Approaches to Cytochalasan Synthesis: Preparation and Diels–Alder Reactions of 3-Alkyl- and 3-Acyl-Δ^3-pyrrolin-2-ones

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A series of *N*-protected Δ^3-pyrrolin-2-ones has been prepared, and their Diels–Alder reactivity assessed. 3-Alkyl- and 3-(oximinoalkyl)-1,5-dibenzyl-Δ^3-pyrrolin-2-ones were found to isomerize to their 5-benzylidenepyrrolidinone isomers rather than undergo Diels–Alder reactions. In contrast *N*-acyl- and *N*-arylsulphonyl-Δ^3-pyrrolin-2-ones were found to undergo Diels–Alder reactions with the major products being formed by an *endo*-selective cycloaddition to the less hindered face of the dienophile.

The cytochalasans, *e.g.* cytochalasin B (**1**) and D (**2**), are an important group of biologically active, macrocyclic, natural products which have attracted considerable synthetic attention.[1,2] We have been interested in developing a cytochalasan synthesis which uses an intramolecular Diels–Alder reaction to form the macrocyclic ring and isoindolone unit simultaneously.[3] Preliminary work has shown that macrocyclic lactones related to cytochalasin B (**1**) can be prepared in this way,[3] and a total synthesis of cytochalasin B using such a Diels–Alder approach has recently been described by Stork.[4]

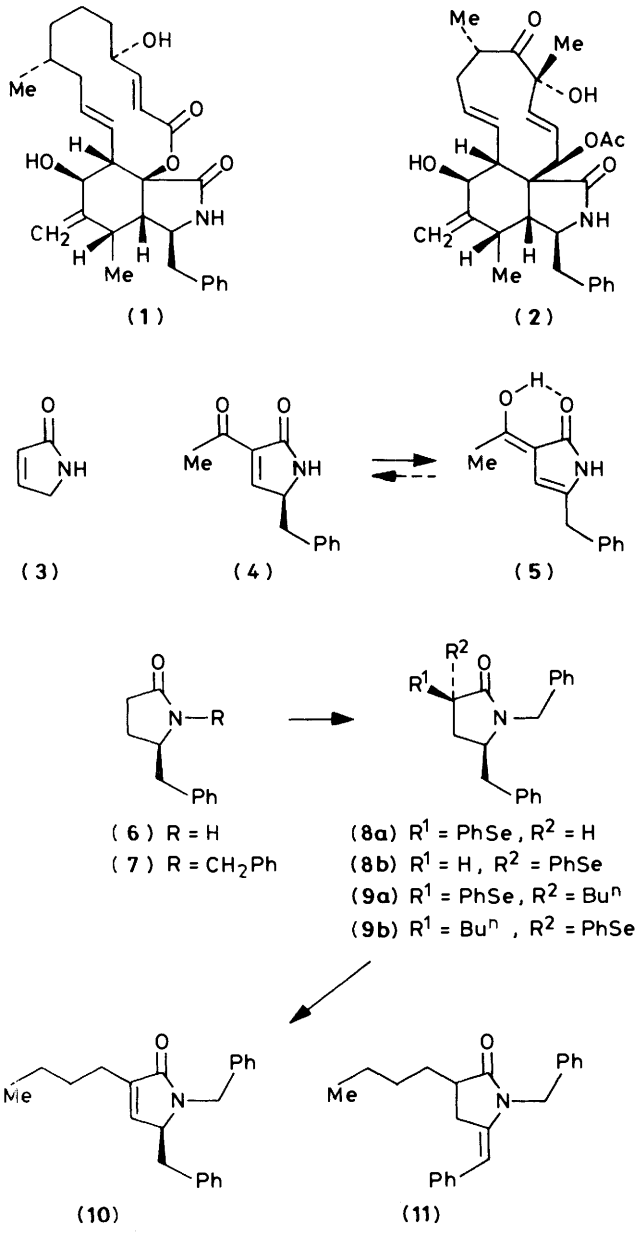
The application of this strategy to a synthesis of a 'carbocyclic' cytochalasan, *e.g.* cytochalasin D (**2**), depends upon the development of a suitable dienophile. The use of a Δ^3-pyrrolin-2-one derived from L-(−)-phenylalanine is attractive since the desired functionality and stereochemistry would be present in the product thus minimizing the number of steps required after the crucial Diels–Alder cyclization. We here describe the synthesis and Diels–Alder reactivity of a series of 3-substituted Δ^3-pyrrolin-2-ones. Our results are consistent with those of Vedejs who has also been developing a Diels–Alder strategy for cytochalasan synthesis.[5]

Since Δ^3-pyrrolin-2-one (**3**) is thermally unstable,[6] and since the 3-acetyl-Δ^3-pyrrolin-2-one (**4**) undergoes irreversible tautomerism to its enol (**5**),[7] it was decided to look at the chemistry of a series of *N*-protected Δ^3-pyrrolin-2-ones. *N*-Alkyl-, *N*-acyl-, and *N*-sulphonyl-Δ^3-pyrroline-2-ones have been prepared, and their chemistry studied. The known 5-benzylpyrrolidin-2-one (**6**) was chosen as the starting material for our work.[8]

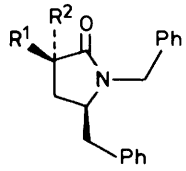
Results and Discussion

N-Benzyl-Δ^3-pyrrolin-2-ones.—5-Benzylpyrrolidin-2-one (**6**) was treated with sodium hydride–benzyl bromide to give the *N*-benzylpyrrolidinone (**7**). Phenylselenenylation was accomplished using 2 mol equiv. of lithium di-isopropylamide (LDA)–benzeneselenenyl chloride, to give a 1:1 mixture of phenylselenopyrrolidinones (**8a**) and (**8b**) which was alkylated using LDA–n-butyl iodide. A mixture of the *cis*- and *trans*-alkylated products (*ca.* 1:10) was obtained, which was treated with hydrogen peroxide–pyridine to give the 3-butyl-Δ^3-pyrrolin-2-one (**10**) (Scheme 1).

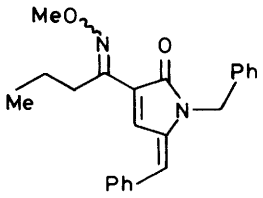
However, all attempts to effect a Diels–Alder reaction of the 3-butyl-Δ^3-pyrrolin-2-one (**10**) with either (2*E*,4*E*)-hexa-2,4-diene or with cyclopentadiene were unsuccessful. Under all the conditions investigated, including both thermal and Lewis acid catalysed procedures, the pyrrolin-2-one (**10**) underwent an isomerization to give the 5-benzylidenepyrrolidinone (**11**) which could be prepared cleanly by heating the pyrrolinone (**10**) at 200 °C for 36 h. The geometry of the exocyclic double-bond of 5-benzylidenepyrrolidinone (**11**) was established by the observation of a nuclear Overhauser enhancement of 16% for the vinylic proton on irradiation of the *N*-benzylic protons.



Scheme 1.



(12a) $R^1 = H, R^2 = CH_3(CH_2)_2C(O)—$
(12b) $R^1 = CH_3(CH_2)_2C(O)—, R^2 = H$
(13) $R^1 = H, R^2 = CH_3(CH_2)_2C(=NOCH_3)—$
(14) $R^1, R^2 = PhSe, R^2, R^1 = CH_3(CH_2)_2C(=NOCH_3)—$



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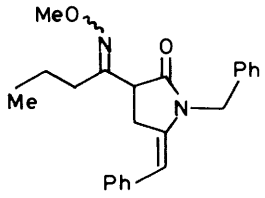

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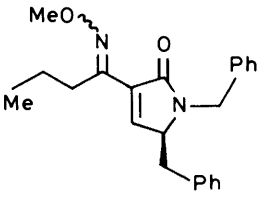


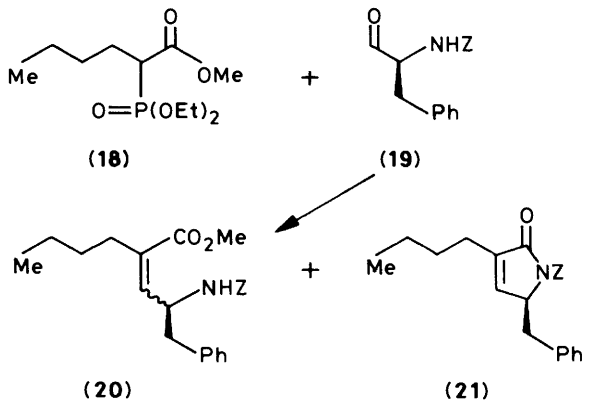
(17)

In order to increase the Diels–Alder reactivity of the pyrrolinone system, it was decided to incorporate an electron-withdrawing group into the 3-substituent. The *O*-methyl oximes (**17**) were selected as potential dienophiles, the *O*-methyl oxime moiety being chosen to reduce the chance of enolization.[7]

Treatment of the *N*-benzylpyrrolidinone (**7**) with LDA and ethyl butyrate gave a 65% yield of a 1:1 mixture of the *cis*- and *trans*-diastereoisomeric pyrrolidinones (**12a**) and (**12b**), which was converted into a mixture of *syn*- and *anti*-*O*-methyl oximes (**13**) in the ratio 4:1. Only two oxime isomers were detected by ^1H n.m.r., and these were not separated, but were phenylselenenylated (LDA, benzeneselenenyl chloride) to give a mixture of all four possible phenylseleno *O*-methyl oximes (**14**). Treatment of this mixture with 1.2 mol equiv. of *m*-chloroperoxybenzoic acid did not give the expected Δ^3-pyrrolinone. Instead a 52% yield of the dienyl *O*-methyl oxime (**15**) was isolated, formed possibly by further oxidation of the initially formed pyrrolinones (**17**) by benzeneselenenic acid. Treatment of the mixture of phenylselenopyrrolidinones (**14**) with an excess of hydrogen peroxide gave two products which were isolated in 56% yield and identified as the *syn*- and *anti*-*O*-methyl oximes (**16**) (1:7). The geometry of the exocyclic double bond in both of these isomers was established as shown by the observation of a nuclear Overhauser enhancement of the vinylic proton on irradiation of the benzylic protons.

It would appear that 1,5-dibenzyl-Δ^3-pyrrolin-2-ones have a propensity to isomerize to their 5-benzylidenepyrrolidinone isomers, and that they are unlikely to prove useful dienophiles for cytochalasan synthesis.

N-*Acyl*-Δ^3-*pyrrolin*-2-*ones*.—The 2-diethylphosphonohexanoate (**18**) was condensed with *N*-benzyloxycarbonylphenylalaninal (**19**) to give a mixture provisionally identified as consisting of the isomeric alkenes (**20**) together with the Δ^3-pyrrolin-2-one (**21**)[9] (Scheme 2). Repeated chromatography of



Scheme 2.

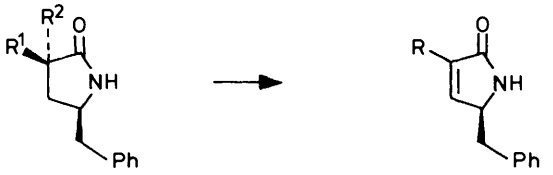
this mixture gave the pyrrolinone in *ca.* 30% overall yield, the other products not being formally characterized. Although quite direct, this *N*-acyl-3-alkylpyrrolin-2-one synthesis was not felt to be suitable for the preparation of more complex systems, and so other routes to these compounds were developed.

Treatment of 5-benzylpyrrolidin-2-one (**6**) with n-butyllithium–TMEDA at 0 °C, followed by the addition of an excess of benzeneselenenyl chloride at −78 °C, gave mixtures of the mono- and bis-phenylselenopyrrolidinones (**22a**) and (**22b**), and (**23**). Use of 2 mol equiv. of n-butyl-lithium led to the preferential formation of the monophenylseleno products (**22a**) and (**22b**) (both isomers, ratio *ca.* 3:2), whereas the use of 3 mol equiv. of base gave more of the bis(phenylselenenylated) product (**23**). The yields of these reactions were fairly modest, *ca.* 20—30%, and some starting material was usually recovered, but this direct phenylselenenylation procedure provided an immediate access to 3-phenylselenopyrrolidinones, with no protecting group on the nitrogen, for alkylation studies.

Attempts to alkylate the 3-phenylselenopyrrolidinones (**22a**) and (**22b**) using 2 mol equiv. of n-butyl-lithium and an alkyl halide gave only low yields of the desired products owing to competing *N*-alkylation, which appeared to predominate in tetrahydrofuran (THF), and dephenylselenenylation presumably *via* competing attack of the n-butyl-lithium on the phenylselenenyl moiety; for example, only a 25% yield of the 3-heptyl-3-phenylselenopyrrolidinones (**24a**) and **24b**), as a mixture of diastereoisomers, ratio *ca.* 3:1, was isolated when heptyl bromide was used as the alkylating agent. However, treatment of the 3,3-bis(phenylseleno)pyrrolidinone (**23**) with 2 mol equiv. of n-butyl-lithium and an alkyl halide was more successful,[10] *e.g.* a good yield (67%) of the two isomers of 3-butyl-3-phenylselenopyrrolidinones (**25a**) and (**25b**) in the ratio 7:2 was obtained using n-butyl iodide. This 3-butylpyrrolidinone was also obtained by a one-pot phenylselenenylation and alkylation of the *N*-silylated pyrrolidinone (**32**).

