

133. *Diels-Alder* Regioselectivity Controlled by Remote Substituents. The Cycloadditions of 1-(Dimethoxymethyl)-2,3-dimethylidene- and -2,3,5,6-tetramethylidene-7-oxabicyclo[2.2.1]heptanes¹⁾

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(2.VI.86)

The syntheses of 2,3-dimethylidene- and 2,3,5,6-tetramethylidene-7-oxabicyclo[2.2.1]heptanes substituted in position C(1) are reported. The 1-dimethoxymethyl group in derivatives **2** and **6** controls the regioselectivity of the *Lewis*-acid-catalyzed *Diels-Alder* additions with methyl vinyl ketone and butynone. For the EtAlCl_2 -catalyzed addition of methyl vinyl ketone to **6**, the regioselectivity can be reversed by a small solvent modification. The tetraene **2** is a versatile reagent for regioselective 'tandem' cycloadditions.

Introduction. – The chemical and spectroscopic properties of the diene moieties in 2,3-dimethylidene- and 2,3,5,6-tetramethylidenebicyclo[2.2.*n*]alkanes can be affected by remote substitution of the bicyclic skeleton [4]. This principle has been applied in the development of our doubly convergent synthesis of anthracyclonones that uses the readily available tetraene **1** as starting material [5]. We report the syntheses of the exocyclic tetraenes **2–5** and dienes **6–10** which were derived quickly and simply from an abundant



- 1** Z = H
2 Z = CH(OMe)₂
3 Z = CHO
4 Z = CH₂OH
5 Z = CH₂OMe



- 6** Z = CH(OMe)₂
7 Z = CHO
8 Z = CH₂OH
9 Z = COOH
10 Z = COOMe

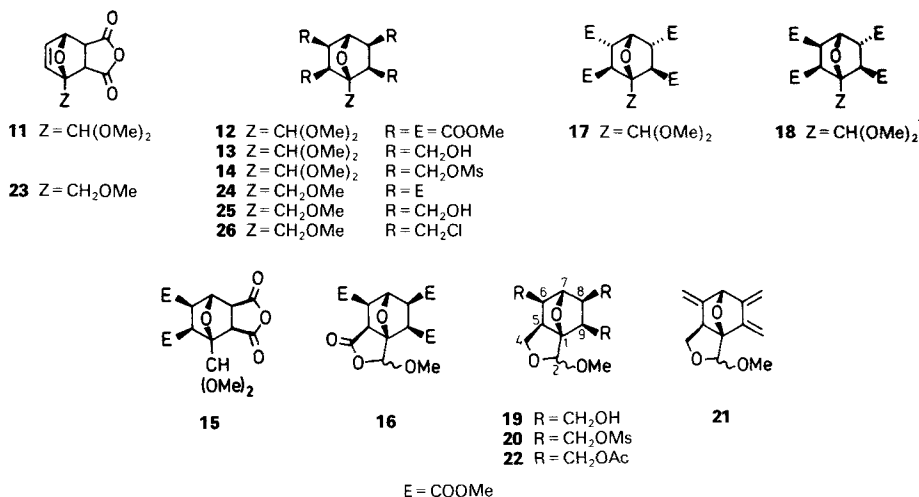
starting material: furfural. We shall show that the acetal group in **2** and **6** can control the regioselectivity of the *Lewis*-acid-catalyzed *Diels-Alder* additions with methyl vinyl ketone (MVK) and butynone. Strikingly, we have found that a small change in the nature of the solvent can reverse the regioselectivity of the EtAlCl_2 -catalyzed reactions of **6** with MVK.

Syntheses of Exocyclic Tetraenes and Dienes. – An equimolar mixture of maleic anhydride and 2-(dimethoxymethyl)furan (derived from 2-furaldehyde and MeOH [6]) in

¹⁾ Interaction between non-conjugated chromophores, Part 25. Part 24, see [1]. For preliminary communications, see [2] [3].

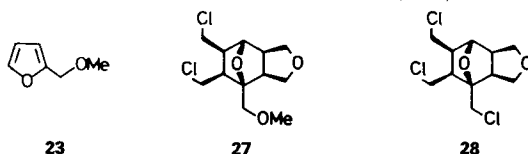
²⁾ Part of the Ph. D. thesis of J. L. Métral, Ecole Polytechnique Fédérale de Lausanne, Dec. 1984. Present address: Ciba-Geigy, Monthey.

Et₂O gave the *Diels-Alder* adduct **11** (70%) [7] after 7 days at 20°. Adduct **11** is very sensitive to moisture. When treated in a *Parr* apparatus with CO (3.5–4 atm), abs. MeOH, 12 mol-equiv. of CuCl₂, and a small amount of 10% Pd/C (0.008 equiv. of Pd) [8], **11** was transformed (20°, 5–7 days) to the tetraester **12** (70%). The all-*exo*-configuration of the four ester groups was established by ¹H-NMR spectroscopy. No vicinal couplings were detected between H–C(3), H–C(4), and H–C(5), and typical vicinal cisoid coupling constants of 10 Hz were measured between the pairs H–C(2), H–C(3) and H–C(5), H–C(6), respectively [8] [9]. The reduction of **12** with LiAlH₄ in THF led to the tetrol **13** (72%) which was transformed into the corresponding tetramesylate **14** (75%) on treatment with methanesulfonyl chloride and pyridine. The latter eliminated 4 equiv. of methanesulfonic acid in the presence of an excess of *t*-BuOK (0°, DMF/HMPT 6:1, 2 h) yielding the tetraene acetal **2** (60%). In THF, the elimination **14**→**2** is much slower (20°, 12–20 h).

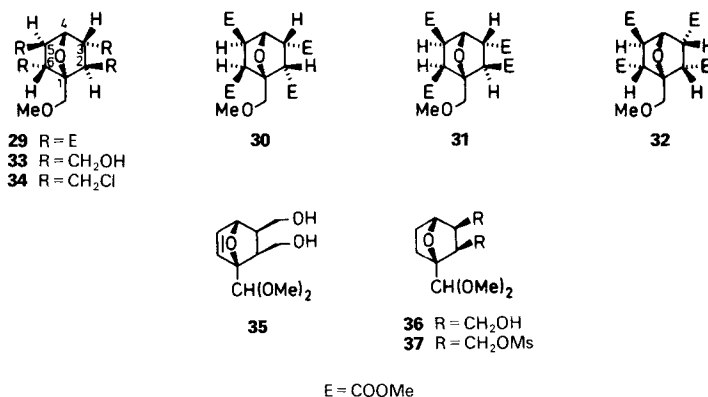


When using wet MeOH for the carbonylation of **11**, the anhydride **15** and the lactone **16** were observed as minor compounds. Lactone **16** was formed as major product on treating **12** in MeOH with charcoal. Base-induced (K₂CO₃/abs. MeOH, 20°) isomerization of **12** gave a 1:1 mixture of the tetraesters **17** and **18**. The amount of H₂O used to destroy the alcoholates and the excess of LiAlH₄ after the reduction **12**→**13** play a critical role on the yield of this reaction. When an excess of H₂O was used, the triol **19** was formed together with **13**. When **13** was treated with 0.1N H₂SO₄ (20°, 7 d), the triol **19** was formed quantitatively (**13** was found to be stable in neutral MeOH). Mesylation of triol **19** (MsCl, pyridine) afforded the corresponding triemesylate **20** which gave the corresponding triene **21** on treatment with an excess of *t*-BuOK in DMF/HMPT. Only one isomeric acetal was observed for **16** and **19**–**22**, the relative configuration of which could not be established unambiguously. The structure of **19** was derived from that of the corresponding triacetate **22** obtained on treatment of **19** with Ac₂O/pyridine.

Acidic solvolysis (H₂O/dioxane/HCl, 90°) of the tetraene acetal **2** afforded the unstable tetraenal **3** which was reduced by NaBH₄ in *i*-PrOH into the tetraenol **4** (45%). The corresponding methyl ether **5** was prepared in the following way.

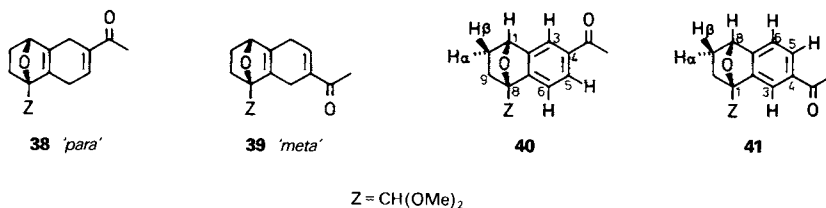


The *Diels-Alder* adduct of maleic anhydride and 2-(methoxymethyl)-furan [10] (**23**) was carbonylated to give tetraester **24** (52%) under the same conditions as those used above for the transformation **11**→**12**. LiAlH_4 reduction of **24** gave **25** (82%). All our attempts to generate the corresponding tetrachloride **26** failed and led to various mixtures of the tetrahydrofuran derivatives **27** and **28**. In order to circumvent this difficulty, the all-*exo*-tetraester **24** was treated with anh. K_2CO_3 in abs. MeOH. After 45 h at 20° , the 'all-*trans*' isomer **29** was isolated in 89.6% yield. The configuration of **29** was determined by its 360-MHz- $^1\text{H-NMR}$ spectrum and with the help of double-irradiation experiments. The bridgehead proton $\text{H-C}(4)$ resonated as a *d* (5.1 ppm), this demonstrating the *exo* configuration of $\text{H-C}(3)$ ($^3J(\text{H}_{\text{exo}}-\text{C}(3), \text{H-C}(4)) = 5$ Hz) and the *endo* configuration of $\text{H-C}(5)$ ($^3J(\text{H-C}(4), \text{H}_{\text{endo}}-\text{C}(5)) \approx 0$ Hz [8] [9]). The isomeric structures **30**–**32** were ruled out because $^3J(\text{H-C}(2), \text{H-C}(3)) = ^3J(\text{H-C}(5), \text{H-C}(6)) = 5.5$ Hz: this value is not compatible with a *cis* type of vicinal coupling constant [8] [9]. LiAlH_4 reduction of **29** gave the tetrol **33** (90%) which was chlorinated ($\text{SOCl}_2/\text{pyridine}$) to **34** (80%). Quadruple elimination of HCl (*t*-BuOK/THF) afforded the tetraene **5** (69%). All our attempts to cleave the methyl ether of **5** to generate the tetraenol **4** led to products of decomposition.



The exocyclic dienes **6**–**10** were obtained readily starting with the *Diels-Alder* adduct **11**. LiAlH_4 reduction of **11** (THF, 0°) yielded the ene-diol **35** which was then hydrogenated (4 atm H_2 , Pd/C, AcOEt, -25°) to diol **36**. Mesylation ($\text{MsCl}/\text{pyridine}$) gave **37** which furnished the diene acetal **6** on treatment with an excess of *t*-BuOK in DMF/HMPT. Acidic hydrolysis of the acetal **6** gave the dienal **7** (60%). Reduction with NaBH_4 (THF/*i*-PrOH) yielded the dienol **8** (70%). Oxidation of the aldehyde **7** with Ag_2O in alkaline (10% NaOH in H_2O) THF afforded the unstable acid **9** whose methyl ester **10** (92%) was obtained on treatment with CH_2N_2 in Et_2O .

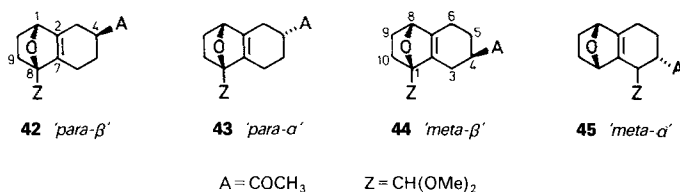
Diels-Alder Stereo- and Regioselectivities. – Under thermal conditions (80 – 100° , 5–16 h, without solvent or with benzene), the additions of tetraenes **2** and **5**, and of the



dienes **6-8** and **10** to methyl propynoate or to butynone were not regioselective. The product ratio of the 'para' vs. 'meta' adducts (see **38** and **39**) varied between 55:45 and 45:55. Attempts to improve the regioselectivity of the cycloaddition of methyl propynoate to the dienes by using *Lewis*-acid catalysts [11] such as AlCl₃, ZnCl₂, BF₃·Et₂O, B(OCH)₃, or EtAlCl₂ in CH₂Cl₂ were unsuccessful³⁾.

However, the catalyzed *Diels-Alder* additions of butynone to **6** were more interesting. When butynone (0.4M) was precomplexed with BF₃·Et₂O (3 mol-equiv.) in CH₂Cl₂ (-75°, 30 min) [12], it reacted with the diene acetal **6** (-75°, 4-5 days) giving a 7:3 mixture of adducts **38** and **39** (83%, isolated yield). Butynone (0.06-0.24M) precomplexed with EtAlCl₂ (3 mol-equiv.) in CH₂Cl₂/hexane 1:1 (-85 to -65°, 20 min) added to **6** (-75°, 1 to 5 days) yielding a 55:45 mixture **38/39**. When the solvent was changed from CH₂Cl₂/hexane 1:1 to CH₂Cl₂/hexane 1.6:1, the regioselectivity varied from 55:45 to 47:53 (±5%; by 360-MHz-¹H-NMR of the crude reaction mixture). These results indicated the importance of the nature of the catalyst on the regioselectivity of the *Lewis*-acid-catalyzed cycloadditions [13]. They also suggested that minor changes in the solvent can also affect the regioselectivity [14]. This will be confirmed for the additions of methyl vinyl ketone (MVK) to **6** (see below).

The adducts **38** and **39** were separated by medium-pressure column chromatography on silica gel. These compounds were unstable in solution and were partially aromatized into **40** and **41**, respectively. The oxidations **38**→**40** and **39**→**41** were nearly quantitative in the presence of dichlorodicyanobenzoquinone (DDQ = 4,5-dichloro-3,6-dioxo-1,4-cyclohexadiene-1,2-dicarbonitrile) in benzene at 60°. The structures of **40** and **41** were established by ¹H-NMR (see below).



On heating **6** with an excess of MVK in benzene to 100°, a 2.3:1:2.3:1 mixture **42/43/44/45** was obtained in 90% yield. The proportion of the isomeric adducts was obtained by integration of the *s*'s between 4.52 and 4.56 ppm attributed to the CH(OMe)₂ groups observed in the 360-MHz-¹H-NMR spectrum of the crude reaction mixture. Adducts **42-45** were separated by HPLC on silica gel; their structure was given by their

³⁾ In the presence of EtAlCl₂ or BF₃·Et₂O in CH₂Cl₂, methyl acrylate did not add to **6** after 3 days at 0°. At higher temperature, decomposition was observed.

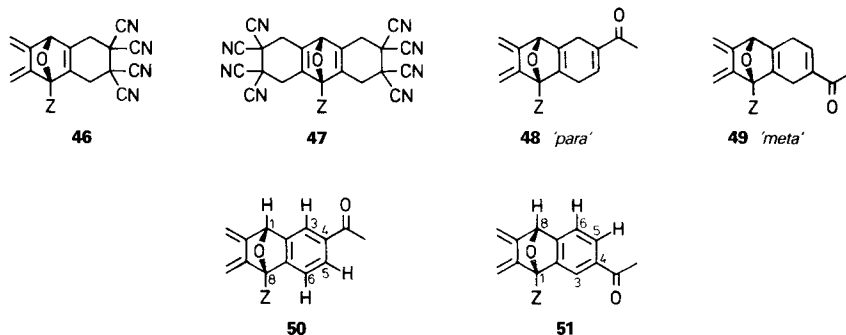
^{13}C - and ^1H -NMR spectra (see below). In the presence of K_2CO_3 in anh. MeOH (20° , 12 h), **42** was equilibrated with **43**, while **44** was equilibrated with **45**. Under thermal conditions, the regioselectivity of the *Diels-Alder* addition of MVK to **6** was nil (product ratio **42** + **43/44** + **45** is 1:1). The stereoselectivity which refers here to the proportion of β vs. α position of the acyl groups in **42–45** was not better than 7:3 for both pairs of regioisomers **42/43** and **44/45**. Better stereo- and regioselectivities were observed under *Lewis*-acid-catalyzed conditions. Reaction of **6** with MVK precomplexed with $\text{BF}_3 \cdot \text{Et}_2\text{O}$ in CH_2Cl_2 (-85° , 20 min) gave a 13.5:1:2.5:1.25 mixture **42/43/44/45** (94%). The same selectivities were observed when CH_2Cl_2 was replaced by toluene (-73°) or $\text{CH}_2\text{Cl}_2/\text{CH}_3\text{NO}_2$ 1:1 (v/v). An even better selectivity for the 'para- β ' isomer **42** was obtained when **6** (0.06M) reacted (-90° , 1 h) with 3 mol-equiv. of MVK precomplexed with 3 mol-equiv. of EtAlCl_2 in CH_2Cl_2 /hexane 5:1. Under the latter conditions, a 28.5:1:3:2 mixture **42/43/44/45** was formed in 95% yield. When the solvent mixture contained higher proportions of hexane, the 'para' regioselectivity was found to decrease and the 'meta- β ' isomer **44** became the favoured adduct. The best 'meta' regioselectivity was observed in CH_2Cl_2 /hexane 1.5:1 which led to a 10:1:24:1 mixture **42/43/44/45**. An adverse effect of increasing the hexane content is that the reaction becomes sluggish due to the decreased solubility of the reactants. Nevertheless, the overall yield was 68%, and the major product **44** was isolated by HPLC (see *Exper. Part*).

The reversal of the *Diels-Alder* regioselectivity by a change of *Lewis* acid has been observed several times [13]. To our knowledge, however, the solvent effect reported here is unprecedented. It can be interpreted in terms of co-coordination [14] of EtAlCl_2 with MVK and the acetal group in **6** which leads to a preferred formation of the 'meta- β ' adduct **44**. This is preferred in an uncoordinating solvent such as hexane. In the presence of a coordinating solvent such as CH_2Cl_2 , the latter competes with **6** for coordination to EtAlCl_2 -MVK, and consequently 'para' attack is favoured for reasons of steric hindrance. This hypothesis implies *exo*-face selectivity for the cycloadditions of **6** to the *Lewis*-acid-coordinated dienophile. This has been found for other dienes grafted on 7-oxabicyclo[2.2.1]heptane systems [15]. Double coordination of BF_3 is also possible [16]. The absence of reversal of the regioselectivity of the cycloaddition of **6** to MVK catalyzed by $\text{BF}_3 \cdot \text{Et}_2\text{O}$ when changing the solvent from CH_2Cl_2 to toluene might be attributed to the presence of Et_2O which coordinates strongly to BF_3 and makes difficult the competitive coordination of MVK- BF_3 with the acetal group in **6**. Solvent effects on the stereoselectivity (*Alder* vs. *anti-Alder* mode of addition [17]) of *Lewis*-acid-catalyzed *Diels-Alder* additions have been reported several times [18]⁴). The principle of temporary binding of the cycloadducts to the same molecule of a *Lewis* acid [20] has been applied recently by *Snider* and coworkers [21a] in their synthesis of (\pm)-pseudomonic acids.

