

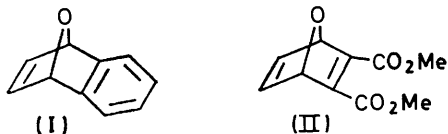
Studies of Bridged Benzo-heterocycles. Part II.¹ Cycloaddition Reactions of Epoxy-bridged Cyclic Olefins with Tropone and Tropolone, and Photochemical Behaviour of the Adducts

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Reactions of 1,4-epoxy-1,4-dihydronaphthalene (I) with tropone and tropolone gave rise to the $[4 + 2]\pi$ *endo,exo*- (IIIa), and *exo,exo*- (Vb) cycloadducts, respectively, in relatively high yield; reactions of dimethyl 7-oxabicyclo[2,2,1]hepta-2,5-diene-2,3-dicarboxylate (II) with tropone and tropolone afforded the $[4 + 2]\pi$ *endo,exo*- (VIIa), and *endo,exo*- cycloadducts (VIIb), respectively, in comparatively low yields. Irradiations of the tropone adducts (IIIa) and (VIIa) in methanol gave exclusively the methyl 12-oxatetracyclo[7,2,1,0^{2,8},0^{3,5}]-dodecadien-4-ylacetates (XIIa and b). Similar irradiations of the tropolone adducts (Vb) and (VIIb) give the 14-oxotetracyclo[9,2,1,0^{2,10},0^{3,7}]tetradecadien-6,9-diones (XV) and (XVII), respectively, each being the only product. The photoproducts (XIIa and b) are formed by addition of methanol to initially formed ketens, and the photoproducts (XV) and (XVII) by [1,3] sigmatropic rearrangements of (Vb) and (VIIb), respectively, followed by hydrogen shifts.

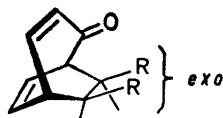
NORBORNADIENYL compounds show a low reactivity towards dienes;² thus cycloaddition reactions with these compounds as dienophiles are rare. However, 7-oxanorborniadienyl compounds, such as 1,4-epoxy-1,4-dihydronaphthalene (I)³ and dimethyl 7-oxabicyclo[2,2,1]hepta-2,5-diene-2,3-dicarboxylate (II),^{4,5} are effective dienophiles.⁶ Their increased dienophilicity is presumably due to ring strain and to orbital participation of the *n*-electrons of the proximate oxygen atom.^{1,7} Thus, compounds (I) and (II) would be expected to react more readily with electron-poor dienes, such as tropone and tropolone.

We have characterized the products of the thermal cycloaddition reactions of compounds (I) and (II) with tropone and tropolone, and have investigated the photochemical behaviour of the adducts.



Reactions of the epoxide (I) with tropone in chlorobenzene at 130–140° gave an adduct in quantitative yield. Elemental analysis and the mass spectrum (M^+ 250) showed the product to be a 1:1 adduct, for which the four stereoisomeric structures (IIIa)–(VIa) are conceivable. The presence of the bicyclo[3,2,2]nona-3,6-dien-2-one system was suggested by spectral data. The n.m.r. spectrum is very similar to those of Diels-Alder adducts from tropone and azo-dienophiles⁸ in the olefinic region. The structure of the adduct was

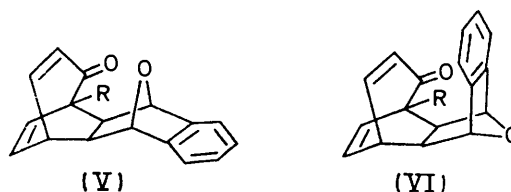
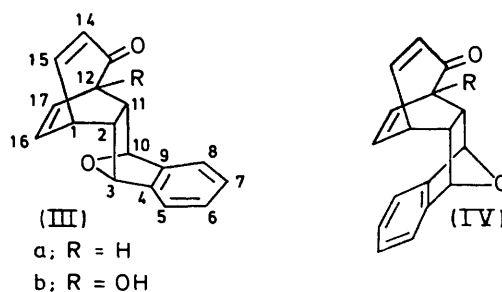
† The former prefix refers to the configuration with respect to the bicyclo[3,2,2]nonadienone system (substituents on the carbonyl side are defined as *exo*); the latter refers to the configuration with respect to the oxanorbornene system.



