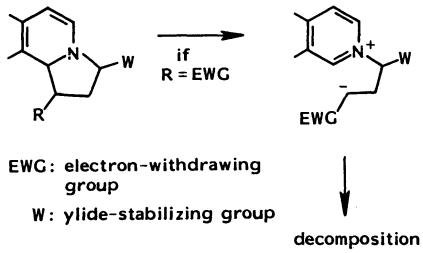
Cycloaddition Reactions of Highly Stabilized Isoquinolinium Methylides to Nonactivated Olefins and Electron-Rich Olefins

Otohiko TSUGE,* Shuji KANEMASA, Kazushige SAKAMOTO, and Shigeori TAKENAKA
Institute of Advanced Material Study, and Department of Molecular Science and Technology,
Interdisciplinary Graduate School of Engineering Sciences,
Kyushu University, Kasugakoen, Kasuga 816
(Received February 3, 1988)

Highly stabilized isoquinolinium methylides bearing two electron-withdrawing substituents at the ylide carbon undergo cycloadditions with aryl-substituted olefins (acenaphthylene, (*E*)- and (*Z*)-stilbenes, indene, and styrene), alkyl-substituted olefins (norbornene, (*Z*)-3-hexene-1,6-dinitrile, 1-hexene, 2-propen-1-ol, and 3-(trimethylsilyloxy)propene), and electron-rich olefins (vinylene carbonate, butyl vinyl ether, and phenyl vinyl sulfide). These cycloadditions proceed in an exclusively regioselective and mostly stereoselective manner.

Heteroaromatic *N*-ylides belong to highly reactive and easily accessible azomethine ylide 1,3-dipoles.[1] Their cycloadditions to electron-deficient activated olefins take place frequently in regio- and stereoselective manners to produce stereochemically pure fused pyrrolidine rings.[2] However the cycloadducts are not often highly stable since cycloaddition stage of heteroaromatic *N*-ylides involves loss of aromaticity of the heterocyclic ring. A major route of decomposition of the cycloadducts involves cleavage of the carbon–carbon bond newly formed in the cycloaddition step generating betaine intermediates. Anion-stabilizing substituents (R=EWG) introduced from the olefin dipolarophiles must accelerate this cleavage.[3]



Several attempts to increase the stability of cycloadducts were previously applied to avoid the undesired decomposition.[4] Replacement of the electron-withdrawing substituent R=EWG with such an ordinary substituent as aryl, alkyl, or electron-donating moiety can be an effective method of stabilization. Formally such stabilized cycloadducts would be accessible from the cycloadditions of heteroaromatic *N*-ylides to the olefins bearing no electron-withdrawing substituent.

Introduction of two anion-stabilizing substituents at the ylide carbon of heteroaromatic *N*-ylides lowers both levels of the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) so that the reactivity with electron-deficient activated olefins may be decreased but the reactivity with electron-rich olefins may be increased instead. So highly stabilized and isolable heteroaromatic *N*-ylides are expected to undergo cycloadditions with electron-rich olefins under a control of $LUMO_{dipole}$–$HOMO_{dipolarophile}$ interaction.[5]

Although several examples have been reported for the cycloadditions of azomethine ylides with nonactivated olefins,[6–8] the reactivity of heteroaromatic *N*-ylides with nonactivated olefins is unknown. The only example is the reaction of isoquinolinium bis(ethoxycarbonyl)methylide with enamines.[9]

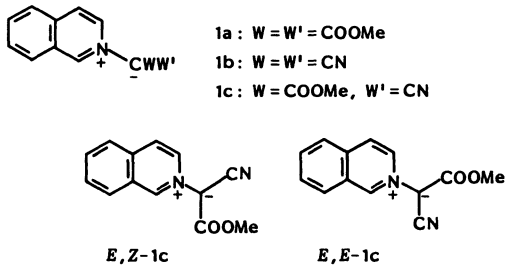
The present paper describes the first example of cycloadditions of highly stable and isolable isoquinolinium ylides with aryl-substituted, alkyl-substituted, and electron-rich olefins. These reactions are found to be exclusively regioselective regardless of the ylide-stabilizing substituent, and mostly stereoselective when the ester-stabilized ylides are employed.

Results and Discussion

Three types of isoquinolinium methylides **1a—c** were employed in the present work. They are all stable enough to be isolated: Bis(methoxycarbonyl)-**1a** and cyano(methoxycarbonyl)methylide **1c** can be prepared via *N*-alkylisoquinolinium bromides and such a weak base as isoquinoline, triethylamine, or aqueous potassium carbonate, and dicyanomethylide **1b** is directly accessible from isoquinoline and tetracyanooxirane. A mixture of ylide and olefin is heated in dry toluene or xylene under nitrogen and the reaction is monitored on TLC. After removal of the solvent, the crude reaction mixture is inspected by means of ^{1}H NMR spectrum to see the content of isomeric cycloadducts.

Two geometric isomers, (*E,Z*)-**1c** and (*E,E*)-**1c**, are possible for the cyano(methoxycarbonyl)methylide **1c** as shown below. As it is already known that the anti forms (or *E,Z*-forms) of carbonyl-stabilized heteroaromatic *N*-ylides show relatively high stability by 1,5-dipole stabilization and are exclusively involved in their cycloadditions to electron-deficient olefins,[2,10] the selective participation of isomer (*E,Z*)-**1c** is anticipated.

Both ^{1}H and ^{13}C NMR spectra of ylide **1c** measured in deuteriochloroform show no contamination by any



isomeric form, indicating either its existence in a single isomeric form, probably in an *E,Z*-form, or a free rotation around the ylide carbon–nitrogen bond. Since both the ester groups of bis(methoxycarbonyl)-methylide **1a** are magnetically equivalent as shown in its ^{1}H and ^{13}C NMR spectra measured at room temperature, the energy barrier for the ylide isomerization of such highly stabilized heteroaromatic *N*-ylides as **1a—c** may not be high so as to restrict the rotation.

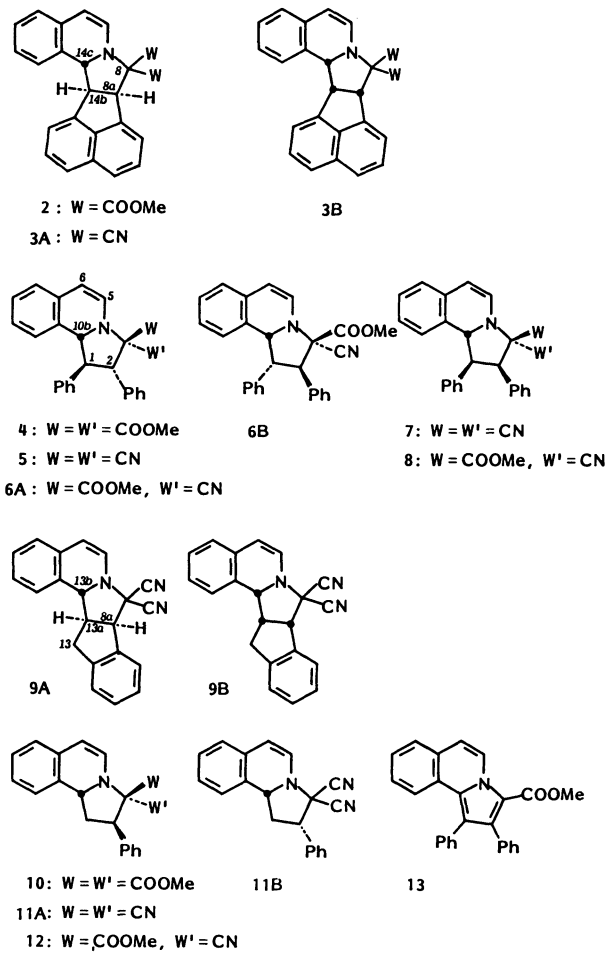
Though NMR spectra of dicyanomethylide **1b** was not available due to its low solubility in organic solvent, the other two **1a** and **1c** as well as 2-[bis(methoxycarbonyl)methyl]isoquinolinium bromide as a precursor of **1a** gave informative ^{1}H and ^{13}C NMR spectra. Both 1- and 3-Cs of cyano(methoxycarbonyl)methylide **1c** (1-C: δ=137.56 and 3-C: 132.88) appear in much upper field than those of bis(methoxycarbonyl)-methylide **1a** (1-C: 153.41 and 3-C: 141.32), indicating that the ylide anion of **1a** hardly flows into the isoquinoline ring but is stabilized by delocalization through the two ester moieties. Thus ylide **1a** and the precursor salt of **1a** show 1-C (**1a**: δ=153.41 and the precursor: 152.85) very close to each other. Stabilization of the anion of ylide **1c** is mainly made by its conjugation with the isoquinoline π-orbitals rather than the delocalization through the ylide-stabilizing cyano and ester moieties so that electron density at the 1-position is relatively increased.

On the other hand, ^{1}H chemical shifts of **1a** and **1c** are inconsistent with the corresponding ^{13}C chemical shifts. Ylide **1c** shows its 1- and 3-Hs (1-H: δ=10.11 and 3-H: 8.83) in much lower field than those of **1a** (1-H: 9.32 and 3-H: 8.33). The low-field shifts of 1- and 3-Hs are presumably caused by anisotropy from the ylide-stabilizing ester moiety. The ester moiety of **1c** can stay in the same plane to the isoquinoline ring so that the 1- and 3-Hs are strongly deshielded. However, the plane including the ylide carbon and two ester moieties of ylide **1a** is forced to cross to the isoquinoline plane due to a considerable steric congestion, deshielding of the 1- and 3-Hs from the ester groups being relatively decreased.

Cycloadditions to Aryl-Substituted Olefins. Heating isoquinolinium bis(methoxycarbonyl)methylide (**1a**) or dicyanomethylide (**1b**), under reflux in toluene, with acenaphthylene as a symmetrically aryl-substituted cyclic olefin produced the cycloadduct **2** or **3**. Though the cycloadduct **2** was obtained as a single isomer, **3** consists of two stereoisomers (3:1 by ^{1}H NMR) whose separation from each other through column chromatography was unsuccessful (Scheme 1 and Table 1). Compared to the major isomer **3A** (5-H: δ=6.02, 6-H: 6.49, and 14c-H: 4.99), the minor isomer **3B** shows strong magnetic shieldings at 5-H (5.03) and 6-H (5.87) as well as deshielding at 14c-H (5.22) from the fused acenaphthylene ring, confirming the exo and endo structures of **3A** and **3B**, respectively.

Similar reactions of the ylides **1a**, **1b**, and isoquinolinium cyano(methoxycarbonyl)methylide (**1c**) with (*E*)- and (*Z*)-stilbenes produced *E*-specific **4—6** and *Z*-specific cycloadducts **7**, **8**, respectively, while **1a** could not be trapped by (*Z*)-stilbene and recovered in 52% yield under reflux in toluene for 72 h (Scheme 1 and Table 1). Heating **1b** with (*Z*)-stilbene under reflux in toluene or xylene for 71 or 76 h gave 34 or 45% yield of cycloadduct **7**, respectively, but no cycloadduct was formed at 110 °C in *N,N*-dimethylformamide (DMF).[11] Thus polar solvents are disfavored in these cycloadditions.