The relatively good β -stereoselectivity for the *Diels-Alder* additions of MVK to **6** was not unexpected as several olefinic dienophiles were found already to add to butadienes grafted onto 7-oxabicyclo[2.2.1]heptane skeletons with high β -stereoselectivity [15] [21b].

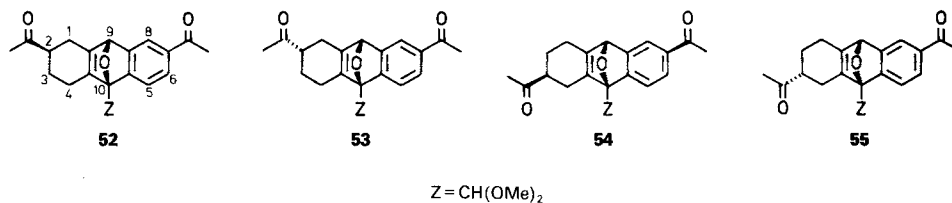
Preliminary experiments on the $\text{BF}_3 \cdot \text{Et}_2\text{O}$ - and EtAlCl_2 -catalyzed cycloadditions of MVK to dienes **7**, **8**, and **10** led to partial or complete decomposition of the cycloadducts and/or of the adducts.

⁴) For solvent effects on the rates and the stereoselectivity of *Lewis*-acid-catalyzed *Diels-Alder* additions, see [19].

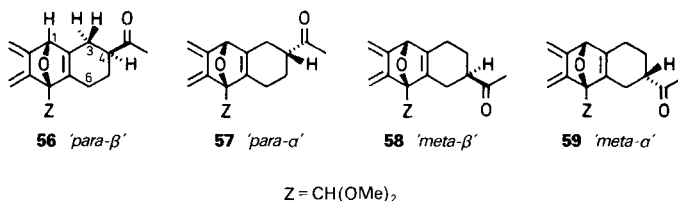


The rate of the *Diels-Alder* addition of tetraene **1** to a given dienophile (k_1) is much higher than that (k_2) of the corresponding monoadduct adding to the same dienophile. A rate constant ratio $k_1/k_2 = 376$ (at 25°) was measured for the two successive cycloadditions of ethylenetetracarbitrile (TCNE) to **1** [4] [22]. Similarly, a large difference in *Diels-Alder* reactivity between tetraene acetal **2** and its corresponding monoadducts was observed. For instance, while **2** in benzene added to one mol.-equiv. of TCNE at 20° to give the monoadduct **46**, the addition of a second equiv. of TCNE to give the bis-adduct **47** required a large excess of the dienophile and heating to 110° (toluene). The product **47** was formed very slowly, concomitantly with the decomposition of **46**.

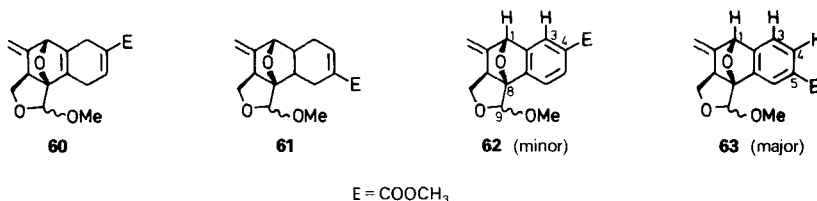
The reaction of tetraene acetal **2** with an excess of butynone (benzene, 80° , 2 d) gave a 1:1 mixture of monoadducts **48/49**. When butynone was precomplexed with 1 equiv. of $\text{BF}_3 \cdot \text{Et}_2\text{O}$ (1.7M) in CH_2Cl_2 , the cycloaddition (0.12M of **2**, -75° , 65 h) gave a 7:3 mixture **48/49** in 80% yield. As for the $\text{BF}_3 \cdot \text{Et}_2\text{O}$ -catalyzed *Diels-Alder* additions of butynone and MVK to **6** (and of MVK to **2** and **50**, see below), the reaction was 'para' regioselective.



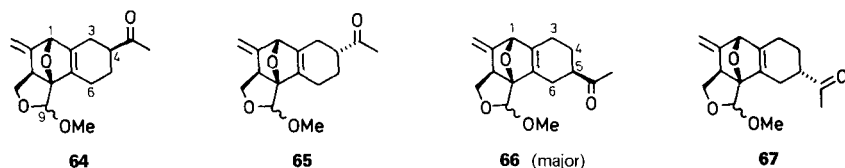
The two monoadducts **48** and **49** were readily separated by column chromatography on silica gel. Treatment of **48** and **49** with 1.1 mol-equiv. of DDQ afforded the aromatic ketones **50** (90%) and **51** (85%), respectively. Their structure was established by $^1\text{H-NMR}$ spectroscopy (see below). The diene moiety in **50** was more reactive than that in **48** toward strong dienophiles. On treating **50** (0.06M) with an excess of MVK complexed with $\text{BF}_3 \cdot \text{Et}_2\text{O}$ (2.1M) in CH_2Cl_2 (-75° , 73 h), a 14:1.1:5:1.3 mixture **52/53/54/55** was obtained in 80% yield. The selectivity was slightly better when **50** (0.06M) was allowed to react with MVK (2.1M) complexed with EtAlCl_2 (2.1M) in CH_2Cl_2 /hexane 5:1 at -75° for 77 h. Under these conditions, a 17.2:1:5.2:1.2 mixture **52/53/54/55** was obtained in 75% yield. The major component **52** could be isolated and purified by two or three recrystallizations from acetone in 60% yield.



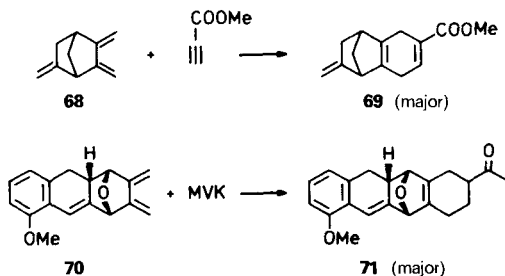
The addition of MVK to tetraene acetal **2** under thermal conditions (without or with C₆H₆, 80°, 10–50 h) gave a mixture of the monoadducts **56–59** for which the 'para' vs. 'meta' regioselectivity was not better than 6:4 (**56 + 57**/**58 + 59**) and the β vs. α stereoselectivity approached 7:3 (**56 + 58**/**57 + 59**) as determined by the 360-MHz-¹H-NMR spectrum of the crude reaction mixture. The reaction of MVK complexed to 1 mol-equiv. of BF₃·Et₂O (2M) in CH₂Cl₂ (0.13M **2**, -85°, 30 min) yielded a 9.3:1:2: < 1 mixture **56/57/58/59** in 71% yield. The addition of **2** (0.05M) to MVK (4.15M) precomplexed with EtAlCl₂ (4.15M) in CH₂Cl₂/hexane 11.5:1 (-85°, 1 h) gave a 34:1:7: < 1 mixture **56/57/58/59**. The major adduct **56** was isolated and purified by HPLC (see *Exper. Part*), and its structure was given by its spectral data (see below). The distinction between the β vs. α isomeric pairs **56/57** and **58/59** was based on their isomerization under basic conditions (K₂CO₃, anh. MeOH, 20°, 12 h). Both catalysts BF₃·Et₂O and EtAlCl₂ led to a 'para' regioselectivity better than 82:18. The isomers **56** and **58** represented more than 90% of the adduct mixtures. Effect of the nature of the solvent on the EtAlCl₂-catalyzed additions of **2** to MVK has not been studied.



Under thermal conditions, the triene **21** added to methyl propynoate (no solvent, 60°, 10 h) and afforded a 35:65 mixture of adducts **60/61** (by ¹H- and ¹³C-NMR of the crude reaction mixture). Their structures were deduced from those of the corresponding benzoates **62** and **63** which were formed in nearly quantitative yield on treatment with 1.1 mol-equiv. of DDQ (benzene, 70°, 3 h). The structures of **62** and **63** were determined by ¹H-NMR spectroscopy (see below). The reaction of MVK with triene **21**, in absence of a Lewis-acid catalyst, was regio- and stereoselective. On heating a 1:20 mixture **21**/MVK in toluene to 100° for 14 h, a 6.2:1:12.4:1.7 mixture **64/65/66/67** was obtained in 85% yield. As observed for the MVK additions to other dienes grafted onto 7-oxabicyclo-[2.2.1]heptane systems [5b] [5c] [21b], the relatively good β vs. α stereoselectivity of the reaction **21** + MVK was expected. Components **64** and **66** constituted more than 85% of the adduct mixture. The regioselectivity of ca. 2:1 observed for the cycloadditions of **21** to MVK and to methyl propynoate are parallel to those observed for the *Diels-Alder* additions of the related trienes **68** [23] and **70** [5b] which were shown to give the favoured adducts **69** and **71**, respectively. These results were interpreted in terms of a homoconjugative interaction between the reacting diene moiety and the homoconjugated double



bond in these trienes [4]. Thus, it appears that the methyldiene group in **21** has a greater effect on the regioselectivity of the *Diels-Alder* additions of **21** than its acetal function. Triene **21** and tetraenes **3–5** were not stable in the presence of strong *Lewis* acids such as $\text{BF}_3 \cdot \text{Et}_2\text{O}$ and EtAlCl_2 . Thus, the catalyzed cycloadditions of these polyenes could not be studied.



Structure of the Adducts. – The position of the acyl groups in the aromatized adducts **40**, **41**, **50**, and **51**, as well as that of the ester groups in **62** and **63** was determined unambiguously by nuclear *Overhauser* enhancement (NOE) measurements in their 360-MHz $^1\text{H-NMR}$ spectra. These measurements allowed one to establish the proximity of the bridgehead proton of the 7-oxabicyclo[2.2.1]heptene system to the aromatic protons.

As an illustration of the method, we describe the results for derivatives **62** and **63**. Irradiation of the *s* at 5.29 ppm ($\text{H-C}(1)$) of **62** (the minor isomer) led to a significant NOE for the *d* ($^4J = 1.5$ Hz) at 8.11 ppm attributed to $\text{H-C}(3)$, the proton adjacent to the COOCH_3 group at C(4). Irradiation of the latter signal also gave a NOE at 5.29 ppm. In contrast, irradiation of the bridgehead-proton signal ($\text{H-C}(1)$) at 5.28 ppm of the major isomer **63** led to a NOE for the *d* ($^3J = 7.9$ Hz) at 7.03 ppm attributed to $\text{H-C}(3)$. Irradiation of the latter *d* gave a NOE at 5.29 ppm. Irradiation of the signals at 8.68 ppm ($^4J(\text{H-C}(4), \text{H-C}(6)) = 1.5$ Hz, $\text{H-C}(6)$) and at 8.15 ppm

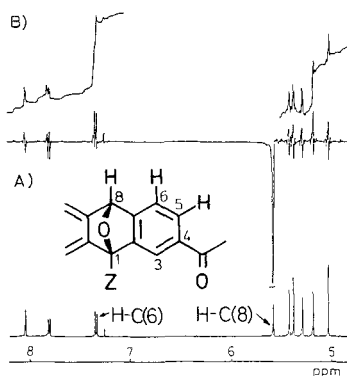


Fig. 1. A) Portion of the 360-MHz $^1\text{H-NMR}$ (CDCl_3) spectrum of **51**. B) Difference of the irradiated spectrum of **51** at 5.6 ppm ($\text{H-C}(8)$) and the non-irradiated spectrum showing the NOE for the *d* at 7.36 ppm ($\text{H-C}(6)$).

($^3J(\text{H}-\text{C}(3), \text{H}-\text{C}(4)) = 7.9$ Hz, $^4J(\text{H}-\text{C}(4), \text{H}-\text{C}(6)) = 1.5$ Hz, $\text{H}-\text{C}(4)$) did not give a NOE at 5.29 ppm ($\text{H}-\text{C}(1)$). Another illustration of the method is given for the structure of the aryl methyl ketone **51** in Fig. 1.

The structure of the adduct **56** was based on the values of the coupling constants between the protons of the cyclohexenyl moiety (see *Exper. Part*). Most of the coupling constants could be measured directly from the experimental spectrum with the help of double-irradiation experiments (Fig. 2) and were consistent with the conformation represented in Fig. 3.

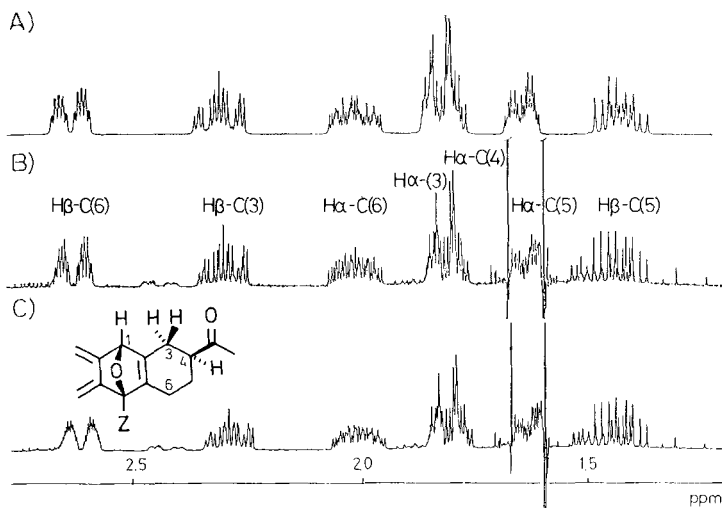


Fig. 2. Portion of the 360-MHz $^1\text{H-NMR}$ (C_6D_6) spectrum of **56**. A) Simulated spectrum (PANIC 81, 7 spins, $^5J(\text{H}-\text{C}(1), \text{H}_\beta-\text{C}(6)) = ^5J(\text{H}-\text{C}(1), \text{H}_\alpha-\text{C}(6)) = 0$). B) Experimental spectrum with irradiation of the signal at 4.71 ppm ($\text{H}-\text{C}(1)$). C) Experimental spectrum without double irradiation (the FID signals were multiplied by a Gaussian function $\exp(at - bt^2)$ with $a = \pi LB$ ($LB = -0.88$) and $b = a/2 \cdot GB \cdot T$ ($GB = 0.4$)). Spectra B) and C) show extra signals of the minor isomer **58** ($< 10\%$).

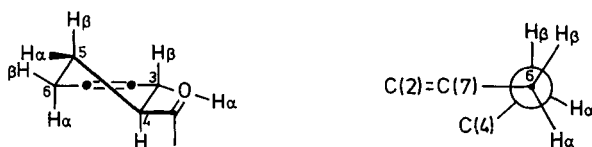


Fig. 3. Favoured conformation of **56**

Simulation of the $^1\text{H-NMR}$ spectrum of **56** (Fig. 2A) was also performed in order to confirm our measurements. The acetyl group in **56** must be attached to C(4) because there is no coupling between $\text{H}-\text{C}(4)$ and $\text{H}_\alpha-\text{C}(6)$ and $\text{H}_\beta-\text{C}(6)$. The values of the vicinal coupling constants between $\text{H}_\beta-\text{C}(3)$, $\text{H}_\alpha-\text{C}(3)$, and $\text{H}-\text{C}(4)$ were consistent only with the conformation represented in Fig. 3. The absence of a *W*-type 4J coupling between $\text{H}-\text{C}(4)$ and $\text{H}_\beta-\text{C}(6)$ confirmed the axial α -position of $\text{H}-\text{C}(4)$. The values obtained for the vicinal coupling constants between $\text{CH}_2(5)$ and $\text{CH}_2(6)$ also confirmed the conformation shown in Fig. 3 (for an analogous compound for which an X-ray structure has been obtained, see [15]).

The signal at 2.61 ppm was attributed unambiguously to $\text{H}_\beta-\text{C}(6)$ because it coupled with the bridgehead proton $\text{H}-\text{C}(1)$ through a typical inter-ring homoallylic coupling constant of ca. 1.2 Hz [15] [24]. As expected [24], the homoallylic coupling constant between $\text{H}-\text{C}(1)$ and $\text{H}_\alpha-\text{C}(6)$, on one hand, and the 4J between $\text{H}-\text{C}(1)$ and $\text{H}_\alpha-\text{C}(3)$, $\text{H}_\beta-\text{C}(3)$ on the other hand, were smaller than 0.5 Hz. The distinction between H_β and $\text{H}_\alpha-\text{C}(3)$ was based on their chemical shift difference ($\delta(\text{H}_\beta) > \delta(\text{H}_\alpha)$) and on the homoannular homoallylic coupling constants

between the protons at C(3) and C(6) (e.g. $^5J(\text{H}_\alpha\text{-C}(3), \text{H}_\beta\text{-C}(6)) = 1.0$ Hz, whereas $^5J(\text{H}_\beta\text{-C}(3), \text{H}_\beta\text{-C}(6)) = 2.8$ Hz [24]). A further confirmation of the favoured conformation represented in Fig. 3 was given by the observation of a *W*-type 4J coupling constant of 1.5 Hz between $\text{H}_\alpha\text{-C}(3)$ and $\text{H}_\alpha\text{-C}(5)$, both protons being equatorial.

Similar $^1\text{H-NMR}$ characteristics were obtained for the regioisomer **58**. The isomeric α adducts **57** and **59** were formed on treating **56** and **58**, respectively, with K_2CO_3 in anh. MeOH (20° , 1 d), thus establishing their structure.

The structure of the diketone **52** was determined in the same way as that of **56**. The 360-MHz $^1\text{H-NMR}$ spectra of these two compounds were very similar for the signals attributed to the protons of the cyclohexenyl moieties (see *Exper. Part*). The $^1\text{H-NMR}$ spectrum of adduct **42** also showed similarities with those of **52** and **56** for the signals of the protons at C(1), C(3), C(4), C(5), and C(6). Although there were complications due to overlap of the cyclohexenyl proton signals with those of the methylene groups at C(9) and C(10), typical coupling constants could be evaluated with the help of double-irradiation experiments. Adduct **42** was isomerized into **43** in the presence of K_2CO_3 in anh. MeOH.

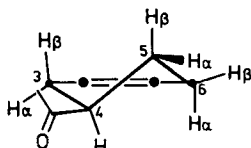


Fig. 4. Favoured conformation of **44**

Out of the 16 $^1\text{H-NMR}$ coupling constants expected for the cyclohexenyl moiety of **42**, 11 could be determined (see *Exper. Part*). A long-range coupling constant of ca. 0.9 Hz was also observed between $\text{H}_\beta\text{-C}(3)$ and $\text{H}_\beta\text{-C}(10)$ or $\text{H}_\beta\text{-C}(9)$. The vicinal coupling constant of 10 Hz measured between $\text{H}_\beta\text{-C}(3)$ and $\text{H-C}(4)$ was consistent only with an axial $\text{H-C}(4)$ and the acetyl group in an equatorial β -position.

The structure of the '*meta*- β ' isomer **44** was established independently. The $^1\text{H-NMR}$ characteristics of this adduct (see *Exper. Part*) were obtained through a combination of double-irradiation experiments, 2D-NMR (δ_{H} vs. δ_{C}) and $^1\text{H-NMR}$ -spectrum simulations. The data were consistent only with the conformation shown in Fig. 4. Isomerization of **44** into **45** was achieved by treatment with K_2CO_3 in anh. MeOH (20° , 1 d).

