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Syntheses and Reactions of Halogenated Pentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-enes

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Abstract. Procedures for converting pentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodecan-11-one (**4**) into 11-Br and 11-Cl substituted pentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-enes (i.e., **8a** and **8b**, respectively) are described. In addition, cage ketone **4** was converted into the corresponding α,α'-dibromo derivative, **10**, which subsequently was reacted sequentially with H_2N-NH_2 and methanolic $CuBr_2$-NEt_3, thereby affording 11,12-dibromopentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-ene (**12**). Reaction of **8a** with Br_2 under a variety of experimental conditions led to the isolation and characterization of 11,11,12-tribromopentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodecane (**7**), **12**, and 2,*exo*-3,*exo*-12-tribromopentacyclo[7.3.0.0^{2,7}.0^{4,11}.0^{6,10}]dodecane (**13**). Similarly, reaction of **8b** with Br_2 under a variety of experimental conditions led to the isolation and characterization of *exo*-11-chloro-*endo*-11,*exo*-12-dibromopentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodecane (**14**), 2-chloro-*exo*-3,*exo*-12-dibromopentacyclo[7.3.0.0^{2,7}.0^{4,11}.0^{6,10}]dodecane (**15**), and 11-chloro-12-bromopentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-ene (**16**). Finally, sequential reaction of pentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodecan-12-one (**9**) with H_2N-NH_2 and methanolic $CuBr_2$-NEt_3 afforded *exo*-7,8-dibromopentacyclo[6.6.0.0^{2,6}.0^{3,11}.0^{5,10}]dodecane (**18**). The structures of **13** and **18** were established unequivocally via application of X-ray crystallographic methods.

INTRODUCTION

During the past several years, our respective research programs have been concerned in large measure with the synthesis and characterization of novel polycarbocyclic "cage" systems.[1] Compounds of this type are of intense current interest as (i) synthetic intermediates, particularly as key intermediates in the synthesis of polyquinane natural products,[2] (ii) templates for the construction of novel "host" systems for use in studies of molecular recognition and inclusion phenomena,[3] and (iii) a novel class of energetic materials.[4] In addition, some amino-functionalized pentacycloundecanes display antiviral activity against Influenza A,[5] and some aminated oxahexacyclic compounds appear to function as *in vivo* calcium antagonists.[6]

As part of this program, we recently have undertaken the synthesis of substituted pentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodecanes. Synthetic access to this ring system has been gained via Tieffenau-Demjanov ring expansion[7] of appropriately functionalized pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecanes[1a] (*vide infra*).

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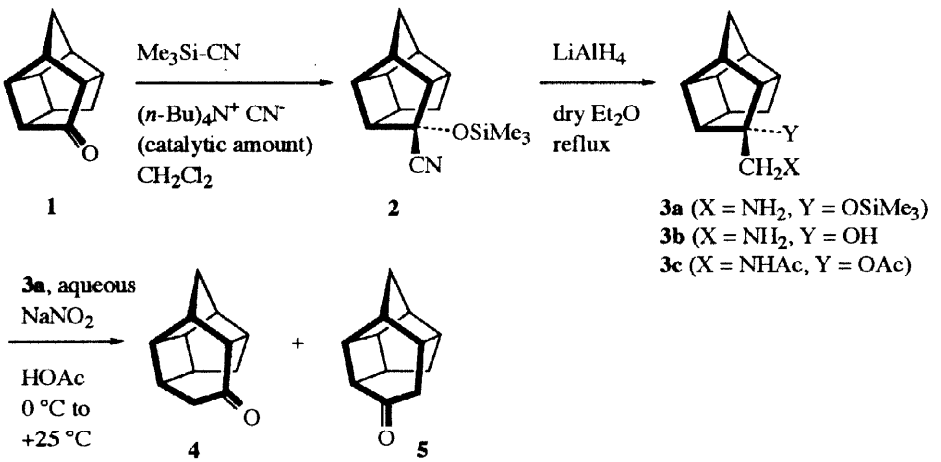
RESULTS AND DISCUSSION

A. Tieffenau-Demjanov Ring Expansion of Pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecan-8-one (1). The procedure emplyed to promote ring expansion of **1**[8] is shown in Scheme 1. Thus, reaction of **1** with Me_3SiCN resulted in addition across the C=O group in **1**, thereby affording **2** (98% yield). Subsequent $LiAlH_4$ promoted reduction of **2** produced **3a**, which was hydrolyzed via treatment with aqueous mineral acid to afford the corresponding aminoalcohol, **3b**. Compound **3b** was further characterized via conversion into the corresponding diacetate derivative, **3c** (see the Experimental Section). Finally, nitrous acid promoted desilylation-deamination of **3a** proceeded with concomitant ring expansion to afford an essentially quantitative yield of a mixture of isomeric ring-expanded cage ketones **4**[9] and **5** (product ratio: **4** : **5** = 95: 5). The individual components of this mixture were separated via column chromatography, and each pure isomer was fully characterized.[9]

Scheme 1



(*product ratio:* **4**:**5** = 95 :5)

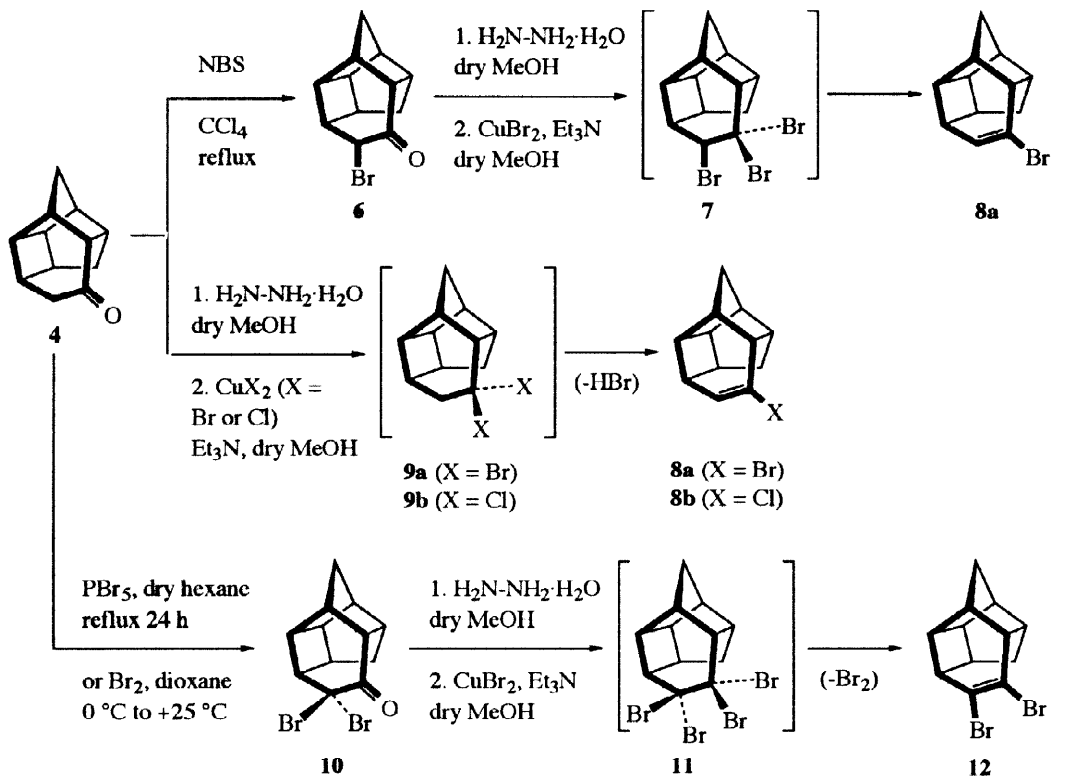
B. Conversion of 4 into Halogenated Pentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-enes. The procedure employed to convert cage ketone **4** into bromine-containing pentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-enes is shown in Scheme 2. Interestingly, 11-bromopentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-ene (**8a**, Scheme 2) could be synthesized from **4** in two ways. Thus, in one procedure (Method A), *N*-bromosuccinimide (NBS) promoted α-monobromination of **4** afforded the corresponding α-bromoketone, **6** (38% yield, 66% conversion based upon recovered **4**). Subsequent conversion of **6** into the corresponding hydrazone derivative followed by reaction of the intermediate hydrazone with methanolic $CuBr_2$-NEt_3[10] resulted in the formation of **7**. Compound **7** could not be isolated; instead, under the reaction conditions employed, **7** spontaneously eliminated Br_2 to afford **8a**.

