composition after 3 days at room temperature. Upon heating some decomposition was observed, but after 24 h at 80 °C <50% decomposition had occurred.

For the alkaline stability test a stock solution of 5% NaOH in aqueous ethanol was prepared by dissolving 5 g of NaOH in 95 g of 95% ethanol. The THP ether was assumed to be stable under basic conditions, but samples of both silyl ethers (50 μL) were placed in NMR tubes containing 0.9 mL of the 5% NaOH in aqueous ethanol solution. The spectrum of **11** showed no change after heating at 80 °C for 3 days; however, **10** was found to decompose slowly under these conditions as ~15% of the silyl ether methyl absorption at δ 0.03 had been converted to a new peak at δ −0.07 after 9 h at 80 °C.

Cleavage of the Di-*tert*-butylmethylsilyl Ether of Cyclohexanol (11) with BF_3. A sample of **11** (0.278 g) was placed in a flask with 10 mL of methylene chloride. Decane (0.081 g) was added as an internal GC standard. The flask was cooled in an ice bath and BF_3 was slowly passed over the stirred solution for 30 min. Saturated aqueous $NaHCO_3$ (15 mL) was added to the mixture and it was allowed to stir at room temperature for 5 h. The mixture was placed in a separatory funnel and the methylene chloride layer drained off. The aqueous layer was then extracted once with 10 mL of diethyl ether and the ether extract combined with the methylene chloride layer. After stirring the solution was found (by GC) to contain di-*tert*-butylmethylfluorosilane and cyclohexanol (94% yield; cyclohexanol was further identified by comparison of GC/MS with authentic material).

Acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, and to the National Institutes of Health (Grant GM 16689) for their support of this work.

Registry No.—**1**, 29681-57-0; **3**, 56310-20-4; **4**, 67124-69-0; **5**, 18159-55-2; **6**, 61150-01-4; **7**, 56348-26-6; triethylsilyl perchlorate, 18244-91-2; **2**–pyridinium complex, 67124-71-4; **4**–pyridinium complex, 67124-73-6; **6**–pyridinium complex, 67124-75-8; *tert*-butyl dimethylsilanol, 18173-64-3; di-*tert*-butylmethylsilanol, 56889-84-0; tri-*tert*-butylsilanol, 56889-90-8; cyclohexanol, 108-93-0; boron trifluoride, 7637-07-2; silver perchlorate, 7783-93-9; potassium hydroxide, 1310-58-3; water, 7732-18-5; trityl perchlorate, 3058-33-1; triethylsilane, 617-86-7; chlorodimethylsilane, 1066-35-9; *tert*-butyllithium, 594-19-4; methyldichlorosilane, 75-54-7.

References and Notes

(1) E. J. Corey and A. Venkateswarlu, *J. Am. Chem. Soc.*, **94**, 6190 (1972).
(2) S. Hanessian and P. Lavellee, *Can. J. Chem.*, **53**, 2975 (1975)
(3) T. J. Barton, A. K. Hovland, and C. R. Tully, *J.* Am. Chem. Soc., **98**, 5695 (1976).
(4) V. Wannagat and W. Liehr, *Angew. Chem.*, **69**, 783 (1957).
(5) J. Y. Corey and R. West, *J. Am. Chem. Soc.*, **85**, 2430 (1963).
(6) The kinetic study of this reaction will be the subject of a separate paper.
(7) M. P. Doyle and C. T. West, *J. Am. Chem. Soc.*, **97**, 3777 (1975).
(8) E. M. Dexheimer and L. Spialter, *J. Organomet. Chem.*, **102**, 21 (1975); L. Spialter and E. M. Dexheimer, *Tetrahedron Lett.*, 1771 (1975).
(9) M. Weiderbruch and W. Peter, *Angew. Chem., Int. Ed. Engl.*, **14**, 642 (1975).
(10) M. P. Doyle and C. T. West, *J. Org. Chem.*, **40**, 3829 (1975).

Enones with Strained Double Bonds: The Bicyclo[3.3.1] System[1]

Herbert O. House,* William A. Kleschick, and Edward J. Zaiko

School of Chemistry, Georgia Institute of Technology, Atlanta, Georgia 30332

Received January 18, 1978

Since examination of models suggests that bridgehead enones of the types **17** and **18** may have unusual chemical and physical properties, a variety of methods (Schemes III–VI) have been explored to form the enone **18**. Although various base-catalyzed elimination reactions (Scheme III) and pyrolytic elimination reactions (Schemes IV–VI) appear to generate the desired enone **18**, the tendency of this strained enone to undergo conjugated addition of nucleophiles or thermal rearrangement has thus far prevented us from isolating it.

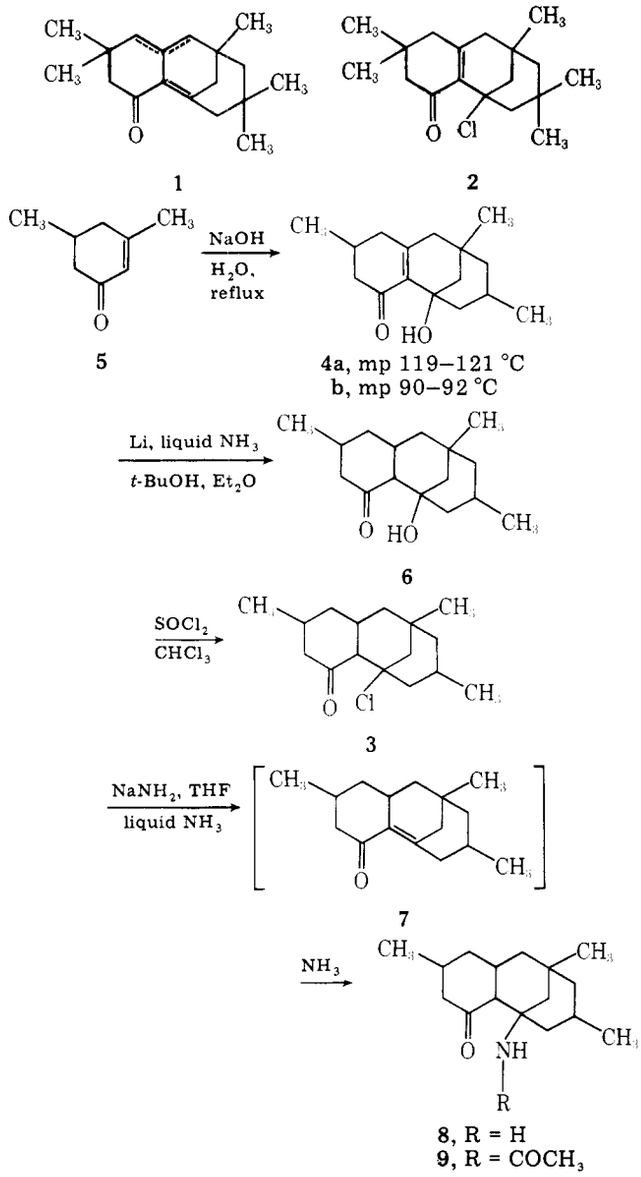
An earlier investigation[2] of the structure of the $C_{27}H_{38}O$ compound formed from isophorone and hot aqueous alkali had suggested the intermediacy of the dienone **1** (Scheme I) with a bridgehead C=C. A stepwise synthesis of this C_{27} compound was effected utilizing as one step the base-catalyzed dehydrohalogenation of the chloro enone **2** to generate the dienone **1** that underwent a rapid Michael reaction. To learn whether this ready dehydrohalogenation **1** → **2** was dependent on the presence of an allylic chloride (albeit a twisted allylic system) in the chloro ketone **2**, we have now examined an analogous reaction with the saturated chloro ketone **3**. This ketone **3** was prepared from dimer **4**[3] of 3,5-dimethylcyclohexenone (**5**) by reduction to the ketol **6** and subsequent reaction with $SOCl_2$. Reaction of this chloro ketone **3** with $NaNH_2$ in a liquid NH_3–THF mixture formed the amino ketone **8**. As in our earlier study,[2] it seems most improbable that the conversion **3** → **8** occurs by either an S_N1 or an S_N2 process. Instead, we presume that a base-promoted dehydrohalogenation formed the enone intermediate **7** that was rapidly trapped by the conjugate addition of either ammonia or amide anion.