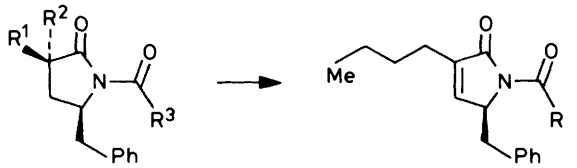
Although oxidative elimination of the phenylselenyl moiety from the pyrrolidinones (**24a**) and (**24b**) and (**25a**) and (**25b**) was successful, and gave good yields of the corresponding 3-alkylpyrrolinones (**26**) and (**27**), difficulties were encountered in the *N*-acylation of these compounds. However, *N*-acylation of the 3-butyl-3-phenylselenopyrrolidinones (**25a**) and (**25b**) using base and either benzoyl or acetyl chloride gave good yields of the corresponding *N*-acylpyrrolidinones (**28a**) and (**28b**) and (**29a**) and (**29b**), which were converted into the *N*-benzoyl- and *N*-acetyl-Δ^3-pyrrolin-2-ones (**30**) and (**31**) after treatment with an excess of hydrogen peroxide (Scheme 3).

Having prepared the *N*-acyl-3-alkyl-Δ^3-pyrrolin-2-ones (**21**), (**30**), and (**31**) their Diels–Alder reactivity was examined. On being heated at 200 °C for 36—40 h in a Carius tube, they were



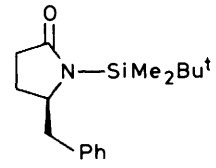
(22a) R^1 = H, R^2 = PhSe
(22b) R^1 = PhSe, R^2 = H
(23) R^1 = R^2 = PhSe
(24a) R^1 = PhSe, R^2 = n-C_7H_{15}
(24b) R^1 = n-C_7H_{15}, R^2 = PhSe
(25a) R^1 = PhSe, R^2 = Bu^n
(25b) R^1 = Bu^n, R^2 = PhSe

(26) R = n-C_7H_{15}
(27) R = Bu^n



(28a) R^1 = PhSe, R^2 = Bu^n, R^3 = Ph
(28b) R^1 = Bu^n, R^2 = PhSe, R^3 = Ph
(29a) R^1 = PhSe, R^2 = Bu^n, R^3 = Me
(29b) R^1 = Bu^n, R^2 = PhSe, R^3 = Me

(30) R = Ph
(31) R = Me



(32)

Scheme 3.

found to undergo Diels–Alder reactions with (2*E*,4*E*)-hexa-2,4-diene to give one major product in each case which was identified as the *endo*-adduct (**33**)—(**35**). Deprotection of the *N*-benzyloxycarbonyl adduct gave the free isoindolone (**36**) in 93% yield after chromatography. The structures of these Diels–Alder adducts were assigned on the basis of the i.r. spectroscopic data. The stereochemistry assigned to the *N*-benzyloxycarbonyl adduct (**33**) was supported by a nuclear Overhauser enhancement of 10% for 7-H on irradiation of the 5-methyl substituent, see Figure 1. The stereochemistry of the other adducts was assigned by analogy.

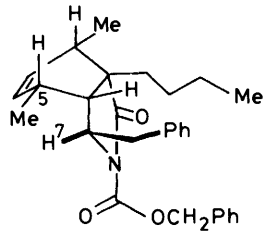
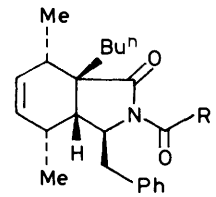
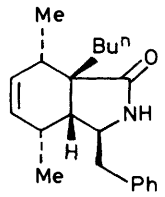


Figure 1. Structure of the adduct (**33**)

These Diels–Alder reactions were found to be quite stereoselective. Traces of minor isomers were visible in the ^1H n.m.r. spectra of the crude reaction mixtures, but insufficient quantities were isolated pure for formal characterization. The major adducts (**33**)—(**35**) would appear to have been formed *via* *endo*-selective Diels–Alder reactions with the diene approaching the less hindered face of the dienophile, and they have the stereochemistry that would be required in a cytochalasan synthesis. However, because of the harsh conditions of these Diels–Alder reactions, the preparation of the more reactive 1,3-diacyl-Δ^3-pyrrolin-2-ones was examined.



(33) R = OCH_2Ph
(34) R = Ph
(35) R = Me



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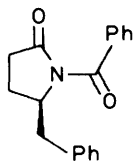

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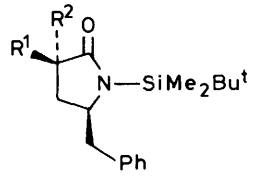
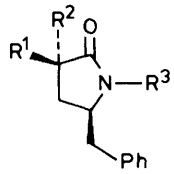
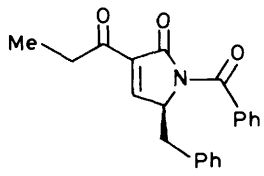


(38a) R^1 = H, R^2 = $CH_3CH_2C(O)$—
(38b) R^1 = $CH_3CH_2C(O)$—, R^2 = H
(39) R^1 = $CH_3CH_2C(O)$—, R^2 = PhSe

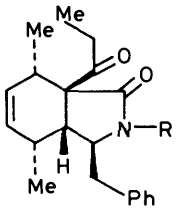


(40a) R^1 = $CH_3CH_2C(O)$—, R^2 = PhSe, R^3 = H
(40b) R^1 = PhSe, R^2 = $CH_3CH_2C(O)$—, R^3 = H
(41a) R^1 = $CH_3CH_2C(O)$—, R^2 = PhSe, R^3 = C(O)Ph
(41b) R^1 = PhSe, R^2 = $CH_3CH_2C(O)$—, R^3 = C(O)Ph

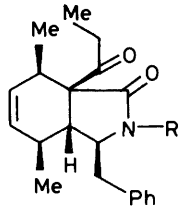


(42)

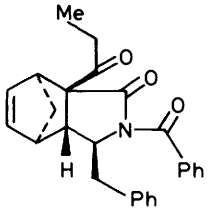
Preliminary attempts to acylate the *N*-benzoylpyrrolidinone (**37**) were unsuccessful, but efficient acylation of the *N*-silylated pyrrolidinone (**32**) was achieved by adding its lithium enolate anion (LDA, −78 °C) to propionylimidazole at −78 °C.[11] The 3-(1-oxopropyl)-*N*-silylpyrrolidinones (**38a**) and (**38b**) were phenylselenenylated (LDA, phenylselenenyl chloride) to give the selenide (**39**) as mainly one isomer (^1H n.m.r.). Desilylation to give a 1:1 mixture of the pyrrolidinones (**40a**) and (**40b**) was carried out using aqueous acid since fluoride-induced deprotection was accompanied by migration of the phenylselenenyl moiety. However, base-catalysed *N*-acylation of the 3-(1-oxopropyl)-3-phenylselenopyrrolidinone (**40**) was also accompanied by loss and migration of the rather labile



(43) R = C(O)Ph
(44) R = H



(45) R = C(O)Ph
(46) R = H



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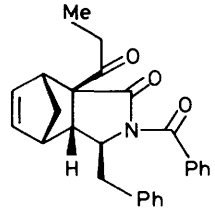


(48)

phenylselenenyl group, and gave rise to complex mixtures of products. This could be avoided by a direct exchange of the *N*-silyl protective group with an *N*-benzoyl group, using benzoyl chloride in benzene at 80 °C.[12] The mechanism of this process is not clear, possibly involving an initial 1,3-silyl migration, but it did provide an efficient method for introducing the desired *N*-acyl substituent. Finally oxidative elimination of the phenylselenenyl moiety was carried out using *m*-chloroperoxybenzoic acid, the *N*-benzoyl-3-(1-oxopropyl)-Δ^3-pyrrolin-2-one (**42**) being obtained in excellent yield. The crude product was shown to be of good quality by ^{1}H n.m.r., and was used without purification in the Diels–Alder reactions.

Good yields of Diels–Alder adducts were obtained when the 3-acyl-Δ^3-pyrrolinone (**42**) and an excess of either (2*E*,4*E*)-hexa-2,4-diene or cyclopentadiene were allowed to react in solution in a Carius tube, at 100—105 °C for 8 h for the hexadiene, and at 20 °C for 3 h for the cyclopentadiene. The reaction with hexa-2,4-diene was quite stereoselective, an 85:15 mixture of the adducts (**43**) and (**45**) being obtained. These could not be separated, but were deprotected to give the separable isoindolones (**44**) and (**46**). The cyclopentadiene reaction was less stereoselective, a 1:1.2 mixture of diastereoisomeric adducts, tentatively identified as (**47**) and (**48**), being formed.

The stereochemical assignments of these adducts were made on the basis of nuclear Overhauser experiments and spin-decoupling data. Of note was the observation of a 3% enhancement of the vinylic 4-H resonance upon irradiation of the methine 7-H for the major deprotected hexadiene adduct. This is only consistent with the stereochemistry assigned, see Figure 2. It would appear that in the Diels–Alder additions to (2*E*,4*E*)-hexa-2,4-diene, the *N*-acylpyrrolin-2-one ring determines the *endo–exo* selectivity.

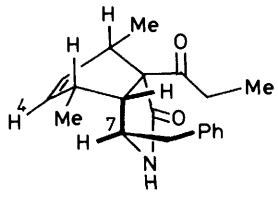
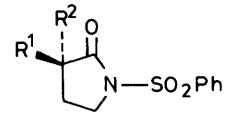
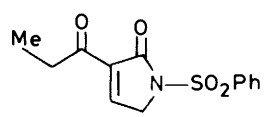


Figure 2. Structure of the adduct (**44**)



(49) $R^1 = R^2 = H$
(50) $R^1 = CH_3CH_2C(O)—$, $R^2 = H$
(51) $R^1 = CH_3CH_2C(O)—$, $R^2 = PhSe$



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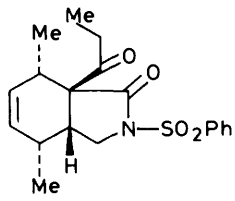

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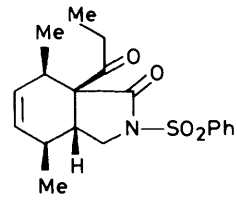

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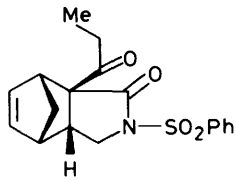

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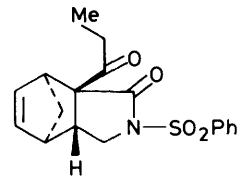

(56)

N-*Sulphonyl*-Δ^3-*pyrrolin*-2-*ones*.—1-Phenylsulphonylpyrrolidin-2-one (**49**) was acylated (LDA, propionyl chloride) to give the 3-(1-oxopropyl)pyrrolidinone (**50**) (63%). Phenylselenenylation (63%) and oxidative elimination then gave the rather sensitive 3-(1-oxopropyl)-1-phenylsulphonyl-Δ^3-pyrrolin-2-one (**52**). This was found to undergo Diels–Alder reactions with both (2*E*,4*E*)-hexa-2,4-diene and cyclopentadiene. The hexadiene gave a *ca.* 6:1 mixture of the *endo–exo* adducts (**53**) and (**54**) at 115 °C (37%), whereas a *ca.* 2:1 mixture of adducts (**55**) and (**56**) (67%) was obtained using cyclopentadiene at 55 °C.

Conclusions.—The *N*-acyl- and *N*-sulphonyl-Δ^3-pyrrolin-2-ones used in this work were found to be useful Diels–Alder dienophiles. The 3-acylpyrrolinones were found to be more reactive than the corresponding 3-alkylpyrrolinones, but were also stable making them more difficult to handle. The Diels–Alder reactions of these compounds were quite stereoselective, and the major isoindolone products had a stereochemistry analogous to the cytochalasans. Work is in progress to develop syntheses of the 'carbocyclic' cytochalasans using intramolecular Diels–Alder reactions related to the intermolecular reactions described here.

Experimental

I.r. spectra were measured on Perkin-Elmer 257 and 297 spectrophotometers, and ^{1}H n.m.r. spectra on a Bruker WH-300 spectrometer (300 MHz). M.p.s were determined on a Buchi 510 apparatus and are uncorrected. Mass spectra were measured on a VG-micromass ZAB-16F spectrometer using either electron impact (E.I.) or chemical ionization (C.I.) modes.

T.l.c. was carried out using Merck aluminium sheets, precoated with silica gel $60F_{245}$; flash chromatography was on Merck silica gel 60, and short column chromatography on Merck kieselgel 60H.

All solvents were dried and distilled before use. Ether refers to diethyl ether throughout and light petroleum to the fraction boiling between 40 and 60 °C.

1,5-*Dibenzylpyrrolidin-2-one* (**7**).—5-Benzylpyrrolidin-2-one (**6**) (2.65 g, 15 mmol) in anhydrous THF (50 ml) was added dropwise to NaH (430 mg, 50% dispersion in oil, 22.5 mmol) in THF (10 ml) under nitrogen at 0 °C. Benzyl bromide (3.87 g, 22.5 mmol) was added, and the mixture heated under reflux for 16 h. Cautious aqueous work-up gave, after flash chromatography, 1,5-*dibenzylpyrrolidin-2-one* (**7**) (3.4 g, 85%), m.p. 41—42 °C (Found: C, 80.2; H, 7.4; N, 5.3. $C_{18}H_{19}NO$ requires C, 80.5; H, 7.2; N, 5.3%); $\nu_{max.}$(film) 1 680, 1 500, 1 400, 1 300, and 740 cm^{-1}; $\delta_H(CDCl_3)$ 1.75 and 1.92 (each 1 H, m, HC*H*), 2.30 (2 H, m, CH_2CO), 2.57 (1 H, dd, *J* 14, 8 Hz, *H*CHPh), 3.03 (1 H, dd, *J* 15, 5 Hz, HC*H*Ph), 3.65 (1 H, m, CHN), 4.05 and 5.10 (each 1 H, d, *J* 15 Hz, N*H*CHPh), and 7.0—7.2 (10 H, m, aromatic H); *m/z* (E.I.) 265 (M^+, 1%), 174 (M^+ − 91, 90), and 91 (M^+ − 174, base peak).

