

19. New Dienophiles: 1-Acetylvinyl Arenecarboxylates. Reactivity toward Cyclopentadiene and Exocyclic Dienes

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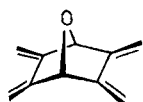
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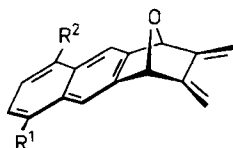
Summary

The preparations of 1-acetylvinyl arenecarboxylates $\text{H}_2\text{C}=\text{C}(\text{COCH}_3)\text{OCOR}$ with R = phenyl, *p*-nitrophenyl, 2,4-dinitrophenyl, α - and β -naphthyl are described (3). The *Diels-Alder* reactivity of these dienophiles toward cyclopentadiene is evaluated and compared with that of methyl vinylketone, 3-trimethylsilyloxy-, 3-ethoxy- and 3-acetoxy-3-buten-2-ones. The stereoselectivity of the cycloadditions of these dienophiles with 2,3,5,6-tetramethylidene-7-oxanorbornane (1) and 5,8-dimethoxy-1,4-epoxy-2,3-dimethylidene-1,2,3,4-tetrahydroanthracene (2) is studied. In principle, the dienophiles 3 allow direct functionalization of the position C(9) of the A-ring of daunomycinone analogs by *Diels-Alder* additions to exocyclic dienes such as 1 and 2.

Introduction. - Anthracyclonones are aglycones of very important antibiotics and anti-tumor drugs [1]. They can be prepared readily [2] [3] by two successive



1



2a $\text{R}^1 = \text{R}^2 = \text{OCH}_3$
b $\text{R}^1 = \text{R}^2 = \text{H}$
c $\text{R}^1 = \text{OCH}_3$, $\text{R}^2 = \text{H}$



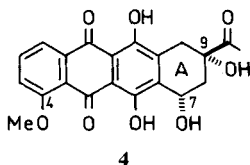
3a-i

$\text{R} = \text{a}$	Me_3Si	f	$2,4-(\text{NO}_2)_2-\text{C}_6\text{H}_3\text{CO}$
b	Et	g	$\alpha\text{-naphthyl-CO}$
c	CH_3CO	h	$\beta\text{-naphthyl-CO}$
d	$\text{C}_6\text{H}_5\text{CO}$	i	CH_3
e	$4-(\text{NO}_2)-\text{C}_6\text{H}_4\text{CO}$	j	H

Diels-Alder additions [4] to 2,3,5,6-tetramethylidene-7-oxanorbornane (1) [5]. The A-ring of daunomycinone (4) [6] bears a hydroxy group at C(9), adjacent to the carbonyl function of the side-chain. This OH group can be introduced, in principle

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[7], by a suitable oxidation [8] of the corresponding 9-deoxy derivative obtained by cycloaddition of methyl vinyl ketone (MVK) to dienes of type 2 [2] [3]. In a more versatile and direct approach, a 3-oxy-3-buten-2-one derivative 3 could be used as a dienophile to generate ring A of the anthracyclinone.



Agosta [9] and *Quick* [10] have shown that α -alkoxy- α,β -unsaturated carbonyl compounds **3b** and **3i** are less reactive toward nucleophiles and dienes than the unsubstituted analogs, as anticipated on electronic [4b] [11] and steric [4b] [12] grounds. The yields of the *Diels-Alder* additions (at 160–190°!) to the relatively reactive cyclopentadiene [4b] [13] were modest. *Wharton* and *Aw* [14] have shown that methyl α -acetoxyvinyl ketone (**3c**) adds with good regioselectivity to 1-isopropenylcyclohexene and the easy dimerization of methyl α -trimethylsilyloxyvinyl ketone (**3a**) has been reported by *Murai et al.* [15] [16].

In order to improve the thermal stability and to enhance the *Diels-Alder* reactivity of the dienophiles **3** we planned to protect the enol by R substituents having a larger electron-withdrawing ability than alkyl [9] [10], trimethylsilyl [15] [16] or acetyl [14] [17] groups. We report a general technique for the preparation of the oxy-substituted methyl vinyl ketones **3** from biacetyl and show that the arene-carboxylates (**3d-h**) give better yields in their cycloadditions with dienes **1** and **2a** than the known derivatives **3a-c**.

Results and discussion. – The dienophiles **3 a,c–h** were prepared by trapping the mono-enolate of biacetyl with the corresponding chloride (R-Cl) in THF containing Et₃N and, sometimes, 10% of hexamethylphosphortriamide (HMPTA) in order to retard C-acylations [18].



Table 1 summarizes our kinetic data on the Diels-Alder additions of **3a-h** and methyl vinyl ketone to cyclopentadiene in CH₂Cl₂ at 50°. The reactions were followed for *ca.* 2 half-lives and were found to obey the following rate law [19]:

$$-\frac{1}{B_0-D-A_0} \ln \frac{A}{A_0} + \frac{1}{B_0-D-A_0} \ln \frac{B_0-D-A_0-A}{B_0-D} = k^{II}t \quad (r > 0.99)$$

where A = conc. of **3** at t (A_0 at t = 0), B_0 = initial conc. of cyclopentadiene (> 30-fold excess) and D = conc. of dicyclopentadiene formed competitively at t.

All the kinetic measurements were repeated 2 to 5 times and were found to be reproducible within a 5% error.

