

# Chemistry of cage-shaped hydrocarbons. Ring transformations on a tricyclo[5.2.1.0<sup>4,10</sup>]decane system

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A series of triquinane (tricyclo[5.2.1.0<sup>4,10</sup>]decane) derivatives were prepared from oxidation of pentaquinandiene **1**. Ozonolysis of **1**, followed by reduction, yielded three products **4**, **5**, and **6** with poly-hydroxy groups. The hydroxy group of **5** was transformed to an iodo group in **8** with triphenylphosphine and iodine. An attempted dehydroiodination of **8** with base upon heating produced **10** with an unexpected geometry. The structure of an isomer **11** has been solved by single-crystal X-ray diffraction analysis, in which an *exo*-oriented cyclopropyl group indicated that an inversion has happened at C(3). The mechanism of the reaction from **8** to **10** was depicted as going through a multi-step sequence as outlined in Scheme 3.

## Introduction

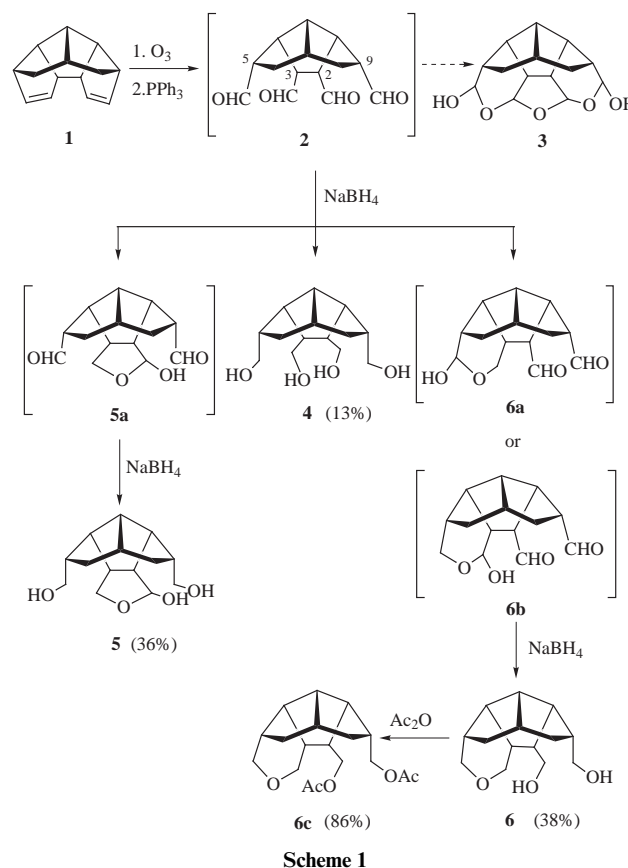
The all-*cisoid* fused pentaquinandiene **1** can be prepared in one step with good yield from norbornadiene.<sup>1</sup> It has been used as a convenient starting material for the preparation of pentaperistylane.<sup>2</sup> In continuation of our study on this molecule and related cage systems,<sup>2,3</sup> we have cleaved the two double bonds by ozonolysis, and transformed the four terminal aldehydes to other functional groups as well as new rings. Since all rings are fused in a *cisoid* manner in these compounds, transannular interactions among the groups on the concave (*endo*) side proceed easily due to their proximity. In this report a sequence of ring transformations is described, yet the basic structure of a triquinane (tricyclo[5.2.1.0<sup>4,10</sup>]decane) is kept intact.<sup>4-7</sup>

## Results and discussion

### Ozonolysis

Compound **1** was oxidized by ozone in a mixture of dichloromethane and methanol, and the product was reduced by triphenylphosphine in an attempt to prepare a tetra-functional aldehyde **2**. Cyclization of the aldehyde groups may lead to the formation of a cage-shaped hemiacetal **3** (Scheme 1).<sup>8</sup> However, the reaction produced a mixture of products, among which no significant yield of either **2** or **3** was observed. An alternative sequence of oxidation has also been examined by using OsO<sub>4</sub> coupled with *N*-methylmorpholine *N*-oxide, followed by NaIO<sub>4</sub>, and again a complicated mixture was obtained.

The ozonolyzed products, without purification, were reduced with sodium borohydride directly. Separation of the products yielded three major components, *i.e.*, compounds **4**, **5** and **6** in 13, 36 and 38% yield, respectively. Mechanisms for the formation of **5** and **6** are depicted as going through intermediates **5a** and **6a,b** (Scheme 1). Compound **2** possesses two chemically different aldehyde groups: the ones at the 2- and 3-position located adjacent to each other and those at the 5- and 9-position on separated rings. If the aldehyde groups at C-2,3 were reduced first, subsequent cyclization proceeded through either **5a** or **6a**. On the other hand, if the aldehyde groups at C-5,9 were reduced first, then cyclization proceeded only through **6b**. At this stage it is not quite clear which intermediate, either **6a** or **6b**, contributed more to the production of **6**. What has been found interesting was an observation that the hemiacetal groups of **6a,b** can be further reduced to a pyran moiety by an excess of borohydride, whereas the hemiacetal of **5a** resists further reduction under similar conditions.