1,5-*Dibenzyl-3-phenylselenopyrrolidin-2-ones* (**8a**) *and* (**8b**).—Lithium di-isopropylamide (LDA) (1.2 ml of a 1M solution in THF–hexane) was added to 1,5-dibenzylpyrrolidin-2-one (**7**) (133 mg, 0.5 mmol) in THF (3 ml) at −78 °C under nitrogen. After 15 min, benzeneselenenyl chloride (PhSeCl) (105 mg, 0.55 mmol) in THF (2 ml) was added, and the reaction mixture allowed to warm to 0 °C. Aqueous work-up gave, after flash chromatography (ether–light petroleum, 2:3), the 1,5-*dibenzyl-3-phenylselenopyrrolidin-2-ones* (**8a**) and (**8b**) as an oily 1:1 mixture of diastereoisomers (Found: M^+, 241.0945. $C_{24}H_{23}NO^{80}Se$ requires *M*, 421.0943); $\nu_{max.}$(film) 1 680, 1 600, 1 580, 1 495, 1 480, 740, and 700 cm^{-1}; $\delta_H(CDCl_3)$ 1.5—4.0 (6 H, overlapping m, 2 × CH_2 + 2 × CH), 3.9, 4.00, 4.8, and 4.9 (each 0.5 H, d *J* 15 Hz, NHC*H*Ph), and 7.2 (15 H, m, aromatic H); *m/z* (E.I.) 419, 421 (M^+, 23%), 328, 330 (M^+ − 91, 50), and 91 (M^+ − 328, 330, base peak).

The use of 1 mol equiv. of LDA in this reaction gave a mixture of the monophenylselenenylated pyrrolidinones (**8a**) and (**8b**) (45%), 1,5-dibenzyl-3,3-bis(phenylseleno)pyrrolidin-2-one (10%), and unchanged starting material (15%).

1,5-*Dibenzyl-3-butyl-3-phenylselenopyrrolidin-2-ones* (**9a**) *and* (**9b**).—LDA (1.2 ml of a 1M-solution in THF–hexane) was added to the phenylselenopyrrolidinones (**8a**) and (**8b**) (420 mg, 1 mmol) in THF (5 ml) at −78 °C under nitrogen. After 15 min, n-butyl iodide (276 mg, 15 mmol) was added, and the mixture allowed to warm to 20 °C. After 14 h, aqueous work-up and flash chromatography gave a 10:1 mixture of the isomers of 1,5-*dibenzyl-3-butyl-3-phenylselenopyrrolidin-2-one* (**9a**) and (**9b**) (86%) as a colourless oil (Found: M^+, 477.1566. $C_{28}H_{29}NO^{80}Se$ requires M^+, 477.1570); $\nu_{max.}$($CHCl_3$) 1 685, 1 600, 1 240, 740, and 700 cm^{-1}; $\delta_H(CDCl_3)$ 0.92 (3 H, m, CH_3), 1.25 (4 H, m, 2 × CH_2), 1.8 (2 H, m, CH_2), 1.9 (2 H, overlapping dd, HC*H*Ph and HC*H*CHN), 2.03 (0.9 H, dd, *J* 15, 9 Hz, HC*H*CHN), 2.3 (0.1 H, dd, *J* 4, 10 Hz, HC*H*CHN), 3.02 (0.9 H, dd, *J* 15, 5 Hz, *H*CHPh), 3.15 (0.1 H, dd, *J* 4, 12 Hz, *H*CHPh), 3.43 (1 H, m, C*H*N), 4.05 and 5.15 (each 0.9 H, d, *J* 15 Hz, NHC*H*Ph), 4.2 and 4.93 (each 0.1 H, d, *J* 15 Hz, HCHPh), and 6.9—7.8 (15 H, m, aromatic H); *m/z* (E.I.) 475, 477 (M^+, 5%), 384, 386 (M^+ − 91, 60), 320 (M^+ − 155, 157, 45), and 91 (M^+ − 384, 386, base peak).

1,5-*Dibenzyl-3-butyl-Δ³-pyrrolin-2-one* (**10**).—Hydrogen peroxide (390 mg, 30% aqueous solution) in water (20 ml) was added to the 3-phenylselenopyrrolidinones (**9a**) and (**9b**) (0.5 g, 1.05 mmol) in CH_2Cl_2 (50 ml) containing pyridine (240 mg, 3.15 mmol) at 20 °C. After 45 min aqueous work-up gave an oil which was chromatographed on silica (ether–light petroleum, 2:3) to give 1,5-*dibenzyl-3-butyl-Δ³-pyrrolin-2-one* (**10**) (280 mg, 84%) as a pale yellow oil (Found: M^+, 319.1963. $C_{22}H_{24}NO$ requires *M*, 319.1963); $\nu_{max.}$($CHCl_3$) 1 670, 1 600, and 1 500 cm^{-1}; $\delta_H(CDCl_3)$ 0.92 (3 H, t, *J* 7 Hz, CH_3), 1.26, 1.45, and 2.25 (each 2 H, m, CH_2), 2.51 (1 H, dd, *J* 16, 9 Hz, *H*CHPh), 3.12 (1 H, dd, *J* 16, 6 Hz, HC*H*Ph), 3.97 (1 H, ddd, *J* 9, 6, 2 Hz, CHN), 4.18 and 5.22 (each 1 H, d, *J* 15 Hz, NHC*H*Ph), 6.47 (1 H, d, *J* 2 Hz, *H*C=), and 7.25 (10 H, m, aromatic H); *m/z* (E.I.) 319 (M^+, 9%), 228 (M^+ − 91, 80), and 91 (M^+ − 228, base peak).

(E)-1-*Benzyl-5-benzylidene-3-butylpyrrolidin-2-one* (**11**).—The Δ³-pyrrolin-2-one (**10**) (250 mg, 0.79 mmol) was heated at 200 °C under nitrogen for 36 h. Flash chromatography (ether–light petroleum, 1:1) gave (E)-1-*benzyl-5-benzylidene-3-butylpyrrolidin-2-one* (**11**) (243 mg, 97%) as an oil (Found: M^+, 319.1947. $C_{22}H_{24}NO$ requires *M*, 319.1963); $\nu_{max.}$($CDCl_3$) 1 705, 1 670, 1 415, 1 340, 1 260, 1 190, and 700 cm^{-1}; $\delta_H(CHCl_3)$ 0.91 (3 H, t, *J* 7 Hz, CH_3), 1.35 (5 H, m, 2 × CH_2 + HC*H*), 2.00 (1 H, m, HC*H*), 2.72 (2 H, m, HCCO + *H*CHCN), 3.20 (1 H, m, HC*H*CN), 4.81 and 4.83 (each 1 H, d, *J* 15 Hz, HC*H*Ph), 5.73 (1 H, t, *J* 2 Hz, CHPh), and 7.25 (10 H, m, aromatic H); *m/z* (E.I.) 319 (M^+, 60%) and 91 (M^+ − 228, base peak).

1,5-*Dibenzyl-3-(1-oxobutyl)pyrrolidin-2-ones* (**12a**) *and* (**12b**).—LDA (2.2 ml of a 1M-solution in THF–hexane) was added to 1,5-dibenzylpyrrolidin-2-one (**7**) (265 mg, 1 mmol) in anhydrous THF (3 ml) at −78 °C under nitrogen. After 15 min, ethyl butanoate (198 mg, 1.3 mmol) was added and the mixture allowed to warm to 20 °C. The mixture was diluted with ether after 3 h, and added to aqueous acid. Ether extraction gave, after flash chromatography (ether–light petroleum, 1:1) a 1:1 mixture of the diastereoisomers 1,5-*dibenzyl-3-(1-oxobutyl)-pyrrolidin-2-one* (**12a**) and (**12b**) (217 mg, 65%) as a colourless oil (Found: M^+, 335.1881. $C_{22}H_{25}NO_2$ requires *M*, 335.1885); $\nu_{max.}$($CHCl_3$) 1 715, 1 680, 1 600, 1 500, 1 250, and 700 cm^{-1}; $\delta_H(CDCl_3)$ 0.93 and 0.98 (each 1.5 H, t, *J* 7.5 Hz, CH_3), 1.5—2.0 (3 H, complex m, HC*H* + CH_2), 2.2—2.7 (3 H, complex m, HC*H* + CH_2), 3.0 (2 H, complex m, CH_2), 3.35 (0.5 H, t, *J* 8 Hz, CHCO), 3.56 (0.5 H, m, CHN), 3.58 (0.5 H, dd, *J* 10, 6 Hz, CHCO), 3.76 (0.5 H, h, *J* 4.5 Hz, CHN), 4.05, 4.07, 5.01, and 5.06 (each 0.5 H, d, *J* 15 Hz, NC*H*Ph), and 7.2 (10 H, m, aromatic H); *m/z* (E.I.) 335 (M^+, 5%), and 244 (M^+ − 91, base peak).

1,5-*Dibenzyl-3-(1-methoxyiminobutyl)pyrrolidin-2-one* (**13**).—The 3-(1-oxobutyl)pyrrolidin-2-one (**12**) (0.53 g, 2 mmol) was added to the filtrate from *O*-methylhydroxylamine hydrochloride (170 mg, 4 mmol) and sodium acetate (164 mg, 4 mmol) in methanol (10 ml), and the mixture heated under reflux for 3 h. The solvent was removed under reduced pressure, and the residue dissolved in ether (50 ml). The ether extract was washed with aq. $NaHCO_3$ (2 × 10 ml), dried ($MgSO_4$), and concentrated to give an oil, which was chromatographed (ethyl acetate–light petroleum, 2:1) to give a 4:1 mixture of isomers of the O-*methyl oximes* (**13**), as a colourless oil (Found: M^+, 364.2155. $C_{23}H_{28}N_2O_2$ requires *M*, 364.2151); $\nu_{max.}$($CHCl_3$) 1 680, 1 600, 1 500, 1 250, 1 050, and 700 cm^{-1}; $\delta_H(CDCl_3)$ 0.95 (2.25 H, t, *J* 7.5 Hz, CH_3), 0.97 (0.75 H, t, *J* 7.5 Hz, CH_3), 1.5, 2.05, and 2.20 (each 2 H, m, CH_2), 2.63 (1 H, dd, *J* 12, 8 Hz, HC*H*Ph), 3.00 (1 H, dd, *J* 6, 8 Hz, *H*CHPh), 3.25 (1 H, t, *J* 5 Hz, CHCO), 3.70 (1 H, m, CHN), 3.7 (2.25 H, s, OCH_3), 3.8 (0.75 H, s, OCH_3), 3.85 and 5.17 (each 0.75 H, d, *J* 15 Hz, N*H*CHPh), 4.26 and 4.95 (each 0.25 H, d, *J* 15 Hz, N*H*CHPh), and 7.25 (10 H, m, aromatic H); *m/z* (C.I.) 365 (M^+ + H, 20%), 273 (M^+ − 91, 60), and 91 (M^+ − 273, base peak).

1,5-*Dibenzyl-3-(1-methoxyiminobutyl)-3-phenylseleno-pyrrolidin-2-ones* (**14**).—LDA (1.2 ml of a 1M-solution in THF–hexane) was added to the *O*-methyl oximes (**13**) (364 mg, 1 mmol) in THF (10 ml) at −78 °C under nitrogen, followed 20 min later by benzeneselenenyl chloride (200 mg, 1.1 mmol) in THF (2 ml), and the mixture allowed to warm to 0 °C. Aqueous work-up gave an oil which after flash chromatography (ether–

light petroleum, 1:3), gave a mixture of 1,5-*dibenzyl*-3-(1-*methoxyiminobutyl*)-3-*phenylselenopyrrolidin*-2-*ones* (**14**) (312 mg, 61%) (Found: M^+, 518.1637. $C_{29}H_{32}N_2O_2{}^{78}Se$ requires M 518.1638); $\nu_{max.}$($CHCl_3$) 1 685, 1 600, 1 540, 1 200, 1 150, 1 020, and 900 cm^{-1}. Two of the isomers were separated by repeated chromatography: major, δ_H($CDCl_3$) 1.02 (3 H, t, J 7.5 Hz, CH_3), 1.65 (2 H, m, CH_2), 1.98 (1 H, dd, J 15, 7 Hz, HC*H*), 2.44 (2 H, m, 2 × HC*H*), 2.65 and 2.84 (each 1 H, dt, J 5, 11 Hz, HC*H*), 3.05 (1 H, dd, J 4, 12 Hz, HC*H*), 3.42 (1 H, m, CHN), 3.75 (3 H, s, OCH_3), 4.1 and 4.9 (each 1 H, d, J 15 Hz, NHC*H*Ph), and 7.0—7.4 (15 H, m, aromatic H); minor, δ_H($CDCl_3$) 0.92 (3 H, t, J 7.5 Hz, CH_3), 1.53 and 1.97 (each 2 H, m, CH_2), 3.35 (1 H, dt, J 5, 11 Hz, HC*H*), 2.56 (2 H, m, 2 × HC*H*), 2.99 (1 H, dd, J 4, 12 Hz, HC*H*Ph), 3.52 (1 H, m, CHN), 3.72 (3 H, s, OCH_3), 3.99 and 5.07 (each 1 H, d, J 15 Hz, NHC*H*Ph), and 6.9—7.6 (15 H, m, aromatic H).

