# Nucleophilic Substitutions of 1-Alkenylcyclopropyl Esters and 1-Alkynylcyclopropyl Chlorides Catalyzed by Palladium(0)[†,1]

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**Abstract:** The 1-ethenylcyclopropylsulfonates **2e,f** and 2-cyclopropylideneethyl esters **10b,c**, readily available from cyclopropanone hemiacetal **1**, undergo regioselective Pd(0) catalyzed nucleophilic substitution via the unsymmetric 1,1-dimethylene-$\pi$-allyl complex **23**. With stabilized anions (enolates of malonic ester, $\beta$-dicarbonyl compounds, $\beta$-sulfonyl ester, and Schiff bases as well as acetate anion, sulfonamide anion, etc.) the nucleophilic substitution occurs at the terminal vinylic position *exclusively*, providing cyclopropylideneethyl derivatives as building blocks of high synthetic potential. Competition experiments have disclosed that 1-ethenylcyclopropyl tosylate (**2e**) and cyclopropylideneethyl acetate (**10b**) are more reactive than dimethylallyl acetates **19** and **22**, respectively. Use of chiral phosphines as ligands in the palladium catalyst can provide optically active methylenecyclopropane derivatives. With phenyl-, methyl-, and even *n*-butylzinc chloride as nucleophiles, the reaction apparently proceeds with initial transfer of the organic residue to palladium, followed by reductive elimination entailing tertiary substitution on the cyclopropane ring *exclusively*; the same type of product is obtained with azide and bis(trimethylsilyl)amide. But the site of hydride attack to yield reduction products depends on the hydride source. 1-Alkynylcyclopropyl chlorides **12**, **13**, and **14** react only with organozinc chlorides (nonstabilized nucleophiles) to provide mixtures of ethenylidenecyclopropanes **65** and alkynylcyclopropanes **66**, via the $\sigma$-palladium complexes **69** and **70**, while chloride **15** undergoes mainly reduction. Other transition metal catalysts (Ni, Mo) also induce substitutions, but with poorer regioselectivity.

## Introduction

Cyclopropane derivatives, which can undergo ring opening, ring enlargement, or cycloaddition reactions selectively, provide building blocks of unprecedented synthetic potential.[2-4] The three-membered carbocycle is also found as a basic structural element in a wide range of naturally occurring compounds or transiently generated in primary or secondary metabolisms. It is well established that the cyclopropane moiety presents a reactivity closely resembling that of an olefinic double bond.[5] In recent years, stereochemical aspects of cyclopropyl compounds have come into play, and development of stereoselective syntheses has been started.[6] While electrophilic substitutions on the three-membered ring occur readily with lithium derivatives derived either from cyclopropanecarboxylate[7] or from 1-bromo-, 1-arylthio-, 1-methyl(phenyl)seleno-, 1-alkoxy-, and 1-trimethylsilyl-substituted cyclopropyl compounds and have been successfully exploited,[8] nucleophilic substitutions with retention of the ring, on the other hand, are rather rare and require either the anchimeric assistance of electron-releasing substituents[9] or a very efficient leaving group such as triflate.[10]

Since the reaction of $\pi$-allyl transition metal complexes with carbon nucleophiles was discovered,[11] this attractive carbon–carbon bond formation has found ever increasing use;[12] thus, a large number of allylic substitution reactions are now achieved under mild conditions with various catalysts (palladium, molybdenum, nickel, tungsten, rhodium, etc.) and nucleophiles,[13] with a high degree of regio-,[14] diastereo-,[15] and enantioselectivity.[16] With unsymmetrical allyl substrates the regioselectivity usually depends on charge distribution, steric hindrance, electronic factors, and stability of the intermediate alkene transition metal complexes; 1-ethenylcycloalkyl esters or sulfones for instance, preferably undergo alkylation at the less substituted carbon atom, i.e. on the terminal vinylic position.[17] However, it has also been reported by Trost et al. that the molybdenum-catalyzed sulfone substitution fails in the cyclopropyl series,[17b] and this behavior appears to be consistent with the well-known fact that cyclopropyl tosylates are relatively sluggish in solvolysis reactions.[4]

Available also by Pd(0)-catalyzed diastereoselective cyclization,[18] the ethenylcyclopropane system is known to undergo either

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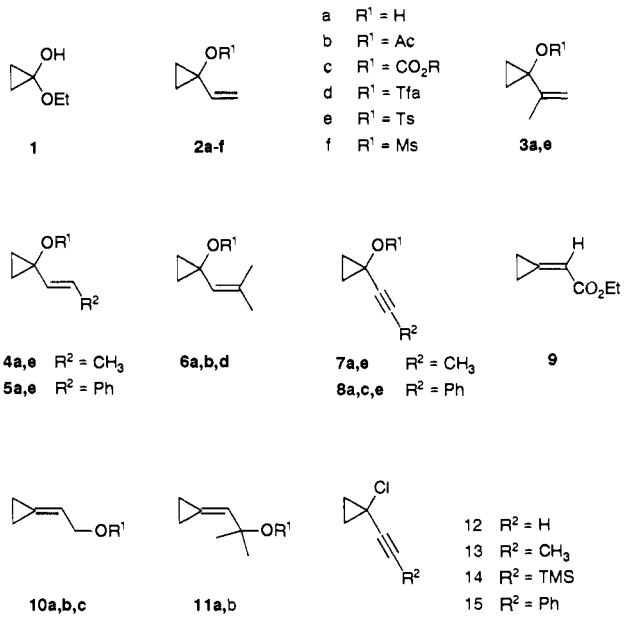
conjugate nucleophilic ring opening,[19] [3 + 2] cycloaddition giving rise to a novel annulation process,[20] or $C_3 \rightarrow C_5$ ring expansion[21] under palladium catalysis. Alkylidenecyclopropanes, for their part, undergo either ring opening with palladium chloride to provide $\pi$-allylpalladium complexes which further react with stabilized carbon nucleophiles,[22] carbopalladation with vinyl or aryl halides and internal nucleophiles in the presence of Pd(0) leading to cyclic compounds (e.g. ethenylcyclopropanes),[23] or Pd(0)-catalyzed regioselective inter- and intramolecular [3 + 2] cycloadditions with olefinic and acetylenic substrates.[24]

Due to our pertaining interest in developing new methodologies for the construction of cyclopropyl building blocks useful in organic synthesis,[3,4,8,25] we have conceived the possibility of nucleophilic substitutions on cyclopropane derivatives under palladium catalysis with complete retention of the three-membered ring. To this end, we have examined the behavior of 1-ethenylcyclopropanol, 2-cyclopropylideneethanol, and 1-alkynylcyclopropanol derivatives as substrates in Pd(0)-catalyzed substitution reactions with stabilized (*soft*) and nondelocalized (*hard*) carbon nucleophiles,[26] under various conditions.[27]

## Preparations of 1-Alkenylcyclopropyl and 1-Alkynylcyclopropyl Substrates 2–15

Cyclopropanone ethyl hemiacetal **1**, the synthesis of which from ethyl 3-chloropropanoate[28,29] has recently been simplified by applying sonication to avoid the tedious preparation of highly dispersed sodium metal,[28b] is the convenient common precursor to 1-alkenyl- **2–6** and 1-alkynylcyclopropanol derivatives **7**, **8** as well as to 2-cyclopropylideneethanol derivatives **10** and **11**. Effectively, as previously reported, the magnesium salt resulting from the reaction of hemiacetal **1** with 1 equiv of methylmagnesium bromide or iodide[30] undergoes nucleophilic addition of vinylmagnesium halides and alkynyllithium or alkynylmagnesium halide derivatives to provide the 1,1-dimethyleneallylic and 1,1-dimethylpropargylic alcohols **2a–8a** in high yields.

Lithium aluminum hydride reduction of the propargylic alcohols **7a** and **8a** in refluxing THF led to (*E*)-1-alkenylcyclopropanols **4a** and **5a**, exclusively.[30] Addition of triethyl phosphonoacetate carbanion to the magnesium salt of **1** gave the ethyl cyclopropylideneacetate **9** in low yield (10%),[31] but the yield for the preparation of **9** was far better in the benzoic acid catalyzed Wittig reaction of **1** with ethoxycarbonylmethylenetriphenylphosphorane.[32] Diisobutylaluminum hydride reduction (DIBAH, $CH_2Cl_2$, −78 °C) of the conjugated ester **9** finally provided 2-cyclopropylideneethanol (**10a**) in 90% yield. Addition of methyllithium (2 equiv) to the ester **9** yielded cyclopropylidene-2-methyl-2-propanol (**11a**).




1 **2a-f** **3a,e** **4a,e** **5a,e** **6a,b,d** **7a,e** **8a,c,e** **9** **10a,b,c** **11a,b**

1-Ethenylcyclopropanol (**2a**) was converted to its acetate (**2b**) (77%), ethyl carbonate (**2c**) (60%), and trifluoroacetate (**2d**) (57%) upon successive treatments with 1 equiv of methylmagnesium bromide and acetyl chloride, ethyl chloroformate, or trifluoroacetic anhydride at 0 °C, respectively. The tosylates **2e**, **3e**, **7e**,[9b] and **8e**[9b] were obtained from the corresponding cyclopropanols with *p*-toluenesulfonyl chloride in pyridine (or in $CH_2Cl_2$, in the presence of $NEt_3$ and (dimethylamino)pyridine (DMAP)); the mesylate **2f** (87%) was made by treatment of **2a** with methanesulfonyl chloride in pyridine. On the other hand, preparation of the tosylate from 1-isobutenylcyclopropanol (**6a**) failed under various conditions (TsCl, pyridine, 8 °C; TsCl, pyridine, $CHCl_3$, or pentane, 0 °C; MeMgCl (*n*-BuLi or MeLi) and TsCl in $Et_2O$ at −78 °C); **6a** also failed to react with mesyl chloride; the reasons for this failure are unknown, but most likely it is attributable to steric hindrance. The acetate **6b** and trifluoroacetate **6d**, however, were obtained in 75 and 50% yield, respectively, upon treating the magnesium salt of **6** ($R^1$ = MgCl) with acetyl chloride at 0 °C and with trifluoroacetic anhydride in $CH_2Cl_2$ in the presence of DMAP, respectively. Cyclopropylidene-2-methyl-2-propanol (**11a**) was acetylated by acetic anhydride (DMAP, $CH_2Cl_2$) to give a 55% yield of the isomeric tertiary acetate **11b**. The acetate **10b** (75%) and ethyl carbonate **10c** (86%) were prepared from **10a** with acetic anhydride ($NEt_3$, $Et_2O$) and ethyl chloroformate (pyridine, $CH_2Cl_2$), respectively. Chlorination of the propargylic alcohols **7a** and **8a** with thionyl chloride (pyridine) gave the cyclopropyl chlorides **13** and **14**; but the chlorides **12** and **15** were prepared from readily available 1-chloro-1-(trichloroethenyl)cyclopropane[3b,25c] upon treatment with alkyllithium reagents and consecutive trapping of the corresponding lithium acetylide with the suitable electrophile ($H_2O$ or $ClSiMe_3$).[25b,c]

## Regioselective Substitutions on 1-Alkenylcyclopropyl Esters at the Vinylic End

Under the typical conditions generally employed for the substitution of allylic acetates by *soft* nucleophiles[26] (stabilized anions) in the presence of tetrakis(triphenylphosphine)palladium(0) ($Pd(PPh_3)_4$, catalyst A),[14a] the acetate **2b** did not undergo any reaction with sodium diethyl malonate upon refluxing in THF for 120 h (Table I, entry 1). However, use of the Pd(0) complex (2 mol %) generated in situ from bis(dibenzylideneacetone)palladium and 1,2-bis(diphenylphosphino)ethane ($Pd(dba)_2$/dppe, catalyst B)[33] provided diethyl (2-cyclopropylideneethyl)malonate (**16'**) (E' = $CO_2Et$) in 31% yield accompanied by diethyl 2-(2-methylene-3-butenyl)malonate (6%) resulting from ring-opening, after 24 h in refluxing THF (entry 2). Longer reaction times (48 h, 65 °C) led to less selective reactions. When treated with diethyl malonate under neutral conditions, i.e. without added base,[34] the

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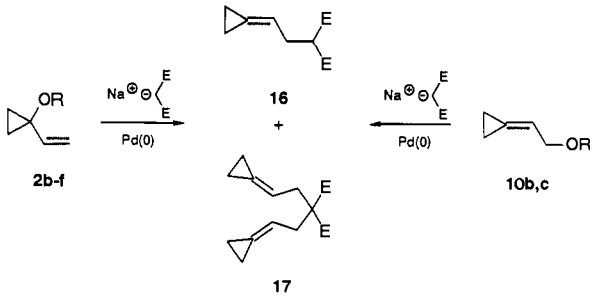
**Scheme I**




ethyl carbonate **2c** remained unchanged, even in the presence of $Pd(dba)_2$/dppe (entry 3). Better leaving groups increased the reactivity, thus the trifluoroacetate **2d** underwent nucleophilic substitution leading to the malonate **16'** and **16** (E = $CO_2Me$) in 23 and 55% yield, respectively, depending on the nature of the catalyst ligand (entries 4 and 5).

Fortuitously, the tosylate **2e** was substituted much more readily. Effectively the reaction with 2 mol % $Pd(dba)_2$/dppe (1:1) as a catalyst was over within 5 min at room temperature, as monitored by TLC, and after flash chromatography provided **16** in 86% yield (entry 6). In this case, the reactivity of **2e** was not sensitive to the nature of the ligand on palladium; indeed use of 2 mol % $Pd(dba)_2/PPh_3$ (ratio 1:2) led to **16-Me** in 84% yield, also within 5 min at ambient temperature (entry 7). The mesylate **2f** reacted as well under the same conditions (entry 8).

The precise stoichiometry of the catalyst is uncertain, but it appeared that the active palladium complex was formed more rapidly when 2 mol % $Pd(dba)_2$ was used with dppe in ratios from 1:1 up to 1:1.5; therefore, subsequently all substitutions were performed according to this protocol. Contrary to 1-ethenylcyclopropyl acetate (**2b**) and carbonate (**2c**), the isomeric cyclopropylideneethyl acetate (**10b**) reacted in the presence of Pd-$(PPh_3)_4$ in refluxing THF for 36 h to provide **16'** in 80% yield (entry 9). With the catalyst $Pd(dba)_2$/dppe, **10b** and ethyl carbonate **10c** gave even higher yields of **16** under milder conditions, i.e. at ambient temperature within 10 min and 4 h, respectively (entries 10 and 11).

In all cases, in which the yields of substitution products were higher than 80%, formation of dimethyl bis(2-cyclopropylideneethyl)malonate (**17**) was observed (3–11% yield) (entries 6–11); this byproduct apparently resulted from the reaction of **2e–f** and **10b,c** with the anion derived from the product malonate **16**, since it was obtained in 91% yield from the reaction of tosylate **2e** with the sodium enolate of **16** (entry 12).

Control experiments with 1-ethenylcyclopropyl esters **2b–f** in the absence of any Pd(0) catalyst showed no or only unselective reactions at ambient and at elevated temperatures (e.g. refluxing THF). On the other hand, acetate **10b** did react with sodium dimethyl malonate in the absence of Pd(0) and was partially consumed in refluxing THF, but only gave the unsymmetrical malonic acid diester **18** in 15% yield (entry 13).

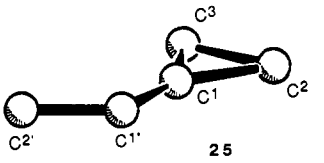
### Competitive Substitutions with Dimethylallyl Acetates

1-Ethenylcyclopropyl tosylate (**2e**) underwent Pd(0) catalyzed regioselective substitution at the terminal vinylic position with stabilized C-nucleophiles[26] (e.g. sodium dimethyl malonate) at room temperature to give exclusively **16** whatever the added phosphine ligand (see Table I, entries 6 and 7), on the other hand it has been reported that the dimethylallyl acetate **19** was substituted by sodium malonates in THF at reflux with a regioselectivity depending on the catalyst providing a mixture of substituted malonates **20** and **21** (entries 14–16).[35]

A competition experiment between 1-ethenylcyclopropyl tosylate (**2e**) (1 equiv) and 1,1-dimethylallyl acetate (**19**) (1 equiv) with sodium dimethyl malonate (1 equiv) at room temperature in the presence of Pd(0) provided a 19:1 mixture of **16** and malonates **20**/**21** and thus showed a surprisingly high reactivity surplus for the cyclopropyl tosylate **2e**.

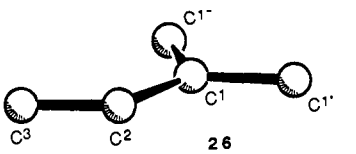
The competition between cyclopropylideneethyl acetate (**10b**) (1 equiv) and 3,3-dimethylallyl acetate **22** (1 equiv) for $NaCH(CO_2Me)_2$ (1 equiv) under Pd(0) catalysis at room temperature showed an even greater chemoselectivity (>99:1) in favor of the three-membered ring derivative.

The unexpectedly high reactivity and the unexpectedly high selectivity for substitution at the primary end by stabilized carbanions (*soft* nucleophiles[26]) of the 1,1-dimethyleneallyl system in 1-ethynylcyclopropylsulfonates **2e,f** and cyclopropylideneethanecarboxylates **10b,c**, with respect to the dimethylallyl acetates **19** and **22**,[35] cannot simply arise from a steric effect. Most likely the intermediate allyl palladium complex **23** is unsymmetric in that palladium would be positioned closer to the cyclopropyl carbon, where the positive charge should be less pronounced[4] as expressed by an equilibrium between a $\pi$-allyl complex **23b** and two possible $\sigma$-complexes **23a** and **23c**, in which **23a** predominates. In fact, reasonably high level calculations (STO-3G, 6-31G, and 6-31G*[36d]) indicate a higher positive charge on the primary carbon C-2' in the 1-ethenylcyclopropyl cation **25** (see Figure 1), whereas MINDO/3,[36a] AM1,[36c] and ab initio calculations[36d] predict a




25

| Method | $C^{2'}$ | $C^{1'}$ | $C^1$ | $C^2$ | $C^3$ |
|---|---|---|---|---|---|
| MINDO/3[36a] | 0.291 | -0.104 | 0.323 | -0.016 | -0.026 |
| MNDO[36b] | 0.333 | -0.169 | 0.156 | -0.027 | -0.041 |
| AM1[36c] | 0.135 | -0.228 | 0.176 | -0.190 | -0.209 |
| STO-3G[36d] | 0.391 | 0.053 | 0.204 | 0.182 | 0.169 |
| 6-31G[36d] | 0.403 | 0.073 | 0.109 | 0.221 | 0.193 |
| 6-31G*[36d] | 0.369 | -0.030 | -0.197 | 0.488 | 0.371 |




26

| Method | $C^3$ | $C^2$ | $C^1$ | $C^{1'}$ | $C^{1''}$ |
|---|---|---|---|---|---|
| MINDO/3[36a] | 0.266 | -0.148 | 0.406 | -0.062 | -0.057 |
| MNDO[36b] | 0.298 | -0.244 | 0.292 | -0.037 | -0.028 |
| AM1[36c] | 0.081 | -0.294 | 0.300 | -0.296 | -0.294 |
| STO-3G[36d] | 0.345 | -0.027 | 0.254 | -0.183 | -0.180 |
| 6-31G[36d] | 0.356 | 0.020 | 0.239 | 0.192 | 0.193 |
| 6-31G*[36d] | 0.452 | 0.116 | 0.675 | 0.070 | 0.059 |

**Figure 1.** Calculated charge distributions in 1-ethenylcyclopropyl cation **25** and 1,1-dimethylallyl cation **26**.

**Scheme II**

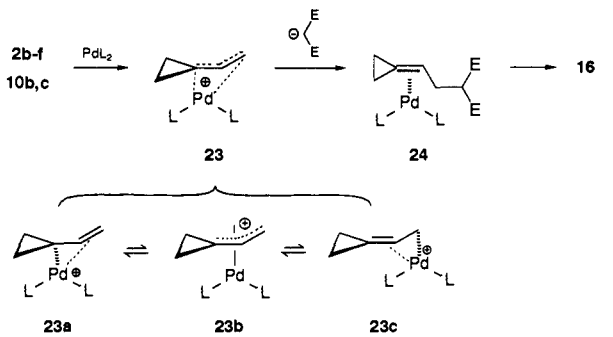



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**Table I.** Palladium Catalyzed Substitution of 1-Alkenylcyclopropyl and 2-Cyclopropylideneethyl Esters at the Vinylic End