The ability to form, and in many cases isolate, bridgehead olefins of the type **10** (Scheme II) is now well established through the efforts of many investigators.[4] Several systems containing a bridgehead C=C that is part of a conjugated enone are also known.[4a,b] These include enones **11**,[5a–c] **12**,[5d–f] **13**,[5d,g] and **14**.[5h] The enone systems **11** appear to be relatively unstrained, while the systems **12** in part minimize strain by some distortion of the C=C accompanied by twisting about the C–C bond of the enone system so that the C=C and C=O functions are not coplanar.[5d] The failure of the enones **12** to undergo Michael additions is attributable both to this nonplanarity (and resultant poor conjugation) in the enone system and to the fact that the enolate anion **15** formed by Michael addition to the enones **12** would be more strained than the starting enone.[5d,f] Other examples of enone systems with considerable internal strain energy are the trans cyclic enones **16**[6] formed by photochemical isomerization.

In examining molecular models of these various bridgehead enone systems, we were impressed by the observation that while enones such as **12**–**14** seemed unlikely to have their C=C and C=O functions coplanar, such coplanarity appeared to add little strain to enones such as **17** (the parent system of intermediates **1** and **7**) and **18**. The main relief of strain in these latter two enones appeared to result from allowing the molecules to twist at the center of the C=C functions (indicated with arrows in structures **17** and **18**). A twist at this location would correspond to the geometry that might be expected for the photochemically excited states[7] or the radical anions derived from these enone systems. Consequently, it was of interest to seek preparative routes to enones such as **17** or **18** to learn whether these systems would exhibit unusual

0022-3263/78/1943-3653$01.00/0

Scheme I



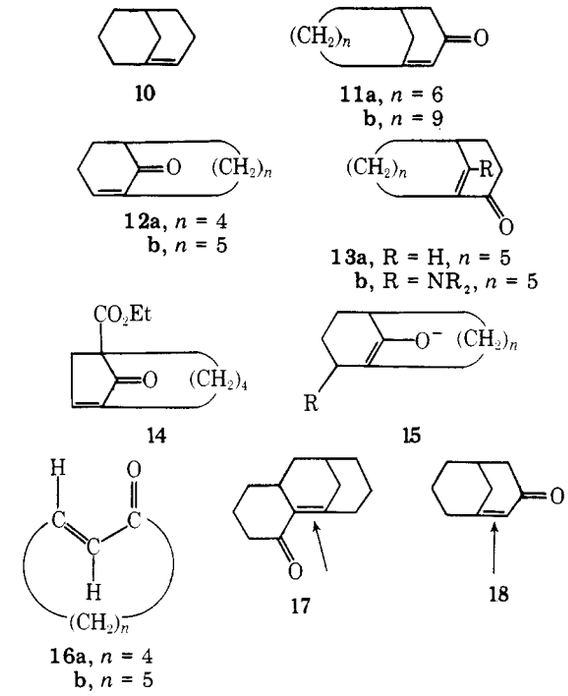
chemical, electrochemical, or photochemical behavior. This paper describes our efforts to prepare the bridgehead enone system **18**.

A suitable synthetic precursor for the enone **18** appeared to be the known ketol **19**[8] (Scheme III) obtained by the Michael addition of ethyl acetoacetate to cyclohexenone followed by decarboethoxylation and an intramolecular aldol reaction. Similar synthetic routes have been employed to obtain the relatively unstrained enones **11**.[5a-c] When we employed mild reaction conditions in the reaction of ethyl acetoacetate with cycloheptenone, the diketone **20** was isolated. However, our preliminary attempts to convert this diketone **20** to a ketol analogous to **19** have produced complex mixtures of aldol products.

Reaction of the ketol **19** with $SOCl_2$ formed the chloro ketone **21**. We presume that this conversion **19** → **21**, like the comparable preparations of chloro ketones **2** and **3**, proceeds by the formation and subsequent ionic decomposition of a chlorosulfite intermediate. An attempt to prepare the chloro ketone **21** by reaction of the ketol **19** with $(COCl)_2$ resulted in the formation of the diketo lactone **22** isolated as one of its enol forms (e.g., **23**).

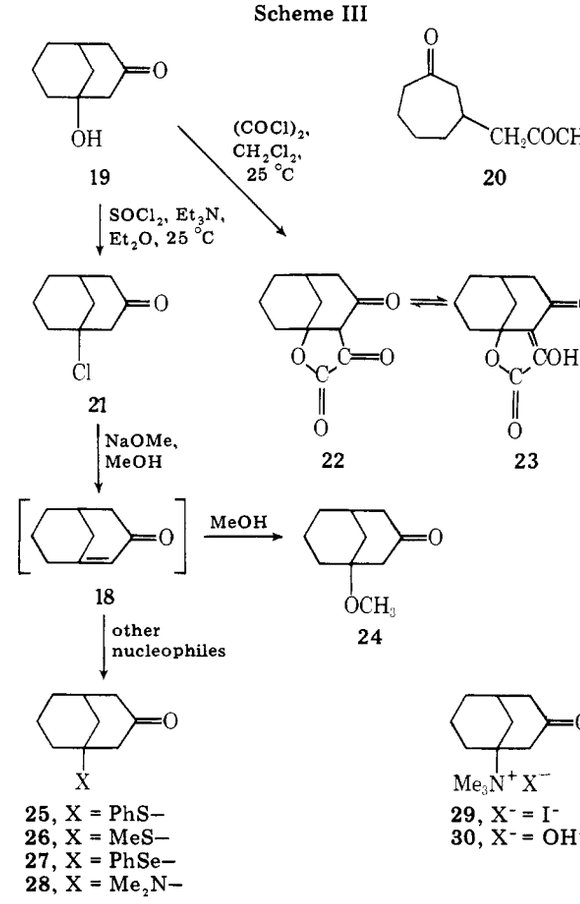
Although the chloro ketone **21** failed to react (or formed an intermediate that was reconverted to **21**) when heated with amine bases (Et_3N, γ-collidine), it reacted rapidly (<15 min

Scheme II

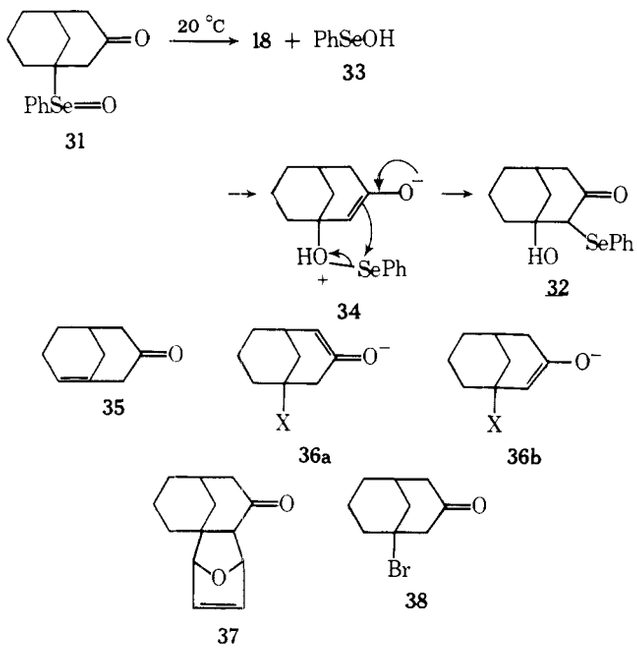


at 25 °C) with methanolic NaOMe to form the ketone **24**. This rapid conversion, **21** → **24**, clearly required the presence of base and was not a solvolytic transformation. Thus, it seems very probable that the enone **18** was generated and then rapidly trapped by the conjugate addition of MeOH. Support for this viewpoint was obtained by performing the chloro ketone–NaOMe reaction in the presence of other good nucleophiles (PhSH, MeSH, PhSeH, Me_2NH) to produce the substituted bicyclic ketones **25–28**.

