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A VERSATILE REGIO- AND STEREOSPECIFIC ANNULATION METHOD - I.

PREPARATION OF 1-ETHOXY-OXATRICYCLO[4.2.1.$0^{4,8}$]NONAN-7-ONE DIMETHYLKETALS AND HOMOLOGUE SYSTEMS

Edda Gössinger* and Renate Müller

Institut für Organische Chemie der Universität Wien, A-1090 Wien, Währingerstraße 38

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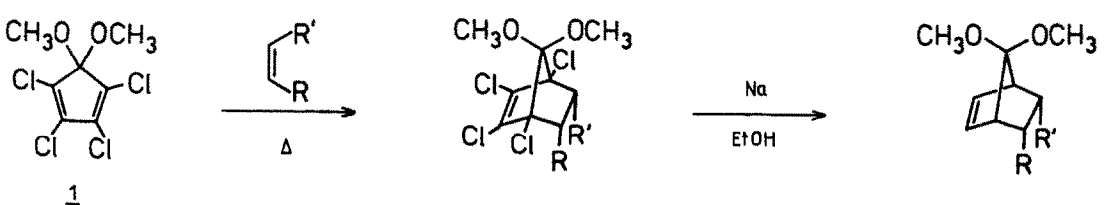
Abstract: The preparation of the title compounds is easily accomplished by cycloaddition of 1,2,3,4-tetrachloro-5,5-dimethoxycyclopentadiene with allylic and homoallylic alcohols yielding tetrachloronorbornene carbinols and their homologues resp., which cyclize under basic conditions by nucleophilic addition to the strained double bond. Dechlorination is achieved by simultaneous or subsequent treatment with sodium in refluxing ethanol. The range and limitations of this reaction sequence are discussed and the dependence of the reaction rate of the intramolecular nucleophilic addition on the structure, the nucleophilicity of the anionic entity and the presence of the chlorine atoms are demonstrated.

Introduction

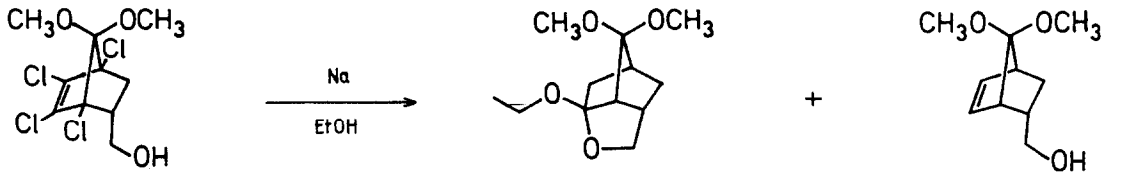
Cycloaddition of 1,2,3,4-tetrachloro-5,5-dimethoxycyclopentadiene 1 to olefins yields tetrachloronorbornene derivatives[1]. This products are easily converted to norbornenes by reductive dechlorination[2].



1

scheme 1

However, attempts to reduce the adduct of **1** and allylalcohol with sodium in refluxing ethanol[2e] led mainly to the tricyclic compound **3** and but small amounts of the expected product[3] **4**.



2 **3** **4**

scheme 2

With diketal **3** a structural type with several stereocenters is stereospecifically synthesized within two simple steps starting with easily available symmetrical substrates and cheap reagents. This is a very advantageous premise for the synthesis of complex, low-molecular-weight molecules. Especially so, because the substitution pattern (β-diketal) and the high energy of strain of 1-ethoxy-2-oxatricyclo[4.2.1.$0^{4,8}$]nonan-7-one dimethylketal **3** should permit facile fragmentation to stereospecifically substituted monocyclic compounds in analogy to simpler bridged systems[4,5]. By this reaction sequence starting with an olefin and yielding a monocyclic compound, a new stereospecific annulation method is achieved. Compared with other annulation methods based on Diels-Alder reaction and fragmentation of the bridged adducts, this new one has the following advantages:

- Monosubstituted and cis-disubstituted olefins add exclusively endo to the reactive 1,2,3,4-tetrachloro-5,5-dimethoxycyclopentadiene **1**, thus yielding but one stereoisomer.
- Addition of **1** to olefins is a borderline case between a neutral[6] and an inverse[12] Diels-Alder reaction, permitting the addition of unactivated olefins so that a very wide range of olefins can be used at moderate reaction conditions.
- Although highly substituted, the tetrachlorodimethoxynorbornene part of the cycloadducts is stable against a variety of reagents (e.g. oxidation and reduction agents, bases, organometallic compounds and even aqueous acids[7]), permitting a diversity of modifications in that part of the cycloadduct arising from the dienophile.

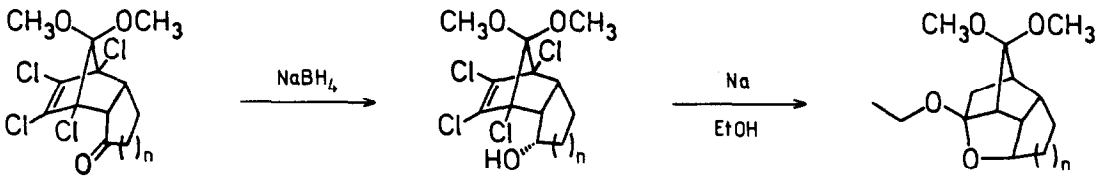
The above mentioned reasons motivated us to test the applicability of the newly found reaction sequence. Therefore adducts derived from **1** with allylic alcohols, 3-buten-1-ol and acrylic acid were prepared. The reaction sequence proceeding under the condition of reductive dechlorination was examined in order to optimize the preparation of the doubly bridged compounds.

Results and Discussion

Cycloadditions of **1** with allylalcohol, 3-buten-1-ol[8], and (Z)-2-hexen-1-ol[9] were achieved in high yields by reaction of the neat substances at 130°C - 140°C. To obtain the stereoselectively pure compounds **12** and **15**

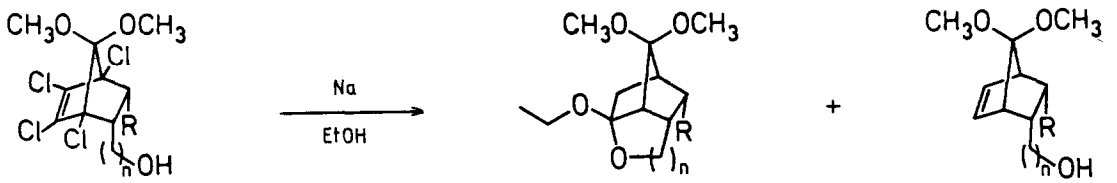
2-cyclohexenone[10] and 2-cyclopentenone respectively were chosen as dienophiles. 2-Cyclohexenone cyclized with 1 at 130°C to the tricyclic compound 11. Under the same conditions 1 and 2-cyclopentenonewere converted to 14 in but moderate yields (30%). However, decrease of temperature to 115°C increased the yield of 14 to acceptable 79%. The tricyclic ketones 11 and 14 were transformed stereoselectively to the endo alcohols 12 and 15 respectively with sodium borohydride. Acrylic acid reacted with 1 faster than the above mentioned dienophiles leading to acid 17[14b] in good yields. The limitations of cycloaddition with 1 are, as M.E.Jung[11] pointed out already, in the use of trisubstituted olefins. The use of Lewis acids does not improve these cycloadditions noticeably, which is in agreement with an inverse Diels-Alder reaction[12]. - At elevated temperatures 1 reacts violently with bases[13], so that the use of allylic amines should be avoided.

The alcohols 2, 5, 8, 12, 15 and the acid 17 were treated with sodium in refluxing ethanol[2e] under the same conditions. The following products were isolated (scheme 3):

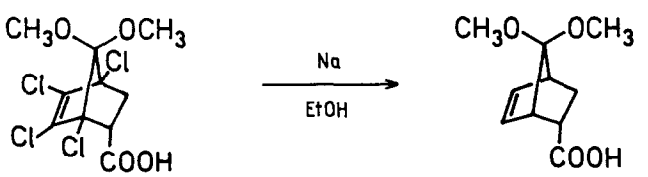


11 n = 2 12 13

14 n = 1 15 16



2	n = 1	R = H	3	4 : 1	4
5	n = 1	R = C_3H_7	6	2,5 : 1	7
8	n = 2	R = H	9	0,4 : 1	10

