A Novel [3+2] Cycloaddition Approach to Nitrogen Heterocycles via Phosphine-Catalyzed Reactions of 2,3-Butadienoates or 2-Butynoates and Dimethyl Acetylenedicarboxylate with Imines: A Convenient Synthesis of Pentabromopseudilin†

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The reactivity of a new three carbon synthon, generated in situ from the reaction of 2,3-butadienoates or 2-butynoates with an appropriate phosphine as the catalyst, toward the electron-deficient imines is described. Triphenylphosphine-catalyzed reaction of methyl 2,3-butadienoate with *N*-sulfonylimines gave the single [3+2] cycloadduct in excellent yield; tributylphosphine-catalyzed reaction of methyl 2,3-butadienoate or 2-butynoate with *N*-tosylimines afforded the corresponding [3+2] cycloadduct as the major product along with a small amount of the three components adduct. Aliphatic *N*-tosylimines gave moderate yield for this reaction. In addition, a new phosphine-catalyzed cyclization reaction of dimethyl acetylenedicarboxylate with *N*-tosylimines is also described. A reaction mechanism is proposed. Further elaborations of the cycloaddition products and the synthesis of pentabromopseudilin using this method are exemplified.

Introduction

The pyrrolidine ring is an important structural unit existing in a large number of natural products and pharmaceutical molecules.[1,2] Efficient synthesis of the pyrrolidine ring has thus attracted much attention in synthetic organic chemistry.[3−7] Of the numerous known methodologies, the [3+2] cycloaddition is an efficient strategy for the construction of the pyrrolidine ring directly from simple building blocks and has been widely utilized in synthesis.[8] Recently, our discovery of a new three carbon synthon, generated in situ from the reaction of 2,3-butadienoates or 2-butynoates with an appropriate phosphine as the catalyst,[9] stimulates us to explore its reaction to other dipolarophiles. *N*-Tosylimines[10] with the highly reactive carbon−nitrogen double bond have been successfully applied in cycloaddition reactions.[11,12] In preliminary studies we have tested the reaction of methyl 2,3-butadienoate with *N*-tosylimines, and the corresponding [3+2] cycloaddition product was formed in excellent yield.[13] The success of this reaction led to the examination of other imines bearing alternative electron-withdrawing groups on a nitrogen atom that similarly activate the imine but are easier to remove after reaction. Thus, *N*-(ethoxycarbonyl)benzaldimine, *N*-(diphenylphosphinyl)benzaldimine (diphenylphosphinyl = DPP), *N*-(*p*-nitrobenzenesulfonyl)benzaldimine (*p*-nitrobenzenesulfo-

† Dedicated to Professor Weiyu Ding on the occasion of her 70th birthday.

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(7) For recent examples, see: (a) Coldham, I.; Hufton, R. *Tetrahedron* **1996**, *52*, 12541. (b) Steiner, A.; Wessig, P.; Polborn, K. *Helv. Chim. Acta* **1996**, *79*, 1843. (c) Hollinshead, S. P. *Tetrahedron Lett.* **1996**, *37*, 9157. (d) Tokuda, M.; Fujita, H.; Nitta, M.; Suginome, H. *Heterocycles* **1996**, *42*, 385. (e) Wu, S.; Lee, S.; Beak, P. *J. Am. Chem. Soc.* **1996**, *118*, 715. (f) Kercher, T.; Livinghouse, T. *J. Am. Chem. Soc.* **1996**, *118*, 4200. (g) Harvey, D. F.; Sigano, D. M. *J. Org. Chem.* **1996**, *61*, 2268. (h) Larock, R. C.; Hightower, T. R.; Hasvold, L. A.; Peterson, K. P. *J. Org. Chem.* **1996**, *61*, 3584. (i) Sole, D.; Cancho, Y.; Llebaria, A.; Moreto, J. M.; Delgado, A. *J. Org. Chem.* **1996**, *61*, 5895. (j) Alvarez-Ibarra, C.; Csaky, A. G.; Lopez de Silanes, I.; Quiroga, M. L. *J. Org. Chem.* **1997**, *62*, 479.

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(10) For recent synthesis of *N*-tosylimines, see: (a) Georg, G. I.; Harriman, G. C. B.; Peterson, S. A. *J. Org. Chem.* **1995**, *60*, 7366. (b) Love, B. E.; Raje, P. S.; Williams, T. C., II *Synlett* **1994**, 493. (c) Boger, D. L.; Corbett, W. L. *J. Org. Chem.* **1992**, *57*, 4777. (d) Trost, B. M.; Marrs, C. *J. Org. Chem.* **1991**, *56*, 6468. (e) Jennings, W. B.; Lovely, C. J. *Tetrahedron* **1991**, *47*, 5561.

(11) For reviews of six-membered rings, see: (a) *Hetero Diels−Alder Methodology in organic synthesis*; Boger, D. L., Weinreb, S. M., Eds.; Academic Press: San Diego, 1987. (b) Weinreb, S. M. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon: Oxford, 1991; Vol. 5, p 401.

(12) For the formation of five-membered rings, see: (a) Jiang, S.; Chen, T.; Turos, E. *Organometallics* **1995**, *14*, 4710. (b) Chen, T.; Jiang, S.; Turos, E. *Tetrahedron Lett.* **1994**, *35*, 8325. (c) Trost, B. M.; Marrs, C. M. *J. Am. Chem. Soc.* **1993**, *115*, 6636. (d) Trost, B. M.; Matelich, M. C. *J. Am. Chem. Soc.* **1991**, *113*, 9007. (e) Saigo, K.; Shimada, S.; Hasegawa, M. *Chem. Lett.* **1990**, 905.

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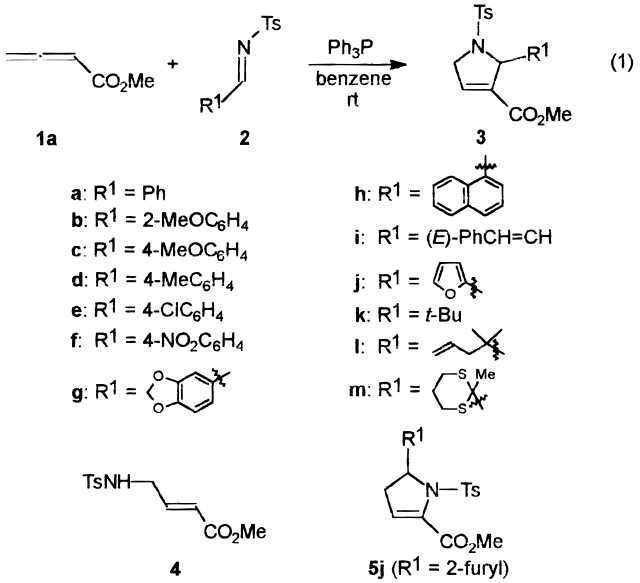
nyl = Ns), and *N*-(β-trimethylsilylethanesulfonyl)benzaldimines (β-trimethylsilylethanesulfonyl = SES) were examined.

In this paper, we wish to report the result of this new [3+2] reaction toward various electron-deficient imines. The further elaborations of the cycloaddition products will also be discussed.

Results and Discussion

Cycloaddition of Methyl 2,3-Butadienoate with *N*-Tosylimines. Our initial attempt explored the reaction of methyl 2,3-butadienoate (**1a**) with *N*-tosyl benzaldimine (**2a**, R^1 = Ph) in the presence of a catalytic amount of triphenylphosphine in dry benzene at room temperature, and the corresponding [3+2] cycloaddition product **3a** was obtained in nearly quantitative yield (eq 1).



Unlike the reaction of 2,3-butadienoates with electron-deficient olefins,[9] the reactions of **1a** with aromatic *N*-tosylimines (**2b**−**h**) in the presence of a catalytic amount of triphenylphosphine all afforded the single cycloaddition products (**3b**−**h**), respectively, in excellent yields and high chemoselectivity (Table 1). Indeed, aryl *N*-tosylimines with both electron-releasing and electron-withdrawing groups in benzene ring all gave satisfactory results. For *N*-tosyl 4-nitrobenzaldimine (**2f**), a small amount of methyl 4-(*p*-toluenesulfonamido)-2-butenoate (**4**), a phosphine-catalyzed γ-addition adduct of *p*-toluenesulfonamide to **1a**, was also isolated due to the decomposition of **2f**.[14] The reaction of **1a** with an α,β-unsaturated *N*-tosylimine, *N*-tosyl cinnamaldimine (**2i**), also gave the normal [3+2] cycloaddition product **3i** in 53% yield. However, under the same conditions, treatment of **1a** with *N*-tosyl 2-furaldimine (**2j**) afforded two cycloaddition products, **3j** and **5j** (R^1 = 2-furyl, 85:15), in excellent overall yield. When aliphatic *N*-tosylimines lacking α-protons **2k** and **2l** were used, merely trace amounts of **3k** and **3l** were detected due to the low reactivity of **2k** and **2l** and to self-cycloaddition of **1a**.[15] The nitrogen nucleophiles such as DABCO and DMAP could not catalyze this reaction.

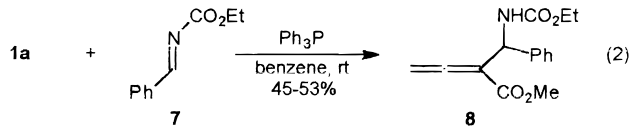
Table 1. Triphenylphosphine-Catalyzed Cycloaddition of Methyl 2,3-Butadienoate with *N*-Tosylimines[a]

		product	
entry	**2**	**3**	yield[b] (%)
1	**2a**	**3a**	98
2	**2b**	**3b**	96
3	**2c**	**3c**	98
4	**2d**	**3d**	98
5	**2e**	**3e**	97
6	**2f**	**3f**	88[c]
7	**2g**	**3g**	98
8	**2h**	**3h**	98
9	**2i**	**3i**	53[d]
10	**2j**	**3j**	83[e]
11	**2k**	**3k**	trace
12	**2l**	**3l**	trace

[a] Reaction conditions: A mixture of **1a** (1.1 mmol), **2** (1.0 mmol), and Ph_3P (0.1 mmol) in dry benzene at room temperature. [b] Isolated yield. [c] A small amount of methyl 4-(*p*-toluenesulfonamido)-2-butenoate (**4**)[14] was isolated. [d] 34% of **2i** was recovered. [e] Another adduct, methyl 4,5-dihydro-5-furyl-1-tosyl-pyrrole-2-carboxylate (**5j**), was isolated in 15% yield.

Cycloaddition of 2,3-Butadienoates with Other Electron-Deficient Imines. To further examine the scope of this three carbon synthon, other imines bearing alternative electron-withdrawing groups on a nitrogen atom that similarly activate the imine but are easier to remove after reaction were tried. Thus, *N*-(diphenylphosphinyl)benzaldimine (diphenylphosphinyl = DPP),[16] *N*-(*p*-nitrobenzenesulfonyl)benzaldimine (*p*-nitrobenzenesulfonyl = Ns),[17] and *N*-(β-trimethylsilylethanesulfonyl)benzaldimines (β-trimethylsilylethanesulfonyl = SES)[18] were reacted with **1** in the presence of a catalytic amount of triphenylphosphine. Again, the cycloaddition reaction occurred. In particular, the SES imines gave the cycloadducts in high yields (Table 2, entries 3−6). The success of the reaction of these imines further expands the synthetic flexibility of the cycloaddition products. For *N*-(*p*-nitrobenzenesulfonyl)benzaldimine, methyl 4-(*p*-nitrobenzenesulfonamido)-2-butenoate (**6**), a phosphine-catalyzed γ-addition adduct of *p*-nitrobenzenesulfonamide to **1a**, was also isolated in 38% yield.[14]

However, under the same conditions, *N*-(ethoxycarbonyl)benzaldimine (**7**) which was employed in place of *N*-sulfonylimines as the dipolarophile reacted with **1a** to afford a noncyclized adduct **8** in 45−53% yield, and no expected [3+2] cycloaddition product was isolated implying that the ethoxycarbonylnitrogen anion is not reactive enough for further reaction (eq 2).