Scheme III



Scheme IV



Several other observations also suggest that the enone **18** is an exceptionally reactive Michael acceptor for nucleophiles. Hofmann degradation of the solvent-free quaternary ammonium hydroxide **30** at 150 °C resulted in sublimation of the ketol **19** (presumably form **18** + H_2O) as the only volatile product. Also, the selenoxide **31** (Scheme IV), formed by oxidation of the selenide **27** with *m*-$ClC_6H_4CO_3H$[9] in furan at 4–5 °C, underwent thermal decomposition at about 20 °C to form the hydroxy selenide **32.** Although the electrophilic addition of benzeneselenenic acid (**33,** present in equilibrium with Ph_2Se_2 and $PhSeO_2H$)[10a] to reactive olefins is now known to be a common side reaction in selenoxide decomposition,[10] the analogous electrophilic addition to the electron-poor C=C of enones is normally not observed.[9] In the present case, we believe we are observing such a nucleophilic addition of the selenenic acid **33** (or its anion) to the strained enone **18,** followed by an intramolecular transfer of a phenylselenide unit (see structure **34**), a process analogous to the addition of benzeneselenenamides to enones.[11] In any case, the conversion **31** → **32** suggests that we have generated the conjugated enone **18** and not its unconjugated isomer **35.** An additional example of the tendency of the enone **18** to undergo conjugate addition reactions was found in the reaction of the chloro ketone with the sterically hindered alkoxide, KOBu-*t*, in various reaction solvents. We did not find any *tert*-butyl ether as had been observed earlier[2] in reaction of the sterically hindered chloro ketone **2** with KOBu-*t*. Instead, reaction of the chloro ketone **21** with KOBu-*t* formed a mixture of polymeric materials with properties suggesting that one of the enolate anions, **36** (X = Cl or *t*-BuO), had undergone Michael addition to the enone **18,** forming a new enolate anion, **36b,** capable of further anionic polymerization with more enone **18.**

The above observations suggested that, although the enone **18** could readily be generated by either base-promoted dehydrochlorination of the chloro ketone **21** or by thermal decomposition of the selenoxide **31** at about 20 °C, the avidity with which the enone **18** added nucleophiles would make its isolation from such reaction mixtures difficult. A number of experiments were performed in which we attempted to trap the enone **18** (generated from **21** and a base) as its cycloadduct with excess furan, CH_2=CHCH=CH_2, CH_2=CHOEt, or PhN_3. In all cases where the enone **18** was generated with NaOMe, the sole product isolated was the methoxy ketone **24** in spite of the fact that only 1 mol equiv of NaOMe and a large excess of the trapping agent were employed. When the enone **18** was generated with 1 mol equiv of KOBu-*t* and excess trapping agent, the major product in all cases was the polymeric material described previously. In one case (**21** + KOBu-*t* in furan) a small amount of a monomeric material was isolated with IR and mass spectral properties suggesting that it may be the cycloadduct **37.** Thus far, we have been unsuccessful in finding reaction conditions that will produce a sufficient amount of this product to permit its adequate characterization. We also sought to trap the enone **18,** generated by thermal decomposition of the selenoxide **31** in CH_2Cl_2, by reaction with Br_2 to form a vicinal dibromide. Unfortunately, this experiment was apparently complicated by reaction of Br_2 with the various selenium-containing byproducts to form HBr; the major reaction product was the bromo ketone **38.** Although the attempted trapping experiments described are hardly definitive, they do suggest that the enone **18** is not an exceptionally reactive component in various cycloaddition reactions.

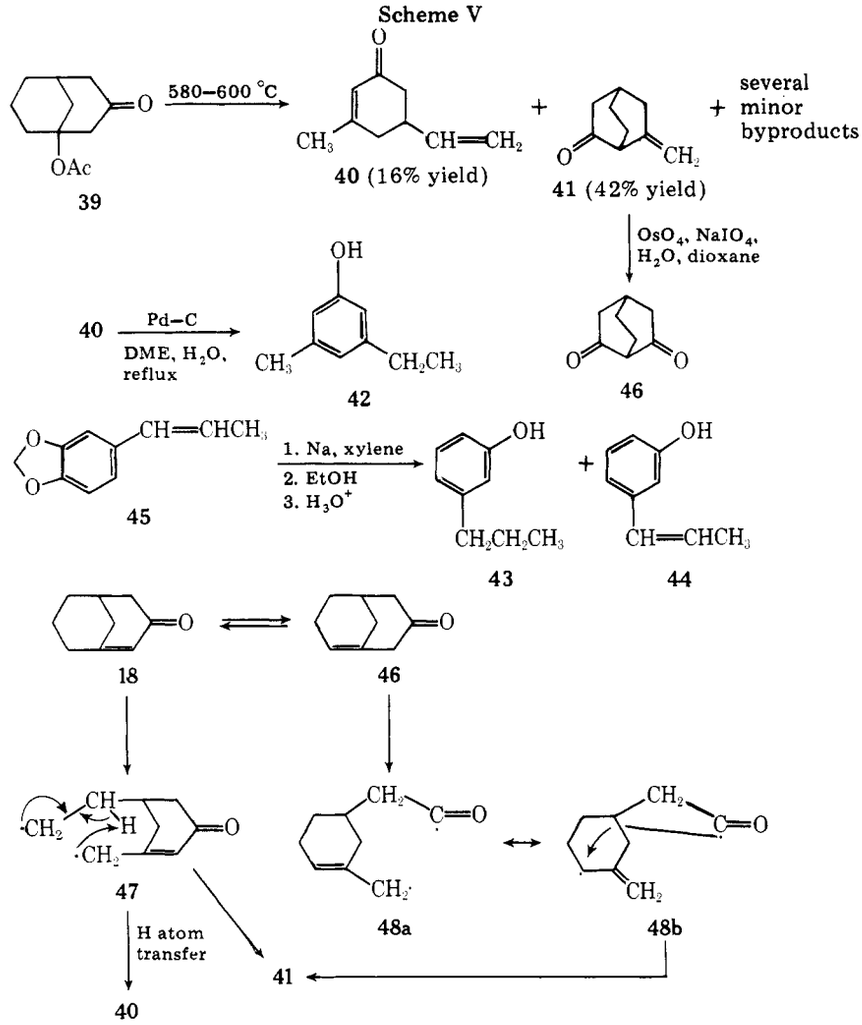
The foregoing experiments suggested the desirability of exploring methods that might generate the enone **18** under circumstances where its subsequent reaction with nucleophilic reagents could be minimized. Accordingly, we turned our attention to gas-phase pyrolysis of the keto acetate **39** (Scheme V). The slow addition of a solution of this acetate **39** in CH_2Cl_2–pentane to a tube packed with glass helices and heated with an oven at 580–600 °C resulted in the complete consumption of the acetate **39** with the formation of two major volatile products, each a $C_9H_{12}O$ ketone. Unfortunately, both of these products were structural isomers of the desired enone **18.** The minor product was demonstrated to have structure **40** both by its spectrometric properties and by isomerization over a Pd–C catalyst to the phenol **42.** This phenol **42** was identified with an authentic sample and shown to be different from the isomeric phenol **43,** prepared along with an unsaturated phenol believed to be **44** by reduction[12] of isosafrole (**45**). The major pyrolysis product was shown to be the bicyclic ketone **41** both by its spectrometric properties and by oxidative degradation to the known crystalline diketone **46.**

