 H, dddd, J = 13.5, 9, 3, 1.5 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 220.51, 219.09, 77.94, 62.28, 50.75, 46.34, 46.56, 45.73, 38.70, 31.50; mass spectrum (CI, CH_4), identical with that of diastereomer **13a**; high-resolution mass spectrum calcd for $C_{10}H_{12}O_3$ 180.0786, found 180.0791.

Retro-Aldol Reaction of 5-Hydroxytricyclo[5.2.1.0^{4,10}]decane-3,8-dione (13a). A small amount of solid diketo alcohol **13a** (10 mg) was added to a solution of sodium methoxide (20 mg) in dry methanol (5.0 mL). The reaction mixture was stirred for 35 min at room temperature. Analysis of the reaction mixture by thin-layer chromatography (10:90, CH_3OH–CH_2Cl_2, SiO_2) confirmed the presence of both tricyclic alcohols **13a,b**; however, none of the starting aldehyde **12a,b** was observed. The epimeric alcohols **13a,b** were present in about equal amounts, having equilibrated presumably via a retro-aldol reaction followed by re-cyclization to **13a,b**.

Tricyclo[5.2.1.0^{4,10}]decane-3,5,8-triols (14a,b). A mixture of epimeric alcohols **13a,b** (2.030 g, 11.3 mmol) was dissolved in dry THF (150 mL) and cooled to 0 °C under argon. A solution of borane–THF (20.0 mL, 1.0 N) was then added to the above solution. The reaction mixture was allowed to stir for 16 h, after which methanol was added to quench the excess borane. The solvent was then removed under reduced pressure and methanol was added (4 × 100 mL), followed by flash evaporation to remove the borate salts as trimethoxyborane. The crude mixture was cooled to 0 °C and aqueous HCl (1.0 N) was added. This solution was extracted with ethyl acetate (4 × 100 mL), after which the organic layers were combined and dried ($MgSO_4$). The solvent was removed under reduced pressure to provide a light yellow oil, which was purified by flash column chromatography (SiO_2, 10:90, CH_3OH–CH_2Cl_2). The weight of the oil **14a,b** was found to be 1.942 g (10.5 mmol, 93.4%). **14a,b**: IR (neat) 3340 (v, br), 2975, 1445, 1360, 1090 cm^{-1}; ^1H NMR (60 MHz, DMSO-d_6 and $CDCl_3$) δ 1.40–2.65 (17 H, m), 2.80–3.30 (3 H, m), 3.50–3.95 (6 H, m), 4.25–4.70 (6 H, m). **14a**: ^{13}C NMR (62.8 MHz, DMSO-d_6) δ 30.87 (t), 31.66 (d), 33.59 (t), 35.15 (t), 41.19 (d), 45.76 (d), 51.92 (d), 69.32 (d), 69.35 (d), 69.81 (d). **14b**: ^{13}C NMR (62.8 MHz, DMSO-d_6) δ 27.08 (t), 30.99 (d), 30.93 (t), 34.89 (t), 37.70 (d), 42.81 (d), 49.78 (d), 67.10 (d), 68.79 (d), 68.83 (d); mass spectrum (EI, 15 eV), m/e (relative intensity) 184 (M^+, 1.0), 166 (42.5), 148 (81.1), 130 (12.9). Anal. Calcd for $C_{10}H_{16}O_3$: C, 65.19; H, 8.75. Found: C, 64.38; H, 8.81. High-resolution mass spectrum calcd for $C_{10}H_{14}O_2$ 166.0994, found 166.0996.

***cis*-3,5,8-Tris(mesyloxy)tricyclo[5.2.1.0^{4,10}]decane (15).** Dry triol **14a** (1.00 g, 5.43 mmol) was dissolved in CH_2Cl_2 (289 mL) and pyridine (27 mL). The reaction mixture was cooled to 0 °C and methanesulfonyl chloride (8.4 mL, 108 mmol) was added. The solution was then placed into a freezer for 7 days, after which the cold reaction mixture was diluted with CH_2Cl_2 (200 mL) and washed with aqueous HCl (100 mL, 1.0 N). The organic layer was then washed with aqueous Na_2CO_3 (100 mL, 10%) and then with brine (100 mL, 10% w/w). The solvent was removed under reduced pressure to provide an oil. The oil was dissolved in $CHCl_3$ (50 mL) and dry ether was added until the solution became cloudy. The reaction mixture was then cooled. A white solid, **15** (458 mg, 1.1 mmol, 21%), precipitated from the solution and was filtered from the medium. The rest of the mass balance, which was still in the mother liquor, was recovered as a mixture of epimeric trimesylates (oil) which could also be employed in the elimination step (see below). **15**: mp 67–70 °C; IR (KBr) 2980 (vbr), 1300, 1185 (vs), 960 cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 2.00–2.20 (6 H, m), 2.95–3.05 (3 H, 2 s), 4.9–5.3 (3 H, m); mass spectrum (CI, CH_4), m/e (relative intensity) 419 (M + 1, 8.0), 323 (73.0), 227 (100), 131 (48.0). Anal. Calcd for $C_{13}H_{22}S_3O_9$: C, 37.31; H, 5.30. Found: C, 36.86; H, 5.49.

Preparation of Triquinacene (1) from the Trimesylate 15. The trimesylate **15** (150 mg, 0.36 mmol) was dissolved in dry CH_2Cl_2 (50 mL). Activated neutral grade alumina (5 g), which had been heated at 300 °C for 1 week, was added to the reaction mixture. The slurry was stirred at room temperature for 10 h. The alumina was filtered from the solution and the solvent was removed by fractional distillation to provide triquinacene (**1**) (30 mg, 0.23 mmol, 63.8%). Analysis of the mixture by GC–MS indicated the presence of triquinacene (**1**) and isotriquinacene in a ratio of 94:6. Isotriquinacene was not detected by ^{13}C NMR or ^1H NMR spectroscopy. The proton and carbon NMR spectra of **1** were identical with those reported for triquinacene in the literature.[2,3] Isotriquinacene had an identical retention time (GC) with that of isotriquinacene prepared by an alternate route (see below). Additional quantities of **1** could be recovered from the CH_2Cl_2 on distillation through a column packed with glass beads.