Both relatively small trans couplings for J_{1-2} (2.0 Hz) and J_{1-10b} (6.2 Hz) of **4** and big trans couplings for J_{1-2} (11.3 Hz) and J_{1-10b} (8.0 Hz) of **5**



Scheme 1.

result from the same 1-exo-2-endo substitution as shown in the following discussion using molecular models: When the 3-endo substituent W′ is small, the most stable conformation of the fused pyrrolidine ring of the 1-exo-2-endo-cycloadduct of ylide **1** to an (*E*)-olefin ($R^1CH=CHR^2$) has trans diaxial geometry between the adjacent two of 10b-, 1-, and 2-Hs (conformer **A** in Fig. 1). The cycloadduct **5** occupies this conformation **A** (W=W′=CN, $R^1=R^2$=Ph) showing two big vicinal couplings J_{1-2} and J_{1-10b}. If the 3-endo substituent W′ becomes bulkier in the conformer **A**, the substituent W′ can not stay at the congested axial position and goes outside by rotations around the C(1)–C(2) and C(2)–C(3) bond leading to conformer **B**. The cycloadduct **4** occupies this conformation **B** (W=W′=COOMe, $R^1=R^2$=Ph) in which very small J_{1-2} (2.0 Hz) is observed.

The cycloadduct of **1c** to (*E*)-stilbene includes two isomers **6A** and **6B** in a 42:33 ratio of isolated products, although two more isomers are possible in this case depending upon the geometry at the 3-position. Both the isomers **6A** and **6B** exhibit big vicinal couplings for J_{1-2} (**6A**: 12.1 and **6B**: 10.9 Hz) which are assigned to a typical trans diaxial geometry. Together with magnetic shielding of the 3-COOMe of **6B** (δ=3.25) by the adjacent 2-phenyl, **6A** and **6B** are assigned to be 1-exo-2-endo and 1-endo-2-exo cycloadducts to the *E,Z*-form of ylide **1c**, respectively. The other big vicinal couplings J_{1-10b} (**6A**: 9.1 and **6B**: 8.2 Hz) are consistent with the assigned stereochemistry. Thus **6A** and **6B** exist as conformations **A** and **C**, respectively (Scheme 1 and Fig. 1, $R^1=R^2$=Ph, W=COOMe, W′=CN).

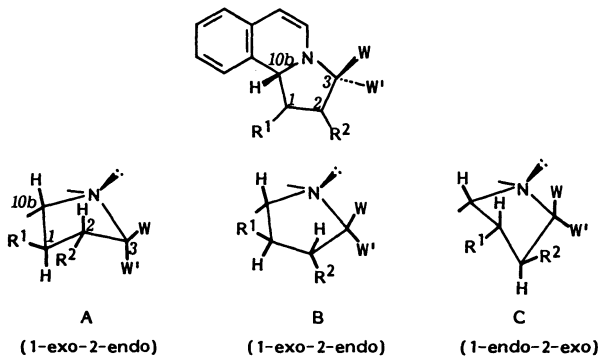


Fig. 1. Stable conformation of the cycloadducts of **1** to (*E*)-olefins.

The cycloadducts **7** and **8** to (*Z*)-stilbene bear trans diaxial stereochemistry between 1-H and 10b-H (J_{1-10b}=10.0 Hz) and are assigned to be the exo-cycloadducts.

The side product **13** obtained together with **4** in the reaction of **1a** with (*E*)-stilbene was assigned as methyl 1,2-diphenylpyrrolo[2,1-*a*]isoquinoline-3-carboxylate. Its formation presumably arose from **4** by homolytic thermal decarboxylation since **4** was quantitatively converted into **13** on treatment with chloranil under reflux in toluene for 0.5 h.[12]

Ylides **1** similarly react with such unsymmetrically aryl-substituted olefins as indene and styrene. In the cycloaddition of **1b** to indene an inseparable mixture of two cycloadducts was obtained in a 3:2 ratio (^{1}H NMR). As both the isomers show 8a-H and 13b-H as doublets, they are stereoisomeric mixtures of regioselective cycloadducts **9A** and **9B** (Scheme 1 and Table 1). The major isomer **9A** showing relatively big $J_{13a-13b}$ (9.5 Hz) and the major one **9B** showing smaller $J_{13a-13b}$ (5.2 Hz) are assigned to be the exo- and endo-cycloadducts, respectively.

The cycloadditions with styrene are also regioselective. Though ester-stabilized ylides **1a** and **1c** produced 2-exo-phenyl-substituted cycloadducts **10** and **12** as single products (Scheme 1 and Table 1), dicyanomethylide **1b** afforded a 3:2 mixture of two stereoisomers (by ^{1}H NMR of the crude reaction mixture). When this mixture is chromatographed over silica gel (hexane:ethyl acetate=10:1 v/v), the major isomer **11A** is isolated in 88% yield, indicating that the minor isomer **11B** has isomerized into **11A** during the chromatographic procedure.

This epimerization is most likely to be acid-

Table 1. Cycloadditions of Isoquinolinium Ylides **1** to Aryl-Substituted Olefins

Olefin	Equiv	Ylide	Solvent	Time/h	Product (Yield/%)[a]	Isomer ratio[b]
Acenaphthylene	3	**1a**	Toluene	3	**2** (42)	
Acenaphthylene	1	**1b**	Toluene	42	**3** (58)	**3A**: **3B**=3:1[c]
(*E*)-Stilbene	1.5	**1a**	Toluene	37	**4** (23)+**13** (6)	
(*E*)-Stilbene	1.2	**1b**	Toluene	48	**5** (61)	
(*E*)-Stilbene	2	**1c**	Toluene	24	**6** (75)	**6A**: **6B**=42:33
(*Z*)-Stilbene	1.2	**1b**	Xylene	76	**7** (45)[d]	
(*Z*)-Stilbene	1.5	**1c**	Toluene	48	**8** (62)	
Indene	1.2	**1b**	Toluene	6.5	**9** (59)	**9A**: **9B**=3:2[e]
Styrene	1	**1a**	Toluene	6	**10** (90)	
Styrene	1	**1b**	Toluene	1.5	**11** (88)	**11A**:**11B**=3:2[e,f]
Styrene	1	**1c**	Toluene	3	**12** (100)	

a) Yield of isolated products. b) Isomer ratio of isolated products. c) Inseparable mixture whose ratio was determined by ^{1}H NMR spectrum. d) Recovered **1b**: 19%. e) Isomer ratio of the crude reaction mixture (^{1}H NMR). f) Compound **11B** isomerizes into **11A** on silica-gel chromatography.

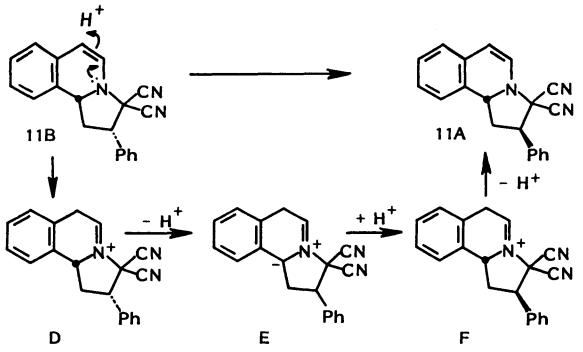


Fig. 2. Possible mechanism for the isomerization of **11B** into **11A**.

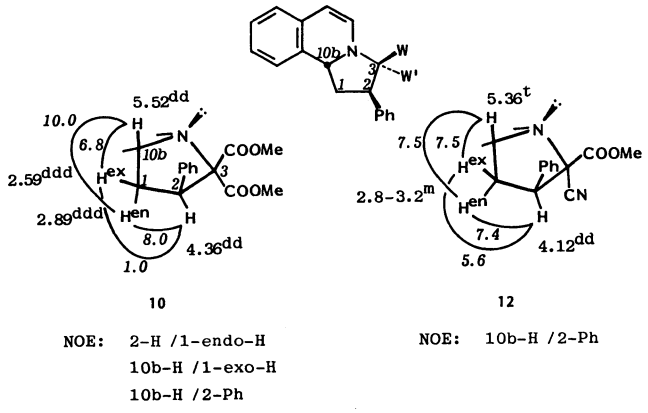
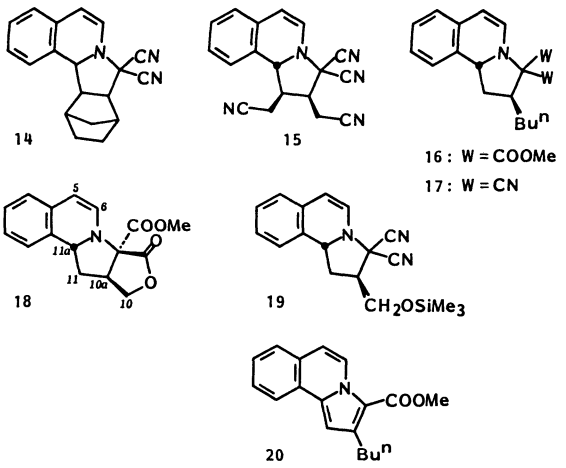


Fig. 3. Stereostructures of two styrene adducts **10** and **12**.

catalyzed via azomethine ylide 1,3-dipole intermediate **D** (Fig. 2). Although neither acetic acid nor phenol in aprotic solvents such as chloroform and dimethyl sulfoxide effects this epimerization, the epimerization is completed on treatment of the mixture of **11A** and **11B** (2:1) with Molecular Sieves 4A in dichloromethane for 3 days or with a catalytic amount of trifluoroacetic acid in ethanol for 1 day, both at room temperature. The epimerization on chromatography is found to be most effective.

Stereostructures of **10** and **12** were determined as the 2-exo-phenyl cycloadducts of **1a** and (*E*,*Z*)-**1c**, respectively, on the basis of the spectral data in which NOE difference spectrum was most informative. Thus notable NOE's were observed between 10b-H/2-phenyl of **10** and **12**, 2-H/1-endo-H of **10**, and 10b-H/1-exo-H of **10** indicating the 2-exo-phenyl substitution. Both cycloadducts **10** and **12** exhibit quite different coupling patterns among the methylene and methine hydrogens on the newly constructed fused pyrrolidine ring as shown in Fig. 3. This difference arises from the bulkiness of the 3-endo substituent W′ (**10**: COOMe and **12**: CN).

Since **11A** and **11B** derived from dicyanomethylide **1b** and styrene are thermodynamic and kinetical



Scheme 2.

products as described above, respectively, the 2-exo-phenyl structure for **11A** and 2-endo-phenyl structure for **11B** are reasonable. Coupling patterns of **11A** (J_{1-2}=8.0, 7.0 and J_{1-10b}=8.0, 7.8 Hz) are close to those of **12** which is carrying a small cyano group as the 3-endo substituent, confirming the 2-exo-phenyl stereochemistry of **12**. The 2-endo-phenyl isomer **11B** has the anti diaxial relationship between 10b-H and 1-endo-H and between 1-endo-H and 2-H as confirmed on the basis of the coupling patterns (J_{1-2}=12.0, 6.6 and J_{1-10b}=9.0, 5.9 Hz).

Cycloadditions to Alkyl-Substituted Olefins. Norbornene as a symmetrically substituted olefin of nonactivated type is so reactive to ylide **1b** that 89% yield of the cycloadduct **14** was produced under reflux in toluene for 0.7 h (Scheme 2 and Table 2). The product **14** consists of two stereoisomers in a 3:1 ratio which can not be separated from each other by silica-gel column chromatography. Among four possible stereostructures (exo, exo-, exo, endo-, endo, exo-, and endo, endo-isomers) in respect of the ylide (exo or endo)-norbornene (exo or endo) approach, **14** would be assigned to be the exo–exo and exo–endo stereoisomers on the basis of the exo-selective cycloadditions of ylides **1** with alkyl-substituted olefins discussed below.

