Model Studies Related to the Cofactor of Oxomolybdoenzymes. Part 3.[1]

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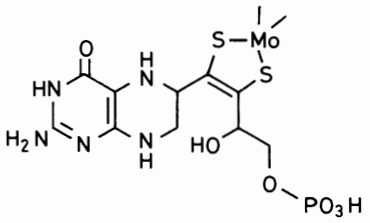
2-(D-*arabino*-Tetrahydroxybutyl)quinoxaline (**2**) reacted selectively to give the diol acetal (**3a**) which was converted into mono- and di-mesylates and -tosylates, and, *via* the ethyl ortho ester (**4**) into the alkene acetal (**5a**). Both thiocyanogen and bromine added to the alkene; all attempted conversions of the former adduct into a 1,2-dithiol failed; attempts to displace halogen from the latter with sulphur nucleophiles led in most cases simply to elimination of halogen. However, dimethyldithiocarbamate effected hydrogen bromide elimination and thus formation of the bromoalkene acetal (**5c**). On further reaction of this with bromine, a tribromo adduct (**6d**) was obtained, methoxide treatment of which gave the dibromoalkene acetal (**5d**). The epoxide acetals (**9a**) and (**9b**) were formed by base treatment of monomesylates (**3d**) and (**3e**), but attempted use of the epoxides for the introduction of sulphur functionality at best caused elimination thence reversion to the alkene acetal (**5a**), and more often resulted in complex product mixtures. Exposure of the di-mesylate (**3f**) and di-tosylate (**3b**) to sodium *N,N*-dimethyldithiocarbamate led to the enol mesylate (**5e**) and tosylate (**5f**). Exposure of the mono-mesylates (**3d**) and (**3e**) to sodium *N,N*-dimethyldithiocarbamate, then acid, then hydrogen sulphide gave, according to exact conditions, the thiole (**13**) or thiolane (**12a**), together with the alcohol (**6f**). The α-bromo ketone (**14b**) was prepared by bromination of the ketone (**14a**), itself available from reaction of the diol acetal (**3a**) with phosphorus pentasulphide, or better from the enol mesylate (**5e**) *via* addition of bromine then hydrolysis. Displacements of bromine in the bromo ketone with sulphur nucleophiles were successful, but the products could not then be converted into thioketones. The pyrazine ring in (**4**) could be selectively reduced with lithium aluminium hydride. Treatment of the dibromoalkene (**5d**) with dipotassium trithiocarbonate gave some thiole (**13**), but mainly the thieno[2,3-*b*]quinoxaline (**16**); similarly, reaction of the thiole (**13**) with base followed by iodomethane and then acetic anhydride gave the thieno[2,3-*b*]quinoxaline (**24**).

The oxomolybdoenzymes, xanthine oxidase, aldehyde oxidase, sulphite oxidase, and nitrate reductase, contain a common cofactor, Moco. There is now a considerable body of evidence[2] which has shown that the molybdenum in Moco is complexed by an organic component and partial structure (**1**) is believed to



(**1**)

represent Moco; no comment has yet been made on the stereochemistry, relative or absolute, at the two asymmetric carbon atoms. Furthermore, we believe that for the native enzyme, neither the oxidation level of the pyrazine ring nor that of the sulphur-bearing carbons has been finally established. The structure of the organic component of Moco, known as molybdopterin, is thus seen to comprise a 5,6,7,8-tetrahydropterin carrying at C-6 a highly functionalised C_4-side chain on which are situated the two sulphur atoms which co-ordinate the metal. It is likely that the mode of action of Moco involves redox processes at the metal centre, possibly linked to changes in the pyrazine ring oxidation level. It was relevant then to construct compounds which would mimic this active portion of the cofactor—we have accordingly set out to study quinoxalines carrying sulphur-substituted side-chains at C-2; this paper describes organic synthetic work towards C_4-side chain substituted quinoxalines.

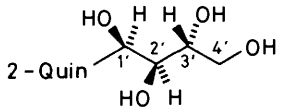
We have described[1,3,4] investigations into the synthesis of quinoxalin-2-ylethane-1,2-dithiols and -ethene-1,2-dithiols and the complexation[5] of some of these products with molybdenum, tungsten, and vanadium, as models for Moco. We were able to convert (protected) side-chain ethane-1,2-dithiols into (protected) ethene-1,2-dithiols. It was also possible to reduce the pyrazine ring of side-chain substituted quinoxalines to the tetrahydro level suggested for the pterin in Moco; the tetrahydro oxidation level was found to revert (re-oxidise) readily to the fully aromatic level. We describe here further model studies in which more elaborate quinoxalines, carrying appropriately oxygenated C_4-side chains, have been produced.

Results

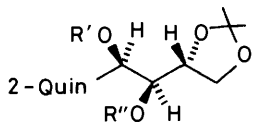
Extensive studies[6] have been made on the quinoxaline side-chain polyols which are produced when *o*-phenylenediamine reacts with sugars, under a variety of conditions. As the starting point for the work described here we have used 2-(D-*arabino*-tetrahydroxybutyl)quinoxaline[7] (**2**), which was first reported[7b] 100 years ago from the condensation of *o*-phenylenediamine with glucose, and can be obtained[7c] conveniently using sucrose as the sugar ingredient. This starting material not only has the desired side-chain length but also has functionality at each of the four carbons, as required.

(*a*) *Approaches to Side-Chain-Saturated* 1′,2′-*Dithiols.*—Reaction of (**2**) with acetone produced as the major product the diol acetal (**3a**) in which the hydroxy groups at C-3′ and C-4′ were now masked and the introduction of two sulphur atoms, at C-1′

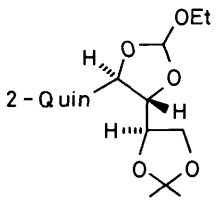
and C-2′, could be addressed. It seemed that the most promising route to a saturated 1,2-dithiol lay *via* thiocyanogen addition to an alkene.[8] Accordingly, the diol acetal (**3a**) was converted into the acetal orthoacetal (**4**), using ethyl orthoformate, and this in



(**2**)



(**3**)



	R′	R″
a;	H	H
b;	Ts	Ts
c;	H	Ts
d;	H	Mes
e;	Mes	H
f;	Mes	Mes

(**4**)

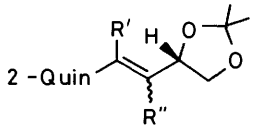
2-Quin = Quinoxalin-2-yl

turn was allowed to react with hot acetic anhydride to bring about elimination[9] and the formation of the *trans*-alkene acetal (**5a**). In work to be described below, mixtures of **5a**) and its *cis* isomer (**5b**) were obtained; it was observed that the *cis* isomer isomerises extremely easily, in solution even in the dark and at 0 °C, into the more stable *trans* isomer.

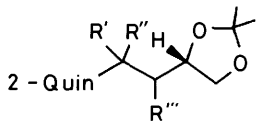
The alkene-acetal (**5a**) reacted with thiocyanogen to give a separable mixture of adducts (**6a**)/(**6b**) in good yield. Using the mixture of adducts, attempts, based on seemingly good literature precedents,[10] were then made to cleave the thiocyanato groups and generate a 1,2-dithiol, but to no avail. Thus sodium sulphide converted (**6a**)/(**6b**) back into the alkene acetal (**5a**), possibly *via* an intermediate thirane,[11] accompanied by a complex mixture of polar materials; treatment with lithium aluminium hydride had the same effect. Sodium methoxide produced a complex mixture of polar products and acid treatment resulted in the formation of 2-(quinoxalin-2-yl)furan (**7**).[12] 1′,2′-Eliminations or, under acidic conditions, the formation of the furan (**7**) were to prove frequently encountered, unwanted complications in this work. The elimination of two vicinal leaving groups or of epoxides or thiranes to produce alkenes is well precedented.[11]

We next turned to the prospect of utilising sulphur-nucleophile displacement reactions on a substrate carrying at C-1′ and C-2′, leaving groups, halide, mesylate, or an epoxide. Despite the many examples[13] of 1,2-eliminations of halogen from vicinal dihalides, undesired in the present context, there were clear precedents[14] for the formation of cyclic trithiocarbonates, *i.e.* protected 1,2-dithiols, from such precursors, relevantly, from 1,2-dibromophenylethane using sodium ethyl xanthate[14a] and sodium sulphide, carbon tetrachloride, and phase transfer catalyst[14b] respectively.

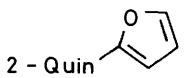
Straightforward addition to the alkene acetal (**5a**) occurred on treatment with bromine at 0 °C to give a single 1,2-dibromo adduct (**6c**) in high yield. Attempted displacements of bromine in (**6c**) with thioacetate, potassium or sodium ethyl xanthate, sodium sulphide in wet tetrahydrofuran or in carbon tetrachloride in the presence of a phase-transfer catalyst, or sodium thiosulphate, all brought about eliminations[13] and the reformation of the alkene acetal (**5a**). Attempted use of potassium dimethyldithiocarbamate was also not productive, in this case effecting dehydrobromination and thus the formation of bromoalkene acetal (**5c**), the regiochemistry following from the



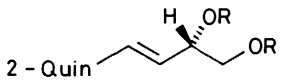
(**5**)	R′	R″	Alkene geometry
a;	H	H	*E*
b;	H	H	*Z*
c;	Br	H	*Z*
d;	Br	Br	?
e;	OMes	H	?
f;	OTs	H	?



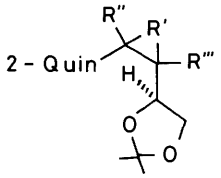
(**6**)	R′	R″	R‴
a;	α-SCN	H	β-SCN
b;	H	β-SCN	α-SCN
c;	α/β-Br	H	β/α-Br
d;	Br	Br	Br
e;	MesO	Br	Br
f;	H	H	OH



(**7**)



(**8**) R
a; H
b; Ac



(**9**)	R′	R″	R‴
a;	β-O	α-H	α-H
b;	α-O	β-H	β-H
c;	O	MesO	H

2-Quin = Quinoxalin-2-yl

7 Hz coupling between alkene proton and its adjacent methine proton and the geometry from the observation of an n.O.e. (14% in one direction, 11% in the other) between the quinoxaline ring proton and the alkene proton. Further reaction of (**5c**) with bromine produced the tribromide (**6d**), and reaction of this with sodium methoxide brought about elimination of hydrogen bromide and the formation of a single dibromoalkene (**5d**), the geometry of which was not determined. The monobromoalkene (**5c**) too was reconverted into a mixture of the *cis*- and *trans*-alkene acetals (**5a**)/(**5b**) on treatment with sodium ethyl xanthate.

Deprotection [→(**8a**)] of the alkene acetal (**5a**) could be

achieved with hydrobromic acid, subsequent acetylation producing (**8b**). We were initially misled by the alkene-proton region of the ^{1}H n.m.r. spectrum of (**5a**): the very similar chemical shifts of the two alkene protons masked the coupling between them. In the spectrum of (**8a**), the shifts were separated by δ 0.38 and a typical *trans* coupling constant of 14 Hz could be discerned. Interestingly, on conversion into the diacetate (**8b**), the alkene proton region reverted visually to the pattern displayed by (**5a**).