Table 1. Kinetic data of the cycloadditions of the dienophiles **3a-h**, methyl vinyl ketone (MVK) and cyclopentadiene (CP) to cyclopentadiene in CH_2Cl_2 at $50^\circ \pm 0.5$.

Dienophile	3a	3b	3c	3d	3e	3f	3g	3h	MVK	CP
$k^{\text{II}} \cdot 10^5 \text{ [mol}^{-1}\text{s}^{-1}\text{]}$	1.05	0.18	1.5	1.9	3.9	8.5	3.9	4.4	10.6 ^{a)}	0.22 ^{b)}
$k^{\text{II}}_{\text{rel}}$	5.8	(1.0)	8.3	10.5	22	47	22	24	59	1.2

^{a)} A rate constant $k^{\text{II}} = 12.1 \cdot 10^{-5} \text{ mol}^{-1}\text{s}^{-1}$ was reported for MVK + CP in BuCl at 35° [30].

^{b)} A rate constant $k^{\text{II}} = 1.67 \cdot 10^{-5} \text{ mol}^{-1}\text{s}^{-1}$ was reported for the dimerization of CP in CCl_4 at 55° [31].

The stronger the electron withdrawing ability of the enol protecting group R in **3**, the more reactive is the oxy-substituted methyl vinyl ketone. Considering the *remote substituent effect* involved here and the various sizes of the R groups investigated, our results are significant. They confirm the hypothesis that electronic factors determine the *Diels-Alder* reactivity of **3**. Interestingly, the 2,4-dinitrobenzoate **3f** is almost as reactive as MVK, whereas the ethoxy derivative **3b** is not a better dienophile than cyclopentadiene.

The expected adducts **5** and **6** were the sole products formed, with the more reactive dienophiles **3** giving higher yields. In general, the stereoselectivity of these additions is not good (Table 2). In most cases it tends to be the reverse of that of MVK + cyclopentadiene (*endo/exo* adduct ratio = 83:17 [20]). The structures of **5** and **6** were deduced from their $^1\text{H-NMR}$ spectra with the help of double irradiation experiments, the use of $\text{Eu}(\text{thd})_3$ induced shift reagent [21] (the preferred site of coordination being the oxygen atom of the acetyl group, see e.g. **5f** and **6f**, exper. part) and by comparison with the data reported for other norbornene derivatives [22].

With strong dienophiles such as benzoquinone and MVK [2] [3] the reaction of **1** to give the corresponding mono-adducts is at least 100 times faster than its cycloaddition to yield the 'symmetrical' bis-adducts. Furthermore, these *Diels-Alder* additions are highly stereoselective (attack of the dienophiles on the dienes along 4 different paths affords 2 different adducts (cf. [23] [24a]). We found that the

Table 2. Stereoselectivity of the *Diels-Alder* additions of **3a-i** to cyclopentadiene (CP)

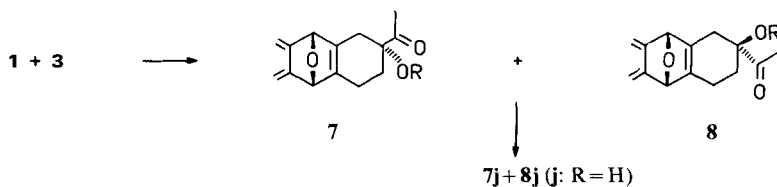
Dienophile	3a	3b [10]	3c	3d	3e	3f	3g	3h	3i [9]
Solvent	-	-	-	-	CH_2Cl_2 (9 mol-equiv.)	CH_2Cl_2 (5 mol-equiv.)	-	-	C_6H_6 (10 mol-equiv.)
Temperature	50°	160°	25°	25°	25°	50°	50°	50°	120°
Time of reaction	11 h	40 h	24 h	48 h	26 h	5 h	13 h	10 h	48 h
Mol-equiv. of CP	9	13	3	3	6	10	9	8	1.4
Isolated yield of the adducts	^{a)}	61%	90%	80%	83%	90%	77%	82%	58%
Adduct ratio 5/6	68:32 ^{b)}	66:34	47:53 ^{c)}	61:39 ^{c)}	67:33 ^{c)}	58:42 ^{d)}	60:40 ^{d)}	58:42 ^{d)}	37:63

^{a)} The adducts were decomposed under our condition of purification (column chromatography, florisil, hexane: AcOEt).

^{b)} Ratio evaluated by GC. (5% Carbowax 20M).

^{c)} Ratio evaluated by $^1\text{H-NMR}$ and GC. (10% SE-30).

^{d)} Ratio evaluated by $^1\text{H-NMR}$ only.



formation of the mono-adducts **7**+**8** from **3** and **1** (CCl_4 , 100 – 140°) is at least 50 times faster than the formation of the corresponding bis-adducts. The best yield was obtained with **3d**, determined after isolation and separation of the alcoholic derivatives **7j** and **8j** (62%) (from saponification of the mixture of **7d**+**8d**). Unfortunately, as in the case of the cycloadditions of **3** to cyclopentadiene, no stereoselectivity was observed either in the reaction of **1** with **3d**, or of **1**+**3c** (50% yield of **7j**/**8j**, 50:50); with **3a**, an unsatisfactory ratio of 66:34 or 34:66 was obtained for **7j**/**8j** (11% yield).

