Difunctional and Heterocyclic Products from the Ozonolysis of Conjugated C_5–C_8 Cyclodienes

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Ozonolyses of the conjugated C_5–C_8 cyclodienes **1a–d** in methanol, followed by reduction with DMS, have been examined. Monoozonolyses gave the corresponding unsaturated dialdehydes **2e** as the primary products. In subsequent reactions, the dialdehydes **2e** derived from the monoozonolyses of **1a**, **1b**, and **1c** gave in high yields the heterocyclic compounds **7**, **8k**, and **9k**, respectively. Diozonolyses of **1a–d** gave the corresponding dialdehydes **3e** as the primary products. In subsequent reactions, the dialdehydes **3e** derived from **1b** and **1c** gave the heterocyclic compounds **8l** and **9l**, respectively. In addition, aldehydes **2e** and **3e** underwent partial acetalization reactions with methanol.

Introduction

In previous work we had shown that ozone attacks the two double bonds of acyclic conjugated dienes stepwise,[1] in contrast to those of nonconjugated dienes.[2] It was the goal of the present investigation to examine whether this principle can be also applied to the ozonolysis of conjugated cyclodienes. To this end, the cyclodienes **1a–d** have been treated with ca. 1 and 2 molar equiv of ozone in methanol, and the peroxidic primary products were immediately reduced with dimethyl sulfide with the goal of producing the corresponding dialdehydes of structures **2e** and **3e**, respectively.

Monoozonolyses. 1,3-Cyclopentadiene (**1a**) afforded a mixture of **2af** (5%),[3] **4** (52%), *cis*-**7** (15%), and *trans*-**7** (28%). Upon prolonged standing of such mixtures, the selectivity for **7** increased to 90%, viz. 14% of *cis*-**7** and 76% of *trans*-**7**.

1,3-Cyclohexadiene (**1b**) gave a mixture of **2bf** (75%),[3] *cis*-**8k** (6%), *trans*-**8k** (9%), and phenol (**14**, 4%). By addition of catalytic amounts of diisopropylamine to this product mixture, the selectivity for **8k** could be increased to 80%, viz. 33% of *cis*-**8k** and 47% of *trans*-**8k**.

1,3-Cycloheptadiene (**1c**) gave a mixture of **2ce** (18%),[3] **2cg** (78%), *cis*-**9k** (1%), and *trans*-**9k** (2%). By addition of catalytic amounts of diisopropylamine to this product mixture, the selectivity for **9k** could be raised to 54%, viz. 22% of *cis*-**9k** and 32% of *trans*-**9k**. Upon standing at room temperature, either neat or, at a much faster rate, in the presence of HCl/methanol, **2cg** was partly isomerized to give **2cf**.

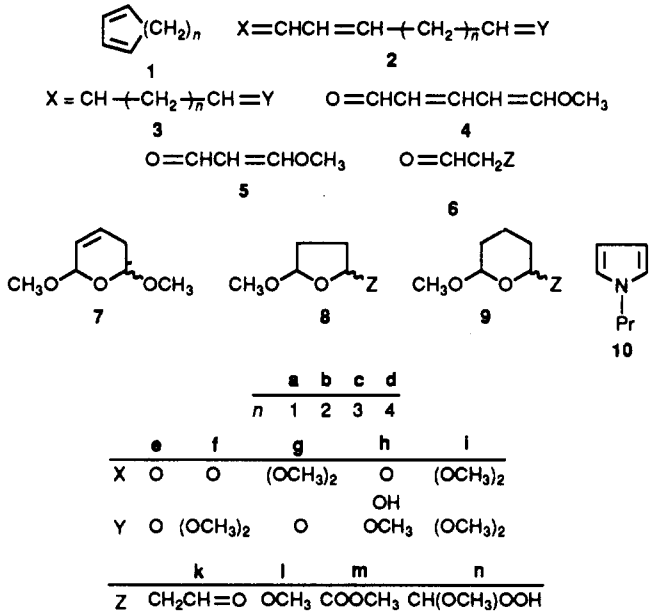
1,3-Cyclooctadiene (**1d**) gave **2de** (32%)[3] and **2dg** (68%). Upon standing at room temperature either as a neat sample or in the presence of HCl/methanol, **2dg** was converted into the isomeric acetal **2df**.

All of the products mentioned above have been isolated and identified by their ^1H NMR and mass spectra. The structure of **7** has been additionally confirmed by hydrogenation of the double bond to give a mixture of *cis*- and *trans*-**9l**.[4]

Diozonolyses. 1,3-Cyclopentadiene (**1a**) gave a mixture of **3af** (12%),[3] **3ai** (2%), **5** (68%), and **6m** (18%). 1,3-Cyclohexadiene (**1b**) afforded **3bf** (25%), **3bi** (22%), *cis*-**8l** (22%), and *trans*-**8l** (31%). When the reduction of the fresh ozonolysis product was carried out in the presence of *n*-propylamine, *N*-*n*-propylpyrrole (**10**) was obtained in 24% yield. 1,3-Cycloheptadiene (**1c**) gave **3cf** (45%), **3ci** (27%), and **9l** (23%); 1,3-cyclooctadiene (**1d**) gave **3df** (28%) and **3di** (69%).

All of the products mentioned above have been isolated and characterized by their ^1H and ^{13}C NMR as well as mass spectra. The structure of **6m**, which could only be obtained in admixture with **3af** and **5**, has been verified with the help of an authentic sample. It was obtained by ozonolysis of methyl 3-butenoate and subsequent reduction of the corresponding ozonide.