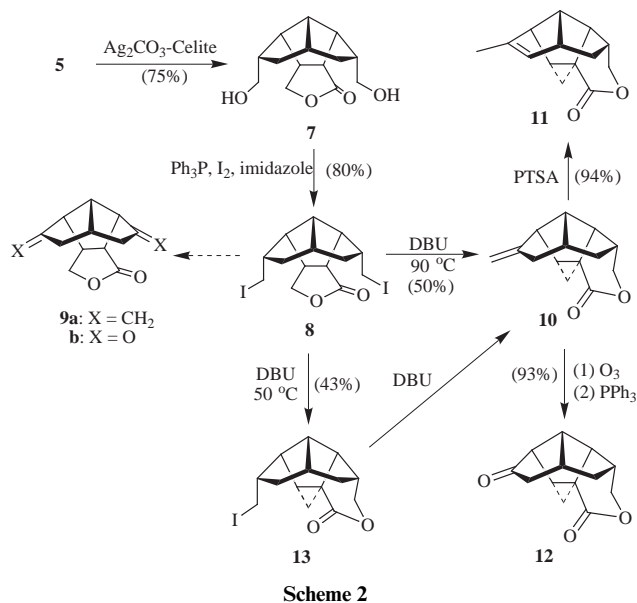


acetal groups of **6a,b** can be further reduced to a pyran moiety by an excess of borohydride, whereas the hemiacetal of **5a** resists further reduction under similar conditions.

The structures **4**, **5**, and **6** were identified by spectroscopic analyses. The geometry of **4** possesses a two-fold symmetry, which is evidenced in its <sup>13</sup>C NMR spectrum by the presence of 8 absorptions. The polarity of **4** is quite high, which results in low solubility in nonpolar organic solvents. A broad IR absorption at 3300–3500 cm<sup>-1</sup> corresponds to the hydroxy groups. For compound **5**, a low-field signal at δ 97.9 in the <sup>13</sup>C NMR spectrum is assigned to the carbon of the hemiacetal. Similarly,

the absence of any low-field signal for **6** indicates the absence of a hemiacetal moiety. The number of peaks in the  $^{13}\text{C}$  spectra of both **5** and **6** correctly matched with their assigned structures. In the mass spectrum of **6**, however, the parent peak at  $m/z$  238 could not be observed. In order to eliminate ambiguities, the hydroxy groups of **6** were converted to acetates by reaction with acetic anhydride in the presence of triethylamine. Compound **6c** was obtained in 86% yield, and gave a mass spectral pattern consistent with the assigned structure including a parent peak at  $m/z$  322 (22% to base peak).

Further oxidation of **5** with silver ion on Celite yielded a lactone **7** (Scheme 2). The reagent is known to oxidize the



hemiacetal moiety selectively, but is ineffective towards primary hydroxy groups.<sup>9</sup> The lactone **7** was then treated with iodine and triphenylphosphine in the presence of imidazole, by which the hydroxy groups were transformed to iodides. The reaction proceeded smoothly at 0 °C in a mixed solvent of acetonitrile and diethyl ether to yield a diiodide **8** in 80% yield. The two high-field signals in the  $^{13}\text{C}$  NMR spectrum at  $\delta$  6.6 and 20.5 are assigned to iodo-carbons. Their difference in chemical shifts is likely to be caused by an uneven environment induced by the lactone moiety. The subsequent step of dehydroiodination of **8** would hopefully lead to a diene **9a**, which could be oxidized later to dione **9b**.

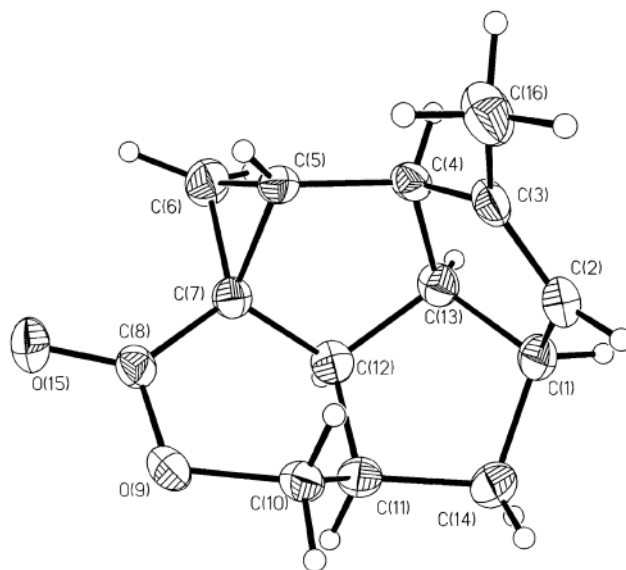
#### Rearrangement upon elimination

Heating of **8** with 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) in toluene at 110 °C yielded **10** as white waxy solid in 40% yield. Its spectra showed the absence of any iodo group but the appearance of a lactone moiety and a double bond. In the NMR spectra a few high-field signals indicate the presence of a cyclopropyl group, e.g. the ones at  $\delta_{\text{H}}$  0.63 and  $\delta_{\text{C}}$  23.1. Under catalysis by toluene-*p*-sulfonic acid (PTSA), the double bond of **10** rearranged from an exocyclic position to an endocyclic one in **11**. Oxidation of **10** with ozone cleaved the double bond to yield ketone **12** in 93% yield. In both reactions the cyclopropyl group and the lactone moiety were not affected. A single crystal of **11** was subjected to X-ray diffraction analysis. A perspective drawing is shown in Fig. 1 to illustrate the stereochemistry of the structure. The crystallographic and refinement data are listed in Table 1. A noteworthy feature in this structure is the orientation of the cyclopropyl group, which is directed toward the *exo*-side of the cage. Such a geometry is contrary to that of the lactone moiety in **8**, which is fused *cisoid* to the triquinane on the *endo*-side. An inversion of configuration at C(3) must

