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]heptanes[1])

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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 anthracyclinones 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 = CH_2OH
5 Z = CH_2OMe

6 Z = $CH(OMe)_2$
7 Z = CHO
8 Z = CH_2OH
9 Z = COOH
10 Z = COOMe

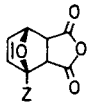
starting material: furfural. We shall show that the acetal group in **2** and **6** can control the regioselectivity of the *Lewis*-acid-catalyzed *Diels-Alder* additions with methyl vinyl ketone (MVK) and butynone. Strikingly, we have found that a small change in the nature of the solvent can reverse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

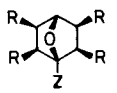
[2]) Part of the Ph. D. thesis of *J.L. Métral*, Ecole Polytechnique Fédérale de Lausanne, Dec. 1984. Present address: *Ciba-Geigy*, Monthey.

Et_2O 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 $CuCl_2$, 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 ^{1}H-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 $LiAlH_4$ 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).

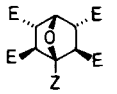


11 Z = $CH(OMe)_2$

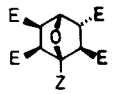
23 Z = CH_2OMe



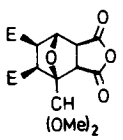
12 Z = $CH(OMe)_2$ R = E = COOMe
13 Z = $CH(OMe)_2$ R = CH_2OH
14 Z = $CH(OMe)_2$ R = CH_2OMs
24 Z = CH_2OMe R = E
25 Z = CH_2OMe R = CH_2OH
26 Z = CH_2OMe R = CH_2Cl



17 Z = $CH(OMe)_2$



18 Z = $CH(OMe)_2$



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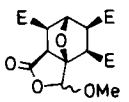

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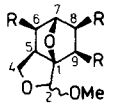
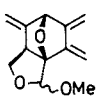


19 R = CH_2OH
20 R = CH_2OMs
22 R = CH_2OAc

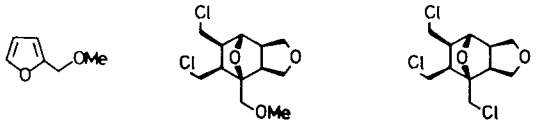


21

E = COOMe

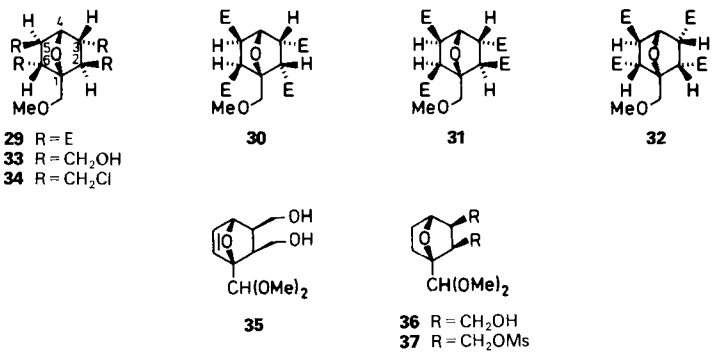
When using wet MeOH for the carbonylation of **11**, the anhydride **15** and the lactone **16** were observed as minor compounds. Lactone **16** was formed as major product on treating **12** in MeOH with charcoal. Base-induced (K_2CO_3/abs. MeOH, 20°) isomerization of **12** gave a 1:1 mixture of the tetraesters **17** and **18**. The amount of H_2O used to destroy the alcoholates and the excess of $LiAlH_4$ after the reduction **12**→**13** play a critical role on the yield of this reaction. When an excess of H_2O was used, the triol **19** was formed together with **13**. When **13** was treated with 0.1N H_2SO_4 (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 trimesylate **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 Ac_2O/pyridine.

Acidic solvolysis (H_2O/dioxane/HCl, 90°) of the tetraene acetal **2** afforded the unstable tetraenal **3** which was reduced by $NaBH_4$ in i-PrOH into the tetraenol **4** (45%). The corresponding methyl ether **5** was prepared in the following way.



23 **27** **28**

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}H-NMR spectrum and with the help of double-irradiation experiments. The bridgehead proton H–C(4) resonated as a *d* (5.1 ppm), this demonstrating the *exo* configuration of H–C(3) ($^3J(H_{exo}–C(3), H–C(4)) = 5$ Hz) and the *endo* configuration of H–C(5) ($^3J(H–C(4), H_{endo}–C(5)) \approx 0$ Hz [8] [9]). The isomeric structures **30–32** were ruled out because $^3J(H–C(2), H–C(3)) = {}^3J(H–C(5), H–C(6)) = 5.5$ 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 ($SOCl_2$/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.



29 R = E
33 R = CH_2OH
34 R = CH_2Cl

30 **31** **32**

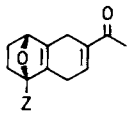
35

36 R = CH_2OH
37 R = CH_2OMs

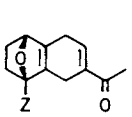
E = COOMe

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 (MsCl/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 alcaline (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.

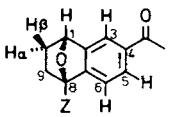
***Diels-Alder* Stereo- and Regioselectivities.** – Under thermal conditions (80–100°, 5–16 h, without solvent or with benzene), the additions of tetraenes **2** and **5**, and of the



38 *'para'*



39 *'meta'*



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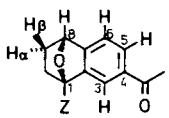


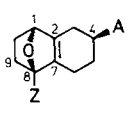
41

Z = $CH(OMe)_2$

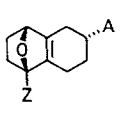
dienes **6–8** and **10** to methyl propynoate or to butynone were not regioselective. The product ratio of the *'para' vs. 'meta'* adducts (see **38** and **39**) varied between 55:45 and 45:55. Attempts to improve the regioselectivity of the cycloaddition of methyl propynoate to the dienes by using *Lewis*-acid catalysts [11] such as $AlCl_3$, $ZnCl_2$, $BF_3 \cdot Et_2O$, $B(OCH)_3$, or $EtAlCl_2$ in CH_2Cl_2 were unsuccessful[3]).

However, the catalyzed *Diels-Alder* additions of butynone to **6** were more interesting. When butynone (0.4M) was precomplexed with $BF_3 \cdot Et_2O$ (3 mol-equiv.) in CH_2Cl_2 (−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 $EtAlCl_2$ (3 mol-equiv.) in CH_2Cl_2/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 CH_2Cl_2/hexane 1:1 to CH_2Cl_2/hexane 1.6:1, the regioselectivity varied from 55:45 to 47:53 (±5%; by 360-MHz-^{1}H-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).

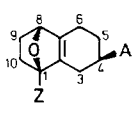
The adducts **38** and **39** were separated by medium-pressure column chromatography on silica gel. These compounds were unstable in solution and were partially aromatized into **40** and **41**, respectively. The oxidations **38**→**40** and **39**→**41** were nearly quantitative in the presence of 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 ^{1}H-NMR (see below).



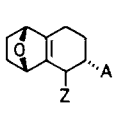
42 *'para-β'*



43 *'para-α'*



44 *'meta-β'*



45 *'meta-α'*

A = $COCH_3$ Z = $CH(OMe)_2$

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-^{1}H-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 $EtAlCl_2$ or $BF_3 \cdot Et_2O$ in CH_2Cl_2, 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 $BF_3 \cdot Et_2O$ 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 CH_2Cl_2/CH_3NO_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 $BF_3 \cdot Et_2O$ 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 (±)-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 $BF_3 \cdot Et_2O$- and $EtAlCl_2$-catalyzed cycloadditions of MVK to dienes **7**, **8**, and **10** led to partial or complete decomposition of the cycloaddents and/or of the adducts.

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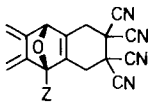
[4]) For solvent effects on the rates and the stereoselectivity of *Lewis*-acid-catalyzed *Diels-Alder* additions, see [19].



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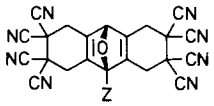

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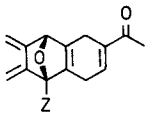
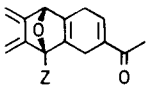
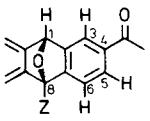


48 *'para'*



49 *'meta'*



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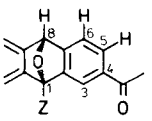
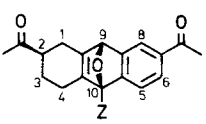


51

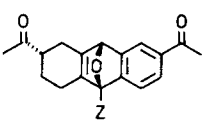
Z = $CH(OMe)_2$

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 ethylenetetracarbonitrile (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**.

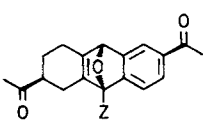
The reaction of tetraene acetal **2** with an excess of butynone (benzene, 80°, 2 d) gave a 1:1 mixture of monoadducts **48**/**49**. When butynone was precomplexed with 1 equiv. of $BF_3 \cdot Et_2O$ (1.7M) in CH_2Cl_2, the cycloaddition (0.12M of **2**, −75°, 65 h) gave a 7:3 mixture **48**/**49** in 80% yield. As for the $BF_3 \cdot Et_2O$-catalyzed *Diels-Alder* additions of butynone and MVK to **6** (and of MVK to **2** and **50**, see below), the reaction was *'para'* regioselective.



52



53



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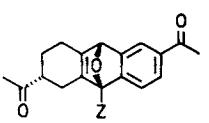
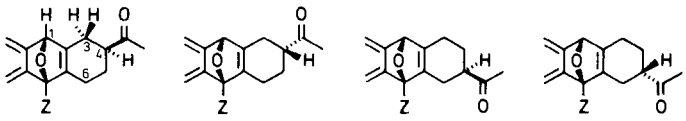


55

Z = $CH(OMe)_2$

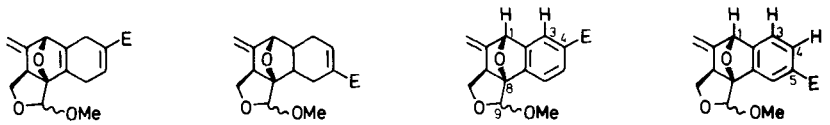
The two monoadducts **48** and **49** were readily separated by column chromatography on silica gel. Treatment of **48** and **49** with 1.1 mol-equiv. of DDQ afforded the aromatic ketones **50** (90%) and **51** (85%), respectively. Their structure was established by ^{1}H-NMR spectroscopy (see below). 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 $BF_3 \cdot Et_2O$ (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.



