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PROPELLANES—XLIX

RELATIVE DIELS–ALDER REACTION OF AN UNSUBSTITUTED AND A SUBSTITUTED DIENE SYSTEM IN PROPELLANES AND 1,6-METHANO[10]ANNULENES†

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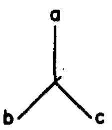
Abstract—The relative reactivity of an unsubstituted cyclohexadiene ring and a substituted cyclohexadiene ring within a propellane system or a 1,6-methano[10]annulene system has been studied.

We have been studying the general steric problem of which sector in the space adjoining the rings in various propellanes accommodates most efficiently, for one reason or another, an incoming reagent. In general, if the propellane is made up of three different rings, there are three different sectors which may be involved in the particular reaction, e.g. sectors *ab*, *bc* and *ac* in **1**.



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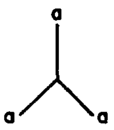

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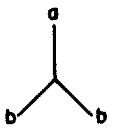

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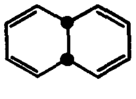
If all the rings are identical as in **2** clearly all the sectors *aa* are identical. We have studied mainly systems of type **3** where due to C_{2v} symmetry there are two possible sectors for attack, *ab* and *bb*. In **1** we have studied Diels–Alder reactions where ring a is a cyclohexadiene and rings *b* and *c* are, e.g. a 5-membered ether ring and a 5-membered thioether ring,[1] or a cyclopropane ring and a cyclohexane ring[2] or a cyclopropane ring and cyclobutane ring,[3] or a cyclopropane ring and a cyclopentane ring.[3]

In **3** we have studied attack by cationoid reagents,[4] carbenoid reagents[5] and again Diels–Alder reactions of tetraenic propellanes.[6] In the latter studies one might say, by hindsight, that we have compared the behavior in Diels–Alder reactions of the *cis* - 9,10 - dihydroaphthalene system **4** in which the two angular H-atoms in **4** were formally replaced by a CH_2 or a substituted CH_2 group,[2,6a] an oxygen,[2] an NH[2] or an NCH_3[2] group to afford the pertinent bridged annulenes, by a $-CH_2CH_2-$ group or a CH=CH group,[6b] by a $-(CH_2)_3-$ group,[6c] a $-CH_2OCH_2-$ group,[6d] a $-CH_2-S-CH_2-$, $-CH_2-SO-CH_2-$, $-CH_2-SO_2-CH_2-$ group,[6e] a $-O-CH_2O$, $-O-C(CH_3)_2-O-$, $-O-CO-O$ group,[6f] a $-CH_2OCO-$ group,[6g] a $-CH_2NRCH_2-$ group,[6c] a $-CO-O-CO$ group,[6c] a $-CO-NR-CO$ group,[6d,h] to afford propellanes (or bridged annulenes) of type **5**.



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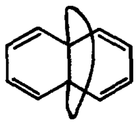

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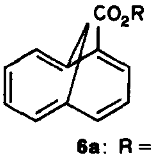
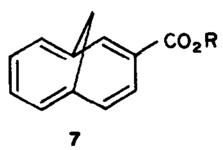
In this paper we extend this study one step further in that we treat compounds which are now formally of type **1** with triazolinediones. In these compounds, however, one of the rings, let us say *a*, is incapable of undergoing Diels–Alder reaction. The other two rings *b* and *c* are capable of undergoing such reaction but one of these rings is an unsubstituted cyclohexadiene whereas the other is a substituted one. Here too we have as exemplars some substrates which are only formally propellanes; they are in their properties substituted 1,6 - methano[10]annulenes **6** and **7** but once they interact in the Diels–Alder reaction they behave analogously to the propellane examplars **8** and **9**.



6a: R = Me
b: R = H



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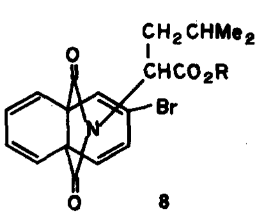

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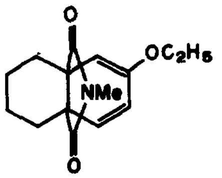

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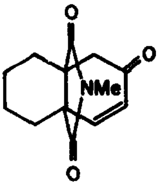