The foregoing results show that ozone attack at the double bond systems of the cyclodienes **1a–d** occurs stepwise to give in good selectivities mono- and diozonolysis products. With the exception of phenol (**14**), the formation of monoozonolysis products can be explained via the dialdehydes **2e** as intermediates: The monoacetals **2af**, **2bf**, **2cg**, and **2dg** are formed by partial acetalization of the corresponding dialdehyde **2e** with methanol. Compounds **4**, **7**, **8k**, and **9k** are formed via the corresponding hemiacetals **2h**. Hemiacetal **2ah** affords **7** by intramolecular reaction of the OH group with the remaining CH=O group, followed by acetalization with methanol. In addition, **2ah** gives **4** by dehydration, which is probably favored by the formation of a conjugated diene system.



(1) Griesbaum, K.; Zwick, G. *Chem. Ber.* **1985**, *118*, 3041.
(2) Griesbaum, K.; Mertens, H.; Jung, I.-Ch. *Can. J. Chem.*, submitted for publication.
(3) Selectivities based on GLC analyses. Of the diozonolysis products only those derived from the $=CH(CH_2)_nCH=$ moieties have been accounted for.
(4) Griesbaum, K.; Neumeister, J. *Chem. Ber.* **1982**, *115*, 2697.

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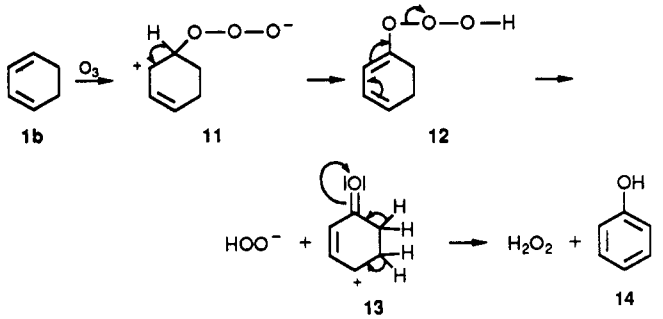
Hemiacetals **2bh** and **2ch** yield **8k** and **9k**, respectively, by intramolecular Michael additions of the OH groups to the respective double bonds. The lack of formation of heterocyclic compounds from cyclooctadiene (**1d**) is probably due to the fact that intramolecular Michael addition of **2dh** would lead to a less favored 7-membered ring system. The formation of the diozonolysis products **3f**, **3i**, **5**, **8l** and **9l** can be explained via the dialdehydes **3e** by reactions analogous to those discussed for the formation of the monoozonolysis products **2**, **4**, and **7**. By analogy with similar results obtained with α,β-unsaturated methoxyhydroperoxides,[5] the formation of **6m** can be rationalized by DMSO-catalyzed dehydration of the peroxidic ozonolysis fragment **6n** during the reduction step.

The formation of small amounts of phenol (**14**) in the monoozonolysis of 1,3-cyclohexadiene (**1b**) can be rationalized by electrophilic attack of ozone at the diene system of **1b** to give the allylic cation **11**, followed by the sequence **11** → **12** → **13** → **14**. A similar mode of reaction, initiated by electrophilic ozone attack, had been formulated for the formation of phenol in the ozonolysis of benzene.[6]



Experimental Section

General Methods. (1) Instruments. ^1H NMR and ^{13}C NMR spectra were recorded in $CDCl_3$ with Me_4Si as internal standard. Unless mentioned otherwise, a Bruker AC 250 instrument, in some cases a Bruker WP 60 instrument, was used. Mass spectra were obtained on a Hewlett-Packard GC/MS system 5985 B. GLC analyses were carried out on a Shimadzu GC-6A instrument using 30 mL/min of nitrogen as carrier gas and the following conditions. Condition 1: glass column, 0.3 × 300 cm, 5% nitrile–silicon oil XE 60 on Chromosorb G; 60–180 °C at 10 °C/min. Condition 2: as condition 1, but 60–160 °C at 4 °C/min. Condition 3: glass column, 0.3 × 500 cm, 5% Carbowax 20 M on Chromosorb G; 60–160 °C at 4 °C/min. High-pressure liquid chromatography (HPLC) separations were carried out on a Siemens model S 100, using Lichrosorb column type Si 60 (3.2 × 12 cm) and 4:1 mixtures of pentane/diethyl ether.

(2) General Procedure for Ozonolysis Reactions. (a) Monoozonolyses. A solution of the respective diene 1 in methanol was treated with 0.7 molar equiv of ozone at −78 °C. Then the appropriate amount of DMS was added; the mixture was warmed up to room temperature and kept for ca. 24 h. A small sample was removed for GLC analysis, and the remaining major portion of the reaction product was concentrated in a rotary evaporator at room temperature and ca. 18 Torr. From the remaining liquid residue the individual reaction products were separated by flash chromatography.

(b) Diozonolyses. A solution of the respective diene 1 in methanol was treated with ozone at −78 °C until the solution turned blue. Dissolved ozone was removed by flushing the solution with nitrogen and the remaining solution was worked up in the same manner as described above. *Caution*: The ozone content in the O_3/O_2 mixture applied in the ozonolysis of conjugated dienes should not exceed ca. 0.45 mmol of O_3 per liter of gas. For, in previous work,[7] it had been found that higher ozone concentrations can lead to explosions.

(3) Conditions for Product Separation by Flash Chromatography.[8] Silica gel 60, 40–63 μm; *n*-pentane/diethyl ether, 4:1, fractions of 50 mL; pressure of 0.5 bar.