**Table 1** Crystallographic and refinement data for compound **11**

Empirical formula	$\text{C}_{14}\text{H}_{16}\text{O}_2$
Formula weight	216.27
Crystal system	Triclinic
Space group	$P\bar{1}$
Cell dimensions	
$a/\text{\AA}$	6.7900(10)
$b/\text{\AA}$	7.614(2)
$c/\text{\AA}$	12.020(2)
$\alpha/^\circ$	93.73(3)
$\beta/^\circ$	99.86(3)
$\gamma/^\circ$	115.41(3)
$V/\text{\AA}^3$	546.3(2)
$Z$	2
$F(000)$	232
$D_c/\text{g cm}^{-3}$	1.315
$\mu/\text{mm}^{-1}$	0.086
Final $R$ indices [ $I_0 > 2\sigma(I_0)$ ] <sup>a</sup>	$R_1 = 0.0403$ , $wR_2 = 0.1216$
$R$ indices (all data) <sup>a</sup>	$R_1 = 0.0593$ , $wR_2 = 0.1396$

$$^a w = 1/[\sigma^2(F_o^2) + (0.1325P)^2 + 0.06P], \text{ where } P = (F_o^2 + 2F_c^2)/3.$$



**Fig. 1** Perspective drawing of crystal structure of compound **11** showing the stereochemistry of ring junctures. The numbering scheme fractions 1–14 corresponds to that of the systematic nomenclature used in the Experimental section.

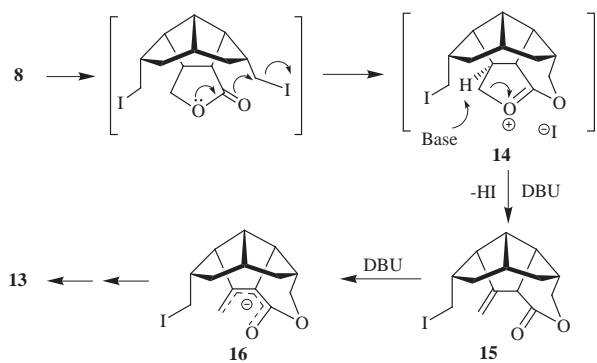
have taken place during the rearrangement. To understand the mechanism of this process, further information is needed.

In order to isolate any possible intermediate, the temperature of reaction was lowered stepwise from 110 °C to 50 °C. At 90 °C the yield of **10** reached an optimal value of 50%, while at 70 °C a new product appeared. At 50 °C the new product was obtained in 43% yield along with a minor amount of **10**. The reaction does not proceed at a temperature below 50 °C. The spectroscopic features of the new product showed the characteristics of a cyclopropane ring and an iodomethyl group. By comparison of its spectra with those of **10**, the new product was assigned structure **13** (Scheme 2). With this structure, it became clear that the double bond of **10** was generated at the last stage of the reaction from **8** to **10**. Besides **13**, no other intermediate with noticeable yield was identified.

The transformation of **8** to **13** requires at least one mole equivalent of base to absorb the HI eliminated. To understand whether the reaction has to be initiated by the formation of an anion, the effect of base was examined. The amount of DBU used in the reaction was adjusted from one to five mole equivalents with respect to the substrate, and the results showed that yields of **10** and **13** are not affected significantly. However, the yield of **13** did increase to 55% by using a stronger base, i.e., potassium *tert*-butoxide at 0 °C. This information suggests

that the generation of an anion must be a key step in this reaction.

The effect of iodide ion has also been explored, as it may assist a thermal rearrangement prior to the formation of an anion. Compound **8** was heated together with a variety of iodide reagents, such as Et<sub>4</sub>NI in THF, Bu<sub>4</sub>NI in THF, and KI in acetone, *etc.* at various temperatures from ambient to reflux. No apparent reaction took place under these conditions. The mechanism for the conversion of **8** to **10** is thus envisaged as in Scheme 3. There are two key steps involved in the reaction, *i.e.*,



Scheme 3

a migration of the lactone ring and an inversion of configuration at C(3). An oxonium salt **14** was produced upon the elimination of iodide, which then reacted with base to yield a  $\beta,\gamma$ -unsaturated ketone **15**. Upon deprotonation it may yield an anion **16**, which rearranges followed by protonation to give **13**. The high stability of anion **16** may be ascribed to an extended electronic delocalization over a planar geometry, which is held rigidly by a polycyclic framework.

## Conclusions

Oxidative cleavage of the double bonds of **2** produced a series of triquinane derivatives. Interactions among polar functional groups on the *endo*-side of the triquinane resulted in the formation of several new rings. Base-promoted elimination from a diiodide **8** yielded a novel product **10** with a cyclopropyl group oriented on the *exo*-side. Anion **16** may have been formed as an intermediate, in which  $6\pi$  electrons are delocalized on a planar U-shaped geometry that is held rigidly by the polycyclic framework.