Contrary to the high reactivity of strained norbornene, (*Z*)-3-hexene-1,6-dinitrile as a 1,2-disubstituted acyclic (*Z*)-olefin is less reactive. Heating ylide **1b** with this olefin at reflux in toluene for 8 days under nitrogen gave 24% yield of cycloadduct **15** as a single stereoisomer and 55% of the starting ylide **1b** was recovered. 1-Hexene as an unsymmetrically substituted 1-olefin regioselectively traps the ylide **1a** and **1b** to furnish 2-exo-butyl-substituted cycloadducts **16** and **17**. In the former case, part of the cycloadduct **16** was again aromatized by the elimination of an ester moiety at the 3-position to give **20**.

The reaction of ylide **1a** with O-unprotected 2-propen-1-ol takes place under similar conditions to

Table 2. Cycloadditions of Isoquinolinium Ylides **1** to Alkyl-Substituted Olefins

Olefin	Equiv	Ylide	Solvent	Time/h	Product (Yield/%)[a]	Isomer ratio
Norbornene	1.2	**1b**	Toluene	0.7	**14** (89)	3:1[b]
(*Z*)-3-Hexene-1,6-dinitrile	1	**1b**	Toluene	8d	**15** (24)[c]	
1-Hexene	4	**1a**	Xylene	5	**16** (21)+**20** (11)	
1-Hexene	1.3	**1b**	Toluene	24	**17** (85)	
2-Propen-1-ol	3.6	**1a**	Toluene	12	**18** (32)	
3-(Trimethylsilyl-oxy)propene	2	**1b**	Toluene	2.5	**19** (60)	

a) Yield of isolated products. b) Inseparable mixture whose ratio was determined by ^{1}H NMR spectrum. c) Recovered **1b**: 55%.

Table 3. Cycloadditions of Isoquinolinium Ylides **1** to Electron-Rich Olefins

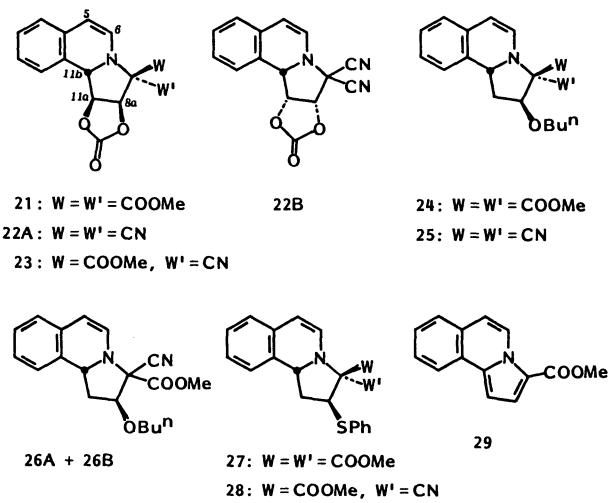
Olefin	Equiv	Ylide	Solvent	Time/h	Product (Yield/%)[a]	Isomer ratio[b]
Vinylene carbonate	3	**1a**	Toluene	42	**21** (32)	
Vinylene carbonate	1.3	**1b**	Toluene	75	**22** (53)	**22A**:**22B**=40:13
Vinylene carbonate	1.2	**1c**	Toluene	21	**23** (23)	
Butyl vinyl ether	2.7	**1a**	Toluene	3	**24** (68)	
Butyl vinyl ether	1.2	**1b**	Toluene	4	**25** (97)	
Butyl vinyl ether	3.3	**1c**	Toluene	3	**26** (61)	34:27[c]
Phenyl vinyl sulfide	1	**1a**[d]	Toluene	44	**27** (30)+**29** (15)[e]	
Phenyl vinyl sulfide	1	**1c**	Toluene	6	**28** (97)	

a) Yield of isolated products. b) Ratio of isolated isomers. c) Mixture of two 3-epimers **26A**+**26B**. d) Ylide **1a** was in situ generated from the corresponding isoquinolinium bromide and triethylamine. e) Inseparable mixture.

provide a lactone **18** in 32% yield (Scheme 2 and Table 2), indicating the regio- and stereoselective formation of 2-exo-hydroxymethyl-substituted cycloadduct followed by an internal lactonization with the 3-exo-ester group. The stereostructure of **18** is confirmed by the shielding of 11a-H (δ=4.12) from the carbonyl group of the fused lactone ring. Similarly 3-(trimethylsilyl-oxy)propene as O-protected 2-propen-1-ol reacts with ylide **1b** to give the 2-exo-substituted cycloadduct **19**.

Cycloadditions to Electron-Rich Olefins. The strained and electron-rich double bond of vinylene carbonate undergoes cycloadditions with electron-deficient ylides **1a—c** under reflux in toluene to give the corresponding cycloadducts **21—23** (Scheme 3 and Table 3). Though **21** and **23** are single isomers, **22** consists of exo- **22A** and endo-cycloadduct **22B** in a 40:13 ratio of isolated products. The major isomer **22A** which shows 11b-H as a singlet signal ($J_{11a-11b}$=0 Hz) is determined to be the exo structure; the single product **23** produced from ylide **1c** is also assigned as the exo-cycloadduct based upon the zero coupling between 11a-H and 11b-H.

The cycloadduct **21** bearing two relatively bulky ester groups at the 8-position must occupy a conformation different from that for the other two exo-cycloadducts **22A** and **23** which bear a small cyano moiety as the 8-endo substituent. The 8-endo-ester group would move to outer side in order to avoid steric congestion so that the coupling between 11a-H and 11b-H becomes bigger. Thus **21** was assigned as the exo-cycloadduct whose $J_{11a-11b}$ is 5.5 Hz. Similar



Scheme 3.

difference has been observed above between the two exo-cycloadducts to acenaphtylene **2** and **3A** ($J_{14b-14c}$: **2**: 7.8 and **3A**: 0 Hz).

Butyl vinyl ether or phenyl vinyl sulfide as an electron-rich olefin readily reacts with ylides **1a—c** to give the regio- and stereoselective 2-exo-butoxy- **24—26** or 2-exo-phenylthio-substituted cycloadducts **27,28** (Scheme 3 and Table 3). The cycloadduct **27** is thermally labile so as to undergo eliminative and decarboxylative aromatization leading to methyl [2,1-*a*]isoquinoline-3-carboxylate (**29**). An authentic sample of **29** is available in the reaction of **1a** with

phenyl vinyl sulfoxide in good yield.

The 2-exo-butoxy stereochemistry of **24** was confirmed on the basis of NOE difference spectrum which showed clear NOE's between 1-endo-H and 2-H and between 1-exo-H and 10b-H. Coupling constants J_{1-10b}(trans)=10.6 and J_{1-2}(trans)=0 Hz are also consistent with the assigned structure.

The other cycloadducts **25**, **27**, and **28** show similar coupling patterns to those of the cycloadducts to 1-hexene **16**—**17** and are assigned to be the 2-exo-substituted cycloadducts as shown in Scheme 3. Resemblance of the coupling patterns of the isomeric cycloadducts **26A** and **26B** indicates the same configuration, and even almost the same conformation, around the 1-, 2-, and 10b-positions. They are assigned as the 3-epimers each other, while it was unsuccessful to determine which is which.

Regioselectivity. As described above, the cycloadditions of highly stabilized isoquinolinium ylides **1a**—**c** with aryl- and alkyl-substituted and electron-rich olefins proceeded all in regioselective manners to give the single regioisomers of cycloadducts **10**—**12**, **16**—**19**, and **24**—**28** bearing the substituent from olefins at the 2-position.

This exclusive regioselection can be explained in terms of frontier molecular orbital (FMO) theory.[13] Interaction between LUMO of ylides **1** and HOMO of olefins would predominantly control reactivity and regioselectivity of their cycloadditions since the ylides **1** are electron-deficient and the olefins are relatively electron-rich. The LUMOs of ylides **1** must carry larger atomic orbital coefficients at the γ-carbon rather than the ylide carbon; β-coefficients must be larger than those at the α-carbons in HOMOs of the olefins employed in the present work (Fig. 4).

Stereoselectivity. Cycloadditions of bis(methoxycarbonyl)methylide **1a** were exclusively stereoselective: The exo-cycloadducts **2** and **21**, 1-exo-2-endo-cycloadduct **4**, and 2-exo-cycloadducts **10**, **16**, **18**, **24**, and **27** were produced. Though there are a few exceptions the *E*,*Z*-ylide isomer of cyano(methoxycarbonyl)methylide **1c** was mostly involved in its stereoselective cycloadditions with olefins leading to **8**, **12**, **23**, and **28**: Only in the reactions with (*E*)-stilbene and butyl vinyl ethers two isomeric cycloadducts **6** and **26** were formed. Compared with these stereoselective reactions of ester-stabilized ylides **1a** and **1c**, cycloadditions using dicyanomethylide **1b** are frequently poor in stereoselectivity: Mixtures of two isomeric cycloadducts **3**, **9**, **11**, **14**, and **22** were formed in the reactions with acenaphthylene, indene, styrene, norbornene, and vinylene carbonate.

In several cases, stereoselectivity can be explained on the basis of secondary orbital interaction and steric repulsion as shown below.

There are two approaches possible for the cycloaddition of ylides **1a**—**c** to (*E*)-stilbene, 1-exo-2-endo **G** and 1-endo-2-exo approach **H** (Fig. 5). Attractive secondary orbital interaction would work between the phenyl and the ester moiety W′ (=COOMe in the approach **G**) or W (=COOMe in **H**), while repulsion would be present in the approach **H** between the phenyl and the isoquinolinium ring. Thus ylide **1a** (W=W′=COOMe) and **1b** (W=W′=CN) react with (*E*)-stilbene through 1-exo-2-endo-selective approach **G** furnishing **4** and **5**. On the other hand, the approach **G** competes with **H** since steric repulsion caused by one of the phenyls is cancelled by attractive interaction working between the ester W (=COOMe) and the other phenyl plane.

The exo-selective cycloadditions of ylides **1b** and **1c** to (*Z*)-stilbene via approach **I** are reasonable from the standpoints of steric repulsion and attractive interaction (Fig. 5).

The ylides **1a** and **1c** which carry at least one ester moiety underwent exo-selective cycloadditions to styrene affording **10** and **12**. Attractive interaction between the phenyl of styrene and the ester W (=COOMe) probably determined the stereoselectivity. If such attraction is absent, both exo and endo approaches occur. Thus two stereoisomers **11A** and

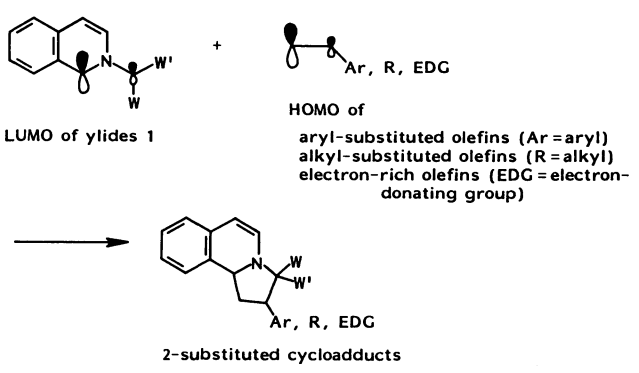


Fig. 4. $LUMO_{ylide}$–$HOMO_{dipolarophile}$ interaction leading to regioselective cycloadducts.