Monoozonolysis of 1,3-Cyclopentadiene (1a). A solution of 1.0 g (15.1 mmol) of **1a** in 20 mL of methanol was ozonized and admixed with 0.84 mL of DMS. GLC analysis (condition 1) showed the presence of **2af** (t_R = 14.2 min), **4** (t_R = 15.93 min), *cis*-**7** (t_R = 9.98 min), and *trans*-**7** (t_R = 9.56 min) in relative proportions of 5, 52, 15, and 28% in the fresh sample and of 3, 7, 14, and 76% in the aged sample after it was kept at room temperature for 24 days. Concentration of the reaction product gave 1.80 g of a liquid residue, from which **2af** (30 mg, 2.0%), **4** (300 mg, 24.4%), *cis*-**7** (70 mg, 4.9%), and *trans*-**7** (260 mg, 17.0%) have been isolated by flash chromatography (column 2.5 × 50 cm; 80 g of silica gel).

5,5-Dimethoxy-2-pentenal (2af): colorless liquid; ^1H NMR (60 MHz) δ 2.55–2.77 (m, 2 H), 3.37 (s, 6 H), 4.53 (t, *J* = 5.1 Hz, 1 H), 6.16 (ddt, *J* = 15.8, 7.7, 1.0 Hz, 1 H), 6.85 (dt, 1 H), 9.53 (d, *J* = 7.7 Hz, 1 H); EI-MS *m/e* (relative intensity) 143 (0.4) $(M - 1)^+$, 113 (16) $(M - OCH_3)^+$, 75 (100) $[M - CH(OCH_3)_2]^+$.

5-Methoxy-2,4-pentadienal (4): slightly yellow liquid; ^1H NMR (60 MHz) δ 3.75 (s, 3 H), 5.61–6.30 (m, 2 H), 6.80–7.31 (m, 2 H), 9.48 (d, *J* = 7.9 Hz, 1 H); ^{13}C NMR δ 57.55, 104.83, 127.78, 150.95, 159.86, 193.04; EI-MS *m/e* (relative intensity) 112 (98) M^+, 111 (56) $(M - H)^+$, 82 (59), 81 (100) $(M - OCH_3)^+$.

***cis*-2,6-Dimethoxy-3,4-dihydropyran (*cis*-7)** in admixture with 8% of *trans*-**7**: colorless liquid; ^1H NMR (60 MHz) δ 2.21–2.39 (m, 2 H), 3.47 (s, 3 H), 3.54 (s, 3 H), 4.81–5.04 (m, 2 H), 5.62–5.96 (m, 2 H); ^{13}C NMR δ 29.78 (negative signal in DEPT spectrum), 55.52, 55.56, 95.43, 96.69, 125.42, 125.46; EI-MS *m/e* (relative intensity) 143 (12) $(M - H)^+$, 113 (80) $(M - OCH_3)^+$, 84 (100) $(M - HCOOCH_3)^+$.

***trans*-2,6-Dimethoxy-3,4-dihydropyran (*trans*-7)**: colorless liquid; ^1H NMR (60 MHz) δ 2.08–2.29 (m, 2 H), 3.50 (s, 3 H), 3.54 (s, 3 H), 4.71–5.12 (m, 2 H), 5.69–5.92 (m, 2 H); ^{13}C NMR δ 30.60 (negative signal in DEPT spectrum), 55.28, 56.02, 95.47, 97,18, 125.55, 126.89; EI-MS *m/e* (relative intensity) 143 (2) $(M - H)^+$, 113 (18) $(M - OCH_3)^+$, 84 (100) $(M - HCOOCH_3)^+$. Anal. Calcd for $C_7H_{12}O_3$: C, 58.32; H, 8.39. Found: C, 58.37; H, 8.34.

Hydrogenation of 7. Through a stirred mixture of 0.34 g (2.4 mmol) of **7** (cis:trans ratio 11:89), 30 mL of methanol, and Raney nickel a stream of hydrogen was passed for 2 h. The solvent was removed by distillation to leave a liquid residue. GLC (condition 1) and GC/MS analysis showed the presence of *cis*-**9l** (t_R = 9.50 min; *m/e* 145, 115, 71, 58) and *trans*-**9l** (t_R = 8.73 min; *m/e* 145, 115, 71, 58). The data were identical with those obtained from authentic samples of *cis*- and *trans*-**9l**.[4]

Monoozonolysis of 1,3-Cyclohexadiene (1b). (a) Isolation of 2bf. A solution of 1.0 g (12.5 mmol) of **1b** in 10 mL of methanol was ozonized and admixed with 0.6 g (9.5 mmol) of DMS. GLC analysis (condition 3) of the residue (2.02 g) showed the presence of **2bf** (t_R = 36.8 min), *cis*-**8k** (t_R = 21.60 min), *trans*-**8k** (t_R = 21.15 min) and **14** (t_R = 46.36 min) in relative proportions of 75%, 6%, 9%, and 4%. By preparative thin-layer chromatography (silica gel 60; area 20 × 20 cm; thickness 2 mm; pentane/diethyl ether, 4:1) a sample of impure **2bf** was obtained. By flash chromatography of the latter (column 2.5 × 50 cm, 80 g of silica gel) pure **2bf** (0.45 g, 32.5%) was isolated.

6,6-Dimethoxy-2-hexenal (2bf): colorless liquid; ^1H NMR (60 MHz) δ 1.60–2.00 (m, 2 H), 2.14–2.80 (m, 2 H), 3.34 (s, 6 H), 4.40 (t, *J* = 5.0 Hz, 1 H), 6.12 (ddt, *J* = 15.5, 7.7, 1.3 Hz, 1 H), 6.90 (dt, *J* = 15.5, 6.2 Hz, 1 H), 9.52 (d, *J* = 7.7 Hz, 1 H); ^{13}C NMR (60 MHz) δ 27.75 (t), 30.85 (t), 53.13 (q), 103.80 (d), 133.13 (dd), 157.42 (d), 193.73 (d); EI-MS *m/e* (relative intensity) 158 (0.5) (M^+), 127 (10) $(M - OCH_3)^+$, 75 (100) $[CH(OCH_3)_2]^+$, 69 (34) $(C_4H_5O)^+$, 67 (91) $[M - CH{=}O - (OCH_3)_2]^+$.