The precursor of these two pyrolysis products, **40** and **41,** would appear to be the dienone **18** or its double bond isomer **46,** formed by isomerization in the pyrolysis column. Either concerted rearrangements or the homolytic cleavage of a C–C bond in each intermediate, **18** and **46,** to yield the diradial intermediates **47** and **48** would constitute reasonable pathways for the formation of the final products **40** and **41.**

Although the photolytic decomposition of the keto lactone **22** (Scheme VI) produced a very complex mixture, pyrolysis in a hot tube (a known procedure for olefin formation)[13] produced a mixture of the two previously described olefins **40** and **41** along with a third $C_9H_{12}O$ ketone, the previously described[14a] C=C isomer (**49**) of ketone **41.** We presume that the enone **49** is formed by an acid-catalyzed isomerization of the enone **41** as it passes through the pyrolysis tube. An authentic sample of the enone **49** was obtained by isomerization of the enone **41** over a supported palladium catalyst. The hot-tube pyrolysis of the sulfoxide **50,**[14b,c] prepared by oxidation of the sulfide **25** with *m*-$ClC_6H_4CO_3H$, produced a mixture of volatile products containing PhSH and the enones **41** and **49.** Presumably the acidic byproducts[14c] formed in this pyrolysis account for the increased amount of the enone **49.**

Thus, our presently completed studies suggest that the bridgehead enone **18** can be generated by several olefin-forming reactions. However, the isolation of pure samples of this enone, **18,** for further study has proved to be a remarkably elusive goal, suggesting that specialized isolation techniques may be required. We plan continued study of possible methods for the generation and isolation of this substance as well as a study of the formation of less strained (and hopefully

Scheme V



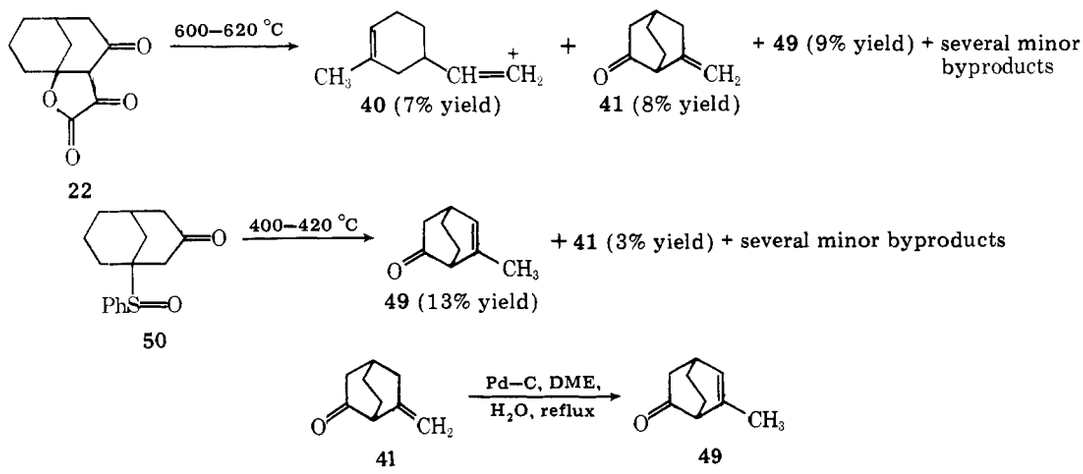
more easily isolated) homologues.

Experimental Section[15]

Preparation of the Dimeric Ketol 4. The enone **5**, prepared as previously described,[16] was obtained as a colorless liquid: bp 89–98 °C (16 mm); $n^{25}D$ 1.4822 [lit.[16] bp 84–86 °C (9 mm)]; NMR (CCl_4) δ 5.6–5.8 (1 H, m, vinyl CH), 1.7–2.6 (8 H, m, aliphatic CH), and 0.9–1.2 (3 H, m, CH_3). Employing a modification of previous procedures,[17] a mixture of 100 g (0.806 mol) of the enone **5**, 300 g of NaOH, and 150 mL of H_2O was refluxed for 40 min and then poured into ice water and extracted with Et_2O. After the ethereal extract had been washed with H_2O, dried, and concentrated, the residual brown semisolid was triturated with cold hexane to leave 46.5 g of crude yellow solid. Recrystallization from hexane afforded 37.0 g (37%) of a mixture of ketols 4 (NMR analysis) as pale yellow needles, mp 96–110 °C. Fractional recrystallization from hexane separated 16.6 g (17%) of the higher melting ketol **4a** as colorless needles: mp 119–121 °C (lit. mp 116–118,[17b] 120 °C[3]); IR (CCl_4) 3470 (OH), 1650 (conjugated C=O), and 1627 cm^{-1} (conjugated C=C); UV max (95% EtOH) 249 nm (ε 9100); NMR (CCl_4) δ 4.93 (1 H, s, OH) and 0.8–2.5 (23 H, m, aliphatic CH); mass spectrum *m/e* (rel intensity) 248 (M^+, 3), 191 (100), 121 (21), and 41 (11).

The hexane solutions from the trituration and the initial recrystallization were combined, concentrated, and distilled under reduced pressure in a short-path still to separate 34.8 g of pale green viscous liquid, bp 118–135 °C (0.01 mm), that solidified on standing. Recrystallization from hexane separated 17.6 g of colorless solid, mp 83–86 °C that contained (NMR analysis) both ketols **4a** (minor) and **4b** (major). A series of fractional crystallizations from hexane separated

Scheme VI



1.49 g (1.5%) of the pure lower melting ketol **4b** as colorless plates: mp 90–92 °C; IR (CCl_4) 3470 (OH), 1645 (conjugated C=O), and 1627 cm^{-1} (conjugated C=C); UV max (95% EtOH) 248 nm (ϵ 8700); NMR (CCl_4) δ 4.89 (1 H, s, OH) and 0.7–2.7 (23 H, m, aliphatic CH); mass spectrum *m/e* (rel intensity), 248 (M^+, 6), 233 (3), 191 (100), and 121 (20).

Anal. Calcd for $C_{16}H_{24}O_2$: C, 77.37; H, 9.74. Found: C, 77.36; H, 9.77.