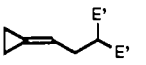
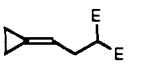
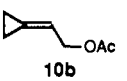
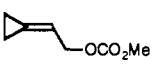
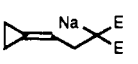
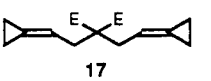
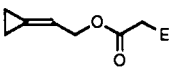
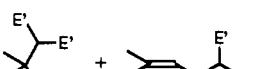
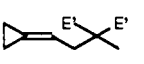
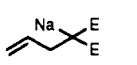
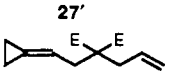
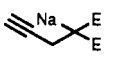
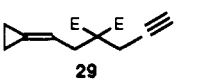
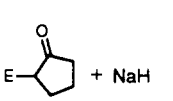
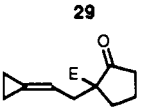
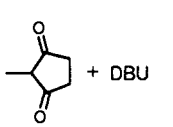
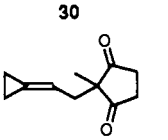
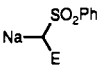
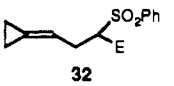
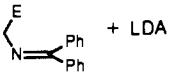
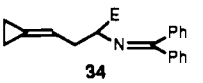
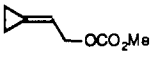
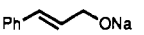
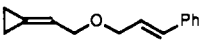
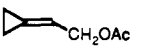
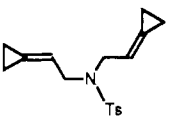
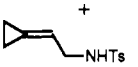
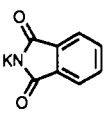
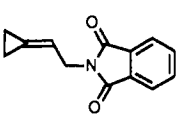
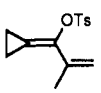
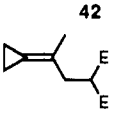
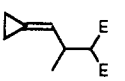
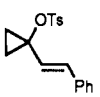
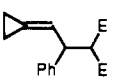
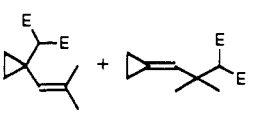
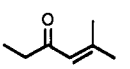
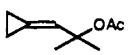
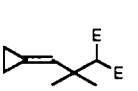
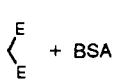
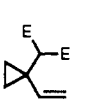
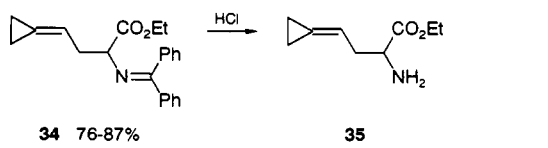
| entry | dimethyleneallyl electrophile | catalyst[a] | nucleophile[b] | condition[c] h/°C | product | yield, % (ratio) |
|---|---|---|---|---|---|---|
| 1 |  **2b** | A |  | 120/65 |  **16′** | no reaction |
| 2 | **2b** | B |  | 24/65 | **16′** | 31[d] |
| 3 |  **2c** | B |  | 48/65 | | no reaction |
| 4 |  **2d** | A |  | 36/65 | **16′** | 23 |
| 5 | **2d** | B |  | 48/rt |  **16** | 55 |
| 6 |  **2e** | A |  | 5 min/rt | **16** | 86[e] |
| 7 | **2e** | C |  | 5 min/rt | **16** | 84[e] |
| 8 | **2f** | B |  | 5 min/rt | **16** | 84[e] |
| 9 |  **10b** | A |  | 36/65 | **16′** | 80[e] |
| 10 | **10b** | B |  | 5 min/rt | **16** | 85[e] |
| 11 |  **10c** | D |  | 4/rt | **16** | 76[e] |
| 12 | **2e** | B |  | 0.5/rt |  **17** | 91 |
| 13 | **10b** | no |  | 7d/65 |  **18** | 15 |
| 14 |  **19** | A |  | 36/65 |  **20** **21** | 62 (73:27)[f] |
| 15 | **19** | B |  | 36/65 | **20** **21** | 100 (37:63)[f] |
| 16 | **19** | A |  | 36/65 | **20** **21** | 80 (80:20)[f] |
| 17 | **2e** | B |  | 1/rt |  **27′** | 82 |
| 18 | **2e** | B |  | 1/rt |  **28** | 91 |
| 19 | **2e** | B |  | 1/rt |  **29** | 91 |
| 20 | **2e** | B |  | 1/rt |  **30** | 93 |
| 21 | **2e** | B |  | 1/rt |  **31** | 72 |

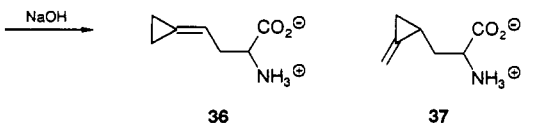
**Table I** (Continued)

| entry | dimethyleneallyl electrophile | catalyst[a] | nucleophile[b] | condition[c] h/°C | product | yield, % (ratio) |
|---|---|---|---|---|---|---|
| 22 | **2e** | B |  | 2/rt |  **32** | 92 |
| 23 | **2e** | B |  **33** | 5 min/rt |  **34** | 87 |
| 24 |  **10c** | B | **33** | 12/rt | **34** | 76 |
| 25 | **2e** | B |  | 2 min/rt |  **38** | 95 |
| 26 | **2e** | B | KOAc, 18-crown-6 | 5 min/rt |  **10b** | 80 |
| 27 |  **2f** | A | $NaNHTs, TsNH_2$ | 2/rt |  **40** +  **41** | 62<br>13 |
| 28 | **2e** | A |  | 2/rt |  **42** | 65 |
| 29 |  **3e** | B |  | 1/rt |  **44** | 81 |
| 30 |  **4e** | B |  | 2/rt |  **45-Me** | 89 |
| 31 | **4e** | $Pd(dba)_2$/(−)BINAP |  | 4/rt | **45-Me** (50% ee) | 86 |
| 32 |  **5e** | B |  | 2/rt |  **45-Ph** | 94 |
| 33 | **5e** | $Pd(dba)_2$/(−)BINAP |  | 4/rt | **45-Ph** (52% ee) | 92 |
| 34 |  **6b** | B |  | 14/65 |  **46** **47** | 33 (25:75) |
| 35 |  **6d** | B |  | 24/rt | **6a** +  | —[g] (70:30) |
| 36 |  **11b** | B |  | 15 min/rt |  **47** | 84 |
| 37 | **2e** | $Mo(CO)_6$ |  | 5/65 | **16** + **17** +  **71** | 90 (78:11:11) |

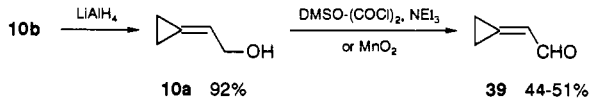
[a] A = $Pd(PPh_3)_4$; B = $Pd(dba)_2$, dppe (1:1); C = $Pd(dba)_2$, $PPh_3$ (1:2); D = $Pd(dba)_2$, dppe (1:4). [b] E = $CO_2Me$, E′ = $CO_2Et$. [c] 3 equiv of nucleophile were used in each run in THF. [d] Plus diethyl 2-(2-methylene-3-butenyl)malonate from ring opening. [e] Plus 3–11% of dialkyl bis(2-cyclopropylideneethyl)malonate **17** or **17′**. [f] From ref 35. [g] Yield not determined.

**Scheme III**




**Scheme IV**



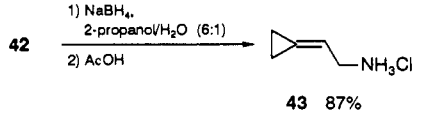

higher positive charge on the tertiary center C-1 of 1,1-dimethylallyl cation **26** (see Figure 1); therefore an unsymmetrical charge distribution in the intermediate complex **23** appears to play a role for the preferred site of attack by a nucleophile. In addition, **24** should be the more stable of the two possible $\pi$-olefin palladium complexes formed after attack of a nucleophile on **23**, because the more highly strained methylenecyclopropane should be a better ligand than an ethenylcyclopropane.[37]

### Variation of Nucleophiles in Pd(0)-Catalyzed Substitutions on 2e,f

With a variety of *soft* carbon nucleophiles (stabilized carbanions)[26] several substitution products were obtained from tosylate **2e** in good to excellent yields (72–93%) (Table I, entries 17–22). These functionally substituted methylenecyclopropane derivatives, for which previously reported methods are mostly nonapplicable, offer a high synthetic potential, as has been demonstrated for a number of simple methylenecyclopropanes.[24] For example, methylenecyclopropane derivatives such as **28** and **29** containing olefinic and acetylenic tethers ought to further undergo transition metal catalyzed intramolecular cycloadditions.[24,38]

The anion of glycine ester Schiff base derivative **33** is also an efficient nucleophile,[39] which has been applied in Pd(0)-catalyzed allylic substitution reactions.[40] Thus, substitution of the tosylate **2e** with **33** in the presence of base (LDA) and under Pd(dba)$_2$/dppe catalysis occurred within 5 min in THF at ambient temperature and provided **34** in 87% yield. Without any added base in the presence of Pd(0) the cyclopropylideneethyl carbonate **10c** was also substituted by **33** within 12 h at ambient temperature

**Scheme V**




(76% yield) (entries 23 and 24).

Deprotection of **34** with 10% hydrochloric acid gave amino ester **35**, and saponification (NaOH, MeOH) yielded amino acid **36** (95%). Compound **36** is an interesting isomer of 2′-methylenecyclopropylalanine (hypoglycine A, **37**), which has been isolated from the unripe fruit of the ackee tree (*Blighia sapida Kon.*) and is the causative agent in Jamaican vomiting sickness with associated hypoglycemia.[41,42]

A series of oxygen and nitrogen nucleophiles also reacted with **2e,f** in the presence of Pd(0) and gave cyclopropylideneethyl substitution products in high yields. The anion of 3-phenylallyl alcohol furnished the bisallylic ether **38** (95%) (entry 25). Potassium acetate (3 equiv) in the presence of [18]-crown-6 (30 mol %) in THF also reacted readily with tosylate **2e** to give the cyclopropylideneethyl acetate **10b** within 30 min at room temperature (80% yield) (entry 26). Thus, the sequence **1**, **2e**, and **10b** provides a more convenient alternative to the previous preparation of **10b** from cyclopropylideneacetate **9** obtained by Wittig alkenylation of **1** (vide supra).

Reduction of the acetate **10b** with LiAlH$_4$ (THF, −78 °C) gave allylic alcohol **10a** (92%) which could be oxidized under Swern conditions (DMSO/(COCl)$_2$, NEt$_3$, THF) or with MnO$_2$ to give cyclopropylideneethanal (**39**) in 44 and 51% yields, respectively.[43] Acetate **10b** can serve as a valuable precursor to various alkylidenecyclopropane derivatives by nucleophilic substitution (vide supra), and thus provide a complementary method to the olefination of cyclopropanone hemiacetal with Wittig reagents.[29,44]

Reaction of mesylate **2f** with sodium *p*-toluenesulfonamide (NaNHTs)[45] in the presence of Pd(PPh$_3$)$_4$ gave *N*-(2-cyclopropylideneethyl)tosylamide (**41**) (13%) and *N*,*N*-bis(2-cyclopropylideneethyl)tosylamide (**40**) (62%) as the major product; apparently, the anion of **41** is a better nucleophile and therefore reacts more rapidly with **2f** than NaNHTs (entry 27). A protected primary amine like **41** can be obtained as the sole product with potassium phthalimide (KPhth)[46] as a stabilized N-nucleophile. KPhth reacted with tosylate **2e** under Pd(0) catalysis to provide **42** in 65% yield (entry 28). Upon reduction with sodium borohydride (NaBH$_4$) in 2-propanol and water,[47] followed by acid hydrolysis, **42** led to cyclopropylideneethylamine hydrochloride (**43**) (87% yield).

To test for the influence of $\alpha$- and $\beta$-disposed substituents on the outcome of the reactions, substrates **3e–5e** were treated with dimethyl malonate anion under the usual conditions (Pd(dba)$_2$/dppe). The tosylate of 1-(2-propenyl)cyclopropanol **3e** cleanly underwent nucleophilic substitution to give dimethyl 1-(2-cyclopropylidenepropyl)malonate (**44**) with normal yield (81%) (entry 29), and reactions of the tosylates **4e** and **5e** gave cyclopropylideneethyl derivatives **45-Me** and **45-Ph**, respectively, containing a tertiary asymmetric center. Use of the chiral phosphine (*S*)-(−)-2,2′-bis(diphenylphosphino)-1,1′-binaphthyl ((−)-BINAP) instead of dppe in the reaction of **4e** and **5e** led to optically active **45-Me** (89%) and **45-Ph** (94% yields) with en-

(36) (a) Bingham, R. C.; Dewar, M. J. S.; Lo, D. H. *J. Am. Chem. Soc.* **1975**, *97*, 1285. The charge distribution in 1,1-dimethylallyl cation has previously been calculated using the MINDO method. Cf. Jarjis, H. M.; Khalil, S. M. *Z. Naturforsch., A: Phys. Sci.* **1987**, *42*, 174. (b) Dewar, M. J. S.; Thiel, W. *J. Am. Chem. Soc.* **1977**, *99*, 4899, 4907. (c) Dewar, M. J. S.; Zoebisch, E. G.; Healy, E. F.; Stewart, J. J. P. *J. Am. Chem. Soc.* **1985**, *107*, 3902. (d) Gaussian 88, Frisch, M. J.; Head-Gordon, M.; Schlegel, H. B.; Raghavachari, K.; Binkley, J. S.; Gonzalez, C.; Defrees, D. J.; Foc, D. J.; Whiteside, R. A.; Seeger, R.; Melius, C. F.; Baker, J.; Martin, R. L.; Kahn, L. R.; Stewart, J. P.; Fluder, E. M.; Topiol, S.; Pople, J. A., Gaussian, Inc., Pittsburgh, PA.

(37) Although no direct competition experiment between a methylenecyclopropane and a vinylcyclopropane has been carried out, the relative stabilities of e.g., iron complexes of both systems can be extrapolated from a comparison of C=O stretching frequencies in the IR spectra of their tetracarbonyliron complexes: see (a) Whitesides, T. H.; Vlaven, R. W.; Calabrese, J. C. *Inorg. Chem.* **1974**, *13*, 1985. (b) Whitesides, T. H.; Vlaven, R. W. *J. Organomet. Chem.* **1974**, *67*, 99. (c) Aumann, R. *J. Am. Chem. Soc.* **1974**, *96*, 2631. (d) Aumann, R. *J. Organomet. Chem.* **1974**, *66*, C6.

(38) Stolle, A.; Salaün, J.; de Meijere, A. Unpublished results.

(39) O'Donnell, M. J.; Polt, R. L. *J. Org. Chem.* **1982**, *47*, 2663.

(40) (a) Ferroud, D.; Genêt, J. P.; Kriolle, R. *Tetrahedron Lett.* **1986**, *27*, 23. (b) Genêt, J.-P.; Juge, S.; Achi, S.; Mallart, S.; Ruiz Montes, J.; Levif, G. *Tetrahedron* **1988**, *44*, 5263. (c) Genêt, J. P.; Kopola, N.; Juge, S.; Ruiz-Montes, J.; Autunes, O. A. C.; Tanier, S. *Tetrahedron Lett.* **1990**, *31*, 3133.

(41) (a) Hassall, C. H.; Reyle, K.; Feng, P. *Nature* **1954**, *173*, 356. (b) Hassall, C. H.; Reyle, K. *Biochem. J.* **1955**, *60*, 334.

(42) For a recent review on hypoglycine, see Sherratt, H. S. A. *Trends Pharmacol. Sci.* **1986**, 186.

(43) **42** has previously been prepared by photooxygenation of 1-methoxy-2-cyclopropylethene or by Wittig reaction of diethoxyethanal with cyclopropylidenetriphenylphosphorane. (a) Rousseau, G.; Lechevallier, A.; Huet, F.; Conia, J. M. *Tetrahedron Lett.* **1978**, 3287. (b) Lechevallier, A.; Huet, F.; Conia, J. M. *Tetrahedron* **1983**, *39*, 3307.

(44) Salaün, J.; Fadel, A. *Tetrahedron Lett.* **1979**, 4375.

(45) See, for example, Byström, S. E.; Aslanian, R.; Bäckvall, J.-E. *Tetrahedron Lett.* **1985**, *26*, 1749.

(46) See: Inoue, Y.; Taguchi, M.; Toyofuku, M.; Hashimoto, H. *Bull. Chem. Soc. Jpn.* **1984**, *57*, 3021.

(47) See: Osby, J. O.; Martin, M. G.; Ganem, B. *Tetrahedron Lett.* **1984**, *25*, 2093.

antiomeric excesses of up to 52% as determined by $^1H$ NMR in the presence of the chiral shift reagent, Eu(hfc)$_3$ (entries 30–33). As recently reported, the alkylation of chiral Schiff bases derived from glycine in the presence of a chiral palladium complex can lead to double asymmetric induction with much higher diastereoisomeric excesses, on the condition that "matched pairs" are used.[40c]

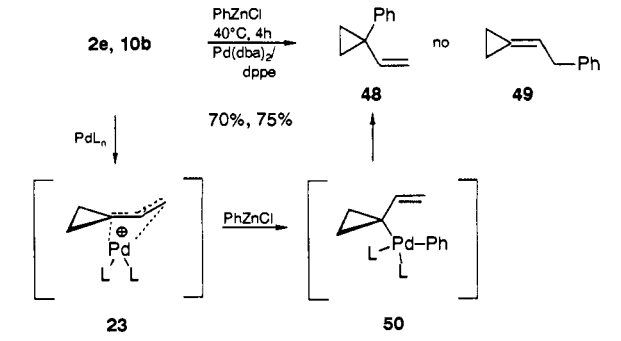
Since preparation of any sulfonate derivative of 1-isobutenylcyclopropanol (**6a**) failed, the acetate **6b** was tested for Pd(0)-catalyzed substitution with sodium dimethyl malonate. A reaction did indeed occur, when the mixture was refluxed in THF for 14 h and provided a 25:75 mixture of products **46** and **47** in 33% yield (entry 34). Surprisingly, trifluoroacetate **6d** showed only cleavage of the ester functionality to give alcohol **6a** and its ring opening product 2-methyl-2-hexen-4-one[48] (entry 35). On the other hand, the isomeric 1,1-dimethyl-3,3-dimethyleneallyl acetate, **11b**, reacted smoothly within 15 min at ambient temperature to yield dimethyl 3-cyclopropylidene-2,2-dimethyl-1,1-propanedicarboxylate (**47**), as the *exclusive* product (84%) (entry 36).

The lack of regioselectivity observed in the reaction of (dimethylethenyl)cyclopropyl acetate (**6b**) which, in contrast to those of **2b** (vide supra) and **11b** led to a mixture of both types of tertiary substitution products **46** and **47**, is noteworthy. It has been checked that the final products **46** and **47** did not interconvert under the conditions employed and that starting materials **6b** and **11b** did not react in the absence of a Pd(0) catalyst. Moreover, reaction of **11b** at 65 °C led also to the single product **47**, thus a thermodynamic control cannot be simply considered to explain this unexpected result. It has been suggested (vide supra, Scheme II) that the palladium should be shifted toward the cyclopropane ring which electronically directs the nucleophile toward the alkyl terminus. It appeared also that increased steric hindrance at the alkyl center changed the regioselectivity only from the acetate **6b**, indicating different reactive intermediates from these two isomeric allyl acetates leading therefore to different product ratios (entries 34 and 36). One possible concomitant pathway[49] might involve otherwise the preliminary formation of a palladate complex with the nucleophile (i.e., malonic ester enolate) which then reacted with **6b**, followed by reductive elimination. As a matter of fact reaction of **6b** following Scheme II, requires the cleavage of a cyclopropyl–oxygen bond which is not favored,[4] particularly when acetate is the leaving group; the resulting low reactivity allows then other reaction pathways to occur (vide supra, entries 2 and 35).

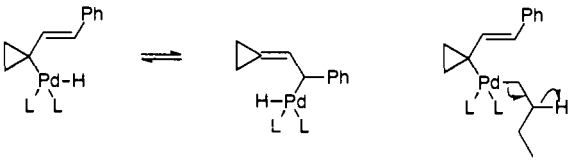
### Regioselective Substitutions of the 1-Ethenylcyclopropyl- (2e) and 1-Styrylcyclopropyl Tosylates (5e) at the Cyclopropyl Position

Reaction of phenylzinc chloride (4 equiv, prepared from phenyllithium or phenylmagnesium bromide and zinc chloride) with 1-ethenylcyclopropyl tosylate (**2e**) in the presence of Pd(dba)$_2$/dppe led to 1-phenyl-1-ethenylcyclopropane (**48**)[50] *exclusively* (68% yield) (Table II, entry 1). The fact that no trace of 1-(2-cyclopropylideneethyl)benzene (**49**) by substitution at the primary carbon center was formed, as observed with stabilized carbanions (vide supra), suggests that this reaction follows a quite different mechanism. This is supported by the observation that cyclopropylideneethyl acetate (**10b**) also reacted with phenylzinc chloride under the same conditions as **2e** to give **48** as the sole product (75%) (entry 2). Contrary to stabilized carbanion (soft)[26] nucleophiles which directly attack the allyl ligand[14a] at the primary cationic center of the $\pi$-allylpalladium complex **23**, nonstabilized (*hard*)[26] nucleophilic organometallics such as phenylzinc chloride primarily react by transmetalation; i.e. transfer of the organic

Scheme VI




Scheme VII




residue from zinc to palladium, as has been pointed out by Keinan,[51] followed by rearrangement to $\sigma$-complex **50**, and transfer of the new organic ligand to the allyl system, i.e., on the cyclopropyl ring, by way of an internal attack (reductive elimination). In this case, the phenyl-substituted $\sigma$-complex **50** must be formed from **23** by kinetic control, and **50** gives the observed product **48**.