Alternatively (Method B), **4** could be converted (via its hydrazone derivative) directly into the corresponding 11,11-dibromide, **9a**.[10] Once again, the geminal dibromide could not be isolated from the reaction; under the reaction conditions employed, spontaneously elimination of HBr occurred from the putative intermediate (**9a**), thereby affording **8a** (Scheme 2). Similarly, reaction of the hydrazone of **4** with methanolic $CuCl_2$-NEt_3[10] ultimately produced the corresponding cage chloroalkene, **8b**.

In a separate experiment, **4** was converted into the corresponding α,α-dibromoketone, **10** (Scheme 2), via reacting it with either PBr_5 or with Br_2-dioxane. Subsequent conversion of **10** into the corresponding hydrazone derivative followed by reaction of the intermediate hydrazone with methanolic $CuBr_2$-NEt_3[10] resulted in

the formation of **11**. Compound **11** could not be isolated; instead, under the reaction conditions employed, **11** spontaneously eliminated Br_2 to afford **12** (Scheme 2).

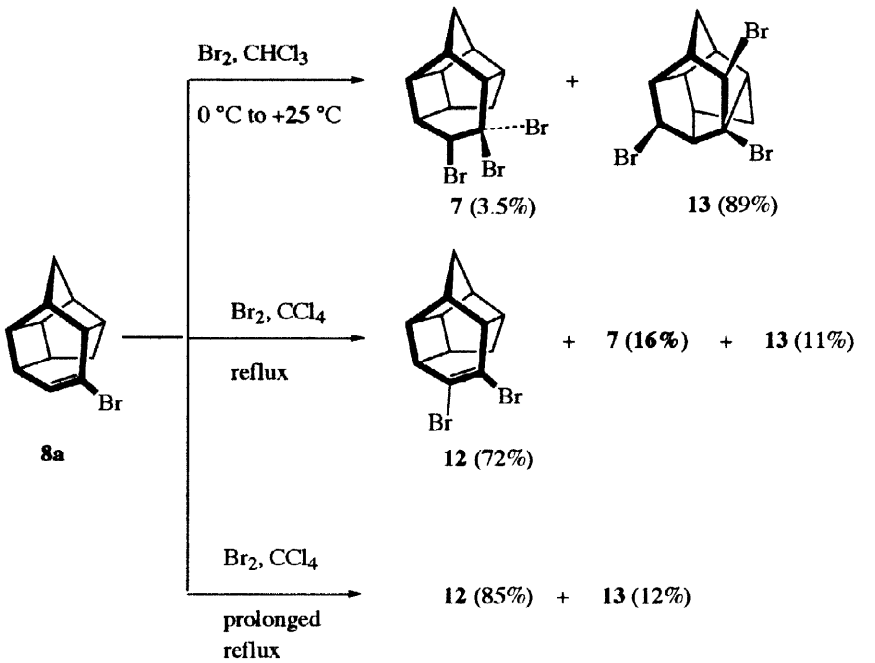
Scheme 2



C. Bromination of 11-Bromo- and 11-Chloropentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-enes (8a and 8b, respectively). With **8a** and **8b** in hand, it became of interest to study their respective reactions with electrophilic Br_2 (i) as a means to extend the range of available, halogen-containing pentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]-dodecanes and (ii) as a possible means to access new halogen-containing cage systems via halogen-promoted, carbocation-mediated intramolecular rearrangements. To this end, reactions of **8a** with Br_2 were studied under three sets of environmental conditions, as indicated in Scheme 3. In Method A, **8a** was reacted with Br_2-$CHCl_3$ over the temperature range 0 °C to +25 °C. Two products were isolated from this reaction: a rearranged and a non-rearranged cage tribromide [i.e., **13** (89%) and **7** (3.5% yield), respectively]. It seems likely that **13** was formed via a sequence of carbocation-mediated rearrangements. The structure of **13** was established unequivocally via application of X-ray crystallographic methods.

Under the conditions employed in Method B, Br_2 was added dropwise to a refluxing solution of **8a** in CCl_4 during 10 minutes, and the reaction was immediately allowed to cool to ambient temperature and was subjected to workup. Under these conditions, three products were obtained: **12** (72%), **7** (16%), and **13** (11%). However, when this reaction was repeated with the distinction that the reaction mixture was refluxed for one hour after addition of Br_2 had been completed (Method C), only compounds **12** (85%) and **13** (12%) were isola-

Scheme 3



ted. These results suggest that **7** may function as an intermediate in the formation of **12** in these reactions (via subsequent slow β-elimination of the elements of Br_2).

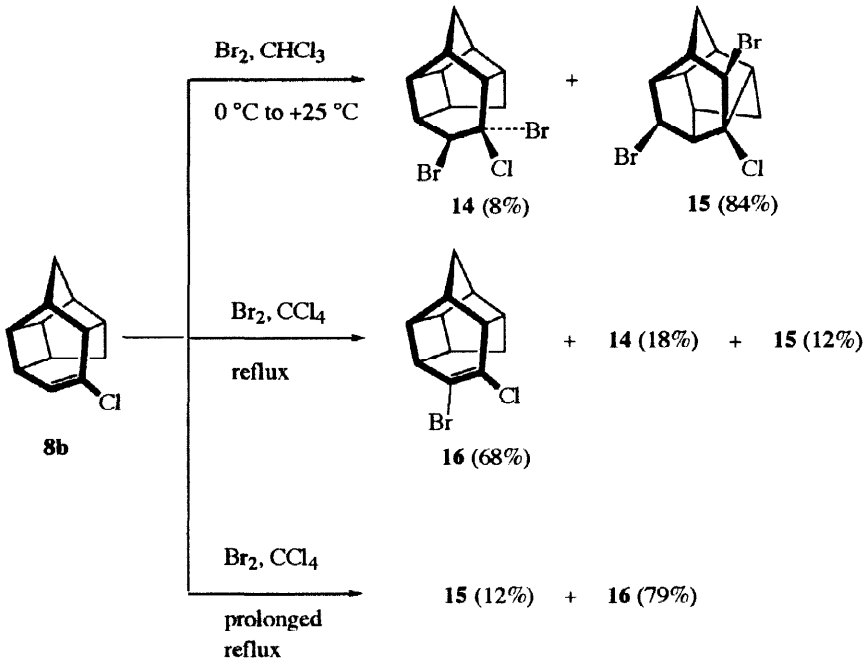
A closely analgous set of results was obtained for the corresponding reactions of **8b** with Br_2 (see Scheme 4). Once again, the results obtained via Method B and Method C, when applied to the reaction of **8b** with Br_2-CCl_4, implicate the intermediacy of a trihalopentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodecane, **14**, in the reaction that leads ultimately to the formation of 11-chloro-12-bromopentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-ene (**16**).

D. Conversion of 5 into a Dibrominated Pentacyclododecane. Cage ketone **5** was converted into the corresponding hydrazone derivative, which subseqently was reacted with methanolic $CuBr_2$-NEt_3.[10] It is anticipated[10] that application of this procedure resulted in the formation of **17**. Compound **17** could not be isolated; instead, under the reaction conditions employed, **17** spontaneously suffered ionization of one of its C-Br bonds with concomitant carbocation-mediated Wagner-Meerwein rearrangement that resulted in the formation of **18** (Scheme 5). The structure of **18** was established unequivocally via application of X-ray crystallographic methods.