We next turned to the possible use of an epoxide as a means for the introduction of sulphur atoms, being aware of good precedents[15] for the conversion of epoxides into thiiranes and/or into cyclic trithiocarbonates. Attempted formation of an epoxide from the alkene acetal (**5a**) by direct epoxidation with *m*-chloroperbenzoic acid (MCPBA) resulted only in a mixture of mono- (main) and di-*N*-oxides; the required epoxides *could* be obtained *via* mono-sulphonate esters of diol acetal (**3a**).

Reaction of (**3a**) with toluene-*p*-sulphonyl chloride in pyridine could be controlled to produce either mainly the ditosylate (**3b**) or a mixture of ditosylate and monotosylate (**3c**). Mesylation similarly produced mixtures of mono- and di-mesylates, though both regioisomeric mono-esters, in a ratio of *ca.* 1:1, were obtained in this case. Because the monomesylate pair were more easily separated from the corresponding diester, than monotosylate from the tosylation mixtures, the mixture of monomesylates (**3d**) and (**3e**) was utilised in most of the following attempts to introduce sulphur functionality, including *via* epoxides. Treatment of the monotosylate (**3c**) with sodium methoxide gave the single epoxide (**9a**); similar treatment of the mixture of mesylates (**3d**) and (**3e**) produced the mixture of epoxides (**9a**) and (**9b**).

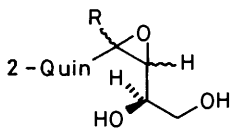
It was disappointing to find that the mixture of epoxides (**9a**) and (**9b**) on treatment[15a] with potassium ethyl xanthate, was simply reconverted into a mixture of isomeric *cis*- and *trans*-alkene acetals (**5a**) and (**5b**). Interestingly, xanthate treatment of the mixture of monomesylates (**3d**) and (**3e**) also produced the alkenes, with the *trans* isomer predominating, but *not via* the epoxide since the reaction was much faster than that with the epoxides themselves as starting material.

In other efforts to utilise the epoxides, (**9a**) and (**9b**) were treated with thiourea in methanol,[15b] but no reaction occurred, though after addition of acid in the hope of catalysis[15c] of the desired displacements, the quinoxalinylfuran (**7**) was produced. Treatments with sodium thiocyanate[15d] or ammonium thiocyanate[10] both produced complex mixtures as did attempted conversions using 3-methylbenzothiazole-2-thione[15e] in the presence of trifluoroacetic acid (TFA) or boron trifluoride. In an effort simply to open the epoxide, it was shown that the acetal protection was removed selectively and cleanly with concentrated hydrobromic acid at 0 °C, generating the epoxide diols (**10a**), but with no cleavage of the three-membered ring.

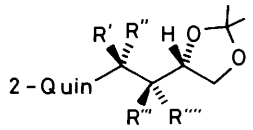
Attempted simple displacement of mesylate in the dimesylate (**3f**) with sodium dimethyldithiocarbamate resulted in elimination of the elements of methanesulphonic acid, producing the enol mesylate (**5e**), thus paralleling the reaction of the dibromide (**6c**) with this reagent. The ditosylate (**3b**) was converted into a comparable enol tosylate (**5f**) on treatment with diazabicycloundecane. The more electron-rich double bond in (**5e**) *could* be epoxidised efficiently using MCPBA, but the resulting epoxide (**9c**) refused to react with the sulphur nucleophile *N*,*N*-dimethyldithiocarbamate. As an alternative we hoped that it might be possible to convert (**9c**) into an α-bromoketone (*vide infra*) by treatment with hydrobromic acid, but only selective removal of the acetal protection took place using hydrobromic acid at 0 °C, producing the diol epoxides (**10b**), and even at room temperature, no cleavage of the epoxide unit was observed.

We have shown[1] that 2-*N*,*N*-dimethyldithiocarbamato-1-mesyloxy-1-quinoxalin-2-ylethane cyclises, with intramolecular sulphur displacement of the mesylate, to produce a salt which reacts with hydrogen sulphide to produce a quinoxalin-2-yl-substituted cyclic trithiocarbonate. This methodology is applied here to the more complex C_4-side chain series. Reaction of the mesylate mixture (**3d**) and (**3e**) with sodium *N*,*N*-dimethyldithiocarbamate, in contrast to efforts to make this reagent react with the dimesylate (**3f**), *vide supra*, proceeded well to give a mixture of regioisomeric *N*,*N*-dimethyldithiocarbamates (**11a**) and (**11b**). This mixture, without further purification, was treated either with methanesulphonyl chloride, or with trifluoroacetic anhydride (TFAA) in pyridine, and then with hydrogen sulphide. From the resulting product mixtures, the relative compositions of which varied with the exact reaction conditions, there could be isolated not only the expected side-chain-saturated cyclic trithiocarbonate (**12a**), but also, as an unexpected bonus, its dehydro analogue (**13**), an acetal trithiocarbonate doubly protected version of the target ene dithiol diol, and, additionally, actually as the major component, the alcohol (**6f**).

When the reaction was carried out by heating briefly in pyridine–TFAA all three products were produced. Conducting the cyclisation at room temperature over 24 h with methanesulphonyl chloride gave rise only to the dithiole (**13**), together with the alcohol (**6f**), but with TFAA and over a period of 48 h, only the dithiole (**13**) was obtained, and in the best (16%) yield, with decreased quantities of the alcohol (**6f**), but more decomposition products. It may be, that the assumed intermediate salt (**12b**) acts as a dehydrogenating agent, to provide a route from (**12a**) to (**13**). An attempt to convert (**12a**) into (**13**) *via* a Pummerer process[1] produced only the cyclic dithiocarbonate (**12c**).

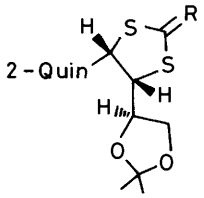


(**10**) R
a; H
b; OMes

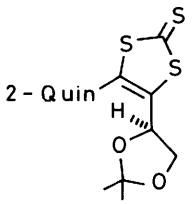


(**11**)

	R′	R″	R‴	R⁗
a;	H	$S(CS)NMe_2$	HO	H
b;	HO	H	H	$S(CS)NMe_2$



(**12**) R
a; S
b; N^+Me_2
c; O

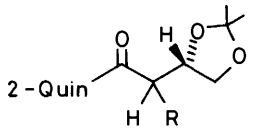


(**13**)

The ^{1}H n.m.r. spectrum of the 1,3-dithiolane (**12a**) showed, in addition to signals for 2-substituted quinoxaline and the 1,3-dioxolane units, a doublet (*J* 2 Hz) at δ 5.88 and a double doublet (*J* 2, 10 Hz) at δ 4.98 for the two protons on the *cis*-substituted cyclic trithiocarbonate. In the spectrum of its dehydro analogue, the 1,3-dithiole (**13**), the corresponding signals were absent; also, the 3′-proton signal had moved downfield from δ 4.67 in (**12a**) to δ 5.75 and was now simplified, showing as a double doublet (*J* 6,7 Hz). Additional evidence for structure (**13**) lay in its u.v. absorption which was at longer wavelength ($\lambda_{max.}$ 375 nm) than that of the unconjugated (**12a**) ($\lambda_{max.}$ 322). The major product of the sequence was assigned structure (**6f**), being distinguishable from the isomeric 1′-alcohol by the presence of major mass spectroscopic fragment ions for quinoxalinyl-CH_2^+ as well as quinoxalinyl-$CH_2CH(OH)^+$.

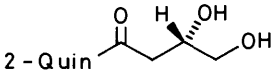
(*b*) *Approaches to Side-chain Unsaturated* 1′,2′,-*Dithiols.*—Conscious that there exist means for the transformation of α-halogeno ketones[3] or of α-hydroxy ketones[16] into ene-1,2-dithiolates, the preparation of an appropriate ketone or an appropriate α-substituted ketone was addressed. The keto group needed to be located at either C-1′ or C-2′ of the side chain. Manganese dioxide treatment of the diol acetal (**3a**) was attempted, in expectation of selective oxidation of the benzylic secondary alcohol function, but only a trace of the corresponding 1′-ketone was obtained, the main product being quinoxaline-2-carbaldehyde. Exactly comparable results came from treatments with silver carbonate–Celite,[17a] bipyridyl-copper permanganate,[17b] and chromium trioxide–dimethylpyrazole.[17c]. Pyridinium dichromate converted the 2′-monotosylate (**3c**) into the ketone (**14a**), but in a poor yield, which could not be improved upon using other oxidants.

We next turned to a route in which a 2′-unsubstituted 1′-ketone would be prepared first, expecting a subsequent halogenation at C-2′. The 2′-unsubstituted 1′-keto acetal (**14b**) could be obtained from the diol acetal (**3a**), in poor yield by treatment with triphenylphosphine–pyridine, and in good yield by reaction with phosphorus pentasulphide, in hot pyridine. Work-up with aqueous acid, or separate reaction of (**14b**) with acid, produced the keto diol (**15**), as well as the quinoxalinylfuran



(**14**)

R
a; β-OTs
b; H
c; Br
d; S(CS)NMe$_2$
e; S(CO)Me



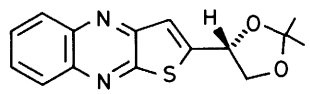
(**15**)

(**7**). An alternative proposed route to a ketone, *via* alkaline hydrolysis of the enol tosylate (**5f**), was thwarted by reverse aldol degradation, 2-acetylquinoxaline being the only product obtained.

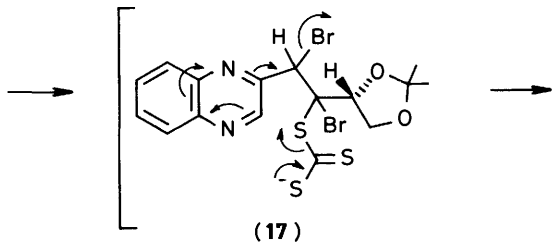
Benzylic bromination of either the keto acetal (**14a**) or of the keto diol (**15**) with pyridinium bromide perbromide in acetic acid could be effected, but the necessary acidic conditions led to substantial quantities of the furan (**7**). A much better route to a 2′-bromo 1′-ketone proceeded from the enol mesylate (**5e**), by addition of bromine [→(**6e**)] and then elimination of hydrogen bromide using aqueous ammonia, with mesylate hydrolysis *in situ*, giving the bromo keto acetal (**14c**) in good yield.

Displacements of the halide in (**14c**) with a sulphur nucleophile succeeded with dimethyl dithiocarbamate and thioacetate generating (**14d**) and (**14e**), respectively. The best route proved to be the reaction of thioacetate with dibromo monomesylate (**6e**), giving (**14e**) directly. However, most disappointingly, attempts to bring about a useful thionation,[18] starting from either (**14d**) or (**14e**), were uniformly unsuccessful using either phosphorus pentasulphide or Lawesson's reagent. Treatment of (**14d**) with TFA led not to a desired 2-(*NN*-dimethylamino)-1,3-ditholium salt,[18] but only to the quinoxalinylfuran (**7**).

