Polycyclic Hydroxyquinones. Part 26.[1] Regio- and Site-selectivity in the Diels–Alder Reactions of 4-Sulphonyliminoanthracene-1,9,10-triones

Francisco Fariña,* M. Carmen Paredes, and Leonor Puebla
Instituto de Química Orgánica General, C.S.I.C., Juan de la Cierva, 3, 28006 Madrid, Spain
Valter Stefani
Instituto de Química U.F.R.G.S., Av. Bento Gonçalves, 9.500, 90.000 Porto Alegre (RS), Brazil

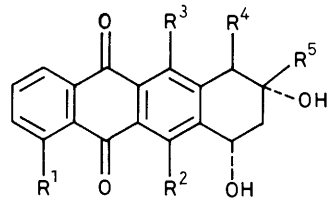
The lead tetra-acetate oxidation of anthraquinones (**9**)—(**11**) afforded the corresponding anthracenediquinone monosulphonylimines (**14**)—(**16**) in good yields. The diquinone imine (**14**) reacted with 2,3-dimethylbuta-1,3-diene (**17**) to furnish mainly the linear Diels–Alder adduct (**23**) whereas with electron-rich dienes, such as (*E*)-1-methoxybuta-1,3-diene (**18**), a mixture of the linear adduct (**24**) and the bridged adduct (**29**) was obtained. The latter reaction is regiospecific and the regiochemistry is controlled by the sulphonylimino group. The cycloaddition of chlorodiquinone imine (**16**) with dienes (**18**), (**20**), and cyclopentadiene occurred only at the internal 4a,9a-double bond to afford bridged adducts. The cycloaddition of (**14**) with less electron-rich dienes, such as 2-acetoxybuta-1,3-diene (**21**) and (*E*)-3-acetoxy-1-trimethylsilylbuta-1,3-diene (**22**), gave only the linear adducts (**26a,b**) and (**27**), respectively. The latter, which is obtained as a sole regioisomer, is a precursor of anthracyclinones.

Anthracycline antibiotics daunomycin and adriamycin are widely used in cancer chemotherapy, although their clinical use is limited because of their dose-limiting cardiotoxicity.[2] Among the most promising anthracyclines of the second generation are aclacinomycin A and other 11-deoxyanthracyclines, which possess high antineoplastic activity and reduced cardiotoxicity.[3] Their 6-deoxy counterparts, hitherto relatively less studied,[4] may also be of interest in the search for more active and less toxic anthracyclines.

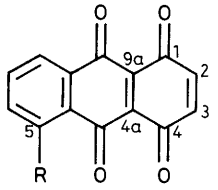
In recent years the development of synthetic approaches to anthracyclines has been the subject of extensive study and has led to a great number of syntheses of their aglycones, the anthracyclinones.[5] One of the first syntheses of 4-demethoxydaunomycinone (**1**) and daunomycinone (**2**) used anthracenediquinone (**5**) and 5-methoxyanthracene-1,4,9,10-diquinone (**6**) as BCD ring synthons in a Diels–Alder approach.[6,7] A limitation of this strategy is the tendency of electron-rich dienes to react preferentially with the internal 4a,9a-double bond to afford bridged adducts;[8] furthermore, this approach is not applicable to the synthesis of aklavinone (**3**) or cytromycinone (**4**) type anthracyclinones, which lack the hydroxy groups found at the 11- or 6-position of daunomycinone, respectively.

It was therefore of interest to study anthradiquinone monoimines of type (**13**), wherein the two 1,4-carbonyls are differentiated chemically. These compounds offered the possibility of using a similar Diels–Alder strategy and removal of the amino group after elaboration of the tetracyclic system to afford 11- or 6-deoxyanthracyclinones.

However, we reported in a previous paper[9] that the oxidation of the acetylaminoanthraquinone (**8**) with lead tetra-acetate, in acetic acid, led to the anthracenetrione (**12**) instead of the diquinone monoimine (**13**). We have now found that the required diquinone monoimines (**14**)—(**16**) can be obtained by oxidation of the corresponding sulphonylaminoanthraquinones (**9**)—(**11**), according to the earlier report by Adams for the synthesis of quinone imine derivatives.[10] It was thought that the use of diquinone imines of type (**14**) could prove advantageous because the regiochemistry of the cycloaddition might be controlled by the sulphonylimino group in accord with previous results reported for 1,4-benzoquinone benzenesulphonylimines.[11]



(**1**) $R^1 = R^4 = H, R^2 = R^3 = OH, R^5 = Ac$
(**2**) $R^1 = OMe, R^2 = R^3 = OH, R^4 = H, R^5 = Ac$
(**3**) $R^1 = R^2 = OH, R^3 = H, R^4 = CO_2Me, R^5 = Et$
(**4**) $R^1 = R^3 = OH, R^2 = H, R^4 = OH, R^5 = Et$

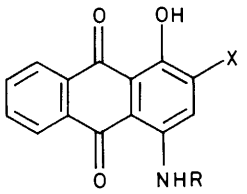


(**5**) R = H
(**6**) R = OMe

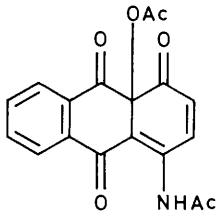
In the present paper we report the preparation of several anthracenediquinone monosulphonylimines (**14**)—(**16**) and the Diels–Alder reactions of (**14**) and (**16**) with various substituted dienes, results which provide information on the regio- and site-selectivity of these cycloadditions.