(b) Isolation of *cis*-8k, *trans*-8k, and 14. A solution of 2.0 g (24.9 mmol) of **1b** in 20 mL of methanol was ozonized and

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(6) Bailey, P. S. In *Ozonation in Organic Chemistry*; Academic Press; New York, 1982; Vol. II, p 30.
(7) Griesbaum, K.; Keul, H.; Zwick, G. *Chem. Eng. News* **1982**, *60* (8), 63.
(8) Still, W. C., Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

sequentially admixed with 1.2 g (18.9 mmol) of DMS and two drops of diisopropylamine. GLC analysis (condition 3) of the residue (3.20 g) showed the presence of **2bf**, *cis*-**8k**, *trans*-**8k**, and **14** in relative proportions of 15%, 33%, 47%, and 4%. Separation of the residue by flash chromatography (column 4 × 50 cm, 150 g of silica gel) gave **14** (fractions 5–6; 35.0 mg, 1.4%) a 4:96 mixture of *cis*- and *trans*-**8k** (fractions 12–16; 0.62 g, 17.2%), a 50:50 mixture of *cis*- and *trans*-**8k** (fractions 17–21; 0.46 g, 12.7%), and a 80:20 mixture of *cis*- and *trans*-**8k** (fractions 22–27; 0.35 g, 9.7%). Separation of part of fractions 12–16 by flash chromatography (column 2.5 × 50 cm, 80 g of silica gel) gave pure *trans*-**8k** and separation of the second part by preparative HPLC gave a 94:6 mixture of *cis*- and *trans*-**8k**.

***cis*-2-Methoxy-5-(formylmethyl)oxolane (*cis*-8k)**: colorless liquid; ^{1}H NMR (60 MHz) δ 1.50–2.25 (m, 4 H), 2.73 (dd, J = 7.1 and 2.0 Hz, 2 H), 3.32 (s, 3 H), 4.47 (quint, J = 7.1 Hz, 1 H), 5.02 (m, 1 H), 9.84 (t, J = 2.0 Hz, 1 H); EI-MS m/e (relative intensity) 144 (1) M^+, 113 (55) $(M - OCH_3)^+$, 112 (49) $(M - CH_3OH)^+$, 101 (27) $(M - CH_2CH{=}O)^+$, 84 (47) $(M - CH{=}O - CH_3O)^+$, 69 (100) $(M - CH_2CH{=}O - CH_3OH)^+$, 71 (63), 67 (41), 61 (59), 55 (81), 41 (80).

***trans*-2-Methoxy-5-(formylmethyl)oxolane (*trans*-8k)**: colorless liquid; ^{1}H NMR (60 MHz) δ 1.10–2.20 (m, 4 H), 2.65 (dd, J = 6.4 and 2.2 Hz, 2 H), 3.34 (s, 3 H), 4.52 (quint, J = 6.4 Hz, 1 H), 5.04 (m, 1 H), 9.82 (t, J = 2.2 Hz, 1 H); ^{13}C NMR, δ 29.5 (t), 32.0 (t), 49.1 (dt), 54.6 (q), 72.5 (d), 105.1 (d), 200.5 (d); EI-MS m/e (relative intensity) 144 (1) M^+, 113 (43) $(M - OCH_3)^+$, 112 (32) $(M - CH_3OH)^+$, 101 (19) $(M - CH_2CH{=}O)^+$, 84 (39) $(M - CH{=}O - CH_3O)^+$, 69 (91) $(M - CH_2CH{=}O - CH_3OH)^+$, 71 (63), 67 (38), 61 (65), 55 (82), 41 (100). Anal. Calcd for $C_7H_{12}O_3$: C, 58.32; H, 8.39. Found: C, 58.07; H, 8.28.

Phenol (14): colorless liquid; ^{1}H NMR (60 MHz) δ 5.64 (s, 1 H), 6.74–7.40 (m, 5 H); EI-MS m/e (relative intensity) 94 (100) (M^+). The data are identical with those obtained from an authentic sample of **14**.

Monoozonolysis of 1,3-Cycloheptadiene (1c). (a) Isolation of 2ce and 2cg. A solution of 1.0 g (10.6 mmol) of **1c** in 10 mL of methanol was ozonized and admixed with 0.6 g (9.5 mmol) of DMS. GLC analysis (condition 1) of the residue (2.25 g) showed the presence of **2ce** (t_R = 20.29 min), **2cg** (t_R = 16.06 min), *cis*-**9k** (t_R = 14.76 min), and *trans*-**9k** (t_R = 13.44 min) in relative amounts of 18, 78, 1, and 2%. Separation of the residue by flash chromatography (column 4 × 50 cm; 120 g of silica gel) gave **2cg** (fractions 8–11; 0.83 g, 45.3%) and mixtures of **2ce** and **2cg** (fractions 12–19; 0.48 g). Renewed separation of fractions 14–19 (0.35 g) by flash chromatography (column 2.5 × 50 cm, 60 g of silica gel) gave **2ce** (0.14 g, 10.4%).