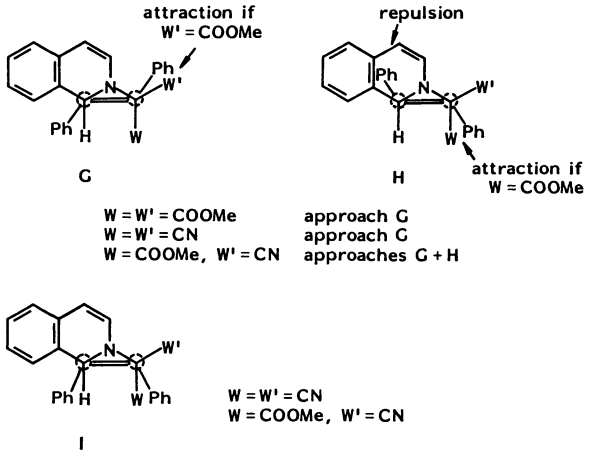


Fig. 5. Stereoselectivity between ylides **1** and (*E*)- and (*Z*)-stilbenes.

11B were formed in the reaction of dicyanomethylide **1b** with styrene.

The competitive formation of sterically unfavorable endo-cycloadducts **3B 9B**, one of **14**, and **22B** in the cycloadditions of dicyanomethylide **1b** can not be interpreted so far. The decrease of ylide-specificity observed in the reaction of ylide **1c** with butyl vinyl ether leading to **26A** and **26B** is not be solved yet.

Use of Other Heteroaromatic N-Ylides. At an early stage of the present work, several derivatives of pyridinium methylides were employed. Compared to satisfactory reactivity of the three isoquinolinium methylides **1a—c**, their pyridinium analogs are absolutely inert to nonactivated olefins: Thus pyridinium dicyanomethylide was recovered intact in the reactions with styrene (reflux in toluene for 33 h), butyl vinyl ether (reflux in toluene for 84 h or at 140 °C for 20 h), and vinylene carbonate (reflux in toluene for 66 h). Attempted cycloadditions of 3,5-dimethylpyridinium bis(methoxycarbonyl)methylide with styrene, vinylene carbonate, or butyl vinyl ether as well as that of 4-methoxypyridinium bis(methoxycarbonyl)methylide with styrene produced no corresponding cycloadducts, but decomposition of the ylides was observed.

Both energy levels of LUMO (+2.046 eV) and HOMO (−8.792 eV) of pyridinium methoxycarbonylmethylide are calculated to be higher than those of isoquinolinium methoxycarbonylmethylide (LUMO: +0.588 and HOMO: −9.082 eV).[14] Accordingly pyridinium methylides must show relatively less enhanced reactivity than the corresponding isoquinolinium methylides, especially in the cycloadditions under control of $LUMO_{dipole}$–$HOMO_{dipolarophile}$. The observed low reactivity of these pyridinium methylides is the case.

Experimental

General. Melting points were determined on a Yanagimoto melting point apparatus and are uncorrected. IR spectra were taken with a JASCO IRA-1 or a JASCO A-702 spectrometer. ^1H NMR spectra were recorded on a Hitachi R-40 (90 Hz), a JEOL FX-100 (100 MHz), or a JEOL GSX-270 instrument (270 MHz) and ^{13}C NMR on a JEOL FX-100 (25.05 MHz) or a GSX-270 spectrometer (67.94 MHz). Chemical shifts are expressed in parts per million downfield from tetramethylsilane as an internal standard. Mass spectra were measured with a JEOL-01SG-2 spectrometer at 70 eV of ionization energy. High resolution mass spectra were also obtained on the same instrument. Elemental analyses were performed on a Hitachi 026 CHN analyzer. For preparative column chromatography, Wakogel C-200, C-300 (Wako), and Silicagel 60 (Merck) were employed. Flash chromatography was carried out on an EYELA EF-10 apparatus using a Lobar column (20×180 mm) packed with Silicagel 60 (Merck, size: 0.04—0.063 mm). Solvents were evaporated with a Tokyo Rikakikai rotary evaporator type-V at about 50 °C unless otherwise stated.

Materials. Isoquinolinium dicyanomethylide (**1b**)[15] or cyano(methoxycarbonyl)methylide (**1c**)[16] is directly available from the reaction of isoquinoline with tetracyanooxirane or methyl 2-bromocyanoacetate, respectively, according to the reported method. 2-[Bis(methoxycarbonyl)methyl]isoquinolinium bromide[16] can be prepared from isoquinoline and dimethyl bromomalonate. Ylide **1a**[16] is either isolated on treatment of the salt with aqueous potassium carbonate or generated in situ by the action with triethylamine in an appropriate reaction solvent. 2-[Bis(methoxycarbonyl)methyl]isoquinolinium bromide: ^1H NMR (DMSO-d_6) δ=3.92 (6H, s, COOMe), 7.55 (1H, br s, CH), 8.0—9.1 (6H, m, Ar), and 10.50 (1H, br s, 1-H); ^{13}C NMR (DMSO-d_6) δ=54.45 (COOMe), 71.68 (ylide C), 124.78, 126.36, 127.30, 131.08, 131.44, 136.31, 137.75, 138.35, 152.85 (1-C), and 163.05 (COOMe). **1a:** ^1H NMR ($CDCl_3$) δ=3.75 (6H, s, COOMe), 7.7—8.3 (5H, m, 3-, 4-, 5-, 6-, and 7-H), 8.33 (1H, dd, J=8.0 and 1.0 Hz 3-H), and 9.32 (1H, s, 1-H); ^{13}C NMR ($CDCl_3$) δ=50.65 (COOMe), 97.26 (ylide C), 123.44, 126.75, 127.66, 129.67, 130.10, 135.53, 136.28, 141.32 (3-C), 153.41 (1-C), and 165.70 (COOMe); **1c:** ^1H NMR ($CDCl_3$) δ=3.80 (3H, s, COOMe), 7.7—8.1 (5H, m, 4-, 5-, 6-, 7-, and 8-H), 8.83 (1H, dd, J=8.0 and 1.0 Hz, 3-H), and 10.11 (1H, s, 1-H); ^{13}C NMR ($CDCl_3$) δ=50.81 (COOMe), 121.02 (CN), 124.29, 126.69, 128.02, 128.49, 130.67, 130.88, 132.11, 132.88 (3-C), 137.56 (1-C), and 165.00 (COOMe).

General Procedure for the Cycloadditions of Isoquinolinium Methylides 1 to Olefins. A mixture of isoquinolinium methylide **1** (1 mmol) and olefin in dry toluene or xylene was heated at reflux under nitrogen. After the reaction was over, the reaction mixture was cooled to room temperature. When some precipitate appeared, it was collected on a filter. The filtrate was evaporated in vacuo and the residue as chromatographed over silica gel by using hexane–ethyl acetate.

2: The residue obtained from the crude reaction mixture by evaporation of the solvent was chromatographed over silica gel with hexane–ethyl acetate (10:1 v/v) to give **2**: Pale yellow prisms (benzene–hexane); mp 209—210 °C; IR (KBr) 1750, 1723, 1610, 1250, 1230, and 770 cm^{-1}; ^1H NMR ($CDCl_3$) δ=3.07, 3.86 (each 3H, s, COOMe), 4.68 (1H, dd, J=8.0 and 7.8 Hz, 14b-H), 4.81 (1H, d, J=8.0 Hz, 8a-H), 5.17 (1H, d, J=7.8 Hz, 14c-H), 5.71 (1H, d, J=7.6 Hz, 5-H), 6.65 (1H, d, J=7.6 Hz, 6-H), and 6.9—7.7 (10H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=50.53 (d, 8a-C), 51.82, 53.36 (each q, COOMe), 55.95 (d, 14b-C), 67.18 (d, 14c-C), 76.65 (s, 8-C), 106.06 (d, 5-C), 120.07, 121.48, 123.48, 123.66, 123.95, 124.54, 126.30, 127.74, 128.25, 131.60, 131.89, 133.83, 134.89, 139.12, 141.30, 144.60, and 169.59 (s, 2C of COOMe); MS m/z (rel intensity, %) 411 (M^+, 19), 260 (16), 259 (base peak), 201 (38), and 143 (25). Found: C, 76.05; H, 5.16; N, 3.46%. Calcd for $C_{26}H_{21}NO_4$: C, 75.90; H, 5.14; N, 3.40%.

3A+3B: The crude reaction mixture was chromatographed, after evaporation of the solvent in vacuo, over silica gel with hexane–ethyl acetate (10:1 v/v) to give an inseparable mixture of **3A** and **3B** (3:1 by ^1H NMR): Colorless solid; IR (KBr) 2360, 1620, 1250, 1169, 783, and 773 cm^{-1}; ^1H NMR ($CDCl_3$) **3A**: δ=4.48 (1H, d, J=6.9 Hz, 8a-H), 4.82 (1H, dd, J=8.8 and 6.9 Hz, 14b-H), 4.99 (1H, d, J=8.8 Hz, 14c-H), 6.02 (1H, d, J=7.6 Hz, 5-H), 6.49 (1H, d, J=7.6 Hz, 6-H), and 7.0—8.0 (10H, m, Ar). **3B**: δ=4.6—4.8 (2H, m, 8a- and 14b-H), 5.03 (1H, d, J=7.6 Hz, 5-H), 5.22 (1H, d, J=6.0 Hz, 14c-H), 5.87 (1H, d, J=7.6 Hz, 6-H), and 7.0—8.0 (9H, m, Ar); MS m/z (rel intensity, %) 345 (M^+, 3),

194 (16), 193 (base peak), 166 (17), 152 (48), 139 (16), 129 (21), 128 (19), and 102 (13). Found: C, 83.38; H, 4.38; N, 12.15%. Calcd for $C_{24}H_{15}N_3$: C, 83.46; H, 4.38; N, 12.16%.

4 and 13: When the crude reaction mixture was subjected to column chromatography over silica gel with hexane–ethyl acetate (10:1 v/v), a mixture of **4** and **13** was obtained. This mixture was again chromatographed with hexane–ethyl acetate (20:1 v/v) to give **13** (6%) and then **4** (23%). As compound **4** is so susceptible as to suffer from ready decarboxylative aromatization leading to **13**, only ^{1}H NMR spectrum is available. **4**: ^{1}H NMR ($CDCl_3$) δ=3.08, 3.72 (each 3H, s, COOMe), 3.97 (1H, dd, J=6.2 and 2.0 Hz, 1-H), 4.58 (1H, d, J=2.0 Hz, 2-H), 5.53 (1H, d, J=7.5 Hz, 6-H), 5.99 (1H, d, J=6.2 Hz, 10b-H), 6.34 (1H, br d, J=7.5, 10-H), 6.63 (1H, d, J=7.5 Hz, 5-H), and 6.5—7.4 (13H, m, Ar). **13**: Colorless prisms (diethyl ether); mp 223—224 °C; IR (KBr) 1690, 1430, 1365, 1245, 1190, 1065, and 700 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.59 (3H, s, COOMe), 7.00 (1H, d, J=7.5 Hz, 6-H), 7.1—7.7 (15H, m, Ar), and 9.33 (1H, d, J=7.5 Hz, 5-H); MS m/z (rel intensity, %) 377 (M^+, 99), 346 (15), 320 (13), 319 (41), 318 (20), 317 (33), 316 (18), 315 (19), 227 (16), 226 (base peak), and 168 (13). Found: C, 82.85; H, 5.16; N, 3.90%. Calcd for $C_{26}H_{19}NO_2$: C, 82.74; H, 5.07; N, 3.71%.