## Experimental

<sup>1</sup>H and <sup>13</sup>C spectra were obtained on either a Bruker APX-400 or a Varian Gemini-200 spectrometer. Chemical shifts of <sup>1</sup>H were measured downfield from TMS in  $\delta$ -units, while those of <sup>13</sup>C were recorded with the central peak of CDCl<sub>3</sub> at  $\delta_C$  77.00 as an internal reference. *J*-Values are in Hz. IR spectra were recorded on a Perkin-Elmer 682 infrared spectrophotometer. Elemental analyses were obtained on a Perkin-Elmer 2400 CHN instrument. Mass spectra were recorded on a VG Trio-2000 spectrometer for routine samples, whereas those of high resolution were recorded on a VG-11-250J spectrometer. Mps were measured by a Thomas-Hoover mp apparatus and are uncorrected.

**(2,3,5,9-Tetrakis(hydroxymethyl)tricyclo[5.2.1.0<sup>4,10</sup>]decane 4, 3-hydroxy-8,12-bis(hydroxymethyl)-4-oxatetracyclo[5.5.1.0<sup>2,6</sup>.0<sup>10,13</sup>]tridecane 5, and 2,13-bis(hydroxymethyl)-8-oxatetracyclo[8.2.1.0<sup>4,12</sup>.0<sup>6,11</sup>]tridecane 6**

In a round-bottom flask (200 mL) a stream of ozone was passed slowly through a solution of diene **1** (3.8 g, 21.0 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (100 mL) and methanol (20 mL) at  $-78^\circ\text{C}$  until the

solution turned bluish. The solution was quenched by the addition of triphenylphosphine (13.9 g, 52.5 mmol), and was allowed to warm up gradually to room temperature. The reaction mixture was evaporated *in vacuo* with a rotary evaporator, then was dissolved again in CH<sub>2</sub>Cl<sub>2</sub> (80 mL). To the solution was added NaBH<sub>4</sub> (4.0 g, 105 mmol), and the resulting mixture was stirred with a magnetic bar at  $0^\circ\text{C}$ , and then at ambient temperature for 12 h. It was washed twice with saturated aq. NH<sub>4</sub>Cl. The aqueous layers were combined, and extracted with CH<sub>2</sub>Cl<sub>2</sub> (20 mL  $\times$  2). The combined organic layer was washed once with brine, dried over anhydrous MgSO<sub>4</sub>, filtered and evaporated *in vacuo*. The three products were collected as white waxy solids from a silica gel column eluted with CH<sub>2</sub>Cl<sub>2</sub>-CH<sub>3</sub>OH (20:1): **4** (0.65 g, 13%), **5** (1.92 g, 36%) and **6** (2.04 g, 38%).

Physical data of **4**: mp  $162\text{--}165^\circ\text{C}$ ;  $\nu_{\text{max}}(\text{KBr})/\text{cm}^{-1}$  3340br, 3271, 2949;  $\delta_{\text{H}}[(\text{CD}_3)_2\text{SO}; 200 \text{ MHz}]$  0.91 (dt, *J* 8 and 13, 2H), 2.00 (dt, *J* 8 and 12, 2H), 2.15–2.60 (m, 6H), 2.88 (q, *J* 11, 1H), 3.41–3.65 (m, 7H), 4.58 (dd, *J* 3 and 8, 2H);  $\delta_{\text{C}}[(\text{CD}_3)_2\text{SO}; 50 \text{ MHz}; ^1\text{H-decoupled}]$  37.83, 40.97, 45.98, 49.94, 50.71, 57.30, 60.31, 62.39; *m/z* (EI) 256 ( $\text{M}^+$ , 15%), 220 (4), 202 (4), 190 (25), 172 (15), 159 (41), 79 (100).

Physical data of **5**: mp  $236\text{--}240^\circ\text{C}$  (Found: C, 66.04; H, 8.71. C<sub>14</sub>H<sub>22</sub>O<sub>4</sub> requires C, 66.12; H, 8.72%);  $\nu_{\text{max}}(\text{KBr})/\text{cm}^{-1}$  3207, 2949, 1498;  $\delta_{\text{H}}(\text{CDCl}_3, 400 \text{ MHz})$  1.21–1.28 (m, 1H), 1.40–1.48 (m, 1H), 1.93–1.99 (m, 3H), 2.07–2.11 (m, 2H), 2.30–2.41 (m, 1H), 2.45–2.53 (m, 1H), 2.56–2.61 (m, 1H), 2.93–3.00 (m, 1H), 3.05–3.10 (m, 1H), 3.27–3.30 (m, 1H), 3.56–3.61 (m, 1H), 3.70–3.93 (m, 4H), 4.71–4.80 (m, 4H);  $\delta_{\text{C}}(\text{CD}_3\text{OD}, 100 \text{ MHz}, ^1\text{H-decoupled})$  36.70, 42.51, 42.57, 44.00, 44.12, 45.84, 49.34, 50.43, 54.78, 58.33, 64.32, 67.56, 68.97, 97.89; *m/z* (EI) 255 ( $\text{M}^+ + 1$ , 10%), 254 ( $\text{M}^+$ , 8), 236 (7), 218 (17), 205 (20), 190 (55), 131 (100).