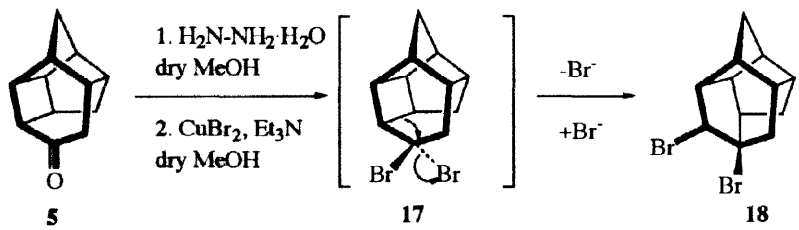
EXPERIMENTAL SECTION

Melting points are uncorrected. Elemental microanalytical data was obtained by personnel at M-H-W Laboratories, Phoenix, AZ. Low-resolution electon impact (EI) mass spectra were obtained by using a Varian Saturn 3 ion trap GC/MS system that was operated at 70 eV. High-resolution mass spectral data for **2** were obtained at the Mass Spectrometry Facility at the Department of Chemistry and Biochemistry, University of Texas at Austin by using a ZAB-E double sector high-resolution mass spectrometer (Micromass, Manchester, England) that was operated in the chemical ionization mode.

Scheme 4



Scheme 5



***exo*-8-cyano-*endo*-8-(trimethylsilyloxy)pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane (2).** To a solution of **1**[8] (4.00 g, 25.0 mmol) in CH_2Cl_2 (40 mL) was added sequentially $(n\text{-Bu})_4N^+ CN^-$ (40 mg, catalytic amount) and $Me_3Si\text{-}CN$ (3.66 mL, 27.5 mmol). After the addition of reagents had been completed, the reaction mixture was stirred at ambient temperature for 1 h and then was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with 2% EtOAc-hexane. Pure **2** (6.28 g, 98%) was thereby obtained as a pale brown oil; IR (neat) 2964 (s), 2909 (m), 1454 (m), 1321 (w), 1249 (m), 1197 cm^{-1} (m); ^{1}H NMR ($CDCl_3$) δ 0.22 (s, 9 H), 1.01 (*AB*, J_{AB} = 10.0 Hz, 1 H), 1.73 (A*B*, J_{AB} = 10.0 Hz, 1 H), 2.12-2.90 (m, 9 H); ^{13}C NMR ($CDCl_3$) δ 1.4 (q), 2.4 (q), 28.6 (t), 35.2 (t), 36.8 (d), 39.8 (d), 42.1 (d), 44.0 (d), 44.3 (d), 47.4 (d), 49.0 (d), 50.7 (d), 76.8 (s), 129.1 (s); EI mass spectrum (70 eV), *m/z* (relative intensity) 259 (M^+, 13.4), 244 (13.8), 234 (21.9), 233 (100.0), 231 (9.3), 117 (7.7), 92 (9.1), 66 (8.2), 65 (8.9). HRMS calcd for $C_{15}H_{21}ONSi$ 259.1392, found 259.1384. Anal. Calcd for $C_{15}H_{21}ONSi$: C, 69.45; H, 8.16. Found: C, 69.64; H, 7.94.

$LiAlH_4$ Promoted Reduction of 2. A solution of **2** (6.28 g, 24.2 mmol) in Et_2O (70 mL) was added dropwise to a stirred suspension of $LiAlH_4$ (1.10 g, 26.7 mmol) in Et_2O (25 mL) at ambient temperature. After the addition of reagents had been completed, the reaction mixture was refluxed for 4 h. The reaction mixture was cooled to 0 °C via application of an external ice-water bath, and the cooled reaction mixture was quenched

via dropwise addition of water (6.0 mL). To the resulting aqueous suspension was added sequentially 15% aqueous NaOH (6 mL) and water (24 mL), and the resulting mixture was stirred at ambient temperature for an additional 30 minutes. The resulting aqueous suspension was filtered through a Florisil® pad, and the residue was washed with Et_2O (100 mL). The combined filtrates were dried ($MgSO_4$) and filtered, and the filtrate was concentrated *in vacuo*. The product, crude *exo*-8-aminomethyl-*endo*-8-(trimethylsilyloxy)pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane (**3a**, 6.0 g, 94%), was used as obtained in the next synthetic step, without additional purification or characterization.

In order to promote hydrolysis of the -OSiMe$_3$ group in **3a**, a solution of concentrated aqueous HCl (1 mL) in MeOH (9 mL) was added to a portion of the residue (100 mg, 0.380 mmol, *vide supra*), and the resulting solution was stirred at ambient temperature for 1 h, at which time the reaction mixture was concentrated *in vacuo*. Water (5 mL) was added to the residue, and solid $NaHCO_3$ (1.31 g, 15.6 mmol) then was added to render the mixture basic. The resulting aqueous suspension was extracted with CH_2Cl_2 (2 x 20 mL). The combined extracts were washed sequentially with water (10 mL) and brine (10 mL), dried ($MgSO_4$) and filtered, and the filtrate was concentrated *in vacuo*. The product, crude *exo*-8-(aminomethyl)pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecan-*endo*-8-ol (**3b**, 58 mg, 81%), was used as obtained in the next synthetic step, without additional purification or characterization: IR ($CHCl_3$) 3375 (br, s), 2949 (s), 2864 (m), 1587 (s), 1462 (s), 1330 (m), 1271 (m), 831 cm^{-1} (m); ^{1}H NMR ($CDCl_3$) δ 1.00-1.10 (m, 1 H), 1.16 (*AB*, J_{AB} = 10.5 Hz, 1 H), 1.64 (A*B*, J_{AB} = 10.5 Hz, 1 H), 1.90-2.12 (m, 4 H), 2.17-2.26 (m, 3 H), 2.35-2.71 (m, 6 H), 2.73-2.83 (m, 1 H); ^{1}H NMR ($CDCl_3$) δ 29.3 (t), 34.7 (t), 36.2 (d), 40.1 (d), 40.2 (d), 41.6 (d), 43.0 (d), 43.2 (d), 46.7 (d), 47.8 (d), 48.9 (t), 78.4 (s).

Compound **3b** was further characterized via its conversion to the corresponding diacetate derivative, **3c**. Thus, To a solution of **3b** (50 mg, 0.26 mmol) and Et_3N (0.1 mL, 0.8 mmol) in dry CH_2Cl_2 (10 mL) was added Ac_2O (0.04 mL, 0.4 mmol), and the resulting mixture was stirred at ambient temperature overnight. Water (5 mL) was added, the layers were separated, and the aqueous layer was extracted with CH_2Cl_2 (10 mL). The combined organic layers were washed with brine (10 mL), dried ($MgSO_4$), and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via chromatography on silica gel by eluting with 60% EtOAc-hexane. Pure **3c** (66 mg, 92%) was thereby obtained as a colorless microcrystalline solid: mp 114-115 °C; IR (KBr) 3314 (s), 2975 (s), 2858 (m), 1748 (s), 1650 (s), 1565 (s), 1363 (s), 1285 (s), 1239 (s), 1226 (m), 1076 cm^{-1} (m); ^{1}H NMR ($CDCl_3$) δ 0.95-1.04 (m, 1 H), 1.14 (*AB*, J_{AB} = 10.0 Hz, 1 H), 1.62 (A*B*, J_{AB} = 10.0 Hz, 1 H), 1.73 (d, J = 12.0 Hz, 1 H), 1.92 (s, 3 H), 1.99 (s, 3 H), 2.19-2.78 (m, 8 H), 3.18-3.45 (m, 2 H), 6.44 (br s, 1 H); ^{13}C NMR ($CDCl_3$) δ 22.7 (q), 23.8 (q), 29.4 (t), 34.9 (t), 36.2 (d), 39.7 (d), 40.6 (d), 42.0 (d), 42.9 (d), 43.5 (d), 45.2 (d), 45.6 (t), 47.4 (d), 88.3 (s), 170.6 (s), 171.2 (s). Anal. Calcd for $C_{16}H_{21}NO_3$: C, 69.79; H, 7.69. Found: C, 70.20; H, 7.50.