¹ Part I, T. Sasaki, K. Kanematsu, and M. Uchide, *Tetrahedron Letters*, 1971, 4855.

² M. P. Cava and F. M. Scel, *J. Org. Chem.*, 1967, **32**, 1304.

eventually proved by a complete analysis of the n.m.r. spectrum.



The absence of appreciable coupling between H-1 and H-2 and between H-11 and H-12 indicated the bridgehead protons (H-2 and H-11) to be *exo* to the bicyclo[3,2,2]nonadienone system,⁹ thus ruling out structures (Va) and (VIa). Furthermore, the oxygen bridgehead protons (H-3 and H-10) each give rise to a sharp singlet (τ 4.88 and 4.98, respectively) with no vicinal coupling to H-2 and H-11. Therefore, H-2 and H-11 must be *endo* to the oxabenzonorbornene system,¹⁰ and structure (IVa) is ruled out. Thus the adduct was assigned structure (IIIa), that of the $[4 + 2]\pi$ cycloadduct with *endo,exo*-configuration.†

³ G. R. Ziegler, *J. Amer. Chem. Soc.*, 1969, **91**, 446.

⁴ H. Prinzbach, M. Argüell, and E. Druchrey, *Angew. Chem.*, 1966, **78**, 1057.

⁵ P. Deslongchamps and J. Kallos, *Canad. J. Chem.*, 1967, **45**, 2235.

⁶ L. F. Fieser and M. J. Naddain, *Canad. J. Chem.*, 1965, **43**, 1599.

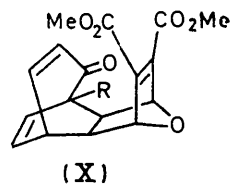
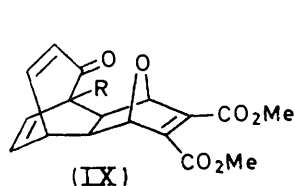
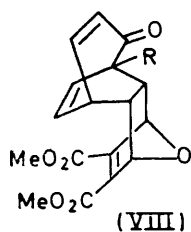
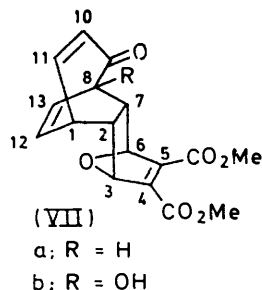
⁷ R. N. Warrener, *J. Amer. Chem. Soc.*, 1971, **93**, 2346.

⁸ T. Sasaki, K. Kanematsu, and K. Hayakawa, (a) *J. Chem. Soc. (C)*, 1971, 2142; (b) *J.C.S. Perkin I*, 1972, 783.

⁹ S. Ito, K. Sakan, and Y. Fujise, *Tetrahedron Letters*, 1969, 775.

¹⁰ J. D. Slee and E. LeGoff, *J. Org. Chem.*, 1970, **35**, 3897.

Reaction of the diester (II) with tropone in benzene at 130° gave an adduct in 21% yield. Elemental analysis and the mass spectrum (M^+ 316) showed it to be a 1:1 adduct. The n.m.r. spectrum was very similar to that of compound (IIIa) except that signals for two methoxy-groups replaced those of the benzene ring. Of the possible Diels–Alder adduct structures (VIIa)—(Xa), only structure (VIIa), accommodates the data, *i.e.* the product was the *endo,exo* [4 + 2] π cycloadduct.†



Reaction of the epoxide (I) with tropolone in chlorobenzene at 130° gave an adduct in quantitative yield. Elemental analysis and the mass spectrum (M^+ 266) showed it to be a 1:1 adduct. The n.m.r. spectrum exhibited signals at τ 2.90 (4H, m, ArH), 2.92 (1H, q, H-15), 3.62 (1H, q, H-16), 3.79 (1H, d, H-14), 4.03 (1H, d, H-17), 4.32 (1H, d, H-10), 4.90 (1H, s, OH, exchangeable), 5.01 (1H, d, H-3), 6.42 (1H, m, H-1), 7.53 (1H, dd, H-2), and 7.91 (1H, d, H-11), and suggested the presence of the bicyclo[3,2,2]nona-3,6-diene-2-one system. The absence of a signal due to H-12 and long-range coupling between H-12 and H-14 indicated that the hydroxy-group is at the bridgehead C-12 rather than at C-14. These data suggest the four possible structures (IIIb)—(VIb). The presence of the coupling between H-1 and H-2 (J 3.5 Hz) indicated the oxabenzonorbornadiene ring to be *exo* to the bicyclo[3,2,2]nonadienone system, ruling out structures (IIIb) and (IVb). The presence of long-range coupling between H-3 and H-10 (J 2.0 Hz), and the absence of vicinal couplings between H-2 and H-3 and between H-10 and H-11 were observed in double-resonance experiments; on irradiation at the frequency of H-10, the signal of H-3 collapsed to a singlet but there was no change in that of H-2. The bridgehead protons (H-2 and H-11) were therefore assigned as *endo* to the

