Synthetic Approaches to [*n*](3,5)-Troponophanes. Novel Rearrangements of 10,10-Dichloro-1,2,6,7,8,9-hexahydro-4a,9a-methano-5*H*-benzocycloheptен-2-one

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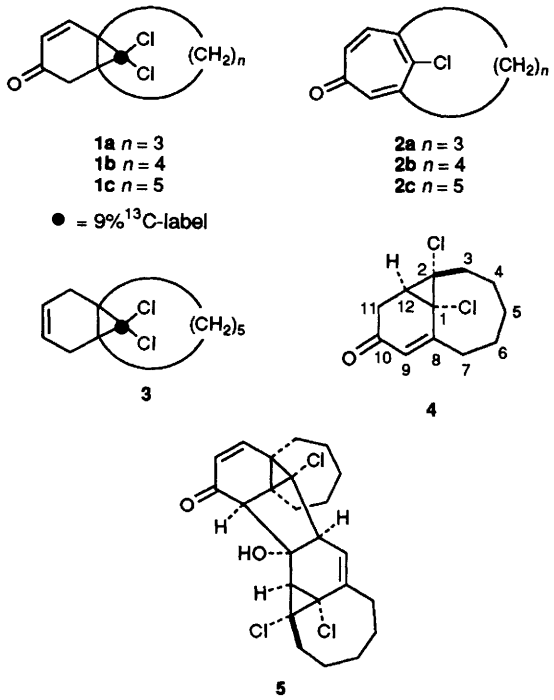
On standing the title compound **1c** gives an enone isomer **4** and the heptacyclic compound **5**; the formation of both of these products has been rationalised in terms of the intermediacy of the bridged tropylium ion **8** and ^{13}C-labelling studies support this proposal.

While examples of isolable short-bridged ($n \leq 6$) [*n*](2,7)-troponophanes have been reported,[1] the related but possibly more strained [*n*](2,4)- and [*n*](3,5)-sembarked on a program directed towards the ystems remain unknown.[2] We have preparation of these latter types of compound and report some preliminary and novel observations herein.

The demonstrated utility[3] of ω-halogeno[*n*.3.1]propellanes as precursors to [*n*]-metacyclophanes, as well as studies[4] showing that 7-halogenobicyclo[4.1.0]heptenones are excellent precursors to troponoids, prompted us to examine the ring-expansion chemistry of [*n*.4.1]propellenones of the general type **1**. It was expected that when the value of *n* was sufficiently large the corresponding [*n*](3,5)-troponophane **2** should result. Our initial studies[4] established that compounds **1a** and **1b** were completely stable entities that did not undergo the desired ring-expansion. Consequently we turned our attention to the next higher homologue **1c**. Compound **1c**† was readily prepared by standard methods from the known[5] alkene **3** but proved to be rather unstable. Thus, on standing at room temperature in chloroform (0.2 mol dm^{-3} solution) for 4 d the isomeric enone **4** was isolated in 73% yield as a low-melting solid. The assignment of structure **4** to this reaction product rests largely on NMR data‡ and the results of key NOE difference experiments are shown in Fig. 1.

A possible mechanistic rationale for the observed conversion **1c** → **4** is shown in Scheme 1. Thus, ketone **1c** could enolise to give the bridged norcaradiene **6** which then undergoes electrocyclic ring-opening[5] to produce the cycloheptatrienol **7**. Loss of chloride ion from this last species would then generate the '*meta*'-bridged tropylium ion **8**[6] which could recombine with Cl^- by a number of distinct pathways