56 *'para-β'* **57** *'para-α'* **58** *'meta-β'* **59** *'meta-α'*

Z = $CH(OMe)_2$

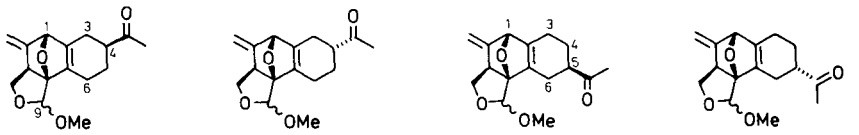
The addition of MVK to tetraene acetal **2** under thermal conditions (without or with C_6H_6, 80°, 10–50 h) gave a mixture of the monoadducts **56–59** for which the *'para' vs. 'meta'* regioselectivity was not better than 6:4 (**56** + **57**/**58** + **59**) and the *β vs. α* stereoselectivity approached 7:3 (**56** + **58**/**57** + **59**) as determined by the 360-MHz-^{1}H-NMR spectrum of the crude reaction mixture. The reaction of MVK complexed to 1 mol-equiv. of $BF_3 \cdot Et_2O$ (2M) in CH_2Cl_2 (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 $EtAlCl_2$ (4.15M) in CH_2Cl_2/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 (K_2CO_3, anh. MeOH, 20°, 12 h). Both catalysts $BF_3 \cdot Et_2O$ and $EtAlCl_2$ 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 $EtAlCl_2$-catalyzed additions of **2** to MVK has not been studied.



60 **61** **62** (minor) **63** (major)

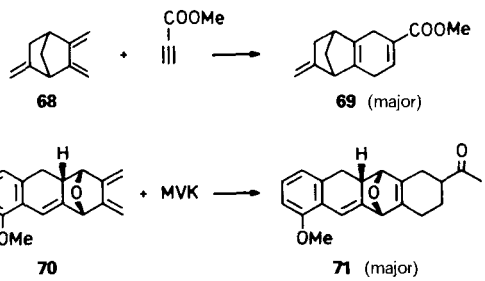
E = $COOCH_3$

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 ^{1}H- and ^{13}C-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 ^{1}H-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



64 **65** **66** (major) **67**

bond in these trienes [4]. Thus, it appears that the methylidene 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 $BF_3 \cdot Et_2O$ and $EtAlCl_2$. Thus, the catalyzed cycloadditions of these polyenes could not be studied.



68 **69** (major)

70 **71** (major)

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}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 NOE experiments for derivatives **62** and **63**. Irradiation of the *s* at 5.29 ppm (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 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 (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 H–C(3). Irradiation of the latter *d* gave a NOE at 5.29 ppm. Irradiation of the signals at 8.68 ppm (^4J(H–C(4), H–C(6)) = 1.5 Hz, H–C(6)) and at 8.15 ppm

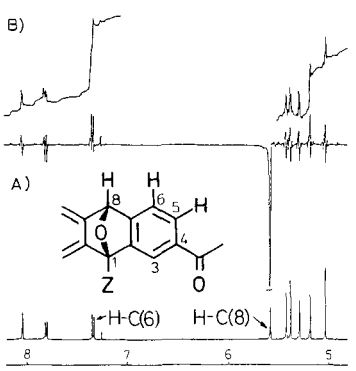


Fig. 1. A) *Portion of the 360-MHz ^{1}H-NMR* ($CDCl_3$) *spectrum of* **51**. B) *Difference of the irradiated spectrum of* **51** *at 5.6 ppm (H–C(8)) and the non-irradiated spectrum showing the NOE for the* d *at 7.36 ppm (H–C(6)).*

(^3J(H–C(3),H–C(4)) = 7.9 Hz, ^4J(H–C(4),H–C(6)) = 1.5 Hz, H–C(4)) did not give a NOE at 5.29 ppm (H–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*.

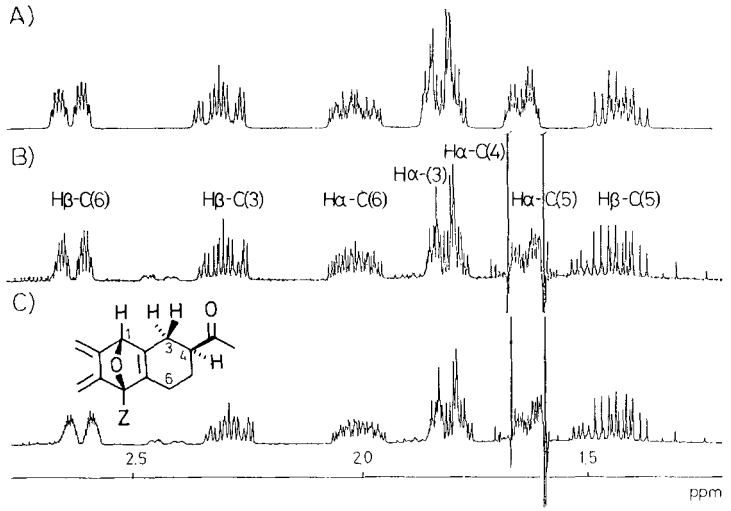


Fig. 2. *Portion of the 360-MHz ^{1}H-NMR (C_6D_6) spectrum of* **56**. A) Simulated spectrum (PANIC 81, 7 spins, ^5J(H–C(1),H_β–C(6)) = ^5J(H–C(1),H_α–C(6)) = 0. B) Experimental spectrum with irradiation of the signal at 4.71 ppm (H–C(1)). C) Experimental spectrum without double irradiation (the FID signals were multiplied by a *Gauss*ian 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%).

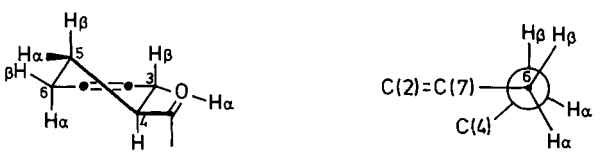


Fig. 3. *Favoured conformation of* **56**

Simulation of the ^{1}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 H–C(4) and H_α–C(6) and H_β–C(6). The values of the vicinal coupling constants between H_β–C(3), H_α–C(3), and H–C(4) were consistent only with the conformation represented in *Fig. 3*. The absence of a *W*-type ^4J coupling between H–C(4) and H_β–C(6) confirmed the axial α-position of H–C(4). The values obtained for the vicinal coupling constants between CH_2(5) and 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 H_β–C(6) because it coupled with the bridgehead proton H–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 H–C(1) and H_α–C(6), on one hand, and the ^4J between H–C(1) and H_α–C(3), H_β–C(3) on the other hand, were smaller than 0.5 Hz. The distinction between H_β and H_α–C(3) was based on their chemical shift difference ($\delta(H_\beta) > \delta(H_\alpha)$) and on the homoannular homoallylic coupling constants

between the protons at C(3) and C(6) (*e.g.* $^5J(H_\alpha\text{–}C(3), H_\beta\text{–}C(6)) = 1.0$ Hz, whereas $^5J(H_\beta\text{–}C(3), H_\beta\text{–}C(6)) = 2.8$ 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 H_α–C(3) and H_α–C(5), both protons being equatorial.

Similar ^{1}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}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}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.

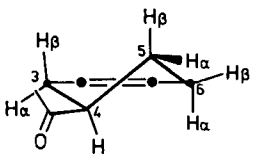


Fig. 4. *Favoured conformation of* **44**

Out of the 16 ^{1}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 H_β–C(3) and H_β–C(10) or H_β–C(9). The vicinal coupling constant of 10 Hz measured between H_β–C(3) and H–C(4) was consistent only with an axial 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}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}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).

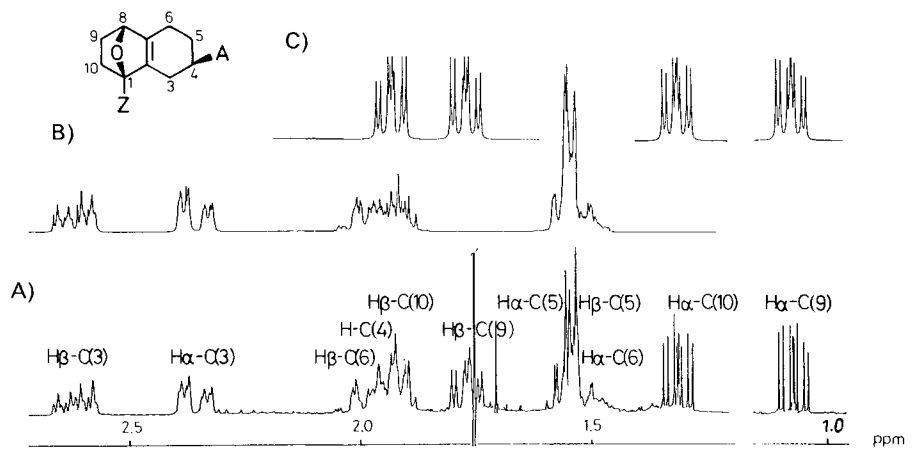


Fig. 5. *Partial 360-MHz ^{1}H-NMR (C_6D_6) spectrum of* **44**. A) Experimental spectrum (*LB* = −0.7, *GB* = 0.5) with irradiation of the signal at 4.53 ppm (H–C(8)). B) Simulated (PANIC 81) spectrum of the cyclohexenyl moiety (7 spins). C) Simulated spectrum of the ethano bridge $CH_2(9)$–$CH_2(10)$ (4 spins).