Cycloaddition of 2-Butynoates with *N*-Tosylimines. The success of the cycloaddition of 2,3-

(14) Addition of carbon and oxygen nucleophiles to 2,3-butadienoates under the catalysis of a phosphine gave γ-addition products regioselectively, see: Zhang, C.; Lu, X. *Synlett* **1995**, 645. While this manuscript was under preparation, Trost et al. reported phosphine-catalyzed γ-addition of nitrogen pronucleophiles to methyl 2-butynoate, see: Trost, B. M.; Dake, G. R. *J. Org. Chem.* **1997**, *62*, 5670.

(15) If a trapping reagent is less active than **1a**, the self-cycloaddition product of **1a** is formed. See ref 9.

(16) Jennings, W. B.; Lovely, C. J. *Tetrahedron* **1991**, *47*, 5561.

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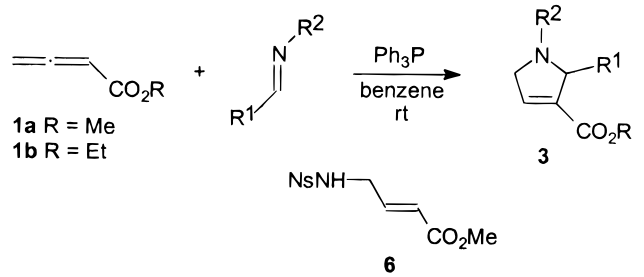
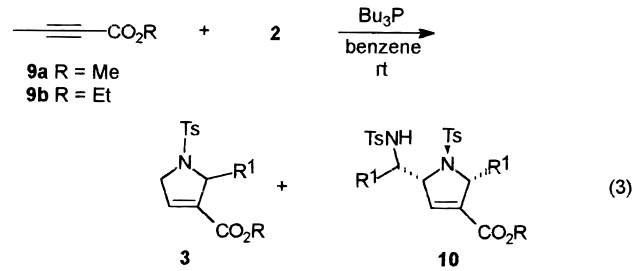
Table 2. Cycloaddition of 2,3-Butadienoates with Other Electron-Deficient Imines Catalyzed by Triphenylphosphine[a]



entry	**1**	R^1	R^2	yield[b] of **3** (%)
1	**1b**	Ph	DPP	26[c]
2	**1a**	Ph	Ns	59[d]
3	**1a**	Ph	SES	96
4	**1b**	Ph	SES	90
5	**1a**	*p*-MeC_6H_4	SES	96
6	**1a**	*p*-ClC_6H_4	SES	97
7	**1a**	(*E*)-PhCH=CH	SES	36[e]

[a] Reaction conditions are similar to Table 1. [b] Isolated yield. [c] 54% of starting material was recovered. [d] Methyl 4-(*p*-nitrobenzenesulfonamido)-2-butenoate (**6**)[14] was isolated in 38% yield. [e] 10% of starting material was recovered.

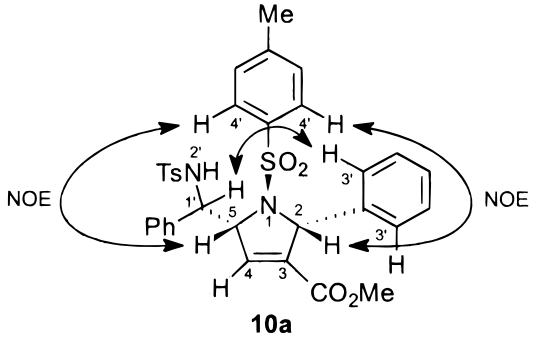
butadienoates with *N*-sulfonylimines encourages us to explore the reaction of 2-butynoates. When a mixture of ethyl 2-butynoate (**9b**) and **2a** in dry benzene in the presence of 15 mol % of triphenylphosphine was heated at 110 °C for 57 h, no reaction occurred, implying that the nucleophilicity of triphenylphosphine was too weak to trigger the 2-butynoate to the active allenic intermediate, which was consistent with our previous result.[9] Thus, tributylphosphine was used instead of triphenylphosphine as the catalyst. Interestingly, treatment of **9b** with **2a** in dry benzene in the presence of a catalytic amount of tributylphosphine at room temperature obtained a small amount of the three components adduct **10a′** besides the corresponding [3+2] cycloadduct **3a′** as the major product in 96% overall yield (eq 3).



Furthermore, the reaction of **1a** with **2a** using tributylphosphine instead of triphenylphosphine as the catalyst was carried out affording an identical result. We, therefore, speculated that the electrophilicity of vinylphosphonium salt intermediate may also play a role in this reaction (*vide infra*).

The structure of **10a** (R = Me, R^1 = Ph) was determined by ^{1}H and ^{13}C NMR spectral analysis, involving COSY, HMQC, NOESY, and deuterium exchange experiments. ^{1}H and ^{13}C NMR spectral data of **10a** are partly summarized in Table 3. In the ^{1}H-^{1}H COSY spectra, H-2, H-4, and H-5 have coupling signals to each other. Both H-5 and H-2′ also have coupling signals with H-1′. In the NOESY spectra, both H-4 and H-1′ have NOE signals with H-5. In particular, H-3′, which has a NOE signal with H-2, also has a NOE signal with H-1′. Here, the chemical shift of H-3′ is shifted to high fields possibly due to the shielding effect of the benzene ring of 1-tosyl. Moreover, H-4′, which has a NOE signal with H-2, also has a NOE signal with H-5 implying that the relative stereochemistry is 1, 2-trans and 2, 5-cis.

Table 3. ^{1}H and ^{13}C NMR Spectral Data of 10a



	^{1}H NMR (300 MHz)	^{13}C NMR (75 MHz)
2	5.43 (br s, 1H)	70.48
4	6.47 (br s, 1H)	136.46
5	4.95 (dt, *J* = 7.5, 2.1 Hz, 1H)	70.98
1′	4.61 (dd, *J* = 7.5, 3.6 Hz, 1H)	62.02
2′	6.05 (d, *J* = 3.6 Hz, 1H)	
3′	6.63 (d, *J* = 7.3 Hz, 2H)	127.65
4′	7.83 (d, *J* = 8.2 Hz, 2H)	128.30

Table 4. Tributylphosphine-Catalyzed Cycloaddition of Methyl 2,3-Butadienoate or 2-Butynoates with *N*-Tosylimines[a]

			products	
entry	**1/9**	**2**	yield[b] (%)	**3:10**[c]
1	**1a**	**2a**	98	87:13 (**3a:10a**)
2	**9b**	**2a**	96	85:15 (**3a′:10a′**)
3	**9a**	**2b**	95	81:19 (**3b:10b**)
4	**9b**	**2c**	86	90:10 (**3c′:10c′**)
5	**9b**	**2d**	93	82:18 (**3d′:10d′**)
6	**9a**	**2e**	87	85:15 (**3e:10e**)
7	**9a**	**2k**	57	100:0 (**3k:10k**)
8	**9a**	**2l**	14	100:0 (**31:101**)
9	**9a**	**2m**	47	100:0 (**3m:10m**)

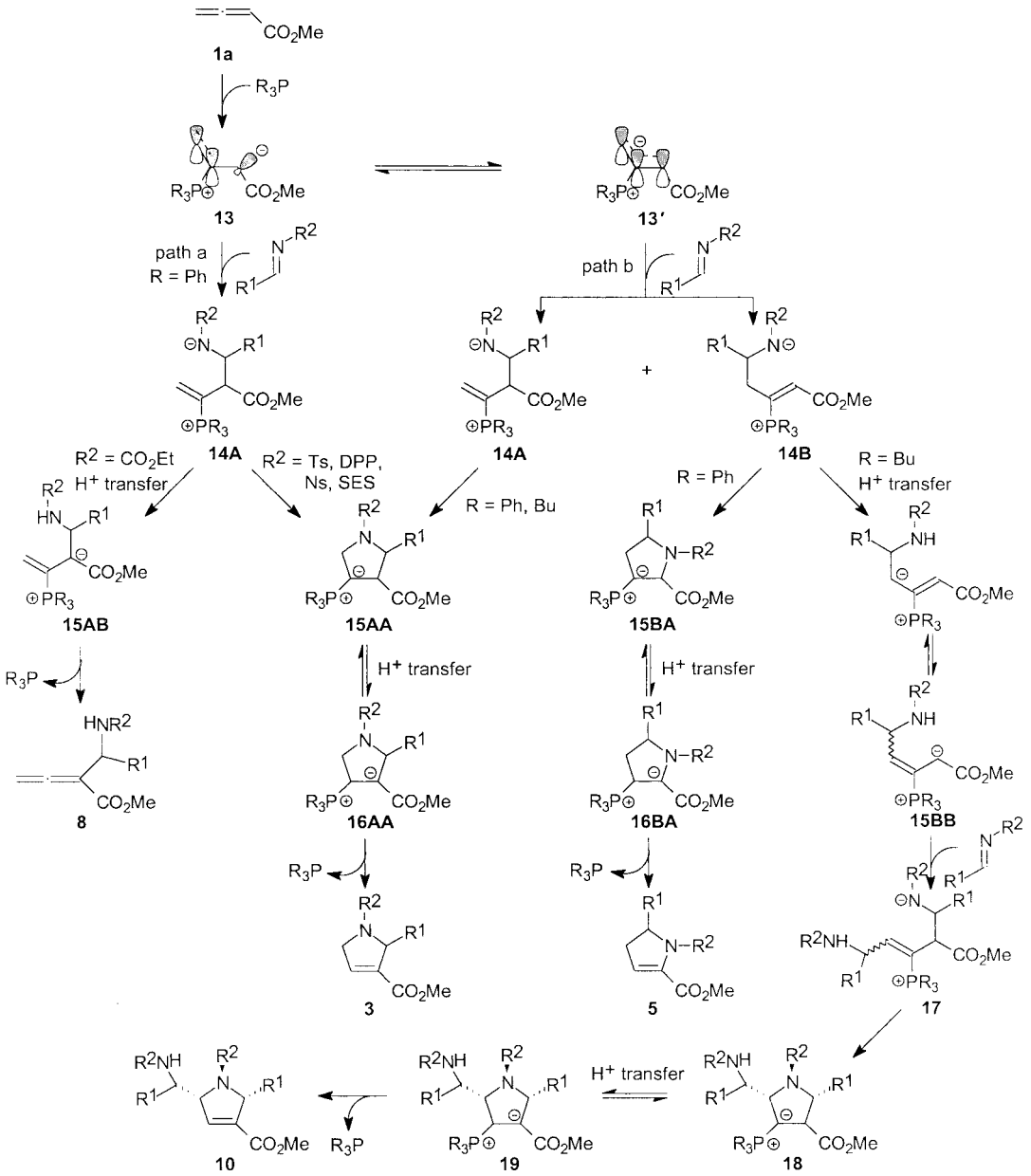
[a] Reaction conditions: A mixture of **1** or **9** (1.1 mmol), **2** (1.0 mmol), and Bu_3P (0.1 mmol) in dry benzene at room temperature. [b] Isolated yield. [c] Ratios were determined by isolation.

Similarly, the reactions of **9** with other *N*-tosylimines (**2b**−**e**) using tributylphosphine as the catalyst afforded identical results (Table 4). For the reaction of **9a** with aliphatic *N*-tosylimine, *N*-tosyl pivalaldimine (**2k**), the corresponding cycloaddition product **3k** was also isolated in 57% yield. Similarly, **3l** and **3m** were obtained in 14% and 47% yields, respectively. Here, the success of the reaction of the aliphatic imines **2k** and **2m** expanded the synthetic utility of this cycloaddition reaction again. For the aliphatic *N*-tosylimines, the tributylphosphine-catalyzed reaction of 2-butynoates gave better results than the triphenylphosphine-catalyzed reaction of 2,3-butadienoates (compare entries 11 and 12 of Table 1 with entries 7−9 of Table 4).

