SYNTHESIS AND CHARACTERIZATION OF PYRROLINONECARBOXYLATES FORMED BY REACTION OF VICINAL TRICARBONYL DERIVATIVES WITH ALDEHYDE SCHIFF BASES

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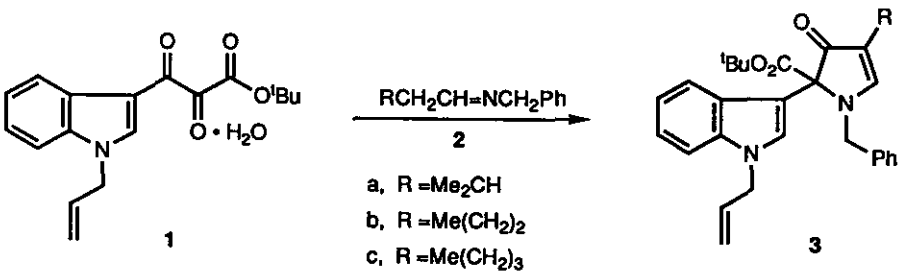
Abstract- A series of vicinal tricarbonyl derivatives undergo reaction with aldehyde Schiff bases forming pyrrolinone derivatives by benzilic acid-related rearrangements. The structures were established by X-ray analyses and, independently by the SESAMI NMR-based computer program.

The central carbonyl group of the 1,2,3-vicinal tricarbonyl system is a highly reactive electrophilic site capable of bond formation with a variety of donor species. We have previously demonstrated the utility of this aggregate in the formation of fused ring β-lactams,[1] and alkaloids in the isoquinoline,[2] indole,[3] erythrina[4] and eudistomin[5] series.

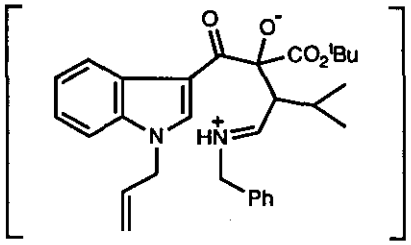
Among the transformations which we have studied in the course of this work, the reactions of aldehyde Schiff bases with tricarbonyl derivatives have attracted particular attention because of the unusual rearrangements accompanying the formation of the pyrrolinone products.

Dedicated to Professor Edward C. Taylor on the occasion of his 70th birthday.



Our first experience with this rearrangement involved the reaction of the N-allylindolyl tricarbonyl ester (**1**) with the Schiff base (**2a**) derived from isovaleraldehyde and benzylamine. We had originally expected attack of the imine (**2a**) at the central carbonyl group, either at nitrogen or, as shown in Figure 1, through the tautomeric enamine form to yield an electrophilic addition product, susceptible to attack by the indolyl residue.[6a] It became apparent, however, that the product resulting from the coupling with loss of a molecule of water was formed by a more complex process. Although our nmr studies and mass spectroscopic analysis did not provide definitive answers, we were able to obtain an X-ray determination which showed that the pyrrolinone (**3**) had formed.[6b, 9] An independent determination of structure was carried out by Munk and coworkers who analyzed this product using the battery of nmr tests developed in their SESAMI program. The results of this study which are in agreement with the X-ray analysis are detailed in a separate section of this paper.

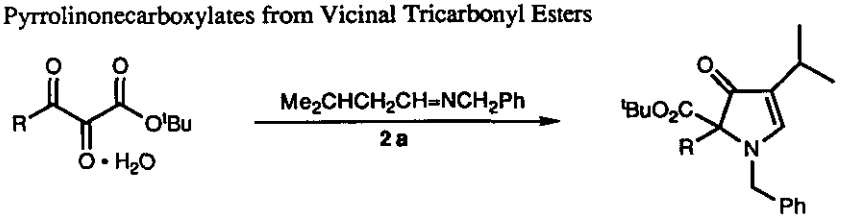
Figure 1

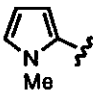


In further studies we have found that this rearrangement takes place generally to form the 3-pyrrolinone system with a range of tricarbonyl derivatives (**4-10**) as outlined in Table 1. All reactions of this series were conducted with Schiff base (**2a**).

The 3-pyrrolinone system so formed is of special interest as a subunit of the antitumor antibiotics, the duocarmycins.[7] In earlier work we have found that this unit may be produced from 3-hydroxypyrrole-2-carboxylates by NaH-promoted alkylation at the 2-position.[8]

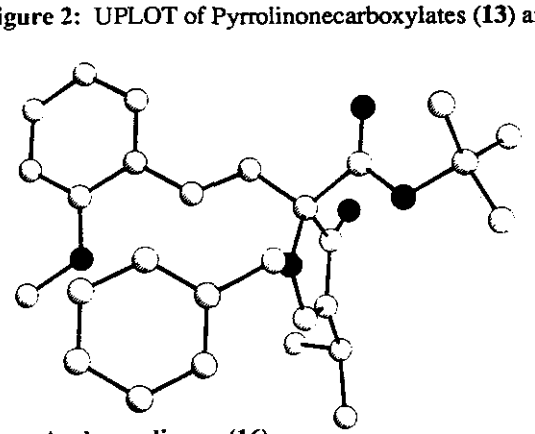
Table 1: Pyrrolinonecarboxylates from Vicinal Tricarbonyl Esters



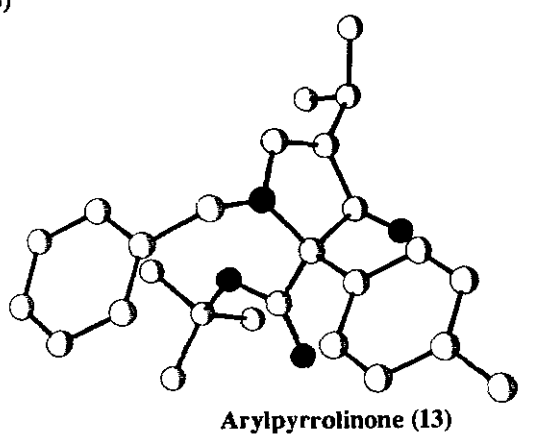
Vicinal Tricarbonyl	Pyrrolinone Carboxylate	Yield(%)
4, R = Ph	**12**, R = Ph	(59)
5, R = 4-MeC_6H_4	**13**, R = 4-MeC_6H_4	(54)
6, R = 4-$MeOC_6H_4$	**14**, R = 4-$MeOC_6H_4$	(63)
7, R = 4-$Me_2NC_6H_4$	**15**, R = 4-$Me_2NC_6H_4$	(61)
8, R = 2-$MeOC_6H_4CH$=CH	**16**, R = 2-$MeOC_6H_4CH$=CH	(53)
9, R = t-Bu	**17**, R = t-Bu	(58)
10, R = 	**18**, R = 	(71)
11, R = 4-$O_2NC_6H_4$	**19**, R = 4-$O_2NC_6H_4$	(2)

As reported in our earlier communication,[9] the vicinal tricarbonyl esters (**4-11**) were treated with two equivalents of imine (**2a**) in benzene at room temperature for 2-48 hours. In all cases studied, with the exception of t-butyl 2,3-dioxo-3-(4-nitrophenyl)propionate monohydrate (**11**), the pyrrolinonecarboxylates were the only products isolated in yields ranging from 53-71%. Derivatives (**13**) and (**16**) were obtained as crystalline solids and X-ray analysis confirmed the formation of the pyrrolinone nucleus (Figure 2).

Figure 2: UPLOT of Pyrrolinonecarboxylates (**13**) and (**16**)

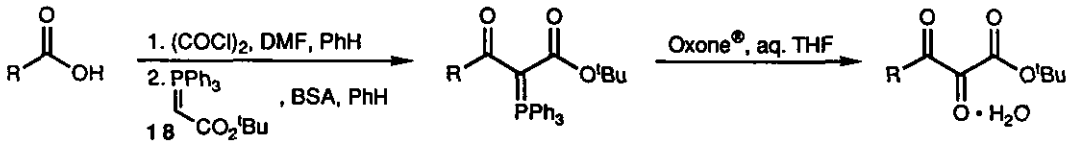


Arylpyrrolinone (16)



Arylpyrrolinone (13)

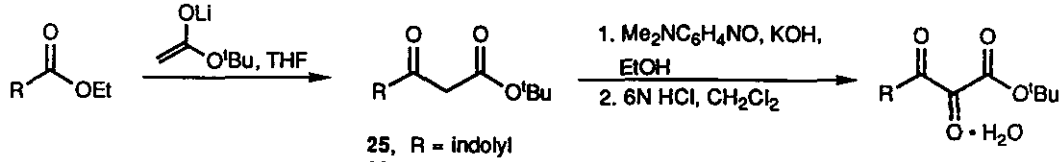
The tricarbonyl monohydrates, with the exception of (**1**, **7** and **10**) were prepared from the corresponding carboxylic acids using the acylphosphorane route (Scheme 1).[10] Coupling of the appropriate carboxylic acid chloride with t-butyl (triphenylphosphoranylidene)acetate (**18**) in the presence of the proton scavanger bis(trimethylsilyl)acetamide (BSA) gave the keto ylide intermediates (**19-24**) which, on reaction with Oxone®,[11] led to the desired tricarbonyls.