A similar argument holds true for the Pd(0)-catalyzed reduction of 1-styrylcyclopropyl tosylate (**5e**), at least for certain hydride sources. Reactions of allylic compounds with hydride as a nucleophile are also well-known and various hydride donors ($LiAlH_4$, $Bu_3SnH$, $NaBH_4$, $LiEt_3BH$, RZnCl, $HCO_2H$, etc.) have been reported to react with $\pi$-allylpalladium complexes.[52]

Reaction of the styryl-substituted tosylate **5e** with sodium formate (3 equiv) in the presence of Pd(dba)$_2$/dppe, gave a 42:58 mixture of isomeric cyclopropane derivatives **49** and **51**[53] in 46% yield (Table II, entry 3). On addition of [15]-crown-5 ether (10 mol %) the yield was 90% of a 37:63 mixture of these reduction products (entry 4). With $HCO_2Na$ (3 equiv), [15]-crown-5 (10 mol %), and Pd(dba)$_2$/$PPh_3$ (1:2) the methylenecyclopropane derivative **49** was favored (**49**:**51** = 62:38) (entry 5). Treatment of **5e** with formic acid/triethylamine using Pd(dba)$_2$ and tri-*n*-butylphosphine, a reducing system known to perform hydrogenolysis of terminal allylic acetates and carbonates by attack of hydride at the more substituted site of the $\pi$-allyl intermediate with 80–100% selectivity,[52a] led to styrylcyclopropane **51** *exclusively* with 96% yield (entry 6).

On the other hand, Pd(0)-catalyzed reactions of allylic acetates with alkylzinc derivatives containing $\beta$-hydrogens have been reported to provide reduction products with the reverse regioselectivity, i.e. by attack of hydride at the less-substituted site;[52b] however, reduction of **5e** with *n*-butylzinc chloride (from *n*-BuLi and $ZnCl_2$) and Pd(dba)$_2$/$PPh_3$ (1:2) led also to **51** *exclusively* (93% yield, entry 5).

Except for one set of conditions (entry 5), the reduction of **5e** gave mainly or exclusively the hydrogenolysis product **51**, most likely by a hydride transfer either from a palladium hydride species such as **52** (HCOOH, $NEt_3$)[54] or from a *n*-butyl-substituted $\sigma$-Pd complex **54** (*n*-BuZnCl) after $\beta$-elimination.[52b] The minor product **49** then most likely arises from the $\sigma$-Pd species **53**. Contrary to the external-direct substitutions observed with *soft* nucleophiles

(48) Simple allyl ester cleavage under such conditions has previously been observed. See: Fiaud, J.-C.; Malleron, J. L. *J. Chem. Soc., Chem. Commun.* **1981**, 1159.

(49) This alternative mechanism has been suggested by one of the referees of this paper.

(50) Doyle, M. P.; Raynolds, P. W.; Barents, R. A.; Bade, T. R.; Danen, W. C.; West, C. T. *J. Am. Chem. Soc.* **1973**, *95*, 5988.

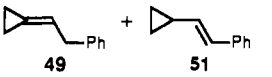
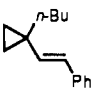
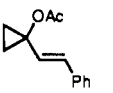
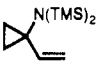
(51) Keinan, E.; Bosch, E. *J. Org. Chem.* **1986**, *51*, 4006, and references cited therein.

(52) (a) Tsuji, J.; Minami, I.; Shimizu, I. *Synthesis* **1986**, 623. (b) Matsushita, H.; Negishi, E. *J. Org. Chem.* **1982**, *47*, 4161, and references cited therein.

(53) Underwood, G. M.; Chan, A. K.; Green, T.; Watts, C. T.; Kingsburg, C. *J. Org. Chem.* **1973**, *38*, 2735.

(54) Cf. (a) Hutchins, R. O.; Learn, K. *J. Org. Chem.* **1982**, *47*, 4380. (b) Bullpitt, M. L.; Kitching, W. *J. Organomet. Chem.* **1972**, *46*, 21.

Table II. Palladium-Catalyzed Substitution of 1-Alkenylcyclopropyl and 2-Cyclopropylideneethyl Esters at the Cyclopropyl Position

| entry | dimethyleneallyl electrophile | catalyst[a] | nucleophile | condition h/°C | product | yield, % (ratio) |
|---|---|---|---|---|---|---|
| 1 | **2e** | B | PhZnCl | 4/40 |  **48** | 66 |
| 2 | **10b** | B | PhZnCl | 4/40 | **48** | 75 |
| 3 | **5e** | B | HCOONa | 48/rt |  **49** + **51** | 46 (42:58) |
| 4 | **5e** | B | HCOONa, 15-C-5 | 48/rt | **49** + **51** | 90 (37:63) |
| 5 | **5e** | C | HCOONa, 15-C-5 | 48/rt | **49** + **51** | 95 (62:38) |
| 6 | **5e** | D | HCOOH, $NEt_3$ | 48/rt | **51** | 96 |
| 7 | **5e** | C | *n*-BuZnCl | 48/rt | **51** | 93 |
| 8 | **5e** | B | *n*-BuZnCl | 14/65 | **49** + **51** +  **55** | 95 (10:30:60) |
| 9 | **5e** | B | KOAc | 0.5/rt | **51** +  **5b** | 52 (14:86) |
| 10 | **2f** | B | $NaN_3$ | 12/rt |  **56** | 99 (gc) |
| 11 | **2f** | B | $NaN(TMS)_2$ | 12/rt |  | 80 (gc) |
| 12 | **2e** | E | PhMgBr | 1/rt | **48** + **49** | 90 (84:16) |

[a] A = $Pd(PPh_3)_4$; B = $Pd(dba)_2$, dppe (1:1); C = $Pd(dba)_2$, $PPh_3$ (1:2); E = $NiCl_2(PPh_3)_2$.

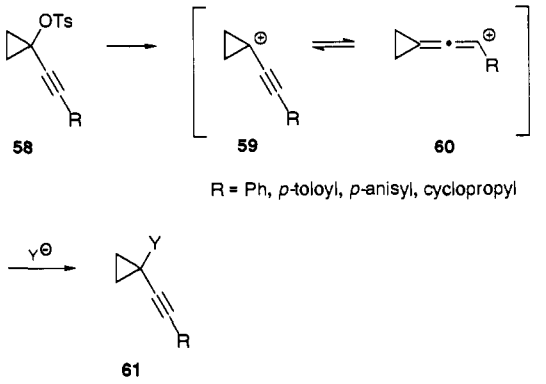
(vide supra), hydride is transferred under most types of conditions preferably onto the three-membered ring.

An unexpected ligand effect was observed in the reaction of **5e** with *n*-BuZnCl in the presence of $Pd(dba)_2$/dppe (1:1); besides the reduction products **49** and **51** formed in 10 and 30% yield, respectively, the alkylation product 1-*n*-butyl-1-styrylcyclopropane (**55**) was obtained in 60% yield, as characterized by its $^1H$ NMR and MS data (entry 8). Thus, in the presence of dppe as the phosphine ligand, the Pd-catalyzed cross coupling reaction with carbon–carbon bond formation between tosylate **5e** and *n*-BuZnCl, comparable to the known coupling reactions between a main group (Mg, Li, Zn, etc.) organometallic reagent and an aryl, vinyl, or allyl electrophile,[55] competes with the usual reduction via β-elimination.[52b] The coupling of alkyl and aryl iodides with alkyl Grignard reagents has been reported to require in situ reduced 1,1′-bis(diphenylphosphino)ferrocenepalladium dichloride (dppfPdCl$_2$), the dppf ligand being considered to suppress β-elimination in the intermediate;[56] however, this effect has recently been reexamined, and (dppf)Pd$^0$ as well as (dppf)PdCl$_2$ have been considered to entail halide reduction mostly.[57]

Surprisingly, reaction of the phenyl-substituted tosylate **5e** with acetate anion (KOAc, [18]-crown-6, $Pd(dba)_2$/dppe) in THF under reflux yielded 1-acetoxy-1-styrylcyclopropane (**5b**) (45%) besides a small amount of reduction product **51**[53] (7%); this contrasts the result with tosylate **2e**, which underwent primary substitution with KOAc exclusively (Table I, entry 26).

Likewise, reaction of the mesylate **2f** with sodium azide ($NaN_3$) in THF in the presence of $Pd(dba)_2$/dppe (5 mol %) and [15]-crown-5 gave solely 1-ethenylcyclopropyl azide **56** (Table II, entry 10). However, this does not preclude that azide primarily attacks at the terminal vinylic position of the intermediate, since allyl azides are known to undergo a very facile 3,3-sigmatropic rearrangement,[58] which in this case would definitely favor the thermodynamically more stable product **56**. Similarly, **2f** reacts with sodium hexamethyldisilazide (NaHMDS) to give **57**, a versatile precursor to aminoethenylcyclopropanes (entry 11). The regioselectivities observed with $NaN_3$ and NaHMDS complement those in the reactions of **2f** with sodium tosylamide and of **2e** with potassium phthalimide (Table I, entries 27 and 28); thus, by proper choice of the reagent it is possible to substitute *regioselectively* the ethenylcyclopropyl system by nitrogen either on the three-membered ring or on the vinylic end.

Scheme VIII




## Regioselective Substitutions of 1-Alkynylcyclopropyl Chlorides 12–15

We had previously reported the solvolytic behavior of 1-alkynylcyclopropyl tosylates **58**.[9b] Although a triple bond, contrary to a double bond, has a destabilizing effect on an adjacent carbenium ion center,[59] we have shown that the solvolysis of tosyloxycyclopropanes **58** led to 1-alkynylcyclopropane derivatives **61**,

(55) (a) Heck, R. F. *Palladium Reagents in Organic Synthesis*; Academic Press: New York, 1985. (b) Trost, B. M.; Verhoeven, T. R. *Comprehensive Organometallic Chemistry*; Wilkinson, G., Stone, F. G. A., Abel, E. W., Eds.; Pergamon Press: Elmsford, NY, 1982; p 799.

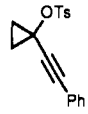
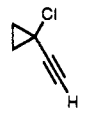
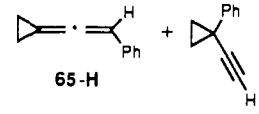
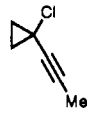
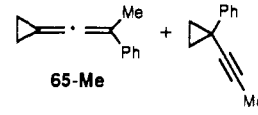
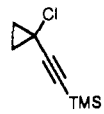
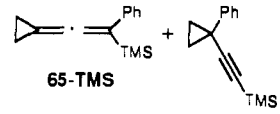
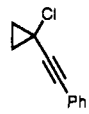
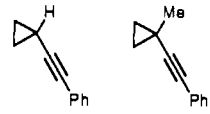
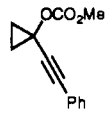
(56) Castle, P. L.; Widdowson, D. A. *Tetrahedron Lett.* **1986**, *27*, 6013. Hayashi, T.; Konishi, M.; Kobori, Y.; Kumada, M.; Higuchi, T.; Hirotsu, K. *J. Am. Chem. Soc.* **1984**, *106*, 1858.

(57) Yuan, K.; Scott, W. J. *Tetrahedron Lett.* **1989**, *30*, 4779.

(58) (a) Gagneux, A.; Winstein, S.; Young, W. G. *J. Am. Chem. Soc.* **1960**, *82*, 5956. (b) VanderWerf, C. A.; Heasley, V. L. *J. Org. Chem.* **1966**, *31*, 3534.

(59) Streitwieser, A., Jr. *Solvolytic Displacement Reactions*; McGraw-Hill: New York, 1962; p 78.

**Table III.** Palladium-Catalyzed Substitution of 1-Alkynylcyclopropyl Chlorides (or Carbonates)

| entry | electrophile | catalyst[a] | nucleophile[b] | condition h/°C | product | yield, % (ratio) |
|---|---|---|---|---|---|---|
| 1 |  **8e** | B |  or MeZnCl | 24/65 | | no reaction or unidentified products |
| 2 |  **12** | B | PhZnCl | 3/65 |  **65-H** + **66-H** | 62 (29:71) |
| 3 |  **13** | B | PhZnCl | 3/65 |  **65-Me** + **66-Me** | 45 (23:77) |
| 4 |  **14** | B | PhZnCl | 2/65 |  **65-TMS** + **66-TMS** | 80 (0:100) |
| 5 |  **15** | B | MeZnCl | 14/65 |  **67** **66-Ph** | 68 (93:7) |
| 6 |  **8c** | B |  or MeZnCl | 24/65 | | no reaction |
| 7 | **8c** | F | MeMgBr | −78 °C to rt | **65-Me** + **66-Ph** + **8a** + **67** + unidentified products | 10, 40, 20, 17, 10 |

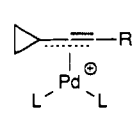
[a] B = $Pd(dba)_2$, $PPh_3$; F = CuI, $PBu_3$. [b] E = COOMe.

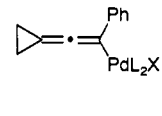
without the well-known disrotatory ring-opening, which normally follows upon ionization of simple cyclopropyl derivatives.[4]

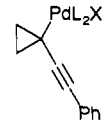
Anchimeric assistance of the triple bond, via the valence tautomeric cations **59** and **60**, involving a $S_Ni$ type ionization process was suggested to rationalize this result.[9b] In view of this it appeared worthwhile to investigate the Pd(0)-induced nucleophilic substitution of such three-membered ring systems.

The linear geometry of the $\eta^3$-allenyl species formed from propargylic electrophiles renders them less favorable for bidentate binding to transition metals.[60] Thus, while the 1,1-dimethylene-$\pi$-allyl complex **23**, considered as an intermediate in Pd(0)-catalyzed nucleophilic substitutions of 1-ethenylcyclopropyl esters **2b–f** and 2-cyclopropylideneethyl esters **10b,c**, smoothly reacts with a wide variety of carbon nucleophiles ranging from stabilized carbanions to simple organometallics, only propargylic substitutions involving transmetalation followed by reductive elimination of two carbon ligands can be expected from the $\eta^3$-1,1-dimethyleneallenylpalladium unit **62**, which would be formed from 1-alkynylcyclopropyl derivatives such as **58**.

The tosylate **8e** of 1-(phenylethynyl)cyclopropanol **8a**[9b] unfortunately remained inert upon treatment with sodium dimethyl malonate in the presence of $Pd(dpa)_2$/dppe in THF or $CH_3CN$ even under reflux for 24 h (Table III, entry 1). Treatment of **8e** with methylzinc chloride (from MeLi and $ZnCl_2$) in the presence of $Pd(dba)_2$/dppe (5 mol %) in refluxing THF, $CH_3CN$, or DMSO for 120 h provided mixtures of unidentified products. Quite a number of attempts to isolate the putative $\sigma$-(2-cyclopropylidene-1-phenylethenyl)- **63** or $\sigma$-(1-phenylethynylcyclopropyl)palladium species **64** by treatment of **8e** with stoichiometric amounts of $Pd(PPh_3)_4$ or $Pd(dba)_2$/dppe and an equimolar amount of zinc chloride, as has been reported to be successful with some propargylic acetates and chlorides,[61] also failed. Exposure of **8e** to methylzinc chloride in refluxing THF for 15 h provided neither the expected 2-phenyl-1-propenylidenecyclopropane (**65-Me**) nor 1-methyl-1-(phenylethynyl)cyclopropane (**66-Me**), although the starting material was completely consumed in each case (entry 2).


**62**


**63**


**64**

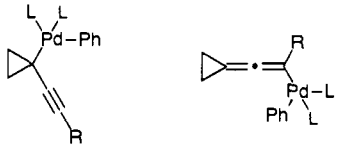
Although 1-alkynylcyclopropyl chlorides **12–15**, like the tosylate **8e**, did not yield isolable $\sigma$-palladium complexes with equimolar amounts of $Pd(PPh_3)_4$ or $Pd(dba)_2$/dppe, treatment of 1-ethynylcyclopropyl chloride (**12**)[25b,c] with phenylzinc chloride (4 equiv) in the presence of $Pd(dba)_2$/dppe (5 mol %) led to complete disappearance of the chloride within 3 h in refluxing THF and gave a 29:71 mixture of the known 2-phenylethenylidenecyclopropane (**65-H**)[62] and 1-ethynyl-1-phenylcyclopropane (**66-H**) in 62% yield (entry 2). Treatment of chloride **13** with PhZnCl and $Pd(dba)_2$/dppe (5 mol %) similarly gave a 23:77 mixture of the allene **65-Me** and 1-phenyl-1-propynylcyclopropane (**66-Me**) in 45% yield (entry 3). Reaction of 1-(trimethylsilylethynyl)-cyclopropyl chloride (**14**)[25b,c] with 4 equiv of PhZnCl, $Pd(dba)_2$/dppe (5 mol %) in THF at room temperature for 48 h or at reflux for 2 h provided 1-phenyl-1-(trimethylsilylethynyl)-cyclopropane (**66-TMS**), *exclusively* (80% yield, entry 5). This cannot be due to a simple steric effect but must have to do with

(60) Mohri, M.; Kinoshita, H.; Inomata, K.; Kotake, M. *Chem. Lett.* **1985**, 451.

(61) (a) Elsevier, C. J.; Kleijn, H.; Boersma, J.; Vermeer, P. *Organometallics* **1986**, *5*, 716. (b) Elsevier, C. J.; Kleijn, H.; Ruitenberg, K.; Veermer, P. *J. Chem. Soc., Chem. Commun.* **1983**, 1529.

(62) Cf. Usieli, V.; Sarel, S. *Tetrahedron Lett.* **1973**, 1349.

the destabilizing electronic effect of a silyl group on an adjacent positively charged center, which through the triple bound would favor formation of the propargylpalladium $\sigma$-complex **68** leading to **66-TMS** rather than formation of the allenylpalladium $\sigma$-complex **69**, expected to provide **65-TMS** from an intermediate $\eta^3$-complex of type **62**.




**68** **69**

Chloride **15** upon treatment with methylzinc chloride (from MeLi and $ZnCl_2$) gave only a poor yield of substitution product **66-Ph**,[63] and predominantly the formal reduction product **67**[64] probably via formation of the (alkynylcyclopropyl)zinc chloride from **15** and methylzinc chloride followed by hydrolysis on silica gel (entry 5).

Propargylic carbonates have been reported to undergo palladium-catalyzed reactions with carbon nucleophiles under neutral conditions.[65] 1-Ethynylcyclopropyl carbonate **8c**, however, did neither react with nonstabilized ($CH_3ZnCl$) nor enolate nucleophiles. In each case **8c** was recovered unchanged after 24 h in refluxing THF containing Pd(dba)/dppe (entry 6).

### Other Transition-Metal Catalysts

In addition to the palladium(0) species, some nickel and molybdenum catalysts have also been tested for their effectiveness in these nucleophilic substitutions on cyclopropyl substrates. Reaction of the tosylate **2e** with sodium dimethyl malonate in refluxing THF failed under nickel(0) catalysis,[66] but treatment of **2e** with PhMgBr in the presence of nickel chloride and triphenylphosphine ($NiCl_2(PPh_3)_2$) in ether at room temperature[66] for 1 h gave a 84:16 mixture of phenyl-substituted products **48** and **49** (90% yield) (Table II, entry 12). This is noteworthy, as formation of the latter compound could not be observed under Pd(0) catalysis.

Reaction of **2e** with dimethyl malonate in the presence of *O,N*-bis(trimethylsilyl)acetamide (BSA) as a base and 20 mol % hexacarbonylmolybdenum ($Mo(CO)_6$) as a catalyst,[17] in refluxing THF for 5 h, provided a 78:11:11 mixture of monosubstituted malonate **16**, disubstituted malonate **17**, and dimethyl 2-(1-ethenylcyclopropyl)malonate **70** in 90% yield (Table I, entry 37). This latter type of product, which results from tertiary substitution, has never been observed under Pd(0) catalysis either from **2e** at room temperature or from **10b** in refluxing THF, but only from the terminally disubstituted acetate **6b**.