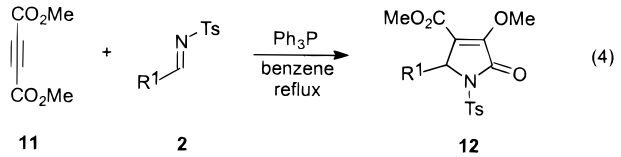
Cycloaddition of Dimethyl Acetylenedicarboxylate and *N*-Tosylimines. Recently, Nozaki et al.[19] reported a triphenylphosphine-catalyzed cyclization of α-keto esters, α-keto nitriles, or α,α,α-trifluoroacetophe-

(19) Nozaki, K.; Sato, N.; Ikeda, K.; Takaya, H. *J. Org. Chem.* **1996**, *61*, 4516.

Scheme 1



none with dimethyl acetylenedicarboxylate to produce highly functionalized α,β-unsaturated γ-butyrolactones in moderate yields. In this reaction, an electron-withdrawing substituent attached to the carbonyl group is essential. From our previous work, we anticipated that *N*-sulfonylimines could also carry out the cyclization reaction instead of the electron-deficient carbonyl compounds as trapping reagents. Treatment of dimethyl acetylenedicarboxylate (**11**) with *N*-tosyl benzaldimine (**2a**) in the presence of 20 mol % of triphenylphosphine in dry benzene under reflux did give 1-tosyl-5-phenyl-3-methoxy-4-methoxycarbonyl-3-pyrrolin-2-one (**12a**) in 84% isolated yield (eq 4).



(4)

Other *N*-tosylimines were also examined under similar conditions, and the results are summarized in Table 5. It is obvious that the steric factors influence yields of the reaction of **11** with aromatic *N*-tosylimines. For example, 2-methoxyphenyl and 1-naphthyl *N*-tosylimines gave the corresponding cyclization products in lower yields with the recovery of the starting materials. In fact, for the less hindered aromatic *N*-tosylimines (e.g., **2a**), the reaction could be carried out at room temperature affording the products in higher yields. The reaction of **11** with the α,β-unsaturated *N*-tosylimine, *N*-tosyl cinnamaldimine (**2i**), also gave the cyclization product **12i** in 85% yield. However, under the same conditions, treatment of **11** with *N*-tosyl 2-methylpropenaldimine (**2n**) afforded the cyclization product **12n** only in 4.2% yield probably due to the instability of **2n**.

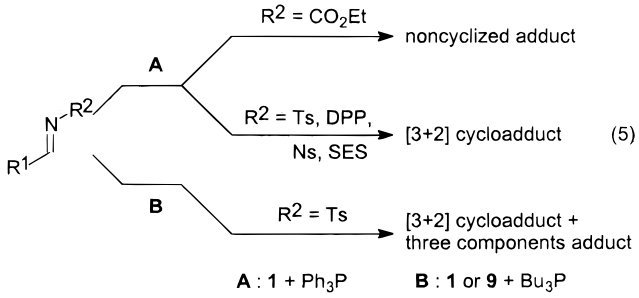
Reaction Mechanism. Since both the phosphine as the catalyst and the imines bearing different electron-withdrawing groups on a nitrogen atom as the dipolaro-

Table 5. Formation of Pyrrolin-2-ones from *N*-Tosylimines and Dimethyl Acetylenedicarboxylate Catalyzed by Triphenylphosphine[a]

			product	
entry	**2**	reaction time (h)	**12**	yield[b] (%)
1	**2a**	4	**12a**	84
2	**2a**	11[c]	**12a**	93
3	**2b**	52	**12b**	27 (68)[d]
4	**2c**	14	**12c**	86 (94)[e]
5	**2d**	14	**12d**	83 (92)[e]
6	**2e**	4	**12e**	96
7	**2g**	3.5	**12g**	97
8	**2h**	28	**12h**	56 (77)[f]
9	**2i**	4	**12i**	85 (95)[g]
10	**2n**[h]	42	**12n**	4.2 (5)[i]

[a] Reaction conditions: A mixture of **11** (1.2 mmol), **2** (1.0 mmol), and Ph_3P (0.2 mmol) in dry benzene was refluxed. [b] Isolated yield. Yields in parentheses are based on the reacted starting materials. [c] The reaction was carried out at room temperature. [d] 60% of starting material was recovered. [e] 9% of starting materials was recovered. [f] 27% of starting material was recovered. [g] 10% of starting material was recovered. [h] R^1 = 2-propenyl. [i] 14% of starting material was recovered.

philes likely change the products formed (eq 5); a reaction

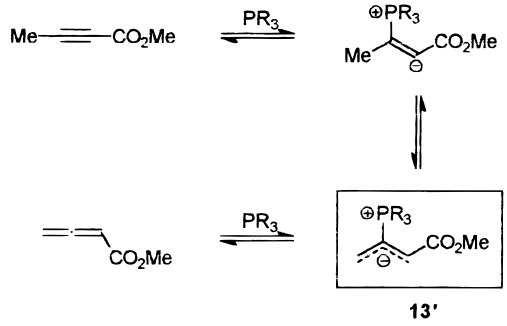


mechanism is proposed as outlined in Scheme 1.

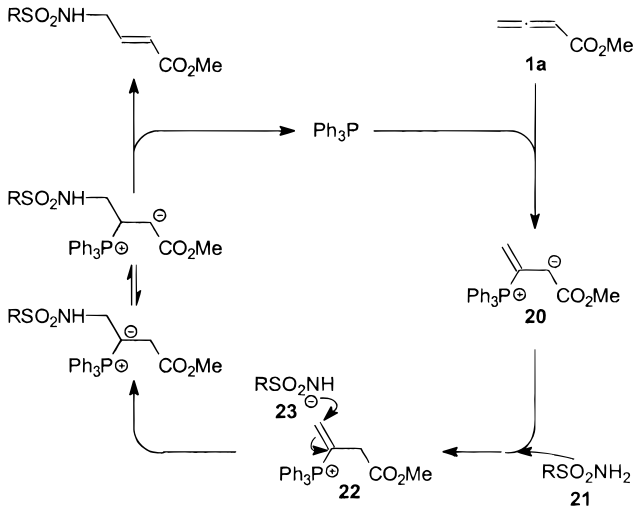
First, allenoate **1a** reacts with a phosphine to generate the reactive dipolar intermediate **13**, which is trapped by the dipolarophilic imine to form an open chain intermediate **14**. Here, both the nucleophilicity of the nitrogen anion and the electrophilicity of the vinylphosphonium salt intermediate are critical for the cycloaddition reaction. For path a, when Ts, DPP, Ns, and SES are used as the activating groups of the imine, the normal cyclization takes place forming the intermediate **15AA**. When the ethoxycarbonyl is used as an activating group, the proton transfer affords the intermediate **15AB**. Finally, the intermediates **15AB** and **15AA** which will first transform to **16AA** by the proton transfer give the corresponding products **3** and **8**, respectively, with the regeneration of the phosphine as the catalytic species. Compound **5j** might be formed by path b due to the lower reactivity of **2j** which could not react with **13** quickly enough to prohibit the transformation of **13** to the delocalized structure **13′**.[20] For the tributylphosphine-catalyzed reaction of **1a**, the intermediate **15BB** is formed by the proton transfer of **14B** and further reacts with another molecule of the imine affording the three components adduct **10**. For the tributylphosphine-catalyzed reaction of 2-butynoates **9**, since the same intermediate

(20) The π orbitals of the two carbon−carbon double bonds in allenes are perpendicular to each other. In the initially generated intermediate **13**, the orbital of the unshared electron pair is also perpendicular to the π orbital of the α,β-carbon−carbon double bond. After a 90° rotation around the $C_\alpha-C_\beta$ bond, the delocalized structure **13′** was formed, which results in the formation of **5**. For a similar result, see: Zhang, C.; Lu, X. *Synlett* **1995**, 645.

Scheme 2



Scheme 3



13′ can be generated, a speculated mechanism is similar to that of the tributylphosphine-catalyzed reaction of **1** via the intermediate **13′** (Scheme 2).

For the phosphine-catalyzed γ-addition reaction of sulfonamides to **1a**, a possible mechanism is outlined in Scheme 3. First, triphenylphosphine attacks the β-carbon of **1a** to give the phosphonium salt intermediate **20**, which then abstracts a proton from the sulfonamide **21** to form the corresponding vinylphosphonium salt **22**, and subsequent Michael addition of sulfonamide anion **23** to **22** followed by a proton transfer affords the γ-addition product with the regeneration of triphenylphosphine to complete the catalytic cycle.

For the reaction of dimethyl acetylenedicarboxylate with *N*-tosylimines catalyzed by triphenylphosphine, a proposed mechanism of the reaction is outlined in Scheme 4. First, nucleophilic attack of triphenylphosphine on the β-carbon of the electron-deficient alkyne **11** generates the zwitterionic intermediate **24**, which is trapped by the electrophilic *N*-tosylimine **2** followed by intramolecular nucleophilic addition of the nitrogen atom of toluenesulfonamide to the carbonyl group of ester and subsequent elimination of methoxy group to form the cyclic phosphonium alkoxide intermediate **25**. Finally, conjugate addition of the methoxy anion to the β-triphenylphosphonium α,β-unsaturated ester counterpart affords the corresponding cyclization product **12** with the regeneration of triphenylphosphine to complete the catalytic cycle.

Elaborations of the Cycloaddition Products. To further confirm the stucture of the cycloaddition product and to develop a new route to pyrrole derivatives, we carried out the aromatization of the cycloadduct using

Scheme 4

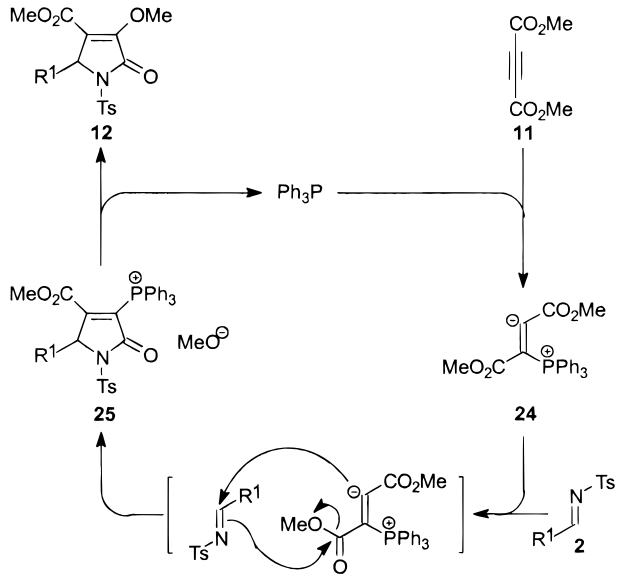
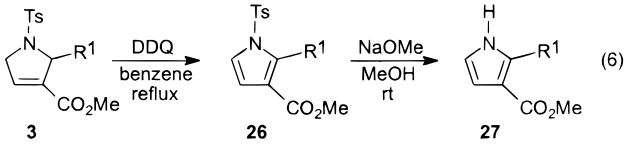


Table 6. Synthesis of 2-Aryl Pyrrole Derivatives

				product			
entry	**3**	DDQ (eq)	time (days)	**26**	yield[a] (%)	**27**	yield[a] (%)
1	**3a**	2.0	1.5	**26a**	92	**27a**	86
2	**3b**	1.5	2.5	**26b**	81	**27b**	92
3	**3e**	1.5	2	**26e**	95	**27e**	88
4	**3g**	2.0	3	**26g**	38	**27g**	87
5	**3h**	1.5	2	**26h**	99	**27h**	95

[a] Isolated yield.

DDQ as the oxidant followed by treatment with sodium methoxide in methanol to eliminate the tosyl group (eq 6).