Results and Discussion

The lead tetra-acetate oxidation of the 1-hydroxy-4-sulphonylamino-9,10-anthraquinones (**9**)—(**11**) gave a good yield of the expected anthracenediquinone monosulphonylimines (**14**)—(**16**), respectively. The starting compounds (**9**) and (**10**) were prepared by tosylation or mesylation of the commercially available 1-amino-4-hydroxy-9,10-anthraquinone (**7**). The



(7) R = X = H
(8) R = Ac, X = H
(9) R = Ts, X = H
(10) R = Ms, X = H
(11) R = Ts, X = Cl



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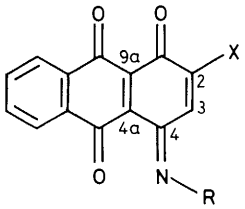
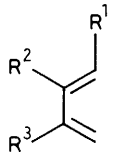


(13) R = Ac, X = H
(14) R = Ts, X = H
(15) R = Ms, X = H
(16) R = Ts, X = Cl



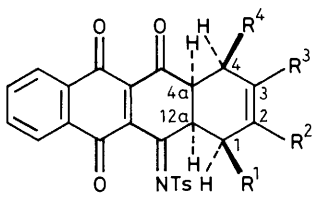
(17) R^1 = H, R^2 = R^3 = Me
(18) R^1 = OMe, R^2 = R^3 = H
(19) R^1 = $OSiMe_3$, R^2 = R^3 = H
(20) R^1 = OMe, R^2 = H, R^3 = $OSiMe_3$
(21) R^1 = R^3 = H, R^2 = OAc
(22) R^1 = $SiMe_3$, R^2 = H, R^3 = OAc

structures of the new diquinone imines (**14**) and (**15**) were confirmed from their ^{1}H n.m.r. spectra, which showed AB systems assignable to the quinonoid protons at δ 6.76/8.29 and 6.69/8.04, respectively. These data are also consistent with the presence of a sulphonyl group in a *syn* relationship to the 2,3-double bond, the deshielded absorption of the 3-H being due to the anisotropic effect of the sulphonyl group.[11] Treatment of the diquinone imine (**14**) with hydrochloric acid provided (**11**), which afforded the chlorodiquinone imine (**16**) on oxidation with lead tetra-acetate. The regiochemistry of the addition was deduced from the presence of a low-field singlet (δ 8.53) attributable to the olefinic proton at C-3, which is deshielded by the *syn* sulphonylimino group.[11]

The cycloaddition of the diquinone imine (**14**) with 1 equivalent of 2,3-dimethylbuta-1,3-diene (**17**) in benzene at room temperature for 48 h afforded the linear adduct (**23**) in 87% yield. The linear structure of the adduct (**23**) was established on the basis of its ^{1}H n.m.r. spectrum, in which there were no signals assignable to the quinone-like protons of the starting quinone imine (**14**). Moreover, the presence of two multiplets centred at δ 4.55 and 3.45, integrating for two protons, confirmed the presence of the ring-junction protons at C-12a and C-4a, respectively.

Reaction of the diquinone imine (**14**) with an excess of 2,3-dimethylbuta-1,3-diene (**17**) in benzene at room temperature gave the major linear adduct (**23**) (75%), and also the bridged adduct (**28**) (15%). The bridged nature of (**28**) was confirmed by its ^{1}H n.m.r. spectrum which showed an AB system at δ 6.57 and 8.10 assignable to the olefinic protons at C-2 and C-3, respectively.

We then investigated the cycloaddition of (**14**) with dienes bearing oxygen substitutents in order to achieve functionalisation of the A ring of anthracyclinones and to gain information on the site- and regio-selectivity of the reaction. Treatment of the diquinone imine (**14**) with 1 equivalent of (*E*)-1-methoxybuta-1,3-diene (**18**) in benzene at room temperature for 24 h afforded

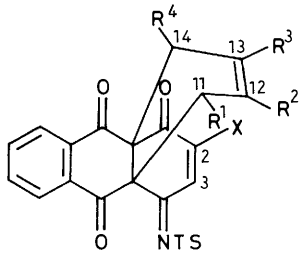


(23) R^1 = R^4 = H, R^2 = R^3 = Me
(24) R^1 = OMe, R^2 = R^3 = R^4 = H
(25) a; R^1 = $OSiMe_3$, R^2 = R^3 = R^4 = H
b; R^1 = R^2 = R^3 = H, R^4 = $OSiMe_3$
(26) a; R^1 = R^2 = R^4 = H, R^3 = OAc
b; R^1 = R^3 = R^4 = H, R^2 = OAc
(27) R^1 = R^3 = H, R^2 = OAc, R^4 = $SiMe_3$

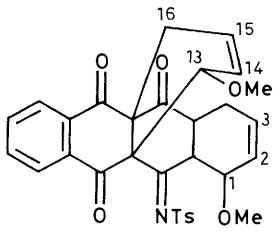
a 40:60 mixture of the linear adduct (**24**) and the bridged adduct (**29**). Since only one regioisomer of each adduct was observed in the ^{1}H n.m.r. spectrum of the crude reaction mixture, the reaction is highly regioselective. The presence of the two isomers (**24**) and (**29**), and their ratio, was deduced from the spectrum, which showed two multiplets centred at δ 4.75 and 3.40 [attributable to the ring-junction protons at C-12a and C-4a in the adduct (**24**)] and an AB system at δ 6.85 and 8.06 [assignable to the olefinic protons at C-2 and C-3 of the bridged adduct (**29**)]; in addition, the low-field resonance at δ 8.06 was indicative of the *syn* disposition of the tosylimino group.

However, reaction of (**14**) with a large excess of the diene (**18**) afforded a 40:60 mixture of the bridged adduct (**29**) and the bis-adduct (**33**), the latter presumably being formed by a subsequent cycloaddition to the internal double bond of (**24**). Alternatively, (**33**) may arise through a second Diels–Alder addition to the bridged adduct (**29**). The structure (**33**) was in good accord with the ^{1}H n.m.r. data (see Experimental section).

