of Southern Methodist University for Lazenbee Postdoctoral Fellowships to M.N.R. and H.P. and Southern Methodist University for a teaching assistantship to R.Y.C. We also thank Dr. F. Dinnino and Dr. P. J. Reider (Merck, Sharp, and Dohme) for helpful discussions and Dr. M. Ohno (University of Tokyo) for providing us with copies of his spectra (corresponding to our compounds **26** and **27**).

Supplementary Material Available: Tables of bond lengths and angles, a list of anisotropic temperature factors for the non-hydrogen atoms, atomic coordinates, and crystal structure data (5 pages). Ordering information is given on any current masthead page.

Studies Related to the Robinson Transposition Reaction[1]

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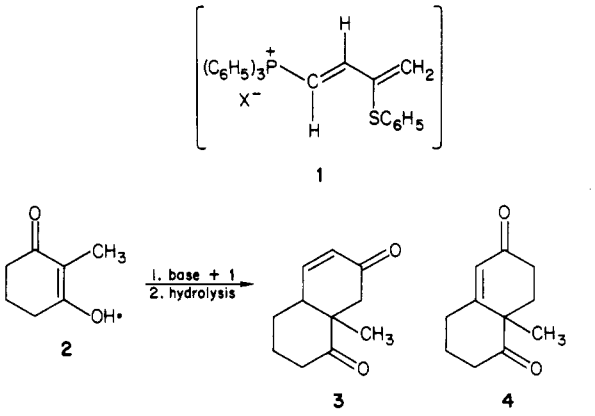
The formation and reactivity of 1,4-dichloro-2-(thio-substituted)-2-butenes is explored, leading to a new bis(phosphonium) salt, **18**. **18** may be used as a reagent to effect a functionalized four-carbon annulation sequence, analogous to the well-known Robinson annulation, but yielding enones that are transposed relative to the standard regiochemistry. Some mechanistic studies on the formation of **18** are described, along with trapping studies during the annulation process and various hydrolysis conditions for the resulting dienyl sulfides. Extensive use is made of ^{13}C and ^{31}P NMR and high-field ^{1}H NMR.

In our efforts to develop synthetic strategies applicable to quassinoid syntheses,[1,2] a reagent, **1**, was conceived which could be used to effect a four-carbon annulation reaction, yielding, after hydrolysis, an enone similar to the result of the widely used Robinson annulation reaction,[5] but transposed regiochemically, as shown in Scheme I. The desired product (**3**) from **1** and 2-methyl-1,3-cyclohexanedione (**2**) would resemble the well-known Wieland–Miescher ketone **4**, and indeed could conceivably be made from it using one of many known carbonyl transposition sequences.[4] Furthermore, the idea of a 1,4-nucleophilic addition to a dienylphosphonium salt is not new, but was demonstrated by Buchi and Pawlak[3a] and Fuchs[3b] several years ago. Martin and Desai[6] used (2-ethoxy-1,3-pentadienyl)triphenylphosphonium iodide to presumably generate unstable masked enones that were directly hydrolyzed to methyl-substituted enones with the standard Robinson[5] regiochemistry. Other reactions leading to ylides, via nucleophilic addition to vinylphosphonium salts, and cyclopropyl- and cyclobutylphosphonium salts have been used to form inter- and intramolecular products.[8] These reactions complement the usual way of generating an ylide: deprotonation of an adjacent carbon. Darling et al.[9] obtained products resulting from the conjugate addition of enolates to butadienylphosphonates, but these

Scheme I



adducts failed to undergo the intramolecular Wadsworth–Emmons[10] reaction. It is known that such reactions require an additional electron-withdrawing substituent to be successful.[11]

We have successfully produced a reagent which nicely fulfills the requirements of the Robinson transposition reaction.[12a] The reactions which are described are clean and can confidently be performed on a laboratory scale. The application of this strategy to the synthesis of bruceantin or other quassinoid compounds has not proven feasible, so alternate chemistry, ironically enough utilizing a standard Robinson sequence, was developed.[12b]

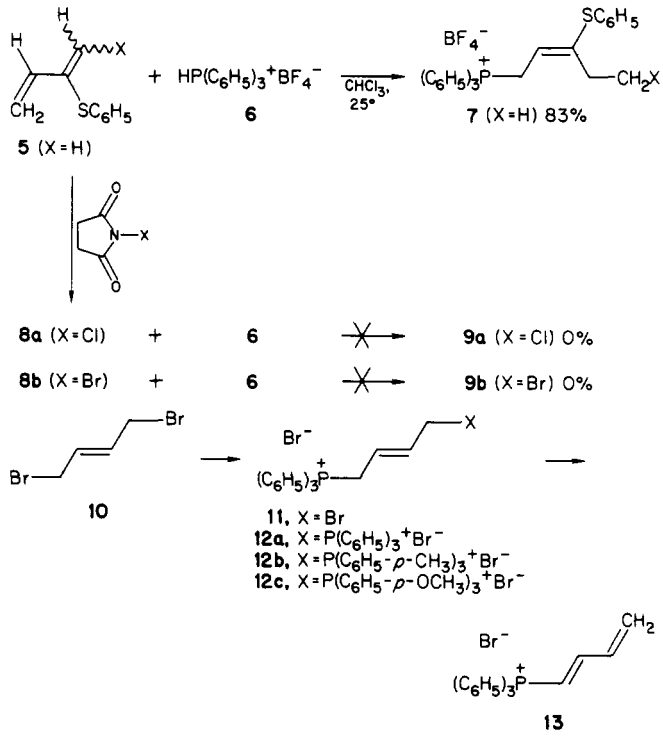
Results and Discussion

The initial attempt at preparation of reagent **1** was based upon the previously observed reaction of 2-thiophenylbutadiene[7a] (**5**) with triphenylphosphonium tetrafluoro-

(1) Bruceantin Support Studies. 8. For previous papers in this series see: Suryawanshi, S. N.; Swenson, C. J.; Jorgensen, W. L.; Fuchs, P. L. *Tetrahedron Lett.* **1984**, *25*, 1859.
(2) (a) Kupchan, S. M.; Britton, R. W.; Ziegler, M. F.; Siegel, C. W. *J. Org. Chem.* **1973**, *38*, 178. (b) Kupchan, S. M.; Britton, R. W.; Lacadie, J. A.; Ziegler, M. F.; Siegel, C. W. *J. Org. Chem.* **1975**, *40*, 648. (c) For studies directed toward the synthesis of Bruceantin and other quassinoids, see: footnote 3 in reference 1.
(3) (a) Büchi, G.; Pawlak, M. *J. Org. Chem.* **1975**, *40*, 100. (b) Fuchs, P. L. *Tetrahedron Lett.* **1974**, 4055. (c) McDonald, R. N.; Campbell, T. W. *J. Org. Chem.* **1959**, *24*, 1969.
(4) Morris, D. G. *Chem. Soc. Rev.* **1983**, 397.
(5) Gawley, R. E. *Synthesis* **1976**, 777. Jung, M. E. *Tetrahedron* **1976**, *32*, 3.
(6) Martin, S. F.; Desai, S. R. *J. Org. Chem.* **1978**, *43*, 4673.
(7) (a) Hopkins, P. B.; Fuchs, P. L. *J. Org. Chem.* **1978**, *43*, 1208. (b) Clark, D. A.; Fuchs, P. L. *Synthesis* **1977**, 628.
(8) Becker, K. B. *Tetrahedron* **1980**, *36*, 1717.
(9) Darling, S. D.; Muralidharan, F. N.; Muralidharan, V. B. *Tetrahedron Lett.* **1979**, 2757.
(10) Wadsworth, W. S.; Emmons, W. D. *J. Am. Chem. Soc.* **1961**, *83*, 1733.
(11) Boutagy, J.; Thomas, R. *Chem. Rev.* **1974**, *74*, 87.
(12) (a) Pariza, R. J.; Fuchs, P. L. *J. Org. Chem.* **1983**, *48*, 2304. (b) Pariza, R. J.; Fuchs, P. L. *Ibid*, 2306.
(13) Trost, B. M.; Ziman, S. D. *J. Org. Chem.* **1973**, *38*, 933.
(14) Smit, W. A.; Zefirov, N. S.; Bodrikov, I. V.; Krimer, M. Z. *Acc. Chem. Res.* **1979**, *12*, 282.

0022-3263/85/1950-4252$01.50/0

Scheme II

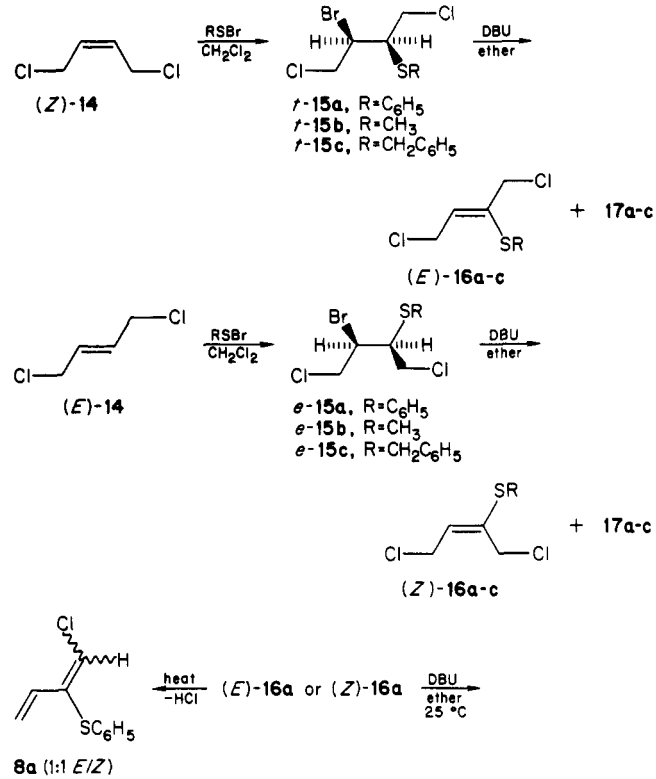


borate[7b] (**6**) to produce (thioallyl)phosphonium salt **7** in 83% yield. Reaction of **5** with NCS or NBS in methylene chloride smoothly afforded the 1-halodienes **8a** and **8b**[15] as a 1:1 mixture of *E* and *Z* isomers. Unfortunately, **8a** and **8b** were virtually unreactive with reagent **6**, thus precluding easy access to phosphonium salts **9a,b**.[15] Scheme II also shows the methods used by Büchi[3a] and Fuchs[3b] to produce the unsubstituted reagent **13**. These routes suggested that a hitherto unknown, appropriately substituted 1,4-dihalo-2-butene might undergo reaction with triphenylphosphine to yield a precursor to the desired reagent.

Chemistry of the Intermediates. In order to utilize a strategy involving a halosulfenylation/dehydrohalogenation sequence,[7a] it seemed desirable to eliminate HBr from an otherwise chlorinated molecule, as opposed to other chloro/bromo permutations. Indeed, simply mixing equivalent amounts of molecular bromine and diphenyl disulfide in CH_2Cl_2 generates the desired bromosulfenylating reagent.[13] When either (*E*)- ((*E*)-**14**) or (*Z*)-1,4-dichloro-2-butene ((*Z*)-**14**) is added to this solution, a rapid and nearly quantitative reaction takes place.[14] The reaction is faster with the *Z* isomer, and the subsequent elimination of HBr proceeds more readily from the threo diastereomer, *t*-**15**. This behavior was also found with the *t*-**15b,c**/*e*-**15b,c** to (*E*)-**16b,c**/(*Z*)-**16b,c** reactions (Scheme III).

The ^1H NMR spectra (see Tables I, II[15]) of these trihalobutane isomers are complex, and indicate that quite different rotamer populations are present. The spectra show that there is considerable similarity between the families of phenylthio, methylthio, and benzylthio erythro and threo diastereomers. The ^1H NMR data show a small coupling between the methines in the two threo examples (ca. 1.9 Hz) and a larger coupling in the erythro examples (ca. 7.6 Hz). This indicates a somewhat larger dihedral angle for the erythro compounds, which is qualitatively in keeping with the expected rotamer populations. The ^{13}C NMR data (see Table 3)[15] is also consistent: the threo isomers show significant shielding of the backbone carbons, which can be accounted for by gauche butane interactions.[16]

Scheme III



The elimination of HBr from *e*-**15a**, *e*-**15b**, *e*-**15c** to yield (*Z*)-**16a**, (*Z*)-**16b**, (*Z*)-**16c** was conducted in 65, 88, and 67% yields, respectively, with a considerable amount of a diene formed, which was identified as **17a** in the phenylthio case. This substituted diene was also seen as a contaminant in the *t*-**15a**, *t*-**15b**, *t*-**15c** dehydrohalogenations yielding (*E*)-**16a**, (*E*)-**16b**, (*E*)-**16c** in 85, 93, and 97% yields, respectively, but far less diene formed from the threo trihalides. The identity of **17a** was somewhat difficult to determine due to the coincidence of the two vinyl protons (H_a, H_b) in the ^1H NMR spectra when run in $CDCl_3$. When benzene-*d* was used as solvent, a clear AB pattern was seen with a 13-Hz coupling. This elimination pattern is similar to that found by Bridges[17] with 1,2,4-trihalo-3-thiophenyl-but-2-enes. It is interesting that attempted distillation of (*E*)- or (*Z*)-**16a** led to HCl loss, resulting in the formation of a mixture of 1-chloro-2-(phenylthio)-1,3-butadienes, **8a**.

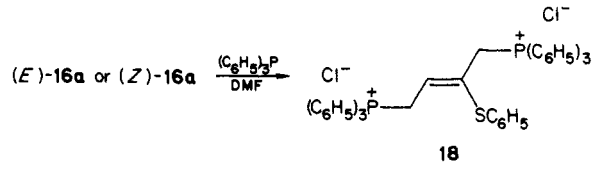
The regiochemical control in these elimination reactions is noteworthy. Apparently the base-catalyzed (DBU) reaction is occurring by an E2 pathway with deprotonation occurring specifically at the C-4 methylene aided by the inductive properties of the vinyl sulfide moiety. The

(15) These Tables can be found in the Supplementary Material.

(16) Levy, G. C.; Nelson, G. L. "Carbon-13 Nuclear Magnetic Resonance for Organic Chemists"; Wiley: New York, 1972.

(17) Bridges, A. J.; Fisher, J. W. *Tetrahedron Lett.* **1983**, *24*, 445, 447.

Scheme IV



thermal elimination would appear to be best accommodated by an E1 mechanism, sulfur assistance to ionization of the C-4 chloride at the elevated temperatures producing a vinyl thionium ion capable of yielding diene **8a** after proton loss from C-1.

There are similarities in the ^{13}C and ^{1}H NMR data (see Table 4)[15] for the 4-dichloro-2-substituted-2-butenes (**16**). The *Z* isomers exhibit an upfield shift of the vinyl proton and a larger coupling constant. Two of the *E* isomers show long-range coupling at the vinyl proton, as does **27**, which also has a trans relationship between the methylenes. The *Z* isomers also show the expected shielding due to γ gauche interactions.[16] Samples of the methylthio- or benzylthio-substituted butenes tended to slowly isomerize in $CDCl_3$ at room temperature to what appeared to be 1,4-dichloro-2-substituted-1-butenes. Such instability was not seen in the phenylthio derivatives, and for that reason they were used almost exclusively in the subsequent studies.

Synthesis of 18. When *either* (*E*)-**16a** *or* (*Z*)-**16a** was allowed to react with excess triphenylphosphine, in degassed DMF or acetone, the same crystalline product **18** was obtained (Scheme IV). The yield and purity were greater for the reaction with (*E*)-**16a**, so it was the isomer generally used. Since the proton spectrum was complicated by ^{31}P couplings and overlapping multiplets and a satisfactory elemental analysis could not be obtained on the chloride salt, the true identity of this product initially proved problematical. A proton-decoupled ^{31}P NMR showed a clear AB pattern indicative of two phosphorus atoms in the same molecule. To directly verify this hypothesis (4-bromo-2-buten-1-yl)triphenylphosphonium bromide (**11**) was reacted with tri-*p*-tolylphosphine as well as tris-(*p*-methoxyphenyl)phosphine, yielding **12b** and **12c**, respectively (Scheme II). These salts also showed an AB pattern in the ^{31}P NMR, indicating that the two phosphorus atoms in the molecule were not identical, similar to the case of **18**. When **18** as the chloride salt was converted to the fluoroborate salt, a satisfactory combustion analysis was obtained for all elements present, and a 470-MHz ^{1}H NMR conclusively showed the product to be **18**. The stereochemistry about the double bond cannot unequivocally be assigned with available information, however.[7b] Scheme IV shows the best route to **18**, which is a substituted variant of Buchi's[3a] salt **12a**, rather than an analogue of either of the salts (**11**, **13**) produced by Fuchs,[3b] which we originally expected to obtain. In fact, even with less than 1 equiv of triphenylphosphine only **18** is isolated, an observation which merited some further mechanistic investigation.