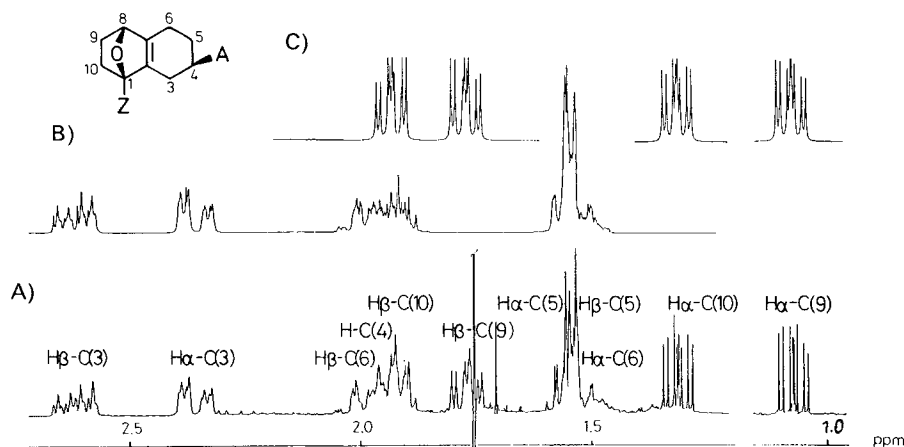


Fig. 5. Partial 360-MHz $^1\text{H-NMR}$ (C_6D_6) spectrum of **44**. A) Experimental spectrum ($LB = -0.7$, $GB = 0.5$) with irradiation of the signal at 4.53 ppm ($\text{H-C}(8)$). B) Simulated (PANIC 81) spectrum of the cyclohexenyl moiety (7 spins). C) Simulated spectrum of the ethano bridge $\text{CH}_2(9)\text{-CH}_2(10)$ (4 spins).

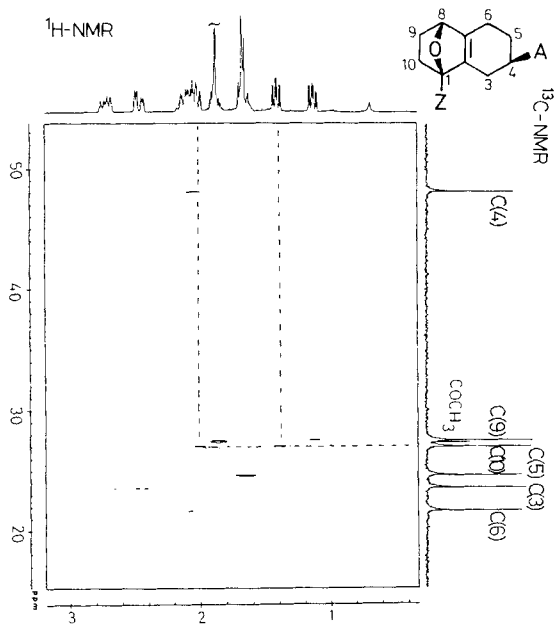


Fig. 6. 2D-NMR spectrum of **44** correlating δ_H vs. δ_C . Obtained with the pulse sequence [25]: $90^\circ(^1\text{H}) - t_1/2 - 180^\circ(^{13}\text{C}) - t_1/2 - \tau_1 - 90^\circ(^1\text{H}, ^{13}\text{C}) - \tau_2$ - acquire with proton-noise decoupling (magnetization transfer through $^1J(\text{C}, \text{H}) \approx 130 \text{ Hz}$). $\tau_1 = (2J)^{-1} = 3.85 \text{ ms}$; $\tau_2 = (4J)^{-1} = 1.92 \text{ ms}$. The number of sample data points was $128 \times 4\text{K}$. Resolution enhancement by phase-shifted sine-bell functions; zero-filling to 256 data points in t_1 ; spectral width $\pm 520 \text{ Hz}$ in t_1 , 12.5 kHz in t_2 ; 128 scans; recycle delay 2 sec; $\Delta t_1/2 = 0.48 \text{ ms}$; acquisition, ca. 7 h; $256 \times 4\text{K}$ Fourier transformation, ca. 1 h.

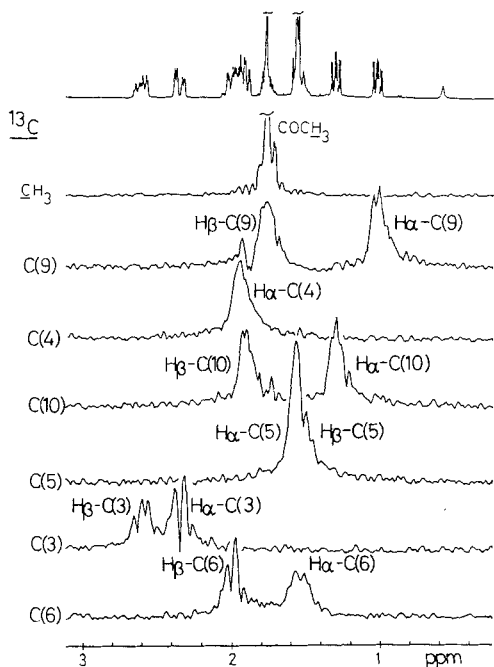


Fig. 7. Cross-sections through the ^{13}C -NMR chemical shifts in the 2D shift-correlated NMR spectrum of Fig. 6. Digital resolution 4.1 Hz/point. The proton assignments are indicated. Top trace: 1D ^1H -NMR spectrum.

As for the other adducts, the signal of H_{β} -C(3) (2.61 ppm) of **44** was recognized by its homoallylic coupling ($^5J = 0.8$ –1 Hz) with the bridgehead proton H-C(8) (4.52 ppm). The direct analysis of the other signals was difficult because of the superposition of several m between 1.9 and 1.6 ppm (see Fig. 5). The 2D-NMR spectrum which correlates δ_H vs. δ_C (see Fig. 6) allowed one to define the positions of the proton signals (see Fig. 7). The digital resolution available (4.1 Hz/point) did not make possible a determination of the $J(H,H)$ by this technique. The proximity of the protons at C(3) with that at C(4) was determined by irradiation of the signal at 2.0 ppm (H-C(4)), thus establishing the position of the acetyl group. The vicinal coupling constants of 8.5 Hz between H_{β} -C(3) and H-C(4) and of 5.5 Hz between H_{α} -C(3) and H-C(4) were consistent only with the axial α -position of H-C(4) (see Fig. 4). Distinction between H_{β} -C(9) and H_{α} -C(9) was based on the vicinal coupling constant of 4.2 Hz observed between H-C(8) and H_{β} -C(9), whereas no coupling was detected between H-C(8) and H_{α} -C(9) [9]. Finally, all other H,H coupling constants were evaluated by simulation of the 1H -NMR spectrum of **44** (see Fig. 5).

Conclusion. – The technique developed for the preparation of 2,3,5,6-tetramethylidene-7-oxabicyclo[2.2.1]heptane (**1**) has been generalized to the preparation of the substituted derivatives **2–5**. The starting materials are the inexpensive maleic anhydride and the dimethyl acetal of 2-furaldehyde or 2-(methoxymethyl)furan. The substituent Z at one of the bridgehead centre of the bicyclic skeleton can be used to control the regio- and the stereoselectivity of the two successive *Diels-Alder* additions of the exocyclic tetraenes. This new principle was demonstrated for the tetraene acetal **2** ($Z = CH(OMe)_2$). It is shown that the regioselectivity of the $EtAlCl_2$ -catalyzed cycloadditions of MVK can be reversed by a small modification in the nature of the solvent. Since the rate constant of the addition of the first equivalent of a dienophile to the tetraene **2** is significantly larger than that of the addition of the second equivalent of the same dienophile, it allows one to isolate the corresponding monoadduct in a good yield and makes possible the use of another dienophile in the second cycloaddition. Thus, the tetraene **2** is a versatile reagent for the tandem regio- and stereoselective *Diels-Alder* additions. It is a potential precursor for the stereoselective synthesis of polycyclic, polyfunctional systems such as the anthracene analogs.

We thank *F. Hoffmann-La Roche & Co., AG*, Basel, the *Swiss National Science Foundation*, and the *Fonds Herbette*, Lausanne, for generous financial support. We thank also Prof. *M. McGlinchey* for reading the manuscript.

Experimental Part

General. See [15] [24]. HPLC: Dupont-830003-904 instrument with a UV (254 nm) detector or Siemens-S112 instrument equipped with a differential diffractometer Knauer 98.00; columns: silica gel, Zorbax Sil 7 μm , 25 cm \times 21.2 mm or (inversed phase) Zorbax ODS, 5–6 μm , 25 cm \times 21.1 mm. Medium-pressure chromatography: Lobar-Merk system, silica gel column (Lichroprep Si60, 40.63 μm , 2.5 cm \times 31 cm), Duramat Prominent CFG pump, and UV detector, LKB (Bromma) 2238 Univord S-II. Cooling: Lauda TK 80 kryostat.

Tetramethyl 1-Dimethoxymethyl-7-oxabicyclo[2.2.1]heptane-2,3,5,6-tetracarboxylate (12). A mixture of 1-dimethoxymethyl-7-oxabicyclo[2.2.1]hept-5-ene-2,3-dicarboxylic anhydride (**11** [7], 17 g, 70.8 mmol), anh. $CuCl_2$ (116 g, 863 mmol), 10% Pd/C (3 g, 2.8 mmol), and abs. MeOH (500 ml) was purged with N_2 (2-l flask, Parr hydrogenation apparatus). Then, the flask was pressurized with 3 atm of CO. This pressure was maintained, and the flask was shaken for 168 h at 20°. The mixture was neutralized with $NaHCO_3$ and filtered on Celite. After solvent evaporation, the crude product was taken in $CHCl_3$ (200 ml, 5 times). The org. phase was washed with sat. aq. NH_4Cl soln. (500 ml), then with H_2O (500 ml, 5 times). After drying ($MgSO_4$), the solvent was evaporated and the crude **12** recrystallized from EtOH, yielding 21.5 g (75%), colourless crystals, m.p. 165–166°. IR ($CHCl_3$): 3000, 2950, 2840, 1750, 1435, 1340, 1200, 1100, 1085, 1030, 960. 1H -NMR ($CDCl_3$): 5.54 (br. s, H-C(4)); 4.71 (s, $(CH_3O)_2CH$); 3.60, 3.59 (2s, 4 $COOCH_3$); 3.31 (s, $(CH_3O)_2CH$); 3.18, 2.89 (2d, $^3J = 10$, H-C(2), H-C(3), H-C(5), H-C(6)). ^{13}C -NMR ($CDCl_3$): 169.9 (br. s, 4 CO); 103.8 (dm, $^1J(C,H) = 167$, $^3J(C,H) = 5$, CH-C(1));

92.2 (*d*, $^3J(\text{C}(1), \text{H}-\text{C}(4)) = 10$, C(1)); 78.3 (*d*, $^1J(\text{C}, \text{H}) = 164$, C(4)); 56.7 (*qd*, $^1J(\text{C}, \text{H}) = 143$, $^3J(\text{C}, \text{H}) = 5$, $(\text{CH}_3\text{O})_2\text{CH}$); 52.8 (*dm*, $^1J(\text{C}, \text{H}) = 142$, C(2), C(6) or C(3), C(5)); 52.0, 51.4 (*2q*, $^1J(\text{C}, \text{H}) = 147$, 4 COOCH_3); 51.0 (*dm*, $^1J(\text{C}, \text{H}) = 134$, C(3), C(5) or C(2), C(6)). CI-MS (*i*- C_4H_{10}): 405 (4, $M^+ + 1$), 404 (5, M^+), 374 (100). Anal. calc. for $\text{C}_{17}\text{H}_{24}\text{O}_{11}$ (404.374): C 50.50, H 5.98; found: C 50.57, H 6.02.

(1RS, 2SR, 3RS, 4SR, 5SR, 6RS)-1-Dimethoxymethyl-5-exo, 6-exo-bis(methoxycarbonyl)-7-oxabicyclo[2.2.1]heptane-2-exo,3-exo-dicarboxylic Anhydride (15). If the MeOH used in the above synthesis contained some H_2O , 15 was formed as a secondary product. It was separated from 11 by fractional crystallization from EtOH, colourless crystals, m.p. 145–146°. IR (KBr): 3040, 3010, 2980, 1810, 1755, 1740, 1450, 1435, 1370, 1250, 1120, 965, 945. $^1\text{H-NMR}$ (360 MHz, CDCl_3): 5.77 (*s*, $\text{CH}-\text{C}(1)$); 5.16 (*br. s*, $\text{H}-\text{C}(4)$); 3.73, 3.70, 3.69, 3.55 (4*s*, 2 CH_3O , 2 COOCH_3); 3.88 (*d*, $^3J = 9.4$, 1 H); 3.21 (2*d*, $^3J = 9.4$, 2 H); 3.15 (*d*, $^3J = 9.4$, 1 H). $^{13}\text{C-NMR}$ (CDCl_3): 171.7, 169.6, 169.4, 169.3 (4*m*, CO); 102.5 (*dm*, $^1J(\text{C}, \text{H}) = 182$, $^3J(\text{C}, \text{H}) = 5$, $\text{C}-\text{C}(1)$); 91.2 (*m*, $^3J(\text{C}, \text{H}) = 10$, C(1)); 81.4 (*d*, $^1J(\text{C}, \text{H}) = 166$, C(4)); 57.4 (*qd*, $^1J(\text{C}, \text{H}) = 144$, $^3J(\text{C}, \text{H}) = 5$, $(\text{CH}_3\text{O})_2\text{CH}$); 52.3, 52.0, 51.8, 51.6, 50.1, 49.9 (*d*, $^1J(\text{C}, \text{H}) = 140$); 47.9 (*d*, $^1J(\text{C}, \text{H}) = 142$). CI-MS (*i*- C_4H_{10}): 359 (100, $M^+ + 1$), 328 (58). Anal. calc. for $\text{C}_{15}\text{H}_{18}\text{O}_{10}$ (358.305): C 50.28, H 5.06; found: C 50.11, H 5.12.

1-Dimethoxymethyl-7-oxabicyclo[2.2.1]heptane-2-exo,3-exo,5-exo,6-exo-tetramethanol (13). LiAlH_4 (16 g, 0.42 mol) was suspended in anhyd. THF (345 ml) at 0° and under N_2 . A soln. of 12 (23 g, 0.057 mol) in anhyd. THF (350 ml) was added dropwise under vigorous stirring and N_2 . The mixture was heated under reflux for 4 h and then cooled to 0°. H_2O (92 ml) was added dropwise under stirring and N_2 . If more H_2O was used, the triol 19 was generated (see below). After the end of the addition of H_2O , 95% EtOH (100 ml) was added and the mixture heated to 80° for 1 h. The hot mixture was filtered on silica gel (40 g). The solid was extracted by hot 95% EtOH (100 ml, heated under reflux for 1 h). The extraction was repeated twice more, and the EtOH extracts were united and reduced by evaporation to 100 ml. The soln. was cooled to -20° and filtered (elimination of Li and Al hydroxides). The solvent was evaporated and the crude 13 recrystallized from hot EtOH, yielding 12 g (72%), white solid, m.p. 144–145°. IR (KBr): 3410, 2980, 2940, 2930, 2910, 1450, 1310, 1200, 1080, 1050, 1005, 935, 855. $^1\text{H-NMR}$ (CD_3OD): 4.45 (*br. s*, $\text{H}-\text{C}(4)$); 4.20 (*s*, $\text{CH}-\text{C}(1)$); 4.0–3.44 (*m*, 8 H, CH_2O); 3.44 (*s*, $(\text{CH}_3\text{O})_2\text{CH}$); 2.36–2.09 (*m*, 4 H). $^{13}\text{C-NMR}$ (CD_3OD): 105.6 (*dm*, $^1J(\text{C}, \text{H}) = 164$, $\text{C}-\text{C}(1)$); 89.3 (*m*, C(1)); 80.5 (*dm*, $^1J(\text{C}, \text{H}) = 161$, C(4)); 60.0, 58.1 (*t*, $^1J(\text{C}, \text{H}) = 141$, 4 CH_2O); 56.0 (*q*, $^1J(\text{C}, \text{H}) = 143$, $(\text{CH}_3\text{O})_2\text{CH}$); 51.0, 47.1 (*dm*, $^1J(\text{C}, \text{H}) = 132$, C(2), C(3), C(5), C(6)). MS (70 eV): 201 (4, $M^+ - \text{CH}_2\text{OH}$), 243 (16), 242 (30), 229 (4), 212 (22), 211 (74), 199 (15), 198 (35), 197 (14), 181 (20), 179 (29), 171 (24), 155 (100). Anal. calc. for $\text{C}_{13}\text{H}_{24}\text{O}_7$ (292.332): C 53.41, H 8.28; found: C 53.30, H 8.10.

[1-Dimethoxymethyl-7-oxabicyclo[2.2.1]heptane-2-exo,3-exo,5-exo,6-exo-tetramethyl] Tetramethanesulfonate (14). Methanesulfonyl chloride (7.8 g, 68 mmol) was added dropwise to a stirred soln. of 13 (2 g, 6.8 mmol) in anhyd. pyridine (7.9 g) maintained at 0°. After stirring at -10° for 96 h, the brown mixture was poured slowly into a vigorously stirred mixture of ice/ H_2O (1 l). The crude 14 was filtered off and dissolved in CH_2Cl_2 (300 ml). The soln. was washed with H_2O (500 ml, 5 times), dried (MgSO_4), and reduced by evaporation to 100 ml. After staying at 20° for several days, the precipitate was collected, yielding 3.1 g (75%) of 14, white solid, m.p. 104–105° (dec.). IR (CH_2Cl_2): 3010, 2950, 2860, 1335, 1310, 1175, 1075, 970, 950, 805. $^1\text{H-NMR}$ (CD_3CN): 4.58–3.8 (2*s* + *m*, 10 H); 3.43 (*s*, $(\text{CH}_2\text{O})_2\text{CH}$); 3.0 (*s*, 4 CH_3SO_3); 2.71–2.3 (*m*, $\text{H}-\text{C}(2)$, $\text{H}-\text{C}(3)$, $\text{H}-\text{C}(5)$, $\text{H}-\text{C}(6)$). $^{13}\text{C-NMR}$ (CD_3CN): 105.7 (*dm*, $^1J(\text{C}, \text{H}) = 160$, $^3J(\text{C}, \text{H}) = 5$, $\text{C}-\text{C}(1)$); 91.1 (*d*, $^3J(\text{C}, \text{H}) = 10$, C(1)); 80.7 (*dm*, $^1J(\text{C}, \text{H}) = 159$, C(4)); 69.5, 68.2 (*t*, $^1J(\text{C}, \text{H}) = 152$); 58.2 (*qm*, $^1J(\text{C}, \text{H}) = 143$, $(\text{CH}_3\text{O})_2\text{CH}$); 48.8, 45.6 (2*d*, $^1J(\text{C}, \text{H}) = 139$, C(2), C(3), C(5), C(6)); 37.8, 37.6 (2*q*, $^1J(\text{C}, \text{H}) = 140$, CH_3SO_3). CI-MS (*i*- C_4H_{10}): 463 (29), 399 (29), 335 (10), 321 (10), 289 (100), 225 (33), 211 (14), 193 (38), 175 (10), 105 (13), 111 (64).