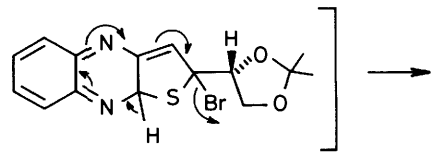
A report[19] of the conversion, albeit in poor yield, of *cis*-1,2-dibromophenylethene into a 1,3-dithiole-2-thione, directly, with dipotassium trithiocarbonate, prompted an investigation into the possible reaction of the dibromoalkene (**5d**) with this reagent. We were aware that the geometry of the dibromoalkene was not known, and also that traces of a geometrical isomer (n.m.r.) were always present in samples of (**5d**). In the event, the desired thiole (**13**) was indeed obtained, but only in trace quantities, perhaps corresponding to conversion of only the minor dibromoalkene isomer into (**13**). However, the structure of the main product isolated is also of considerable relevance to Moco chemistry. This product, formed in good yield, was assigned the tricyclic thienoquinoxaline structure (**16**), the key evidence for which was the absence of a quinoxaline 3-proton, and the presence, as well as signals for the four benzenoid protons and the 1,3-dioxolane unit, of a thiophen-type singlet at δ 7.45. We view this unexpected product as being formed reasonably *via* intermediates (**17**) and (**18**). Very few examples of



(**16**)



(**17**)

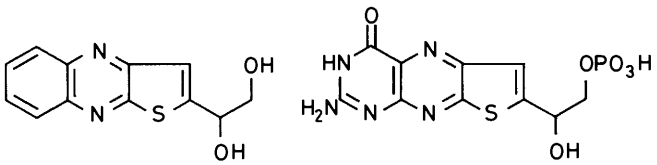


(**18**)

synthetic approaches to the thieno[2,3-*b*]quinoxaline ring system have been reported;[20] we intend investigating the possible generality of the process here discovered, including the relevance of alkene geometry to product type.

The acetal unit in (**16**) could be readily hydrolysed producing the corresponding diol (**19**) which can be seen to be a direct analogue to the pteridine degradation product (**20**) of Moco.[2b] Further, we suggest that a route, *via* intermediates such as (**17**) and (**18**), to a thienoquinoxaline may well parallel in part that by which the Moco degradation product (**20**) is produced.

(*c*) *Approaches to* 1,2,3,4-*Tetrahydroquinoxalines.*—Since the

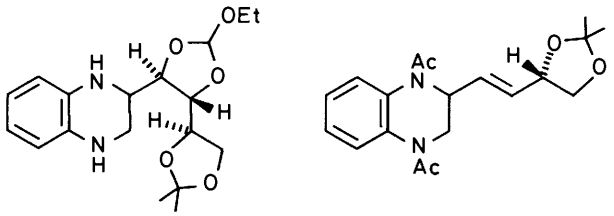


(19) (20)

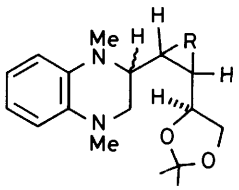
pyrazine ring in Moco may be at a tetrahydro level it was important to establish that the heterocyclic ring of the quinoxalines in this study could indeed be appropriately reduced. It was also the hope that the 1′,2′-eliminations which were a complication, *vide supra*, might be minimised by the removal of the quinoxaline conjugation.

Catalytic hydrogenations presented complications in the form of benzylic oxygen hydrogenolyses, however lithium aluminium hydride smoothly reduced the pyrazine ring in the acetal orthoester (**4**), giving (**21**), which on reaction with acetic anhydride afforded the alkene diamide acetal (**22**). Attempted simple addition of bromine to the double bond in (**22**) gave rise to a complex mixture, probably associated with benzene ring substitution; thiocyanogen failed to react with (**22**) at 0 °C, the conditions used for reaction with the conjugated alkene (**5a**), or even at room temperature over several days.

The epoxide (**9a**) was reduced/methylated by treatment with sodium cyanoborohydride–formaldehyde in acetic acid to afford the tetrahydro epoxide (**23a**) which, in turn, was



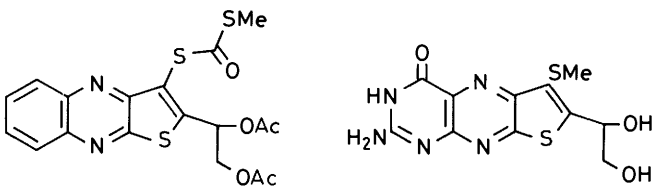
(21) (22)



(23) R
α ; β-O
b ; α-S

converted into the thiirane (**23b**). Unfortunately, attempts to force this reaction to produce a cyclic trithiocarbonate failed.

(*d*) *Attempted Release of Ene Dithiolate from* (**13**).—In a simpler quinoxalinyl-dithiole, alkaline hydrolysis released the ene-1,2-dithiolate unit, destined eventually for complexation with a metal centre, and this was demonstrated by trapping with iodomethane.[1] Application of the same reaction conditions to the more complex dithiole (**13**) led, after trapping with iodomethane and subsequent acetylation, not to the desired product but intriguingly to thienoquinoxaline (**24**), an analogue of the Moco degradation product (**25**).



(24) (25)

Experimental

General.—M.p.s were determined on a Kofler hot-stage microscope and are uncorrected. Wet organic solutions/extracts were dried with anhydrous $MgSO_4$, Na_2SO_4, or K_2CO_3 and evaporated at *ca.* 29 mmHg at *ca.* 40—70 °C using a rotary evaporator. Unless otherwise stated, u.v./vis. spectra (reported in nm) were measured in ethanol using a Shimadzu UV/VIS 260 instrument; i.r. spectra (in cm^{-1}) were measured using Pye-Unicam SP3-200 or Perkin-Elmer 1710 FT spectrometers. ^1H N.m.r. spectra of deuteriochloroform solutions, reported as δ values in p.p.m. with respect to internal $SiMe_4$ (0 p.p.m.) with coupling constants, *J*, given in Hz, were measured on Perkin-Elmer R12B (60 MHz), Perkin-Elmer R34 (220 MHz), Varian SC300 (300 MHz), or Varian XL300 (300 MHz) spectrometers; ^{13}C spectra of deuteriochloroform solutions, with δ values with respect to spectroscopic solvent as internal standard, were obtained using Brucker WP80 (20 MHz) or Varian XL300 (75 MHz) spectrometers, signal multiplicity being determined using Single Frequency Off Resonance Decoupling (SFORD). Unless otherwise stated, mass spectra were determined by the electron impact method on an AEI MS30 instrument coupled to a DS55 data system. Chemical ionisation (c.i.) mass spectra, using NH_3, were obtained with a Kratos MS25 instrument, coupled to a DS55 data system. For ^1H n.m.r. spectra, only signals which are clearly distinguished and unambiguously identifiable are assigned to particular protons. For i.r. spectra, only those absorptions of obvious structural relevance are detailed. Only ions of >10% of base peak are given for mass spectra, except where a less intense ion is of importance for structure establishment.

(4R)-2,2-*Dimethyl*-4-[(1S,2R)-1,2-*dihydroxy*-2-(*quinoxalin*-2-*yl*)*ethyl*]-1,3-*dioxolane* (**3a**).—A suspension of the tetrol (**2**) (7 g) in dry acetone (350 ml) was shaken with concentrated sulphuric acid (4.4 ml) at room temperature for 4 h. The mixture was then added to a slurry of potassium carbonate (50 g) in water (50 ml), with stirring, and the whole stirred for 15 h. The acetone solution was decanted, and the residue washed with hot acetone several times. The washings were combined with the decanted solution, dried, and evaporated under reduced pressure, to give a brown gum. Crystallisation from ethyl acetate gave the *diol acetal* (**3a**) as an off-white crystalline solid (4.1 g, 51%), m.p. 145—146 °C, $\nu_{max.}$ 3 360; δ_H 9.04 (1 H, s, quinoxalin-2-yl-H), 8.18 (1 H, m, ArH), 8.09 (1 H, m, ArH), 7.82 (2 H, m, ArH), 5.26 (1 H, d, *J* 5, 2′-H), 4.32 (2 H, m, OH and 4-H), 4.19 (1 H, m), 4.09 (2 H, m), 3.17 (1 H, d, *J* 5, OH), 1.48 (3 H, s, CMe), and 1.40 (3 H, s, CMe); *m/z* (c.i.) 291 (MH^+, 88%), 275 (12), 257 (11), 173 (16), 159 (100), and 131 (79) (Found: C, 62.3; H, 6.2; N, 9.6. $C_{15}H_{18}N_2O_4$ requires C, 62.1; H, 6.3; N, 9.7%).

(4S,5R)-2-*Ethoxy*-4-[(4R)2,2-*dimethyl*-1,3-*dioxolan*-4-*yl*]-5-(*quinoxalin*-2-*yl*)-1,3-*dioxolane* (**4**).—A mixture of the diol acetal (**3a**) (1.2 g), pyridinium toluene-*p*-sulphonate (0.35 g), and triethyl orthoformate (2.8 g) were stirred together at room temperature in dichloromethane (8 ml) for 4 h. The resultant clear solution was washed with water, dried and evaporated under reduced pressure, to give a pale brown gum. Purification of this by column chromatography over silica gel, eluting with dichloromethane–ethyl acetate gave a mixture of the two

diastereoisomers of the *acetal orthoacetal* (**4**) as a pale yellow gum (1.33 g, 93%); δ_H 9.27 (0.4 H, s, quinoxalin-2-yl-H), 9.05 (0.6 H, s, quinoxalin-2-yl-H), 8.16 (2 H, m, ArH, 7.81 (2 H, m, ArH), 6.16 [0.6 H, s, OCH(O)O], 6.12 [0.4 H, s, OCH(O)O], 5.54 (0.6 H, d, *J* 6, 2′-H), 5.37 (0.4 H, d, *J* 6, 2′-H), 4.78 (0.4 H, t, *J* 6, 1′-H), 4.52—4.46 (*1.6 H*, m), 4.18 (2 H, m), 3.70 (2 H, m) and 1.27 (9 H, m); *m/z* (c.i.) 347 (MH^+, 30%), 301 (100), 273 (18), 257 (28), 199 (34), 173 (71), and 101 (48) [Found: *m/z* 331.1288. $C_{17}H_{19}N_2O_5$ ($M - CH_3$) requires 331.1294].

(4S)-2,2-*Dimethyl*-4-[(E)-2-(*quinoxalin*-2-*yl*)*vinyl*]-1,3-*dioxolane* (**5a**).—A solution of the acetal orthoacetal (**4**) (0.5 g) in acetic anhydride (50 ml) was refluxed for 4 h. The acetic anhydride was evaporated under reduced pressure to leave a brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane–ethyl acetate gave the *alkene acetal* (**5a**) as a pale brown gum (0.28 g, 76%); δ_H 8.96 (1 H, s, quinoxalin-2-yl-H), 8.08 (2 H, m, ArH), 7.76 (2 H, m, ArH), 7.01 (2 H, m, HC:CH), 4.84 (1 H, m, 4-H), 4.28 (1 H, dd, *J* 6, 8, 5-H), 3.80 (1 H, dd, *J* 7, 8, 5-H), 1.44 (3 H, s, CMe), and 1.50 (3 H, s, CMe); δ_C 149.39 (s), 143.88 (d), 142.01 (s), 141.53 (s), 135.31 (d), 130.13 (d), 129.39 (d), 129.18 (d), 129.09 (d), 128.95 (d), 109.83 (s), 76.23 (d), 69.23 (t), 26.66 (q), and 25.87 (q); *m/z* 256 ($M^{+\bullet}$, 1%), 241 (5), 198 (34), 181 (26), 169 (34), 72 (53), and 43 (100) (Found: M^+, 256.1205; $C_{15}H_{16}N_2O_2$ requires *M*, 256.1212).