If the formation of **18** were simply two consecutive S_N2 reactions, one could reasonably expect to isolate either a monophosphonium salt or surely two different products, depending on whether (*E*)-**16a** or (*Z*)-**16a** was used. Since this is not the case, several experiments were conducted (Scheme V). When (1,3-butadienyl-1-triphenyl)-phosphonium bromide[3b] was treated with triphenylphosphonium tetrafluoroborate (**6**),[2b] a new phosphonium salt was obtained, with a ^{31}P NMR signal at 21.56 ppm. This value is very close to that of Büchi's[3a] dibromide salt **12a**, which comes at 21.71 ppm. Furthermore, when **12a** is prepared according to the Büchi citation[3c] and an

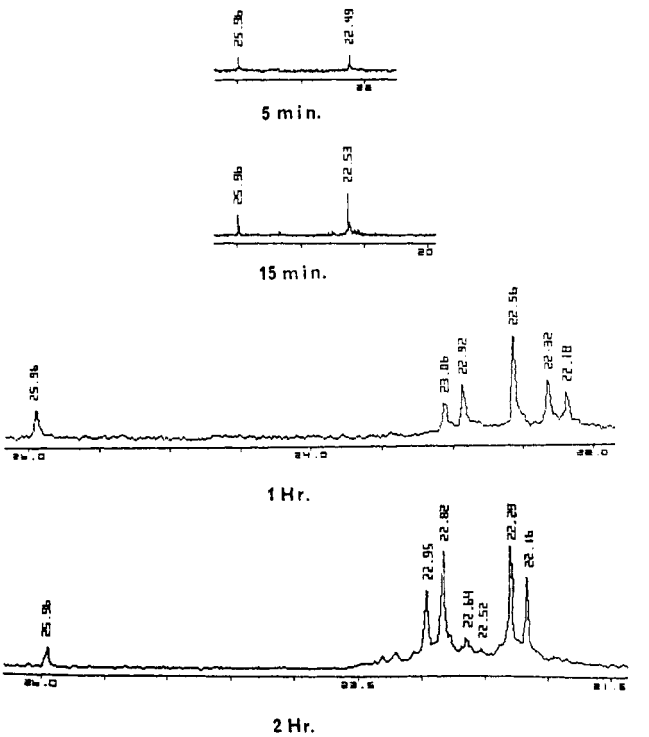
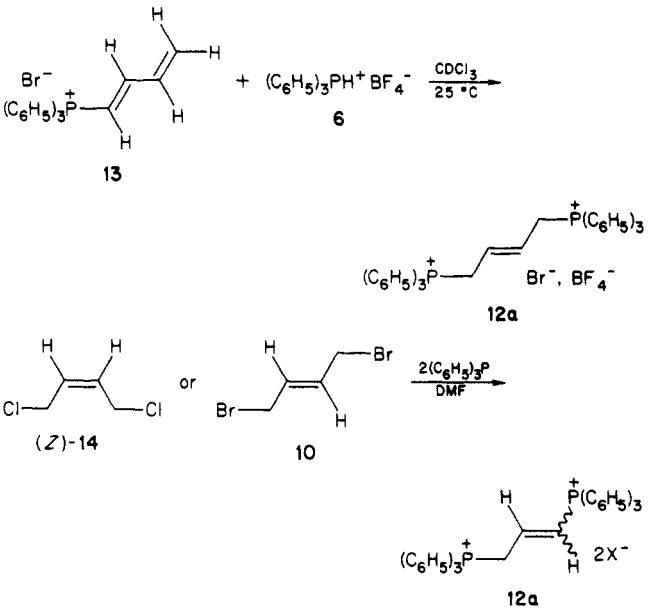


Figure 1. ^{31}P NMR spectra of the formation of **18**. Chemical shifts are in ppm, with $(C_6H_5)_3PO$ at 25.96.

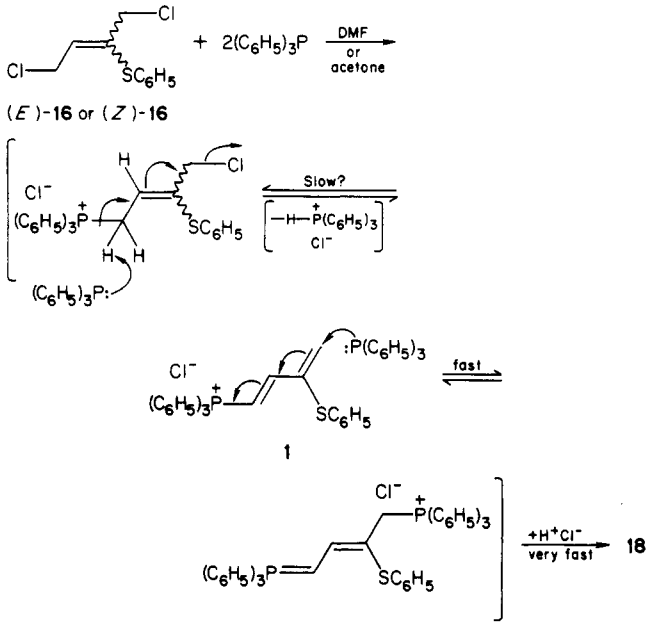
Scheme V



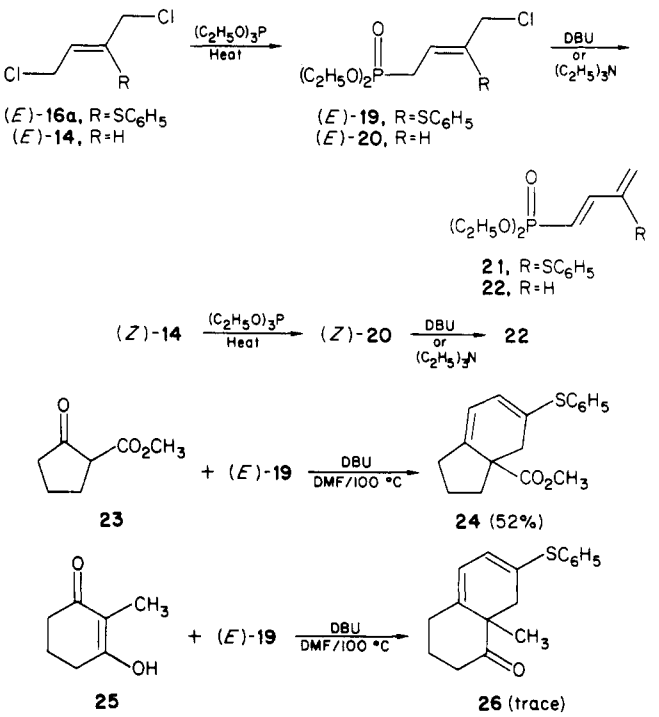
analogous preparation is conducted with (*Z*)-1,4-dichloro-2-butene (*Z*)-**14**, the dichloride salt, which should have had a *Z* geometry, *has a set of NMR spectra essentially identical with that of* **12a** (^{1}H, ^{13}C, ^{31}P). When equimolar amounts of the two salts are mixed, a single ^{31}P NMR signal is seen; this signal resonates precisely between the values of the separate salts (rapid counterion exchange). The conditions of the reaction to form **12a** are quite vigorous, xylene at reflux for 59 h, and an isomerization is apparently occurring.

As a more direct probe of the mechanism of the formation of **18**, the synthesis was conducted in an NMR tube, and the ^{31}P NMR spectrum was followed. A small amount of triphenylphosphine oxide, which served as an additional internal reference, was present. The spectra for this study are shown in Figure 1. After the reaction

Scheme VI



Scheme VII



between triphenylphosphine and (*E*)-**16a** had proceeded in DMF for just a few minutes, a signal at 22.5 ppm was seen. This signal grew larger, and after 1 h it was flanked by the expected AB pattern of **18**. By the end of 2 h, however, the 22.5 ppm signal was essentially gone, and only the characteristic AB pattern of **18** was seen. The chemical shift of this new peak is similar to that of (4-bromo-2-buten-1-yl)triphenylphosphonium bromide (**11**), 22.41 ppm, and it is in accord with the shift expected for the S_N2 product **9a** (cf. Table V).[15] However, triphenylphosphine is a moderately strong base (pK_b = 9.9 in acetone[19]) and apparently serves to deprotonate this intermediate, leading to butadienylphosphonium salt **1**, which is rapidly attacked by triphenylphosphine as a nucleophile (cf. **13** and **6–12a**). This sequence is shown in Scheme VI and simply explains the observations discussed.

Chemistry of the 2-(Phenylthio)-1,4-dichloro-2-butenes. Before reagent **18** was used, some of the chemistry of the 2-(phenylthio)-1,4-dichloro-2-butenes ((*Z*)-**16a**, (*E*)-**16a**) was investigated. These compounds exhibit differential reactivity at the allylic chloride carbons due to the effect of the phenylthio group, and therefore a number of specific substitutions were conducted. Carbon-4 is electronically activated, while carbon-1 is sterically shielded. When (*E*)-**16a** was reacted with triethylphosphite at reflux, compound (*E*)-**19** was formed in 57% yield. This compound exhibits very similar ^{31}P (see Table 6)[15] and ^{13}C NMR shifts to (*E*)-**20**, made by an Arbuzov reaction with the unsubstituted (*E*)-1,4-dichloro-2-butene (*E*)-**14**. When (*E*)-**19** is treated with DBU, elimination of HCl takes place, yielding **21**. This phosphonate, in contrast to the unsubstituted compound (**22**) reported by Darling,[9] does (sluggishly) undergo the intramolecular Wadsworth–Emmons[10] reaction. Thus, when (*E*)-**19** and 2-carbomethoxy-1-cyclopentanone (**23**) were treated with DBU in DMF at ca. 100 °C, a 52% yield of **24** was obtained (Scheme VII). Apparently the allylic phenylthio group is sufficiently electron withdrawing to effect this reaction.[11]

A similar reaction with 2-methyl-1,3-cyclohexanedione (**25**) was quite slow, showing only a trace of annulation product **26**, as seen by TLC, after several hours. When either (*E*)- or (*Z*)-**20** are treated with triethylamine, the same butadienylphosphonate (**22**) is formed.

Scheme VIII shows that a simple enolate can be monoalkylated, attacking at C-4 of (*E*)- or (*Z*)-**16a**. Although some dialkylated products are obtained, these reactions were simple and in high yield. (See Table 8 for NMR data for **27**, **28**.)[15] Neither **27** nor **28** would react with triphenylphosphine in benzene at reflux or in hot DMF, indicating apparent steric hindrance, which could also have some bearing on the formation of **18**. This observation is in marked contrast to that of Fuchs,[3b] who easily formed a phosphonium salt (C_6H_6, 3 h at reflux) from an unsubstituted analogue. Compound **27** did react with tetramethylammonium acetate (as did **28**) and triethyl phosphite (hot), affording **29** and **30**, the expected S_N2 reaction products, in high yields. Some other rather interesting reactions took place, such as the formation of **31** when either **27** or **28** was reacted with diethyl phosphite and base. Apparently the phosphite anion attacks the carbonyl preferentially, as in a Perkow reaction, and an intramolecular S_N2' reaction ensues. The initial attack could be from either side of the molecule, but only when the carbonyl is attacked from the face on which the ester group lies can the resulting alkoxide reach the appendage to complete the observed reaction.

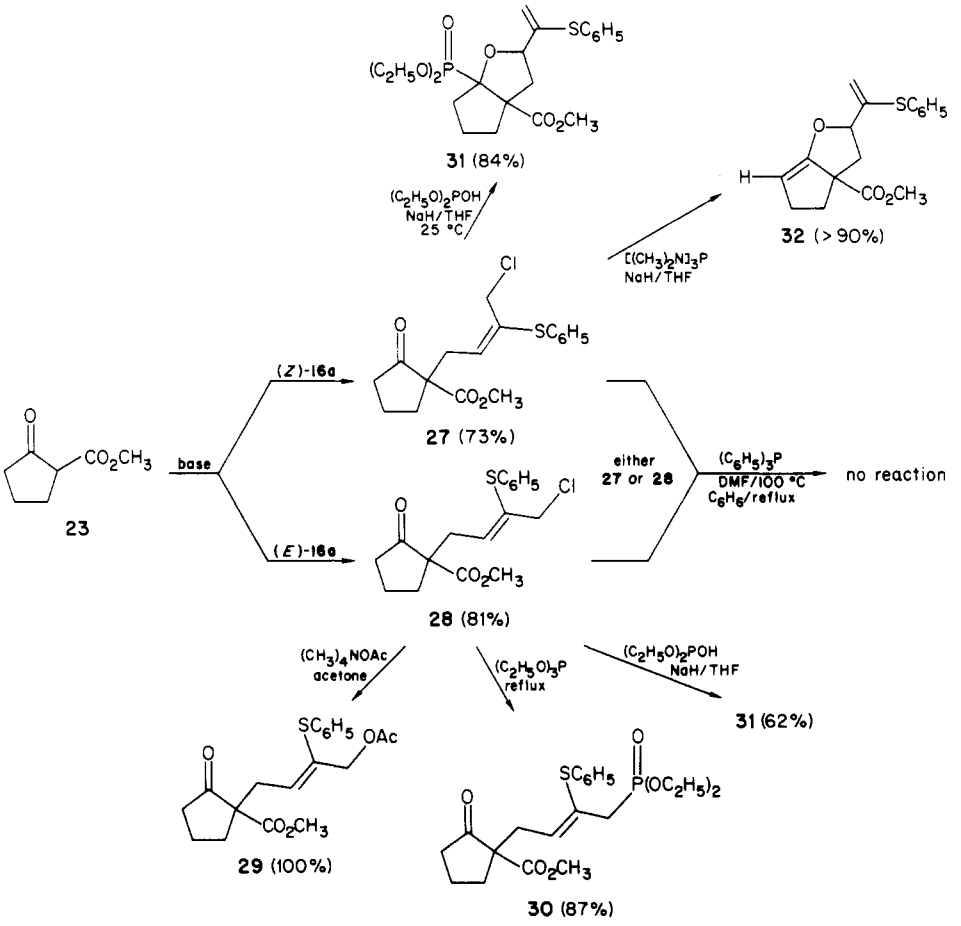
In the reaction of **28** with hexamethylphosphorus triamide in the presence of base, the phosphorus compound apparently attacked the ketone, in a similar fashion to the formation of **31**. After the intramolecular S_N2' reaction, the hexamethylphosphorus triamide was eliminated to yield **32**.

The Annulation Reaction. Slow addition (3–5 h) of a DMF solution of reagent **18** (1.07 equiv) to a solution of 2-carbomethoxy-1-cyclopentanone (**23**) in the presence of excess (2.9 equiv) dry, pulverized K_2CO_3 produced an orange to red solution. Workup (addition of a few drops of cold 30% H_2O_2 to convert the liberated triphenylphosphine to triphenylphosphine oxide; hexane vs. water

(18) For counterion exchange reactions of phosphonium salts leading to the excellently crystalline nonhygroscopic fluoroborates see: (a) Vedejs, E.; Bershas, J. P.; Fuchs, P. L. *J. Org. Chem.* **1973**, *38*, 3625. (b) Fuchs, P. L. *J. Am. Chem. Soc.* **1974**, *96*, 1607.

(19) Kosolapoff, G. M.; Maier, L. "Organic Phosphorous Compounds"; Wiley: New York, 1977; Vol 1.

Scheme VIII



extraction) afforded dienyl sulfide **24** in 85% yield and high purity. Scheme IX lists several other substrates, along with the temperatures and yields of reactions run under similar conditions[12a] (see Table 9 for ^{1}H NMR and ^{13}C NMR of the adducts).[15]

When less stabilized enolates, such as those obtained from simple ketones, were used with reagent **18**, only tarry products were obtained. This is apparently due to the rapid polymerization of the transient dienylphosphonium intermediate, **1**, under the strongly basic conditions needed to generate such enolates.

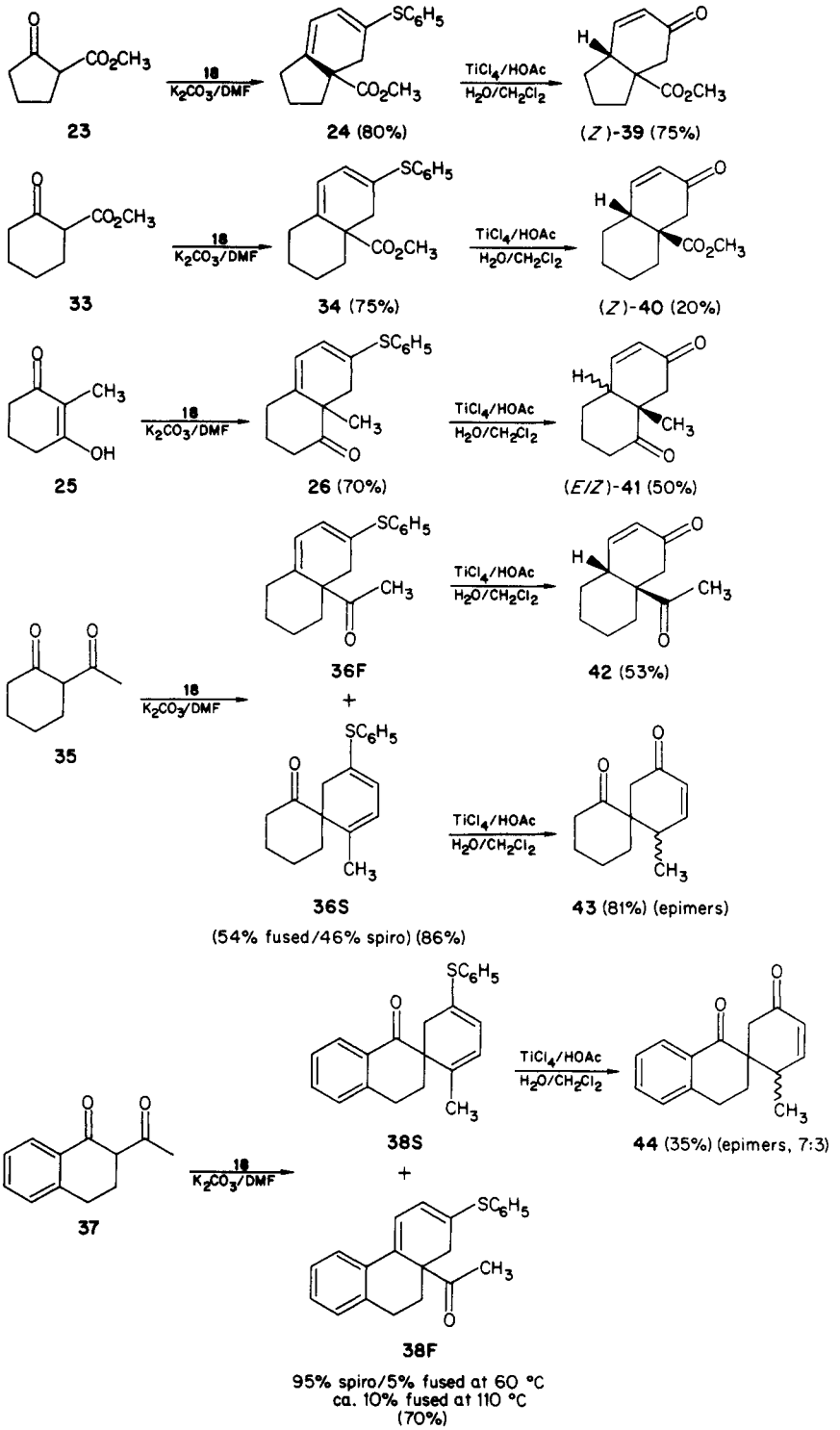
Using methanol as solvent or including benzaldehyde (1.3 equiv) in the reaction medium with 2-carbomethoxy-1-cyclopentanone in DMF produced vinyl sulfides (*E*)-/(*Z*)-**45** or dienyl sulfides **46**, respectively (Scheme X). Furthermore, when benzaldehyde was present and methanol was used as the solvent, ring-opening methanolysis of an intermediate that has been "trapped" by benzaldehyde yields **47**. Less than 10% (*E*)-/(*Z*)-**45** was detected by HPLC or ^{1}H NMR in the **47** product mixture despite the fact that nearly 300 equiv of methanol was present, compared with only 1.1 equiv of benzaldehyde. When methanol was used as the solvent and 2-methyl-1,3-cyclohexanedione (**25**) (a less reactive substrate) was present, only **48**, as a mixture of isomers, was isolated; these isomers are the products of methoxide attack on the eliminated reagent followed by benzaldehyde trapping.