(E)-1-*Benzyl*-5-*benzylidene*-3-(1-*methoxyiminobutyl*)-Δ^3-*pyrrolin*-2-*one* (**15**).—*m*-Chloroperbenzoic acid (MCPBA) (99 mg, 0.58 mmol) was added to the selenide (**14**) (250 mg, 0.48 mmol) in anhydrous CH_2Cl_2 (15 ml) at 20 °C. After 45 min, aqueous work-up gave an oil which was chromatographed on silica (ether–light petroleum, 1:1) to give 1-*benzyl*-5-*benzylidene*-3-(1-*methoxyiminobutyl*)-Δ^3-*pyrrolin*-2-*one* (**15**) (170 mg, 52%) as an oil (Found: M^+, 360.1836. $C_{23}H_{24}N_2O_2$ requires M, 360.1838); $\nu_{max.}$($CHCl_3$) 1 690, 1 630, 1 500, and 1 050 cm^{-1}; δ_H($CDCl_3$) 0.96 (3 H, t, J 7 Hz, CH_3), 1.57 (2 H, m, CH_2), 2.78 (2 H, t, J 7 Hz, CH_2), 3.98 (3 H, s, OCH_3), 5.0 (2 H, s, NCH_2Ph), 6.47 (1 H, s, vinylic H), 7.25 (10 H, m, aromatic H), and 7.54 (1 H, s, vinylic H); m/z (E.I.) 360 (M^+).

(E)-1-*Benzyl*-5-*benzylidene*-3-(1-*methoxyiminobutyl*)-*pyrrolidin*-2-*one* (**16**).—H_2O_2 (3.4 g of 30%) in water (25 ml) was added to the selenide (**14**) (1.04 g, 2 mmol) in CH_2Cl_2 (40 ml) at −5 °C. After 30 min of vigorous stirring, 20% aqueous sodium bisulphite was cautiously added, and the mixture extracted with CH_2Cl_2. Chromatography (ether–light petroleum, gradient elution) gave a mixture of isomers of (E)-1-*benzyl*-5-*benzylidene*-3-(1-*methoxyiminobutyl*)*pyrrolidin*-2-*ones* (**16**) (410 mg, 56%). Repeated short column chromatography separated the two isomers. Major isomer; $\nu_{max.}$($CHCl_3$) 1 710, 1 650, 1 600, 1 410, 1 350, 1 185, 1 050, and 700 cm^{-1}; δ_H($CDCl_3$) 0.97 (3 H, t, J 7 Hz, CH_3), 1.60, 2.43 and 3.45 (each 2 H, m, CH_2), 3.35 (1 H, dd, J 10, 6 Hz, CHCO), 3.85 (3 H, s, OCH_3), 4.75 and 4.95 (each 1 H, d, J 15 Hz, NHC*H*Ph), 5.77 (1 H, t, J 1 Hz, vinylic H), and 7.25 (10 H, m, aromatic H); m/z (E.I.) 362 (M^+, 40%) and 91 (M^+ − 271, base peak). Minor isomer; $\nu_{max.}$($CHCl_3$) 1 715, 1 670, 1 600, 1 500, 1 415, 1 350, 1 185, 1 050, and 700 cm^{-1}; δ_H($CDCl_3$) 0.99 (3 H, t, J 7 Hz, CH_3), 1.63 and 2.33 (each 2 H, m, CH_2), 3.09 (1 H, ddd, J 15, 6, 2 Hz, HC*H*), 3.30 (1 H, ddd, J 15, 9, 0.5 Hz, *H*CH), 3.70 (1 H, dd, J 8.5, 6 Hz, CHCO), 3.78 (3 H, s, OCH_3) 4.65 and 5.06 (each 1 H, d, J 15 Hz, NHCHPh), 5.77 (1 H, narrow m, vinylic H), and 7.25 (10 H, m, aromatic H).

Methyl 2-*Diethylphosphonohexanoate* (**18**).—Methyl 2-bromohexanoate (2.1 g, 10 mmol) and triethyl phosphite (1.66 g, 10 mmol) were heated at 150 °C for 16 h under nitrogen. Distillation gave methyl 2-diethylphosphonohexanoate (**18**) (2.15 g, 81%), b.p. 129 °C/7 mmHg; $\nu_{max.}$(film) 1 740, 1 256, 1 161, 1 052, 1 025, and 967 cm^{-1}; δ_H($CDCl_3$) 0.89 (3 H, t, J 6.7 Hz, CH_2CH_3), 1.33 (9 H, m, J 7.1 Hz, 2 × OCH_2CH_3 + $CHCH_2$), 1.74—2.05 (3 H, m, $CHCH_2$), 2.95 (1 H, ddd, J 20.5, 10.5, 4 Hz, CHP), 3.75 (3 H, s, OCH_3), and 4.09—4.19 (4 H, m, OCH_2 × 2); m/z (E.I.) 267 (M^+, 3%) and 210 (M^+ − 57, 100).

5-*Benzyl*-1-*benzyloxycarbonyl*-3-*butyl*-Δ^3-*pyrrolin*-2-*one* (**21**).—LDA (2.2 ml of a 1M-solution in THF–hexane) was added to the phosphonate (**18**) (530 mg, 2 mmol) in THF (12 ml) at −40 °C under nitrogen, followed after 30 min by the aldehyde (**19**) (554 mg, 2 mmol) in THF (8 ml). After 10 min at −40 °C, the mixture was allowed to warm to 0 °C. Aqueous work-up gave, after repeated chromatography (ether–light petroleum–CH_2Cl_2, 6:4:1), 5-*benzyl*-1-*benzyloxycarbonyl*-3-*butyl*-Δ^3-*pyrrolin*-2-*one* (**21**) (223 mg, 30%) as an oil (Found: M^+, 363.1835. $C_{23}H_{25}NO_3$ requires M, 363.1834); $\nu_{max.}$($CHCl_3$) 1 775, 1 705, 1 600, 1 380, 1 300, 1 000, 720, and 700 cm^{-1}; δ_H($CDCl_3$) 0.88 (3 H, t, J 7 Hz, CH_3), 1.4 (4 H, m, 2 × CH_2), 2.18 (2 H, m, CH_2), 2.78 (1 H, dd, J 9, 13 Hz, HC*H*Ph), 3.46 (1 H, dd, J 13, 4 Hz, *H*CHPh), 4.70 (1 H, m, CHN), 5.38 and 5.40 (each 1 H, d, J 15 Hz, OCH_2Ph), 6.68 (1 H, d, J 2 Hz, vinylic H), and 7.15 (10 H, m, aromatic H); m/z (E.I.) 363 (M^+, 2%), 304 (M^+ − 59, 70), 260 (M^+ − 103, 80), and 91 (M^+ − 272, 100).

Phenylselenenylation of (5R)-5-*Benzylpyrrolidin*-2-*one* (**6**).—n-Butyl-lithium (24 ml of 1.7M-solution in hexane) was added dropwise to the pyrrolidinone (**6**) (3.44 g, 19.6 mmol) and TMEDA (6 ml, 40 mmol) in THF at 0 °C under nitrogen. After 1 h at 0 °C, the dark red solution was cooled to −78 °C and benzeneselenenyl chloride (4.13 g, 21.6 mmol) in THF added. The mixture was stirred for 15 min and allowed to warm to 0 °C. Aqueous work-up followed by short column chromatography (ether–light petroleum, gradient elution) gave, in order of elution, diphenyl diselenide, the 3,3-bis(phenylseleno)pyrrolidinone (**23**) (900 mg, 11%), and the two mono(phenylseleno)pyrrolidinones (**22a**) and (**22b**) (1.63 g, 25%). These were separated by chromatography, the faster moving fraction being identified as (3S,5S)-5-*benzyl*-3-*phenylselenopyrrolidin*-2-*one* (**22a**); $[\alpha]_D{}^{20}$ +41.3° (*c* 0.525 in $CHCl_3$); $\nu_{max.}$(CCl_4) 3 440, 3 200br, 3 070, 3 040, 1 700, and 692 cm^{-1}; δ_H($CDCl_3$) 2.33 (2 H, m, CH_2), 2.66 (1 H, dd, J 13, 8 Hz, HC*H*Ph), 2.79 (1 H, dd, J 13, 6 Hz, *H*CHPh), 3.65 (1 H, m, CHN), 3.84 (1 H, t, J 6 Hz, CHSe), 6.1 (1 H, br s, NH), and 7.2 (10 H, m, aromatic H); m/z (C.I.) 330, 332 (M^+ + H, 73%), and 232 (M^+ − 97, 99, 100). The slower moving fraction isomer was identified as (3R,5S)-5-*benzyl*-3-*phenylselenopyrrolidin*-2-*one* (**22b**); $[\alpha]_D{}^{20}$ +45.8° (*c* 1.4 in $CHCl_3$); $\nu_{max.}$(CCl_4) 3 440, 3 200, 3 070, 3 040, 1 715, 1 702, and 693 cm^{-1}; δ_H($CDCl_3$) 1.96 (1 H, ddd, J 14, 7.5, 6 Hz, HC*H*), 2.46 (1 H, dd, J 13.5, 8.5 Hz, *H*CHPh), 2.63 (1 H, dd, J 13.5, 6 Hz, HC*H*Ph), 2.74 (1 H, ddd, J 14, 9.5 7.5 Hz, *H*CH), 3.81 (1 H, m, CHN), 3.92 (1 H, dd, J 9.5, 7.5 Hz, CHSe), 6.10 (1 H, br s, NH), and 7.25 (10 H, m, aromatic H); m/z (C.I.) 330, 332 (M^+ + H, 38%). Finally, the starting pyrrolidinone (**6**) (1.7 g, 49%) was recovered.

When the pyrrolidinone (**6**) (277 mg, 1.3 mmol) was treated with n-butyl-lithium (2.3 ml; 1.7M in hexane), TMEDA (0.6 ml, 4 mmol) and benzeneselenenyl chloride (630 mg, 3.3 mmol), as described above, the major product isolated after chromatography was (5S)-5-*benzyl*-3,3-*bis*(*phenylseleno*)*pyrrolidin*-2-*one* (**23**) (140 mg, 22%), m.p. 135.5—138 °C (ether–CH_2Cl_2) (Found: C, 56.7; H, 4.5; N, 3.0. $C_{23}H_{21}NOSe_2$ requires C, 56.9; H, 4.4; N, 2.9%); $[\alpha]_D{}^{20}$ −19.1° (*c* 1.06 in $CHCl_3$); $\nu_{max.}$($CHCl_3$) 3 425, 3 070, 1 700, and 694 cm^{-1}; δ_H($CDCl_3$) 2.21 and 2.48 (each 2 H, m, CH_2), 3.45 (1 H, m, CHN), 5.60 (1 H, br s, NH), and 7.3 (15 H, m, aromatic H); m/z (E.I.) 485, 487 (M^+, 2%), and 328, 330 (M^+ − 157, 100). The unchanged pyrrolidinone (**6**) (78 mg, 34%) and mono(phenylseleno)pyrrolidinones (**22**) (42 mg, 10%) were also isolated.

5-*Benzyl*-3-*heptyl*-3-*phenylselenopyrrolidin*-2-*ones* (**24a**) *and* (**24b**).—n-Butyl-lithium (1.4 ml; 1.7M) was added to a solution of the mono(phenylseleno)pyrrolidinones (**22**) (373 mg, 1.13 mmol) in ether (10 ml) at 0 °C. After 1 h, n-heptyl bromide (215 mg, 1.2 mmol) was added and the mixture allowed to warm to 20 °C. After 14 h, aqueous work-up gave after chromatography (ether–light petroleum, 4:1), 5-*benzyl*-3-*heptyl*-3-*phenylselenopyrrolidin*-2-*one* (**24a**) and (**24b**) (129 mg, 27%) as a

mixture of diastereoisomers in the ratio 3:1 (Found: M^+, 429.1574. $C_{24}H_{31}NO^{80}Se$ requires M, 429.1571); $\nu_{max.}(CCl_4)$ 3 440, 3 200, 3 070, 3 040, 1 714, 1 698, 910, and 694 cm^{-1}; $\delta_H(CDCl_3)$ 0.89 (3 H, t, J 7.5 Hz, CH_3), 1.18—1.60 (10 H, m, 5 × CH_2), 1.82 (2 H, m, CH_2CSe), 1.98 (0.25 H, dd, J 13.5, 7.5 Hz, *H*CHCN), 2.12 (0.75 H, dd, J 15, 5 Hz, *H*CHCN), 2.26 (0.75 H, dd, J 14, 8 Hz, HC*H*Ph), 2.33 (0.25 H, dd, J 14, 6.5 Hz, HC*H*CN), 2.5 (1.5 H, m, *H*CHCN + *H*CHPh), 2.62 (0.25 H, dd, J 13, 8 Hz, HC*H*Ph), 2.80 (0.25 H, dd, J 12.5, 5 Hz, *H*CHPh), 3.54 (0.25 H, m, CHN), 3.69 (0.75 H, m, CHN), 5.7 (0.25 H, br s, NH), 5.89 (0.75 H, br s, NH), and 7.0—7.8 (10 H, m, aromatic H); *m/z* (E.I.) 426, 428 (M^+ − 1, 20%) and 210 (M^+ − 217, 219, base peak). A second product eluted was tentatively identified as 5-benzyl-3-heptylpyrrolidin-2-one (16 mg, 5%), as a mixture of diastereoisomers in the ratio *ca.* 85:15; $\delta_H(CDCl_3)$ 0.91 (3 H, t, J 6.5 Hz, CH_3), 1.22—1.50 (10 H, m, 5 × CH_2), 1.76—2.24 (3.85 H, m, CH_2CHO + CH_2CN), 2.29—2.47 (0.85 H, m, CHCO), 2.62—2.91 (0.3 H, m, CHCN and CHCO), 2.7 (0.85 H, dd, J 13, 9 Hz, HC*H*Ph), 2.82 (0.85 H, dd, J 13, 5 Hz, *H*CHPh), 3.0 (0.15 H, dd, J 12.5, 7 Hz, HC*H*Ph), 3.21 (0.15 H, dd, J 12.5, 3 Hz, *H*CHPh), 3.79 (0.85 H, m, CHN), 3.92 (0.15 H, m, CHN), 5.82 (0.15 H, br s, NH), 5.90 (0.85 H, br s, NH), and 7.3 (5 H, m, aromatic H); *m/z* (C.I.) 274 (M^+ + H, 100%).