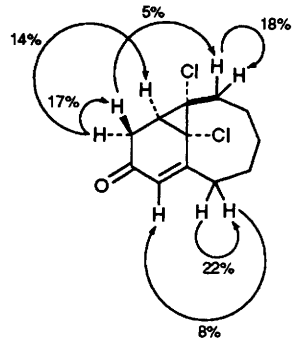
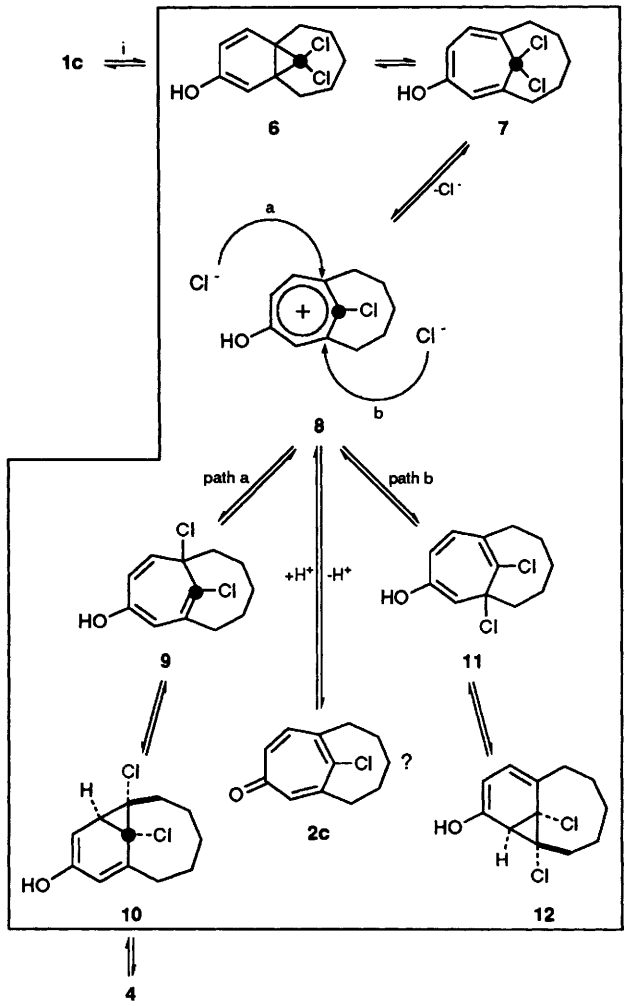


Fig. 1 Selected NOE difference measurements for compound **4**



Scheme 1 *Reagents and conditions*: i, $CHCl_3$, 18 °C. ● = 9% ^{13}C-label

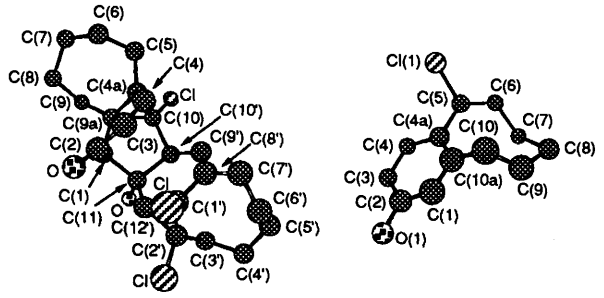


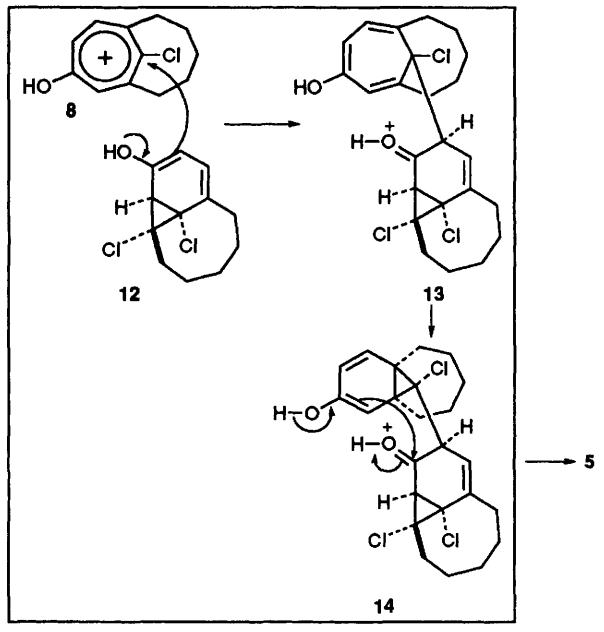
Fig. 2 Chem3D Plus™ generated images of compounds **5** (left) and **15** (right) derived from x-ray crystal data (hydrogen atoms omitted for clarity). Compound **5** selected bond angles (°): O(1)–C(2)–C(3) 122.3, O(1)–C(2)–C(1) 121.4, O(1′)–C(11′)–C(1) 107.8, C(9a)–C(4a)–C(10) 59.2, C(4a)–C(9a)–C(10) 60.5, Cl(1)–C(10)–C(4a) 119.0, Cl(1)–C(10)–C(9a) 121.7, Cl(1)–C(10)–C(10′) 113.9, C(3)–C(4)–C(4a) 124.0, C(4a)–C(5)–C(6) 112.8, C(1)–C(11′)–C(10′) 105.7. Selected bond lengths (Å): O(1)–C(2) 1.226, O(1′)–C(11′) 1.418, C(1)–C(2) 1.500, C(2)–C(3) 1.448, C(3)–C(4) 1.330, C(4)–C(4a) 1.477, C(1′)–C(12′)–1.501, C(1′)–C(8′) 1.483, C(8′)–C(9′) 1.317, C(9′)–C(10′) 1.498, C(4a)–C(9a) 1.520, C(4a)–C(10) 1.524, C(9a)–C(10) 1.504, Cl(1)–C(10) 1.769.