The minor to major isomer ratio of **45** is about 1.0–1.7 (^{1}H NMR or HPLC). It is clear that the minor isomer is more shielded and has slightly longer ^{13}C NMR T_1 relaxation times (see Table 10).[15] This strongly indicates that the minor isomer has the *Z* configuration.[16] Additionally, the major isomer has a doublet of triplets at 1.87 ppm, J = 6.6, 0.9 Hz in the ^{1}H NMR, while the minor isomer shows only a doublet, at 1.76, J = 7 Hz. This could be the long-range coupling to the vinyl proton which was seen in (*E*)-**16a**, (*Z*)-**16c**, and **27**, indicative of the trans-phenylthio configuration. In order to account for the formation of (*Z*)-**45** a double bond isomerization must take place. Since the benzaldehyde trapping is much faster than the ring-opening methanolysis, and yet **24** is still formed in the presence of benzaldehyde, the rate of the intramolecular Wittig reaction is comparable to that of the intermolecular reaction with the aldehyde. Since essentially no **24** was seen when methanol was solvent, it appears that the methanolysis is fast once the 2,2-disubstituted β-keto ester intermediate is formed. For a significant amount of (*Z*)-**45** to be obtained the isomerization must therefore take place after the ring-opening methanolysis, with the ylide and phenylthio group in conjugation.

Hydrolysis of the Dienyl Sulfides. The hydrolysis of the dienyl sulfides presented some problems, and low yields were obtained in some examples which were not optimized, possibly owing to the labile nature of the enones (Scheme IX). Two substrates, **24** and **26**, were studied under several conditions, as shown in Scheme XI. When **24** was treated with $TiCl_4$ in acetic acid/CH_2Cl_2 and some water was added,[20a] the desired enone apparently formed and was reattacked by the liberated thiophenol.[20b] Com-

(20) (a) Mukaiyama, T.; Kamio, K.; Kobayasi, S.; Takei, H. *Bull. Soc. Chem. Jpn.* **1972**, 3723. (b) In their synthesis of Acoronene B, Trost *et al.*, were unable to hydrolyze a simple phenylthiodiene with $TiCl_4$, "... which caused extensive decomposition". Trost, B. M.; Hiroi, K.; (in part) Holy, N. *J. Am. Chem. Soc.* **1975**, *97*, 5873. It is interesting that at first we assumed decomposition was taking place, since the product observed was not an enone, was not a single spot on TLC, and had aryl signals in the ^{1}H NMR. It may be that this readdition of the liberated thiophenol to the conjugated enone phenomenon has caused problems for other workers.

Scheme IX



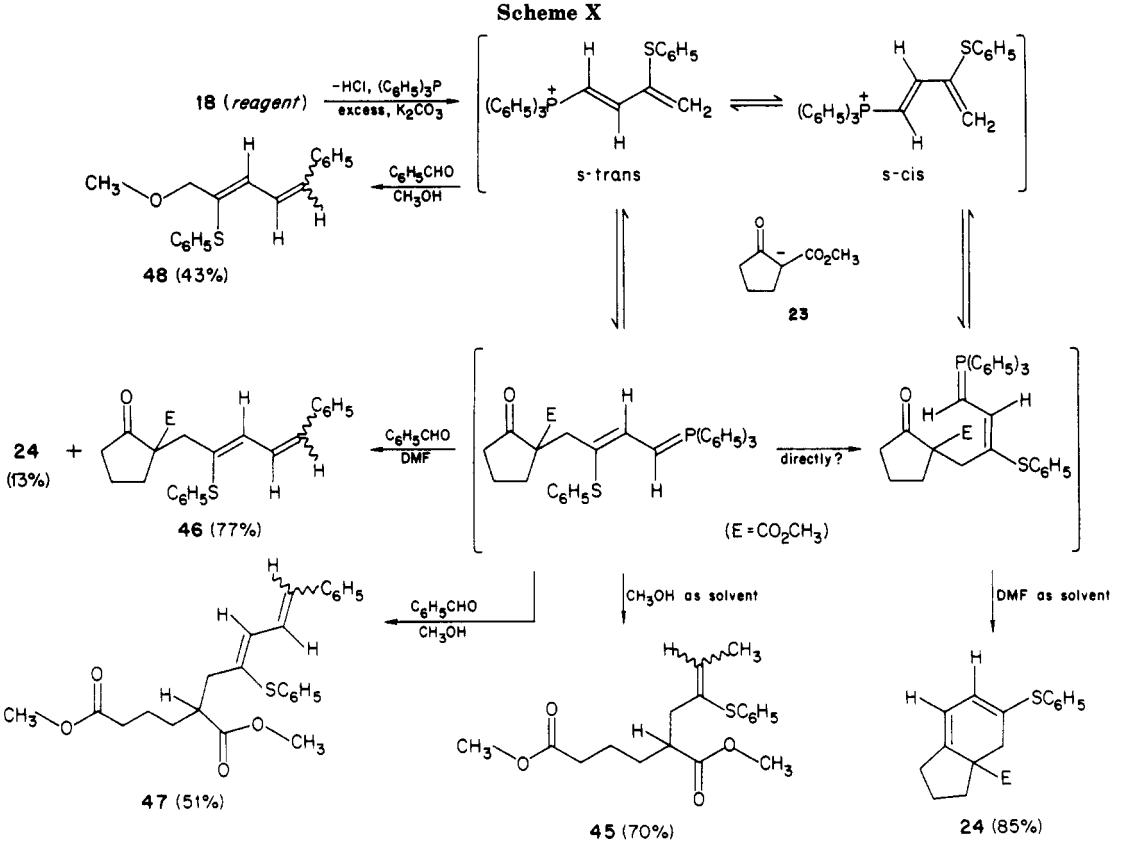
pound **49** was isolated in 83% yield, and it was shown that (*Z*)-**39** also leads to **49** under the hydrolysis conditions. It is not necessary to isolate **49**, and in most cases this more efficient direct approach was taken. If the reaction mixture was simply extracted with water, dried, and treated with excess DBU at 0 °C, (*Z*)-**39** was obtained in 75% overall yield.

When **24** was heated to reflux in CH_3CN, with water and excess $HgCl_2$ present,[21] only a 15% yield of (*Z*)-**39** was obtained, but the deconjugated isomer **50** was present in 35% yield. No **50** was seen in $TiCl_4$ reactions with **24**. This deconjugated enone was recovered in 89% yield when treated with DBU and then reacidified, suggesting that the $TiCl_4$ complexation activates the dienyl system, while the $HgCl_2$ is more associated with the vinyl sulfide. CuO in CF_3CO_2H also hydrolyzes the phenylthio diene **24** and leads to low yields of a mixture of (*E*)- and (*Z*)-**39**.

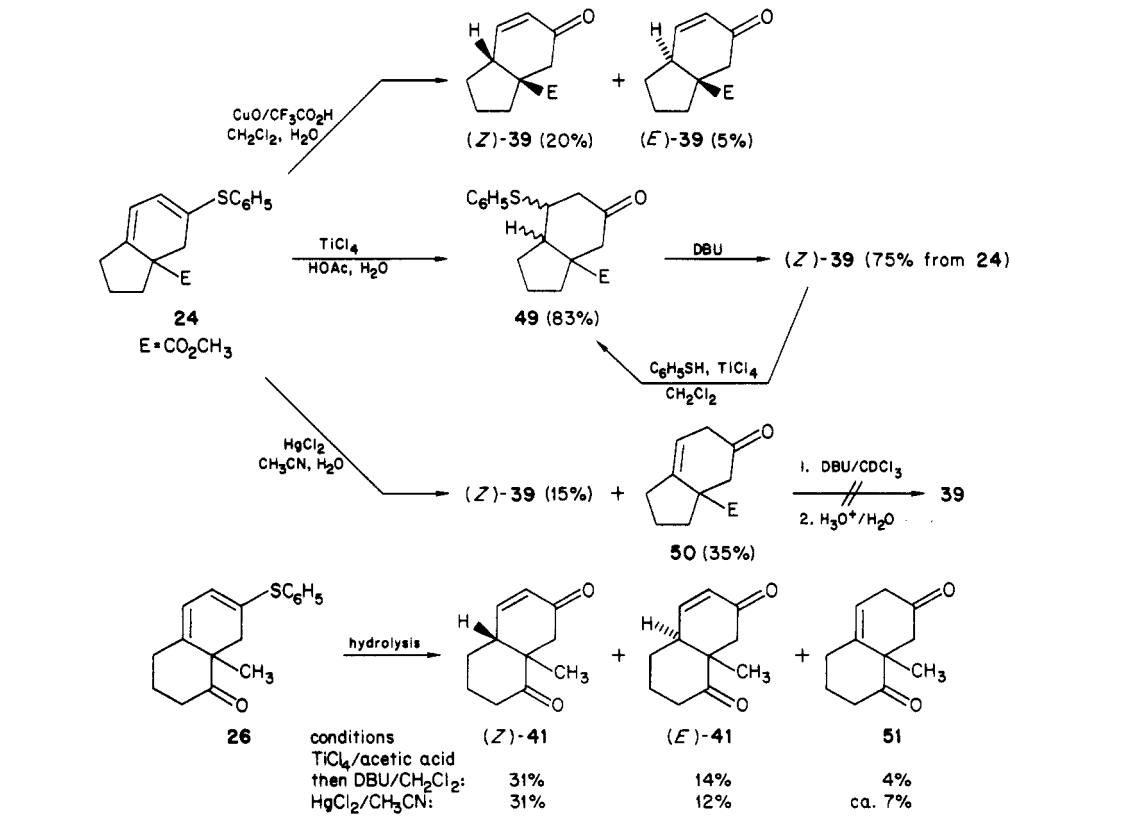
Similar results were seen for the hydrolysis of **26**, leading to isomeric mixtures of the transposed Wieland–Miescher ketone **41**. In the case of **26**, however, small amounts of the deconjugated enone, **51**, were detected in the $TiCl_4$ catalyzed reaction. It should be noted that the ^1H NMR signals for (*E*)- and (*Z*)-**41** are very similar, but an assignment of the isomers was made on the basis of the ^{13}C

(21) Mura, A. J.; Majetich, G.; Grieco, P. A.; Cohen, T. *Tetrahedron Lett.* **1975**, 4437. Corey, E. J.; Schulman, J. I. *J. Org. Chem.* **1970**, *35*, 777.

Scheme X



Scheme XI



NMR shifts (see Tables 11, 12).[15]

Experimental Section

Reactions were monitored by thin-layer chromatography (TLC) on precoated (0.25 mm) silica gel 60F-254 plates from EM Reagents; the plates were observed with 254-nm light to detect quenching of the fluorescent binder: UV+ indicates such absorption of the light. The TLC plates were developed with acidified alcoholic *p*-anisaldehyde spray (*p*-AA spray: 1350 mL of absolute ethanol, 50 mL of concentrated H_2SO_4, 15 mL of glacial acetic acid, and 37 mL of *p*-anisaldehyde mixed together) and heated to 175 °C until the colors were clearly visible. CAB refers to a TLC solvent system developed by Dr. Charles A. Bunnell

and consists of the following (parts by volume): 3:1:2:2 hexane:ether:chloroform:methanol. It was made less polar by mixing with ether where noted. EH indicates mixtures of ether and hexane.

Melting points were measured on a Fisher-Johns melting point apparatus, were uncorrected, and are reported in degrees Celsius. Infrared spectra were recorded in $CHCl_3$ or neat between NaCl plates, on a Perkin-Elmer Model 267 grating infrared spectrometer, and are reported in μm. NMR spectra were obtained in $CDCl_3$ (with Me_4Si internal standard; Aldrich) and are reported in parts per million downfield from Me_4Si; proton NMR were recorded on a Perkin-Elmer R-32 (90 MHz), a Varian XL-200 (200 MHz), or a Nicholet 360- or 470-MHz instrument and carbon NMR on a Varian CFT-20 (20 MHz) or XL-200 (50 MHz) instrument. Carbon T_1 values were obtained on the Varian XL-200 spectrometer by using the inversion–recovery sequence, with delays between pulses of at least 4 times the longest measured T_1, and total computed errors well below 10%. LW refers to line widths at half-height, calculated by the XL-200 instrument, after transforming with no weighting function. Phosphorus NMR spectra were also run on the Varian XL-200 (81 MHz) instrument. Coupling constants were measured in hertz. Mass spectra exact mass determinations reported to three decimal places were obtained on a CEC-21-110-B high-resolution mass spectrometer, and those reported to five decimal places were run on a Kratos high-resolution instrument. Low-resolution spectra were obtained on a Finnigan 4121 GC–mass spectrometer (EI: 70-eV electron impact. CI: chemical ionization with isobutane). The combustion analyses were run by Dr. C. S. Yeh or Dr. H. D. Lee of the Purdue Microanalytical Laboratory.

General Procedure for Bromosulfenylations. *threo*-1,4-Dichloro-2-bromo-3-(phenylthio)butane (*t*-15a). Diphenyl disulfide (54.6 g; 0.25 mol; 1.00 equiv) was dissolved in 1.0 L of CH_2Cl_2 in a 3-L flask equipped with a stirrer, an addition funnel, and a N_2 line. The solution was cooled to about 5 °C and briefly swept with N_2. Bromine (40.0 g; 0.25 mol; 1.00 equiv) in 50 mL of CH_2Cl_2 was added over a few minutes, and the solution was stirred at 5–10 °C for 30 min. (*Z*)-1,4-Dichloro-2-butene ((*Z*)-14) (ca. 95% pure; redistilled;) (65.0 g; ca. 0.50 mol; 2.0 equiv) was then added rapidly. The red solution was allowed to warm to room temperature and stirred for a total of 8–12h. A TLC (1:1 EH) showed a faint pair of spots at R_f 0.21, maroon–purple with *p*-AA spray, UV+, and the product was at R_f 0.59, blue-gray with *p*-AA spray, UV+. The solvent was removed in vacuo, and the crude yield was nearly quantitative. The material was purified by plug filtration on 1 lb of silica gel (Fisher 60–200 mesh; 9.5 cm diameter column) using 5% CH_2Cl_2 in hexane as eluent. After 1 L of forerun, 80% of the product was in the next liter, and a total of 3 L yielded, after removal of the solvent in vacuo, 152.7 g of (97.3%) a clear, colorless oil, which was pure by TLC, ^1H NMR, and VPC (SE-30, 150 °C/4 min, 8°/min to 230 °C): 13.86 min. Mass spectrum (EI, partial): (ratio) of m/e to M^+; 277 (M – Cl, 0.043); 233 (M – Br, 0.352); 188 (PhSBr, 0.947). ^{13}C NMR (20 MHz, T_1, in s, run at 50 MHz): δ 133.27, CH, 4.215; 132.30, C_q, long; 129.37, CH, 4.19; 128.31, CH, 2.32; 53.74, CH, 2.95; 51.05, CH, 2.41; 45.27, CH_2, 1.44; 44.91, CH_2, 1.345. ^1H NMR (360 MHz): δ 7.6, 2 H, m; 7.45, 3 H, m; 4.40, 1 H, t, J = 10.9; 4.09, 1 H, dd, J = 4.58, 10.9; 3.75, 1 H, ddd, J = 1.82, 4.32, 11.1; 3.93, 1 H, t, J = 11.1; 3.84, 1 H, dd, J = 4.32, 11.1.

Anal. Calcd for $C_{10}H_{11}BrCl_2S$: 311.914. Found: 311.913.

***erythro*-1,4-Dichloro-2-bromo-3-(phenylthio)butane (*e*-15a).** In a reaction sequence identical with that given for *t*-**15a**, 23.4 g of diphenyl disulfide in 350 mL of CH_2Cl_2 was treated with 16.0 g of bromine and 25.0 g of (*E*)-1,4-dichloro-2-butene (*E*)-**14**. The crude oil was obtained in nearly quantitative yield, and was quite pure by TLC and ^1H NMR. TLC (1:1 EH): R_f 0.59, purple with *p*-AA spray, UV+. It was recrystallized from hexane, and 48.2 g (76.8%; 3–4 crops) of colorless crystals were obtained, mp: 68–68.5 °C. Mass spectrum (EI, partial): (ratio) of m/e to M^+, 277 (M – Cl, 0.096); 233 (M – Br, 0.827); 188 (PhSBr, 0.909). ^{13}C NMR (20 MHz, T_1, in s, run at 50 MHz): δ 133.29, CH, 4.38; 132.50, Cq, long; 129.44, CH, 4.365; 128.56, CH, 2.77; 54.18, CH, 3.67; 53.61, CH, 2.69; 47.85, CH_2, 1.55; 46.67, CH_2, 1.74. ^1H NMR (360 MHz): δ 7.6–7.3, 5 H, m; 4.55, 1 H, dt, J = 5.00, 7.47; 4.25, 1 H, dd, J = 5.00, 12.09; 4.12, 1 H, dd, J = 5.00, 12.09; 3.97, 2 H, d, J = 4.75; 3.785, 1 H, dt, J = 4.75, 7.47.

Anal. Calcd for $C_{10}H_{11}BrCl_2S$: C, 38.24; H, 3.53; Br, 24.41; Cl, 22.58; S, 10.21. Found: C, 38.39; H, 3.63; Br, 25.21; Cl, 22.58; S, 10.33.

General Procedure for HBr Eliminations with DBU. (*E*)-1,4-Dichloro-2-(phenylthio)-2-butene (*E*-16a). *t*-**15a** (131 g; 417-mmol; 1.00 equiv) was dissolved in 1300 mL of dry ether in a 2-L flask equipped with a good overhead stirrer, low-temperature thermometer, and N_2 line. The system was flushed with dry N_2 and cooled to ca. –55 °C in a dry-ice bath. DBU (66.0 g; 434 mmol; 1.04 equiv) was added dropwise with good stirring. After about 1 h the reaction was allowed to warm slowly to room temperature, while still being stirred. After about 8 h the reaction was thick with precipitated DBU–HBr, and showed little *t*-**15a** by TLC. The mixture was filtered, and the filter cake was washed well with 500 mL of ether. The ether solution was washed with 500 mL of water, 250 mL of 0.6 N HCl solution, and 250 mL of saturated NaCl solution, and dried over $MgSO_4$. The ether was evaporated to yield 95.0 g of a very dark purple oil. The ^1H NMR (90 MHz) showed about 5% unreacted *t*-**15a** (TLC (Hexane)): R_f 0.28), and 5–10% (*E*)-1-chloro-3-(phenylthio)-1,3-butadiene, **17a** (TLC (hexane)): R_f 0.36, red with *p*-AA spray, UV+). The product, (*E*)-**16a**, has an R_f of 0.22 with hexane, and is dark red with *p*-AA spray, UV+. VPC(SE-30, 150 °C/4 min, 4°/min to 230 °C): **17a**, 7.74 min (5.93%); (*E*)-**16a**, 8.10 min (86.36%); *t*-**15a**, 18.85 min, 7.14%. The 95.0g crude yield represents a 83–88% yield of (*E*)-**16a**, and is typical of many runs. Mass spectrum (EI): 234 (21); 232 (26); 197 (52); 161 (100); 147 (20); 135 (16); 129 (13); 128 (49); 110 (17); 109 (49); 94 (14); 87 (14); 77 (14); 71 (14); 69 (17); 65 (35); 53 (22); 51 (44); 45 (14); 39 (27). CI: 235 (12); 233 (17); 229 (7); 219 (15); 211 (26); 199 (49); 198 (18); 197 (100); 193 (18); 163 (21); 97 (14). ^{13}C NMR (20 MHz): δ 135.50, C_q; 133.09, CH; 131.98, C_q; 131.21, CH; 129.34, CH; 127.77, CH; 46.34, CH_2; 40.63, CH_2. ^1H NMR (90 MHz): δ 7.3, 5 H, m; 6.41, 1 H, tt, J = 7.5, 1.1; 4.35, 2 H, d, J = 7.5; 3.98, 2 H, br s.