Preparation of the Dihydro Ketol 6. To a refluxing solution of 580 mg (76 mg-atom) of Li and 100 mL of Et_2O in 400 mL of liquid NH_3 was added, rapidly with stirring, a solution of 5.35 g (21.6 mmol) of the ketol **4a** and 5.0 mL of *t*-BuOH in 95 mL of Et_2O. After the reaction mixture had been stirred at −33 °C for 45 min, 10 mL of H_2O was added and the NH_3 was allowed to evaporate. The residue was partitioned between Et_2O and H_2O and the organic phase was washed with aqueous NaCl, dried, and concentrated. A cold (0 °C) solution of the residual semisolid in 50 mL of acetone was treated with excess aqueous 8 N H_2CrO_4, and then *i*-PrOH was added to consume the excess oxidant. After the resulting mixture had been neutralized with $NaHCO_3$, it was concentrated and partitioned between H_2O and Et_2O. The ethereal layer was washed with aqueous NaCl, dried, and concentrated to leave 4.96 g of gray-green semisolid. Recrystallization from EtOH afforded 2.50 g of a mixture (IR analysis) of conjugated and nonconjugated ketones as a colorless solid. Chromatography on silica gel with an EtOAc–hexane eluent (1:6 v/v) separated 1.75 g (32%) of the ketol **6** as colorless needles: mp 120–122 °C (lit.[3] mp 124 °C); IR (CCl_4) 3550 (OH) and 1700 cm^{-1} (C=O); UV max (95% EtOH) 294 nm (ϵ 25); ^1H NMR (CCl_4) δ 3.20 (1 H, s, OH) and 0.6–2.8 (25 H, m, aliphatic CH); mass spectrum *m/e* (rel intensity), 250 (M^+ <1), 232 (31), 217 (13), 193 (100), 175 (15), 125 (75), 124 (66), 111 (93), 109 (62), 108 (54), 107 (34), 83 (21), 69 (41), 55 (52), 43 (38), and 41 (53); ^{13}C NMR ($CDCl_3$, multiplicity in off-resonance decoupling) 211.3 (s), 70.8 (s), 62.6 (d), 50.1 (t), 49.9 (t), 46.9 (t), 45.4 (t), 43.4 (t), 42.5 (t), 38.2 (d), 34.2 (s), 32.8 (d), 31.9 (q), 28.3 (d), 24.1 (q), and 22.0 ppm (q).

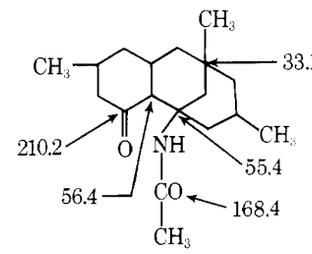
Preparation of the Chloro Ketone 3. A solution of 511 mg (2.04 mmol) of the ketol **6** and 492 mg (4.14 mmol) of $SOCl_2$ in 2.5 mL of $CHCl_3$ (EtOH free) was stirred at 25 °C for 19 h and then concentrated to leave 621 mg of red solid, mp 89–91 °C. Chromatography on silica gel with PhH as the eluent separated 494 mg (92%) of the chloro ketone **3** as a pink solid, mp 93.5–94.5 °C. Recrystallization from MeOH afforded the pure chloro ketone **3** as colorless plates: mp 93.5–94.5 °C; IR (CCl_4) 1725 cm^{-1} (C=O); UV max (95% EtOH) 294 nm (ϵ 40); ^1H NMR (CCl_4) δ 3.33 (1 H, d of d, J = 4.3 and 12.6 Hz), 2.55 (1 H, d, J = 12 Hz), and 0.5–2.4 (23 H, m, aliphatic CH); at 100 MHz, the CH_3 signals in the ^1H NMR spectrum were resolved into a doublet (J = 6.1 Hz) at δ 0.84, a singlet at δ 0.92, and a doublet (J = 5.6 Hz) at δ 1.00; mass spectrum *m/e* (rel intensity) 232 (25), 217 (17), 125 (25), 124 (100), 111 (40), 109 (81), 108 (83), 107 (60), 105 (25), 93 (31), 91 (35), 79 (26), 77 (24), 69 (32), 67 (23), 55 (45), 43 (29), 41 (74), and 39 (27); ^{13}C NMR ($CDCl_3$, multiplicity in off-resonance decoupling) 206.3 (s), 69.3 (s), 63.4 (d), 54.6 (t), 51.0 (t), 45.8 (t), 44.8 (t), 44.7 (t), 43.3 (t), 41.1 (d), 35.2 (s), 34.2 (d), 31.6 (q), 29.3 (d), 23.7 (q), and 22.0 ppm (q).

Anal. Calcd for $C_{16}H_{25}ClO$: C, 71.49; H, 9.37; Cl, 13.19. Found: C, 71.48; H, 9.38; Cl, 13.18.

Preparation of the Amino Ketone 8. A cold (−33 °C) mixture of $NaNH_2$ [from 340 mg (15 mg-atom) of Na], 1.00 g (3.73 mmol) of the chloro ketone **3**, 125 mL of liquid NH_3, and 20 mL of THF was stirred for 5 h, during which time the NH_3 was allowed to evaporate. After 5 mL of H_2O had been added, the reaction mixture was partitioned between Et_2O and aqueous NaCl. The ethereal layer was extracted successively with aqueous 1 M HCl and with H_2O and then dried and concentrated to leave 371 mg of colorless viscous liquid containing (TLC, silica gel with an EtOAc–hexane eluent, 1:9 v/v) the starting chloride **3** (R_f 0.58) and two unknown components (R_f 0.0 and 0.74). The acidic aqueous extract was made basic (aqueous NaOH) and extracted with Et_2O. This Et_2O extract was dried and concentrated to leave 451 mg (49%) of the amino ketone **8** as a liquid that solidified on standing, mp 69–71 °C. Recrystallization from pentane afforded the pure amino ketone **8** as colorless prisms: mp 72–73 °C; IR (CCl_4) 3370 (NH) and 1710 cm^{-1} (C=O); NMR (CCl_4) δ 0.7–2.9 (m, NH and aliphatic CH); UV max (95% EtOH) 295 nm (ϵ 23); mass spectrum *m/e* (rel intensity) 249 (M^+, 3), 234 (5), 192 (65), and 124 (100).

Anal. Calcd for $C_{16}H_{27}NO$: C, 77.06; H, 10.91; N, 5.62. Found: C, 77.03; H, 10.95; N, 5.61.

Preparation of the Keto Amide 9. A solution of 52 mg (0.21 mmol) of the amino ketone **8** and 0.5 mL of Ac_2O in 1.0 mL of pyridine was stirred at 25 °C for 11.5 h and then partitioned between Et_2O and aqueous 1 M HCl. The ethereal solution was washed with aqueous 5% NaOH, dried, and concentrated to leave 58 mg (95%) of the crude amide **9**, mp 134–135 °C. Recrystallization from hexane separated the pure keto amide **9** as colorless needles: mp 135–137 °C; IR (CCl_4) 3430 (NH), 1708 (C=O), and 1672 cm^{-1} (amide C=O); UV max (95% EtOH) 293 nm (ϵ 25); ^1H NMR ($CDCl_3$) δ 5.68 (1 H, br, NH), 3.40 (1 H, d, J = 13.2 Hz), and 0.7–2.9 (27 H, m, aliphatic CH); mass spectrum *m/e* (rel intensity) 291 (M^+, 33), 234 (49), 232 (55), 217 (31), 216 (34), 192 (68), 189 (77), 166 (57), 124 (100), 109 (42), 108 (45), 107 (38), 91 (34), 69 (41), 55 (51), 43 (64), and 41 (82). Although the ^{13}C NMR spectrum ($CDCl_3$ solution) of the keto amide **9** was complicated by restricted rotation of the amide C–N bond that caused a number of ^{13}C signals to appear as two lines, the assignments indicated in the following formula are consistent both with off-resonance decoupling measurements and with the values observed for the structurally related hydroxy ketone **6** and chloro ketone **3**.



Anal. Calcd for $C_{18}H_{29}NO_2$: C, 74.18; H, 10.03; N, 4.81. Found: C, 74.08; H, 10.04; N, 4.79.