The presence of *Lewis* acid catalysts such as ZnCl_2 , SnCl_4 , TiCl_4 or $\text{Et}_2\text{O} \cdot \text{BF}_3$ [25] caused the decomposition of **1** and **3** without improving the yields and stereoselectivities of their cycloadditions.

Table 3 summarizes our results on the reactivities of **3a–h** toward the exocyclic diene **2a**, an intermediate in the synthesis of 1-methoxy-daunomycinone [3]. Once again, better yields were obtained with our 1-acetylvinyl arenecarboxylates **3d–h** than with the 3-trimethylsilyloxy- or 3-ethoxy-3-buten-2-one (**3a,b**). The stereoselectivity (ratio of adducts **9/10**) is generally low and varies within narrow limits (Table 3). This loss of stereoselectivity with respect to that observed in the cycloadditions of methyl vinyl ketone to the same dienes (**1**, **2** and cyclopentadiene) confirms the hypothesis that attractive *van der Waals* [26] and dipole-dipole interactions [27] between the dienophile substituents and the dienes are responsible for the *Alder* rule [28].

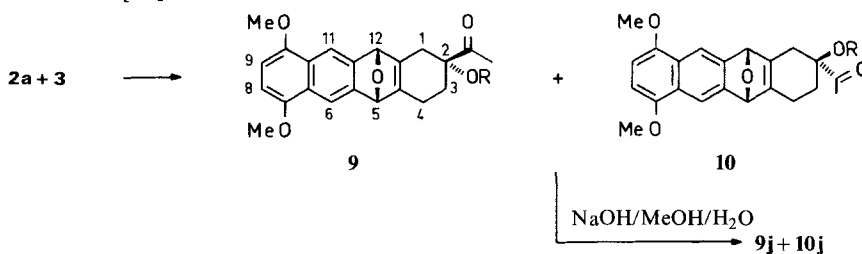
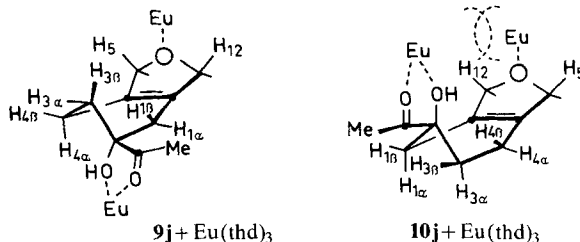


Table 3. Yields of the adducts **9a–h**+**10a–h** obtained by cycloaddition of **2a** to the dienophiles **3a–h** in xylene and stereoselectivities of the hydrolyzed adducts **9j/10j**

Dienophile	3a	3b	3c	3d	3e	3f	3g	3h
Temperature [$^\circ\text{C}$]	160	160	160	160	140	140	140	140
Time [h]	12	5	4	3	5	3	8	8.5
Yield of 9 + 10 [%]	30	21	68	70	50	66	63	69
Product ratio								
9j/10j	50:50 ^a)	50:50 ^b)	65:35	60:40	60:40	40:60	38:62	50:50

^a) Measured on **9a/10a**. ^b) Measured on **9b/10b**.

The alcohols **9j** and **10j** obtained by saponification of the esters **9(c-h)** **10(c-h)** were easily separated by chromatography. The proposed structures were deduced from their $^1\text{H-NMR}$ (360 MHz) spectra with the help of double irradiation experiments, the use of $\text{Eu}(\text{thd})_3$ complexing agent and by comparison with analogs [2] [24a].



The 'exo' allylic protons $\text{H-C}(1\beta, 4\beta)$ are assumed to be more deshielded than the 'endo' hydrogens $\text{H-C}(1\alpha, 4\alpha)$ due to the anisotropy of the 5,12-epoxide. Typical coupling constants between $\text{H}_2\text{C}(1, 3, 4)$ confirm a half-chair conformation of the cyclohexene systems [29] and allow the distinction between pseudo-axial and pseudo-equatorial H-atoms (*cf.* Table 4). Interestingly, a long-range $^5J(\text{H}, \text{H})$ coupling constant of *ca.* 1 Hz was measured in **9j** between the pseudo-axial

Table 4. $^1\text{H-NMR}$ (360 MHz, *ca.* 0.03M) of the alcohols **9j** and **10j**
(δ_{H} in ppm, $\delta_{\text{TMS}} = 0.0$ ppm, $J(\text{H}, \text{H})$ in Hz)

	$\text{H-C}(1\alpha)$ (1 β)		(3 α)	(3 β)	(4 α)	(4 β)	(5)	(6)
9j (in CD_2Cl_2) δ_{H}	1.81	2.87	1.56	1.92	2.02	2.51	5.53	7.93
relative LIS ^a)	0.70	0.58	0.54	0.53	0.27	0.30	0.96	0.33
10j (in C_6D_6) δ_{H}	1.90	2.03	0.87	1.22	1.59	2.32	5.34	8.19
relative LIS ^b)	0.6	0.47	0.65	(1.0)	0.52	0.55	0.37	0.1

	$\text{H-C}(8, 9)$ (11)		(12)	$\text{CH}_3\text{O-C}(7, 10)$	$\text{CH}_3\text{CO-C}(2)$
9j (in CD_2Cl_2) δ_{H}	6.75	7.90	5.50	3.92/3.93	2.20
relative LIS ^a)	0	0.27	(1.0)	–	0.38
10j (in C_6D_6) δ_{H}	6.48	8.19	5.29	3.54	1.39
relative LIS	0	0.1	0.42	–	0.52

