furan), had an ORD spectrum enantiomeric to that of the previously prepared sample, (+)-(*R*)$_C$-(*S*)$_S$-**15**, $[\alpha]^{25}D$ +22.53° (*c* 0.75, tetrahydrofuran) (see above). *Anal.* Calcd for $C_{22}H_{24}N_2O_2S_2$: C, 64.06; H, 5.87. Found: C, 63.92; H, 5.74.

N-*p*-**Toluenesulfonyl**-*p*-**toluenesulfinimidoyl Chloride.** This compound was obtained (90%),[16] mp 141.5–142.5°, from dichloromethane–ether. *Anal.* Calcd for $C_{14}H_{14}ClNO_2S_2$: C, 51.29; H, 4.30. Found: C, 51.21; H, 4.25.

Stereoselective Synthesis of Hydroazulenes from Cyclodecadienols

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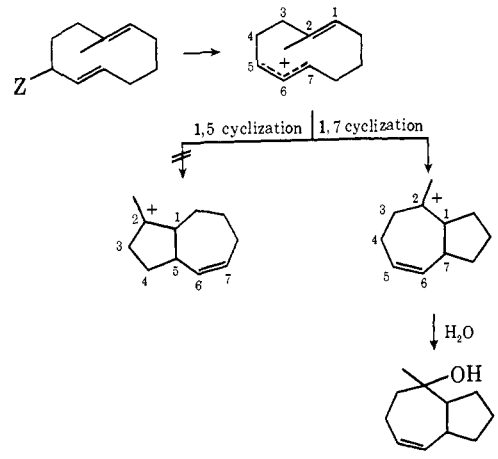
Abstract: The feasibility of a new synthetic route to hydroazulenes *via* transannular cyclization of cyclodecadienol derivatives was demonstrated with four systems. In each case an incipient allylic cation was generated through solvolysis of the *p*-nitrobenzoate derivative or the alcohol itself. The first system, 8-methyl-*trans*,*trans*-2,7-cyclodecadien-1-yl *p*-nitrobenzoate (**3a**), afforded 2-*anti*-methyl-*trans*-bicyclo[5.3.0]dec-5-en-2-ol (**4a**) in 80% yield upon solvolysis in buffered aqueous dioxane. The 4-methyl homolog of the aforementioned *p*-nitrobenzoate yielded 2-*anti*,8-*anti*-dimethyl-*trans*-bicyclo[5.3.0]dec-5-en-2-ol (**4b**) in nearly 60% yield upon similar treatment. An allylic isomer of cyclodecadienyl *p*-nitrobenzoate **3a**, namely 6-methyl-*cis*,*trans*-2,6-cyclodecadien-1-yl *p*-nitrobenzoate (**16**), gave rise to the previously obtained hydroazulenol **4a** in over 40% yield. Finally, the tertiary alcohol 1,6-dimethyl-*cis*,*trans*-2,6-cyclodecadien-1-ol, a homolog of alcohol **15**, afforded 2,7-*anti*-dimethyl-*trans*-bicyclo[5.3.0]dec-5-en-2-yl acetate (**19**) in over 70% yield upon acetolysis at room temperature. The structures of the hydroazulenols were deduced from spectral data and by comparison with authentic samples of the dihydro derivatives.

In the 35 years since Pfau and Plattner's brilliant work on the structure of azulene[2] a considerable number of natural products with the parent hydroazulene ring system have been identified as constituents of diverse plant extracts.[3] Progress in stereoselective synthetic approaches to this rapidly growing family of sesquiterpenes has by no means kept pace with the structure work. Thus, but a small handful of even the simpler hydroazulenes have been synthesized to date.[4,5] In this report we describe initial work on a new stereoselective route to substituted hydroazulenols which should find applications in natural product synthesis.[6]

Cyclodecenyl cations have been implicated in hydroazulene biosynthesis[7] and this concept of synthesis has been applied *in vitro* with cyclodecadienes[8] and related epoxides.[9] Our plan for cyclodecadiene cyclization envisioned the selective electrophilic activation of a specific double bond of the appropriate precursor through solvolysis of an allylic alcohol derivative (Scheme I).

Scheme I



A priori, two possible pathways, namely 1,5 and 1,7 cyclization, might be considered for the presumed allyl cation thereby generated. However, as will be shown, an analysis of the controlling geometric factors clearly indicates that 1,7 cyclization should be the favored reaction course.

The starting material for our initial studies was prepared from the unsaturated keto mesylate **1a**[10] as outlined in Chart I. Accordingly, hydroboration followed by base treatment led directly to the *trans*,*trans*-cyclodecadienol **2a** in 60% yield.[11] The *p*-nitrobenzoate

(1) Predoctoral Fellow of the Department of Health, Education, and Welfare, Institute of General Medical Sciences, 1968–1971.

(2) A. St. Pfau and Pl. Plattner, *Helv. Chim. Acta*, **19**, 858 (1936).

(3) *Cf.* F. Sorm and L. Dolejs, "Guaianolides and Germacranolides," Holden-Day, San Francisco, Calif., 1966; T. Nozoe and S. Ito, *Fortschr. Chem. Org. Naturst.*, **19**, 25 (1961); J. Romo, *Pure Appl. Chem.*, **21**, 123 (1970); T. A. Geissman and M. A. Irwin, *ibid.*, **21**, 167 (1970); S. M. Kupchan, *ibid.*, **21**, 227 (1970); F. Sorm, *ibid.*, **21**, 263 (1970).

(4) *Cf.* G. L. Buchanan and G. A. R. Young, *J. Chem. Soc. D*, 643 (1971); J. A. Marshall, A. E. Greene, and R. A. Ruden, *Tetrahedron Lett.*, 855 (1971).

(5) *Cf.* G. Buchi, W. Hofheinz, and J. V. Paukstelis, *J. Amer. Chem. Soc.*, **91**, 6473 (1969); J. A. Marshall and J. J. Partridge, *Tetrahedron*, **25**, 2159 (1969); M. Kato, H. Kosugi, and A. Yoshikoshi, *J. Chem. Soc. D*, 185, 934 (1970); E. Piers and K. F. Ching, *Can. J. Chem.*, **48**, 2234 (1970).