(4R)-2,2-*Dimethyl*-4-[(1R,2S)-1,2-*dithiocyanato*-2-(*quinoxalin*-2-*yl*)*ethyl*]-1,3-*dioxolane* (**6a**) *and* (4R)-2,2-*Dimethyl*-4-[1S,2R)-1,2-*dithiocyanato*-2-(*quinoxalin*-2-*yl*)-1,3-*dioxolane* (**6b**).—To a solution of the alkene acetal (**5a**) (1.17 g) in dry dichloromethane (50 ml) at 0 °C was added a solution of thiocyanogen [generated[8] from $Pb(SCN)_2$ (3 g) and Br_2 (2.6 g)] in dry dichloromethane (50 ml). The solution was brought to room temperature and set aside for 2 h, after which it was washed with aqueous sodium metabisulphite, dried, and evaporated under reduced pressure to give an orange gum. Purification of this by column chromatography over silica gel eluting with dichloromethane–ethyl acetate followed by recrystallisation from methanol gave a mixture (0.946 g, 56%) of the two isomers of the *dithiocyanates* (**6a,b**) in a ratio of 6:4, m.p. 137—139 °C (from methanol), $\nu_{max.}$ 2 254 and 2 158; major δ_H 9.04 (1 H, s, quinoxalin-2-yl-H), 8.22 (2 H, m, ArH), 7.91 (2 H, m, ArH), 5.22 (1 H, dt, *J* 2, 6, 4-H), 5.07 (1 H, d, *J* 9, 2′-H), 4.48 (1 H, dd, *J* 2, 9, 1′-H), 4.40 (1 H, dd, *J* 7, 8 5-H), 4.14 (1 H, dd, *J* 6, 8, 5-H), 1.54 (3 H, s, CMe), and 1.44 (3 H, s, CMe); minor δ_H 9.06 (1 H, s, quinoxalin-2-yl-H), 8.16 (2 H, m, ArH), 7.90 (2 H, m, ArH), 5.66 (1 H, d, *J* 4, 2′-H), 4.42 (1 H, m), 4.27 (2 H, m), 3.90 (1 H, m), 1.55 (3 H, s, CMe), and 1.30 (3 H, s, CMe); *m/z* (c.i.) 373 (MH^+, 2%), 314 (19), 257 (100), 199 (88), 169 (80), and 145 (41) (Found: C, 54.5; H, 4.3; N, 14.9; S, 16.8. $C_{17}H_{16}N_4O_2S_2$ requires C, 54.8; H, 4.3; N, 15.0; S, 17.2%).

(4R)-2,2-Dimethyl-4-[1,2-*dibromo*-2-(*quinoxalin*-2-*yl*)*ethyl*]-1,3-*dioxolane* (**6c**).—A solution of bromine (80 mg) in dichloromethane (1 ml) was added dropwise to a stirred solution of the alkene acetal (**5a**) (140 mg) in dichloromethane (5 ml) at 0 °C. The solution was stirred at 0 °C for a further 2 h after which aqueous sodium metabisulphite was added to quench the reaction. The organic phase was separated, washed with water, dried, then evaporated under reduced pressure to give the dibromide as a brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane gave the pure *dibromo adduct* (**6c**) as white crystals (150 mg, 67%), m.p. 112—113 °C (decomp.) (from methanol); δ_H 8.90 (1 H, s, quinoxalin-2-yl-H), 8.15 (2 H, m, ArH), 7.84 (2 H, m, ArH), 5.65 (1 H, d, *J* 10, 2′-H), 5.08 (1 H, dd, *J* 2, 10, 1′-H), 5.00 (1 H, m, 4-H), 4.29 (1 H, dd, *J* 7, 8, 5-H), 4.08 (1 H, dd, *J* 6, 8, 5-H), and 1.56 (6 H, s, 2 × CMe); δ_C 153.03 (s), 144.30 (d), 142.01 (s), 141.99 (s), 130.49 (d), 129.29 (d), 129.21 (d), 110.39 (s), 74.53 (d), 68.30 (t), 55.21 (d), 49.98 (d), 26.04 (q), and 25.29 (q); *m/z* (c.i.) 415, 417, 419 (MH^+, 0.2, 0.4, 0.1%), 351 (2), 301 (2), 257 (97), 199 (100), 183 (45), and 169 (77) (Found: C, 43.5; H, 3.9; Br, 38.7; N, 6.5. $C_{15}H_{16}Br_2N_2O_2$ requires C, 43.3; H, 3.9; Br, 38.4; N, 6.7%).

(4S)-2,2-*Dimethyl*-4-[(Z)-2-*bromo*-2-(*quinoxalin*-2-*yl*)*vinyl*]-1,3-*dioxolane* (**5c**).—To a solution of the dibromide (**6c**) (0.5 g) in methanol (10 ml), was added sodium dimethyldithiocarbamate (0.3 g) dissolved in hot methanol (10 ml). The resultant mixture was stirred at reflux for 3 h. Addition of water and dichloromethane followed by separation, drying, and evaporation of the organic phase under reduced pressure gave the product as well as some starting material. Purification by column chromatography over silica gel eluting with dichloromethane–ethyl acetate gave the pure *bromoalkene acetal* (**5c**) (0.17 g, 40%), m.p. 46—48 °C (from dichloromethane–hexane); δ_H 9.27 (1 H, s, quinoxalin-2-yl-H), 8.14 (2 H, m, ArH), 7.82 (2 H, m, ArH), 7.35 (1 H, d, *J* 7, 1′-H), 5.20 (1 H, dt, *J* 7, 7, 4-H), 4.42 (1 H, dd, *J* 7, 8, 5-H), 3.85 (1 H, dd, *J* 7, 8, 5-H), 1.50 (3 H, s, CMe), and 1.45 (3 H, s, CMe); *m/z* (c.i.) 335, 337 (MH^+, 93, 93%), 257 (96), 199 (100), and 169 (90) (Found: C, 54.1; H, 4.45; Br, 23.7; N, 8.5. $C_{15}H_{15}BrN_2O_2$ requires C, 53.8; H, 4.5; Br, 23.8; N, 8.4%).

(4R)-2,2-*Dimethyl*-4-[1,2,2-*tribromo*-2-(*quinoxalin*-2-*yl*)-*ethyl*]-1,3-*dioxolane* (**6d**).—Bromine (0.1 ml) was added at 0 °C with stirring to a solution of the bromoalkene acetal (**5c**) (100 mg) in dichloromethane (5 ml) in the presence of solid sodium hydrogen carbonate (100 mg). The mixture was stirred for 1 h after which the dichloromethane layer was separated, washed with aqueous sodium metabisulphite, dried, and evaporated under reduced pressure to give the unstable *tribromide* (**6d**) as a brown gum (126 mg, 86%), a mixture of two isomers in a ratio of 8:2; δ_H 9.64 (0.2 H, s, quinoxalin-2-yl-H), 9.55 (0.8 H, s, quinoxalin-2-yl-H), 8.16 (1 H, m, ArH), 8.08 (1 H, m, ArH), 7.83 (2 H, m, ArH), 5.78 (0.8 H, d, *J* 5, 1′-H), 5.66 (0.2 H, d, *J* 4, 1′-H), 4.94 (1 H, m, 4-H), 4.37 (1 H, m, 5-H), 4.24 (0.8 H, dd, *J* 6, 9, 5-H), 4.07 (0.2 H, dd, *J* 8, 9, 5-H), 1.56 (0.6 H, s, CMe), 1.45 (0.6 H, s, CMe), 1.27 (2.4 H, s, CMe), and 1.18 (2.4 H, s, CMe); *m/z* (c.i.) 493, 495, 497, 499 (MH^+, 56, 57, 32, 5%), 413, 415, 417 (66, 74, 63), 335, 337 (98, 95), 295, 297 (77, 76), 277 (71), 197 (100), and 169 (97) (Found: 492.8767, 494.8752, 496.8714, and 498.8704. $C_{15}H_{16}Br_3N_2O_2$ requires 492.8763, 494.8744, 496.8724, and 498.8704).

(4R)-2,2-*Dimethyl*-4-[1,2-*dibromo*-2-(*quinoxalin*-2-*yl*)*vinyl*]-1,3-*dioxolane* (**5d**).—To the tribromide (**6d**) (126 mg) in methanol (10 ml) sodium (0.1 g) was added, and the mixture left at room temperature for 30 min. The mixture was then evaporated under reduced pressure and the residue dissolved in dichloromethane and the solution washed with water, dried, and evaporated under reduced pressure, to give a brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane–ethyl acetate gave the pure *dibromoalkene* (**5d**) as a pale brown gum (42 mg, 34%); δ_H 8.94 (1 H, s, quinoxalin-2-yl-H), 8.14 (2 H, m, ArH), 7.83 (2 H, m, ArH), 5.49 (1 H, t, *J* 7, 4-H), 4.35 (1 H, dd, *J* 7, 8, 5-H), 3.97 (1 H, dd, *J* 7, 8, 5-H), 1.58 (3 H, s, CMe), and 1.48 (3 H, s, CMe); *m/z* (c.i.) 413, 415, 417 (MH^+, 6, 13, 6%), 335, 337 (2, 2), 255 (100), 239 (20), 197 (91), 181 (34), and 169 (59) (Found: 412.9509, 414.9493, and 416.9466. $C_{15}H_{15}Br_2N_2O_2$ requires 412.9501, 414.9482, and 416.9462).

(2S,E)-4-(*Quinoxalin*-2-*yl*)*but*-3-*ene*-1,2-*diol* (**8a**).—A solution of the alkene acetal (**5a**) (400 mg) was treated with hydrobromic acid (48%; 0.5 ml) in methanol (50 ml) for 2 h at room temperature. The solvents were then removed under

reduced pressure to leave a brown gum which was purified by column chromatography over silica gel, eluting with chloroform–methanol to give the pure *alkenediol* (**8a**) (265 mg, 78%), as a pale pink crystalline solid, m.p. 108—110 °C (from chloroform–hexane); $\nu_{max.}$ 3 421 and 3 345; δ_H[$(CD_3)_2SO$] 9.11 (1 H, s, quinoxalin-2-yl-H), 8.01 (2 H, m, ArH), 7.77 (2 H, m, ArH), 7.19 (1 H, dd, *J* 3, 14, 4-H), 6.92 (1 H, d, *J* 14, 3-H), 5.18 (1 H, d, *J* 5, OH), 4.76 (1 H, t, *J* 6, OH), 4.27 (1 H, m, 2-H), and 3.43 (2 H, t, *J* 6, 1-H_2); *m/z* 216 ($M^{+\bullet}$, 4%), 198 (3), 185 (100), 157 (91), 129 (62), and 102 (44) (Found: C, 66.3; H, 5.5; N, 12.9%; *M*, 216.0912. $C_{12}H_{12}N_2O_2$ requires C, 66.7; H, 5.6; N, 13.0%; *M*, 216.0899).