19, R = Ph
20, R = 4-MeC_6H_4
21, R = 4-$MeOC_6H_4$
22, R = 2-$MeOC_6H_4CH$=CH
23, R = t-Bu
24, R = 4-$O_2NC_6H_4$

Scheme 1

In the formation of tricarbonyls (**1**, **7** and **10**) by the above sequence, oxidative cleavage with either singlet oxygen, ozone or Oxone® were unsuccessful, presumably due to conflicting oxidation with the electron-rich aromatic system. The tricarbonyl starting materials were therefore prepared according to the Sachs' procedure (Scheme 2).[12] By this route, a Claisen condensation reaction afforded the intermediate β-keto esters (**25-27**) followed by oxidation with N, N-dimethyl-4-nitrosoaniline and subsequent acid hydrolysis to furnish the desired tricarbonyls.



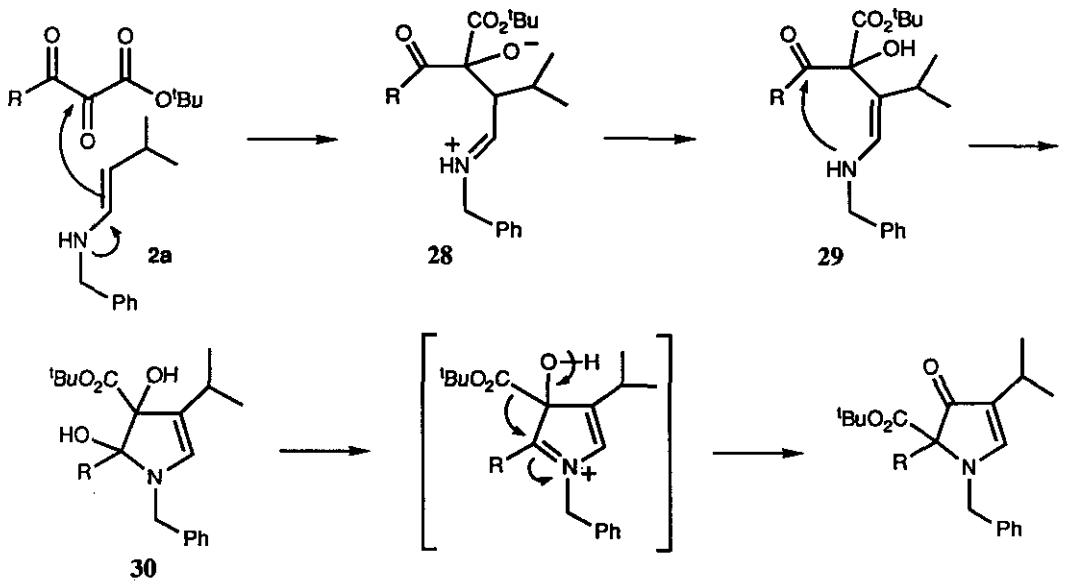
25, R = indolyl
26, R = 4-$Me_2NC_6H_4$
27, R = pyrryl

Scheme 2

We suggest that the formation of pyrrolinonecarboxylate derivatives in this process takes place through the intermediate (**28**), formed by attack of the enamine tautomer of the Schiff base at the central carbonyl group

(Scheme 3). Proton transfer leading to **29** followed by cyclization to **30** then sets the stage for an iminium-ion driven benzilic acid type of rearrangement, yielding the observed products.[13]

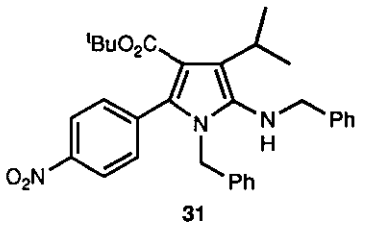
This rearrangement with acyl group migration has precedent in benzylic acid rearrangements observed in studies on FK506.[14]

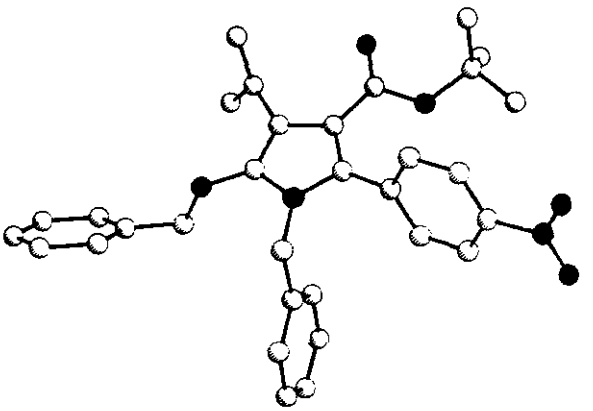


Scheme 3

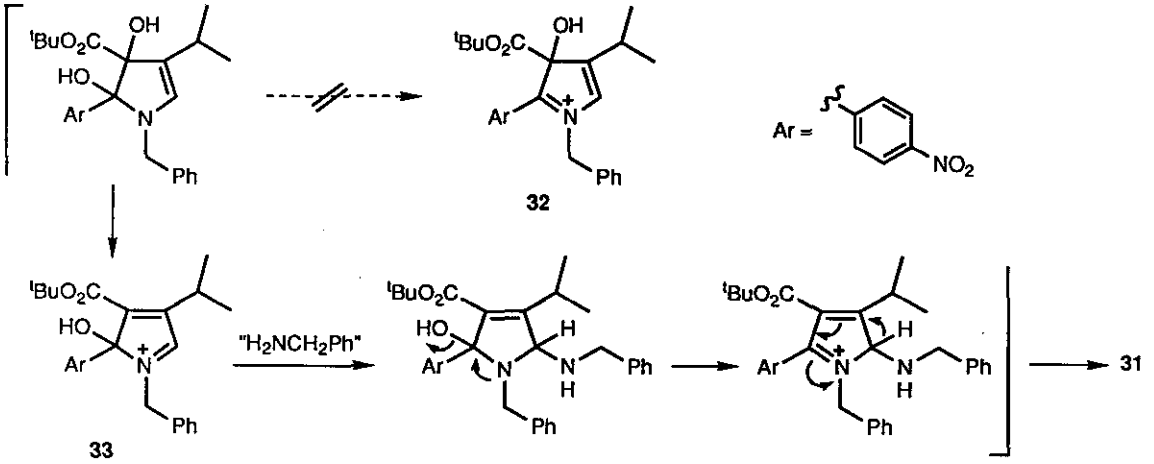
A different result was obtained with tricarbonyl (**11**). As shown in Table 1, treatment of **11** with Schiff base (**2a**) according to the general method gave pyrrolinonecarboxylate (**17**) in only 2% yield. The major product isolated in 68% yield was the tetrasubstituted pyrrole (**31**), as confirmed by an X-ray crystal structure (Figure 3).

Figure 3: UPLOT of Tetrasubstituted Pyrrole (**31**)





Examination of the reaction pathway described in Scheme 3 suggests that cyclic diol (**30**) could be a common intermediate in the formation of either pyrrolinonecarboxylate or tetrasubstituted pyrrole. In the case of ester (**11**), formation of the iminium ion leading to a benzilic acid type rearrangement is disfavoured since **32** would be expected to be destabilized by the para-nitro substituent. It is, however, feasible for an alternative pyrrolinium ion (**33**) to form (Scheme 4). Now, ester-migration to a pyrrolinone product is no longer possible. Instead, benzylamine (regenerated in the dehydration step by hydrolysis of the second equivalent of Schiff base (**2a**)) could attack the iminium ion (**33**), and this process would be followed by aromatization to the pyrrole (**31**).



Scheme 4

In accord with this view we have observed that addition of butylamine to the reaction of tricarbonyl (**11**) with imine (**2a**) results in competitive incorporation of a butylamine residue at the 2-position of the pyrrole.

Computer-Based Characterization of Rearrangement Product 3

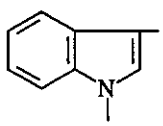
SESAMI is a family of linked computer programs which is being developed to enhance the productivity of the chemist involved in the elucidation of the structure of complex organic compounds.[15] Its function is to directly reduce the collective spectroscopic properties of an unknown to one or more plausible molecular structures consistent with those data. Although SESAMI is an experimental program still under development, it already possesses some problem solving capabilities. Currently, SESAMI is largely an nmr-based system which interprets both 1-D and 2-D nmr data. Software for the interpretation of other spectral data is under development. The program is interactive and can accept any structural information known to the chemist from whatever the source.

The input to SESAMI includes the molecular formula of the rearrangement product, its 1-D ^{1}H and ^{13}C nmr spectral data shown in Table 2 and atom correlations derived from COSY (hydrogen-hydrogen correlations), HETCOR/HMQC (one-bond hydrogen-carbon correlations) and HMBC (long-range hydrogen carbon correlations) 2-D nmr experiments (Table 3). SESAMI recognizes the presence of symmetry in the unknown (fewer carbon signals than carbon atoms) and generates structures compatible with this information.