Reaction of propargylic electrophiles with organocopper reagents is one of the most popular methods for allene synthesis; various propargylic substrates from ethers to more or less reactive esters have been used.[67] In a test reaction, therefore, the carbonate **8c** was treated with methylmagnesium bromide (2 equiv) in the presence of CuI (5 mol %) complexed by tri-*n*-butylphosphine (10 mol %)[67] in $Et_2O$ at −78 °C; the mixture was allowed to reach room temperature within 3 h. After this, **8c** had been totally consumed, and five products had formed: allene **65-Me** (10%), alkyne **66-Ph**[63] (40%), 1-(phenylethynyl)cyclopropanol (**8a**) (20%, from carbonate cleavage), cyclopropylphenylacetylene (**67**)[64] (17%, from hydrogenolysis), and 10% of an unidentified compound (Table III, entry 7).

### Conclusion

Cyclopropyl halides and esters are known to be sluggish in any substitution reaction under normal circumstances and rarely undergo substitutions with retention of the ring.[4,9,10] In addition, ethenylcyclopropane,[68] 2,2-bisacceptor-substituted[19,20] and 2,2-dihalo-substituted[68] ethenylcyclopropane, and 1-ethenylcyclopropanol (or cyclopropanolate)[69] derivatives undergo palladium-induced ring opening. In spite of these facts, 1-ethenylcyclopropyl tosylate (**2e**) (or mesylate **2f**) as well as cyclopropylideneethyl acetate (**10b**) and carbonate (**10c**) under appropriate conditions, can be substituted with a wide variety of nucleophiles in the presence of palladium(0) catalysts without ring opening and with complete regioselectivity. These substitutions apparently involve unsymmetric $\pi$-allylpalladium complexes such as **23** in which the palladium is positioned closer to the cyclopropyl carbon, unlike those derived from simple allyl esters.[13,14] With stabilized carbanions, carboxylates, and alkoxides, acceptor-substituted amides, the products are formed under kinetic control, as they all are the thermodynamically less stable cyclopropylideneethyl rather than the more stable ethenylcyclopropane derivatives. This is of particularly high synthetic value, because the methylenecyclopropane moiety in these new compounds can serve as a specific functionality, e.g. for further transition metal induced cyclizations.

The reverse regioselectivity, i.e. substitution at the cyclopropyl site, is observed, when ethenylcyclopropyl tosylate (**2e**) (or mesylate **2f**) and cyclopropylideneethyl acetate (**10b**) are reacted with phenylzinc chloride. In this case, the hard nucleophile must primarily attack at the metal in the initially formed $\pi$-allylpalladium complex **23**, the intermediate **23** then rearranges to a 1-ethenylcyclopropylpalladium $\sigma$-complex **50** and the nucleophile is transferred intramolecularly from Pd to the cyclopropyl carbon by simple reductive elimination. This type of regioselective coupling may also be quite useful for the preparation of ethenylcyclopropane derivatives, as it should be applicable for introduction of additional alkenyl and alkynyl substituents.[70] Similar goals can be achieved by the new regioselective coupling of phenylzinc chloride with 1-chloro-1-(trimethylsilylethynyl)-cyclopropane (**14**) under Pd(0) catalysis. In this reaction a similar mechanism must be operative as in that of **23**/**50**, and it should also be applicable to alkenyl- as well as alkynylzinc halides.

In all cases tested, palladium(0) catalysts were superior to nickel and molybdenum complexes.

### Experimental Section

All reagents obtained from commercial suppliers were distilled before use. Tetrahydrofuran (THF) was freshly distilled from sodium benzophenone prior to use. Ether was distilled from sodium; dimethyl sulfoxide, pyridine, and dichloromethane were distilled from calcium hydride. All reactions were run under an argon atmosphere in oven-dried glassware (or flame-dried under vacuum) unless otherwise stated. Anhydrous solvents or reaction mixtures were generally transferred by oven-dried syringe or cannula. Flash chromatography employed E. Merck silica gel (Kieselgel 60, 200–400 mesh) or E. Merck $Al_2O_3$ (Aluminiumoxid 90, neutral, 63–200 $\mu$m). Analytical thin layer chromatography (TLC) was performed with 0.2-mm coated commercial plates (E. Merck, DC-Fertigglasplatten, Kieselgel 60 $F_{254}$; Macherey-Nagel, Fertigfolien, Alugram Sil G/$UV_{254}$; E. Merck, DC-Fertigglasplatten, Aluminiumoxid 60 $F_{254}$; Macherey-Nagel, Fertigfolien, Polygram Alox N/$UV_{254}$). Melting points were obtained on a Büchi apparatus in open capillary tubes and are uncorrected. Boiling points are also uncorrected.

Proton nuclear magnetic resonance ($^1$H NMR) spectra were recorded on Bruker AC 200, AW 250, AM 250, or Varian XL 200, VXR 200 instruments. Chemical shifts are reported in $\delta$, downfield from tetramethylsilane. Carbon-13 nuclear magnetic resonance ($^{13}$C NMR) spectra were recorded on Bruker AC 200 (50.3 MHz), AW 250 (62.9 MHz), AM 250 (62.9 MHz), or Varian XL 200 (50.3 MHz) spectrometers and are reported in $\delta$ relative to the center line of a triplet at 77.00 ppm for deuteriochloroform.

Infrared (IR) spectra were recorded on Perkin-Elmer 297, 298, 399, or 682 instruments. Analytical gas chromatography (GC) was performed on a Siemens Sichromat 3 (25-m capillary column CB-SE-54, carrier gas

(63) Vo Quang, L.; Vo Quang, Y. *Bull. Soc. Chim. Fr.* **1974**, 2575.
(64) Newman, M. S.; Gromelski, S. J. *J. Org. Chem.* **1972**, *37*, 3220.
(65) (a) Tsuji, J.; Watanabe, H.; Minami, I.; Shimizu, I. *J. Am. Chem. Soc.* **1985**, *107*, 2196. (b) Tsuji, J.; Sugiura, T.; Yuhara, M.; Minami, I. *J. Chem. Soc., Chem. Commun.* **1986**, 922. (c) Tsuji, J.; Sugiura, T.; Minami, I. *Synthesis* **1987**, 603.
(66) For allylic alkylations catalyzed by Ni, see (a) Alvarez, E.; Cuvigny, T.; Julia, M. *J. Organomet. Chem.* **1988**, *399*, 199. (b) Consiglio, G.; Piccolo, O.; Roncetti, L. *Tetrahedron* **1986**, *42*, 2053.
(67) Cf. Alexakis, A.; Marek, I.; Mangeney, P.; Normant, J. F. *J. Am. Chem. Soc.* **1990**, *112*, 8042, and references cited therein.
(68) Ketley, A. D.; Braatz, J. A. *J. Organomet. Chem.* **1967**, *9*, 5.
(69) Ollivier, J.; Legros, J.-Y.; Fiaud, J.-C.; de Meijere, A.; Salaün, J. *Tetrahedron Lett.* **1990**, *31*, 4135.
(70) Piers, E.; Michel, J.; Marrs, P. S. *Tetrahedron Lett.* **1987**, *28*, 5075.

$H_2$) and preparative gas chromatography was performed with an Varian Aerograph 920 (carrier gas $H_2$; $^3/_8$ in. Teflon column with 10% SE-54 on Chromosorb W-AW-DMCS). Mass spectra (MS) were recorded on a Varian MAT CH 7 with Varian Aerograph 1740, NERMAG R-10 with capillary gas chromatograph OKI DP 125, Varian MAT 311 A (high resolution) at an ionization voltage of 70 eV, unless otherwise noted, and are reported as *m/z* (relative intensity). Microanalyses were carried out in the analytical laboratories of the university of Hamburg and Göttingen and the Service de Microanalyse, CNRS-ICSN in Gif-sur-Yvette.

The following compounds were prepared according to literature procedures: tetrakis(triphenylphosphine)palladium(0) ($Pd(PPh_3)_4$,[71] bis(dibenzylidenacetone)palladium(0) ($Pd(dba)_2$),[72] bis(triphenylphosphine)dichloronickel(II),[73] cyclopropanone hemiacetal (**1**),[28] 1-ethenylcyclopropanol (**2a**),[74] 1-acetoxy-1-ethenylcyclopropane (**2b**),[74] 1-(1-propenyl)cyclopropanol (**3a**),[30] 1-styrylcyclopropanol (**5a**),[31] 1-isobutenylcyclopropanol (**6a**),[74] 1-acetoxy-1-isobutenylcyclopropane (**6b**),[74] 1-(1-propynyl)cyclopropanol (**7a**),[9b] 1-(phenylethynyl)cyclopropanol (**8a**),[9b] 1-(1-propynyl)-1-(tosyloxy)cyclopropane (**7e**),[9b] 1-(phenylethynyl)-1-(tosyloxy)cyclopropane (**8e**),[9b] ethyl 2-cyclopropylideneacetate (**9**),[32] 1-chloro-1-ethynylcyclopropane (**12**),[25b,c] 1-chloro-1-(trimethylsilylethynyl)cyclopropane (**14**),[25b,c] ethyl 2-(diphenylmethylene)iminoacetate (**33**).[39] The two allyl acetates **19** and **22** were prepared from the corresponding allyl alcohols and acetic anhydride in ether[75] and were identified by comparison with reported data: 2-acetoxy-2-methyl-3-butene (**19**),[76] 1-acetoxy-3-methyl-2-butene (**22**).[77]

**1-[(Ethoxycarbonyl)oxy]-1-ethenylcyclopropane (2c).** A solution of 1.14 g (14 mmol) of 1-ethenylcyclopropanol (**2a**) in 10 mL of ether was added at 0 °C to 17 mL (17 mmol) of a 1 M methylmagnesium bromide solution in ether, followed by 1.95 g (18 mmol) of ethyl chloroformate at 0 °C. The mixture was stirred for 3 h while warming to room temperature and then partitioned between saturated $NaHCO_3$ (20 mL) and ether (50 mL). The ether layer was washed with $NaHCO_3$ (3 × 25 mL), saturated NaCl (2 × 25 mL), dried ($Na_2SO_4$), and concentrated by distillation of the solvent through a 30-cm Vigreux column. Trap to trap distillation gave 1.32 g (60%) of **2c**: IR (film) 3095, 2986, 1757 (C=O), 1643, 1371, 1235, 1201, 1010, 902, 792 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 0.94–1.02 (m, 2 H, Cpr-H), 1.15–1.24 (m, 2 H, Cpr-H), 1.31 (t, 3 H, $^3J$ = 7.2 Hz, $OCH_2CH_3$), 4.92 (q, 2 H, $^3J$ = 7.2 Hz, $OCH_2CH_3$), 5.08 (dd, 1 H, $^3J$ = 17.4 Hz, $^2J$ = 0.8 Hz, 2′-$H_Z$), 5.09 (dd, 1 H, $^3J$ = 10.5 Hz, $^2J$ = 0.8 Hz, 2′-$H_E$), 5.76 (dd, 1 H, $^3J$ = 17.4 Hz, $^2J$ = 10.5 Hz, 1′-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 14.21 ($CH_2CH_3$), 14.68 (C-2(3)), 61.07 (C-1), 63.99 ($OCH_2CH_3$), 112.18 (C-2′), 137.02 (C-1′), 154.50 ($OCO_2$); MS (70 eV) *m/z* (%) 156 (2) [$M^+$], 131 (2), 111 (2) [$M^+$ – OEt], 83 (100) [$M^+ - CO_2Et$]. Anal. Calcd for $C_8H_{12}O_3$ (156.2): C, 61.52; H, 7.74. Found: C, 61.90; H, 7.75.

**1-(Trifluoroacetoxy)-1-ethenylcyclopropane (2d).** To 13 mL (13 mmol) of a 1 M methylmagnesium bromide solution in ether was added 1.0 g (11.9 mmol) of **2a** in 8 mL of ether. The mixture was heated at reflux for 1 h, then 1.84 g (13.5 mmol) trifluoroacetic anhydride was slowly added under reflux, and the mixture was stirred under reflux for an additional 2 h, cooled to room temperature, diluted with 50 mL of pentane, and hydrolyzed with saturated $NaHCO_3$ solution (50 mL). The organic layer was washed with $NaHCO_3$ solution (2 × 20 mL) and saturated NaCl (10 mL), dried ($Na_2SO_4$), and then concentrated by distillation of solvent through a 30-cm Vigreux column. Trap to trap distillation and preparative GC isolation (1.5 m 10% SE 54, 30 °C) afforded 1.22 g (57%) **2d**: IR (film) 3102, 3021, 1796 (C=O), 1644, 1424, 1364, 1148, 1030, 912, 847 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) $\delta$ 1.07–1.18 (m, 2 H, Cpr-H), 1.19–1.30 (m, 2 H, Cpr-H), 5.10 (d, 1 H, $^3J$ = 17.0 Hz, 2′-$H_Z$), 5.17 (d, 1 H, $^3J$ = 8.8 Hz, 2′-$H_E$), 5.76 (dd, 1 H, $^3J$ = 17.0 Hz, $^3J$ = 8.8 Hz, 1′-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 14.05 (C-2(3)), 62.67 (C-1), 113.83 (q, $^1J_{C-F}$ = 286.2 Hz, $CF_3$), 134.60 (C-1′), 157.17 (q, $^2J_{C-F}$ = 37.7 Hz, $CF_3CO_2$); MS (70 eV) *m/z* (%) 180 (3) [$M^+$], 179 (10) [$M^+$ – H], 111 (100) [$M^+ - CF_3$]. Anal. Calcd for $C_7H_7O_2F_3$ (180.2): C, 46.68; H, 3.92. Found: C, 46.52; H, 3.82.

**1-(Tosyloxy)-1-ethenylcyclopropane (2e).**[9a] To a solution of 1.0 g (11.9 mmol) of **2a** in 18 mL of pyridine at 0 °C was added 3.40 g (17.9 mmol) of *p*-toluenesulfonyl chloride. The mixture was maintained at 0 °C for 14 h and poured into 30 mL of crushed ice and water. The aqueous layer was then washed with ether (3 × 60 mL) and the combined ethereal solutions were extracted with 10% HCl (3 × 60 mL) and saturated NaCl (50 mL) and dried ($MgSO_4$). Flash chromatography (silica gel, hexane/ether 4:1) afforded 2.35 g (93%) of product **2e** as a white solid: mp 31 °C; IR (film) 3018, 1599, 1496, 1365, 1199, 1176, 1027, 919, 576, 445 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 0.89–0.97 (m, 2 H, Cpr-H), 1.33–1.40 (m, 2 H, Cpr-H), 2.45 (s, 3 H, Ar-$CH_3$), 4.94 (d, 1 H, $^3J$ = 10.7 Hz, 2′-$H_E$), 5.03 (d, 1 H, $^3J$ = 17.1 Hz, 2′-$H_Z$), 5.83 (dd, 1 H, $^3J$ = 17.1 Hz, $^3J$ = 10.7 Hz), 7.30–7.36 (m, 2 H, $^3J$ = 8.4 Hz, Ar-H), 7.74–7.82 (m, 2 H, $^3J$ = 8.4 Hz, Ar-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 13.99 (C-2(3)), 21.64 (Ar-$CH_3$), 65.39 (C-1), 113.48 (C-2′), 127.87, 129.68 (Ar-C), 135.10 (Ar-C), 136.55 (C-1′), 144.7; MS (70 eV) *m/z* (%) 238 (1) [$M^+$], 155 (44), 91 (81), 55 (100).

**1-(Mesyloxy)-1-ethenylcyclopropane (2f).** To a solution of 1.07 g (12.7 mmol) of **2a** in 18 mL of pyridine at 0 °C was added 1.97 mL (2.9 g, 35 mmol) of methanesulfonyl chloride. The mixture was maintained at 0 °C for 14 h and poured into 30 mL of crushed ice and water. The aqueous layer was then washed with ether (3 × 60 mL), and the combined ethereal solutions were extracted with 10% HCl (3 × 60 mL) and saturated NaCl (50 mL) and dried ($MgSO_4$). Evaporation of the solvent afforded 1.8 g (93%) of **2f** as a yellow liquid: IR (film) 3100, 3030, 2940, 1595, 1420, 1360, 1275, 1260, 945, 920, 820 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 0.95–1.06 (m, 2 H, Cpr-H), 1.45–1.52 (m, 2 H, Cpr-H), 3.02 (s, 3 H, $SO_2-CH_3$), 5.18 (d, 1 H, $^3J$ = 8.8 Hz, 2′-$H_E$), 5.26 (d, 1 H, $^3J$ = 17.2 Hz, 2′-$H_Z$), 6.00 (dd, 1 H, $^3J$ = 17.2 Hz, $^3J$ = 8.8 Hz, 1′-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 13.86 (C-2(3)), 39.72 ($SO_2CH_3$), 65.11 (C-1), 114.60 (C-2′), 136.16 (C-1′); MS (70 eV) *m/z* (%) 162 (1) [$M^+$], 84 (16), 83 (14) [$M^+ - SO_2CH_3$], 79 (5) [$SO_2CH_3$], 66 (14), 55 (100) [$C_3H_3O$]. Anal. Calcd for $C_6H_{10}O_3S$ (162.2): C, 44.43; H, 6.21; S, 19.77. Found: C, 44.51; H, 6.10; S, 19.65.

**1-(2-Propenyl)cyclopropanol (3a).**[78] To 2.97 mL (2.97 mmol) of a 1.0 M methylmagnesium bromide solution in ether was added 3.0 g (2.97 mmol) of hemiacetal **1** in 4 mL of THF at 0 °C, followed by 4.45 mmol of 2-propenylmagnesium bromide in 5 mL of THF, prepared from 1.07 g (4.45 mmol) of magnesium and 5.38 g (4.45 mmol) of 2-bromo-2-propene. The mixture was heated at reflux for 14 h, and then hydrolyzed with saturated $NH_4Cl$ (50 mL); the aqueous layer was extracted with ether (3 × 20 mL each), and the ethereal solutions were dried ($Na_2SO_4$). Evaporation of the solvent, followed by trap to trap distillation, afforded 2.18 g (75%) of **3a**, identified by its spectroscopic data as reported.[78]

**1-(2-Propenyl)-1-(tosyloxy)cyclopropane (3e).** A mixture of 100 mg (1.02 mmol) of **3a** and 214.1 mg (1.12 mmol) of tosyl chloride in 1 mL of dry pyridine was allowed to stand at 8 °C for 36 h. Work-up as for **2e**, followed by flash chromatography ($Al_2O_3$ neutral, act. III) afforded 183 mg (64%) of **3e** as a colorless oil: IR (neat) 3100, 2980, 2930, 1600, 1285, 1200, 1190, 1180, 1100, 915, 895 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) $\delta$ 0.87–0.99 (m, 2 H, Cpr-H), 1.21–1.29 (m, 2 H, Cpr-H), 1.68 (dd, 3 H, $^4J$ = 0.9 Hz, $^4J$ = 1.6 Hz, 3′-H), 2.45 (s, 3 H, Ar-$CH_3$), 4.82 (dq, 1 H, $^4J$ = 1.6 Hz, $^2J$ = 1.2 Hz, 1′-$H_Z$), 5.96–5.99 (m, 1 H, 1′-$H_E$), 7.28–7.33 (m, 2 H, $^3J$ = 7.8 Hz, Ar-H), 7.73–7.80 (m, 2 H, $^3J$ = 8.2 Hz, Ar-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 12.33 (Cpr-C), 19.21 (C-3′), 21.58 (Ar-$CH_3$), 68.24 (C-1), 113.49 (C-1′), 128.04, 129.49, 135.17 (Ar-C), 141.54 (C-2′), 144.49 (Ar-C); MS (70 eV) *m/z* (%) 252 (1) [$M^+$], 155 (45) [Ts], 97 (60), 91 (94), 69 (100) [$C_4H_5O$]. Anal. Calcd for $C_{13}H_{16}O_3S$ (252.3): C, 61.88; H, 6.39; S, 12.71. Found: C, 61.75; H, 6.29; S, 12.88.