† See footnote on page 1951.

¹¹ L. M. Jackman and S. Sternkell, 'Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry,' Pergamon, Oxford, 1969.

¹² Y. Kitahara, I. Murata, and T. Nitta, *Tetrahedron Letters*, 1967, 3003.

¹³ S. Ito, H. Takeshita, Y. Shoji, Y. Toyooka, and T. Nozoe, *Tetrahedron Letters*, 1968, 3215.

oxabenzonorbornene system, and structure (VIb) was ruled out. Furthermore, H-14 was deshielded by the anisotropic effect of the bridge oxygen atom¹¹ in comparison with H-14 in (IIIa). Thus, the product was concluded to be the *exo,exo* [4 + 2] π cycloadduct (Vb).

Reaction of the diester (II) with tropolone in chlorobenzene at 130° gave an adduct in 21% yield. Its elemental analysis and mass spectrum (M^+ 332) showed it to be a 1:1 adduct. The n.m.r. spectrum was very similar to that of compound (Vb) except that the signals of two methoxy-groups replaced those of the benzene ring, and that there was no coupling between H-1 and H-2, and between H-2 and H-3 and also between H-6 and H-7, which indicated the bridgehead protons (H-2 and H-7) to be *endo* to the oxanorbornadiene system. Thus, the product was concluded to be the *endo,exo* [4 + 2] π cycloadduct (VIIb), and the other three possible structures (VIIIb)—(Xb) were ruled out.

The cycloaddition reactions of tropolone with compounds (I) and (II) were in contrast to the reactions of tropolone with azodienophiles, giving ene-adducts.^{8,12} Furthermore, the reaction of compound (I) with tropolone afforded only the *exo*-adduct (Vb), although the reaction of maleic anhydride with tropolone gives both *endo*- and *exo*-adducts.¹³

Attempted reactions of compound (I) with cycloheptatriene and cyclo-octatetraene were unsuccessful even under more drastic conditions, although similar reactions of these compounds with electron-deficient dienophiles have been reported.^{14,15} This seems to stem from the fact that compounds (I) and (II) are electron-rich dienophiles and react preferably with more electron-deficient dienes in inverse Diels–Alder reactions.¹⁶ The electron density at the reactive double bond of structure (I) is increased by through-space interaction¹⁷ with the electron-rich benzene ring, whereas that of compound (II) is decreased by interaction with the electron-poor double bond bearing two electron-attracting methoxycarbonyl groups; this might be the cause of the difference in the reactivity between compounds (I) and (II).

Irradiations of the tropone adducts (IIIa) and (VIIa) in methanol at room temperature for 3 h with a high pressure 100 W mercury lamp in a Pyrex vessel under nitrogen gave only one product in each case [(XIIa), 95%; (XIIb), 94%]. Elemental analysis and the mass spectrum (M^+ 272) of compound (XIIa) showed it to be a methyl ester, presumably formed by addition of methanol to an initially formed keten (XIa). The n.m.r. spectrum was very similar to that of a photoproduct formed from tropone and 2,3-dihydrophthalazine-1,4-dione.⁸ The photoproduct (XIIb) was similarly shown to be a methyl ester, formed through the keten intermediate (XIb).