Input of spectral data is facilitated by a user-friendly keyboard entry system. Input of the 2-D nmr data consists simply of the chemical shifts of coupled signals, element type and the minimum and maximum number of intervening bonds. In Table 3 hydrogen-hydrogen correlations have been entered first, one-bond hydrogen-carbon correlations next, and long-range hydrogen-carbon correlations last. Note that in some cases the number of intervening bonds is not precisely defined. Although the COSY experiment largely detects vicinally coupled hydrogen atoms (geminal relationships are revealed by the HETCOR/HMQC experiments, i.e., hydrogens coupled to the same carbon atom), if one or both hydrogens are alkenyl or aromatic, the observed coupling could also be occurring through 4 or 5 bonds. ^{1}H Nmr signals with chemical shifts greater than δ 4.25 ppm may be of that type and therefore the number of possible intervening bonds is extended to 5 for each correlation involving such a signal, e.g., see Table 3, lines 1-8.

2-D Nmr experiments giving rise to long-range hydrogen-carbon correlations (e.g., HMBC) generally do not precisely define the number of intervening bonds. It is usually 2 or 3, but it can be 4, especially where alkenyl/aromatic hydrogens are possible. Therefore, a 2 to 4 rather than a 2 to 3 intervening bond range is used for correlations involving hydrogen signals of chemical shift greater than δ 4.25 ppm.

The interactive nature of SESAMI can be used to advantage in solving this structure problem. It is a reasonable assumption that the indole moiety and the benzyl-bearing nitrogen atom shown below, which are present in the



Ph–CH_2–N–

reactants leading to the rearrangement product, will survive the reaction conditions intact. These substructures have been provided to SESAMI as user-derived constraints.

Given the molecular formula, the 1-D and 2-D nmr data, and the two user-entered substructures as the only input, SESAMI produces a single structure which is identical to that derived by means of X-ray determination. The user of SESAMI has the assurance that no equally compatible structural assignment has been overlooked

since the program has no preconceived ideas about the nature of the correct structure and no intrinsic limitations on the types of structures generated.

Table 2: 1-D ^{1}H and ^{13}C-Nmr Data for Compound (3)

^{13}C-Nmr		^{1}H-Nmr			
Shift (ppm)	Mult.	Shift (ppm)	Integral	Coupling Mult.	J
195.27	S	7.52	1	S	
165.19	S	7.49	1	S	
160.05	D	7.33	1	D	6.9 Hz
136.45	S	7.29	1	D	6.9 Hz
135.69	S	7.24	1		
133.29	D	7.23	2		
129.91	D	7.18	1	T	7.8 Hz
129.24	D	7.06	2		
128.60	D	7.03	1	T	7.8 Hz
127.89	D	6.02	1	8	7.7 Hz
126.52	S	5.22	1	D	9.5 Hz
121.87	D	5.13	1	D	17.6 Hz
120.00	D	4.72	2	D	5.4 Hz
119.71	D	4.38	1	D	14.3 Hz
117.62	T	4.18	1	D	14.3 Hz
117.18	S	2.74	1	7	6.4 Hz
109.91	D	1.48	9	S	
107.60	S	1.15	3	D	7.2 Hz
82.87	S	1.12	3	D	7.2 Hz
77.74	S				
50.85	T				
49.09	T				
27.94	Q				
23.25	D				
22.30	Q				
22.13	Q				

Table 3: 2-D Nmr Correlations for Compound (3)

Signal 1[a]	Signal 2[a]	Min.[b]	Max.[c]
H 7.18	H7.29	3	5
H 7.03	H7.33	3	5
H 7.03	H7.18	3	5
H 5.22	H6.02	3	5
H 5.13	H6.02	3	5
H 4.72	H6.02	3	5
H 4.72	H5.13	3	5
H 4.72	H5.22	3	5
H 1.15	H2.74	3	3
H 1.12	H2.74	3	3

Table 3: 2-D Nmr Correlations for Compound (3) (Continued)

C160.05	H7.52	1	1
C133.29	H6.02	1	1
C129.91	H7.49	1	1
C129.24	H7.06	1	1
C128.60	H7.24	1	1
C127.89	H7.23	1	1
C121.87	H7.18	1	1
C120.00	H7.33	1	1
C119.71	H7.03	1	1
C117.62	H5.22	1	1
C117.62	H5.13	1	1
C109.91	H7.29	1	1
C 50.85	H4.38	1	1
C 50.85	H4.18	1	1
C 49.09	H4.72	1	1
C 27.94	H1.48	1	1
C 23.25	H2.74	1	1
C 22.30	H1.12	1	1
C 22.13	H1.15	1	1
C195.27	H7.49	2	4
C195.27	H2.74	2	3
C160.05	H4.38	2	4
C160.05	H4.18	2	4
C160.05	H2.74	2	3
C136.45	H7.49	2	4
C136.45	H7.33	2	4
C136.45	H7.18	2	4
C136.45	H4.72	2	4
C135.69	H4.38	2	4
C135.69	H4.18	2	3
C133.29	H4.72	2	4
C129.91	H4.72	2	4
C129.24	H4.38	2	4
C129.24	H4.18	2	3
C126.52	H7.49	2	4
C126.52	H7.29	2	4
C126.52	H7.03	2	4
C121.87	H7.33	2	4
C117.18	H7.52	2	4
C117.18	H2.74	2	3
C117.18	H1.15	2	3
C117.18	H1.12	2	3
C109.91	H7.03	2	4
C107.60	H7.49	2	4
C107.60	H7.33	2	4
C 82.87	H1.48	2	3
C 77.74	H7.52	2	4
C 77.74	H4.38	2	4
C 77.74	H4.18	2	3
C 50.85	H7.52	2	4
C 49.09	H7.49	2	4
C 49.09	H6.02	2	4
C 49.09	H5.13	2	4
C 23.25	H7.52	2	4
C 22.30	H2.74	2	3
C 22.30	H1.15	2	3
C 22.13	H2.74	2	3
C 22.13	H1.12	2	3

[a]Element, chemical shift (ppm). [b]Minimum number of intervening bonds.
[c]Maximum number of intervening bonds.

EXPERIMENTAL

General. ^{1}H Nmr spectra were recorded on a Bruker WM 250 spectrometer operating at 250 MHz. The 1-D ^{1}H nmr, 1-D ^{13}C nmr and 2-D nmr spectra of compound (3) were recorded in $CDCl_3$ on a 500 MHz Varian Unity Spectrometer. Ir spectra were recorded on a Perkin-Elmer 1420 spectrophotometer. Mass spectra were recorded on a Kratos MS 80RFA spectrometer. Microanalyses were performed by Atlantic Microlab Inc., Georgia. Methylene chloride, benzene, ethyl acetate and hexane were distilled from calcium hydride before use; THF was distilled from sodium-benzophenone (note: in reactions with Oxone®, use of distilled THF was detrimental to the product yield). Commercial nitrogen was used to provide an inert atmosphere in appropriate reactions. Mp were recorded on a Hoover capillary melting point apparatus and are uncorrected.

t-Butyl (Triphenylphosphoranylidene)acetate (18)

Triphenylphosphine (9.58 g, 37 mmol) and *t*-butyl chloroacetate (5.0 g, 33 mmol) in benzene (50 ml) were heated under reflux for 48 h. The salt was collected by suction-filtration and washed with ether (50 ml).

The ylide salt (12.49 g, 30 mmol) was dissolved in water (250 ml) and cooled in an ice bath. A solution of potassium hydroxide (1.9 g, 33 mmol) in water (50 ml) was added to the salt and the reaction stirred at 0 °C for 5 min. The aqueous solution was then washed with methylene chloride (3 x 30 ml), the organic extracts combined, dried over $MgSO_4$ and the solvent removed in vacuo. The resultant yellow oil was triturated with ether and evaporated to give the ylide (**18**) (10.26 g, 90%) as a colorless solid, mp 149-151 °C (lit.,[16] mp 151-152 °C); ^{1}H nmr (250 MHz, $CDCl_3$) 7.65 (m, 6H), 7.52 (m, 3H), 7.45 (m, 6H), 2.67 (br s, 1H), 1.21 (br s, 9H) ppm; ir (KBr), 3070, 2920, 1650, 1440, 1169 and 705 cm^{-1}.

t-Butyl 3-Oxo-3-(N-allylindolyl-3-)propanoate (25)

Indole-3-carboxylic acid (1.61 g, 10 mmol) was treated with pyridine (0.87 g, 11 mmol) and oxalyl chloride (1.4 g, 11 mmol) in THF (60 ml) at 0 °C. After evolution of gas had ceased, an excess of absolute ethanol (20 ml) was added. The reaction mixture was allowed to reach ambient temperature, then diluted with methylene chloride (100 ml) and poured into water (100 ml). The organic layer was washed with 1N HCl (2 x 50 ml), saturated $NaHCO_3$ (50 ml) and brine (2 x 50 ml), dried ($MgSO_4$) and concentrated in vacuo to give the ester (1.87 g, 98%) as a colorless solid, mp 96-97 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 9.25 (br s, 1H), 8.22 (m, 1H), 7.90 (s, 1H), 7.47 (m, 1H), 7.30 (m, 2H), 4.44 (q, J = 7.0 Hz, 2H), 1.40 (t, J = 7.0 Hz, 3H) ppm; ir ($CDCl_3$), 3490, 1690 and 1190 cm^{-1}; ms (70 eV) 189 (M^+, 46%), 161 (15), 144 (100) and 117 (9); HRms for $C_{11}H_{11}NO_2$: Calcd 189.0790. Found 189.0802.