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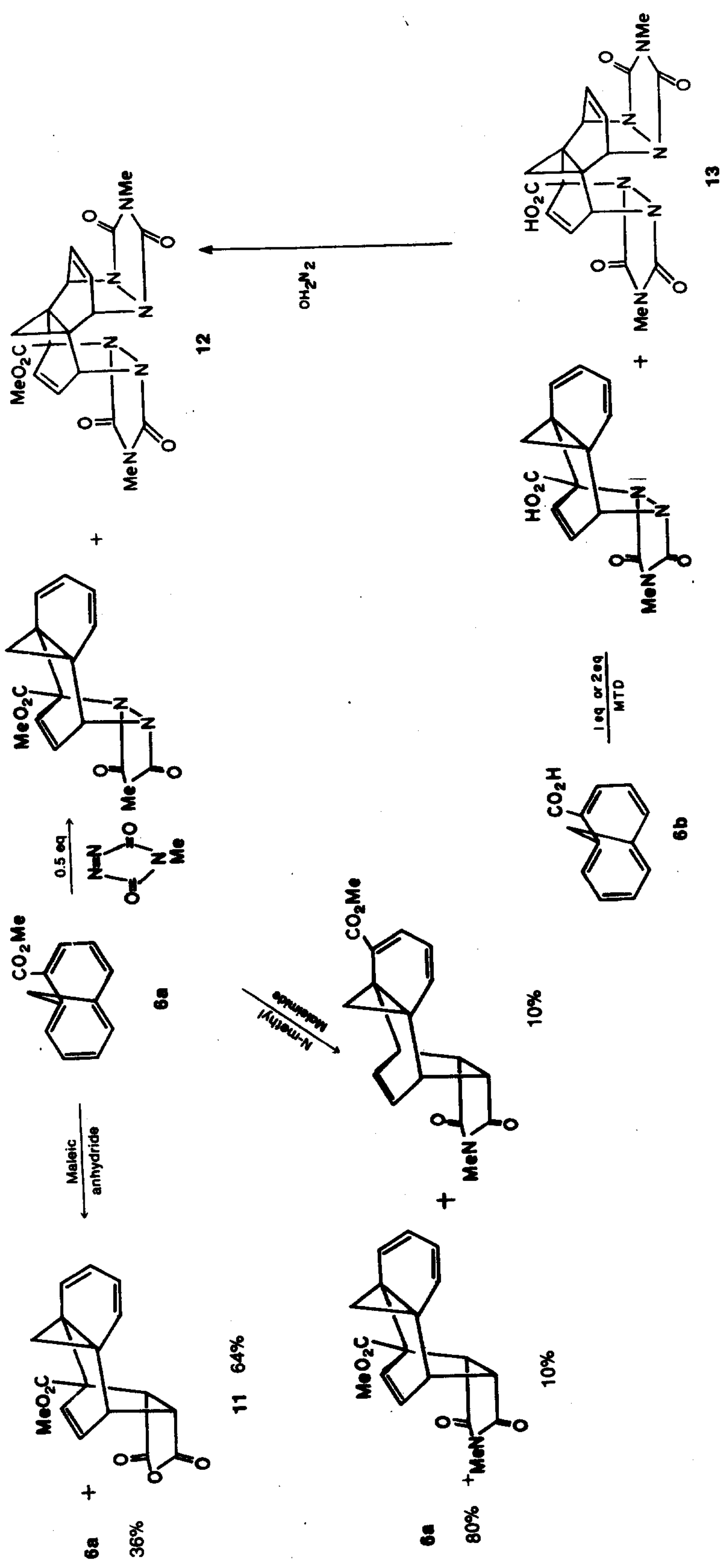
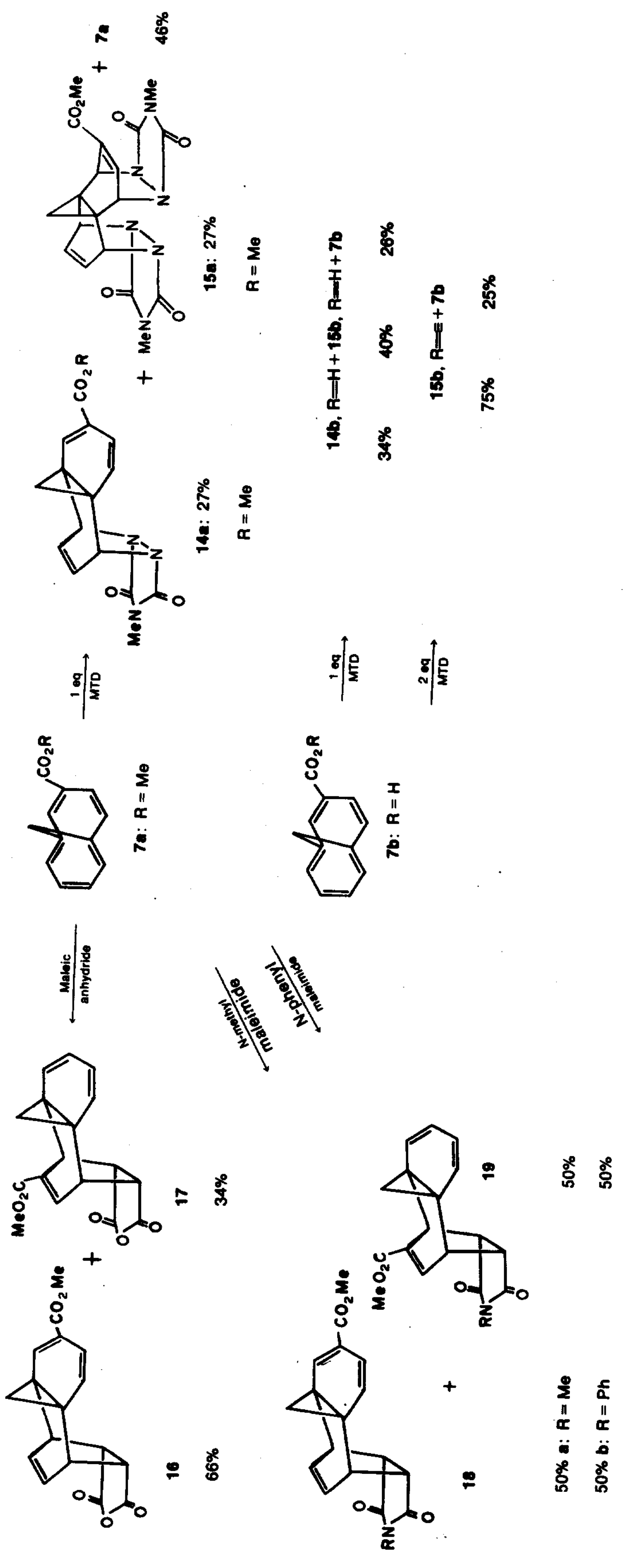
†Part XLVIII. P. Ashkenazi and D. Ginsburg, *Tetrahedron* **35**, 1317 (1979).