Reaction of 3a with Aqueous Nitrous Acid. Crude **3a** obtained as described above (6.00 g, 21.7 mmol) was dissolved in glacial HOAc (40 mL), and the resulting solution was stirred at ambient temperature for 30 minutes. This solution then was cooled to 0 °C via application of an external ice-water bath. To this cooled solution was added dropwise with stirring a solution of $NaNO_2$ (7.00 g, 101 mmol) in water (20 mL). After all of the aqueous $NaNO_2$ solution had been added, the resulting mixture was stirred at 0 °C, at which time the external cold bath was removed, and the reaction mixture was allowed to warm gradually to ambient temperature with stirring during 3 h. Water (160 mL) was added, and the resulting aqueous suspension was extracted with CH_2Cl_2 (3 x 100 mL) The combined organic layers were washed sequentially with water (2 x 100 mL), saturated aqueous $NaHCO_3$ (2 x 50 mL), water (50 mL) and brine (50 mL). The organic layer was dried ($MgSO_4$) and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via chromatography on silica gel by eluting with 6% EtOAc-hexane. Workup of the first chromatography fraction thereby obtained afforded pure **4** (3.55 g, 94%) as a colorless microcrystalline solid: mp 218-219 °C (lit.[9] mp 220-221 °C); IR ($CHCl_3$) 2935 (s), 2838 (s), 1720 (m), 1475 (s), 1383 (m), 1217 cm^{-1} (w); ^{1}H NMR ($CDCl_3$) δ 2.92-2.71 (m, 3 H), 2.59-2.40 (m, 3 H), 2.36-2.25 (m, 1 H), 2.06 (d, J = 4.2 Hz, 2 H), 1.62-1.50 (m, 3 H), 1.42 (d, J = 12.6 Hz, 2 H); ^{13}C NMR ($CDCl_3$) δ 29. 1 (t), 30.7 (t), 38.5 (d), 39.0 (d), 38.6 (d), 43.0 (d), 44.5 (d), 47.2 (d), 54.1 (d), 216.0 (s).

Continued elution of the chromatography column afforded a second fraction that contained pure **5** (190 mg, 5%), which subsequently was isolated as a colorless microcrystalline solid: mp 191-192 °C; IR ($CHCl_3$) 2962 (s), 2853 (s), 1716 (s), 1505 (m), 1222 (s), 1053 (m), 771 cm^{-1} (w); ^1H NMR ($CDCl_3$) δ 1.29 (*AB*, J_{AB} = 11.3 Hz, 1 H), 1.44 (*AB*, J_{AB} = 11.3 Hz, 1 H), 1.48-1.54 (m, 1 H), 1.62 (d, J = 9.7 Hz, 1 H), 1.96-2.08 (m, 1 H), 2.21-2.33 (m, 3 H), 2.41-2.60 (m, 3 H), 2.72-2.89 (m, 2 H), 2.94-3.18 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 31.7 (t), 35.8 (t), 36.8 (t), 37.7 (d), 38.6 (d), 38.7 (d), 39.2 (d), 42.3 (d), 44.4 (d), 44.7 (d), 49.1 (d), 214.1 (s); EI Mass Spectrum (70 eV) *m/z* (relative intensity) 174 (M^+, 22.1), 117 (21.9), 108 (86.6), 107 (100), 91 (60.0), 79 (59.7), 66 (38.1), 51 (26.3), 39 (74.6). Anal. Calcd for $C_{12}H_{14}O$: C, 82.72; H, 8.10. Found: C, 82.65; H, 7.97.

12-Bromopentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodecan-11-one (6). A mixture of **4** (1.00 g, 5.74 mmol) and *N*-bromosuccinimide (NBS, 1.12 g, 6.32 mmol) in dry CCl_4 (25 mL) was refluxed for 36 h. The reaction mixture was allowed to cool gradually to ambient temperature and then was washed sequentially with water (20 mL) and brine (20 mL). The organic layer was dried ($MgSO_4$) and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with 10% EtOAc-hexane. Pure **6** (560 mg, 38%, which corresponds to 66% net conversion from **4**, *vide infra*) was thereby obtained as a colorless microcrystalline solid: mp 113-114 °C; IR (KBr) 2960 (s), 2874 (m), 1720 (s), 1462 (m), 1336 (m), 1215 (s). 611 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 1.39 (*AB*, J_{AB} = 15.4 Hz, 1 H), 1.48 (*AB*, J_{AB} = 15.4 Hz, 1 H), 1.51-1.60 (m, 1 H), 1.65 (d, J = 11.5 Hz, 1 H), 2.49-2.91 (m, 7 H), 3.03-3.15 (m, 1 H), 3.98 (d, J = 3.8 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 30.6 (t), 33.9 (t), 36.8 (d), 38.7 (d), 38.8 (d), 40.1 (d), 42.9 (d), 43.7 (d), 47.0 (d), 47.3 (d), 53.4 (d), 207.4 (s); EI Mass spectrum (70 eV) *m/z* (relative intensity) 173 [(M - $^{79}Br)^+$, 3.4], 145 (1.9), 107 (2.8), 79 (3.6), 32 (37.6), 28 (100). Anal. Calcd for $C_{12}H_{13}BrO$: C, 56.94; H, 5.18. Found: C, 57.00; H, 5.32.

Continued elution of the chromatography column resulted in the recovery of unreacted **4** (580 mg, 58%).

11-Bromopentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-ene (8a). Method A.[10] To a solution of hydrazine hydrate (2.0 mL, 39.52 mmol) in dry MeOH (10 mL) at ambient temperature was added powdered, activated molecular sieves (4 Å, 1 g). The resulting suspension was stirred at ambient temperature for 20 minutes, at which time a solution of **6** (500 mg, 1.97 mmol) in dry MeOH (5 mL) was added. The resulting mixture was stirred at ambient temperature for 2 h. The reaction mixture then was filtered, and the residue was washed with Et_2O (2 x 10 mL). The combined filtrates were concentrated *in vacuo*, and the residue was further dried under high vacuum (1 mm Hg) for an additional 1 h. The resulting material (i.e., the hydrazone of **6**, 510 mg, 94%) was used as obtained, without further purification or characterization.

A mixture of $CuBr_2$ (2.56 g, 11.46 mmol) and Et_3N (0.8 mL, 5.73 mmol) in dry MeOH (15 mL) (15 mL)was stirred at ambient temperature for 20 minutes. The resulting mixture was cooled to 0 °C via application of an external ice-water bath. To the cooled reaction mixture was added portionwise with stirring a solution of the hydrazone of **6** (*vide supra*, 510 mg, 1.91 mmol) in dry MeOH (10 mL). The reaction mixture was stirred at 0 °C for 15 minutes after the addition of the hydrazone of **6** had been completed. The external cold bath then was removed, and the reaction mixture was allowed to warm gradually to ambient temperature with stirring during 1 h. To the resulting mixture was added 3% aqueous NH_4OH (100 mL), and the resulting aqueous suspension was extracted with CH_2Cl_2 (2 x 50 mL). The combined organic extracts were washed sequentially with water (20 mL) and brine (20 mL). The organic layer was dried ($MgSO_4$) and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with hexane. Pure **8a** (298 mg, 64%) was thereby obtained as a colorless oil; IR (KBr) 2955 (s), 2876 (m), 1620 (s), 1330 (m), 1045 (m), 979 (m), 841 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 1.24 (*AB*, J_{AB} = 10.6 Hz, 1 H), 1.31-1.41 (m, 2 H), 1.48 (*AB*, J_{AB} = 10.6 Hz, 1 H), 2.04-2.12 (m, 1 H), 2.22-2.37 (m, 1 H), 2.41-2.53 (m, 2 H), 2.57-2.70 (m, 2 H), 2.75-2.84 (m, 1 H), 2.95-3.08 (m, 1 H), 5.96 (dd, J = 10.6, 8.5 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 31.0 (t), 33.4 (t), 34.4 (d), 36.7 (d), 39.3 (d), 40.0 (d), 41.1 (d), 44.2 (d), 48.0 (d), 51.4 (d), 122.6 (d), 134.0 (s); EI Mass Spectrum (70 eV), *m/z* (relative intensity) 238 ($C_{12}H_{13}{}^{80}Br$, 1.4), 236 ($C_{12}H_{13}{}^{78}Br$, 1.9). Anal. Calcd for $C_{12}H_{13}Br$: C, 60.78; H, 5.53. Found: C, 60.57; H, 5.76.