To a solution of allyl bromide (1.32 g, 11 mmol) and sodium hydride (1.2 g, 50 mmol, 60% dispersion in oil) in THF (20 ml) at 0 °C was added, dropwise, a solution of the ester (1.89 g, 10 mmol) in THF (50 ml). The reaction mixture was allowed to reach ambient temperature and stirring was continued for 8 h. Cold, dilute HCl was then added cautiously. The reaction mixture was diluted with methylene chloride (250 ml) and the organic phase washed with 1N HCl (50 ml), saturated $NaHCO_3$ (50 ml), brine (50 ml), dried ($MgSO_4$) and concentrated in vacuo. Chromatography (silica gel, hexane/ether, 9/1) gave the protected indole ester (1.32 g, 58%) as a yellow oil; ^1H nmr (250 MHz, $CDCl_3$) 8.31 (m, 1H), 7.84 (s, 1H), 7.41 (m, 3H), 6.03 (m, 1H), 5.19 (m, 2H), 4.68 (d, J = 5.0 Hz, 2H), 4.35 (q, J = 7.0 Hz, 2H), 1.41 (t, J = 7.0 Hz, 3H); ir ($CDCl_3$), 3050, 1700 and 1200 cm^{-1}; ms (70 eV) 229 (M^+, 100%), 214 (6), 200 (17), 184 (54) and 156 (49); HRms for $C_{14}H_{15}NO_2$: Calcd 229.1104. Found 229.1100.

To a solution of LDA (17.4 mmol) in THF (100 ml) at -78 °C was added *t*-butyl acetate (2.02 g, 17.4 mmol). The mixture was stirred at this temperature for 0.5 h, after which time, it was transferred via cannula into a solution of protected indole (1.32 g, 5.8 mmol) in THF (60 ml). The reaction mixture was then stirred at 0 °C for 1 h. The reaction was diluted with methylene chloride (250 ml), the organic layer washed with 1N HCl (2 x 75 ml) and saturated $NaHCO_3$ solution (75 ml), dried ($MgSO_4$) and the solvent removed in vacuo. Column chromatography (silica gel, hexane/ether, 3/1) gave β-keto ester (**25**) (0.87 g, 50%) as a colorless solid, mp 72-73 °C; ^1H nmr (250 MHz, $CDCl_3$) 8.40 (m, 1H), 7.79 (s, 1H), 7.32 (m, 3H), 6.04 (m, 1H), 5.23 (m, 2H), 4.77 (s, 2H), 4.75 (d, J = 5.0 Hz, 2H), 1.45 (s, 9H); ir ($CDCl_3$), 3020, 2359, 1725, 1652, 1527 and 1195 cm^{-1}; ms (70 eV) 299 (M^+, 49%), 243 (14), 199 (25) and 184 (100); HRms for $C_{18}H_{21}NO_3$: Calcd 299.1522. Found 299.1530.

t-Butyl 2,3-Dioxo-3-(N-allylindolyl-3-)propionate Monohydrate (1)

β-Keto ester (**25**) (0.3 g, 1 mmol) was treated with N, N-dimethyl-4-nitrosoaniline (0.15 g, 1 mmol) and an ethanolic solution of KOH (4 mg, 10 mol %) in ethanol (10 ml) at 25 °C for 48 h. The solvent was then removed in vacuo affording the corresponding imine (0.21 g, 48%) as an orange solid, mp 165-166 °C, which was used without further purification.

The imine was then treated with 6N HCl (15 ml) in methylene chloride (10 ml) at 0 °C. The aqueous phase immediately turned bright yellow, and after 5 min was partially replaced with fresh 6N HCl (10 ml). This process was repeated until the organic phase changed in color from deep red to yellow/green. The organic layer was then washed with 1N HCl (5 x 20 ml), saturated $NaHCO_3$ solution (20 ml), brine (25 ml), dried ($MgSO_4$) and the solvent evaporated to give tricarbonyl monohydrate (**1**) (0.13 g, 100%) as a dark yellow solid, mp 95-96

°C; ^{1}H nmr (250 MHz, $CDCl_3$) 8.44 (m, 1H), 8.30 (s, 1H), 7.38 (m, 3H), 6.02 (m, 1H), 5.66 (br s, 2H), 5.25 (m, 2H), 4.82 (d, J = 5.0 Hz, 2H), 1.64 (s, 9H) ppm; ir (CDCl3) 3050, 1750, 1660, 1540 and 1250 cm^{-1}; ms (70 eV) 313 (M^+-H_2O, 2%), 184 (100) and 57 (2); HRms for $C_{18}H_{19}NO_4$: Calcd 313.1315. Found 313.1305.

t-Butyl 2,3-Dioxo-3-phenylpropionate Monohydrate (4)

Bis(trimethylsilyl)acetamide (BSA) (2.11 ml, 8.5 mmol) was added to a solution of *t*-butyl (triphenylphosphoranylidene)acetate (**18**) (2.67 g, 7.11 mmol) in benzene (30 ml) at 0 °C and the reaction mixture was stirred for 5 min. The reaction was allowed to warm to room temperature, whereupon benzoyl chloride (1.0 g, 7.11 mmol) was added and stirring was continued at this temperature for 1 h. After this time, brine (20 ml) was added and the organic product was extracted with ether (3 x 20 ml), dried ($MgSO_4$) and evaporated to give the crude product. Purification by column chromatography (silica gel, ethyl acetate/hexane, 2/1) afforded pure *t*-butyl 3-oxo-(2-triphenylphosphoranylidine)-3-phenylpropionate (**19**) (3.26 g, 96%) as a colorless solid, mp 172-173 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 7.79 (m, 6H), 7.69 (dd, J = 3.75 and 3.33 Hz, 2H), 7.48 (m, 9H), 7.33 (m, 3H), 0.98 (s, 9H) ppm; ir (KBr), 3090, 2990, 2940, 2878, 1742, 1670, 1532, 1085, 767 and 694 cm^{-1}; Anal. Calcd for $C_{31}H_{29}O_3P$: C, 77.5; H, 6.04. Found: C, 77.46; H, 6.00.

The keto ylide (**19**) (2.0 g, 4.17 mmol) was treated with Oxone® (3.83 g, 6.26 mmol) in THF/H_2O (30 ml, 2/1) at room temperature for 2 h. The reaction mixture was then diluted with brine (20 ml), the product extracted with ethyl acetate (3 x 20 ml), dried ($MgSO_4$) and the solvent removed in vacuo to give the crude product as a yellow oil. Chromatographic purification (silica gel, ethyl acetate/hexane, 2/1) afforded tricarbonyl monohydrate (**4**) (0.73 g, 69%) as a yellow solid, mp 75.5-76.5 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 8.07 (dd, J = 0.47 and 6.98 Hz, 2H), 7.62 (t, J = 7.08 Hz, 1H), 7.48 (t, J = 6.88 Hz, 2H), 5.31 (s, 2H), 1.31 (s, 9H) ppm; ir (KBr), 3390, 3088, 2990, 1755, 1742, 1694, 1601, 1456, 1254, 1135, 1014, and 689 cm^{-1}; ms (CI) 253 (M^++H, 2%), 235 (19); HRms for $C_{13}H_{17}O_5$: Calcd 253.1076. Found 253.1073; Anal. Calcd for $C_{13}H_{16}O_5$: C, 61.90; H, 6.35. Found: C, 61.92; H, 6.39.

t-Butyl 2,3-Dioxo-3-(4-tolyl)propionate Monohydrate (5)

Oxalyl chloride (0.77 ml, 8.8 mmol) and DMF (50 µl, catalytic) were added to 4-toluic acid (1.0 g, 7.3 mmol) in benzene (20 ml) at 10 °C and the reaction stirred at this temperature for 2 h. Removal of the solvent afforded 4-tolyl chloride (1.09 g, 96%) which was used without further purification.