5-Benzyl-3-butyl-3-phenylselenopyrrolidin-2-ones (**25a**) *and* (**25b**).—*From* *5-benzyl-3,3-bis(phenylseleno)pyrrolidin-2-one* (**23**). n-Butyl-lithium (1.1 ml of a 1.65M-solution in hexane, 1.81 mmol) was added to a solution of the pyrrolidinone (**23**) (410 mg, 0.85 mmol) in THF (5 ml) at 0 °C under nitrogen. After 1 h, n-butyl iodide (220 mg, 1.19 mmol) in THF (1.5 ml) was added and the solution stirred for 3 h at 0 °C before being allowed to warm to 20 °C. Aqueous work-up followed by flash chromatography gave a mixture of the two diastereoisomers of *5-benzyl-3-butyl-3-phenylselenopyrrolidin-2-ones* (**25a**) and (**25b**) (221 mg, 67%) in the ratio 7:2, not separated as an oil (Found: M^+, 387.1105. $C_{21}H_{25}NO^{80}Se$ requires M, 387.1101); $\nu_{max.}$ (CCl_4) 3 440, 3 200br, 3 065, 3 035, 1 714, 1 698, and 693 cm^{-1}; $\delta_H(CDCl_3)$ 0.92 (3 H, t, J 7 Hz, CH_3), 1.2—1.6 (4 H, m, 2 × CH_2), 1.81 (2 H, m, CH_2), 1.99 (0.22 H, dd, J 13, 7.5 Hz, HC*H*CN), 2.12 (0.78 H, dd, J 15, 5 Hz, *H*CHCN), 2.25—2.55 (2.56 H, m, HC*H*CN and 2 × HC*H*Ph), 2.66 (0.22 H, dd, J 13, 7 Hz, HC*H*Ph), 2.77 (0.22 H, dd, J 13, 6 Hz, *H*CHPh), 3.50 (0.22 H, m, CHN), 3.69 (0.78 H, m, CHN), 6.11 (0.22 H, br s, NH), 6.39 (0.78 H, br s, NH), and 7.0—7.8 (10 H, m, aromatic H); *m/z* (C.I.) 386, 388 (M^+ + H, 20%).

From *5-benzyl-1-(t-butyldimethylsilyl)pyrrolidin-2-one* (**32**). The silylated pyrrolidinone (**32**) (336 mg, 1.16 mmol) in THF (1.5 ml) was added to LDA (2.64 mmol) in THF–hexane (4 ml) at −78 °C under nitrogen. After 50 min, benzeneselenyl chloride (280 mg, 1.46 mmol) in THF (2 ml) was added and the mixture stirred for 35 min and n-butyl iodide (260 mg, 1.41 mmol) in THF added. After a further 1.5 h at −78 °C, the mixture was allowed to warm to 20 °C, and was stirred for 14 h. The reaction mixture was then poured into 3M-aqueous HCl (20 ml), stirred for 30 min, and extracted with ether to give an oil. Flash chromatography gave the pyrrolidinone (**25**) (231 mg, 52%), identical with the sample prepared above.

(5S)-*5-Benzyl-3-heptyl-Δ³-pyrrolin-2-one* (**26**).—Hydrogen peroxide (1 ml of a 2.5% aqueous solution) was added to a briskly stirred solution of the 3-heptylpyrrolidinones (**24a**) and (**24b**) (105 mg, 0.25 mmol) and pyridine (0.05 ml, 0.6 mmol) in CH_2Cl_2 (2 ml) at 0 °C. The mixture was allowed to warm to 20 °C, stirred for 50 min, and a mixture of $NaHCO_3$ (2.5 ml, 10% aqueous solution) and CH_2Cl_2 (7 ml) added. After 30 min, the layers were separated, and the organic layer was washed with 3M-aqueous HCl (10 ml) and brine, and dried ($MgSO_4$). Concentration under reduced pressure gave an oil which was flash chromatographed (ether–methanol, 49:1) to give (5S)-*5-benzyl-3-heptyl-Δ³-pyrrolin-2-one* (**26**) (51 mg, 77%) as an oil (Found: M^+, 271.1939. $C_{18}H_{25}NO$ requires M, 271.1936); $[\alpha]_D^{20}$ +90.6° (*c* 0.46 in CCl_4); $\nu_{max.}$ (CCl_4) 3 465, 3 200br, 3 090, 3 070, 3 040, 1 714, 1 698, 1 642, and 695 cm^{-1}; δ_H ($CDCl_3$) 0.89 (3 H, t, J 7 Hz, CH_3), 1.31 (8 H, m, 4 × CH_2), 1.52 and 2.24 (each 2 H, m, CH_2), 2.72 (1 H, dd, J 13.5, 8.5 Hz, HC*H*Ph), 2.88 (1 H, dd, J 13.5, 6 Hz, *H*CHPh), 4.24 (1 H, m, CHN), 6.53 (1 H, br s, NH), 6.64 (1 H, t, J 1.8 Hz, vinylic H), and 7.3 (5 H, m, aromatic H); *m/z* (E.I.) 271 (M^+, 21%), 180 (M^+ − 91, 90), and 91 (M^+ − 180, 100).

(5S)-*5-Benzyl-3-butyl-Δ³-pyrrolin-2-one* (**27**).—Using the procedure described above for the pyrrolin-2-one (**26**), the 3-butylpyrrolidinones (**25a**) and (**25b**) (204 mg, 0.53 mmol) gave, after flash chromatography (ether), (5S)-*5-benzyl-3-butyl-Δ³-pyrrolin-2-one* (**27**) (85 mg, 70%), as an oil (Found: M^+, 229.1469. $C_{15}H_{19}NO$ requires M, 229.1467); $\nu_{max.}(CCl_4)$ 3 450, 3 250br, 1 712, 1 650, and 700 cm^{-1}; $\delta_H(CDCl_3)$ 0.92 (3 H, t, J 7 Hz, CH_3), 1.35, 1.5, and 2.26 (each 2 H, m, CH_2), 2.69 (1 H, dd, J 13.5, 8 Hz, HC*H*Ph), 2.90 (1 H, dd, J 13.5, 6 Hz, *H*CHPh), 4.24 (1 H, m, CHN), 6.31 (1 H, br s, NH), 6.65 (1 H, t, J 1.9 Hz, vinylic H), and 7.3 (5 H, m, aromatic H); *m/z* (E.I) 229 (M^+, 33%), 138 (M^+ − 91, 90), and 91 (M^+ − 138, 100).

1-Benzoyl-5-benzyl-3-butyl-3-phenylselenopyrrolidin-2-ones (**28a**) *and* (**28b**).—n-Butyl-lithium (0.28 ml of a 1.6M-solution in hexane, 0.46 mmol) was added to the pyrrolidinones (**25a**) and (**25b**) (180 mg, 0.46 mmol) in THF (3 ml) at 0 °C followed, after 10 min, by benzoyl chloride (0.33 ml, 2.84 mmol) in THF (4.7 ml). The mixture was stirred at 0 °C for 50 min and allowed to warm to 20 °C before being concentrated under reduced pressure. The residue was taken up in ether, filtered (Celite), concentrated, and the remaining oil purified by flash chromatography (ether–light petroleum, 2:1) to give a 5:1 mixture of *1-benzoyl-5-benzyl-3-butyl-3-phenylselenopyrrolidin-2-ones* (**28a**) and (**28b**) (206 mg, 91%) as an oil; $\nu_{max.}(CCl_4)$ 3 070, 3 040, 1 800, 1 739, 1 684, 1 351, 1 291, 1 213, and 690 cm^{-1}; $\delta_H(CDCl_3)$ 0.81 (3 H, t, J 7 Hz, CH_3), 1.1—1.8 (6 H, m, 3 × CH_2), 2.14 (1 H, dd, J 15, 3 Hz, HC*H*CN), 2.29 (1 H, dd, J 15, 9.5 Hz, *H*CHCN), 2.79 (0.17 H, dd, J 13, 10.6 Hz, HC*H*Ph), 2.92 (0.83 H, dd, J 13, 9.5 Hz, HC*H*Ph), 3.39 (0.17 Hz, dd, J 13, 3.5 Hz, *H*CHPh), 3.46 (0.83 H, dd, J 13, 3.5 Hz, *H*CHPh), 4.45 (0.17 H, m, C*H*N), 4.69 (0.83 H, m, CHN), and 7.2—8.3 (15 H, m, aromatic H); *m/z* (E.I.) 490, 492 (M^+, 1%).

1-Acetyl-5-benzyl-3-butyl-3-phenylselenopyrrolidin-2-ones (**29a**) *and* (**29b**).—Using the procedure described above, the pyrrolidinones (**25a**) and (**25b**) (86 mg, 0.224 mmol), n-butyl-lithium (0.22 mmol), and acetyl chloride (90 μl, 1.26 mmol) in THF (5 ml) gave, after flash chromatography (ether–light petroleum, 1:3), a 3:1 mixture of *1-acetyl-5-benzyl-3-butyl-3-phenylselenopyrrolidin-2-ones* (**29a**) and (**29b**) (67 mg, 70%), as an oil (Found: M^+, 429.1212. $C_{23}H_{27}NO_2{}^{80}Se$ requires M, 429.1206); $\nu_{max.}(CCl_4)$ 3 075, 3 040, 1 738, 1 704, 1 377, 1 352, 1 275, 1 118, and 699 cm^{-1}; $\delta_H(CDCl_3)$ 0.88 (3 H, m, CH_3), 1.27 (4 H, m, 2 × CH_2), 1.5—2.2 (4 H, m, 2 × CH_2), 2.56 and 2.58 (3 H, s, CH_3CO), 2.73 (0.75 H, dd, J 14, 8 Hz, HC*H*Ph), 2.89 (0.25 H, dd, J 12, 10 Hz, HC*H*Ph), 3.13 (0.75 H, dd, J 14, 4 Hz, *H*CHPh), 3.44 (0.25 H, dd, J 12, 4 Hz, *H*CHPh), 4.4 (1 H, m, CHN), and 7.1—7.7 (10 H, m, aromatic H); *m/z* (C.I.) 428, 430 (M^+, 30%).

(5S)-*1-Benzoyl-5-benzyl-3-butyl-Δ³-pyrrolin-2-one* (**30**).—The phenylselenopyrrolidin-2-ones (**28a**) and (**28b**) (160 mg, 0.33 mmol) were treated with an excess of hydrogen peroxide and pyridine as described above to give, after flash chromatography (ether–light petroleum, 1:3), (5S)-*1-benzoyl-5-benzyl-3-butyl-Δ³-*

pyrrolin-2-one (**30**) (81 mg, 75%), as an oil (Found: M^+, 333.1728. $C_{22}H_{23}NO_2$ requires M^+, 333.1729); $[\alpha]_D^{20}$ +432.1° (*c* 0.79 in $CHCl_3$); $\nu_{max.}$(CCl_4) 3 070, 3 040, 1 738, 1 676, 1 348, 1 305, 1 220, 1 168, and 600 cm^{-1}; δ_H($CDCl_3$) 0.80 (3 H, t, *J* 7 Hz, CH_3), 1.2, 1.35, and 2.07 (each 2 H, m, CH_2), 3.0 (1 H, dd, *J* 13.5, 8 Hz, HC*H*Ph), 3.30 (1 H, dd, *J* 13.5, 3 Hz, *H*CHPh), 5.08 (1 H, m, CHN), 6.79 (1 H, narrow m, vinylic H), and 7.1—7.5 (10 H, m, aromatic H); *m/z* (E.I.) 333 (M^+, 17%) and 105 (M^+ − 228, 100%).

(5S)-1-*Acetyl*-5-*benzyl*-3-*butyl*-Δ^3-*pyrrolin*-2-*one* (**31**).—The phenylselenopyrrolidin-2-ones (**29a**) and (**29b**) (118 mg, 0.275 mmol) were treated with an excess of hydrogen peroxide and pyridine as described above to give, after flash chromatography (ether–light petroleum, 1:6) (5S)-1-*acetyl*-5-*benzyl*-3-*butyl*-Δ^3-*pyrrolin*-2-*one* (**31**) (47 mg, 64%), as an oil (Found: M^+, 271.1575. $C_{17}H_{21}NO_2$ requires *M*, 271.1572); $[\alpha]_D^{20}$ +47.6° (*c* 0.25 in $CHCl_3$); $\nu_{max.}$(CCl_4) 3 070, 3 040, 1 730, 1 700, 1 378, 1 355, 1 290, and 700 cm^{-1}; δ_H($CDCl_3$) 0.89 (3 H, t, *J* 7 Hz, CH_3), 1.25, 1.4, and 2.17 (each 2 H, m, CH_2), 2.57 (3 H, s, CH_3CO), 2.84 (1 H, dd, *J* 13.5, 9 Hz, HC*H*Ph), 3.47 (1 H, dd, *J* 13.5, 3.5 Hz, *H*CHPh), 4.81 (1 H, m, CHN), 6.75 (1 H, narrow m, vinylic H), and 7.1—7.4 (5 H, m, aromatic H).