Compound **15**: selected mean bond angles (°): C(5)–C(4a)–C(10a) 120.8, C(4a)–C(5)–C(6) 126.4, C(5)–C(6)–C(7) 124.6, C(6)–C(7)–C(8) 113.4, C(7)–C(8)–C(9) 114.9, C(8)–C(9)–C(10) 115.6, C(9)–C(10)′–C(10a) 115.4, C(10)–C(10a)–C(4a) 122.9, C(4)–C(4a)–C(5) 120.0, C(4)–C(4a)–C(10a) 119.3, C(6)–C(5)–Cl 119.0, C(4a)–C(5)–Cl 114.7, C(1)–C(10a)–C(4a) 118.5, C(1)–C(10a)–C(10) 118.6. Selected mean bond lengths (Å): C(4a)–C(5) 1.476, C(4a)–C(10a) 1.405, C(5)–C(6) 1.320, C(6)–C(7) 1.498, C(7)–C(8) 1.532, C(8)–C(9) 1.521, C(9)–C(10) 1.537, C(10)–C(10a) 1.506, C(5)–Cl 1.760, C(4a)–C(4) 1.398

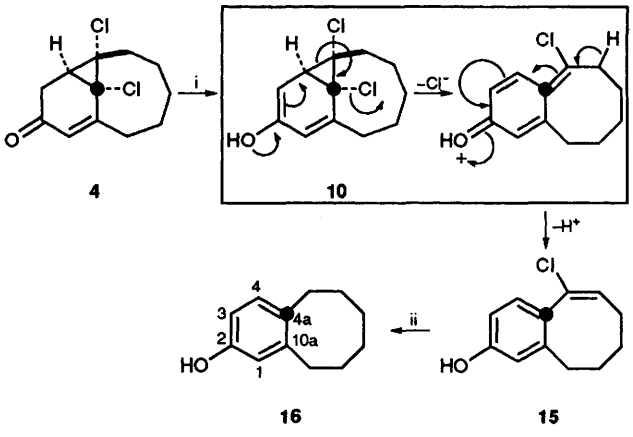
(*e.g.* a and b), one of which (a) leads to cycloheptatriene **9**. Electrocyclic ring-closure of this product should give the norcaradiene **10** which upon ketonisation would afford the observed enone **4**.

It is not clear if the originally targeted troponophane **2c**, which would result from deprotonation of the tropylium ion **8**, is present at any point during these conversions. However, there is some evidence for the operation of path b shown in Scheme 1. Thus, when a chloroform solution of the original enone **1c** was allowed to stand at room temperature for *ca.* two weeks and then concentrated (rotary evaporator), the novel compound **5**[7] (10%) [mp 229–231 °C (decomp.)] was obtained together with enone **4** (38%). The structure of heptacycle **5** was established by single-crystal X-ray analysis§ (Fig. 2) and a possible pathway for formation of this compound is shown in Scheme 2. Thus, nucleophilic attack by the norcaradienol **12** on the tropylium ion **8** as shown[8,9] would give intermediate **13**. Electrocyclic ring-closure of the cycloheptatrienyl moiety within this last species would then produce norcaradienol **14**, the enol moiety of which could attack the nearby oxonium ion resulting in an intramolecular aldol condensation and formation of the observed product **5**. Presumably for steric reasons, no product derived from an analogous condensation between tropylium ion **8** and enol **10** is observed.

Labelling studies have been carried out in an attempt to provide support for the above proposals. When enone **1c** containing 9% ^{13}C (•) at C^{10}[10] was allowed to rearrange, under the originally described conditions, isomer **4** was again obtained but it was not possible to establish, in direct manner at least, which of the two chlorinated carbons within this product carried the label. An unexpected resolution to this problem occurred when it was observed that heating a THF solution of enone **4** resulted in its smooth conversion, presumably *via* the pathway shown in Scheme 3., into benzocyclooctene **15** (88%) (mp 101–103 °C). The structure of compound **15** was established by X-ray crystallographic methods (Fig. 2).§ Unequivocal location of the ^{13}C-label within compound **15** required its conversion, *via* a hydrogenation/hydrogenolysis sequence, into benzocyclooctene **16** (74%). Using a combination of DEPT and ^{13}C-substituent additivity techniques¶ it was then possible to establish that the label contained within compound **16** was located at C^{4a}. This result strongly suggests that the ^{13}C-label is located at C^{1} in compound **4** which, in turn, supports the mechanistic proposals advanced in Scheme 1.



Scheme 2



Scheme 3 *Reagents and conditions*: i, thf, reflux, 24 h; ii, H_2, Pd on C, ethanol, 18 °C, 24 h. ● = 9% ^{13}C-label.