4-Tolyl chloride (1.0 g, 6.5 mmol) was added to a solution of BSA (1.92 ml, 7.8 mmol) and ylide (**18**) (2.43 g, 6.5 mmol) in benzene (20 ml) at 25 °C and stirring was continued for 2 h. Workup in the normal manner followed by chromatographic purification (silica gel, ethyl acetate/hexane, 2/1) gave keto ylide (**20**) (3.06 g,

96%) as a colorless solid, mp 135-137 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 7.78 (m, 6H), 7.63 (d, J = 7.99 Hz, 2H), 7.49 (m, 9H), 7.13 (d, J = 7.99 Hz, 2H), 2.34 (s, 3H), 0.96 (s, 9H) ppm; ir (KBr), 3070, 2969, 1732, 1660, 1364, 1082 and 758 cm^{-1}; Anal. Calcd for $C_{32}H_{31}O_3P$: C, 77.73; H, 6.28. Found: C, 77.82; H, 6.24.

Treatment of keto ylide (**20**) (1.0 g, 2 mmol) with Oxone® (1.86 g, 3 mmol) in THF/H_2O (15 ml, 2/1) at room temperature for 2 h and workup as for **4** gave crude tricarbonyl. Column chromatography (silica gel, ethyl acetate/hexane, 1/1) afforded pure tricarbonyl monohydrate (**5**) (0.49 g, 91%) as a yellow solid, mp 69.5-70.5 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 7.96 (d, J = 8.24 Hz, 2H), 7.27 (d, J = 8.24 Hz, 2H), 5.31 (s, 2H), 2.43 (s, 3H), 1.32 (s, 9H) ppm; ir (KBr), 3430, 3082, 2984, 1756, 1732, 1693, 1610, 1260, 1100, 1012 and 630 cm^{-1}; ms (70 ev) 266 (M^+ -H_2O, 18%), 193 (100) and 91 (72); HRms for $C_{14}H_{18}O_5$: Calcd 266.1154. Found 266.1159; Anal. Calcd for $C_{14}H_{18}O_5$: C, 63.16; H, 6.77. Found: C, 63.23; H, 6.80.

t-Butyl 2,3-Dioxo-3-(4-methoxyphenyl)propionate Monohydrate (6)

4-Methoxybenzoic acid (2.0 g, 13 mmol) was treated with oxalyl chloride (1.27 ml, 14.3 mmol) and DMF (catalytic) in benzene (30 ml) at 10 °C for 2 h. After this time, the solvent was removed in vacuo to give the crude acid chloride (2.02 g, 90%) which was used without further purification.

BSA (3.5 ml, 14 mmol) was added to ylide (**18**) (4.45 g, 12 mmol) in benzene (30 ml) at 0°C for 5 min. 4-Methoxybenzoyl chloride (2.0 g, 12 mmol) was then added at 25 °C and the reaction stirred at this temperature for 2 h. Workup as for **19** gave the crude keto ylide which was purified by column chromatography (silica gel, ethyl acetate/hexane, 2/1) affording the pure phosphorane (**21**) (4.69 g, 78%) as a colorless solid, mp 180.5-182 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 7.78 (m, 9H), 7.48 (m, 8H), 6.88 (d, J = 7.62 Hz, 2H), 3.82 (s, 3H), 0.99 (s, 9H) ppm; ir (KBr), 3095, 2990, 2960, 2874, 1740, 1670, 1532, 1441, 1086, 890 and 698 cm^{-1}; Anal. Calcd for $C_{32}H_{31}O_4P$: C, 75.29; H, 6.08. Found: C, 74.96; H, 6.14.

Phosphorane (**21**) (1.0 g, 2 mmol) was treated with Oxone® (1.81 g, 3 mmol) in THF/H_2O (20 ml, 2/1) at 25 °C for 2 h. Workup as for **4** followed by chromatographic purification (silica gel, ethyl acetate/hexane, 2/1) gave the tricarbonyl monohydrate (**6**) (0.35 g, 63%) as a yellow oil which crystallized in vacuo to give a yellow solid, mp 87.5-88.5 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 8.06 (d, J = 9.04 Hz, 2H), 6.95 (d, J = 9.04 Hz, 2H), 5.35 (s, 2H), 3.88 (s, 3H), 1.33 (s, 9H) ppm; ir (KBr), 3420, 3080, 2980, 1735, 1688, 1604, 1270, 1130, 1020, 853 and 630 cm^{-1}; ms (CI) 265 (M^++H-H_2O, 15%), 208 (11), 192 (100) and 108 (26); HRms for $C_{14}H_{17}O_5$: Calcd 265.1076. Found 265.1079; Anal. Calcd for $C_{14}H_{16}O_6$: C, 59.57; H, 6.38. Found: C, 59.98; H, 6.42.

t-Butyl 2,3-Dioxo-3-(4-dimethylaminophenyl)propionate Monohydrate (7)

Dimethylaminobenzoic acid (1.0 g, 6.1 mmol) was treated with oxalyl chloride (0.63 ml, 7.3 mmol) and DMF (catalytic) in benzene (20 ml) at 10 °C for 2 h. Ethanol (20 ml) was then added and the reaction allowed to warm to room temperature. Workup as described in the preparation of **25** afforded the aryl ester (1.03 g, 88%) as a yellow solid, mp 59.5-60 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 7.91 (d, J = 9.04 Hz, 2H), 6.64 (d, J = 9.04 Hz, 2H), 4.33 (q, J = 7.13 Hz, 2H), 3.03 (s, 6H), 1.36 (t, J = 7.19 Hz, 3H) ppm; ir (KBr), 2990, 2820, 1693, 1610, 1282, 1026, 830 and 772 cm^{-1}; ms (70 eV) 193 (M^+, 100%), 164 (86), 148 (97) and 120 (32).

The lithium enolate of *t*-butyl acetate (7.8 mmol) (preparation as described for **25**) was added to a solution of the ester (0.5 g, 2.6 mmol) in THF (10 ml) at -78 °C. The reaction was warmed to 25 °C and stirring was continued for 16 h. Workup as described for **25** afforded **26** (0.35 g, 52%) as a yellow solid, mp 43-44 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 7.85 (d, J = 9.09 Hz, 2H), 6.65 (d, J = 9.09 Hz, 2H), 3.81 (s, 2H), 3.06 (s, 6H), 1.45 (s, 9H) ppm; ir ($CDCl_3$), 2996, 1725, 1662, 1600, 1250, 1048 and 820 cm^{-1}; ms (70 eV) 263 (M^+, 58%) 207 (13), 189 (16), 163 (57) and 148 (100); HRms for $C_{15}H_{21}NO_3$: Calcd 263.1522. Found 263.1539. Anal. Calcd for $C_{15}H_{21}NO_3$: C, 68.44; H, 7.98; N, 5.32. Found: C, 68.39; H, 8.06; N, 5.32.

β-Keto ester (**26**) (1.02 g, 3.9 mmol) in ethanol (30 ml) was treated with N, N-dimethyl-4-nitrosoaniline (0.58 g, 3.9 mmol) and an ethanolic solution of KOH (4 mg, 10 mol %) at 25 °C for 48 h. The solvent was removed in vacuo to give the imine (0.72 g, 47%) which was used without purification.

Acid hydrolysis of this imine (0.5 g, 1.3 mmol) (as described earlier in the preparation of **1**) afforded tricarbonyl monohydrate (**7**) as an orange solid, mp 77-78 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 7.95 (d, J = 9.08 Hz, 2H), 6.63 (d, J = 9.08 Hz, 2H), 5.44 (s, 2H), 3.09 (s, 6H), 1.36 (s, 9H) ppm; ir ($CDCl_3$) 3520, 3000, 2945, 1739, 1720, 1667, 1602, 1280, 1022 and 842 cm^{-1}; ms (70 eV) 277 (M^+-H_2O, 4%), 221 (4), 148 (100), 105 (12) and 77 (14); HRms for $C_{15}H_{19}NO_4$: Calcd 277.1315. Found 277.1324; Anal. Calcd for $C_{15}H_{21}NO_5$: C, 61.02; H, 7.12; N, 4.75. Found: C, 60.89; H, 7.06; N, 4.71.

t-Butyl 2,3-Dioxo-3-ethenyl-5-(2-methoxyphenyl)propionate Monohydrate (8)

2-Methoxycinnamic acid (1.0 g, 5.6 mmol) was treated with oxalyl chloride (0.54 ml, 6.2 mmol) and DMF (catalytic) in benzene (20 ml) at 10 °C for 2 h. Removal of the solvent by evaporation gave 2-methoxycinnamyl chloride (1.02 g, 93%) as a yellow solid which was used without purification.

The acid chloride (1.0 g, 5.1 mmol) was added to a solution of BSA (1.51 ml, 6.1 mmol) and ylide (**18**) (1.91 g, 5.1 mmol) in benzene (30 ml) at 25 °C and the reaction was stirred at this temperature for 4 h. Workup as for **19** and purification by column chromatography (silica gel, ethyl acetate/hexane, 2/1) gave keto ylide (**22**) (1.97 g,

72%) as a yellow solid, mp 156.5-157.5 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 8.20 (d, J = 15.83 Hz, 1H), 7.81 (d, J = 15.83, 1H), 7.73 (m, 8H), 7.46 (m, 9H), 7.23 (m, 1H), 6.91 (m, 1H), 6.83 (m, 1H), 3.89 (s, 3H), 1.09 (s, 9H) ppm; ir (KBr), 3070, 2980, 1736, 1654, 1252, 1088, and 698 cm^{-1}; Anal. Calcd for $C_{34}H_{33}O_4P$: C, 76.12; H, 6.16. Found: C, 75.92; H, 6.12.