(5R)-5-*Benzyl*-1-(*t-butyldimethylsilyl*)*pyrrolidin*-2-*one* (**32**).—n-Butyl-lithium (3.7 ml of a 1.6M-solution in hexane, 5.92 mmol) was added dropwise to the pyrrolidinone (**6**) (1.04 g, 5.95 mmol) in THF (25 ml) at 0 °C. After 30 min chloro-t-butyldimethylsilane (0.89 g, 5.9 mmol) in THF (8 ml) was added, and the mixture was allowed to warm to 20 °C and stirred for 14 h. Concentration under reduced pressure followed by trituration with ether gave, after flash chromatography, (5R)-5-*benzyl*-1-(*t-butyldimethylsilyl*)*pyrrolidin*-2-*one* (**32**) (1.37 g, 80%), recrystallized from ether, m.p. 53—56 °C (Found: 70.2; H, 9.2: N, 5.2. $C_{17}H_{27}NOSi$ requires C, 70.5; H, 9.4; N, 4.8%); $[\alpha]_D^{20}$ +63.6° (*c* 0.538 in CCl_4); $\nu_{max.}$(CCl_4) 3 090, 3 070, 3 035, 1 611, 1 650, 1 378, 1 354, 1 295, 1 234, 1 108, 950, and 702 cm^{-1}; δ_H($CDCl_3$) 0.25 and 0.33 (each 3 H, s, $SiCH_3$), 0.92 (9 H, s, CMe_3), 1.8 (2 H, m, CH_2), 2.1 (1 H, dd, *J* 17, 8 Hz, HC*H*), 2.30 (1 H, m, HC*H*), 2.48 (1 H, dd, *J* 13, 10.6 Hz, HC*H*Ph), 2.84 (1 H, dd, *J* 13, 3 Hz, *H*CHPh), 3.73 (1 H, m, CHN), and 7.0—7.3 (5 H, m, aromatic H); *m/z* (C.I.) 290 (M^+ + H, 5%).

(1S,2S,5R,6R,7S)-7-*Benzyl*-8-*benzyloxycarbonyl*-1-*butyl*-2,5-*dimethyl*-8-*azabicyclo*[4.3.0]*non*-3-*en*-9-*one* (**33**).—The Δ^3-pyrrolinone (**21**) (150 mg, 0.41 mmol) and (2*E*,4*E*)-hexa-2,4-diene (100 mg, 1.2 mmol) containing a trace (*ca.* 1 mg) of hydroquinone were heated at 200 °C in a sealed tube under nitrogen for 36 h. Short column chromatography (ether–light petroleum, gradient elution) gave (1S,2S,5R,6R,7S)-7-*benzyl*-8-*benzyloxycarbonyl*-1-*butyl*-2,5-*dimethyl*-8-*azabicyclo*[4.3.0]*non*-3-*en*-9-*one* (**33**) (123 mg, 68%) as an oil (Found: M^+, 445.2615. $C_{29}H_{35}NO_3$ requires *M*, 445.2617); $\nu_{max.}$($CHCl_3$) 3 060, 3 020, 1 780, 1 738, 1 710, 1 600, 1 580, 1 370, 1 280, 1 210, 1 075, 1 005, and 695 cm^{-1}; δ_H(C_6D_6) 0.645 (3 H, d, *J* 7.4 Hz, CH_3), 0.8—1.2 (8 H, m, CH_3 + HC*H* + 2 × CH_2), 1.30 (3 H, d, *J* 7.4 Hz, CH_3), 1.5 (1 H, m, *H*CH), 1.87 (2 H, m, *H*CC=CC*H*), 2.08 (1 H, t, *J* 4.6 Hz, CH), 2.83 (1 H, dd, *J* 4.5, 15 Hz, HC*H*Ph), 3.16 (1 H, dd, *J* 9, 15 Hz, *H*CHPh), 4.05 (1 H, m, CHN), 5.12 and 5.25 (each 1 H, d, *J* 12 Hz, OHC*H*Ph), 5.39 and 5.54 (each 1 H, m, vinylic H), and 7.25 (10 H, m, aromatic H); *m/z* (C.I.) 446 (M^+ + H, 100%), together with unchanged Δ^3-pyrrolinone (**21**) (35 mg).

(1S,2S,5R,6R,7S)-8-*Benzoyl*-7-*benzyl*-1-*butyl*-2,5-*dimethyl*-8-*azabicyclo*[4.3.0]*non*-3-*en*-9-*one* (**34**).—The Δ^3-pyrrolinone (**30**) (38 mg, 0.114 mmol) and an excess of (2*E*,4*E*)-hexa-2,4-diene in anhydrous toluene were heated in a sealed tube at 170—190 °C for 40 h. Short column chromatography then gave (1S,2S,5R,6R,7S)-8-*benzoyl*-7-*benzyl*-1-*butyl*-2,5-*dimethyl*-8-*azabicyclo*[4.3.0]*non*-3-*en*-9-*one* (**34**) (9 mg, 19%) as an oil; $[\alpha]_D^{20}$ +207.9° (*c* 0.19 in $CHCl_3$); $\nu_{max.}$(CCl_4), 3 065, 3 035, 1 737, 1 676, 1 288, 695, and 658 cm^{-1}; δ_H($CDCl_3$) 0.8—1.3 (5 H, m, 2 × CH_2 + *H*CH), 0.91 (3 H, t, *J* 7 Hz, CH_3), 1.02 and 1.15 (each 3 H, d, *J* 7 Hz, CHCH_3), 1.55 (1 H, m, *H*CH), 2.2 (2 H, m, 2 × C*H*CH_3), 2.38 (1 H, t, *J* 4.9 Hz, CH), 3.08 (1 H, dd, *J* 13.5, 3 Hz, HC*H*Ph), 3.19 (1 H, dd, *J* 13.5, 6.5 Hz, *H*CHPh), 4.25 (1 H, m, CHN), 5.69 (2 H, m, vinylic H), and 7.1—7.6 (10 H, m, aromatic H); *m/z* (C.I.) 416 (M^+ + H, 100%), together with unchanged Δ^3-pyrrolinone (**30**) (23 mg, 62%).

(1S,2S,5R,6R,7S)-8-*Acetyl*-7-*benzyl*-1-*butyl*-2,5-*dimethyl*-8-*azabicyclo*[4.3.0]*non*-3-*en*-9-*one* (**35**).—Following the above procedure, the Δ^3-pyrrolinone (**31**) (38 mg, 0.14 mmol) gave (1S,2S,5R,6R,7S)-8-*acetyl*-7-*benzyl*-1-*butyl*-2,5-*dimethyl*-8-*azabicyclo*[4.3.0]*non*-3-*en*-9-*one* (**35**) (17 mg, 34%) as an oil (Found: M^+, 353.2355. $C_{23}H_{31}NO_2$ requires *M*, 353.2355); $[\alpha]_D^{20}$ +123.1° (*c* 0.52 in $CHCl_3$); $\nu_{max.}$($CHCl_3$) 1 727, 1 690, 1 385, and 1 288 cm^{-1}; δ_H($CDCl_3$) 0.8—1.3 (11 H, m, 2 × CH_2 + HC*H* + 2 × CH_3), 1.17 (3 H, d, *J* 7.4 Hz, CHCH_3), 1.54 (1 H, m, *H*CH), 2.15 (3 H, m, HCC=CCH + CH), 2.47 (3 H, s, CH_3CO), 2.90 (1 H, dd, *J* 13.5, 3 Hz, HC*H*Ph), 3.03 (1 H, dd, *J* 13.5, 7 Hz, *H*CHPh), 4.03 (1 H, m, CHN), 5.58 (2 H, m, vinylic H), and 7.1—7.4 (5 H, m, aromatic H); *m/z* (E.I.) 354 (M^+ + 1, 3%), together with unchanged Δ^3-pyrrolinone (**31**) (12 mg, 30%).

(1S,2S,3R,6R,7S)-7-*Benzyl*-1-*butyl*-2,5-*dimethyl*-8-*azabicyclo*[4.3.0]*non*-3-*en*-9-*one* (**36**).—The benzyloxycarbonyl adduct (**33**) (96 mg, 0.2 mmol) was stirred in a mixture of methanol–benzene (6 ml) and 50% aqueous KOH (2 ml) at 20 °C for 3 h. Acidification (HCl) and ether extraction gave an oil which was chromatographed (ether–light petroleum, gradient elution) to give (1S,2S,3R,6R,7S)-7-*benzyl*-1-*butyl*-2,5-*dimethyl*-8-*azabicyclo*[4.3.0]*non*-3-*en*-9-*one* (**36**) (65 mg, 97%) as an oil (Found: M^+, 311.2249. $C_{21}H_{29}NO$ requires *M*, 311.2249); $\nu_{max.}$($CHCl_3$) 3 440, 1 690, 1 600, 1 470, 1 310, 1 265, 980, 800, 740, and 700 cm^{-1}; δ($CDCl_3$) 0.88 (3 H, d, *J* 7.5 Hz, CHCH_3), 0.89 (3 H, m, CH_2CH_3), 1.2—1.7 (5 H, m, 2 × HC*H*), 1.45 (3 H, d, *J* 7 Hz, CHCH_3), 1.65 (1 H, m, *H*CH), 1.89 (1 H, m, C=CC*H*), 2.03 (2 H, m, C=CCH + CH), 2.28 (1 H, dd, *J* 13.5, 7 Hz, HC*H*Ph), 2.69 (1 H, dd, *J* 13.5, 3 Hz, *H*CHPh), 3.11 (1 H, m, CHN), 5.46 and 5.68 (each 1 H, m, vinylic H), 6.5 (1 H, br s, NH), and 7.15 (5 H, m, aromatic H); *m/z* (E.I.) 311 (M^+, 2%) and 220 (M^+ − 91, 40).

(5R)-1-*Benzoyl*-5-*benzylpyrrolidin*-2-*one* (**37**).—The pyrrolidinone (**6**) (780 mg, 4.45 mmol) in THF (4.5 ml) was added to a suspension of NaH (240 mg, 50% dispersion in oil, washed with light petroleum) at 0 °C. After 30 min, benzoyl chloride (685 mg, 4.87 mmol) in THF (2.5 ml) was added, and after a further 30 min the mixture was allowed to warm to 20 °C. Aqueous work-up followed by flash chromatography (ether–light petroleum, 9:1) gave (5R)-1-*benzoyl*-5-*benzylpyrrolidin*-2-*one* (**37**) (950 mg, 76%) as an oil (Found: M^+, 279.1262. $C_{18}H_{17}NO_2$ requires *M*, 279.1259); $[\alpha]_D^{20}$ +164.3° (*c* 0.375 in $CHCl_3$); $\nu_{max.}$(CCl_4) 3 065, 3 040, 1 752, 1 680, 1 295, and 693 cm^{-1}; δ_H($CDCl_3$) 1.95 and 2.15 (each 2 H, m, HC*H*), 2.41 (2 H, m, CH_2), 2.90 (1 H, dd, *J* 13, 8 Hz, HC*H*Ph), 3.30 (1 H, dd, *J* 13, 3 Hz, *H*CHPh), 4.73 (1 H, m, CHN), and 7.2—7.7 (10 H, m, aromatic H); *m/z* (E.I.) 279 (M^+, 15%) and 105 (M^+ − 172, 100).

5-*Benzyl*-1-(*t-butyldimethylsilyl*)-3-(1-*oxopropyl*)*pyrrolidin*-2-*ones* (**38a**) *and* (**38b**).—The *N*-silylated pyrrolidinone (**32**) (2.5 g, 8.1 mmol) in THF (2.5 ml) was added slowly to LDA (17.85 mmol) in THF (20 ml) at −75 °C. After being stirred for 50

min, this solution was added to 1-(1-oxopropyl)imidazole [from 1,1'-carbonyldi-imidazole (1.46 g, 9 mmol) and propanoic acid (0.67 ml, 8.98 mmol) in THF (12 ml)] at −75 °C. After 1 h the mixture was allowed to warm to 0 °C and was poured into 2M-aqueous HCl. Ether extraction gave an oil which was purified by flash chromatography (ether–light petroleum, 1:3) to give *5-benzyl-1-(t-butyldimethylsilyl)-3-(1-oxopropyl)pyrrolidin-2-ones* (**38a**) and (**38b**) (2.0 g, 74%), as a *ca.* 3:2 mixture of diastereoisomers; $\nu_{max.}(CCl_4)$ 3 090, 3 070, 3 035, 1 722, 1 683, 1 375, 1 352, 1 230, and 1 103; $\delta_H(CDCl_3)$ 0.35 and 0.47 (each 1.8 H, s, $SiCH_3$), 0.41 and 0.44 (each 1.2 H, s, $SiCH_3$), 0.97 (5.4 H, s, CMe_3), 1.00 (3.6 H, s, CMe_3), 1.07 (1.8 H, t, *J* 7.5 Hz, CH_3), 1.14 (1.2 H, t, *J* 7.5 Hz, CH_3), 1.9 (1 H, m, HC*H*), 2.4—2.7 (3 H, overlapping m, 3 × HC*H*), 3.0 (2 H overlapping m, 2 × HC*H*), 3.5 (1 H, m, CH), 3.8 (1 H, m, CHN), and 7.1—7.4 (5 H, m, aromatic H); *m/z* (E.I.) 346 (M^+ + 1, 3%) and 288 (M^+ − 57, 100).

5-Benzyl-1-(t-butyldimethylsilyl)-3-(1-oxopropyl)-3-phenylselenopyrrolidin-2-one (**39**).—The pyrrolidinones (**38a**) and (**38b**) (1.6 g, 4.4 mmol) in THF (2.5 ml) were added slowly to LDA (5.27 mmol) in THF (7 ml) at −75 °C. Benzeneselenenyl chloride (1.04 g, 5.4 mmol) in THF (2.5 ml) was added after 35 min, and the mixture then allowed to warm to −5 °C, added to 2M-aqueous HCl and extracted with ether to give a solid which was purified by flash chromatography to afford *5-benzyl-1-(t-butyldimethylsilyl)-3-(1-oxopropyl)-3-phenylselenopyrrolidin-2-one* (**39**) (1.2 g, 55%), recrystallized from pentane, m.p. 109—110 °C (Found: C, 62.4; H, 6.95; N, 3.0. $C_{26}H_{35}NO_2SeSi$ requires C, 62.4; H, 7.05; N, 2.8%); $\nu_{max.}(CCl_4)$ 3 070, 3 040, 1 685, 1 374, 1 352, 1 234, 1 097, and 692 cm^{-1}; $\delta_H(CDCl_3)$ 0.40 and 0.44 (each 3 H, s, CH_3), 1.04 (9 H, s, CMe_3), 1.19 (3 H, t, *J* 7.3 Hz, CH_3), 2.17 (2 H, m, CH_2), 2.63 (1 H, dd, *J* 13.5, 1.2 Hz, HC*H*), 2.81 (2 H, m, 2 × HC*H*), 3.47 (1 H, m, HC*H*), 3.66 (1 H, m, CHN), and 7.1—7.6 (10 H, m, aromatic H); *m/z* (C.I.) 500, 502 (M^+ + H, 50%) and 346 (M^+ − 153, 155, 100).