1-Dimethoxymethyl-2,3,5,6-tetramethylidene-7-oxabicyclo[2.2.1]heptane (2). *t*-BuOK (13 g, 0.116 mol) was added portionwise to a stirred mixture of 14 (3.5 g, 5.8 mmol) in DMF/HMPT 6:1 (49 ml) under Ar and maintained at 0°. After stirring at 0° for 2 h, a minimum amount of H_2O was added to make the mixture translucent and the soln. was extracted with petroleum ether (100 ml, 5 times). The extracts were united and washed with H_2O (100 ml, 4 times). After drying (MgSO_4), the soln. was filtered through Florisil (20 g) and concentrated to ca. 10 ml. After staying at 20° for a few h, the precipitate was collected, yielding 765 mg (60%) of colourless needles, m.p. 66–68°. UV (isooctane): 265 (sh, 2600), 250 (sh, 7600), 240 (sh, 9400), 229 (18 100), 222 (17 800), 216 (sh, 14 000). UV (95% EtOH): 263 (sh, 1900), 249 (sh, 6400), 239 (sh, 7900), 228 (15 500), 222 (15 300), 216 (sh, 13 400). IR (KBr): 3100, 3020, 2970, 2940, 2850, 1445, 1420, 1365, 1100, 1080, 1000, 975, 920, 895. $^1\text{H-NMR}$ (CDCl_3): 5.40, 5.35 (2*s*, 4 H); 5.30, 5.10 (2*s*, 4 H); 5.00 (*br. s*, $\text{H}-\text{C}(4)$); 4.85 (*s*, $\text{CH}-\text{C}(1)$); 3.60 (*s*, $(\text{CH}_3\text{O})_2\text{CH}$). $^{13}\text{C-NMR}$ (CDCl_3): 146.7 (*m*, C(3), C(5)); 144.9 (*m*, C(2), C(6)); 104.3 (*dq*, $^1J(\text{C}, \text{H}) = 158$, $^3J(\text{C}, \text{H}) = 5$, $\text{CH}-\text{C}(1)$); 103.3 (*t*, $^1J(\text{C}, \text{H}) = 161$); 101.6 (*t*, $^1J(\text{C}, \text{H}) = 161$); 90.1 (*m*, C(1)), 83.5 (*dm*, $^1J(\text{C}, \text{H}) = 164$, C(4)); 56.5 (*qd*, $^1J(\text{C}, \text{H}) = 143$, $^3J(\text{C}, \text{H}) = 5$, $(\text{CH}_3\text{O})_2\text{CH}$). CI-MS (C_4H_4): 221 (4, $M^+ + 1$), 184 (18), 57 (100), 43 (43). Anal. calc. for $\text{C}_{13}\text{H}_{16}\text{O}_3$ (220.271): C 70.88, H 7.32; found: C 70.97, H 7.38.

(1RS,2(RS or SR),5RS,6SR,7SR,8RS,9SR)-2-Methoxy-3,10-dioxatricyclo[5.2.1.0^{1,5}]decane-6-exo,8-exo,9-exo-trimethanol (**19**). A mixture of **13** (1 g, 3.4 mmol) and 0.1N H₂SO₄ (50 ml) was stirred at 20° for 7 d. After neutralisation with NaHCO₃, the mixture was evaporated to dryness and the residue taken with anh. MeOH. Cooling to -20° afforded a crystalline precipitate which was recrystallized from MeOH, yielding 0.88 g (99%), colourless crystals, m.p. 140–141°. The same product was obtained in 80% yield when using 300 ml instead of 92 ml of H₂O for the hydrolysis of the **12**/LiAlH₄ reduction mixture. IR (KBr): 3310, 2975, 2945, 1470, 1370, 1200, 1110, 1100, 1050, 1020, 950, 910, 860. ¹H-NMR (CD₃OD): 4.96 (s, H-C(2)); 4.16 (s, H-C(7)); 4.10–3.38 (m, 8 H); 3.36 (s, CH₃O); 2.73–1.95 (m, H-C(5), H-C(6), H-C(8), H-C(9)). ¹³C-NMR (CD₃OD): 101.8 (dq, ¹J(C,H) = 172, ³J(C,H) = 5, C(2)); 97.3 (d, ³J(C,H) = 9, C(1)); 81.1 (dm, ¹J(C,H) = 157, C(7)); 64.5 (tm, ¹J(C,H) = 152); 60.8, 60.4 (m, ¹J(C,H) = 141); 58.5 (m, ¹J(C,H) = 142); 53.2 (qd, ¹J(C,H) = 142, ³J(C,H) = 5, CH₃O); 49.2, 48.6, 47.1, 45.4 (4 dm, C(5), C(6), C(8), C(9)). MS (70 eV): 261 (2, M⁺ + 1), 211 (100).

(1RS,2(RS or SR),5SR,6RS,7RS,8SR,9RS)-2-Methoxy-3,10-dioxatricyclo[5.2.1.0^{1,5}]decane-6-exo,8-exo,9-exo-trimethyl Triacetate (**22**). Ac₂O (5 ml) was added to a stirred mixture of **19** (0.3 g, 1.15 mmol) and anh. pyridine (6 ml). After stirring at 20° for 12 h, toluene (5 ml) was added and the soln. evaporated. The process was repeated 5 times (5 ml of toluene). The residue was taken with CH₂Cl₂ (5 ml) and the soln. washed with aq. 0.1N HCl (10 ml), then with aq. sat. NaHCO₃ soln., and finally with H₂O (10 ml). After drying (MgSO₄), the solvent was evaporated and the residue recrystallized from Et₂O, yielding 0.44 g (100%) of colourless crystals, m.p. 93–94°. IR (KBr): 2980, 2940, 2910, 1740, 1390, 1370, 1240, 1225, 1090, 1040, 945. ¹H-NMR (CDCl₃): 4.96 (s, H-C(2) or H-C(7)); 4.49–3.56 (m, 9 H); 3.38 (s, CH₃O); 2.90–2.15 (m, 4 H), 2.00 (s, 3 CH₃CO). ¹³C-NMR (CDCl₃): 170.2 (m, CO); 101.6 (dm, ¹J(C,H) = 162, ³J(C,H) = 5, C(2)); 96.8 (m, C(1)); 80.9 (dm, ¹J(C,H) = 162, C(7)); 64.5, 63.2, 62.6, 61.2 (4 t); 54.1 (q, CH₃O); 47.2, 45.9 (dm, ¹J(C,H) = 135); 45.0 (dm, ¹J(C,H) = 131); 41.8 (dm, ¹J(C,H) = 138); 20.5 (q, ¹J(C,H) = 129, CH₃CO). MS (70 eV): 386 (1, M⁺), 146 (22), 43 (100). Anal. calc. for C₁₈H₂₆O₉ (386.403): C 55.95, H 6.78; found: C 55.85, H 6.73.

(1RS,2(RS or SR),5SR,6RS,7RS,8SR,9RS)-2-Methoxy-3,10-dioxatricyclo[5.2.1.0^{1,5}]decane-6-exo,8-exo,9-exo-trimethyl Trimethansulfonate (**20**). Same procedure as for the preparation of **14**, starting with **19**. Yield 65%, colourless solid, m.p. 159–161° (dec.). IR (KBr): 3050, 3030, 2980, 2950, 1470, 1340, 1175, 1095, 975, 950, 940, 835, 820. ¹H-NMR (CD₃CN): 5.03 (s, H-C(2)); 4.56–3.37 (m, 9 H); 3.35 (s, CH₃O); 3.05 (s, 9 H); 2.90–2.40 (m, 4 H). ¹³C-NMR (90 MHz, CD₃CN): 102.5 (dq, ¹J(C,H) = 171, ³J(C,H) = 5, C(2)); 97.9 (m, ³J(C,H) = 8, C(1)); 81.2 (d, ¹J(C,H) = 160, C(7)); 70.2, 69.7, 67.7 (3td, ¹J(C,H) = 152); 54.8 (qd, ¹J(C,H) = 143, ³J(C,H) = 5, CH₃O); 48.2, 47.0, 46.3, 41.6 (4d, ¹J(C,H) = 138, C(5), C(6), C(8), C(9)); 37.5, 37.4 (2q, ¹J(C,H) = 139, 3 CH₃SO₃). MS (70 eV): 494 (1, M⁺), 303 (20), 289 (28), 175 (29), 57 (100). Anal. calc. for C₁₅H₂₆O₁₂S₃ (494.559): C 36.43, H 5.30; found: C 36.11, H 5.27.

(1RS,2(RS or SR),5RS,7RS)-2-Methoxy-6,8,9-trimethylidene-3,10-dioxatricyclo[5.2.1.0^{1,5}]decane (**21**). Same procedure as for the preparation of **2**, starting with **20**. Yield 65%, colourless crystals, m.p. 68–69°. UV (isooctane): 253 (sh, 5000), 247 (6100), 240 (5000). UV (95% EtOH): 253 (sh, 5300), 247 (6400), 240 (5500). IR (CH₂Cl₂): 3080, 3000, 2970, 2940, 2910, 2840, 1680, 1605, 1400, 1190, 1140, 1100, 1045, 1005, 995, 975, 945, 915, 870, 825. ¹H-NMR (CDCl₃): 5.57, 5.35 (2s, 2 H); 5.31 (d, ²J = 0.5, 1 H); 5.17 (s, H-C(2)); 5.15, 5.04 (2s, 2 H); 4.98 (br. s, H-C(7)); 4.87 (s, 1 H); 4.28, 3.70 (2dd, ²J = 8.2, ³J = 9.6, CH₂(4)); 3.48 (s, CH₃O); 3.10 (m, H-C(5)). ¹³C-NMR (90 MHz, CDCl₃): 151.6 (br. s, C(6)); 147.3 (m, C(8)); 141.8 (m, C(9)); 106.3 (t, ¹J(C,H) = 159); 103.7 (dm, ¹J(C,H) = 171, ³J(C,H) = 5, C(2)); 103.3, 102.3 (2t, ¹J(C,H) = 166); 96.3 (m, C(1)); 85.4 (dm, ¹J(C,H) = 161, ³J(C,H) = 13, 6.5, C(7)); 71.1 (td, ¹J(C,H) = 150, ³J(C,H) = 6, C(4)); 54.8 (qd, ¹J(C,H) = 143, ³J(C,H) = 4, CH₃O); 50.8 (dm, ¹J(C,H) = 139, C(5)). MS (70 eV): 206 (18, M⁺), 149 (13), 148 (16), 147 (26), 146 (10), 145 (19), 118 (100), 117 (15), 116 (54). Anal. calc. for C₁₂H₁₄O₃ (206.244): C 69.88, H 6.84; found: C 69.85, H 6.90.

Tetramethyl 1-Dimethoxymethyl-7-oxabicyclo[2.2.1]heptane-2-exo,3-endo,5-endo,6-exo-tetracarboxylate (**17**). A mixture of **12** (25 g, 62 mmol), anh. K₂CO₃ (0.5 g), and abs. MeOH (300 ml) was stirred at 20° under N₂ for 45 h. The precipitate was filtered off and the soln. evaporated. The residue was dissolved in CHCl₃ and the soln. washed with H₂O until neutrality (pH 7). After drying (MgSO₄), the solvent was evaporated and the residue crystallized from MeOH/Et₂O 3:1, yielding 0.45 g (90%) of a 3:2 mixture **17/18**. The latter were separated by column chromatography on silica gel (32 g, CHCl₃/AcOEt 7:3). The 1st fraction contained **17**, m.p. 112–114° (recrystallized from MeOH/Et₂O). IR (KBr): 2885, 2845, 1750, 1740, 1440, 1350, 1265, 1215, 1185, 1170, 1115, 975, 1100. ¹H-NMR (CDCl₃): 5.15 (t, ³J = 5.3, H-C(4)); 4.73 (s, CH-C(1)); 3.72 (dd, ³J = 6.7, 5.3, H-C(3), H-C(5)); 3.71, 3.64 (2s, 4 COOCH₃); 3.35 (s, (CH₃O)₂CH); 3.24 (d, ³J = 6.7, H-C(2), H-C(6)). ¹³C-NMR (CDCl₃): 171.6, 169.6 (2m, 4 C); 101.5 (dm, ¹J(C,H) = 161, CH-C(1)); 95.6 (m, C(1)); 78.3 (dm, ¹J(C,H) = 161, C(4)); 55.5 (qd, ¹J(C,H) = 143, ³J(C,H) = 5, (CH₃O)₂CH); 52.0, 51.5 (2q, ¹J(C,H) = 147, COOCH₃); 49.9, 48.2 (2d, ¹J(C,H) = 132, C(2), C(3), C(5), C(6)). MS (70 eV): 373 (45, M⁺ - 31), 267 (21), 169 (83), 112 (100). Anal. calc. for C₁₇H₂₄O₁₁ (404.374): C 50.50, H 5.98; found: C 50.27, H 6.06.

Tetramethyl 1-Dimethoxymethyl-7-oxabicyclo[2.2.1]heptane-2-exo,3-exo,5-endo,6-exo-tetracarboxylate (18). The 2nd fraction of the above chromatography yielded **18**, colourless crystals, m.p. 136–137°. IR (KBr): 3040, 3000, 2960, 2840, 1750, 1730, 1440, 1385, 1270, 1235, 1215, 1110, 1085, 1035, 1025, 990, 960, 955. ¹H-NMR (360 MHz, CDCl₃): 5.35 (*d*, ³*J* = 5.6, H–C(4)); 4.69 (*s*, CH–C(1)); 3.73 (*dd*, *J* = 5.6, 5.9, H–C(5)); 3.70, 3.68, 3.67, 3.65 (4s, 4 CH₃OOC); 3.39, 3.36 (2s, 2 CH₃O acetal); 3.31 (*d*, 9.7, H–C(2)); 3.14 (*d*, 9.7, H–C(3)); 3.06 (*d*, 5.9, H–C(6)). ¹³C-NMR (CDCl₃): 171.7, 170.6, 170.0 (*m*, 4 CO); 103.7 (*dm*, ¹*J*(C,H) = 160, C–C(1)); 94.2 (*d*, ³*J*(C,H) = 8, C(1)); 78.2 (*dm*, ¹*J*(C,H) = 160, ³*J*(C,H) = 4, C(4)); 57.4, 56.0, 54.4, 52.1, 51.9, 51.5, 51.2, 50.5, 48.1 (4 CH₃OOC, C(2), C(3), C(5), C(6), CH₃O acetal). MS (70 eV): 404 (3, *M*⁺), 374 (17), 373 (100), 327 (57), 267 (68). Anal. calc. for C₁₇H₂₄O₁₁ (404.374): C 50.50, H 5.98; found: C 50.35, H 5.97.

Tetramethyl 1-Methoxymethyl-7-oxabicyclo[2.2.1]heptane-2-exo,3-exo,5-exo,6-exo-tetracarboxylate (24). A mixture of 1-methoxymethyl-7-oxabicyclo[2.2.1]hept-5-ene-2-exo,3-exo-dicarboxylic anhydride (the *Diels-Alder* adduct of maleic anhydride to 2-(methoxymethyl)furan [10] (**23**; 16 g, 0.076 mol), anh. CuCl₂ (102 g, 0.76 mol), methyl orthoformate (30 g, 0.283 mol), 10% Pd/C (3 g, 2.8 mmol), and anh. MeOH (300 ml) was degassed with N₂ (1-l flask, *Parr* hydrogenation apparatus). Then, the flask was pressurized by 4 atm of CO and shaken for 5 d at 20°. Same workup conditions as for the preparation of **12**: 12 g (52%) of **24**, white crystals, m.p. 171–173°. IR (CHCl₃): 3040, 2960, 1750, 1440, 1340, 1200, 1120, 1030, 945. ¹H-NMR (CDCl₃): 5.54 (*s*, H–C(4)); 3.71 (*s*, OCH₂–C(1)); 3.65 (*s*, 4 COOCH₃); 3.29 (*d*, *J* = 10, H–C(2), H–C(6) or H–C(3), H–C(5)); 3.23 (*s*, CH₃OCH₂); 2.97 (*d*, *J* = 10, H–C(3), H–C(5) or H–C(2), H–C(6)). ¹³C-NMR (CDCl₃): 170.1, 169.9 (br. *s*, 4 C); 88.6 (*d*, ³*J*(C,H) = 10, C(1)); 78.06 (*d*, ¹*J*(C,H) = 166, C(4)); 69.5 (*im*, ¹*J*(C,H) = 144, ³*J*(C,H) = 5, C–C(1)); 59.3 (*qt*, ¹*J*(C,H) = 142, ³*J*(C,H) = 5, CH₃OCH₂); 53.9 (*dm*, ¹*J*(C,H) = 146); 51.9, 51.7 (2*q*, ¹*J*(C,H) = 147, 4 CH₃OOC); 51.2 (*dm*, ¹*J*(C,H) = 134). MS (70 eV): 343 (35, *M*⁺ – OMe), 283 (65), 251 (42), 250 (50), 223 (65), 197 (54), 179 (54), 103 (81), 59 (100). Anal. calc. for C₁₆H₂₂O₁₀ (374.348): C 51.34, H 5.92; found: C 51.42, H 6.02.

1-Methoxymethyl-7-oxabicyclo[2.2.1]heptane-2-exo,3-exo,5-exo,6-exo-tetramethanol (25). Portionwise, **24** (3 g, 8 mmol) was added to a stirred suspension of LiAlH₄ (1.82 g, 48 mmol) in anh. THF (50 ml) maintained at 0° under N₂. The mixture was then heated under reflux for 12 h. Then, 95% EtOH (150 ml) was added slowly and the mixture heated under reflux for 45–60 min. The hot mixture was filtered, and the precipitate was taken with 95% EtOH (150 ml) and heated under reflux for 45 min. Hot filtration gave a second extract fraction. The extraction with boiling 95% EtOH was repeated twice more, and the extracts were united and evaporated. The residue was dissolved in a minimal amount of H₂O and filtered through a sulfonic resin (*Dowex 50 W*, X 8100/200 mesh). The solvent was evaporated, yielding 1.73 g (82%), white solid, m.p. 92–94°. IR (KBr): 3320, 2930, 2900, 1430, 1390, 1310, 1110, 1070, 1045, 1015, 935, 915, 850. ¹H-NMR (D₂O): 4.28 (*s*, H–C(4)); 3.85–3.25 (*m*, 13 H); 2.32–2.0 (*m*, 4 H). ¹³C-NMR (CD₃OD): 86.5 (*m*, C(1)); 80.4 (*dm*, ¹*J*(C,H) = 160, C(4)); 68.7 (*im*, ¹*J*(C,H) = 144, CH₂–C(1)); 59.9, 57.9 (2*tm*, ¹*J*(C,H) = 139); 57.6 (*qm*, ¹*J*(C,H) = 143, CH₃O); 50.25, 48.2 (2*tm*, ¹*J*(C,H) = 137, C(2), C(7), C(5), C(6)). CI-MS (i-C₄H₁₀): 263 (4, [*M* + H]⁺), 227 (10), 57 (100). Anal. calc. for C₁₂H₂₂O₆ (262.306): C 54.95, H 8.45; found: C 55.01, H 8.52.