Keto ylide (**22**) (1.0 g, 1.9 mmol) was treated with Oxone® (1.7 g, 2.8 mmol) in THF/H_2O (20 ml, 2/1) at 25 °C for 4 h. Usual workup procedure gave the crude product. Column chromatography (silica gel, ethyl acetate/hexane, 2/1) afforded pure tricarbonyl monohydrate (**8**) (0.45 g, 78%) as a pale yellow solid, mp 72-73 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 8.22 (d, J = 15.83, 1H), 7.56 (d, J = 7.50 Hz, 1H), 7.42 (m, 1H), 6.99 (m, 1H), 6.96 (d, J = 15.83 Hz, 1H), 5.19 (s, 2H), 3.88 (s, 3H), 1.47 (s, 9H) ppm; ir (KBr), 3400, 3009, 2980, 1740, 1690, 1595, 1250, 1066, 840 and 706 cm^{-1}; ms (CI) 291 (M^++H-H_2O, 10%), 218 (16) and 161 (100); HRms for $C_{16}H_{19}O_5$: Calcd 291.1233. Found 291.1237; Anal. Calcd for $C_{16}H_{20}O_5$: C, 62.34; H, 6.49. Found: C, 62.37; H, 6.58.

t-Butyl 2,3-Dioxo-3-(t-butyl)propionate Monohydrate (9)

Trimethylacetyl chloride (1.0 g, 8.3 mmol) was added to a solution of BSA (2.46 ml, 10 mmol) and ylide (**18**) (3.12 g, 8.3 mmol) in benzene (30 ml) at 5 °C. The mixture was immediately warmed to room temperature and stirring was continued for 16 h. Workup in the usual manner followed by column chromatography (silica gel, ethyl acetate/hexane, 2/1) afforded keto ylide (**23**) (2.33 g, 61%) as a colorless solid, mp 125-127 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 7.68 (dd, J = 1.67 and 5.41 Hz, 3H), 7.63 (dd, J = 0.83 and 5.83 Hz, 3H), 7.41 (m, 9H), 1.31 (s, 9H), 1.04 (s, 9H) ppm; ir (KBr), 3078, 2980, 1745, 1664, 1352, 1076, 750 and 694 cm^{-1}.

Keto ylide(**23**)(0.5 g, 1.1 mmol) in methanol (15 ml) was treated with excess ozone at -78 °C for 15 min (reaction was stopped on development of a blue solution). The flask was then flushed with nitrogen and the solvent evaporated to give the crude product. Purification by chromatography (silica gel, ethyl acetate/hexane, 2/1) afforded tricarbonyl monohydrate (**9**) (0.15 g, 59%) as a yellow oil; ^{1}H nmr (250 MHz, $CDCl_3$) 5.12 (br s, 2H), 1.50 (s, 9H), 1.27 (s, 9H) ppm; ir ($CDCl_3$), 3450, 2990, 1740, 1707, 1428, 1257, 1056 and 842 cm^{-1}; ms (CI) 215 (M^++H-H_2O, 47%), 159 (73), 126 (26), 99 (22) and 85 (100); HRms for $C_{11}H_{19}O_4$: Calcd 215.1283. Found 215.1289.

t-Butyl 2,3-Dioxo-3-[2-(1-methylpyrryl)]propionate Monohydrate (10)

1-Methylpyrryl-2-carboxylic acid (1.0 g, 8 mmol) was treated with oxalyl chloride (0.84 ml, 9.6 mmol) and DMF (catalytic) in benzene (20 ml) at 10 °C for 2 h. Ethanol (20 ml) was then added and the reaction allowed

to reach ambient temperature. Workup as in the indolyl example (see preparation of **25**) gave the pyrrole ester (1.11 g, 91%) as a yellow oil (used without purification).

Claisen condensation reaction of the pyrrole ester (1.0 g, 6.5 mmol) and the lithium enolate of *t*-butyl acetate (19.5 mmol) (prepared as for **25**) gave β-keto ester (**27**) (1.15 g, 79%) as a yellow oil; ^{1}H nmr (250 MHz, $CDCl_3$) 6.93 (dd, J = 1.69 and 2.52 Hz, 1H), 6.83 (m, 1H), 6.13 (dd, J = 2.52 and 1.78 Hz, 1H), 3.94 (s, 3H), 3.70 (s, 2H), 1.46 (s, 9H) ppm; ir (neat), 3120, 2980, 1730, 1653, 1070, 744 and 612 cm^{-1}; ms (70 eV) 223 (M^+, 72%), 167 (21), 149 (11) and 108 (100); HRms for $C_{12}H_{17}NO_3$: Calcd 223.1209. Found 223.1218.

β-Keto ester (**27**) (1.0 g, 4.5 mmol) was treated with N, N-dimethyl-4-nitrosoaniline (0.67 g, 4.5 mmol) and an ethanolic solution of KOH (4 mg, 10 mol %) in ethanol (30 ml) at 25 °C for 24 h. Evaporation of the solvent gave the crude imine which on acid hydrolysis (as described for tricarbonyls **1** and **7**) and chromatographic purification (silica gel, ethyl acetate/hexane, 1/2) afforded pure tricarbonyl monohydrate (**10**) (0.31 g, 87%) as a yellow solid, mp 94-96 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 7.10 (dd, J = 1.66 and 2.69 Hz, 1H), 6.94 (t, J = 0.64 Hz, 1H), 6.16 (dd, J = 2.34 and 2.0 Hz, 1H), 5.39 (s, 2H), 3.98 (s, 3H), 1.39 (s, 9H) ppm; ir ($CDCl_3$), 3500, 3380, 2985, 1730, 1643, 1402, 1068 and 820 cm^{-1}; ms (CI) 256 (M^++H, 3%), 238 (14), 200 (24), 182 (100), 148 (9), 108 (99) and 80 (27); HRms for $C_{12}H_{18}NO_5$: Calcd 256.1185. Found 256.1186; Anal. Calcd fof $C_{12}H_{17}NO_5$: C, 56.47; H, 6.67; N, 5.49. Found: C, 56.53; H, 6.73; N, 5.52.

t-Butyl 2,3-Dioxo-3-(4-nitrophenyl)propionate Monohydrate (11)

4-Nitrobenzoic acid (1.0 g, 6 mmol) was treated with oxalyl chloride (0.63 ml, 7.2 mmol) and DMF (50 µl, catalytic) in benzene (20 ml) at 10 °C for 2 h. Evaporation of the solvent gave crude acid chloride (1.0 g, 90%). BSA (1.61 mL, 6.5 mmol) was added to ylide (**18**) (2.04 g, 5.4 mmol) in benzene (20 ml) at 0 °C. After 5 min, the reaction was warmed to 25 °C and 4-nitrobenzoyl chloride (1.0 g, 5.4 mmol) was added and stirring was continued for 2 h. Workup as for **19** followed by column chromatography (silica gel, ethyl acetate/hexane, 1/1) gave the pure phosphorane (**24**) (2.42 g, 88%) as a bright yellow solid, mp 203-205 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 8.19 (d, J = 8.77 Hz, 2H), 7.76 (m, 7H), 7.52 (m, 10H), 0.94 (s, 9H) ppm; ir (KBr), 3060, 2980, 1678, 1575,1520, 1078, 722 and 697 cm^{-1}; Anal. Calcd for $C_{31}H_{28}NO_5P$: C, 70.86; H, 5.33; N, 2.67. Found: C, 70.80; H, 5.46; N, 2.49.

Phosphorane (**24**) (1.0 g, 2 mmol) was treated with excess Oxone® (1.80 g, 3 mmol) in THF/H_2O (20 ml, 2/1) at 25 °C for 12 h. Usual workup and purification (silica gel, ethyl acetate/hexane, 2/1) gave tricarbonyl monohydrate (**11**) (0.45 g, 79%) as a yellow solid, mp 99-101 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 8.33 (d, J = 9.08 Hz, 2H), 8.26 (d, J = 9.08 Hz, 2H), 5.26 (br s, 2H), 1.33 (s, 9H) ppm; ir (KBr), 3400, 3120, 2986, 1760, 1718,

1704, 1608, 1530, 1240, 1107 and 714 cm^{-1}; ms (CI) 280 (M^++H-H_2O, 100%), 224 (13) and 150 (39); HRms for $C_{13}H_{14}NO_6$: Calcd 280.0821. Found 280.0821; Anal. Calcd for $C_{13}H_{15}NO_7$: C, 52.53; H, 5.05; N, 4.71. Found: C, 52.58; H, 5.10; N, 4.70.