Tricyclo[5.2.1.0^{4,10}]decane-2,5,8-triene (Triquinacene, 1). The mixture of dry epimeric triols **14a,b** (1.94 g, 10.5 mmol) was dissolved in dry distilled HMPA (130 mL). The reaction flask was equipped with a magnetic stirrer, heating mantle, and a 6-ft coil condensor equipped with a cold finger condensor (dry ice–acetone). The reaction mixture was heated to reflux and maintained at reflux for a period of 2 days. The reaction flask was cooled with a dry ice bath and the condenser was washed with pure pentane. The solution was then diluted with water (200 mL) and extracted with pentane (5 × 100 mL). The pentane layer was then percolated through a wash column (basic alumina). Additional pentane (300 mL) was used to elute **1** from the column. The product obtained from the column was analyzed by GC–MS and was found to contain triquinacene (**1**) and isotriquinacene.[22] The two compounds were present in a ratio of 78:22. The crude reaction mixture also contained trace quantities of diene (MW = 148) and HMPA (MW = 180). The pentane was removed via fractional column distillation (4-ft column which contained glass beads) to provide an oil (0.95 g, 7.35 mmol, 70%). The reaction mixture was rearranged as described below and distilled in a microdistillation apparatus to provide pure triquinacene (**1**). A yield of 90% (80% triquinacene) has been achieved when the dehydration reaction was conducted on a smaller scale. Material may be lost by evaporation as well as by incomplete dehydration. **1**: bp 78–79 °C. All spectral an analytical data are in agreement with the values cited in the literature for **1**.[2,3] When this reaction was run on a smaller scale, the ratio of triquinacene (**1**) to isotriquinacene was 92:8.

Rearrangement of Isotriquinacene to Triquinacene (1) via Acid Catalysis (*p*-Toluenesulfonic Acid).[10,11,24] A solution of crude triquinacene (**1**) and isotriquinacene (0.95 g, 7.35 mmol) in dry pentane (2.5 mL) was diluted with dry CH_2Cl_2 (40 mL). *p*-Toluenesulfonic acid (5–10 mg) was added to the well-stirred solution. The reaction was monitored by gas chromatography (25-ft capillary column, retention time of **1**, isotriquinacene, 11.25, 12.30 min, respectively). Isomerization was usually complete after 3.0 h (**1**:isotriquinacene, 99%:<1%), although in one case additional acid and a longer reaction time (10 h) were required. The reaction solution was then percolated through a wash column (basic alumina). The solvent was removed via fractional distillation to provide triquinacene. The light yellow product was purified by distillation at atmospheric pressure to provide pure **1** (458 mg, 3.5 mmol, 48%). Additional quantities (32%) of **1** were contained in the pentane fractions and could be isolated on redistillation through a column packed with glass beads: GC column, 5% phenyl methyl silicone; carrier gas, He; pressure, 18 psi; flow rate, 50 mL/min; initial oven temperature, 60 °C; time at initial oven temperature, 12 min; rate of oven temperature increase, 10 °C/min.

2,4,6,8-Tetrakis(*tert*-butoxycarbonyl)-1,5-dimethyl-*cis*-bicyclo[3.3.0]octane-3,7-dione (7c). Di-*tert*-butyl 3-oxoglutarate (**6b**) (60 g, 0.23 mol) was dissolved in MeOH (200 mL). Potassium carbonate (K_2CO_3·1.5H_2O, 38 g, 0.229 mol), and aqueous sodium bicarbonate (200 mL, 5%) were added to the stirred solution. The mixture was heated until it became a clear yellow solution. It was allowed to cool to room temperature and became slightly cloudy. Biacetyl **5b** (11 g, 0.127 mol) was added and the solution first turned bright yellow, followed by precipitation of a white solid within 15 min. The mixture was stirred at room temperature for 24 h. The solid which had formed was filtered, washed with hot H_2O (3 × 50 mL), and dried in vacuum to provide **8** (60.3 g, 91%); mp 158–162 °C. The reaction has been repeated on scales from 5.0 g to 90.0 g, and yields have ranged from 83 to 93%. An analytical sample was obtained through recrystallization from EtOAc–hexane; TLC (silica gel, 25% EtOAc–hexane) R_f 0.23; the UV-active spot turns purple upon spraying with $FeCl_3$ solution; mp 179–181 °C; FTIR (KBr) 3080, 2940, 2903, 2882, 1729, 1661, 1621 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 1.36 (6 H, s), 1.48 (18 H, s), 1.56 (18 H, s), 3.80 (2 H, s), 11.05 (2 H, s) [note: repeating the NMR experiment at 333 K (60 °C) did not result in any peak broadening or change in the chemical shifts. This ruled out the occurrence of isomer equilibration over this temperature range]; ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 171.96 (s), 170.29 (s), 169.70 (s), 110.73 (s), 82.32 (s), 82.03 (s), 59.33 (q), 54.33 (d), 28.61 (q), 28.16 (q), 18.03 (q); mass spectrum (CI, CH_4), m/e (relative intensity) 567 (M + 1, 1.4), 511 (–isobutylene, 5.8), 493 (4.0), 455 (–2 isobutylene, 15.7), 437 (12.6), 399 (–3 isobutylene, 34.5), 381 (39.9), 363 (32.1), 343 (–4 isobutylene, 97.6), 325 (tetraacid–H_2O, 85.1), 307 (tetraacid–2 H_2O, 100), 263 (22.5), 289 (tetraacid–3 H_2O, 20.1), 271 (3.5). Anal. Calcd for $C_{30}H_{46}O_{10}$: C, 63.57; H, 8.20. Found: C, 63.90; H, 8.41.