2-Heptene-1,7-dial (2ce): colorless liquid; ^{1}H NMR (60 MHz) δ 1.71–2.70 (m, 6 H), 6.11 (ddt, J = 15.8, 7.5, and 1.1 Hz, 1 H), 6.85 (dt, J = 15.8 and 6.0 Hz, 1 H), 9.53 (d, J = 7.5 Hz, 1 H), 9.81 (t, J = 1.1 Hz, 1 H); ^{13}C NMR (60 MHz) δ 20.25, 31.82, 42.95, 133.64, 156.48, 193.54, 201.02; EI-MS m/e (relative intensity) 125 (1) $(M - H)^+$, 97 (65) $(M - CH{=}O)^+$, 83 (55) $(M - CH_2CH{=}O)^+$, 70 (100) $(M - CH_2{=}CHCH{=}O)^+$, 55 (59) $(C_3H_3O)^+$.

1,1-Dimethoxy-2-hepten-7-al (2cg): colorless liquid; ^{1}H NMR (60 MHz) δ 1.61–2.60 (m, 6 H), 3.31 (s, 6 H), 5.04 (d, J = 5.3 Hz, 1 H), 5.39–5.71 (m, 2 H), 9.78 (t, J = 1.5 Hz, 1 H); ^{13}C NMR (60 MHz) δ 21.73, 27.34, 43.11, 52.28, 99.49, 127.91, 133.93, 201.94; EI-MS m/e (relative intensity) 171 (1) $(M - H)^+$, 141 (38) $(M - OCH_3)^+$, 97 (95) $[M - CH(OCH_3)_2]^+$, 81 (100).

Isomerization of 2cg. A mixture of 0.50 g (2.9 mmol) of **2cg** and one drop of 1 N HCl/methanol was kept at room temperature for 3 h. Subsequent separation by flash chromatography (column 2.5 × 50 cm, 80 g of silica gel; pentane/diethyl ether, 4:1) afforded **2cf** (0.27 g, 54%). When a neat sample of **2cg** was kept at room temperature for 10 days, GLC analysis (condition 1) showed the presence of 12% of **2cf** in the product mixture.

7,7-Dimethoxy-2-hepten-1-al (2cf): colorless liquid; ^{1}H NMR δ 1.55–1.73 (m, 4 H), 2.33–2.42 (m, 2 H), 3.33 (s, 6 H), 4.38 (t, J = 5.2 Hz, 1 H), 6.13 (ddt, J = 15.6, 7.9, 1.5 Hz, 1 H), 6.85 (dt, J = 15.6, 6.7 Hz, 1 H), 9.51 (d, J = 7.9 Hz, 1 H); ^{13}C NMR δ 22.97, 32.10, 32.14 (negative signals in DEPT spectrum), 52.98, 104.59, 133.34, 157.73, 193.74; EI-MS m/e (relative intensity) 171 (1) $(M - H)^+$, 141 (6) $(M - OCH_3)^+$, 97 (4) $[M - CH(OCH_3)_2]^+$, 75 (100) $[CH(OCH_3)_2]^+$; GLC t_R = 18.57 min (condition 1). Anal. Calcd for $C_9H_{16}O_3$: C, 62.77; H, 9.36. Found: C, 62.67; H, 9.36.

(b) Isolation of *cis*- and *trans*-9k. A solution of 1.0 g (10.6 mmol) of **1c** in 10 mL of methanol was ozonized and admixed with 0.6 g (9.5 mmol) of DMS. At 0 °C two drops of diisopropylamine were added, the mixture was warmed up to room temperature, and the solvent was removed. GLC analysis (condition 1) of the liquid residue (1.95 g) showed the presence of **2ce**, **2cf**, **2cg**, *cis*-**9k**, and *trans*-**9k** in relative amounts of 15, 16, 12, 22, and 32%. Separation of the residue by flash chromatography (column 4 × 50 cm, 120 g of silica gel) gave mixtures of *cis*- and *trans*-**9k** (fractions 5–9; 0.56 g, 33.3%). Renewed separation (column 2.5 × 50 cm, 60 g of silica gel) of fractions 5 + 6 gave pure *trans*-**9k** (160 mg, 9.5%) and of fractions 7–9 gave *cis*-**9k** in admixture with 9% of *trans*-**9k** (86 mg, 5.1%).

***cis*-2-Methoxy-6-(formylmethyl)tetrahydropyran (*cis*-9k)**: colorless liquid; ^{1}H NMR (60 MHz) δ 1.12–1.80 (m, 6 H), 2.54–2.74 (m, 2 H), 3.46 (s, 3 H), 3.72–4.06 (m, 1 H), 4.17–4.38 (m, 1 H), 9.84 (t, J = 2.0 Hz, 1 H); EI-MS m/e (relative intensity) 158 (1) M^+, 127 (13) $(M - OCH_3)^+$, 126 (33) $(M - CH_3OH)^+$, 98 (34) $(M - OCH_3 - CH{=}O)^+$, 61 (100), 58 (51), 43 (30) $(CH_2CH{=}O)^+$, 29 (35) $(CH{=}O)^+$.

***trans*-2-Methoxy-6-(formylmethyl)tetrahydropyran (*trans*-9k)**: colorless liquid; ^{1}H NMR δ 1.54–1.92 (m, 6 H), 2.39–2.64 (m, 2 H), 3.36 (s, 3 H), 4.24–4.35 (m, 1 H), 4.69 (s, 1 H), 9.82 (dd, J = 2.2 and 1.7 Hz, 1 H); ^{13}C NMR δ 17.89, 29.36, 31.05, 49.78, 54.68, 64.23, 98.56, 201.00; EI-MS m/e (relative intensity) 158 (1) (M^+), 127 (100) $(M - OCH_3)^+$, 85 (25) $(M - OCH_3 - CH_2CH{=}O)^+$. Anal. Calcd for $C_8H_{14}O_3$: C, 60.74; H, 8.92. Found: C, 60.28; H, 8.72.