Adducts (**24**), (**29**), and (**33**) could be separated by fractional crystallisation. The regiochemistry of (**24**), in which the



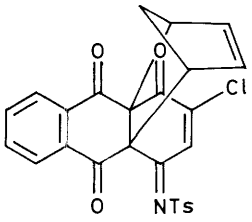
(28) R^1 = R^4 = H, R^2 = R^3 = Me, X = H
(29) R^1 = OMe, R^2 = R^3 = R^4 = H, X = H
(30) a; R^1 = $OSiMe_3$, R^2 = R^3 = R^4 = H, X = H
b; R^1 = R^2 = R^3 = H, R^4 = $OSiMe_3$, X = H
(31) a; R^1 = OMe, R^2 = R^3 = R^4 = H, X = Cl
b; R^1 = R^2 = R^3 = H, R^4 = OMe, X = Cl
(32) R^1 = OMe, R^2 = R^4 = H, R^3 = $OSiMe_3$, X = Cl



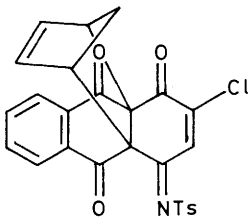
(33)

methoxy substituent is adjacent to the sulphonylimino group, was assigned on the basis of its ^{1}H n.m.r. spectrum and decoupling experiments. Thus the 12a-H was coupled (J 4.5 Hz) to the methine proton on the carbon bearing the OMe group, and the spectral pattern of the compound is similar to that reported for the cycloadducts of 1,4-benzoquinone monosulphonylimine with the same diene. The regiochemistry of (**29**) and (**33**) was tentatively assigned on the expectation that the sulphonylimino group is also the dominant director of the cycloaddition to the internal double bond.[11]

The Diels–Alder reaction of the diquinone imine (**14**) with (*E*)-1-trimethylsilyloxybuta-1,3-diene (**19**) was less selective than the corresponding reaction with 1-methoxybuta-1,3-diene and afforded a mixture of linear (**25a,b**) and bridged adducts (**30a,b**). The two isomeric linear adducts (**25a**) (10%) and (**25b**) (8%) could be isolated by fractional precipitation with diethyl ether, along with an inseparable mixture of the bridged adducts (30%), presumed to be the regioisomers (**30a,b**). In this case, however, no signals corresponding to bis-adducts could be observed on the ^{1}H n.m.r. of the crude reaction mixture. The structures of the adducts (**25a**) and (**25b**) were assigned on the basis of their ^{1}H n.m.r. spectral data and on the assumption that the Diels–Alder reaction would involve an *endo*-transition state. In fact, the ^{1}H n.m.r. spectral pattern of adduct (**25a**) was very similar to that of (**24**), thus indicating that the TMSO substituent is adjacent to the tosylimino group. Moreover, structure (**25a**) was confirmed by a series of decoupling experiments.



(**34a**)



(**34b**)

We then turned our attention to the Diels–Alder reactions of the chlorodiquinone imine (**16**), in which the presence of the halogen could modify the site- and regio-selectivity of the cycloaddition. The reaction of (**16**) with (*E*)-1-methoxybuta-1,3-diene (**18**) or the Danishefsky's diene (**20**) in chloroform at room temperature proceeded exclusively at the internal double bond to give the adducts (**31a,b**), presumed to be regioisomers, and (**32**), respectively, the latter as a single isomer. Structure (**32**) could not be ascertained from spectral data but was tentatively assigned on the expectation that the sulphonylimino group is the dominant director of the cycloaddition.

In view of the difficulties in obtaining linear adducts with the chlorodiquinone imine (**16**), we attempted to protect its internal 4a,9a-double bond by addition of cyclopentadiene. Diels–Alder reaction of (**16**) with cyclopentadiene occurred rapidly in chloroform at room temperature to afford the internal adduct (**34**), shown by ^{1}H n.m.r. spectroscopy to be a mixture of diastereoisomers (**34a,b**) in the ratio 60:40 (estimated by integration of the respective olefinic 3-H signals at δ 8.21 and 8.32, respectively). Although the mixture could not be separated, we have tentatively assigned structure (**34a**) to the major product, in which the 3-H proton was shifted upfield (δ 8.21) due to the shielding effect of the proximate cyclopentene double bond.[12] However, attempts to bring about reaction of the mixture (**34a,b**) with a reactive diene, such as Danishefsky's diene (**20**), at room temperature or in benzene at 40 °C, failed to give the expected adduct, presumably due to steric factors.

In an attempt to achieve selective terminal annelation to the diquinone imine (**14**), we also used a less electron-rich diene, 2-acetoxybuta-1,3-diene (**21**), which, on the basis of its reaction with anthracenediquinone (**5**),[7] was expected to react preferentially with the external 2,3-double bond. However, it was found that cycloaddition of the diquinone imine (**14**) with the diene (**21**) in benzene at room temperature for 4 days afforded the linear adduct as a 57:43 mixture of the regioisomers (**26a**) and (**26b**).

In view of the reported reaction of (*E*)-3-acetoxy-1-trimethylsilylbuta-1,3-diene (**22**) with anthracenediquinone (**5**) to give exclusively the linear adduct,[6,13] we also studied the behaviour of this diene with the diquinone imine (**14**). When (**14**) was allowed to react with the bifunctionalised diene (**22**) in benzene at 55 °C for 4 days, a single adduct (**27**) was isolated in 77% yield. The regiochemistry of (**27**) was assigned on the basis of its ^{1}H n.m.r. data. Decoupling experiments indicated that the ring-junction 4a-H (δ 3.61) was coupled (J 4.6 Hz) to the methine proton (δ 2.02) on the carbon bearing the Me_3Si group. The exclusive formation of the regioisomer (**27**) can be reasonably explained by consideration of steric factors, which in this case play the major role.

In summary, the Diels–Alder reaction of the 1,4,9,10-anthracenediquinone monosulphonylimines can occur either at the singly activated external 2,3-double bond, to give linear adducts, or at the doubly-activated internal 4a,9a-double bond, to afford bridged adducts. As reported previously for anthracenediquinone (**5**),[8] the nature of the substituents of the butadiene plays a significant role in controlling the site-selectivity; when electron-rich dienes are used bridged or bis-adducts predominate, the regioselectivity being controlled in any case by the sulphonylimino group. However, the partial formation of linear adducts of the quinone imine (**14**) with electron-rich dienes, and the exclusive formation of such terminal adducts with less electron-rich dienes, indicate that in the present case the external 2,3-double bond competes with the 4a,9a-double bond more favourably than in anthracenediquinone (**5**). In contrast, the presence of one chlorine atom at the external 2,3-double bond of the quinone imine (**14**) does not enhance its reactivity towards the Diels–Alder reaction and the cycloaddition with several dienes results in the exclusive formation of bridged adducts, as previously reported for 2-chloroanthracene-1,4,9,10-tetraone.[14]

Experimental

M.p.s are uncorrected. I.r. spectra were recorded on a Perkin-Elmer model 257 grating spectrophotometer as Nujol mulls, ν values in cm^{-1}. ^{1}H N.m.r. spectra were determined with either a Varian EM-390 or a model XL-300 spectrometer, in $CDCl_3$ solution (unless otherwise stated). Chemical shifts are reported in p.p.m. (δ) downfield from Me_4Si. Mass spectra were determined on a Hitachi Perkin-Elmer RMU-6MG spectrometer. Silica gel Merck 60 (70—230 mesh) and DC-Alufolien $60F_{254}$ were normally used for preparative column and analytical t.l.c., respectively.