**(*E*)-1-(1-Propenyl)-1-(tosyloxy)cyclopropane (4e).** A mixture of 99 mg (1.1 mmol) of **3a**[31] and 208 mg (1.2 mmol) of *p*-toluenesulfonyl chloride in 1 mL of pyridine was allowed to stand at 8 °C for 48 h. The mixture was poured onto 2 g of crushed ice. After warming to room temperature, 10 mL of ether was added and the organic layer was separated and washed with saturated $NaHCO_3$ (3 × 2 mL), saturated NaCl (2 × 3 mL), 10% HCl (3 × 2 mL), and saturated NaCl (2 × 3 mL). Drying ($Na_2SO_4$) and removal of the solvent gave 157 mg (57%) of **4e** as a colorless oil. An analytically pure sample was obtained by flash chromatography ($Al_2O_3$ neutral, act. IV, hexane/ether 5:1): IR (film): 3040, 2960, 2910, 1600, 1450, 1365 ($SO_2O$), 1195, 1170, 1095, 585, 555 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 0.77–0.88 (m, 2 H, Cpr-H), 1.21–1.34 (m, 2 H, Cpr-H), 1.55 (dd, 3 H, $^3J$ = 3.6 Hz, $^4J$ = 1.2 Hz, 3′-H), 2.42 (s, 3 H, Ar–$CH_3$), 5.52–5.61 (m, 2 H, 1′(2′)-H), 7.26–7.32 (m, 2 H, $^3J$ = 8.4 Hz, Ar-H), 7.70–7.76 (m, 2 H, $^3J$ = 8.4 Hz, Ar-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 12.96 (C-2(3)), 17.34 (C-3′), 21.58 (Ar-$CH_3$), 65.61 (C-1), 127.10, 127.90, 128.45, 129.46, 135.25, 144.41; MS (70 eV) *m/z* (%) 252 (1) [$M^+$], 155 (12) [Ts], 97 (12) [$M^+$ – Ts], 91 (58), 69 (100) [$C_4H_5O$]. Anal. Calcd for $C_{13}H_{16}O_3S$ (252.3): C, 61.88; H, 6.39; S, 12.71. Found: C, 61.93; H, 6.30; S, 12.42.

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**(*E*)-1-(1-Styryl)-1-(tosyloxy)cyclopropane (5e).** A mixture of 104.3 mg (0.65 mmol) of **5a**[31] and 136 mg (0.72 mmol) of tosyl chloride in 1 mL of dry pyridine was allowed to stand at 8 °C for 48 h. The mixture was added onto 2 g of crushed ice, and the product precipitated. It was filtered off and dissolved in ether (20 mL), and the solution was dried ($Na_2SO_4$). After removal of the solvent, the residue was recrystallized (3 mL, pentane/dichloromethane 4:1) affording 184 mg (90%) of **5e**: IR (film) 3030, 2980, 1600, 1495, 1450, 1260, 1175, 910, 815, 730, 580, 555 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) $\delta$ 0.99–1.08 (m, 2 H, Cpr-H), 1.45–1.51 (m, 2 H, Cpr-H), 2.35 (s, 3 H, Ar-$CH_3$), 6.14 (d, 1 H, $^3J$ = 16.8 Hz, 1'-H), 6.35 (d, 1 H, $^3J$ = 16.8 Hz, 2'-H), 7.14–7.21 (m, 2 H, $^3J$ = 8.4 Hz, Ts-Ar-H), 7.24–7.30 (m, 5 H, Ar-H), 7.76–7.79 (m, 2 H, $^3J$ = 8.4 Hz, Ts-Ar-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 13.92 (C-2(3)), 21.74 (Ar-$CH_3$), 65.51 (C-1), 126.32, 126.95, 127.73, 127.97, 128.38, 129.58, 134.88, 135.79, 144.68; MS (70 eV) *m/z* (%) 159 (67) [$M^+$ – Ts], 155 (25) [Ts], 142 (50), 131 (67), 117 (42), 103 (58), 91 (100). Anal. Calcd for $C_{18}H_{18}O_3S$ (314.4): C, 68.76; H, 5.77; S, 10.20. Found: 68.61; H, 5.70; S, 10.22.

**1-(Trifluoracetoxy)-1-isobutenylcyclopropane (6d).** To a solution of 112 mg (1 mmol) of **6a**[70] and 169 mg (1.1 mmol) of *p*-(dimethylamino)pyridine (DMAP) in 2 mL of dichloromethane at 0 °C was added 320 $\mu$L (1.1 mmol) of trifluoroacetic anhydride during which a yellow precipitate occurred. After 10 min at 0 °C (TLC control) the reaction mixture was partitioned between saturated $NaHCO_3$ (5 mL) and ether (15 mL). The organic layer was washed with $NaHCO_3$ (2 × 2 mL), saturated NaCl (1 × 2 mL), 10% HCl (3 × 2 mL), and saturated NaCl (1 × 2 mL) and dried ($MgSO_4$). Distillation of the solvent through a 20-cm Vigreux column and trap to trap distillation of the residue afforded 102 mg (50%) of **6d** (98% pure according to GC). An analytically pure sample was obtained by GC separation (1.5 m, 20% SE 54, 25 °C): IR (film) 2980, 2930, 1790 (C=O), 1370, 1230, 1170, 1035, 855, 780 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 0.88–0.98 (m, 2 H, Cpr-H), 1.12–1.22 (m, 2 H, Cpr-H), 2.73 (d, 3 H, $^4J$ = 1.8 Hz, $CH_3$), 1.88 (d, 3 H, $^4J$ = 1.8 Hz, $CH_3$), 5.66 (bs, 1 H, 1'-H); $^{13}C$ NMR (50.3 MHz, $CDCl_3$) $\delta$ 13.27, 13.35 (Cpr-C), 19.44 ($CH_{3trans}$), 25.36 ($CH_{3cis}$), 60.41 (C-1), 114.49 (q, $^2J$ = 286 Hz, $CO_2CF_3$), 120.60 (C-1'), 144.36 (C-2'), 157.14 (q, $^3J$ = 41.1 Hz, $CO_2CF_3$); MS (70 eV) *m/z* (%) 208 (1) [$M^+$], 193 (5) [$M^+$ – $CH_3$], 139 (100) [$M^+$ – $CF_3$]. Anal. Calcd for $C_9H_{11}O_2F_3$ (208.2): C, 51.93; H, 5.33. Found: C, 51.82; H, 5.29.

**1-[(Methoxycarbonyl)oxy]-1-(2-phenylethynyl)cyclopropane (8c).** To a solution of 1.0 g (6.33 mmol) of **8a**[9b] and 538 $\mu$L (7.00 mmol) of ethyl chloroformate in 7.5 mL of dichloromethane kept at 0 °C was added dropwise 562 $\mu$L (7.00 mmol) of pyridine. The mixture was stirred for 4 h, while it reached room temperature. Then 0.5 M HCl (2 mL) was added and the aqueous layer was extracted with $CH_2Cl_2$ (5 mL). The organic layer was washed with saturated $NaHCO_3$ (3 × 5 mL) and saturated NaCl (2 × 5 mL), dried ($Na_2SO_4$), and concentrated in vacuo. Chromatography of the residual oil (silica gel, hexane/ether 9:1) gave 1.07 g (78%) of carbonate **8c**: IR (film) 2225, 1765 (C=O), 1595 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) $\delta$ 1.35 (s, 4 H, Cpr-H), 3.84 (s, 3 H, $OCH_3$), 7.28–7.50 (m, 5 H, Ar-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 16.28 (Cpr-C), 51.05 (C-1), 14.21 ($CH_2CH_3$), 54.74 ($OCH_3$), 83.29 (C-1'), 86.74 (C-2'), 122.14, 128.04, 131.71 (Ar-C), 154.72 ($OCO_2$); MS (70 eV) *m/z* (%) 216 (9) [$M^+$], 201 (29), 157 (27), 141 (58), 140 (33), 129 (100). Anal. Calcd for $C_{13}H_{12}O_2$ (216.24): C, 72.21; H, 5.59. Found: C, 72.22; H, 5.29.

**2-Cyclopropylideneethanol (10a).**[79] To a solution of 71 mL of 1.0 M diisobutylaluminum hydride in hexane (71 mmol) kept at −78 °C was added 75 mL of dichloromethane and then 3.34 g (29.8 mmol) of ester **9** in 50 mL of dichloromethane over a period of 1.5 h. The mixture was stirred for 1 h while it reached room temperature, cooled to −20 °C, and quenched with 3 mL of methanol and 50 mL of a saturated aqueous solution of sodium potassium tartrate. The reaction mixture was vigorously stirred for 1 h by which time two layers had formed. The organic layer was washed with saturated NaCl (3 × 30 mL), dried ($MgSO_4$), and concentrated by distillation through a 30-cm Vigreux column. Distillation of the residue (55 °C, 35 Torr) afforded 2.26 g (90%) of **10a**: $^1H$ NMR (250 MHz, $CDCl_3$) $\delta$ 1.08 (mc, 4 H, Cpr-H), 2.20 (s, 1 H, OH), 4.26 (mc, 2 H, 1-H), 6.00 (mc, 1 H, 2-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 1.59, 1.63 (C-2'(3')), 63.10 (C-1), 117.29 (C-2), 124.62 (C-1'). IR and MS are in accord with reported literature data.[79]

**1-Acetoxy-2-cyclopropylideneethane (10b).** To a solution of 660 mg (7.8 mmol) of alcohol **10a**, 1.0 g (9.96 mmol) of triethylamine, and 17.1 mg (0.14 mmol) *p*-(dimethylamino)pyridine (DMAP) in 15 mL ether kept at 0 °C was added dropwise 0.9 mL (0.93 g, 9.13 mmol) of acetic anhydride, and the resulting mixture was stirred for 2 h at room temperature. After 50 mL of ether was added, the organic layer was extracted with 10% HCl (4 × 15 mL), saturated $NaHCO_3$ (4 × 15 mL), and saturated NaCl (20 mL) and dried ($Na_2SO_4$), and the solvents were distilled through a 20-cm Vigreux column. Distillation of the residue (60 °C, 30 Torr) gave 739 mg (75%) of **10b**: IR (film) 3093, 3059, 2986, 1741 (C=O), 1445, 1230, 954, 840, 641 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) $\delta$ 1.12 (mc, 4 H, Cpr-H), 2.07 (s, 3 H, $CH_3CO_2$), 4.96 (mc, 2 H, 1-H), 5.92 (mc, 1 H, 2-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 1.75, 2.33 (C-2'(3')), 20.99 ($CH_3CO_2$), 64.70 (C-1), 112.50 (C-2), 128.53 (C-1'), 170.92 ($CH_3CO_2$); MS (70 eV) *m/z* (%) 67 (100) [$M^+$ – $CH_3CO_2$], 66 (20), 65 (17), 39 (38). Anal. Calcd for $C_7H_{10}O_2$ (126.2): C, 66.65; H, 7.99. Found: C, 66.63; H, 8.13.

**1-[(Ethoxycarbonyl)oxy]-2-cyclopropylideneethane (10c).** A mixture of 104 mg (1.23 mmol) of **10a** and 474 mg (5.9 mmol) of pyridine in 4 mL of dichloromethane at 0 °C was reacted with 226 mg (2.4 mmol) of ethyl chloroformate. The mixture was allowed to come to room temperature. After 30 min it was quenched with 5 mL of saturated $NaHCO_3$ and diluted with 20 mL of ether. The organic layer was washed with $NaHCO_3$ (2 × 7 mL) and water (4 × 15 mL), dried ($Na_2SO_4$), and concentrated. Chromatography (silica gel, petroleum ether/ether 8:1, $R$ = 0.54) afforded 162 mg (86%) of **10c**: IR (film) 3071, 2986, 1746 (C=O), 1381, 1256, 1010, 928, 875, 793 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) $\delta$ 1.11–1.14 (m, 4 H, Cpr-H), 1.30 (t, 3 H, $^3J$ = 7.2 Hz, $OCH_2CH_3$), 4.92 (q, 2 H, $^3J$ = 7.2 Hz, $OCH_2CH_3$), 4.72–4.76 (m, 2 H, $^3J$ = 6.7 Hz, 1-H), 5.96 (m, 1 H, $^3J$ = 6.7 Hz, 2-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 1.78, 2.41 (C-2'(3')), 14.29 ($OCH_2CH_3$), 63.88 ($OCH_2CH_3$), 67.84 (C-1), 112.07 (C-2), 129.43 (C-1'), 155.16 ($OCO_2$); MS (70 eV) *m/z* (%) 156 (3) [$M^+$], 128 (11), 84 (30), 83 (41) [$M^+$ – $CO_2Et$], 67 (76) [$M^+$ – $OCO_2Et$], 66 (37), 65 (31), 56 (54), 53 (36), 44 (100) [$CO_2$]. Anal. Calcd for $C_8H_{12}O_3$ (156.2): C, 61.52; H, 7.74. Found: C, 61.83; H, 7.85.

**1-Cyclopropylidene-2-methylpropan-2-ol (11a).**[80] To 80 mL of a 1.0 M solution (80 mmol) of methyllithium (containing LiBr) in ether kept at −78 °C was added, dropwise within 2 h, 4.0 g (36 mmol) of ester 9[32] in 50 mL of ether, and the mixture was stirred for 1.5 h, while it reached room temperature. It was poured into 50 g of ice and 150 mL of a saturated $NH_4Cl$ solution. The aqueous layer was washed with ether (3 × 25 mL), and the combined ethereal solutions were extracted with water (2 × 50 mL) and saturated NaCl (50 mL), dried ($MgSO_4$), and concentrated. Trap to trap distillation yielded 3.0 g (75%) of **11a**, identified by its spectroscopic data as reported.[80]

**2-Acetoxy-1-cyclopropylidene-2-methylpropane (11b).** To a solution of 100 mg (0.79 mmol) of **11a** and 120 mg (0.98 mmol) of DMAP in 3 mL of dichloromethane kept at 0 °C was added 123 mg (1.10 mmol) of acetic anhydride. The mixture was stirred for 14 h at room temperature. After addition of 10 mL of ether, extraction with saturated $NaHCO_3$ (3 × 2 mL), saturated NaCl (2 mL), and 10% HCl (3 × 2 mL), and drying ($Na_2SO_4$), the solvents were evaporated and flash chromatography of the yellow residue ($Al_2O_3$, act. IV, pentane/ether 30:1) gave 80 mg (60%) of **11b**: IR (film) 3080, 2990, 1730 (C=O), 1375, 1265, 1130, 915, 740 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 0.94–1.06 (m, 2 H, Cpr-H), 1.13–1.28 (m, 2 H, Cpr-H), 1.58 (s, 6 H, 1''(3)-H), 1.99 (s, 3 H, $CO_2CH_3$), 6.07–6.14 (m, 1 H, 1-H); $^{13}C$ NMR (50.3 MHz, $CDCl_3$) $\delta$ 0.46, 3.56 (Cpr-C), 22.29 ($CO_2CH_3$), 27.01 (C-1(1'')), 81.69 (C-2), 121.62 (C-1'), 122.38 (C-3), 170.11 (C=O); MS (70 eV) *m/z* (%) 154 (1) [$M^+$], 139 (8) [$M^+$ – $CH_3$], 112 (37), 97 (60), 83 (88), 43 (100).

**1-Chloro-1-(1-propynyl)cyclopropane (13).** To a solution of 15 g (73.5 mmol) of 1-chloro-1-(trichlorovinyl)cyclopropane[25b] in 250 mL of diethyl ether at −78 °C was added 301.4 mmol of methyllithium (1.6 M in ether). After 30 min at −78 °C the mixture was stirred until it reached room temperature and 14.5 g (115 mmol) of dimethyl sulfate was added. The mixture was stirred for 14 h and then quenched with 50 mL of water. The organic layer was washed with saturated sodium bicarbonate (40 mL, twice) and with water, dried on sodium sulfate, and concentrated through a 20-cm Vigreux column. Trap to trap distillation of the residue afforded 6.7 g (80%) of **13** (90% pure according to GC): IR ($CCl_4$) 3100, 3020, 2940, 2925, 2860, 2250, 2230, 1410, 1315, 1060, 1030, 1015, 1000, 890 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) 1.24 (s, 4 H), 1.82 (s, 3 H); $^{13}C$ NMR (50.3 MHz, $CDCl_3$) $\delta$ 3.5 ($CH_3$), 19.5 (Cpr-C), 29.9 (Cpr-C), 78.3 (C-2'), 79.7 (C-1'); MS (70 eV) *m/z* (%) 116 (8), 114 (28), 101 (4), 99 (13), 80 (7), 79 (80), 78 (22), 77 (100), 63 (14), 51 (26).

**1-Chloro-1-(phenylethynyl)cyclopropane (15).** A solution of 474 mg (3 mmol) of 1-(phenylethynyl)cyclopropanol (**8a**), 730 $\mu$L (9 mmol) of pyridine, and 36 $\mu$L (10%) of DMAP was treated with 328 $\mu$L (4.5 mmol) of thionyl chloride at 0 °C for 3 h. Work-up as for **13** and chromatography (silica gel, hexane/ether 9:1) gave 322 mg (61%) of **15** and 131 mg (28%) of **8a**: IR (film) 3090, 3060, 3020, 2930, 2200, 1600

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$cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 1.27–1.37 (m, 2 H, Cpr-H), 1.55–1.65 (m, 2 H, Cpr-H), 7.2–7.5 (m, 5 H, Ar-H); MS (70 eV) *m/z* (%) 178 (23) [$M^+$], 176 (69) [$M^+$], 141 (100), 115 (59). Anal. Calcd for $C_{11}H_9Cl$ (176.0): C, 74.79; H, 5.14. Found: C, 74.37; H, 4.89.

**Procedures for Allylic Substitution of 1-Ethenylcyclopropyl and Cyclopropylideneethyl Esters by Stabilized Nucleophiles Catalyzed by Palladium(0). Procedure A[35] (Table I, Entries 1, 4, 9, 27, and 28).** A mixture of 221 mg (1.76 mmol) of **10b**, 102 mg (88 $\mu$mol, 5 mol %) of $Pd(PPh_3)_4$ (catalyst A), and 92 mg (0.35 $\mu$mol) of $PPh_3$ in 2 mL of THF was stirred for 15 min, followed by addition of a solution of 4.64 mmol of sodium diethyl malonate (prepared in a separate flask from 900 mg (5.63 mmol) of diethyl malonate in 6 mL of THF, which was added slowly to 127 mg (5.28 mmol) of pentane-washed sodium hydride in 6 mL of THF) in 12 mL of THF. After the reaction mixture had been heated under reflux for 36 h, it was partitioned between ether (10 mL) and water (3 mL), the aqueous phase was extracted with ether (3 × 15 mL) and the ether extracts were washed with saturated NaCl (20 mL) and dried ($Na_2SO_4$). Evaporation of the solvents and flash chromatography (silica gel, pentane/ether 12:1) of the residue gave 318 mg (80%) of **16′** as a colorless oil.

**Procedure B[33] (Table I, Entries 2, 5, 6, 8, 10, 12, 17–26, 30, 32, 34–36).** A 234-mg (1.86 mmol) portion of **10b** was added to a stirred solution of 21.4 mg (37 $\mu$mol, 2 mol %) of $Pd(dba)_2$ and 14.7 (37 $\mu$mol) of 1,2-bis(diphenylphosphino)ethane (dppe) (catalyst B) in 3 mL of THF. After 10 min the mixture had turned green, and a solution of 5.58 mmol sodium dimethyl malonate (prepared as above) in 12 mL of THF was added. Stirring for additional 10 min, followed by aqueous workup as above, and flash chromatography (silica gel, hexane/ether 4:1) gave 316 mg (85%) of **16-Me** and 20 mg (8%) of **17-Me**.

**Procedure C[34] (Table I, Entry 11).** To a solution of 15 mg (13 $\mu$mol, 2 mol %) of $Pd(dba)_2$ and 22 mg (52 $\mu$mol) of dppe (catalyst D) in 2 mL of THF were added 200 mg (1.28 mmol) of **10c** and 524 mg (3.98 mol) of dimethyl malonate in 1 mL of THF. The resulting solution was stirred at ambient temperature for 4 h, the solvent was evaporated, and chromatography of the residue (silica gel, hexane/ether 4:1) gave 220 mg (89%) of **16** and 9 mg (11%) of **18**.

**Diethyl (2-Cyclopropylideneethyl)malonate (16′)[23b] (Table I, Entry 1).** IR (film) 3055, 2982, 1733 (C=O), 1446, 1369, 1153, 963, 859 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) $\delta$ 1.00–1.10 (m, 4 H, Cpr-H), 1.24 (t, 6 H, $CH_3$), 2.79 (m, 2 H, 2-H), 3.52 (t, 1 H, 1-H), 4.17 (q, 4 H, $CO_2CH_2$), 5.71 (m, 1 H, 3′-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 2.02, 2.32 (C-2′(3′)), 14.06 ($CH_3$), 31.07 (C-2), 51.81 (C-1), 61.29 ($CO_2CH_2$), 117.76 (C-3), 124.41 (C-1′), 169.23 ($CO_2CH_2$); MS (70 eV) *m/z* (%) 226 (15) [$M^+$], 180 (11) [$M^+$ − EtOH], 152 (79), 153 (19), 135 (39), 124 (36), 107 (47), 79 (100) [$M^+$ − $2EtCO_2H$].