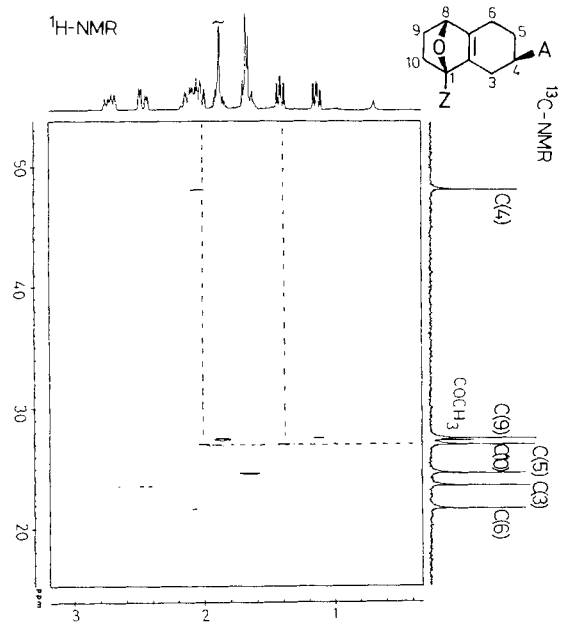


Fig. 6. *2D-NMR spectrum of* **44** *correlating* δ_H vs. δ_C. Obtained with the pulse sequence [25]: 90°(^{1}H) – $t_1/2$ – 180°(^{13}C) – $t_1/2$ – τ_1 – 90° (^{1}H, ^{13}C) – τ_2 – acquire with proton-noise decoupling (magnetization transfer through ^1J(C,H) ≈ 130 Hz). $\tau_1 = (2J)^{-1} = 3.85$ ms; $\tau_2 = (4J)^{-1} = 1.92$ ms. The number of sample data points was 128 × 4K. Resolution enhancement by phase-shifted sine-bell functions; zero-filling to 256 data points in t_1; spectral width ± 520 Hz in t_1, 12.5 kHz in f_2; 128 scans; recycle delay 2 sec; $\Delta t_1/2 = 0.48$ ms; acquisition, *ca.* 7 h; 256 × 4K *Fourier* transformation, *ca.* 1 h.

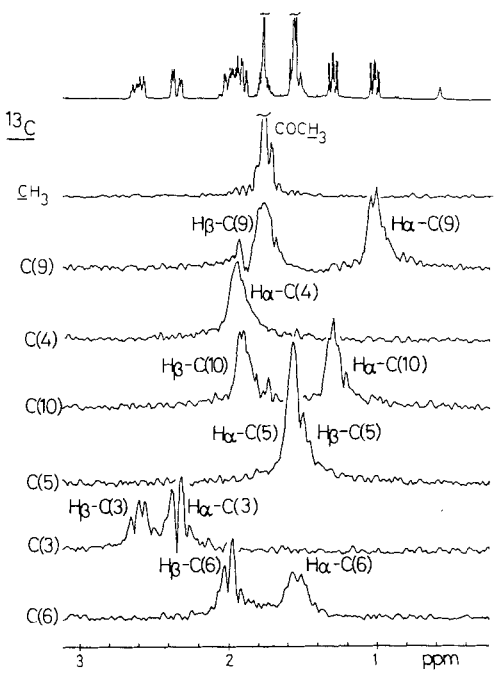


Fig. 7. *Cross-sections through the* ^{13}*C-NMR chemical shifts in the 2D shift-correlated NMR spectrum of* Fig. 6. Digital resolution 4.1 Hz/point. The proton assignments are indicated. Top trace: 1D ^{1}H-NMR spectrum.

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 ^{1}H-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 anthracycline analogs.

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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 × 21.2 mm or (inversed phase) *Zorbax ODS*, 5–6 μm, 25 cm × 21.1 mm. Medium-pressure chromatography: *Lobar-Merk* system, silica gel column (*Lichroprep Si60*, 40.63 μm, 2.5 cm × 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. ^{1}H-NMR ($CDCl_3$): 5.54 (br. *s*, H–C(4)); 4.71 (*s*, $(CH_3O)_2CH$); 3.60, 3.59 (2*s*, 4 $COOCH_3$); 3.31 (*s*, $(CH_3O)_2CH$); 3.18, 2.89 (2*d*, ^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, *C*H–C(1));

92.2 (*d*, ^3J(C(1),H–C(4)) = 10, C(1)); 78.3 (*d*, ^1J(C,H) = 164, C(4)); 56.7 (*qd*, ^1J(C,H) = 143, ^3J(C,H) = 5, $(CH_3O)_2CH$); 52.8 (*dm*, ^1J(C,H) = 142, C(2), C(6) or C(3), C(5)); 52.0, 51.4 (2*q*, ^1J(C,H) = 147, 4 $COOCH_3$); 51.0 (*dm*, ^1J(C,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 $C_{17}H_{24}O_{11}$ (404.374): C 50.50, H 5.98; found: C 50.57, H 6.02.

*(1*RS, *2*SR, *3*RS, *4*SR, *5*SR, *6*RS*)-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}H-NMR (360 MHz, $CDCl_3$): 5.77 (*s*, CH–C(1)); 5.16 (br. *s*, H–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}C-NMR ($CDCl_3$): 171.7, 169.6, 169.4, 169.3 (4*m*, CO); 102.5 (*dm*, ^1J(C,H) = 182, ^3J(C,H) = 5, *C*–C(1)); 91.2 (*m*, ^3J(C,H) = 10, C(1)); 81.4 (*d*, ^1J(C,H) = 166, C(4)); 57.4 (*qd*, ^1J(C,H) = 144, ^3J(C,H) = 5, $(CH_3O)_2CH$); 52.3, 52.0, 51.8, 51.6, 50.1, 49.9 (*d*, ^1J(C,H) = 140); 47.9 (*d*, ^1J(C,H) = 142). CI-MS (i-C_4H_{10}): 359 (100, $M^+ + 1$), 328 (58). Anal. calc. for $C_{15}H_{18}O_{10}$ (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 anh. THF (345 ml) at 0° and under N_2. A soln. of **12** (23 g, 0.057 mol) in anh. THF (350 ml) was added dropwise under vigourous 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}H-NMR (CD_3OD): 4.45 (br. *s*, H–C(4)); 4.20 (*s*, CH–C(1)); 4.0–3.44 (*m*, 8 H, CH_2O); 3.44 (*s*, $(CH_3O)_2CH$); 2.36–2.09 (*m*, 4 H). ^{13}C-NMR (CD_3OD): 105.6 (*dm*, ^1J(C,H) = 164, *C*–C(1)); 89.3 (*m*, C(1)); 80.5 (*dm*, ^1J(C,H) = 161, C(4)); 60.0, 58.1 (*t*, ^1J(C,H) = 141, 4 CH_2O); 56.0 (*q*, ^1J(C,H) = 143, $(CH_3O)_2CH$); 51.0, 47.1 (*dm*, ^1J(C,H) = 132, C(2), C(3), C(5), C(6)). MS (70 eV): 201 (4, $M^+ - CH_2OH$), 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 $C_{13}H_{24}O_7$ (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 anh. pyridine (7.9 g) maintained at 0°. After stirring at –10° for 96 h, the brown mixture was poured slowly into a vigourously 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}H-NMR (CD_3CN): 4.58–3.8 (2*s* + *m*, 10 H); 3.43 (*s*, $(CH_2O)_2CH$); 3.0 (*s*, 4 CH_3SO_3); 2.71–2.3 (*m*, H–C(2), H–C(3), H–C(5), H–C(6)). ^{13}C-NMR (CD_3CN): 105.7 (*dm*, ^1J(C,H) = 160, ^3J(C,H) = 5, *C*–C(1)); 91.1 (*d*, ^3J(C,H) = 10, C(1)); 80.7 (*dm*, ^1J(C,H) = 159, C(4)); 69.5, 68.2 (*t*, ^1J(C,H) = 152); 58.2 (*qm*, ^1J(C,H) = 143, $(CH_3O)_2CH$); 48.8, 45.6 (2*d*, ^1J(C,H) = 139, C(2), C(3), C(5), C(6)); 37.8, 37.6 (2*q*, ^1J(C,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 translucid 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 (18100), 222 (17800), 216 (sh, 14000). UV (95% EtOH): 263 (sh, 1900), 249 (sh, 6400), 239 (sh, 7900), 228 (15500), 222 (15300), 216 (sh, 13400). IR (KBr): 3100, 3020, 2970, 2940, 2850, 1445, 1420, 1365, 1100, 1080, 1000, 975, 920, 895. ^{1}H-NMR ($CDCl_3$): 5.40, 5.35 (2*s*, 4 H); 5.30, 5.10 (2*s*, 4 H); 5.00 (br. *s*, H–C(4)); 4.85 (*s*, CH–C(1)); 3.60 (*s*, $(CH_3O)_2CH$). ^{13}C-NMR ($CDCl_3$): 146.7 (*m*, C(3), C(5)); 144.9 (*m*, C(2), C(6)); 104.3 (*dq*, ^1J(C,H) = 158, ^3J(C,H) = 5, *C*H–C(1)); 103.3 (*t*, ^1J(C,H) = 161); 101.6 (*t*, ^1J(C,H) = 161); 90,1 (*m*, C(1)), 83.5 (*dm*, ^1J(C,H) = 164, C(4)); 56.5 (*qd*, ^1J(C,H) = 143, ^3J(C,H) = 5, $(CH_3O)_2CH$). CI-MS (CH_4): 221 (4, $M^+ + 1$), 184 (18), 57 (100), 43 (43). Anal. calc. for $C_{13}H_{16}O_3$ (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 H_2SO_4 (50 ml) was stirred at 20° for 7 d. After neutralisation with $NaHCO_3$, 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 H_2O for the hydrolysis of the **12**/$LiAlH_4$ reduction mixture. IR (KBr): 3310, 2975, 2945, 1470, 1370, 1200, 1110, 1100, 1050, 1020, 950, 910, 860. ^{1}H-NMR (CD_3OD): 4.96 (*s*, H–C(2)); 4.16 (*s*, H–C(7)); 4.10–3.38 (*m*, 8 H); 3.36 (*s*, CH_3O); 2.73–1.95 (*m*, H–C(5), H–C(6), H–C(8), H–C(9)). ^{13}C-NMR (CD_3OD): 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 (*tm*, ^1J(C,H) = 141); 58.5 (*tm*, ^1J(C,H) = 142); 53.2 (*qd*, ^1J(C,H) = 142, ^3J(C,H) = 5, CH_3O); 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**). Ac_2O (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 CH_2Cl_2 (5 ml) and the soln. washed with aq. 0.1N HCl (10 ml), then with aq. sat. $NaHCO_3$ soln., and finally with H_2O (10 ml). After drying ($MgSO_4$), the solvent was evaporated and the residue recrystallized from Et_2O, 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. ^{1}H-NMR ($CDCl_3$): 4.96 (*s*, H–C(2) or H–C(7)); 4.49–3.56 (*m*, 9 H); 3.38 (*s*, CH_3O); 2.90–2.15 (*m*, 4 H), 2.00 (*s*, 3 CH_3CO). ^{13}C-NMR ($CDCl_3$): 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*, CH_3O); 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, CH_3CO). MS (70 eV): 386 (1, M^+), 146 (22), 43 (100). Anal. calc. for $C_{18}H_{26}O_9$ (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. ^{1}H-NMR (CD_3CN): 5.03 (*s*, H–C(2)); 4.56–3.37 (*m*, 9 H); 3.35 (*s*, CH_3O); 3.05 (*s*, 9 H); 2.90–2.40 (*m*, 4 H). ^{13}C-NMR (90 MHz, CD_3CN): 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 (3*td*, ^1J(C,H) = 152); 54.8 (*qd*, ^1J(C,H) = 143, ^3J(C,H) = 5, CH_3O); 48.2, 47.0, 46.3, 41.6 (4*d*, ^1J(C,H) = 138, C(5), C(6), C(8), C(9)); 37.5, 37.4 (2*q*, ^1J(C,H) = 139, 3 CH_3SO_3). MS (70 eV): 494 (1, M^+), 303 (20), 289 (28), 175 (29), 57 (100). Anal. calc. for $C_{15}H_{26}O_{12}S_3$ (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 (CH_2Cl_2): 3080, 3000, 2970, 2940, 2910, 2840, 1680, 1605, 1400, 1190, 1140, 1100, 1045, 1005, 995, 975, 945, 915, 870, 825. ^{1}H-NMR ($CDCl_3$): 5.57, 5.35 (2*s*, 2 H); 5.31 (*d*, ^2J = 0.5, 1 H); 5.17 (*s*, H–C(2)); 5.15, 5.04 (2*s*, 2 H); 4.98 (br. *s*, H–C(7)); 4.87 (*s*, 1 H); 4.28, 3.70 (2*dd*, ^2J = 8.2, ^3J = 9.6, CH_2(4)); 3.48 (*s*, CH_3O); 3.10 (*m*, H–C(5)). ^{13}C-NMR (90 MHz, $CDCl_3$): 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 (2*t*, ^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, CH_3O); 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 $C_{12}H_{14}O_3$ (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. K_2CO_3 (0.5 g), and abs. MeOH (300 ml) was stirred at 20° under N_2 for 45 h. The precipitate was filtered off and the soln. evaporated. The residue was dissolved in $CHCl_3$ and the soln. washed with H_2O until neutrality (pH 7). After drying ($MgSO_4$), the solvent was evaporated and the residue crystallized from MeOH/Et_2O 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, $CHCl_3$/AcOEt 7:3). The 1st fraction contained **17**, m.p. 112–114° (recrystallized from MeOH/Et_2O). IR (KBr): 2885, 2845, 1750, 1740, 1440, 1350, 1265, 1215, 1185, 1170, 1115, 975, 1100. ^{1}H-NMR ($CDCl_3$): 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 (2*s*, 4 $COOCH_3$); 3.35 (*s*, $(CH_3O)_2CH$); 3.24 (*d*, ^3J = 6.7, H–C(2), H–C(6)). ^{13}C-NMR ($CDCl_3$): 171.6, 169.6 (2*m*, 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, $(CH_3O)_2CH$); 52.0, 51.5 (2*q*, ^1J(C,H) = 147, $COOCH_3$); 49.9, 48.2 (2*d*, ^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 $C_{17}H_{24}O_{11}$ (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. ^{1}H-NMR (360 MHz, $CDCl_3$): 5.35 (*d*, ^3J = 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 (4*s*, 4 CH_3OOC); 3.39, 3.36 (2*s*, 2 CH_3O 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)). ^{13}C-NMR ($CDCl_3$): 171.7, 170.6, 170.0 (*m*, 4 CO); 103.7 (*dm*, ^1J(C,H) = 160, *C*–C(1)); 94.2 (*d*, ^3J(C,H) = 8, C(1)); 78.2 (*dm*, ^1J(C,H) = 160, ^3J(C,H) = 4, C(4)); 57.4, 56.0, 54.4, 52.1, 51.9, 51.5, 51.2, 50.5, 48.1 (4 *C*H_3OOC, C(2), C(3), C(5), C(6), CH_3O acetal). MS (70 eV): 404 (3, M^+), 374 (17), 373 (100), 327 (57), 267 (68). Anal. calc. for $C_{17}H_{24}O_{11}$ (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. $CuCl_2$ (102 g, 0.76 mol), methyl orthoformiate (30 g, 0.283 mol), 10% Pd/C (3 g, 2.8 mmol), and anh. MeOH (300 ml) was degassed with N_2 (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 ($CHCl_3$): 3040, 2960, 1750, 1440, 1340, 1200, 1120, 1030, 945. ^{1}H-NMR ($CDCl_3$): 5.54 (*s*, H–C(4)); 3.71 (*s*, OCH_2–C(1)); 3.65 (*s*, 4 $COOCH_3$); 3.29 (*d*, *J* = 10, H–C(2), H–C(6) or H–C(3), H–C(5)); 3.23 (*s*, CH_3OCH_2); 2.97 (*d*, *J* = 10, H–C(3), H–C(5) or H–C(2), H–C(6)). ^{13}C-NMR ($CDCl_3$): 170.1, 169.9 (br. *s*, 4 C); 88.6 (*d*, ^3J(C,H) = 10, C(1)); 78.06 (*d*, ^1J(C,H) = 166, C(4)); 69.5 (*tm*, ^1J(C,H) = 144, ^3J(C,H) = 5, *C*–C(1)); 59.3 (*qt*, ^1J(C,H) = 142, ^3J(C,H) = 5, *C*H_3OCH_2); 53.9 (*dm*, ^1J(C,H) = 146); 51.9, 51.7 (2*q*, ^1J(C,H) = 147, 4 CH_3OOC); 51.2 (*dm*, ^1J(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 $C_{16}H_{22}O_{10}$ (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 $LiAlH_4$ (1.82 g, 48 mmol) in anh. THF (50 ml) maintained at 0° under N_2. 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 H_2O 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. ^{1}H-NMR (D_2O): 4.28 (*s*, H–C(4)); 3.85–3.25 (*m*, 13 H); 2.32–2.0 (*m*, 4 H). ^{13}C-NMR (CD_3OD): 86.5 (*m*, C(1)); 80.4 (*dm*, ^1J(C,H) = 160, C(4)); 68.7 (*tm*, ^1J(C,H) = 144, *C*H_2–C(1)); 59.9, 57.9 (2*tm*, ^1J(C,H) = 139); 57.6 (*qm*, ^1J(C,H) = 143, CH_3O); 50.25, 48.2 (2*tm*, ^1J(C,H) = 137, C(2), C(7), C(5), C(6)). CI-MS (i-C_4H_{10}): 263 (4, $[M + H]^+$), 227 (10), 57 (100). Anal. calc. for $C_{12}H_{22}O_6$ (262.306): C 54.95, H 8.45; found: C 55.01, H 8.52.