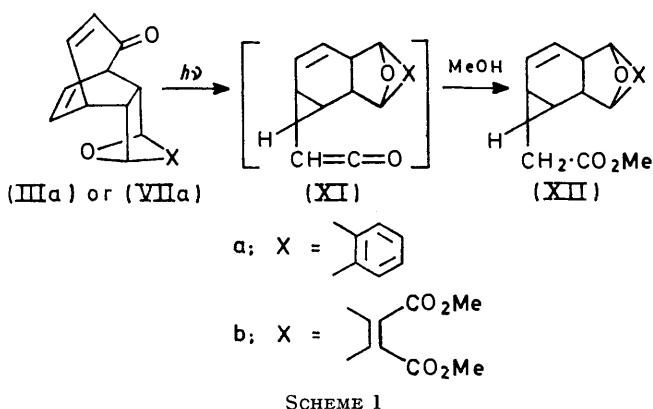
¹⁴ R. C. Cookson, S. S. H. Gilani, and I. D. R. Stevens, *J. Chem. Soc. (C)*, 1967, 1905.

¹⁵ A. B. Evnin, A. Y. Lam, J. J. Maher, and J. J. Blyskal, *Tetrahedron Letters*, 1969, 4497.

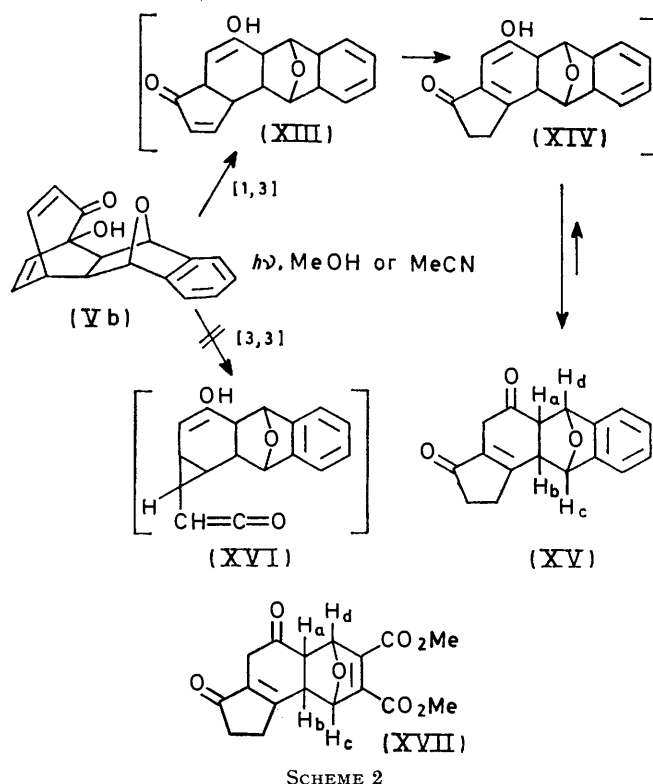
¹⁶ R. Huisgen, R. Grashey, and J. Sauer, 'The Chemistry of Alkenes,' ed. S. Patai, Interscience, New York, 1964, p. 923.

¹⁷ R. Hoffmann, *Accounts Chem. Res.*, 1971, 4, 1.

Irradiation of the adduct (Vb) in methanol under similar conditions gave compound (XV) in 73% yield. When acetonitrile was employed as solvent, the yield of



compound (XV) was only 50%. Elemental analysis and mass spectroscopy ($M^+ 266$) showed the product to be an isomer of (Vb). The i.r. spectrum exhibited absorptions at 1745 and 1700 cm^{-1} due to a carbonyl group on a six-membered ring and an $\alpha\beta$ -unsaturated



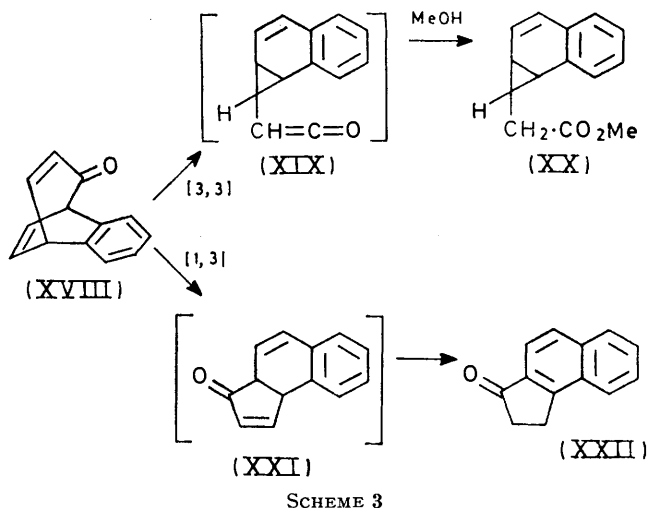
carbonyl group on a five-membered ring; compound (Vb) showed a carbonyl band at about 1660 cm^{-1} .¹⁸ The n.m.r. spectrum of compound (XV) showed no signals for olefinic or hydroxy-protons. The formation of compound (XV) could be explained in terms of an