(*1RS,2SR,6RS,7SR,8RS,9SR*)-*1,8-exo,9-exo-tris(chloromethyl)-4,10-dioxatricyclo[5.2.1.0^{2,6}]decane (28)*. Freshly distilled SOCl₂ (11.6 g, 98 mmol) was added dropwise to a stirred soln. of **25** (2.1 g, 8 mmol) in anh. pyridine (2.5 g, 32 mmol) maintained at 0° and under N₂. The mixture was then stirred at 60° for 24 h. After cooling to 20°, CHCl₃ (50 ml) was added, then H₂O was added dropwise until the end of HCl/SO₂ evolution. The org. layer was separated and washed with H₂O until pH 7. After drying (MgSO₄), the solvent was evaporated. The residue contained at least 4 compounds. Chromatography on silica gel (120 g, CCl₄/AcOEt 5:1) afforded 1.6 g (70%) of **28**, colourless crystals, m.p. 103–105°. IR (KBr): 3030, 2990, 2960, 2870, 1400, 1300, 1200, 1165, 1030, 985, 925, 915, 845, 750. ¹H-NMR (CDCl₃): 4.35 (*s*, H–C(7)); 3.98 (*s*, CH₂–C(1)); 3.80–3.20 (*m*, 10 H); 2.75–2.20 (*m*, 4 H). ¹³C-NMR (CDCl₃): 98.5 (*m*, C(1)); 82.6 (*dm*, ¹*J*(C,H) = 162, C(7)); 67.3, 65.9 (2*t*, ¹*J*(C,H) = 128, C(3), C(5)); 51.0, 50.0, 49.4, 47.9 (4*dm*, C(2), C(6), C(8), C(9)); 43.5, 42.6, 41.3 (3*tm*, 3 ClCH₂). CI-MS (i-C₄H₁₀): 289 (35), 287 (97), 285 (100, [*M* + H]⁺). Anal. calc. for C₁₁H₁₅Cl₃O₂ (285.6): C 46.26, H 5.29; found: C 46.13, H 5.42.

(*1RS,2SR,3SR,4RS,5SR,6SR*)-*Tetramethyl 1-Methoxymethyl-7-oxabicyclo[2.2.1]heptane-2-exo,3-endo,5-exo,6-endo-tetracarboxylate (29)*. Anh. K₂CO₃ (0.5 g, preheated in a glass tube in the flame) was added to a soln. of **24** (22.65 g, 60.5 mmol) in abs. MeOH (320 ml). The mixture was stirred at 20° for 45 h under Ar. After filtration, the solvent was evaporated and the oily residue dissolved in CHCl₃ (200 ml). The soln. was washed with H₂O until pH 7. After drying (MgSO₄), the solvent was evaporated and the residue recrystallized from MeOH, yielding 20.3 g (89.6%), white crystals, m.p. 83–84°. IR (CHCl₃): 3040, 2970, 1740, 1440, 1375, 1335, 1290, 1230, 1075, 1015. ¹H-NMR (360 MHz, CDCl₃): 5.10 (*d*, *J* = 5, H–C(4)); 3.92 (*d*, ²*J* = 11.5, 1 H, CH₂O); 3.80 (*dd*, ³*J* = 5.5, 5, H–C(3)); 3.78 (*s*, COOCH₃); 3.76 (*d*, 11.5, 1 H, CH₂O); 3.75 (*s*, 2 COOCH₃); 3.73 (*s*, COOCH₃); 3.68 (*d*, *J* = 5.5, H–C(6)); 3.40 (*s*, CH₃OCH₂); 3.32 (*d*, *J* = 5.5, H–C(5)); 3.13 (*d*, *J* = 5.5, H–C(2)). ¹³C-NMR (CDCl₃): 171.6, 170.9, 170.0, 169.9 (*m*); 91.0 (*m*, C(1)); 79.8 (*d*, ¹*J*(C,H) = 167, C(4)); 69.9 (*t*, ¹*J*(C,H) = 141, CH₂O); 59.3 (*qm*,

$^1J(\text{C,H}) = 142$, CH_3O); 52.1, 51.9 (q , $^1J(\text{C,H}) = 147$, COOCH_3); 50.8 (d , $^1J(\text{C,H}) = 137$, 2 C); 47.7 (d , $^1J(\text{C,H}) = 136$); 46.9 (d , $^1J(\text{C,H}) = 134$). MS (70 eV): 343 (28, $M^+ - \text{OMe}$), 325 (22), 283 (31), 223 (40), 197 (10), 140 (100). Anal. calc. for $\text{C}_{12}\text{H}_{22}\text{O}_6$ (374.348): C 51.34, H 5.92; found: C 51.15, H 5.98.

(*1RS,2SR,3SR,4RS,5SR,6SR*)-1-Methoxymethyl-7-oxabicyclo[2.2.1]heptane-2-exo,3-endo,5-exo,6-endo-tetramethanol (33). Same procedure as for the preparation of 25, starting with 29. Yield 90%, colourless crystals, m.p. 106–108°. IR (KBr): 3490, 3340, 2930, 1465, 1110, 1085, 990, 960, 870, 850. $^1\text{H-NMR}$ (CD_3OD): 4.73 (br. s, 4 OH); 4.23 (d , $J = 5$, H–C(4)); 3.65 (s, CH_2O); 3.31 (s, CH_3O); 4.0–3.3 (m , 8 H); 2.2–1.65 (m , 4 H). MS (70 eV): 213 (51), 200 (20), 181 (100), 173 (56).

(*1RS,2SR,3SR,4RS,5SR,6SR*)-2-exo,3-endo,5-exo,6-endo-Tetrakis(chloromethyl)-1-methoxymethyl-7-oxabicyclo[2.2.1]heptane (34). Freshly distilled SOCl_2 (10 g, 84 mmol) was added dropwise to a stirred soln. of 33 (2.35 g, 9 mmol) in anhyd. pyridine (2.85 g, 36 mmol) maintained at 0° under N_2 . After stirring at 20° for 2 h, CHCl_3 (25 ml) was added. The excess of SOCl_2 was destroyed by dropwise addition of H_2O at 0° and under vigorous stirring. The org. layer was separated and washed with sat. aq. NaHCO_3 soln., then with H_2O until pH 7. After drying (MgSO_4), the solvent was evaporated and the residue recrystallized from CHCl_3 , yielding 2.42 g (80%), white crystals, m.p. 114–115°. IR (KBr): 2920, 2900, 1445, 1315, 1285, 1265, 1195, 1120, 945, 920, 735, 715. $^1\text{H-NMR}$ (CDCl_3): 4.48 (d , $J = 5$, H–C(4)); 4.10–3.10 ($m + s$, 13 H); 2.69–1.80 (m , 4 H). $^{13}\text{C-NMR}$ (CDCl_3): 89.4 (m , C(1)); 80.8 (dm , $^1J(\text{C,H}) = 160$, C(4)); 71.7 (tm , $^1J(\text{C,H}) = 142$, CH_3OCH_2); 59.3 (q , $^1J(\text{C,H}) = 142$, CH_3OCH_2); 52.4, 51.1 (2 dm); 46.1, 45.5, 43.1 (m). MS (70 eV): 299 (100, $M^+ - \text{Cl}$), 301 (100), 303 (30). Anal. calc. for $\text{C}_{16}\text{H}_{18}\text{Cl}_4\text{O}_2$ (336.088): C 42.89, H 5.40; found: C 42.65, H 5.52.

1-Methoxymethyl-2,3,5,6-tetramethylidene-7-oxabicyclo[2.2.1]heptane (5). *t*-BuOK (6.7 g, 59.7 mmol) was added portionwise to a stirred soln. of 34 (2 g, 5.95 mmol) in anhyd. THF (15 ml) maintained at 0° under Ar. The brownish suspension was stirred at 20° for 12 h. After addition of a minimal amount of H_2O to dissolve KCl, the mixture was extracted with pentane (50 ml, 3 times). The org. extract was washed with H_2O (100 ml, 5 times), dried (MgSO_4), and filtered on Florisil. The solvent was evaporated and the residue recrystallized from ca. 2 ml of pentane, yielding 0.79 g (69.7%), colourless crystals, m.p. 59–61°. UV (isooctane): 263 (sh, 2400), 249 (sh, 6800), 239 (sh, 8800), 229 (17 400), 222 (16 700), 216 (sh, 12 300). UV (95% EtOH): 263 (sh, 2300), 249 (sh, 7000), 241 (sh, 8900), 228 (17 400), 222 (17 200), 215 (sh, 13 100). IR (CH_2Cl_2): 3060, 2980, 2920, 2880, 2820, 1800, 1660, 1450, 1410, 1320, 1200, 1140, 1100, 920, 900, 835, 805. $^1\text{H-NMR}$ (CD_2Cl_2): 5.30 (s, 2 H); 5.20 (br. s, 3 H); 5.00 (s, 2 H); 4.90 (s, 2 H); 3.90 (s, 2 H); 3.35 (s, CH_3O). $^{13}\text{C-NMR}$ (CD_2Cl_2): 147.5, 146.7 (2 m , 4 C); 102.3 (t , $^1J(\text{C,H}) = 160$, 4 $\text{CH}_2=\text{C}$); 89.9 (m , C(1)); 83.9 (dm , $^1J(\text{C,H}) = 164$, C(4)); 70.0 (qt , $^1J(\text{C,H}) = 141$, $^3J(\text{C,H}) = 5$, CH_3OCH_2); 59.9 (qt , $^1J(\text{C,H}) = 141$, $^3J(\text{C,H}) = 5$, CH_3OCH_2). MS (70 eV): 190 (19, M^+), 175 (16), 161 (30), 145 (82), 129 (51), 107 (100), 105 (85), 91 (100), 86 (50), 83 (69), 77 (69), 51 (76). Anal. calc. for $\text{C}_{16}\text{H}_{14}\text{O}_2$ (190.244): C 75.76, H 7.42; found: C 75.92, H 7.32.

2,3,5,6-Tetramethylidene-7-oxabicyclo[2.2.1]heptane-1-methanol (4). A mixture of 2 (0.8 g, 3.65 mmol), dioxane (22 ml), and 1N HCl (15 ml) was degassed in a Pyrex tube and sealed under vacuum. The ampoule was heated in an oil bath to 90° for 30 min. After cooling, the ampoule was opened and the yellow-orange mixture was poured into CH_2Cl_2 (10 ml). The org. phase was washed with aq. sat. NaHCO_3 soln., then with H_2O . After drying (MgSO_4), the soln. was concentrated to 1 ml, and 6 ml of dioxane were added. The soln. was concentrated to ca. 5 ml, and *i*-PrOH (0.5 ml) and NaBH_4 (0.48 g, 12.7 mmol) were added. The mixture was stirred at 20° for 40 min. H_2O (50 ml) was added under vigorous stirring. The mixture was extracted with Et_2O (50 ml, 3 times). The extract was washed with H_2O , dried (MgSO_4), and concentrated by distillation (Vigreux column) of the solvent. Chromatography on a column of neutral alumina (act. I, 60 g, AcOEt/hexane 1:4) yielded 0.21 g of 2 and 0.26 g (45%) of 4, colourless crystals, m.p. 123–125°. UV (isooctane): 263 (sh, 2300), 250 (sh, 6500), 238 (sh, 8500), 228 (17 000), 221 (16 300), 214 (12 200). UV (95% EtOH): 262 (sh, 2500), 249 (sh, 6100), 240 (sh, 8000), 226 (15 600), 221 (15 400), 216 (11 700). IR (CHCl_3): 3600, 3100, 3010, 2940, 2090, 2010, 1990, 1420, 1230, 1075, 1030, 1000, 970, 915, 900. $^1\text{H-NMR}$ (860 MHz, CDCl_3): 5.39, 5.31, 5.13, 4.96 (4s, 8 H); 5.07 (br. s, H–C(4)); 4.23 (d , $^3J = 6$, CH_2OH); 1.89 (t , $J = 6$, OH). $^{13}\text{C-NMR}$ (90 MHz, CDCl_3): 146.9, 145.5 (2 m , 4 C); 102.6, 102.2 (t , $^1J(\text{C,H}) = 161$, 4 $\text{CH}_2=\text{C}$); 90.8 (m , C(1)); 83.7 (dm , $^1J(\text{C,H}) = 164$, $^3J(\text{C,H}) = 13$, 6.5, C(4)); 59.7 (t , $^1J(\text{C,H}) = 144$, $\text{CH}_3\text{O}-\text{H}$). MS (70 eV): 176 (17, M^+), 195 (12), 115 (17), 91 (14), 51 (100). Anal. calc. for $\text{C}_{11}\text{H}_{12}\text{O}_2$ (176.217): C 74.97, H 6.86; found: C 75.08, H 6.88.

(*1RS,2RS,3SR,4SR*)-1-Dimethoxymethyl-7-oxabicyclo[2.2.1]hept-2-ene-2-exo,3-exo-dimethanol (35). A soln. of 11 [7] (32 g, 0.133 mmol) in THF (150 ml) was cooled to 0° and LiAlH_4 (12.5 g, 0.33 mol) was added portionwise under stirring and N_2 . After stirring at 0° for 3 h, the mixture was heated under reflux for 3 h. After cooling to 20°, H_2O was added dropwise (60 ml) and the mixture filtered through Celite. The precipitate was heated in THF (150 ml) under reflux for 1 h and filtered. This extractive process was repeated twice more. The THF extracts were united and evaporated. The residue was taken with CH_2Cl_2 , dried (MgSO_4), filtered, and concen-

trated until apparition of crystalline **35**. The soln. was allowed to stand overnight at 0°. Filtration yielded 21.5 g (70%), colourless crystals, m.p. 113–114°. IR (CH₂Cl₂): 3625, 3450, 3060, 2950, 2850, 1440, 1390, 1360, 1210, 1190, 1130, 1110, 1080, 1040, 1010, 980. ¹H-NMR (CDCl₃): 6.36 (*m*, H–C(5), H–C(6)); 4.83 (*br. s*, H–C(4)); 4.71 (*s*, CH–C(1)); 3.90 (*m*, 2 CH₂OH); 3.56 (*s*, 2 (CH₃O)₂CH); 2.24–1.85 (*m*, H–C(2), H–C(3)). ¹³C-NMR (90 MHz, CDCl₃): 136.1 (*d*, ¹J(C,H) = 177, C(6)); 135.7 (*d*, ¹J(C,H) = 175, C(5)); 104.0 (*dm*, ¹J(C,H) = 161, ³J(C,H) = 5, CH–C(1)); 91.2 (*m*, C(1)); 81.0 (*dm*, ¹J(C,H) = 163, C(4)); 62.1, 59.5 (2*t*, ¹J(C,H) = 141, 2 CH₂OH); 57.1, 56.3 (*qd*, ¹J(C,H) = 142, ³J(C,H) = 5, CH₃O); 44.2, 44.4 (2*d*, ¹J(C,H) = 135, C(2), C(3)). CI-MS (CH₄): 231 (2, M⁺ + 1), 145 (100). Anal. calc. for C₁₁H₁₈O₅ (230.263): C 57.38, H 7.88; found: C 57.22, H 7.73.

(1RS,2RS,3SR,4SR)-1-Dimethoxymethyl-7-oxabicyclo[2.2.1]heptane-2-exo,3-exo-dimethanol (**36**). A soln. of **35** (20 g, 87 mmol) in AcOEt (150 ml) was cooled to –25° under N₂ in a Parr hydrogenation apparatus (0.5-l flask). Then, 10% Pd/C (1.4 g, 1.3 mmol) was added and the mixture degassed. A pressure of 4 atm of H₂ was maintained and the flask shaken for ca. 100 min. The end of the hydrogenation was controlled by TLC (SiO₂, AcOEt/hexane 3:1; **35** and **36** have same R_f, but **35** was revealed with KMnO₄ instantaneously whereas **36** was revealed only on heating). After filtration and solvent evaporation, 20.2 g (100%) of colourless crystals, m.p. 58–60°, were obtained. IR (CH₂Cl₂): 3630, 3440, 2970, 2840, 1480, 1440, 1390, 1360, 1210, 1190, 1130, 1100, 1085, 1030, 980, 945, 910, 850. ¹H-NMR (CDCl₃): 4.53 (*s*, CH–C(1)); 4.35 (*m*, *J* = 2.5, H–C(4)); 4.00 (*br. s*, 2 OH); 3.9–3.65 (*m*, 4 H); 3.51 (*s*, 6 H); 2.43–2.10 (*m*, 2 H); 2.0–1.38 (*m*, 4 H). ¹³C-NMR (90 MHz, CDCl₃): 106.5 (*d*, ¹J(C,H) = 159, CH–C(1)); 88.4 (*m*, ³J(C,H) = 8, C(1)); 79.2 (*d*, ¹J(C,H) = 156, C(4)); 61.4, 59.0 (2*t*, ¹J(C,H) = 144); 57.6, 56.3 (2*qd*, ¹J(C,H) = 143, ³J(C,H) = 5, (CH₃O)₂CH); 50.0, 49.4 (2*d*, ¹J(C,H) = 133, C(2), C(3)); 31.6, 30.2 (2*t*, ¹J(C,H) = 135, C(5), C(6)). MS (70 eV): 201 (5, M⁺ – OMe), 95 (16), 81 (15), 79 (13), 75 (100). Anal. calc. for C₁₁H₂₀O₅ (232.279): C 56.88, H 8.68; found: C 56.76, H 8.59.

((1RS,2RS,3SR,4SR)-1-Dimethoxymethyl-7-oxabicyclo[2.2.1]heptane-2-exo,3-exo-dimethyl) Dimethanesulfonate (**37**). Same procedure as for the preparation of **14**, starting with **36**. Yield 70%, colourless solid, m.p. 114–115° (dec.). IR (CH₂Cl₂): 3060, 2970, 2890, 2840, 1360, 1335, 1175, 1100, 1085, 970, 950, 805. ¹H-NMR (CDCl₃): 4.75–3.80 (*m*, 6 H); 3.50 (*s*, (CH₃O)₂CH); 3.00 (*s*, 2 CH₃S); 2.73–2.21 (*m*, H–C(2), H–C(3)); 2.03–1.38 (*m*, 4 H). ¹³C-NMR (90 MHz, CDCl₃): 106.6 (*dd*, ¹J(C,H) = 158, ³J(C,H) = 5, C–C(1)); 88.5 (*m*, C(1)); 78.4 (*d*, ¹J(C,H) = 159, C(4)); 68.4, 67.0 (2*t*, ¹J(C,H) = 152); 57.6, 56.9 (2*qd*, ¹J(C,H) = 143, ³J(C,H) = 5, (CH₃O)₂CH); 46.5, 46.4 (2*d*, ¹J(C,H) = 136, C(2), C(3)); 37.5, 37.2 (2*q*, ¹J(C,H) = 139); 32.7, 29.0 (2*t*, ¹J(C,H) = 140, C(5), C(6)). MS (70 eV): 358 (5, M⁺ – OMe), 293 (11), 183 (10), 111 (10), 29 (100). Anal. calc. for C₁₃H₂₄O₉S₂ (388.459): C 40.20, H 6.23; found: C 40.20, H 6.19.