**Dimethyl (2-Cyclopropylideneethyl)malonate (16) (Table I, Entry 5).** IR (film) 3055, 2956, 2847, 1737, 1438, 1235, 1047, 850, 751, 430 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) $\delta$ 1.02–1.05 (m, 4 H, Cpr-H), 2.67 (m, 2 H, $^3J$ = 8 Hz), 3.45 (t, 1 H, $^3J$ = 7.6 Hz), 3.74 (s, 6 H), 5.69–5.80 (m, 1 H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 1.98, 2.35, 31.12, 51.49, 52.47, 113.55, 124.70, 169.58 ($CO_2CH_3$); MS (70 eV) *m/z* (%) 198 (5) [$M^+$], 166 (5), 138 (49), 107 (35), 79 (100). Anal. Calcd for $C_{10}H_{14}O_4$ (198.2): C, 60.59; H, 7.12. Found: C, 60.46; H, 7.17.

**Dimethyl 2-Bis(2-cyclopropylideneethyl)malonate (17) (Table I, Entry 12).** IR (film) 3035, 2095, 1080, 1740 (C=O), 1440, 1283, 1210, 1110, 1070 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 0.99 (mc, 4 H, $^3J$ = 7.6 Hz, 1′(1″)-H), 3.66 (s, 6 H, $CO_2CH_3$), 5.63 (m, 2 H, $^3J$ = 7.6 Hz, 2′(2″)-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 1.70–2.84 (Cpr-C), 34.99 (C-1′(1″)), 52.24 ($CO_2CH_3$), 111.97 (C-2′(2″)), 126.19 (C-1‴(1‴)), 171.60 (C-$O_2CH_3$); MS (CI ($NH_3$)) *m/z* (%) 282 (16) [M + $NH_4^+$], 265 [M + $H^+$], 205 (2) [$M^+$ − $CO_2Me$], 145 (11).

**Control Experiment without Catalyst (Table I, Entry 13).** To a suspension of 350 mg (14.6 mmol) of NaH in 15 mL of anhydrous THF were added 632 mg (5 mmol) of cyclopropylideneethyl acetate (**10b**) and 2.38 g (14.9 mmol) of diethyl malonate, and the mixture was heated for 7 days. After addition of 100 mL of pentane and 50 mL of water, the organic phase was washed with water (3 × 50 mL) and with saturated NaCl (25 mL) and then dried ($Na_2SO_4$). The solvents were removed by distillation through a 20-cm Vigreux column, and the residue was purified by gas chromatography (1.5 m, 10% SE 54, 70 °C) to give 150 mg (15%) of diester **18**. IR (film) 3055, 2985, 1735 (C=O), 1447, 1370, 1334, 1150, 1034 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) $\delta$ 1.12 (m, 4 H, Cpr-H), 1.20 (t, 3 H, $CH_3$), 3.40 (s, 2 H, 2-H), 4.23 (q, 2 H, $CO_2CH_2$), 4.78 (m, 2 H, 1-H), 5.93 (m, 2 H, 2′-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 1.80, 2.42 (C-2″(3″)), 14.05 ($CH_3$), 41.36 (C-2), 129.30 (C-1″), 166.56 (C-1(3)); MS (70 eV) *m/z* (%) 198 (2) [$M^+$], 124 (4), 115 (100) [$C_5H_6O_3$].

**Competition Experiments. 2e versus 19 (Scheme I).** A mixture of 50.4 mg (0.212 mmol) of tosylate **2e** and 27.1 mg (0.212 mmol) of acetate **19** in 1 mL of THF was added to a solution of 2.4 mg (4.2 mmol) of $Pd(dba)_2$ and 1.3 mg (4.2 mmol) of dppe in 1 mL of THF while the mixture turned green. Addition of 0.75 mL of a 0.28 M (0.21 mmol) solution of sodium dimethyl malonate gave an orange mixture, which changed to green again. After 48 h at room temperature the reaction mixture was filtered through silica gel; $^1H$ NMR and GC analysis showed five compounds (**2e**, **19**, **16-Me**, **20**, and **21**) with a product ratio **16-Me**:(**20** + **21**) of 19:1. The spectral data of **20** and **21** were in complete accord with the literature.[35,81]

**10b versus 22 (Scheme I).** A mixture of 97.7 mg (0.775 mmol) of **10b** and 99.2 mg (0.775 mmol) of **22** in 2 mL of THF was added to a solution of 8.6 mg (15 mmol) of $Pd(dba)_2$ and 4.6 mg (15 mmol) of dppe in 1 mL of THF, and the mixture was stirred until the solution had turned green (5 min). Addition of 0.78 mL (0.76 mmol) of a 0.98 M solution of sodium dimethyl malonate in THF and stirring of the mixture for 48 h (color turned to orange) was followed by workup as described above; $^1H$ NMR and GC analysis of the residue showed **16-Me** as the only reaction product, contaminated with **22**.

**Diethyl 2-(2-Cyclopropylideneethyl)-2-methylmalonate (27′) (Table I, Entry 17).** According to procedure B, reaction of 91 mg (0.38 mmol) of **2e** with 1.15 mmol of sodium dimethyl methylmalonate for 1 h gave after flash chromatography (silica gel, hexane/ether 10:1) 75 mg (82%) of **27′** as a colorless oil: IR (film) 3040, 2990, 2942, 1735 (C=O), 1395, 1270, 1240, 1190, 1110, 1025, 860 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 0.90–1.13 (m, 4 H, Cpr-H), 1.22 (t, $CH_2CH_3$), 1.36 (s, 3 H, $CH_3$), 2.72 (d, 2 H, 1-H), 4.16 (q, 4 H, $CO_2CH_2$), 5.54–5.70 (m, 1 H, 2′-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 1.77–2.85 (Cpr-C), 14.00 ($CO_2CH_2CH_3$), 19.73 ($CH_3$), 38.09 (C-1), 53.89 (C-2), 61.07 ($CO_2CH_2$), 112.38 (C-2′), 126.15 (C-1″), 172.11 ($CO_2CH_2$); MS (70 eV) *m/z* (%) 240 (21) [$M^+$], 166 (10) [$M^+$ − $CO_2Et$ − H], 121 (10), 93 (100) [$M^+$ − $2CO_2Et$ − H]. Anal. Calcd for $C_{13}H_{20}O_4$ (240.3): C, 64.98; H, 8.39. Found: C, 65.02; H, 8.12.

**Dimethyl 2-(Cyclopropylideneethyl)-2-(2-butenyl)malonate (28) (Table I, Entry 18).** According to procedure B, the reaction of 143 mg (0.60 mmol) of **2e** with 1.80 mmol of sodium dimethyl allylmalonate for 1 h gave after flash chromatography (silica gel, hexane/ether 8:1) 130 mg (91%) of **28** as a colorless oil: IR (film) 3080, 2990, 2960, 2850, 1740 (C=O), 1440, 1285, 1220, 1145, 920, 730 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 0.86–1.12 (m, 4 H, Cpr-H), 2.62 (d, 2 H, 1″-H), 2.75 (d, 2 H, 1′-H), 3.69 (s, 6 H, $CO_2CH_3$), 4.95–5.13 (m, 2 H, 3″-H), 5.50–5.80 (m, 2 H, 2′(2″)-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 1.80, 2.80 (Cpr-C), 35.02 (C-1′), 36.98 (C-1″), 52.17 ($CO_2CH_3$), 57.93 (C-2), 111.84 (C-2′), 119.05 (C-2″), 126.39 (C-1‴), 132.56 (C-3″), 171.30 ($CO_2CH_3$); MS (70 eV) *m/z* (%) 238 (1) [$M^+$], 178 (17) [$M^+$ − $CO_2Me$], 137 (18), 119 (46) [$M^+$ − $2CO_2Me$ − H], 105 (20), 91 (100) [$C_7H_7$]. Anal. Calcd for $C_{13}H_{18}O_4$ (238.3): C, 65.53; H, 7.61. Found: C, 65.32; H, 7.37.

**Dimethyl 2-(2-Cyclopropylideneethyl)-2-(2-butynyl)malonate (29) (Table I, Entry 19).** According to procedure B, the reaction of 145 mg (0.61 mmol) of **2e** with 0.92 mmol of sodium dimethyl propargylmalonate for 30 min gave after flash chromatography (silica gel, hexane/ether 5:1) 130 mg (91%) of **30** as a colorless oil: IR (film) 3490, 2980, 2955, 1740 (C=O), 1440, 1290, 1210, 1090, 915, 730 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 0.98–1.23 (m, 4 H, Cpr-H), 2.00 (t, 1 H, $^4J$ = 2.6 Hz, 3″-H), 2.80 (d, 2 H, $^4J$ = 2.6 Hz, 1″-H), 2.94 (d, 2 H, $^3J$ = 7.6 Hz, 1′-H), 3.73 (s, 6 H, $CO_2CH_3$), 5.51–5.61 (m, 1 H, 2′-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 1.96, 2.97 (Cpr-C), 22.78 (C-1″), 34.76 (C-1′), 52.64 ($CO_2CH_3$), 57.23 (C-2), 71.10 (C-3″), 111.31 (C-2′), 127.49 (C-1‴), 170.39 ($CO_2CH_3$); MS (70 eV) *m/z* (%) 236 (1) [$M^+$], 176 (13) [$M^+$ − $HCO_2Me$], 145 (16) [$M^+$ − $HCO_2Me$ − OMe], 117 (100) [$M^+$ − $2CO_2Me$ − H]. Anal. Calcd for $C_{13}H_{16}O_4$ (236.3): C, 66.09; H, 6.83. Found: C, 65.82; H, 6.70.

**2-Methoxycarbonyl-2-(2-cyclopropylideneethyl)cyclopentanone (30) (Table I, Entry 20).** According to procedure B, reaction of 142 mg (0.59 mmol) of **2e** with 1.15 mmol of sodium 2-methoxycarbonylcyclopentanonate for 1 h gave after flash chromatography (silica gel, hexane/ether 8:1) 114 mg (93%) of **30** as a colorless oil: IR (film) 3025, 2080, 2060, 1707 (C=O), 1733 (C=O), 1435, 1228, 1165, 1150, 1120 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) $\delta$ 0.94–1.17 (m, 4 H, Cpr-H), 1.81–2.06 (m, 3 H), 2.16–2.60 (m, 5 H), 2.80 (d, 2 H, 1′-H), 3.70 (s, 3 H, $CO_2CH_3$), 5.59–5.82 (m, 1 H, 2′-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) $\delta$ 1.94, 2.95 (Cpr-C), 19.49 (C-4), 32.19 (C-1′), 35.97 (C-3), 36.09 (C-5), 52.41 ($CO_2CH_3$), 60.05 (C-2), 112.65 (C-2′), 126.32 (C-1″), 172.06 ($CO_2CH_3$), 214.54 ($CO_2CH_3$); MS (70 eV) *m/z* (%) 208 (1) [$M^+$], 149 (11) [$M^+$ − $CO_2Me$], 148 (21), 131 (10), 106 (22), 105 (23), 92 (100). Anal. Calcd for $C_{12}H_{10}O_3$ (208.26): C, 60.21; H, 7.74. Found: C, 69.05; H, 7.62.

**2-(2-Cyclopropylideneethyl)-2-methylcyclopentane-1,3-dione (31) (Table I, Entry 21).** According to procedure B, to a green solution of

(81) Torii, S.; Uneyama, K.; Ymasaki, N. *Bull. Chem. Soc. Jpn.* **1980**, *57*, 819.

4.8 mg (8.3 μmol) of $Pd(dba)_2$, 4.5 mg (11.2 μmol) of dppe, 100 mg (0.42 mmol) of **2e**, and 52 mg (0.46 mmol) of 2-methyl-1,3-cyclopentanedione was added 70.3 mg (0.46 mmol) of 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU). After the mixture was stirred for 1 h, evaporation of the solvent and flash chromatography (silica gel, hexane/ether 4:1) afforded 54 mg (72%) of **31** as a colorless oil: IR (film) 3028, 2935, 2915, 2850, 1725, 1455, 1420, 1370, 1210, 1075, 1040, 990 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) δ 0.93–1.06 (m, 4 H, Cpr-H), 1.12 (s, 3 H, $CH_3$), 2.49 (d, 2 H, 1′-H), 2.68 (s, 4 H, 3(4)-H), 5.50–5.64 (m, 1 H, 2′-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) δ 1.97, 2.98 (Cpr-C), 18.24 ($CH_3$), 35.35 (C-2), 38.79 (C-1′), 56.96 (C-2), 111.14 (C-2′), 127.39 (C-1″); MS (70 eV) *m/z* (%) 178 (4) [$M^+$], 163 (15) [$M^+ - CH_3$], 123 (22) [$M^+ - CH_3CO_2$], 105 (19), 95 (70), 79 (100). HRMS calcd for $C_{11}H_{14}O_2$, *m/z* 178.0991; found, 178.0989.

**Methyl 4-Cyclopropylidene-6-(phenylsulfonyl)butanoate (32) (Table I, Entry 22).** According to procedure B, reaction of 133 mg (0.56 mmol) of **2e** with 1.75 mmol of sodium methyl 2-phenylsulfonylacetate for 2 h gave after flash chromatography (silica gel, hexane/ether 4:1) 144 mg (92%) of **32** as a white solid: mp 62–63 °C; IR (film) 3060, 2995, 2975, 1700 (C=O), 1500, 1328, 1312, 1150, 1072, 720, 685 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) δ 0.94–1.09 (m, 4 H, Cpr-H), 2.80–2.89 (m, 2 H, 3-H), 3.61 (s, 3 H, $CO_2CH_3$), 4.12 (dd, 1 H, 2-H), 5.61 (m, 1 H, 4-H), 7.55–7.72 (m, 3 H, Ar-H), 7.82–7.89 (m, 2 H, Ar-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) δ 2.04–2.41 (Cpr-C), 29.02 (C-3), 52.65 ($CO_2CH_3$), 70.09 (C-2), 111.36 (C-4), 126.82 (C-1′), 128.95, 129.08, 134.15, 137.19 (Ar-C), 165.92 ($CO_2CH_3$); MS (70 eV) *m/z* (%) 280 (1) [$M^+$], 139 (4) [$M^+ - CO_2Ph$], 138 (7) [$M^+ - SO_2Ph - H$], 107 (25), 80 (10) [$M^+ - SO_2Ph - CO_2Me$], 79 (100) [$M^+ - SO_2Ph - CO_2Me - H$]. Anal. Calcd for $C_{14}H_{16}O_4S$ (280.3): C, 59.98; H, 5.75; S, 11.44. Found: C, 60.05; H, 5.79; S, 11.52.

**Ethyl 4-Cyclopropylidene-2-[(diphenylmethylene)imino]butanoate (34). (a).** According to procedure B, reaction of 120 mg (0.50 mmol) of **2e** with 0.8 mmol of lithium ethyl (diphenylmethylene)iminoacetate (prepared in a separate flask from 216 mg (0.81 mmol) of ethyl (diphenylmethylene)iminoacetate (**33**) in 2 mL of THF which was added slowly to 0.81 mmol of LDA in 1 mL of THF) for 5 min gave, after flash chromatography ($Al_2O_3$ neutral, act. III, hexane/ether 5:1), 144 mg (87%) of **34** as a yellow oil, contaminated with up to 5% benzophenone (entry 23).

**(b).** According to procedure C, reaction of 100 mg (0.64 mmol) of **10b** with 171 mg (0.64 mmol) of **33** for 12 h at ambient temperature gave after flash chromatography 161 mg (76%) of **34** (entry 24): IR (film) 3035, 2980, 2960, 1740 (C=O), 1622, 1445, 1285, 1175, 1038, 780, 695 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) δ 0.81–1.06 (m, 4 H, Cpr-H), 1.26 (t, 3 H, $^3J$ = 7.7 Hz, $CO_2CH_3$), 2.65–2.93 (m, 2 H, 3-H), 4.11–4.29 (m, *J* = 7.1 Hz, $CO_2CH_2$, 2-H), 5.6–5.73 (m, 1 H, 4-H), 7.13–7.24 (m, 2 H, Ar-H), 7.29–7.52 (m, 6 H, Ar-H), 7.62–7.72 (d, 2 H, Ar-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) δ 1.69, 2.85 (Cpr-C), 14.17 ($CO_2CH_2CH_3$), 35.93 (C-3), 60.79 ($CO_2CH_2$), 65.78 (C-2), 113.83 (C-4), 124.06 (C-1′), 127.91, 128.01, 128.28, 128.38, 128.52, 128.81, 130.06, 130.23, 136.50, 139.60 (Ar-C), 170.22 (C=N), 172.11 (C=O); MS (70 eV) *m/z* (%) 333 (5) [$M^+$], 260 (44) [$M^+ - CO_2Et$], 238 (21), 193 (100) [$CHNCPh_2$]. HRMS calcd for $C_{22}H_{23}NO_2$, *m/z* 333.1729; found, 333.1700; ($M^+ - 1$) calcd, 332.1651; found, 332.1652.

**Ethyl 2-Amino-4-cyclopropylidenebutanoate (35) (Scheme III).** A mixture of 440 mg (1.32 mmol) of **34** in 15 mL of ether and 7 mL of 10% HCl solution was stirred at room temperature for 3 h (TLC monitoring). The aqueous phase was separated and washed with ether (2 mL) to remove benzophenone, and then ether (7 mL) was added and the mixture neutralized by addition of solid $NaHCO_3$ until saturation and stirred for 12 h. After separation of the ethereal layer and evaporation of the solvent 218 mg (98% purity according to GC) of the amino ester **35** was isolated as a colorless oil: IR (film) 3700–3080, 3035, 2993, 1735 (C=O), 1600, 1265, 1190, 1035 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) δ 0.98–1.16 (m, 4 H, Cpr-H), 0.28 (t, 3 H, $^3J$ = 7.0 Hz, $CO_2CH_2CH_3$), 1.80 (bs, 2 H, $NH_2$), 1.32–1.71 (m, 2 H, 3-H), 3.60 (dd, 1 H, $^3J$ = 5.2 Hz, $^3J$ = 6.8 Hz, 2-H), 4.18 (q, 2 H, $CO_2CH_2$), 5.65–5.77 (m, 1 H, 4-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) δ 1.89, 2.75 (Cpr-C), 14.18 ($CO_2CH_2CH_3$), 37.09 (C-3), 54.23 (C-2), 60.83 ($CO_2CH_2$), 112.84 (C-4), 125.82 (C-1′), 175.38 ($CO_2CH_2$); MS (70 eV) *m/z* (%) 136 (33), 96 (100) [$M^+ - CO_2Et$], 80 (18) [$M^+ - CO_2Et - NH_2$].

**2-Amino-4-cyclopropylidenebutanoic Acid (36) (Scheme III).** A 100-mg (0.59 mmol) portion of **35** was stirred at room temperature for 14 h with 360 μL (0.708 mmol) of a 2 M solution of NaOH in methanol. Filtration over an acidic cation exchange resin (3 g of Dowex 50, 50 mL of water/pyridine 4:1) and removal of the solvents afforded 80 mg (96%) of amino acid **36** as a light yellow solid: mp 206–208 °C; IR (KBr) 3300–2500, 2100, 1665, 1590 (C=O), 1420, 1350, 1340, 1087 $cm^{-1}$; $^1H$ NMR (200 MHz, $D_2O$) δ 0.90–1.10 (Cpr-H), 2.50–2.70 (m, 2 H, 3-H), 3.83 (dd, 1 H, 2-H), 5.58–5.70 (m, 1 H, 4-H); $^{13}C$ NMR (50.3 MHz, $D_2O$) δ 1.66, 2.62 (Cpr-C), 33.12 (C-3), 54.62 (C-2), 110.62 (C-4), 129.11 (C-1′), 174.55 (C=O). Anal. Calcd for $C_7H_{11}NO_2$ (141.2): C, 59.56; H, 7.85; N, 9.92. Found: C, 59.39; H, 7.83; N, 9.90.