Method B.[10] To a solution of hydrazine hydrate (2.80 mL, 57.8 mmol) in dry MeOH (10 mL) at ambient temperature was added powdered, activated molecular sieves (4 Å, 1.0 g). The resulting suspension was stirred at ambient temperature for 20 minutes, at which time a solution of **4** (500 mg, 2.87 mmol) in dry MeOH (5 mL) was added. The resulting mixture was stirred at ambient temperature for 2 h. The reaction mixture then was filtered, and the residue was washed with Et_2O (2 x 10 mL). The combined filtrates were concentrated *in vacuo*, and the residue was further dried under high vacuum (1 mm Hg) for an additional 1 h. The resulting material (i.e., the hydrazone of **4**, 515 mg, 95%) was used as obtained, without further purification or characterization.

A mixture of $CuBr_2$ (3.56 mg, 15.9 mmol) and Et_3N (1.1 mL, 8.0 mmol) in dry MeOH (15 mL) was stirred at ambient temperature for 20 minutes. The resulting mixture was cooled to 0 °C via application of an external ice-water bath. To the cooled reaction mixture was added portionwise with stirring a solution of the hydrazone of **4** (*vide supra*, 515 mg, 2.73 mmol) in dry MeOH (10 mL). The reaction mixture was stirred at 0 °C for 15 minutes after the addition of the hydrazone of **4** had been completed. The external cold bath then was removed, and the reaction mixture was allowed to warm gradually to ambient temperature with stirring during 1 h. To the resulting mixture was added 3% aqueous NH_4OH (100 mL), and the resulting aqueous suspension was extracted with CH_2Cl_2 (2 x 50 mL). The combined organic extracts were washed sequentially with water (20 mL) and brine (20 mL). The organic layer was dried ($MgSO_4$) and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with hexane. Pure **8a** (456 mg, 67%) was thereby obtained as a colorless oil. The IR, ^1H NMR, and ^{13}C NMR spectra of this material were essentially identical to the corresponding spectra obtained for **8a** that had been prepared previously via Method A (*vide supra*).

11-Chloropentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-ene (8b).[10] To a solution of hydrazine hydrate (2.80 mL, 57.8 mmol) in dry MeOH (10 mL) at ambient temperature was added powdered, activated molecular sieves (4 Å, 1 g). The resulting suspension was stirred at ambient temperature for 20 minutes, at which time a solution of **4** (500 mg, 2.87 mmol) in dry MeOH (5 mL) was added. The resulting mixture was stirred at ambient temperature for 2 h. The reaction mixture then was filtered, and the residue was washed with Et_2O (2 x 10 mL). The combined filtrates were concentrated *in vacuo*, and the residue was further dried under high vacuum (1 mm Hg) for an additional 1 h. The resulting material (i.e., the hydrazone of **4**, 515 mg, 95%) was used as obtained, without further purification or characterization.

A mixture of $CuCl_2$ (2.14 mg, 15.9 mmol) and Et_3N (1.1 mL, 8.0 mmol) in dry MeOH (15 mL) was stirred at ambient temperature for 20 minutes. The resulting mixture was cooled to 0 °C via application of an external ice-water bath. To the cooled reaction mixture was added portionwise with stirring a solution of the hydrazone of **4** (*vide supra*, 515 mg, 2.73 mmol) in dry MeOH (10 mL). The reaction mixture was stirred at 0 °C for 15 minutes after the addition of the hydrazone of **4** had been completed. The external cold bath then was removed, and the reaction mixture was allowed to warm gradually to ambient temperature with stirring during 12 h. To the resulting mixture was added 3% aqueous NH_4OH (100 mL), and the resulting aqueous suspen-sion was extracted with CH_2Cl_2 (2 x 50 mL). The combined organic extracts were washed sequentially with water (20 mL) and brine (20 mL). The organic layer was dried ($MgSO_4$) and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with hexane. Pure **8b** (339 mg, 66%) was thereby obtained as a colorless oil; IR (neat) 2953 (s), 2879 (m), 1622 (s), 1452 (m), 1342 (m), 1035 (s), 977 (s), 835 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 1.27-1.38 (m, 3 H), 1.53 (d, J = 10.0 Hz, 1 H), 2.05-2.14 (m, 1 H), 2.24-2.38 (m, 1 H), 2.44-2.55 (m, 2 H), 2.63-2.72 (m, 3 H), 2.99-3.15 (m, 1 H), 5.73 (dd, J = 8.3, 6.7 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 31.0 (t), 33.4 (t), 34.4 (d), 36.7 (d), 39.3 (d), 40.0 (d), 41.1 (d), 44.2 (d), 48.0 (d), 51.4 (d), 122.6 (d), 134.0 (s); EI Mass Spectrum (70 eV), *m/z* (relative intensity) 192 ($C_{12}H_{13}{}^{35}Cl$, 2.8), 157 ($C_{12}H_{13}$, 7.3), 91 (100), 80 (52.8), 79 (62.8), 67 (52.5). Anal. Calcd for $C_{12}H_{13}Cl$: C, 74.80; H, 6.80. Found: C, 75.00; H, 6.82

12,12-Dibromopentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodecan-11-one (10). A solution of **4** (500 mg, 2.87 mmol) in dioxane (20 mL) was cooled to 0 °C via application of an external ice-water bath. To this cooled solution was added dropwise with stirring Br_2 (0.44 mL, 8.5 mmol). After the addition of bromine had been completed, the external cold bath was removed, and the reaction mixture was allowed to warm gradually to ambient temperature. Stirring was continued at ambient temperature for 12 h, at which time the reaction was poured into water (100 mL). The resulting aqueous suspension was extracted with CH_2Cl_2 (2 x 25 mL). The combined organic layers were washed sequentially with saturated aqueous $NaHSO_3$ (20 mL), water (20 mL), and brine (20 mL). The organic layer was dried ($MgSO_4$) and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with 5% EtOAc-hexane. Pure **10** (940 mg, 99%) was thereby obtained as a colorless microcrystalline solid: mp 133-134 °C; IR (KBr) 2962 (s), 2872 (m), 1720 (s), 1456 (m), 1325 (m), 1190 (s), 1163 (s), 958 (s), 860 (s), 767 (s), 624 cm^{-1} (s); ^{1}H NMR ($CDCl_3$) δ 1.41 (d, J = 11.3 Hz, 1 H); 1.49-1.69 (m, 3 H), 2.54-2.73 (m, 5 H), 2.85-3.08 (m, 2 H), 3.52-3.62 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 30.9 (t), 38.3 (t), 38.8 (d), 39.2 (d), 40.5 (d), 41.5 (d), 44.0 (d), 47.2 (d), 47.6 (d), 63.9 (d), 66.7 (s), 199.6 (s); EI Mass Spectrum (70 eV), *m/z* (relative intensity) 253 ($C_{12}H_{12}{}^{79}Br^{79}BrO$, 24.5), 251 ($C_{12}H_{12}{}^{79}Br^{81}BrO$, 24.2). Anal. Calcd for $C_{12}H_{12}Br_2O$: C, 43.41; H, 3.64. Found: C, 43.62; H, 3.80.