Monoozonolysis of 1,3-Cyclooctadiene (1d). A solution of 2.0 g (18.4 mmol) of **1d** in 20 mL of methanol was ozonized at −50 °C and admixed with 1.0 g (15.7 mmol) of DMS. GLC analysis (condition 1) of the residue (4.05 g) showed the presence of **2de** (t_R = 23.51 min) and **2dg** (t_R = 21.84 min) in relative amounts of 32 and 68%. Separation of the residue by flash chromatography (column 4 × 50 cm, 150 g of silica gel) gave **2de** in 87% purity (fractions 13–27; 0.5 g) and **2dg** in 92% purity (fractions 6–10; 2.2 g). Renewed separation of fractions 6–10 by flash chromatography (column 2.5 × 50 cm, 80 g of silica gel) gave **2dg** (1.56 g, 46.1%). Separation of fractions 13–27 by preparative HPLC gave **2de** (0.25 g, 9.8%).

2-Octene-1,8-dial (2de): ^{1}H NMR δ 1.44–1.76 (m, 4 H), 2.24–2.53 (m, 4 H), 6.13 (ddt, J = 15.6, 7.9, 1.4 Hz, 1 H), 6.85 (dt, J = 15.6, 6.8 Hz, 1 H), 9.51 (d, J = 7.9 Hz, 1 H), 9.79 (t, J = 1.5 Hz, 1 H); ^{13}C NMR δ 21.54, 23.38, 32.39, 43.52, 133.38, 157.35, 193.72, 201.65; EI-MS m/e (relative intensity) 139 (2) $(M - H)^+$, 111 (11) $(M - CH{=}O)^+$, 96 (50) $(M - C_2H_4O)^+$, 55 (44) $(C_3H_3O)^+$, 41 (62), 39 (58), 29 (62) $(CH{=}O)^+$, 28 (100) $(CO)^+$.

1,1-Dimethoxy-2-octen-8-al (2dg): colorless liquid; ^{1}H NMR δ 1.38–1.50 (m, 2 H), 1.60–1.72 (m, 2 H), 2.07–2.40 (m, 2 H), 2.41–2.47 (m, 2 H), 3.31 (s, 6 H), 5.07 (dd, J = 6.3 and 1.1 Hz, 1 H), 5.45 (ddt, J = 11.2, 6.3, 1.4 Hz, 1 H), 5.64 (ddt, J = 11.2, 7.4, 1.1 Hz, 1 H), 9.77 (t, J = 1.7 Hz, 1 H); ^{13}C NMR δ 21.67, 27.76, 28.84, 43.66, 52.24, 52.50, 99.55, 127.19, 134.63, 202.17; EI-MS m/e (relative intensity) 122 (26) $(M - 2CH_3OH)^+$, 94 (42), 68 (91), 67 (96), 55 (43), 41 (61), 39 (70), 32 (21) $(CH_3OH)^+$, 29 (70) $(CH{=}O)^+$, 28 (100) $(CO)^+$.

Isomerization of 2dg. A mixture of 0.80 g (43 mmol) of **2dg** and 1 drop of 1 N HCl/methanol was kept at room temperature for 2 h. Subsequent separation by flash chromatography (column 2.5 × 50 cm, 80 g of silica gel; pentane/diethyl ester, 4.5:1) gave **2df** (0.50 g, 62%). When a neat sample of **2dg** was kept at room temperature for 5 days, ^{1}H NMR analysis showed only the signals of **2df**.

8,8-Dimethoxy-2-octen-1-al (2df): colorless liquid; ^{1}H NMR δ 1.37–1.67 (m, 6 H), 2.31–2.41 (m, 2 H), 3.32 (s, 6 H), 4.37 (t, J = 5.6 Hz, 1 H), 6.12 (ddt, J = 15.6, 7.9, 1.5 Hz, 1 H), 6.86 (dt, J = 15.6 and 6.8 Hz, 1 H), 9.51 (d, J = 7.9 Hz, 1 H); ^{13}C NMR δ 38.09, 40.76, 44.14, 44.31, 59.19, 97.20, 118.29, 136.59, 162.84; EI-MS m/e (relative intensity) 155 (1) $(M - OCH_3)^+$, 111 (3) $[M - CH(OCH_3)_2]^+$, 75 (100) $[CH(OCH_3)_2]^+$; GLC t_R = 21.84 min (condition 1).

Diozonolysis of 1,3-Cyclopentadiene (1a). A solution of 1.0 g (15.1 mmol) of **1a** in 30 mL of methanol was ozonized and admixed with 2.4 mL of DMS. GLC analysis (condition 1) of the residue (1.9 g) showed the presence of **3af** (t_R = 8.43 min), **3ai** (t_R = 9.43 min), **5** (t_R = 9.98 min), and **6m** (t_R = 6.67 min) in

relative amounts of 12, 2, 68, and 18%. Separation of the residue by flash chromatography (column 2.5 × 50 cm, 80 g of silica gel) gave **3af** (fractions 7 and 8; 107 mg, 6%), **3ai** (fraction 6; trace amounts only), **5** (fractions 15–17; 547 mg, 42%), and a mixture of **3af**, **5**, and **6m** (fractions 9–14; 260 mg).

3,3-Dimethoxypropanal (3af): colorless liquid; ^{1}H NMR (60 MHz) δ 2.73 (dd, J = 5.5 and 2.2 Hz, 2 H), 3.38 (s, 6 H), 4.85 (t, J = 5.5 Hz, 1 H), 9.75 (t, J = 2.2 Hz, 1 H); ^{13}C NMR (60 MHz) δ 47.25, 53.29, 100.64, 199.28; EI-MS m/e (relative intensity) 118 (2) (M^+), 87 (42) $(M - OCH_3)^+$, 75 (100) $[CH(OCH_3)_2]^+$.