*(1*RS,*2*SR,*6*RS,*7*SR,*8*RS,*9*SR*)-1,8-*exo,*9-*exo-*tris(chloromethyl)-4,10-dioxatricyclo[5.2.1.0^{2,6}]decane* (**28**). Freshly distilled $SOCl_2$ (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° und under N_2. The mixture was then stirred at 60° for 24 h. After cooling to 20°, $CHCl_3$ (50 ml) was added, then H_2O was added dropwise until the end of HCl/SO_2 evolution. The org. layer was separated and washed with H_2O until pH 7. After drying ($MgSO_4$), the solvent was evaporated. The residue contained at least 4 compounds. Chromatography on silica gel (120 g, CCl_4/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. ^{1}H-NMR ($CDCl_3$): 4.35 (*s*, H–C(7)); 3.98 (*s*, CH_2–C(1)); 3.80–3.20 (*m*, 10 H); 2.75–2.20 (*m*, 4 H). ^{13}C-NMR ($CDCl_3$): 98.5 (*m*, C(1)); 82.6 (*dm*, ^1J(C,H) = 162, C(7)); 67.3, 65.9 (2*t*, ^1J(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 $ClCH_2$). CI-MS (i-C_4H_{10}): 289 (35), 287 (97), 285 (100, $[M + H]^+$). Anal. calc. for $C_{11}H_{15}Cl_3O_2$ (285.6): C 46.26, H 5.29; found: C 46.13, H 5.42.

*(1*RS,*2*SR,*3*SR,*4*RS,*5*SR,*6*SR*)-Tetramethyl 1-Methoxymethyl-7-oxabicyclo[2.2.1]heptane-2-*exo,*3-*endo,*5-*exo,*6-*endo-*tetracarboxylate* (**29**). Anh. K_2CO_3 (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 $CHCl_3$ (200 ml). The soln. was washed with H_2O until pH 7. After drying ($MgSO_4$), the solvent was evaporated and the residue recrystallized from MeOH, yielding 20.3 g (89.6%), white crystals, m.p. 83–84°. IR ($CHCl_3$): 3040, 2970, 1740, 1440, 1375, 1335, 1290, 1230, 1075, 1015. ^{1}H-NMR (360 MHz, $CDCl_3$): 5.10 (*d*, *J* = 5, H–C(4)); 3.92 (*d*, ^2J = 11.5, 1 H, CH_2O); 3.80 (*dd*, ^3J = 5.5, 5, H–C(3)); 3.78 (*s*, $COOCH_3$); 3.76 (*d*, 11.5, 1 H, CH_2O); 3.75 (*s*, 2 $COOCH_3$); 3.73 (*s*, $COOCH_3$); 3.68 (*d*, *J* = 5.5, H–C(6)); 3.40 (*s*, *C*H_3OCH_2); 3.32 (*d*, *J* = 5.5, H–C(5)); 3.13 (*d*, *J* = 5.5, H–C(2)). ^{13}C-NMR ($CDCl_3$): 171.6, 170.9, 170.0, 169.9 (*m*); 91.0 (*m*, C(1)); 79.8 (*d*, ^1J(C,H) = 167, C(4)); 69.9 (*t*, ^1J(C,H) = 141, CH_2O); 59.3 (*qm*,