5-Benzyl-3-(1-oxopropyl)-3-phenylselenopyrrolidin-2-ones (**40a**) *and* (**40b**).—3M-Aqueous HCl (5 ml) was slowly added to the pyrrolidinone (**39**) (310 mg, 0.62 mmol) in THF (5 ml) at 0 °C. The mixture was allowed to warm to 20 °C, stirred for 11 h, and poured into water. Ether extraction and flash chromatography (ether–light petroleum, 2:1) gave *5-benzyl-3-(1-oxopropyl)-3-phenylselenopyrrolidin-2-ones* (**40a**) and (**40b**) (188 mg, 79%), as 1:1 mixture of isomers recrystallized from ether, m.p. 118.5 °C (Found: C, 62.3; H, 5.5; N, 3.6. $C_{20}H_{21}NO_2Se$ requires C, 62.2; H, 5.5; N, 3.6%); $\nu_{max.}(CCl_4)$ 3 430, 1 717, 1 700, and 692 cm^{-1}; δ_H 1.10 and 1.15 (each 3 H, t, *J* 7.2 Hz, CH_3), 1.99 (1 H, dd, *J* 14, 7 Hz, HC*H*), 2.18 (1 H, dd, *J* 15, 6.5 Hz, HC*H*), 2.46 (1 H, dd, *J* 15, 7.5 Hz, HC*H*), 2.59 (2 H, m, 2 × HC*H*), 2.8—3.1 (5 H, overlapping m, 5 × HC*H*), 3.3 (2 H, m, 2 × HC*H*), 3.74 (2 H, m, 2 × CHN), 5.59 (2 H, br s, 2 × NH), and 7.1—7.5 (10 H, m, aromatic H); *m/z* (C.I.) 386, 388 (M^+ + H, 32%).

1-Benzoyl-5-benzyl-3-(1-oxopropyl)-3-phenylselenopyrrolidin-2-ones (**41a**) *and* (**41b**).—Benzoyl chloride (0.5 ml of a 1.43M-solution in benzene) was added to a solution of the *N*-silylated pyrrolidinone (**39**) (360 mg, 0.72 mmol) in benzene (3 ml) and the mixture heated under reflux under argon for 8 h. Concentration under reduced pressure, and flash chromatography (ether–light petroleum 1:4) gave *1-benzoyl-5-benzyl-3-(1-oxopropyl)-3-phenylselenopyrrolidin-2-ones* (**41a**) and (**41b**) as an oily 4:1 mixture of diastereoisomers; $\nu_{max.}(CCl_4)$ 3 070, 3 040, 1 735, 1 695, 1 352, 1 286, 1 220, 908, 692, and 656 cm^{-1}; δ_H ($CDCl_3$) 1.02 (0.6 H, t, *J* 7 Hz, CH_3), 1.10 (2.4 H, t, *J* 7 Hz, CH_3), 1.99 (0.8 H, dd, *J* 14.5, 6.5 Hz, HC*H*), 2.09 (0.2 H, dd, *J* 13, 6 Hz, HCH), 2.29 (1 H, m, HC*H*), 2.49 (0.8 H, dd, *J* 15, 8 Hz, HC*H*Ph), 2.6—2.95 (1.2 H, overlapping m, HC*H*), 3.05—3.35 (2 H, m, HC*H*Ph + HC*H*CH_3), 4.56 (1 H, m, CHN), and 7.05—7.65 (15 H, m, aromatic H); *m/z* (E.I.) 489, 491 (M^+, 1%).

(5S)-*1-Benzoyl-5-benzyl-3-(1-oxopropyl)-Δ³-pyrrolin-2-one* (**42**).—*m*-Chloroperoxybenzoic acid (85 mg, 0.4 mmol) was added slowly to a solution of the pyrrolidinones (**41a**) and (**41b**) (100 mg, 0.2 mmol) in CH_2Cl_2 (1.5 ml) at 20 °C. After 10 min additional stirring the mixture was poured into ice-cold saturated aqueous Na_2CO_3 and extracted with CH_2Cl_2. Concentration under reduced pressure gave (5*S*)-1-benzoyl-5-benzyl-3-(1-oxopropyl)-Δ³-pyrrolin-2-one (**42**) (63 mg, 94%) as a yellow oil which was used without purification; $\nu_{max.}(CCl_4)$ 3 070, 3 040, 1 742, 1 698, 1 679, 1 620, 1 346, 1 297, 1 223, 693, and 644 cm^{-1}; $\delta_H(CDCl_3)$ 1.04 (3 H, t, *J* 7 Hz, CH_3), 2.82 (2 H, q, *J* 7 Hz, CH_2), 3.18 (1 H, dd, *J* 14.5, 8 Hz, HC*H*Ph), 3.49 (1 H, dd, *J* 14.5, 3.5 Hz, *H*CHPh), 5.34 (1 H, ddd, *J* 8, 3.5, 2.5 Hz, CHN), 7.10—7.6 (10 H, m, aromatic H), and 7.99 (1 H, d, *J* 2.5 Hz, vinylic H).

Diels–Alder Reactions of the Δ³-Pyrrolin-2-one (**42**).—*With (2E,4E)-hexa-2,4-diene.* A solution of the Δ³-pyrrolin-2-one (**42**) (205 mg, 0.62 mmol) and (2*E*,4*E*)-hexa-2,4-diene (0.55 ml, 4.82 mmol) in benzene (1.5 ml) was heated to 100 °C in a Carius tube for 8 h. Short column chromatography (ether–light petroleum, 2:7) of the product gave a mixture of *8-benzoyl-7-benzyl-2,5-dimethyl-1-(1-oxopropyl)-8-azabicyclo*[4.3.0]*non-3-en-9-ones* (**43**) and (**45**) (4:1; 177 mg, 69%) as an oil (Found: M^+, 415.2147. $C_{27}H_{29}NO_3$ requires *M*, 451.2149); $\nu_{max.}(CCl_4)$ 3 090, 3 070, 3 040, 1 738, 1 712, 1 681, 1 604, 1 288, 1 216, and 693 cm^{-1}; $\delta_H(CDCl_3)$ 0.73 (0.6 H, d, *J* 7 Hz, CH_3), 0.89 (2.4 H, t, *J* 7 Hz, CH_2CH_3), 1.07 (0.6 H, d, *J* Hz, CH_3), 1.10 (2.4 H, d, *J* 7.2 Hz, CH_3), 1.13 (0.6 H, t, *J* 7.1 Hz, CH_2CH_3), 1.16 (2.4 H, d, *J* 7.1 Hz, CH_3), 1.48 (0.8 H, dq, *J* 19.1, 7 Hz, HC*H*CO), 1.91 (0.2 H, m, HC*H*CO), 2.24—2.74 (2 H, m, *H*CHCO and C*H*CH_3), 2.64 (1 H, dd, *J* 6, 5.4 Hz, 6-H), 2.79 (1 H, m, 2-H), 2.95 (1 H, dd, *J* 13.6, 3.0 Hz, HC*H*Ph), 3.17 (1 H, dd, *J* 13.7, 6.5 Hz, *H*CHPh), 4.39 (1 H, m, CHN), 5.69 (2 H, m, vinylic H), and 7.1—7.7 (10 H, m, aromatic H); *m/z* (C.I.) 416 (M^+ + H, 100%).

With cyclopentadiene. A solution of Δ³-pyrrolin-2-one (**42**) (50 mg, 0.15 mmol) and freshly distilled cyclopentadiene (0.13 ml, 1.57 mmol) in benzene (0.5 ml) was stirred at 20 °C for 3 h. Chromatography gave a mixture of the adducts *2-benzoyl-1-benzyl-3a-(1-oxopropyl)-1,2,3a,4,7,7a-hexahydro-4,7-methanoisoindol-3-ones* (**47**) and (**48**) (Found: M^+, 399.1834. $C_{26}H_{25}NO_3$ requires *M*, 399.1836); $\nu_{max.}(CCl_4)$ 2 980, 1 732, 1 704, 1 687, 1 280, 1 226, 1 140, 692, and 659 cm^{-1}; *m/z* (E.I.) 399 (M^+, 4%). Repeated chromatography partially separated the isomers for n.m.r. characterization. The faster moving product was tentatively identified as the *exo*-adduct (**47**) (15 mg, 26%); $\delta_H(CDCl_3)$ 1.05 (3 H, t, *J* 7 Hz, CH_2CH_3), 1.54 (2 H, m, CH_2), 2.5 (1 H, dq, *J* 19.2, 7 Hz, HC*H*CH_3), 2.55 (1 H, br s, CH), 2.66 (1 H, br s, 6-H), 2.78 (1 H, dd, *J* 12.8, 10.5 Hz, HC*H*Ph), 3.02 (1 H, dq, *H*CHCH_3), 3.35 (1 H, dd, *J* 13, 3.5 Hz, *H*CHPh), 3.49 (1 H, br s, CH), 4.41 (1 H, dt, *J* 10, 3 Hz, CHN), 6.0 and 6.15 (each 1 H, dd, *J* 5.7, 3 Hz, vinylic H), and 7.2—7.6 (10 H, m, aromatic H). The slower moving product was tentatively identified as the *endo*-adduct (**48**) (19 mg, 32%); $\delta_H(CDCl_3)$ 1.05 (3 H, t, *J* 7 Hz, CH_2CH_3), 1.52 (2 H, m, CH_2), 2.7 (2 H, m, CH_2CH_3), 2.82 (1 H, m, 7-H), 2.85 (1 H, dd, *J* 12, 10 Hz, HC*H*Ph), 3.16 (1 H, dd, *J*, 5.5, 3 Hz, 6-H), 3.24 (1 H, dd, *J* 12.5, 3 Hz, HC*H*Ph), 3.35 (1 H, m, 1-H), 4.22 (1 H, dt, *J* 10, 3 Hz, CHN), 6.26 and 6.35 (each 1 H, dd, *J*, 5.5, 3 Hz, vinylic H), and 7.2—7.6 (10 H, m, aromatic H).

7-Benzyl-2,5-dimethyl-1-(1-oxopropyl)-8-azabicyclo[4.3.0]*non-3-en-9-ones* (**44**) *and* (**46**).—50% Aqueous KOH (4 ml) was added dropwise to a solution of the Diels–Alder adducts (**43**) and (**44**) (177 mg, 0.426 mmol) in benzene–methanol

(10 ml, 1:2), and the mixture was stirred briskly for 5 h, then added to 3M-HCl (15 ml), extracted with ether, and subjected to short column chromatography (ether–light petroleum, 1:2) to give two products. The first was identified as (1S,2S,5R,6R,7S)-7-*benzyl*-2,5-*dimethyl*-1-(1-*oxopropyl*)-8-*azabicyclo*[4.3.0]*non*-3-*en*-9-*one* (**44**) (101 mg, 77%), recrystallized from pentane, m.p. 138.5—140 °C (Found: C, 76.8; H, 7.9; N, 4.6. $C_{20}H_{25}NO_2$ requires C, 77.1; H, 8.1; N, 4.5%); $[\alpha]_D^{20}$ +13.1° (*c* 0.282 in CCl_4); $\nu_{max.}$(CCl_4) 3 430, 3 190br, 3 030, 1 707, 1 692, 1 453, 1 378, and 698 cm^{-1}; δ_H($CDCl_3$) 1.03 (3 H, t, *J* 7 Hz, CH_2CH_3), 1.20 and 1.25 (each 3 H, d, *J* Hz, CH_3), 2.32 (1 H, dq, *J* 18.5, 7. Hz, HC*H*CH_3), 2.45 (2 H, m, 6-H + 5-H), 2.55 (1 H, dd, *J* 13.5, 9 Hz, HC*H*Ph), 2.75 (1 H, dq, *J* 18.5, 7 Hz, *H*CHCH_3), 2.94 (1 H, m, 2-H), 3.02 (1 H, dd, *J* 13.5, 3.5 Hz, *H*CHPh), 3.47 (1 H, m, CHN), 5.57 (1 H, br s, NH), 5.64 (1 H, m, vinylic H), 5.74 (1 H, dt, *J* 9, 2 Hz, vinylic H), and 7.15—7.4 (5 H, m, aromatic H); *m/z* (E.I.) 312 (M^+ + 1, 17%). The second was identified as (1S,2R,5S,6R,7S)-7-*benzyl*-2,5-*dimethyl*-1-(1-*oxopropyl*)-8-*azabicyclo*[4.3.0]*non*-3-*en*-9-*one* (**46**) (24 mg, 18%), a colourless oil (Found: M^+, 311.1885. $C_{20}H_{25}NO_2$ requires *M*, 311.1885); $\nu_{max.}$(CCl_4) 3 430, 3 200br, 3 035, 1 709, 1 458, 1 382, and 699 cm^{-1}; δ_H($CDCl_3$) 1.00 (3 H, d, *J* 7 Hz, CH_3), 1.06 (3 H, t, *J* 7 Hz, CH_2CH_3), 1.18 (3 H, d, *J* 7.5 Hz, CH_3), 2.06 (1 H, m, 5-H), 2.24 (1 H, t, *J* 4 Hz, 6-H), 2.46 (1 H, dq, *J* 18.5, 7 Hz, HC*H*CH_3) 2.49 (1 H m, 2-H), 2.59 (1 H, dd, *J* 13.5, 8.5 Hz, HC*H*Ph), 2.78 (1 H, dq, *J* 18.5, 7 Hz, *H*CHCH_3), 2.88 (1 H, dd, *J* 13.5, 5 Hz, *H*CHPh), 3.49 (1 H, m, CHN), 5.63 (2 H, m, vinylic H), 6.08 (1 H, br s, NH), and 7.15—7.35 (5 H, m, aromatic H); *m/z* (E.I.) 312 (M^+ + 1, 60%).