(*Z*)-1,4-Dichloro-2-(phenylthio)-2-butene ((*Z*)-16a). (*Z*)-**16a** was prepared as (*E*)-**16a** by using 13.1 g (15.0 mmol; 1.00 equiv) of *e*-**15a** in 130 mL of ether, and 6.60 g (43.0 mmol; 1.04 equiv) of DBU. The resulting product mixture was typically 15–20% unreacted *e*-**15a**, 15% **17a**, and 65–70% (*Z*)-**16a**, and the 9.50 g of crude material from this reaction represents a 63–68% yield. All attempts to purify this material (more DBU, distillation, or chromatography) resulted in further decomposition. TLC (Hexane): R_f 0.20, bright red with *p*-AA spray, UV+. ^{13}C NMR (50 MHz): δ 139.01, C_q; 127.40, CH; 40.08, CH_2; 39.25, CH_2; the aryl signal overlaps with the *e*-**15a** present, and cannot reliably be assigned. ^1H NMR (90 MHz): Vinyl triplet at δ 5.82, J = 8.5; no long range coupling was seen.

(*E*)-1-Chloro-3-(phenylthio)-1,3-butadiene (17a). (*E*)-**16a** (370 mg; 1.59 mmol; 1.00 equiv) in 10 mL ether was cooled in a dry-ice bath. DBU (254 mg; 1.67 mmol; 1.05 equiv) was added dropwise, and the bath removed to facilitate stirring. The reaction was allowed to warm to room temperature and stirred for 1 h. The mixture was poured into a separatory funnel containing 10 mL of water and 10 mL of hexane. The organic layer was washed with water and dried over $MgSO_4$. The solvent was removed in vacuo. The light colored oil, which rapidly darkened on concentration, was distilled bulb-to-bulb, bp: 70–90 °C at 0.15 mmHg. A colorless oil (285 mg (91%)) was obtained, which darkened only slowly when kept below –20 °C, and could be stored for several days at low temperatures. TLC (Hexane): R_f 0.36, bright red with *p*-AA spray, UV+. Mass spectrum (EI, 25 °C probe): 198 (29; calcd 27 based on m/e 196); 197 (17.7); 196 (72); 161 (100; M – Cl); 128 (36); 115 (10); 110 (41; $PhSH^+$); 109 (20; PhS^+); 107 (19); 105 (54); 91 (19); 89 (18); 87 (53); 77 (14); 69 (15); 65 (29); 51 (90); 45 (13). CI: 198 (42); 197 (14); 196 (100). IR (neat film): 3.23; 3.35; 6.29; 6.74; 6.91; 7.95; 9.30; 9.70; 10.7; 11.75; 13.25; 14.2. ^{13}C NMR (50 MHz): δ 138.26, C_q; 132.32, CH; 132.28, C_q; 131.19, CH; 129.20, CH; 127.40, CH; 123.02, CH; 121.17, CH_2. ^1H NMR (90 MHz, $CDCl_3$ solvent): δ 7.4–7.2, 5 H, m; 6.59, 2 H, s; 5.49, 1 H, s; 5.25, 1 H, s; (C_6D_6 solvent): 7.2–6.85, 5 H, m; AB, 2 H, 6.55, 6.33, J = 13.3; 5.02, 2 H, s.

2-(Phenylthio)-2-butenyl-1,4-bis(triphenylphosphonium chloride) (18). (*E*)-**16a** (9.5 g; 90% pure; 36.7 mmol; 1.00 equiv) was dissolved in 100 mL of DMF, and 21.1 g (80.7 mmol; 2.20 equiv) of triphenylphosphine was added. The reaction flask was flushed with N_2, and stirred at room temperature for 3 days. The

mixture, containing a purple precipitate, was added to 200 mL of dry acetone and stored in the freezer overnight. The solid was filtered off and dissolved in a small amount of warm CH_2Cl_2, treated with Darco, and diluted with 2–3 volumes acetone. After crystallization in the freezer, the nearly white salt was harvested, and dried at 55 °C at <1 mmHg overnight. A second crop was obtained by mixing the filtrates, adding ether, and recrystallizing the precipitate. The total yield was 17 g (61%) of white crystals: mp, 164–166 °C (darkening). ^{31}P NMR (81 MHz): AB, δ 21.36, 22.31, J = 11.35. ^{13}C NMR (20 MHz; partial): δ 27.16, CH_2, J_P = 51.95, and 30.66, CH_2, J_P = 48.34; 117.38, C_q, J_P = 85.17; 117.15, C_q, J_P = 85.34. ^1H NMR (470 MHz): δ 7.9, 6 H, m; 7.7, 24 H, m; 7.16, 3 H, m; 6.57, 2 H, m; 6.37, 1 H, ddd, $^3J_{PH}$ = 7.7, $^4J_{PH}$ = 5.1, $^3J_{HH}$ = 6.5; 5.19, 2 H, ddd, $^2J_{PH}$ = 14.6, $^5J_{PH}$ = 5.0, $^3J_{HH}$ = 6.5; 5.09, 2 H, br d, $^2J_{PH}$ = 14.4. Converted to the tetrafluoroborate salt by reacting with 2.5 equiv of $NaBF_4$ in DMF, this salt shows nearly identical ^{31}P and ^{13}C NMR's, and its ^1H NMR is similar, but more spread out.

Anal. Calcd for $C_{46}H_{40}B_2F_8P_2S$: C, 64.24; H, 4.69; B, 2.51; F, 17.67; P, 7.16; S, 3.73. Found: C, 64.30; H, 4.95; B, 2.80; F, 17.87; P, 6.88; S, 3.88; *No* Cl found.

Diethyl (1-Chloro-2-(phenylthio)-2-buten-4-yl)-phosphonate ((*E*)-19). (*E*)-**16a** (7.1 g; 85% pure; 25.9 mmol; 1.00 equiv) and 6.0 mL (4.8 g; 28.9 mmol; 1.12 equiv) of triethylphosphite were heated together, under N_2, to 160 °C. Gas evolution was noted for a few minutes and then ceased after about 1 h. The reaction was cooled and placed on the Rotovap for 15 min, bath at 75 °C, aspirator pressure. The residue was 10.5 g (104%); it was poured into a separatory funnel containing 25 mL ether and 25 mL hexane, washed with saturated $NaHCO_3$ and water, and dried over $MgSO_4$. The solvent was removed in vacuo. The residue was plug filtered on 100 mL silica gel (230–400 mesh) in a 35-mm diameter column. Elution with 500 ml 1:3 ether in hexane yielded the impurities from the starting material, and a further 700 mL solvent brought off 4.68 g (57%) orange oil, TLC (Ether): R_f 0.17–.20, maroon with *p*-AA spray, UV+. ^{31}P NMR (81 MHz): δ 26.08. ^{13}C NMR (20 MHz and 50 MHz): δ 134.67, C_q ($^3J_{PCCC}$ = 15.6); 132.72, C_q ($^5J_{PCCCSC}$ = 1.6); 130.73, CH; 129.25, CH; 128.80, CH ($^2J_{POC}$ = 10.7); 127.39, CH; 62.09, CH_2 ($^2J_{POC}$ = 6.7); 47.03, CH_2 ($^4J_{PCCCC}$ = 1.4); 28.77, CH_2 ($^1J_{PC}$ = 139.8); 16.46, CH_3 ($^3J_{POCC}$ = 5.8). ^1H NMR (90 MHz): δ 7.5–7.2, 5 H, m; 6.37, 1 H, dt, $^3J_{HH}$ = 8, $^3J_{PCCH}$ = 8; 4.3–3.95, 6 H, m; A_2BX, 3.18, 2.95, $^3J_{HH}$ = 8; $^2J_{PCH}$ = 23; 1.32, 6 H, t, J = 8; on the irradiation of 6.37, the A_2BX pattern collapses to a d, J = 23.

Anal. Calcd for $C_{14}H_{20}ClO_3PS$: 334.056. Found: 334.057.

Diethyl (3-(Phenylthio)-1,3-butadien-1-yl)phosphonate (21). (*E*)-**19** (8.98 g; 26.8 mmol; 1.00 equiv) was dissolved in 100 mL CH_2Cl_2 under N_2, and cooled to −70 °C. DBU (4.08 g; 26.8 mmol; 1.00 equiv) was added dropwise, and the reaction was allowed to warm to −15 °C over 1.5 h. The mixture was poured into a separatory funnel containing 100 mL 1.2 N HCl solution, further washed with water, and dried over $MgSO_4$. Darco was mixed with the dark solution before filtering off the drying agent. The solvent was removed in vacuo to yield 7.94 g (99%) of crude material, which was quite pure by ^1H NMR (90 MHz) and TLC (Ether): R_f 0.18, orange with *p*-AA spray, UV+. An analytical sample was prepared by plug filtration on silica gel, using 1:1 ether in hexane as eluent. ^{13}C NMR (20 MHz): δ 146.83, CH (J_P = 7.40); 140.72, C_q (J_P = 25.9); 132.62, C_q; 131.62, CH; 129.29, CH; 127.62, CH; 126.20, CH_2; 118.55, CH (J_P = 187.4); 61.78, CH_2 (J_P = 5.50); 16.30, CH_3 (J_P = 6.2). ^1H NMR (360 MHz): δ 7.4–7.25, 5 H, m; 7.187, ca. $^1/_2$ H, J_{obsd} = 16.99, coupled at 6.084; 6.084, t, J = 17.33; 5.797, 1 H, s; 5.532, 1 H, d, J_P = 3.03; 4.05, 4 H, m; 1.30, 6 H, m.

General Procedure for Annulation Reactions. Specific reagent equivalents, reaction temperatures, and purification methods are given for each example.

4-(Phenylthio)-6-carbomethoxybicyclo[4.3.0]nona-1,3-diene (24). 2-Carbomethoxy-1-cyclopentanone **23** (90 mg; 0.633 mmol; 1.00 equiv) was dissolved in 5 mL of dry DMF in a 25 mL flask, 400 mg of K_2CO_3 (2.9 mmol, excess; anhydrous reagent grade, lightly ground) was added, and the system was degassed by partial evacuation and filling with N_2 several times. The reaction was stirred magnetically while 515 mg (0.680 mmol; 1.07 equiv) of reagent **18** dissolved in 3 mL of DMF (degassed as above) was added dropwise over several hours. The reaction immediately became golden orange in color. The mixture was stirred an additional 8 h, then treated with 0.5 mL of 30% H_2O_2 (excess, to convert the liberated triphenylphosphine to triphenylphosphine oxide), with external cooling as necessary, to keep the temperature below 30 °C. The mixture was poured into a separatory funnel containing 25 mL of hexane and 25 mL of ice water, shaken, and allowed to stand undisturbed for ca. 5 h at room temperature. Nearly all the triphenylphosphine oxide crystallized out. The hexane layer was washed with two 15-mL portions of water, and dried over K_2CO_3. The solvent was removed in vacuo leaving 184 mg of yellow oil, of at least 95% purity by ^1H NMR. The oil was distilled, bulb-to-bulb at ca. 200 °C/0.2 mmHg pressure, yielding 153 mg (84.5%) of pure **24** as a colorless oil: n^{20}_D 1.5975; TLC (1:1 EH), R_f 0.61, gray (hot), green (cool) with *p*-AA spray, UV+; HPLC (5% THF:Hexane, 3.0 mL/min, 600 psi, 254 nm detector), 2.24 min. Mass Spectrum (EI): 288 (3); 287 (12); 286 (61); 227 (72); 177 (35); 149 (100); 108 (31); 107 (84); 106 (30); 105 (31). IR (film): 3.38; 5.79; 6.32; 6.39; 6.80; 6.95; 8.40; 8.55; 8.80; 9.45; 9.80; 13.5; 14.25. ^1H NMR (90 MHz): δ 7.3, 5 H, m; 6.08, 1 H, dd, J = 5.5, 2.7; 5.85, 1 H, m; 3.61, 3 H, s; 2.95, 1 H, d, J = 16; 2.7–1.4, 7 H, m. (200 MHz): 6.056, dd, J = 5.32, 2.75; 5.860, dm, J = 5.32, m; CH_2 AB (2nd order), 2.284, J = 17.04, (LW) = 9.5 Hz on decoupling at 2.915; 2.915, J = 17.04, (LW) = 4.0 Hz on decoupling at 2.284. ^{13}C NMR (50 MHz; chemical shift, proton multiplicity, T_1): δ 175.89, C_q, 37.4; 144.43, C_q, 14.9; 134.02, C_q, 32.3; 131.84, CH, 2.28; 129.99, C_q, 23.8; 128.81, CH, 2.49; 127.24, CH, 1.87; 125.80, CH, 1.57; 117.49, CH, 1.68; 53.27, C_q, 19.3; 52.00, CH_3, 4.66; 38.85, CH_2, 1.2; 38.51, CH_2, 0.90; 30.43, CH_2, 1.12; 23.79, CH_2, 1.57. $<T_1$ error $>$ = 4.64% (s = 2.44).

Anal. Calcd for $C_{17}H_{18}O_2S$: 286.101. Found: 286.102. With M = 1.00, calcd/found: M + 1 (0.208/0.202).

4-(Phenylthio)-6-methylbicyclo[4.4.0]deca-1,3-dien-7-one (26). 2-Methyl-1,3-cyclohexanedione (**25**) (1.00 mmol), 1.0 g of K_2CO_3, 10 mL of DMF, 72 °C, degassed/Ar, 600 mg (0.792 equiv) of reagent **18** added slowly yielded 265 mg golden oil, 33% $Ph_3P{=}O$/^1H NMR, 82% crude yield (based on reagent), purified by Lobar (Size B column) using 10% ethyl acetate in hexane. In another run, by using 6.0 mmol of substrate and 1.10 equiv of reagent at 70 °C, degassed/N_2, 848 mg (52%, based on substrate) of crude yield was obtained, and only 373 mg of (23%) pure material was obtained after Lobar purification as above. TLC (1:1 EH): 0.44, brown with *p*-AA spray, UV+. Mass spectrum (EI, 140 °C probe): 270 (100); 255 (5; M − CH_3); 252 (3; M − H_2O); 242 (8; M − CO); 227 (14; M − C_2H_3O); 213 (21); 151 (16); 150 (18); 139 (26); 123 (90); 105 (100). ^{13}C NMR (20): δ 212.77, C_q; 140.81, C_q; 133.34, C_q; 132.37, CH; 131.46, C_q; 129.07, CH; 127.58, CH; 122.55, CH; 119.17, CH; 49.37, C_q; 38.51, CH_2; 36.61, CH_2; 30.33, CH_2; 23.25, CH_2; 22.20, CH_3. IR ($CDCl_3$, corrected): C=O at 5.85. ^1H NMR (90 MHz): δ 7.6–7.1, 5 H, m; 5.88, 1 H, dd, J = 6.0, 13; 5.67, 1 H, dd, J = 3.8, 13; 2.8–1.2, 8 H, m (one proton of an AB is at 2.29, J = 18).

Anal. Calcd for $C_{17}H_{18}OS$: 270.110. Found: 270.110.

2-Carbomethoxy-2-(4-chloro-3-(phenylthio)-(*E*)-2-butenyl)-1-cyclopentanone (27). 2-Carbomethoxy-1-cyclopentanone (**23**) (683 mg 4.80 mg; 1.00 eq) was dissolved in 25 mL THF. K_2CO_3 (2 g; 6 equiv; excess) was added, followed by 1.48 g (86% pure: 5.45 mmol; 1.14 equiv) of (*E*)-**16a**. The reaction was heated to reflux for 24 h. After cooling, the reaction was worked up by extraction, hexane vs water, and dried over $MgSO_4$. After the solvent was removed in vacuo, the residue was purified by plug-filtration silica gel, using hexane for the forerun, and 20% ether in hexane to elute the product. The solvent was removed in vacuo, yielding 1.32 g (81%) of **27** as a yellow oil. The color depends on how long the reaction stands after workup, before chromatography. TLC (1:1 EH): R_f 0.31, green with *p*-AA spray, UV+. Mass spectrum (EI, 120 °C probe): 340 (3.65; calcd for M + 2, 4.11); 338 (11); 302 (20, M − HCl); 228 (10, M − PhSH); 215 (35); 199 (17, $C_{10}H_{10}{}^{37}Cl^{32}S$ or $C_{10}H_{10}{}^{35}Cl^{34}S$; calcd 18.5% based on m/e 197); 197 (48, $C_{10}H_{10}{}^{35}Cl^{32}S$); 171 (36, calcd, 38% for $C_8H_6{}^{37/35}Cl^{32/34}S$, based on m/e 169); 170 (10); 169 (100; 197 − C_2H_4, $PhS^+{=}C{=}CHCl$); 162 (11); 161 (77); 160 (18); 149 (11); 147 (16); 135 (26); 134 (24); 133 (26); 128 (25); 123 (10); 119 (13); 110 (25); 109 (54, PhS+); 105 (29); 91 (47); 79 (22); 78 (13); 77 (49); 67 (11); 65 (32); 59 (30); 55 (31); 53 (22); 51 (22); 45 (15); 41 (20). CI: 323 (36.7; M (with ^{37}Cl or ^{34}S) + 1 − H_2O; calcd: 37.4 based on m/e 321); 322 (20.4; calcd 19.6); 321 (100; M + 1 − H_2O); 199 (18.07;

calcd 19.3 for $C_{10}H_{10}{}^{37/35}Cl^{32/24}S$, based on m/e 197); 197 (51.5; $C_{10}H_{10}{}^{35}Cl^{32}S$). Note that **28** and **46** also show loss of water and then loss of the side chain (as R+) in their CI spectra, and that all three of these compounds are 2-substituted-2-carbomethoxy-1-cyclopentanones. ^{13}C NMR (20 MHz): δ 213.87, C_q; 171.31, C_q; 134.60, CH; 133.92, C_q; 133.01, C_q; 130.44, CH; 129.27, CH; 127.21, CH; 59.71, C_q; 52.66, CH_3; 47.40, CH_2; 37.81, CH_2; 33.42, CH_2; 32.91, CH_2; 19.60, CH_2. ^1H NMR (90 MHz): δ 7.27, 5 H, m; 6.31, 1 H, tt, 7.33, ca. 1.0; 4.02, 2 H, s; 3.67, 3 H, s; ABX (coupled to 6.31, shown by decoupling experiment), 2.87, 2 H, J = 7.3, 14.6; 2.6–1.8, 6 H, m.