^1J(C,H) = 142, CH_3O); 52.1, 51.9 (*q*, ^1J(C,H) = 147, $COOCH_3$); 50.8 (*d*, ^1J(C,H) = 137, 2 C); 47.7 (*d*, ^1J(C,H) = 136); 46.9 (*d*, ^1J(C,H) = 134). MS (70 eV): 343 (28, $M^+ - OMe$), 325 (22), 283 (31), 223 (40), 197 (10), 140 (100). Anal. calc. for $C_{12}H_{22}O_6$ (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}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 anh. 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 vigourous 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}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}C-NMR ($CDCl_3$): 89.4 (*m*, C(1)); 80.8 (*dm*, ^1J(C,H) = 160, C(4)); 71.7 (*tm*, ^1J(C,H) = 142, CH_3OCH_2); 59.3 (*q*, ^1J(C,H) = 142, CH_3OCH_2); 52.4, 51.1 (2*dm*); 46.1, 45.5, 43.1 (*m*). MS (70 eV): 299 (100, $M^+ - Cl$), 301 (100), 303 (30). Anal. calc. for $C_{16}H_{18}Cl_4O_2$ (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 anh. 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 (17400), 222 (16700), 216 (sh, 12300). UV (95% EtOH): 263 (sh, 2300), 249 (sh, 7000), 241 (sh, 8900), 228 (17400), 222 (17200), 215 (sh, 13100). IR (CH_2Cl_2): 3060, 2980, 2920, 2880, 2820, 1800, 1660, 1450, 1410, 1320, 1200, 1140, 1100, 920, 900, 835, 805. ^{1}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}C-NMR (CD_2Cl_2): 147.5, 146.7 (2*m*, 4 C); 102.3 (*t*, ^1J(C,H) = 160, 4 CH_2=C); 89.9 (*m*, C(1)); 83.9 (*dm*, ^1J(C,H) = 164, C(4)); 70.0 (*tq*, ^1J(C,H) = 141, ^3J(C,H) = 5, CH_3OCH_2); 59.9 (*qt*, ^1J(C,H) = 141, ^3J(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 $C_{16}H_{14}O_2$ (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 vigourous 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 (17000), 221 (16300), 214 (12200). UV (95% EtOH): 262 (sh, 2500), 249 (sh, 6100), 240 (sh, 8000), 226 (15600), 221 (15400), 216 (11700). IR ($CHCl_3$): 3600, 3100, 3010, 2940, 2090, 2010, 1990, 1420, 1230, 1075, 1030, 1000, 970, 915, 900. ^{1}H-NMR (360 MHz, $CDCl_3$): 5.39, 5.31, 5.13, 4.96 (4*s*, 8 H); 5.07 (br. *s*, H–C(4)); 4.23 (*d*, ^3J = 6, CH_2OH); 1.89 (*t*, *J* = 6, OH). ^{13}C-NMR (90 MHz, $CDCl_3$): 146.9, 145.5 (2*m*, 4 C); 102.6, 102.2 (*t*, ^1J(C,H) = 161, 4 CH_2=C); 90.8 (*m*, C(1)); 83.7 (*dm*, ^1J(C,H) = 164, ^3J(C,H) = 13, 6.5, C(4)); 59.7 (*t*, ^1J(C,H) = 144, CH_2O–H). MS (70 eV): 176 (17, M^+), 195 (12), 115 (17), 91 (14), 51 (100). Anal. calc. for $C_{11}H_{12}O_2$ (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 (CH_2Cl_2): 3625, 3450, 3060, 2950, 2850, 1440, 1390, 1360, 1210, 1190, 1130, 1110, 1080, 1040, 1010, 980. ^{1}H-NMR ($CDCl_3$): 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 CH_2OH); 3.56 (*s*, 2 ($CH_3O)_2CH$); 2.24–1.85 (*m*, H–C(2), H–C(3)). ^{13}C-NMR (90 MHz, $CDCl_3$): 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, *C*H–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 CH_2OH); 57.1, 56.3 (*qd*, ^1J(C,H) = 142, ^3J(C,H) = 5, CH_3O); 44.2, 44.4 (2*d*, ^1J(C,H) = 135, C(2), C(3)). CI-MS (CH_4): 231 (2, M^+ + 1), 145 (100). Anal. calc. for $C_{11}H_{18}O_5$ (230.263): C 57.38, H 7.88; found: C 57.22, H 7.73.

*(1*RS,*2*RS,*3*SR,*4*SR*)-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 N_2 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 H_2 was maintained and the flask shaken for *ca.* 100 min. The end of the hydrogenation was controlled by TLC (SiO_2, AcOEt/hexane 3:1; **35** and **36** have same R_f, but **35** was revealed with $KMnO_4$ 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 (CH_2Cl_2): 3630, 3440, 2970, 2840, 1480, 1440, 1390, 1360, 1210, 1190, 1130, 1100, 1085, 1030, 980, 945, 910, 850. ^{1}H-NMR ($CDCl_3$): 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). ^{13}C-NMR (90 MHz, $CDCl_3$): 106.5 (*d*, ^1J(C,H) = 159, *C*H–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, ($CH_3O)_2CH$); 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 $C_{11}H_{20}O_5$ (232.279): C 56.88, H 8.68; found: C 56.76, H 8.59.

*[(1*RS,*2*RS,*3*SR,*4*SR*)-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 (CH_2Cl_2): 3060, 2970, 2890, 2840, 1360, 1335, 1175, 1100, 1085, 970, 950, 805. ^{1}H-NMR ($CDCl_3$): 4.75–3.80 (*m*, 6 H); 3.50 (*s*, ($CH_3O)_2CH$); 3.00 (*s*, 2 CH_3S); 2.73–2.21 (*m*, H–C(2), H–C(3)); 2.03–1.38 (*m*, 4 H). ^{13}C-NMR (90 MHz, $CDCl_3$): 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, ($CH_3O)_2CH$); 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 $C_{13}H_{24}O_9S_2$ (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 anh. DMF/HMPT 6:1 (70 ml) maintained at 0° and under N_2. After stirring at 0° for 2 h, H_2O (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 (CH_2Cl_2): 3060, 3000, 2960, 2920, 2880, 2840, 1450, 1390, 1310. ^{1}H-NMR ($CDCl_3$): 5.28 (*s*, 1 H); 5.18 (br. *s*, ^4J = 1, 1 H); 5.15 (br. *s*, 1 H); 4.90 (br. *s*, 1 H); 4.80 (*dm*, ^3J = 3, ^4J = 1, H–C(4)); 4.68 (*s*, CH–C(1)); 3.57, 3.55 (2*s*, ($CH_3O)_2CH$); 2.07–1.92 (*m*, 2 H); 1.72–1.66 (*m*, 2 H). ^{13}C-NMR (90 MHz, $CDCl_3$): 148.9 (*m*, C(3)); 147.2 (*m*, C(2)); 105.0 (*dm*, ^1J(C,H) = 162, ^3J(C,H) = 5, $(CH_3O)_2CH$); 101.3, 100.0 (2*t*, ^1J(C,H) = 162, 2 CH_2=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, ($CH_3O)_2CH$); 29.7, 28.9 (2*t*, ^1J(C,H) = 138, C(5), C(6)). CI-MS (CH_4): 197 (8, M^+ + 1), 166 (42), 137 (12), 106 (30), 57 (100). Anal. calc. for $C_{11}H_{16}O_3$ (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 1N 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 CH_2Cl_2 (50 ml) and aq. 5% $NaHCO_3$ (50 ml). The org. layer was washed with H_2O (50 ml) and dried ($MgSO_4$). 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 (CH_2Cl_2): 3060, 2995, 2960, 2880, 2840, 1735, 1425, 1040. ^{1}H-NMR ($CDCl_3$): 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). ^{13}C-NMR (90 MHz, $CDCl_3$): 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 CH_2=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 $C_9H_{10}O_2$ (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 $NaBH_4$ (0.49 g, 13 mmol) was stirred at 20° for 1 h (TLC control). H_2O (5 ml) was added and the mixture extracted with CH_2Cl_2 (10 ml, 5 times). The org. extracts were united and washed with H_2O (10 ml) and dried ($MgSO_4$). 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 (CH_2Cl_2): 3600, 3500, 3060, 2990, 2960, 2880, 1455, 1400. ^{1}H-NMR ($CDCl_3$): 5.25, 5.15, 4.90, 4.81 (4*s*, 4 H); 4.78 (*d*, H–C(4)); 4.00 (*m*, J = 6, CH_2OH); 2.90 (*t*, J = 6, OH); 2.30–1.00 (*m*, 4 H). ^{13}C-NMR (90 MHz, $CDCl_3$): 148.5, 147.3 (2*m*), 100.3, 99.9 (2*t*, ^1J(C,H) = 163, 2 CH_2=C); 88.7 (*m*, C(1)); 79.8 (*dm*, ^1J(C,H) = 164, C(4)); 60.8 (*t*, ^1J(C,H) = 142); 30.2, 29.4 (2*tm*, ^1J(C,H) = 139). MS (70 eV): 152 (1, M^+), 134 (10), 124 (30), 123 (30), 106 (40), 77 (100). Anal. calc. for $C_9H_{12}O_2$ (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**). Ag_2O (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 H_2O (4 ml) maintained at 0°. After stirring at 0° for *ca.* 30 min, the precipitate was filtered off and washed with H_2O (2 ml). The soln. was evaporated, H_2O (5 ml) was added and the mixture extracted with CH_2Cl_2 (10 ml). The aq. phase was collected and acidified at 0° with 10% HCl until pH 4. The mixture was extracted with CH_2Cl_2 (10 ml, 5 times). The extracts were united and washed with brine, dried ($MgSO_4$), and evaporated, yielding an unstable oil which polymerized rapidly at 20°. IR (CH_2Cl_2): 3470, 3060, 2990, 2950, 2870, 1780, 1750, 1725, 1435, 1375, 1260, 1195, 1140, 1090, 1065, 1050, 1040, 965, 950. ^{1}H-NMR ($CDCl_3$): 8.2–7.9 (br. *s*, OH); 5.33, 5.30, 5.25, 4.99 (4*s*, 4 H); 4.86 (*d*, J = 4, H–C(4)); 2.3–1.6 (*m*, 4 H). ^{13}C-NMR (90 MHz, $CDCl_3$): 174.3 (br. *s*); 146.4, 145.2 (*m*, C(2), C(3)); 101.9, 101.8 (2*t*, ^1J(C,H) = 164, 2 CH_2=C); 86.7 (*m*, C(1)); 80.5 (*dm*, ^1J(C,H) = 168, C(4)); 32.9, 29.7 (2*t*, ^1J(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 CH_2N_2 in Et_2O was added slowly to a stirred soln. of **9** (1 g, 6.02 mmol) in Et_2O (10 ml) cooled to 0°. The excess of CH_2N_2 was destroyed with 10% AcOH in Et_2O. The solvent was eliminated by distillation (*Vigreux* column) and the residue dried *in vacuo*, yielding 1 g (92%), colourless oil. IR (CH_2Cl_2): 3080, 3000, 2960, 1760, 1740, 1445, 1350, 1230, 1090, 1050, 965, 935, 900. ^{1}H-NMR ($CDCl_3$): 5.33, 5.26, 5.20, 5.00 (4*s*, 4 H); 4.93 (*d*, J = 4, H–C(4)); 3.88 (*s*, $COOCH_3$); 2.3–1.5 (*m*, 4 H). ^{13}C-NMR (90 MHz, $CDCl_3$): 169.5 (*m*, CO); 147.4, 146.6 (2*m*); 101.5, 101.3 (2*t*, ^1J(C,H) = 160); 87.5 (*m*); 80.8 (*dq*, ^1J(C,H) = 160); 52.2 (*q*, ^1J(C,H) = 149); 33.3, 29.9 (2*t*, ^1J(C,H) = 136). MS (70 eV): 180 (72, M^+), 152 (100). Anal. calc. for $C_{10}H_{12}O_3$ (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. CH_2Cl_2 (8 ml), but-3-yn-2-one (90 µl, 1.13 mmol), and $BF_3 \cdot Et_2O$ (146 µl, 1.13 mmol, *ca.* 48% BF_3) were mixed and allowed to react for 20 min. The mixture was cooled to −100°, and **2** (74 mg, 0.38 mmol) in anh. CH_2Cl_2 (1 ml) was added dropwise. Anh. CH_2Cl_2 (1 ml) was used for the rinsing. After standing at −75° for 4 d, the mixture was poured into a vigourously stirred mixture of Et_2O (25 ml) and sat. aq. $NaHCO_3$ soln. (25 ml). The org. layer was dried ($MgSO_4$) 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. $Na_2S_2O_5$ soln., then with sat. aq. $NaHCO_3$ soln., and finally with H_2O (pH 7). After drying ($MgSO_4$), 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 (CH_2Cl_2): 3010, 2970, 2840, 1685, 1620, 1580, 1360, 1115, 1095, 1080. ^{1}H-NMR (360 MHz, C_6D_6): 7.69 (*d*, ^4J(H–C(3),H–C(5)) = 1.6, H–C(3)); 7.69 (*dd*, J = 8, 1.6, H–C(5)); 7.56 (*d*, ^3J(H–C(5),H–C(6)) = 8, H–C(6)); 5.03 (*d*, ^3J(H–C(1),H_β–C(10)) = 5, H–C(1)); 4.67 (*s*, $(CH_3O)_2CH$); 3.38, 3.34 (2*s*, $(CH_3O)_2CH$); 2.16 (*m*, H_β–C(9)); 2.15 (*s*, $COCH_3$); 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)). ^{13}C-NMR (90 MHz, $CDCl_3$): 197.8 (*m*, CO); 149.8, 146.8 (2*m*, C(2), C(7)); 136.2 (*d*, ^3J(C,H) = 7, C(4)); 127.9 (*dm*, ^1J(C,H) = 161, C(3)); 119.9 (*d*, ^1J(C,H) = 164, C(6)); 118.2 (*dd*, ^1J(C,H) = 162, ^3J(C,H) = 7, C(5)); 105.4 (*dm*, ^1J(C,H) = 158, C(8)); 89.5 (*m*, C(8)); 78.7 (*d*, ^1J(C,H) = 166, C(1)); 57.4, 56.5 (2*qd*, ^1J(C,H) = 143, ^3J(C,H) = 5, $(CH_3O)_2CH$); 28.0, 27.0 (2*t*, ^1J(C,H) = 136, C(9), C(10)); 26.7 (*q*, ^1J(C,H) = 127, CH_3CO). 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 $C_{15}H_{18}O_4$ (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 C_6H_6 (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 (CH_2Cl_2): 3000,