**2-Cyclopropylideneethyl(3-phenylpropen-2-yl) Ether (38) (Table I, Entry 25).** According to procedure B, to a green solution of 5.8 mg (10.1 μmol) of $Pd(dba)_2$, 4.0 mg (10.1 μmol) of dppe, and 125 mg (0.53 mmol) of **2e** was added 1.0 mmol of sodium phenylallyl alcoholate (prepared in a separate flask from 134 mg (1.0 mmol) of phenylallyl alcohol in 2 mL of THF, which was added slowly to 24 mg (1.0 mmol) of pentane-washed sodium hydride in 2 mL of THF), while the reaction mixture turned dark and a precipitate occurred. Aqueous workup, followed by flash chromatography (silica gel, hexane/ether 12:1) afforded 103 mg (97%) of **38** as a colorless oil: IR (film) 3060, 3030, 2990, 2930, 2860, 1450, 1365, 1110, 1080, 970, 750, 695 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) δ 1.09–1.18 (m, 4 H, Cpr-H), 4.14–4.21 (m, 4 H, 1(1′)-H), 5.93–6.08 (m, 1 H, 2-H), 6.33 (dt, 1 H, $^3J$ = 15.9 Hz, $^2J_{1-2}$ = 6.0 Hz, 2′-H), 6.67 (d, 1 H, $^3J$ = 15.9 Hz, 3′-H), 7.22–7.41 (m, 5 H, Ar-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) δ 1.81–2.33 (Cpr-C), 70.36 (C-1), 70.56 (C-1′), 114.78 (C-2), 126.47, 127.02 (C-1‴), 127.61, 128.54, 136.81 (Ar-C); MS (70 eV) *m/z* (%) 200 (1) [$M^+$], 199 (4) [$M^+ - 1$], 169 (29), 155 (50), 129 (51), 117 (100) [$C_8H_5O$]. HRMS calcd for $C_{11}H_{16}O$, *m/z* 200.1201; found, 200.1201.

**Preparation of Acetate 10b from 2e Catalyzed by Palladium(0) (Table I, Entry 26).** A mixture of 50 mg (0.21 mmol) of **2e**, 2.3 mg (4 μmol) of $Pd(dba)_2$, and 1.6 mg (4 μmol) of dppe in 2 mL of THF was stirred at ambient temperature, until it had turned green. Then 61 mg (0.63 mmol) of potassium acetate and 22.6 mg (0.06 mmol) of [18]-crown-6 were added. Aqueous workup after 30 min, followed by flash chromatography (silica gel, hexane/ether 6:1), afforded 21.1 mg (80%) of **10b**.

***N,N*-Bis(2-cyclopropylideneethyl)-*p*-toluenesulfonamide (40) and *N*-(2-Cyclopropylideneethyl)-*p*-toluenesulfonylamide (41) (Table I, Entry 27).** To a solution of 31 mg (26.8 μmol) of $Pd(PPh_3)_4$ in 4 mL of THF was added 111 mg (0.68 mmol) of **2f**, and then after 10 min 1 mL of DMSO, 320 mg (3 mmol) of tosyl amide, and 170 mg (0.88 mmol) of sodium tosyl amide were added. The reaction mixture was stirred for 2 h at ambient temperature, diluted with 15 mL of ether, extracted with saturated $NaHCO_3$ (3 × 5 mL) and saturated NaCl (5 mL), and dried ($MgSO_4$). Removal of the solvents and flash chromatography (silica gel, hexane/ether 4:1 to 1:1) of the residual oil gave 58 mg (62%) of **40** as a white solid, mp 76 °C, and 19 mg (13%) of **41** as a colorless oil.

**40**: IR (KBr) 3060, 2990, 2930, 1600, 1340, 1270, 1165, 900, 810, 745 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) δ 0.89–1.09 (m, 8 H, Cpr-H), 2.43 (s, 3 H, Ar-$CH_3$), 3.94 (d, 4 H, $^3J$ = 6.6 Hz, 1(1′)-H), 5.59–5.68 (m, 2 H, 2(2′)-H), 7.29 (d, 2 H, $^3J$ = 8.1 Hz, Ar-H), 7.46 (d, 2 H, $^3J$ = 8.1 Hz, Ar-H); $^{13}C$ NMR (50.3 MHz, $CDCl_3$) δ 1.74, 2.45 (Cpr-C), 21.51 (Ar-C), 48.33 (C-1(1′)), 113.11 (C-2(2′)), 126.53 (C-1″(1‴)), 127.15 (Ar-$C_{ortho}$), 129.50 (Ar-$C_{meta}$), 137.73 (Ar-$C_{para}$), 142.92 (Ar-C1); MS (70 eV) *m/z* (%) 303 (4) [$M^+$], 250 (5) [$M^+ - C_4H_5$], 155 (39), 91 (100) [$C_7H_7$]. Anal. Calcd for $C_{17}H_{21}NO_2S$ (303.4): C, 67.29; H, 6.98; S, 10.57. Found: C, 67.17; H, 6.90; S, 10.65.

**41**: $^1H$ NMR (200 MHz, $CDCl_3$) δ 1.02 (m, 4 H, Cpr-H), 1.43 (s, 3 H, Ar-$CH_3$), 3.66–3.76 (m, 2 H, 1-H), 4.52 (t, 1 H, $^3J$ = 4.7 Hz, N-H), 5.64–5.72 (m, 1 H, 2-H), 7.3 (d, 2 H, $^3J$ = 8.1 Hz, Ar-H), 7.76 (d, 2 H, $^3J$ = 8.1 Hz, Ar-H).

***N*-(2-Cyclopropylideneethyl)phthalimide (42) (Table I, Entry 28).** To a green solution of 300 mg (1.26 mmol) of **2e** and 84 mg (72 μmol) of $Pd(PPh_3)_4$ in 6 mL of THF was added 275 mg (2.9 mmol) of potassium phthalimide and 45 mg (0.13 mmol) of dibenzo-[18]-crown-6. After the suspension had been stirred under reflux for 2 h, the solvent was evaporated and the residue dissolved in hexane (100 mL), filtered, and evaporated. Recrystallization from 5 mL of hexane gave 176 mg (65%) of **42**: mp 82–83 °C; IR (film) 3040, 3010, 2980, 1780 (C=O), 1420, 1280, 1180, 985, 780 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) δ 0.92–1.03 (m, 4 H, Cpr-H), 4.20–4.43 (m, 2 H, $^3J$ = 5 Hz), 5.76–5.90 (m, 1 H, 2′-H), 7.49–7.71 (m, 2 H, Ar-H), 7.76–7.83 (m, 2 H, Ar-H); $^{13}C$ NMR (50.3 MHz, $CDCl_3$) δ 1.03, 1.75 (Cpr-C), 32.83 (C-1′), 111.87 (C-2′), 123.23, 125.49 (C-1″), 132.26 (C-2a(6a)), 133.89, 168.17 (CO-N); MS (70 eV) *m/z* (%) 213 (33) [$M^+$], 198 (19), 173 (100) [$M^+ - Cpr$]. Anal. Calcd for $C_{13}H_{11}NO_2$ (213.2): C, 77.23; H, 5.20. Found: C, 73.29; H, 5.34.

**2-Cyclopropylideneethanal (39) (Scheme IV). (a) By Swern Oxidation.** A solution of 3.40 mL of DMSO in 1 mL of $CH_2Cl_2$ was slowly added at −60 °C to a stirred solution of 0.2 mL (2.16 mmol) of oxalyl chloride in 5 mL of $CH_2Cl_2$. After 2 min, a solution of 140 mg (1.67 mmol) of **10a** in 3 mL of $CH_2Cl_2$ was added dropwise within 15 min, and the mixture was stirred at −60 °C for 15 min. Then 1.74 mL (12.5 mmol) of triethylamine was added and the mixture was allowed to reach room temperature. Water (5 mL) was added and the aqueous layer extracted with $CH_2Cl_2$ (2 × 20 mL). The combined organic layers were washed with saturated NaCl (2 × 20 mL), dried ($Na_2SO_4$), and con-

centrated in vacuo. Ether (20 mL) was added to the residue, which was filtered through Celite and concentrated to give 60 mg (44%) of crude aldehyde **39**,[43] contaminated by two inseparable unknown products.

**(b) By $MnO_2$ Oxidation.** To a stirred suspension of $MnO_2$ (3 g) in 10 mL of $CH_2Cl_2$ was added at ambient temperature a solution of 100 mg (1.2 mmol) of **10a** in 2 mL of $CH_2Cl_2$. After 1 h, the mixture was filtered and the solvent evaporated to give 50 mg (51%) of crude **39**, identified by its spectroscopic data as reported.[43]

**2-Cyclopropylideneethylamine Hydrochloride (43) (Scheme V).** To a solution of 60 mg (0.28 mmol) of **42** in 2.5 mL of 2-propanol and 0.4 mL of water was added 530 mg (1.4 mmol) of $NaBH_4$. After the mixture was stirred for 24 h at ambient temperature, 300 μL of acetic acid was added carefully, and the resulting mixture was heated at 80 °C for 2 h. The reaction mixture was partitioned between water (6 mL) and ether (2 mL), the aqueous phase was washed with ether (2 × 2 mL), treated with 10% NaOH, and extracted with ether (3 × 5 mL), and the combined ethereal phases were extracted with 10% HCl (4 × 5 mL). Evaporation of the water yielded pure hydrochloride **43**, which was recrystallized from methanol/water (8:1) to yield 32 mg (95%) of **43** as a white solid: mp 154 °C; IR (KBr) 3425, 1610, 1560, 1380, 1280, 1120, 710 $cm^{-1}$; $^1H$ NMR (250 MHz, $D_2O$) δ 1.04 (bs, 4 H, Cpr-H), 3.61 (d, 2 H, 1-H), 5.74–5.83 (m, 1 H, 2-H); $^{13}C$ NMR (50.3 MHz, $D_2O$) δ 1.79, 1.95 (Cpr-C), 40.76 (C-1), 109.28 (C-2′), 126.32 (C-1′).

**Dimethyl 2-(2-Cyclopropylidenepropyl)malonate (44) (Table I, Entry 29).** According to procedure B, reaction of 126 mg (0.50 mmol) of **3e** with 0.65 mmol of sodium dimethyl malonate for 1 h gave, after flash chromatography (silica gel, hexane/ether 4:1), 86 mg (81%) of **44** as a colorless oil: IR (film) 2980, 2960, 2900, 1770 (C=O), 1420, 1375, 1280, 1200, 1180, 1025, 1010 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) δ 0.75–0.98 (m, 2 H, Cpr-H), 0.98–1.10 (m, 2 H, Cpr-H), 1.81 (m, 3 H, 3′-H), 2.52–2.59 (m, 2 H, $^3J$ = 7.1 Hz, 1′-H), 3.72 (s, 6 H, $CO_2CH_3$), 3.79 (t, 1 H, $^3J$ = 7.1 Hz, 2-H); $^{13}C$ NMR (50 MHz, $CDCl_3$) δ 1.30, 3.31 (Cpr-C), 20.93 (C-3′), 35.53 (C-1′), 49.99 (C-2), 52.44 ($CO_2CH_3$), 117.51 (C-2′), 120.36 (C-1″), 169.82 ($CO_2CH_3$); MS (70 eV) *m/z* (%) 212 (3) [$M^+$], 180 (5), 152 (33) [$M^+ - CO_2Me - H$], 121 (56), 93 (100) [$M^+ - 2CO_2Me - H$].

**Dimethyl 2-(2-Cyclopropylidene-1-methyl)ethylmalonate (45-Me) (Entries 30 and 31). (a) With dppe.** According to procedure B, reaction of 120 mg (0.50 mmol) of **4e** with 0.60 mmol of sodium dimethyl malonate for 2 h gave after flash chromatography (silica gel, hexane/ether 5:1) 90 mg (89%) of **45-Me** as a colorless oil.

**(b) With (*S*)-(−)-BINAP.** According to procedure B, the reaction of 60 mg (0.25 mmol) of **4e**, 2.7 mg (4.8 μmol) of $Pd(dba)_2$, and 3.0 mg (4.8 μmol) of (*S*)-BINAP with 0.33 mmol of sodium dimethyl malonate for 4 h gave after flash chromatography (silica gel, hexane/ether 4:1) 44 mg (86%) of **45-Me** (50% ee, determined from its 250 MHz $^1H$ NMR spectra recorded in the presence of a chiral shift reagent ($Eu(hfc)_3$ and comparatively to racemic **45-Me**): IR (film) 2980, 2950, 1760 (C=O), 1740 (C=O), 1435, 1250, 1195, 1150, 1020 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) δ 0.96–1.07 (m, 4 H, Cpr-H), 1.12 (d, 3 H, $^3J$ = 8.8 Hz, $CH_3$), 3.02–3.26 (m, 1 H, 2′-H), 3.40 (d, 1 H, $^3J$ = 9.2 Hz, 2-H), 3.65 (s, 3 H, $CO_2CH_3$), 3.73 (s, 3 H, $CO_2CH_3$), 5.67–5.76 (m, 1 H, 3′-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) δ 1.76, 2.41 (Cpr-C), 18.32 (C-1), 36.83 (C-2′), 52.21, 52.30 ($CO_2CH_3$), 57.57 (C-2), 119.37 (C-3′), 122.85 (C-1‴), 168.88, 168.97 ($CO_2CH_3$); MS (70 eV) *m/z* (%) 212 (2) [$M^+$], 197 (5) [$M^+ - CH_3$], 153 (19), 121 (17), 93 (100). Anal. Calcd for $C_{11}H_{16}O_4$ (212.2): C, 62.25; H, 7.60. Found: C, 62.29; H, 7.56.

**Dimethyl 2-(2-Cyclopropylidene-1-phenyl)ethylmalonate (45-Ph) (Table I, Entries 32 and 33). (a) With dppe**: According to procedure D, the reaction of 126 mg (0.40 mmol) of **5e** with 0.60 mmol of sodium dimethyl malonate for 2 h gave after flash chromatography (silica gel, hexane/ether 4:1) 102 mg (94%) of **45-Ph** as a colorless oil.

**(b) With (*S*)-(−)-BINAP.** According to procedure B, reaction of 39 mg (0.12 mmol) of **5e**, 1.4 mg (2.4 μmol) of $Pd(dba)_2$, and 1.5 mg (2.4 μmol) of (*S*)-BINAP with 0.23 mmol of sodium dimethyl malonate for 4 h gave after flash chromatography (silica gel, hexane/ether 4:1) 30 mg (92%) of **45-Ph** (52% ee determined from its 250-MHz $^1H$ NMR spectra recorded in the presence of a chiral shift reagent ($Eu(hfc)_3$ and comparatively to racemic **45-Ph**)): IR (film) 3030, 2980, 2960, 1760 (C=O), 1740 (C=O), 1435, 1320, 1260, 1160, 700 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) δ 0.95–1.14 (m, 4 H, Cpr-H), 3.40 (s, 3 H, $CO_2CH_3$), 3.64 (s, 3 H, $CO_2CH_3$), 3.93 (d, 1 H, $^3J$ = 11.2 Hz, 2-H), 4.25 (dd, 1 H, $^3J$ = 11.2 Hz, $^3J$ = 11.4 Hz, 1′-H), 5.86–5.98 (m, 1 H, 2′-H), 7.07–7.29 (m, 5 H, Ar-H); $^{13}C$ NMR (62.9 MHz, $CDCl_3$) δ 2.26, 2.66 (Cpr-C), 48.34 (C-1′), 52.44, 52.28 ($CO_2CH_3$), 57.37 (C-2), 117.85 (C-2′), 124.04 (C-1″), 126.9 (C-4‴), 127.29 (C-2‴), 128.48 (C-3‴), 140.81 (C-1‴), 168.12, 168.42 ($CO_2CH_3$); MS (70 eV) *m/z* (%) 274 (2) [$M^+$], 182 (22), 155 (24), 142 (100). HRMS calcd for $C_{16}H_{18}O_4$, *m/z* 274.1205; found, 274.1204.

**Dimethyl 1-(1-Isobutylidenecyclopropyl)malonate (46) and Dimethyl 2-(Cyclopropylidene-*tert*-butyl)malonate (47) (Table I, Entries 34 and 36). (a).** According to procedure B, reaction of 55 mg (0.32 mmol) of **6b** with 0.64 mmol of sodium dimethyl malonate for 14 h under reflux gave after flash chromatography (silica gel, hexane/ether 5:1) 24 mg (33%) of **46** and **47** (ratio 25:75 by GC), which were separated by preparative GC.

**(b).** According to procedure B, reaction of 46 mg (0.30 mmol) of **11b** with 0.81 mmol of sodium dimethyl malonate for 15 min at ambient temperature gave after flash chromatography (silica gel, hexane/ether 5:1) 57 mg (84%) of **47**.

**(c).** According to procedure B, reaction of 30 mg (0.18 mmol) of **11b** with 0.5 mmol of sodium dimethyl malonate for 5 min at 65 °C gave after flash chromatography (silica gel, hexane/ether 5:1) 28 mg (69%) of **47**.

**46**: $^1H$ NMR (250 MHz, $CDCl_3$) δ 0.64–0.71 (m, 2 H, Cpr-H), 0.76–0.83 (m, 2 H, Cpr-H), 1.67 (d, 3 H, $^4J$ = 2.2 Hz, $CH_3$), 1.71 (d, 3 H, $^4J$ = 1.8 Hz, $CH_3$), 3.08 (s, 1 H, 2-H), 3.75 (s, 6 H, $CO_2CH_3$), 5.32 (bs, 2′-H); $^{13}C$ NMR (50.3 MHz, $CDCl_3$) δ 13.21 (Cpr-C), 18.82, 25.52 ($CH_3$), 38.77 (C-1′), 55.89 ($CO_2CH_3$), 59.15 (C-2), 124.63 (C-2′), 120.30 (C-3′), 146.14 (C-3′), 161.70 ($CO_2CH_3$); MS (70 eV) *m/z* (%) 226 (3) [$M^+$], 211 (15) [$M^+ - CH_3$], 167 (52) [$M^+ - CO_2CH_3$], 107 (46) [$M^+ - 2CO_2CH_3 - H$], 79 (100) [$C_6H_7$]. HRMS calcd for $C_{12}H_{18}O_4$, *m/z* 226.1205; found, 226.1205.

**47**: IR (film) 3060, 2970, 1740 (C=O), 1440, 1270, 1145, 1140 $cm^{-1}$; $^1H$ NMR (200 MHz, $CDCl_3$) δ 0.88–1.00 (2 H, Cpr-H), 1.11–1.22 (m, 2 H, Cpr-H), 1.32 (s, 6 H, $CH_3$), 3.49 (s, 1 H, 2-H), 3.69 (s, 6 H, $CO_2CH_3$), 5.89–5.97 (m, 1 H, 3′-H); $^{13}C$ NMR (50.0 MHz, $CDCl_3$) δ 0.20, 3.81 (Cpr-C), 26.03 ($C(CH_3)_2$), 39.54 (C-2′), 51.90 ($CO_2CH_3$), 60.69 (C-2), 120.31 (C-1″), 124.35 (C-3′), 168.49 ($CO_2CH_3$); MS (70 eV) *m/z* (%) 226 (3) [$M^+$], 211 (30) [$M^+ - CH_3$], 167 (35) [$M^+ - CO_2Me$], 162 (34), 151 (23), 135 (70), 107 (10). HRMS calcd for $C_{12}H_{18}O_4$, *m/z* 226.1205; found, 226.1205.

**Reaction of 2e with Phenylzinc Chloride (Table II, Entry 1).** According to procedure B, to a solution of 4.6 mg (8.4 μmol) of $Pd(dba)_2$ and 3.3 mg (8.4 μmol) of dppe and 100 mg (0.42 mmol) of **2e** in 2 mL of THF was added 2 mmol of phenylzinc chloride (prepared in a separate flask from 2 mL of a 1 M solution (2 mmol) of phenyllithium and 2 mL of a 1 M solution (2 mmol) of zinc chloride in THF). The reaction mixture was kept at 40 °C for 4 h. Then 20 mL of ether was added, the solvents were evaporated, and flash chromatography of the residual oil (silica gel, hexane/ether 8:1) yielded 40 mg (66%) of 1-ethenyl-1-phenylcyclopropane (**48**).[50]

**Reaction of 10b with Phenylzinc Chloride (Table II, Entry 2).** To a solution of 11.5 mg (20 μmol) of $Pd(dba)_2$ and 7.9 mg (20 μmol) of dppe and 126 mg (1.0 mmol) of **10b** in 2 mL of THF was added 4 mmol of phenylzinc chloride (prepared as above). The reaction mixture was kept at 40 °C for 4 h. Then 20 mL of ether was added, the solvents were evaporated, and flash chromatography of the residual oil (silica gel, hexane/ether 8:1) yielded 107 mg (75%) of 1-ethenyl-1-phenylcyclopropane (**48**).[50]

**Reduction of 5e by Hydride (Table II, Entry 4).** In accord with procedure B, to a solution of 80 mg (0.25 mmol) of **5e**, 2.9 mg (5 μmol) of $Pd(dba)_2$, and 2.0 mg (5 μmol) of dppe was added 8.4 mg (0.07 mmol) of [15]-crown-5, followed by 25 mg (0.77 mmol) of sodium formate. The reaction mixture was stirred for 48 h at room temperature. Aqueous workup and flash chromatography (silica gel, pentane/ether 7:1) gave 32.4 mg (90%) of a mixture of **49** and **51**[53] (ratio 37:63 according to GC).