1,1,3,3-Tetramethoxypropane (3ai): colorless liquid; ^{1}H NMR (60 MHz) δ 1.92 (t, J = 6.0 Hz, 2 H), 3.34 (s, 12 H), 4.49 (t, J = 6.0 Hz, 4 H). The data were consistent with those of an authentic sample.

3-Methoxy-2-propenal (5): colorless liquid; ^{1}H NMR (60 MHz) δ 3.79 (s, 3 H), 5.62 (dd, J = 12.6 and 7.9 Hz, 1 H), 7.42 (d, J = 12.6 Hz, 1 H), 9.39 (d, J = 7.9 Hz, 1 H); ^{13}C NMR (60 MHz) δ 57.96 (q), 109.62 (dd), 171.09 (d), 191.07 (d); EI-MS m/e (relative intensity) 86 (65) (M^+), 85 (100) $(M - H)^+$, 54 (17) $(M - CH_3OH)^+$, 29 (36) $(CH{=}O)^+$. ^{1}H NMR and MS data were consistent with those reported.[9,10]

Preparation of (Formylmethyl)propionate (6m). A solution of 0.50 g (5 mmol) of methyl 3-butenoate in 10 mL of pentane was treated with ozone at −78 °C until it turned blue. Excess ozone was flushed out with nitrogen, and the solvent was removed at room temperature and 18 Torr. To the liquid residue (0.74 g) was added dropwise 0.31 g of DMS. After 1 h, the mixture was distilled at room temperature (10^{-3} Torr) into a trap cooled to −25 °C to give 0.20 g of **6m**: ^{1}H NMR δ 3.42 (d, J = 2.4 Hz, 2 H), 3.79 (s, 3 H), 9.82 (t, J = 2.4 Hz, 1 H); ^{13}C NMR, δ 48.36 (t), 52.36 (q), 167.22 (s), 194.60 (d); EI-MS m/e (relative intensity) 102 (13) (M^+), 71 (63) $(M - OCH_3)^+$, 43 (100) $(M - COOCH_3)^+$; GLC t_R = 6.67 min (condition 1). GLC and GC/MS analysis of the impure **6m**, which was isolated from the diozonolysis product of **1a**, gave the same data.

Diozonolysis of 1,3-Cyclohexadiene (1b). (a) Isolation of 3bf, 3bi, and 8l. A solution of 2.0 g (25 mmol) of **1b** in 20 mL of methanol was ozonized and admixed with 3.4 g (54 mmol) of DMS. GLC analysis (condition 1) of the residue (3.5 g) showed the presence of **3bf** (t_R = 10.28 min), **3bi** (t_R = 11.43 min), *cis*-**8l** (t_R = 7.05 min), and *trans*-**8l** (t_R = 6.09 min) in relative amounts of 25, 22, 22, and 31%. Separation of the residue by flash chromatography (column 4.0 × 50 cm, 150 g of silica gel) gave **3bf** (fractions 14–18; 0.4 g, 12%), **3bi** (fractions 9–11; 0.49 g, 11%), and a mixture of *cis*- and *trans*-**8l** (fractions 4 and 5; 1.55 g, 47%).

4,4-Dimethoxybutanal (3bf): colorless liquid; ^{1}H NMR (60 MHz) δ 1.74–2.65 (m, 4 H), 3.34 (s, 6 H), 4.39 (t, J = 5.4 Hz, 1 H), 9.78 (t, J = 1.5 Hz, 1 H); ^{13}C NMR δ 25.49, 38.89 (negative signals in DEPT spectrum), 53.49, 103.92, 201.69; EI-MS m/e (relative intensity) 101 (34) $(M - OCH_3)^+$, 75 (100) $[CH(OCH_3)_2]^+$.

1,1,4,4-Tetramethoxybutane (3bi): colorless liquid; ^{1}H NMR (60 MHz) δ 1.66 (t, J = 2.6 Hz, 4 H), 3.32 (s, 12 H), 4.38 (m, 2 H); ^{13}C NMR δ 27.61 (t, negative signal in DEPT spectrum), 52.77 (q), 104.30 (d); EI-MS m/e (relative intensity) 147 (10) $(M - OCH_3)^+$, 115 (86) $(M - OCH_3 - CH_3OH)^+$, 75 (100) $[CH(OCH_3)_2]^+$.

***cis*- and *trans*-2,5-dimethoxytetrahydrofuran (8l)** have been assigned based on the identity of their GLC/MS data (m/e 132, 101, 72, 71, 69, 59, 57) with those of authentic samples.

(b) Formation and Isolation of 10. A solution of 1.0 g (12.5 mmol) of **1b** in 10 mL of methanol was ozonized and sequentially admixed with 1.80 g (29 mmol) of DMS and 0.74 g (12.5 mmol) of *n*-propylamine. Separation of the residue (1.88 g) by flash chromatography (column 2.5 × 50 cm, 80 g of silica gel) gave 0.32 g (24%) of **10**.

***N*-*n*-Propylpyrrole (10)**: yellowish liquid; ^{1}H NMR δ 0.90 (t, J = 7.3 Hz, 3 H), 1.78 (m, 2 H), 3.83 (t, J = 7.3 Hz, 2 H), 6.13 (t, J = 2.1 Hz, 2 H), 6.65 (t, J = 2.1 Hz, 2 H); ^{13}C NMR δ 24.91, 51.42 (negative signals in DEPT spectrum), 11.38, 107.84, 120.57; GLC t_R = 7.50 min (condition 1).