$J(\text{H}, \text{H})$	(1 α , 1 β)	(1 α , 3 α)	(1 α , 3 β)	(1 α , 4 α)	(1 α , 4 β)	(1 α , 5)	(1 β , 3 α)	(1 β , 3 β)	(1 β , 4 α)
9j	17.5	2.0	<0.5	2.0	<1.0	<0.5	<1.0	<1.0	4.0
10j	17.5	<0.5	<0.5	2.5	4.0	~1.0	<0.5	<1.0	1.25

$J(\text{H}, \text{H})$	(1 β , 4 β)	(1 β , 5)	(3 α , 3 β)	(3 α , 4 α)	(3 α , 4 β)	(4 α , 4 β)	(4 α , 12)	(4 β , 12)	(3 β , 4 α)
9j	3.0	1.0	13.0	5.4	2.4	17.0	1.0	<1.0	12.3
10j	2.5	<0.5	13.1	6.6	10.0	16.6	<0.5	~1.0	2.5

^a) LIS induced by $\text{Eu}(\text{thd})_3$, linear LIS as function of added complex was observed for $[\text{Eu}(\text{thd})_3]/[\text{9j}]$ up to 0.7.

^b) LIS induced by $\text{Eu}(\text{thd})_3$, linear LIS as function of added complex for $[\text{Eu}(\text{thd})_3]/[\text{10j}]$ up to 0.4, at higher complex/substrate ratio, a significant deviation from linearity was observed for $\text{H-C}(1\alpha, 1\beta, 3\alpha)$ and $\text{CH}_3\text{CO-C}(2)$.

H–C(1 β) and H–C(4 α) and the bridgehead H–C(5) and H–C(12), respectively. In **10j**, a similar coupling constant was found between H–C(1 α) and H–C(5) and between H–C(4 β) and H–C(12). Addition of Eu(thd)₃ led to induced chemical shifts (LIS), suggesting a relatively strong complexation of the 5,12-epoxy function. Competitive complexation of the 2-hydroxy and 2-acetyl groups was also observed. The LIS ratios H–C(6)/CH₃CO and H–C(11)/CH₃CO are one probe for the conformation and configuration of **9j** and **10j**. In agreement with our assignments, we found these LIS ratios to be significantly larger for **9j** (ca. 0.85) than for **10j** (ca. 0.2). A further confirmation was given by the observation of linear LIS as function of the Eu(thd)₃ concentration for all the proton signals of **9j** (cf. Table 4). In the case of **10j**, remarkable deviations from linearity were observed for the CH₃CO and H–C(1 α ,1 β ,3 α) chemical shifts when the concentration ratio Eu(thd)₃/**10j** was larger than 0.4. This suggests a change in the conformation of the cyclohexene system of **10j** upon increase of the Eu(thd)₃ concentration because of steric crowding in the complexes (cf. scheme here above).

Conclusion. – 1-Acetylvinyl arenecarboxylates are better dienophiles than 3-trimethylsilyloxy- and 3-alkoxy-3-buten-2-one. The larger the electron-withdrawing ability of the enol protecting group, the faster is the *Diels-Alder* addition with an *endo*- or *exocyclic* diene. These new dienophiles are useful building blocks as shown by their cycloadditions to the dienes **1** and **2a**, two intermediates in our doubly-convergent approach to the synthesis of anthracyclinones.

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Experimental Part

General remarks. See [2]. TMSCl = trimethylchlorosilane.

3-Trimethylsilyloxy-3-buten-2-one (3a). TMSCl (15.2 ml, 0.12 mol) was added in 45 min to a stirred mixture of biacetyl (8.6 g, 0.1 mol), Et₃N (33.6 ml, 0.24 mol) in anh. THF (140 ml) at RT. After heating under reflux for 6 h, the mixture was left overnight at 0°. After filtration, the solvent was removed i.v. and ether was added (70 ml). The solution was extracted successively with 1.5N HCl (2 × 10 ml), saturated aq. NaHCO₃-solution (2 × 10 ml) and sat. NaCl-solution (3 × 20 ml). After drying (Na₂SO₄) and solvent removal i.v., the residue was distilled. Yield 9 g (57%) (the best yield obtained following *Conia's* procedure [16] was 10% in our hands), b.p. 45°/0.1 Torr. – UV. (isooctane): 289 (166), 244 (1360), does not vary with the concentration, whereas in CH₃CN the UV. spectrum is strongly dependent upon the concentration:

	Conc. of 3a [mol l ⁻¹]					
	1.77 × 10 ⁻³	1.64 × 10 ⁻³	3.54 × 10 ⁻⁴	3.28 × 10 ⁻⁴	1.77 × 10 ⁻⁴	8.2 × 10 ⁻⁵
λ _{max}	266	266	255	255	252	248
ε _{max}	282	312	689	774	875	1024

IR. (film): 1980s, 1700vs, 1620vs, 850vs. – ¹H-NMR. (CDCl₃): 5.3 (*d*, *J* = 2, 1 H); 4.8 (*d*, *J* = 2, 1 H); 2.2 (*s*, 3 H); 0.2 (*s*, 9 H). – ¹³C-NMR. (CDCl₃): 196.1 (*m*); 153.7 (*m*); 101.5 (*d* × *d*, 158.8, 162.5); 25.3 (*qa*, 128); –4.0 (*qa* × *m*, 118). – MS. (70 eV): 143 (100, *M*⁺ – 15), 101 (9), 75 (55), 45 (22), 43 (55).