2-Carbomethoxy-2-(4-chloro-3-(phenylthio)-(*Z*)-2-butenyl)-1-cyclopentanone (28). (*Z*)-**16a** (3.7 g; 50% pure/^1H NMR (90 MHz); 7.96 mmol; 1.00 equiv) was dissolved in 50 mL of DMF and degassed and N_2 flushed. 2-Carbomethoxy-1-cyclopentanone **23** (1.4 g 10 mmol; 1.26 equiv) was then added, followed by 2–3 g (excess) K_2CO_3. After the reaction had been stirred for 4 h at room temperature, TLC showed no (*Z*)-**16a**, and a product spot was seen. The workup was the same as for **27**. TLC (1:1 EH): R_f 0.25, green with *p*-AA spray, UV+. The yield of pure **20** was 1.96 g (73%) as a yellow oil, and later chromatography fractions contained ca. 300 mg (11%) of what appeared to be (by ^1H NMR) bis-alkylated (*Z*)-**16a** as a mixture of diastereomers. Mass spectrum (EI, 80 °C probe): 340 (5.52; calcd for M + 2, 5.57); 302 (28; M – HCl); 228 (10; M–PhSH); 215 (41); 199 (8.9; $C_{10}H_{10}{}^{37}Cl^{32}S$ or $C_{10}H_{10}{}^{35}Cl^{34}S$; calcd 10.9% based on m/e 197); 197 (29, $C_{10}H_{10}{}^{35}Cl^{32}S$); 171 (25, calcd, 38% for $C_8H_6{}^{37/35}Cl^{32/34}S$, based on m/e 169); 169 (100, 197 – C_2H_4, $PhS^+{=}C{=}CHCl$); 161 (74); 160 (14); 147 (13); 135 (24); 134 (19); 133 (17); 128 (24); 110 (26); 109 (84: PhS^+); 105 (22); 91 (55); 79 (21); 78 (18); 77 (85); 69 (13); 67 (11); 66 (12); 65 (58); 59 (69); 55 (54); 54 (10); 53 (41); 51 (50); 45 (30); 42 (11); 41 (61); 39 (83). CI: 323 (38.4; M (with ^{37}Cl or ^{34}S) + 1 – H_2O; calcd, 37.4 based on m/e 321); 322 (19.1; calcd 19.6); 321 (100; M + 1 – H_2O); 199 (21.61; calcd 22.1 for $C_{10}H_{10}{}^{37/35}Cl^{32/34}S$, based on m/e 197); 197 (59.1; $C_{10}H_{10}{}^{35}Cl^{32}S$). Note that **27** and **46** also show loss of water and then loss of the side chain (as R^+) in their CI spectra, and that all three of these compounds are 2-substituted-2-carbomethoxy-1-cyclopentanones. ^{13}C NMR (20 MHz): δ 213.57, C_q; 170.90, C_q; 134.64, C_q; 134.22, CH; 133.49, C_q; 131.40, CH; 129.22, CH; 127.56, CH; 59.56, C_q; 52.62, CH_3; 41.16, CH_2; 37.80, CH_2; 33.02, CH_2; 32.70, CH_2; 19.56, CH_2. ^1H NMR (90 MHz): δ 7.31, 5 H, m; 5.87, 1 H, t, J = 7.8; 4.08, 2 H, s; 3.64, 3 H, s; 3.67, 2 H, ABX, J = 14, 7.8; 2.5–1.7, 6 H, m. ^1H NMR (470 MHz): δ 5.870, t, J = 7.84; 4.108, s; 3.710, s; ABX, 2.840 and 2.553, J = 14.94 and 7.87.

2-Carbomethoxy-2-(4-acetoxy-3-(phenylthio)-(*E*)-butenyl)-1-cyclopentanone (29). **27** (132 mg; 0.39 mmol; 1.00 equiv) in 10 mL of acetone was added to a suspension of 104 mg of tetramethylammonium acetate in 5 mL of acetone, and heated to reflux for 24 h. The cooled reaction was poured into a separatory funnel containing 25 mL water, and extracted with three 20-mL portions of hexane. The hexane layers were washed with saturated NaCl solutions, and dried over $MgSO_4$. The solvent was removed in vacuo, yielding 149 mg (106%; hexane present by ^1H NMR, even after pumping at 0.5 mmHg at room temperature for 12 h) of oil, TLC (1:1 EH): R_f 0.23, gray with *p*-AA spray, UV+. ^{13}C NMR (20 MHz): δ 213.92, C_q; 171.37, C_q; 170.28, C_q; 133.84, CH; 133.54, C_q; 131.95, C_q; 130.03, CH; 129.14, CH; 126.92, CH; 66.49, CH_2; 59.80, C_q; 52.62, CH_3; 37.84, CH_2; 33.19, CH_2; 20.74, CH_3; 19.58, CH_2. ^1H NMR (90 MHz): δ 7.27, 5 H, m; 6.18, 1 H, tt, J = 7.3, 1; 4.53, 2 H, br s; 3.69, 3 H, s; ABX, 2 H, 2,8], J = 7.3, ca. 6.7; 2.7–1.7, 9 H, m, including a singlet at 1.96, probably 3 H.

2-Carbomethoxy-2-(4-diethylphosphonyl-3-(phenylthio)-(*E*)-3-butenyl)-1-cyclopentanone (30). **27** (238.5 mg; 0.70 mmol; 1.00 equiv) was heated together with 1.0 mL (800 mg; 4.81 mmol; 6.84 equiv) of triethyl phosphite at 160 °C (reflux) for 5.5 h. Gas evolution was noted. The cooled reaction was poured into a separatory funnel containing 10 mL of hexane and 20 mL of water, and the reaction flask washed out with 10 mL of ether, which was added to the separatory funnel. The organic layer was washed with water, and dried over $MgSO_4$. The solvent was removed in vacuo, and the residue heated to 73 °C at <0.3 mmHg for several hours, yielding 270 mg (87%) of yellow oil. TLC (1:1 E–CAB): R_f 0.51, brown with *p*-AA spray, UV+. A trace of unreacted **27** was also seen, R_f 0.76. ^{31}P NMR (81 MHz): δ 25.96 (90%) and 25.43 (10%); shifts in ppm relative to external 85% H_3PO_4. ^{13}C NMR (50 MHz): δ 214.09, C_q; 171.37, C_q; 134.98, CH ($^3J_{PCCC}$ = 10.0); 133.87, C_q; 130.05, CH; 129.16, CH; 127.55, C_q ($^2J_{PCC}$ = 11.1); 126.82, CH; 62.02, CH_2 ($^2J_{POC}$ = 6.7); 60.00, C_q ($^5J_{PCCCC}$ = 3.6); 52.63, CH_3; 37.91, CH_2; 34.28, CH_2 ($^1J_{PC}$ = 138.2); 33.91, CH_2 ($^4J_{PCCCC}$ = 2.3); 32.53, CH_2; 19.63, CH_2; 16.39, CH_3 ($^3J_{POCC}$ = 6.1). Small signals for **27** were also observed. ^1H NMR (470 MHz): δ 7.3–7.2, 5 H, m; 6.086, 1 H, dt, $^4J_{P,H}$ = 5.51, $J_{H,H}$ = 7.18; 4.063, 4 H, dq, $J_{H,H}$ = 7.20, $^3J_{POCH}$ = 5.61; 3.272, 3 H, s; ABMX, 2.983, 1 H, ddd, J = 14.53, 6.89, J_P = 4.57, and 2.821, 1 H, ddd, J = 14.53, 7.69, J_P = 3.60; 2.718, 2 H, dd, J = 2.15, J_P = 21.07; 2.52–1.95, 6 H, m; 1.298, dt, $J_{H,H}$ = 7.20, J_P = 2.60.

Diethyl (2-Oxabicyclo[3.3.0]-3-(2-(phenylthio)ethenyl)-5-carbomethoxyoctan-1-yl)phosphonate (31). NaH (22 mg 60% oil dispersion; 0.55 mmol; 1.17 equiv) was placed in a dry 25-mL flask, evacuated, and N_2 filled. Dry pentane (10 mL) was added, mixed well, and after the NaH was allowed to settle, withdrawn via syringe. The system was again evacuated, to remove the residual pentane, and N_2 filled. Dry THF (6 mL) was added, followed by 0.08 mL (86 mg; 0.62 mmol; 1.3 equiv) diethyl phosphite, and the reaction stirred for several minutes while gas evolution was noted. **28** (159.4 mg; 0.47 mmol; 1.00 equiv) in 4 mL of THF was then added, and the reaction was stirred at room temperature for several hours. The reaction mixture was poured into a separatory funnel containing 25 mL of water and 25 mL of hexane; the hexane layer was separated, and the aqueous layer was extracted with two 25-mL portions of ether. The product was almost completely in the hexane extract by TLC, so the ether extracts were discarded. The hexane layer was washed with saturated $NaHCO_3$ and saturated NaCl solutions, and dried over $MgSO_4$. The solvent was removed in vacuo, pumping at <1 mmHg pressure, yielding 175 mg (84%) of yellow oil. TLC (ether): R_f 0.12–14, rust colored with *p*-AA spray, UV+. An analytical sample was prepared by preparative layer TLC purification, using ether as eluent, and the product was in a band of R_f 0.19–.35. ^{31}P NMR (81 MHz): δ 19.18 ppm relative to external 85% H_3PO_4. ^{13}C NMR (20 MHz): δ 173.32, (J_P = 2.8); 143.80; 132.99; 132.50; 129.19; 127.70; 115.05; 90.35 (J_P = 173.5); 81.90 (J_P = 4.5); 62.78 (J_P = 6.5); 43.75; 37.65 (J_P = 13.1); 37.03 (J_P = 11.9); 24.86 (J_P = 14.3); 16.50 (J_P = 5.7). ^1H NMR (470 MHz): δ 7.45, 7.30, 5 H, m; 5.818, 1 H, d, J = 1.12; 5.115, 1 H, s; 4.526, 1 H, br dd, J = 11.28, 5.02, 1.12, ca. 1; 4.143, 4 H, dq, J_H = 7.14, J_P = 6.17; 3.733, 3 H, s; 2.796, 1 H, dd, J = 12.50, 11.28; 2.524, 1 H, ddd, J = 13.47, 9.11, 9.01; 2.300, 1 H, m, J = 13.33, 5.59, m; 2.198, dd, J = 12.50, 5.02; 2.094, 1 H, ddd, J = 13.37, 6.62, 3.85; 1.929, 1 H, m; 1.765, 1 H, m; 1.617, ddd, J = 13.39, 9.19, 2.99; 1.325, dt, J_H = 7.14, J_P = 3.30.

5-Carbomethoxy-7-(2-(phenylthio)ethenyl)-8-oxabicyclo-[3.3.0]-1-octene (32). **27** (122 mg; 0.36 mmol; 1.00 equiv) was dissolved in 6 mL THF, and 81 mg (0.50 mmol; 1.38 equiv) of hexamethylphosphorus triamide was added. The reaction was heated to reflux. After 12 h, **27** was still prominent by TLC. Excess NaH (60% oil dispersion) was added, and gas evolution was noted. After 24 h at reflux, the reaction showed no **27** by TLC. The mixture was poured into a separatory funnel containing hexane and water. The hexane layer was washed with saturated NaCl solution, and dried over $MgSO_4$. The solvent was removed in vacuo, yielding 108.5 mg (99%) of crude material, which was pure by ^1H NMR (90 MHz) except for the presence of hexane. An analytical sample was prepared by preparative layer TLC purification, using 30% ether in hexane as eluent. TLC (1:1 EH): R_f 0.48–.51, pale green with *p*-AA spray, UV+. Mass spectrum (EI, 40 °C probe): 302 (19); 285 (8); 243 (26; M – CO_2CH_3); 215 (16); 193 (66); 165 (14); 162 (15); 161 (49); 147 (17); 137 (11); 134 (17); 133 (44); 110 (17); 109 (29; PhS^+); 105 (34); 91 (45); 79 (20); 78 (10); 77 (43); 71 (10); 65 (22); 59 (22); 55 (100); 53 (26); 51 (18); 45 (13); 41 (15). CI: 305 (5); 304 (17); 303 (100). IR (neat film): 5.77; 5.93; 6.20; 6.30; 6.75; 7.52, d; 7.75, d; 8.03; 8.25; 8.49; 9.21; 10.15; 13.3. ^{13}C NMR (20 MHz): δ 174.44, C_q; 162.05, C_q; 145.46, C_q; 133.43, C_q; 133.14, CH; 129.26, CH; 128.01, CH; 114.48, CH_2; 93.93, CH; 90.77, CH; 61.52, C_q; 52.34, CH_3; 41.56, CH_2; 36.11, CH_2; 33.81, CH_2. ^1H NMR (90 MHz): δ 7.55–7.10, 5 H, m; 5.66, 1 H, d, J = 1; 5.37, 1 H, dd, J = 6, 10; 4.98, 1 H, s; 4.63, 1 H, m; 3.68, 3 H, s; 3.05–2.5, 6 H, m.

Anal. Calcd for $C_{17}H_{18}O_3S$: 302.09767. Found 302.09772.

Dimethyl 2-(2-(Phenylthio)-2-butenyl)adipate ((*E*)-45 and (*Z*)-45). 2-Carbomethoxy-1-cyclopentanone (**23**) (82 mg; 0.577

mmol, 1.00 equiv) was added to a dry 25-mL flask containing 500 mg of K_2CO_3 (3.6 mmol, excess; anhydrous reagent grade, lightly ground), 4 mL of DMF and 1 mL of CH_3OH (43 equiv), and flushed with dry N_2. While the mixture was stirred at room temperature, 480 mg of reagent **18** in 2.4 mL DMF was added dropwise over several hours. After 12 h **45** and only a trace of **24** were seen by TLC. The reaction was treated with several drops of 30% H_2O_2 (excess, to convert the liberated triphenylphosphine to triphenylphosphine oxide), with external cooling as necessary, to keep the temperature below 30 °C. The mixture was poured into a separatory funnel containing 25 mL of hexane and 25 mL of ice water. The hexane layer was washed with saturated $NaHCO_3$ and saturated NaCl solutions, and dried over $MgSO_4$. The solvent was removed in vacuo, yielding 182 mg of colorless oil, containing ca. 25% triphenylphosphine oxide, a 70% yield. The analytical sample was purified by Lobar (Size B column) using 40% ether:hexane as eluent. A colorless oil (70.5 mg) was obtained, R_f 0.45 (1:1 EH), maroon with *p*-AA spray, UV+, along with ca. 1 mg **24** in another fraction (identified by TLC analysis only). HPLC analysis (5% THF:hexane, 3.0 mL/min, 600 psi, 254 nm detector): 6.72 min and 6.97 min, ratio of 1.00 to 1.67; 1.00 *Z* to 1.78 *E* by ^1H NMR integration (vide infra). VPC (SE-30, 200 °C/2 min, 16°/min to 230 °C): 12.06 min (59.38%) and 12.16 min (40.62%); this is a 1.00 to 1.46 ratio, however, the peaks were merged. Several other temperature programs also did not separate the isomers. Mass spectrum (EI): 336 (28); 304 (14; loss of CH_3OH); 277 (4, loss of CO_2CH_3); 227 (20, loss of SPh); 195 (27); 167 (30); 164 (28); 163 (32); 135 (100); 125 (30); 110 (58); 109 (43; SPh^+); 107 (51); 93 (92); 91 (48); 79 (50); 77 (44); 73 (20); 71 (30); 67 (28); 65 (39); 59 (99.9); 55 (69); 53 (46); 52 (22). CI: 338 (19); 337 (100, M + 1); 305 (38); 277 (12). IR (neat): 3.37, 5.74, 6.30, 6.75, 6.93, 7.25 (br); 8.33 (br), 8.55 (br), 10.87, 13.51, 14.39. ^1H NMR (200 MHz): δ 7.35–7.15, 5 H, m; 6.036 (minor*) q, J = 7.05, 6.018 (major*) q, J = 6.60; 3.650, 0.54 H, s; 3.644, 0.96 H, s; 3.640, 0.54 H, s; 3.619, 0.96 H, s; 2.566 (major*) t, J = 13.5, 2.526 (minor*) t, J = 13.7; 2.25, 4 H, m; 1.872, 0.64 H, dt, J = 6.60, 0.9, 1.759, 0.36 H, d, J = 7.05; 1.5, 4 H, m. *major + minor = 1 H, where separate integration was not practical due to overlapping peaks. ^1H NMR (470 MHz): δ Vinyl region, decoupling at 1.76: 6.041, s; 6.022, q, J = 6.35; decoupling at 1.86, 6.040, q, J = 6.65; 6.022, s. CH, no decoupling: 2.58, minor, dd, J = 13.3, 8.1; 2.51, major, dd, J = 14.1, 7.8. ^{13}C NMR (50 MHz) data presented as follows: Chemical shift, proton multiplicity (from off-resonance decoupling, confirmed by T_1 measurements), T_1 value (seconds), and M = Major isomer, m = minor isomer based on intensities at long delay times; C = coincidental peaks, ? = unassignable, δ 175.50, C_q, 17.39, M; 175.47, C_q, 18.81, m; 173.34, C_q, 24.92, C; 134.96, C_q, 19.00, m; 134.76, C_q, 19.27, M; 133.59, CH, 1.04, m; 133.49, CH, 1.31, M; 131.53, C_q, 11.12, m; 131.20, C_q, 10.93, M; 130.06, CH, 1.85, m; 129.20, CH, 1.83, M; 128.82, CH, ---, ?; 128.80, CH, 1.80, ?; 126.43, CH, 1.26, m; 125.94, CH, 1.34, M; 51.48, CH_3, 3.22, C; 51.39, CH_3, 3.92, C; 43.94, CH, 1.10, M; 43.79, CH, 1.08, m; 40.11, CH_2, 0.59, M; 33.66, CH_2, 1.17, C; 32.75, CH_2, 0.60, m; 31.16, CH_2, 0.67, m; 31.09, CH_2, 0.72, M; 22.63, CH_2, 1.19, m; 22.52, CH_2, 0.89, M; 15.75, CH_3, 3.17, M; 14.86, CH_3, 4.05, m.