2960, 2840, 1680, 1620, 1580, 1355, 1235, 1115, 1095, 1080. ^{1}H-NMR (360 MHz, C_6D_6): 8.27 (*t*, ^4J(H–C(3), H–C(5)) = 1.6, ^5J(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*, $(CH_3O)_2CH$); 3.38, 3.34 (2*s*, $(CH_3O)_2CH$); 2.19 (*s*, $COCH_3$); 2.19 (*m*, H_β–C(10)); 1.86 (*m*, H_β–C(9)); 1.43 (*dm*, ^2J = –11.4, ^3J(H_α–C(10),H_α–C(9)) = 9, ^3J(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)). ^{13}C-NMR (90 MHz, $CDCl_3$): 197.8 (*m*); 151.1 (*m*, C(2)); 145.5 (*m*, C(7)); 136.2 (*m*, ^3J(C,H) = 6, C(4)); 127.9, 119.6 (2*dd*, ^1J(C,H) = 165, ^3J(C,H) = 6, C(3), C(5)); 118.6 (*d*, ^1J(C,H) = 162, C(6)); 105.4 (*dm*, ^1J(C,H) = 160, *C*H–C(1)); 89.4 (*m*, C(1)); 78.7 (*d*, ^1J(C,H) = 165, C(8)); 57.4, 56.4 (2*qd*, ^1J(C,H) = 143, ^3J(C,H) = 5, $(CH_3O)_2CH$); 27.8, 27.0 (2*t*, ^1J(C,H) = 137, C(9), C(10)); 26.7 (*q*, ^1J(C,H) = 128). MS (70 eV): 262 (12, M^+), 235 (13), 234 (87), 219 (25), 203 (100), 183 (15), 75 (44). Anal. calc. for $C_{15}H_{18}O_4$ (262.306): C 68.69, H 6.92; found: C 68.63, H 6.94.

*(1*RS,*4*SR,*8*SR*)-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. CH_2Cl_2 (3 ml) and MVK (340 mg, 4.83 mmol) were introduced *via* a syringe. After cooling to –85°, $BF_3 \cdot Et_2O$ (*ca.* 48% BF_3, 603 µl) were added. After stirring at –85° for 20 min, **6** (316 mg, 1.61 mmol) in anh. CH_2Cl_2 (2 ml) was added slowly (rinsing with 1 ml of anh. CH_2Cl_2). After stirring at –85° for 20 min, the mixture was poured into a vigourously stirred mixture of Et_2O (25 ml) and sat. aq. $NaHCO_3$ soln. (25 ml). The org. layer was washed with H_2O (20 ml) and dried ($MgSO_4$). 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-^{1}H-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 $EtAlCl_2$ in hexane instead of $BF_3 \cdot Et_2O$ and a total amount of 11 ml of CH_2Cl_2 (solvent ratio CH_2Cl_2/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 ($CHCl_3$): 3020, 2960, 2840, 1720, 1440, 1360, 1230, 1065, 1045, 1110, 1075, 940, 875. ^{1}H-NMR (360 MHz, CD_3COCD_3): 4.64 (*d*, *J* = 4.3, H–C(1)); 4.54 (*s*, CH–C(1)); 3.45, 3.43 (2*s*, $(CH_3O)_2CH$); 2.50–2.43 (*m*, 4 H); 2.13 (*s*, CH_3CO); 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). ^{1}H-NMR (360 MHz, C_6D_6): 4.54 (*dd*, ^3J(H–C(1), H_β–C(10)) = 4.1, ^5J(H–C(1), H_β–C(6)) = 1.2, H–C(1)); 4.51 (*s*, $(CH_3O)_2CH$); 3.36 (2*s*, $(CH_3O)_2CH$); 2.53 (*m*, H_β–C(6)); 2.22 (*m*, ^2J = –17.3, ^3J(H_β–C(3),H_α–C(4)) = 10, H_β–C(3)); 2.00–1.69 (*m* + *s*, 5 H + $COCH_3$); 1.46 (*m*, H_β–C(5)); 1.33 (*m*, ^2J = –10.8, ^3J(H_α–C(9),H_α–C(10)) = 8.6, ^3J(H_α–C(9),H_β–C(10)) = 3.5, H_α–C(9)); 1.00 (*m*, ^2J = –10.8, ^3J(H_α–C(10),H_α–C(9)) = 8.6, ^3J(H_α–C(10),H_β–C(9)) = 3.4, H_α–C(10)). ^{13}C-NMR (90 MHz, C_6D_6): 208.5 (*m*, CO); 140.5, 139.5 (2*m*, C(2), C(7)); 106.4 (*dm*, ^1J(C,H) = 157, *C*–C(8)); 91.3 (*m*, C(8)); 79.8 (*d*, ^1J(C,H) = 160, C(1)); 56.6, 56.1 (*qd*, ^1J(C,H) = 142, ^3J(C,H) = 5, $(CH_3O)_2CH$); 48.2 (*dm*, ^1J(C,H) = 126, C(4)); 27.4 (*q*, ^1J(C,H) = 128, $COCH_3$); 27.2, 27.1 (2*t*, ^1J(C,H) = 135, C(9),C(10)); 25.1, 23.1, 22.2 (3*t*, ^1J(C,H) = 129). MS (70 eV): 267 (15, M^+ + H). Anal. calc. for $C_{15}H_{22}O_4$ (266.340): C 67.65, H 8.33; found: C 67.87, H 8.41.

*(1*RS,*4*RS,*8*SR*)-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. CH_2Cl_2 (1.5 ml) and MVK (390 µl, 4.7 mmol) were introduced. After cooling to –85°, $EtAlCl_2$ (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. N_2, and **6** (307 mg, 1.56 mmol) in anh. CH_2Cl_2 (1.5 ml) was introduced (rinsing with 1.5 ml of anh. CH_2Cl_2; final concentration of **6**: 0.24M). After stirring at –85° for 100 min, the mixture was poured into a vigourously stirred mixture of Et_2O (25 ml) and ice-cold sat. aq. $NaHCO_3$ soln. The org. layer was separated and the aq. layer extracted with Et_2O (10 ml, 2 times). The extracts were united and washed with H_2O (20 ml) and dried ($MgSO_4$). 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, $CHCl_3$/acetone 9.5:0.5, 1000 psi). IR (CH_2Cl_2): 3000, 2960, 2920, 2880, 2840, 1730, 1440, 1365, 1195, 1165, 1145, 1110, 1080, 945. ^{1}H-NMR (360 MHz, C_6D_6): 4.53 (*s*, CH–C(1)); 4.52 (br. *d*, *J* = 4.2, ^5J = 0.8 1.0, H–C(8)); 3.36, 3.34 (2*s*, $(CH_3O)_2CH$); 2.61 (*m*, ^2J = –18.5 (–17.8)[5]), ^3J(H_β(ax)–C(3), H_α(ax)–C(4)) = 8.5 (10.5)[5]), ^5J(H_β(ax)–C(3), H_α(ax)–C(6)) = 3.5 (4.2)[5]), ^5J(H_β(ax)–C(3), H_β(eq)–C(6)) = 2.5 (2.8)[5]), ^5J(H_β–C(3), H–C(8)) = 0.8–1.0, H_β(ax)–C(3)); 2.35 (*m*, ^2J = –18.5 (–17.8)[5]), ^3J(H_α(eq)–C(3), H_α(ax)–C(4)) = 5.5[6]), ^4J(H_α–C(3), H_α(eq)–C(5)) = 1.5[6]), ^5J(H_α–C(3), H_α(ax)–C(6)) = 2.1[6]), ^5J(H_α–C(3), H_β(eq)–C(6)) = 1.0[6]), H_α(eq)–C(3)); 2.14 (*s*, $COOCH_3$); 1.91 (*m*, ^3J(H_α–C(3), H_α(ax)–C(4)) = 5.5[6]), ^3J(H_β–C(3), H_α–C(4)) = 8.5 (10.5)[5]), ^3J(H_α–C(4), H_β(ax)–C(5)) = 10.8 (11.4)[5]), ^3J(H_α–C(4), H_α(eq)–C(5)) = 3.3[6]), H_α(ax)–C(4)); 1.54 (*m*, ^2J = –15.0 (–13.1)[5]), ^3J(H_α(eq)–C(4), H_β(ax)–C(5)) = 10.8 (11.4)[5]), ^3J(H_β–C(5), H_α(ax)–C(6)) = 11.1[6]), ^3J(H_β–C(5)),