3-Acetoxy-3-buten-2-one (3c). Acetylchloride (17.1 ml, 0.24 mol) was added dropwise to a stirred mixture of biacetyl (17.2 g, 0.2 mol), Et₃N (41 ml, 0.29 mol) and anh. THF (100 ml) maintained at –20°

under N_2 . After the addition, the mixture was allowed to warm up to RT. and stirred for 8 h. After addition of Et_2O (50 ml) and filtration, the solvent was evaporated i.v. The residue was dissolved in Et_2O (60 ml) and washed successively with ice-cold 1.5N HCl (2×10 ml), sat. $NaHCO_3$ -solution (2×10 ml) and sat. NaCl-solution (4×30 ml). After drying (Na_2SO_4), the solvent was eliminated i.v. and the residue distilled. Yield 6.33 g (25%, cf. [14]), b.p. $32^\circ/5$ Torr [17]. – UV. (isooctane): 324 (37), 214 (7300) does not vary with the concentration, whereas in CH_3CN , the UV. spectrum varies strongly with the concentration:

	Conc. of 3c [mol l ⁻¹]					
	4.14×10^{-3}	2.21×10^{-3}	2.07×10^{-3}	1.105×10^{-3}	8.28×10^{-4}	2.21×10^{-4}
λ_{max}	243	240	240	237	236	230
ϵ_{max}	43	64	69.5	99.5	123	239

IR. (film): 1770_{vs}, 1705_{vs}, 1650_s, 1210_{vs}. – 1H -NMR. ($CDCl_3$): 5.9 (*d*, $J=2$, 1 H); 5.7 (*d*, $J=2$, 1 H); 2.37 (*s*, 3 H); 2.25 (*s*, 3 H). – ^{13}C -NMR. ($CDCl_3$): 191.2 (*m*); 168.4 (*m*); 151.4 (*m*); 113.4 (*t*, 162); 24.9 (*qa*, 128.3); 19.9 (*qa*, 130). – MS. (70 eV): 128 (12), 101 (6.2), 43 (100).

General procedure for the preparation of 1-acetylvinyl arenecarboxylates (3d–3h). The corresponding acyl chloride ($R-COCl$) (0.12 mol) in anhyd. THF (60 ml) was added dropwise (*ca.* 30 min) to a stirred solution of Et_3N (33.6 ml, 0.24 mol) in anhyd. THF/HMPTA 8:2 (100 ml) maintained at 0° . Then, biacetyl (8.6 g, 0.1 mol) in anhyd. THF (30 ml) was added dropwise (*ca.* 15 min) under N_2 . After the addition, the mixture was stirred at RT. for 24 h under N_2 . Light petroleum/ethyl acetate 9:1 (300 ml) was added. After vigorous stirring for 10 min, ice/water (100 ml) was added, the organic layer was collected and the water layer extracted with light petroleum (2×100 ml). The combined organic extracts were washed successively with ice-cold 5% HCl-solution (2×50 ml), aq. $NaHCO_3$ -solution (2×50 ml) and H_2O (4×100 ml). After drying ($MgSO_4$), the solvent was evaporated i.v. The residue contains the crude dienophile. **3d** was purified by flash distillation, b.p. *ca.* $90^\circ/0.001$ Torr, 8.94 g (47%). – UV. (CH_3CN): 229 (16100), 274 (1100), 280 (870). – IR. (film): 3060_w, 1740_{vs}, 1700_{vs}, 1690_s, 1640_s, 1600_s, 1250_{vs}. – 1H -NMR. ($CDCl_3$): 8.22 (*m*, 2 H); 8.1 (*m*, 3 H); 6.1 (*d*, $J=2$, 1 H); 5.7 (*d*, $J=2$, 1 H); 2.42 (*s*, 3 H). – ^{13}C -NMR. ($CDCl_3$): 191.6 (*m*); 164.4 (*m*); 151.1 (*m*); 133.6 (*d* $\times$ *t*, 159.3, $^3J(C,H)=8$); 130 (*d* $\times$ *t*, 161.6, $^3J(C,H)=6.4$); 128.5 (*m*); 128.4 (*d* $\times$ *d*, 162, 6.4); 113.7 (*t*, 163); 25.2 (*qa*, 128). – MS. (70 eV): 190 (1.5, M^+), 149 (3.7), 106 (18), 105 (100), 77 (99), 51 (48), 43 (28).