(6) A preliminary account of a portion of this work has appeared: J. A. Marshall and W. F. Huffman, *J. Amer. Chem. Soc.*, **92**, 6358 (1970). A related system has recently been examined: P. S. Wharton and M. D. Baird, *J. Org. Chem.*, **36**, 2932 (1971).

(7) *Cf.* J. B. Hendrickson, *Tetrahedron*, 7, 82 (1959).

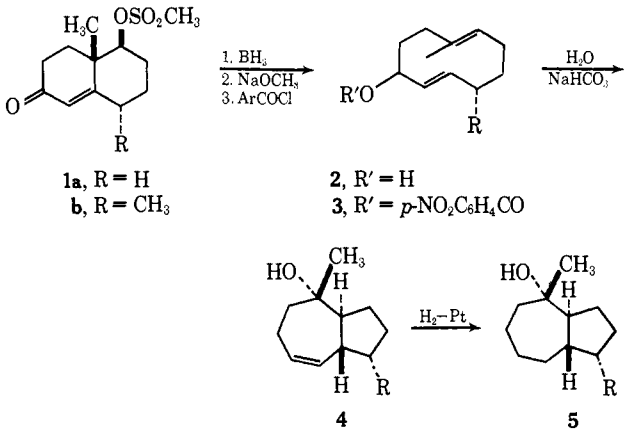
(8) *Cf.* E. D. Brown, M. D. Solomon, J. K. Sutherland, and A. Torre, *Chem. Commun.*, 111 (1967); K. Nishimura, N. Shinoda, and Y. Hirose, *Tetrahedron Lett.*, 3097 (1969).

(9) A. S. Barvdekar, G. R. Kelkar, and S. C. Bhattacharyya, *ibid.*, 1225 (1966); E. D. Brown and J. K. Sutherland, *ibid.*, 1060 (1968); E. D. Brown, T. W. Sam, and J. K. Sutherland, *ibid.*, 5025 (1969); K. Wada, Y. Enomoto, and K. Munakata, *ibid.*, 3357 (1969); H. Hikino, C. Konn, T. Nagashima, T. Kohama, and T. Takemoto, *ibid.*, 337 (1971).

(10) J. D. Cocker and T. G. Halsall, *J. Chem. Soc.*, 3441 (1957).

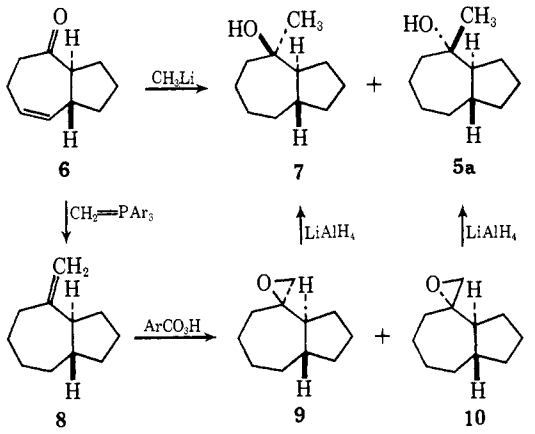
(11) *Cf.* J. A. Marshall and G. L. Bundy, *J. Amer. Chem. Soc.*, **88**, 4291 (1966).

Chart I



derivative **3a** afforded the hydroazulenol **4a** in 80% yield upon solvolysis in buffered aqueous dioxane. Minor amounts of unidentified hydrocarbons, presumably elimination products, were also formed in the solvolysis reaction. The structure of hydroazulenol **4a** was ascertained through an independent synthesis of its dihydro derivative **5a** as outlined in Chart II. To that

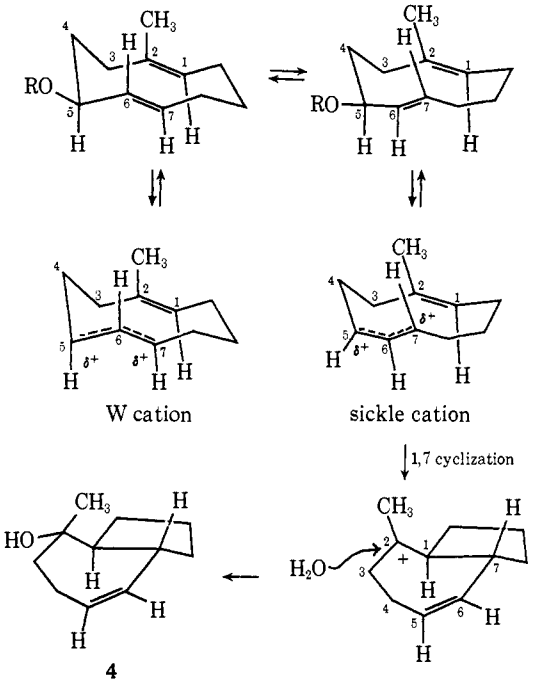
Chart II



end, the known *trans*-hydroazulenone **6**[12] (contaminated with 20% of the cis isomer) was treated with methyllithium to give a roughly 9:1 mixture of alcohols **7** and **5a** (likewise contaminated with the cis-fused isomers). Molecular models indicate that attack at the less hindered face of the carbonyl group in ketone **6** should lead to the former alcohol and the assignment is made accordingly. The minor alcohol epimer exhibited identical spectral properties and chromatographic behavior as the solvolytically derived material. A more convenient synthesis of alcohol **5a** was effected through the olefin **8** *via* epoxidation and subsequent hydride reduction which afforded the alcohols **7** and **5a** in the ratio 45:55. Here again the major epimer can be seen to arise *via* approach of the attacking reagent (*m*-chloroperoxybenzoic acid, in this case) at the less hindered face of the double bond in olefin **8**. Interestingly, the cis isomer of ketone **6** was converted to the trans fused olefin **8** during the course of the Wittig condensation when DMSO was employed as the solvent. Apparently, epimerization can occur under these conditions and the trans fused ketone **8** is the more reactive epimer. Similar behavior has been observed in decalone systems.[13]