11,12-Dibromopentacyclo[5.5.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-ene (12).[10] To a solution of hydrazine hydrate (0.60 mL, 11.5 mmol) in dry MeOH (10 mL) at ambient temperature was added powdered, activated molecular sieves (4 Å, 0.5 g). The resulting suspension was stirred at ambient temperature for 20 minutes, at which time a solution of **10** (100 mg, 0.29 mmol) in dry MeOH (5 mL) was added. The resulting mixture was stirred at ambient temperature for 2 h. The reaction mixture then was filtered, and the residue was washed with Et_2O (2 x 10 mL). The combined filtrates were concentrated *in vacuo*, and the residue was further dried under high vacuum (1 mm Hg) for an additional 1 h. The resulting material (i.e., the hydrazone of **10**, 101 mg, 97%) was used as obtained, without further purification or characterization.

A mixture of $CuBr_2$ (432 mg, 1.9 mmol) and Et_3N (0.13 mL, 0.9 mmol) in dry MeOH (10 mL) was stirred at ambient temperature for 20 minutes. The resulting mixture was cooled to 0 °C via application of an external ice-water bath. To the cooled reaction mixture was added portionwise with stirring a solution of the hydrazone of **10** (*vide supra*, 101 mg, 0.29 mmol) in dry MeOH (5 mL). The reaction mixture was stirred at 0 °C for 15 minutes after the addition of the hydrazone of **10** had been completed. The external ice-water bath then was removed, and the reaction mixture was allowed to warm gradually to ambient temperature with stirring for 12 h. To the resulting mixture was added 3% aqueous NH_4OH (50 mL), and the resulting aqueous suspension was extracted with CH_2Cl_2 (2 x 25 mL). The combined organic extracts were washed sequentially with water (20 mL) and brine (20 mL). The organic layer was dried ($MgSO_4$) and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with hexane. Pure **12** (52 mg, 52%) was thereby obtained as a colorless oil; IR (neat) 2962 (s), 2866 (s), 1610 (s), 1448 (m), 1315 (s), 1134 (s), 958 (s), 879 (s), 642 cm^{-1} (s); ^{1}H NMR ($CDCl_3$) δ 1.27 (d, J = 12.9 Hz, 2 H), 1.40-1.58 (m, 2 H), 2.12-2.20 (m, 1 H), 2.32-2.42 (m, 1 H), 2.46-2.52 (m, 1 H), 2.64-2.74 (m, 2 H), 2.76-2.91 (m, 1 H), 2.97-3.05 (m, 1 H), 3.37-3.48 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 31.6 (t), 34.9 (t), 39.8 (d), 40.1 (d), 40.9 (d), 41.2 (d), 44.2 (d), 44.7 (d), 48.4 (d), 55.7 (d), 118.8 (s), 123.0 (s); EI Mass Spectrum (70 eV), *m/z* (relative intensity) 314 ($C_{12}H_{12}{}^{79}Br^{79}Br$, 5.9), 316 ($C_{12}H_{12}{}^{79}Br^{81}Br$, 12.1), 318 ($C_{12}H_{12}{}^{81}Br^{81}Br$, 4.3). Anal. Calcd for $C_{12}H_{12}Br_2$: C, 45.61; H, 3.83. Found: C, 45.79; H, 3.90.

Bromination of 8a. Method A. A solution of **8a** (200 mg, 0.84 mmol) in $CHCl_3$ (20 mL) was cooled to 0-5 °C via application of an external ice bath. To this cooled solution was added with stirring a solution of bromine (0.8 mL, 0.9 mmol) in $CHCl_3$ (5 mL). After all of the bromine solution had been added, the external cold bath was removed, and the reaction mixture was allow to warm gradually to ambient temperature with stirring overnight. The reaction mixture was washed with saturated aqueous $Na_2S_2O_3$ (2 x 10 mL), and the combined aqueous layers were extracted with $CHCl_3$ (25 mL). The combined organic layers were washed sequentially with water (20 mL) and brine (20 mL), dried ($MgSO_4$), and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with 2% EtOAc-

hexane. The first chromatography fraction afforded pure **7** (12 mg, 3.5%) as a colorless oil; IR (neat) 2960 (s), 2881(m), 1473 (m), 1296 (s), 1276 (s), 864 (s), 831 (s), 673 (s), 642 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 1.16 (*AB*, J_{AB} = 5.2 Hz, 1 H), 1.23 (A*B*, J_{AB} = 5.2 Hz, 1 H), 1.38 (*AB*, J_{AB} = 10.5 Hz, 1 H), 1.64 (A*B*, J_{AB} = 10.5 Hz, 1 H), 2.02-2.54 (m, 1 H), 2.26-2.48 (m, 3 H), 2.74-2.94 (m, 2 H), 3.02-3.24 (m, 2 H), 5.18 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 26.1 (t), 36.8 (t), 43.5 (d), 44.5 (d), 37.1 (d), 47.3 (d), 46.4 (d), 53.4 (d), 54.5 (d), 58.6 (d), 60.1 (d), 72.1 (s); EI Mass Spectrum (70 eV), *m/z* (relative intensity) (no parent ion) 319 (8.9), 317 (21.1), 315 (9.6), 237 (5.2), 235 (5.4), 91 (9.6), 79 (7.6), 44 (18.3), 32 (100). Anal. Calcd for $C_{12}H_{13}Br_3$: C, 36.31; H, 3.30. Found: C, 36.52; H, 3.36.

Continued elution of the chromatography column by using 6% EtOAc-hexane afforded pure **13** (298 mg, 89%) as a colorless microcrystalline solid: mp 134-136 °C; IR (KBr) 2928 (s), 2864 (s), 976 (s), 862 (s), 723 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 1.48-1.85 (m, 4 H), 2.12-2.36 (m, 2 H), 2.54-2.76 (m, 2 H), 2.80-3.03 (m, 2 H), 3.05-3.14 (m, 1 H), 4.30 (s, 1 H), 5.71 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 37.4 (t), 38.0 (t), 44.9 (d), 46.4 (d), 46.8 (d), 48.2 (d), 51.9 (d), 52.6 (d), 57.9 (d), 59.1 (d), 61.5 (d), 70.8 (s); EI Mass Spectrum (70 eV), *m/z* (relative intensity) (no parent ion), 319 (22.0), 317 (41.9), 315 (21.3), 237 (10.9), 235 (9.3), 157 (6.8), 155 (19.0), 91 (16.7), 79 (16.6), 77 (21.1), 32 (41.8), 28 (100). Anal. Calcd for $C_{12}H_{13}Br_3$: C, 36.31; H, 3.30. Found: C, 36.16; H, 3.50. The structure of **13** was established unequivocally via application of X-ray crystallographic methods (*vide infra*).

Method B.[11] To a refluxing solution of **8a** (500 mg, 2.10 mmmol) in CCl_4 (30 mL) was added dropwise with stirring bromine (0.1 mL, 2.1 mmol) during 10 minutes. After the addition of bromine had been completed, the reaction mixture was allowed to cool gradually to ambient temperature. The reaction mixture then was washed with saturated aqueous $Na_2S_2O_3$ (2 x 25 mL). The combined aqueous layers were extracted with CH_2Cl_2 (2 x 25 mL). The combined organic extracts were washed sequentially with water (25 mL) and brine (25 mL), dried ($MgSO_4$), and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with hexane. The first chromatography fraction afforded pure **12** (480 mg, 72%) as a colorless oil. The IR, ^1H NMR, and ^{13}C NMR spectra of the material thereby obtained were essentially identical to the corresponding spectra of **12** prepared via the method described previously (*vide supra*).

Continued elution of the chromatography column with 2% EtOAc-hexane afforded pure **7** (134 mg, 16%). The IR, ^1H NMR, and ^{13}C NMR spectra of the material thereby obtained were identical in all respects with the corresponding spectra obtained for **7** via bromination of **8a** by using Method A (*vide supra*).