2,4,6,8-Tetrakis(*tert*-butoxycarbonyl)-3,7-dimethoxy-1,5-dimethyl-*cis*-bicyclo[3.3.0]octa-2,6-diene (16). An ethereal solution of diazomethane (25.2 g, 0.43 mol) was prepared by addition of a solution of

Diazald (92.7 g, 0.43 mol) in ether (600 mL) to a stirred mixture of 2-(2-ethoxyethoxy)ethanol (152 mL), potassium hydroxide (26 g), water (45 mL), and ether (100 mL). [**Caution**: diazomethane is highly toxic and potentially explosive. Work in an efficient fume hood, and follow the precautions outlined in ref 30.] Tetraester **8** (70.0 g, 0.124 mol) was added as a solid to the ethereal diazomethane solution, which was maintained at −50 to −60 °C (dry ice). The mixture was stirred for 2 h at this temperature and then at 0 °C for 6–8 h. The mixture was allowed to slowly come to room temperature in a fume hood. The solvent was removed under reduced pressure (rotary evaporator) to leave a viscous yellow oil. This oil was triturated with hexane and dried under vacuum to afford **16** (72.5 g) as an off-white solid. The crude product was purified by recrystallization from EtOAc–hexane to provide pure **16** (93%, 68.5 g): mp 127–128 °C; IR (KBr) 3055, 3051, 2981, 2854, 1721, 1709, 1682, 1366, 1170, 1163, 1142, 1134 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 1.41 (6 H, s), 1.50 (18 H, s), 1.55 (18 H, s), 3.75 (6 H, s), 4.06 (2 H, s); ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 18.60 (q), 28.04 (q), 28.55 (q), 55.52 (s), 57.58 (d), 58.01 (q), 80.36 (s), 82.07 (s), 115.26 (s), 163.84 (s), 165.52 (s), 170.29 (s); mass spectrum (CI CH_4), *m/e* (relative intensity) 595 (M + 1, 1.4), 539 (−isobutylene, 4.8), 521 (−isobutylene−H_2O, 9.5), 483 (−2 isobutylene, 19.0), 427 (−3 isobutylene, 21.4), 371 (−4 isobutylene, 100), 353 (−4 isobutylene−H_2O, 4.7), 334 (−4 isobutylene−2 H_2O, 1.4); EI (15 eV) 594 (M^+, 2.3), 482 (−2 isobutylene, 16.3), 464 (−2 isobutylene−H_2O, 32.6), 370 (−4 isobutylene, 13.9), 352 (−4 isobutylene−H_2O, 62.8), 334 (−4 isobutylene−2 H_2O, 100). Anal. Calcd for $C_{32}H_{50}O_{10}$: C, 64.61; H, 8.49. Found: C, 64.60; H, 8.35.

2,4,6,8-Tetrakis(*tert*-butoxycarbonyl)-3,7-dimethoxy-2-allyl-1,5-dimethyl-*cis*-bicyclo[3.3.0]octa-2,6-diene (17). To a suspension of potassium hydride (3.5 g, 0.097 mol) in dry DMF (150 mL) under an argon atmosphere was added bis(enol ether) **16** (20 g, 0.034 mol). The clear yellow solution was stirred at room temperature for 45 min and then cooled to −25 °C (dry ice−CCl_4). Allyl iodide (10.0 mL, 0.11 mol) was added and the mixture stirred for 7 h at −25 °C. The reaction was quenched by the addition of aqueous HCl (125 mL, 10%) to the cold ice mixture. The mixture was warmed to room temperature and extracted with EtOAc (5 × 125 mL). The combined EtOAc fractions were back-extracted with brine (4 × 100 mL), dried ($MgSO_4$), and concentrated under reduced pressure to afford tetraester **17**, (20.7 g, 96%) as a viscous, dark oil. Upon sitting, a solid crystallized from the crude oil and was separated by filtration. This solid accounted for ca. 40% of the mass balance and examination of the residual oil by ^{13}C NMR indicated that more of this isomer (50%) still remained. An analytical sample of this material was obtained through recrystallization from MeOH. The combined yield of stereoisomeric tetraester **17** obtained from this procedure was in excess of 85%. **17**: mp 163–165 °C; FTIR (KBr) 3007, 2979, 2934, 1733, 1715, 1394, 1381, 1367, 1277, 1244, 1168 1145 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 0.97 (3 H, s), 1.31 (3 H, s), 1.36, 1.37, 1.39 (36 H, 3 s), 2.55 (2 H, d, J = 6.9), 3.61 (1 H, s), 3.64 (3 H, s), 3.69 (3 H, s), 4.89 (2 H, m), 5.79 (1 H, m); ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 15.77, 21.04, 27.98, 29.14, 28.25, 40.01, 54.58, 55.76, 58.52, 60.21, 60.75, 65.24, 80.29, 80.58, 81.15, 81.28, 113.66, 116.46, 134.94, 158.13, 162.17, 164.68, 165.49, 170.02, 170.11. Anal. Calcd for $C_{34}H_{54}O_{10}$: C, 66.21; H, 8.59. Found: C, 66.56; H, 8.80.

2-Allyl-1,5-dimethyl-*cis*-bicyclo[3.3.0]octane-3,7-dione (18a,b). To a stirred solution of glacial acetic acid (120 mL) and aqueous HCl (150 mL, 10%) was added **17** (20.5 g). The temperature was quickly elevated to 85–90 °C (oil bath) and maintained there until gas evolution ceased (ca. 6 h). The mixture was allowed to cool to room temperature and H_2O (400 mL) was added; the solution was filtered and extracted with $CHCl_3$ (4 × 100 mL). The $CHCl_3$ fractions were back-extracted with H_2O (3 × 50 mL) and washed with aqueous $NaHCO_3$ until the aqueous layer remained basic to pH paper (2 × 100 mL, 5%). The solution was dried ($MgSO_4$) and concentrated under reduced pressure to provide **18a,b** (5.8 g, 87.3%) as a viscous oil. Analysis of this material by capillary GLC indicated a >95% yield of the monoallyl product with an isomer ratio of endo (**18b**, t_R 12.37 min):exo (**18a** t_R 12.52 min) of 67:33. A sample was purified by Kuglerohr distillation: bp 91–105 °C (1.5–2.0 mmHg); GC–MS, *m/e* (relative intensity), t_R 12.6 min, 206 (M^+, 8.7), 163 (11.8), 148 (6.5), 110 (19.5), 109 (20.4), 97 (19.2), 96 (100), 95 (62.0), 94 (19.2), 83 (21.2), 82 (26.2), 81 (18.7), 79 (32.3); t_R 12.8 min, 206 (M^+, 9.9), 163 (8.7), 148 (6.3), 110 (16.5), 109 (14.7), 97 (15.0), 96 (100), 95 (83.5), 94 (31.1), 83 (22.5), 82 (24.6), 81 (19.8), 79 (24.0); ^{13}C NMR (62.86 MHz, $CDCl_3$) (minor isomer **18a**, exo allyl) δ 216.13, 136.04, 116.81, 57.21, 50.75, 49.22, 48.8, 48.15, 43.38, 29.92, 22.68, 16.22; ^{13}C NMR (major isomer **18b**, endo allyl) δ 216.70, 215.91, 136.68, 116.31, 56.5, 52.12, 50.36, 49.50, 47.84, 31.23, 22.04, 21.36; high-resolution mass spectrum calcd, for $C_{13}H_{18}O_2$ 206.1307, found 206.1290.