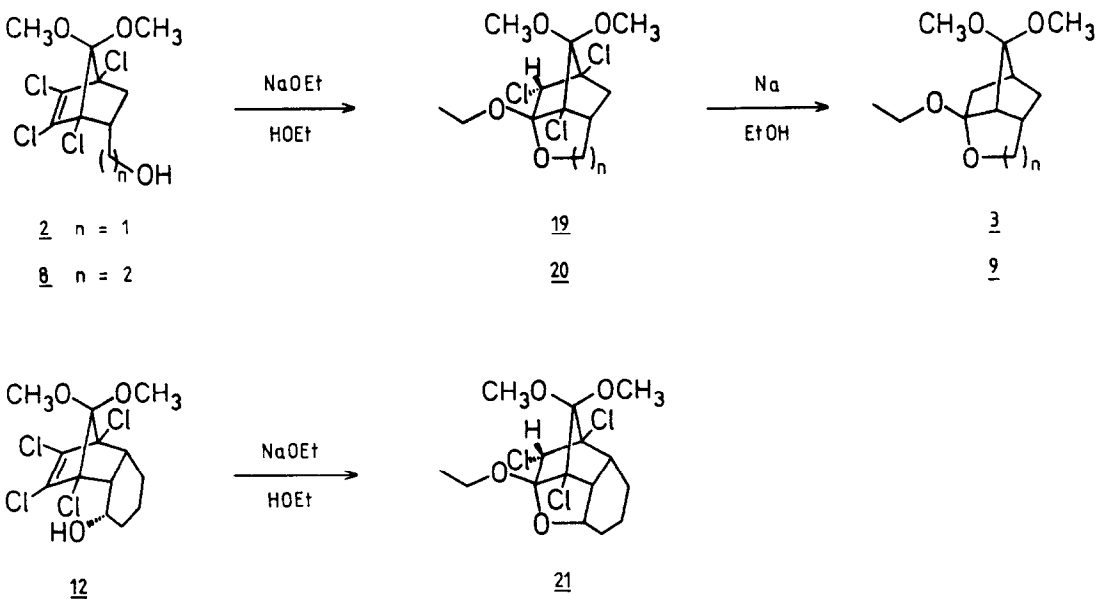


17 18

scheme 3

Structure determination of the resulting products was based on spectroscopic data. Lack of signals of olefinic protons in the ^{1}H-NMR-and the IR-spectra as well as the presence of signals of an ethoxy group in the ^{1}H-NMR spectrum indicated an addition to the double bond in compounds **3**, **6**, **9**, **13**, and **16**. Furthermore, the shift of the 16 line pattern of the diastereotopic α-protons of the ethoxy group showed that it has to be part of an ether or ketal group, and the pattern of the signal itself that it is close to a chiral center. Neither a hydroxy group nor chlorine atoms were encountered. Therefore ring closure and subsequent substitution of the geminal chlorine by ethoxide were assumed. The coupling constants of the protons of the norbornane part indicated that the cyclization has led to the five membered heterocycle in the case of compounds **3**, **6**, **13**, and **16**, and to the six-membered heterocycle in compound **9**.

The ratio of cyclized products (**3**, **6** and **9** resp.) to norbornene derivatives (**4**, **7** and **10** resp.) shifted in favour of the cyclized products, if the period of sodium addition was extended, thus indicating that the cyclization is a concurring reaction to the reductive dechlorination. Obviously this reaction is base initiated. To test this assumption the tetrachloronorbornene derivatives **2**, **8**, and **12** were treated with sodium ethoxide in refluxing ethanol. The conversion to products **19**, **20**, and **21** was completed within 4 hours, 12 hours, and 10 minutes respectively (scheme 4).



2 n = 1
8 n = 2

19
20

3
9

12

21

scheme 4

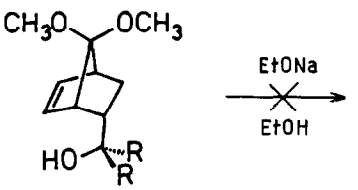
The long range coupling of the proton in geminal position to the chlorine atom with the exo proton at C-6 in the ^{1}H-NMR spectrum proved that the proton of the solvent attacked the exo side of the norbornene, exclusively.

Thus, the reaction, which proceeds in protic solvents under basic conditions, is a nucleophilic trans addition to the double bond followed by substitution of the geminal chlorine atom of the newly formed, α-chloroether by ethoxide. This was confirmed by the recently published cyclization of the adduct of 1 and methacrylic amide under basic conditions (Thompson et al.[14]).

To transform this reaction sequence in a preparative method the adducts of 1 and allylicalcohols as well as 3-buten-1-ol were pretreated with sodium ethoxide and by subsequent addition of sodium converted to 1-ethoxy-2-oxatricyclo[4.2.1.$0^{4,8}$]nonan-7-one dimethylketals 3 and 6, and 1-ethoxy-2-oxatricyclo[5.2.1.$0^{5,9}$]-decan-8-one dimethylketal 9 respectively in good to excellent yields.

Normally nucleophilic addition to the isolated double bond is not or only under forcing conditions to achieve[15]. But in the cases under discussion several favourable factors are responsible for the comparatively mild conditions.

The inductive effect of the chlorine atoms renders the double bond electron deficient, thus facilitating the nucleophilic attack. The negative charge which develops at the vicinal carbon atom during nucleophilic attack is stabilized by the chlorine atom attached to this carbon atom[16]. The importance of the presence of the chlorine atoms could be demonstrated. The dechlorinated compound 4 did not cyclize under the same reaction conditions even with prolonged reaction times. Compound 22, although altered by the adaption of the geminal dimethyl groups (Ingold-Thorpe effect), did not undergo nucleophilic addition under identical reaction conditions.



4 R = H

22 R = CH_3

scheme 5

Nucleophilic additions to polyhalogenated double bonds are known[17,21], but to our knowledge the reactions under discussion and Thompson's results[14] are the first examples of nucleophilic attack to a vicinal dichloroolefin under moderate conditions.

The facility of this nucleophilic addition is attributable to the fact that this is an intramolecular reaction (we were unable to detect products deriving from concurring intermolecular addition of ethoxide under these reaction conditions) and to the high reactivity of the norbornene double bond[28].

To which extent different factors are contributing to the acceleration of intramolecular reaction compared to intermolecular ones is subject to controversal explanations[22-26].

In the reactions under discussion the inflexibility of the bridged molecules[27], the short distance as well as the stereoelectronically favourable position of nucleophile and double bond[29], strain release and/or reduction of repulsive forces in the late transition state[18,19,24] promote the reaction rate.

The difference in the ratios of cyclization product to norbornene derivative in the first (five) examples in scheme 3 seems mainly to reflect the entropic parameters, as the ratios increase with the decrease in numbers of rotational degrees of freedom. But to answer this question would imply to verify more than one assumption. For example: i) The rate of the dechlorination is similar in each case; in a rough approximation this seems to be the case as the same tendency is found in the rate of cyclization of **2** to **19**, **8** to **20**, and **12** to **21** with sodium ethoxide in ethanol (scheme 4). ii) The cyclization is either a concerted reaction as was proven for the nucleophilic intramolecular addition to the isolated double bond[18,19,20] or a retro- E1cB- reaction with slow rate of nucleophilic addition and fast protonation step as H.F. Koch et al.[17] have ascertained for the nucleophilic attack on polyhalogenated olefins and A.J. Kirby et al.[18] for the intramolecular addition to the monosubstituted triple bond. iii) The consecutive substitution reaction is not rate determining.

In the last example of scheme 3 the failure to cyclize acid **17** is attributable to the weaker nucleophilicity (basicity) of the carboxylate anion compared with the alcoholate, because steric hindrance and entropic factors can be excluded as main causes by comparison with Thompson's results[14].

Conclusion

We developed a simple method to prepare 1-ethoxy-2-oxatricyclo[4.2.1.$0^{4,8}$]nonan-7-one dimethylketals and one homologue, which are convenient intermediates for the preparation of stereospecifically substituted cyclopentanone and cyclohexanone derivatives[30]. The range and limitations of this reaction sequence consisting of a Diels-Alder reaction, nucleophilic addition to the double bond and consecutive substitution of the chlorine atom of the α-chloroether with ethoxide were demonstrated. The dependence of the reaction rate on the structure of the compounds, on the nucleophilicity of the addend, and the existence of the chlorine atoms attached to the olefin were demonstrated.

Experimental

General notes: ^{1}H-NMR- and ^{13}C-NMR spectra were recorded on a Bruker Spectrospin WM 250 (250 MHz). Tetramethylsilane served as internal standard. Mass spectra were recorded on a spectrometer CH-7 (Varian) and IRspectra on a Perkin Elmer 377 spectrometer. The data of the recorded IRspectra are reproduced only in part for substances with significant bands. Melting points were obtained using a Reichert "Kofler" hot stage microscope and are uncorrected. Adsorption chromatography was conducted on silica gel (70-230 mesh ASTM, Merck) or aluminium oxide 90 standardized acc. to Brockmann (70-230 mesh ASTM, Merck). Silica gel (230-400 mesh ASTM, Merck) was used for flash chromatography.