3-Methylbutanal-N-benzylimine (2a)

Isovaleraldehyde (0.5 ml, 4.7 mmol) and benzylamine (0.51 ml, 4.7 mmol) were dissolved in methylene chloride (15 ml). Excess anhydrous $MgSO_4$ (0.5 g) was then added and stirring was continued for 3 h. After this time, the reaction mixture was filtered and the solvent removed in vacuo to give the Schiff base (**2a**) (0.71 g, 87%) as a colorless oil; ^1H nmr (250 MHz, $CDCl_3$) 7.78 (t, J = 4.85 Hz, 1H), 7.29 (m, 4H), 4.57 (s, 2H), 2.20 (t, J = 6.02 Hz, 2H), 1.95 (septet, 1H), 0.97 (d, J = 6.64 Hz, 6H) ppm; ir (neat), 3100, 3042, 2964, 2878,1670, 1458, 1032 and 740 cm^{-1}.

Arylpyrrolinone (12)

Imine (**2a**) (0.42 g, 2.4 mmol) in benzene (1 ml) was added to a solution of tricarbonyl (**4**) (0.3 g, 1.2 mmol) in benzene (20 ml) at room temperature and the reaction was stirred for 48 h. Removal of the solvent in vacuo followed by column chromatography (silica gel, ethyl acetate/hexane, 1/3) afforded pure pyrrolinone (**12**) (0.29 g, 59%) as a colorless oil; ^1H nmr (250 MHz, $CDCl_3$) 7.50 (s, 1H), 7.35 (m, 8H), 7.16 (m, 2H), 4.46 (d, J = 15.0 Hz, 1H), 4.29 (d, J = 15.0 Hz, 1H), 2.66 (septet, J = 6.8 Hz, 1H), 1.48 (s, 9H), 1.08 (d, J = 3.17 Hz, 3H), 1.06 (d, J = 3.17 Hz, 3H) ppm; ir (neat), 3340, 3078, 3044, 2970, 1740, 1680, 1586, 1504, 1034 and 704 cm^{-1}; ms (70 eV) 391 (M^+, 20%), 334 (12), 290 (70), 105 (26), 104 (33) 91 (100), 77 (18) and 65 (22); HRms for $C_{25}H_{29}NO_3$: Calcd 391.2149. Found 391.2150.

Arylpyrrolinone (13)

Tricarbonyl (**5**) (0.3 g, 1.1 mmol) was treated with Schiff base (**2a**) (0.4 g, 2.3 mmol) in benzene (20 ml) at 25 °C for 24 h. Workup and purification as for **12** afforded arylpyrrolinone (**13**) (0.24 g, 54%) as a colorless solid, mp 100-101 °C; ^1H nmr (250 MHz, $CDCl_3$) 7.47 (s, 1H), 7.33 (m, 2H), 7.20 (m, 7H), 4.43 (d, J = 15.0 Hz, 1H), 4.27 (d, J = 15.0 Hz, 1H), 2.65 (septet, J = 7.0 Hz, 1H), 2.34 (s, 3H), 1.48 (s, 9H), 1.07 (d, J = 3.07 Hz, 3H), 1.05 (d, J = 3.07 Hz, 3H) ppm; ir (neat), 3040, 2970, 2875, 1736, 1672, 1580, 1252, 1035, 849 and 642 cm^{-1}; ms (CI) 406 (M^++H, 80%), 350 (26), 304 (42), 206 (19), 139 (36), 105 (15), 91 (100) and 77 (14); HRms for $C_{26}H_{32}NO_3$: Calcd 406.2384. Found 406.2380; Anal. Calcd for $C_{26}H_{31}NO_3$: C, 77.04; H, 7.65; N, 3.46. Found: C, 77.21; H, 7.82; N, 3.44; **X-ray Analysis**: Arylpyrrolinonecarboxylate (**13**) was recrystallized from ethyl acetate/hexane (1:1) at 25 °C and the crystals were isolated as colorless plates, $C_{26}H_{31}NO_3$ (FW 405.54): monoclinic, $P2_1/n$, a = 9.025 (2) Å, b = 21.744 (4) Å, c = 12.816 (2) Å, ß = 108.89 (2)°, V = 2379.7 (9) $Å^3$, Z =

4, CuKα radiation (λ = 1.54178 Å), 298 K, Rigaku AFC5S diffractometer with graphite monochromator; 3925 total reflections were collected of which 3669 were unique reflections (Rint = 0.019) with 2θ ≤ 114 °C, of those reflections, 2099 (52%) with I ≥ 3σ (I) were adjudged observed. The structure was solved using MITHRIL and refined by full-matrix least square to R = 0.063 and Rw = 0.077.

Arylpyrrolinone (14)

To a solution of tricarbonyl (**6**) (0.3 g, 1.1 mmol) in benzene (15 ml) was added the freshly prepared Schiff base (**2a**) (0.37 g, 2.2 mmol) and the reaction mixture was stirred at 25 °C for 48 h. Usual workup and purification (silica gel, ethyl acetate/hexane, 2/1) gave arylpyrrolinone (**14**) (0.28 g, 63%) as a pale yellow oil; ^{1}H nmr (250 MHz, $CDCl_3$) 7.48 (s, 1H), 7.33 (m, 3H), 7.26 (d, J = 8.75 Hz, 2H), 7.16 (m, 2H), 6.91 (d, J = 8.75 Hz, 2H), 4.44 (d, J = 13.75 Hz, 1H), 4.27 (d, J = 13.75 Hz, 1H), 3.82 (s, 3H), 2.65 (septet, J = 6.1 Hz, 1H), 1.49 (s, 9H), 1.09 (d, J = 2.92 Hz, 3H), 1.06 (d, J 2.92 Hz, 3H) ppm; ir (KBr), 3330, 3080, 2970, 1743, 1680, 1589, 1255, 1038 and 706 cm^{-1}; ms (70 eV) 421 (M^+, 23%), 320 (93), 230 (28), 91 (100), 77 (10) and 65 (20); HRms for $C_{26}H_{31}NO_4$: Calcd 421.2254. Found 421.2258.

Arylpyrrolinone (15)

Imine (**2a**) (0.24 g, 13.6 mmol) was added to tricarbonyl (**7**) (0.2 g, 6.8 mmol) in benzene (15 ml) at 25 °C and the reaction was stirred for 24 h. Removal of the solvent followed by chromatographic purification (silica gel, ethyl acetate/hexane, 2/3) gave pyrrolinonecarboxylate (**15**) (0.18 g, 61%) as a yellow solid, mp 92-93 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 7.45 (s, 1H), 7.33 (m, 3H), 7.17 (m, 4H), 6.71 (d, J = 8.94 Hz, 2H), 4.43 (d, J = 14.2 Hz, 1H), 4.24 (d, J = 14.2 Hz, 1H), 2.94 (s, 6H), 2.62 (septet, J = 7.2 Hz, 1H), 1.48 (s, 9H), 1.07 (d, J = 1.54 Hz, 3H), 1.04 (d, J = 1.54 Hz, 3H) ppm; ir ($CDCl_3$), 3082, 2960, 1730, 1670, 1618, 1589, 1238, 1036 and 820 cm^{-1}; ms (70 eV) 434 (M^+, 13%), 378 (2), 333 (100), 305 (5) 243 (19) and 91 (16); HRms for $C_{27}H_{34}N_2O_3$: Calcd 434.2571. Found 434.2572; Anal. Calcd for $C_{27}H_{34}N_2O_3$: C, 74.65; H, 7.83; N, 6.45. Found: C, 74.38; H, 7.76; N, 6.42.