1,5-Dimethyl-2-(2-oxoethyl)-*cis*-bicyclo[3.3.0]octane-3,7-dione (19a,b). Monoallyl-*cis*-bicyclo[3.3.0]octane-3,7-dione **18a,b** (2.0 g, 9.8 mmol) was dissolved in EtOAc (50 mL) in a 250-mL three-necked flask equipped with a magnetic stirrer and a low-temperature thermometer. The flask was placed into 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 L/min, 114 VAC; pressure, 5.9 psi) and bubbled through the cold solution. After 10–20 min the solution took on a light blue coloration. The reaction was monitored by TLC (silica gel, EtOAc–hexane 40:60). After 10–20 min a new spot of lower R_f was observed. Close examination of the TLC indicated that the major product had an R_f identical with that of the starting material and was observable by its color change over time or when heated. At this time N_2 was bubbled through the solution until the blue color had vanished. Methanol (50 mL) and dimethyl sulfide (DMS, 50 mL) were poured into the solution at −60 °C. The mixture was allowed to slowly warm to room temperature and the reaction progress was monitored by TLC (silica gel, EtOAc–hexane 60:40). After ca. 14 h the spot corresponding to the ozonide had disappeared and was replaced by a 2,4-DNP-active product of slightly lower R_f. The solvents were removed under reduced pressure (water aspirator), and the residue was flash evaporated with $CHCl_3$ (3 × 100 mL). The residual DMSO present in the crude mixture was removed by Kuglerohr distillation (50 °C, 1.5 mmHg) to provide 2.2 g of a viscous, brown oil (110% material balance based on free aldehyde). The material was purified by elution through a short silica gel column with EtOAc to afford 1.9 g of a colorless oil, **19a,b** (93%): FTIR (neat) 3456, 2963, 2931, 2875, 2735, 1739, 1406 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 9.88 (s, 1 H), 9.85 (s, 1 H), 2.04–3.10 (complex pattern of overlapping multiplets), 1.33 (s, 3 H), 1.22 (s, 3 H), 1.17 (s, 3 H), 0.98 (s, 3 H). On one occasion, a small amount of 2-(carboxymethyl)-*cis*-bicyclo[3.3.0]octane-3,7-dione was observed by mass spectroscopy [CI, *m/e* 255 (M + 1), 207 ($M^+ - H_2O$)] and ^{13}C NMR [acid carbonyl carbon at δ 171]; presumably this originated by overoxidation of the double bond or the corresponding aldehyde.

1,10-Dimethyl-3,8-dioxotricyclo[5.2.1.0^{4,10}]decan-5-ol (20a,b). A mixture of *endo*- and *exo*-diketo aldehyde **19a,b** (1.12 g, 5.4 mmol) was dissolved in dry THF (150 mL). Aqueous HCl (6 mL, 4%) was added and the mixture was stirred at room temperature under a nitrogen atmosphere. The reaction was allowed to continue until TLC analysis (silica gel, 75% EtOAc–hexane) showed the absence of the starting aldehyde **19** (ca. 72 h). Solid $NaHCO_3$ was added to neutralize the excess acid and the mixture was filtered. The volume of the mixture was reduced under reduced pressure, and the layers were separated. The water layer was extracted with EtOAc (4 × 50 mL). The organic layers were combined, washed once with water (50 mL), and dried ($MgSO_4$). The solvents were removed under reduced pressure to afford a brown, viscous oil, **20** (0.92 g, 83%).

The crude reaction product was purified by flash column chromatography (silica gel, 1:1 EtOAc–hexane). The initial fractions contained 10–20% unreacted diketoaldehyde **19a,b**. The major product (ca. 70%, R_f 0.20–0.26, silica gel, 60% EtOAc–hexane, 2,4-DNP active) was a mixture of *endo*- and *exo*-tricyclic diketo alcohols **20a,b**: FTIR (neat) 3450, 2932, 1746.7 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.22 (s, 3 H), 1.26 (s, 3 H), 1.34 (s, 3 H), 1.47 (s, 3 H), 2.15–2.85 (complex pattern of overlapping multiplets), 4.40 (m, 1 H), 4.56 (m, 1 H); high-resolution mass spectrum calcd for $C_{12}H_{16}O_3$ 208.1099, found 208.1082. Anal. Calcd for $C_{12}H_{16}O_3 \cdot {}^1/_2H_2O$: C, 66.34; H, 7.42. Found: C, 66.25; H, 7.47. One of these isomers was obtained pure from the flash column chromatographic separation. **20a** (exo alcohol): ^1H NMR (500 MHz, $CDCl_3$) δ 4.39 (1 H, ddd, J = 4, 4, 4.5 Hz), 2.805 (1 H, dddd, J = 7.5, 9, ~1, ~1 Hz), 2.56 (1 H, dd, J = 17.5, 2 Hz), 2.53 (1 H, ddd, J = 4, 2, 1 Hz), 2.41 (1 H, dd, J = 18.0, 2 Hz), 2.375 (1 H, d, J = 17.5 Hz), 2.27 (1 H, d, J = 18.0 Hz), 2.225 (1 H, dddd, J = 14.0, 9, 4, 1 Hz), 1.90 (1 H, ddd, J = 14.0, 7.5, 4.5 Hz), 1.61 (3 H, s), 1.33 (3 H, s); ^{13}C NMR (75.6 MHz, $CDCl_3$) δ 218.99, 217.40, 78.63, 68.93, 59.55, 57.31, 53.51, 53.26, 42.7, 39.11, 23.44, 23.26; high-resolution mass spectrum calcd for $C_{12}H_{16}O_3$ 208.1099, found 208.1106. The final cuts from the column provided a polar (R_f 0.12–0.15) white solid (ca. 12%): mass spectrum (EI 15 eV), *m/e* (relative percentage) 208 (M^+, 21.9), 190 (M − H_2O, 33.9), 165 (80.1), 123 (98.7), 110 (100); (CI, CH_4) *m/e* (relative intensity) 249 (M^+ + 41, 5.3), 237 (M^+ + 29, 11), 209 (M^+ + 1, 34.1), 191 (M^+ + 1 − H_2O, 100); ^1H NMR (500 MHz, CD_3OD) δ 3.98 (1 H, ddd, J = 11.5, 6.75, 4.75 Hz), 2.45 (1 H, d, J = 20 Hz), 2.42 (1 H, d, J = 20 Hz), 2.34 (1 H, ddd, J = 4.75, 1.75, 1 Hz), 2.27 (1 H, dd, J = 20, 1.75 Hz), 2.265 (1 H, ddd, J = 4, 3.5, 1.75 Hz), 2.25 (1 H, dd, J = 20, 1.75 Hz), 2.067 (1 H, dddd, J = 14.0, 6.75, 3.5, 1.0 Hz), 1.75 (1 H, ddd, J = 14.0, 11.5, 4.0 Hz), 1.08 (3 H, s), 1.07 (3 H, s). See i of ref 25 for the proposed structure of this material. The highest yields obtained for **20** via this process were 80%.