1-*Hydroxy*-4-*tosylamino*-9,10-*anthraquinone* (**9**).—To a stirred suspension of the quinone (**7**) (11.95 g, 50 mmol) in pyridine (150 ml) was added tosyl chloride (11.40 g, 60 mmol) and the mixture was heated at 70 °C for 24 h. The reaction was monitored by t.l.c. (chloroform) and if starting material remained, further tosyl chloride (3.80 g, 20 mmol) was added and the reaction mixture heated at 70 °C for a further 24 h. The suspension was poured into water (1 000 ml), with vigorous stirring, and the solid was filtered off and washed successively with water, 10% aqueous HCl, and water. The crude mixture was dissolved in 10% aqueous NaOH, filtered, and reprecipitated with 10% aqueous HCl. The precipitate was filtered off, washed with water, dried, and purified by column chrom-

atography (chloroform) to give the quinone (**9**) (9.40 g, 48%), m.p. 202—204 °C (from ethyl acetate) (Found: C, 64.4; H, 3.75; N, 4.0; S, 8.3. $C_{21}H_{15}NO_5S$ requires C, 64.1; H, 3.8; N, 3.6; S, 8.15%); $\lambda_{max.}$(*CHCl*$_3$) 254, 278, and 472 nm (log ε 4.2, 3.8, and 3.6); $\nu_{max.}$ 1 640, 1 590, 1 365, and 1 160 cm^{-1}; δ_H 13.14 (1 H, s, OH), 12.13 (1 H, br s, NH), 8.43—7.10 (8 H, m, ArH), 8.08 (1 H, d, B of AB, $J_{2,3}$ 9.0 Hz, 3-H), 7.26 (1 H, d, A of AB, $J_{2,3}$ 9.0 Hz, 2-H), and 2.33 (3 H, s, Me); *m*/*z* 393 (M^+), 238 (100), 203, 155, 144, and 91.

1-*Hydroxy*-4-*mesylamino*-9,10-*anthraquinone* (**10**).—To a stirred suspension of the quinone (**7**) (4.78 g, 20 mmol) in pyridine (50 ml) was added methanesulphonyl chloride (5.70 g, 50 mmol) and the mixture was allowed to stand at room temperature for 24 h. After monitoring of the reaction by t.l.c. (chloroform), the suspension was poured into water (500 ml) with vigorous stirring. The precipitate was filtered off and washed successively with water, 10% aqueous HCl, and water to give the quinone (**10**). The crude product was dissolved in 5% aqueous NaOH, filtered, and reprecipitated with 10% aqueous HCl. The precipitate was filtered off, washed with water, dried, and purified by column chromatography (chloroform), to afford the pure quinone (**10**) (4.44 g, 70%), m.p. 223.5—224.5 °C (from ethyl acetate) (Found: C, 57.1; H, 3.5; N, 4.45; S, 10.4. $C_{15}H_{11}NO_5S$ requires C, 56.8; H, 3.5; N, 4.4; S, 10.1%); $\lambda_{max.}$(dioxane) 231, 252, 279, 325sh, and 470 nm (log ε 4.4, 4.5, 4.1, 3.5, and 3.9); $\nu_{max.}$ 1 630, 1 590, 1 355, and 1 145 cm^{-1}; δ_H 13.20 (1 H, s, OH), 11.89 (1 H, br s, NH), 8.40—7.53 (4 H, m, ArH), 8.09 (1 H, d, B of AB, $J_{2,3}$ 9.9 Hz, 3-H), 7.37 (1 H, d, A of AB, $J_{2,3}$ 9.9 Hz, 2-H), and 3.12 (3 H, s, Me); *m*/*z* 317 (M^+), 238 (100), 210, 183, 154, and 127.

2-*Chloro*-1-*hydroxy*-4-*tosylamino*-9,10-*anthraquinone* (**11**).—*Method A*. To a stirred solution of the diquinone imine (**14**) (100 mg, 0.26 mmol) in chloroform (10 ml) was added concentrated hydrochloric acid (3 drops). The orange solution was washed successively with water, aqueous sodium hydrogen carbonate, and water, and then dried (Na_2SO_4) and evaporated under reduced pressure. The residue was purified by preparative t.l.c. or column chromatography (chloroform) to give the anthraquinone (**11**) (101 mg, 94%), m.p. 225—226 °C (from ethyl acetate) (Found: C, 58.9; H, 3.2; Cl, 7.7; N, 3.3; S, 8.6. $C_{21}H_{14}ClNO_5S$ requires C, 59.0; H, 3.3; Cl, 7.5; N, 3.3; S, 8.3%); $\lambda_{max.}$($CHCl_3$) 254, 259, 289, and 472 nm (log ε 4.6, 4.5, 4.1, and 3.9); $\nu_{max.}$ 1 635, 1 595, 1 275, and 1 160 cm^{-1}; δ_H 13.68 (1 H, s, OH), 12.07 (1 H, br s, NH), 8.40—7.10 (8 H, m, ArH), 8.22 (1 H, s, 3-H), and 2.34 (3 H, s, Me); *m*/*z* 429 (M^+ + 2), 427 (M^+), 274, and 272 (100).

Method B. To a stirred suspension of the quinone (**9**) (1.0 g, 2.5 mmol) in glacial acetic acid (50 ml) at room temperature was added, in one portion, lead tetra-acetate (2.0 g, 4 mmol). After 45 min, the solution was filtered and concentrated hydrochloric acid (10 ml) was added. The resulting suspension was diluted with water (50 ml), and filtered. The precipitate was washed with water and dissolved in chloroform, and the solution was dried (Na_2SO_4) and evaporated under reduced pressure. [The product could be used without further purification for the oxidation to the diquinone imine (**16**)]. The residue was purified by column chromatography (chloroform–acetone, 20:1) to give the quinone (**11**) (1.04 g, 96%), m.p. 225—226 °C (from ethyl acetate), identical with the product described above.