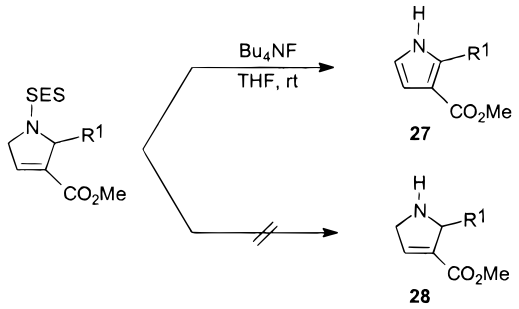


(6)

Heating the mixture of the cycloadduct, **3a**, **3b**, **3e**, **3g**, or **3h**, and DDQ (1.5−2.0 equiv) in dry benzene at about 130 °C for about 2−3 days until the starting material completely disappeared as monitored by TLC gave the dehydrogenation product, **26a**, **26b**, **26e**, **26g** or **26h**, in moderate to good yield (Table 6). Subsequent detosylation of **26** using sodium methoxide produced the pyrrole **27** in excellent yield. Surprisingly, aromatization of **3i** gave the defurylated product (**26**, R^1 = H) in 14% yield.

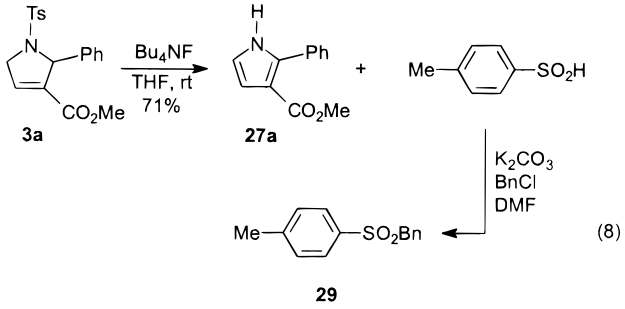
The SES group has been shown to be easily removed from amines by fluoride.[21] Thus, we carried out the deprotection of its corresponding cycloaddition products using Bu_4NF in THF at room temperature or reflux. Unexpectedly, the desulfonylated aromatized products (**27**) were directly obtained instead of the corresponding desulfonylated products (**28**) in moderate yields (eq 7).

It is worth noting that this reaction can also be applied to the aromatization of *N*-tosyl derivative **3a**. In this case, it was suggested that the reaction occurred via a tandem desulfination−isomerization process by the isolation of *p*-toluenesulfinic acid as the by-product, the structure of which was further confirmed by its conversion to the benzyl sulfone **29** (eq 8).[22]



(7)

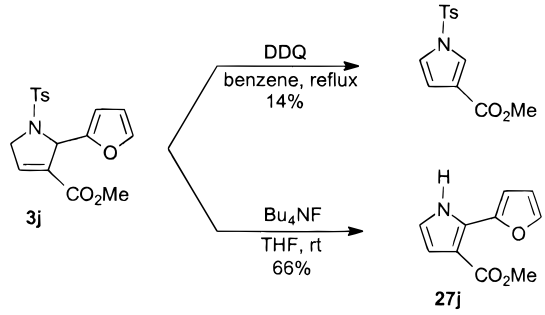
R^1 = Ph, 49%; *p*-MeC_6H_4, 65%; *p*-ClC_6H_4, 62%



(8)

While sodium methoxide was used instead of Bu_4NF as a base, no expected product was isolated.

The aromatization reaction mediated by Bu_4NF is a convenient and efficient method for the synthesis of pyrrole derivatives. For instance, methyl 2-furyl-1*H*-pyrrole-3-carboxylate (**27j**) was synthesized in 66% yield using this method, which could not be obtained using DDQ dehydrogenation method (eq 9).



(9)

Furthermore, 2-aryl-substituted pyrroles can also be formed readily via the decarboxylation of **27** as shown in eq 10.[23] Thus, this provides a new and efficient route

(10)

to 2-aryl-substituted pyrrole derivatives.

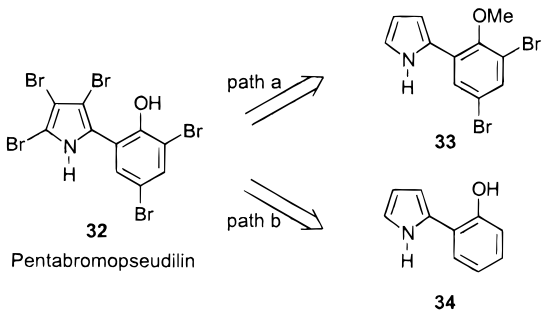
The removal of the tosyl group from *p*-toluenesulfonylamide usually requires relatively harsh reaction conditions.[24] We applied the radical approach developed by

(21) Weinreb, S. M.; Demko, D. M.; Lessen, T. A. *Tetrahedron Lett.* **1986**, *27*, 2099.

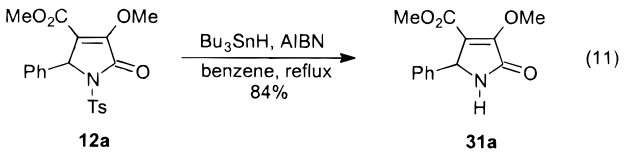
(22) Kamiyama, T.; Enomoto, S.; Inoue, M. *Chem. Pharm. Bull.* **1988**, *36*, 2652.

(23) Pavri, N. P.; Trudell, M. L. *J. Org. Chem.* **1997**, *62*, 2649.

Scheme 5



Parsons et al.[25] to the N-desulfonation of the highly functionalized substrate **12a**, yielding the expected detosylated product **31a** in 84% yield (eq 11). This provides



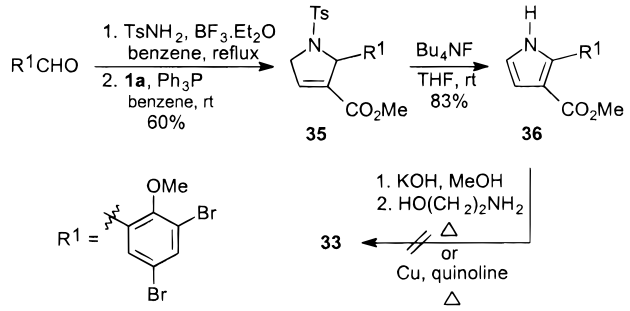
(11)

a convenient synthesis of pyrrolin-2-one derivatives.

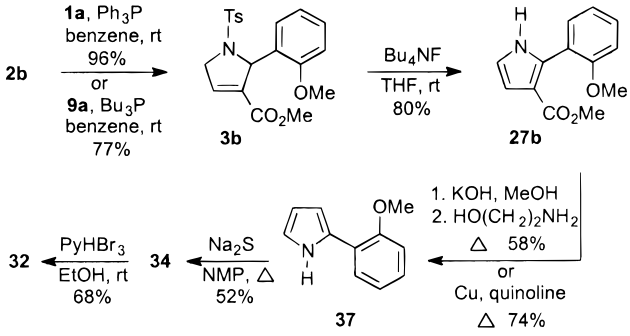
Synthesis of Pentabromopseudilin. Pentabromopseudilin (**32**), a potent marine antibiotic isolated from *Pseudomonas bromoutiliz*,[26] *Chromobacteria*,[27] and *Alteromonas luteoviolaceus*,[28] is a stronger antibiotic than penicillin[29] and exhibits antitumor, antimicrobial, and phytotoxic activities.[30] The interesting biological properties and the high bromine content (over 70%) made it an interesting object. To date, two different syntheses have been reported,[28,31] and the biosynthesis was also investigated.[29] At the same time, numerous analogues have been synthesized, and their biological and pharmacological activities were tested.[28,30,32] We now report a novel synthesis of pentabromopseudilin on the basis of this new [3+2] cycloaddition.

All syntheses reported involved the same key intermediate, 2-(3,5-dibromo-2-methoxyphenyl)-1*H*-pyrrole (**33**) (Scheme 5, path a). Initially, we also attempted to synthesize the intermediate as shown in Scheme 6. The easy hydrolysis of *N*-tosyl 2-methoxy-3,5-dibromobenzaldimine led to direct use of the crude product in the cycloaddition without further purification. The cycloadduct **35** was obtained in 60% yield based on the starting aldehyde. Subsequent aromatization mediated by Bu_4NF afforded 2-aryl-substitued pyrrole carboxylate **36** in 83% yield. However, hydrolysis and subsequent decarboxylation of **36** with ethanolamine or Cu powder/

Scheme 6



Scheme 7



quinoline methods was unsuccessful due to the thermoinstability of **33**.

Then, we chose the parent compound, 2-(2-hydroxyphenyl)-1*H*-pyrrole (**34**), as the key intermediate as shown in Scheme 7. The adduct **3b** is available from *N*-tosyl 2-methoxybenzaldimine (**2b**) and methyl 2,3-butadienoate (**1a**) or methyl 2-butynoate (**9a**) under the catalysis of a phosphine. Aromatization of **3b** gave the pyrrole derivative **27b** readily by treatment of Bu_4NF in THF at room temperature. Hydrolysis and subsequent decarboxylation of **27b** with ethanolamine or Cu powder/quinoline followed by demethylation with sodium sulfide in *N*-methylpyrrolidone (NMP)[33] afforded the key intermediate **34**. Subsequent bromination to introduce five bromine atoms to **34** in a single operation is a challenging step. Several attempts directly using elemental bromine as a bromination reagent were unsucessful. The desired bromination was finally achieved by employing pyridinium bromide perbromide,[34] and the target molecule **32** was thus obtained in 20% overall yield from *N*-tosylimine **2b**.

Conclusion

In summary, we presented the reactivity of the new three carbon synthon, generated in situ from the reaction of **1** or **9** with an appropriate phosphine toward imines bearing an electron-withdrawing group on nitrogen atoms such as sulfonyl (Ts, Ns, SES), diphenylphosphinyl, and ethoxycarbonyl. It was found that the phosphine used can influence the electrophilic reactivity of vinylphosphonium salt intermediate **14**. That is, vinyltriphenylphosphonium salt has stronger electrophilicity and

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(25) Parsons, A. F.; Pettifer, R. M. *Tetrahedron Lett.* **1996**, *37*, 1667.
(26) Burkholder, P. R.; Pfister, R. M.; Leitz, F. H. *Appl. Microbiol.* **1966**, *14*, 649.
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(28) Laatsch, H.; Pudleiner, H. *Liebigs Ann. Chem.* **1989**, 863.
(29) Hanefeld, U.; Floss, H. G.; Laatsch, H. *J. Org. Chem.* **1994**, *59*, 3604.
(30) Laatsch, H.; Renneberg, B.; Hanefeld, U.; Kellner, M.; Pudleiner, H.; Hamprecht, G.; Kraemer, H. P.; Anke, H. *Chem. Pharm. Bull.* **1995**, *43*, 537.
(31) Hanessian, S.; Kaltenbronn, J. S. *J. Am. Chem. Soc.* **1966**, *88*, 4509.
(32) (a) Pudleiner, H.; Laatsch, H. *Liebigs Ann. Chem.* **1990**, 423. (b) Hanefeld, U.; Laatsch, H. *Liebigs Ann. Chem.* **1991**, 865. (c) Renneberg, B.; Kellner, M.; Laatsch, H. *Liebigs Ann. Chem.* **1993**, 847.
(33) Newman, M. S.; Sankaran, V.; Olson, D. R. *J. Am. Chem. Soc.* **1976**, *98*, 3237.
(34) *Reagents for Organic Synthesis*; Fieser, L. F., Fieser, M., Eds; Wiley-Interscience: New York, 1967; Vol. 1, p 967.

takes advantage of [3+2] cycloaddition.[35,36] Although nucleophilic attack of tributylphosphine is easier than that of triphenylphosphine, the electrophility of its correspounding vinylphosphonium salt intermediate is weaker. On the other hand, the stronger the electron-withdrawing group on the nitrogen atom of imines as the dipolarophiles, the more favored the cycloaddition. For the ethoxycarbonyl, no cycloaddition product was produced due to the nucleophilicity of the corresponding nitrogen anion. For the diphenylphosphinyl, the cycloadduct was obtained only in low yield with the recovery of the starting material due to the low electrophilicity of the carbon atom of the corresponding imine. For the *p*-nitrobenzenesulfonyl, the cycloaddition product was obtained in moderate yield due to the low stability of the imine. Thus, Ts and SES are the most suitable activating groups for this cycloaddition reaction. In addition, a new phosphine-catalyzed cyclization reaction of dimethyl acetylenedicarboxylate with *N*-tosylimines was developed. The transformation of the cycloaddition products was also studied, and as an illustration, pentabromopseudilin was synthesized efficiently from easily available *N*-tosyl 2-methoxybenzaldimine. The investigation of the appropriate dipolarophiles and the synthetic utilization of the three carbon synthon is in progress.