General procedure: According to B.V.Lap and M.N.Paddon-Row[2e] 50 equ. sodium in small pieces were added to a refluxing solution (0.2M) of 1 equ. tetrachloronorbornene derivative in ethanol within 2 h. 45 min after starting the reaction an additional amount of 15% of the original amount of ethanol was added and again after 75 min to maintain stirring. After the addition of sodium was finished (2 h) the refluxing was continued for 1 hr. The cooled mixture was treated with crushed ice. After the ice had melted the solution was extracted six times with dichloromethane. The org. layers were washed with brine, dried over $MgSO_4$ and the solvent evaporated. The resulting reaction mixture was purified by chromatography on silica gel.

(±)-(1S*,4R*,5R*)-1,2,3,4-Tetrachloro-5-hydroxymethylbicyclo[2.2.1]hept-2-en-7-one dimethyl-

ketal (2): 1 (8.3g; 32mmol), allyl alcohol (1.74g; 30mmol), and a trace of hydroquinone were heated under an atmosphere of argon in a sealed tube at 140°C for 70 h. The reaction mixture was distilled (Kugelrohr; 0.02mm) and the resulting crystals recrystallized from petroleum ether : diethyl ether yielding 2 (8.4g; 82%). Instead of distillation and crystallization purification by chromatography on silica gel with petroleum ether : diethyl ether = 1 : 1 is possible. **IR(CCl_4)(cm^{-1}):** 3640, 3630. **^{1}H-NMR($CDCl_3$)(δ):** 1.58(1H)(exchangeable with D_2O) O-H; 1.65(dd)(1H) $J_{6,6}$= 11.5Hz, $J_{6endo,5}$= 4.5Hz C-H(6endo); 2.52(dd)(1H) $J_{6,6}$= 11.5Hz, $J_{6exo,5}$= 9Hz C-H(6exo); 2.89(m)(1H) $J_{5,6exo}$= 9Hz, $J_{5,6endo}$= 4.5Hz, $J_{5,1'a}$= 7Hz, $J_{5,1'b}$= 5Hz C-H(5); 3.38(dd)(1H) $J_{1',1'}$= 10.5Hz, $J_{1'a,5}$= 7Hz C-H(1'a); 3.56(s)(3H) OC-H_3; 3.62(s)(3H) OC-H_3; 3.77(dd)(1H) $J_{1',1'}$= 10.5Hz, $J_{1'b,5}$= 5Hz C-H(1'b). **^{13}C-NMR($CDCl_3$)(δ):** 39.5 C-6; 48.9 C-5; 51.6 OCH_3; 52.7 OCH_3; 62.3 C-1'; 74.6 C-1; 77.1 C-4; 112.0 C-7; 128.1 C-3; 130.3 C-2. **MS:** 289(33%), 287(98%), 285(100%)(M^+-Cl); 257(11%), 255(28%), 257(28%) (M^+-CH_3OH-Cl).

Treatment of 2 with sodium in ethanol: (±)-(1R*,4S*,6S*,8R*)-1-Ethoxy-2-oxatricyclo[4.2.1.$0^{4,8}$]-nonan-7-one dimethylketal (3) and (±)-(1S*,4S*,5S*)-5-hydroxymethylbicyclo[2.2.1]hept-2-en-7-one dimethylketal (4). 2 (2.14g; 7mmol) was treated as described under general procedure. After chromatography on silica gel with petroleum ether : diethyl ether = 1 : 3 compounds 3 (1.15g; 76%) and 4 (0.19g; 15.5%) were obtained.

(±)-(1R*,4S*,6S*,8R*)-1-Ethoxy-2-oxatricyclo[4.2.1.$0^{4,8}$]nonan-7-one dimethylketal (3): A) Sodium (3.5g) was added to a refluxing solution of ethanol (abs.; 40 ml) and stirred under reflux until all of the sodium was converted to sodium ethoxide. A solution of 2 (1.3g) in ethanol (abs.; 4ml) was added and the stirring under reflux was continued for 3 1/2 h. After this period sodium (3.5g) in small pieces was added within 1 1/2 h. After work up and purification as mentioned above 3 (0.819g; 89%) was obtained as colourless oil. **B)** To a refluxing solution of 19 (380mg) in ethanol (abs., 10 ml) sodium in small pieces was added within 1 h. The reaction mixture was stirred under reflux for one further hour. After work up as mentioned above 3 (234mg; 89%) was obtained as sole product.

3: ^{1}H-NMR($CDCl_3$)(δ): 1.15(m)(1H) $J_{5,5}$= 12Hz, $J_{5endo,4}$= 2Hz C-H(5endo); 1.23(t)(3H) $J_{2',1'}$= 7Hz C-H(2'); 1.6(m)(1H) $J_{9,9}$= 11.5Hz, $J_{9,6}$= 2Hz C-H(9endo); 1.29-2.16(m)(3H) C-H(5exo,6,9exo); 2.52(m)(1H) C-H(8); 2.57(m)(1H) $J_{4,3}$= 4Hz, $J_{4,5exo}$= 8.5Hz, $J_{4endo,5}$= 1.5Hz C-H(4); 3.25(s)(3H) OC-H_3; 3.27(s)(3H) OC-H_3; 3.55(m)(1H) $J_{1',1'}$= 8.3Hz, $J_{1'a,2'}$= 7Hz C-H(1'a); 3.7(m)(1H) $J_{1',1'}$= 8.3Hz, $J_{1'b,2'}$= 7Hz C-H(1'b); 3.61(d)(1H) $J_{3,3}$= 7.7Hz C-H(3endo); 3.92(dd)(1H) $J_{3,3}$= 7.7Hz, $J_{3exo,4}$= 3Hz C-H(3exo). **^{13}C-NMR($CDCl_3$)(δ):** 15.8 C-2'; 34.6 C-5; 37.8 and 38.4 C-4 and C-6; 44.0 C-9; 48.2 C-8; 49.7 OCH_3; 50.8 OCH_3; 58.6 C-1'; 71.6 C-3; 114.1 and 114.4 C-1 and C-7. **MS:** 228(M^+)(5%), 213(M^+-CH_3)(23%), 199(M^+-Et)(14%), 198(M^+-CH_2O)(100%).

4: IR(CCl_4)(cm^{-1}): 3640, 3410 br., 3070, 1580. **^{1}H-NMR($CDCl_3$)(δ):** 0.56(dd)(1H) $J_{6,6}$= 11.3Hz, $J_{6endo,5}$= 4.2Hz C-H(6endo); 1.86(br.)(1H)(exchangeable with D_2O) O-H; 2.03(m)(1H) $J_{6,6}$= 11.3Hz, $J_{6exo,1}$= 4.5Hz, $J_{6exo,5}$= 8.7Hz C-H(6exo); 2.51(m)(1H) $J_{5,6exo}$= 8.7Hz, $J_{5,6endo}$= 4.2Hz, $J_{5,1'a}$= 10.8Hz, $J_{5,1'b}$= 7Hz C-H(5); 2.81(t)(1H) $J_{1,2}$= $J_{1,6}$= 3Hz C-H(1); 2.98(t)(1H) $J_{4,3}$= $J_{4,5}$= 3Hz C-H(4); 3.17(s)(3H) OC-H_3; 3.24(s)(3H) OC-H_3; 3.31(dd)(1H) $J_{1',1'}$= 10.5Hz, $J_{1'a,5}$= 10.8Hz C-H(1'a); 3.37(dd)(1H) $J_{1',1'}$= 10.5Hz, $J_{1'b,5}$= 7Hz C-H(1'b); 6.0(m)(1H) $J_{3,2}$= 5.7Hz, $J_{3,4}$= 3Hz C-H(3); 6.12(m)(1H) $J_{2,3}$= 5.7Hz, $J_{2,1}$= 3Hz C-H(2). **^{13}C-NMR($CDCl_3$)(δ):** 27.3 C-6; 39.1 C-5; 44.8 C-1; 46.5 C-4; 49.7 OCH_3; 51.9 OCH_3; 65.0 C-1'; 119.5 C-7; 130.8 C-3; 134.4 C-2. **MS:** 184(M^+)(19%), 153(M^+-OCH_3)(53%), 45(100%).