4-*Tosyliminoanthracene*-1,9,10-*trione* (**14**).—To a stirred suspension of the quinone (**9**) (2.0 g, 5.11 mmol) in glacial acetic acid (200 ml), at room temperature, was added lead tetra-acetate (4.0 g, 8.0 mmol). After 30 min, the solution was filtered, diluted with benzene (500 ml), washed repeatedly with water, dried (Na_2SO_4), and concentrated under reduced pressure. Heptane (50—100 ml) was added to the residue and the resulting precipitate was filtered off and washed with heptane to yield the diquinone imine (**14**) (1.75 g, 93%), m.p. 190 °C (from toluene–heptane) (Found: C, 64.6; H, 3.3; N, 3.9; S, 8.3. $C_{21}H_{13}NO_5S$ requires C, 64.45; H, 3.3; N, 3.6; S, 8.2%); $\lambda_{max.}$($CHCl_3$) 247, 284, and 350 nm (log ε 4.3, 4.3, and 3.8); $\nu_{max.}$ 1 690, 1 325, 1 298, and 1 162 cm^{-1}; δ_H 8.29 (1 H, d, B of AB, $J_{2,3}$ 11.7 Hz, 3-H), 8.17—7.20 (8 H, m, ArH), 6.76 (1 H, d, A of AB, $J_{2,3}$ 11.7 Hz, 2-H), and 2.46 (3 H, s, Me); *m*/*z* 393 (M^+ + 2), 238 (100), and 91.

4-*Mesyliminoanthracene*-1,9,10-*trione* (**15**).—To a stirred suspension of the quinone (**10**) (200 mg, 0.63 mmol) in glacial acetic acid (2 ml), at room temperature, was added lead tetra-acetate (400 mg, 0.8 mmol). After 45 min, ethylene glycol (3 drops) was added and the stirring was maintained for 3—5 min. The solution was diluted with toluene (40 ml), washed with water, dried (Na_2SO_4), concentrated under reduced pressure, diluted with heptane to give (**15**) (150 mg, 75%), m.p. 234—235 °C (from ethyl acetate) (Found: C, 57.0; H, 3.1; N, 4.2; S, 10.0. $C_{15}H_9NO_5S$ requires C, 57.1; H, 2.85; N, 4.4; S, 10.15%); $\lambda_{max.}$(dioxane) 241, 287, and 350sh nm (log ε 4.4, 4.1, and 3.6); $\nu_{max.}$ 1 670, 1 680, 1 650, 1 620, 1 590, 1 320, 1 300, and 1 155 cm^{-1}; δ_H 8.16—7.63 (4 H, m, ArH), 8.04 (1 H, d, B of AB, $J_{2,3}$ 9.9 Hz, 3-H), 6.69 (1 H, d, A of AB, $J_{2,3}$ 9.9 Hz, 2-H), and 3.38 (3 H, s, Me); *m*/*z* 317 (M^+ + 2), 240, 238 (100), and *m** 178.7 (317 ⟶ 238).

2-*Chloro*-4-*tosyliminoanthracene*-1,9,10-*trione* (**16**).—To a stirred suspension of the quinone (**11**) (1.0 g, 2.3 mmol) in glacial acetic acid (150 ml), at room temperature, was added in one portion lead tetra-acetate (2.0 g, 4 mmol). After 1 h, the colour of the suspension changed from red to pale brown. The precipitate was filtered off and washed with carbon tetrachloride to yield the chlorodiquinone imine (**16**) (870 mg, 82%), m.p. 131 °C (from ethyl acetate) (Found: C, 59.25; H, 2.7; Cl, 8.55; N, 3.4; S, 7.8. $C_{21}H_{12}ClNO_5S$ requires C, 59.2; H, 2.5; Cl, 8.3; N, 3.3; S, 7.5%); $\lambda_{max.}$(dioxane) 237, 290, and 345sh nm (log ε 4.6, 4.1, and 3.8); $\nu_{max.}$ 1 705, 1 680, 1 570, 1 292, and 1 164 cm^{-1}; δ_H 8.53 (1 H, s, 3-H), 8.17—7.30 (8 H, m, ArH), and 2.50 (3 H, s, Me); *m*/*z* 429 (M^+ + 4), 427 (M^+ + 2), 202, and 91 (100).

Reaction of the Diquinone Imine (**14**) *with* 2,3-*Dimethylbuta*-1,3-*diene* (**17**).—(a) To a solution of (**14**) (200 mg, 0.5 mmol) in benzene (20 ml) was added the diene (**17**) (50 mg, 0.6 mmol) and the mixture was allowed to stand at room temperature for 48 h. The solvent was removed under reduced pressure, and the crude residue recrystallised from chloroform–heptane to give the adduct (**23**) (206 mg, 87%), m.p. 194—196.5 °C (Found: C, 68.4; H, 4.75; N, 2.7; S, 6.65. $C_{27}H_{23}NO_5S$ requires C, 68.5; H, 4.9; N, 2.6; S, 6.8%); $\nu_{max.}$ 1 715, 1 685, 1 635, 1 600, 1 285, and 1 160 cm^{-1}; δ_H 8.32—7.20 (8 H, m, ArH), 4.40—4.70 (1 H, m, 12a-H), 3.25—3.60 (1 H, m, 4a-H), 2.43 (3 H, s, Me), 2.80—1.70 (4 H, m, 1-H and 4-H), 1.66 (3 H, s, Me), and 1.55 (3 H, s, Me); *m*/*z* 475 (M^+ + 2), 473 (M^+), 393, 317 (100), 156, and 92.