¹⁸ J. Ciabattoni, J. E. Crowley, and A. S. Kende, *J. Amer. Chem. Soc.*, 1967, **89**, 2778.

initial [1,3]sigmatropic rearrangement of (Vb) to (XIII) followed by isomerization to the conjugated diene (XIV) and ultimate enol-keto tautomerization as shown in Scheme 2.

Analogously, irradiation of the adduct (VIIb) in methanol under similar conditions afforded one product (XVII) in 80% yield. The structure was similarly confirmed by elemental analysis and spectroscopy.

Kende *et al.*¹⁹ have reported that the chemical behaviour of the excited tropone-benzynes adduct (XVIII) involves two distinct and competitive primary processes; the more rapid of these is stereospecific [3,3] rearrangement to a keten intermediate (XIX) which might be trapped by nucleophiles but otherwise reverts rapidly to



the ketone (XVIII), and the minor pathway is a [1,3] acyl migration producing the labile ketone (XXI) which is rapidly converted by weak bases to the ketone (XXII). In contrast, irradiations of compounds (Vb) and (VII), even in methanol, did not afford the [3,3] rearrangement product (XVI) which might be trapped as a methyl ester, but instead gave the [1,3] rearrangement products only. Thus, the hydroxy-group at C-12 (Vb) [C-8 in (VIIb)] caused a marked variation in the photochemical behaviour of the bicyclo[3,2,2]nonadienone system.

EXPERIMENTAL

M.p.s were measured with a Yanagimoto apparatus. Microanalyses were performed with a Perkin-Elmer 240 elemental analyser. N.m.r. spectra were taken with a JEOL C-60-XL spectrometer and with a Varian A60 recording spectrometer, with tetramethylsilane as internal standard. I.r. spectra were taken with a JASCO-IR-S spectrophotometer. Mass spectra were obtained with a Hitachi RMU-D double-focusing spectrometer operating at an ionization potential of 70 eV. The solid samples were ionized by electron bombardment after sublimation directly into the electron beam at 100–150°.

18-Oxapentacyclo[10,3,2,0^{2,11},1^{3,10},0^{4,9}]octadeca-4,6,8,14,16-pentaen-13-one (IIIa).—A solution of tropone (1.1 g) and the

¹⁹ A. S. Kende, Z. Goldschmidt, and P. T. Izzo, *J. Amer. Chem. Soc.*, 1969, **91**, 6858.

oxabenzonorbornadiene (I) (1.4 g) in chlorobenzene (30 ml) was heated at 130–140° in a sealed tube for 10 h. Chromatography on silica gel, followed by recrystallization from benzene–n-hexane gave the *adduct* (IIIa) (2.1 g) as prisms, m.p. 164–165° (Found: C, 81.4; H, 5.85. $C_{17}H_{14}O_2$ requires C, 81.6; H, 5.65%), ν_{\max} (KBr) 1655, 1635, and 1460 cm^{-1} , m/e 250 and 118 (base), τ ($CDCl_3$) 2.88 (4H, m, ArH), 2.92 (1H, q, H-15, J 12.0 and 7.9 Hz), 3.53 (1H, t, H-16, J 7.5 Hz), 3.87 (1H, t, H-17, J 7.5 Hz), 4.41 (1H, dd, H-14, J 12.0 and 2.0 Hz), 4.88 (1H, s, H-3), 4.98 (1H, s, H-10), 6.25 (1H, dd, H-12, J 7.5 and 2.0 Hz), 6.50 (1H, dd, H-1, J 7.9 and 7.5 Hz), 7.47 (1H, d, H-2, J 7.8 Hz), and 7.68 (1H, d, H-11, J 7.8 Hz), λ_{\max} (EtOH) 224 (ϵ 5580), 265sh (1330), 272sh (990), and 350 nm (100).