1,10-Dimethyltricyclo[5.2.1.0^{4,10}]deca-2,5,8-triene (1,10-Dimethyltriquinacene, 3). Reduction of Diketo Alcohols 20a,b with DIBAL-H. The mixture of *endo*- and *exo*-diketo alcohols **20a,b** (1.0 g, 5.0 mmol) was dissolved in dry CH_2Cl_2 (50 mL). The mixture was cooled to 0 °C (ice bath) and diisobutylaluminum hydride (DIBAL-H, 1 N in hexanes, 30

mL) was added dropwise over 1 h. The mixture was allowed to come to room temperature and stirred for a total of 5 h. Methanol (1.5 mL) was slowly added to destroy the excess hydride reagent. The mixture was then allowed to stir for 15 min and water (5 mL) was added to hydrolyze the borate esters. The mixture was stirred for 10 min at room temperature and the aluminum salts were removed by filtration through Celite. The filtered materials were washed with dry CH_2Cl_2 (3 × 20 mL) and the combined filtrate and washes were dried ($MgSO_4$) and concentrated under reduced pressure to afford triol **21** as a viscous clear oil (700 mg, 66%). Analysis of the mixture by TLC (silica gel, 10% MeOH–CH_2Cl_2) showed the consumption of starting material and the presence or two 2,4-DNP-inactive products (R_fs 0.35 and 0.45). Examination of the FTIR spectrum indicated the absence of a carbonyl and the presence of a broad hydroxyl absorption at 3409 cm^{-1}. The complex ^1H and ^{13}C NMR spectra of the crude material were consistent with a mixture of triols. Mass spectrum (EI, 15 eV), *m/e* (relative intensity) 194 ($M^+ - H_2O$, 41.6), 176 ($M^+ - 2\ H_2O$, 98.0), 158 ($M^+ - 3\ H_2O$, 20.3). This material was employed directly in the next experiment.

HMPA-Mediated Dehydration of the Epimeric Mixture of Tricyclic Triols 21 To Provide 1,10-Dimethyltriquinacene (3). The crude product from the DIBAL-H reduction, **21**, (270 mg) was transferred into a custom one-piece reflux apparatus equipped with a cold finger condensor (dry ice–acetone) with a minimal amount of methanol. The methanol was removed under reduced pressure and freshly distilled hexamethylphosphoramide (HMPA, 26 mL) was added. The atmosphere was replaced with argon and the mixture was heated (oil bath) at reflux (ca. 230 °C) for 25 h. The mixture was allowed to cool to room temperature. Pentane (25 mL) was added and the contents of the apparatus were transferred to a separatory funnel. The apparatus was washed with pentane, and the washes were added to the separatory funnel along with water (50 mL). The layers were separated, and the aqueous phase was extracted with pentane (3 × 25 mL). The combined pentane extracts were washed with water (3 × 30 mL) and dried ($MgSO_4$). Capillary GC analysis (80 °C isothermal) of the pentane extracts showed the presence of two major components with retention times of 5.7 min (**3**, 83%) and 6.5 min (17%). GC–MS analysis: t_R (*m/e*) 2.3 min (158), 2.5 min (158). The pentane solution was concentrated to ca. 0.8 mL by careful distillative removal of the pentane through a 16-in. column packed with glass beads. To obtain a sample of the volatile hydrocarbon for NMR analysis, CD_2Cl_2 (25 mL) was added and the solution was concentrated to ca. 0.5 mL by careful distillation. This process was repeated and the ^1H and ^{13}C NMR spectra were recorded: ^1H NMR (300 MHz, $CDCl_3$) δ 1.15 (3 H, s), 1.24 (3 H, s), 3.20 (2 H, s), 5.48 (2 H, dd, J = 5.75, 1.4 Hz), 5.51 (2 H, dd, J = 5.75, 1.9 Hz), 5.59 (2 H, s); ^{13}C (75.6 MHz, CD_2Cl_2) δ 138.99, 132.28, 129.66, 67.10, 23.09, 21.03. On treatment of the mixture of **3** and its olefinic isomeric **22a** or **22b** with *p*-toluenesulfonic acid in pentane–CH_2Cl_2 at room temperature for several hours, **22** disappeared leaving **3** in pure form. High-resolution mass spectrum calcd, for $C_{12}H_{14}$ 158.1095, found 158.1084.