Physical data of **6**: mp  $244\text{--}250^\circ\text{C}$ ;  $\nu_{\text{max}}(\text{KBr})/\text{cm}^{-1}$  3400, 2949;  $\delta_{\text{H}}(\text{CD}_3\text{OD}, 200 \text{ MHz})$  0.83 (q, *J* 10, 1H), 1.09 (dt, *J* 8, 12, 1H), 1.46–1.62 (m, 1H), 1.82–2.45 (m, 7H), 2.64 (q, *J* 8, 1H), 2.87 (q, *J* 9, 1H), 3.10–3.24 (m, 1H), 3.42–3.78 (m, 7H);  $\delta_{\text{C}}(\text{CD}_3\text{OD}, 50 \text{ MHz}, ^1\text{H-decoupled})$  35.42, 40.60, 43.25, 46.08, 48.56, 49.87, 53.63, 56.00 (2C), 57.86, 63.63, 64.22, 64.33, 66.97; *m/z* (EI) 236 ( $\text{M}^+ - 2$ , 6%), 208 (10), 190 (15), 159 (18), 28 (100).

## 2,13-Bis(acetoxymethyl)-8-oxatetracyclo[8.2.1.0<sup>4,12</sup>.0<sup>6,11</sup>]tridecane 6c

In a round-bottom flask (25 mL) a mixture of diol **6** (0.11 g, 0.46 mmol), acetic anhydride (0.23 g, 2.2 mmol) and triethylamine (0.28 g, 2.75 mmol) was stirred at room temperature for 2 h. The resulting product was poured into distilled water and was extracted four times with CH<sub>2</sub>Cl<sub>2</sub>. The combined organic layer was washed twice with distilled water and once with brine, dried over anhydrous MgSO<sub>4</sub>, then was filtered. The filtrate was concentrated *in vacuo*, and was purified through a silica gel column eluted with CH<sub>2</sub>Cl<sub>2</sub>-hexane (4:1). The acetate product **6c** was collected as a colorless oil (0.13 g, 86%),  $\nu_{\text{max}}(\text{KBr})/\text{cm}^{-1}$  2949, 1742, 1475, 1365;  $\delta_{\text{H}}(\text{CDCl}_3, 200 \text{ MHz})$  1.14 (q, *J* 10, 1H), 1.19 (dt, *J* 8 and 12, 1H), 1.80–1.89 (m, 1H), 2.04 (s, 3H), 2.05 (s, 3H), 2.05–2.12 (m, 2H), 2.21–2.38 (m, 3H), 2.41–2.56 (m, 2H), 2.74 (q, *J* 8, 1H), 2.99 (q, *J* 9, 1H), 3.92 (dt, *J* 5 and 12, 1H), 4.06 (dd, *J* 8 and 11, 1H), 4.12–4.22 (m, 6H);  $\delta_{\text{C}}(\text{CDCl}_3, 50 \text{ MHz}, ^1\text{H-decoupled})$  21.43 (2C), 34.53, 39.84, 42.44, 43.12, 45.27, 45.82, 47.55, 48.23, 48.36, 57.04, 64.42, 65.51, 65.82, 66.71, 171.37, 171.49; *m/z* (EI) 323 ( $\text{M}^+ + 1$ , 20%), 322 ( $\text{M}^+$ , 22), 321 (65), 304 (12), 262 (10), 245 (24), 244 (90), 202 (33), 184 (80), 145 (100).

## 8,12-Bis(hydroxymethyl)-4-oxatetracyclo[5.5.1.0<sup>2,6</sup>.0<sup>10,13</sup>]tridecan-3-one 7

To a solution of **5** (2.05 g, 8.05 mmol) in toluene (20 mL) in a round-bottom flask (50 mL) were added Ag<sub>2</sub>CO<sub>3</sub> (6.3 g) and Celite. The mixture was heated to  $105^\circ\text{C}$  for 45 min, then was

filtered after having cooled. The filtrate was concentrated *in vacuo*, and was purified through a silica gel column eluted with CH<sub>2</sub>Cl<sub>2</sub>–methanol (100:3). **Lactone 7** was collected (1.53 g, 75%) as a colorless oil (Found: C, 66.51; H, 8.01. C<sub>14</sub>H<sub>20</sub>O<sub>4</sub> requires C, 66.65; H, 7.99%);  $\nu_{\max}(\text{KBr})/\text{cm}^{-1}$  3382, 2940, 1710;  $\delta_{\text{H}}(\text{CDCl}_3, 200 \text{ MHz})$  1.04 (q, *J* 10, 1H), 1.32 (dt, *J* 8 and 12, 1H), 1.80–2.15 (m, 3H), 2.24–2.73 (m, 5H), 2.91 (q, *J* 8, 1H), 3.19 (q, *J* 9, 1H), 3.50–3.70 (m, 3H), 3.75–3.90 (m, 2H), 4.29–4.37 (m, 3H);  $\delta_{\text{C}}(\text{CDCl}_3, 50 \text{ MHz}, ^1\text{H-decoupled})$  35.27, 35.73, 40.72, 43.64, 45.58, 48.45, 48.95, 49.86 (2C), 59.31, 63.25, 67.94, 70.32, 176.27; *m/z* (EI) 253 (M<sup>+</sup> + 1, 12%), 252 (M<sup>+</sup>, 32), 251 (10), 234 (12), 222 (28), 192 (96), 91 (100).