1-Dimethoxymethyl-2,3-dimethylidene-7-oxabicyclo[2.2.1]heptane (**6**). *t*-BuOK (18 g, 0.16 mol) was added portionwise to a stirred soln. of **37** (6.02 g, 15.5 mmol) in anhyd. DMF/HMPT 6:1 (70 ml) maintained at 0° and under N₂. After stirring at 0° for 2 h, H₂O (20 ml) was added and the mixture extracted with pentane (200 ml, 5 times). The solvent was eliminated by distillation (Vigreux column) and the residue distilled (bulb-to-bulb, 90°/0.5 Torr), yielding 2.13 g (70%), colourless oil. UV (isooctane): 251 (sh, 8800), 243 (9500), 237 (sh, 7000). UV (95% EtOH): 250 (sh, 9000), 242 (9600), 237 (sh, 7000). IR (CH₂Cl₂): 3060, 3000, 2960, 2920, 2880, 2840, 1450, 1390, 1310. ¹H-NMR (CDCl₃): 5.28 (*s*, 1 H); 5.18 (*br. s*, ⁴*J* = 1, 1 H); 5.15 (*br. s*, 1 H); 4.90 (*br. s*, 1 H); 4.80 (*dm*, ³*J* = 3, ⁴*J* = 1, H–C(4)); 4.68 (*s*, CH–C(1)); 3.57, 3.55 (2*s*, (CH₃O)₂CH); 2.07–1.92 (*m*, 2 H); 1.72–1.66 (*m*, 2 H). ¹³C-NMR (90 MHz, CDCl₃): 148.9 (*m*, C(3)); 147.2 (*m*, C(2)); 105.0 (*dm*, ¹J(C,H) = 162, ³J(C,H) = 5, (CH₃O)₂CH); 101.3, 100.0 (2*t*, ¹J(C,H) = 162, 2 CH₂=C); 88.6 (*m*, C(1)); 80.2 (*ddd*, ¹J(C,H) = 160, ³J(C,H) = 12, 6, C(4)); 57.5, 56.2 (2*qd*, ¹J(C,H) = 146, ³J(C,H) = 5, (CH₃O)₂CH); 29.7, 28.9 (2*t*, ¹J(C,H) = 138, C(5), C(6)). CI-MS (CH₄): 197 (8, M⁺ + 1), 166 (42), 137 (12), 106 (30), 57 (100). Anal. calc. for C₁₁H₁₆O₃ (196.248): C 67.32, H 8.22; found: C 67.28, H 8.21.

2,3-Dimethylidene-7-oxabicyclo[2.2.1]heptane-1-carbaldehyde (**7**). A mixture of **6** (1.5 g, 7.7 mmol), dioxane (41 ml), and 1*N* HCl (27.1 ml) was degassed and sealed *in vacuo* in a Pyrex tube. The tube was heated to 90° for 40–60 min in an oil bath. After cooling to 20° and opening of the tube, the yellowish mixture was poured into a stirred mixture of CH₂Cl₂ (50 ml) and aq. 5% NaHCO₃ (50 ml). The org. layer was washed with H₂O (50 ml) and dried (MgSO₄). The solvent was removed by distillation at room pressure (Vigreux column) and the residue distilled (bulb-to-bulb, 60°/0.2 Torr), yielding 0.69 g (60%), colourless liquid with a strong odor. UV (isooctane): 250 (sh, 6200), 242 (8600), 237 (sh, 7800). UV (95% EtOH): 251 (sh, 6500), 242 (9200), 237 (sh, 8700). IR (CH₂Cl₂): 3060, 2995, 2960, 2880, 2840, 1735, 1425, 1040. ¹H-NMR (CDCl₃): 9.81, 5.29, 5.23 (3*s*, 3 H); 5.01 (*s*, 2 H); 4.93 (*d*, *J* = 4, H–C(4)); 2.20–1.55 (*m*, 4 H). ¹³C-NMR (90 MHz, CDCl₃): 198.8 (*d*, ¹J(C,H) = 184, HCO); 146.9, 144.8 (*m*, C(2), C(3)); 101.9, 101.8 (2*t*, ¹J(C,H) = 163, 2 CH₂=C); 90.8 (*m*, C(1)); 80.7 (*dm*, ¹J(C,H) = 166, C(4)); 30.6, 29.6 (2*t*, ¹J(C,H) = 140, C(5), C(6)). MS (70 eV): 150 (20, M⁺), 122 (59), 121 (29), 94 (18), 91 (72), 77 (100). Anal. calc. for C₉H₁₀O₂ (150.179): C 71.98, H 6.71; found: C 71.86, H 6.78.

2,3-Dimethylidene-7-oxabicyclo[2.2.1]heptane-1-methanol (8). A mixture of **7** (0.65 g, 4.3 mmol), THF (2 ml), *i*-PrOH (0.5 ml), and NaBH₄ (0.49 g, 13 mmol) was stirred at 20° for 1 h (TLC control). H₂O (5 ml) was added and the mixture extracted with CH₂Cl₂ (10 ml, 5 times). The org. extracts were united and washed with H₂O (10 ml) and dried (MgSO₄). The solvent was distilled off (*Vigreux* column) at room pressure and the residue distilled (bulb-to-bulb, 110°/7·10⁻³ Torr), yielding 0.46 g (70%), colourless liquid, UV (isooctane): 250 (sh, 6800), 242 (9200), 237 (sh, 8600). UV (95% EtOH): 251 (sh, 6400), 242 (8600), 238 (sh, 8400). IR (CH₂Cl₂): 3600, 3500, 3060, 2990, 2960, 2880, 1455, 1400. ¹H-NMR (CDCl₃): 5.25, 5.15, 4.90, 4.81 (4s, 4 H); 4.78 (*d*, H-C(4)); 4.00 (*m*, *J* = 6, CH₂OH); 2.90 (*t*, *J* = 6, OH); 2.30–1.00 (*m*, 4 H). ¹³C-NMR (90 MHz, CDCl₃): 148.5, 147.3 (2*m*), 100.3, 99.9 (2*t*, ¹*J*(C,H) = 163, 2 CH₂=C); 88.7 (*m*, C(1)); 79.8 (*dm*, ¹*J*(C,H) = 164, C(4)); 60.8 (*t*, ¹*J*(C,H) = 142); 30.2, 29.4 (2*tm*, ¹*J*(C,H) = 139). MS (70 eV): 152 (1, *M*⁺), 134 (10), 124 (30), 123 (30), 106 (40), 77 (100). Anal. calc. for C₉H₁₂O₂ (152.195): C 71.03, H 7.95; found: C 70.93, H 7.95.

2,3-Dimethylidene-7-oxabicyclo[2.2.1]heptane-1-carboxylic Acid (9). Ag₂O (1.2 g), then 10% aq. NaOH soln. (3 ml) were added to a stirred soln. of **7** (1.15 g, 7.7 mmol) in THF (3 ml) and H₂O (4 ml) maintained at 0°. After stirring at 0° for ca. 30 min, the precipitate was filtered off and washed with H₂O (2 ml). The soln. was evaporated, H₂O (5 ml) was added and the mixture extracted with CH₂Cl₂ (10 ml). The aq. phase was collected and acidified at 0° with 10% HCl until pH 4. The mixture was extracted with CH₂Cl₂ (10 ml, 5 times). The extracts were united and washed with brine, dried (MgSO₄), and evaporated, yielding an unstable oil which polymerized rapidly at 20°. IR (CH₂Cl₂): 3470, 3060, 2990, 2950, 2870, 1780, 1750, 1725, 1435, 1375, 1260, 1195, 1140, 1090, 1065, 1050, 1040, 965, 950. ¹H-NMR (CDCl₃): 8.2–7.9 (br. s, OH); 5.33, 5.30, 5.25, 4.99 (4s, 4 H); 4.86 (*d*, *J* = 4, H-C(4)); 2.3–1.6 (*m*, 4 H). ¹³C-NMR (90 MHz, CDCl₃): 174.3 (br. s); 146.4, 145.2 (*m*, C(2), C(3)); 101.9, 101.8 (2*t*, ¹*J*(C,H) = 164, 2 CH₂=C); 86.7 (*m*, C(1)); 80.5 (*dm*, ¹*J*(C,H) = 168, C(4)); 32.9, 29.7 (2*t*, ¹*J*(C,H) = 140, C(5), C(6)). MS (70 eV): 166 (11, *M*⁺), 138 (33), 121 (20), 91 (100).

Methyl 2,3-Dimethylidene-7-oxabicyclo[2.2.1]heptane-1-carboxylate (10). A soln. of CH₂N₂ in Et₂O was added slowly to a stirred soln. of **9** (1 g, 6.02 mmol) in Et₂O (10 ml) cooled to 0°. The excess of CH₂N₂ was destroyed with 10% AcOH in Et₂O. The solvent was eliminated by distillation (*Vigreux* column) and the residue dried *in vacuo*, yielding 1 g (92%), colourless oil. IR (CH₂Cl₂): 3080, 3000, 2960, 1760, 1740, 1445, 1350, 1230, 1090, 1050, 965, 935, 900. ¹H-NMR (CDCl₃): 5.33, 5.26, 5.20, 5.00 (4s, 4 H); 4.93 (*d*, *J* = 4, H-C(4)); 3.88 (*s*, COOCH₃); 2.3–1.5 (*m*, 4 H). ¹³C-NMR (90 MHz, CDCl₃): 169.5 (*m*, CO); 147.4, 146.6 (2*m*); 101.5, 101.3 (2*t*, ¹*J*(C,H) = 160); 87.5 (*m*); 80.8 (*dq*, ¹*J*(C,H) = 160); 52.2 (*q*, ¹*J*(C,H) = 149); 33.3, 29.9 (2*t*, ¹*J*(C,H) = 136). MS (70 eV): 180 (72, *M*⁺), 152 (100). Anal. calc. for C₁₀H₁₂O₃ (180.204): C 66.65, H 6.71; found: C 66.62, H 6.78.

8-Dimethoxymethyl-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-trien-4-yl Methyl Ketone (40). Under Ar and in a flask cooled to -75°, anh. CH₂Cl₂ (8 ml), but-3-yn-2-one (90 μl, 1.13 mmol), and BF₃·Et₂O (146 μl, 1.13 mmol, ca. 48% BF₃) were mixed and allowed to react for 20 min. The mixture was cooled to -100°, and **2** (74 mg, 0.38 mmol) in anh. CH₂Cl₂ (1 ml) was added dropwise. Anh. CH₂Cl₂ (1 ml) was used for the rinsing. After standing at -75° for 4 d, the mixture was poured into a vigorously stirred mixture of Et₂O (25 ml) and sat. aq. NaHCO₃ soln. (25 ml). The org. layer was dried (MgSO₄) and the solvent eliminated by distillation (*Vigreux* column) at room pressure. The residue was dried at 10⁻¹ Torr, yielding 83 mg (83%) of a 7:3 mixture **38/39**, white solid. Separation by column chromatography on silica gel (*Lobar-Merk*), yielded first **38**, the less polar adduct (58 mg, 0.22 mmol). It was treated with (65 mg, 0.24 mmol) in anh. benzene (4 ml) at 60° for 3 h. After filtration, the soln. was washed with 5% aq. Na₂S₂O₅ soln., then with sat. aq. NaHCO₃ soln., and finally with H₂O (pH 7). After drying (MgSO₄), the soln. was filtered on silica gel and the solvent evaporated, yielding 49 mg (85%) of **40**, yellowish oil. UV (isooctane): 292 (1200), 281 (1400), 256 (sh, 10400), 252 (11800), 205 (19200). UV (95% EtOH): 280 (sh, 2100), 255 (13200), 203 (22200). IR (CH₂Cl₂): 3010, 2970, 2840, 1685, 1620, 1580, 1360, 1115, 1095, 1080. ¹H-NMR (360 MHz, C₆D₆): 7.69 (*d*, ⁴*J*(H-C(3), H-C(5)) = 1.6, H-C(3)); 7.69 (*dd*, *J* = 8, 1.6, H-C(5)); 7.56 (*d*, ³*J*(H-C(5), H-C(6)) = 8, H-C(6)); 5.03 (*d*, ³*J*(H-C(1), H_β-C(10)) = 5, H-C(1)); 4.67 (*s*, (CH₃O)₂CH); 3.38, 3.34 (2*s*, (CH₃O)₂CH); 2.16 (*m*, H_β-C(9)); 2.15 (*s*, COCH₃); 1.84 (*m*, H_β-C(10)); 1.43 (*dm*, *J* = 11.4, 9.4, H_α-C(9)); 1.07 (*dm*, *J* = 11.4, 9.4, H_α-C(10)). ¹³C-NMR (90 MHz, CDCl₃): 197.8 (*m*, CO); 149.8, 146.8 (2*m*, C(2), C(7)); 136.2 (*d*, ³*J*(C,H) = 7, C(4)); 127.9 (*dm*, ¹*J*(C,H) = 161, C(3)); 119.9 (*d*, ¹*J*(C,H) = 164, C(6)); 118.2 (*dd*, ¹*J*(C,H) = 162, ³*J*(C,H) = 7, C(5)); 105.4 (*dm*, ¹*J*(C,H) = 158, CH-C(8)); 89.5 (*m*, C(8)); 78.7 (*d*, ¹*J*(C,H) = 166, C(1)); 57.4, 56.5 (2*qd*, ¹*J*(C,H) = 143, ³*J*(C,H) = 5, (CH₃O)₂CH); 28.0, 27.0 (2*t*, ¹*J*(C,H) = 136, C(9), C(10)); 26.7 (*q*, ¹*J*(C,H) = 127, CH₃CO). MS (70 eV): 262 (8, *M*⁺), 243 (47), 219 (14), 203 (100), 173 (13), 115 (17), 94 (10), 89 (13), 75 (78), 47 (21). Anal. calc. for C₁₅H₁₈O₄ (262.306): C 68.89, H 6.92; found: C 68.64, H 6.94.

1-Dimethoxymethyl-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-trien-4-yl Methyl Ketone (41). The 2nd fraction of the above medium-pressure chromatography yielded 24 mg (0.091 mmol) of adduct **39**. Treatment with 22 mg of DDQ in 2 ml of C₆H₆ (see above) afforded 19 mg (80%) of **41**, yellowish oil. UV (isooctane): 289 (1100), 280 (1400), 256 (sh, 11400), 250 (13200), 209 (25800). UV (95% EtOH): 254 (12800), 206 (24200). IR (CH₂Cl₂): 3000,

2960, 2840, 1680, 1620, 1580, 1355, 1235, 1115, 1095, 1080. ¹H-NMR (360 MHz, C₆D₆): 8.27 (*t*, ⁴*J*(H–C(3), H–C(5)) = 1.6, ⁵*J*(H–C(3), H–C(6)) = 0.8, H–C(3)); 7.66 (*dd*, *J* = 8, 1.6, H–C(5)); 6.83 (*dd*, *J* = 8, 0.8, H–C(6)); 5.05 (*d*, *J* = 5, H–C(8)); 4.71 (*s*, (CH₃O)₂CH); 3.38, 3.34 (2*s*, (CH₃O)₂CH); 2.19 (*s*, COCH₃); 2.19 (*m*, H_β–C(10)); 1.86 (*m*, H_β–C(9)); 1.43 (*dm*, ²*J* = –11.4, ³*J*(H_α–C(10), H_α–C(9)) = 9, ³*J*(H_α–C(10), H_β–C(9)) = 4, H_α–C(10)); 1.07 (*dm*, *J* = –11.4, 9, 4, H_α–C(9)). ¹³C-NMR (90 MHz, CDCl₃): 197.8 (*m*); 151.1 (*m*, C(2)); 145.5 (*m*, C(7)); 136.2 (*m*, ³*J*(C,H) = 6, C(4)); 127.9, 119.6 (2*dd*, ¹*J*(C,H) = 165, ³*J*(C,H) = 6, C(3), C(5)); 118.6 (*d*, ¹*J*(C,H) = 162, C(6)); 105.4 (*dm*, ¹*J*(C,H) = 160, CH–C(1)); 89.4 (*m*, C(1)); 78.7 (*d*, ¹*J*(C,H) = 165, C(8)); 57.4, 56.4 (2*qd*, ¹*J*(C,H) = 143, ³*J*(C,H) = 5, (CH₃O)₂CH); 27.8, 27.0 (2*t*, ¹*J*(C,H) = 137, C(9), C(10)); 26.7 (*q*, ¹*J*(C,H) = 128). MS (70 eV): 262 (12, M⁺), 235 (13), 234 (87), 219 (25), 203 (100), 183 (15), 75 (44). Anal. calc. for C₁₅H₁₈O₄ (262.306): C 68.69, H 6.92; found: C 68.63, H 6.94.

(*1RS,4SR,8SR*)-8-Dimethoxymethyl-11-oxatricyclo[6.2.1.0^{2,7}]undec-2(7)-en-4-exo-yl Methyl Ketone (**42**).

A) Into a flask (dried in a flame under Ar and sealed with a septum), anh. CH₂Cl₂ (3 ml) and MVK (340 mg, 4.83 mmol) were introduced *via* a syringe. After cooling to –85°, BF₃·Et₂O (*ca.* 48% BF₃, 603 μl) were added. After stirring at –85° for 20 min, **6** (316 mg, 1.61 mmol) in anh. CH₂Cl₂ (2 ml) was added slowly (rinsing with 1 ml of anh. CH₂Cl₂). After stirring at –85° for 20 min, the mixture was poured into a vigorously stirred mixture of Et₂O (25 ml) and sat. aq. NaHCO₃ soln. (25 ml). The org. layer was washed with H₂O (20 ml) and dried (MgSO₄). The solvent was evaporated and the residue dried (20°/10^{–1} Torr, 3 h) yielding 403 mg (94%) of a colourless oil containing 13.5:1:2.5:1.25 of **42/43/44/45** (by 360-MHz-¹H-NMR). HPLC (*Zorbax-Sil*, 7 μm, hexane/AcOEt 96:4) yielded a fraction containing a 9:1 mixture **42/44**.