(b) To a solution of (**14**) (200 mg, 0.5 mmol) in benzene (20 ml) was added an excess of the diene (**17**) (200 mg, 2.43 mmol) and the mixture was allowed to stand at room temperature for 24 h. The solvent was evaporated and the residue was recrystallised from chloroform–heptane to give the adduct (**23**) (177 mg, 75%), m.p. 194—196.5 °C, identical with the product described above. The mother liquor was concentrated under reduced pressure and the residue was purified by crystallisation from chloroform–heptane to give the adduct (**28**) (36 mg, 15%), m.p. 83—86 °C; $\nu_{max.}$ 1 715, 1 685, 1 600, 1 260, and 1 160 cm^{-1}; δ_H 8.13—7.10 (8 H, m, ArH), 8.10 (1 H, d, B of AB, $J_{2,3}$ 11.7 Hz, 3-H), 6.57 (1 H, d, A of AB, $J_{2,3}$ 11.7 Hz, 2-H), 2.70—2.20 (4 H, m, 11-H and 14-H), 2.42 (3 H, s, Me), and 1.57 (6 H, s, Me); *m*/*z* 475 (M^+ + 2), 473 (M^+), 393, 318, 237, 186, and 91 (100).

Reaction of the Diquinone Imine (**14**) *with* (E)-1-*Methoxybuta*-1,3-*diene* (**18**).—(a) To a stirred solution of (**14**) (400 mg, 1 mmol) in benzene (30 ml) was added the diene (**18**) (86 mg, 1 mmol) and the mixture was allowed to stand at room temperature for 24 h. The solvent was removed and the residue was estimated by ^{1}H n.m.r. to be a 40:60 mixture of the adducts (**24**) and (**29**). The mixture was separated by fractional crystallisation from chloroform–diethyl ether to afford (**24**) (270 mg, 55%), m.p. 180—185 °C (Found: C, 65.6; H, 4.7; N, 2.9; S, 7.1. $C_{26}H_{21}NO_6S$ requires C, 65.7; H, 4.4; N, 2.9; S, 6.8%); $\nu_{max.}$ 1 725, 1 680, 1 605, 1 315, 1 290, 1 285, 1 275, and 1 155 cm^{-1}; δ_H 8.17—7.30 (8 H, m, ArH), 6.00 (2 H, m, 2-H and 3-H), 4.90—4.60 (1 H, m, 12a-H), 4.46—4.23 (1 H, m, 1-H), 3.40 (1 H, t, 4a-H), 3.12 (3 H, s, OMe), 3.25—2.88 (1 H, m, 4-H), 2.46 (3 H, s, Me), and 2.40—2.00 (1 H, m, 4-H′); *m/z* 475 (M^+), 443, *m** 413.2 (475 ⟶ 443), 393, 289 (100), *m** 188.5 (443 ⟶ 289), 289 (100), and 156; and (**29**) (150 mg, 30%), m.p. 175—180 °C (Found: C, 65.6; H, 4.7; N, 2.6; S, 6.7. $C_{26}H_{21}NO_6S$ requires C, 65.7; H, 4.4; N, 2.9; S, 6.7%); $\nu_{max.}$ 1 730, 1 710, 1 695, 1 610, 1 330, 1 265, and 1 160 cm^{-1}; δ_H 8.06 (1 H, d, B of AB, $J_{2,3}$ 10.8 Hz, 3-H), 8.04—7.10 (8 H, m, ArH), 6.85 (1 H, d, A of AB, $J_{2,3}$ 10.8 Hz, 2-H), 6.25—5.72 (2 H, m, 12-H and 13-H), 4.46 (1 H, m, 11-H), 3.40—3.00 (1 H, m, 14-H), 3.20 (3 H, s, OMe), 2.44 (3 H, s, Me), and 2.20—1.80 (1 H, m, 14-H′); *m/z* 475 (M^+), 443, 393, 371, 320 (100), 289, 240, *m** 215.6 (475 ⟶ 320), 209, 188, and *m** 180 (320 ⟶ 240).

(b) To a stirred solution of (**14**) (400 mg, 1 mmol) in benzene (30 ml) was added a large excess of the diene (**18**) (300 mg, 3.6 mmol). After 1 h, the solvent was removed and the residue was estimated by ^{1}H n.m.r. to be a 40:60 mixture of adduct (**29**) and bis-adduct (**33**). The mixture was separated by fractional crystallisation from chloroform–diethyl ether to afford (**29**) (135 mg, 27%), m.p. 175—180 °C, identical (i.r., ^{1}H n.m.r., m.s.) with the product described above, and (**33**) (270 mg, 47%), m.p. 194—196 °C (Found: C, 66.2; H, 5.5; N, 2.6; S, 5.6. $C_{31}H_{29}NO_7S$ requires C, 64.5; H, 5.2; N, 2.5; S, 5.7%); $\nu_{max.}$ 1 735, 1 700, 1 685, 1 615, 1 600, 1 325, 1 255, and 1 150 cm^{-1}; δ_H 8.20—7.30 (8 H, m, ArH), 6.12—5.59 (4 H, m, 2-H, 3-H, 14-H, and 15-H), 4.62 (1 H, t, 1-H), 4.30 (1 H, m, 13-H), 4.20 (1 H, m, 12a-H), 4.05—3.60 (1 H, m, 16-H), 3.35—2.50 (3 H, m, 4-H, 4a-H, and 16-H′), 3.25 (3 H, s, OMe), 2.78 (3 H, s, OMe), 2.45 (3 H, s, Me), and 2.05—1.70 (1 H, m, 4-H′); *m/z* 559 (M^+), 525, 475, 393, 370, 240 (100), and 91.

(c) A solution of the diene (**18**) (150 mg, 1.8 mmol) and the diquinone imine (**14**) (200 mg, 0.5 mmol) in toluene (100 ml) was heated at 100 °C for 30 min. The solvent was removed under reduced pressure and the residue was estimated by ^{1}H n.m.r. to be a 16:60:24 mixture of adducts (**24**), (**29**), and (**33**).