7,9,10,12-Tetrakis(*tert*-butoxycarbonyl)tricyclo[4.3.3.0^{1,6}]dodecane-8,11-dione (24). Di-*tert*-butyl 3-oxoglutarate (**6b**) (39.22 g, 0.152 mol) was dissolved in 300 mL of distilled MeOH followed by addition of 100 mL of a 3% solution of $NaHCO_3$. Anhydrous K_2CO_3 (32.5 g, 0.235 mol) was added to the mixture with warming until it became a clear yellow solution. It was allowed to cool to room temperature, at this point the solution became slightly turbid. A solution of cyclohexane-1,2-dione **23** (8.5 g, 0.076 mol) in MeOH (25 mL) was added dropwise over a period of 45 min with rapid stirring with an overhead stirrer. The orange solution was stirred for 72 h at room temperature. The precipitate which formed was filtered from the medium and washed with cold methanol (2 × 50 mL) and dried in vacuum. The orange precipitate was dissolved in chloroform (300 mL) and was treated with cold aqueous 1 N HCl (200 mL) until the aqueous layer became slightly acidic. The chloroform layer was separated, washed with water and brine, dried ($MgSO_4$), and concentrated to give 22.5 g of a pale white solid **24** (50%). This solid was recrystallized using ethyl acetate–hexane to give pure, white crystalline product **24**: mp 196–198 °C; the TLC (silica gel, 70% hexane ethyl acetate, R_f 0.58) spot is active toward $FeCl_3$; FTIR (KBr) 2950, 1725, 1660, 1400, 1150, 790 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 1.26 (8 H, s), 1.50 (18 H, s), 1.55 (18 H, s), 3.77 (2 H, s), 10.90 (2 H, s); ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 171.34, 169.89, 169.34, 112.91, 81.94, 81.88, 57.95, 53.01, 31.19, 28.51, 28.16, 21.17; mass spectrum (CI, CH_4), *m/e* (relative intensity) 481 (M + 1 − 2 isobutylene, 2.2), 463 (2.7), 425 (M + 1 − 3 isobutylene, 2.2), 407 (7.6), 389 (16.6), 369 (3.9), 351 (28.0), 333 (46.7), 307 (48.2), 289 (39.0), 263 (65.0), 219 (45.8), 193 (100). Anal. Calcd for $C_{32}H_{48}O_{10}$: C, 64.84; H, 8.16. Found: C, 64.56; H, 8.06. This reaction was run on a 100-g scale with no loss in yield.

7,9,10,12-Tetrakis(*tert*-butoxycarbonyl)-8,11-dimethoxytricyclo-[4.3.3.0^{1,6}]dodeca-7,10-diene (25). An ethereal solution of diazomethane (0.3 mol) was prepared by addition of a solution of Diazald (64.2 g, 0.3 mol) in ether (400 mL) to a stirred mixture of 2-(2-ethoxyethoxy)ethanol (105 mL), potassium hydroxide (18 g, 0.32 mol), water (30 mL), and ether (40 mL). Tetraester **24** (25.0 g, 42.23 mmol) was added to the ethereal diazomethane solution, which was stirred at 0 °C for 8 h and then allowed to come to room temperature in a fume hood. The solvent was removed under reduced pressure (rotary evaporator) to leave a viscous, yellow oil. This oil was triturated with hexane and dried under vacuum to afford 26.0 g of white solid. The crude product was purified by recrystallization from EtOAc–hexane to provide pure bis(enol ether) **25** (24.5 g, 94%): mp 124–125 °C; FTIR (KBr) 2990, 1725, 1700, 1650, 1450, 1330, 1250, 1150, 1060 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 1.51 (8 H, s), 1.53 (18 H, s), 1.56 (18 H, s), 3.70 (6 H, s), 3.97 (2 H, s); ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 170.24, 164.55, 163.74, 117.48, 81.85, 79.97, 57.23, 56.41, 54.38, 31.22, 28.38, 27.98, 21.16; mass spectrum (CI, CH_4), *m/e* (relative intensity) 622 (M + 2, 3.1), 566 (−isobutylene, 1.2), 509 (−2 isobutylene, 33.1), 491 (63.2), 453 (−3 isobutylene, 4.1), 397 (−4 isobutylene, 22.3), 379 (tetraacid–H_2O, 71.0), 361 (tetraacid–2 H_2O, 100). Anal. Calcd for $C_{34}H_{52}O_{10}$: C, 65.81; H, 8.38. Found: C, 66.11; H, 8.79.

7,9,10,12-Tetrakis(*tert*-butoxycarbonyl)-8,11-dimethoxy-7-allyltricyclo[4.3.3.0^{1,6}]dodeca-7,10-diene (26). A mixture of KH in mineral oil was added to a 250-mL round-bottom flask. The solution was washed twice with dry hexane. The hexane was pulled off under vacuum using a sintered-glass stick. A vacuum aspirator with a trap and a drying tube was then applied to remove any residual hexane and the system was flushed with Ar. The weight of the KH was then determined (0.52 g, 13.2 mmol); while under argon, dry DMF (10 mL) was added with a syringe. The tetra-*tert*-butyl ester **25** (3.72 g, 6 mmol) was dissolved in dry DMF (80 mL) and added to a three-necked round-bottom flask which contained KH. The clear yellow solution was stirred at room temperature for 45 min and then cooled to −25 °C (dry ice–CCl_4). Allyl iodide (2.2 g, 13.2 mmol) was added and the mixture was stirred for 7 h at −25 °C. The reaction was quenched by the addition of aqueous HCl (50 mL, 10%) to the cold mixture. The mixture was warmed to room temperature and extracted with ethyl acetate (3 × 100 mL). The combined ethyl acetate layer was washed with water (2 × 50 mL) and brine (100 mL), dried ($MgSO_4$), and concentrated under reduced pressure to give 3.7 g (93%) of **26** as a viscous oil. Upon sitting, a solid crystallized from the crude oil and was separated by filtration. An analytical sample of this material was obtained through recrystallization from ethyl acetate–hexane: mp 195–196 °C; FTIR (KBr) 2990, 1730, 1715, 1680, 1625, 1450, 1360, 1190, 1150, 920 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 1.50 (36 H, br s), 1.70–2.82 (8 H, m), 3.68 (1 H, s), 3.77 (3 H, s), 3.84 (3 H, s), 4.97 (2 H, m), 5.92 (1 H, m); ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 170.48, 169.95, 165.47, 165.01, 164.06, 157.48, 134.76, 116.81, 111.44, 81.23, 80.53, 66.19, 60.37, 58.63, 54.91, 53.86, 41.15, 32.71, 28.23, 26.02, 22.54, 20.13; mass spectrum (CI, CH_4), *m/e* (relative intensity) 661 (M + 1, 13.9), 605 (−isobutylene, 20.8), 549 (−2 isobutylene, 67.4), 531 (100), 493 (−3 isobutylene, 34.7), 475 (25.7), 437 (−4 isobutylene, 9.7). Anal. Calcd for $C_{37}H_{56}O_{10}$: C, 67.27; H, 8.55. Found: C, 66.95; H, 8.52.