As noted above the cyclization of cyclodecadiene **3a** proceeds stereoselectively and regioselectively to give the hydroazulenol **4a**. A satisfactory rationale for this result can be formulated in terms of likely transition state requirements for this reaction as indicated in Scheme II. Thus, solvolysis of the *p*-nitrobenzoate

Scheme II



should take place with retention of double bond geometry to afford either a sickle cation or an isomeric W cation, depending upon the orientation of the allylic system.[14] 1,5-Cyclization of the sickle cation would lead to a highly strained *trans*-cycloheptene whereas the 1,7-cyclization pathway would result in a *cis*-cycloheptene system. Both modes of cyclization would afford prohibitively strained *trans*-cycloheptenes in the case of the W cation. Regioselectivity[15] may therefore be directed by the geometry of the allyl cation. Conceivably, this selectivity could also arise from a preferred SN2′ reaction pathway of cyclodecadiene **3a**. This alternative seemed *a priori* less likely[16] and, as will be detailed below, no evidence could be obtained in its favor.

The observed stereoselectivity of the cyclodecadienyl cyclization reaction seems best explained on the basis of likely steric interactions which develop during 1,7-bond formation. The trans staggered arrangement of C-1 and C-7 depicted in Scheme II should be preferred to alternative cis eclipsed conformations which would lead to the (unobserved) cis fused hydroazulenol. Finally, the carbinyl stereochemistry appears to be controlled by the steric environment of the hydroazulenyl cation intermediate, as shown in Scheme II, with attack by water taking place preferentially on the less hin-

(12) W. Huckel and L. Schnitzspahn, *Justus Liebigs Ann. Chem.*, 505, 274 (1933).

(13) J. A. Marshall, M. T. Pike, and R. D. Carroll, *J. Org. Chem.*, 31, 2933 (1966).

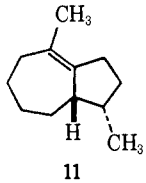
(14) For a discussion of allyl cation isomerizations see N. Deno, R. C. Haddon, and E. N. Nowak, *J. Amer. Chem. Soc.*, 92, 6691 (1970); J. M. Bollinger, J. M. Brinich, and G. A. Olah, *ibid.*, 92, 4025 (1970).

(15) *Cf.* A. Hassner, *J. Org. Chem.*, 33, 2684 (1968).

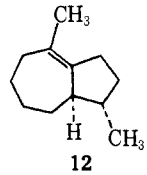
(16) *Cf.* F. G. Bordwell, *Accounts Chem. Res.*, 3, 281 (1970).

dered face of this cation. The steric situation here is similar to that of the carbonyl carbon of ketone **6** which likewise shows a marked preference for bottomside attack in its reaction with methyllithium.

A number of naturally occurring hydroazulenes contain a methyl group at C-4 which is trans to the adjacent ring fusion hydrogen (*e.g.*, **4b**).[3] It was of interest, therefore, to examine a cyclodecadiene cyclization which might generate this structural feature. To that end, the mesylate derivative **1b** of the requisite dimethyl hydroxyoctalone[17] was subjected to the hydroboration–fragmentation sequence affording the cyclodecadienol **2b**. The crystalline *p*-nitrobenzoate derivative **3b** led to a mixture of solvolysis products containing 88% of an alcoholic substance whose spectral properties were compatible with hydroazulenol **4b**. As before, the minor solvolysis products appeared to consist mainly of olefinic materials according to the gas chromatographic retention times. Confirmation of the gross structure **4b** and support for the assigned stereochemistry was secured *via* dehydration of the dihydro derivative **5b** to the known hydroazulene **11**.[18] The alternative isomer **12** could not be detected thus indicating that the cyclization of *p*-nitrobenzoate **3b** is highly stereoselective. The carbinyl and ring-fusion stereochemistry of hydroazulenol **4b** can be assigned by analogy with **4a**.



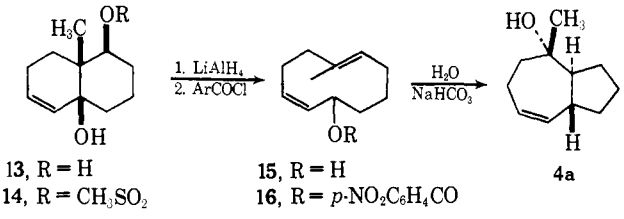
11



12

The proposed cyclodecadiene cyclization pathway (Scheme II) depicts a solvolysis step leading to an allyl cation intermediate as opposed to a concerted SN2′ displacement of the *p*-nitrobenzoate. In order to gain further insight regarding this point we undertook a synthesis of the allyl isomer of *p*-nitrobenzoate **3b** to examine its solvolysis behavior. This synthesis (Chart III) employed the diol **13**[19] whose mesylate derivative **14**

Chart III



13, R = H
14, R = CH_3SO_2

15, R = H
16, R = *p*-$NO_2C_6H_4CO$

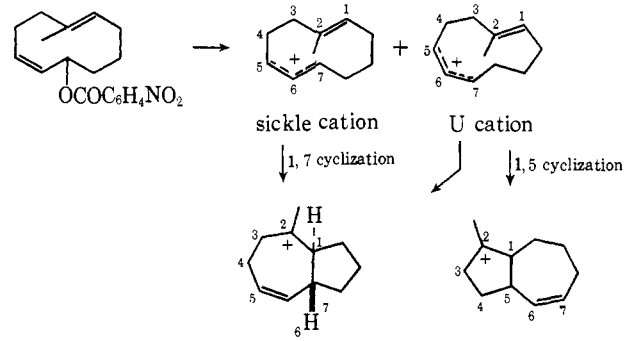
4a

afforded the *cis,trans*-cyclodecadienol **15** upon treatment with lithium aluminum hydride. The choice of a hydride base to initiate the fragmentation of hydroxy mesylate **14** was governed by our fears (later found to be groundless—see below) that the more conventional alkoxide bases would effect isomerization of the resulting conjugated cyclodecenone.[20]

Solvolysis of the *p*-nitrobenzoate **16** in buffered aqueous dioxane led to the previously encountered hydroazulenol **4a** as the predominant alcoholic product. These findings support a dissociative cyclization pathway for these systems.