$C_{11}H_{10}O_3$ (190.98) Calc. C 69.46 H 5.30% Found C 69.76 H 5.30%

Compound **3e** was recrystallized from $AcOEt/MeOH$ 7:3. Yield: 10.5 g (45%), m.p. 114.5 – 115.5° . – UV. (CH_3CN): 260 (14900); 209 (15000). – IR. (CH_2Cl_2): 3040_w, 1745_{vs}, 1700_{vs}, 1640_s, 1610_s, 1350_{vs}, 1120_{vs}, 1090_{vs}, 920_s, 870_s, 850_s. – 1H -NMR. ($CDCl_3$): 8.4 (*m*, 4 H); 6.13 (*d*, $J=3$, 1 H); 5.86 (*d*, $J=3$, 1 H); 2.46 (*s*, 3 H). – ^{13}C -NMR. ($CDCl_3$): 190.2 (*m*); 162.2 (*m*); 151.1 (*m*, C(3)); 150.4 (*m*); 133.6 (*m*); 130.6 (*d* $\times$ *m*, 169.4); 122.8 (*d* $\times$ *m*, 172); 114.2 (*t*, 163); 25.17 (*qa*, 128). – MS. (70 eV): 235 (1.8, M^+), 150 (91), 120 (12), 104 (47), 92 (45), 76 (68), 75 (23), 74 (18), 50 (50), 43 (100), 42 (26).

$C_{11}H_9NO_3$ (235.196) Calc. C 56.17 H 3.86 N 5.96% Found C 56.29 H 3.93 N 6.1%

Compound **3f** was purified by filtration on a florisil column (60 g, light petroleum/ $AcOEt$ 8:2) and recrystallization from $AcOEt/MeOH$ 3:2. Yield: 14.8 g (53%), colourless crystals, m.p. 108 – 109° . – UV. (CH_3CN): 289 (3100), 236 (15400), 208 (21100). – IR. (CH_2Cl_2): 3050_w, 1765_{vs}, 1700_{vs}, 1645_s, 1610_s, 1540_{vs}, 1350_{vs}, 1240_{vs}, 1120_{vs}, 1100_{vs}, 1050_{vs}, 930_s, 850_s, 830_s. – 1H -NMR. ($CDCl_3$): 8.96 (*d*, $J=2$, 1 H); 8.7 (*d* $\times$ *d*, $J=2$, 9, 1 H); 6.21 (*d*, $J=3$, 1 H); 6.02 (*d*, $J=3$, 1 H); 2.47 (*s*, 3 H). – ^{13}C -NMR. ($CDCl_3$): 190.3 (*m*); 161.5 (*d* $\times$ *m*, $^3J(C,H)=5.5$); 150.8 (*m*); 148.8 (*m*); 147.7 (*m*); 131.8 (*t*, $^3J(C,H)=5.5$); 131.6 (*d*, 174); 127.6 (*d* $\times$ *d*, 174.8, 4.5); 119.4 (*d* $\times$ *d*, 176.7, 4.5); 115.5 (*t*, 164); 24.8 (*qa*, 129). – MS. (70 eV): 223 (100), 195 (17), 188 (25), 160 (30), 115 (50), 91 (26), 77 (27). – MS. (CI, *i*- C_4H_{10}): 281 ($M^+ + 1$).

$C_{11}H_8N_2O_7$ (280.193) Calc. C 47.15 H 2.88 N 9.99% Found C 47.20 H 3.07 N 9.93%

Compound **3g** was purified by filtration on a florisil column (200 g, light petroleum/ $AcOEt$ 9:1) and recrystallization from $MeOH$. Yield: 10.33 g (43%), slightly yellow crystals, m.p. 62 – 63° . – UV. (CH_3CN): 320 (4300), 300 (6800), 233 (23700), 215 (46700), 211 (48800). – IR. (KBr): 3050_w, 1740_{vs}, 1700_{vs}, 1640_s, 1280_{vs}, 1240_{vs}, 1190_{vs}, 1120_{vs}, 780_{vs}. – 1H -NMR. ($CDCl_3$): 9.0 (*m*, 1 H); 8.45

($d \times d$, $J = 1.5$, 6.5, 1 H); 8.21–7.33 (m , 5 H); 6.1 (d , $J = 2.3$, 1 H); 5.81 (d , $J = 2.3$, 1 H); 2.43 (s , 3 H). – ^{13}C -NMR. (CDCl_3): 191.5 (m); 165.0 (d , $^3J(\text{C},\text{H}) = 5.0$); 151.7 (t , $^3J(\text{C},\text{H}) = 5.5$); 134.0 ($d \times d \times d$, 159.6, 7.3 and 4.5); 133.5 (m); 131.0 (m); 131.0 ($d \times d$, 163, $^3J = 8.3$); 128.3 (d , 163); 127.8 (d , 160); 126.1 (d , 148); 125.3 (d , 162); 124.9 (m); 124.2 ($d \times m$, 164); 113.7 (t , 162.5); 25.2 (qa , 128.2). – MS. (70 eV): 240 (18), 156 (5), 155 (33), 128 (8), 127 (57), 126 (22), 101 (9), 77 (15), 76 (6), 75 (13), 43 (100), 42 (29).