Experimental Section

Materials. Methyl 2,3-butadienoate (**1a**),[37] ethyl 2,3-butadienoate (**1b**),[38] *N*-tosylimines **2a**−**k**,[39] **2l**,[10e] and **2n**,[40] and *N*-(diphenylphosphinyl)benzaldimine[10e] were prepared by the reported methods. Tetrabutylammonium fluoride (1.0 M solution in tetrahydrofuran) was purchased from Aldrich and used directly. All solvents were purified by distillation from the indicated drying agents: benzene (sodium), dichloromethane (CaH_2), and THF (sodium, benzophenone). ^{1}H NMR spectra were recorded on a 300 MHz spectrometer in $CDCl_3$ using tetramethylsilane as the internal standard. Infrared spectra were measured using KBr disk unless otherwise stated.

***N*-(*p*-Nitrobenzenesulfonyl)benzaldimine and *N*-(*β*-Trimethylsilylethanesulfonyl)benzaldimines**[18] were synthesized according to a procedure analogous to that described by McKay.[39] To a solution of benzaldehyde (1 mL, 10 mmol) and *β*-trimethylsilylethanesulfonamide (1.81 g, 10 mmol) in benzene (80 mL) was added BF_3·Et_2O (0.08 mL). The mixture was refluxed on a Dean−Stark apparatus for 24 h. The cooled solution was poured into saturated $NaHCO_3$ (100 mL), the benzene layer was isolated, and the water layer was extracted once with ethyl acetate (50 mL). The combined organic phase was dried over Na_2SO_4. After solvents were evaporated under reduced pressure, the residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 9:1) to yield a solid which was recrystallized from petroleum ether or CH_2Cl_2/petroleum ether.

***N*-(*p*-Nitrobenzenesulfonyl)benzaldimine.** Yield 81%; mp 148.5−149.5 °C (EtOAc/petroleum ether); ^{1}H NMR δ 9.14 (s, 1H), 8.41 (d, J = 8.80 Hz, 2H), 8.22 (d, J = 8.75 Hz, 2H), 7.97 (deformed d, J = 7.13 Hz, 2H), 7.69 (deformed t, J = 7.44 Hz, 1H), 7.54 (deformed t, J = 7.67 Hz, 2H); IR 1528, 1351, 1164 cm^{-1}; MS *m*/*z* 290 (M^+, 15.75), 104 ($PhCH{=}N^+$, 100.00); HRMS calcd for $C_{13}H_{10}N_2O_4S$ 290.0361, found 290.0381.

***N*-(*β*-Trimethylsilylethanesulfonyl)benzaldimine.** Yield 82%; mp 54−56 °C (hexane); ^{1}H NMR δ 9.04 (s, 1H), 7.97 (deformed d, J = 7.06 Hz, 2H), 7.66 (deformed t, J = 7.35 Hz, 1H), 7.53 (deformed t, J = 7.60 Hz, 2H), 3.18−3.12 (m, 2H), 1.09−1.03 (m, 2H), 0.06 (s, 9H); IR 1609, 1316, 1136 cm^{-1}; MS *m*/*z* 192 (M^+−Ph, 56.96), 104 (M^+−SES, 19.43), 73 (TMS^+, 100.00); HRMS calcd for $C_{12}H_{19}NO_2SSi$ 269.0906, found 269.0871.

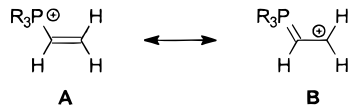
***N*-(*β*-Trimethylsilylethanesulfonyl)cinnamaldimine.** Yield 69%; mp 93−94 °C (petroleum ether); ^{1}H NMR δ 8.77 (d, J = 9.38 Hz, 1H), 7.62−7.42 (m, 6H), 7.04 (dd, J = 15.80, 9.49 Hz, 1H), 3.13−3.06 (m, 2H), 1.07−1.01 (m, 2H), 0.07 (s, 9H); IR 1621, 1584, 1312, 1141 cm^{-1}; MS *m*/*z* 295 (M^+, 0.17), 188 ($M^+-SO_2-C_2H_4-CH_3$, 42.46), 130 (M^+−SES, 25.51), 73 (TMS^+, 100.00). Anal. calcd for $C_{14}H_{21}NO_2SSi$: C, 56.91; H, 7.16; N, 4.74. Found: C, 56.82; H, 7.29; N, 4.73.

***N*-Tosyl 2-methyl-1,3-dithiane-2-carboxaldimine (2m)** was similarly synthesized from 2-methyl-1,3-dithiane-2-carboxaldehyde.[39] Yield 56%; mp 85−88 °C; ^{1}H NMR δ 8.34 (s, 1H), 7.84 (d, J = 8.2 Hz, 2H), 7.35 (d, J = 8.2 Hz, 2H), 3.06 (ddd, J = 14.7, 12.9, 2.6 Hz, 2H), 2.56 (ddd, J = 14.7, 4.2, 3.3 Hz, 2H), 2.44 (s, 3H), 2.11−2.04 (m, 1H), 1.85−1.69 (m, 1H), 1.56 (s, 3H); IR 1618, 1316, 1153 cm^{-1}; MS *m*/*z* 315 (M^+, 3.32), 133 ($M^+-CH{=}NTs$, 100.00); HRMS calcd for $C_{13}H_{17}NO_2S_3$ 315.0421, found 315.0382.

***N*-(Ethoxycarbonyl)benzaldimine (7)**[41] was synthsized according to a procedure analogous to that described by Greene.[42] Benzaldehyde (3 mL, 29 mmol) in methanol (10 mL) and 88% formic acid (5 mL) was added to a solution of urethane (2.23 g, 25 mmol) and sodium benzenesulfinate dihydrate (5.01 g, 25 mmol) in water (25 mL). The mixture was heated at 70 °C for 2 h and then allowed to stir overnight at room temperature. The resulting white precipitate was filtered and washed sequentially with water, petroleum ether, and diisopropyl ether and dried in vacuo to give 3.69 g (46%) of *N*-ethoxycarbonyl-α-(phenylsulfonyl)benzylamine, suitable for use in the next step without purification. Data for sulfone: ^{1}H NMR (90 MHz) δ 7.90−7.77 (m, 2H), 7.67−7.18 (m, 8H), 5.98 (br s, 2H), 3.97 (q, J = 7.5 Hz, 2H), 1.12 (t, J = 7.5 Hz, 3H). A mixture of sulfone (0.58 g, 1.8 mmol), obtained as described above, and anhydrous K_2CO_3 (1.5 g, 10.8 mmol) in THF (20 mL) under nitrogen was refluxed at 95−100 °C on an oil bath for 12 h. The mixture was then allowed to cool to room temperature and filtered through filter paper, and the solid was washed with THF (5 mL). The combined filtrate was concentrated under reduced pressure and then dried in vacuo at room temperature for several hours, furnishing 0.31 g (97%) of imine **7**.[41] ^{1}H NMR (90 MHz, CCl_4) δ 8.71 (s, 1H), 7.90−7.68 (m, 2H), 7.50−7.23 (m, 3H), 4.18 (q, J = 7.5 Hz, 2H), 1.28 (t, J = 7.5 Hz, 3H).

Triphenylphosphine-Catalyzed Cycloaddition of Methyl 2,3-Butadienoate with *N*-Tosylimines. General Procedure for the Preparation of Methyl 2,5-Dihydro-2-substitued-1-tosyl-pyrrole-3-carboxylate (3). To a mixture of triphenylphosphine (30 mg, 0.1 mmol) and *N*-tosylimine **2**

(35) The extent of the electron deficientcy of the β carbon in vinylphosphonium salts is interpreted as due to the overlap of the π orbital of the vinyl group with an empty d orbital on phosphorus, that is dπ-pπ bonding between phosphorus and carbon. A comparison of the ^{31}P chemical shifts or the ^{13}C chemical shifts of the β vinyl carbon in vinyltriphenylphosphonium bromide (**38**) and vinyltributylphosphonium bromide (**39**) shows that the phosphorus in **38** (δ 19.3 ppm) is shifted to high fields relative to the phosphorus in **39** (δ 27.4 ppm) and that the β vinyl carbon in **38** (δ 145.2 ppm) is shifted to low fields relative to the β vinyl carbon in **39** (δ 141.2 ppm). Indeed, these both indicate that the contribution of significant dπ-pπ conjugation in vinyltriphenylphosphonium salt with resonance structure **B** is important and that the β vinyl carbon of vinyltriphenylphosphonium salt can be regarded as positive. Therefore, the cycloaddition of vinyltriphenylphosphonium salt is preferred.[36]



A **B**

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(1.0 mmol) in benzene (5 mL) was added a solution of methyl 2,3-butadienoate (**1a**) (110 mg, 1.1 mmol) in benzene (5 mL). The mixture was then stirred at room temperature under nitrogen and monitored by TLC (eluent: petroleum ether/ethyl acetate = 4/1). After the reaction was complete, the reaction mixture was concentrated under reduced pressure and the residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 17:3) to give **3**.

Methyl 2,5-Dihydro-2-phenyl-1-tosyl-pyrrole-3-carboxylate (3a). Mp 109−110 °C; ^{1}H NMR δ 7.42 (d, J = 8.2 Hz, 2H), 7.23 (s, 5H), 7.14 (d, J = 8.2 Hz, 2H), 6.77 (q, J = 1.9 Hz, 1H), 5.75 (dt, J = 5.7, 1.9 Hz, 1H), 4.53 (dt, J = 17.1, 2.4 Hz, 1H), 4.37 (ddd, J = 17.1, 5.7, 1.9 Hz, 1H), 3.58 (s, 3H), 2.36 (s, 3H); IR 1726, 1648, 1341, 1159 cm^{-1}; MS m/z 357 (M^+, 3.89), 280 (M^+-Ph, 42.20), 202 (M^+-Ts, 68.89), 91 ($CH_3C_6H_4^+$, 100.00). Anal. calcd for $C_{19}H_{19}NO_4S$: C, 63.85; H, 5.36; N, 3.92. Found: C, 63.59; H, 5.18; N, 3.65.

Methyl 4-(*p*-Toluenesulfonamido)-2-butenoate (4). Mp 100−101 °C; ^{1}H NMR δ 7.75 (d, J = 8.2 Hz, 2H), 7.33 (d, J = 7.9 Hz, 2H), 6.78 (dt, J = 15.7, 5.20 Hz, 1H), 5.95 (dt, J = 15.7, 1.84 Hz, 1H), 4.58 (deformed t, J = 6.07 Hz, 1H), 3.79−3.74 (m, 2H), 3.72 (s, 3H), 2.44 (s, 3H); IR 3265, 3242, 1726, 1702, 1663, 1160 cm^{-1}; MS m/z 238 (M^+-OMe, 1.16), 114 (M^+-Ts, 100.00), 82 (M^+-TsH−OMe, 52.30). Anal. calcd for $C_{12}H_{15}NO_4S$: C, 53.51; H, 5.61; N, 5.20. Found: C, 53.48; H, 5.38; N, 5.00.