The successful cyclization of the *cis,trans*-cyclodecadienyl *p*-nitrobenzoate **16** introduces an additional geometric consideration which is relevant to the question of regioselectivity. Reasoning along the lines of Scheme II we might expect the solvolysis of **16** to give two isomeric allylic cations, the previously postulated sickle cation and a U cation (Scheme III). Whereas

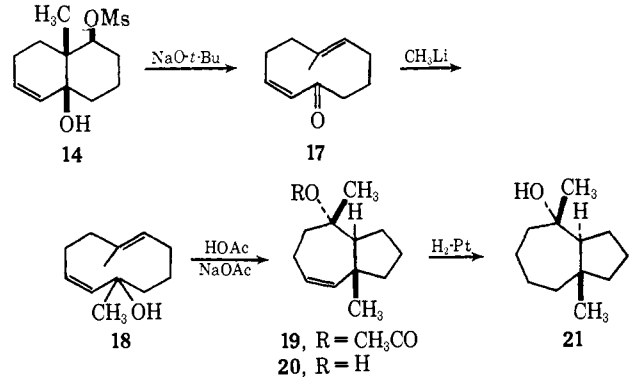
Scheme III



the sickle cation is geometrically constrained to undergo 1,7 cyclization, the U cation suffers no such constraint and thus 1,5, and 1,7 cyclizations are both geometrically allowed. Our failure to observe the 1,5 cyclization product may stem from an intrinsically unfavorable formation of the U as opposed to the sickle cation, or possibly to an unfavorable conformational arrangement for 1,5 cyclization in the U cation. Clarification of this point will require additional studies.

The successful realization of Scheme III prompted our consideration of an extension to the synthesis of angularly methylated hydroazulenes related to the naturally occurring pseudoguaianolides.[21] This goal was easily reached as shown in Chart IV starting with

Chart IV



14

17

18

19, R = CH_3CO
20, R = H

21

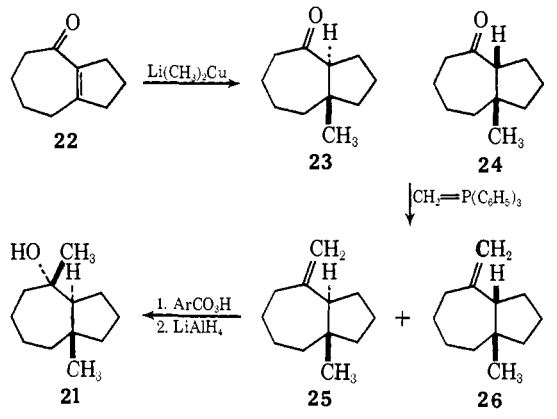
the hydroxy mesylate **14**. Treatment with sodium *tert*-butoxide afforded the *cis,trans*-cyclodecenone **17** whose stereochemical integrity was confirmed by reduction to the previously prepared *cis,trans*-cyclodecadienol **15**. Addition of methyllithium to enone **17** afforded the tertiary alcohol **18**. Cyclization of this substance was readily effected in acetic acid–sodium acetate at room temperature affording the acetate **19**, which was purified by conversion to the crystalline alcohol **20** (68% overall yield from dienol **18**). As be-

(17) M. Kato, H. Kosugi, and A. Yoshikoshi, *J. Chem. Soc. D*, 185 (1970).
(18) J. A. Marshall and J. J. Partridge, *Tetrahedron*, 25, 2159 (1969).
(19) P. S. Wharton, *J. Org. Chem.*, 26, 4781 (1961).
(20) *Cf.* J. A. Marshall, C. J. V. Scanio, and W. J. Iburg, *ibid.*, 32, 3750 (1967).
(21) *Cf.* "Terpenes and Steroids," Vol. 1, The Chemical Society, Burlington House, London, 1970, pp 117–119.

fore, the principal by-products of the cyclization reaction appeared to be unsaturated hydrocarbons.

The structure of hydroazulenol **19** was confirmed along the lines indicated in Chart V. Addition of

Chart V



lithium dimethylcuprate[22] to hydroazulenone **22** afforded a 60:40 mixture of trans and cis fused ketones **23** and **24**. These two isomers were easily distinguished on the basis of the markedly differing chemical shifts of their angular methyl groups.[23] The trans fused isomer **23** likewise exhibited a larger paramagnetic shift upon addition of europium(III)-2,2,6,6-tetramethylheptanedioate to the mixture.[24] The corresponding exocyclic methylene compounds **25** and **26**, prepared *via* condensation of the ketone mixture with methylenetriphenylphosphorane in tetrahydrofuran, also showed marked differences in the chemical shift of the angular methyl groups. As before, extensive epimerization took place when the Wittig condensation was carried out in dimethyl sulfoxide. Epoxidation of the trans fused olefin **25** followed by reduction with lithium aluminum hydride afforded the hydroazulenol **21** identical with material obtained through hydrogenation of unsaturated alcohol **20** derived solvolytically. The stereochemical considerations underlying this assignment of structure were noted above in connection with alcohol **5a** (Chart II).

Experimental Section[25]

***cis*-1-Methanesulfonoxy-9-methyl-5(10)-octalin-6-one (1a).** A solution of 5.07 g of *cis*-1-hydroxy-9-methyl-5(10)-octalin-6-one[10] and 3.0 ml of methanesulfonyl chloride in 25 ml of pyridine at 0° was allowed to reach room temperature with stirring over 4 hr. Isolation with ether–ethyl acetate afforded 6.6 g (91%) of solid. Recrystallization from ethyl acetate yielded 4.35 g of material, mp 131–132°, in the first crop and 0.36 g, mp 129–131°, in the second crop. The analytical sample, mp 131–132°, was twice recrystallized from ethyl acetate. *Anal.* Calcd for $C_{12}H_{18}O_4S$: C, 55.78; H, 7.04; S, 12.41. Found: C, 55.6; H, 7.0; S, 12.7.