5: Part of **5** precipitated out when the crude solution was cooled to room temperature. Silica-gel chromatography of the filtrate, after evaporation of the solvent in vacuo, with hexane–ethyl acetate (10:1 v/v) afforded major part of **5**. Colorless prisms (diethyl ether); mp 182—182.5 °C; IR (KBr) 2220, 1630, 1454, 1294, 1256, 1167, 779, 761, and 706 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=4.09 (1H, dd, J=11.3 and 1.0 Hz, 1-H), 4.27 (1H, dd, J=11.3 and 8.0 Hz, 2-H), 5.32 (1H, br d, J=8.0 Hz, 10b-H), 5.95 (1H, d, J=7.8 Hz, 6-H), 6.40 (1H, d, J=7.8 Hz, 5-H), and 6.6—7.5 (14H, m, Ar); MS m/z (rel intensity, %) 373 (M^+, 2), 194 (14), 193 (base peak), 180 (32), 179 (50), 178 (34,) 166 (22), 165 (35), 139 (16), 129 (24), 128 (24), 115 (12), 103 (13), and 102 (20). Found: C, 83.66; H, 5.12; N, 11.20%. Calcd for $C_{26}H_{19}N_3$: 83.62; H, 5.13; N, 11.25%.

6A and 6B: Column chromatography of the crude reaction mixture over silica gel with hexane–ethyl acetate (15:1 v/v) provided **6A** and then **6B**. **6A**: Pale yellow needles (benzene–diethyl ether); mp 215—215 °C; IR (KBr) 3020, 1750, 1620, 1240, and 770 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.84 (3H, s, COOMe), 3.99 (1H, d, J=12.1 Hz, 2-H), 4.26 (1H, dd, J=12.1 and 9.1 Hz, 1-H), 5.47 (1H, d, J=9.1 Hz, 10b-H), 5.72 (1H, d, J=7.5 Hz, 6-H), 6.12 (1H, d, J=7.5 Hz, 5-H), and 6.6—7.4 (14H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=54.18 (q, COOMe), 55.29 (d, 2-C), 61.83 (d, 1-C), 64.00 (d, 10b-C), 71.77 (s, 3-C), 106.71 (d, 6-C), 115.66 (s, CN), 124.07, 124.48, 126.83, 127.95, 128.18, 128.89, 129.00, 129.13, 129.36, 132.25, 138.18, and 167.71 (s, COOMe); MS m/z (rel intensity, %) 406 (M^+, 4), 227 (13), 226 (base peak), 168 (29), 143 (18), 140 (13), and 115 (10). Found: C, 79.82; H, 5.55; N, 6.83%. Calcd for $C_{27}H_{22}N_2O_2$: C, 79.78; H, 5.46; N, 6.89%. **6B**: Pale yellow prisms (benzene–hexane); mp 160—162 °C; IR (KBr) 3010, 1750, 1610, 1440, 1290, 1220, 770, and 700 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.25 (3H, s, COOMe), 4.11 (1H, d, J=10.9 Hz, 2-H), 4.30 (1H, dd, J=10.9 and 8.2 Hz, 1-H), 5.32 (1H, d, J=8.2 Hz, 10b-H), 5.74 (1H, d, J=7.8 Hz, 6-H), 6.28 (1H, d, J=7.8 Hz, 5-H), and 6.6—7.4 (14H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=53.30 (q, COOMe), 53.42 (d, 2-C), 63.83 (d, 1-C), 64.24 (d, 10b-C), 70.06 (s, 3-C), 107.07 (d, 6-C), 117.83 (s, CN), 123.83, 124.36, 126.77, 127.95, 128.24, 128.83, 129.01, 129.42, 129.89, 131.01, 132.60, 133.95, 138.72, and 165.83 (s, COOMe); MS m/z (rel intensity, %) 406 (M^+, 5), 227 (15), 226 (base peak), 217 (10), 168 (27), 143 (19), and 140 (13). Found: C, 79.85; H, 5.46; N, 6.87%. Calcd for $C_{27}H_{22}N_2O_2$: C, 79.78; H, 5.46; N, 6.89%.

7: Unreacted **1b** (19%) was recovered when the mixture was cooled to room temperature. The filtrate was chromatographed over silica gel by using hexane–ethyl acetate (10:1 v/v) to give **7**. Colorless prisms (diethyl ether–hexane); mp 155—156 °C; IR (KBr) 2220, 1628, 1489, 1454, 1294, 1261, 1137, 785, and 698 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=4.03 (1H, d, J=7.0 Hz, 2-H), 4.53 (1H, dd, J=10.0 and 7.0 Hz, 1-H), 5.54 (1H, d, J=7.0 Hz, 10b-H), 6.06 (1H, d, J=7.0 Hz, 6-H), 6.48 (1H, d, J=7.0 Hz, 5-H), and 6.7—7.3 (14H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=55.03 (d, 2-C), 59.33 (d, 1-C), 59.86 (d, 10b-C), 60.25 (s, 3-C), 111.33 (d, 6-C), 112.21, 115.00 (each s, CN), 124.12, 125.10, 126.22, 127.93, 128.22, 128.37, 128.80, 128.91, 129.00, 129.20 129.98, 131.05, 133.05, and 135.49; MS m/z (rel intensity, %) 373 (M^+, 20), 194 (17), 193 (base peak), 180 (34), 179 (57), 178 (39), 166 (15), 165 (32), 154 (24), 153 (13), 139 (11), 129 (18), 128 (29), 127 (21), 115 (13), 103 (29), and 102 (20). Found: C, 83.50; H, 5.15; N, 11.19%. Calcd for $C_{26}H_{19}N_3$: C, 83.62; H, 5.13; N, 11.25%.

8: Column chromatography of the reaction mixture over silica gel with hexane–ethyl acetate (10:1 v/v) gave **8**. Colorless prisms (ethyl acetate–hexane); mp 225—227 °C; IR (KBr) 1760, 1650, 1245, 770, and 705 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.40 (3H, s, COOMe), 4.05 (1H, d, J=7.0 Hz, 2-H), 4.57 (1H, dd, J=10.0 and 7.0 Hz, 1-H), 5.71 (1H, d, J=10.0 Hz, 10b-H), 5.89 (1H, d, J=7.5 Hz, 6-H), 6.49 (1H, d, J=7.5 Hz, 5-H), 6.58 (1H, br d, J=7.0 Hz, 10-H), and 6.7—7.2 (13H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=53.47 (q, COOMe), 55.12 (d, 2-C), 60.24 (d, 1-C),69.95 (d, 10b-C), 108.95 (d, 6-C), 118.36 (s, CN), 60.24 (d, 1-C), 69.95 (d, 10b-C), 108.95 (d, 6-C), 118.36 (s, CN), 124.24, 124.41, 127.07, 127.42, 127.89, 128.25, 128.42, 128.60, COOMe); MS m/z (rel intensity, %) 406 (M^+, 6), 227 (16), 226 (base peak), 168 (82), and 143 (12). Found: C, 79.65; H, 5.46; N, 7.00%. Calcd for $C_{27}H_{22}N_2O_2$: C, 79.78; H, 5.46; N, 6.89%.

9A and 9B: The crude reaction mixture was chromatographed over silica gel with chloroform to give a mixture of **9A** and **9B** (59%, 3:2 by ^{1}H NMR). This mixture was separated through flash chromatography in a Lobar column with hexane–ethyl acetate (20:1 v/v) to give **9A** and then **9B**. **9A**: Colorless prisms (diethyl ether–hexane); mp 148—149 °C; IR (KBr) 1620, 1480, 1450, 1410, 1290, 1240, and 1160 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.11 (1H, dd, J=16.0 and 3.3 Hz, 13-exo-H), 3.50 (1H, dd, J=16.0 and 9.4 Hz, 13-endo-H), 3.6—3.7 (1H, m, 13a-H), 4.36 (1H, d, J=8.4 Hz, 8a-H), 4.64 (1H, d, J=10.3 Hz 13b-H), 5.97 (1H, d, J=7.7 Hz, 5-H), 6.48 (1H, d, J=7.7 Hz, 6-H), and 7.1—7.6 (8H, m, Ar); MS m/z (rel intensity, %) 309 (M^+, 10), 194 (16), 193 (base peak), 166 (18), 139 (21), 129 (16), 128 (17), 116 (69), and 115 (77). Found: C, 81.75; H, 4.66; N, 13.39%. Calcd for $C_{21}H_{15}N_3$: C, 81.53; H, 4.89; N, 13.58%. **9B**: Pale yellow prisms (diethyl ether–hexane); mp 115—156 °C; IR (KBr) 1620, 1450, 1400, 1290, 1240, and 1180 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.26 (1H, dd, J=16.0 and 9.2 Hz, 13-endo-H), 3.34 (1H, dd, J=16.0 and 7.0 Hz, 13-exo-H), 3.8—3.9 (1H, m, 13a-H), 4.43 (1H, d, J=7.7 Hz, 8a-H), 5.07 (1H, d, J=5.1 Hz, 13b-H), 5.79 (1H, d, J=7.7 Hz, 5-H), 6.36 (1H, d, J=7.7 Hz, 6-H), and 7.0—7.5 (8H m, Ar); MS m/z (rel intensity, %) 309 (M^+, 8), 193 (95), 166 (22), 139 (21), 129 (24), 128 (29), 116 (77), 115 (base peak), 89 (23), 77 (22), and 63 (26). Found: C, 81.34; H, 4.72; N,

13.43%. Calcd for $C_{21}H_{15}N_3$: C, 81.53; H, 4.89; N, 13.58%.

10: The crude reaction mixture was chromatographed, after evaporation of the solvent in vacuo, over silica gel with hexane–ethyl acetate (5:1 v/v) to afford **10**: Colorless prisms (ethyl acetate–hexane); mp 164 °C; IR (KBr) 1757, 1734, 1608, 1454, 1288, 1271, 1227, 1207, 1038, 769, and 706 cm^{-1}; ^1H NMR ($CDCl_3$) δ=2.59 (1H, ddd, J=12.5, 6.8, and 1.0 Hz, 1-endo-H), 2.89 (1H, ddd, J=12.5, 10.0, and 8.0 Hz, 1-exo-H), 3.20, 3.67 (each 3H, s, COOMe), 4.36 (1H, dd, J=8.0 and 1.0 Hz, 2-H), 5.52 (1H, dd, J=10.0 and 6.8 Hz, 10b-H), 5.62 (1H, d, J=7.5 Hz, 6-H), 6.61 (1H, d, J=7.5 Hz, 5-H), 6.7—7.4 (4H, m, Ar), and 7.22 (5H, s, Ph); ^{13}C NMR ($CDCl_3$) δ=37.00 (t, 1-C), 50.47 (d, 2-C), 51.95, 52.83 (each q, COOMe), 60.36 (d, 10b-C), 103.77 (d, 6-C), 123.07, 123.36, 125.83, 127.36, 128.48, 128.72, 131.19, 132.89, 133.30, 140.72, 168.78 (q, COOMe), and 169.07 (q, COOMe); MS m/z (rel intensity, %) 363 (M^+, 17), 304 (35), 245 (20), 244 (78), 243 (33), 201 (29), 167 (64), 166 (24), 143 (88), 130 (25), 129 (46), 128 (38), 116 (26), 115 (73), 104 (72), and 103 (32). Found: C, 72.65; H, 5.94; N, 4.09%. Calcd for $C_{22}H_{21}NO_4$: C, 72.71; H, 5.82; N, 3.85%.