$\text{C}_{15}\text{H}_{12}\text{O}_3$ (240.258) Calc. C 74.99 H 5.03% Found C 75.04 H 5.16%

Compound **3h** was purified by filtration on *florisil* (200 g, light petroleum/AcOEt 9:1) and double recrystallization from MeOH. Yield: 8.5 g (35%), m.p. 84–85°. – UV. (CH_3CN): 335 (1800), 292 (6040), 281 (8600), 273 (7000), 239 (62200), 215 (29500). – IR. (CH_2Cl_2): 3060 w , 1740 vs , 1700 vs , 1640 s , 1220 vs , 1200 vs , 1130 vs , 1080 vs . – ^1H -NMR. (CDCl_3): 8.77 (br. s , 1 H); 8.37–7.42 (m , 6 H); 6.1 (d , $J = 2$, 1 H); 5.8 (d , $J = 2$, 1 H); 2.42 (s , 3 H). – ^{13}C -NMR. (CDCl_3): 191.4 (m); 164.5 (m); 151.8 (t , $^3J(\text{C},\text{H}) = 6.4$); 135.6 (m); 132.2 (m); 131.8 (m); 129.1 ($d \times d$, 161, $^3J = 7.3$); 128.4 (d , 160); 128.1 (d , 160.5); 127.5 (d , 160); 126.6 ($d \times d$, 161, $^3J = 7.3$); 125.4 (m); 125.1 ($d \times d$, 165, $^3J = 7.3$); 113.2 (t , 163); 25.2 (qa , 129). – MS. (70 eV): 240 (3.7), 155 (70), 127 (100), 126 (36), 101 (13), 77 (21), 75 (15), 43 (63).

$\text{C}_{15}\text{H}_{12}\text{O}_3$ (240.258) Calc. C 74.99 H 5.03% Found C 75.12 H 5.06%

2,7-Dehydro-4-hydroxy-9,10-dimethylidene-11-oxa-4-tricyclo[6.2.1.0 2,7]undecyl methyl ketones (**7j** + **8j**). The tetraene **1** (0.1 g, 0.68 mmol [5]), the dienophile **3d** (0.258 g, 1.35 mmol) and hydroquinone (1 mg) were heated in CCl_4 (0.35 ml) to 110° for 5 h under N_2 . The crude adducts **7d** + **8d** were purified by column chromatography (60 g *florisil*, hexane/AcOEt 9:1) and saponified in MeOH/ H_2O /THF/1N NaOH (18:2.5:1.1 ml) (RT., 4 h). After neutralization with 5% HCl-solution and solvent distillation i.v., the aqueous residue was extracted with AcOEt (3 $\times$ 20 ml). The organic extract was washed with a sat. NaCl-solution (2 $\times$ 10 ml). After drying (Na_2SO_4), the solvent was distilled off under normal pressure. The crude **7j** + **8j** were purified and separated by TLC. (Al_2O_3 150, F 254 Type T, Merck, hexane/AcOEt 6:4).

Compound **7j**, yield: 0.05 g (31.6%), oil. – UV. (EtOH): 240 (15900), 231 (21000), 223 (24500), 210 (28700). – IR. (CH_2Cl_2): 3450 w , 3010 w , 2930 s , 1710 vs , 1670 s , 1360 s , 1200 s , 1100 s . – ^1H -NMR. (CDCl_3): 5.21 (s , 2 H); 5.01 (s , 1 H); 4.96 (s , 1 H); 4.91 (s , 2 H); 3.06 (s , 2 H); 2.76 (d , $J = 17.2$, 1 H); 2.25 (s , 4 H); 1.65–2.05 (m , 4 H). – MS. (70 eV): 232 (0.7, M^+), 214 (4.3), 189 (13), 185 (12), 171 (21), 161 (9.0), 143 (18), 137 (28), 128 (10), 115 (21), 91 (31), 77 (21), 55 (30), 43 (100).

$\text{C}_{14}\text{H}_{16}\text{O}_3$ (292.279) Calc. C 72.39 H 6.94% Found C 72.07 H 7.02%

Compound **8j**, yield: 0.048 g (30.4%), oil. – UV. (EtOH): 241 (13600), 231 (18200), 223 (21200), 209 (26900). – IR. (CH_2Cl_2): 3440 s , 3005 w , 2920 s , 1700 vs , 1660 s , 1355 s , 1190 s , 1100 vs . – ^1H -NMR. (CDCl_3): 5.17 (s , 2 H); 5.0 (s , 2 H); 4.92 (s , 1 H); 4.85 (s , 1 H); 3.48 (s , 1 H); 2.35 (s , 3 H); 2.15 (s , 4 H); 1.68 (m , 2 H). – MS. (70 eV): 232 (0.4, M^+), 214 (2.0), 189 (12), 185 (15), 167 (20), 149 (60), 137 (20), 91 (18), 69 (43), 57 (75), 55 (50), 43 (100).

$\text{C}_{14}\text{H}_{16}\text{O}$ (232.279) Calc. C 72.39 H 6.94% Found C 72.26 H 6.99%