Anal. Calcd for $C_{18}H_{24}O_4S$: 336.13954. Found: 336.13931.

2-Carbomethoxy-(2-(phenylthio)-5-phenyl-2,4-pentadienyl)-1-cyclopentanone (46-*E*,*E* and 46-*E*,*Z*). 2-Carbomethoxy-1-cyclopentanone **23** (92 mg; 0.647 mmol; 1.00 equiv) was added to a dry 25-mL flask containing 500 mg of K_2CO_3 (3.6 mmol, excess; anhydrous reagent grade, lightly ground), 5 mL of DMF, and 87 mg (0.820 mmol; 1.27 equiv) of benzaldehyde, under dry N_2. To this light yellow mixture 540 mg of reagent **18** (0.713 mmol; 1.10 equiv) in 5 mL of DMF was added dropwise over several hours, with good stirring. The reaction was treated with several drops of 30% H_2O_2 (excess, to convert the liberated triphenylphosphine to triphenylphosphine oxide), with external cooling as necessary, to keep the temperature below 30 °C. The mixture was poured into a separatory funnel containing 25 mL of hexane and 25 mL of ice water. The hexane layer was washed with saturated $NaHCO_3$ and saturated NaCl solutions, and dried over $MgSO_4$. The solvent was removed in vacuo, yielding 188 mg golden oil (77% crude yield, which was a mixture of **46** isomers and **24** by ^1H NMR (90 MHz)). TLC analysis (1:1 EH) showed four spots: 0.38, blue-green with *p*-AA spray, UV+; 0.44, purple with *p*-AA spray, UV+; 0.50, gray with *p*-AA spray, UV+; and 0.58, green with *p*-AA spray, UV+ (**24**). The mixture was submitted to preparative layer chromatography, using 1:3 EH, two elutions. The fastest band was 13 mg (0.045 mmol; 7%) of **24**. The two slower bands (86 mg, 34%: 2.3:1.0 and 2:3 mixtures of isomers, based on the integration of the ester methyls at 3.62 and 3.57 ppm, 90-MHz instrument) were again (separately) chromatographed, using 1:2 EH. Three fractions were obtained and analyzed by HPLC (5% THF:hexane, 3.0 mL/min, 600 psi, 254-nm detector) (ratio of the peaks eluting at 7.08 min and 9.60 min): (1) 85/15, 15 mg; (2) 68/32, 26 mg, this fraction shows a 64/36 ratio of the methyl groups at 3.64 and 3.59 ppm respectively, by integration of the ^1H NMR (200 MHz); (3) 98.8/1.2, 7 mg. The total recovery was 23.8 mg (faster eluting: *E*,*Z* isomer) and 14.6 mg (slower eluting: *Z*,*Z* isomer), in a ratio of 62% *E*,*Z* to 38% *Z*,*Z*.

Mixture of Isomers, Fraction 2. Mass spectrum (EI, 120 °C probe): 393 (12); 392 (54); 251 (28); 223 (14); 195 (12); 173 (57); 167 (19); 165 (19); 142 (51); 141 (100); 128 (19); 117 (10); 115 (50); 109 (12); 91 (57); 84 (11); 77 (12); 55 (14); 41 (11). CI: 394 (25); 393 (100); 376 (20); 375 (83; M + 1 − H_2O); 335 (23); 317 (12); 253 (19); 251 (94; $CH_2C(SPh)$=$CHCH$=$CHPh$); 143 (52); 111 (11). Note that **27** and **28** also show loss of water and then loss of the side chain (as R^+) in their CI spectra, and that all three of these compounds are 2-substituted-2-carbomethoxy-1-cyclopentanones. IR (film): 5.69; 5.77; 6.3; 6.75; 6.95; 8.15; 8.65; 9.8; 10.25; 10.9; 12.6; 14.4.

Anal. Calcd for $C_{24}H_{24}O_3S$: 392.1446. Found: 392.14514.

46-*E*,*Z*, Fraction 1, Faster Isomer/HPLC. TLC (1:1 EH): R_f 0.47, gray (hot), green (cool) with *p*-AA spray, UV+. ^1H NMR (200 MHz): δ 7.6–7.1, 10 H, m; 7.00, 1 H, d, J = 10.85; 6.86, 1 H, dd, J = 10.85, 11.04; 6.60, 1 H, d, J = 11.04; 3.59, 3 H, s; 2.91, 2.61, AB, 2 H, J = 14.11; 2.6–1.8, 6 H, m.

46-*E*,*E*, Fraction 3, Slower Isomer/HPLC. TLC (1:1 EH): R_f 0.40, gray (hot), green (cool) with *p*-AA spray, UV+. IR (film): 5.68; 5.77. ^1H NMR (200 MHz): δ 7.6–7.1, 11 H, m; 7.43, dd, J = 10.4, 15.7; 6.71, 1 H, d, J = 15.7; 6.70, 1 H, d, J = 10.4; 3.64, 3 H, s; 3.06, 2.68, AB, 2 H, J = 14.51; 2.48–1.73, 6 H, m.

Dimethyl 2-(2-(Phenylthio)-5-phenyl-2,4-pentadienyl)-adipate (47-*E*,*E* and 47-*E*,*Z*). 2-Carbomethoxy-1-cyclopentanone (**23**) (90.0 mg; 0.633 mmol; 1.00 equiv) was added to a dry 25-mL flask containing 500 mg of K_2CO_3 (3.6 mmol, excess; anhydrous reagent grade, lightly ground), 5 mL of CH_3OH, and 68.2 mg (0.643 mmol; 1.015 equiv) of benzaldehyde, under a N_2 atmosphere. While stirring, 500 mg of reagent **18** (0.660 mmol; 1.12 equiv) in 7 mL of CH_3OH was added dropwise over several hours. After the mixture was stirred at room temperature for 12 h, a TLC (1:1 EH) showed the expected triphenylphosphine as well as two tight spots, 0.39 and 0.44, gray (hot) pale yellow (cool) with *p*-AA spray, UV+. The reaction was treated with several drops of 30% H_2O_2 (excess, to convert the liberated triphenylphosphine to triphenylphosphine oxide), with external cooling as necessary, to keep the temperature below 30 °C. The mixture was poured into a separatory funnel containing 25 mL of hexane and 25 mL of ice water. The hexane layer was washed with three 15-mL portions of water, and dried over K_2CO_3. The solvent was removed in vacuo yielding 137 mg (51%) of crude product, which was a mixture of **45**-*E*/*Z* and **47** (isomers) by ^1H NMR (90 MHz). The material was purified by preparative layer chromatography using 1:3 EH as eluent. After two elutions, the main band (R_f 0.32, 34 mm wide) was cut in two and extracted. The upper half (38.4 mg) showed one spot by TLC (1:1 EH), 0.48 gray with *p*-AA spray, UV+, while the slower half (70.0 mg), which was visibly yellow, showed two tight spots, 0.43, greenish-gray and 0.48, gray with *p*-AA spray, both UV+. HPLC analysis (5% THF:hexane, 3.0 mL/min, 600 psi, 25-nm detector) showed them to be more complex. The faster fraction contained 20.7% (19% by ^1H NMR (200 MHz) integration of vinyl region) **45**-*E*/*Z* at 6.22 min, 61.6% faster isomer (7.62 min, *E*,*Z*), a 8.8% shoulder (8.13 min, Z,E) and 8.9% of a slower isomer (10.12 min, *E*,*E*). The slower fraction contained 3.9% **45**-*E*/*Z*, 31.2% faster isomer, 7.0% shoulder, and 57.9% slower isomer. Based on this data the mixture is 9.9% **45**-*E*/*Z*, 42.0% faster isomer (*E*,*Z*), 42.0% faster isomer (*E*,*Z*), 7.6% "shoulder", and 40.6% slower isomer (*E*,*E*).

Data from slower fraction: mass spectrum (EI, 120 °C probe), 425 (6); 424 (30); 213 (12); 185 (43); 181 (12); 173 (38); 167 (18); 153 (11); 142 (47); 141 (100); 135 (24); 129 (10); 128 (20);

117 (13); 115 (53); 110 (17); 109 (20); 93 (15); 91 (64); 77 (17); 65 (13); 59 (41); 55 (23); 45 (15); 41 (19). CI: 426 (28); 425 (100); 393 (10); 337 (15, could be **45-*E*/*Z***). IR (film): 3.2–3.5; 5.7–5.8; 6.3; 6.7; 6.9; 7.3; 7.7–8.9; 9.3; 9.8; 10.3; 11.0; 13.3; 14.3.

Anal. Calcd for $C_{25}H_{28}O_4S$: 424.17084. Found: 424.17097.

47-*E*,*Z*, faster isomer/HPLC: IR (film): same as above except no peaks at 10.3 and 11.0. ^{1}H NMR (200 MHz): δ 7.5–7.15, 10 H, m; 6.91, 1 H, d, J = 10.74; 6.83, 1 H, dd, J = 10.46, 10.74; 6.55, 1 H, d, J = 10.46; 3.64, 3.62, 6 H, 2s; 2.9–2.1, 5 H, m; 1.7–1.2, 4 H, m. (Integration on the 90-MHz instrument.)

47-*E*,*E*, slower isomer/HPLC: ^{1}H NMR (200 MHz): δ 7.5–7.15, 12 H, m; 7.40, dd, J = 10.69, 15.20; 7.22, d, J = 10.69; 6.67, 1 H, d, J = 15.20; 3.64, 3.62, 6 H, 2 s; 2.9–2.1, 5 H, m; 1.7–1.2, 4 H, m. (Integration on the 90-MHz instrument.)

1-Phenyl-4-(phenylthio)-5-methoxy-1,3-pentadiene (48-*E*,*E*, 48-*E*,*Z*, and 48-*Z*,*E*). 2-Methyl-1,3-cyclohexanedione (76.0 mg; 0.602 mmol; 1.00 equiv) was added to a dry 25-mL flask containing 500 mg of K_2CO_3 (3.6 mmol, excess; anhydrous reagent grade, lightly ground) and 5 mL of CH_3OH. Reagent **18** (500 mg, 0.660 mmol, 1.12 equiv) dissolved in 3 mL of CH_3OH was added dropwise over several hours. After 12 h, the reaction mixture was treated with a few drops of 30% H_2O_2 (excess, to convert the liberated triphenylphosphine to triphenylphosphine oxide), with external cooling as necessary, to keep the temperature below 30 °C. The mixture was poured into a separatory funnel containing 25 mL of hexane and 25 mL of ice water. The hexane layer was washed with three 15-mL portions of water, and dried over K_2CO_3. The solvent was removed in vacuo yielding 188 mg (99%) of crude product. The material was purified by preparative layer chromatography using 1:2 EH as eluent. There was essentially one band of UV activity, 32 mm wide; the lower 10 mm was visibly yellow. It was cut into two bands: faster, colorless, 57.8 mg; slower, yellow, 24.0 mg; total: 81.8 mg, 43%. The two fractions were analyzed by HPLC (5% THF:hexane, 3.0 mL/min, 600 psi, 254-nm detector): faster, 64% at 1.88 min, 36% at 2.24 min; slower, 98.3% at 2.24 min; 1.7% at 1.88 min. TLC (1:1 EH): R_f 0.65, purple with p-AA spray, UV+, essentially the same for both fractions.

48-*E*,*E* with some 48-*Z*,*E*, slower fraction: mass spectrum (EI, 50 °C probe), 283 (19; M + 1, calcd, 21); 282 (100); 218 (11, M - CH_3OH,S); 173 (41; M - SPh); 172 (13); 171 (15); 157 (20); 143 (13); 142 (22); 141 (82); 129 (30); 128 (38); 115 (54); 110 (17); 109 (24); 105 (20); 104 (10); 91 (28); 77 (22); 65 (16); 51 (13); 45 (92). CI: 283 (2); 282 (3); 267 (4); 252 (21); 251 (100; M - CH_3O). IR (film): 6.3; 6.68; 6.75; 6.68; 6.94; 8.35; 9 (br); 9.7; 10.3 (split); 13.3; 14.5. ^{1}H NMR (200 MHz): δ 7.55–7.15, 11 H, m; 7.46, dd, J = 10.71, 15.66; 6.90, 1 H, d (broadened by allylic coupling to 3.98), J = 10.71; 6.75, 1 H, d, J = 15.66; 3.98, 2 H, s; 3.32, 3 H, s. Decoupling at 6.83 revealed 7.46, and decoupling at 3.98 sharpened the 6.90 doublet. About 10% **48-*Z*,*E*** was in this fraction: ^{1}H NMR (200 MHz), δ 6.48, d, J = 14.16; 6.42, d, J = 10.75; CH_2 at 4.23, s; CH_3 at 3.36, s.

Anal. Calcd for $C_{18}H_{18}OS$: 282.10784. Found: 282.10815.

48-*E*,*Z*, data from faster fraction: IR (film), same as above except weaker 10.3 band. ^{1}H NMR (200 MHz): 7.5–7.15, 11 H, m; 7.42, d, J = 10.71; 6.91, 1 H, dd, J = 11.52, 11.04; 6.65, 1 H, d, J = 11.52; 3.94, 2 H, s; 3.27, 3 H, s. 8% **48-*Z*,*E*** was present in this fraction. Apparently, the *Z*,*E* isomer elutes with the *E*,*E* isomer. Overall isomer ratios, by ^{1}H NMR (200 MHz) integration: 47.1% *E*,*E*; 44.3% *E*,*Z*; 8.6% *Z*,*E*.

4-(Phenylthio)-6-Carbomethoxybicyclo[4.4.0]deca-1,3-diene (34). Reagent **18** (1.20 equiv) at room temperature, 78% yield; it can be purified by plug filtration on silica gel with hexane. TLC (1:1 EH): R_f 0.44 gray (hot), green (cool), both with yellow center, with p-AA spray, UV+. Mass spectrum (EI, 120 °C probe): 300 (80); 241 (74; M - CO_2CH_3); 163 (78); 131 (94); 115 (34); 109 (51; SPh^+); 104 (48); 91 (83); 77 (60); 51 (92); 39 (100). IR ($CDCl_3$, corrected): C=O at 5.80. ^{1}H NMR (90 MHz): δ 7.4–7.1, 5 H, m; 6.02, 1 H, dd, J = 6.0, 12.8; 5.78, 1 H, d (br), J = 12.8; 3.62, 3 H, s; 2.79, 1 H, d (part of AB, J = 18); 2.5–2.1, 3 H, m; 1.9–1.1, 6 H, m. ^{13}C NMR (50 MHz; chemical shift, proton multiplicity, T_1): δ 175.63, C_q, 40; 138.54, C_q, 19.6; 134.17, C_q, 34.8; 131.32, CH, 2.91; 129.10, C_q, 10.5; 128.91, CH, 2.94; 127.11, CH, 2.39; 126.02, CH, 1.80; 120.98, CH, 1.93; 52.10, CH_3, 5.31; 48.22, C_q, 19.9; 41.19, CH_2, 1.17; 39.02, CH_2, 1.03; 32.35, CH_2, 1.09; 26.10, CH_2, 0.93; 23.34, CH_2, 1.09.

Table I

temp, °C	equiv reagent	crude yield[a]	% fused/spiro
25	0.788	30% (reagent)	<5/>95[b]
60	0.826	81% (reagent)	6/94[b]
110	0.788	68% (reagent)	10/90[b]
120	1.10	85% (substrate)	35/65[c]

[a] Yields based on equivalents of reagent **18** or substrate. [b] Determined by ^{1}H NMR (90 MHz) integration. [c] Isolated.

Anal. Calcd for $C_{18}H_{20}O_2S$: 300.118. Found: 300.116.

4-(Phenylthio)-6-acetylbicyclo[4.4.0]deca-1,3-diene (36F) and 1-Methyl-4-(phenylthio)spiro[5.5]undeca-1,3-dien-7-one (36S). 2-Acetylcyclohexanone **35** (2.26 mmol) 0.905 equiv of reagent **18** in DMF at 60 °C under N_2: 547 mg (94%, based on reagent) crude oil, containing both fused (**36F**) and spiro (**36S**) product. Part was purified by preparative layer chromatography, and part by Lobar (Size B column). The results were as follows:

	PLC	Lobar	total ratio
fused	77.6 mg	108.6 mg	186.2 mg (54%)
spiro	68.0 mg	89.0 mg	157.0 mg (46%)
			401.8 mg (69%)

In another run, with use of 2.13 mmol of substrate and 1.10 equiv of reagent **18**, at 80 °C, a 410 mg (68%, based on substrate) crude yield was obtained.

36F: TLC (1:1 EH) R_f 0.57–.62, bright blue with p-AA spray, UV+. Mass spectrum (EI, 150 °C probe): 284 (26); 282 (19); 241 (100; M - CH_3CO); 163 (74; M - CH_3CO,PhH); 131 (40; M - CH_3CO,PhH,S); 109 (21; SPh^+); 104 (25); 91 (28); 43 (40; CH_3CO^+). ^{13}C NMR (20): δ 211.25, C_q; 139.36, C_q; 133.13, C_q; 132.22, CH; 129.71, C_q; 129.11, CH; 127.65, CH; 124.59, CH; 121.04, CH; 53.92, C_q; 40.97, CH_2; 38.05, CH_2; 33.16, CH_2; 26.57, CH_2; 26.27, CH_3; 23.45, CH_2. IR ($CDCl_3$, corrected): 5.85–5.88. ^{1}H NMR (90 MHz): δ 7.45–7.15, 5 H, m; AB, 6.9, 2 H, m (there is one 6-Hz coupling present in each of the AB pairs; the upfield pair also has ca. a 2-Hz coupling); 2.9–1.1, 13 H, m (CH_3 singlet 2.09).

Anal. Calcd for $C_{18}H_{20}OS$: 284.123. Found: 284.125.

36S: TLC (1:1 EH): R_f 0.52, greenish with p-AA spray, UV+. Mass spectrum (EI, 150 °C probe): 284 (100); 256 (34; M - 28); 241 (6); 213 (38); 109 (16; SPh^+); 105 (97); 91 (32); 77 (31); 65 (20) 55 (15); 51 (23); 39 (27). ^{13}C NMR (20): δ 213.25, C_q; 138.79, C_q; 134.28, C_q; 131.53, CH; 131.12, C_q; 129.14, CH; 127.34, CH; 127.01, CH; 122.74, CH; 54.81, C_q; 38.73, CH_2; 38.21, CH_2; 32.95, CH_2; 25.95, CH_2; 20.01, CH_3; 19.77, CH_2. IR ($CHCl_3$): 5.85. ^{1}H NMR (90 MHz): δ 7.45–7.15, 5 H, m; AB, 6.08, 1 H, d, J = 6, and 5.82, 1 H, dd, J = 6,1; 2.85–1.35, 13 H, m (CH_3 singlet at 1.73).