Continued elution of the chromatography column with 4% EtOAc-hexane afforded pure **13** (92 mg, 11%) as a colorless microcrystalline solid: mp 134-136 °C. The IR, ^1H NMR, and ^{13}C NMR spectra of the material thereby obtained were identical in all respects with the corresponding spectra obtained for **13** via bromination of **8a** by using Method A (*vide supra*).

Method C. To a refluxing solution of **8a** (500 mg, 2.10 mmmol) in CCl_4 (30 mL) was added dropwise with stirring bromine (0.1 mL, 2.1 mmol) during 10 minutes. The reaction mixture was refluxed for 1 h after the addition of bromine had been completed. The reaction mixture then was allowed to cool gradually to ambient temperature, and workup was performed in the manner described in Method B (*vide supra*). The crude reaction product was purified via column chromatography on silica gel by eluting with with hexane. Pure **14** (569 mg, 85%) was thereby obtained as a colorless oil. The IR, ^1H NMR, and ^{13}C NMR spectra of the material thereby obtained were identical in all respects with the corresponding spectra obtained for **14** by using Method B (*vide supra*).

Continued elution of the chromatography column with 6% EtOAc-hexane afforded pure **13** (101 mg, 12%).The IR,^1H NMR, and ^{13}C NMR spectra of the material thereby obtained were identical in all respects with the corresponding spectra obtained for **13** by using Method B (*vide supra*)

Bromination of 8b. Method A. A solution of **18b** (250 mg, 1.30 mmol) in $CHCl_3$ (20 mL) was cooled to 0-5 °C via application of an external ice bath. To this cooled solution was added with stirring a solution of Br_2 (0.07 mL, 1.4 mmol) in $CHCl_3$ (5 mL). After all of the bromine solution had been added, the external cold bath was removed, and the reaction mixture was allowed to warm gradually to ambient temperature with stirring overnight. The reaction mixture was washed with saturated aqueous $Na_2S_2O_3$ (2 x 10 mL), and the combined aqueous layers were extracted with $CHCl_3$ (25 mL). The combined organic layers were washed sequentially with water (20 mL) and brine (20 mL), dried ($MgSO_4$), and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with 2% EtOAc-hexane. The first chromatography fraction afforded pure **14** (37 mg, 8%) as a colorless oil; IR (film) 2955 (s), 2864 (m), 1298 (m), 867 (m), 828 (m), 665 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 1.26-1.31 (m, 1 H), 1.43 (*AB*, J_{AB} = 9.8 Hz,1 H), 1.69 (*AB*, J_{AB} = 9.8 Hz,1 H), 2.28-2.57 (m, 6 H), 2.72-2.91 (m, 2 H), 3.04-3.12 (m, 1 H), 5.10 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 26.5 (t), 37.3 (t), 43.5 (d), 44.4 (d), 46.7 (d), 47.0 (d), 47.3 (d), 53.6 (d), 54.0 (d), 58.8 (d), 60.56 (d), 86.6 (s). Anal. Calcd for $C_{12}H_{13}Br_2Cl$: C, 40.89; H, 3.72. Found: C, 41.13; H, 4.04.

Continued elution of the chromatography column by using 6% EtOAc-hexane afforded pure **15** (385 mg, 84%) as a colorless microcrystalline solid: mp 137-138 °C; IR (KBr) 2968(s), 2871 (m), 1285 (s), 1220 (m), 828 (s), 795 (m), 730 (m), 678 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 1.46 (*AB*, J_{AB} = 10.0 Hz, 1 H), 1.63-1.78 (m, 2 H), 2.12 (*AB*, J_{AB} = 10.0 Hz, 1 H), 2.22-2.31 (m, 1 H), 2.35-2.40 (m, 1 H), 2.63-2.72 (m, 1 H), 2.74-2.79 (m, 1 H), 2.83-2.92 (m, 2 H), 3.01-3.12 (m, 1 H), 4.18 (s, 1 H), 5.64 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 36.5 (t), 38.0 (t), 45.0 (d), 46.0 (d), 46.4 (d), 47.8 (d), 52.0 (d), 52.6 (d), 56.9 (d), 58.4 (d), 61.2 (d), 76.0 (s). Anal. Calcd for $C_{12}H_{13}Br_2Cl$: C, 40.89; H, 3.72. Found: C, 41.29; H, 3.96.

Method B. [11] To a refluxing solution of **8b** (500 mg, 2.60 mmmol) in CCl_4 (30 mL) was added dropwise with stirring Br_2 (0.15 mL, 2.9 mmol) during 10 minutes. After the addition of bromine had been completed, the reaction mixture was allowed to cool gradually to ambient temperature. The reaction mixture then was washed with saturated aqueous $Na_2S_2O_3$ (2 x 25 mL). The combined aqueous layers were extracted with CH_2Cl_2 (2 x 25 mL). The combined organic extracts were washed sequentially with water (25 mL) and brine (25 mL), dried ($MgSO_4$), and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with hexane. The first chromatography fraction afforded pure **16** (480 mg, 68%) as a colorless oil; IR (neat) 2960 (s), 2872 (m), 1668 (s), 1452 (m), 1309 (s), 1278 (m), 1140 (s), 1074 (s), 979 (m), 885 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 1.18-1.32 (m, 2 H), 1.38-1.56 (m, 2 H), 2.08-2.18 (m, 1 H), 2.28-2.40 (m, 1 H), 2.42-2.52 (m, 1 H), 2.58-2.72 (m, 2 H), 2.76-2.89 (m, 2 H), 3.32-3.42 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 31.0 (t), 34.4 (t), 39.6 (d), 39.7 (d), 40.4 (d), 40.7 (d), 43.5 (d), 43.7 (d), 47.8 (d), 52.3 (d), 114.8 (s), 132.4 (s). Anal. Calcd for $C_{12}H_{12}BrCl$: C, 53.07; H, 4.45. Found: C, 52.93; H,4.64.

Continued elution of the chromatography column with 2% EtOAc-hexane afforded pure **14** (165 mg, 18%). The IR, ^1H NMR, and ^{13}C NMR spectra of the material thereby obtained were identical in all respects with the corresponding spectra obtained for **14** via bromination of **8b** by using Method A (*vide supra*).

Continued elution of the chromatography column with 6% EtOAc-hexane afforded pure **15** (109 mg, 12%) as a colorless microcrystalline solid: mp 137-138 °C. The IR, ^1H NMR, and ^{13}C NMR spectra of the material thereby obtained were identical in all respects with the corresponding spectra obtained for **15** via bromination of **8b** by using Method A (*vide supra*).

Method C. To a refluxing solution of **8b** (500 mg, 2.60 mmmol) in CCl_4 (30 mL) was added dropwise with stirring Br_2 (0.15 mL, 2.86 mmol) during 10 minutes. The reaction mixture was refluxed for 1 h after the addition of Br_2 had been completed. The reaction mixture then was allowed to cool gradually to ambient temperature, and workup was performed in the manner described in Method B (*vide supra*). The crude reaction product was purified via column chromatography on silica gel by eluting with hexane. Pure **16** (557 mg, 79%) was thereby obtained as a colorless oil. The IR, ^1H NMR, and ^{13}C NMR spectra of the material thereby

obtained were identical in all respects with the corresponding spectra obtained for **16** by using Method B (*vide supra*).

Continued elution of the chromatography column with 6% EtOAc-hexane afforded pure **15** (109 mg, 12%). The IR, ^{1}H NMR, and ^{13}C NMR spectra of the material thereby obtained were identical in all respects with the corresponding spectra obtained for **15** by using Method B (*vide supra*).