(1S,E)-4-(*Quinoxalin-2-yl*)*but-3-ene*-1,2-*diol Diacetate* (**8b**).—To a solution of the diol (100 mg) in dry pyridine (5 ml) at 0 °C was added acetic anhydride (1 ml). The mixture was brought to room temperature for 4 h and then added to ice. The product was extracted into ethyl acetate, and the extract washed with water, dried, and evaporated under reduced pressure to give a brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane–ethyl acetate gave the pure *diacetate* (**8b**) (87 mg, 62%) as a pale brown gum; $\nu_{max.}$ 1 745; δ_H 8.91 (1 H, s, quinoxalin-2-yl-H), 8.05 (2 H, m, ArH), 7.74 (2 H, m, ArH), 6.96 (2 H, m, HC:CH), 5.80 (1 H, m, 3-H), 4.42 (1 H, dd, *J* 2, 12, 1-H), 4.23 (1 H, dd, *J* 6, 12, 1-H), 2.12 (3 H, s, OCOMe), and 2.06 (3 H, s, OCOMe), *m/z* (c.i.) 301 (MH^+, 4%), 257 (5), 198 (22), 181 (34), 169 (26), 157 (17), 129 (16), and 43 (100) (Found: *M*, 301.1193. $C_{16}H_{17}N_2O_4$ requires *M*, 301.1188).

(4R)-2,2-*Dimethyl*-4-[(1S,2R)-2-(*quinoxalin-2-yl*)-1,2-*ditosyloxyethyl*]-1,3-*dioxolane* (**3b**) *and* (4R)-2,2-*Dimethyl*-4-[(1S,2R)-2-*hydroxy*-2-(*quinoxalin-2-yl*)-1-*tosyloxyethyl*]-1,3-*dioxolane* (**3c**).—To a solution of the diol acetal (**3a**) (0.49 g), in dry pyridine (5 ml) at room temperature was added toluene-*p*-sulphonyl chloride (1.0 g). The mixture was kept at 0 °C for 20 h and then poured into a slurry of potassium carbonate in ice–water and the product extracted into ether. The ether extract was dried and evaporated under reduced pressure to give a pale brown gum purification of which by column chromatography, eluting with dichloromethane–ethyl acetate, gave first the *ditosylate* (**3b**) (0.41 g, 40%), as a crystalline solid, m.p. 159—161 °C (from dichloromethane–hexane); δ_H 8.67 (1 H, s, quinoxalin-2-yl-H), 8.02 (2 H, m, ArH), 7.83 (2 H, m, ArH), 7.76 (2 H, d, *J* 9), 7.22 (4 H, m, ArH), 6.82 (2 H, d, *J* 9, ArH), 6.06 (1 H, d, *J* 2, 2′-H), 5.19 (1 H, dd, *J* 2, 8, 1′-H), 4.16 (3 H, m), 2.32 (3 H, s, ArMe), 2.20 (3 H, s, ArMe), 1.40 (3 H, s, CMe), and 1.22 (3 H, s, CMe); *m/z* (c.i.) 599 (MH^+, 100%), 427 (5), and 257 (33) (Found: C, 58.2; H, 5.1; N, 4.8; S, 10.9. $C_{29}H_{30}N_2O_8S_2$ requires C, 58.2; H, 5.1; N, 4.7; S, 10.7%), followed by the *monotosylate* (**3c**) (0.31 g, 42%) as a crystalline solid, m.p. 115—117 °C (from dichloromethane–hexane); $\nu_{max.}$ 3 250, 1 350, and 1 180; δ_H 8.96 (1 H, s, quinoxalin-2-yl-H), 8.09 (1 H, m, ArH), 7.99 (1 H, m, ArH), 7.80 (2 H, m, ArH), 7.72 (2 H, d, *J* 9, ArH), 7.16 (2 H, d, *J* 9, ArH), 5.91 (1 H, br s, 2′-H), 4.08 (4 H, m), 3.68 (1 H, br s, OH), 2.25 (3 H, s, ArMe), 1.31 (3 H, s, CMe), and 1.22 (3 H, s, CMe); *m/z* (c.i.) 445 (MH^+, 49%), 273 (100), 257 (19), and 173 (15) (Found: C, 59.2; H, 5.4; N, 6.3; S, 7.1. $C_{22}H_{24}N_2O_6S$ requires C, 59.5; H, 5.5; N, 6.3; S, 7.2%).

(4R)-2,2-*Dimethyl*-4-[(1S,2R)-2-*hydroxy*-1-*mesyloxy*-2-(*quinoxalin-2-yl*)*ethyl*]-1,3-*dioxolane* (**3d**), (4R)-2,2-*Dimethyl*-4-[(1S,2R)-1-*hydroxy*-2-*mesyloxy*-2-(*quinoxalin-2-yl*)*ethyl*]-1,3-*dioxolane* (**3e**), *and* (4R)-2,2-*Dimethyl*-4-[(1S,2R)-1,2-*dimesyloxy*-2-(*quinoxalin-2-yl*)*ethyl*]-1,3-*dioxolane* (**3f**).—Methanesulphonyl chloride (1.2 g) was added to a solution of the diol acetal (**3a**) (1.5 g) in pyridine (5 ml). After 1 h at room temperature, ice and dichloromethane were added, and the organic layer was separated, washed with water, dried, and evaporated under reduced pressure to give a pale brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane–ethyl acetate gave first the *dimesylate* (**3f**) (0.7 g, 30%) as a colourless gum; $\nu_{max.}$ 1 364 and 1.177; δ_H 9.12 (1 H, s, quinoxalin-2-yl-H), 8.15 (2 H, m, ArH), 7.86 (2 H, m, ArH), 6.10 (1 H, d, *J* 4, 1′-H), 5.28 (1 H, dd, *J* 4, 7, 1′-H), 4.34 (1 H, dt, *J* 5, 7, 4-H), 4.16 (2 H, m, 5-H_2), 3.16 (3 H, s, O_2SMe), 2.76 (3 H, s, O_2SMe), 1.41 (3 H, s, CMe), and 1.30 (3 H, s, CMe), *m/z* (c.i.) 447 (MH^+, 19%), 351 (3), 273 (1), 257 (100), and 199 (74) (Found: MH^+, 447.0868. $C_{17}H_{23}N_2O_8S_2$ requires 447.0896), followed by the mixture of *monomesylates* (**3d**/**e**) (1.0 g, 53%) as a colourless gum, $\nu_{max.}$ 3 387, 1 362, and 1 177; δ_H 9.08 (0.5 H, s, quinoxalin-2-yl-H), 8.98 (0.5 H, s, quinoxalin-2-yl-H), 8.02 (2 H, m, ArH), 7.74 (2 H, m, ArH), 5.98 (0.5 H, d, *J* 2, 2′-H), 5.30 (0.5 H, br d, 2′-H), 5.16 (0.5 H, dd, *J* 3, 6, 1′-H), 4.75 (0.5 H, br s, OH), 4.63 (0.5 H, br s, OH), 4.30 (0.5 H, dt, *J* 6, 6, 4-H), 4.10 (3 H, m), 3.11 (1.5 H, s, O_2SMe), 2.64 (1.5 H, s, O_2SMe), 1.38 (1.5 H, s, CMe), 1.35 (1.5 H, s, CMe), 1.28 (1.5 H, s, CMe), and 1.26 (1.5 H, s, CMe); *m/z* (c.i.) 369 (MH^+, 16%), 273 (100), 257 (13), 215 (38), 197 (63), and 173 (65) (Found: MH^+, 369.1121. $C_{16}H_{21}N_2O_6S$ requires 369.1120).

(1S,2R)-[(4R)-2,2-*Dimethyl*-1,3-*dioxolan*-4-*yl*)-2-(*quinoxalin-2-yl*)*oxirane* (**9a**) *and* (1R,2S)-1-[(4R)-2,2-*Dimethyl*-1,3-*dioxolan*-4-*yl*]-2-(*quinoxalin-2-yl*)*oxirane* (**9b**).—(a) Sodium metal (100 mg) was added to a solution of the monotosylate (**3c**) (0.7 g) in methanol (20 ml). After 10 min the resulting red solution was mixed with water and dichloromethane, and the organic layer separated, dried, and evaporated under reduced pressure to give the *oxirane* (**9a**) (0.3 g, 76%) as white crystals, m.p. 99—100 °C (from dichloromethane–hexane); δ_H 8.92 (1 H, s, quinoxalin-2-yl-H), 8.17 (2 H, m, ArH), 7.85 (2 H, m, ArH), 4.48 (1 H, d, *J* 4, 2-H), 4.16 (2 H, d, *J* 6, 5-H_2), 3.84 (1 H, dt, *J* 6, 8, 4′-H), 3.50 (1 H, dd, *J* 4, 8, 1-H), 1.16 (3 H, s, CMe), and 0.95 (3 H, s, CMe); *m z* (c.i.) 273 (MH^+, 100%), 257 (16), 229 (14), 215 (12), 197 (12), and 173 (35) (Found: C, 66.2; H, 5.9; N, 10.3%. $C_{15}H_{16}N_2O_3$ requires: C, 66.2; H, 5.9; N, 10.3%).

(b) To a solution of the monomesylates (**3d**/**e**) (1.5 g) in methanol (50 ml) was added sodium metal (200 mg). After 10 min, the resultant red solution was treated with water and dichloromethane, and the organic layer then separated, dried, and evaporated under reduced pressure to give an inseparable mixture of the two oxiranes (**9a**/**b**) (0.8 g, 72%), as a colourless gum; for (**9b**) δ_H 9.05 (1 H, s, quinoxalin-2-yl-H), 8.15 (2 H, m, ArH), 7.84 (2 H, m, ArH), 4.41 (1 H, d, *J* 4, 1-H), 3.77 (3 H, m), 3.51 (1 H, m), 1.44 (3 H, s, CMe), and 1.22 (3 H, s, CMe).

1-[(1R)-1,2-*Dihydroxyethyl*]-2-(*quinoxalin-2-yl*)*oxiranes* (**10a**).—A solution of the oxiranes (**9a**/**b**) (0.36 g) in dichloromethane (50 ml) was treated with hydrobromic acid (48%; 0.1 ml) for 24 h at room temperature. The solvents were removed under reduced pressure to leave a brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane–ethyl acetate gave the pure *diols* (**10a**) (0.23 g, 73%) as white crystals, m.p. 145—148 °C (from ethanol); $\nu_{max.}$ 3 344; δ_H[$(CD_3)_2SO$] 8.88 (1 H, s, quinoxalin-2-yl-H), 8.11 (2 H, m, ArH), 7.87 (2 H, m, ArH), 4.82 (1 H, d, *J* 7, OH), 4.70 (1 H, t, *J* 7, OH), 4.44 (1 H, d, *J* 5, 1-H), 3.52 (2 H, m), 3.37 (1 H, m), and 3.24 (1 H, m); *m/z* (c.i.) 233 (MH^+, 89%), 217 (58), 199 (39), 185 (53), 173 (100), 159 (41), and 145 (62) (Found: C, 61.9; H, 5.3; N, 11.7. $C_{12}H_{12}N_2O_3$ requires C, 62.1; H, 5.2; N, 12.1%).