**(2-Cyclopropylideneethyl)benzene (49) (Table II, Entries 3–5).** $^1H$ NMR (250 MHz, $CDCl_3$) δ 1.08 (m, 4 H, Cpr-H), 3.53 (d, 2 H, *J* = 7.1 Hz, 1′-H), 5.95 (m, 1 H, 2′-H), 7.20 (m, 5 H, Ar-H); $^{13}C$ NMR (50.0 MHz, $CDCl_3$) δ 1.86, 2.59 (Cpr-C), 38.31 (C-1′), 117.06 (C-2′), 122.91 (C-1″), 125.84, 128.33, 128.51, 141.32 (Ar-C); MS (70 eV) *m/z* (%) 144 (7) [$M^+$], 129 (100), 104 (53), 91 (48), 77 (16), 65 (25).

**Cross Coupling of 5e with *n*-Butylzinc Chloride (Table II, Entry 8).** To a solution of 9.5 mg (16 μmol, 2 mol %) of $Pd(dba)_2$ and 7.6 mg (19 μmol) of dppe in 1 mL of THF was added 100 mg (0.32 mmol) of **5e** in 1 mL of THF. The resulting mixture was stirred at ambient temperature for 10 min, then a solution of 0.32 mmol of *n*-butylzinc chloride (prepared in a separate flask from 0.2 mL of a 1.58 M solution of *n*-butyllithium (0.32 mmol) and 0.32 mL of a 1.0 M solution of zinc chloride (0.32 mmol) in ether) was added. The mixture was heated at reflux for 14 h and cooled to room temperature, 20 mL of ether was added, and the solution was filtered through $Al_2O_3$ (neutral). Evaporation of the solvents and flash chromatography (silica gel, pentane/ether 5:1) of the residual oil gave 4.6 mg (10%) of **48**, 15 mg (30%) of **51**,[53] and 39 mg (60%) of **55**.

**1-*n*-Butyl-1-styrylcyclopropane (55).** IR ($CHCl_3$) 3080, 2980, 2940, 1650, 1625, 1605, 1500, 1450 $cm^{-1}$; $^1H$ NMR (250 MHz, $CDCl_3$) δ 0.67 (m, 4 H, Cpr-H), 0.91 (t, 3 H, *J* = 7 Hz, $CH_3$), 1.40 (calcd for m, 6 H),

6.04 (d, 1 H, $J$ = 16 Hz, 1'-H), 6.28 (d, 1 H, $J$ = 16 Hz, 2'-H), 7.30 (m, 5 H, Ar-H); $^{13}$C NMR (62.9 MHz, $CDCl_3$) $\delta$ 14.15, 14.54, 22.41, 23.01, 29.42, 36.38, 38.33, 123.69, 126.17, 126.55, 128.46, 136.49, 137.95; MS (70 eV) $m/z$ (%) 200 (4) [$M^+$], 143 (100), 103 (2), 77 (6), 57 (2), 43 (1). HRMS calcd for $C_{15}H_{20}$, $m/z$ 200.1564; found, 200.1559.

**1-Acetoxy-1-styrylcyclopropane (5b) (Table II, Entry 9).** According to preparation of **2b**, reaction of 144 mg (1.0 mmol) of **5e** with 3 mmol of KOAc for 14 h in THF at reflux gave after flash chromatography (silica gel, hexane/ether 10:1) 84 mg (45%) of **5b** and 11 mg (7%) of **51**.[53]

**5b.** IR (film) 2965, 1755, 1655, 1600, 1450, 1420, 1260, 1060 cm$^{-1}$; $^1$H NMR (200 MHz, $CDCl_3$) $\delta$ 1.09 (m, 2 H, Cpr-H), 1.18 (m, 2 H, Cpr-H), 2.09 (s, 3 H, $CH_3CO_2$), 6.15 (d, 2 H, $^3J$ = 16 Hz), 6.34 (d, 1 H, $^3J$ = 16 Hz), 7.15–7.34 (m, 5 H, Ar-H); MS (70 eV) $m/z$ (%) 202 (5) [$M^+$], 161 (10), 160 (90), 159 (100) [$M^+ - CH_3CO$], 145 (32), 144 (13), 143 (9), 142 (25) [$M^+ - CH_3COOH$], 131 (66), 128 (11), 127 (14), 118 (15), 117 (23), 103 (61) [$C_6H_5CH{=}CH$], 77 (81) [$C_6H_5$], 43 [$CH_3CO$]. Anal. Calcd for $C_{13}H_{14}O_2$ (202.3): C, 77.20; H, 6.98. Found: C, 77.08; H, 6.98.

**1-Azido-1-ethenylcyclopropane (56) (Table II, Entry 10).** To a green solution of 8.4 mg (14.6 $\mu$mol) of $Pd(dba)_2$, 8.7 mg (32 $\mu$mol) of $PPh_3$, and 106 mg (0.65 mmol) of **2e** in 3 mL of THF were added 87 mg (1.34 mmol) of $NaN_3$ and 16.8 mg (0.14 mmol) of [15]-crown-5, and the mixture was stirred for 12 h at room temperature. Aqueous workup and distillation of the solvents through a 20-cm Vigreux column in vacuo gave the crude azide **56** (99% yield (GC)) which was purified by preparative GC (1.5 m, 20% SE 30, 25 °C): IR (film) 3075, 2975, 2210, 1770, 1660, 1440, 1180, 1120, 745, 700 cm$^{-1}$; $^1$H NMR (250 MHz, $CDCl_3$) $\delta$ 0.86–0.93 (m, 2 H, Cpr-H), 1.09–1.17 (m, 2 H, Cpr-H), 5.14 (dd, 1 H, $^3J$ = 10.0 Hz, $^2J$ = 0.9 Hz, 2'-$H_Z$), 5.57 (dd, 1 H, $^3J$ = 17.1 Hz, $^2J$ = 0.9 Hz, 2'-$H_E$), 5.57 (dd, 1 H, $^3J$ = 17.1 Hz, $^3J$ = 10.0 Hz, 1'-H); $^{13}$C NMR (62.9 MHz, $CDCl_3$) $\delta$ 14.49 (Cpr-C), 46.88 (C-1), 113.34 (C-2'), 137.87 (C-1'); MS (70 eV) $m/z$ (%) 83 (14), 82 (23), 68 (6), 55 (17).

**1-[*N*,*N*-Bis(trimethylsilyl)amino]-1-ethenylcyclopropane (57) (Table II, Entry 11).** To a green solution of 16.8 mg (29.2 $\mu$mol) of $Pd(dba)_2$, 17.4 mg (59.4 $\mu$mol) of $PPh_3$, and 200 mg (1.23 mmol) of **2f** was added 240 mg (2.4 mmol) NaHMDS, and the reaction mixture was stirred for 12 h; aqueous workup and evaporation of the solvent in vacuo gave crude **57** (80% yield (GC)): IR (KBr) 3060, 2990, 2930, 1600, 1340, 1270, 1165, 900, 810, 745 cm$^{-1}$; $^1$H NMR (250 MHz, $CDCl_3$) $\delta$ 0.07 (s, 9 H, $Si(CH_3)_3$), 0.60–0.73 (m, 2 H, Cpr-H), 0.90–1.02 (m, 2 H, Cpr-H), 5.20 (dd, 1 H, $^3J$ = 11.3 Hz, $^2J$ = 0.8 Hz, 2'-$H_Z$), 5.20 (dd, 1 H, $^3J$ = 18.2 Hz, $^2J$ = 0.9 Hz, 2'-$H_E$), 5.55 (dd, 1 H, $^3J$ = 18.2 Hz, $^3J$ = 11.3 Hz, 1'-H).

**Procedure for Alkylation of 1-Alkynylcyclopropyl Chlorides Catalyzed by Palladium(0) (Table III, Entry 2).** To a solution of 28.7 mg (50 $\mu$mol, 5 mol %) of $Pd(dba)_2$ and 20 mg (50 $\mu$mol) of dppe in 1 mL of THF was added 100 mg (1 mmol) of 1-chloro-1-ethynylcyclopropane (**12**) in 2 mL of THF, and the mixture was stirred at room temperature for 10 min. Then a solution of 4 mmol of phenylzinc chloride (prepared in a separate flask from 4 mL of a 1 M solution (4 mmol) of phenyllithium (or phenylmagnesium chloride) and 4 mL of a 1 M solution (4 mmol) of zinc chloride in ether) was added dropwise under argon. The mixture was heated at reflux for 3 h until the chloride **12** had completely disappeared (TLC). Then the mixture was cooled to room temperature, 20 mL of ether was added, and the solution was filtered through neutral alumina. After removal of the solvents in vacuo, chromatography of the residual oil (silica gel, pentane/ether 5:1) gave 25 mg of **65-H**[62] and 63 mg of **66-H**.

**1-Phenyl-1-ethynylcyclopropane (66-H).** IR ($CCl_4$) 3300, 2105, 1600 cm$^{-1}$; $^1$H NMR (250 MHz, $CDCl_3$) $\delta$ 1.22–1.28 (m, 2 H, Cpr-H), 1.44–1.48 (m, 2 H, Cpr-H), 2.12 (s, 1 H, 2'-H), 7.10–7.50 (m, 5 H, Ar-H); MS (70 eV) $m/z$ (%) 142 (80) [$M^+$], 141 (100), 115 (50), 102 (35). HRMS calcd for $C_{11}H_{10}$, $m/z$ 142.0782; found, 142.0791.

**(2-Phenylpropylidene)cyclopropane (65-Me) and 1-Phenyl-1-(1-propynyl)cyclopropane (66-Me) (Table III, Entry 3).** Reaction of 114 mg (1 mmol) of **13** with 4.0 mmol of phenylzinc chloride for 3 h at 65 °C gave after flash chromatography (silica gel, pentane/ether 5:1), 16 mg (70%) of **65-$CH_3$** and 34 mg (34%) of **66-Me**.

**65-Me.** IR ($CCl_4$) 2000, 1600 cm$^{-1}$; $^1$H NMR (250 MHz, $CDCl_3$) $\delta$ 1.61–1.74 (m, 4 H, Cpr-H), 2.18 (m, 3 H, $CH_3$), 7.15–7.51 (m, 5 H, Ar-H); MS (70 eV) $m/z$ (%) 156 (100) [$M^+$], 155 (38), 151 (57), 77 (35). HRMS calcd for $C_{12}H_{12}$, $m/z$ 156.0939; found, 156.0927.

**66-Me.** IR ($CCl_4$) 2160, 1600 cm$^{-1}$; $^1$H NMR (250 MHz, $CDCl_3$) $\delta$ 1.12–1.15 (m, 2 H, Cpr-H), 1.31–1.37 (m, 2 H, Cpr-H), 1.81 (s, 3 H, $CH_3$), 7.15–7.41 (m, 5 H, Ar-H); $^{13}$C NMR (62.9 MHz, $CDCl_3$) $\delta$ 3.5 ($CH_3$), 19.6 (Cpr-C), 29.7 (Cpr-C), 73.5 (C-2'), 83.0 (C-1'), 125–130 (Ar-C), 142 (Ar-C); MS (70 eV) $m/z$ (%) 156 (100) [$M^+$], 155 (58), 141 (84), 128 (44), 115 (55), 77 (43), 76 (31), 51 (30).

**1-Phenyl-1-[1-(trimethylsilyl)ethynyl]cyclopropane (66-TMS) (Table III, Entry 4).** Reaction of 173 mg (1 mmol) of **14** with 4.0 mmol of phenylzinc chloride for 2 h at 65 °C gave after flash chromatography (silica gel, pentane/ether 4:1), 171 mg (80%) of **66-TMS**: IR ($CCl_4$) 2160, 1600 cm$^{-1}$; $^1$H NMR (250 MHz, $CDCl_3$) $\delta$ 0.23 (s, 9 H, $Si(CH_3)_3$), 1.23–1.32 (m, 2 H, Cpr-H), 1.46–1.55 (m, 2 H, Cpr-H), 7.13–7.50 (m, 5 H, Ar-H); $^{13}$C NMR (62.9 MHz, $CDCl_3$) $\delta$ 0.2 ($Si(CH_3)_3$), 16.4 (Cpr-C), 20.7 (Cpr-C), 82.3 and 110.3 (C-2'), 125.2, 125.9, 128.2, and 141.5 (Ar-C); MS (70 eV) $m/z$ (%) 214 (36), 199 (69), 183 (19), 99 (15), 83 (48), 73 (100).

**Alkylation of 2e with Phenylmagnesium Bromide Catalyzed by Nickel(0) (Table II, Entry 12).** A green suspension of 120 mg (0.50 mmol) of tosylate **2e** and 16.5 mg (25 mmol, 5 mol %) of bis(triphenylphosphino)dichloronickel(II)[73] in 1 mL of ether was cooled to −78 °C, and 2.5 mL (1.5 mmol) of a 0.6 M solution of phenylmagnesium bromide in ether was added in one portion, while the mixture turned black. Additional stirring, while the reaction mixture reached room temperature (1 h), and usual workup (as described in the general procedure D) gave, after flash chromatography (silica gel, hexane), a mixture of **48** (84%) and **49** (16%) in 90% yield (GC) contaminated with a small amount of biphenyl.

**Reaction of 2e with Sodium Dimethyl Malonate Catalyzed by Nickel(0).** To a yellow solution of 120 mg (0.5 mmol) of **2e** and 29.6 mg (4.5 $\mu$mol) of bis(triphenylphosphino)dichloronickel(II)[73] in 1 mL of THF kept at 0 °C was added 4.5 $\mu$L of methylmagnesium bromide followed by 120 mg (0.50 mmol) of **2e**, while the mixture turned green. A solution of sodium dimethyl malonate (1.5 mmol) was added and the resulting mixture heated at reflux for 48 h. TLC and $^1$H NMR control showed no reaction products.

**Alkylation of 15 with Methylzinc Chloride Catalyzed by Pailadium(0) (Table III, Entry 5).** To a solution of 18 mg (32 $\mu$mol, 5 mol %) of $Pd(dba)_2$ and 13 mg (50 $\mu$mol) of dppe in 2 mL of THF was added 113 mg (0.64 mmol) of 1-chloro-1-(phenylethynyl)cyclopropane (**15**) in 2 mL of THF, and the mixture was stirred at room temperature for 10 min. Then a solution of 4 mmol of methylzinc chloride (prepared in a separate flask from 0.85 mL of a 3 M solution (2.56 mmol) of methylmagnesium bromide in ether and 2.56 mL of a 1 M solution (2.56 mmol) of zinc chloride in ether) was added dropwise under argon. The mixture was heated at reflux for 14 h until the chloride **14** had completely disappeared (TLC). Then the mixture was cooled to room temperature, 20 mL of ether was added, and the solution was filtered through neutral alumina. After removal of the solvents in vacuo, chromatography of the residual oil (silica gel, hexane) gave 57 mg of **67**[64] and 5 mg of **68**,[63] with analytical data in complete accord with the literature.

**Alkylation of 2e with Sodium Dimethyl Malonate Catalyzed by Mo(CO)$_6$ (Table I, Entry 37).** A solution of 100 mg (0.42 mmol) of tosylate **2e** in 2 mL of toluene containing 11 mg (0.04 mmol) of $Mo(CO)_6$ was stirred under argon at room temperature for 15 min. Then a solution prepared from 94 mg (0.71 mmol) of dimethyl malonate and 160 mL (0.64 mmol) of bis(trimethylsilylacetamide) in 2 mL of toluene was added, and the mixture was refluxed for 5 h, until **2e** had completely disappeared (TLC). Then 20 mL of ether was added to the cooled solution and it was filtered through $Al_2O_3$ (act. V), dried ($MgSO_4$), and concentrated in vacuo. Chromatography of the residue (silica gel, hexane/ether 8:2) gave 58 mg (70%) of **16**, 8 mg (10%) of **70**, and 11 mg (10%) of **17**.

**Dimethyl 2-(1-Vinylcyclopropyl)malonate (70).** IR ($CCl_4$) 2980, 1730, 1440, 1370, 1015 cm$^{-1}$; $^1$H NMR (200 MHz, $CDCl_3$) $\delta$ 0.8–0.9 (m, 4 H, Cpr-H), 3.16 (s, 1 H, 2-H), 3.75 (s, 6 H, $CO_2CH_3$), 4.9 (m, 2 H, $J$ = 16.8 and 9.9 Hz, 2''-H), 6.1 (dd, 1 H, $J$ = 17 and 10 Hz, 1''-H); MS (70 eV) $m/z$ 139 (100) [$M^+ - CO_2CH_3$], 107 (33), 79 (82), 77 (32), 59 (28). Anal. Calcd for $C_{10}H_{14}O_4$ (198.2): C, 60.59; H, 7.12. Found: C, 60.45; H, 7.22.

**Alkylation of 8c with Methylmagnesium Bromide Catalyzed by Cu(I) (Table III, Entry 7).** To a solution of 108 mg (0.50 mmol) of **8c** in 2 mL of ether were added 4.75 mg (0.025 mmol, 5 mol %) of CuI and 12.45 $\mu$L (0.05 mmol, 10 mol %) tributyl phosphite. The mixture was cooled to −78 °C and 333 $\mu$L (1.0 mmol) of a 3.0 M solution of methylmagnesium bromide was added. After the reaction mixture had warmed up to room temperature (2 h), it was hydrolyzed with 1 mL of a mixture of $NH_4OH$ and $NH_4Cl$ (1:4). The aqueous phase was extracted with ether (2 × 5 mL) and the combined organic phases were dried ($Na_2SO_4$) and concentrated in vacuo. Flash chromatography (silica gel, hexane/ether 93:7) gave 11 mg (15%) of phenylethynylcyclopropane **67**,[64] 7 mg (9%) of **65-Me**, 26 mg (34%) of **68**,[63] and 14 mg (18%) of **8a**.

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# Diastereofacial Selectivity in Reactions of Substituted Cyclohexyl Radicals. An Experimental and Theoretical Study

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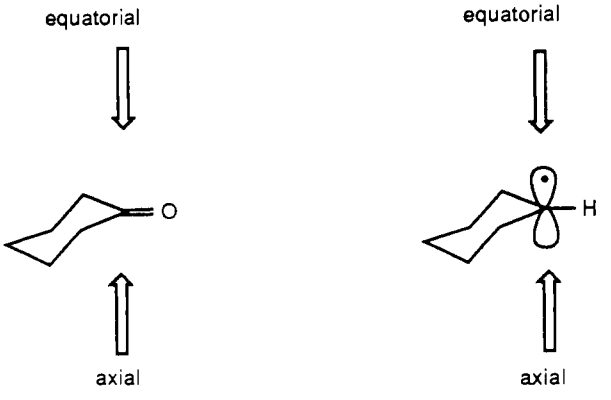
**Abstract:** The diastereofacial selectivity in reactions of a series of alkyl-substituted cyclohexyl radicals has been investigated. In additions of cyclohexyl radicals to alkenes, it has been found that only substituents bound at the olefinic center being attacked by the radical influence the equatorial–axial selectivity. Substituents bound to the radical center or axial substituents $\beta$ to the radical center lead to increased axial attack. Equatorial $\beta$-substituents or axial $\gamma$-substituents increase the amount of equatorial attack. The same trends are observed for halogen and hydrogen abstraction reactions; the amount of axial reaction product is usually somewhat higher than in the addition reactions. The stereoselectivities can be explained with steric and torsional effects very similar to those suggested for nucleophilic addition reactions to cyclohexanones. A MM2 force field has been parameterized to gain further insight into the stereochemistry of the reaction.

## Introduction

Substituent effects on the stereoselectivities of addition reactions to cyclic ketones have been investigated by several groups, and a number of models have been developed to rationalize the observed results.[1] For the majority of the systems studied so far the torsional strain transition-state model[2] can explain the stereochemical outcome of the reactions, even though the effects of remote functionalization by polar groups are still intensely discussed.[1,3]




Cyclic radicals are closely related to ketones topologically but have been studied much less.[4a] The largest body of information was obtained from carbohydrate radicals in addition and atom abstraction reactions.[4a,b] It was established that equatorial substituents adjacent to the radical center ($\beta$-substituents) lead to increased equatorial product formation, whereas axial substitution enhances the formation of axial products. The influence of remote functional groups on the diastereoselectivity through electronic effects has been investigated just recently.[4c] Another stereoelectronic effect was found to be of major importance in carbohydrates bearing the radical center at C-1. In these systems the ring oxygen atom adjacent to the radical center leads to predominantly axial attack.[4a,b]

However, the detailed analysis of substituent effects is complicated by the large number of substituents present in carbohydrates. We therefore decided to study the effects of ring substitution by investigating the reactions of mono- and disubstituted cyclohexyl radicals.

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