12-Hydroxy-18-oxapentacyclo[10,3,2,0^{2,11},1^{3,10},0^{4,9}]octadeca-4,6,8,14,16-pentaen-13-one (Vb).—A solution of tropolone (0.6 g) and the dienophile (I) (0.7 g) in chlorobenzene (20 ml) was heated at 120–130° in a sealed tube for 10 h. Chromatography on silica gel followed by recrystallization from acetone–ether gave the *adduct* (Vb) (1.25 g) as prisms, m.p. 168–172° (Found: C, 76.95; H, 5.05. $C_{17}H_{14}O_3$ requires C, 76.65; H, 5.3%), ν_{\max} (KBr) 3460, 1660, and 1460 cm^{-1} , m/e 266 and 118 (base), λ_{\max} (EtOH) 230 (ϵ 5780), 263sh (1690), 272sh (1100), and 342 nm (100).

Dimethyl 9-Oxo-14-oxatetracyclo[6,3,2,0^{2,7},1^{3,6}]tetradeca-4,10,12-triene-4,5-dicarboxylate (VIIa).—A solution of tropolone (1.2 g) and the oxanorbornadiene dimethyl ester (II) (2.02 g) in benzene (10 ml) was heated at 130° in a sealed tube for 15 h. Work-up as before gave the *adduct* (VIIa) (0.68 g) as prisms, m.p. 100–102° (Found: C, 64.45; H, 5.2. $C_{17}H_{16}O_8$ requires C, 64.55; H, 5.1%), ν_{\max} (KBr) 1730, 1700, 1660, and 1635 cm^{-1} , m/e 316 and 184 (base), τ ($CDCl_3$) 2.87 (1H, q, H-11, J 10.5 and 8.7 Hz), 3.60 (1H, t, H-12, J 8.7 and 6.8 Hz), 3.95 (1H, t, H-13, J 7.5 and 6.8 Hz), 4.35 (1H, dd, H-10, J 10.5 and 2.0 Hz), 5.03 (1H, s, H-3), 5.11 (1H, s, H-6), 6.22 (6H, s, 2 \times OMe), 6.26 (1H, m, H-8), 6.56 (1H, t, H-1, J 8.7 Hz), 7.31 (1H, dd, H-2, J 8.3 and 1.5 Hz), and 7.53 (1H, d, H-7, J 8.7 Hz), λ_{\max} (EtOH) 226 (ϵ 10,190) and 350 nm (92).

Dimethyl 8-Hydroxy-9-oxo-14-oxatetracyclo[6,3,2,0^{2,7},1^{3,6}]tetradeca-4,10,12-triene-4,5-dicarboxylate (VIIb).—A solution of tropolone (0.66 g) and the diester (II) (1.0 g) in chlorobenzene (20 ml) was heated at 130° in a sealed tube for 13 h; similar work-up gave the *adduct* (VIIb) (0.35 g) as prisms, m.p. 114–115° (Found: C, 61.45; H, 4.85. $C_{17}H_{16}O_7$ requires C, 61.4; H, 4.9%), ν_{\max} (KBr) 3480, 1730, 1715, 1665, and 1640 cm^{-1} , m/e 332 and 184 (base), τ ($CDCl_3$) 2.72 (1H, q, H-11, J 11.0 and 8.4 Hz), 3.69 (1H, t, H-12, J 8.4 and 7.0 Hz), 4.10 (1H, d, H-13, J 7.0 Hz), 4.12 (1H, d, H-10, J 11.0 Hz), 4.50 (1H, d, H-3, J 2.0 Hz), 5.11 (1H, d, H-6, J 2.0 Hz), 5.39 (1H, s, OH, exchangeable), 6.21 (6H, s, 2 \times OMe), 6.50 (1H, t, H-1, J 8.4 Hz), 7.41 (1H, d, H-2, J 8.3 Hz), and 7.76 (1H, d, H-7, J 8.3 Hz), λ_{\max} (EtOH) 226 (ϵ 10,410) and 342 nm (115).