7-Allyltricyclo[4.3.3.0^{1,6}]dodecane-8,11-dione (27a,b). The alkylated tetraester **26** (3.0 g, 5.45 mmol) was hydrolyzed and decarboxylated with 50 mL of glacial acetic acid and 50 mL of 1 N HCl. The solution was held at reflux for 2 h and then brought to room temperature. It was diluted with water (100 mL) and extracted with chloroform (3 × 100 mL). The chloroform layer was washed with water (2 × 50 mL) and then aqueous $NaHCO_3$ until the aqueous layer remained basic to pH paper. It was then dried ($MgSO_4$). The solvent was removed under reduced pressure to provide 1.20 g of viscous oil. This material was further purified by column chromatography with ethyl acetate–hexane (20:80) to give pure dione **27a,b** (1.12 g, 89%) as a mixture of endo and exo stereoisomers: FTIR (neat) 2950, 2870, 1750, 1640, 1450, 1400, 1200, 1170, 910 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 1.20–1.50 (4 H, m), 1.52–1.85 (4 H, m), 2.01–2.58 (9 H, m), 4.91–5.04 (2 H, m), 5.74–5.87 (1 H, m); ^{13}C NMR (62.86 MHz, $CDCl_3$) (major isomer) δ 216.72, 215.81, 136.51, 115.90, 58.22, 52.57, 50.59, 47.32, 44.36, 31.32, 29.98, 28.54, 26.29, 20.12; ^{13}C NMR (minor isomer) δ 216.70, 215.81, 136.11, 116.29, 56.14, 51.06, 48.35, 48.12, 45.01, 42.27, 40.65, 30.99, 29.39, 20.81, 19.82; mass spectrum (CI, CH_4), *m/e* (relative intensity) 233 (M + 1, 100), 205 (4.8), 191 (11.7); high-resolution mass spectrum calcd for $C_{15}H_{20}O_2$ 232.1463, found 232.1453.

7-(2-Oxoethyl)tricyclo[4.3.3.0^{1,6}]dodecane-8,11-dione (28a,b). Monoallyltricyclododecane-8,11-diones **27a,b** (0.55 g, 2.4 mmol) were dissolved in EtOAc (80 mL) in a 250-mL three-necked flask equipped with a magnetic stirrer and a low-temperature thermometer. The flask was placed into a dry ice–acetone cooling bath and the temperature allowed to drop to −60 to −65 °C. Ozone was generated (O_3 flow, 3.5 L/min, 114 VAC; pressure, 5.9 psi) and bubbled through the cold solution. After 10–15 min the solution took on a light blue color. Excess ozone was

purged from the reaction medium with dry nitrogen. Methanol (20 mL) and dimethyl sulfide (DMS, 20 mL) were poured into the solution while the solution was still at −60 °C. The mixture was allowed to slowly warm to room temperature and the reaction's progress was monitored by TLC (silica gel, EtOAc–hexane, 60:40). After 24 h the spot corresponding to the ozonide had disappeared and was replaced by a 2,4-DNP-active product of slightly lower R_f. The solvents were removed under reduced pressure (water aspirator) and the residue flash evaporated with toluene (2 × 20 mL) under vacuum. The residual DMSO present in the crude mixture was removed by Kuglerohr distillation (50 °C, 1.5 mm/Hg) to provide 0.56 g of a viscous oil. The material was purified by eluting it through a short silica gel column with ethyl acetate to afford **28a,b** (0.520 g) as a colorless oil (93%): FTIR (neat) 3020, 2950, 2830, 1750, 1400, 1250 cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ 1.25–2.0 (8 H, m), 2.15–3.45 (9 H, m), 9.90 (1 H, s); ^{13}C NMR (62.86 MHz, $CDCl_3$) (**28a**, endo, major isomer) δ 215.05, 214.44, 198.60, 52.02, 49.45, 47.07, 45.62, 44.80, 42.29, 39.40, 30.70, 29.04, 20.11, 19.42; mass spectrum (CI, CH_4), *m/e* (relative intensity) 235 (M + 1, 69.9) 217 (M − 18, 100), 175 (11.5); high-resolution mass spectrum calcd for $C_{14}H_{18}O_3$ 234.1255, found 234.1267.