***exo*-7,8-Dibromopentacyclo[6.6.0.0^{2,6}.0^{3,11}.0^{5,10}]dodecane (18).**[10] To a solution of hydrazine hydrate (0.60 mL, 11.5 mmol) in dry MeOH (10 mL) at ambient temperature was added powdered, activated molecular sieves (4 Å, 0.5 g). The resulting suspension was stirred at ambient temperature for 20 minutes, at which time a solution of **5** (100 mg, 0.57 mmol) in dry MeOH (5 mL) was added. The resulting mixture was stirred at ambient temperature for 2 h. The reaction mixture then was filtered, and the residue was washed with Et_2O (2 x 10 mL). The combined filtrates were concentrated *in vacuo*, and the residue was further dried under high vacuum (1 mm Hg) for an additional 1 h. The resulting material (i.e., the hydrazone of **5**, 103 mg, 96%) was used as obtained, without further purification or characterization.

A mixture of $CuBr_2$ (712 mg, 3.2 mmol) and Et_3N (0.22 mL, 1.6 mmol) in dry MeOH (10 mL) was stirred at ambient temperature for 20 minutes. The resulting mixture was cooled to 0 °C via application of an external ice-water bath. To the cooled reaction mixture was added portionwise with stirring a solution of the hydrazone of **5** (*vide supra*, 103 mg, 0.54 mmol) in dry MeOH (5 mL). To the resulting mixture was added 3% aqueous NH_4OH (50 mL), and the resulting aqueous suspension was extracted with CH_2Cl_2 (2 x 25 mL). The combined organic extracts were washed sequentially with water (20 mL) and brine (20 mL). The organic layer was dried ($MgSO_4$) and filtered, and the filtrate was concentrated *in vacuo*. The residue was purified via column chromatography on silica gel by eluting with hexane. Pure **18** (111 mg, 61%) was thereby obtained as a colorless microcrystalline solid: mp 74-75 °C; IR (KBr) 2958 (s), 2879 (s), 1469 (m), 1298 (m), 995 (s), 904 (s), 864 (s), 746 cm^{-1} (s); ^{1}H NMR ($CDCl_3$) δ 1.19 (*AB*, J_{AB} = 10.5 Hz, 1 H), 1.28-1.41 (m, 2 H), 1.48 (*AB*, J_{AB} = 10.5 Hz, 1 H), 1.69-1.82 (m, 2 H), 2.04-2.54 (m, 6 H), 2.77-2.84 (m, 1 H), 4.52 (dd, J = 4.9, 2.4 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 27.4 (t), 32.4 (t), 36.3 (t), 36.9 (d), 37.4 (d), 41.5 (d), 45.1 (d), 47.4 (d), 50.9 (d), 51.9 (d), 63.2 (d), 67.2 (s); EI Mass Spectrum (70 eV), *m/z* (relative intensity) 239 ($C_{12}H_{14}{}^{79}Br$, 77.9), 237 ($C_{12}H_{14}{}^{81}Br$, 76.4). Anal. Calcd for $C_{12}H_{14}Br_2$: C, 45.32; H, 4.44. Found: C, 45.19; H, 4.58. The structure of **18** was established unequivocally via application of X-ray crystallographic methods (*vide infra*).

X-ray Crystal Structures of 13 and 18. All data were collected on an Enraf-Nonius CAD-4 diffractometer by using the ω–2θ scan technique, Mo Kα radiation (λ = 0.71073 Å) and a graphite monochromator. Standard procedures used in our laboratory for this purpose have been described previously.[12] Pertinent X-ray data are given in Table 1. Data were corrected for Lorentz and polarization effects but not for absorption. The structures were solved by Patterson and difference maps, and the model was refined by using full-matrix least-squares techniques. All non-hydrogen atoms were refined by using anisotropic thermal parameters. Hydrogen atoms were located on difference maps and then were included in the model in idealized positions [U(H) = 1.3 B_{eq}(C)] and allowed to ride upon the attached carbon atom. All computations other than those specified were performed by using MolEN.[13] Scattering factors were taken from the usual sources.[14] X-ray structure drawings of **13** and **18** are shown in Figure 1.

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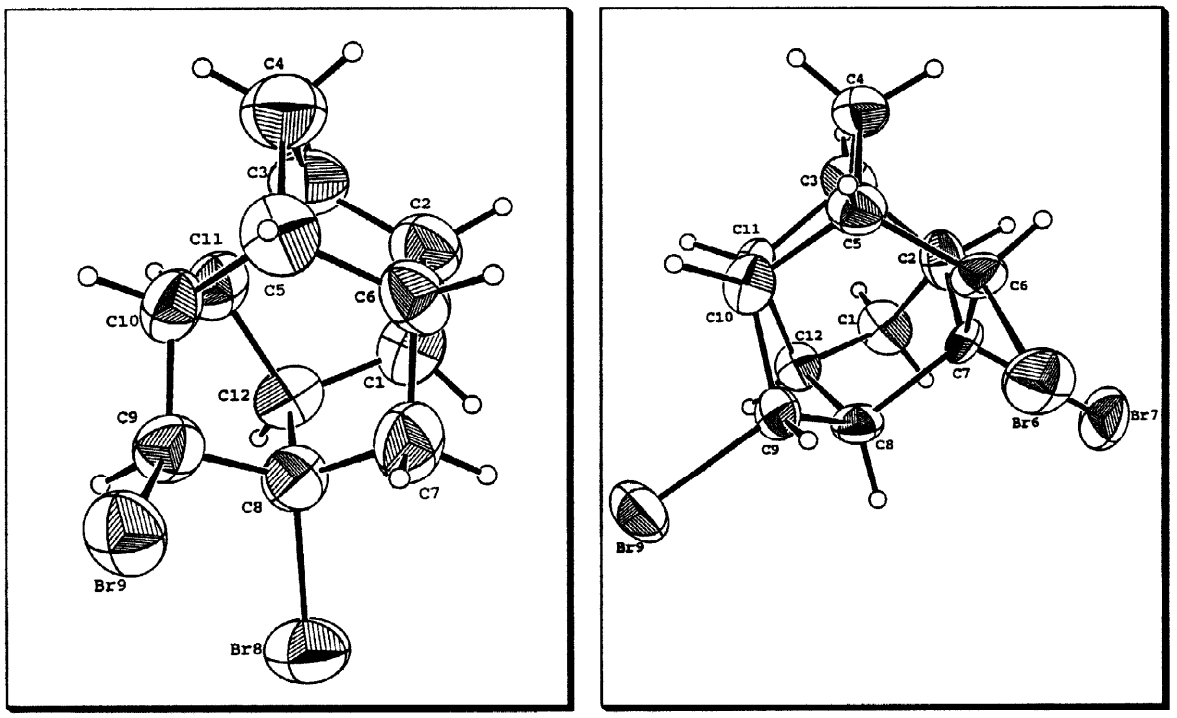

Figure 1. X-ray structure drawings for **13** (left) and **18** (right).

Table 1. X-ray data collection and processing parameters for **13** and **18**.

Compound	**13**	**18**
Formula	$C_{12}H_{14}Br_2$	$C_{12}H_{13}Br_3$
Size (mm)	0.18 x 0.42 x 0.78	0.11 x 0.13 x 0.14
Space Group	$P2_1/n$	$P2_1/c$
a (Å)	7.314 (1)	12.513 (1)
b (Å)	12.762 (1)	7.1905 (5)
c (Å)	11.982 (2)	13.526 (1)
α (°)	90	90
β (°)	101.27 (1)	97.739 (8)
γ (°)	90	90
V (Å^3)	1096.8 (2)	1205.9 (2)
Z-value	4	4
D_{calc} (g-cm^{-3})	1.926	2.19
μ (cm^{-1})	72.78	99.07
T (K)	295	295
$2\theta_{max}$ (°)	50	44
Total reflections	2173	1692
Unique reflections	2021	1620
R_{int}	0.020	0.022
$I \geq 3\sigma(I)$	1193	840
Parameters	127	136
R, R_w	0.0413, 0.0417	0.0354, 0.0388
$(\Delta/\sigma)_{max}$	< 0.01	< 0.01
ρ_{max}; ρ_{min} (eÅ^{-3})	0.89; -0.80	0.48; -0.32

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