8-Methyl-*trans,trans*-2,7-cyclodecadien-1-ol (2a). To a solution containing 100 ml of 0.5 *M* diborane in tetrahydrofuran (THF) and 50 ml of THF at 0° was added a solution of 4.68 g (18.1 mmol) of mesylate **1a** in 100 ml of THF over a 10-min period with stirring. An additional 50 ml of THF was added *via* the dropping funnel and the solution was stirred at 0° for 1 hr and at room temperature for 1 hr. Methanol (26 ml) was carefully added followed by 190 ml of 2 *M* sodium methoxide. The resulting solution was stirred at room temperature for 19 hr and at reflux for 20 min. Isolation with ether afforded 2.41 g of yellow liquid which was chromatographed on 75 g of Woelm neutral alumina (grade II–III). The hexane fractions yielded 0.29 g of 2-methyl-*trans,trans*-1,6-cyclodecadiene and the 1:1 benzene–hexane and benzene fractions gave 1.86 g of dienol **2a**. Distillation of this latter material yielded 1.76 g (59%) of oil, bp 100° (0.02 mm), which solidified upon cooling. The analytical sample, mp 46.5–48°, was secured after two recrystallizations from pentane: $\delta_{TMS}^{CCl_4}$ 1.70 (vinyl CH_3), 3.89 (carbinyl H multiplet), 4.74 and 5.20 ppm (vinyl H multiplets). *Anal.* Calcd for $C_{11}H_{18}O$: C, 79.46; H, 10.91. Found: C, 79.2; H, 11.1.

The *p*-nitrobenzoate derivative exhibited mp 74–75° after crystallization from hexane–chloroform. *Anal.* Calcd for $C_{18}H_{21}NO_4$: C, 68.55; H, 6.71; N, 4.44. Found: C, 68.5; H, 6.8; N, 4.5.

***t*-2-Methyl-*r*-1H,*t*-7H-bicyclo[5.3.0]dec-5-en-*c*-2-ol (4a).** **A. From *p*-Nitrobenzoate 3a.** A solution of 963 mg of *p*-nitrobenzoate **3a** and 505 mg of sodium bicarbonate in 200 ml of 3:1 dioxane–water was stirred at reflux for 52 hr. The product was isolated with ether and distilled affording 434 mg of colorless liquid consisting of alcohol **4a** (78%), hydrocarbons (10%), and small amounts of other impurities according to the gas chromatogram. The analytical sample was isolated by preparative gas chromatography and short-path distillation (bp 70° (0.05 mm)): $\delta_{TMS}^{CCl_4}$ 1.22 (CH_3) and 5.36 ppm (vinyl H multiplet). *Anal.* Calcd for $C_{11}H_{18}O$: C, 79.46; H, 10.91. Found: C, 79.4; H, 11.1.

B. From *p*-Nitrobenzoate 16. A solution of 212 mg of *p*-nitrobenzoate **16** and 104 mg of sodium bicarbonate in 40 ml of 3:1 dioxane–water was stirred at reflux for 65 hr and processed as described above to give 59 mg of material containing 80% of alcohol **4a** according to the gas chromatogram and infrared spectrum.

***t*-2-Methyl-*r*-1H,*t*-7H-bicyclo[5.3.0]decan-*c*-2-ol (5a).** **A. From Olefin 8.** To a stirred mixture of 352 mg of olefin **8** and 2.02 g of potassium hydrogen phosphate in 8 ml of methylene chloride at 0° was added a solution of 708 mg of 82% *m*-chloroperoxybenzoic acid in 20 ml of methylene chloride. After 40 min at 0° and 40 min at room temperature the mixture was poured into cold aqueous NaOH and the product was isolated with ether and reduced with 230 mg of lithium aluminum hydride in 14 ml of ether (0° for 40 min, room temperature for 1 hr) to give 368 mg of material containing two alcohol components in the ratio 67:33 according to the gas chromatogram. The major alcohol **5a** was isolated by preparative gas chromatography and short-path distillation (73° (0.01 mm)): $\delta_{TMS}^{CCl_4}$ 1.05 ppm (CH_3). *Anal.* Calcd for $C_{11}H_{20}O$: C, 78.51; H, 11.98. Found: C, 78.4; H, 11.9.

B. From Alcohol 4a. A solution of 208 mg of alcohol **4a** in 10 ml of ethyl acetate was hydrogenated at 1 atm over 124 mg of 84% platinum oxide. After 0.5 hr the uptake of hydrogen ceased and the mixture was filtered and distilled affording 204 mg of alcohol **5a** which had identical spectral and chromatographic properties, after purification *via* preparative gas chromatography, as material prepared in part A.

***c*-2-Methyl-*r*-1H,*t*-7H-bicyclo[5.3.0]decan-*t*-2-ol (7).** **A. From Olefin 8.** The minor alcohol product obtained in part A of the above experiment was isolated by preparative gas chromatography and short-path distillation (70° (0.01 mm)): $\delta_{TMS}^{CCl_4}$ 1.15 ppm (CH_3). *Anal.* Calcd for $C_{11}H_{20}O$: C, 78.51; H, 11.98. Found: C, 78.6; H, 12.0.

B. From Ketone 6.[12] To 1.0 ml of 1.7 *M* ethereal methyllithium was added with stirring a solution of 48 mg of ketone **6** (contaminated with 20% of the cis epimer)[12] in 3 ml of ether. After 0.5 hr at 0° and 5 hr at room temperature the product was isolated with ether and distilled affording 40 mg of material whose nmr and infrared spectra matched those of the material obtained in part A above. The gas chromatogram contained two peaks in the ratio 96:4 which were identified as alcohols **7** and **5a**, respectively, by peak enhancement.

2-Methylene-*trans*-bicyclo[5.3.0]decane (8). The methylenephosphorane was prepared from 0.34 g of 57% NaH in mineral oil and

(22) H. O. House, W. L. Respess, and G. M. Whitesides, *J. Org. Chem.*, **31**, 3128 (1966).