5-Hydroxytetracyclo[5.5.2.0^{1,8}.0^{4,8}]tetradecane-3,14-dione (29). A mixture of *endo*- and *exo*-diketo aldehydes **28a,b** (2.0 g, 8.5 mmol) was dissolved in dry THF (150 mL). Aqueous HCl (12 mL, 4%) was added and the mixture was stirred at room temperature under an argon atmosphere. The reaction was allowed to continue until TLC analysis (silica gel, 75% EtOAc–hexane) indicated the absence of the starting aldehyde **28** (2–3 days). Solid $NaHCO_3$ was added to neutralize the excess acid and the mixture was filtered. The volume of the mixture was reduced under reduced pressure and the aqueous layer was extracted with EtOAc (4 × 50 mL). The organic layers were combined, washed with water and brine, and dried ($MgSO_4$). The solvent was removed under reduced pressure to afford a brown, viscous oil. It was purified by flash chromatography (silica gel, 1:1 EtOAc–hexane). The initial fractions contained 10–15% unreacted diketoaldehyde **28a,b** (0.25 g). The major product was the exo tetracyclic diketo alcohol **29** (1.5 g, 86% yield based on reacted diketo aldehyde): FTIR (neat) 3450, 2920, 1735, 1440, 1400 cm^{-1}; ^1H NMR (500 MHz, CD_3OD) δ 4.43 (1 H, ddd, J = 7, 5, 2 Hz), 2.755 (1 H, J_{gem} = 18 Hz), 2.67 (1 H, ddd, J = 7, 2 Hz, broadening), 2.603 (1 H, dd, J = 18, 2 Hz), 2.54 (1 H, dddd, J = 5, 9, 2 Hz, broadening), 2.435 (1 H, dd, J = 18, 2 Hz), 2.29 (1 H, J_{gem} = 18 Hz), 2.28 (1 H, ddd, J = 13, 9, 3 Hz), 1.958 (1 H, ddd, J = 13, 5, 5 Hz), 1.5–1.75 (8 H, m); ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 219.88, 217.69, 73.76, 66.12, 56.72, 56.71, 53.15, 51.77, 42.07, 40.93, 34.66, 34.26, 22.67, 21.27; mass spectrum (CI, CH_4), *m/e* (relative intensity) 235 (M + 1, 17.9), 217 (M − 18, 100), 175 (6.0); high-resolution mass spectrum calcd for $C_{14}H_{18}O_3$ 234.1255, found 234.1259.

Tetracyclo[5.5.2.0^{1,8}.0^{4,8}]tetradecane-3,5,14-triol (30). Hydroxytetracylodione **29** (0.5 g, 2.14 mmol) was dissolved in dry THF (25 mL) and cooled to 0 °C under argon. A solution of borane THF (6 mL, 1.0 N) was then added to the above solution. The reaction mixture was allowed to stir for 16 h, after which methanol (5 mL) was added to quench the excess borane. The solvent was then removed under reduced pressure. It was further treated with methanol (3 × 50 mL) and kept under reduced pressure to remove the last traces of $B(OCH_3)$. The crude product was further purified by flash column chromatography (SiO_2, 10:90, CH_3OH–CH_2Cl_2) to give **30** (0.490 g, 95% yield) as a stereoisomeric mixture of triols. Examination of the FTIR spectrum showed the absence of a carbonyl and the presence of a broad hydroxyl absorption at 3400 cm^{-1}. The complex ^1H and ^{13}C NMR spectra of the crude material were consistent with a mixture of triols. FTIR (neat) 3400, 2925, 1340, 1050 cm^{-1}; mass spectrum (CI, CH_4) *m/e* (relative intensity) 221 (M + 1 − H_2O, 70.9), 203 (M + 1 − 2 H_2O, 91.7), 185 (M + 1 − 3 H_2O, 8.1); high-resolution mass spectrum calcd, for $C_{14}H_{20}O_2$ 202.1357 (M + 1 − 2 H_2O), found 202.1367.

Tetracyclo[5.5.2.0^{1,8}.0^{4,8}]tetradeca-2,5,13-triene (4). The mixture of dry epimeric triols **30** (1 g, 4.2 mmol) was dissolved in dry HMPA (80 mL) and transferred into a custom one-piece reflux apparatus. The air was replaced with argon and the mixture was heated (oil bath) at reflux (230–240 °C) for about 20 h. The mixture was cooled to room temperature. Pentane (100 mL) was added and the contents of the apparatus was transferred to a separatory funnel. The apparatus was washed two times with pentane, and the washes were added to the separatory funnel along with water (100 mL). The organic layer was separated and the aqueous phase was extracted with pentane (4 × 50 mL). The combined pentane extracts were washed with water (3 × 50 mL) and dried ($MgSO_4$). Capillary GC analysis of the pentane extracts showed the presence of propellane triquinacene along with two other minor isomers, (GC ratio 90:4:6). The pentane solution was concentrated to about 1 mL by careful distillative removal of the pentane through a 16 in. column packed with glass beads and then was carefully distilled to give the required product (0.500 g) in 60–65% yield, bp 60–65 °C (10 mmHg). When the mixture of propellane triquinacenes **4**, **31a,b** was stirred in the presence of *p*-toluenesulfonic acid (CH_2Cl_2–pentane), the minor isomers disappeared and **4** was isolated in pure form: FTIR (neat) 3050, 2940, 2900, 2850, 1625, 1450, 1350, 1220, 960, 775, 700 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 5.54 (2 H, dd, J = 6.0, 2.8 Hz), 5.53 (2 H, s), 5.40 (2 H, dd, J = 6.0, 1.7 Hz), 3.27 (2 H, t, J = 2.8, 1.7 Hz), 1.48 (8 H, br s); ^{13}C NMR (125 MHz, $CDCl_3$) δ 137.38, 132.13, 131.31, 64.76, 63.92, 59.08, 30.08, 27.69, 17.18, 16.10; mass spectrum (EI), *m/e* (relative intensity) M^+ (184); high-resolution mass spectrum calcd for $C_{14}H_{16}$ 184.1252, found 184.1275.

Tetracyclo[5.5.2.0^{1,8}.0^{4,8}]tetradecane (32). A suspension of 10% Pd–C (10 mg) was added to a solution of **4**, **31a,b** (60 mg, 0.32 mmol) in ethyl acetate (30 mL), and the mixture was stirred under H_2 (15 psi) for 5 h at room temperature, at which time H_2 uptake ceased. The reaction mixture was then filtered and the filter cake (catalyst) was washed with ethyl acetate. The combined ethyl acetate filtrate and washings were concentrated in vacuo to give 55 mg (92%) of **32**: ^1H NMR (250 MHz, $CDCl_3$) δ 1.20–2.0 (mm, 22 H); ^{13}C NMR (62.86 MHz, $CDCl_3$) δ 63.58, 51.80 (2 C), 38.48, 34.19, 33.86, 30.62, 29.93, 21.15, 19.69; mass spectrum (CI, CH_4), *m/e* (relative intensity) 191 (M + 1, 54.8), 189 (100), 161 (7.1), 135 (10.0).

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Supplementary Material Available: Attempted cyclization of **12a,b** with glacial acetic acid and HCl(g), trifluoroacetic acid, and glacial acetic acid and acetic anhydride and attempted preparation of **15** and **1** (4 pages). Ordering information is given on any current masthead page.