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[5]) In parenthesis the values used to initiate the iterative PANIC 81 (version 810515.1) programm (7 spins, final ΔJ = 0.06 Hz). For **44**, the δ_H were derived from the ^{1}H,^{13}C-correlated spectra.

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

H_β(eq)–C(6)) = 5.8[6]), H_β(ax)–C(5)); 1.55 (*m*, ^2J = –15.0 (–13.1)[5]), ^3J(H_α–C(4), H_α–C(5)) = 3.3[6]), ^3J(H_α–C(5), H_α(ax)–C(6)) = 5.0[6]), ^3J(H_α–C(5), H_β(eq)–C(6)) = 3.0[6]), ^4J(H_α–C(3), H_α–C(5)) = 1.5[6]), H_α(eq)–C(5)); 1.52 (*m*, ^2J = –18.0[6]), ^3J(H_β(ax)–C(5), H_α(ax)–C(6)) = 11.1[6]), ^3J(H_α(eq)–C(5), H_α–C(6)) = 5.0[6]), ^5J(H_β–C(3), H_α–C(6)) = 3.5 (4.2)[5]), ^5J(H_α–C(3), H_α–C(6)) = 2.1[6]), H_α(ax)–C(6)); 1.98 (*m*, ^2J = –18.0[6]), ^3J(H_β–C(5), H_β–C(6)) = 11.1[6]), ^3J(H_α–C(5), H_β–C(6)) = 5.0[6]), ^5J(H_β–C(3), H_β–C(6)) = 3.5 (4.2)[5]), ^5J(H_α–C(3), H_β–C(6)) = 2.1[6]), H_β(eq)–C(6)); 1.03 (*m*, ^2J = –10.8, ^3J(H_α–C(9), H_α–C(10)) = 8.6, ^3J(H_α–C(9), H_β–C(10)) = 3.4, H_α–C(9)); 1.78 (*m*, ^2J = –10.8, ^3J(H–C(8), H_β–C(9)) = 4.2, ^3J = 3.5, 9.2, H_β–C(9)); 1.33 (*m*, ^2J = –10.8, ^3J(H_α–C(9), H_α–C(10)) = 8.6, ^3J(H_β–C(9), H_α–C(10)) = 3.5, H_α–C(10)); 1.94 (*m*, ^2J = –10.8, ^3J(H_α–C(9), H_β–C(10)) = 3.4, ^3J(H_β–C(9), H_β–C(10)) = 9.2, H_β–C(10)). ^{13}C-NMR (90 MHz, C_6D_6): 208.6 (*m*, CO); 141.3, 138.9 (2*m*, C(2), C(7)); 106.6 (*d*, ^1J(C,H) = 157, *C*H–C(1)); 91.6 (*m*, C(1)); 80.2 (*d*, ^1J(C,H) = 162, C(8)); 56.5, 56.2 (2*qd*, ^1J(C,H) = 143, ^3J(C,H) = 5, (*C*H_3O)$_2$CH); 48.2 (*d*, ^1J(C,H) = 125, C(4)); 27.6 (*t*, ^1J(C,H) = 133); 27.4 (*q*, ^1J(C,H) = 127); 27.1, 24.7, 23.7, 21.7 (4*t*, ^1J(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 $C_{15}H_{22}O_4$ (266.340): C 67.65, H 8.33; found: C 67.49, H 8.20.

(±)-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}H-NMR (360 MHz, C_6D_6): 4.16 (*d*, *J* = 4, H–C(8)); 4.14 (*s*, CH–C(1)); 3.14 (*dm*, 1 H); 3.12, 3.10 (2*s*, (*C*H_3O)$_2$CH); 2.73, 2.10 (2*dm*, ^2J = 18, 2 H); 1.66 1.47 (*m*, 3 H); 1.15, 0.83 (2*m*, 2 H). ^{13}C-NMR (90 MHz, C_6D_6): 135.7, 135.6 (2*m*, C(2), C(7)); 111.2, 111.1, 111.0 (3*m*, 4 C); 105.4 (*d*, ^1J(C,H) = 161, (CH$_3$O)$_2$*C*H); 91.9 (*m*, C(1)); 79.4 (*d*, ^1J(C,H) = 165, C(8)); 56.6, 56.5 (2*qd*, ^1J(C,H) = 143, ^3J(C,H) = 5, (*C*H$_3$O)$_2$CH); 38.7 (*m*, C(4), C(5)); 31.0, 29.7 (2*t*, ^1J(C,H) = 141, C(9), C(10)); 26.3, 26.2 (2*t*, ^1J(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 $C_{17}H_{16}N_4O_3$ (324.342): C 62.96, H 4.97; found: C 62.81, H 5.10.

(±)-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}H-NMR (360 MHz, C_6D_6); 5.25, 5.20, 5.08, 4.69 (4*s*, 4 H); 4.39 (br. *s*, H–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}C-NMR (90 MHz, $CDCl_3$): 142.0, 140.6 (2*m*, C(9), C(10)); 136.9, 136.0 (2*m*, C(2), C(7)); 110.4, 110.35, 110.2, 109.9 (4*m*, 4 CN); 105.2, 103.5 (2*t*, ^1J(C,H) = 160); 103.7 (*dm*, ^1J(C,H) = 161, ^3J(C,H) = 5); 92.2 (*m*, C(1)); 83.0 (*dm*, ^1J(C,H) = 168, ^3J = 12, 6, C(8)); 57.1, 56.7 (2*qd*, ^1J(C,H) = 139, ^3J(C,H) = 5, 2 CH_3O); 38.4, 38.3 (2*m*, ^3J(C,H) = 4, C(4), C(5)); 31.4, 31.0 (2*t*, ^1J(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 $BF_3 \cdot Et_2O$ (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 vigourously 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}H-NMR (360 MHz, $CDCl_3$): 7.87 (*m*, H–C(3)); 7.82 (*dd*, *J* = 8, 2, H–C(5)); 7.59 (*d*, *J* = 8, H–C(6)); 5.61 (*s*, H–C(1)); 5.44, 5.41, 5.30, 5.20 (4*s*, 4 H), 5.02 (*s*, CH–C(8)); 3.66, 3.61 (2*s*, (*C*H_3O)$_2$CH); 2.58 (*s*, $COCH_3$). ^{13}C-NMR (90 MHz, $CDCl_3$): 197.4 (*m*, CO); 148.5 (*m*, C(7)); 145.5 (*d*, ^3J(C,H) = 7, C(2)); 144.8, 143.1 (2*m*, C(9), C(10)); 136.6 (*d*, ^3J(C,H) = 7, C(4)); 128.6 (*dd*, ^1J(C,H) = 162, ^3J(C,H) = 5, C(3) or C(5)); 121 (*d*, ^1J(C,H) = 168, C(6)); 119.0 (*dm*, ^1J(C,H) = 163, C(5) or C(3)); 104.8 (*t*, ^1J(C,H) = 159, CH_2=C(9), CH_2=C(10)); 104.4 (*dm*, ^1J(C,H) = 159, ^3J(C,H) = 5, *C*H–C(8)); 90.6 (*m*, C(8)); 82.2 (*dm*, C(1)); 56.9, 56.7 (2*qd*, ^1J(C,H) = 143, ^3J(C,H) = 5, (*C*H$_3$O)$_2$CH); 26.6 (*q*, ^1J(C,H) = 127, *C*H$_3$CO). MS (70 eV): 286 (12, M^+), 75 (100). Anal. calc. for $C_{17}H_{18}O_4$ (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 (13900), 230 (15300), 206 (20400). UV (isooctane): 296 (1100), 286 (1300), 260 (sh, 12200), 254 (16200), 230 (17000), 208 (sh, 23300), 204 (24800). IR (CH_2Cl_2): 3000, 2965, 2940, 2840, 1685, 1360, 1235, 1175. ^{1}H-NMR (360 MHz, $CDCl_3$): 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*, $(CH_3O)_2CH$); 2.58 (*s*, $COCH_3$). ^{13}C-NMR (90 MHz, $CDCl_3$): 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*, ^3J(C,H) = 7, C(4)); 128.4 (*dd*, ^1J(C,H) = 161, ^3J(C,H) = 5); 120.7 (*dd*, ^1J(C,H) = 165, ^3J(C,H) = 7, C(3), C(5)); 119.4 (*d*, ^1J(C,H) = 163, C(6)); 104.5, 103.2 (2*t*, ^1J(C,H) = 162, CH_2=C(9), CH_2=C(10)); 104.3 (*dd*, ^1J(C,H) = 159, ^3J(C,H) = 5, *C*H–C(1)); 90.4 (*m*, C(1)); 82.1 (*dm*, ^1J(C,H) = 165, C(8)); 56.8, 56.8 (2*qd*, ^1J(C,H) = 142, ^3J(C,H) = 5, $(CH_3O)_2CH$); 26.6 (*q*, ^1J(C,H) = 127, CH_3CO). 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 $C_{17}H_{18}O_4$ (286.339): C 71.31, H 6.34; found: C 71.18, H 6.41.