Preparation of the Ketol 19. Following a previously described procedure,[8] a solution of 48.7 g (375 mmol) of ethyl acetoacetate and 30.0 g (312 mmol) of 2-cyclohexenone in methanolic NaOMe [from 450 mL of anhydrous MeOH and 7.20 g (313 mg-atom) of Na] was refluxed for 72 h and then cooled to 25 °C and treated with a solution of 43.7 g (797 mmol) of KOH in 120 mL of H_2O. The resulting yellow solution was refluxed for 12.5 h and then concentrated and extracted with CH_2Cl_2. After the organic extract had been washed successively with aqueous 4 M HCl, aqueous NaCl, aqueous $NaHCO_3$, and aqueous NaCl, it was dried and concentrated. The residual yellow semisolid was recrystallized from Et_2O to separate 25.3 g (53%) of the ketol **19** as colorless plates: mp 233–240 °C dec (lit. mp 192–193,[8] 232–239 °C[18]); IR (CCl_4) 3595, 3430 (OH), and 1709 cm^{-1} (C=O); UV max (95% EtOH) 280 nm (ϵ 18); ^1H NMR ($CDCl_3$) δ 3.38 (1 H, s, OH), 2.1–2.7 (5 H, m, aliphatic CH), and 1.1–2.0 (8 H, m, aliphatic CH); ^{13}C NMR ($CDCl_3$, multiplicity in off-resonance decoupling) 210.5 (s, C=O), 70.6 (s, COH), 55.1 (t, CH_2), 45.5 (t, CH_2), 41.1 (t, CH_2), 40.2 (t, CH_2), 30.5 (t and d, CH_2 and CH), and 20.0 ppm (t, CH_2); mass spectrum *m/e* (rel intensity) 154 (M^+, 12), 111 (30), 97 (100), 58 (17), 55 (19), 43 (20), and 41 (24).

Anal. Calcd for $C_9H_{14}O_2$: C, 70.10; H, 9.15. Found: C, 70.08; H, 9.20.

Preparation of the Diketone 20. A solution of NaOEt [from 5 mg (0.2 mg-atom) of Na], 1.10 g (10.0 mmol) of cycloheptenone, and 1.33 g (10.2 mmol) of ethyl acetoacetate in 5 mL of anhydrous EtOH was stirred at 25 °C for 21 h. The solution was then treated with 2 mL of an H_2O solution containing 3.10 mmol of KOH and the resulting mixture was refluxed for 47 h, cooled, and concentrated under reduced pressure. After the reaction mixture had been partitioned between H_2O and CH_2Cl_2, the organic phase was washed successively with aqueous 1 M HCl, with aqueous $NaHCO_3$, and with aqueous NaCl and then dried and concentrated. The residual green liquid (1.17 g) contained (TLC, silica gel coating with an EtOAc–hexane eluent, 1:4 v/v) the diketone **20** (R_f 0.16) and several minor unidentified byproducts (R_f 0.40, 0.33, and 0.03). Chromatography on silica gel with an EtOAc–hexane eluent (1:4 v/v) separated 867 mg (52%) of the diketone **20** as a colorless liquid; $n^{25}D$ 1.4751; IR (CCl_4) 1720 and 1705 cm^{-1} (C=O); UV max (95% EtOH) 280 nm (ϵ 47); NMR (CCl_4) δ 2.35 (6 H, br s, CH_2CO), 2.08 (3 H, s, $COCH_3$), and 1.0–2.1 (7 H, m, aliphatic CH); mass spectrum *m/e* (rel intensity) 168 (M^+, 8), 111 (100), 110 (37), 83 (64), 67 (22), 58 (30), 55 (59), 43 (82), 42 (24), 41 (36), and 39 (30).

Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.17; H, 9.68.

Preparation of the Chloro Ketone 21. A mixture of 7.85 g (51.0 mmol) of the ketol **19**, 14.5 g (102 mmol) of anhydrous Na_2HPO_4, and 12.1 g (102 mmol) of $SOCl_2$ in 100 mL of CH_2Cl_2 was stirred at 25 °C for 38 h and then the pale yellow suspension was partitioned between H_2O and CH_2Cl_2. The organic solution was dried and concentrated to leave 8.93 g of yellow-orange semisolid that was chromatographed on silica gel. The fractions eluted with Et_2O–hexane (3:7 v/v) contained 3.16 g (36%) of the chloro ketone **21**: mp 126.5–127.5 °C; TLC R_f 0.41 (silica gel coating with an Et_2O–hexane eluent, 3:7 v/v). Recrystallization from Et_2O afforded the pure chloro ketone **21** as col-

orless plates: mp 126.5–127.5 °C; IR (CCl_4) 1713 and 1722 cm^{-1} (C=O); UV max (95% EtOH) 283 nm (ϵ 22); ^1H NMR (CCl_4) δ 2.82 (2 H, s, CH_2) and 1.2–2.7 (11 H, m, aliphatic CH); ^{13}C NMR ($CDCl_3$, multiplicity in off-resonance decoupling) 207.1 (s, C=O), 67.2 (s, CCl), 56.7 (t, CH_2), 45.1 (t, CH_2), 43.3 (t, CH_2), 42.7 (t, CH_2), 31.4 (d, CH), 30.1 (t, CH_2), and 20.9 ppm (t, CH_2); mass spectrum *m/e* (rel intensity) 174 (M^+, 11), 172 (M^+, 36), 137 (100), 136 (26), 121 (21), 95 (54), 94 (56), 93 (39), 81 (26), 79 (32), 67 (30), 55 (22), 41 (23), and 39 (28).

Anal. Calcd for $C_9H_{13}ClO$: C, 62.61; H, 7.59; Cl, 20.53. Found: C, 62.70; H, 7.61; Cl, 20.53.

In a more satisfactory procedure, 8.21 g (69.0 mmol) of $SOCl_2$ was added, dropwise and with stirring during 15 min, to a solution of 9.25 g (60.0 mmol) of the ketol **19** and 7.03 g (69.5 mmol) of Et_3N (distilled from $LiAlH_4$) in 270 mL of Et_2O. The reaction mixture, which warmed to boiling with separation of a white precipitate, was filtered and concentrated to leave the crude product as a red solid. Chromatography on silica gel with an Et_2O–hexane eluent (3:7 v/v) separated 7.40 g of the crude chloro ketone **21** as a yellow solid, mp 114–122.5 °C. Recrystallization from Et_2O afforded 6.44 g (62%) of the previously described pure chloro ketone **21** as colorless plates, mp 126.5–127.5 °C.

Reaction of the Chloro Ketone 21 With NaOMe. A solution of NaOMe, from 32.9 mg (1.43 mg-atom) of Na and 5 mL of anhydrous MeOH, was added, dropwise and with stirring during 50 min, to a refluxing solution of 178 mg (1.03 mmol) of the chloro ketone **21** in 30 mL of anhydrous MeOH. The resulting solution was refluxed for 9 h and then cooled, neutralized with aqueous NH_4Cl, concentrated, and partitioned between Et_2O and H_2O. After the organic layer had been dried and concentrated, the residual yellow liquid [166 mg containing (TLC, silica gel coating with an EtOAc–hexane eluent, 1:4 v/v) the methoxy ketone **24** R_f 0.18] was chromatographed on silica gel with an EtOAc–hexane eluent (2:1 v/v) to separate 158 mg (91%) of the methoxy ketone **24** as a colorless liquid, n^{25}_D 1.4887. The product exhibited a single GLC peak (silicone DC-710 on Chromosorb P) corresponding to the methoxy ketone **24** (retention time 34.6 min) under conditions where the retention time for the chloro ketone **21** was 29.4 min. The spectral properties of the methoxy ketone **24** follow: IR (CCl_4) 1712 (C=O) and 1098 cm^{-1} (COC); UV max (95% EtOH) 278 nm (ϵ 21) with weak end absorption (ϵ 103 at 211 nm); ^1H NMR (CCl_4) δ 3.19 (3 H, s, OCH_3) and 0.8–2.7 (13 H, m, aliphatic CH); ^{13}C NMR ($CDCl_3$, multiplicity in off-resonance decoupling) 210.9 (s, C=O), 74.9 (s, C-O), 51.3 (t, CH_2), 48.4 (q, OCH_3), 46.1 (t, CH_2), 37.6 (t, CH_2), 35.9 (t, CH_2), 31.1 (t, CH_2), 30.4 (d, CH), and 19.7 ppm (t, CH_2); mass spectrum *m/e* (rel intensity) 168 (M^+, 5), 125 (60), 111 (100), 97 (18), 72 (16), 43 (18), and 41 (29).

Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.43; H, 9.62.

To demonstrate the rapidity of the reaction of the chloro ketone **21** with NaOMe, a solution of 91.8 mg (0.53 mmol) of the chloro ketone **21** in 3 mL of anhydrous MeOH was treated with 0.15 mL of a MeOH solution containing 0.65 mmol of NaOMe and the resulting solution was stirred at 25 °C for 15 min. After the solution had been neutralized by the addition of 1 mL of saturated aqueous NH_4Cl, the MeOH was evaporated under reduced pressure and the residue was partitioned between Et_2O and H_2O. The ethereal layer was dried and concentrated to leave 80.1 mg (90%) of the methoxy ketone **24** that was identified with the previously described sample by comparison of IR and NMR spectra. To demonstrate the need for NaOMe in this reaction, a solution of 101 mg (0.59 mmol) of the chloro ketone **21** in 3 mL of MeOH was stirred at 25 °C for 15 min and then concentrated under reduced pressure. The recovered chloro ketone **21**, mp 127–127.5 °C, amounted to 100 mg (99%) and was identified with an authentic sample by comparison of IR spectra. However, when a solution of 51.6 mg (0.30 mmol) of the chloro ketone **21** in 10 mL of MeOH was refluxed for 9 h and then concentrated, 37.9 mg (76%) of the methoxy ketone **24** (identified by comparison of IR, NMR, and TLC data) was isolated.

Our attempts to effect the dehydrochlorination of the chloro ketone **21** by reaction with Et_3N in Et_2O for 24 h or by reaction with a suspension of KH (prewashed with pentane) in THF at −3 °C for 40 min or at 23 °C for 18 h resulted in the recovery of 79–94% of the unchanged chloro ketone **21**. Similarly, after a solution of 51 mg (0.29 mmol) of the chloro ketone **21** and 58 mg (0.57 mmol) of Et_3N in 2 mL of heptane had been refluxed (98 °C) for 15 h, all of the starting chloro ketone **21** (IR and TLC analyses) was recovered. After a mixture of 61 mg (0.36 mmol) of the chloro ketone **21** and 2 mL of 2,4,6-collidine had been refluxed for 22 h, the neutral product (55 mg separated in the usual way) again contained (TLC analyses) the starting chloro ketone **21**. Chromatography separated 50 mg (82%) of the pure chloro ketone **21**, mp 126–127 °C.

A solution of NaOMe, from 32.3 mg (1.40 mg-atom) of Na and 0.5 mL of MeOH, was added, dropwise and with stirring during 2 min, to a solution of 183 mg (1.06 mmol) of the chloro ketone **21** in 35 mL of furan. The resulting mixture, from which a precipitate began to separate within a few seconds, was stirred for 25 °C for 16.5 h and then concentrated and partitioned between Et_2O and H_2O. The organic layer was dried and concentrated to leave 154 mg (87%) of the methoxy ketone **24** (IR and NMR analysis) with no other product being detected. In a similar experiment NaOMe [from 32.1 mg (1.40 mg-atom) of Na and 0.5 mL of MeOH] was added to a solution of 175 mg (1.01 mmol) of the chloro ketone **21** in 35 mL of butadiene. The resulting mixture was stirred under reflux for 2 h, allowed to stand overnight, and then subjected to the previously described isolation procedure to separate 158 mg (93%) of the methoxy ketone **24**. When the same procedure was repeated with 1.07 mmol of the chloro ketone **21** and 1.02 mmol (0.95 equiv) of NaOMe, the product again contained (GLC, IR, NMR) mainly the methoxy ketone **24** accompanied by a small amount of the starting chloro ketone **21**. In a similar procedure, 192 mg (1.11 mmol) of the chloro ketone **21** in 50 mL of $EtOCH{=}CH_2$ was treated with 0.26 mL of a MeOH solution containing 1.11 mmol of NaOMe and stirred at 25 °C for 5 h. After following the previously described isolation procedure, an aliquot of the crude product (194 mg of pale yellow liquid) was mixed with a known amount of n-$C_8H_{17}Ph$ (an internal standard) for GLC analysis (silicone DC-710 on Chromosorb P, apparatus calibrated with known mixtures). The product contained methoxy ketone **24** (86% yield, retention time 28.4 min) and n-$C_8H_{17}Ph$ (20.9 min); the product was identified with an authentic sample of the methoxy ketone **24** by comparison of IR and NMR spectra, GLC retention times, and TLC R_f values (R_f 0.39, silica gel coating with an EtOAc–hexane eluent, 4:6 v/v).

The mixture obtained by the dropwise addition during 60 min of KOBu-*t* [from 55.4 mg (1.42 mg-atom) of K and 5 mL of *t*-BuOH] to a refluxing solution of 177 mg (1.03 mmol) of the chloro ketone **21** in 30 mL of *t*-BuOH was refluxed for an additional 2 h and then cooled, neutralized with aqueous NH_4Cl, concentrated, and partitioned between H_2O and CH_2Cl_2. The organic layer was dried and concentrated to leave 169 mg of a viscous liquid (contains halogen) that appeared to be a mixture of polymeric materials: IR ($CHCl_3$) 1690 cm^{-1} (C=O); NMR ($CDCl_3$) δ 1.0–2.8 (m, aliphatic CH including a *t*-BuO singlet at δ 1.27). Very similar crude product mixtures were obtained when a solution of the chloro ketone **21** in *t*-BuOH was added to *t*-BuOK in *t*-BuOH and then stirred at 25 °C and when a solution of the chloro ketone **21** in DME was added to a solution of alcohol-free KOBu-*t* in DME and then stirred at 2–4 °C for 30 min. Comparable crude products were also obtained when the chloro ketone **21** was allowed to react at 25 °C with 2 mol equiv of KOBu-*t* in $CH_2{=}CHOEt$ or with a mixture of 1 mol equiv of PhN_3 and 2 mol equiv of KOBu-*t* in THF. After a solution of 173 mg (1.00 mmol) of the chloro ketone **21** in 20 mL of anhydrous furan had been treated with 271 mg (2.42 mmol) of alcohol-free KOBu-*t*, the resulting suspension was stirred at 25 °C for 4.5 h and then partitioned between CH_2Cl_2 and H_2O. The organic phase was dried and concentrated to leave 147 mg of viscous liquid containing (TLC, silica gel coating with an Et_2O–hexane eluent, 3:7 v/v) mainly the previously described high molecular weight material (R_f 0–0.1) accompanied by a small amount of a more rapidly eluted component (R_f 0.25). Chromatography on silica gel separated 3.7 mg (1.8%) of this component, which may be the adduct **37**, as a colorless liquid: IR (CCl_4) 3070 (vinyl CH) and 1705 cm^{-1} (C=O); mass spectrum *m/e* (rel intensity) 204 (M^+, 10), 161 (27), 136 (32, M^+ − furan), 119 (32), 118 (41), 108 (55), 94 (23), 91 (30), 82 (100), 81 (20), 79 (23), 68 (38), 57 (24), 56 (20), 55 (25), 43 (26), 41 (44), 40 (36), and 39 (62). Our attempts to obtain larger amounts of this material have thus far been unsuccessful. In an attempt to trap the enone **18** as an α,β-epoxy ketone, a solution of 104 mg (0.602 mmol) of the chloro ketone **21** in 5 mL of *t*-BuOH was treated with 40 mg (3.8 mmol) of aqueous 30% H_2O_2 and 0.61 mL (4.6 mmol) of aqueous 7.3 M NaOH. After the resulting suspension had been stirred at 25 °C for 1 h, it was partitioned between Et_2O and aqueous NH_4Cl. The organic solution was dried and concentrated to leave 79.6 mg (86%) of the crude ketol **19**, mp 232–240 °C dec, that was identified with an authentic sample by comparison of IR spectra and TLC R_f values.