### 8,12-Bis(iodomethyl)-4-oxatetracyclo[5.5.1.0<sup>2,6</sup>.0<sup>10,13</sup>]tridecan-3-one **8**

To a round-bottom flask (50 mL) containing a magnetic stirring bar under a nitrogen atmosphere were added **7** (0.87 g, 3.46 mmol), PPh<sub>3</sub> (2.73 g, 10.4 mmol), imidazole (0.72 g, 10.38 mmol), anhydrous CH<sub>3</sub>CN (9 mL) and diethyl ether (15 mL). The flask was cooled in an ice-bath, and to it was added iodine (2.64 g, 10.36 mmol). The resulting mixture was stirred for 40 min under nitrogen, then was quenched by the addition of water and extracted several times with CH<sub>2</sub>Cl<sub>2</sub>. The combined organic layer was washed twice with saturated Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> and once with brine, dried over anhydrous MgSO<sub>4</sub>, filtered, and evaporated *in vacuo*. **Diiodide 8** was purified by a silica gel column eluted with CH<sub>2</sub>Cl<sub>2</sub>–hexane (3:1) and was isolated as a white solid (1.31 g, 80%), mp 263–264 °C (Found: C, 35.76; H, 3.89. C<sub>14</sub>H<sub>18</sub>O<sub>2</sub>I<sub>2</sub> requires C, 35.62; H, 3.84%);  $\nu_{\max}(\text{KBr})/\text{cm}^{-1}$  2949, 1715;  $\delta_{\text{H}}(\text{CDCl}_3, 200 \text{ MHz})$  1.04 (q, *J* 10, 1H), 1.35 (dt, *J* 8 and 12, 1H), 2.00–2.29 (m, 3H), 2.44–2.72 (m, 4H), 2.80–3.04 (m, 2H), 3.12–3.28 (m, 3H), 3.53 (dd, *J* 4 and 10, 1H), 3.80 (dd, *J* 3 and 10, 1H), 4.25 (dd, *J* 3 and 10, 1H), 4.40 (dd, *J* 3, 10, 1H);  $\delta_{\text{C}}(\text{CDCl}_3, 50 \text{ MHz}, ^1\text{H-decoupled})$  6.55, 20.54, 35.62, 40.47, 40.90, 43.86, 46.17, 46.36, 50.80, 50.90, 53.59, 58.82, 69.84, 174.59; *m/z* (EI) 472 (M<sup>+</sup>, 24%), 345 (100), 327 (4), 299 (10), 217 (58).

### 3-Methylene-9-oxapentacyclo[9.2.1.0<sup>4,13</sup>.0<sup>5,7</sup>.0<sup>7,12</sup>]tetradecan-8-one **10**

In a sealed tube a solution of diiodide **8** (150 mg, 0.32 mmol) and DBU (150 mg, 0.95 mmol) in toluene (6 mL) was heated at 90 °C for 2 h. It was then poured into ethyl acetate and was extracted with saturated aq. NH<sub>4</sub>Cl. The organic solution was washed with brine, dried over anhydrous MgSO<sub>4</sub>, and concentrated *in vacuo*. **Compound 10** was collected by silica gel column chromatography and elution with CH<sub>2</sub>Cl<sub>2</sub>–hexane (3:1) as a white waxy solid (35 mg, 50%), mp 55–56 °C (Found: C, 77.73; H, 7.47. C<sub>14</sub>H<sub>16</sub>O<sub>2</sub> requires C, 77.75; H, 7.46%);  $\nu_{\max}(\text{KBr})/\text{cm}^{-1}$  2940, 1719;  $\delta_{\text{H}}(\text{CDCl}_3, 200 \text{ MHz})$  0.63 (dd, *J* 5 and 5, 1H), 1.50 (q, *J* 10, 1H), 1.71–1.93 (m, 2H), 2.00–2.09 (m, 1H), 2.15–2.34 (m, 2H), 2.52–2.73 (m, 3H), 2.89–3.13 (m, 2H), 4.34 (dd, *J* 4 and 12, 1H), 4.41 (dd, *J* 4 and 12, 1H), 4.92 (s, 1H), 5.00 (s, 1H);  $\delta_{\text{C}}(\text{CDCl}_3, 50 \text{ MHz}, ^1\text{H-decoupled})$  23.06, 32.51, 33.85, 40.05, 41.02, 44.47, 44.80, 48.64, 50.95, 60.16, 69.43, 108.73, 155.71, 174.12; *m/z* (EI) 217 (M<sup>+</sup> + 1, 82%), 216 (M<sup>+</sup>, 3), 202 (3), 189 (12), 91 (100).