6a
CO2Me
Maleic anhydride
6a 36%
MeO2C
11 64%
0.5 eq
N=N
Me
MeO2C
12
MeN
NMe
CH2N2
HO2C
13
N-methyl Maleimide
CO2Me
10%
MeN
6a 80%
MeO2C
10%
6b
CO2H
1eq or 2eq MTD


CO2R
7a: R = Me
1 eq MTD
MeN
14a: 27%
R = Me
CO2R
MeN
NMe
CO2Me
15a: 27%
R = Me
7a
46%
CO2R
7b: R = H
1 eq MTD
2 eq MTD
14b, R=H + 15b, R=H + 7b
34% 40% 26%
15b, R=≡ + 7b
75% 25%
Maleic anhydride
N-methyl maleimide
N-phenyl maleimide
CO2Me
16
66%
MeO2C
17
34%
CO2Me
RN
18
MeO2C
RN
19
50% a: R = Me 50%
50% b: R = Ph 50%

Scheme 1.

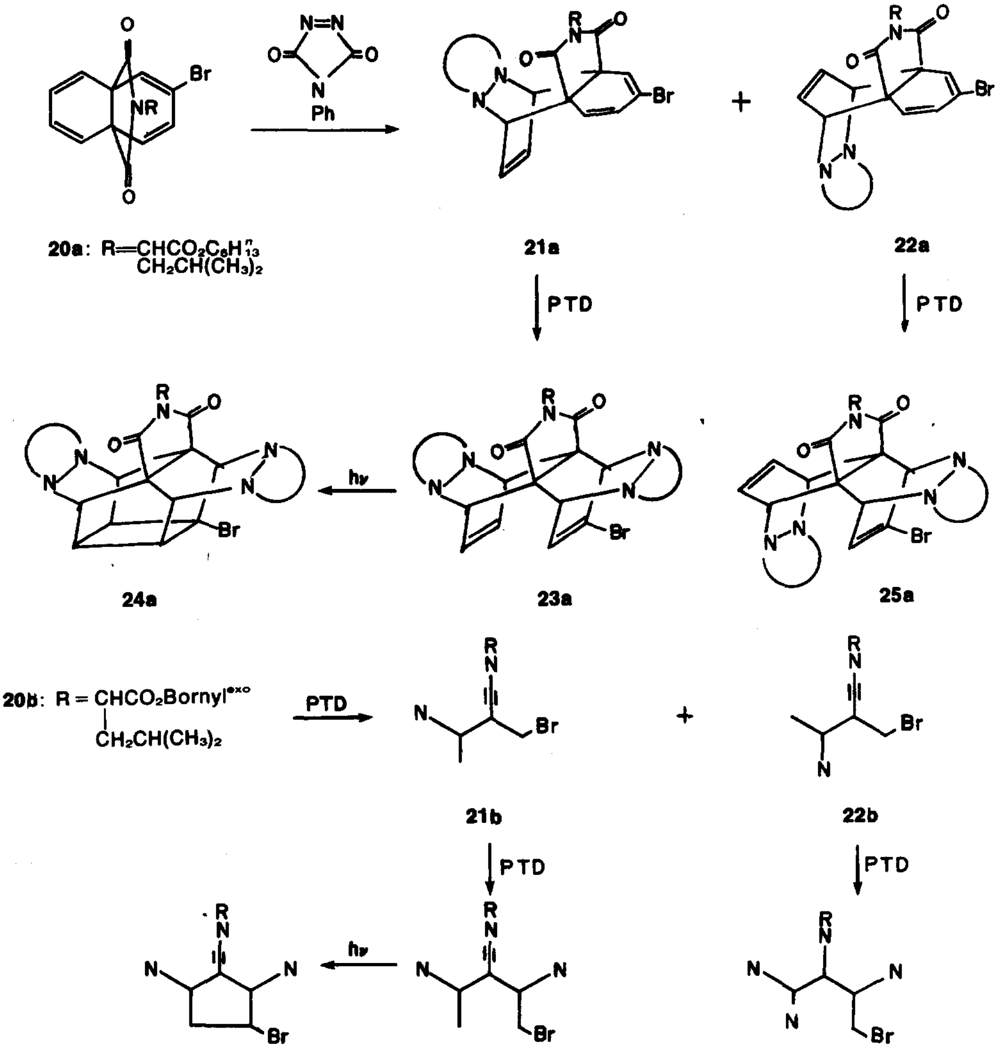
The question of whether attack by the dienophile occurs *syn*- to the methylene bridge in **6** and **7** or *anti*- to it is still present herein but on the basis of the above mentioned previous work on the bridged annulenes we would predict that *anti*-attack would occur exclusively. But superimposed on this is the question whether the dienophile will attack the unsubstituted diene in **6** and **7** or the 1-carbethoxylbutadiene portion in **6a** and the 2-carbethoxybutadiene portion in **7a**. The corresponding acids **6b** and **7b** were also studied. Similarly, since we have a large N-substituent in **8**, we expect a rather large extent of *anti*-attack to the imide ring as compared to *syn*-attack. But again we had no experience as to whether the unsubstituted diene system in **8** would be attacked or the bromo-diene system, or both. For **9** with a small N-substituent in the imide ring we would predict only attack *syn*- to that ring but we did not possess experience as to whether the ethoxy-substituent would aid attack or hinder it. Although **9** is not directly comparable to compounds **6**–**8** its availability to us through the intermediacy of **10**, enabled us to study its behavior in the present context.

The 1-substituted compounds **6a** and **6b** appear to be less reactive towards dienophiles than the 2-substituted ones **7a** and **7b** but the results show that attack of either the substituted or unsubstituted diene occurs to afford the products shown in Scheme 1.

1,6-Methano[10]annulenes are relatively sluggish in their reactions with dienophiles and it is necessary to heat in a sealed tube for a long time in order to obtain the products of maleic anhydride or maleimides. Although N-methyltriazolinedione reacts at room temperature, retro-Diels–Alder reaction of the adducts makes it very difficult to isolate or characterize these. Nevertheless it is clearly apparent from the experimental section that adducts bearing a quaternary carboxyl or carbomethoxy group are readily distinguishable from the isomers where these groups are substituted in the diene moiety. Thus a clearcut conclusion may be drawn even in those cases where isolation was not possible.