Cinnamylpyrrolinone (16)

Tricarbonyl (**8**) (0.3 g, 1.0 mmol) was treated with Schiff base (**2a**) (0.34 g, 2.0 mmol) (freshly prepared) in benzene (20 ml) at 25 °C for 24 h. Removal of the solvent in vacuo and purification by column chromatography (silica gel, ethyl acetate/hexane, 1/3) gave the pyrrolinone (**16**) (0.23 g, 53%) as a colorless solid, mp 117-118.5 °C; ^{1}H nmr (250 MHz, $CDCl_3$) 7.48 (m, 7H), 6.97 (d, J = 16.64 Hz, 1H), 6.90 (m, 3H), 6.65 (d, J = 16.64 Hz, 1H) 4.41 (s, 2H), 3.84 (s, 3H), 2.58 (septet, J = 7.5 Hz, 1H), 1.49 (s, 9H), 1.04 (t, J = 6.6 Hz, 6H) ppm; ir (KBr), 3078, 2960, 1725, 1655, 1574, 1243, 1151, 1030 and 840 cm^{-1}; ms (CI) 448 (M^++H, 16%), 392 (14), 346 (30)

and 91 (100); HRms for $C_{28}H_{34}NO_4$: Calcd 448.2489. Found 448.2479; **X-ray Analysis:** Arylpyrrolinonecarboxylate (**16**) was recrystallized from ethyl acetate/hexane (1:1) at 25 °C and the crystals were isolated as colorless plates, $C_{28}H_{33}NO_4$ (FW 447.57): monoclinic, $P2_1/c$, a = 11.476 (4) Å, b = 18.216 (8) Å, c = 12.276 (2) Å, ß = 103.80 (2)°, V = 2492 (1) $Å^3$, Z = 4, CuKα radiation (λ = 1.54178 Å), 298 K, Rigaku AFC5S diffractometer with graphite monochromator; 3703 total reflections were collected of which 3507 were unique reflections (Rint = 0.033) with 2θ ≤ 114 °C, of those reflections, 2008 (57%) with I ≥ 3σ (I) were adjudged observed. The structure was solved using MITHRIL and refined by full-matrix least square to R = 0.049 and Rw = 0.057.

t-Butylpyrrolinone (17)

Tricarbonyl (**9**) (0.17 g, 7.4 mmol) was treated with imine (**2a**) (0.26 g, 14.8 mmol) in benzene (15 ml) at 25 °C for 48 h. Workup as for **12** gave the crude product which was purified by column chromatography (silica gel, ethyl acetate/hexane, 1/10) to give *t*-butylpyrrolinone (**17**) (0.16 g, 58%) as a yellow oil; ^1H nmr (250 MHz, $CDCl_3$) 7.39 (m, 5H), 7.30 (s, 1H), 4.52 (d, J = 14.46 Hz, 1H), 4.27 (d, J = 14.46 Hz, 1H), 2.58 (septet, J = 7.7 Hz, 1H), 1.47 (s, 9H), 1.22 (s, 9H), 1.03 (d, J = 4.81 Hz, 3H), 1.01 (d, J = 4.81 Hz, 3H) ppm; ir ($CDCl_3$), 3080, 2975, 1725, 1676, 1603, 1460, 1254, 1156 and 847 cm^{-1}; ms (70 eV) 371 (M^+, 11%), 259 (35), 241 (76), 91 (95) and 57 (100); HRms for $C_{23}H_{33}NO_3$: Calcd 371.2462. Found 371.2463.

Pyrrylpyrrolinone (18)

Freshly prepared imine (**2a**) (0.42 g, 2.4 mmol) was added to a solution of tricarbonyl (**10**) (0.3 g, 1.2 mmol) in benzene (20 ml) at 25 °C for 24 h. Workup and chromatographic purification (silica gel, ethyl acetate/hexane, 1/3) gave pyrrylpyrrolinone (**18**) (0.33 g, 71%) as a pale yellow solid, mp 103-105 °C; ^1H nmr (250 MHz, $CDCl_3$) 7.56 (s, 1H), 7.29 (m, 3H), 6.90 (m, 2H), 6.54 (t, J = 2.26 Hz, 1H), 6.32 (dd, J = 1.81 and 1.94 Hz, 1H), 6.09 (dd, J = 2.87 and 0.81 Hz, 1H), 4.41 (d, J = 14.26 Hz, 1H), 4.14 (d, J = 14.26 Hz, 1H), 3.14 (s, 3H), 2.63 (septet, J = 8.1 Hz, 1H), 1.53 (s, 9H), 1.08 (d, J = 5.4 Hz, 3H), 1.05 (d, J = 5.4 Hz, 3H) ppm; ir (KBr), 3050, 2968, 1730, 1660, 1574, 1237, 1070 and 712 cm^{-1}; ms (70 eV) 394 (M^+, 14%), 294 (78), 293 (93), 203 (41), 91 (100), 77 (11) and 65 (14); HRms for $C_{24}H_{31}N_2O_3$: Calcd 395.2336. Found 395.2335; Anal. Calcd for $C_{24}H_{30}N_2O_3$: C, 73.10; H, 7.61; N, 7.11. Found: C, 73.00; H, 7.69; N, 7.04.

1-Benzyl-2-benzylamino-3-isopropyl-4-t-butoxycarbonyl-5-(4-nitrophenyl)pyrrole (31)

Tricarbonyl (**11**) (0.3 g, 1.0 mmol) was treated with imine (**2a**) (0.35 g, 2.0 mmol) in benzene (20 ml) at 25 °C for 48 h. Workup and purification as for **12** gave the tetrasubstituted pyrrole (**31**) (0.36 g, 68%) as an orange oil which crystallized on standing affording an orange solid, mp 148-150 °C; ^1H nmr (250 MHz, $CDCl_3$) 8.11 (d, J

= 7.07 Hz, 2H), 7.28 (m, 7H), 6.71 (d, J = 7.07 Hz, 2H), 4.86 (s, 2H), 3.99 (s, 2H), 3.43 (septet, J = 7.5 Hz, 1H), 2.94 (br s, 1H), 1.42 (d, J = 7.08 Hz, 6H), 1.21 (s, 9H) ppm; ir (KBr), 3370, 3360, 3062, 2940, 1680, 1588, 1520, 1135 and 842 cm^{-1}; ms (70 eV) 525 (M^+, 44%), 495 (5), 469 (18), 434 (5), 378 (55), 106 (21), 91 (100) and 77 (17); HRms for $C_{32}H_{35}N_3O_4$: Calcd 525.2630. Found 525.2633; Anal. Calcd for $C_{32}H_{35}N_3O_4$: C, 73.14; H, 6.67; N, 8.00. Found: C, 73.22; H, 6.71; N, 8.02; **X-ray Analysis**: Substituted pyrrole (**31**) was recrystallized from ethyl acetate at 25 °C and the crystals were isolated as orange plates, $C_{32}H_{35}N_3O_4$ (FW 525.65): monoclinic, Cc, a = 6.024 (1) Å, b = 22.065 (3) Å, c = 21.983 (5) Å, β = 93.58 (2)°, V = 2916 (1) $Å^3$, Z = 4, CuKα radiation (λ = 1.54178 Å), 298 K, Rigaku AFC5S diffractometer with graphite monochromator; 2275 total reflections were collected with 2047 unique reflections (Rint = 0.021) with 2θ ≤ 114 °C, of those reflections, 1648 (72%) with I ≥ 3σ (I) were adjudged observed. The structure was solved using SHELXS86 and refined by full-matrix least square to R = 0.050 and Rw = 0.061.

Indolylpyrrolinone (3)

A solution of freshly prepared imine (**2a**) (0.21 g, 1.2 mmol) in benzene (1 ml) was added to a solution of the indolyl tricarbonyl (**1**) (0.2 g, 0.6 mmol) in benzene (15 ml) at room temperature. The resulting reaction mixture was stirred at 55-60 °C for 6 h. The reaction was then cooled to room temperature and concentrated under reduced pressure. Chromatography (silica gel, ethyl acetate/hexane, 1/4) afforded **3** (0.18 g, 63%) as a pale yellow solid, mp 78-79 °C; ^1H nmr (250 MHz, $CDCl_3$) 7.51 (d, J = 7.0 Hz, 1H), 7.18 (m, 10H), 6.04 (m, 1H), 5.19 (m, 2H), 4.73 (d, J = 5.0 Hz, 2H), 4.40 (d, J = 14.0 Hz, 1H), 4.19 (d, J = 14.0 Hz, 1H), 2.78 (m, 1H), 1.50 (s, 9H), 1.15 (t, J = 7.0 Hz, 6H) ppm; ir ($CDCl_3$), 3050, 2995, 2940, 1745 and 1675 cm^{-1}; ms (70 eV) 470 (M^+, 10%), 371 (26), 370 (100) and 369(87); HRms for $C_{30}H_{34}N_2O_3$: Calcd 470.2571. Found 470.2560; **X-ray Analysis**: Indolylpyrrolinonecarboxylate (**3**) was recrystallized from ethyl acetate/hexane (1:1) at 25 °C and the crystals were isolated as colorless plates, $C_{30}H_{33}N_2O_3$ (FW 469.60): monoclinic, C2/c, a = 20.020 (1) Å, b = 9.5982 (9) Å, c = 28.861 (4) Å, β = 100.596 (7)°, V = 5451.2 (9) $Å^3$, Z = 8, CuKα radiation (λ = 1.54178 Å), 298 K, Rigaku AFC5S diffractometer with graphite monochromator; 4497 total reflections were collected with 4348 unique reflections (Rint = 0.023) with 2θ ≤ 120 °C, of those reflections, 2227 (51%) with I ≥ 3σ (I) were adjudged observed. The structure was solved using MITHRIL and refined by full-matrix least square to R = 0.059 and Rw = 0.073.

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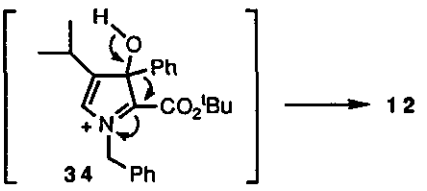
13. Alternatively, the imine nitrogen could attack the central carbonyl group forming the intermediate (**34**). Subsequent aryl migration would give the observed product.



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