B) By using 2.85 ml (4.7 mmol) of a 25% soln. of EtAlCl₂ in hexane instead of BF₃·Et₂O and a total amount of 11 ml of CH₂Cl₂ (solvent ratio CH₂Cl₂/hexane 5:1), a 28.5:1:3:2 mixture **42/43/44/45** was obtained in 95% yield. Characteristics of the major adduct **42**: IR (CHCl₃): 3020, 2960, 2840, 1720, 1440, 1360, 1230, 1065, 1045, 1110, 1075, 940, 875. ¹H-NMR (360 MHz, CD₃COCD₃): 4.64 (*d*, *J* = 4.3, H–C(1)); 4.54 (*s*, CH–C(1)); 3.45, 3.43 (2*s*, (CH₃O)₂CH); 2.50–2.43 (*m*, 4 H); 2.13 (*s*, CH₃CO); 2.12–1.89 (*m*, 2 H); 1.81–1.62 (*m*, 2 H); 1.56–1.41 (1 H); 1.28–1.13 (*m*, 2 H). ¹H-NMR (360 MHz, C₆D₆): 4.54 (*dd*, ³*J*(H–C(1), H_β–C(10)) = 4.1, ³*J*(H–C(1), H_β–C(6)) = 1.2, H–C(1)); 4.51 (*s*, (CH₃O)₂CH); 3.36 (2*s*, (CH₃O)₂CH); 2.53 (*m*, H_β–C(6)); 2.22 (*m*, ²*J* = –17.3, ³*J*(H_β–C(3), H_α–C(4)) = 10, H_β–C(3)); 2.00–1.69 (*m* + *s*, 5 H + COCH₃); 1.46 (*m*, H_β–C(5)); 1.33 (*m*, ²*J* = –10.8, ³*J*(H_α–C(9), H_α–C(10)) = 8.6, ³*J*(H_α–C(9), H_β–C(10)) = 3.5, H_α–C(9)); 1.00 (*m*, ²*J* = –10.8, ³*J*(H_α–C(10), H_α–C(9)) = 8.6, ³*J*(H_α–C(10), H_β–C(9)) = 3.4, H_α–C(10)). ¹³C-NMR (90 MHz, C₆D₆): 208.5 (*m*, CO); 140.5, 139.5 (2*m*, C(2), C(7)); 106.4 (*dm*, ¹*J*(C,H) = 157, C–C(8)); 91.3 (*m*, C(8)); 79.8 (*d*, ¹*J*(C,H) = 160, C(1)); 56.6, 56.1 (*qd*, ¹*J*(C,H) = 142, ³*J*(C,H) = 5, (CH₃O)₂CH); 48.2 (*dm*, ¹*J*(C,H) = 126, C(4)); 27.4 (*q*, ¹*J*(C,H) = 128, COCH₃); 27.2, 27.1 (2*t*, ¹*J*(C,H) = 135, C(9), C(10)); 25.1, 23.1, 22.2 (3*t*, ¹*J*(C,H) = 129). MS (70 eV): 267 (15, M⁺ + H). Anal. calc. for C₁₅H₂₂O₄ (266.340): C 67.65, H 8.33; found: C 67.87, H 8.41.

(*1RS,4RS,8SR*)-1-Dimethoxymethyl-11-oxatricyclo[6.2.1.0^{2,7}]undec-2(7)-en-4-exo-yl Methyl Ketone (**44**).

Into a flask (dried in a flame under Ar and sealed with a septum), anh. CH₂Cl₂ (1.5 ml) and MVK (390 μl, 4.7 mmol) were introduced. After cooling to –85°, EtAlCl₂ (2.85 ml, 4.7 mmol) in 25% (*w/w*) soln. in anh. hexane was added. After stirring at –85° for 20 min, the mixture was frozen in liq. N₂, and **6** (307 mg, 1.56 mmol) in anh. CH₂Cl₂ (1.5 ml) was introduced (rinsing with 1.5 ml of anh. CH₂Cl₂; final concentration of **6**: 0.24M). After stirring at –85° for 100 min, the mixture was poured into a vigorously stirred mixture of Et₂O (25 ml) and ice-cold sat. aq. NaHCO₃ soln. The org. layer was separated and the aq. layer extracted with Et₂O (10 ml, 2 times). The extracts were united and washed with H₂O (20 ml) and dried (MgSO₄). The solvent was eliminated by distillation at room pressure (*Vigreux* column) and the residue dried at 20°/10^{–2} Torr (3 h), yielding 283 mg (68%) of a 10:1:24:1 mixture **42/43/44/45** as a colourless oil. The major adduct **44** was isolated by HPLC (*Zorbax-Sil* 7 μm, CHCl₃/acetone 9.5:0.5, 1000 psi). IR (CH₂Cl₂): 3000, 2960, 2920, 2880, 2840, 1730, 1440, 1365, 1195, 1165, 1145, 1110, 1080, 945. ¹H-NMR (360 MHz, C₆D₆): 4.53 (*s*, CH–C(1)); 4.52 (*br. d*, *J* = 4.2, ⁵*J* = 0.8 1.0, H–C(8)); 3.36, 3.34 (2*s*, (CH₃O)₂CH); 2.61 (*m*, ²*J* = –18.5 (–17.8)⁵), ³*J*(H_β(ax)–C(3), H_α(ax)–C(4)) = 8.5 (10.5)⁵, ⁵*J*(H_β(ax)–C(3), H_α(ax)–C(6)) = 3.5 (4.2)⁵, ⁵*J*(H_β(ax)–C(3), H_β(eq)–C(6)) = 2.5 (2.8)⁵, ⁵*J*(H_β–C(3), H–C(8)) = 0.8–1.0, H_β(ax)–C(3)); 2.35 (*m*, ²*J* = –18.5 (–17.8)⁵), ³*J*(H_β(eq)–C(3), H_α(ax)–C(4)) = 5.5⁶, ⁴*J*(H_α–C(3), H_α(eq)–C(5)) = 1.5⁶, ⁵*J*(H_α–C(3), H_α(ax)–C(6)) = 2.1⁶, ⁵*J*(H_α–C(3), H_β(eq)–C(6)) = 1.0⁶, H_α(eq)–C(3)); 2.14 (*s*, COOCH₃); 1.91 (*m*, ³*J*(H_α–C(3), H_α(ax)–C(4)) = 5.5⁶), ³*J*(H_β–C(3), H_α–C(4)) = 8.5 (10.5)⁵, ³*J*(H_α–C(4), H_β(ax)–C(5)) = 10.8 (11.4)⁵, ³*J*(H_α–C(4), H_α(eq)–C(5)) = 3.3⁶, H_α(ax)–C(4)); 1.54 (*m*, ²*J* = –15.0 (–13.1)⁵), ³*J*(H_α(eq)–C(4), H_β(ax)–C(5)) = 10.8 (11.4)⁵, ³*J*(H_β–C(5), H_α(ax)–C(6)) = 11.1⁶, ³*J*(H_β–C(5),

⁵) In parenthesis the values used to initiate the iterative PANIC 81 (version 810515.1) program (7 spins, final $\Delta J = 0.06$ Hz). For **44**, the δ_{H} were derived from the ¹H, ¹³C-correlated spectra.

⁶) Non-refined values; they were read directly from the experimental spectrum.

$H_{\beta}(\text{eq})-C(6) = 5.8^6$, $H_{\beta}(\text{ax})-C(5)$; 1.55 (m , $^2J = -15.0$ (-13.1) 5), $^3J(H_{\alpha}-C(4), H_{\alpha}-C(5)) = 3.3^6$, $^3J(H_{\alpha}-C(5), H_{\alpha}(\text{ax})-C(6)) = 5.0^6$, $^3J(H_{\alpha}-C(5), H_{\beta}(\text{eq})-C(6)) = 3.0^6$, $^4J(H_{\alpha}-C(3), H_{\alpha}-C(5)) = 1.5^6$, $H_{\alpha}(\text{eq})-C(5)$; 1.52 (m , $^2J = -18.0^6$), $^3J(H_{\beta}(\text{ax})-C(5), H_{\alpha}(\text{ax})-C(6)) = 11.1^6$, $^3J(H_{\alpha}(\text{eq})-C(5), H_{\alpha}-C(6)) = 5.0^6$, $^3J(H_{\beta}-C(3), H_{\alpha}-C(6)) = 3.5$ (4.2) 5 , $^5J(H_{\alpha}-C(3), H_{\alpha}-C(6)) = 2.1^6$, $H_{\alpha}(\text{ax})-C(6)$; 1.98 (m , $^2J = -18.0^6$), $^3J(H_{\beta}-C(5), H_{\beta}-C(6)) = 11.1^6$, $^3J(H_{\alpha}-C(5), H_{\beta}-C(6)) = 5.0^6$, $^5J(H_{\beta}-C(3), H_{\beta}-C(6)) = 3.5$ (4.2) 5 , $^5J(H_{\alpha}-C(3), H_{\beta}-C(6)) = 2.1^6$, $H_{\beta}(\text{eq})-C(6)$; 1.03 (m , $^2J = -10.8$, $^3J(H_{\alpha}-C(9), H_{\alpha}-C(10)) = 8.6$, $^3J(H_{\alpha}-C(9), H_{\beta}-C(10)) = 3.4$, $H_{\alpha}-C(9)$; 1.78 (m , $^2J = -10.8$, $^3J(H-C(8), H_{\beta}-C(9)) = 4.2$, $^3J = 3.5$, 9.2, $H_{\beta}-C(9)$; 1.33 (m , $^2J = -10.8$, $^3J(H_{\alpha}-C(9), H_{\alpha}-C(10)) = 8.6$, $^3J(H_{\beta}-C(9), H_{\alpha}-C(10)) = 3.5$, $H_{\alpha}-C(10)$; 1.94 (m , $^2J = -10.8$, $^3J(H_{\alpha}-C(9), H_{\beta}-C(10)) = 3.4$, $^3J(H_{\beta}-C(9), H_{\beta}-C(10)) = 9.2$, $H_{\beta}-C(10)$). $^{13}\text{C-NMR}$ (90 MHz, C_6D_6): 208.6 (m , CO); 141.3, 138.9 ($2m$, C(2), C(7)); 106.6 (d , $^1J(\text{C,H}) = 157$, $\text{CH}-\text{C}(1)$); 91.6 (m , C(1)); 80.2 (d , $^1J(\text{C,H}) = 162$, C(8)); 56.5, 56.2 ($2qd$, $^1J(\text{C,H}) = 143$, $^3J(\text{C,H}) = 5$, $(\text{CH}_3\text{O})_2\text{CH}$); 48.2 (d , $^1J(\text{C,H}) = 125$, C(4)); 27.6 (t , $^1J(\text{C,H}) = 133$); 27.4 (q , $^1J(\text{C,H}) = 127$); 27.1, 24.7, 23.7, 21.7 ($4t$, $^1J(\text{C,H}) = 130$). MS (70 eV): 266 (1 , M^+), 234 (34), 208 (13), 207 (99), 206 (42), 191 (25), 173 (13), 164 (12), 163 (100), 161 (14), 159 (16), 149 (11), 131 (16), 91 (16), 77 (11), 75 (73). Anal. calc. for $\text{C}_{15}\text{H}_{22}\text{O}_4$ (266.340): C 67.65, H 8.33; found: C 67.49, H 8.20.

(\pm)-1-Dimethoxymethyl-11-oxatricyclo[6.2.1.0 2,7]undec-2(7)-ene-4,4,5,5-tetracarbonitrile (TCNE adduct of 6). A mixture of 6 (200 mg, 1.02 mmol), TCNE (131 mg, 1.02 mmol), and anh. C_6H_6 (3.5 ml) was stirred at 20° for 72 h. After filtration on a short column of silica gel and solvent evaporation, the residue was recrystallized from CH_2Cl_2 , yielding 265 mg (80%) of colourless crystals, m.p. 173–175°. IR (CH_2Cl_2): 3000, 2960, 2910, 2880, 2840, 2220, 1190, 1100, 1080, 975, 850. $^1\text{H-NMR}$ (360 MHz, C_6D_6): 4.16 (d , $J = 4$, $\text{H}-\text{C}(8)$); 4.14 (s , $\text{CH}-\text{C}(1)$); 3.14 (dm , 1 H); 3.12, 3.10 ($2s$, $(\text{CH}_3\text{O})_2\text{CH}$); 2.73, 2.10 ($2dm$, $^2J = 18$, 2 H); 1.66 1.47 (m , 3 H); 1.15, 0.83 ($2m$, 2 H). $^{13}\text{C-NMR}$ (90 MHz, C_6D_6): 135.7, 135.6 ($2m$, C(2), C(7)); 111.2, 111.1, 111.0 ($3m$, 4 C); 105.4 (d , $^1J(\text{C,H}) = 161$, $(\text{CH}_3\text{O})_2\text{CH}$); 91.9 (m , C(1)); 79.4 (d , $^1J(\text{C,H}) = 165$, C(8)); 56.6, 56.5 ($2qd$, $^1J(\text{C,H}) = 143$, $^3J(\text{C,H}) = 5$, $(\text{CH}_3\text{O})_2\text{CH}$); 38.7 (m , C(4), C(5)); 31.0, 29.7 ($2t$, $^1J(\text{C,H}) = 141$, C(9), C(10)); 26.3, 26.2 ($2t$, $^1J(\text{C,H}) = 138$, C(3), C(6)). MS (70 eV): 324 (2 , M^+), 296 (22), 267 (87), 200 (21), 91 (11), 78 (100), 65 (11), 55 (11), 51 (12), 48 (38), 45 (11). Anal. calc. for $\text{C}_{17}\text{H}_{16}\text{N}_4\text{O}_3$ (324.342): C 62.96, H 4.97; found: C 62.81, H 5.10.

(\pm)-1-Dimethoxymethyl-9,10-dimethylidene-11-oxatricyclo[6.2.1.0 2,7]undec-2(7)-ene-4,4,5,5-tetracarbonitrile (46). A mixture of 2 (127 mg, 0.58 mmol), TCNE (71 mg, 0.57 mmol), and anh. C_6H_6 (2.5 ml) was stirred at 20° for 72 h. After solvent evaporation, the residue was purified by flash chromatography on Florisil (13 g, AcOEt/hexane 1:3) yielding 140 mg (70%) of colourless crystals, m.p. 151–152°. UV (CH_3CN): 246 (7700). IR (CH_2Cl_2): 3005, 2975, 2950, 2850, 2260, 1425, 1300, 1210, 1195, 1100, 1075, 980, 945, 910. $^1\text{H-NMR}$ (360 MHz, C_6D_6): 5.25, 5.20, 5.08, 4.69 ($4s$, 4 H); 4.39 ($br. s$, $\text{H}-\text{C}(8)$); 4.34 (s , 1 H); 3.17 (s , CH_3O); 3.08 (dm , 1 H); 3.04 (s , CH_3O); 2.75, 2.18, 1.88 ($3 dm$, 3 H). $^{13}\text{C-NMR}$ (90 MHz, CDCl_3): 142.0, 140.6 ($2m$, C(9), C(10)); 136.9, 136.0 ($2m$, C(2), C(7)); 110.4, 110.35, 110.2, 109.9 ($4m$, 4 CN); 105.2, 103.5 ($2t$, $^1J(\text{C,H}) = 160$); 103.7 (dm , $^1J(\text{C,H}) = 161$, $^3J(\text{C,H}) = 5$); 92.2 (m , C(1)); 83.0 (dm , $^1J(\text{C,H}) = 168$, $^3J = 12$, 6, C(8)); 57.1, 56.7 ($2qd$, $^1J(\text{C,H}) = 139$, $^3J(\text{C,H}) = 5$, 2 CH_3O); 38.4, 38.3 ($2m$, $^3J(\text{C,H}) = 4$, C(4), C(5)); 31.4, 31.0 ($2t$, $^1J(\text{C,H}) = 143$, C(3), C(6)). MS (70 eV): 348 (3 , M^+), 265 (52), 75 (100).

8-Dimethoxymethyl-9,10-dimethylidene-11-oxatricyclo[6.2.1.0 2,7]undeca-2,4,6-trien-4-yl Methyl Ketone (50). Into a flask dried in a flame under Ar and sealed with a septum, anh. CH_2Cl_2 (35 ml), but-3-yn-2-one (1.18 ml, 14.82 mmol), and $\text{BF}_3 \cdot \text{Et}_2\text{O}$ (48% BF_3 , 2.1 ml) were introduced successively at -85° . After stirring at -85° for 20 min, 2 (1.09 g, 4.94 mmol) in anh. CH_2Cl_2 (5 ml) was added slowly. After stirring at -75° for 3 d, the mixture was poured in a vigorously stirred mixture of Et_2O (125 ml) and ice-cold sat. aq. NaHCO_3 soln. (125 ml). The org. layer was separated and the aq. layer extracted with Et_2O (100 ml). The Et_2O extracts were united, washed with H_2O (50 ml, 3 times), and dried (MgSO_4). Solvent evaporation, yielded 1.28 g (90%) of a 7:3 mixture 48/49 as a colourless oil. They were separated by medium-pressure column chromatography (Lobar-Merk, silica gel, AcOEt/hexane 1:4). The 1st fraction contained 49, the 2nd 48. The latter was aromatized with 1.1 equiv. of DDQ following the procedure described for the preparation of 40, yielding 682 mg (48%) of 50 as slightly yellow oil. UV (95% EtOH): 257 (16200), 228 (16900), 209 (sh, 23000), 205 (23600). IR (CH_2Cl_2): 3010, 2980, 2950, 2850, 1740, 1620, 1365, 1215, 1195, 1060, 1110, 1080. $^1\text{H-NMR}$ (360 MHz, CDCl_3): 7.87 (m , $\text{H}-\text{C}(3)$); 7.82 (dd , $J = 8$, 2, $\text{H}-\text{C}(5)$); 7.59 (d , $J = 8$, $\text{H}-\text{C}(6)$); 5.41 (s , $\text{H}-\text{C}(1)$); 5.44, 5.41, 5.30, 5.20 ($4s$, 4 H); 5.02 (s , $\text{CH}-\text{C}(8)$); 3.66, 3.61 ($2s$, $(\text{CH}_3\text{O})_2\text{CH}$); 2.58 (s , COCH_3). $^{13}\text{C-NMR}$ (90 MHz, CDCl_3): 197.4 (m , CO); 148.5 (m , C(7)); 145.5 (d , $^3J(\text{C,H}) = 7$, C(2)); 144.8, 143.1 ($2m$, C(9), C(10)); 136.6 (d , $^3J(\text{C,H}) = 7$, C(4)); 128.6 (dd , $^1J(\text{C,H}) = 162$, $^3J(\text{C,H}) = 5$, C(3) or C(5)); 121 (d , $^1J(\text{C,H}) = 168$, C(6)); 119.0 (dm , $^1J(\text{C,H}) = 163$, C(5) or C(3)); 104.8 (t , $^1J(\text{C,H}) = 159$, $\text{CH}_2=\text{C}(9)$, $\text{CH}_2=\text{C}(10)$); 104.4 (dm , $^1J(\text{C,H}) = 159$, $^3J(\text{C,H}) = 5$, $\text{CH}-\text{C}(8)$); 90.6 (m , C(8)); 82.2 (dm , C(1)); 56.9, 56.7 ($2qd$, $^1J(\text{C,H}) = 143$, $^3J(\text{C,H}) = 5$, $(\text{CH}_3\text{O})_2\text{CH}$); 26.6 (q , $^1J(\text{C,H}) = 127$, CH_3CO). MS (70 eV): 286 (12 , M^+), 75 (100). Anal. calc. for $\text{C}_{17}\text{H}_{18}\text{O}_4$ (286.331): C 71.31, H 6.34; found: 71.26, H 6.33.

1-Dimethoxymethyl-9,10-dimethylidene-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-trien-4-yl Methyl Ketone (51).