Methyl 2,5-Dihydro-2-cinnamyl-1-tosyl-pyrrole-3-carboxylate (3i). Mp 118.5−119.5 °C (CCl_4); ^{1}H NMR (400 MHz) δ 7.71 (d, J = 8.3 Hz, 2H), 7.30−7.22 (m, 7H), 6.69 (d, J = 15.8 Hz, 1H), 6.66 (q, J = 1.6 Hz, 1H), 6.01 (dd, J = 15.8, 7.1 Hz, 1H), 5.39 (tm, J = 5.5 Hz, 1H), 4.44 (dt, J = 17.2, 2.3 Hz, 1H), 4.32 (ddd, J = 17.3, 5.4, 1.9 Hz, 1H), 3.71 (s, 3H), 2.38 (s, 3H); IR 1717, 1647, 1271, 1167 cm^{-1}; MS m/z 383 (M^+, 0.72), 280 (M^+-PhCH=CH, 7.23), 228 (M^+-Ts, 55.77), 196 (M^+-TsH−OMe, 100.00). Anal. calcd for $C_{21}H_{21}NO_4S$: C, 65.77; H, 5.52; N, 3.65. Found: C, 65.35; H, 5.38; N, 3.40.

Methyl 2,5-Dihydro-2-furyl-1-tosyl-pyrrole-3-carboxylate (3j). Mp 136−137 °C (CCl_4); ^{1}H NMR (400 MHz) δ 7.47 (d, J = 8.3 Hz, 2H), 7.19 (d, J = 8.2 Hz, 2H), 7.15 (dd, J = 1.7, 0.7 Hz, 1H), 6.81 (dt, J = 2.4, 1.8 Hz, 1H), 6.36 (dd, J = 3.2, 0.8 Hz, 1H), 6.27 (dd, J = 3.2, 1.8 Hz, 1H), 5.86 (dt, J = 5.6, 1.7 Hz, 1H), 4.47 (dt, J = 16.9, 2.3 Hz, 1H), 4.30 (ddd, J = 16.8, 5.6, 1.9 Hz, 1H), 3.65 (s, 3H), 2.38 (s, 3H); IR 1726, 1647, 1343, 1163 cm^{-1}; MS m/z 347 (M^+, 0.82), 192 (M^+-Ts, 84.68), 160 (M^+-TsH−OMe, 89.01), 91 ($CH_3C_6H_4^+$, 100.00). Anal. calcd for $C_{17}H_{17}NO_5S$: C, 58.78; H, 4.93; N, 4.03. Found: C, 58.71; H, 4.86; N, 3.87.

Methyl 4,5-Dihydro-5-furyl-1-tosyl-pyrrole-2-carboxylate (5j). Mp 104−106 °C; ^{1}H NMR δ 7.86 (d, J = 8.4 Hz, 2H), 7.67 (d, J = 1.4 Hz, 1H), 7.31 (d, J = 8.3 Hz, 2H), 7.32−7.25 (m, 2H), 7.11 (d, J = 3.6 Hz, 1H), 6.56 (dd, J = 3.7, 1.6 Hz, 1H), 3.75 (s, 3H), 2.42 (s, 3H), 1.77 (d, J = 7.2 Hz, 2H); IR 1726, 1648, 1261, 1157 cm^{-1}; MS m/z 348 (M^+ + 1, 4.64), 192 (M^+-Ts, 40.57), 160 (M^+-TsH−OMe, 43.87), 91 ($CH_3C_6H_4^+$, 100.00); HRMS calcd for $C_{17}H_{17}NO_5S$ 347.0828, found 347.0829.

Cycloadditions of 2,3-Butadienoates with Other Electron-Deficient Imines Catalyzed by Triphenylphosphine. The procedure was similar to that described above.

Ethyl 2,5-Dihydro-2-phenyl-1-diphenylphosphinylpyrrole-3-carboxylate. Syrup; ^{1}H NMR δ 7.83−7.77 (m, 2H), 7.58−7.07 (m, 11H), 6.87−6.84 (m, 3H), 5.54−5.48 (m, 1H), 4.43−4.32 (m, 2H), 4.06−3.93 (m, 2H), 1.09 (t, J = 7.14 Hz, 3H); IR 1718, 1650, 1440, 1262, 1209, 1124 cm^{-1}; MS m/z 418 (M^+ + 1, 80.25), 216 (M^+-DPP, 49.92), 201 (DPP^+, 100.00); HRMS calcd for $C_{25}H_{24}NO_3P$ 417.1494, found 417.1462.

Methyl 2,5-Dihydro-2-phenyl-1-(*p*-nitrobenzenesulfonyl)-pyrrole-3-carboxylate. Mp 181.5−182.5 °C (benzene/hexane); ^{1}H NMR δ 8.06 (d, J = 8.87 Hz, 2H), 7.47 (d, J = 8.74 Hz, 2H), 7.25−7.08 (m, 5H), 6.88−6.86 (m, 1H), 5.86−5.83 (m, 1H), 4.70 (dt, J = 16.63, 2.27 Hz, 1H), 4.38 (ddd, J = 16.62, 5.96, 1.84 Hz, 1H), 3.60 (s, 3H); IR 1728, 1648, 1531, 1350, 1165 cm^{-1}; MS m/z 388 (M^+, 6.62), 329 (M^+-CO_2Me, 76.79), 311 (M^+-Ph, 73.06), 202 (M^+-Ns, 99.73), 170 (M^+-NsH−OMe, 100.00). Anal. calcd for $C_{18}H_{16}N_2O_6S$: C, 55.66; H, 4.15; N, 7.21. Found: C, 55.72; H, 3.92; N, 7.15.

Methyl 2,5-Dihydro-2-phenyl-1-(β-trimethylsilylethanesulfonyl)-pyrrole-3-carboxylate. Mp 98.5−99.5 °C (benzene/hexane); ^{1}H NMR δ 7.35−7.31 (m, 5H), 6.92 (q, J = 1.91 Hz, 1H), 5.81 (dt, J = 6.11, 2.07 Hz, 1H), 4.75 (dt, J = 17.03, 2.50 Hz, 1H), 4.39 (ddd, J = 17.00, 6.20, 1.92 Hz, 1H), 3.61 (s, 3H), 2.31 (dtd, J = 30.50, 13.54, 4.40 Hz, 2H), 0.71 (dtd, J = 44.16, 13.7, 4.47 Hz, 2H), −0.19 (s, 9H); IR 1724, 1639, 1149, 1091 cm^{-1}; MS m/z 352 (M^+-CH_3, 1.99), 202 (M^+-SES, 33.47), 170 (M^+-SESH−OMe, 33.01), 73 (TMS^+, 100.00). Anal. calcd for $C_{17}H_{25}NO_4SSi$: C, 55.55; H, 6.86; N, 3.81. Found: C, 55.77; H, 7.10; N, 3.99.

Methyl 2,5-Dihydro-2-cinnamyl-1-(β-trimethylsilylethanesulfonyl)-pyrrole-3-carboxylate. Mp 82−84 °C (hexane); ^{1}H NMR δ 7.40−7.23 (m, 5H), 6.82 (q, J = 1.85 Hz, 1H), 6.76 (d, J = 15.75 Hz, 1H), 6.07 (dd, J = 15.77, 8.16 Hz, 1H), 5.50−5.46 (m, 1H), 4.65 (dt, J = 17.10, 2.30 Hz, 1H), 4.31 (ddd, J = 17.13, 5.74, 1.91 Hz, 1H), 3.81 (s, 3H), 2.97−2.88 (m, 2H), 1.10−0.89 (m, 2H), −0.09 (s, 9H); IR 1722, 1642, 1334, 1272, 1147 cm^{-1}; MS m/z 393 (M^+, 1.17), 228 (M^+-SES, 8.80), 196 (M^+-SESH−OMe, 6.89), 73 (TMS^+, 100.00). Anal. calcd for $C_{19}H_{27}NO_4SSi$: C, 57.98; H, 6.91; N, 3.56. Found: C, 58.17; H, 6.98; N, 3.73.

Triphenylphosphine-Catalyzed Reaction of Methyl 2,3-Butadienoate with *N*-(Ethoxycarbonyl)benzaldimine. To a solution of triphenylphosphine (30 mg, 0.10 mmol) in benzene (4 mL) was added a solution of allenoate **1a** (0.14 g, 1.43 mmol) and imine **7** (0.215 g, 1.21 mmol) in benzene (10 mL) at room temperature under nitrogen with a springe pump at 0.35 mL/h rate for 22 h, and the mixture was stirred for 24 h. The reaction mixture was then concentrated under reduced pressure, and the residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 17:3) to afford 0.255 g (54%) of a noncyclized adduct **8** as a syrup. ^{1}H NMR δ 7.37−7.24 (m, 5H), 5.79 (deformed d, J = 9.1 Hz, 1H), 5.71 (deformed d, J = 9.1 Hz, 1H), 5.35 (br s, 2H), 4.12 (q, J = 7.1 Hz, 2H), 3.66 (s, 3H), 1.22 (t, J = 7.1 Hz, 3H); ^{13}C NMR (75 MHz) δ 213.1 (allenic C), 165.8 (C), 155.6 (C), 140.2 (C), 128.4 (CH), 127.5 (CH), 126.5 (CH), 101.8 (C), 81.3 (CH_2), 61.0 (CH_2), 53.8 (CH), 52.1 (CH_3), 14.4 (CH_3); IR (film) 3333, 1966 (allene), 1719, 1506, 1269, 1252 cm^{-1}; MS m/z 275 (M^+, 17.86), 187 (M^+-NHCO_2Et, 43.13), 178 ($PhCHNHCO_2Et^+$, 100.00); HRMS calcd for $C_{15}H_{17}NO_4$ 275.1157, found 275.1170.

Tributylphosphine-Catalyzed Cycloaddition of 2-Butynoates with *N*-Tosylimines. General Procedure for the Preparation of 2,5-Dihydro-2-substitued-1-tosyl-pyrrole-3-carboxylates (3) and 2,5-Dihydro-2,5-disubstitued-1-tosyl-pyrrole-3-carboxylates (10). 2-Butynoate (1.1 mmol) in benzene (4 mL) and tributylphosphine (0.17 M in benzene, 0.6 mL, 0.1 mmol) were added to *N*-tosylimine **2** (1.0 mmol) in benzene (5 mL). The mixture was then stirred at room temperature under nitrogen and monitored by TLC (eluent: petroleum ether/ethyl acetate = 4/1). After the reaction was complete, the reaction mixture was concentrated under reduced pressure and the residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 17:3 for first fraction and then 3:1 for second fraction) to afford **3** and **10**.

Tributylphosphine-Catalyzed Reaction of Methyl 2,3-Butadienoate with *N*-Tosyl Benzaldimine. The procedure was similar to that described above except that methyl 2,3-butadienoate was used instead of 2-butynoates.

Methyl 2,5-Dihydro-2-phenyl-5-(1-phenyl-*p*-toluenesulfonamidomethyl)-1-tosyl-pyrrole-3-carboxylate (10a). Mp 101−104 °C; ^{1}H NMR δ 7.83 (d, J = 8.2 Hz, 2H), 7.64 (d, J = 8.2 Hz, 2H), 7.35−7.29 (m, 5H), 7.19−7.03 (m, 7H), 6.63 (d, J = 7.3 Hz, 2H), 6.47 (br s, 1H), 6.05 (d, J = 3.5 Hz, 1H), 5.43 (br s, 1H), 4.95 (dt, J = 7.5, 2.1 Hz, 1H), 4.61 (dd, J = 7.5, 3.6 Hz, 1H), 3.49 (s, 3H), 2.43 (s, 3H), 2.36 (s, 3H); ^{13}C NMR (75 MHz) δ 161.89 (C), 144.63 (C), 143.25 (C), 138.74 (C), 136.86 (C), 136.46 (CH), 136.27 (C), 135.39 (C), 132.75 (C), 130.08 (CH), 129.48 (CH), 128.97 (CH), 128.53 (CH), 128.30 (CH), 128.13 (2CH), 127.82 (CH), 127.65 (CH), 127.22 (CH), 70.98 (CH), 70.48 (CH), 62.02 (CH), 51.89 (CH_3), 21.58 (CH_3), 21.54 (CH_3); IR 3280, 1728, 1335, 1163 cm^{-1}; MS m/z 617 (M^+

+ 1, 0.34), 260 (PhCHNHTs$^+$, 52.61), 202 (M^+ + 1−PhCHNHTs−Ts, 20.39), 91 ($CH_3C_6H_4^+$, 100.00); HRMS calcd for $C_{33}H_{32}N_2O_6S_2$ 616.1702, found 616.1723.