5,12-Epoxy-1,2,3,4,5,12-hexahydro-2-hydroxy-7,10-dimethoxy-2-naphtacenyl methyl ketone (**9j** + **10j**). The diene **2a** [3] (0.3 g, 1.07 mmol), the dienophile **3d** (0.6 g, 3.15 mmol) and hydroquinone (5 mg) were heated in xylene (0.9 ml) at 160° for 3 h under N_2 . The mixture was purified by column chromatography (*Florisil*, 25 g; hexane/AcOEt 9:1). The adducts **9d** + **10d** (0.35 g, 0.75 mmol) were saponified in MeOH/ H_2O /1N NaOH 27:3:15 (32 ml, RT., 8 h, under N_2 and stirring). The mixture was neutralized with 5% HCl-solution and the solvent distilled i.v. After extraction with AcOEt (3 $\times$ 30 ml), the organic phase was washed with sat. NaCl-solution (2 $\times$ 20 ml), dried (Na_2SO_4) and concentrated i.v. The crude **9j** + **10j** mixture was purified and separated by TLC. (Al_2O_3 , F-254, Type T, Merck, hexane/AcOEt 6:4). **9j**, yield: 0.129 g (33%), colourless crystals, m.p. 183–184.5° (dec.). – UV. (dioxane): 341 (6360), 325 (6800), 293 (9960), 262 (64500), 220 (65300). – IR. (CH_2Cl_2): 3480 s , 3010 w , 2900 vs , 1710 vs , 1620 vs , 1460 vs , 1380 s , 1340 vs , 1200 s , 1140 vs , 1090 vs , 1050 vs , 800 s . – ^1H -NMR. (CD_2Cl_2 ; cf. Table 4. – MS. (70 eV): 366 (100, M^+), 351 (8.2), 323 (23), 319 (9.6), 305 (26), 295 (15), 277 (20), 265 (13), 252 (20), 237 (23), 221 (15), 165 (12), 43 (11).

$\text{C}_{22}\text{H}_{22}\text{O}_5$ (366.413) Calc. C 72.11 H 6.05% Found C 72.05 H 6.11%

Compound **10j**, yield: 0.09 g (23%), oil. – UV. (dioxane): 340 (6410), 325 (6520), 294 (10000), 260 (64600), 219 (63500). – IR. (CH_2Cl_2): 3480s, 3020w, 2910vs, 2860vs, 1715vs, 1620vs, 1470vs, 1340vs, 1220vs, 1200vs, 1140vs, 1090vs, 1060vs, 800–700vs. – $^1\text{H-NMR}$., cf. Table 4. – MS. (70 eV): 366 (100, M^+), 351 (12), 333 (11), 323 (21), 305 (18), 277 (27), 252 (21), 237 (28), 165 (20), 43 (32).

$\text{C}_{22}\text{H}_{22}\text{O}_5$ (366.413) Calc. C 72.11 H 6.05% Found C 72.29 H 6.14%

Cyclopentadiene adduct with 3f. A mixture of the dienophile **3f** (0.05 g, 0.178 mmol), cyclopentadiene (0.17 g, 2.57 mmol) and hydroquinone (3 mg) was heated in CH_2Cl_2 (0.06 ml) at 50° for 5 h under N_2 . The precipitate was isolated by filtration and washed with hexane (2×5 ml). The crude **5f**+**6f** mixture was purified by recrystallization from $\text{AcOEt}/\text{Et}_2\text{O}$ 7:3: yield: 0.056 g (90%) colourless crystals. – UV. (dioxane): 260 (18000), 242 (25600). – IR. (KBr): 3100w, 1740–1710vs, 1600s, 1550–1530vs, 1340vs, 1300vs, 1250vs, 1100vs, 1050vs. – $^1\text{H-NMR}$. (CDCl_3): 8.82 (d, $J=1.6$, 1 H); 8.72 (d, $J=1.6$, 1 H); 8.61 (d, $J=3.2$ and 1.6, 1 H); 8.52 (d, $J=3.2$ and 1.6, 1 H); 8.03 (d, $J=3.2$, 1 H); 7.92 (d, $J=3.2$, 1 H); 6.46 (m, 2 H); 6.05 (d, $J=6.0$, 3.0, 1 H); 5.85 (d, $J=6.0$, 3.0, 1 H); 3.1 (m, 4 H); 2.8 (d, $J=13.0$, 4.0, 1 H); 2.51 (d, $J=2.6$, $\frac{1}{2}$ H); 2.31 (s, 4 H); 2.21 (s, 3 H); 2.08 (d, $J=3.2$, $\frac{1}{2}$ H); 1.35–1.96 (m, $4\frac{1}{2}$ H); 1.3 (d, $J=3.2$, $\frac{1}{2}$ H). – MS. (70 eV): 195 (20), 151 (5), 149 (4), 123 (6), 91 (7.7), 77 (11), 75 (26), 66 (100), 43 (99). – MS. (CI, $i\text{-C}_4\text{H}_{10}$): 347 ($M^+ + 1$).

$\text{C}_{16}\text{H}_{14}\text{N}_2\text{O}_7$ (346.293) Calc. C 55.49 H 4.07 N 8.09% Found C 55.58 H 4.19 N 8.17%

Kinetic measurements. The reaction of cyclopentadiene (at least 30-fold excess, redistilled twice, 100% pure by GC.) with the dienophiles **3a–h** (redistilled or recrystallized before use, 0.18 to 0.27 M) in degassed (Ar) CH_2Cl_2 was followed by GC. (Hewlett Packard 5710 A, catharometer, internal standard: $n\text{-C}_{10}$ to $n\text{-C}_{18}$, SE-30 10%– $4' \times 0.25''$ or Carbowax 20 M 5%– $4' \times 0.25''$ or OV-101 10%– $4' \times 0.25''$, 100–200°, ~30 ml/min He). The disappearance of **3a–h** was measured (Hewlett-Packard integrator HP 3380 A) as a function of time. The solutions (~0.6 ml) were placed in 10 ml pyrex tubes sealed with a septum and immersed in a thermostated ($50^\circ \pm 0.1^\circ$) bath (Colora NBDS thermostat). The concentration of the formed dicyclopentadiene was measured simultaneously with that of unreacted **3a–h**.

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