Reaction of the Diquinone Imine (**14**) *with* (E)-1-*Trimethylsilyloxybuta*-1,3-*diene* (**19**).—A solution of the diene (**19**) (1.0 g, 6.5 mmol) and (**14**) (200 mg, 0.5 mmol) in toluene (100 ml) was heated at 100 °C for 30 min. The solvent was removed under reduced pressure and the residue was analysed (Found: C, 63.1; H, 5.2; N, 2.6; S, 5.9. $C_{28}H_{27}NO_6SSi$ requires C, 63.0; H, 5.1; N, 2.6; S, 6.0%). The crude mixture was separated by fractional precipitation from diethyl ether to afford (**25a**) (272 mg, 10%), m.p. 188—189 °C; $\nu_{max.}$ 1 720, 1 680, 1 600, 1 320, 1 280, 1 160, and 840 cm^{-1}; δ_H 8.22—7.30 (8 H, m, ArH), 5.90 (2 H, m, 2-H and 3-H), 4.78 (2 H, m, 1-H and 12a-H), 3.58—3.32 (1 H, m, 4a-H, upon irradiation at δ 4.78 collapses to a doublet), 3.32—2.88 (1 H, m, 4-H), 2.50 (3 H, s, Me), 2.34—2.00 (1 H, m, 4-H′), and −0.11 (9 H, s, $OSiMe_3$); *m/z* 535 (M^+ + 2), 533 (M^+), 466, *m** 407.4 (533 ⟶ 466), *m** 405.9 (435 ⟶ 466), 393, 378, 289, and *m** 185.5 (443 ⟶ 289); (**25b**) (220 mg, 8%), m.p. 168—169 °C; $\nu_{max.}$ 1 720, 1 685, 1 640, 1 600, 1 310, 1 150, and 845 cm^{-1}; δ_H 8.33—7.16 (8 H, m, ArH), 6.05—5.45 (2 H, m, 2-H and 3-H), 4.60—4.40 (1 H, m, 4-H, collapses to a doublet on decoupling of the 2,3-vinyl protons), 3.86—3.60 (1 H, m, 12a-H, collapses to a doublet upon irradiation at 3.30 and 2.20), 3.40—3.20 (1 H, m, 4a-H), 3.20—2.80 (1 H, m, 1-H), 2.42 (3 H, s, Me), 2.40—2.00 (1 H, m, 1-H′), and −0.11 (9 H, s, $OSiMe_3$); *m/z* 535 (M^+ + 2), 533 (M^+), 466, 393, 378, and 289; and the mixture (**30a**) and (**30b**) (820 mg, 30%); $\nu_{max.}$ 1 725, 1 705, 1 685, 1 635, 1 600, 1 325, 1 260, 1 160, and 845 cm^{-1}; δ_H 8.26, 8.02 (1 H, d, B of AB, $J_{2,3}$ 9.9 Hz, 3-H), 7.82—7.09 (8 H, m, ArH), 6.86, 6.34 (1 H, d, A of AB, $J_{2,3}$ 9.9 Hz, 2-H), 6.07—5.62 (2 H, m, 12-H and 13-H), 4.90 [1 H, m, 11-H (**30a**) and 14-H (**30b**)], 3.32—3.12 [1 H, m, 14-H (**30a**) and 11-H (**30b**)], 2.43 (3 H, s, Me), 2.10—1.86 [1 H, m, 14-H′ (**30a**) and 11-H′ (**30b**)], and 0.08, 0.04 (9 H, s, $OSiMe_3$); *m/z* 535 (M^+ + 2), 533 (M^+), 518, 378 (100), 350, 298, 288, *m** 267.07 (535 ⟶ 378), 238, *m** 234.9 (378 ⟶ 298), 209, and 142.

Reaction of the Chlorodiquinone Imine (**16**) *with* (E)-1-*Methoxybuta*-1,3-*diene* (**18**).—To a solution of (**16**) (100 mg, 0.23 mmol) in chloroform (15 ml) was added the diene (**18**) (21 mg, 0.25 mmol). The reaction mixture was stirred at room temperature for 10 min after which the solvent was removed under reduced pressure to afford a mixture of the adducts (**31a**) and (**31b**) (96 mg, 82%), δ_H 8.64, 8.33 (1 H, s, 3-H), 8.08—7.23 (8 H, m, ArH), 6.19—5.78 (2 H, m, 12-H and 13-H), 4.67, 4.45 (1 H, dd, 14-H and 11-H), 3.33—3.24 (1 H, m, 14-H and 11-H), 3.23, 3.18 (3 H, s, OMe), 2.46, 2.44 (3 H, s, Me), and 2.20—2.15, 2.15—2.04 (1 H, m, 11-H′ and 14-H′). The crude mixture was separated by fractional precipitation from diethyl ether to give pure (**31a**), m.p. 190—195 °C (Found: C, 61.5; H, 4.1; Cl, 7.2; N, 3.0; S, 7.0. $C_{26}H_{20}ClNO_6S$ requires C, 61.3; H, 3.9; Cl, 6.9; N, 2.75; S, 6.3%); $\nu_{max.}$ 1 735, 1 710, 1 690, 1 595, 1 335, 1 260, and 1 162 cm^{-1}; δ_H 8.33 (1 H, s, 3-H), 8.04—7.63 (4 H, m, ArH), 7.49, 7.21 (4 H, d, AA′BB′ system, *J* 8.1 Hz, ArH), 6.19—5.85 (2 H, m, 12-H and 13-H), 4.45 (1 H, dd, $J_{11,12}$ 5.05 Hz, $J_{11,14}$ 0.9 Hz, 11-H), 3.34—3.21 (1 H, m, 14-H), 3.23 (3 H, s, OMe), 2.44 (3 H, s, Me), and 2.17—2.04 (1 H, m, J_{gem} 18.3 Hz, 14-H′); *m/z* 511 (M^+ + 2), 509 (M^+), 476, 474, 356, 354, 322, 294, 163, and 91 (100).

Reaction of the Chlorodiquinone Imine (**16**) *with* (E)-1-*Methoxy*-3-*trimethylsilyloxybuta*-1,3-*diene* (**20**).—To a solution of (**16**) (100 mg, 0.23 mmol) in chloroform (15 ml) was added the diene (**20**) (46 mg, 0.25 mmol). The reaction mixture was stirred at room temperature for 10 min, after which the solvent was removed under reduced pressure and the residue was triturated with diethyl ether to afford the adduct (**32**) (100 mg, 80%), m.p. 190—194 °C (Found: C, 58.3; H, 4.8; Cl, 5.9; N, 2.6; S, 5.7. $C_{29}H_{28}ClNO_7SSi$ requires C, 58.3; H, 4.7; Cl, 5.9; N, 2.3; S, 5.4%); $\nu_{max.}$ 1 730, 1 710, 1 690, 1 672, 1 600, 1 345, 1 260, 1 170, and 850 cm^{-1}; δ_H 8.30 (1 H, s, 3-H), 8.03—7.63 (4 H, m, ArH), 7.49, 7.21 (4 H, d, AA′BB′ system, *J* 8.2 Hz, ArH), 5.27 (1 H, dd, $J_{11,12}$ 5.6 Hz, 12-H), 4.54 (1 H, dd, $J_{11,12}$ 5.6 Hz, 11-H), 3.15 (3 H, s, OMe), 3.22—3.13 (1 H, m, J_{gem} 18.2 Hz, 14-H), 2.43 (3 H, s, Me), 2.13—2.04 (1 H, m, J_{gem} 18.2 Hz, 14-H′), and 0.20 (9 H, s, $OSiMe_3$); *m/z* 599 (M^+ + 2), 597 (M^+), 584, 582, 444, 442, 328, 91, and 73 (100).