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Footnotes

† All new compounds had spectroscopic data [IR, UV (where appropriate), NMR, mass spectrum] consistent with the assigned structure. Satisfactory combustion and/or high-resolution mass spectral analytical data were obtained for new compounds and/or suitable derivatives. Reported yields refer to isolated materials.

‡ *Selected spectral data* for **4**; NMR ($CDCl_3$) ^{13}C (100 MHz), δ 194.1 (C), 160.5 (C), 128.5 (CH), 55.4 (C), 47.3 (C), 36.2 (CH_2), 34.2 (CH),

31.8 (CH_2), 30.1 (CH_2), 26.6 (CH_2), 25.9 (CH_2), 24.9 (CH_2); ^{1}H (400 MHz), δ 5.97 (d, *J* 1.2, 1H H^9), 2.98 (dd, *J* 20.0, 9.3, 1H, H^{11}), 2.95 (m, ^{1}H), 2.58 (dd, *J* 20.0, 1.5, 1H, H^{11}), 2.24 (dd, *J* 9.3, 1.5 Hz, 1H, H^{12}), 2.16–2.05 (complex m, 2H), 1.94–1.65 (complex m, 4H), 1.61–1.45 (complex m, 2H), 1.22 (m, 1H); MS *m/z* (EI, 70 eV) 248 (<1%) 246 (8) 244 (13) [M^+], 206 (7) 204 (41) 202 (100) [$M - CH_2CO$], 169 (27) 167 (75) [$M - CH_2CO - Cl$]; ν_{max}/cm^{-1} 3037, 2930, 2858, 1668, 1621, 1452, 1305, 1257, 893, 733.

§ *Crystallographic data* for **5**: $T = 294(1)$ K; monoclinic, space group *C2/c* with $a = 32.795(5)$, $b = 7.7526(7)$, $c = 22.793(4)$ Å, $\beta = 131.726(13)°$, $U = 4325(1)$ Å^3, D_m(flotation) 1.38(1) g cm^{-3}, D_c ($Z = 4$) = 1.394 g cm^{-3}, $F(000) = 1904$, μ(Mo-Kα) = 3.89 cm^{-1} analytical absorption corrections; 4258 unique data with $I > 2\sigma(I)$ used in refinement; $R = 0.038$, $R_W = 0.043$, GOF = 1.773.

For **15**: $T = 291(1)$ K; triclinic, space group $P\bar{1}$ (confirmed on refinement) with $a = 8.074(1)$, $b = 8.771(1)$, $c = 15.512(2)$ Å, $\alpha = 74.43(1)$, $\beta = 80.33(2)$, $\gamma = 82.64(2)°$, $U = 1039.2(3)$ Å^3, D_m (flotation) = 1.32(1) g cm^{-3}, D_c ($Z = 4$) = 1.334 g cm^{-3}, $F(000) = 440$, μ(Cu-Kα) = 29.8 cm^{-1} analytical absorption corrections; 4647 unique data with $I > 3\sigma(I)$ used in refinement; $R = 0.043$, $R_W = 0.064$, GOF = 0.752. Atomic coordinates, bond lengths and angles and thermal parameters for both structures have been deposited at the Cambridge Crystallographic Data Centre. See Information for Authors, Issue No. 1.

¶ Calculated (and observed) ^{13}C NMR chemical shifts for the resonances due to the sp^2-hybridised carbons in compound **16**: δ 115.3 (115.6, C^1H), 153.0 (153.7, C^2), 113.2 (112.9, C^3H), 129.4 (130.0, C^4H), 136.3 (133.6, C^{4a}), 145.0 (142.7, C^{10a}).

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2 Seebach *et al.*, (*Helv. Chim. Acta*, 1977, **60**, 1151), have provided some evidence for the transient existent of [4](3,5)-troponophanes; Itô *et al.* (*Tetrahedron Lett.*, 1987, **28**, 585), have reported the preparation of [7]- and [9]3,5-troponophane.

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7 It has been proposed[2] that a [4](3,5)-troponophane derivative undergoes a [3 + 2]-cycloaddition reaction thereby giving a dimer which bears some structural resemblance to compound **5**.

8 For examples involving nucleophilic interception of tropylium cations by enols see I. D. Reingold, H. A. Trujillo and B. E. Kahr, *J. Org. Chem.*, 1986, **51**, 1627.

9 For a discussion of the regioselectivities observed in nucleophilic attack on chlorotropylium cations see B. Föhlisch and E. Haug, *Chem. Ber.*, 1971, **104**, 2324.

10 Labelled **1c** was readily prepared by adding ^{13}C-enriched dichlorocarbene (generated from 9% ^{13}C-chloroform and base) to 4,5,6,7,8,9-hexahydro-1*H*-benzocycloheptene[5] and then elaborating the resulting labelled tricycle **3** in the same manner as used earlier.