(4S)-2,2-*Dimethyl*-4-[*mesyloxy*-2-(*quinoxalin-2-yl*)*vinyl*]-1,3-*dioxolane* (**5e**).—A solution of the dimesylate (**3f**) (5 g) in ethanol (50 ml) was added to a solution of sodium dimethyldithiocarbamate (2.5 g) in hot ethanol (50 ml) and the mixture heated on a steam-bath for 20 min. The ethanol was

removed under reduced pressure, the residue dissolved in dichloromethane, and the solution washed with water, dried, and evaporated under reduced pressure to give a brown gum. This was purified by column chromatography over silica gel eluting with dichloromethane–ethyl acetate to give the pure *enol mesylate* (**5e**) (3.5 g, 85%), as white crystals, m.p. 141—142 °C (from dichloromethane–hexane); $\nu_{max.}$ 1 361 and 1 177; δ_H 9.23 (1 H, s, quinoxalin-2-yl-H), 8.17 (2 H, m, ArH), 7.89 (2 H, m, ArH), 6.83 (1 H, d, *J* 8, C=CH), 5.34 (1 H, dt, *J* 6, 8, 4-H), 4.45 (1 H, dd, *J* 6, 8, 5-H), 3.94 (1 H, dd, *J* 6, 8, 5-H), 3.54 (3 H, s, O_2SMe), 1.55 (3 H, s, CMe) and 1.47 (3 H, s, CMe); *m/z* 351 (MH^+, 40%), 301 (6), 273 (7), 257 (52), 199 (89), and 169 (100) (Found: C, 54.9; H, 5.0; N, 7.8; S, 9.5. $C_{16}H_{18}N_2O_5S$ require C, 54.8; H, 5.2; N, 8.0; S, 9.2%).

(4S)-2,2-*Dimethyl*-4-[2-(*quinoxalin*-2-*yl*)-2-*tosyloxyvinyl*]-1,3-*dioxolane* (**5f**).—A solution of DBU (0.82 g) in ether (5 ml) was added to a suspension of the ditosylate (**3b**) (0.78 g) in ether (8 ml), and the mixture stirred at room temperature for 2 h. The ether layer was decanted, diluted to 50 ml, and then washed with hydrochloric acid (3M; 2 × 30 ml) and water (2 × 30 ml), dried, and evaporated under reduced pressure to give the *enol tosylate* (**5f**) (0.47 g, 84%), as a pale yellow gum; $\nu_{max.}$ 1 370 and 1 180; δ_H 8.88 (1 H, s, quinoxalin-2-yl-H), 8.08 (1 H, m, ArH), 8.00 (1 H, m, ArH), 7.82 (4 H, m, ArH), 7.26 (2 H, d, *J* 9, ArH), 6.80 (1 H, d, *J* 10, C=CH), 5.10 (1 H, m, 4-H), 4.23 (1 H, dd, *J* 6, 8, 4′-H), 3.84 (1 H, dd, *J* 6, 8, 5-H), 2.32 (3 H, s, O_2SMe), 1.48 (3 H, s, CMe), and 1.38 (3 H, s, CMe); *m/z* (c.i.) 427 (MH^+, 100%), 273 (25), and 213 (9) (Found: MH^+, 427.1331. $C_{22}H_{23}N_2O_5S$ requires 427.1328).

1-[(4R)-2,2-*Dimethyl*-1,3-*dioxolan*-4-*yl*]-2-*mesyloxy*-2-(*quinoxalin*-2-*yl*)*oxirane* (**9c**).—To a solution of the enol mesylate (**5e**) (15 mg) in dry dichloromethane (2 ml) was added MCPBA (12 mg). The mixture was stirred for 48 h at room temperature and then washed with aqueous sodium hydrogen carbonate, dried, and evaporated under reduced pressure to give the *oxirane* (**9c**) (13 mg, 83%) as white crystals, m.p. 160—163 °C (from dichloromethane–hexane); $\nu_{max.}$ 1 367 and 1 177; δ_H 8.68 (1 H, s, quinoxalin-2-yl-H), 8.59 (1 H, d, *J* 7, ArH), 8.12 (1 H, d, *J* 7, ArH), 7.89 (1 H, t, *J* 7, ArH), 7.80 (1 H, t, *J* 7, ArH), 6.80 (1 H, d, *J* 8, 1-H), 5.23 (1 H, dt, *J* 6, 8, 4′-H), 4.38 (1 H, dd, *J* 6, 8, 5-H), 3.90 (1 H, dd, *J* 6, 8, 5-H), 1.49 (3 H, s, CMe), and 1.41 (3 H, s, CMe); *m/z* (c.i.) 367 (MH^+, 13%), 351 (66), 273 (17), 257 (89), and 199 (100) (Found: C, 51.9; H, 5.0; N, 7.6; S, 8.9%; MH^+, 367.0955. $C_{16}H_{18}N_2O_6S$ requires C, 52.45; H, 5.0; N, 7.7; S, 8.8%; 367.0964).

1-[(1R)-1,2-*Dihydroxyethyl*]-2-*mesyloxy*-2-(*quinoxalin*-2-*yl*)*oxirane* (**10b**).—To a solution of the oxirane (**9c**) (28 mg) in dry dichloromethane (5 ml) at 5 °C was added hydrobromic acid (48%; 0.02 ml). After 10 h at 5 °C, potassium carbonate and methanol (0.5 ml) were added and the organic layer was separated, washed with water, dried, and evaporated under reduced pressure to give a brown gum. Purification of this by column chromatography over silica gel eluting with ethyl acetate–methanol gave the pure *diol* (**10b**) (19 mg, 76%) as white crystals, m.p. 164—66 °C (from EtOH); δ_H 8.64 (1 H, s, quinoxalin-2-yl-H), 8.55 (1 H, d, *J* 8, ArH), 8.08 (1 H, d, *J* 8, ArH), 7.85 (1 H, t, *J* 8, ArH), 7.76 (1 H, t, *J* 8, ArH), 6.89 (1 H, d, *J* 9, 2′-H), 4.89 (1 H, m, 4′-H), 3.92 (1 H, dd, *J* 3, 11, 5′-H), 3.75 (1 H, dd, *J* 6, 11, 5′-H), 3.13 (1 H, br s, OH), and 2.83 (1 H, br s, OH); *m/z* (c.i.) 327 (MH^+, 10%), 311 (26), 215 (46), 199 (42), and 185 (81).

(4R)-2,2-*Dimethyl*-4-[(1R,2S)1-*hydroxy*-2-*dimethyldithiocarbamato*-2-(*quinoxalin*-2-*yl*)*ethyl*]-1,3-*dioxolane* (**11a**) *and* (4R)-2,2-*Dimethyl*-4-[(1R,2S)-2-*hydroxy*-1-*dimethyldithiocarbamato*-2-(*quinoxalin*-2-*yl*)*ethyl*]-1,3-*dioxolane* (**11b**).—A solution of the monomesylates (**3d**/**e**) (47 mg) in ethanol (2 ml) was added to a hot solution of sodium dimethyldithiocarbamate (25 mg) in ethanol (5 ml). The solution was refluxed for 20 min and then evaporated under reduced pressure and the residue dissolved in dichloromethane and the solution washed with water, dried, and evaporated under reduced pressure. Purification of this by column chromatography over silica gel eluting with dichloromethane gave the two *dimethyldithiocarbamates* (**11a**,**b**) (37 mg, 73%) in a ratio of 2:3, as a pale brown gum; $\nu_{max.}$ 3 406; δ_H 9.04 (0.6 H, s, quinoxalin-2-yl-H), 8.98 (0.4 H, s, quinoxalin-2-yl-H), 8.08 (1 H, m, ArH), 8.01 (1 H, m, ArH), 7.73 (2 H, m, ArH), 6.03 (0.6 H, d, *J* 5, 2-H), 5.81 (0.4 H, d, *J* 2, 2-H), 4.52 (1 H, m, 1′-H), 4.22—4.03 (3.4 H, m), 3.88 (0.6 H, dd, *J* 7, 9, 5-H), 3.52 (1.8 H, s, NMe), 3.47 (1.2 H, s, NMe), 3.34 (1.8 H, s, NMe), 3.30 (1.2 H, s, NMe), 1.39 (1.8 H, s, CMe), 1.28 (1.8 H, s, CMe), 1.08 (1.2 H, s, CMe), and 1.02 (1.2 H, s, CMe); *m/z* (c.i.) 394 (MH^+, 38%), 376 (19), 360 (28), 289 (10), 275 (34), 273 (23), 257 (100), 232 (26), and 199 (79) (Found: MH^+, 394.1251. $C_{18}H_{24}N_3O_3S$ requires 394.1260).

(4R,5S)-[(4R)-2,2-*Dimethyl*-1,3-*dioxolan*-4-*yl*)-5-(*quinoxalin*-2-*yl*)-1,3-*dithiolane*-2-*thione* (**12a**), 4-[(4R)-2,2-*Dimethyl*-1,3-*dioxolan*-4-*yl*)-5-(*quinoxalin*-2-*yl*)-1,3-*dithiole*-2-*thione* (**13**), *and* (4R)-2,2-*Dimethyl*-4-[1-*hydroxy*-2-(*quinoxalin*-2-*yl*)-1,3-*dioxolane* (**6f**).—(a) To a solution of the alcohols (**11a**,**b**) (100 mg) in dry pyridine (2 ml) at 0 °C was added TFAA (50 mg). The mixture was then heated at reflux for 5 min, after which it was cooled and hydrogen sulphide bubbled through it for 5 min; the solution was then maintained at room temperature for 2 h. Dichloromethane and water were added, and the organic layer separated, dried, and evaporated under reduced pressure to give a brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane gave first the *dithiole* (**13**) (2 mg, 2%) as a yellow crystalline solid, m.p. 162—165 °C (from dichloromethane–hexane), $\lambda_{max.}$ 253 and 375 nm; δ_H 8.86 (1 H, s, quinoxalin-2-yl-H), 8.14 (1 H, m, ArH), 8.06 (1 H, m, ArH), 7.85 (2 H, m, ArH), 5.75 (1 H, dd, *J* 6, 7, 1′-H), 4.77 (1 H, dd, *J* 7, 9, 2′-H), 4.13 (1 H, dd, *J* 6, 9, 2′-H), 1.59 (3 H, s, CMe), and 1.44 (3 H, s, CMe); *m/z* 362 ($M^{+\bullet}$, 3%), 304 (35), 200 (17), 186 (30), 113 (29), 103 (44), and 43 (100) (Found: $M^{+\bullet}$, 362.0226. $C_{16}H_{14}N_2O_2S_3$ require 362.0217); followed by the *dithiolane* (**12a**) (4 mg, 4%) as a pale yellow gum; $\lambda_{max.}$ 238, 303sh, and 322 nm; δ_H 9.02 (1 H, s, quinoxalin-2-yl-H), 8.13 (2 H, m, ArH), 7.80 (2 H, m, ArH), 5.88 (1 H, d, *J* 2, 5-H), 4.98 (1 H, dd, *J* 2, 10, 4-H), 4.67 (1 H, m, 1′-H), 4.32 (1 H, dd, *J* 6, 9, 2-H), 3.95 (1 H, dd, *J* 4, 9, 4′-H), 1.47 (3 H, s, CMe), and 1.40 (3 H, s, CMe); *m/z* (c.i.) 365 (MH^+, 13%), 257 (59), 199 (51), 169 (46), and 30 (100) (Found: MH^+, 365.0447. $C_{16}H_{17}N_2O_2S_3$ requires 365.0452); and finally, elution with ethyl acetate gave the *alcohol* (**6f**) (43 mg, 70%), as a pale brown gum, $\nu_{max.}$ 3 377; δ_H 8.86 (1 H, s, quinoxalin-2-yl-H), 8.18 (1 H, m, ArH), 8.09 (1 H, m, ArH), 7.83 (2 H, m, ArH), 4.73 (1 H, d, *J* 2, OH), 4.22 (2 H, m), 4.11 (2 H, m), 3.45 (1 H, dd, *J* 2, 17, 5-H), 3.18 (1 H, dd, *J* 9, 17, 5-H), 1.43 (3 H, s, CMe), and 1.37 (3 H, s, CMe); *m/z* (c.i.) 275 (MH^+, 100%), 259 (7), 173 (18), and 145 (31) (Found: *M*, 274.1321. $C_{15}H_{18}N_2O_3$ requires 274.1317).