Reaction of the Chlorodiquinone Imine (**16**) *with Cyclopentadiene*.—To a solution of (**16**) (100 mg, 0.23 mmol) in chloroform (15 ml) was added cyclopentadiene (23 mg, 0.35 mmol). The reaction mixture was stirred at room temperature for 15 min, after which the solvent was removed under reduced pressure and the residue was triturated with diethyl ether to afford the adduct (**34a,b**) (88 mg, 78%), m.p. 168—171 °C (Found: C, 63.7; H, 3.1; Cl, 7.25; N, 2.8; S, 6.8. $C_{26}H_{18}ClNO_5S$ requires C, 63.5; H, 3.6; Cl, 7.1; N, 2.85; S, 6.5%); $\nu_{max.}$ 1 718, 1 708, 1 672, 1 600, 1 325, 1 160, and 1 098 cm^{-1}; δ_H 8.32, 8.21 (1 H, s, 3-H), 7.98—7.40 (8 H, m, ArH), 6.32—6.12 (2 H, m, 14-H and 15-H), 4.28—4.13 (2 H, m, 11-H and 13-H), 2.50 (3 H, s, Me), and 1.67—1.33 (2 H, m, 12-H); *m/z* 493 (M^+ + 2), 491 (M^+), 457, 429, 427, 302, 272 (100), and 91.

Attempted Reaction of the Adduct (**34a,b**) *with* 1-*Methoxy*-3-*trimethylsilyloxybuta*-1,3-*diene* (**20**).—To a solution of (**35a,b**) (100 mg, 0.20 mmol) in chloroform (15 ml) was added the diene (**20**) (60 mg, 0.35 mmol), and the mixture was allowed to stand at room temperature for 4 days. The solvent was removed under reduced pressure and the residue was estimated by ^{1}H n.m.r. to be recovered adduct (**34a,b**). Attempts to effect the reaction in benzene at 40 °C were unsuccessful.

Reaction of the Diquinone Imine (**14**) *with* 2-*Acetoxybuta*-1,3-*diene* (**21**).—To a solution of (**14**) (100 mg, 0.25 mmol) in benzene (20 ml) was added the diene (**21**) (36 mg, 0.3 mmol). The reaction mixture was stirred at room temperature for 4 days, after which the solvent was removed under reduced pressure and the residue was triturated with diethyl ether to afford the mixture of regioisomeric adducts (**26a**) and (**26b**) (75 mg, 60%), m.p. 112—114 °C (Found: C, 64.3; H, 4.3; N, 2.6; S, 6.5. $C_{27}H_{21}NO_7S$ requires C, 64.4; H, 4.2; N, 2.8; S, 6.4%); $\nu_{max.}$ 1 760, 1 725, 1 680, 1 610, 1 310, 1 272, 1 220, and 1 150 cm^{-1}; δ_H 8.10—7.30 (8 H, m, ArH), 5.54—5.51, 5.40—5.35 [1 H, m, 2-H (**26a**) and 3-H (**26b**)], 4.83—4.74, 4.74—4.67 (1 H, m, 12a-H), 3.68—3.62, 3.52—3.47 (1 H, m, 4a-H), 3.00—2.00 (4 H, m, 1-H and 4-H), 2.47, 2.45 (3 H, s, Me), and 2.16, 2.09 (3 H, s, OAc); *m/z* 503 (M^+ + 2), 501 (M^+), 459, 347, 306, and 91.

Reaction of the Diquinone Imine (**14**) *with* (E)-3-*Acetoxy*-1-*trimethylsilylbuta*-1,3-*diene* (**22**).—To a solution of (**14**) (100 mg, 0.25 mmol) in benzene (20 ml) was added the diene (**22**) (40 mg, 0.25 mmol), and the reaction mixture was heated under argon at 55 °C for 4 days. After this it was stirred at room temperature for 12 h. The solvent was removed under reduced pressure and the residue was triturated with diethyl ether to afford the adduct (**27**) (110 mg, 77%), m.p. 178—182 °C (Found: C, 62.5; H, 5.2; N, 2.3; S, 5.7. $C_{30}H_{29}NO_7SSi$ requires C, 62.6; H, 5.0; N, 2.4; S, 5.6%); $\nu_{max.}$ 1 755, 1 730, 1 690, 1 275, 1 215, 1 150, 1 090, and 845 cm^{-1}; δ_H 8.07—7.74 (4 H, m, ArH), 7.98, 7.41 (4 H, d, AA′BB′ system, *J* 7.9 Hz, ArH), 5.49 (1 H, br s, 3-H), 4.76—4.69 (1 H, m, 12a-H), 3.61 (1 H, t, $J_{12a,4a}$ 4.6 Hz, $J_{4a,4}$ 4.6 Hz, 4a-H), 2.69—2.61 (1 H, m, J_{gem} 18.3 Hz, 1-H), 2.47 (3 H, s, Me), 2.45—2.35 (1 H, m, 1-H′), 2.06 (3 H, s, OAc), 2.00—2.04 (1 H, m, 4-H), and 0.19 (9 H, s, $SiMe_3$); *m/z* 577 (M^+ + 2), 562, 532, 377, 347, 305, and 73 (100).

Acknowledgements

Financial support from Secretaría de Estado de Universidades e Investigación is gratefully acknowledged.

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Received 14*th November* 1988; *Paper* 8/04523B