Anal. Calcd for $C_{18}H_{20}OS$: 284.123. Found: 284.122.

2-(Phenylthio)-10a-acetyl-9,10-dihydro-1*H*-phenanthrene (38F) and Spiro[2-methyl-5-(phenylthio)-2,4-cyclohexadiene-1,2′-tetralone] (38S). (See Table I.)

Thus, 300 mg (1.60 mmol; 1.00 equiv) of 2-acetyl-1-tetralone (**37**) and 1.33 g (1.76 mmol; 1.10 equiv) of reagent **18** at 120 °C yielded 450 mg (85%, based on substrate) of crude **38F**/**38S**. Purification by Lobar (size B column) using 10% ethyl acetate-/hexane yielded 61.8 mg **38F** (fused) and 136.9 mg **38S** (spiro), 39.5; after purification.

38F: TLC (1:1 EH): R_f 0.48, brown with p-AA spray, UV+. Mass spectrum (EI, 90 °C probe): 332 (21); 288 (38; M - CH_3CO); 181 (14); 180 (100; M - CH_3CO, SPh); 179 (75); 178 (34); 165 (22); 43 (71). CI: 335 (8.5); 334 (25); 333 (100); 179 (12). IR ($CHCl_3$): 5.86. ^{1}H NMR (200 MHz): δ 7.745, d, J = 1.9; 7.704, 1 H, s (br); 7.5–7.0, 8 H, m; AB, 6.737, 1 H, d, J = 5.95, 5.958, 1 H, dd, J = 5.95, 2.74; AB, 2.795, 1 H, d, J = 16.8, 2.431, 1 H, dd, J = 16.8, 2.81; 2.71–2.51, 2 H, m; 2.037, 3 H, s; 2.2–2.1, 2 H, m. Decoupling at 5.96 reduces 2.431 to a doublet, J = 16.8, and 6.737 to a singlet.

Anal. Calcd for $C_{22}H_{20}OS$: 332.12349. Found: 332.12342.

38S: TLC (1:1 EH): R_f 0.53, brown with p-AA spray, UV+. Mass spectrum (EI, 120 °C probe): 332 (8); 96 (54); 94 (86); 58 (32); 49 (31); 47 (41); 43 (100). IR ($CHCl_3$): 5.95, 6.23, 6.30. ^{1}H NMR (200 MHz): δ 8.022, 1 H, d, J = 7.81; 7.5–7.1, 8 H, m; AB, 6.121, 1 H, dd, J = 2.52, 5.74 and 5.837, 1 H, dd, J = 1.46, 5.74; AB, 2.774, 1 H, d (br), J = 16.8, 2.341, 1 H, d, J = 16.8; 2.8–2.7, 2 H, m; 2.25–1.81, 2 H, m; 1.698, 3 H, s. Decoupling at 7.25 reduces

8.022 to a singlet; decoupling at 6.12 sharpens 2.774. ^{13}C NMR (20 MHz); δ 200.89, C_q; 143.04, C_q; 138.54, C_q; 133.67, C_q; 133.36, C_q; 132.40, C_q; 131.85, CH; 129.03, CH; 128.53, CH; 128.06, C_q; 127.90, CH; 127.37, CH; 126.74, CH; 125.34, CH; 122.47, CH; 51.58, C_q; 35.96, CH_2; 28.88, CH_2; 24.58, CH_2; 19.75, CH_3.

Anal. Calcd for $C_{22}H_{20}OS$: 332.1235. Found: 332.124.

General Procedure for Dienyl Sulfide Hydrolysis with $TiCl_4$/Acetic Acid, Then DBU Treatment: 6-Carbomethoxybicyclo[4.3.0]non-2-en-4-one ((*E*)-39 and (*Z*)-39). **24** (113 mg; 0.395 mmol; 1.00 equiv) was dissolved in 5 mL of CH_2Cl_2, cooled to 0 °C, and treated with 1.0 mL of a 0.5 M suspension of $TiCl_4$ in glacial acetic acid, added dropwise. This represents 1.34 equiv of $TiCl_4$. A brown precipitate rapidly formed. After ca. 30 min, 0.025 mL (3.5 equiv) of water was added, and the reaction was stirred at room temperature for 24 h. Hexane (25 mL) was added to the clear brown solution, and the fuming mixture was transferred to a separatory funnel, with a little more hexane used in the transfer. The hexane layer was washed with 2 × 25 mL of water and 25 mL of saturated $NaHCO_3$ solution. The organic phase was dried over anhydrous K_2CO_3, decanted from the solid, and treated with 0.01 mL (0.67 mmol; 1.69 equiv) of DBU. The reaction was stirred at 25 °C for several hours and poured into 25 mL water, and the layers were separated. The organic phase was washed with 10 mL of 0.6 N HCl and 10 mL of saturated $NaHCO_3$ solution, and dried over $MgSO_4$, and the solvent was removed in vacuo. The resulting oil was chromatographed on silica gel, by using hexane, then 25% ether/hexane as eluent. 58 mg (75%) (*Z*)-**39**, as a nearly colorless oil was obtained. TLC (1:1 EH): R_f 0.14 (.21), 0.34 (7:3 EH), purple (hot) green (cool) with *p*-AA spray, UV+. VPC (SE-30, 150 °C/2 min, 8°/min to 230 °C: 6.43 min.

((*Z*)-**39**): Mass spectrum (EI): 79 (10); 77 (10); 69 (19); 65 (10); 59 (21); 55 (10); 53 (24); 52 (16); 51 (16); 50 (19); 42 (14); 41 (35); 39 (100); 38 (19). IR ($CDCl_3$): 3.15; 3.37; 5.48–5.56; 5.78 (s); 5.95 (s, br); 6.33; 6.83; 8.01; 9.13; 11; 14. ^{13}C NMR (50 MHz): δ 197.10, C_q; 176.32, C_q; 150.84, CH; 127.89, CH; 54.11, C_q; 52.49, CH_3; 44.06, CH; 42.14, CH_2; 35.88, CH_2; 31.56, CH_2; 23.8, CH_2. ^1H NMR (360 MHz): δ Vinyl ABX, 6.80, 1 H, dd, *J* = 10.67, 4.59, and 5.95, 1 H, dd, *J* = 10.67, 1.99; 3.695, 3 H, s; 3.17, 1 H, dtd, *J* = 12.7, 8.12, 1.62; AB, 2.78, 1 H, and 2.53, 1 H, *J* = 16.3; 2.24, 2 H, m; 1.84, 2 H, dt, *J* = 7.2, 7.2; 1.69, 2 H, dt, *J* = 12.7, 8.14.

Anal. Calcd for $C_{11}H_{14}O_3$: 194.09430. Found: 194.09421.

1-Carbomethoxy-5-(phenylthio)bicyclo[4.3.0]nonan-3-one (49). **24** (113 mg; 0.395 mmol; 1.00 equiv) was dissolved in 5 mL of CH_2Cl_2, cooled to 0 °C, and treated with 1.0 mL of a 0.5 M suspension of $TiCl_4$ in glacial acetic acid, added dropwise. This represents 1.34 equiv of $TiCl_4$. A brown precipitate rapidly formed. After ca. 30 min, 0.025 mL (3.5 equiv) water was added, and the reaction was stirred at room temperature for 24 h. Hexane (25 mL) was added to the clear brown solution, and the fuming mixture was transferred to a separatory funnel, with a little more hexane used in the transfer. The hexane layer was washed with 2 × 25 mL water and 2 × 25 mL saturated $NaHCO_3$ solution. The organic phase was dried over anhydrous $MgSO_4$, and the solvent removed in vacuo. A yellow oil (100 mg; 83%), which was pure (as a mixture of diastereomers) by TLC and ^1H NMR (90 MHz), was obtained. It was further purified by Lobar (Size B column) using 20% THF in hexane, yielding 60 mg colorless oil. TLC (1:1 EH): R_f 0.34–0.39, dark gray with *p*-AA spray, UV+. mass spectrum (EI, 70 °C probe): 304.1 (10.3); 195.1 (27.6; M – SPh); 163 (11); 135 (100; M – CO_2CH_3, SPh); 110 (12); 109 (33, SPh^+); 107 (67); 93 (39); 91 (19); 79 (39); 77 (18); 65 (16); 59 (12). CI (100 °C probe): 306.1 (7.9); 305.1 (43.6); 196.1 (12); 195.1 (100; HM–SPh). IR (film): 3.37; 3.46; 5.71 (vs, br); 6.3; 6.76; 6.93; 8.3 (br); 13.3; 14.4. ^1H NMR (90 MHz): δ 7.5–7.1, 5 H, m; 3.64 (minor), 3.61 (major), 3 H, sharp singlets; 3.15, 1 H, m; 2.9–1.4, 11 H, m.

6-Carbomethoxybicyclo[4.3.0]non-1-en-4-one (50). **24** (276.1 mg; 0.946 mmol; 1.00 equiv) was dissolved in 5 mL of CH_3CN and 1 mL water was added. $HgCl_2$ (800 mg; 2.95 mmol; 3.06 equiv) was added, and the mixture was heated to reflux for 24 h. After being cooled and filtered the mixture was poured into a separatory funnel containing 10 mL of ether and 10 mL of saturated NaCl solution; the ether layer was washed with 5 mL each water, saturated $NaHCO_3$ solution, and saturated NaCl solution, and dried over K_2CO_3. The solvent was removed in vacuo, and the residue was purified by Lobar (Size B column) using 20% ethyl acetate in hexane. **24** (35 mg) was recovered, along with 57.5 mg (35.2%) **50** and 24.1 mg (14.7%) **39**, yields based on unrecovered **24**. This represents a 50% yield of enone, in a 70 to 30 ratio of **50** to **39**.

50: TLC (1:1 EH), R_f 0.17, brown to purple, with *p*-AA spray, UV–. VPC (SE-30, 150 °C/2 min, 8°/min to 230 °C): 6.02 min. Mass spectrum (EI, 30 °C probe): 195 (3); 194 (9); 152 (4; M – $CH_2C{=}O$); 151 (3); 136 (7); 135 (100; M – CO_2CH_3); 134 (8); 120 (12); 107 (37); 106 (11); 93 (22); 92 (14); 91 (36); 79 (48); 77 (16); 43 (12); 41 (15); 40 (23). CI: 196 (8); 195 (100). IR ($CHCl_3$): 5.68–5.95, very broad and strong. ^{13}C NMR (50 MHz): δ 208.53, C_q; 174.52, C_q; 145.15, C_q; 117.49, CH; 53.90, C_q; 52.33, CH_3; 48.10, CH_2; 38.16, CH_2; 37.13, CH_2; 30.82, CH_2; 24.11, CH_2. ^1H NMR (90 MHz): δ 5.75, 1 H, m; 3.63, 3 H, s; 3.0–2.8, 3 H, m, and 2.65–2.35, 3 H, m, including an AB, 2.89 and 2.13, *J* = 16; 2.3–2.0, 2 H, m; 2.0–1.6, 2 H, m. ^1H NMR (200 MHz): δ 5.747, 1 H, six lines in a 1:3:4:4:3:1 pattern, with spacings of 2.28, 2.34, 2.33, 2.28, 2.22 Hz. This represents a dddd with *J* = 4.6, 2.3, 2.3, 2.3. ^1H NMR (470 MHz): 5.735, 1 H, m; 3.654, 3 H, s; AB: 2.164, 1 H, and 2.899, 1 H, *J* = 15.78.

Anal. Calcd for $C_{11}H_{14}O_3$: 194.09430. Found: 194.09421.

6-Carbomethoxybicyclo[4.4.0]dec-2-en-4-one ((*E*)- and (*Z*)-40). Synthesis from CuO in CF_3CO_2H; see **39** for conditions: 1.50 g (5.00 mmol; 1.00 equiv) of **34** gave 507 mg (49%) of a mixture of (*E*)-**40**, (*Z*)-**40**. Synthesis from $TiCl_4$ in acetic acid: 147 mg (0.49 mmol; 1.00 equiv) of **34** in 0.5 mL of $TiCl_4$ in 2.5 mL of acetic acid, 0.030 mL of water, and 0.75 mL (1.5 equiv) of DBU gave 20.0 mg (20%) of the enone, 23% (*E*)-**40** to 77% (*Z*)-**40**. VPC (SE-30, 150 °C/2 min, 8°/min to 230 °C): (*E*)-**40**, 7.47 min; (*Z*)-**40**, 8.00 min. TLC (1:1 EH): R_f 0.33, gray (hot), green (cool) with *p*-AA spray, UV+; both isomers together. GC/MS (OV-101 column, 150 °C/2 min, 8°/min to 230 °C): 2.65 min, minor component ((*E*)-**40**). EI: 208 (8); 150 (27); 149 (100; M – CO_2CH_3); 148 (14); 121 (13); 120 (12); 108 (6); 107 (28); 93 (12); 91 (21); 81 (17); 79 (21); 77 (16); 59 (15); 55 (15); 53 (14); 41 (15). CI: 211 (3); 210 (20); 209 (100); 149 (2): 2.97 min, major component ((*E*)-**40**), EI: 209 (2); 208 (3); 150 (13); 149 (100; M – CO_2CH_3); 107 (37); 91 (18); 79 (19); 77 (15); 59 (13); 55 (12); 53 (14); 41 (13). CI: 211 (2); 210 (20); 209 (100); 149 (2). IR ($CDCl_3$, mixture): 5.78, 5.95.

Anal. Calcd for $C_{12}H_{16}O_3$: 208.10995. Found: 208.11051.

(*E*)-**40**: ^{13}C NMR (50 MHz): δ 197.61*; 176.72*; 155.69; 128.65; 51.89; 51.57; 44.21; 41.90; 36.54; 26.98; 26.04; 22.01 (* refers to peaks which may be coincident with (*Z*)-**40**; the intensity ratio for the ten unique peaks, as compared with the corresponding peaks of (*Z*)-**40** was 1.00 to 2.33 (s = 0.70)). ^1H NMR (200 MHz), partial: Vinyl ABX, 6.85, 1 H, d, *J* = 10.1, and 5.93, 1 H, dd, *J* = 10.1, 1.1; 3.63, 3 H, s.

(*Z*)-**40**: ^{13}C NMR (50 MHz): δ 197.61; 176.42; 153.51; 128.57; 52.40; 50.74; 48.13; 38.56; 32.21; 28.16; 23.84; 21.55. ^1H NMR (200 MHz): δinyl ABX, δ 6.85, 1 H, dd, *J* = 10.11, 4.72, and 5.96, 1 H, dd, *J* = 10.11, 1.49 (reducing to an AB at 6.897 and 6.004, *J* = 10.09 on decoupling at 2.98); 3.678, 3 H, s; 2.98, 1 H, m; AB, 2.94, 1 H, and 2.31, 1 H, *J* = 16.6; 1.98–1.03, 8 H, m.

6-Methylbicyclo[4.4.0]dec-2-ene-4,7-dione ((*E*)-41 and (*Z*)-41). **26** (78 mg; 0.288 mmol; 1.00 equiv) in 1 mL of CH_2Cl_2 was cooled to 0 °C and treated with 0.5 mL of 1.0 M (1.00 mmol; 1.73 equiv) $TiCl_4$ in CH_2Cl_2, and 0.5 mL acetic acid. The dark brown turbid mixture became clear and dark red on adding the acetic acid. After 20 min, .021 mL (4 equiv) of water was added, and the reaction was stirred an additional 20 min at 0 °C. The reaction was then stirred for 12 h at room temperature. The mixture was poured into a separatory funnel containing 10 mL 1:1 ether in hexane, and 10 mL water. The organic phase was washed with 10 mL 10% K_2CO_3 solution, and the aqueous phase was neutralized with K_2CO_3 and extracted with 10 mL 1:1 ether in hexane. The combined organic phases were dried over K_2CO_3, and treated with 0.100 mL (0.67 mmol; 2.3 equiv) of DBU. Immediate white turbidity was noted. After stirring for 1 h at room temperature, the reaction mixture was extracted with 3 mL of 1.2 N HCl, which remained acidic. The organic phase was dried over K_2CO_3, and the solvent was removed in vacuo, yielding 58 mg crude oil. After two preparative-layer TLC purifications (1:1 EH), two bands were obtained: 15.4 mg (*Z*)-**41**, TLC (3:1 EH), R_f 0.22, VPC (SE-30, 150 °C/2 min, 8°/min to 230 °C), 98% at 7.74 min; and 8.9 mg, TLC (3:1 EH), R_f 0.13, VPC (SE-30, 150

°C/2 min, 8°/min to 230 °C), 23% at 6.57 min, **51**, vide infra, and 76% at 7.44 min, (*E*)-**41**. This represents a 47% yield of enones, and an additional less pure band (6.9 mg) was also obtained. A 49% yield of a virtually identical mixture (by ^{1}H NMR) was obtained in another run.

(*E*)- and (*Z*)-41 from $HgCl_2$ in aqueous CH_3CN: **26** (330 mg; 1.22 mmol; 1.00 equiv) in 7.0 mL of CH_3CN and 2.0 mL of water was treated with 1200 mg (4.4 mmol; 3.6 equiv) of $HgCl_2$, and heated to reflux for 28 h. The reaction mixture was thick with heavy crystals. On cooling more crystals formed, the reaction was filtered, and the crystals were washed with a little more cold CH_3CN. The mixture was poured into a separatory funnel containing 30 mL ether and 20 mL saturated $NaHCO_3$ solution, whence much more precipitate formed, so another filtration was conducted. The solid was washed with three 10-mL portions of ether, and the combined organic phases were washed with saturated $NaHCO_3$ and saturated NaCl solutions. After drying over K_2CO_3 and $MgSO_4$, the solvent was removed in vacuo, yielding 198.6 mg semi-solid oil, which was purified by Lobar (Size B column) by using 20% ethyl acetate in hexane, 254 nm detector. Starting material (12 mg; 3.6%) was recovered, along with two main enone fractions: 24 mg (12%, based on unrecovered **26**) of (*E*)-**41**, TLC (3:1 EH), R_f 0.24, brown with *p*-AA spray, UV+, VPC (SE-30, 150 °C/2 min, 8°/min to 230 °C), 7.45 min; and 63 mg (31%) of (*Z*)-**41**, TLC (1:1 EH), R_f 0.15, brown with *p*-AA spray, UV+, VPC (SE-30, 150 °C/2 min, 8°/min to 230 °C), 7.66 min. VPC analysis of the crude material prior to purification by Lobar indicated ca. 1 part **51** to 6 parts (*E*)- and (*Z*)-**41**; during chromatography the **51** was not detected, probably owing to low UV absorption, and hence was not isolated. The isolated yield was 43% (*E*)- and (*Z*)-**41**, and VPC yield was 50% total enones.