Fortunately the other substrates used in this work were better behaved. Scheme 2 summarizes the results obtained for the substituted imides **20a** and **b**.[7]

Here it is clear that because of the large substituent on the imide nitrogen attack by the dienophile occurs both *syn*- and *anti*- to the heterocyclic ring. But in these cases



Scheme 2.

there is a clear preference for attack of the unsubstituted diene. All of the mono-adducts shown in Scheme 2 retain the bromo-diene moiety. However, these readily form *bis*-adducts so that the preference shown at the first stage is not due to the refusal to attack a bromo-diene. The latter is attacked at the second stage, i.e. during formation of *bis*-adducts.

In this paper we do not discuss the significance of the *syn–anti*-ratio in the attack of **20a** and **b** within the context of other N-substituted imides of this type. This will be discussed elsewhere.[7]

Finally, Scheme 3 shows that when there is only one diene system in the molecule with a EtO substituent Diels–Alder reaction with PTD readily occurs.

EXPERIMENTAL

IR spectra were measured using a Perkin Elmer 257 or 237 spectrometer. NMR spectra were measured on a Varian T-60 instrument and mass spectra on an Atlas CH4 (70 eV) or a Varian MAT-711 (100 eV) mass spectrometer. M.ps are uncorrected. Preparative silica plates 20 × 20 cm were made of 70 g silica gel 60 PF 254 produced by E. Merck.

Reaction of **6a** *with maleic anhydride.* The acid **6b**[8] (152 mg) was methylated with CH_2N_2 and the methyl ester[9] without isolation was treated with maleic anhydride (503 mg) in benzene (10 ml) in a sealed tube at 130° for 7 days. The mono-adduct **11** (145 mg) was separated ($CHCl_3$ as eluant) from recovered starting material. It had m.p. 160–162° (benzene–pentane). (Found: C, 67.13; H, 4.97; M.W. 298.0823. $C_{17}H_{14}O_5$ requires: C, 68.45; H, 4.73%; M.W. 298.0841). IR ($CHCl_3$): 1860, 1790, 1720, 1640, 1150, 1100 cm^{-1}. NMR ($CDCl_3$): τ 2.90 (d, 1 vinylic H, $C\underline{H}{=}C{-}CO_2Me$); 3.40–3.90 (m, 5 vinylic H); 6.10 (s, 3H, $CO_2C\underline{H}_3$); 6.50 (m, 1H, $C\underline{H}{-}C{=}C{-}CO_2Me$); 6.90 (m, 2H, $C\underline{H}CO_2$); 8.10, 10.30 (AB, 2 cyclopropyl H). M.S.: M^+, 298(11); 200(24); 185(44); 169(64); 165(25); 141(100).

Reaction of **6a** *with* N-*methylmaleimide.* The acid **6b** (102 mg) was converted as above in to **6a** which was treated with N-methylmaleimide (343 mg) in benzene (10 ml) at 140° for 7 days. The crude material (470 mg) was separated on a prep silica plate using CH_2Cl_2 as eluant. Starting material (78 mg) was recovered and a mixture of mono-adducts was obtained in the ratio of 1 : 1. These could not be separated but exhibited the following spectral results. IR ($CHCl_3$): 1780, 1710 cm^{-1}. NMR ($CDCl_3$): τ 3.00 (d, $C\underline{H}{=}C{-}CO_2Me$); 3.40–4.20 (m, 5 vinylic H); 6.15 (s, 3H, $CO_2C\underline{H}_3$); 6.50 (m, 1H, $-C\underline{H}{-}C{=}$); 7.15 (s, 3H, $N{-}C\underline{H}_3$; m, 2H, $C\underline{H}CON$); 8.10, 10.35 (AB, 2 cyclopropyl H).

Reaction of **6a** *with 4 - methyl - 1,2,4 - triazoline - 3,5 - dione.* The methyl ester (45 mg) was treated with dienophile (20 mg) in CH_2Cl_2 at room temp. for 2 hr. It was not possible to isolate the mono-adduct but its structure (as shown in Scheme 1) is clear from the NMR spectrum. NMR ($CDCl_3$): τ 3.30–4.10 (m, 5 vinylic H); 4.80 (m, 1H, $C\underline{H}N$); 6.15 (s, 3H, $CO_2C\underline{H}_3$); 7.10 (s, 3H, $NC\underline{H}_3$); 8.15, 10.50 (AB, 2 cyclopropyl H).

The *bis*-adduct **12**, also obtained by esterification of the corresponding *bis*-adduct of **6b**, had m.p. 144–145° (CH_2Cl_2–hexane). (Found: C, 53.86; H, 4.53. $C_{19}H_{18}N_6O_6$ requires: C, 53.52; H, 4.76%). IR ($CHCl_3$): 1800, 1780, 1740, 1730, 1470 cm^{-1}. NMR ($CDCl_3$): τ 3.10–3.40 (m, 1H, $C\underline{H}{=}CCO_2CH_3$); 3.60–3.80 (m, 3 vinylic H); 4.20 (m, 1H, $C\underline{H}N$); 4.50 (m, 2H, $C\underline{H}N$); 5.90 (s, 3H, $CO_2C\underline{H}_3$); 7.05, 7.10 (s, s, 6H, $NC\underline{H}_3$); 9.00 (s, 2 cyclopropyl H). M.S.: 312(6); 282(9); 200(34); 198(85); 185(20); 168(32); 141(100).

Reaction of **6b** *with MTD.* Reaction of **6b**[8] (29 mg) with N-methyltriazolinedione (17 mg) in CH_2Cl_2 (10 ml) gave after 20 hr at room temp. crude product (53 mg). This gave *bis*-adduct **13** (8 mg) and an inseparable mixture of mono-adduct and starting material.