(b) By conducting the TFAA treatment at 100 °C for 15 min and then reaction with hydrogen sulphide and work-up as in (a), only the dithiole (**13**) (11%) and the alcohol (**6f**) (24%), together with decomposition products, were obtained.

(c) By conducting the TFAA treatment at room temperature for 48 h, and then reaction with hydrogen sulphide as in (a), only the dithiole (**13**) (16%) and the alcohol (**6f**) (20%) were obtained.

(d) By conducting the cyclisation by reaction of the alcohols (**11a**,**b**) (100 mg) in dry pyridine (2 ml) with methanesulphonyl chloride (0.2 ml) at room temperature for 24 h followed by treatment with hydrogen sulphide and work-up as in (*a*), only the dithiole (**13**) (7 mg, 6%) and the alcohol (**6f**) (27 mg, 53%) were obtained.

Attempted Conversion of (**12a**) *into* (**13**)*; Synthesis of the Dithiocarbonate* (**12c**).—To a stirred solution of the dithiolane (**12a**) (4 mg) in methylene dichloride (5 ml) at 0 °C was added *m*-chloroperbenzoic acid (5 mg) and the whole stirred for 15 min. The mixture was washed with aqueous sodium hydrogen carbonate, dried, and evaporated. The residue, in dry methylene dichloride, was treated with trifluoroacetic anhydride (10 μl) at 0 °C to room temperature for 2 h. The mixture was washed with aqueous sodium hydrogen carbonate, dried, and evaporated, and the product was isolated by chromatography over silica eluting with methylene dichloride, to give the *dithiocarbonate* (**12c**) (2 mg); δ_H 9.06 (1 H, s, quinoxalin-2-yl-H), 7.81 (2 H, m, ArH), 5.70 (1 H, d, *J* 2, 1′-H), 4.75 (1 H, dd, *J* 2, 10, 2′-H), 4.54 (1 H, m, 3′-H), 4.27 (1 H, dd, *J* 6, 9, 4′-H), 3.93 (1 H, dd, *J* 4, 9, 4′-H), 1.49 (3 H, s, CMe), and 1.41 (3 H, s, CMe); *m/z* (c.i.) 349 (MH^+, 10%), 257 (52), 242 (100), 225 (97), 199 (40), and 101 (45) (Found: MH^+, 349.0684. $C_{16}H_{17}N_2O_3S_2$ requires 349.0681).

2-[(4R)-2,2-*Dimethyl*-1,3-*dioxolan*-4-*yl*]-1-(*quinoxalin*-2-*yl*)-2-*tosyloxyethanone* (**14a**).—A solution of the monotosylate (**3c**) (0.17 g) in dichloromethane (2 ml) was stirred with pyridinium dichromate (0.12 g) at room temperature for 24 h. The solvents were removed under reduced pressure, and the residue purified by column chromatography over silica gel when dichloromethane–ethyl acetate eluted the *ketone* (**14a**) (16 mg, 13%) as a pale brown gum; δ_H 9.38 (1 H, s, quinoxalin-2-yl-H), 8.24 (2 H, m, ArH), 7.97 (2 H, m, ArH), 7.77 (2 H, d, *J* 9, ArH), 7.16 (2 H, d, *J* 9, ArH), 6.53 (1 H, d, *J* 8, 2-H), 4.65 (1 H, m, 1′-H), 4.19 (1 H, dd, *J* 4, 9, 2′-H), 4.10 (1 H, dd, *J* 8, 9, 2′-H), 2.27 (3 H, s, ArMe), 1.23 (3 H, s, CMe), and 1.21 (3 H, s, CMe); *m/z* (c.i.) 443 (MH^+, 59%), 367 (10), 287 (23), 273 (88), 257 (31), 215 (100), 197 (81), and 175 (70).

2-[(4R)-2,2-*Dimethyl*-1,3-*dioxolan*-4-*yl*]-1-(*quinoxalin*-2-*yl*)-*ethanone* (**14b**).—A solution of the diol (**3a**) (1 g) in pyridine (30 ml) was stirred with phosphorus pentasulphide (1.2 g) for 1 h at room temperature. The mixture was added to ice and the product extracted into ethyl acetate. The extract was washed, dried, and evaporated under reduced pressure to give a pale brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane–ethyl acetate gave the pure *ketone* (**14b**) (0.44 g, 47%) as a crystalline solid, m.p. 96—97 °C (from hexane); $\nu_{max.}$ 1 680; δ_H 9.54 (1 H, s, quinoxalin-2-yl-H), 8.24 (2 H, m, ArH), 7.96 (2 H, m, ArH), 4.79 (1 H, quintet, *J* 7, 1′-H), 4.34 (1 H, dd, *J* 6, 8, 2′-H), 3.95 (1 H, dd, *J* 6, 15, 2-H), 3.78 (1 H, dd, *J* 6, 8, 2′-H), 3.49 (1 H, dd, *J* 6, 15, 2-H), 1.45 (3 H, s, CMe), and 1.39 (3 H, s, CMe); *m/z* (c.i.) 273 (MH^+, 26%), 215 (37), 197 (100), 173 (47), 131 (35), and 94 (22) (Found: C, 66.3; H, 6.0; N, 10.1. $C_{15}H_{16}N_2O_3$ requires C, 66.2; H, 5.9; N, 10.3%).

(3S)-4-*Dihydroxy*-1-(*quinoxalin*-2-*yl*)*butan*-1-*one* (**15**).—Hydrobromic acid (48%; 0.5 ml) was added dropwise to a solution of the ketone (**14a**) (0.5 g) in dry dichloromethane (10 ml) at 0 °C. After 2 h at 0 °C, the solution was washed with aqueous sodium hydrogen carbonate, dried, and evaporated under reduced pressure to give a brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane–ethyl acetate gave the *diol ketone* (**15**) (0.27 g, 64%) as pale brown crystals, m.p. 123—125 °C (from methanol); $\nu_{max.}$ 3 382 and 1 695; δ_H[$(CD_3)_2SO$] 9.38 (1 H, s, quinoxalin-2-yl-H), 8.21 (2 H, m, ArH), 8.0 (2 H, m, ArH), 4.78 (1 H, d, *J* 6, OH), 4.68 (1 H, t, *J* 6, OH), 4.15 (1 H, m, 3-H), and 3.35 (4 H, m); *m/z* 232 ($M^{+\bullet}$, 7%), 214 (7), 201 (15), 196 (13), 183 (24), 173 (88), 144 (30), 129 (100), 102 (78), and 76 (52) (Found: C, 61.8; H, 5.3; N, 11.7. $C_{12}H_{12}N_2O_3$ requires C, 62.1; H, 5.2; N, 12.1%).

(4R)-2,2-*Dimethyl*-4-[1,2-*dibromo*-2-*mesyloxy*-2-(*quinoxalin*-2-*yl*)*ethyl*]-1,3-*dioxolane* (**6e**) *and* 2-*Bromo*-2-[(4R)-2,2-*dimethyl*-1,3-*dioxolan*-4-*yl*]-1-(*quinoxalin*-2-*yl*)*butan*-1-*one* (**14c**).— Bromine (0.3 ml) was added with stirring to a solution of the enol mesylate (**5e**) (0.5 g) in dichloromethane (15 ml) in the presence of solid sodium hydrogen carbonate (0.5 g). After being stirred for a further 3 h, the solution was washed with aqueous sodium metabisulphite, dried, and evaporated under reduced pressure to give the unstable *dibromo compound* (**6e**) (0.65 g, 89%), as a brown gum; δ_H 9.35 (1 H, s, quinoxalin-2-yl-H), 8.18 (1 H, m, ArH), 8.10 (1 H, m, ArH), 7.84 (2 H, m, ArH), 5.02 (1 H, d, *J* 7, 1′-H), 4.64 (1 H, m, 4-H), 4.19 (1 H, dd, *J* 7, 10, 5-H), 3.95 (1 H, dd, *J* 7, 10, 5-H), 3.32 (3 H, s, O_2SMe), 1.07 (3 H, s, CMe), and 1.00 (3 H, s, CMe); *m/z* (c.i.) 509, 511, 513 (MH^+, 1, 2, 1%), 493, 495, 497 (1, 2, 1), 429, 431 (1, 1), 395 (6), 379 (7), 351 (56), 275 (65), 213 (80), 197 (59), 183 (86), 129 (83), 91 (74), and 43 (100). Without purification this unstable dibromide was dissolved in THF (15 ml) in the presence of sodium hydrogen carbonate (0.5 g) and, with stirring, aqueous ammonia (10%; 0.5 ml) was added dropwise; the mixture was then stirred for a further 24 h. After this the solvents were removed under reduced pressure, and the residue dissolved in dichloromethane, and the solution washed with water, dried, and evaporated under reduced pressure to give a brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane–ethyl acetate gave the pure *bromo ketone* (**14c**) (0.35, 70%) as a pale yellow gum; $\nu_{max.}$ 1 704; δ_H 9.60 (1 H, s, quinoxalin-2-yl-H), 8.27 (2 H, m, ArH), 7.95 (2 H, m, ArH), 6.10 (1 H, d, *J* 10, 2-H), 4.94 (1 H, m, 3-H), 4.37 (2 H, m, 4-H_2), 1.45 (3 H, s, CMe), and 1.39 (3 H, s, CMe); *m/z* (c.i.) 351, 353 (MH^+, 30, 23%), 293 (12), 273 (87), 257 (62), 215 (100), 197 (79), 185 (57), 173 (60), and 131 (60) (Found: MH^+, 351.0347. $C_{15}H_{16}BrN_2O_3$ requires 351.0345).

2-[(4R)-2,2-*Dimethyl*-1,3-*dioxolan*-4-*yl*]-2-*dimethyldithiocarbamato*-1-(*quinoxalin*-2-*yl*)*butan*-1-*one* (**14d**).—To a solution of the bromo ketone (**14c**) (20 mg) in dry THF (5 ml) at 0 °C was added, with stirring, sodium dimethyldithiocarbamate (30 mg). The mixture was stirred at 0 °C for a further 30 min and then water and dichloromethane were added. The organic layer was separated, dried, and evaporated under reduced pressure to give an orange gum. Purification of this by column chromatography over silica gel eluting with dichloromethane gave the pure *ketone* (**14d**) (17 mg, 74%) as a pale yellow gum; $\nu_{max.}$ 1 697; δ_H 9.51 (0.5 H, s, quinoxalin-2-yl-H), 9.49 (0.5 H, s, quinoxalin-2-yl-H), 8.19 (2 H, m, ArH), 7.87 (2 H, m, ArH), 6.67 (1 H, m, 2-H), 4.95 (1 H, m, 3-H), 4.16 (2 H, m, 4-H_2), 3.48 (2 × 3 H, 2 × s, NMe_2), and 1.35 (2 × 3 H, 2 × s, CMe_2); *m/z* (c.i.) 392 (MH^+, 84%), 273 (77), 255 (45), 215 (79), 197 (35), and 90 (100) (Found: MH^+, 392.1101. $C_{18}H_{22}N_3O_3S_2$ requires 392.1103).