(±)-(1R*,4R*,6S*,8S*,9S*)-1-Ethoxy-6,8,9-trichloro-2-oxatricyclo[4.2.1.$0^{4,8}$]nonan-7-one dimethylketal (19): Sodium (1.9g) in small pieces was added to ethanol (abs., 20ml) under reflux. After the sodium was converted to sodium ethoxide 2 (650mg) dissolved in ethanol (abs., 2ml) was added to the refluxing solution and kept under reflux for 7 h. To the cooled reaction mixture ice water was added and the solution extract-

ed with dichloromethane for several times. The org. layers were washed with brine, dried over $MgSO_4$ and the solvent evaporated. The resulting crystals were recrystallized from petroleum ether yielding **19** (590mg; 88%; m.p. 70-72°C). **^{1}H-NMR($CDCl_3$)(δ):** 1.27(t)(3H) $J_{1',2'}$= 7Hz C-H(2'); 2.18(dd)(1H) $J_{5,5}$= 12Hz, $J_{5endo,4}$= 2.5Hz C-H(5endo); 2.46(m)(1H) $J_{5,5}$= 12Hz, $J_{5exo,4}$= 11Hz, $J_{5exo,9}$= 2.5Hz C-H(5exo); 2.68(m)(1H) $J_{4,5exo}$= 11Hz, $J_{4,3exo}$= 4Hz, $J_{4,5endo}$= 2.5Hz C-H(4); 3.67(s)(6H) OC-H_3; 3.79(d)(1H) $J_{3,3}$= 8.3Hz C-H(3endo); 3.73-3.95(m)(2H) C-H(1'); 4.31(dd)(1H) $J_{3,3}$= 8.3Hz, $J_{3exo,4}$= 4Hz C-H(3exo); 4.61(d)(1H) $J_{9,5}$= 2.5Hz. **^{13}C-NMR($CDCl_3$)(δ):** 15.6 C-2'; 37.6 C-5; 46.1 C-4; 51.2 OCH_3; 52.0 OCH_3; 60.5 C-1'; 71.4 C-3; 71.5 C-6; 71.7 C-9; between 76.6 and 77.6 C-8; 103.0 C-7; 106.6 C-1. **MS:** 297(M^+-Cl)(18%), 295(M^+-Cl)(28%), 193(69%), 191(100%).

(±)-(1S*,4R*,5R*,6R*)-1,2,3,4-Tetrachloro-5-hydroxymethyl-6-propylbicyclo[2.2.1]hept-2-en-7-one dimethylketal (5): (Z)-2-Hexen-1-ol (1g), **1** (2.64g), and a trace of hydroquinone under an atmosphere of argon were heated in a sealed tube at 130°C for 3 d. The reaction mixture was chromatographed on silica gel with petroleum ether : diethyl ether = 10 : 1 yielding **5** (2.67g; 73%) as colourless oil. **IR(CCl_4)(cm^{-1}):** 3640, 3500 br., 1610. **^{1}H-NMR($CDCl_3$)(δ):** 0.91(t)(3H) $J_{3'',2''}$= 7Hz C-H(3"); 1.17-1,33(m)(2H) C-H(2"); 1.39-1.57(m)(2H) C-H(1"); 1.71(1H)(exchangeable with D_2O) O-H; 2.76(m)(1H) $J_{6,5}$= 9,2Hz, $J_{6,1''a}$= 7.9Hz, $J_{6,1''b}$= 4.7Hz C-H(6); 2.9(m)(1H) $J_{5,6}$= 9.2Hz, $J_{5,1'a}$= 7.1Hz, $J_{5,1'b}$= 5.1Hz C-H(5); 3.54(s)(3H) OC-H_3; 3.58(dd)(1H) $J_{1'',1''}$= 11.5Hz, $J_{1'a,5}$= 7.1Hz C-H(1'a); 3.61(s)(3H) OC-H_3; 3.83(dd)(1H) $J_{1'',1''}$= 11.5Hz, $J_{1'b,5}$= 5.1Hz C-H(1'b). **^{13}C-NMR($CDCl_3$)(δ):** 14.3 C-3"; 22.4 C-2"; 27.1 C-1"; 49.3 OCH_3; 51.7 C-5 or C-6; 52.0 OCH_3; 52.7 C-5 or C-6; 59.0 C-1'; 77.8 C-1 or C-4; 79.4 C-1 or C-4; 111.4 C-7; 128.2 C-2 or C-3; 129.5 C-2 or C-3. **MS:** 333(6%), 329(94%), 327(M^+-Cl)(100%).

Treatment of 5 with sodium in refluxing ethanol: (±)-(1R*,4S*,5R*,6R*,8R*)-1-Ethoxy-5-propyl-2-oxatricyclo[4.2.1.0^{4,8}]nonan-7-one dimethylketal (6) and (±)-(1R*,4S*,5R*,6R*)-5-hydroxymethyl-6-propylbicyclo[2.2.1]hept-2-en-7-one dimethylketal (7). **5** (0.5g; 1.37mmol) was treated as described under general procedure. Separation on silica gel with petroleum ether : diethyl ether = 9 : 1 yielded **6** (210mg; 57%) and **7** (70mg; 23%).

(±)-(1R*,4S*,5R*,6R*,8R*)-1-Ethoxy-5-propyl-2-oxatricyclo[4.2.1.0^{4,8}]nonan-7-one dimethylketal (6): Sodium (0.35g) was added in small pieces to refluxing ethanol (abs.; 6ml). After sodium was converted to sodium ethoxide a solution of **5** (540mg) in ethanol (abs.; 1.5ml) was added and stirring under reflux continued for 3 h. After this period sodium in small pieces (1.2 g) was added to the refluxing solution within 1 1/2 h. Work up and chromatography as mentioned above yielded **6** (360mg; 81%).

6: ^{1}H-NMR($CDCl_3$)(δ): 0.93(t)(3H) $J_{3'',2''}$= 7.3Hz C-H(3"); 1.23(t)(3H) $J_{2',1'}$= 7.3Hz C-H(2'); 1.30(m)(4H) $w_{1/2}$= 18Hz C-H(1",2"); 1.77(dd)(1H) $J_{9,9}$= 13.8Hz, $J_{9endo,6}$= 1.9Hz C-H(9endo); 2.04-2.14(m)(2H) $J_{9,9}$= 13.8Hz, $J_{9exo,6}$= 3.8Hz, $J_{9exo,5}$= 1.5Hz C-H(9exo); $J_{6,5}$= 1.5Hz, $J_{6,9endo}$= 1.9Hz, $J_{6,8}$= 1Hz C-H(6); 2.32(br.m)(1H) $w_{1/2}$= 20Hz C-H(5); 2.52(ddd)(1H) $J_{4,5}$= 9.4Hz, $J_{4,8}$= 4.8Hz, $J_{4,3\beta}$= 3.2Hz C-H(4); 2.58(dd)(1H) $J_{8,4}$= 4.8Hz, $J_{8,6}$= 1Hz, C-H(8); 3.27(s)(6H) OC-H_3; 3.53(part A of an ABX_3-system)(1H) $J_{1',1''}$= 9.3Hz, $J_{1'a,2'}$= 7.3Hz C-H(1'a); 3.68(part B of an ABX_3-system)(1H) $J_{1',1''}$= 9.3Hz, $J_{1'b,2'}$= 7.3Hz C-H(1'b); 3.67(part A of an ABX-system)(1H) $J_{3,3}$= 8.5Hz C-H(3α); 3.73(part B of an ABX-system)(1H) $J_{3,3}$= 8.5Hz, $J_{3\beta,4}$= 3.2Hz C-H(3β). **^{13}C-NMR($CDCl_3$)(δ):** 14.3 C-3"; 15.8 C-2'; 21.7 C-2"; 29.0 C-1"; 38.0 C-9; 38.1, 40.8 and 41.2 C-4, C-5 and C-6; 49.7 C-8; 49.73 OCH_3; 50.6 OCH_3; 58.6 C-1'; 65.7 C-3; 112.1 and 114.0 C-1 and C-7. **MS:** 270(M^+)(7.5%), 239(M^+-OCH_3)(29%), 225(M^+-OEt)(24%), 195(M^+ -CH_3-O-CH=O-CH_3)(10%), 109(70%), 88(100%). High resolution mass spectrum: found: 270.179[2] ± 0.002[7], calc.: 270.183[1].

7: IR(CCl_4)(cm^{-1}): 3640, 3500 br., 3070. **^{1}H-NMR($CDCl_3$)(δ):** 0.90(t)(3H) $J_{3'',2''}$= 7Hz C-H(3"); 1.09-1.47(m)(4H) C-H(1",2"); 1.62(1H)(exchangeable with D_2O) O-H; 2.41(tt)(1H) $J_{6,1''a}$= $J_{6,5}$= 9.5Hz, $J_{6,1''b}$= $J_{6,1}$= 4Hz C-H(6); 2.52(tdd)(1H) $J_{5,6}$= $J_{5,1'b}$= 9.5Hz, $J_{5,1'a}$= 6.5Hz, $J_{5,4}$= 4Hz C-H(5); 2.90(m)(1H) $w_{1/2}$= 8Hz

C-H(1); 2.89(m)(1H) $w_{1/2}$= 8Hz C-H(4); 3.16(s)(3H) OC-H_3; 3.24(s)(3H) OC-H_3; 3.33(dd)(1H) $J_{1',1}$= 10Hz, $J_{1'b,5}$= 9.5Hz C-H(1'b); 3.52(dd)(1H) $J_{1',1}$= 10Hz, $J_{1'a,5}$= 6.5Hz C-H(1'a); 6.17(m)(2H) $w_{1/2}$= 7Hz C-H(2,3). **^{13}C-NMR($CDCl_3$)(δ):** 14.3 C-3"; 22.1 C-2"; 29.8 C-1"; 39.1 and 42.0 C-5 and C-6; 48.0 C-1; 48.7 C-4; 49.7 OCH_3; 51.8 OCH_3; 62.4 C-1'; 118.3 C-7; 132.4 and 133.0 C-2 and C-3. **MS:** 226(M^+)(24%), 195(M^+-CH_2OH)(100%), 183(M^+-C_3H_7)(40%), 75(CH_3-O-CH=O^+-CH_3)(70%).