(23) *Cf.* G. J. Karabatsos, G. C. Sonnichsen, N. Hsi, and D. J. Fenoglio, *J. Amer. Chem. Soc.*, **89**, 5067 (1967); N. S. Bhacca and D. H. Williams, "Applications of NMR Spectroscopy in Organic Chemistry," Holden-Day, San Francisco, Calif., 1966, pp 13–32. Compare chemical-shift values of 18-methyl groups in steroids with 14-α *vs.* 14-β hydrogens.

(24) *Cf.* P. Kristiansen and T. Ledaal, *Tetrahedron Lett.*, 2817 (1971).

(25) Reactions were conducted under a nitrogen atmosphere using the apparatus described by W. S. Johnson and W. P. Schneider ("Organic Syntheses," Collect. Vol. IV, Wiley, New York, N. Y., 1963, p 132). Reaction products were isolated by addition of water and extraction with the specified solvent. The combined extracts were washed with saturated brine and dried over anhydrous magnesium sulfate. The solvent was removed from the filtered solutions on a rotary evaporator. Short-path distillations were carried out on a Büchi kugelrohrofen using bulb-to-bulb apparatus. Stereochemical designations of substituents in bicyclic compounds are indicated by *c* (cis) and *t* (trans) relative to a reference substituent *r*.

2.87 g of methyltriphenylphosphonium bromide in 23 ml of DMSO as described by Corey.[26] To the resulting solution was added 0.61 g of ketone **6** (80:20 trans:cis) in 4.5 ml of DMSO with stirring. After 10.5 hr the product was isolated with pentane and purified by chromatography on 30 g of alumina and short-path distillation to give 0.585 g (97%) of olefin **8**: $\delta_{TMS}^{CCl_4}$ 4.64 (vinylic H multiplet). *Anal.* Calcd for $C_{11}H_{18}$: C, 87.93; H, 12.07. Found: C, 87.95; H, 12.1.

***c*-1-Methanesulfonoxy-*t*-4,*r*-9-dimethyl-5(10)-octalin-6-one (1b).** The mesylate **1b** was prepared from the corresponding alcohol[18] as described above for **1a**. The analytical sample, mp 132–133°, was secured by crystallization from ether–ethyl acetate: $\delta_{TMS}^{CDCl_3}$ 5.88 (H-5), 4.48 (H-1 triplet, J = 8 Hz), 3.05 (CH_3SO_3), 1.28 (CH_3), and 1.08 ppm (CH_3 doublet, J = 6 Hz). *Anal.* Calcd for $C_{13}H_{20}O_4S$: C, 57.32; H, 7.42; S, 11.77. Found: C, 57.3; H, 7.4; S, 11.6.

4,8-Dimethyl-*trans*,*trans*-2,7-cyclodecadien-1-ol (2b). The hydroboration–fragmentation sequence described above for **1a** was carried out on mesylate **1b** to give the cyclodecadienol **2b** in 22% yield: $\delta_{TMS}^{CCl_4}$ 5.12, 4.74 (vinyl H multiplets), 3.92 (carbinyl H multiplet), 1.47 (vinyl CH_3), and 0.91 ppm (CH_3 doublet, J = 7 Hz). The *p*-nitrobenzoate derivative **3b**, prepared in 93% yield, exhibited mp 90–92.5° after two recrystallizations from hexane. *Anal.* Calcd for $C_{19}H_{23}NO_4$: C, 69.28; H, 7.04; N, 4.25. Found: C, 69.4; H, 7.1; N, 4.0.

***t*-2,*c*-8-Dimethyl-*r*-1H,*t*-7H-bicyclo[5.3.0]dec-5-en-*c*-2-ol (4b).** A solution of 82 mg of *p*-nitrobenzoate **3b** and 57 mg of sodium bicarbonate in 18 ml of 3:1 dioxane–water was stirred at reflux for 84 hr. The product was isolated with ether and distilled affording 30 mg (66%) of material containing 17% of hydrocarbons and 83% of alcohol **4b**: $\delta_{TMS}^{CCl_4}$ 5.56 (vinyl H's), 1.07 (CH_3), and 0.82 ppm (CH_3 doublet, J = 7 Hz). The analytical sample was secured *via* preparative gas chromatography and short-path distillation. *Anal.* Calcd for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 80.1; H, 11.2.

***t*-2,*c*-8-Dimethyl-*r*-1H,*t*-7H-bicyclo[5.3.0]decan-*c*-2-ol (5b).** A 21-mg sample of unsaturated alcohol **4b** in 3 ml of ethyl acetate was hydrogenated over 28 mg of platinum oxide as described above for **4a** to give 17 mg (80%) of distilled alcohol **5b**: bp 100° (0.05 mm); $\delta_{TMS}^{CCl_4}$ 1.07 (CH_3) and 0.82 ppm (CH_3 doublet, J = 7 Hz). *Anal.* Calcd for $C_{12}H_{22}O$: C, 79.06; H, 12.17. Found: C, 78.9; H, 12.0.

2,*t*-8-Dimethyl-*r*-7H-bicyclo[5.3.0]dec-1-ene (11). A mixture of 27 mg of alcohol **5b** and 65 mg of sodium acetate in 1.65 ml of acetic anhydride was stirred at reflux for 17 hr. The cooled solution was stirred with aqueous sodium bicarbonate for 1 hr and the product was isolated with ether and chromatographed on Woelm neutral alumina (grade II) to give 20 mg of a mixture of olefin isomers containing roughly 50% of the tetrasubstituted isomer **11**, 20% of the exocyclic isomer, and 30% of the trisubstituted isomer according to the nmr spectrum. This spectrum showed the same characteristic features, including a CH_3 doublet at 0.85 ppm (J = 7 Hz), as that of authentic olefin **11**. The epimeric substance, olefin **12**, shows its methyl doublet at 1.02 ppm (J = 5 Hz). This feature was not present in the spectrum of the above mixture.

***r*-9-Methyl-5-octalin-*c*-1,*c*-10-diol (13).** A solution of 3.15 g of hydroxy benzoate **13** (R = COC_6H_5) and 2.4 g of KOH in 72 ml of ethanol was stirred at reflux for 14 hr. The solution was concentrated under reduced pressure and the product was isolated with ether and purified by chromatography on 50 g of Woelm basic alumina (grade III). Elution with 1:1 ether–benzene gave 1.49 g (75%) of oil which crystallized, mp 84–91°. The analytical sample, mp 88.5–90°, was obtained after two recrystallizations from ether–pentane. *Anal.* Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95. Found: C, 72.5; H, 9.9.