### 3-Methyl-9-oxapentacyclo[9.2.1.0<sup>4,13</sup>.0<sup>5,7</sup>.0<sup>7,12</sup>]tetradec-2-en-8-one **11**

To a solution of **10** (50 mg, 0.23 mmol) in methanol (5 mL) was added a catalytic amount of toluene-*p*-sulfonic acid. The mixture was stirred at room temperature for 20 min, and was evaporated *in vacuo*. The title product was purified by a silica gel column eluted with CH<sub>2</sub>Cl<sub>2</sub>–hexane (4:1), and was collected as a white waxy solid (47.2 mg, 94%), mp 102–103 °C (Found: C, 77.86; H, 7.50. C<sub>14</sub>H<sub>16</sub>O<sub>2</sub> requires C, 77.75; H, 7.46%);  $\nu_{\max}(\text{KBr})/\text{cm}^{-1}$  2940, 1728;  $\delta_{\text{H}}(\text{CDCl}_3, 200 \text{ MHz})$  0.60 (t, *J* 5,

1H), 1.54 (d, *J* 14, 1H), 1.72 (s, 3H), 1.73–1.85 (m, 1H), 1.97–2.04 (m, 2H), 2.46–2.63 (m, 1H), 2.75 (t, *J* 8, 1H), 3.08 (d, *J* 7, 1H), 3.21–3.26 (m, 2H), 4.09 (dd, *J* 6 and 11, 1H), 4.20 (t, *J* 11, 1H), 5.21 (s, 1H);  $\delta_{\text{C}}(\text{CDCl}_3, 50 \text{ MHz}, ^1\text{H-decoupled})$  15.69, 18.53, 32.05, 34.90, 39.83, 40.62, 49.88, 51.70, 57.24, 58.02, 70.54, 131.59, 141.05, 175.18; *m/z* (EI) 216 (M<sup>+</sup>, 12%), 188 (4), 175 (3), 171 (3), 160 (8), 28 (100).

### Crystal structure of **11**

A crystal of size 0.42 × 0.38 × 0.36 mm was subjected to X-ray diffraction analysis. Diffraction data were collected at room temperature on an Enraf-Nonius CAD4 diffractometer with graphite-monomochromated Mo-K $\alpha$  radiation,  $\lambda = 0.71069 \text{ \AA}$ . The unit-cell parameters and orientation matrix were established from a least-squares fit of 25 reflections. Intensity data were collected in the  $\omega$ - $2\theta$  scanning mode with three standard reflections monitored for intensity variation throughout the experiment. No significant variation in standards was observed. The *hkl* ranges were:  $-8 < h < 7$ ,  $0 < k < 9$ ,  $-14 < l < 14$ . Of the 2090 reflections collected ( $2\theta_{\max} = 50^\circ$ ), 1355 unique reflections were considered observed [ $I > 2\sigma(I)$ ] after Lorentz polarization and empirical absorption corrections. The structure was solved by direct methods using NRCVAX<sup>10</sup> and refined by full-matrix least-squares (based on F<sup>2</sup>) using SHELXL-93.<sup>11</sup> All non-hydrogen atoms were refined with anisotropic displacement parameters and all hydrogen atoms were constrained to geometrically calculated positions. The reliability factors converged to  $R_1 = 0.040$ ,  $wR_2 = 0.122$  and  $GOF = 0.78$ .

CCDC reference number 207/332. See <http://www.rsc.org/suppdata/p1/1999/1847> for crystallographic files in .cif format.

### 9-Oxapentacyclo[9.2.1.0<sup>4,13</sup>.0<sup>5,7</sup>.0<sup>7,12</sup>]tetradecane-3,8-dione **12**

In a round-bottom flask (50 mL) a stream of ozone was passed slowly through a solution of enone **10** (60 mg, 0.28 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (10 mL) and methanol (2 mL) at  $-78^\circ\text{C}$  until the solution turned bluish. The solution was quenched by the addition of triphenylphosphine (1.76 g, 0.66 mmol), and was allowed to warm up gradually to room temperature. It was stirred for 6 h, then was concentrated *in vacuo*. **Product 12** was collected (56.2 mg, 93%) as a white waxy solid by silica gel column chromatography and elution with CH<sub>2</sub>Cl<sub>2</sub>. Physical data of **12**: mp 246–247 °C (Found: C, 71.50; H, 6.62. C<sub>13</sub>H<sub>14</sub>O<sub>3</sub> requires C, 71.54; H, 6.47%);  $\nu_{\max}(\text{KBr})/\text{cm}^{-1}$  2976, 1730, 1724;  $\delta_{\text{H}}(\text{CDCl}_3, 200 \text{ MHz})$  0.70 (t, *J* 5, 1H), 1.50 (q, *J* 12, 1H), 1.85–2.07 (m, 2H), 2.24–2.46 (m, 3H), 2.48–2.88 (m, 4H), 3.22–3.34 (m, 1H), 4.35 (dd, *J* 3 and 10, 1H), 4.55 (dd, *J* 3 and 10, 1H);  $\delta_{\text{C}}(\text{CDCl}_3, 50 \text{ MHz}, ^1\text{H-decoupled})$  23.57, 31.79, 34.73, 39.81, 40.05, 41.49, 45.27, 49.53, 54.69, 55.48, 68.96, 173.03, 219.33; *m/z* (EI) 218 (M<sup>+</sup>, 39%), 190 (14), 189 (3), 148 (6), 68 (100).