(±)-(1S*,4R*,5S*)-1,2,3,4-Tetrachloro-5-(2'-hydroxyethyl)bicyclo[2.2.1]hept-2-en-7-one dimethylketal (8): 1 (5g), 3-buten-1-ol (1.16g), and a trace of hydroquinone were heated under an atmosphere of argon in a sealed tube at 140°C for 64 h. The reaction mixture was distilled (Kugelrohr; 0.02mm) yielding 8 (4.96g; 92%) as colourless oil. **IR(CCl_4)(cm^{-1}):** 3640, 3360 br., 1610. **^{1}H-NMR($CDCl_3$)(δ):** 1.16(m)(1H) $J_{1',1}$= 13.5Hz, $J_{1'a,5}$= 11Hz, $J_{1'a,2'a}$=$J_{1'a,2'b}$= 5-6Hz C-H(1'a); 1.54(dd)(1H) $J_{6,6}$= 11.5Hz, $J_{6endo,5}$= 4Hz C-H(6endo); 1.85(1H)(exchangeable with D_2O) O-H; 1.9(m)(1H) $J_{1',1}$= 13.5Hz, $J_{1'b,2'a}$= $J_{1'b,2'b}$= 6.7-7Hz, $J_{1'b,5}$= 3.5Hz C-H(1'b); 2.52(dd)(1H) $J_{6,6}$= 11.5Hz, $J_{6exo,5}$= 9Hz C-H(6exo); 2.75(m)(1H) $J_{5,1'a}$= 11Hz, $J_{5,1'b}$= 3.5Hz, $J_{5,6exo}$= 9Hz, $J_{5,6endo}$= 4Hz C-H(5); 3.56(s)(3H) OC-H_3; 3.61(s)(3H) OC-H_3; ~3.6(m)(1H) $J_{2',2'}$= 8Hz, $J_{2'a,1'a}$= 5-6Hz, $J_{2'a,1'b}$≈ 7Hz C-H(2'a); 3.71(m)(1H) $J_{2',2'}$= 8Hz, $J_{2'b,1'a}$= 5-6Hz, $J_{2'b,1'b}$≈ 7Hz C-H(2'b). **^{13}C-NMR($CDCl_3$)(δ):** 32.8 C-1'; 41.8 C-6; 44.1 C-5; 51.5 OCH_3; 52.6 OCH_3; 60.2 C-2'; 74.7 C-4; 79.0 C-1; 111.8 C-7; 128.6 C-3; 130.0 C-2. **MS:** 303(16%), 301(40%), 299(42%)(M^+-Cl); 257(M^+-Cl -EtOH)(4.5%); 43(100%).

Treatment of 8 with sodium in refluxing ethanol: (±)-(1R*,5R*,7S*,9R*)-1-Ethoxy-2-oxatricyclo-[5.2.1.$0^{5,9}$]decan-8-one dimethylketal (9) and (±)-(1S*,4R*,5R*)-5-(2'-hydroxyethyl)bicyclo[2.2.1]-hept-2-en-7-one dimethylketal (10). 8 (1.5g) was treated as described under general procedure. Chromatography on silica gel with petroleum ether : diethyl ether = 3 : 1 yielded 9 (214mg; 20%) and 10 (430mg; 49%).

(±)-(1R*,5R*,7S*,9R*)-1-Ethoxy-2-oxatricyclo[5.2.1.$0^{5,9}$]decan-8-one dimethylketal (9): 20 (1.33g) was dissolved in ethanol (abs.,30ml) and sodium (3g) in small pieces was added to the refluxing solution within 2 h. Work up and chromatography as mentioned above 9 yielded (884mg; 95%).

9: **^{1}H-NMR($CDCl_3$)(δ):** 1.1(dd)(1H) $J_{6,6}$= 12Hz, $J_{6endo,5}$= 4Hz C-H(6endo); 1.2(t)(3H) $J_{2',1'}$= 7Hz C-H(2'); 1.35(m)(1H) $J_{4,4}$= 14Hz, $J_{4endo,3endo}$= $J_{4endo,5}$= 2-3Hz C-H(4endo); 1.66(d)(1H) $J_{10,10}$= 13Hz C-H(10endo); 1.76(m)(1H) $J_{4,4}$= 14Hz, $J_{4exo,3endo}$= 12Hz, $J_{4exo,3exo}$= 6Hz, $J_{4exo,5}$= 3.5Hz C-H(4exo); 1.92(m)(1H) $J_{6,6}$= 12Hz, $J_{6exo,5}$= 10Hz, $J_{6exo,7}$= 4.5Hz, $J_{6exo,10exo}$= 2.5Hz C-H(6exo); 1.98(d)(1H) $J_{9,5}$= 4Hz C-H(9); 2.15(m)(1H) $J_{10,10}$= 13Hz, $J_{10exo,7}$= 4.5Hz, $J_{10exo,6exo}$= 2.5Hz C-H(10exo); 2.26(m)(1H) $J_{7,10exo}$=$J_{7,6exo}$= 4Hz C-H(7); 2.53(m)(1H) $J_{5,6exo}$= 10Hz, $J_{5,4endo}$= 3.5Hz, $J_{5,6endo}$=$J_{5,4exo}$= $J_{5,9}$= 3-4Hz C-H(5); 3.23(s)(3H) OC-H_3; 3.28(s)(3H) OC-H_3; 3.58(q)(2H) $J_{1',2'}$= 7Hz C-H(1'); 3.7(m)(1H) $J_{3,3}$= 12Hz, $J_{3endo,4exo}$= 12Hz, $J_{3endo,4endo}$= 3.5Hz C-H(3endo); 3.83(m)(1H) $J_{3,3}$= 12Hz, $J_{3exo,4exo}$= 6Hz, $J_{3exo,4endo}$= 1Hz C-H(3exo). **^{13}C-NMR($CDCl_3$)(δ):** 15.75 C-2'; 27.3 and 29.5 C-4 and C-6; 29.2 C-5; 36.9 C-10; 39.3 C-7; 45.9 C-9; 49.3 OCH_3; 51.0 OCH_3; 56.75 C-1'; 58.9 C-3; 104.4 C-1; 113.3 C-8. **MS:** 242(M^+)(3.4%), 227(M^+-CH_3)(35%), 197(M^+-OEt)(100%), 109(45%).

10: **IR(CCl_4)(cm^{-1}):** 3640, 3480, 3070. **^{1}H-NMR($CDCl_3$)(δ):** 0.61(dd)(1H) $J_{6,6}$= 11.5Hz, $J_{6endo,5}$= 4.2Hz C-H(6endo); 1.32(m)(1H) $J_{1',1}$= 13.8Hz, $J_{1'a,5}$= 8Hz, $J_{1'a,2'}$= 6.5Hz C-H(1'a); 1.46(m)(1H) $J_{1',1}$= 13.8Hz, $J_{1'b,5}$= 7.5Hz, $J_{1'b,2'}$= 6.5Hz C-H(1'b); 1.96(1H)(exchangeable with D_2O) O-H; 2.08(m)(1H) $J_{6,6}$= 11.5Hz, $J_{6exo,5}$= 8.5Hz, $J_{6exo,1}$= 4.2Hz C-H(6exo); 2.34(m)(1H) $J_{5,6exo}$= 8.5Hz, $J_{5,6endo}$= 4.2Hz, $J_{5,1'a}$= 8Hz, $J_{5,1'b}$= 7.5Hz, $J_{5,4}$= 3.5Hz C-H(5); 2.77(dd)(1H) $J_{1,6}$= 4Hz, $J_{1,2}$= 3Hz C-H(1); 2.82(dd)(1H) $J_{4,5}$= 3.5Hz, $J_{4,3}$= 3Hz C-H(4); 3.16(s)(3H) OC-H_3; 3.21(s)(3H) OC-H_3; 3.61(t)(2H) $J_{2',1'a}$= $J_{2',1'b}$= 6.5Hz C-H(2'); 6.02(dd)(1H) $J_{3,2}$= 6.7Hz, $J_{3,4}$= 3Hz C-H(3); 6.19(dd)(1H) $J_{2,3}$= 6.7Hz, $J_{2,1}$= 3Hz C-H(2). **^{13}C-NMR($CDCl_3$)(δ):** 30.7 C-6; 32.6 C-5; 36.7 C-1'; 45.0 C-1; 48.3 C-4; 49.6 OCH_3; 51.8 OCH_3; 61.3 C-2'; 119.4 C-7; 130.8 C-3; 134.2 C-2. **MS:**

198(M^+)(28%), 167(M^+-OCH_3)(17%), 153(M^+-CH_2CH_2OH)(77%), 105(76%), 91(79%), 79(100%), 77(91%), 75(88%).