1-*Phenylsulphonylpyrrolidin*-2-*one* (**49**).—n-Butyl-lithium (21.7 ml of a 2.3M-solution in hexane) was added to pyrrolidin-2-one (3.8 ml, 50 mmol) in THF (160 ml) at 0 °C. After 35 min, benzenesulphonyl chloride (7 ml, 54.8 mmol) was added, and the mixture stirred for a further 50 min. Concentration under reduced pressure, and trituration with ether, gave 1-*phenylsulphonylpyrrolidin*-2-*one* (**49**) (7.6 g, 67%), m.p. 83.5—84 °C (ethanol–pentane) (Found: C, 53.3; H, 4.95; N, 6.4; S, 14.3. $C_{10}H_{11}NO_3S$ requires C, 53.3; H, 4.9; N, 6.2; S, 14.2%); $\nu_{max.}$($CHCl_3$) 3 030, 1 742, 1 360, 1 174, 1 123, 960, and 687 cm^{-1}; δ_H($CDCl_3$) 2.09 (2 H, p, *J* 7.5 Hz, CH_2), 2.45 (2 H, t, *J* 7.5 Hz, CH_2CO), 3.92 (2 H, t, *J* 7 Hz, CH_2N), and 7.5—8.1 (5 H, m, aromatic H); *m/z* (E.I.) 226 (M^+ + 1, 4%).

3-(1-*Oxopropyl*)-1-*phenylsulphonylpyrrolidin*-2-*one* (**50**).—The pyrrolidin-2-one (**49**) (1.5 g, 6.7 mmol) in THF (6 ml) was added to LDA (13.6 mmol) in THF (20 ml) at −78 °C, and the mixture stirred for 30 min. The solution was cooled to −100 °C, propionyl chloride (0.65 ml, 7.45 mmol) was added, and the mixture quenched after 20 min by the addition of 3M-aqueous HCl (10 ml). Continuous extraction with CH_2Cl_2 gave an oil which was purified by flash chromatography (ether–light petroleum, 3:1) to give 3-(1-*oxopropyl*)-1-*phenylsulphonylpyrrolidin*-2-*one* (**50**) (1.17 g, 63%), as a pale yellow oil (Found: M^+, 281.0722. $C_{13}H_{15}NO_4S$ requires *M*, 281.0722); $\nu_{max.}$(CCl_4) 3 080, 1 742, 1 721, 1 685, 1 640, 1 453, 1 381, 1 177, 1 094, and 688 cm^{-1}; δ_H($CDCl_3$) 0.99 (3 H, t, *J* 7 Hz, CH_2CH_3), 2.11 (1 H, m, HC*H*), 2.49 (2 H, overlapping m, *H*CH + HC*H*CH_3), 2.86 (1 H, dq, *J* 19, 7 Hz, *H*CHCH_3), 3.61 (1 H, dd, *J* 9, 7 Hz, CHCO), 3.9 (2 H, m, CH_2N), and 7.5—8.1 (5 H, m, aromatic H); *m/z* (E.I.) 281 (M^+, 4%).

3-(1-*Oxopropyl*)-3-*phenylseleno*-1-*phenylsulphonylpyrrolidin*-2-*one* (**51**).—The pyrrolidinone (**50**) (306 mg, 1.09 mmol) in THF (1.5 ml) was added to LDA (1.2 mmol) in THF (2 ml) at −75 °C. After 15 min, benzeneselenenyl chloride (290 mg, 1.51 mmol) was added, and the mixture allowed to warm to 0 °C. Aqueous work-up and flash chromatography (ether–light petroleum, 1:1) gave 3-(1-*oxopropyl*)-3-*phenylseleno*-1-*phenylsulphonylpyrrolidin*-2-*one* (**51**) (298 mg, 63%), m.p. 90 °C (from ether) (Found: C, 52.3; H, 4.65; N, 3.4. $C_{19}H_{19}NO_4SSe$ requires C, 52.3; H, 4.4; N, 3.2%); $\nu_{max.}$($CHCl_3$) 1 728, 1 701, 1 188, 1 174, 1 092, and 688 cm^{-1}; δ_H($CDCl_3$) 1.04 (3 H, t, *J* 7 Hz, CH_2CH_3), 1.88, 2.56, 2.71, 3.05, 3.68, and 3.86 (each 1 H, m, HC*H*), and 7.2—8.2 (10 H, m, aromatic H); *m/z* (E.I.) 435, 437 (M^+, 6%).

3-(1-*Oxopropyl*)-1-*phenylsulphonyl*-Δ³-*pyrrolin*-2-*one* (**52**).—*m*-Chloroperoxybenzoic acid (58 mg, 0.3 mmol) was added slowly to the pyrrolidinone (**51**) (55 mg, 0.14 mmol) in CH_2Cl_2 (1.3 ml) at 20 °C. After 5 min, the mixture was poured into ice–water and extracted into CH_2Cl_2. Concentration under reduced pressure gave 3-(1-*oxopropyl*)-1-*phenylsulphonyl*-Δ³-*pyrrolin*-2-*one* (**52**) (36 mg, 94%), as an oil, used without further purification; $\nu_{max.}$(CH_2Cl_2) 1 735, 1 700, 1 626, 1 374, 1 189, 1 179, and 1 091 cm^{-1}; δ_H($CDCl_3$) 1.07 (3 H, t, *J* 7.2 Hz, CH_2CH_3), 2.88 (2 H, q, *J* 7 Hz, CH_2CH_3), 4.56 (2 H, d, *J* 2 Hz, CH_2N), and 7.5—8.2 (6 H, overlapping m, vinylic and aromatic H).

Diels–Alder Reactions of Δ³-*Pyrrolinone* (**52**).—*With* (2E,4E)-*hexa*-2,4-*diene*. The Δ³-pyrrolinone (**52**) (33 mg, 0.12 mmol) and (2*E*,4*E*)-hexa-2,4-diene (0.4 ml, 3.4 mmol) in CH_2Cl_2 (0.8 ml) were heated at 115 °C for 8.5 h in a Carius tube. Concentration under reduced pressure and flash chromatography (ether–light petroleum, 1:1) gave the Diels–Alder adduct 4,7-*dimethyl*-3a-(1-*oxopropyl*)-2-*phenylsulphonyl*-1,2,3a,4,7,7a-*hexahydroisoindol*-3-*ones* (**53**) and (**54**) (16 mg, 37%) as a mixture in the ratio 6:1 (Found: M^+, 361.1350. $C_{19}H_{23}NO_4S$ requires *M*, 361.1348); $\nu_{max.}$($CHCl_3$) 3 035, 1 731, 1 710, 1 453, 1 370, 1 188, 1 175, and 1 091 cm^{-1}; δ_H($CDCl_3$) 0.72 (0.45 H, d, *J* 7.5 Hz, CH_3), 0.75 (2.55 H, d, *J* 7.5 Hz, CH_3) 0.82 (0.45 H, t, *J* 7.2 Hz, CH_2CH_3), 1.01 (2.55 H, t, *J* 7.2 Hz, CH_2CH_3), 1.09 (2.55 H, d, *J* 7.5 Hz, CH_3), 1.10 (0.45 H, d, *J ca.* 7 Hz, CH_3), 2.42 (1 H, m, 5-H), 2.55 (2 H, q, *J* 7.2 Hz, CH_2CH_3), 2.78 (1 H, m, 2-H), 2.88 (1 H, m, 6-H), 3.42 (0.85 H, t, *J* 10 Hz, CHN), 3.64 (0.3 H, m, CH_2N), 3.92 (0.85 H, dd, *J* 9.5, 8.5 Hz, CHN), 5.3 (0.3 H, m, vinylic H), 5.42 and 5.53 (each 0.85 H, m, vinylic H), and 7.5—8.1 (5 H, m, aromatic H); *m/z* (E.I.) 361 (M^+, 7%).

With cyclopentadiene. The Δ³-pyrrolinone (**52**) (33 mg, 0.12 mmol) and freshly distilled cyclopentadiene (0.6 ml, 7.3 mmol) were dissolved in CH_2Cl_2 (0.5 ml) and the solution heated in a Carius tube at 55 °C for 5 h. Concentration under reduced pressure, and flash chromatography (ether–light petroleum 1:1) gave the *adducts* (**55**) and (**56**) (28 mg, 67%) as a mixture in the ratio 2:1 (Found: M^+, 345.1035. $C_{18}H_{19}NO_4S$ requires *M*, 345.1035); $\nu_{max.}$(CCl_4) 3 075, 1 731, 1 712, 1 382, 1 188, 1 179, 1 130, 1 090, and 688 cm^{-1}; δ_H($CDCl_3$) 0.87 (1 H, t, *J* 7 Hz, CH_2CH_3), 0.95 (2 H, t, *J* 7 Hz, CH_2CH_3), 1.0—1.3 (2 H, m, CH_2), 2.3 (0.34 H, dq, *J* 18, 7 Hz, HC*H*CH_3), 2.65 (1.34 H, m, CH_2CH_3), 2.82 (0.34 H, br s, 7-H), 2.9 (0.34 H, dq, *J* 18, 7 Hz, *H*CHCH_3), 3.0 (0.66 H, br s, 7-H), 3.15 (1 H, m, 6-H), 3.23 (0.66 H, br s, 1-H), 3.25 (0.66 H, dd, *J* 12, 2 Hz, HC*H*N), 3.32 (0.34 H, br s, 1-H), 3.45 (0.34 H, dd, *J* 11, 3 Hz, HC*H*N), 3.87 (0.66 H, dd, *J* 13, 11 Hz, *H*CHN), 4.04 (0.34 H, dd, *J* 11, 12 Hz, *H*CHN), 5.58 and 5.85 (each 0.66 H, m, vinylic H), 5.92 and 6.16 (each 0.34 H, m, vinylic H), and 7.5—8.0 (5 H, m, aromatic H).

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References

1 M. Binder and C. Tamm, *Angew. Chem., Int. Ed. Engl.*, 1973, **12**, 370.
2 J. Auerbach and S. M. Weinreb, *J. Org. Chem.*, 1975, **40**, 3311; R. Brettle and D. P. Cummings, *J. Chem. Soc., Perkin Trans. 1*, 1977, 2385; G. Stork, Y. Nakahara, Y. Nakahara, and W. J. Greenlee, *J. Am. Chem. Soc.*, 1978, **100**, 7775; C. Owens and R. A. Raphael, *J. Chem. Soc., Perkin Trans. 1*, 1978, 1504; D. A. Clark and P. A. Fuchs, *J. Am. Chem. Soc.*, 1979, **101**, 3567; S. G. Pyne, M. J. Hensel, S. R. Byrn, A. T. McKenzie, and P. L. Fuchs, *J. Am. Chem. Soc.*, 1980, **102**, 5960; M. Y. Kim, J. E. Starrett, and S. M. Weinreb, *J. Org. Chem.*, 1981, **46**, 5383; T. Schmidlin, W. Zürcher, and C. Tamm, *Helv. Chim. Acta*, 1981, **64**, 235; S. G. Pyne, M. J. Hensel, and P. L. Fuchs, *J. Am. Chem. Soc.*, 1982, **104**, 5719; S. G. Pyne, D. C. Spellmeyer, S. Chen, and P. L. Fuchs, *J. Am. Chem. Soc.*, 1982, **104**, 5728; R. Brettle and I. A. Jafri, *J. Chem. Soc., Perkin Trans. 1*, 1983, 387.
3 S. J. Bailey, E. J. Thomas, W. B. Turner, and J. A. J. Jarvis, *J. Chem. Soc., Chem. Commun.*, 1978, 474; S. J. Bailey, E. J. Thomas, S. M. Vather, and J. Wallis, *J. Chem. Soc., Perkin Trans. 1*, 1983, 851.
4 G. Stork and E. Nakamura, *J. Am. Chem. Soc.*, 1983, **105**, 5510.
5 E. Vedejs and R. C. Gadwood, *J. Org. Chem.*, 1978, **43**, 376; E. Vedejs, J. B. Campbell, R. C. Gadwood, J. D. Rodgers, K. L. Spear, and Y. Watanabe, *J. Org. Chem.*, 1982, **47**, 1534; E. Vedejs, M. J. Arnost, J. M. Eustache, and G. A. Kraft, *ibid*, p. 4384.
6 V. Bocchi, L. Chierici, and G. P. Gardini, *Tetrahedron*, 1970, **26**, 4073; J. K. Baker and S. Sifniades, *J. Org. Chem.*, 1979, **44**, 2798.
7 T. Schmidlin and C. Tamm, *Helv. Chim. Acta*, 1980, **63**, 121.
8 C. C. Tseng, S. Terashima, and S.-I. Yamada, *Chem. Pharm. Bull.*, 1977, **25**, 29.
9 E. Nakamura, *Tetrahedron Lett.*, 1981, 663; G. Stork and R. Matthews, *Chem. Commun.*, 1970, 445.
10 K. Hirai, Y. Iwano, and K. Fujimoto, *Tetrahedron Lett.*, 1982, **34**, 4021.
11 T. N. Salzmann, R. W. Ratcliffe, B. G. Christensen, and F. A. Bouffard, *J. Am. Chem. Soc.*, 1980, **102**, 616.
12 M. Sakakibara and M. Matsui, *Agric. Biol. Chem.*, 1973, **37**, 1139.

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