11A: The crude product obtained by evaporation of the solvent in vacuo was subjected to ^1H NMR measurement which showed a 3:2 mixture of **11A** and **11B**, and then chromatographed over silica gel with hexane–ethyl acetate (10:1 v/v) to provide 88% of **11A** as a single product: Colorless prisms (diethyl ether); IR (KBr) 2773, 2229, 1618, 1456, 1406, 1290, 1253, 1217, 773, and 702 cm^{-1}; ^1H NMR ($CDCl_3$) δ=2.90 (1H, dd, J=8.0 and 7.0 Hz, one of 1-H), 2.92 (1H, dd, J=8.0 and 7.8 Hz, the other of 1-H), 4.08 (1H, dd, J=8.0 and 7.0 Hz, 3-H), 4.94 (1H, dd, J=8.0 and 7.8 Hz, 10b-H), 6.01 (1H, d, J=7.5 Hz, 6-H), 6.47 (1H, d, J=7.5 Hz, 5-H), 6.9—7.3 (4H m, Ar), and 7.42 (5H, s, Ph); ^{13}C NMR ($CDCl_3$) δ=33.36 (t, 1-C), 54.83 (d, 2-C), 59.00 (d, 10b-C), 61.00 (s, 3-C) 110.77 (d, 6-C), 123.60, 124.95, 127.71, 128.25, 128.54, 129.36, 129.48, 129.66, 131.36, and 134.54; MS m/z (rel intensity, %) 297 (M^+, 13), 194 (16), 193 (base peak), 166 (13), 129 (15), 128 (17), 115 (16), 104 (916), 103 (14), 102 (12), and 77 (15). Found: C, 80.80; H, 5.10; N, 14.06%. Calcd for $C_{20}H_{15}N_3$: C, 80.78; H, 5.08; N, 14.13%.

^1H NMR spectrum ($CDCl_3$) of **11B** which was abstracted from the spectrum of the mixture with **11A**: δ=2.7—3.0 (2H, m, 1-H), 4.14 (1H, dd, J=12.0 and 6.6 Hz, 2-H), 5.10 (1H, dd, J=9.0 and 5.9 Hz, 10b-H), 5.87 (1H, d, J=7.3 Hz, 6-H), and 6.33 (1H, d, J=7.3 Hz, 5-H).

12: The reaction mixture was evaporated in vacuo to dryness to give residue which solidified on standing: Colorless prisms (diethyl ether); mp 130—132 °C; IR (KBr) 2240, 1750, 1605, 1450, 1220, 1210, 765, and 700 cm^{-1}; ^1H NMR ($CDCl_3$) δ=2.8—3.2 (2H, m, 1-H), 3.38 (3H, s, COOMe), 4.12 (1H dd, J=7.4 and 5.6 Hz, 2-H), 5.36 (1H, t, J=7.5 H, 10b-H), 5.86 (1H, d, J=7.5 Hz, 6-H), 6.34 (1H, d, J=7.5 Hz, 5-H), 6.8—7.5 (4H, m, Ar), and 7.29 (5H, s, Ph); ^{13}C NMR ($CDCl_3$) δ=35.65 (t, 1-C), 53.06 (q, COOMe), 54.47 (d, 2-C), 59.65 (d, 10b-C), 70.42 (s, 3-C), 107.89 (d, 6-C), 117.71 (s, CN), 123.42, 124.13, 126.95, 127.60, 128.36, 128.77, 129.77, 130.95, 131.83, 136.72, and 165.72 (s, COOMe); MS m/z (rel intensity, %) 330 (M^+, 56), 329 (29), 271 (45), 227 (17), 226 (base peak), 168 (29), 143 (98), 129 (22), and 115 (26). Found: C, 76.27; H, 5.58; N, 8.41%. Calcd for $C_{21}H_{18}N_2O_2$: C, 76.34; H, 5.49; N, 8.48%.

14 (an inseparable mixture of two stereoisomers (3:1 by ^1H NMR)): The crude reaction mixture was evaporated in vacuo and the residue was chromatographed over silica gel with hexane–ethyl acetate (5:1 v/v) to give **14** as a 3:1 mixture of two isomers): Colorless crystals (diethyl ether); IR (KBr) 2964, 1622, 1483, 1456, 1409, 1284, 1250, 1178, 777, and 710 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.0—2.0 (6H, m, CH_2), 2.4—3.0 (4H, m, CH), 4.15 (3/4H, d, J=5.9 Hz, 10b-H), 4.83 (1/4H, d, J=6.1 Hz, 10b-H), 5.72 (1/4H, d, J=8.0 Hz, =CH), 5.91 (3/4H, d, J=7.8 Hz, =CH), 6.33 (1/4H, d, J=8.0 Hz, =CHN), 6.42 (3/4H, d, J=7.8 Hz, =CHN), and 6.9—7.3 (4H, m, Ar); ^{13}C NMR ($CDCl_3$) major isomer: δ=27.59, 28.47, 34.37 (each t, CH_2), 38.72, 39.21, 52.88 (each d, CH), 57.67 (d and s, CH and q-C), 63.87 (d, CHN), 110.55 (d, =CH), 112.74, 114.65 (each s, CN), 123.48, 124.75, 127.54, 128.07, 128.76, 131.15, and 131.74; minor isomer: δ=27.59, 29.25, 34.96 (each t, CH_2), 36.67, 40.67, 47.02, 56.59 (each d, CH), 57.32 (s, q-C), 62.65 (d, CHN), 108.40 (d, =CH), 112.04, 113.50 (each s, CN), 125.20, 125.82, 126.86, 129.69, and 132.56; MS m/z (rel intensity, %) 287 (M^+, 7), 194 (19), 193 (73), 166 (32), 165 (21), 139 (24), 129 (base peak), 128 (36), 103 (21), 102 (45), 91 (20), 79 (63), and 77 (52). Found: C, 79.20; H, 5.94; N, 14.56%. Calcd for $C_{19}H_{17}N_3$: C, 79.41; H, 5.96; N,14.62%.

15: Unreacted ylide **1b** precipitated out when the reaction mixture was cooled to room temperature. The filtrate was evaporated in vacuo and chromatographed over silica gel with hexane–ethyl acetate (3:1 v/v) to afford **15.** The fraction eluted with hexane–ethyl acetate (1:1 v/v) gave additional **1b** (The combined yield of recovered **1b** was 55%): Colorless plates (diethyl ether–hexane); mp 151—152 °C; 2220, 1620, 1405, 1280, 1245, 1170, and 770 cm^{-1}: ^1H NMR ($CDCl_3$) δ=2.6—3.6 (6H, m, 1-, 2-H, and CH_2), 5.14 (1H, d, J=4.9 Hz, 10b-H), 5.72 (1H, d, J=7.5 Hz, 6-H), 6.63 (1H, d, J=7.5 Hz, 5-H), and 6.9—7.3 (4H, m, Ar); MS m/z (rel intensity, %) 299 (M^+, 6), 194 (15), 193 (base peak), 192 (10), and 129 (14). Found: C, 72.08; H, 4.37; N, 23.16%. Calcd for $C_{18}H_{13}N_3$: C, 72.23; H, 4.38; N, 23.40%.

16: The reaction mixture was chromatographed, after evaporation of the solvent in vacuo, over silica gel with hexane–ethyl acetate (8:1 v/v) to give **16** and then **20: 16**: Colorless liquid; IR (neat) 2980, 1750, 1740, 1610, 1455, and 770 cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.7—1.6 (9H, m, n-Bu), 2.40 (2H, dd, J=8.1 and 4.5 Hz, 1-H), 2.8—3.2 (1H, m, 2-H), 3.65, 3.77 (each 3H, s, COOMe), 4.91 (1H, t, J=8.1 Hz, 10b-H), 5.49 (1H, d, J=7.5 Hz, 6-H), 6.50 (1H, d, J=7.5 Hz, 5-H), and 6.7—8.2 (4H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=13.94 (q, n-Bu), 22.59, 29.30, 30.06 (each t, n-Bu), 33.24 (t, 1-C), 44.36 (d, 2-C), 52.47, 52.83 (each q, COOMe), 58.77 (d, 10b-C), 77.71 (s, 3-C), 102.30 (d, 6-C), 123.07, 123.30, 125.54, 127.36, 131.07, 133.13, 133.89, 169.25 (s, COOMe), and 169.72 (s COOMe); MS m/z (rel intensity, %) 343 (M^+, 10), 284 (17), 132 (90), 100 (18), 85 (71), and 83 (base peak). HRMS Found: m/z 343.1778. Calcd for $C_{20}H_{25}NO_4$: M, 343.1782. **20**: Colorless prisms (hexane); mp 80—81 °C; IR (KBr) 2980, 1680, 1440, and 1350 cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.8—1.1 (3H, m, n-Bu), 1.2—2.0 (4H, m, n-Bu), 3.00 (2H, t, J=7.5 Hz, n-Bu), 3.96 (3H, s, COOMe), 6.88 (1H, s, 1-H), 6.92 (1H d, J=7.5 Hz, 6-H), 7.3—7.7 (3H, m, Ar), 7.9—8.2 (1H, m, Ar), and 9.20 (1H, d, J=7.5 Hz, 5-H); MS m/z (rel intensity, %) 281 (M^+, 48), 239 (base peak), 181 (20), 180 (42), and 41 (25). Found: C, 76.62; H, 6.84; N, 4.72%. Calcd for $C_{18}H_{19}NO_2$: C, 76.84; H, 6.81; N, 4.98%.

17: The crude mixture was chromatographed over silica gel by using hexane–ethyl acetate (10:1 v/v) to provide **17**: Colorless viscous liquid; IR (neat) 2958, 2926, 2210, 1618,

1456, 1406, 1256, 1178, and 775 cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.8—3.0 (12H, m, 1-, 2-H, and *n*-Bu), 4.59 (1H, dd, *J*=8.2 and 7.5 Hz, 10b-H), 5.90 (1H, d, *J*=7.5 Hz, 6-H), 6.42 (1H, d, *J*=7.5 Hz, 5-H), and 6.8—7.3 (4H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=13.82 (q, *n*-Bu), 22.53, 29.77, 31.06 (each t, *n*-Bu), 33.00 (t, 1-C), 49.47 (d, 2-C), 58.36 (d, 10b-C), 59.00 (s, 3-C), 110.13 (d, 6-C), 111.77, 114.00 (each s, CN), 123.60, 124.83, 127.54, 128.18, 128.48, 131.19, and 131.66; MS *m/z* (rel intensity, %) 277 (M^+, 18), 276 (11), 194 (16), and 193 (base peak). HRMS Found: *m/z* 277.1583. Calcd for $C_{18}H_{19}N_3$: M, 277.1578.

18: The crude reaction mixture was chromatographed over silica gel with hexane–ethyl acetate to afford **18**: Pale yellow prisms (diethyl ether–hexane); mp 158—159 °C; IR (KBr) 1760, 1740, 1610, 1240, 1175, 1020, and 760 cm^{-1}: ^1H NMR ($CDCl_3$) δ=2.3—2.7 (2H, m, 11-H), 3.3—3.6 (1H, m, 10a-H), 3.79 (3H, s, COOMe), 4.12 (1H, dd, *J*=9.5 and 4.5 Hz, 11a-H), 4.61 (1H, dd, *J*=9.5 and 3.0 Hz, one of 10-H), 4.67 (1H, dd, *J*=9.5 and 5.0 Hz, the other of 10-H), 5.60 (1H, d, *J*=7.8 Hz, 5-H), 6.68 (1H, *J*=7.8Hz, 6-H), and 6.8—7.2 (4H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=34.41 (t, 11-C), 44.18 (d, 10a-C), 53.42 (q, COOMe), 59.18 (d, 11a-C), 71.83 (s 7a-C), 72.24 (t, 10-C), 104.13 (d, 5-C), 123.48, 123.77, 126.07, 127.89, 130.30, 131.95, 133.30, 168.54 (s, 8-C), and 172.03 (s, COOMe); MS *m/z* (rel intensity, %) 285 (M^+, 50), 284 (base peak), 226 (40), 182 (13), 181 (20), 180 (27), 168 (19), 167 (47), 143 (28), 129 (41), 128 (21), and 115 (29). Found: C, 67.39; H, 5.34; N, 4.86%. Calcd for $C_{16}H_{15}NO_4$: C, 67.36; H, 5.30; N, 4.91%.