(±)-(1R*,5S*,7S*,9S*,10S*)-7,9,10-Trichloro-1-ethoxy-2-oxatricyclo[5.2.1.$0^{5,9}$]decan-8-one dimethylketal (20): Sodium (2g) in small pieces was added to refluxing ethanol (abs., 30ml). After conversion to sodium ethoxide a solution of 8 (1.65g) in ethanol (abs.; 9ml) was added and refluxing continued for 20 h. After work up as mentioned above chromatography on silica gel with petroleum ether : ethyl acetate = 9 : 1 yielded crystalline 20 (1.33g; 79%; m.p. 82.5-83.5°C). **^{1}H-NMR($CDCl_3$)(δ):** 1.24(t)(3H) $J_{2',1'}$= 7.2Hz C-H(2'); 1.35(m)(1H) $J_{4,4}$= 15Hz, $J_{4exo,3exo}$= 4Hz, $J_{4exo,3endo}$= $J_{4exo,5}$= 3.5Hz C-H(4exo); 2.06(m)(1H) $J_{4,4}$= 15Hz, $J_{4endo,3exo}$= 13Hz, $J_{4endo,3endo}$= 6Hz, $J_{4endo,5}$= 3.5Hz C-H(4endo); 2.20(m)(1H) $J_{6,6}$= 13Hz, $J_{6endo,5}$= 5.5Hz C-H(6endo); 2.28(m)(1H) $J_{6,6}$= $J_{6exo,5}$= 13Hz, $J_{6exo,10}$= 2Hz C-H(6exo); 2.81(m)(1H) $J_{5,6exo}$= 13Hz, $J_{5,6endo}$= 5.5Hz, $J_{5,4endo}$= $J_{5,4exo}$= 3.5Hz C-H(5); 3.64(s)(3H) OC-H_3; 3.67(s)(3H) OC-H_3; 3.66(dq)(1H) $J_{1',1'}$= 10Hz, $J_{1'a,2'}$= 7.2Hz C-H(1'a); 3.88(dq)(1H) $J_{1',1'}$= 10Hz, $J_{1'b,2'}$= 7.2Hz C-H(1'b); 3.9(m)(1H) $J_{3,3}$= 13Hz, $J_{3endo,4}$= 6Hz, $J_{3endo,4}$= 3.5Hz C-H(3endo); 4.4(td)(1H) $J_{3,3}$= $J_{3exo,4}$= 13Hz, $J_{3exo,4}$= 4Hz C-H(3exo); 4.75(d)(1H) $J_{10,6exo}$= 2Hz C-H(10). **^{13}C-NMR($CDCl_3$)(δ):** 15.3 C-2'; 21.4 C-4; 32.8 C-6; 37.5 C-5; 51.1 OCH_3; 51.7 OCH_3; 57.7 C-1'; 60.1 C-3; 71.6 C-10; 71.8 C-7; 72.4 C-9; 97.0 C-1; 103.3 C-8. **MS:** 346(M^+)(0.3%), 344(M^+)(0.3%); 313(13%), 311(66%), 309(M^+-Cl)(100%).

(±)-(1R*,2R*,7R*,8S*)-1,8,9,10-Tetrachloro-11,11-dimethoxytricyclo[6.2.1.$0^{2,7}$]undec-9-en-3-one (11): 1 (408g; 15.5mmol), 2-cyclohexenone (1.3g; 13.5mmol), and a trace of hydroquinone were heated under an atmosphere of argon in a sealed tube at 130°C for 93 h. The reaction mixture was distilled (Kugelrohr; 0.02mm) and the resulting crystals recrystallized from petroleum ether/diethyl ether yielding 11 (3.15g; 65%; m.p. 115°C). **IR(CCl_4)(cm^{-1}):** 1723, 1602. **^{1}H-NMR($CDCl_3$)(δ):** 1.00(m)(1H) $J_{6,6}$= $J_{6endo,7}$= $J_{6endo,5exo}$= 12.5Hz, $J_{6endo,5endo}$= 3Hz C-H(6endo); 1.80(m)(1H) $J_{5exo,6endo}$= 12.5Hz, $J_{5exo,4exo}$= 7Hz C-H(5exo); 1.92(m)(1H) $J_{5endo,6endo}$= 3Hz C-H(5endo); 2.06(m)(1H) $J_{6,6}$= 12.5Hz, $J_{6exo,7}$= 5.5Hz C-H(6exo); 2.19(m)(1H) $J_{4,4}$= 18Hz, $J_{4endo,5}$= 10Hz, $J_{4endo,5}$= 8Hz C-H(4endo); 2.45(m)(1H) $J_{4,4}$= 18Hz, $J_{4exo,5exo}$= 7Hz, $J_{4exo,5endo}$= $J_{4exo,6exo}$= 2Hz C-H(4exo); 3.26(m)(1H) $J_{7,2}$= 10,5Hz, $J_{7,6endo}$= 12.5Hz, $J_{7,6exo}$= 5.5Hz C-H(7); 3.39(d)(1H) $J_{2,7}$= 10.5Hz C-H(2); 3.58(s)(3H) OC-H_3; 3.64(s)(3H) OC-H_3. **^{13}C-NMR($CDCl_3$)(δ):** 20.3 and 22.5 C-5 and C-6; 38.8 C-4; 49.9 C-7; 51.8 OCH_3; 53.0 OCH_3; 56,7 C-2; 75.8 C-8; 78.1 C-1; 112.9 C-11; 129.2 C-9; 131.2 C-10; 207.0 C-3. **MS:** 327(5%), 325(13%), 323(M^+-Cl)(16%); 31(100%).

(±)-(1R*,2R*,3S*,7R*,8S*)-1,8,9,10-Tetrachloro-3-hydroxytricyclo[6.2.1.$0^{2,7}$]undec-9-en-11-one dimethylketal (12): 11 (4.95g; 13.7mmol) was dissolved in methanol (42.5ml) and cooled to 0°C. After addition of an excess of sodium borohydride the reaction mixture was stirred at 0°C for 5 h. Addition of water was followed by extraction with dichloromethane for five times. The org. layers were washed with brine, dried over $MgSO_4$ and the solvent evaporated. The resulting product was crystallized from petroleum ether : diethyl ether yielding 12 (4.29g; 86%; m.p. 171°C). **IR(KCl)(cm^{-1}):** 3520, 1610. **^{1}H-NMR($CDCl_3$)(δ):** 1.2-1.95(m)(6H) C-H(4,5,6); 1.48(1H)(exchangeable with D_2O) O-H; 2.55(m)(1H) $J_{2,7}$= 10.3Hz, $J_{2,3}$= 4Hz C-H(2); 2.65(m)(1H) $J_{7,6endo}$= 12.9Hz, $J_{7,2}$= 10.3Hz, $J_{7,6exo}$= 4.3Hz C-H(7); 3.57(s)(3H) OC-H_3; 3.61(s)(3H) OC-H_3; 4.33(m)(1H) $w_{1/2}$= 8.3Hz C-H(3). **^{13}C-NMR($CDCl_3$)(δ):** 16.6 C-5; 17.9 C-6; 16.9 C-4; 47.7 C-7; 50.5 C-2; 51.5 OCH_3; 52.9 OCH_3; 64.4 C-3; between 76.5 and 77.5 C-8; 79.0 C-1; 113.8 C-11; 127.8 C-9; 130.3 C-10. **MS:** 329(21%), 327(65%), 325(M^+-Cl)(64%); 59(100%).