### 3-Iodomethyl-9-oxapentacyclo[9.2.1.0<sup>4,13</sup>.0<sup>5,7</sup>.0<sup>7,12</sup>]tetradecan-8-one **13**

To a round-bottom flask (25 mL) was added *t*-BuOK (17.8 mg, 0.16 mmol) and anhydrous THF (5 mL) under nitrogen. It was cooled in an ice-bath, then to it was added diiodide **8** (50 mg, 0.11 mmol). The solution was stirred for 1 h at 0 °C, and was quenched by the addition of saturated aq. NH<sub>4</sub>Cl. It was extracted several times with diethyl ether. The ethereal layers were combined, washed with brine, dried over anhydrous MgSO<sub>4</sub>, filtered and concentrated *in vacuo*. **Compound 13** was obtained from silica gel column chromatography and elution with CH<sub>2</sub>Cl<sub>2</sub>–hexane (2:1) as a white waxy solid (21 mg, 55%), mp 238–239 °C (Found: C, 48.98; H, 5.07. C<sub>14</sub>H<sub>17</sub>O<sub>2</sub>I requires C, 48.86; H, 4.98%);  $\nu_{\max}(\text{KBr})/\text{cm}^{-1}$  2912, 1710;  $\delta_{\text{H}}(\text{CDCl}_3, 200 \text{ MHz})$  0.72–0.92 (m, 1H), 1.23–1.34 (m, 1H), 1.50–1.68 (m, 1H), 1.89–2.0 (m, 2H), 2.12–2.54 (m, 6H), 2.71–2.81 (m, 1H), 3.0–3.12 (m, 1H), 3.25–3.32 (m, 2H), 4.31 (d, *J* 12, 1H), 4.53 (d, *J* 12, 1H);  $\delta_{\text{C}}(\text{CDCl}_3, 50 \text{ MHz}, ^1\text{H-decoupled})$  7.17, 29.31,

33.33, 36.00, 37.23, 41.74, 42.61, 44.82, 49.25, 50.96, 52.48, 63.68, 69.47, 174.73; *m/z* (EI) 344 ( $M^+$ , 5%), 217 (49), 189 (45), 171 (43), 131 (67), 91 (100), 79 (67), 67 (32).

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## References

- 1 T.-a. Mitsudo, S.-W. Zhang and Y. Watanabe, *J. Chem. Soc., Chem. Commun.*, 1994, 435.
- 2 T. J. Chow, Y.-S. Hon, C.-C. Jen, S.-S. Liu, J.-H. Chern and K.-J. Lin, *J. Chem. Soc., Perkin Trans. 1*, 1998, 1095.
- 3 (a) T. J. Chow, C.-C. Wei and T.-K. Wu, *J. Org. Chem.*, 1995, **60**, 5651; (b) T. J. Chow, L.-P. Li, V. Y. R. Lee, K.-J. Lin and C.-Y. Chen, *J. Chem. Soc., Perkin Trans. 2*, 1996, 2681; (c) T. J. Chow, T.-K. Wu and H.-J. Shih, *J. Chem. Soc., Chem. Commun.*, 1989, 490; (d) T. J. Chow and T.-K. Wu, *J. Org. Chem.*, 1988, **53**, 1102.
- 4 I. T. Jacobson, (a) *Acta Chem. Scand.*, 1967, **21**, 2235; (b) *Chem. Scr.*, 1974, **5**, 174.
- 5 L. A. Paquette, W. B. Farnham and S. V. Ley, *J. Am. Chem. Soc.*, (a) 1975, **97**, 7273; (b) 1974, **96**, 312; (c) L. A. Paquette, S. V. Ley, S. Maiorana, D. F. Schneider, M. J. Broadhurst and R. A. Boggs, *J. Am. Chem. Soc.*, 1975, **97**, 4658.
- 6 (a) C. Mercier, P. Soucy, W. Rosen and P. Deslongchamps, *Synth. Commun.*, 1973, **3**, 161; (b) P. Deslongchamps, U. O. Cheriyan, Y. Lambert, J.-C. Mercier, L. Ruest, R. Russo and P. Soucy, *Can. J. Chem.*, 1978, **56**, 1687; (c) P. Deslongchamps and P. Soucy, *Tetrahedron*, 1981, **37**, 4385.
- 7 (a) C. Almansa, E. Carceller, A. Moyano and F. Serratosa, *Tetrahedron*, 1986, **42**, 3637; (b) E. Carceller, M. L. Garcia, F. Serratosa, M. Font-Altava and X. Solans, *Tetrahedron*, 1987, **43**, 2147; (c) C. Almansa, E. Carceller, M. L. Garcia, A. Torrent and F. Serratosa, *Synth. Commun.*, 1988, **18**, 381; (d) C. Almansa, E. Carceller, M. L. Garcia and F. Serratosa, *Synth. Commun.*, 1988, **18**, 1079.
- 8 (a) G. Mehta and H. S. Rao, *J. Chem. Soc., Chem. Commun.*, 1986, 472; (b) H. J. Wu and C. Y. Wu, *Tetrahedron Lett.*, 1997, **38**, 2493; G. Mehta and R. Vidya, *Tetrahedron Lett.*, 1997, **38**, (c) 4173; (d) 4177.
- 9 M. Fetizon, M. Golfier and J. M. Louis (a) *Chem. Commun.*, 1969, 1118; (b) *Tetrahedron*, 1975, **31**, 171.
- 10 E. J. Gabe, Y. Lepage, J.-P. Charland, F. L. Lee and P. S. White, *J. Appl. Crystallogr.*, 1989, **22**, 384.
- 11 G. M. Sheldrick, *SHELXL-93, Program for Crystal Structure Refinement*, Univ. of Göttingen, Germany, 1993.

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