The minor adduct **49** obtained as the 1st fraction of the above chromatography was aromatized with DDQ as for the preparation of **40**, yielding 290 mg (21%) of **51** as a yellowish oil. UV (95% EtOH): 293 (sh, 1300), 256 (13 900), 230 (15 300), 206 (20 400). IR (CH₂Cl₂): 3000, 2965, 2940, 2840, 1685, 1360, 1235, 1175. ¹H-NMR (360 MHz, CDCl₃): 8.07 (*m*, H-C(3)); 7.83 (*dd*, *J* = 8, 2, H-C(5)); 7.36 (*d*, *J* = 8, H-C(6)); 5.60, 5.43, 5.39, 5.30, 5.20 (5*s*, 5 H); 3.68, 3.62 (2*s*, (CH₃O)₂CH); 2.58 (*s*, COCH₃). ¹³C-NMR (90 MHz, CDCl₃): 197.4 (*m*, CO), 149.6, 144.6 (2*m*, C(2), C(7)); 144.3, 143.2 (2*m*, C(9), C(10)); 136.7 (*d*, ³*J*(C,H) = 7, C(4)); 128.4 (*dd*, ¹*J*(C,H) = 161, ³*J*(C,H) = 5); 120.7 (*dd*, ¹*J*(C,H) = 165, ³*J*(C,H) = 7, C(3), C(5)); 119.4 (*d*, ¹*J*(C,H) = 163, C(6)); 104.5, 103.2 (2*t*, ¹*J*(C,H) = 162, CH₂=C(9), CH₂=C(10)); 104.3 (*dd*, ¹*J*(C,H) = 159, ³*J*(C,H) = 5, CH-C(1)); 90.4 (*m*, C(1)); 82.1 (*dm*, ¹*J*(C,H) = 165, C(8)); 56.8, 56.8 (2*qd*, ¹*J*(C,H) = 142, ³*J*(C,H) = 5, (CH₃O)₂CH); 26.6 (*q*, ¹*J*(C,H) = 127, CH₃CO). MS (70 eV): 286 (20, *M*⁺), 239 (12), 211 (11), 203 (21), 197 (11), 183 (13), 139 (11), 75 (100), 47 (12). Anal. calc. for C₁₇H₁₈O₄ (286.339): C 71.31, H 6.34; found: C 71.18, H 6.41.

(2RS,9RS,10SR)-10-Dimethoxymethyl-1,2,3,4,9,10-hexahydro-9,10-epoxy-anthracene-2,7-diyl Bis (Methyl Ketone) (**52**). Into a flask dried in a flame under Ar and sealed with a septum, anh. CH₂Cl₂ (9.5 ml), MVK (147 mg, 2.1 mmol), and BF₃·Et₂O (26.5 μl) were introduced successively at -75°. After stirring at -75° for 20 min, **50** (200 mg, 0.7 mmol) in anh. CH₂Cl₂ (1 ml) was introduced slowly at -95° (rinsing with 1 ml of CH₂Cl₂; final concentration of **50**: 0.06M). After stirring at -75° for 80 h, the mixture was poured into a vigorously stirred mixture of Et₂O (50 ml) and ice-cold sat. aq. NaHCO₃ soln. (50 ml). The org. layer was washed with H₂O (30 ml) and dried. After solvent evaporation, the residue was filtered through a column of silica gel (AcOEt/hexane 5:3.5) to eliminate the aldehyde impurities. After solvent evaporation, 187 mg (75%) of a 17.2:1.2:5.2:1 mixture **52/53/54/55** was obtained as a yellowish oil. Several crystallizations from acetone yielded 110 mg (44%) **52** as colourless crystals, m.p. 130-132°. UV (CH₃CN): 301 (2900), 276 (3700), 234 (17 600), 201 (19 300). IR (CHCl₃): 3010, 2940, 2860, 2840, 1715, 1680, 1610, 1420, 1355, 1280, 1250, 1115, 1075. ¹H-NMR (360 MHz, C₆D₆): 7.83 (*dd*, ⁴*J* = 1.6, ³*J* = 0.8, H-C(8)); 7.53 (*dd*, *J* = 7.4, 0.8, H-C(5)); 7.49 (*dd*, *J* = 7.4, 1.6, H-C(6)); 5.10 (br. *s*, H-C(9)); 4.73 (*s*, CH-C(10)); 3.37, 3.38 (2*s*, (CH₃O)₂CH); 2.62 (*m*, ²*J* = -17.4, ³*J*(H_α-C(2), H_β-C(4)) = 9.2, ⁵*J*(H_β-C(1), H_β-C(4)) = 3.2, ⁵*J*(H_α-C(1), H_β-C(4)) = 4.4, H_β-C(4)); 2.34 (*m*, H_β-C(1)); 2.13 (*s*, CH₃CO); 1.89 (*m*, H_α-C(4)); 1.71-1.33 (*m*, 3 H); 1.55 (*s*, CH₃CO). ¹³C-NMR (90 MHz, CDCl₃): 210.1, 197.0 (2*m*, 2 CO); 154.3 (*m*, C(10)); 150.8 (*d*, ³*J*(C,H) = 6, C(5a)); 148.5, 147.2 (2*m*, C(4a), C(1a)); 134.7 (*d*, ³*J*(C,H) = 6, C(7)); 127.4 (*dm*, ¹*J*(C,H) = 158); 119.9 (*dd*, ¹*J*(C,H) = 163, ³*J*(C,H) = 4); 117.7 (*dd*, ¹*J*(C,H) = 163, ³*J*(C,H) = 7); 103.9 (*dm*, ¹*J*(C,H) = 158, ³*J*(C,H) = 5); 93.7 (*d*, ³*J*(C,H) = 7, C(10)); 83.25 (*d*, ¹*J*(C,H) = 167, C(9)); 57.0, 56.95 (2*qd*, ¹*J*(C,H) = 144, ³*J*(C,H) = 5, (CH₃O)₂CH); 47.3 (*dm*, ¹*J*(C,H) = 129, C(2)); 28.03, 26.6 (2*q*, ¹*J*(C,H) = 128, 2 CH₃CO); 24.8, 24.3, 23.2 (3*m*, ¹*J*(C,H) = 128, C(1), C(3), C(4)); the signal corresponding to C(8a) must be hidden by one of the aromatic signals. MS (70 eV): 281 (99), 279 (19), 267 (15), 266 (13), 265 (42), 264 (68), 283 (100), 253 (45), 252 (14), 251 (41), 179 (60), 178 (43), 165 (91), 164 (19), 163 (27), 152 (18). Anal. calc. for C₂₁H₂₄O₅ (356.419): C 70.77, H 6.79; found: C 70.73, H 6.97.

(1RS,4SR,8SR)-8-Dimethoxymethyl-9,10-dimethylidene-11-oxatricyclo[6.2.1.0^{2,7}]undec-2(7)-en-4-exo-yl Methyl Ketone (**56**). Into a flask dried in a flame under Ar and sealed with a septum, anh. CH₂Cl₂ (22 ml) and MVK (291 mg, 4.15 mmol) were introduced. After cooling to -100°, a 25% soln. of EtAlCl₂ in hexane (2.52 ml, 4.15 mmol) was introduced. After stirring at -85° for 20 min, the mixture was frozen in liq. N₂, and **2** (305 mg, 1.39 mmol) in anh. CH₂Cl₂ (15 ml) was introduced (rinsing with anh. CH₂Cl₂, 1 ml, 2 times). After stirring at -85° for 1 h, the mixture was poured into a vigorously stirred mixture of Et₂O (125 ml) and ice-cold sat. aq. NaHCO₃ soln. The org. layer was washed with H₂O until pH 7. After drying (MgSO₄), the solvent was distilled at reduced pressure under reflux (Vigreux column). Chromatography on silica gel (30 g, AcOEt/hexane 1:1) gave 315 mg of a 83:17 mixture **56/58**. HPLC (inverse-phase octadecyl, MeOH/H₂O/THF 45:50:5) yielded 61 mg (15%) of pure **56** as a colourless oil. UV (isooctane): 242 (sh, 6000), 232 (7600), 224 (sh, 9200). UV (95% EtOH): 241 (sh, 6500), 232 (sh, 8200), 223 (sh, 9900), 210 (12 600). IR (CH₂Cl₂): 3040, 3000, 2940, 2840, 1720, 1360, 1115, 1100, 1075, 940. ¹H-NMR (360 MHz, C₆D₆): 5.44, 5.34, 5.12, 4.79 (4*s*, 4 H); 4.71 (br. *s*, ⁵*J*(H-C(1), H_β-C(6)) = 1.2, H-C(1)); 4.6 (*s*, CH-C(8)); 3.38, 3.35 (2*s*, (CH₃O)₂CH); 2.61 (*m*, ²*J* = -18.0⁶), ³*J*(H_β(ax)-C(5), H_β-C(6)) = 5.8⁶), ³*J*(H_α(eq)-C(5), H_β-C(6)) = 3.0⁶), ⁵*J*(H_β(ax)-C(3), H_β-C(6)) = 2.8⁶), ³*J*(H_α(eq)-C(3), H_β-C(6)) = 1.0⁶), ⁵*J*(H-C(1), H_β-C(6)) = 1.2, H_β(eq)-C(6)); 2.29 (*m*, ²*J* = -17.8⁶), ³*J*(H_β(ax)-C(3), H_α(ax)-C(4)) = 10.5 (11.4)⁵), ⁵*J*(H_β-C(3), H_β(eq)-C(6)) = 2.8⁶), ⁵*J*(H_β-C(3), H_α(ax)-C(6)) = 4.2 (3.8)⁵), H_β(ax)-C(3)); 2.15 (*s*, COCH₃); 2.00 (*m*, ²*J* = -18.0⁶), ³*J*(H_β(ax)-C(5), H_α(ax)-C(6)) = 11.1 (11.0)⁵), ³*J*(H_α(eq)-C(5), H_α(ax)-C(6)) = 5.0⁶), ⁵*J*(H_β(ax)-C(3), H_α-C(6)) = 4.2 (3.8)⁵), ⁵*J*(H_α(eq)-C(3), H_α-C(6)) = 2.1⁶), H_α(ax)-C(6)); 1.82 (*m*, ²*J* = -17.8 (-18.4)⁵), ³*J*(H_α(eq)-C(3), H_α(ax)-C(4)) = 5.5⁶), ⁴*J*(H_α(eq)-C(3), H_α(eq)-C(5)) = 1.5⁶), ⁵*J*(H_α-C(3), H_β(eq)-C(6)) = 1.0⁶), ⁵*J*(H_α-C(3), H_α(ax)-C(6)) = 2.1⁶), H_α(eq)-C(3)); 1.80 (*m*, ³*J*(H_α(ax)-C(4),

$H_{\alpha}(\text{eq})-C(5) = 3.3^6$, ${}^3J(H_{\alpha}C(4), H_{\beta}(\text{ax})-C(5)) = 11.4 (10.8)^5$, ${}^3J(H_{\beta}(\text{ax})-C(3), H_{\alpha}C(4)) = 10.5 (11.4)^5$, ${}^3J(H_{\alpha}(\text{eq})-C(3), H_{\alpha}(\text{ax})-C(4)) = 5.5^6$, $H_{\alpha}(\text{ax})-C(4)$; 1.64 (*m*, ${}^2J = -13.1 (-13.0)^5$, ${}^3J(H_{\alpha}(\text{eq})-C(5), H_{\beta}(\text{eq})-C(6)) = 3.0^6$), ${}^3J(H_{\alpha}C(5), H_{\alpha}(\text{ax})-C(6)) = 5.0^6$, ${}^3J(H_{\alpha}(\text{ax})-C(4), H_{\alpha}(\text{eq})-C(5)) = 3.3^6$, ${}^4J(H_{\alpha}(\text{eq})-C(3), H_{\alpha}C(5)) = 1.5^6$, $H_{\alpha}(\text{eq})-C(5)$; 1.43 (*m*, ${}^2J = -13.1 (-13.0)^5$, ${}^3J(H_{\beta}(\text{ax})-C(5), H_{\beta}(\text{eq})-C(6)) = 5.8^6$), ${}^3J(H_{\beta}-C(5), H_{\alpha}(\text{ax})-C(6)) = 11.1 (11.0)^5$, ${}^3J(H_{\alpha}(\text{ax})-C(4), H_{\beta}-C(5)) = 11.4 (10.8)^5$, $H_{\beta}(\text{ax})-C(5)$. ${}^{13}\text{C-NMR}$ (90 MHz, CDCl_3): 210.4 (*m*, CO); 145.3, 146.2 (2*m*, C(9), C(10)); 141.7, 140.8 (2*m*, C(2), C(7)); 103.5 (*dq*, ${}^1J(\text{C,H}) = 160$, ${}^3J(\text{C,H}) = 5$, $\text{CH}-\text{C}(8)$); 101.5, 100.0 (2*t*, ${}^1J(\text{C,H}) = 160$, $\text{CH}_2=\text{C}(9)$, $\text{CH}_2=\text{C}(10)$); 91.8 (*m*, C(8)); 83.6 (*dm*, ${}^1J(\text{C,H}) = 166$, C(1)); 56.3 (*qm*, ${}^1J(\text{C,H}) = 143$, ${}^3J(\text{C,H}) = 5$, $(\text{CH}_3\text{O})_2\text{CH}$); 48.0 (*d*, ${}^1J(\text{C,H}) = 129$, C(4)); 24.0 (*q*, ${}^1J(\text{C,H}) = 127$, COCH_3); 24.8, 23.2, 22.2 (3*tm*, C(3), C(5), C(6)). MS (70 eV): 215 (18), 207 (27), 155 (10), 128 (10), 75 (100), 47 (14). Anal. calc. for $\text{C}_{17}\text{H}_{22}\text{O}_4$ (290.362): C 70.32, H 7.64; found: C 70.44, H 7.75.

Mixture of Methyl (1RS,8SR,9RS or 9SR,12RS)-9-Methoxy-13-methylidene-10,14-dioxatetracyclo[6.5.1.0^{2,7}.0^{8,12}]tetradeca-2,4,6-triene-4-carboxylate (62) and -5-carboxylate (63). A mixture of **21** (250 mg, 1.21 mmol) and methyl propynoate (6 ml) was heated to 60° for 10 h in a Pyrex tube sealed *in vacuo*. After elimination of the excess of the dienophile by distillation *in vacuo*, the residue was purified by column chromatography (SiO_2 , $\text{AcOEt}/\text{hexane}$ 1:4), yielding 264 mg (75%) of a 4:6 mixture **60/61**. On treating with 1.1 equiv. of DDQ (see prep. of **40**; 60°, C_6H_6 , 4 h) and bulb-to-bulb distillation, 188 mg of a 2:3 mixture **62/63** was obtained as a colourless oil. IR (CHCl_3): 3030, 3010, 2960, 2810, 1720, 1435, 1290, 1260, 1240, 1060, 1050, 1100, 1045, 1015, 935, 905. ${}^1\text{H-NMR}$ (360 MHz, C_6D_6) of **62**: 8.21 (*dd*, $J = 8, 1.5$, $\text{H}-\text{C}(5)$); 8.11 (*m*, $\text{H}-\text{C}(3)$); 7.66 (*d*, $J = 8$, $\text{H}-\text{C}(6)$); 5.47 (*s*, $\text{H}-\text{C}(9)$); 5.29 (*br. s*, $\text{H}-\text{C}(1)$); 5.01 (*d*, 1 H); 4.64 (*m*, 1 H); 4.29 (*dd*, $J = 9.4, 8.1$, 1 H) and 4.00 (*t*, $J = 8.1$, $\text{CH}_2(11)$); 3.63 (*s*, COOMe); 3.37 (CH_3O); 1.93–1.88 (*m*, $\text{H}-\text{C}(12)$). ${}^1\text{H-NMR}$ (360 MHz, C_6D_6) of **63**: 8.68 (*m*, $J = 1.5$, $\text{H}-\text{C}(6)$); 8.15 (*dd*, $J = 7.9, 1.5$, $\text{H}-\text{C}(4)$); 7.03 (*d*, $J = 7.9$, $\text{H}-\text{C}(3)$); 5.49 (*s*, $\text{H}-\text{C}(9)$); 5.28 (*br. s*, $\text{H}-\text{C}(1)$); 5.03 (*d*, $J = 2, 1$ H), 4.66 (*dd*, $J = 2, 1$, $\text{CH}_2=\text{C}(13)$); 4.29 (*dd*, $J = 9.4, 8.0$, $\text{H}-\text{C}(11)$); 4.00 (*t*, $J = 8$, $\text{H}-\text{C}(11)$); 3.60, 3.33 (2*s*, 6 H); 1.93–1.88 (*m*, $\text{H}-\text{C}(12)$). ${}^{13}\text{C-NMR}$ (90 MHz, CDCl_3): 166.9; 166.8 (CO); 150.0; 148.4, 148.3; 146.4; 145.6; 141.9; 129.35; 121.5; 120.8; 120.4; 119.7; 108.4; 108.1; 103.3; 103.2; 97.5; 97.4; 84.05; 84.0; 71.3; 71.1; 55.2; 52.0; 48.95; 48.9. CI-MS (CH_4): 289 (54, $M^+ + 1$); 271 (19), 257 (18), 229 (13), 29 (100). Anal. calc. for $\text{C}_{16}\text{H}_{16}\text{O}_5$ (288.303): C 66.66, H 5.59; found: C 66.58, H 5.69.

Mixture of (1RS,4SR,8SR,9RS or SR,12RS)- and (1RS,5RS,8SR,9RS or SR,12RS)-9-Methoxy-13-methylidene-10,14-dioxatetracyclo[6.5.1.0^{2,7}.0^{8,12}]tetradec-2(7)-en-4-exo- and -5-exo-yl Methyl Ketones (64 and 66). A mixture of **21** (140 mg, 0.68 mmol), MVK (950 mg, 13.5 mmol), and anhyd. benzene (6 ml) was heated to 100° for 14 h in a Pyrex tube sealed *in vacuo*. After solvent elimination (15 Torr, Vigreux column) and drying at 10^{-2} Torr (5 h), 160 mg (85%) of a colourless oil was obtained composed of 6.2:1:12.4:1.7 of adducts **64/65/66/67** (by 360-MHz- ${}^1\text{H-NMR}$). IR (CHCl_3): 3040, 3000, 2960, 2940, 2900, 2840, 1710, 1680, 1430, 1410, 1230, 1100, 1030, 1015, 950, 890. ${}^1\text{H-NMR}$ (360 MHz, CDCl_3): 5.07, 5.02, 4.85 (3*s*); 4.80, 4.78 (2 *br. s*, $\text{H}-\text{C}(1)$); 4.21, 3.65 (2*t*, $\text{CH}_2(11)$); 3.40 (*s*, 3 H); 2.74 (*m*, $\text{H}-\text{C}(12)$); 2.56–0.69 (*m*). ${}^{13}\text{C-NMR}$ (90 MHz, CDCl_3): 200.5; 200.4; 149.7, 149.3 (C(13)); 142.6; 140.5; 139.4, 137.7 (C(2), C(7)); 105.9; 105.8; 102.4, 102.2 (C(9)); 99.1, 98.9 (C(8)); 85.6, 85.3 (C(1)); 70.4; 55.0; 54.95; 48.0; 47.35; 47.3; 47.2; 28.0; 27.95; 23.7; 23.2; 22.7; 21.9. The NMR characteristics of the minor adducts **65** and **67** (ca. 15%) are not given here. MS (70 eV): 276 (2, M^+), 129 (100). Anal. calc. for $\text{C}_{16}\text{H}_{20}\text{O}_4$ (276.335): C 69.55, H 7.30; found: C 69.42, H 7.41.

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