(±)-(1S*,3R*,5R*,7R*,8S*,9R*)-3-Ethoxy-2-oxatetracyclo[6.4.0.$0^{3,7}$.$0^{5,9}$]dodecan-6-one dimethylketal (13): 12 (4.29g; 11.8mmol) was treated as described under general procedure. After chromatography on silica gel with petroleum ether : diethyl ether = 6 : 1 compound 13 (2.93g; 92%) was obtained as colourless oil. **^{1}H-NMR($CDCl_3$)(δ):** 1.25(t)(3H) $J_{1',2'}$= 7Hz C-H(2'); 1.33(m)(2H) C-H(11endo, 12exo); 1.67(m)(3H) C-H(10endo,10exo, 11exo); 1.90(m)(1H) $J_{12,12}$= 13Hz, $J_{12endo,1}$= $J_{12endo,11exo}$= $J_{12endo,11endo}$= 3Hz C-

H(12endo); 2.07(m)(2H) C-H(4endo,5); 2.18(m)(1H) $J_{4,4}$= 12.5Hz, $J_{4exo,5}$= 4Hz, $J_{4exo,7}$= 1.5Hz C-H(4exo); 2.37(m)(2H) C-H(8,9); 2.69(m)(1H) $J_{7,8}$=3.5Hz, $J_{7,4exo}$= 1.5Hz C-H(7); 3.24(s)(3H) OC-H_3; 3.25(s)(3H) OC-H_3; 3.56(part A of an ABX_3-system)(1H) $J_{1',1}$= 9Hz, $J_{1'a,2}$= 7Hz C-H(1'a); 3.73(part B of an ABX_3-system)(1H) $J_{1',1}$= 9Hz, $J_{1'b,2}$= 7Hz C-H(1'b); 4.27(m)(1H) $J_{1,12endo} \approx J_{1,12exo} \approx J_{1,8} \approx$ 2Hz C-H(1). **^{13}C-NMR($CDCl_3$)(δ):** 15.7 C-2'; 17.1 C-11; 23.4 C-10; 27.6 C-12; 31.6 C-9; 38.9 C-4; 39.6 C-8; 43.4 C-5; 49.6 OCH_3; 50.6 OCH_3; 51.0 C-7; 58.5 C-1'; 73.3 C-1; 111.8 and 113.3 C-3 and C-6. **MS:** 268(M^+)(15%), 253(M^+-CH_3)(2.5%), 238(M^+-CH_2O)(42%), 237(M^+-OCH_3)(29%), 223(M^+-OEt)(11%), 195(M^+-C(OCH_3)$_2$+H)(11%), 163(111%).

(±)-(1S*,2R*,6R*,7S*)-1,7,8,9-Tetrachloro-10,10-dimethoxytricyclo[5.2.1.0^{2,6}]dec-8-en-3-one (14): 1 (13.5g), 2-cyclopentenone (4.2g), and a trace of hydroquinone were heated under an atmosphere of argon in a sealed tube at 115°C (higher temperatures destroy the product slightly!) for 75 h. The reaction mixture was purified by flash chromatography with petroleum ether : diethyl ether = 7 : 1 yielding 14 (13.6g; 79%; white crystals, m.p. 68-74°C). **IR(CCl_4)(cm^{-1}):** 1750, 1602. **^{1}H-NMR($CDCl_3$)(δ):** 1,95-2,32(br.m)(4H) C-H(4,5); 3,14(d)(1H) $J_{2,6}$= 9Hz C-H(2); 3,42(m)(1H) $J_{6,2}$= $J_{6,5exo}$= 9Hz, $J_{6,5endo}$= 4Hz C-H(6); 3,56(s)(3H) OC-H_3; 3,62(s)(3H) OC-H_3. **^{13}C-NMR($CDCl_3$)(δ):** 19,0 C-5; 38,4 C-4; 48,9 C-6; 51,8 OCH_3; 52,7 OCH_3; 57,4 C-2; 76,0 C-7; 77,9 C-1; 114,5 C-10; 129,0 and 129,2 C-8 and C-9; 213,3 C-3. **MS:** 346(M^+)(0,6%), 344(M^+)(0.3%); 311(100%), 309(M^+-Cl)(100%); 273(M^+-Cl -HCl)(22%).

(±)-(1R*,2R*,3S*,6R*,7S*)-1,7,8,9-Tetrachloro-3-hydroxytricyclo[5.2.1.0^{2,6}]dec-8-en-10-one dimethylketal (15): 14 (1.6g) was dissolved in methanol (20ml) and cooled to 0°C. After addition of an excess of sodium borohydride (0.6g) the mixture was stirred at 0°C for 3 h. Addition of water was followed by five times extraction with dichloromethane. The org. layers were washed with brine, dried over $MgSO_4$ and the solvent evaporated yielding 15 (1.5g; 94%; m.p. 125°C) as white crystals. Further purification if necessary can be done by crystallization from petroleum ether or chromatography on silica gel with petroleum ether : diethyl ether = 4 : 1. **^{1}H-NMR($CDCl_3$)(δ):** 1.42(m)(1H) $J_{4,4}$= 13Hz, $J_{4endo,3} \approx J_{4endo,5endo} \approx J_{4endo,5exo} \approx$ 9Hz C-H(4endo); 1.66(m)(2H) C-H(5endo,5exo); 1.70(1H)(exchangeable with D_2O) O-H; 1.91(m)(1H) $J_{4,4}$= 13Hz, $J_{4exo,3} \approx$ 9Hz, $J_{4exo,5exo}$= 7.6Hz, $J_{4exo,5endo}$= 3Hz C-H(4exo); 3.07(m)(1H) $J_{6,2} \approx J_{6,5exo} \approx$ 9Hz, $J_{6,5endo} \approx$ 3.5Hz C-H(6); 3.17(m)(1H) $J_{2,3} \approx J_{2,6} \approx$ 9Hz C-H(2); 3.54(s)(3H) OC-H_3; 3.60(s)(3H) OC-H_3; 4.48(m)(1H) $J_{3,2} \approx J_{3,4exo} \approx J_{3,4endo} \approx$ 9Hz C-H(3). **^{13}C-NMR($CDCl_3$)(δ):** 21.5 C-4; 34.3 C-5; 51.6 OCH_3; 52.6 OCH_3; 53.5 C-6; 55.1 C-2; 73.9 C-3; 76.6 C-1; 77.6 C-7; 115.3 C-10; 128.4 C-9; 130.3 C-8. **MS:** 315(33%), 313(100%), 311(100%)(M^+-Cl); 255(50%), 253(53%)(M^+-Cl -HCl).

(±)-(1S*,3R*,5R*,7R*,8S*,9R*)-3-Ethoxy-2-oxatetracyclo[6.3.0.0^{3,7}.0^{5,9}]undecan-6-one dimethylketal (16): 15 (5.08g) was treated as described under general procedure. Flash chromatography on silica gel with petroleum ether : diethyl ether = 4 : 1 yielded 16 (2.6g; 71%) as colourless oil. **^{1}H-NMR($CDCl_3$)(δ):** 1.24(t)(3H) $J_{2',1'}$= 7.3Hz C-H(2'); 1.5-1.85(m)(3H) C-H(10endo,10exo,11endo); 1.89(part A of an ABX-system)(1H) $J_{4,4}$= 14Hz, $J_{4,5}$= 1.5Hz C-H(4endo); 2.05(m)(1H) $J_{11,11}$= 13.5Hz, $J_{11exo,10exo}$= 9Hz C-H(11exo); 2.18(m)(2H) $w_{1/2}$= 13.5Hz C-H(4exo,5); 2.68(m)(1H) $w_{1/2}$= 7.4Hz C-H(7); 2.79(m)(2H) C-H(8,9); 3.26(s)(3H) OC-H_3; 3.29(s)(3H) OC-H_3; 3.55(part A of an ABX_3-system)(1H) $J_{1',1}$= 9Hz, $J_{1'a,2}$= 7.3Hz C-H(1'a); 3.73(part B of an ABX_3-system)(1H) $J_{1',1}$= 9Hz, $J_{1'b,2}$= 7.3Hz C-H(1'b); 4.44(m)(1H) $w_{1/2}$= 8.2Hz C-H(1). **^{13}C-NMR($CDCl_3$)(δ):** 15.7 C-2'; 23.1 C-10; 36.1 C-11; 38.0 C-4; 41.5 and 41.7 C-8 and C-9; 49.9 OCH_3; 50.0 and 50.7 C-5 and C-7; 50.6 OCH_3; 58.8 C-1'; 80.7 C-1; 113.6 C-6; 116.5 C-3. **MS:** 254(M^+)(4.6%); 239(M^+-CH_3)(5.2%), 224(M^+-CH_2O)(91%), 209(M^+-OEt)(100%), 75(CH_3-O-HC=O^+-CH_3)(23%).

(±)-(1R*,2R*,4S*)-1,4,5,6-Tetrachloro-7,7-dimethoxybicyclo[2.2.1]hept-5-en-2-ylcarboxylic acid (17): 1 (3.9g), acrylic acid (1g), and a trace of hydroquinone were heated under reflux for 3 h. The cooled reaction mixture was extracted five times with aqu. sat. $NaHCO_3$. THe aqu. solutions were acidified with dil. aqu.