Reaction between **6b** (28 mg) and the dienophile (35 mg) in CH_2Cl_2 (10 ml) afforded crude product (79 mg) which afforded on separation **13** (28 mg) and again a mixture of mono-adduct and **6b**. The *bis*-adduct was insoluble in EtOAc, m.p. 190–192°. IR (KBr): 1770, 1705, 1690, 1460 cm^{-1}.

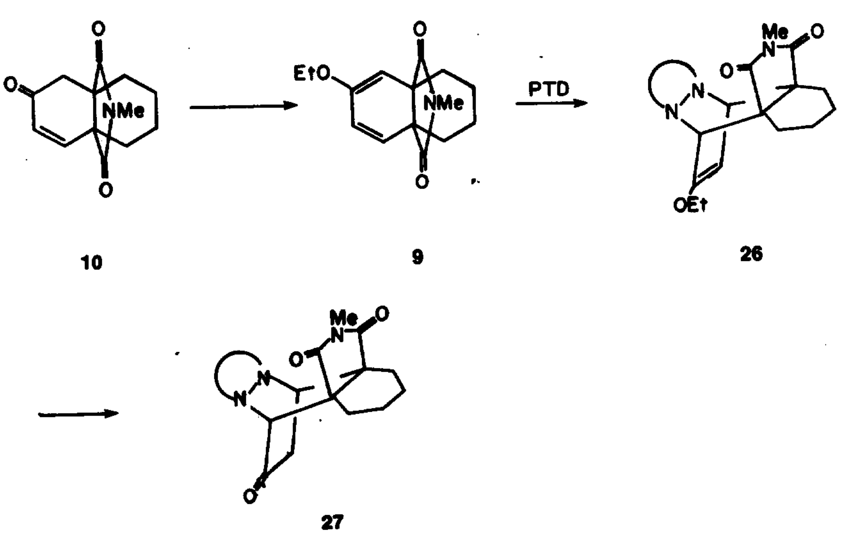
Methylation of **13** with CH_2N_2 gave the analytically pure **12**, m.p. 144–145° in nearly quant yield.

Reaction of **7b** *with MTD.* From **7b**[10] (29 mg) and dienophile (17 mg) in CH_2Cl_2 (10 ml) was obtained after 24 hr at room temp. crude product (53 mg). Precipitate begins to form after 6 hr. The *bis*-adduct **15b** (17 mg), is insoluble in CH_2Cl_2. The mono-adduct was separated (17 mg) on silica from recovered **7b** (12 mg). When **7b** (28 mg) was treated with 2 eq dienophile (35 mg) in CH_2Cl_2 (10 ml) the *bis*-adduct (60 mg) was obtained.

The mono-adduct **14b** had m.p. 180–182° (benzene–hexane). IR ($CHCl_3$): 1770, 1720, 1670 cm^{-1}. NMR ($CDCl_3$): τ 2.70 (s, 1H, $C\underline{H}{=}CCO_2H$); 3.50 (d, 1 vinylic H); 3.70 (t, 2 vinylic H); 4.70 (AB, 2H, $C\underline{H}N$); 7.15 (s, 3H, $NC\underline{H}_3$); 8.00, 10.00 (AB, 2 cyclopropyl H). M.S.: 186(45); 141(100).

The *bis*-adduct had m.p. 235–237° (DMSO). (Found: C, 51.96; H, 4.14; N, 20.05; $C_{18}H_{16}N_6O_6$ requires: C, 52.43; H, 3.91; N, 20.38%). IR (KBr): 3000, 1770, 1700, 1640 cm^{-1}. NMR (DMSO-d_6): τ 3.10 (dd, 1H, $C\underline{H}{=}CCO_2H$); 3.80 (t, 2 vinylic H); 4.40 (m, 4H, $C\underline{H}N$); 7.20 (s, 6H, $NC\underline{H}_3$); 8.90 (s, 2 cyclopropyl H). M.S.: 198(21); 186(43); 141(100).

Reaction of **7a** *with maleic anhydride.* **7a** was made by treating **7b**[10] (152 mg) with CH_2N_2 and the methyl ester[10] was heated in a sealed tube with maleic anhydride (500 mg) in benzene (10 ml) at



Scheme 3.

130° for 4 days. The product was formed in 10% yield and comprises (by NMR) a 2:1 mixture of **16**:**17**. Separation did not succeed. The NMR spectrum ($CDCl_3$) of the mixture contained bands belonging to both **16** and **17** defined as follows:

Compound **16**. 2.75 (m, $C\underline{H}{=}CCO_2Me$); 3.40–4.10 (m, vinylic); 6.30 (s, $CO_2C\underline{H}_3$); 6.45 (m, $C\underline{H}-\overset{\|}{C}-CO_2$); 6.90 (m, $C\underline{H}CON$); 8.00; 10.30 (AB, cyclopropyl H).

Compound **17**. 2.95 (m, $C\underline{H}{=}CHCO_2Me$); 4.00 (s, dienic H); 5.95 (m, $C\underline{H}-\overset{\|}{C}-CO_2$); 6.30 (s, $CO_2C\underline{H}_3$); 7.05 (m, $C\underline{H}CON$); 8.55, 10.30 (AB, cyclopropyl H).

Reaction of **7a** *with* N-*methylmaleimide*. **7b** (102 mg) was treated with CH_2N_2. The methyl ester thus formed was treated with the dienephile (500 mg) in benzene (10 ml) at 140° for 7 days. Separation on silica using $CHCl_3$ as eluent gave **7b** (30 mg) and a mixture (152 mg) of **18a** and **19a** in a ratio (NMR) of 1:1. This was eventually separated into its components using prep. silica plates.