19: The crude mixture was chromatographed over silica gel with hexane–ethyl acetate (7:1 v/v) to give **19**: Colorless prisms (hexane); mp 92—93 °C; IR (KBr) 2950, 1610, 1470, 1450, 1400, 1245, 1080, 855, and 830 cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.19 (9H, s, $SiMe_3$), 2.13 (1H, ddd, *J*=12.1, 7.5, and 5.9 Hz, 1-endo-H), 2.53 (1H, ddd, *J*=12.1, 10.0, and 8.5 Hz, 1-exo-H), 3.0—3.2 (1H, m, 2-H), 3.89 (1H, d, *J*=8.4 Hz, one of 2-CH_2), 3.90 (1H, d, *J*=7.0 Hz, the other of 2-CH_2), 4.58 (1H, dd, *J*=8.5 and 7.5 Hz, 10b-H), 5.91 (1H, d, *J*=7.5 Hz, 6-H), 6.49 (1H, d, *J*=7.5 Hz, 5-H), and 6.8—7.3 (4H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=0.64 (q, $SiMe_3$), 29.12 (t, 1-C), 51.53 (d, 2-C), 57.53 (s, 3-C), 58.95 (d, 10b-C), 62.24 (t, CH_2O), 110.18 (d, 6-C), 111.24, 114.01 (each s, CN), 123.77, 125.01, 127.66, 128.42, 128.83, 131.48, and 131.83; MS *m/z* (rel intensity, %) 323 (M^+, 11), 308 (19), 281 (15), 220 (29), 194 (12), 193 (60), 145 (12), 144 (base peak), and 73 (14). Found: C, 66.62; H, 6.60; N, 12.80%. Calcd for $C_{18}H_{21}N_3OSi$: C, 66.84; H, 6.54; N, 12.99%.

21: This compound was obtained by column chromatography of the crude reaction mixture over silica gel with hexane–ethyl acetate (5:1 v/v): Colorless viscous liquid; IR (neat) 2960, 1820, 1750, 1620, 1560, 1440, and 780 cm^{-1}; ^1H NMR ($CDCl_3$) δ=3.67, 3.84 (each 3H, s, COOMe), 5,03 (d, *J*=5.5 Hz, 11b-H), 5.43 (1H, dd, *J*=7.5 and 5.5 Hz, 11a-H), 5.72 (1H, d, *J*=7.5 Hz, 8a-H), 5.75 (1H, d, *J*=7.8 Hz, 5-H), 6.52 (1H d, *J*=7.8 Hz, 6-H), and 6.8—7.3 (4H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=53.59 (q, 2C, COOMe), 66.54 (d, 11b-C) 75.59 (s, 8-C), 80.01, 81.77 (each d, 8a- and 11a-C), 107.66 (d, 5-C), 120.77, 123.12, 124.42, 127.19, 128.65, 131.19, 132.18, 153.13 (s, 10-C), 165.77, and 166.37 (each s, COOMe); MS *m/z* (rel intensity, %) 345 (M^+, 5), 259 (9), 226 (16), 225 (base peak), 194 (32), 167 (34), 166 (26), 139 (18), 129 (82), 128 (20), 102 (20), and 91 (17). HRMS Found: *m/z* 345.0846. Calcd for $C_{17}H_{15}NO_7$: M, 345.0847.

22A and 22B: When the reaction mixture was cooled to room temperature, less soluble **22A** precipitated out. The filtrate was evaporated in vacuo and the residue was chromatographed over silica gel by using hexane–ethyl acetate (10:1 v/v) to provide **22B**. **22A:** Pale yellow prisms (benzene–ethanol); mp 177—178 °C; IR (KBr) 1813, 1632, 1377, 1255, 1167, 1093, 962, 777, and 761 cm^{-1}; ^1H NMR (DMSO-d_6:$CDCl_3$=1:4 v/v) δ=4.78 (1H, br s, 11b-H), 5.85, 5.87 (each 1H, s, 8a- and 11a-H), 5.98 (1H, d, *J*=7.8 Hz, 5-H), 6.46 (1H, d, *J*=7.8 Hz, 6-H), and 7.0—7.4 (4H, m, Ar); MS *m/z* (rel intensity, %) 279 (M^+, 8), 194 (15), 193 (base peak), 129 (24), and 128 (13). Found: C, 64.53; H, 3.50; N, 14.99%. Calcd for $C_{15}H_9N_3O_3$: C, 64.52; H, 3.25; N, 15.05%. **22B**: Pale yellow needles (benzene–ethanol); mp 193—194 °C; IR (KBr) 1808, 1628, 1182, 1159, 1149, and 775 cm^{-1}; ^1H NMR ($CDCl_3$) δ=4.82 (1H, d, *J*=3.6 Hz, 11b-H), 5.46 (1H, d, *J*=6.5 Hz, 8a-H), 5.64 (1H, dd, *J*=6.5 and 3.6 Hz, 11a-H), 6.02 (1H, d, *J*=8.0 Hz, 5-H), 6.42 (1H, d, *J*=8.0 Hz, 6-H), and 7.0—7.2 (4H, m, Ar); MS *m/z* (rel intensity, %) 279 (M^+, 5), 193 (54), 166 (11), 130 (12), 129 (81), 128 (52), 115 (15), 103 (19), 102 (40), and 86 (base peak). Found: C, 64.55; H, 3.41; N, 14.89%. Calcd for $C_{15}H_9N_3O_3$: C, 64.52; H, 3.25; N, 15.05%.

23: The reaction mixture was chromatographed, after evaporation of the solvent in vacuo, over silica gel with hexane–ethyl acetate (3:1 v/v) to give **23**: Colorless prisms (diethyl ether); mp 154—156 °C; IR (KBr) 2220, 1830, 1795, 1770, 1620, 1210, 1140, and 755 cm^{-1}; ^1H NMR ($CDCl_3$) δ=3.95 (3H, s, COOMe), 5.22 (1H, br s, 11b-H), 5.53 (2H, m, 8a- and 11a-H), 5.94 (1H, d, *J*=7.5 Hz, 5-H), 6.33 (1H, d, *J*=7.5 Hz, 6-H), and 6.9—7.2 (4H, m, Ar); MS *m/z* (rel intensity, %) 312 (M^+, 8), 227 (15), 226 (base peak), 209 (15), 168 (36), 144 (40), 143 (26), 129 (30), 128 (18), and 115 (14). HRMS Found: *m/z* 312.0749. Calcd for $C_{16}H_{12}N_2O_5$: M, 312.0745.

24: The mixture was evaporated in vacuo and the residue was chromatographed over silica gel with hexane–ethyl acetate (10:1 v/v) to give **24**: Pale yellow prisms (diethyl ether–hexane); mp 101—102 °C; IR (KBr) 2970, 1770, 1740, 1600, 1460, 1420, 1210, 1120, 1070, and 765 cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.8—1.7 (7H, m, *n*-Bu), 2.26 (1H, ddd, *J*=12.5, 10.6 and 4.1 Hz, 1-endo-H), 2.64 (1H, dd, *J*=12.5 and 5.0 Hz, 1-exo-H), 3.3—4.0 (2H, m OCH_2), 3.64, 3.76 (each 3H, s, COOMe), 4.63 (1H, d, *J*=4.1 Hz, 2-H), 5.06 (1H, dd, *J*=10.6 and 5.0 Hz, 10b-H), 5.45 (1H, d, *J*=7.5 Hz, 6-H), 6.51 (1H, d, *J*=7.5 Hz, 5-H), and 6.8—7.1 (4H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=13.82 (q, *n*-Bu), 19.30, 31.88 (each t, *n*-Bu), 35.59 (t, 1-C), 52.59, 52.95 (each q, COOMe), 59.42 (d, 10b-C), 70.42 (t, OCH_2), 78.30 (s, 3-C), 82.95 (d, 2-C), 101.78 (d, 6-C), 123.12, 123.48, 125.54, 127.48, 130.95, 133.01, 133.95, 167.95 (s, COOMe), and 168.30 (s, COOMe); MS *m/z* (rel intensity, %) 359 (M^+, 38), 358 (20), 300 (30), 259 (22), 226 (27), 225 (22), 201 (22), 167 (34), 143 (base peak), and 130 (11). Found: C, 67.39; H, 5.34; N, 4.86%. Calcd for $C_{20}H_{25}NO_5$: C, 67.36; H, 5.30; N, 4.91%.

25: The crude reaction mixture was chromatographed over silica gel with hexane–ethyl acetate (10:1 v/v) to provide **25**: Pale yellow prisms (diethyl ether–hexane); mp 79—80 °C; IR (KBr) 2933, 1622, 1456, 1402, 1254, 1182, 1108, and 777 cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.93 (3H, t, *J*=6.9 Hz, *n*-Bu), 1.2—1.8 (4H, m, *n*-Bu), 2.59 (2H, dd, *J*=8.0 and 5.0 Hz, 1-H), 3.5—4.0 (2H, m, OCH_2), 4.51 (1H, t, *J*=5.0 Hz, 10b-H), 4.85 (1H, t, *J*=8.0 Hz, 2-H), 5.85 (1H, d, *J*=7.5Hz, 6-H), 6.35 (1H, d, *J*=7.5 Hz, 5-H), and 6.8—7.3 (4H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=13.82 (q, *n*-Bu), 19.14, 31.59 (each t,

n-Bu), 35.84 (t, 1-C), 58.25 (d, 10b-C), 59.62 (s, 3-C), 72.27 (t, OCH_2), 85.74 (d, 2-C), 109.62 (d, 6-C), 111.13, 113.67 (each s, CN), 123.78, 124.90, 127.59, 127.93, 128.27, 130.86, and 131.45; MS *m/z* (rel intensity, %) 293 (M^+, 3), 193 (33), 58 (40), and 42 (base peak). Found: C, 73.55; H, 6.54; N, 14.31%. Calcd for $C_{18}H_{19}N_3O$: C, 73.70; H, 6.53; N, 14.32%.