2-*Acetylthio*-2-[(4R)-2,2-*dimethyl*-1,3-*dioxolan*-4-*yl*]-1-(*quinoxalin*-2-*yl*)*butan*-1-*one* (**14e**).—The dibromo acetal (**6e**) (0.65 g) was dissolved in dry THF (15 ml) and the whole stirred in the presence of sodium hydrogen carbonate (0.5 g) with potassium thioacetate (4.0 g) for 24 h. The solvents were removed under reduced pressure, the residue dissolved in dichloromethane, and the solution washed with water, dried, and evaporated under reduced pressure to yield a brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane–ethyl acetate gave the pure *acetylthio ketone* (**14e**) (0.21 g, 42%) as a brown gum; $\nu_{max.}$ 1 696; δ_H 9.54 (1 H, s, quinoxalin-2-yl-H), 8.23 (2 H, m, ArH), 7.91 (2 H, m, ArH), 6.11 (1 H, d, *J* 9, 2-H), 4.88 (1 H, m, 3-H), 4.22 (1 H, dd, *J* 6, 9, 4-H), 4.00 (1 H, dd, *J* 5, 9, 4-H), 2.38 (3 H, s, COMe), 1.45 (3 H, s, CMe) and 1.34 (3 H, s, CMe); *m/z* 346 (M^+, 2%), 331 (3), 303 (18), 271 (25), 246 (27), 229 (32), 213 (20), 203 (31), 129 (63), 101 (63), and 43 (43) (Found: $M^{+\bullet}$, 346.0985. $C_{17}H_{18}N_2O_4S$ requires 346.0987).

2-[(4R)-2,2-*Dimethyl*-1,3-*dioxolan*-4-*yl*]*thieno*[2,3-b]*quinoxaline* (**16**).—A solution of the dibromoalkene (**5d**) (50 mg) in methanol (1 ml) was added to an aqueous solution of disodium trithiocarbonate[21] (33%, 1 ml) with stirring. The solution was stirred for a further 30 min after which water and dichloromethane were added. The organic layer was separated, dried, and evaporated under reduced pressure to give a brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane gave first the quinoxalinyl thiole (**13**) (3 mg) and then the *thienoquinoxaline* (**16**) (25 mg, 72%) as white crystals, m.p. 84—86 °C; δ_H 8.18 (2 H, m, ArH), 7.81 (2 H, m, ArH), 7.45 (1 H, s, 3-H), 5.52 (1 H, t, *J* 7, 4′-H), 4.48 (1 H, dd, *J* 7, 9, 5′-H), 4.08 (1 H, dd, *J* 7, 9, 5′-H), 1.61 (3 H, s, CMe), and 1.51 (3 H, s, CMe); *m*/*z* 286 (M^+, 37%), 229 (35), 199 (13), 72 (100), and 43 (88) (Found: *M*, 286.0777. $C_{15}H_{14}N_2O_2S$ requires 286.0776).

2-[(1R)-1,2-*Dihydroxyethyl*]*thieno*[2,3-b]*quinoxaline* (**19**).—The acetal (**16**) (10 mg) in dichloromethane (3 ml) and methanol (0.3 ml) was cleaved by reaction with hydrobromic acid (48%; 0.3 ml) at room temperature for 24 h. Water and dichloromethane were added, and the organic layer was separated, dried, and evaporated under reduced pressure to give a brown gum which was purified by column chromatography over silica gel eluting with ethyl acetate to give the pure *diol* (**19**) as an off-white amorphous solid (6 mg, 70%); $\nu_{max.}$ 3 340; δ_H 8.19 (2 H, m, ArH), 7.83 (2 H, m, ArH), 7.52 (1 H, s, 3-H), 5.27 (1 H, m, 1′-H), 4.08 (1 H, dd, *J* 4, 12, 2′-H), 3.97 (1 H, dd, *J* 6, 12, 2′-H), and 3.50 (2 H, br s, OH); *m*/*z* 246 (M^+, 38%), 215 (100), 187 (82), 149 (69), and 102 (36) (Found: $M^{+\bullet}$, 246.0466. $C_{12}H_{10}N_2O_2S$ requires *M*, 246.0463).

(4S,5R)-2-*Ethoxy*-4-[(4R)-2,2-*dimethyl*-1,3-*dioxolan*-4-*yl*]-5-(1,2,3,4-*tetrahydroquinoxalin*-2-*yl*)-1,3-*dioxolane* (**21**).—To a solution of the acetal (**4**) (1.33 g) in dry THF (30 ml) was added lithium aluminium hydride (320 mg) in portions at room temperature. The mixture was left for a further 30 min after which aqueous ammonium chloride and ethyl acetate were added. The organic layer was separated, dried, and evaporated under reduced pressure to give the *tetrahydroquinoxalinyl acetal* (**21**) as a pale brown gum (1.05 g, 73%); $\nu_{max.}$ 3 377; δ_H 6.55 (4 H, m, ArH), 5.80 (1 H, m, 2-H), 4.08 (6 H, m), 3.50 (6 H, m), and 1.34 (9 H, m); *m*/*z* 350 ($M^{+\bullet}$, 39%), 335 (7), 304 (62), 203 (38), 145 (40), and 133 (100) (Found: $M^{+\bullet}$, 350.1845. $C_{18}H_{26}N_2O_5$ requires *M*, 350.1842).

(4S)-2,2-*Dimethyl*-4-[(E)-2-(1,4-*diacetyl*-1,2,3,4-*tetrahydroquinoxalin*-2-*yl*)*vinyl*]-1,3-*dioxolane* (**22**).—A solution of the reduced acetal (**21**) (100 mg) was heated at reflux in acetic anhydride (10 ml) for 2 h. Evaporation of the acetic anhydride under reduced pressure gave a dark brown gum. Purification of this by column chromatography over silica gel eluting with dichloromethane–ethyl acetate gave the pure *diacetamidoalkene* (**22**) (71 mg, 72%) as a pale brown gum; $\nu_{max.}$ 1 667; δ_H 7.26 (4 H, m, ArH), 5.64 (2 H, m, HC=CH), 5.34 (1 H, br s, 2′-H), 4.80 (1 H, br s, 3′-H), 4.43 (1 H, m, 4-H), 4.04 (1 H, dd, *J* 6, 7, 5-H), 3.48 (1 H, m, 5-H), 3.06 (1 H, br s, 3′-H), 2.18 (2 × 3 H, 2 × s, 2 × COMe), 1.33 (3 H, s, CMe), and 1.30 (3 H, s, CMe); *m*/*z* 344 ($M^{+\bullet}$, 50%), 329 (22), 301 (11), 227 (38), 201 (49), and 43 (100) (Found: $M^{+\bullet}$, 344.1741. $C_{19}H_{24}N_2O_4$ requires *M*, 344.1736).

(1S,2R)-1-[(4R)-2,2-*Dimethyl*-1,3-*dioxolan*-4-*yl*]-2-(1,2,3,4-*tetrahydro*-1,4-*dimethylquinoxalin*-2-*yl*)*oxirane* (**23a**).—To a solution of the epoxide (**9a**) (50 mg) and formaldehyde (37%; 0.15 ml) in acetonitrile (3 ml) sodium cyanoborohydride (40 mg) was added at room temperature. Glacial acetic acid (0.018 ml) was added over 10 min, and the mixture stirred for a further 2 h. More sodium cyanoborohydride (20 mg) and glacial acetic acid (0.018 ml) were then added as before and the mixture stirred for a further 30 min. After this, water and dichloromethane were added, and the organic layer separated, dried, and evaporated under reduced pressure to give a colourless gum. Purification of this by column chromatography over silica gel eluting with dichloromethane gave the pure *oxirane* (**23a**) (31 mg, 56%) as a colourless gum; δ_H 6.70 (2 H, br s, ArH), 6.60 (2 H, br s, ArH), 4.22 (1 H, dd, *J* 6, 8, 5′-H), 4.06 (1 H, dd, *J* 8, 8, 5′-H), 3.97 (1 H, dt, *J* 6, 9, 4′-H), 3.25 (3 H, br s), 3.12 (1 H, dd, *J* 4, 9, 1-H), 2.90 (7 H, m), 1.48 (3 H, s), and 1.37 (3 H, s); *m*/*z* 304 ($M^{+\bullet}$, 34%), 289 (6), 161 (47), 147 (33), 49 (68), and 43 (100) (Found: $M^{+\bullet}$, 304.1790. $C_{17}H_{24}N_2O_3$ requires *M*, 304.1792).

(1R,2S)-[(4R)-2,2-*Dimethyl*-1,3-*dioxolan*-4-*yl*]-2-(1,2,3,4-*tetrahydro*-1,4-*dimethylquinoxalin*-2-*yl*)*thiirane* (**23b**).—A mixture of the oxirane (**23a**) (50 mg) and potassium ethyl xanthate (130 mg) were refluxed together in methanol (15 ml) for 24 h. Water and dichloromethane were added, and the organic layer separated, dried, and evaporated under reduced pressure to give a colourless gum. Purification of this by column chromatography over silica gel, eluting with dichloromethane, gave first the *thiirane* (**23b**) (20 mg, 38%) as a colourless gum; δ_H 6.74 (2 H, m, ArH), 6.61 (1 H, dd, *J* 2, 7, ArH), 6.51 (1 H, dd, *J* 2, 7, ArH), 4.02 (1 H, dd, *J* 6, 8, 2′-H), 3.87 (1 H, q, *J* 6, 1′-H), 3.76 (1 H, dd, *J* 6, 8, 2′-H), 3.27 (2 H, m), 3.10 (2 H, m), 2.99 (3 H, s, NMe), 2.97 (1 H, m), 2.92 (3 H, s, NMe), 1.43 (3 H, s, CMe), and 1.32 (3 H, s, CMe); *m*/*z* (c.i.) 320 ($M^{+\bullet}$, 33%), 288 (4), 161 (100), 147 (16), and 43 (7) (Found: $M^{+\bullet}$, 320.1556. $C_{17}H_{24}N_2O_2S$ requires 320.1561), followed by recovered starting material (18 mg, 36%).

2-[(1R)-1,2-*Diacetoxyethyl*]-3-*methylthiocarbonylthiothieno*-[2,3-b]*quinoxaline* (**24**).—To the trithiocarbonate (**13**) (10 mg) in methanol (saturated with potassium hydroxide; 5 ml) was added iodomethane (5 ml) and the mixture stirred at room temperature for 48 h. After this the solvent was removed under reduced pressure and water and dichloromethane were added to the residue. The organic layer was separated, dried, and evaporated and the residue immediately treated with acetic anhydride (1 ml) and pyridine (1 ml). After 4 h at room temperature, removal of reactants gave a pale yellow gum from which the thienoquinoxaline (**24**) (4 mg) was obtained by chromatography over silica eluting with methylene dichloride; δ_H 8.32 (1 H, ArH), 8.18 (1 H, ArH), 7.85 (1 H, ArH), 6.74 (1 H, dd, *J* 4, 6, 1′-H), 4.58 (1 H, dd, *J* 4, 12, 2′-H), 4.49 (1 H, dd, *J* 6, 12, 2′-H), 2.42 (3 H, s, CH_3S), 2.19 (3 H, s, CH_3CO), and 2.10 (3 H, s, CH_3CO); *m*/*z* (*c.i.*) 436 (MH^+, 98%), 377 (31), and 243 (100) (Found: MH^+, 437.0307. $C_{18}H_{17}N_2O_5S_3$ requires 437.0300).

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