Compound **18a** was an oil. (Found: M.W. 311.1133. $C_{18}H_{17}NO_3$ requires: 311.1157). IR ($CHCl_3$): 1780, 1710 cm^{-1}. NMR ($CDCl_3$): τ 2.76 (m, 1H, $C\underline{H}{=}CCO_2Me$); 3.40–4.30 (m, 4 vinylic H); 6.20 (s, 3H, $CO_2C\underline{H}_3$); 6.40 (m, 2H, $C\underline{H}-C{=}C$); 7.15 (s, 3H, $NC\underline{H}_3$); 7.25 (m, 2H, $C\underline{H}CON$); 7.95, 10.30 (AB, 2 cyclopropyl H). M.S.: M$^+$, 311(8); 200(31); 186(29); 169(25); 141(100).

Compound **19a** was also an oil. (Found: M.W. 311.1148). IR ($CHCl_3$): 1780, 1710, 1400 cm^{-1}. NMR ($CDCl_3$): τ 3.10 (dd, 1H, $C\underline{H}{=}CCO_2Me$); 4.00 (s, 4 vinylic H); 5.90 (m, 1H, $C\underline{H}-\overset{\overset{C}{\|}}{C}-CO_2Me$); 6.25 (s, 3H, $CO_2C\underline{H}_3$); 6.30 (m, 1H, $C\underline{H}-CH{=}CCO_2Me$); 7.10 (m, 2H, $C\underline{H}CON$); 7.20 (s, 3H, $NC\underline{H}_3$); 8.50, 10.35 (AB, 2 cyclopropyl H). M.S.: 311(3); 200(36); 185(23); 169(36); 141(100).

Reaction of **7a** *with* N-*phenylmaleimide*. **7b** (145 mg) was again converted *in situ* in to **7b** which was reacted with the dienophile (500 mg) in benzene at 140° for 4 days, affording crude product (676 mg). Separation on silica plates using chloroform as eluant gave **18b** (84 mg) and **19b** (62 mg) although by NMR these were formed in a 1:1 ratio.

Compound **18b** had m.p. 128–130° (benzene–hexane). (Found: N, 3.97; M.W. 373.1317. $C_{23}H_{19}NO_3$ requires: N, 3.75%; M.W. 373.1314). IR ($CHCl_3$): 1780, 1720, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.40–3.00 (m, 5 arom H + 1H, $C\underline{H}{=}CCO_2Me$); 3.30–4.00 (m, 4 vinylic H); 6.15 (s, 3H, $CO_2C\underline{H}_3$); 6.30 (m, 2H, $C\underline{H}-C{=}C$); 7.10 (2m, 2H, $C\underline{H}CON$); 7.90, 10.30 (AB, 2 cyclopropyl H). M.S.: M$^+$, 373(14); 200(42); 185(24); 173(22); 169(18); 141(100).

Compound **19b** had m.p. 187–188° (benzene–hexane). (Found: N, 3.89; M.W. 373.1253). IR ($CHCl_3$): 1780, 1720, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.30–3.00 (m, 5 arom H + 1H, $CH{=}CCO_2Me$); 3.95 (s, 4 vinylic H); 5.80 (m, 1H, ${=}C-C\underline{H}CO_2H$); 6.20 (s, 3H, $CO_2C\underline{H}_3$); 6.25 (m, 1H, $C\underline{H}-C{=}C$); 6.95 (m, 2H, $C\underline{H}CON$); 8.45, 10.40 (AB, 2 cyclopropyl H). M.S.: M$^+$, 373(5); 200(68); 185(10); 173(54); 169(40); 141(100).

Reaction of **7a** *with MTD*. **7a** (16 mg) was reacted with dienophile (10 mg) in CH_2Cl_2 (10 ml), affording crude product (31 mg) after 6 hr. NMR shows a 1:1 mixture of **7a** and mono-adduct. When 2 eq MTD was used 46% of **7a** was recovered and a mixture of mono-adduct **14a** (27%) and **15a** (27%) was obtained.

Compound **14a** was an oil. NMR ($CDCl_3$): τ 3.45–3.80 (m, 5 vinylic H); 4.80 (t, 2H $C\underline{H}N$); 6.20 (s, 3H, $CO_2C\underline{H}_3$); 7.05 (s, 3H, $NC\underline{H}_3$); 8.00, 10.00 (AB, 2 cyclopropyl H).

Compound **15a** had m.p. 114–115° (CH_2Cl_2–hexane). IR ($CHCl_3$): 1800, 1780, 1740, 1730, 1480 cm^{-1}. NMR ($CDCl_3$): τ 3.80 (m, 3 vinylic H); 4.55 (m, 4H, $C\underline{H}N$); 6.20 (s, 3H, $CO_2C\underline{H}_3$); 7.02 (s, 6H, $NC\underline{H}_3$).

Reaction of 1,6-*methano*[10]*annulene with* N-*methylmaleimide*. This reaction was carried out as a frame of reference for the ring-substituted compounds described above. Reaction conditions are quite similar. The dienic component (100 mg) was treated with the dienophile (300 mg) in benzene (10 ml) at 140° for 7 days, giving recovered starting material (71 mg) and mono-adduct (44 mg; 21%), m.p. 141–142°. (Found: N, 5.46; M.W. 253.1094. $C_{16}H_{15}NO_2$ requires: N, 5.53%; M.W. 253.1112). IR ($CHCl_3$): 1780, 1710 cm^{-1}. NMR ($CDCl_3$): τ 4.00 (m, 6 vinylic H); 6.50 (m, 2H, $C\underline{H}-C{=}C$); 7.15 (m, 2H, $C\underline{H}CON$); 7.15 (s, 3H, $NC\underline{H}_3$); 8.15, 10.40 (AB, 2 cyclopropyl H). M.S.: M$^+$, 253(7); 200(12); 165(15); 142(100).