Diozonolysis of 1,3-Cycloheptadiene (1c). A solution of 1.0 g (10.6 mmol) of **1c** in 10 mL of methanol was ozonized and admixed with 1.67 g (26.8 mmol) of DMS. GLC analysis (condition 1) of the residue (1.90 g) showed the presence of **3cf** (t_R = 12.5 min), **3ci** (t_R = 12.90 min), *cis*-**9l** (t_R = 9.45 min), and *trans*-**9l** (t_R = 8.73 min) in relative amounts of 45, 27, 9, and 14%. Separation of the residue by flash chromatography (column 2.5 × 50 cm, 80 g of silica gel) gave **3cf** (fractions 14–17; 496 mg, 32%), **3ci** (fractions 8–11; 326 mg, 16.3%), *cis*-**9l** (in admixture with 44% of *trans*-**9l**; fraction 5; 120 mg, 7.7%), and *trans*-**9l** (in admixture with 12% of *cis*-**9l**; fraction 4; 160 mg, 10.3%).

5,5-Dimethoxypentanal (3cf): colorless liquid; ^{1}H NMR (60 MHz) δ 1.58–1.78 (m, 4 H), 2.45–2.52 (m, 2 H), 3.32 (s, 6 H), 4.32–4.40 (m, 1 H), 9.78 (t, J = 1.5 Hz, 1 H); ^{13}C NMR, δ 17.28 (t), 39.90 (t), 43.54 (dt), 52.90 (q), 104.29 (d), 202.17 (d); EI-MS m/e (relative intensity) 115 (17) $(M - OCH_3)^+$, 75 (100) $[CH(OCH_3)_2]^+$, 71 (44) $[(CH_2)_3CH{=}O]^+$.

1,1,5,5-Tetramethoxypentane (3ci): colorless liquid; ^{1}H NMR (60 MHz) δ 1.40–1.84 (m, 6 H), 3.32 (s, 12 H), 4.19–4.52 (m, 2 H); ^{13}C NMR (60 MHz) δ 19.78 (t), 32.30 (t), 52.65 (q), 104.58 (d); EI-MS m/e (relative intensity) 129 (17) $(M - CH_3O - CH_3OH)^+$, 75 (100) $[CH(OCH_3)_2]^+$. The above data are identical with those obtained from an authentic sample.[4]

***cis*- and *trans*-2,6-dimethoxytetrahydropyrans (9l)** have been identified based on the identity of their GLC retention times and their EI-MS data with those of authentic samples.

Diozonolysis of 1,3-Cyclooctadiene (1d). A solution of 1.50 g (13.9 mmol) of **1d** in 10 mL of methanol was ozonized at −50 °C and admixed with 1.90 g (30.1 mmol) of DMS. GLC analysis (condition 1) of the residue (2.70 g) showed the presence of **3df** (t_R = 13.80 min) and **3di** (t_R = 14.55 min) in relative amounts of 28 and 69%, along with an unidentified peak. Separation by flash chromatography (column 4 × 50 cm, 120 g of silica gel) gave **3df** (fractions 9–14; 377 mg, 16.9%) and **3di** (fractions 4 and 5; 1.17 g, 40.9%).

6,6-Dimethoxyhexanal (3df): colorless liquid; ^{1}H NMR (60 MHz) δ 1.32–1.72 (m, 6 H), 2.42–2.50 (m, 2 H), 3.32 (s, 6 H), 4.22–4.51 (m, 1 H), 9.78 (t, J = 1.6 Hz, 1 H); ^{13}C NMR δ 21.95, 24.21, 32.36, 43.83 (negative signals in DEPT spectrum), 52.84, 104.41, 202.39; EI-MS m/e (relative intensity) 129 (6) $(M - OCH_3)^+$, 75 (100) $[CH(OCH_3)_2]^+$, 29 (15) $(CH{=}O)^+$.

1,1,6,6-Tetramethoxyhexane (3di): colorless liquid; ^{1}H NMR (60 MHz) δ 1.30–1.71 (m, 8 H), 3.31 (s, 12 H), 4.30–4.39 (m, 2 H); ^{13}C NMR δ 24.50 (t), 32.45 (t) (negative signals in DEPT spectrum), 52.64 (q), 104.53 (d); EI-MS m/e (relative intensity) 143 (14) $(M - OCH_3 - CH_3OH)^+$, 75 (100) $[CH(OCH_3)_2]^+$.

Registry No. **1a**, 542-92-7; **1b**, 592-57-4; **1c**, 4054-38-0; **1d**, 1700-10-3; **2af**, 2203-39-6; **2bf**, 129732-27-0; **2ce**, 129732-28-1; **2cf**, 129732-34-9; **2cg**, 129732-29-2; **2de**, 105582-16-9; **2df**, 129732-35-0; **2dg**, 129732-32-7; **3af**, 19060-10-7; **3ai**, 102-52-3; **3bf**, 56681-97-1; **3bi**, 6922-39-0; **3cf**, 50789-30-5; **3ci**, 4454-02-8; **3df**, 55489-11-7; **3di**, 54286-89-4; **4**, 129732-33-8; **5**, 4652-35-1; **6m**, 63857-17-0; *cis*-**7**, 129756-58-7; *trans*-**7**, 129756-59-8; *cis*-**8k**, 129732-25-8; *trans*-**8k**, 129732-26-9; *cis*-**8l**, 13269-48-2; *trans*-**8l**, 13269-49-3; *cis*-**9k**, 129732-30-5; *trans*-**9k**, 129732-31-6; *cis*-**9l**, 26243-73-2; *trans*-**9l**, 26243-74-3; **10**, 5145-64-2; **14**, 108-95-2.

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