6-Methyl-*cis*,*trans*-2,6-cyclodecadien-1-ol (15). A. From Diol 13. A solution of 437 mg of diol **13** in 5.3 ml of pyridine at 0° was treated with 0.62 ml of methanesulfonyl chloride with stirring. After 0.5 hr at room temperature the product was isolated with ether affording 600 mg (96%) of oily mesylate. This material in 10 ml of THF was added to 920 mg of lithium aluminum hydride in 25 ml of THF. The mixture was stirred at reflux for 19 hr, 150 ml of ether was added, and the excess hydride was destroyed with 0.9 ml of water, 0.9 ml of 15% NaOH, and finally 2.7 additional ml of water. After 6 hr the stirred mixture was filtered and distilled affording 274 mg (71%) of dienol **15**, bp 100° (0.1 mm). This material was purified by chromatography on 11 g of Woelm neutral alumina (grade II-III) and distillation which gave 190 mg of semisolid alcohol: $\delta_{TMS}^{CCl_4}$ 5.32 (H-2, H-3), 4.77 (H-7), 3.98 (H-1), 2.72 (OH), and 1.58 ppm (CH_3).

The *p*-nitrobenzoate **16** had mp 89–90° after two recrystallizations from ether–pentane. *Anal.* Calcd for $C_{18}H_{21}NO_4$: C, 68.54; H, 6.72; N, 4.44. Found: C, 68.4; H, 6.7; N, 4.3.

B. From Enone 17. To a suspension of 47 mg of aluminum chloride in 2 ml of ether at 0° was added 41 mg of lithium aluminum hydride and 2 ml of ether with stirring. After 0.5 hr, 37 mg of dienone **17** in 1 ml of ether was added and stirring was continued for 0.5 hr. The mixture was poured into a saturated solution of sodium–potassium tartrate and the product was isolated with ether affording 33 mg (88%) of solid dienol whose spectral properties matched those of material prepared in part A of this experiment.

6-Methyl-*cis*,*trans*-2,6-cyclodecadien-1-one (17). To a suspension of sodium *tert*-butoxide (from 65 mg of NaH and 7 ml of *tert*-butyl alcohol) was added a solution of 778 mg of hydroxy mesylate **14** in 6 ml of *tert*-butyl alcohol. The mixture was stirred at reflux for 17 hr and the product was isolated with ether and distilled affording 275 mg (57%) of oily dienone **17**. Purification was effected *via* preparative layer chromatography on silica gel and short-path distillation at 80° (0.03 mm): $\delta_{TMS}^{CCl_4}$ 5.84, 4.74 (vinyl H's), and 1.42 ppm (CH_3 doublet, J = 1 Hz). *Anal.* Calcd for $C_{11}H_{16}O$: C, 80.44; H, 9.82. Found: C, 80.5; H, 9.9.

1,6-Dimethyl-*cis*,*trans*-2,6-cyclodecadien-1-ol (18). To 3.6 ml of 1.85 *M* ethereal methyllithium at 0° was added with stirring 272 mg of dienone **17** in 2 ml of ether. After 0.5 hr at 0° and 0.5 hr at room temperature, the mixture was poured onto ice and the product was isolated with ether and distilled affording 286 mg (96%) of dienol **18** which crystallized, mp 25–33°, upon cooling: $\delta_{TMS}^{CCl_4}$ 5.37 and 5.00 (vinyl H's), 1.68 (CH_3 doublet, J = 1 Hz), and 1.18 ppm (CH_3). *Anal.* Calcd for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 79.8; H, 10.9.

***t*-2,*t*-7-Dimethyl-*r*-1H-bicyclo[5.3.0]dec-5-en-*c*-2-ol (20).** A solution of 267 mg of dienol **18** in 3 ml of acetic acid saturated with sodium acetate was stirred for 14 hr and the product was isolated with ether affording 276 mg of acetate **19**. This material was reduced with 179 mg of lithium aluminum hydride in 7.5 ml of ether at 25° for 0.5 hr to give 244 mg (91%) of crude alcohol **20** containing 20% of hydrocarbons according to gas chromatography. This material was purified by preparative layer chromatography on silica gel and short-path distillation (78° (0.07 mm)) to afford 188 mg (70%) of solid: mp 75.5–78°; $\delta_{TMS}^{CCl_4}$ 5.37 (vinyl H's), 1.15 (CH_3), and 0.94 ppm (CH_3). The analytical sample, mp 77.5–78.5°, was obtained after recrystallization from pentane. *Anal.* Calcd for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 79.8; H, 11.1.

***t*-2,*t*-7-Dimethyl-*r*-1H-bicyclo[5.3.0]decan-*c*-2-ol (21). A. From Olefin 20.** A 46-mg sample of olefin **20** was hydrogenated over 39 mg of platinum oxide in 4 ml of ethyl acetate as described above for olefin **4a** affording 44 mg (95%) of dihydro compound **21**: bp 70° (0.04 mm); $\delta_{TMS}^{CCl_4}$ 1.08 (CH_3) and 0.88 ppm (CH_3). *Anal.* Calcd for $C_{12}H_{22}O$: C, 79.06; H, 12.17. Found: C, 78.9; H, 12.1.

B. From Olefin 25. A mixture of 57 mg of olefin **25** (containing 10% of the cis-fused isomer **26**) and 309 mg of potassium hydrogen phosphate in 2 ml of methylene chloride at 0° was treated with a solution of 107 mg of 82% *m*-chloroperoxybenzoic acid in 3 ml of methylene chloride. The mixture was stirred at 0° for 40 min and at room temperature for 20 min and poured into aqueous sodium hydroxide. The product was isolated with ether and reduced with 54 mg of lithium aluminum hydride in 2 ml of ether at room temperature for 3 hr to give 58 mg (91%) of alcohol **21** whose spectral properties and gas chromatographic retention time were identical with those of alcohol **2i** prepared as described in part A above.