Reaction of **20a** *with PTD*. The tetraene **20a** (71 mg) in CH_2Cl_2 (5 ml) reacted at once with PTD (15 mg; 1 eq) in CH_2Cl_2 (10 ml). After separation on silica plates **21a** (15 mg; 18%) and **22a** (37 mg, 43%) were obtained.

Compound **21a** had m.p. 144–145° (hexane). (Found: N, 8.44. $C_{32}H_{34}BrN_4O_6$ requires: N, 8.61%. IR (KBr): 2960–2840, 1790, 1730, 1510, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.62 (s, 5 arom H); 3.34 (2 vinylic H); 3.64–4.30 (m, 3 dienic H); 4.73 (m, 2 allylic H); 5.20 (dd, 1H, $NC\underline{H}CO_2$); 5.87 (t, 2H, $CO_2C\underline{H}_2$); 7.60–9.20 (m, 20 aliphatic H). M.S.: 239(2); 237(3); 227(100); 119(98).

Compound **22a** had m.p. 58–60° (CH_2Cl_2–hexane). IR (KBr): 3100–2840, 1790, 1720, 1610, 1510, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.58 (s, 5 arom H); 3.54 (m, 2 vinylic H); 3.50–4.40 (m, 3 dienic H); 4.60–5.00 (m, 2 allylic H); 5.25 (dd, H, $NC\underline{H}CO_2$); 5.91 (t, 2H, $CO_2C\underline{H}_2$); 7.60–9.20 (m, 20 aliphatic H). M.S.: 296(24); 294(24); 266(5); 264(4); 255(10); 253(15); 227(6); 119(14).

Reaction of **21a** *with PTD*. A soln of **21a** (21 mg) in CH_2Cl_2 was treated with one of PTD (6 mg) in CH_2Cl_2 (2 ml). The whole was colorless after mag. stirring for 20 min. Only the *bis*-adduct **23a** (25 mg; 93%) was obtained, m.p. 195–198° (hexane). (Found: Br, 10.01; N, 11.95, M.W. 827.2061; 825.2099. $C_{38}H_{40}BrN_7O_8$ requires: Br, 9.67; N, 11.86%; 827.2071; 825.2121). IR (KBr): 2900, 1780, 1730, 1600, 1500, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.59 (s, 10 arom H); 3.00–4.00 (m, 3 vinylic H); 4.40–4.70 (m, 4 allylic H); 5.15 (dd, 1H, $NC\underline{H}CO_2$); 5.95 (t, 2H, $CO_2C\underline{H}_2$); 7.30–9.20 (m, 20 aliphatic H). M.S.: 307(45); 305(49); 240(6); 238(6); 227(70); 119(100).

Reaction of **22a** *with PTD*. A soln of **22a** (13 mg) in CH_2Cl_2 (3 ml) treated with PTD (4 mg) in CH_2Cl_2 (1 ml) gave after 30 min mag. stirring the *bis*-adduct **25a** (15 mg; 91%), m.p. 125° (dec, hexane). IR (KBr): 2900, 1780, 1730, 1600, 1500, 1400, 1250 cm^{-1}. NMR ($CDCl_3$): τ 2.57 (s, 10 arom H); 3.00–3.50 (m, 3 vinylic H); 4.20–4.80 (m, 4 allylic H); 5.30 (dd, 1H, $NC\underline{H}CO_2$); 5.89 (t, 2H, $CO_2C\underline{H}_2$); 7.60–9.20 (m, 20 aliphatic H). M.S.: 231(24); 221(18); 112(100). (Found: Br, 9.98. $C_{38}H_{40}BrN_7O_8$ requires Br, 9.67%).

Reaction of **20a** *with* 2 *eq PTD*. To a soln of **20a** (292 mg) in CH_2Cl_2 (5 ml) was added PTD (200 mg) in CH_2Cl_2 (5 ml) and the whole was stirred magnetically for 30 min. After removal of solvent the products were separated on silica plates with pentane (3): EtOAc (1). The *bis*-adduct **23a** (146 mg; 29%) and **25a** (322 mg; 63%) were isolated.

The same reaction at −78° rather than room temp. gave **23a** (64 mg; 32%) and **25a** (95 mg; 48%) from **20a** (115 mg) and PTD (75 mg) during 1 hr in CH_2Cl_2 (10 ml).

Irradiation of **23a** (26 mg) in degassed acetone (30 ml) at 300 nm overnight and removal of solvent gave the cage product **24a** (25 mg; 99%), m.p. 132–134° (hexane). (Found: M.W. 827.2125; 825.2097. $C_{40}H_{40}BrN_7O_8$ requires: 827.2101; 825.2121). IR (KBr): 3000, 1730, 1500, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.53 (s, 10 arom H): 4.60–5.30 (m, 4H, $C\underline{H}N$); 5.96 (t, 2H, $CO_2C\underline{H}_2$); 6.40 (m, 3 cyclobutyl H); 7.20–9.20 (m, 20 aliphatic H).

Reaction of **20b** *with PTD*. Immediate reaction took place upon mixing a soln of **20b** (324 mg) in CH_2Cl_2 (10 ml) with one of PTD (75 mg; 1 eq) in CH_2Cl_2 (5 ml). Separation on prep. silica plates gave recovered **20b** (55 mg), mono-adduct **21b** (91 mg; 25%), its isomer **22b** (163 mg; 45%) and unidentified material (35 mg).

Compound **21b** had m.p. 223–224°C (hexane). (Found: Br, 11.49, $C_{36}H_{39}BrN_4O_6$ requires: Br, 11.35%). IR (KBr): 3000–2850, 1800, 1740, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.63 (s, 5 arom H); 3.30–3.60 (m, 2 vinylic H); 3.90–4.30 (m, dienic H); 4.70–4.90 (m, 2 allylic H); 5.00–5.50 (m, $NC\underline{H}CO_2 + C\underline{H}O$); 8.00–9.50 (m, 25 aliphatic H). M.S.: 296(9); 294(6); 227(100).