HCl and extracted several times with dichloromethane. The org. layers were dried over $MgSO_4$. Several recrystallizations from petroleum ether : diethyl ether yielded pure 17 (2.9g; 63%; m.p. 165-166°C). **IR($CHCl_3$)(cm^{-1}):** 3350-2500, 1750, 1715, 1605. **^{1}H-NMR($CDCl_3$)(δ):** 2.18(part A of an ABM-system)(1H) $J_{3,3}$= 11.8Hz, $J_{3endo,2}$= 4.4Hz C-H(3endo); 2.54(part B of an ABM-system)(1H) $J_{3,3}$= 11.8Hz, $J_{3exo,2}$= 9.3Hz C-H(3exo); 3.48(part M of an ABM-system)(1H) $J_{2,3exo}$= 9.3Hz, $J_{2,3endo}$= 4.4Hz C-H(2); 3.55(s)(3H) OC-H_3; 3.61(s)(3H) OC-H_3; 10.6 (br.)(1H) (exchangeable with D_2O) O-H. **^{13}C-NMR($CDCl_3$)(δ):** 39.1 C-3; 50.6, 51.8 and 52.9 C-2; OCH_3 and OCH_3; 74.1 C-1; 76.9 C-4; 112.1 C-7; 128.0 and 130.9 C-5 and C-6; 175.9 COOH. **MS:** 303(35%), 301(100%), 299(M^+-Cl)(100%).

(±)-(1S*,2S*,4S*)-7,7-Dimethoxybicyclo[2.2.1]hept-5-en-2-ylcarboxylic acid (18)[14b]: 17 (3.5g) was treated as described under general procedure. The work up had to be modified. After addition of ice the reaction mixture was twice extracted with diethyl ether. The org. layers were discarded, the aqu. layer was acidified with aqu. HCl and extracted with dichloromethane for several times. The dichloromethane solutions were washed with brine, dried over $MgSO_4$ and the solvent evaporated. The resulting crystals were recrystallized from petroleum ether : diethyl ether yielding 18 (2g; 97%; m.p. 86°C). **IR(CCl_4)(cm^{-1}):** 3500-2400, 3070, 1790, 1710. **^{1}H-NMR($CDCl_3$)(δ):** 1.42(dd)(1H) $J_{3,3}$= 12.5 Hz, $J_{3endo,2}$= 4Hz C-H(3endo); 2.12(m)(1H) $J_{3,3}$= 12.5Hz, $J_{3exo,2}$= 9Hz, $J_{3exo,4}$= 4Hz C-H(3exo); 2.89(m)(1H) $J_{4,3}$= 4Hz, $J_{4,5}$= 3.5-4Hz C-H(4); 3.17(s)(3H) OC-H_3; 3.24(s)(3H) OC-H_3; 3.15-3.22(m)(2H) C-H(1,2); 6.07(m)(1H) and 6.26(m)(1H) C-H(5,6); 10.73(br.)(1H) (exchangeable with D_2O) O-H. **^{13}C-NMR($CDCl_3$)(δ):** 27.3 C-3; 41.4 C-2; 44.9 C-4; 47.5 C-1; 49.8 OCH_3; 52.0 OCH_3; 118.8 C-7; 133.6 and 135.6 C-5 and C-6; 180.1 COOH. **MS:** 198(M^+)(43%), 153(M^+-COOH)(100%).

(±)-(1S*,3R*,4S*,5S*,7S*,8R*,9R*)-4,5,7-Trichloro-3-ethoxy-2-oxatetracyclo[6.4.0.0^{3,7}.0^{5,9}]dodecan-6-one dimethylketal (21): 12 (0.47mmol; 170mg) was added to a solution of ethoxide in ethanol(1mmol; 50ml) and kept under reflux for 15 min. The solution was poured on ice and extracted with dichloromethane for several times. The org. layers were washed with brine, dried over $MgSO_4$ and the solvent evaporated. Flash chromatography on silica gel with petroleum ether : diethyl ether = 15 : 1 yielded 21 (160mg; 92% m.p. 94-97°C). **^{1}H-NMR($CDCl_3$)(δ):** 1.25(t)(3H) $J_{2',1'}$= 7Hz; 1.36(m)(2H) C-H(11endo,12endo); 1.58(m)(1H) C-(10endo); 2.07(m)(2H) C-H(10exo,12exo); 2.38(m)(1H) C-H(11exo); 2.45(dd)(1H) $J_{8,9}$= 11Hz, $J_{8,1}$= 3.5Hz C-H(8); 2.80(m)(1H) $J_{9,8}$= 11Hz, $J_{9,10endo}$= 9.5Hz, $J_{9,4}$= 1.5Hz, $J_{9,10exo}$= 1.5-2Hz C-H(9); 3.76(s)(3H) OC-H_3; 3.77(s)(3H) OC-H_3; 3.89(part A of an ABX_3-system)(1H) $J_{1',1'}$= 8.5Hz, $J_{1'a,2}$= 7Hz C-H(1'a); 3.94(part B of an ABX_3-system)(1H) $J_{1',1'}$= 8.5Hz, $J_{1'b,2}$= 7Hz C-H(1'b); 4.66(m)(1H) $w_{1/2}$= 18Hz C-H(1); 4.75(d)(1H) $J_{4,9}$= 1.5Hz C-H(4). **^{13}C-NMR($CDCl_3$)(δ):** 15.7 C-11; 15.8 C-2'; 18.3 C-10; 26.1 C-12; 39.6 C-9; 48.0 C-8; 51.2 OCH_3; 52.1 OCH_3; 60.6 C-1'; 69.9 C-4; 74.5 C-1; 74.7 C-5; 79.7 C-7; 103.0 C-6; 106.0 C-3. **MS:** 337(21%), 335(32%)(M^+-Cl); 235(11%), 233(61%), 231(100%)(M^+-Cl -$C_5H_{12}O_2$).

(±)-(1S*,4S*,5S*)-5-(1'-Hydroxy-1'-methyl)ethylbicyclo[2.2.1]hept-2-en-7-one dimethylketal (22): To acid 18 (0.751g), dissolved in diethyl ether, was added an excess diazomethane in diethyl ether. After the excess of diazomethane and the solvent were removed by evaporation the resulting ester was chromatographed on silica gel with petroleum ether : diethyl ether = 8 : 1. The methyl ester (3.8mmol) was dissolved in diethyl ether (abs., 50ml) and added dropwise to an excess of methyl magnesium iodide in diethyl ether (abs., 50ml) at room temp. A cooled solution of aqu. sat. NH_4Cl was added dropwise into the reaction mixture followed by extraction with diethyl ether. The org. layers were washed with brine, dried over $MgSO_4$ and the solvent evaporated yielding the tertiary alcohol 22 (0.7g; 3.3mmol; 87% from 18). **IR(CCl_4)(cm^{-1}):** 3580, 3480 br., 3060. **^{1}H-NMR($CDCl_3$)(δ):** 1.01(s)(3H) C(1')-CH_3; 1.15(m)(1H) $J_{6,6}$= 12.8Hz, $J_{6endo,5}$= 5.1Hz C-H(6endo); 1.23(s)(3H) C(1')-CH_3; 1.45(br.)(1H) (exchangeable with D_2O) O-H; 2.03(m)(1H) $J_{6,6}$= 12.8Hz, $J_{6exo,5}$= 9.3Hz, $J_{6exo,1}$= 4Hz C-H(6exo); 2.40(m)(1H) $J_{5,6exo}$= 9.3Hz, $J_{5,6endo}$= 5.1Hz, $J_{5,4}$= 3.5Hz C-H(5);

2.86(m)(1H) $J_{1,6exo}$= 4Hz, $J_{1,2}$= 3.5Hz, $J_{1,3}\leq$ 1Hz C-H(1); 2.96(m)(1H) $J_{4,5}$= 3.5Hz, $J_{4,3}$= 3Hz, $J_{4,2}\leq$ 1Hz C-H(4); 3.15(s)(3H) OC-H_3; 3.22(s)(3H) OC-H_3; 6.17(m)(1H) $J_{3,2}$= 5.8Hz, $J_{3,4}$= 3Hz, $J_{3,1}\leq$ 1Hz C-H(3); 6.27(m)(1H) $J_{2,3}$= 5.8Hz, $J_{2,1}$= 3.5Hz, $J_{2,4}\leq$ 1Hz C-H(2). **^{13}C-NMR($CDCl_3$)(δ):** 26.5 C-6; 29.7 and 29.8 C(1´) and $(\underline{C}H_3)_2$; 45.3 C-5; 46.7 C-1; 47.2 C-4; 49.6 OCH_3; 51.9 OCH_3; 71.6 C-1´; 119.6 C-7; 130.2 and 135.0 C-2 and C-3. **MS:** 212(M^+)(26%), 197(M^+-CH_3)(12%), 194(M^+-H_2O)(30%), 153(M^+-$(CH_3)_2$C-OH)(67%), 151(153 -2H, aromatization)(98%), 137(M^+-CH_3-O-CH=O-CH_3)(36%), 79(benzeniumion)(55%), 75(CH_3-O-CH=O^+-CH_3)(100%).

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least a borderline case between an inverse and a neutral Diels-Alder reaction. This assumption is confirmed by the fact that unsaturated carbonyl compounds add only slightly faster to **1** than alkenes (R.Müller, Diplomarbeit, Vienna 1985). This effect is small enough to be due to steric differences between the vicinal dialkyl substituted alkenes and the unsaturated carbonyl compounds.

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