***trans*- and *cis*-2-Methylene-7-methylbicyclo[4.3.0]decane (25 and 26).** To a suspension of 4.66 g of CuI in 100 ml of ether at 0° was added 25 ml of 1.85 *M* ethereal methyllithium. After 10 min, 940 mg of enone **22**[12] in 3 ml of ether was added and the mixture was stirred at 0° for 40 min, poured into aqueous ammonium chloride, and treated with aqueous ammonia. The product was isolated with ether and distilled affording 994 mg (95%) of ketones **23** and **24** (60:40 according to gas chromatography): $\delta_{TMS}^{CCl_4}$ 1.17 (CH_3 of **24**) and 0.70 ppm (CH_3 of **23**).

Equilibration of this mixture according to the method of House and Kramar[27] led to a 66:33 mixture of trans–cis ketones.

A solution of 994 mg of the 60:40 mixture of ketones **23** and **24** was added to the phosphorane prepared from 10.74 g of methyltriphenylphosphonium bromide and 10 ml of 3.0 *M* butyllithium

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(27) H. O. House and V. Kramar, *ibid.*, **28**, 3362 (1963).

(hexane solution) in 110 ml of THF. The reaction mixture was stirred at room temperature for 19 hr and at 57° for 7 hr and the product was isolated with ether and purified by chromatography on 50 g of Fisher Alumina. The combined pentane fractions yielded 750 mg (76%) of olefins **25** and **26**, a 1:1 mixture according to the gas chromatogram. This mixture was separated by preparative gas chromatography to give the *trans*-hydroazulene **23**: $\delta_{TMS}^{CCl_4}$ 4.75 (vinyl H's) and 1.03 ppm (CH_3). *Anal.* Calcd for $C_{12}H_{20}$: C, 87.71; H, 12.29. Found: C, 87.9; H, 12.1.

The *cis*-hydroazulene **24** exhibited $\delta_{TMS}^{CCl_4}$ 4.69 (vinyl H's) and 0.73 ppm (CH_3). *Anal.* Calcd for $C_{12}H_{20}$: C, 87.71; H, 12.29. Found: C, 87.7; H, 12.2.

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The Generation and Isomerization of *cis,trans,cis*-1,3,5-Cyclooctatriene at 180°[1]

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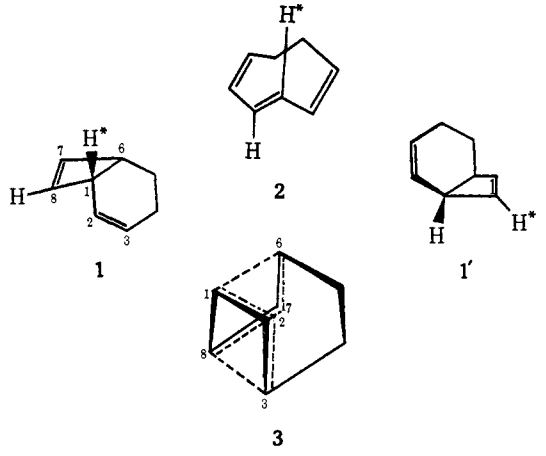
Abstract: The Diels–Alder adduct from *cis,trans,cis*-1,3,5-cyclooctatriene and furan, *trans*-13-oxatricyclo-[8.2.1.$0^{2,9}$]trideca-3,7,11-triene, has been synthesized indirectly and pyrolyzed at 180°. The distributions of products, bicyclo[4.2.0]octa-2,7-diene and *cis,cis,cis*-1,3,5-cyclooctatriene, as a function of reaction time demonstrate that the initial detectable product is bicyclo[4.2.0]octa-2,7-diene. The putative initially formed C_8 hydrocarbon, *cis,trans,cis*-1,3,5-cyclooctatriene, is not directly partitioned between bicyclic and monocyclic isomers; it may lie along the reaction path of the degenerate bicyclo[4.2.0]octa-2,7-diene valence isomerization, but not on the path of the bicyclo[4.2.0]octa-2,7-diene to 1,3,5-cyclooctatriene conversion.

Two mechanistic problems are posed by the thermal isomerizations of bicyclo[4.2.0]octa-2,7-diene (**1**).



1 **2** **1′** **3**

The automeric valence isomerization of this system may occur by way of *cis,trans,cis*-1,3,5-cyclooctatriene (**2**),[2,3] or possibly through a direct concerted cycloreaction, an antara,antara Cope rearrangement[4,5] with an orbital symmetry allowed transition-state electronic structure **3**.[6]

The isomerization of the bicyclic diene **1** to *cis,cis,cis*-1,3,5-cyclooctatriene (**4**)[7] might involve a direct dis-

4 **5**

rotatory and orbital symmetry disallowed cyclobutene to butadiene valence isomerization, or some more subtle but symmetry-allowed pathway, such as an s,a intramolecular cycloaddition of C(1)–C(2) with C(6)–C(7),[8] or the intermediacy of *cis,trans,cis*-triene **2**. The latter might give *all-cis*-triene either through trans,cis isomerization of the strained double bond, or through 1,5-hydrogen migrations and another isomer, the *all-cis*-1,3,6-triene **5**.[7,9]

In the present work *cis,trans,cis*-1,3,5-cyclooctatriene has been generated at 180° and found to give bicyclo-[4.2.0]octa-2,7-diene (**1**), exclusively.

Results

Synthesis of a thermally labile precursor of *cis,trans,cis*-1,3,5-cyclooctatriene that would decompose at a convenient rate at 180° was desired.

In earlier work with deuterium-labeled bicyclo[4.2.0]-octa-2,7-dienes,[2,3] in which rates of deuterium scrambling and skeletal rearrangement to cyclooctatriene **4** were determined at 180°, there existed data sufficient for predicting quantitatively molar fractions of **1** and **4** as a function of time, given the rate at which *cis,trans,cis*-triene was produced. Thus, with a suitable precursor, the thermal behavior of *cis,trans,cis*-1,3,5-cyclooctatriene

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