(*E*)-**41**: mp, softened at 55 °C, liquid at 65 °C. Mass spectrum (EI, 35 °C probe): 179 (15); 178 (50); 160 (3; M − H_2O); 150 (37; M − CO); 135 (32; M − CH_3CO); 134 (65; M − CH_2=C=O); 122 (20); 121 (40); 119 (8); 108 (19); 107 (31); 106 (25); 97 (12); 95 (22); 94 (80); 93 (62); 91 (39); 84 (18); 82 (16); 81 (35); 80 (33); 79 (100); 78 (14); 77 (46); 69 (16); 68 (22); 67 (34); 66 (47); 65 (21); 55 (64); 54 (11); 53 (50); 52 (17); 51 (23); 43 (21); 42 (29); 41 (79); 40 (22); 39 (93). CI: 181 (1); 180 (11); 179 (100); 161 (1.3); 117 (1.4). IR ($CDCl_3$): 5.83; 5.95. ^{13}C NMR (50 MHz): δ 211.98, C_q; 198.70, C_q; 149.75, CH; 129.47, CH; 50.20, C_q; 46.55, CH_2; 45.19, CH; 36.18, CH_2; 25.86, CH_2; 25.25, CH_2; 16.44, CH_3. ^{1}H NMR (200 MHz): Vinyl ABX (Y), 6.618, 1 H, dd, *J* = 9.95, 2.04, and 6.012, 1 H, ddd, *J* = 9.95, 3.10, 0.96; 2.75–1.5, 9 H, m; 1.183, 3 H, s. ^{1}H NMR (470 MHz): Vinyl ABX, 6.616, dd, *J* = 10.11, 1.59, and 6.018, dd, *J* = 10.11, 3.06.

Anal. Calcd for $C_{11}H_{14}O_2$: 178.09938. Found: 178.10103.

(*Z*)-**41**: mp, 70-72 °C. Mass spectrum (EI, 35 °C probe): 180 (1); 179 (6); 178 (47); 163 (3; M − CH_3); 160 (3; M − H_2O); 150 (7; M − CO); 135 (20; M − CH_3CO); 134 (88; M − CH_2=C=O); 122 (17); 121 (50); 108 (29); 107 (27); 106 (16); 97 (11); 95 (26); 94 (79); 93 (55); 91 (27); 82 (12); 81 (30); 80 (37); 79 (100); 77 (40); 68 (20); 67 (29); 66 (26); 65 (13); 55 (33); 53 (34); 52 (10); 51 (13); 42 (24); 41 (50); 40 (24); 39 (63). CI: 181 (1); 180 (9); 179 (100); 161 (1). IR ($CDCl_3$): 5.83; 5.90, 5.95 (doublet). ^{13}C NMR (50 MHz): δ 212.26, C_q; 197.41, C_q; 151.38, CH; 130.70, CH; 50.80, C_q; 45.73, CH_2; 45.21, CH; 37.51, CH_2; 26.27, CH_2; 23.50, CH_2; 24.12, CH_3. ^{1}H NMR (200 MHz): Vinyl ABX, δ 6.611, 1 H, dd ⟨LW⟩ = 1.20 Hz, *J* = 10.19, 2.61, and 6.029, 1 H, dd ⟨LW⟩ = 2.22 Hz, *J* = 10.19, 2.48; 3.0–1.6, 9 H, m, with AB, 2.949 (⟨LW⟩ = 2.16 Hz; sharpened to ⟨LW⟩ = 1.67 Hz by decoupling at 6.03) and 2.133 (⟨LW⟩ = 1.31 Hz; broadened to ⟨LW⟩ = 1.72 Hz by decoupling at 6.03), *J* = 16.30; 1.355, 3 H, s. ^{1}H NMR (470 MHz): Vinyl ABX, δ 6.609, dd, *J* = 10.17, 2.52, and 6.031, dd, *J* = 10.17, 2.21.

Anal. Calcd for $C_{11}H_{14}O_2$: 178.09938. Found: 178.10103.

6-Methylbicyclo[4.4.0]dec-1-ene-4,7-dione (51). The synthesis is given in (*E*)- and (*Z*)-**41**, above, using $TiCl_4$ in acetic acid, then DBU: This isomer represents 8.6% of the total enones, 4% absolute. Analyzed as mixture with (*E*)-**41**. VPC (SE-30, 150 °C/2 min, 8°/min to 230 °C): 6.57 min. GC/MS (OV-101 column, 150 °C/2 min, 8°/min to 230 °C): minor component, 3.10 min. EI: 178 (35); 121 (9); 112 (49); 108 (27); 107 (19); 94 (16); 93 (72); 91 (40); 81 (16); 80 (38); 79 (65); 78 (12); 77 (48); 69 (13); 68 (51); 67 (49); 66 (16); 65 (23); 55 (42); 54 (33); 53 (50); 52 (13); 51 (26); 42 (49); 41 (78); 40 (31); 39 (100). CI: 181 (1); 180 (7); 179 (100); 161 (1); 112 (1). The (*E*)-**41** isomer had a 4.00-min retention time under these conditions, and gave a mass spectrum which was very similar to the one listed above for purified (*E*)-**41**. ^{1}H NMR (200 MHz): δ 5.797, dd (broad), *J* = 6.45, 1.85; other signals obscured by the (*E*)-**41**.

(*Z*)-6-Acetylbicyclo[4.4.0]dec-2-en-4-one ((*Z*)-42). From $TiCl_4$ in acetic acid, then DBU: 96.1 mg (0.338 mmol; 1.00 equiv) of **36F** led to 34 mg (52%) of product as a single isomer. TLC (2:1 EH): R_f 0.23, bright blue with *p*-AA spray, UV+. Mass spectrum (EI, 30 °C probe): 193 (1); 192 (2); 150 (31); 149 (60; M − CH_3C=O); 121 (19); 108 (30); 107 (42); 93 (16); 91 (21); 86 (13); 84 (23); 81 (11); 79 (36); 77 (22); 67 (16); 55 (28); 53 (19); 43 (100). CI: 195 (1); 194 (16); 193 (100); 151 (2); 149 (1). IR (Neat): 3.39; 3.47; 5.85; 5.94; 6.88; 7.35; 8.00; 10.87; 11.56; 11.72; 13.51. ^{1}H NMR (90 MHz): Vinyl ABX, δ 6.87, 1 H, dd, *J* = 9.90, 5.0, and 5.95, 1 H, d (broad), *J* = 9.90; 3.1–1.1, 14 H, m [2.12, probably 3 H, s]. ^{1}H NMR (200 MHz): Vinyl ABX, δ 6.869, dd, *J* = 10.10, 4.69 and 5.934, d, *J* = 10.10; CH_3 at 2.145; upfield AB, 2.68 and 2.56, *J* = 16.74.

Anal. Calcd for $C_{12}H_{16}O_2$: 192.115034. Found: 192.114613.

1-Methylspiro[5.5]undec-2-ene-4,7-dione (43). From $TiCl_4$ in acetic acid, then DBU: 58 mg (0.204 mmol; 1.00 equiv) of **36S** led to two very close fractions after plug filtration (230–400 mesh silica gel): 8.5 mg and 23.3 mg (total of 31.8 mg, 81%), TLC (1:1 EH): R_f 0.21 and 0.19, respectively, both green (hot), gray (cool) with *p*-AA spray, UV+. Both fractions contained both isomers, but in different ratios by ^{1}H NMR (200 MHz): 8.5 mg, faster/TLC, 1.00 to 1.93 ratio of methyl doublets at 1.14 and 1.01 ppm, respectively; 23.3 mg, slower/TLC, 1.44 to 1.00 ratio of the same methyl doublets. This represents about a 1 to 1 ratio of isomers. Mass spectrum (EI, 30 °C probe): 193 (1); 192 (4); 122 (17); 93 (10); 91 (12); 86 (26); 84 (45); 82 (59); 81 (12); 79 (32); 77 (23); 67 (12); 55 (38); 54 (29); 53 (34); 51 (15); 39 (80); 28 (100). CI: 195 (1); 194 (13); 193 (100); 85 (2.5). IR (neat): 3.39; 3.47; 5.83; 5.93; 6.85/6.92; 7.95; 8.85; 10.93; 13.61.

Anal. Calcd for $C_{12}H_{16}O_2$: 192.115034. Found: 192.114613.

***R_f* 0.19 isomer:** ^{1}H NMR (200 MHz), Vinyl ABX, δ 6.73, dd, *J* = 10.08, 4.78 and 5.92, d, *J* = 10.08; CH at 3.12, m, *J* = 7.22, 4.78, m; AB, 3.074 and 2.105, *J* = 17.33; CH_3 at 1.14, d, *J* = 7.22. Decoupling at 3.12 leaves a vinyl AB: 6.73 and 5.92, *J* = 10.04, and a singlet at 1.14. ^{1}H NMR (470 MHz): Vinyl ABX, 6.701, dd, *J* = 10.05, 4.75, and 5.893, dd, *J* = 10.05, 1.47; decoupling at 1.14 reduced the CH at 3.12 to a dd, *J* = 4.9, 2.0.

***R_f* 0.21 isomer:** ^{1}H NMR (200 MHz), Vinyl ABX, δ 6.76, dd, *J* = 10.04, 5.76, and 5.93, d (broad), *J* = 10.04; AB, 3.07 and 2.10, *J* = 17.4; CH at 2.99, m, *J* = 7.00, 5.86, m; CH_3 at 1.01, *J* = 7.00. Decoupling at 2.99 leaves a vinyl ABX: 6.76, d, *J* = 10.01, and 5.94, dd, *J* = 10.01, 0.92, and a singlet at 1.01. ^{1}H NMR (470 MHz): Vinyl ABX, δ 6.748, dd, *J* = 10.00, 5.76, and 5.933, d, *J* = 10.00; CH at 2.99, broad dd.

Spiro[2-methylcyclohex-3-en-5-one-1,2′-tetralone] (44). From $TiCl_4$ in acetic acid, then DBU: 125 mg (0.376 mmol; 1.00 equiv) **38S** yielded 32 mg (35%) oil after preparative layer TLC purification, along with additional material at the edges of the band. Two isomers were seen by ^{1}H NMR (200 MHz): methyl doublets at 1.16 and 1.00, in a ratio of 2.14 to 1.00, respectively. Mass spectrum (EI, 40 °C probe): 240.10 (5); 121 (17); 118 (13); 90 (14); 86 (59); 84 (100); 51 (12). CI: 242 (26); 241 (100). IR (neat): 5.88–5.96, strong and broad; 6.23; 6.85; 13.51. ^{1}H NMR (200 MHz): Common to both isomers: δ 8.04–7.9, 1 H, m; 7.55–7.2, 3 H, m; AB, 2.58, 2.47, *J* = 16.22; 3.0, 2 H, m; 2.1, 2 H, m.

Anal. Calcd for $C_{16}H_{16}O_2$: 240.115 034. Found: 240.115 21.

Major isomer: ^{1}H NMR (200 MHz), Vinyl ABX, δ 6.675, dd, *J* = 9.99, 3.47, and 6.036, dd, *J* = 9.99, 2.28; 3.40, ddd, *J* = 7.1, 3.6, 2.9; 1.16, d, *J* = 7.27. Decoupling at 3.40 reduced the vinyl ABX to an AB and the CH_3 doublet at 1.16 to a singlet; the CH_3 doublet at 1.00, in the same sample, was not affected. ^{1}H NMR (470 MHz): Vinyl ABX, 6.673, dd, *J* = 10.08, 3.27, and 6.036, dd, *J* = 10.08, 2.27.

Minor isomer: ^{1}H NMR (200 MHz), 6.798, dd, *J* = 10.14, 5.43, and 5.998, dd, *J* = 10.14, 0.97; 2.82, m; 1.00, d, *J* = 7.11. Decoupling at 2.82 reduced the vinyl ABX to an AB (*J* = 9.88), and the CH_3 doublet at 1.00 to a singlet, while reducing the doublet at 1.16 only from *J* = 7.27 to *J* = 7.06. ^{1}H NMR (470 MHz): Vinyl ABX, 6.795, dd, *J* = 10.05, 5.44, and 5.998, d, *J* = 10.05.

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Registry No. **5**, 7326-64-9; (*E*)-**8b**, 97654-73-4; (*Z*)-**8b**, 97654-74-5; **11**, 55795-17-0; (*E*)-**12a**, 97645-11-9; (*Z*)-**12a**, 61893-91-2; **12b**, 97654-72-3; (*E*)-**14**, 110-57-6; (*Z*)-**14**, 1476-11-5; *t*-**15a**, 85335-83-7; *e*-**15a**, 85335-84-8; *t*-**15b**, 97645-03-9; *e*-**15b**, 97645-04-0; *t*-**15c**, 97645-05-1; *e*-**15c**, 97645-06-2; (*Z*)-**16a**, 85335-85-9; (*E*)-**16a**, 85335-86-0; (*Z*)-**16b**, 97645-07-3; (*E*)-**16b**, 97645-08-4; (*Z*)-**16c**, 97645-09-5; (*E*)-**16c**, 97645-10-8; **17a**, 85336-07-8; **17b**, 97654-75-6; **17c**, 97654-76-7; **18**, 97644-82-1; (*Z*)-**19**, 97644-83-2; (*E*)-**20**, 51870-34-9; (*Z*)-**20**, 97645-12-0; **21**, 97644-84-3; **22**, 25145-58-8; **23**, 10472-24-9; **24**, 85335-96-2; **25**, 32774-63-3; **26**, 85335-98-4; **27**, 97644-85-4; **28**, 97644-86-5; **29**, 97645-14-2; **30**, 97644-87-6; **31**, 97644-88-7; **32**, 97644-89-8; **33**, 41302-34-5; **34**, 85335-94-0; **35**, 874-23-7; **36F**, 85336-00-1; **36S**, 85336-02-3; **37**, 17216-08-9; **38S**, 85336-05-6; **38F**, 85336-04-5; *cis*-**39**, 85335-97-3; *trans*-**39**, 97644-98-9; *cis*-**40**, 97644-94-5; *trans*-**40**, 85335-95-1; *cis*-**41**, 97644-96-7; *trans*-**41**, 97644-95-6; **42**, 97644-99-0; *cis*-**43**, 97645-00-6; *trans*-**43**, 97645-13-1; *cis*-**44**, 97645-01-7; *trans*-**44**, 97645-02-8; (*E*)-**45**, 85335-88-2; (*Z*)-**45**, 85335-89-3; **46**-*Z*,*E*, 85336-08-9; **46**-*Z*,*Z*, 85336-09-0; **47**-*Z*,*E*, 85335-90-6; **47**-*Z*,*Z*, 85335-91-7; **48**-*E*,*E*, 97644-90-1; **48**-*E*,*Z*, 97644-91-2; **48**-*Z*,*E*, 85335-92-8; **49**, 97644-92-3; **50**, 97644-93-4; **51**, 97644-97-8; C_6H_5SBr, 28074-23-9; CH_3SBr, 18681-52-2; $C_6H_5CH_2SBr$, 57490-10-5; C_6H_5CHO, 100-52-7; $(C_6H_5)_3PO$, 791-28-6; (*E*)-$Cl(CH_2)_2C(SCH_3)=CH_2$, 97654-77-8; (*Z*)-$Cl(CH_2)_2C(SCH_3)=CH_2$, 97654-79-0; (*E*)-$(CH_2Ph(CH_2)_2C(SCH_3)=CH_2$, 97654-78-9; (*Z*)-$CH_2Ph(CH_2)_2C(SCH_3)=CH_2$, 97654-80-3; C_6H_5SH, 108-98-5; 2-(Phenythio)-2-sulfolene, 32132-55-1.

Supplementary Material Available: Synthesis and extensive tabular spectral information available for (*E*)-**8b**, (*Z*)-**8b**, *t*-**15b**, *e*-**15b**, *t*-**15c**, *e*-**15c**, (*E*)-**16b**, (*Z*)-**16b**, (*E*)-**16c**, (*Z*)-**16c**, **18**, **24**, **12b**, **12c**, (*E*,*Z*)-**20**, **22**, and **24** (26 pages). Ordering information is given on any current masthead page.

A Silyl Enol Ether Variation of the Robinson Annulation

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The Lewis acid catalyzed reaction of regioselectively generated silyl enol ethers with vinyl ketones has been explored as an alternative to the Robinson annulation sequence. Alkylation of the trimethylsilyl enol ethers of cyclohexanone, 2-methylcyclohexanone, and 2,3-dimethylcyclohexanone with ethyl vinyl ketone, 3-penten-2-one, and methyl vinyl ketone ethylene ketal gave a series of 1,5-diketones. Cyclization of the diketones affords 2-octalones in fair to good overall yield. This procedure has been used to prepare in good yield 5,10-dimethyl-$\Delta^{1(9)}$-2-octalone, an important intermediate for sesquiterpene synthesis, with a cis/trans ratio of 3 to 1. Alkylation of the trimethylsilyl enol ether of isobutyraldehyde with 3-penten-2-one, methyl vinyl ketone, and its ethylene ketal followed by cyclization affords 4,4,5-trimethyl- and 4,4-dimethyl-2-cyclohexen-1-one. This method has been employed in the synthesis of 5-(hydroxymethyl)-2,4,4-trimethyl-2-cyclohexen-1-one, a potential synthon for ring A of the taxane diterpenes.

Since it was first developed 50 years ago[1] the Robinson annulation sequence has found extensive use in the synthesis of a variety of cyclic molecules.[2] Although this synthetic procedure is of great value, it has long been recognized that it is beset with several serious problems which limit its utility: the yields with relatively weakly acidic ketones are usually moderate at best and the vinyl ketones used as Michael acceptors tend to polymerize under the strongly basic reaction conditions. As a consequence of the sensitivity of vinyl ketones to strong base and the reversible nature of the initial Michael reaction, it is not usually possible to employ regioselectively generated enolates in traditional Robinson annulations.[2b] In order to circumvent these problems a variety of modifications have been devised which include the use of catalytic amounts of base[3] or strong acids[4] to effect the annulation. Modified vinyl ketones[5] or vinyl ketone equivalents[6] have also been used. Very recently, a procedure for carrying out the Robinson annulation with strong base under aprotic conditions has been described.[7]

In the course of a variety of projects being carried out in our laboratory, and in connection with several projected problems, we needed a mild, general alternative to the Robinson annulation which was applicable to both aldehydes and ketones, and which would permit the use of either kinetically or thermodynamically generated enolates. An attractive possibility for such an alternative annulation sequence is based on the reaction of silyl enol ethers with vinyl ketones as described several years ago by Mukaiyama's group.[8] Although the extension of this reaction to the preparation of the 1,5-diketones needed for the second step of the annulation seems obvious, at the time our work was initiated there appeared to be only one report in the literature of the use of this reaction as an alternative to the Robinson annulation.[9]

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