Compound **22b** had m.p. 133–135° (hexane). (Found: Br, 11.29). IR (KBr): 3000–2850, 1800, 1740, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.65 (s, 5 arom H); 3.30–3.50 (m, 2 vinylic H); 3.60–4.20 (m, 3 dienic H); 4.70–4.90 (m, 2 allylic H); 5.00–5.50 (m, $NC\underline{H}CO_2 +$ $C\underline{H}O$); 8.00–9.50 (m, 25 aliphatic H). M.S.: 297(3); 296(9); 295(6); 294(11); 240(9); 238(9); 227(39).

Reaction of **21b** *with PTD*. Reaction of **21b** (50 mg) in CH_2Cl_2

(5 ml) with PTD (12 mg) in CH_2Cl_2 (2 ml) was over in 2 min affording a single product **23b**, m.p. 291° (dec, hexane). (Found: Br, 8.52. $C_{44}H_{44}BrN_7O_8$ requires: Br, 9.09%). IR (KBr): 2950–2850, 1790, 1740, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.40 (s, 10 arom H); 3.30–3.60 (m, 3 vinylic H); 4.40–4.70 (m, 4 allylic H); 5.00–5.50 (m, NC$\underline{H}$CO$_2$ + C$\underline{H}$O); 8.00–9.50 (m, 25 aliphatic H). M.S.: 227(54); 181(7); 160(12); 137(11); 119(100).

Reaction of **22b** *with PTD.* Reaction of **22b** (38 mg) in CH_2Cl_2 (3 ml) with PTD (10 mg) in CH_2Cl_2 (1 ml) also required 2 min affording only **25b**, m.p. 284° (dec, hexane). (Found: Br, 8.38). IR (KBr): 2950–2850, 1790, 1730, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.40 (s, 10 arom H); 3.20–3.40 (m, 3 vinylic H); 4.40–4.70 (m, 4 allylic H): 5.00–5.50 (m, NC$\underline{H}$CO$_2$ + C$\underline{H}$O) 8.00–9.50 (m, 25 aliphatic H). M.S.: 296(15); 294(18); 253(9); 251(9); 239(19); 237(19); 227(45); 177(19); 119(100).

Irradiation of **23b** as described above for **23a** gave the cage product **24b**, m.p. 292–293°. (Found: Br, 9.12. $C_{44}H_{44}BrN_7O_8$ requires: Br, 9.09%). IR (KBr): 3000–2850, 1790, 1740, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.40 (s, 10 arom H); 4.50–5.50 (m, 4 C$\underline{H}$N + NC$\underline{H}$CO$_2$ + C$\underline{H}$O); 6.30–6.60 (m, 3 cyclobutyl H); 8.00–9.50 (m, 25 aliphatic H). M.S.: 366(26); 363(12); 355(55); 149(10); 146(28); 112(100).

Preparation of **9**. To a soln of **10**[11] (327 mg) in dry benzene (10 ml) was added ethyl orthoformate (400 mg) in EtOH and satd ethanolic HCl (2 ml) and the whole was stirred at 40° overnight. Triethylamine (3 ml) was added and the solvent removed at the water pump. The residue was treated with hexane, the ppt removed by filtration and the solvent removed. The product was distilled at 140° (0.3 torr) affording **9** (330 mg; 89%) as an oil. (Found: M.W. 261.1362. $C_{15}H_{19}NO_3$ requires: 261.1364). IR ($CHCl_3$): 3000–2850, 1790, 1720, 1680, 1620, 1400 cm^{-1}. NMR ($CDCl_3$): τ (ABC, 3 vinylic H: A, 5.53, B, 4.09, C, 4.34; J_{AB} = 1.5 Hz, J_{AC} = 0.6 Hz; J_{AC} = 10 Hz); 6.17 (q, 2H, OC$\underline{H}_2$CH$_3$); 7.00 (s, 3H, NC$\underline{H}_3$); 8.00–9.00 (m, 11 aliphatic H).

Reaction of **9** *with PTD.* To a soln of **9** (167 mg) in CH_2Cl_2 (10 ml) was added PTD until a stable red color was attained; reaction is immediate. A single mono-adduct **26** was obtained after chromatography on silica (200 mg; 79%), m.p. 193–195° (hexane). (Found: M.W. 436.1455. $C_{23}H_{24}N_4O_5$ requires: 436.1746. IR (KBr): 3000–2840, 1790, 1720, 1640, 1520, 1420 cm^{-1}. NMR ($CDCl_3$): τ 2.50 (s, 5 arom H); 4.80–5.40 (ABC, 3H); 6.20 (q, 2H, OC$\underline{H}_2$C$\underline{H}_3$); 6.87 (s, 3H, NC$\underline{H}_3$); 7.80–9.00 (m, 11 aliphatic H). M.S.: 272(20); 271(100); 124(54).

Acid hydrolysis of **26**. A soln of **26** (110 mg) in EtOH (4 ml) and 32% ethanolic HCl (1 ml) was warmed to 60° for 30 min. Triethylamine was added and the solvent removed. Purification on a prep. silica plate gave **27** in quant yield, m.p. 231° (hexane). (Found: M.W. 408.1502. $C_{21}H_{20}N_4O_5$ requires: 408.1467). IR ($CHCl_3$): 2960–2820, 1780, 1750, 1730, 1400 cm^{-1}. NMR ($CDCl_3$): τ 2.56 (s, 5 arom H); 5.13 (t, 1H, C$\underline{H}$N); 5.29 (s, 1H, C$\underline{H}$N); 6.84 (s, 3H, NC$\underline{H}_3$); 7.26 (dd, 2H, C$\underline{H}_2$CO); 7.50–9.00 (m, 8 aliphatic H). M.S.: 243(10); 214(57); 119(100).

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