Methyl 2,5-Dihydro-2-*tert*-butyl-1-tosyl-pyrrole-3-carboxylate (3k). Mp 135−136 °C; ^{1}H NMR δ 7.67 (d, J = 8.3 Hz, 2H), 7.23 (d, J = 8.0 Hz, 2H), 6.37 (br s, 1H), 4.68 (d, J = 3.1 Hz, 1H), 4.16−4.00 (m, 2H), 3.66 (s, 3H), 2.38 (s, 3H), 0.97 (s, 9H); IR 1720, 1629, 1239, 1162 cm^{-1}; MS m/z 338 (M^+ + 1, 100.00), 280 (M^+−t-Bu, 93.03). Anal. calcd for $C_{17}H_{23}NO_4S$: C, 60.51; H, 6.87; N, 4.15. Found: C, 60.29; H, 6.74; N, 3.81.

Methyl 2,5-Dihydro-2-(2-methyl-1,3-dithiane-2-yl)-1-tosyl-pyrrole-3-carboxylate (3m). Mp 186−188 °C (benzene/hexane); ^{1}H NMR δ 7.76 (d, J = 8.2 Hz, 2H), 7.26 (d, J = 8.0 Hz, 2H), 6.41 (br s, 1H), 5.65 (d, J = 3.2 Hz, 1H), 4.16 (dd, J = 18.3, 2.9 Hz, 1H), 4.01 (ddd, J = 18.3, 3.2, 1.5 Hz, 1H), 3.71 (s, 3H), 3.35 (ddd, J = 14.7, 11.6, 2.9 Hz, 1H), 3.16 (ddd, J = 14.5, 11.9, 2.9 Hz, 1H), 2.76 (dt, J = 14.7, 4.2 Hz, 1H), 2.60 (dt, J = 14.6, 4.0 Hz, 1H), 2.40 (s, 3H), 2.15−2.08 (m, 1H), 1.92−1.82 (m, 1H), 1.39 (s, 3H); IR 1717, 1638, 1354, 1254, 1163 cm^{-1}; MS m/z 413 (M^+, 0.17), 280 (M^+−$C_5H_9S_2$, 2.10), 133 ($C_5H_9S_2^+$, 100.00). Anal. calcd for $C_{18}H_{23}NO_4S_3$: C, 52.27; H, 5.60; N, 3.39. Found: C, 52.14; H, 5.61; N, 3.28.

Triphenylphosphine-Catalyzed Cyclization Reaction of Dimethyl Acetylenedicarboxylate and *N*-Tosylimines. A Typical Procedure for the Preparation of 1-Tosyl-5-phenyl-3-methoxy-4-methoxycarbonyl-3-pyrrolin-2-one (12a). A mixture of dimethyl acetylenedicarboxylate (**11**, 0.170 g, 1.20 mmol), *N*-tosyl benzaldimine (**2a**, 0.260 g, 1.00 mmol), and triphenylphosphine (0.052 g, 0.20 mmol) in dry benzene (5 mL) was degassed and then refluxed for 4 h under nitrogen. The reaction mixture was concentrated in vacuo, and the residue was chromatographed on silica gel (petroleum ether/ethyl acetate = 17:3) to give **12a** (0.335 g, 84% yield). Mp 126.5−127.5 °C (benzene/hexane); ^{1}H NMR δ 7.31−7.23 (m, 5H), 7.12−7.07 (m, 4H), 5.82 (s, 1H), 4.27 (s, 3H), 3.62 (s, 3H), 2.36 (s, 3H); IR 1732, 1707, 1643, 1201, 1174 cm^{-1}; MS m/z 401 (M^+, 31.88), 342 (M^+−CO_2Me, 100.00), 246 (M^+−Ts, 86.89). Anal. calcd for $C_{20}H_{19}NO_6S$: C, 59.84; H, 4.77; N, 3.49. Found: C, 59.71; H, 4.66; N, 3.31.

1-Tosyl-5-cinnamyl-3-methoxy-4-methoxycarbonyl-3-pyrrolin-2-one (12i). Mp 129.5−130.5 °C (benzene/hexane); ^{1}H NMR δ 7.86 (d, J = 8.35 Hz, 2H), 7.35−7.27 (m, 5H), 7.21 (d, J = 8.09 Hz, 2H), 6.83 (d, J = 15.34 Hz, 1H), 5.56 (dd, J = 15.36, 8.44 Hz, 1H), 5.46 (d, J = 8.62 Hz, 1H), 4.22 (s, 3H), 3.76 (s, 3H), 2.40 (s, 3H); IR 1727, 1718, 1642, 1162 cm^{-1}; MS m/z 427 (M^+, 9.14), 272 (M^+−Ts, 100.00). Anal. calcd for $C_{22}H_{21}NO_6S$: C, 61.81; H, 4.95; N, 3.28. Found: C, 62.10; H, 4.94; N, 3.27.

Dehydrogenation of 2,5-Dihydro-2-aryl-1-tosyl-pyrrole-3-carboxylates with DDQ. A Typical Procedure for the Preparation of Methyl 2-Phenyl-1-tosyl-pyrrole-3-carboxylate (26a). A mixture of the cycloadduct **3a** (0.23 g, 0.64 mmol) and DDQ (0.30 g, 1.32 mmol, 2.0 equiv) in benzene (5 mL) was heated at about 130 °C under nitrogen and monitored by TLC (eluent: petroleum ether/ethyl acetate = 4/1). After the reaction was complete, the reaction mixture was concentrated under reduced pressure and the residue was purified twice by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 17:3 for the first time and then 9:1 for the second time) to afford 0.21 g (92%) of **26a**. Mp 113−114 °C (benzene/hexane); ^{1}H NMR δ 7.48 (d, J = 3.4 Hz, 1H), 7.40 (tt, J = 7.5, 1.5 Hz, 1H), 7.28 (t, J = 7.6 Hz, 2H), 7.19 (d, J = 8.4 Hz, 2H), 7.12 (d, J = 8.3 Hz, 2H), 7.04 (dd, J = 7.5, 1.5 Hz, 2H), 6.73 (d, J = 3.4 Hz, 1H), 3.58 (s, 3H), 2.38 (s, 3H); IR 1719, 1358, 1173 cm^{-1}; MS m/z 355 (M^+, 52.35), 200 (M^+−Ts, 100.00). Anal. calcd for $C_{19}H_{17}NO_4S$: C, 64.21; H, 4.82; N, 3.94. Found: C, 64.21; H, 4.65; N, 3.81.

Detosylation of 2-Aryl-1-tosyl-pyrrole-3-carboxylates with Sodium Methoxide. A Typical Procedure for the Preparation of Methyl 2-Phenyl-1*H*-pyrrole-3-carboxylate (27a). A mixture of **26a** (0.065 g, 0.18 mmol) and sodium methoxide (0.57 M in methanol, 5.5 mL) was stirred at room temperature and monitored by TLC (eluent: petroleum ether/ethyl acetate = 4/1). After the reaction was complete, the reaction mixture was concentrated under reduced pressure and the residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 9:1) to afford 0.032 g (86%) of **27a**. Mp 99.5−100.5 °C (benzene/hexane), lit.,[43] 96.5−97.5 °C; ^{1}H NMR δ 8.51 (br s, 1H), 7.59 (dd, J = 7.9, 1.4 Hz, 2H), 7.45−7.37 (m, 3H), 6.76 (t, J = 2.7 Hz, 1H), 6.74 (t, J = 2.9 Hz, 1H), 3.74 (s, 3H); IR 3314, 3298, 1701, 1682, 1292, 1146 cm^{-1}; MS m/z 201 (M^+, 84.47), 170 (M^+−OMe, 100.00).

Aromatization of the Cycloaddition Products Mediated by Bu_4NF. General Procedure for the Synthesis of 2-Aryl-1*H*-pyrrole-3-carboxylates (27). To a solution of methyl 2,5-dihydro-2-aryl-1-sulfonyl-pyrrole-3-carboxylate (1.0 mmol) in THF (3 mL) was added a solution of Bu_4NF in THF (1M, 3 mL, 3 equiv). The mixture was then stirred at room temperature for 24−36 h. Methanol (2 mL) was added, and the mixture was concentrated under reduced pressure. The residue was diluted with ethyl acetate and washed with saturated $NaHCO_3$, and the aqueous layer was extracted twice with ethyl acetate. The combined organic phase was washed with brine, dried (Na_2SO_4), and concentrated. The residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 37/3) to afford **27**.

Methyl 2-Furyl-1*H*-pyrrole-3-carboxylate (27j). Mp 109−109.5 °C (benzene/hexane); ^{1}H NMR δ 8.91 (br s, 1H), 7.44 (d, J = 3.65 Hz, 1H), 7.36 (d, J = 1.54 Hz, 1H), 6.70 (t, J = 2.85 Hz, 1H), 6.64 (t, J = 2.98 Hz, 1H), 6.46 (dd, J = 3.32, 1,70 Hz, 1H), 3.80 (s, 3H); IR 3351, 1683, 1304, 1135 cm^{-1}; MS m/z 191 (M^+, 100.00), 160 (M^+−OMe, 75.67). Anal. calcd for $C_{10}H_9NO_3$: C, 62.82; H, 4.74; N, 7.33. Found: C, 63.04; H, 4.51; N, 7.28.

Synthesis of 2-Phenyl-1*H*-pyrrole (30). A mixture of **3a** (0.177 g, 0.88 mmol) and KOH (0.635 g, 12 equiv) in methanol (2 mL) was refluxed at 120 °C for 2.5 h. The cooled mixture was poured into water, acidified with concentrated HCl, and then extracted three times with ethyl acetate. After drying (Na_2SO_4), the solvent was evaporated under reduced pressure, and the residue (0.152 g) was heated in ethanolamine (2 mL) at 220 °C for 2 h. The cooled mixture was acidified with dilute HCl and extracted three times with ethyl acetate. The combined organic phase was washed with brine and dried over Na_2SO_4. After the solvent was evaporated under reduced pressure, the residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 50/1) to give 0.069 g (55%) of **30**. Mp 128−129 °C (hexane), lit.,[44] mp 129−130 °C; ^{1}H NMR δ 8.45 (br s, 1H), 7.50−7.46 (m, 2H), 7.39−7.34 (m, 2H), 7.24−7.18 (m, 1H), 6.88−6.86 (m, 1H), 6.55−6.52 (m, 1H), 6.32−6.30 (m, 1H); IR 3435, 3391, 757, 718, 691 cm^{-1}; MS m/z 143 (M^+, 100.00).