26A and 26B: The crude mixture was chromatographed over silica gel with hexane–ethyl acetate (10:1 v/v) to give **26A** and **26B** which are still contaminated by each other. They were further purified by preparative thin-layer chromatography using the same eluent to give pure **26A** and **26B**. **26A**: Colorless liquid; IR (neat) 2970, 2200, 1760, 1740, 1620, 1560, and 770 cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.8—1.7 (7H, m, *n*-Bu), 2.50 (1H, ddd, *J*=13.0, 9.5, and 5.0 Hz, 1-endo-H), 2.77 (1H, ddd, *J*=13.0, 6.0, and 2.0 Hz, 1-exo-H), 3.4—3.8 (2H, m, OCH_2), 3.88 (3H, s, COOMe), 4.54 (1H, dd, *J*=5.0 and 2.0 Hz, 2-H), 5.22 (1H, dd, *J*=9.5 and 6.0 Hz, 10b-H), 5.66 (1H, d *J*=7.5 Hz, 6-H), 6.26 (1H, d, *J*=7.5 Hz, 5-H), and 6.8—7.3 (4H, m, Ar); ^{13}C NMR ($CDCl_3$) δ=13.77 (q, *n*-Bu), 19.12, 31.65 (each t, *n*-Bu), 37.00 (t, 1-C), 53.65 (q, COOMe), 58.83 (d, 10b-C), 69.89 (s, 3-C), 71.30 (t, OCH_2), 85.24 (d, 2-C), 105.59 (d, 6-C), 116.95 (s, CN), 123.71, 124.18, 126.60, 127.77, 129.83, 130.72, 132.18, and 165.07 (s, COOMe); MS *m/z* (rel intensity, %) 326 (M^+, 24), 227 (21), 226 (96), 195 (18), 194 (22), 193 (72), 192 (56), 168 (97), 167 (20), 143 (base peak), 140 (23), 139 (19), 129 (37), 128 (33), and 115 (38). HRMS Found: *m/z* 326.1627. Calcd for $C_{19}H_{22}N_2O_3$: M, 326.1629. **26B**: Colorless liquid; IR (neat) 2970, 2200, 1750, 1620, 1560, 1455, 1240, and 760 cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.8—1.8 (7H, m, *n*-Bu), 2.50 (1H, dd, *J*=9.5 and 5.5 Hz, 1-endo-H), 2.54 (1H, dd, *J*=6.8 and 2.8 Hz, 1-exo-H), 3.4—4.0 (2H, m, OCH_2), 3.81 (3H, s, COOMe), 4.40 (1H, dd, *J*=5.5 and 2.8 Hz, 2-H), 4.92 (1H, dd, *J*=9.5 and 6.8 Hz, 10b-H), 5.34 (1H, d, *J*=7.5 Hz, 6-H), 6.34 (1H, d, *J*=7.5 Hz, 5-H), and 6.8—7.3 (4H, m, Ar); MS *m/z* (rel intensity, %) 326 (M^+, 10), 269 (14), 227 (19), 226 (88), 194 (24), 193 (base peak), 192 (56), 168 (61), 167 (23), 143 (54), 140 (25), 129 (40), 128 (33), and 115 (33). HRMS Found: *m/z* 326.1630. Calcd for $C_{19}H_{22}N_2O_3$: M, 326.1629.

27 and 29: The crude mixture was chromatographed over silica gel with hexane–ethyl acetate (5:1 v/v) to give a mixture of **27** and **29**. As compound **27** was so susceptible as to suffer from the decarboxylative aromatization leading to **29**, only ^1H NMR spectrum was measured. **27**: ^1H NMR ($CDCl_3$) δ=2.6—2.8 (2H, m, 1-H), 3.60, 3.64 (each 3H, s, COOMe), 4.54 (1H, m, 10b-H), 5.10 (1H, dt, *J*=8.0, 8.0, and 1.0 Hz, 2-H), 5.47 (1H, d, *J*=7.0 Hz, 6-H), 6.48 (1H, d, *J*=7.0 Hz, 5-H), and 6.6—7.7 (9H, m, Ar). Authentic sample of **29** was synthesized according to the following procedure: A mixture of 1-[bis(methoxycarbonyl)methyl]isoquinolinium bromide (0.34 g, 1 mmol), phenyl vinyl sulfoxide (0.152 g, 1 mmol), and triethylamine (0.14 ml, 1 mmol) in dry toluene (5 ml) was heated under reflux for 64 h. The mixture was poured into water (100 ml), extracted with dichloromethane (30 ml×2), the combined extracts were dried over magnesium sulfate, and evaporated in vacuo. The residue was chromatographed over silica gel by using hexane to give diphenyl disulfide (0.051 g, 47%) and the fraction eluted with hexane–ethyl acetate (10:1 v/v) afforded **29** (0.102 g, 45%). **29**: Colorless prisms (diethyl ether); mp 111—112 °C; IR (KBr) 1685, 1530, 1355, 1260, 1190, 1110, 785, and 745 cm^{-1}; ^1H NMR ($CDCl_3$) δ=3.89 (3H, s, COOMe), 6.9—7.2 (2H, m), 7.3—7.8 (4H, m), 8.0—8.2 (1H, m), and 9.20 (1H, d, *J*=7.7 Hz); MS *m/z* (rel intensity, %) 225 (M^+, 90), 194 (57), 167 (base peak), 166 (69), 140 (33), and 139 (51). Found: C, 74.55; H, 4.96; N, 6.20%. Calcd for $C_{14}H_{11}NO_2$: C, 74.65; H, 4.92; N, 6.22%.

28: The crude reaction mixture was chromatographed over silica gel by using hexane–ethyl acetate (4:1 v/v) to give **28**: Colorless prisms (diethyl ether); mp 109—111 °C; IR (KBr) 2220, 1775, 1620, 1250, and 780 cm^{-1}; ^1H NMR ($CDCl_3$) δ=2.84 (1H, ddd, *J*=13.0, 7.2, and 4.0 Hz, 1-endo-H), 3.02 (1H, ddd, *J*=13.0, 8.0, and 6.5 Hz, 1-exo-H), 3.74 (3H, s, COOMe), 4.24 (1H, dd, *J*=6.5 and 4.0 Hz, 10b-H), 5.17 (1H, dd, *J*=8.0 and 7.2 Hz, 2-H), 5.76 (1H, d, *J*=7.3 Hz, 6-H), 6.25 (1H, d, *J*=7.3 Hz, 5-H), and 6.7—7.8 (9H, m, Ar); MS *m/z* (rel intensity, %) 362 (M^+, 8), 253 (39), 226 (20), 194 (27), 193 (base peak), 192 (43), 168 (28), 167 (27), 143 (23), 129 (22), 110 (22), and 109 (56). Found: C, 69.80; H, 5.03; N, 7.68%. Calcd for $C_{21}H_{18}N_2O_2S$: C, 69.61; H, 4.97; N, 7.73%.

The present research was financially supported in part by a Grant-in-Aid for Scientific Research No. 62101008 from the Ministry of Education, Science and Culture.

References

1) I. Zugravescu and M. Petrovanu, "N-Ylide Chemistry," McGraw-Hill Internatl. New York (1976); J. W. Lown, "Azomethine Ylides", as chapter 6 of "1,3-Dipolar Cycloaddition Chemistry," ed by A. Padwa, A Wiley-Interscience Publication, New York, Chichester, Brisbane, Toronto, Shingapore (1984), Vol. 2, pp. 653—732; R. M. Kellogg, *Tetrahedron*, **32**, 2165 (1976); C. G. Stuckwisch, *Synthesis*, **1973**, 469.

2) O. Tsuge, S. Kanemasa, and S. Takenaka, *Bull. Chem. Soc. Jpn.*, **58**, 3137, 3320 (1985) and references cited therein; M. Hori, T. Kataoka, H. Shimizu, E. Imai, Y. Matsumoto, M. Kawachi, and K. Kuratani, *J. Chem. Soc., Perkin Trans. 1*, **1987**, 1211.

3) O. Tsuge, S. Kanemasa, S. Kuraoka, and S. Takenaka, *Chem. Lett.*, **1984**, 281; O. Tsuge, S. Kanemasa, S. Takenaka, and S. Kuraoka, *ibid.*, **1984**, 465; O. Tsuge, S. Kanemasa, and S. Takenaka, *Bull. Chem. Soc. Jpn.*, **60**, 1489 (1987).

4) O. Tsuge, S. Kanemasa, and S. Takenaka, *J. Org. Chem.*, **51**, 1853 (1986); O. Tsuge, S. Kanemasa, and S. Takenaka, *Bull. Chem. Soc. Jpn.*, **59**, 3631 (1986).

5) R. Sustmann, *Tetrahedron Lett.*, **1971**, 2717.

6) Cycloadditions of azomethine ylides to the following olefins of nonactivated types are known: with norbornene: R. Huisgen, W. Scheer, G. Szeimies, and H. Huber, *Tetrahedron Lett.*, **1966**, 397; J. A. Deyrup and G. S. Kuta, *J. Org. Chem.*, **43**, 501 (1978). With acenaphthylene: R. Huisgen, H. Gotthardt, and H. O. Bayer, *Chem. Ber.*, **103**, 2368 (1970); R. Grigg and S. Thianpatanagul, *J. Chem. Soc., Chem. Commun.*, **1984**, 180. With styrene: O. Tsuge, S. Kanemasa, M. Ohe, and S. Takenaka, *Chem. Lett.*, **1986**, 973; O. Tsuge, S. Kanemasa, M. Ohe, and S. Takenaka, *Bull. Chem. Soc. Jpn.*, **60**, 4079 (1987). With vinylene carbonate and vinyl ethers: P. Deshong, D. A. Kell, and D. R. Sidler, *J. Org. Chem.*, **50**, 2309 (1985); P. Deshong, D. R. Sidler, D. A. Kell, and N. N. Aronson, Jr., *Tetrahedron Lett.*, **26**, 3734 (1985).

7) Nonstabilized azomethine ylides generated from *N*-oxides and an alkyllithium are highly reactive to nonactivated olefins: R. Beugelmans, G. Negron, and G.

Roussi, *J. Chem. Soc., Chem. Commun.*, **1983**, 31; J. Chastanet and G. Roussi, *Heterocycles*, **23**, 653 (1985); R. Beugelmans, L. B.-Iguertsira, J. Chastanet, G. Negron, and G. Roussi, *Can. J. Chem.*, **63**, 725 (1985); J. Chastanet and G. Roussi, *J. Org. Chem.*, **50**, 2910 (1985).

8) R. Huisgen and K. Niklas, *Heterocycles*, **22**, 21 (1984).

9) N. S. Basketter and A. O. Plunkett, *J. Chem. Soc., Chem. Commun.*, **1973**, 188.

10) O. Tsuge, S. Kanemasa, and S. Takenaka, *Heterocycles*, **20**, 1907 (1983).

11) The ylide **1b** decomposes quite readily when heated in DMF at 110 °C. Only (*Z*)-stilbene was recovered in a good yield after the reaction in DMF.

12) Homolytic dehydrogenation by DDQ has been already discussed: A. J. Fatiadi, "Preparation and Synthetic Applications of Cyano Compounds," as chapter 26 of "The Chemistry of Triple-Bonded Functional Groups," ed by S. Patai and Z. Rappoport, John Wiley and Sons, Chichester, New York, Brisbane, Toronto, Singapore (1983), p. 1210.

13) K. N. Houk, J. Sims, R. E. Duke, Jr., R. W. Strozier, and J. K. George, *J. Am. Chem. Soc.*, **95**, 7287 (1973); K. N. Houk, J. Sims, C. R. Watts, and L. J. Luskus, *ibid.*, **95**, 7301 (1973); K. N. Houk, *Acc. Chem. Res.*, **8**, 361 (1975).

14) G. Surpateanu and A. L.-Combier, *Heterocycles*, **22**, 2079 (1984).

15) W. J. Linn, O. W. Webster, and R. E. Benson, *J. Am. Chem. Soc.*, **87**, 3651 (1965).

16) Y. Kobayashi, T. Kutsumura, K. Morinaga, M. Fugita, and Y. Hanzawa, *Chem. Pharm. Bull.*, **18**, 2489 (1970).