Irradiation of Compound (IIIa).—The adduct (IIIa) (0.15 g) was irradiated in methanol (100 ml) for 3.5 h with a high-pressure 100 W mercury lamp in a Pyrex vessel under nitrogen. Evaporation to dryness at reduced pressure and recrystallization from benzene–n-hexane gave *methyl 16-oxapentacyclo[7,6,1,0^{2,8},0^{3,5},0^{10,15}]hexadeca-6,10,12,14-tetraen-4-ylacetate* (XIIa) (0.16 g) as prisms, m.p. 103–104° (Found: C, 76.55; H, 6.4. $C_{18}H_{18}O_3$ requires C, 76.55; H, 6.45%), ν_{\max} (KBr) 1730 and 1440 cm^{-1} , m/e 282 and 118 (base), τ ($CDCl_3$) 2.84 (4H, m, ArH), 4.05 (1H, dd, H-6, J 11.0 and 3.9 Hz), 4.27 (1H, dd, H-7, J 11.0 and 2.0 Hz), 4.80 (1H, s, H-1 or H-9), 5.07 (1H, s, H-9 or H-1), 6.42 (3H, s, OMe), 7.77–8.03 (4H, m, H-2 and -8 and CH_2), and 8.33–8.65 (3H, m, H-3, -4, and -5).

Irradiation of Compound (VIIa).—The adduct (VIIa) (0.25 g) was irradiated in methanol (100 ml) under the same conditions; work-up as before gave *methyl 10,11-bismethoxycarbonyl-12-oxatetracyclo[7,2,1,0^{2,8},0^{3,5}]dodeca-6,10-dien-4-ylacetate* (XIIb) (0.26 g) as an oil, n_D^{20} 1.5294 (Found: C, 62.2; H, 5.8. $C_{18}H_{20}O_7$ requires C, 62.05; H, 5.8%), ν_{\max} (film) 1735, 1720, and 1645 cm^{-1} , m/e 348 and 184 (base), τ ($CDCl_3$) 4.05 (1H, dd, H-6, J 10.5 and 3.6 Hz), 4.34 (1H, dd, H-7, J 10.5 and 2.0 Hz), 4.96 (1H, s, H-1 or H-9), 5.22 (1H, s, H-9 or H-1), 6.21 (6H, s, 2 \times OMe), 6.37 (3H, s, OMe), 7.68–7.95 (4H, m, H-2 and -8 and CH_2), and 8.38–8.70 (3H, m, H-3, -4, and -5).

Irradiation of Compound (Vb).—(a) *In methanol.* The adduct (Vb) (0.25 g) was irradiated in methanol (100 ml) under the same conditions. Evaporation to dryness and chromatography on silica gel followed by recrystallization from benzene–n-hexane gave 18-oxapentacyclo[9,6,1,0^{2,10},0^{3,7},0^{12,17}]octadeca-3(7),12,14,16-tetraene-6,9-dione (XV) (0.18 g) as prisms, m.p. 186–188° (Found: C, 76.75; H, 5.5. $C_{17}H_{14}O_3$ requires C, 76.65; H, 5.3%), ν_{\max} (KBr) 1745, 1700, and 1465 cm^{-1} , m/e 266 and 118 (base), τ ($CDCl_3$) 2.82 (4H, m, ArH), 4.13 (1H, s, H_c), 4.66 (1H, s, H_a), 6.50 (1H, d, H_a , J 6.0 Hz), 7.34 (1H, d, H_b , J 6.0 Hz), and 7.57–8.52 (6H, complex m).

(b) *In acetonitrile.* The adduct (Vb) (0.06 g) was irradiated in acetonitrile (50 ml) under the same conditions; work-up as before gave the photoproduct (XV) (0.03 g).

Irradiation of Compound (VIIb).—The adduct (VIIb) (0.20 g) was irradiated in methanol (100 ml) under the same conditions; similar work-up gave *dimethyl 6,9-dioxo-14-oxatetracyclo[9,2,1,0^{2,10},0^{3,7}]tetradeca-3(7),12-diene-12,13-dicarboxylate* (XVII) (0.16 g) as prisms, m.p. 154–156° (Found: C, 61.65; H, 4.9. $C_{17}H_{16}O_7$ requires C, 61.45; H, 4.85%), ν_{\max} (KBr) 1735, 1700, and 1640 cm^{-1} , m/e 332 and 184 (base), τ ($CDCl_3$) 4.36 (1H, s, H_c or H_d), 4.81 (1H, s, H_d or H_c), 6.20 (3H, s, OMe), 6.22 (3H, s, OMe), 6.46 (1H, d, H_a , J 6.0 Hz), 7.25 (1H, d, H_b , J 6.0 Hz), and 7.43–8.55 (6H, complex m, 3 \times CH_2).