*(2*RS*,9*RS*,10*SR*)-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. CH_2Cl_2 (9.5 ml), MVK (147 mg, 2.1 mmol), and $BF_3 \cdot Et_2O$ (26.5 µl) were introduced successively at −75°. After stirring at −75° for 20 min, **50** (200 mg, 0.7 mmol) in anh. CH_2Cl_2 (1 ml) was introduced slowly at −95° (rinsing with 1 ml of CH_2Cl_2; final concentration of **50**: 0.06M). After stirring at −75° for 80 h, the mixture was poured into a vigourously stirred mixture of Et_2O (50 ml) and ice-cold sat. aq. $NaHCO_3$ soln. (50 ml). The org. layer was washed with H_2O (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 impureties. 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 (CH_3CN): 301 (2900), 276 (3700), 234 (17600), 201 (19300). IR ($CHCl_3$): 3010, 2940, 2860, 2840, 1715, 1680, 1610, 1420, 1355, 1280, 1250, 1115, 1075. ^{1}H-NMR (360 MHz, C_6D_6): 7.83 (*dd*, ^4J = 1.6, ^5J = 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*, $(CH_3O)_2CH$); 2.62 (*m*, ^2J = −17.4, ^3J(H_α–C(2), H_β–C(4)) = 9.2, ^5J(H_β–C(1), H_β–C(4)) = 3.2, ^5J(H_α–C(1), H_β–C(4)) = 4.4, H_β–C(4)); 2.34 (*m*, H_β–C(1)); 2.13 (*s*, CH_3CO); 1.89 (*m*, H_α–C(4)); 1.71–1.33 (*m*, 3 H); 1.55 (*s*, CH_3CO). ^{13}C-NMR (90 MHz, $CDCl_3$): 210.1, 197.0 (2*m*, 2 CO); 154.3 (*m*, C(10)); 150.8 (*d*, ^3J(C,H) = 6, C(5a)); 148.5, 147.2 (2*m*, C(4a), C(1a)); 134.7 (*d*, ^3J(C,H) = 6, C(7)); 127.4 (*dm*, ^1J(C,H) = 158); 119.9 (*dd*, ^1J(C,H) = 163, ^3J(C,H) = 4); 117.7 (*dd*, ^1J(C,H) = 163, ^3J(C,H) = 7); 103.9 (*dm*, ^1J(C,H) = 158, ^3J(C,H) = 5); 93.7 (*d*, ^3J(C,H) = 7, C(10)); 83.25 (*d*, ^1J(C,H) = 167, C(9)); 57.0, 56.95 (2*qd*, ^1J(C,H) = 144, ^3J(C,H) = 5, $(CH_3O)_2CH$); 47.3 (*dm*, ^1J(C,H) = 129, C(2)); 28.03, 26.6 (2*q*, ^1J(C,H) = 128, 2 CH_3CO); 24.8, 24.3, 23.2 (3*tm*, ^1J(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 $C_{21}H_{24}O_5$ (356.419): C 70.77, H 6.79; found: C 70.73, H 6.97.

*(1*RS*,4*SR*,8*SR*)-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. CH_2Cl_2 (22 ml) and MVK (291 mg, 4.15 mmol) were introduced. After cooling to −100°, a 25% soln. of $EtAlCl_2$ in hexane (2.52 ml, 4.15 mmol) was introduced. After stirring at −85° for 20 min, the mixture was frozen in liq. N_2, and **2** (305 mg, 1.39 mmol) in anh. CH_2Cl_2 (15 ml) was introduced (rinsing with anh. CH_2Cl_2, 1 ml, 2 times). After stirring at −85° for 1 h, the mixture was poured into a vigourously stirred mixture of Et_2O (125 ml) and ice-cold sat. aq. $NaHCO_3$ soln. The org. layer was washed with H_2O until pH 7. After drying ($MgSO_4$), 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/H_2O/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 (12600). IR (CH_2Cl_2): 3040, 3000, 2940, 2840, 1720, 1360, 1115, 1100, 1075, 940. ^{1}H-NMR (360 MHz, C_6D_6): 5.44, 5.34, 5.12, 4.79 (4*s*, 4 H); 4.71 (br. *s*, ^5J(H–C(1), H_β–C(6)) = 1.2, H–C(1)); 4.6 (*s*, CH–C(8)); 3.38, 3.35 (2*s*, $(CH_3O)_2CH$); 2.61 (*m*, ^2J = −18.0[6]), ^3J(H_β(ax)–C(5), H_β–C(6)) = 5.8[6]), ^3J(H_α(eq)–C(5), H_β–C(6)) = 3.0[6]), ^5J(H_β(ax)–C(3), H_β–C(6)) = 2.8[6]), ^3J(H_α(eq)–C(3), H_β–C(6)) = 1.0[6]), ^5JH–C(1), H_β–C(6)) = 1.2, H_β(eq)–C(6)); 2.29 (*m*, ^2J = −17.8[6]) (−18.4)[5]), ^3J(H_β(ax)–C(3), H_α(ax)–C(4)) = 10.5 (11.4)[5]), ^5J(H_β–C(3), H_β(eq)–C(6)) = 2.8[6]), $^5J$$H_\beta$–C(3), H_α(ax)–C(6)) = 4.2 (3.8)[5]), H_β(ax)–C(3)); 2.15 (*s*, $COCH_3$); 2.00 (*m*, ^2J = −18.0[6]), ^3J(H_β(ax)–C(5), H_α(ax)–C(6)) = 11.1 (11.0)[5]), ^3J(H_α(eq)–C(5), H_α(ax)–C(6)) = 5.0[6]), ^5J(H_β(ax)–C(3), H_αC(6)) = 4.2 (3.8)[5]), ^5J(H_α(eq)–C(3), H_αC(6)) = 2.1[6]), H_α(ax)–C(6)); 1.82 (*m*, ^2J = −17.8 (−18.4)[5]), ^3J(H_α(eq)–C(3), H_α(ax)–C(4)) = 5.5[6]), ^4J(H_α(eq)–C(3), H_α(eq)–C(5)) = 1.5[6]), ^5J(H_αC(3), H_β(eq)–C(6)) = 1.0[6]), ^5J(H_αC(3), H_α(ax)–C(6)) = 2.1[6]), H_α(eq)–C(3)); 1.80 (*m*, ^3J(H_α(ax)–C(4),

H_α(eq)–C(5)) = 3.3[6]), ^3J(H_αC(4), H_β(ax)–C(5)) = 11.4 (10.8)[5]), ^3J(H_β(ax)–C(3), H_αC(4)) = 10.5 (11.4)[5]), ^3J(H_α(eq)–C(3), H_α(ax)–C(4)) = 5.5[6]), H_α(ax)–C(4)); 1.64 (*m*, ^2J = –13.1 (–13.0)[5]), ^3J(H_α(eq)–C(5), H_β(eq)–C(6)) = 3.0[6]), ^3J(H_αC(5), H_α(ax)–C(6)) = 5.0[6]), $^3JH_\alpha$(ax)–C(4), H_α(eq)–C(5)) = 3.3[6]), ^4J(H_α(eq)–C(3), H_αC(5)) = 1.5[6]), H_α(eq)–C(5)); 1.43 (*m*, ^2J = –13.1 (–13.0)[5]), ^3J(H_β(ax)–C(5), H_β(eq)–C(6)) = 5.8[6]), ^3J(H_β–C(5), H_α(ax)–C(6)) = 11.1 (11.0)[5]), ^3J(H_α(ax)–C(4), H_β–C(5)) = 11.4 (10.8)[5]), H_β(ax)–C(5)). ^{13}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(C,H) = 160, ^3J(C,H) = 5, CH–C(8)); 101.5, 100.0 (2*t*, ^1J(C,H) = 160, CH_2=C(9), CH_2=C(10)); 91.8 (*m*, C(8)); 83.6 (*dm*, ^1J(C,H) = 166, C(1)); 56.3 (*qm*, ^1J(C,H) = 143, ^3J(C,H) = 5, $(CH_3O)_2$CH); 48.0 (*d*, ^1J(C,H) = 129, C(4)); 24.0 (*q*, ^1J(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 $C_{17}H_{22}O_4$ (290.362): C 70.32, H 7.64; found: C 70.44, H. 7.75.

*Mixture of Methyl (1*RS,*8*SR,*9*RS *or 9*SR,*12*RS*)-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, AcOEt/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}H-NMR (360 MHz, C_6D_6) of **62**: 8.21 (*dd*, *J* = 8, 1.5, H–C(5)); 8.11 (*m*, H–C(3)); 7.66 (*d*, *J* = 8, H–C(6)); 5.47 (*s*, H–C(9)); 5.29 (br. *s*, H–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, CH_2(11)); 3.63 (*s*, COOMe); 3.37 (CH_3O); 1.93–1.88 (*m*, H–C(12)). ^{1}H-NMR (360 MHz, C_6D_6) of **63**: 8.68 (*m*, *J* = 1.5, H–C(6)); 8.15 (*dd*, *J* = 7.9, 1.5, H–C(4)); 7.03 (*d*, *J* = 7.9, H–C(3)); 5.49 (*s*, H–C(9)); 5.28 (br. *s*, H–C(1)); 5.03 (*d*, *J* = 2, 1 H), 4.66 (*dd*, *J* = 2, 1, CH_2=C(13)); 4.29 (*dd*, *J* = 9.4, 8.0, H–C(11)); 4.00 (*t*, *J* = 8, H–C(11)); 3.60, 3.33 (2*s*, 6 H); 1.93–1.88 (*m*, H–C(12)). ^{13}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 $C_{16}H_{16}O_5$ (288.303): C 66.66, H 5.59; found: C 66.58, H 5.69.

*Mixture of (1*RS,*4*SR,*8*SR,*9*RS *or* SR,*12*RS*)- and (1*RS,*5*RS,*8*SR,*9*RS *or* SR,*12*RS*)-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 anh. 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}H-NMR). IR ($CHCl_3$): 3040, 3000, 2960, 2940, 2900, 2840, 1710, 1680, 1430, 1410, 1230, 1100, 1030, 1015, 950, 890. ^{1}H-NMR (360 MHz, $CDCl_3$): 5.07, 5.02, 4.85 (3*s*); 4.80, 4.78 (2 br. *s*, H–C(1)); 4.21, 3.65 (2*t*, CH_2(11)); 3.40 (*s*, 3 H); 2.74 (*m*, H–C(12)); 2.56–0.69 (*m*). ^{13}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 $C_{16}H_{20}O_4$ (276.335): C 69.55, H 7.30; found: C 69.42, H 7.41.

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