Desulfonylation of 12a. The solution of **12a** (0.370 g, 0.92 mmol) in dry benzene (20 mL) was heated to reflux under nitrogen, and Bu_3SnH (0.55 mL, 2.0 mmol) and AIBN (0.030 g, 0.18 mmol) in dry benzene (5 mL) were added as a solution. After 2 h, the reaction was completed as monitored by TLC analysis. After an additional hour, the solvent was removed in vacuo to afford a white solid. Diethyl ether (70 mL), saturated KF (15 mL), and water (55 mL) were added, and the resulting mixture was stirred overnight. After filtering off the precipitated solid, the water layer was extracted with benzene. The combined organic layer was dried (Na_2SO_4), and the solvents were removed to afford a white solid. The solid was combined with the precipitated solid above and crystallized in acetone to give 5-phenyl-3-methoxy-4-methoxycarbonyl-3-pyrrolin-2-one (**31a**, 0.190 g, 84%) as a white crystal. Mp 189−190 °C (acetone); ^{1}H NMR δ 7.38−7.34 (m, 3H), 7.32−7.25 (m, 2H), 6.47 (br s, 1H), 5.26 (s, 1H), 4.32 (s, 3H), 3.64 (s, 3H); ^{13}C NMR (75 MHz) δ 166.98, 162.49, 153.23, 136.45, 128.71, 128.59, 127.23, 118.72, 60.10, 57.81, 51.70; IR 3182, 3086, 1701, 1634, 1228 cm^{-1}; MS m/z 247 (M^+, 8.15), 188 (M^+−CO_2Me, 100.00). Anal. calcd for $C_{13}H_{13}NO_4$: C, 63.15; H, 5.30; N, 5.67. Found: C, 63.05; H, 5.25; N, 5.80.

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***N*-Tosyl 3,5-Dibromo-2-methoxybenzaldimine** was prepared according to a procedure analogous to that described above. After solvents were evaporated under reduced pressure, the crude product was obtained as a gum and was directly utilized in the next step without further purification. Data for the imine: ^{1}H NMR (90 MHz) δ 9.21 (s, 1H), 8.07−7.70 (m, 3H), 7.41−7.20 (m, 3H), 3.92 (s, 3H), 2.45 (s, 3H).

Methyl 2,5-Dihydro-2-(3,5-dibromo-2-methoxyphenyl)-1-tosyl-pyrrole-3-carboxylate (35). To a solution of the crude imine (1.126 g, 2.5 mmol), obtained as described above, and triphenylphosphine (0.080 g, 0.3 mmol) in dry benzene (25 mL) was added a solution of methyl 2,3-butadienoate (0.30 g, 3.0 mmol) in benzene (5 mL). The mixture was then stirred at room temperature for 18 h. The reaction mixture was concentrated under reduced pressure, and the residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 17/3) to give 0.814 g (60%) of **35**. Mp 120.5−121.5 °C (benzene/hexane); ^{1}H NMR δ 7.535 (d, J = 8.31 Hz, 2H), 7.534 (d, J = 2.56 Hz, 1H), 7.22 (d, J = 8.16 Hz, 2H), 7.01 (d, J = 2.58 Hz, 1H), 6.84 (q, J = 1.94 Hz, 1H), 5.99−5.96 (m, 1H), 4.52−4.48 (m, 2H), 3.99 (s, 3H), 3.61 (s, 3H), 2.41 (s, 3H); IR 1725, 1645, 1353, 1165 cm^{-1}; MS m/z 548, 546, 544 (M^+ + 1, 2.06, 4.02, 2.14), 360, 358, 356 (M^+−TsH−OMe, 34.42, 68.87, 35.03), 91 ($MeC_6H_4^+$, 100.00). Anal. calcd for $C_{20}H_{19}Br_2NO_5S$: C, 44.06; H, 3.51; N, 2.57; Br, 29.31. Found: C, 44.45; H, 3.51; N, 2.43; Br, 29.55.

Methyl 2-(3,5-Dibromo-2-methoxyphenyl)-1*H*-pyrrole-3-carboxylate (36). To a solution of **35** (1.366 g, 2.50 mmol) in THF (7.5 mL) was added a solution of Bu_4NF in THF (1 M, 7.5 mL, 3 equiv). The mixture was then stirred at room temperature for 22.5 h. After workup, the residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 19/1) to afford 0.808 g (83%) of **36**. Mp 119.5−120 °C (benzene/hexane); ^{1}H NMR δ 9.08 (br s, 1H), 7.82 (d, J = 2.22 Hz, 1H), 7.68 (d, J = 2.26 Hz, 1H), 6.84 (deformed t, J = 2.76 Hz, 1H), 6.76 (deformed t, J = 2.86 Hz, 1H), 3.78 (s, 3H), 3.51 (s, 3H); IR 3356, 1710 cm^{-1}; MS m/z 391, 389, 387 (M^+, 38.83, 71.74, 36.80), 360, 358, 356 (M^+−OMe, 54.36, 100.00, 52.32). Anal. calcd for $C_{13}H_{11}Br_2NO_3$: C, 40.13; H, 2.85; N, 3.60. Found: C, 40.03; H, 2.73; N, 3.32.

Methyl 2-(2-Methoxyphenyl)-1*H*-pyrrole-3-carboxylate (27b). To a solution of **3b** (1.854 g, 4.78 mmol) in THF (14 mL) was added a solution of Bu_4NF in THF (1 M, 14 mL, 3 equiv). The mixture was then stirred at room temperature for 24.5 h. After workup, the residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 17/3) to give 0.880 g (80%) of **27b**, idential with the sample obtained by the DDQ dehydrogenation method.

2-(2-Methoxyphenyl)-1*H*-pyrrole (37). A mixture of **27b** (1.247 g, 5.39 mmol) and KOH (3.79 g, 12 equiv) in methanol (15 mL) was refluxed at 100−110 °C for 4 h. The cooled mixture was poured into water, acidified with concentrated HCl, and extracted three times with ethyl acetate. After drying (Na_2SO_4), the solvent was evaporated under reduced pressure and the residue (1.160 g) was heated with Cu powder (0.336 g) in quinoline (20 mL) at 170 °C for 3 h. The reaction mixture was cooled and acidified with dilute HCl and then extracted three times with ethyl acetate. The combined organic phase was washed with brine and dried over Na_2SO_4. After the solvent was evaporated under reduced pressure, the residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 97/3) to afford 0.695 g (74%) of **37** as an oil which solidified on refrigeration. Mp 69−70 °C, lit.,[45] mp 66−67 °C; ^{1}H NMR δ 9.85 (br s, 1H), 7.68 (dd, J = 7.67, 1.69 Hz, 1H), 7.17 (deformed td, J = 7.73, 1.65 Hz, 1H), 7.01 (deformed td, J = 7.45, 1.24 Hz, 1H), 6.98 (d, J = 8.15 Hz, 1H), 6.88 (m, 1H), 6.65−6.63 (m, 1H), 6.32−6.29 (m, 1H), 3.97 (s, 3H); IR 3443, 1492, 1235, 1112, 1023 cm^{-1}; MS m/z 173 (M^+, 100.00), 158 (M^+-CH_3, 43.69).

2-(2-Hydroxyphenyl)-1*H*-pyrrole (34).[46] A mixture of **37** (0.426 g, 2.46 mmol) and anhydrous Na_2S (1.149 g, 6 equiv) in *N*-methylpyrrolidone (NMP, 10 mL) was heated at about 160 °C for 3.5 h. The cooled mixture was poured into dilute HCl and extracted twice with ethyl acetate. The combined organic phase was washed with brine and dried over Na_2SO_4. After the solvent was evaporated under reduced pressure, the residue was purified by column chromatography on silica gel (eluent: petroleum ether/ethyl acetate = 9/1) to give 0.203 g (52%) of **34** as a solid. Mp 99−101 °C (benzene/hexane); ^{1}H NMR δ 9.42 (br s, 1H), 7.54 (dd, J = 7.68, 1.51 Hz, 1H), 7.10 (deformed td, J = 7.63, 1.51 Hz, 1H), 6.97 (deformed td, J = 7.52, 1.13 Hz, 1H), 6.90 (m, 1H), 6.86 (d, J = 7.94 Hz, 1H), 6.58 (m, 1H), 6.34−6.31 (m, 1H), 5.48 (m, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 152.62, 128.65, 126.11, 125.82, 119.69, 119.34, 118.05, 116.14, 108.05, 106.85; IR 3433, 1496, 1466, 1099, 749 cm^{-1}; MS m/z 159 (M^+, 100.00). Anal. calcd for $C_{10}H_9NO$: C, 75.45; H, 5.70; N, 8.80. Found: C, 75.28; H, 5.65; N, 8.65.

2,3,4-Tribromo-5-(3,5-dibromo-2-hydroxyphenyl)-1*H*-pyrrole (Pentabromopseudilin, 32). To a solution of **34** (0.129 g, 0.81 mmol) in absolute ethanol (20 mL) was added pyridinium bromide perbromide (1.58 g, 6 equiv), and the mixture was then stirred at room temperature for 65 h. The reaction mixture was concentrated under reduced pressure, and the residue was purified by column chromatography on silica gel (eluent: petroleum ether/dichloromethane = 3/2) to afford 0.303 g (68%) of **32** as a solid. Mp 150 °C dec (benzene/hexane), lit.,[28] mp 152 °C dec; ^{1}H NMR δ 9.50 (br s, 1H), 8.11 (d, J = 2.17 Hz, 1H), 7.58 (d, J = 2.10 Hz, 1H), 6.05 (s, 1H); ^{1}H NMR (300 MHz, DMSO-d_6) δ 12.61 (br s, 1H), 9.81 (br s, 1H), 7.80 (d, J = 2.36 Hz, 1H), 7.40 (d, J = 2.45 Hz, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 151.54, 134.95, 133.11, 126.48, 122.03, 112.80, 110.44, 100.99, 100.41, 98.52; IR 3460, 3427, 3064, 1471, 1429, 1344, 1321, 1232, 1153, 1125, 994, 976, 858, 749, 688 cm^{-1}; MS m/z 559, 557, 555, 553, 551, 549 (M^+, 5.10, 24.15, 49.62, 50.77, 25.81, 5.14), 479, 477, 475, 473, 471 (M^+ + 1−Br, 15.85, 63.13, 100.00, 71.06, 21.74), 478, 476, 474, 472, 470 (M^+−Br, 21.03, 65.03, 93.03, 59.91, 15.87), 451, 449, 447, 445, 443 (M^+−Br−HCN, 5.90, 24.50, 38.41, 26.45, 7.80), 398, 396, 394, 392 (M^+ + 1−2Br, 10.18, 33.20, 42.59, 25.56), 397, 395, 393, 391 (M^+−2Br, 35.29, 80.29, 71.62, 23.35), 371, 369, 367, 365 (M^+−2Br−CN, 17.21, 55.10, 59.56, 26.53), 317, 315, 313 (M^+ + 1−3Br, 46.33, 89.43, 48.01), 316, 314, 312 (M^+−3Br, 38.15, 46.60, 18.04). Anal. calcd for $C_{10}H_4Br_5NO$: C, 21.69; H, 0.73; N, 2.53; Br, 72.16. Found: C, 21.39; H, 0.80; N, 2.44; Br, 72.40.

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Supporting Information Available: Characterization data for *N*-(*β*-trimethylsilylethanesulfonyl)-4-methylbenzaldimine, *N*-(*β*-trimethylsilylethanesulfonyl)-4-chlorobenzaldimine, **3b**−**h**, **6**, ethyl 2,5-dihydro-2-phenyl-1-(*β*-trimethylsilylethanesulfonyl)-pyrrole-3-carboxylate, methyl 2,5-dihydro-2-(4-methylphenyl)-1-(*β*-trimethylsilylethanesulfonyl)-pyrrole-3-carboxylate, methyl 2,5-dihydro-2-(4-chlorophenyl)-1-(*β*-trimethylsilylethanesulfonyl)-pyrrole-3-carboxylate, **3a′**, **10a′**, **10b**, **3c′**, **10c′**, **3d′**, **10d′**, **10e**, **3l**, **12b**−**e**, **12g**, **12h**, **12n**, **26b**, **26e**, **26g**, **26h**, **26** (R^1 = H), **27b**, **27e**, **27g**, **27h**, and **27d** (12 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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