Preparation of the Sulfide 25 and the Sulfoxide 50. To a solution of 193 mg (1.12 mmol) of the chloro ketone **21** and 429 mg (3.9 mmol) of PhSH (freshly distilled) in 5 mL of anhydrous MeOH was added, dropwise and with stirring during 5 min, 1.2 mL of a MeOH solution containing 5.12 mmol of NaOMe. The resulting solution, from which a white precipitate began to separate after two-thirds of the NaOMe solution had been added, was stirred at 25 °C for 2 h and then concentrated under reduced pressure and partitioned between Et_2O and H_2O. The Et_2O solution was dried and concentrated to leave 261 mg of liquid product that solidified on standing and contained (TLC,

silica gel coating with an EtOAc–hexane eluent, 1:9 v/v) an unknown component (R_f 0.41), the keto sulfide **25** (R_f 0.32), and the methoxy ketone **24** (R_f 0.09). Chromatography on silica gel with an EtOAc–hexane eluent (1:9 v/v) separated 247 mg (89%) of early fractions containing the keto sulfide **25**, mp 66–67 °C. This product crystallized from an Et_2O–pentane mixture as colorless plates with the same melting point; IR (CCl_4) 1709 cm^{-1} (C=O); UV max (95% EtOH) 222 (ϵ 11 000) and 267 nm (ϵ 1300); ^1H NMR (CCl_4) δ 7.2–7.8 (5 H, m, aryl CH) and 1.2–2.9 (13 H, m, aliphatic CH); mass spectrum *m/e* (rel intensity) 246 (M^+, 85), 137 (77), 110 (76), 109 (51), 96 (71), 95 (100), 93 (49), 67 (41), 55 (21), and 41 (29); ^{13}C NMR ($CDCl_3$, multiplicity in off-resonance decoupling) 209.9 (s, C=O), 137.3 (d, 2 C atoms), 129.3 (s), 128.9 (d, 2 C atoms), 128.3 (d), 53.0 (t), 49.2 (s), 45.6 (t), 39.3 (t), 38.4 (t), 30.9 (d and t, 2 C atoms), and 20.1 ppm (t).

Anal. Calcd for $C_{15}H_{18}OS$: C, 73.13; H, 7.36; S, 13.01. Found: C, 73.01; H, 7.39; S, 12.96.

To a cold (−70 °C) solution of 547 mg (2.22 mmol) of the keto sulfide **25** in 55 mL of CH_2Cl_2 was added, dropwise and with stirring during 7 min, a solution of 384 mg (2.22 mmol) of freshly purified[19] *m*-$ClC_6H_4CO_3H$ in 16 mL of CH_2Cl_2. After the resulting mixture has been stirred at −70 °C for 10 min, it was partitioned between Et_2O and aqueous Na_2SO_3. The organic layer was washed with aqueous $NaHCO_3$, dried, and concentrated to leave 578 mg of a colorless solid that contained (TLC, silica gel coating with an EtOAc–hexane eluent, 7:3 v/v) the sulfoxide **50** (R_f 0.31) and two minor unidentified impurities (R_f 0.69 and 0.18). This material was chromatographed on silica gel with an EtOAc–hexane (7:3 v/v) eluent to separate 554 mg (95%) of the sulfoxide **50** (a mixture of stereoisomers) as a viscous liquid that crystallized on standing: mp 129–138 °C; IR (CCl_4) 1713 (C=O) and 1053 cm^{-1} (S=O); NMR ($CDCl_3$) δ 7.3–7.7 (5 H, m, aryl CH) and 1.0–3.1 (13 H, m, aliphatic CH); UV max (95% EtOH) 251 nm (ϵ 4700) with end absorption (ϵ 9060 at 211 nm); mass spectrum *m/e* (rel intensity) 262 (M^+, 9), 218 (21), 138 (41), 137 (100), 126 (37), 109 (88), 95 (87), 93 (62), 82 (40), 81 (46), 79 (34), 78 (30), 77 (40), 67 (48), 55 (37), and 41 (32).

Anal. Calcd for $C_{15}H_{18}O_2S$: C, 68.67; H, 6.91; S, 12.22. Found: C, 68.61; H, 6.94; S, 12.18.

Preparation of the Sulfide 26. After a cold (4 °C) solution of 1.73 g (10.0 mmol) of the chloro ketone **21** and 2.00 g (41.6 mmol) of MeSH in 25 mL of MeOH had been treated with 10.3 mL of an MeOH solution containing 54.3 mmol of NaOMe, the resulting mixture was warmed to 25 °C and allowed to stand for 10 h. The resulting mixture was concentrated and partitioned between Et_2O and H_2O. After the organic layer had been dried and concentrated, the residual yellow liquid (1.79 g) was chromatographed on silica gel with an EtOAc–hexane eluent (1:9 v/v) to separate 1.59 g (86%) of the keto sulfide **26** as a pale yellow liquid: n^{25}_D 1.5372; IR (CCl_4) 1710 cm^{-1} (C=O); UV max (95% EtOH) 240 (shoulder, ϵ 181) and 287 nm (ϵ 30); ^1H NMR (CCl_4) δ 2.1–2.6 (6 H, m, aliphatic CH) and 1.2–2.1 (10 H, m, aliphatic CH including a CH_3S singlet at δ 2.02); mass spectrum *m/e* (rel intensity) 184 (M^+, 74), 137 (75), 109 (39), 95 (100), 93 (66), 67 (50), and 41 (34); ^{13}C NMR ($CDCl_3$, multiplicity in off-resonance decoupling) 209.4 (s), 52.1 (t), 45.7 (t), 44.5 (s), 38.2 (t), 37.7 (t), 30.8 (t and d, 2 C atoms), 19.7 (t), and 9.5 ppm (q).

Anal. Calcd for $C_{10}H_{16}OS$: C, 65.17; H, 8.75; S, 17.40. Found: C, 65.06; H, 8.77; S, 17.36.

Preparation of the Amino Ketone 28. To a refluxing (7 °C) solution of 1.73 g (10.0 mmol) of the chloro ketone **21** in 300 mL of Me_2NH (freshly distilled from Na) was added, dropwise and with stirring during 3 min, 2.35 mL of a MeOH solution containing 10.2 mmol of NaOMe. After the resulting solution had been refluxed for 2 h, the Me_2NH was allowed to evaporate and the residue was partitioned between Et_2O and aqueous 1 M HCl. The aqueous phase was made basic (pH 10) with NaOH and extracted with Et_2O. After this final ethereal extract had been dried and concentrated, the residual pale green liquid was distilled to separate 1.67 g (92%) of the amino ketone **28** as a colorless liquid: bp 79–80 °C (0.05 mm); n^{25}_D 1.5049; IR (CCl_4) 1709 cm^{-1} (C=O); UV max (95% EtOH) 215 (ϵ 709) and 279 nm (shoulder, ϵ 60); ^1H NMR ($CDCl_3$) δ 1.2–3.3 (19 H, m, aliphatic CH including a 6 H singlet for the Me_2N group at δ 2.35); mass spectrum *m/e* (rel intensity) 181 (M^+, 58), 139 (20), 138 (100), 124 (84), 110 (21), and 85 (29); ^{13}C NMR ($CDCl_3$, multiplicity in off-resonance decoupling) 211.4 (s, C=O), 57.5 (s), 46.7 (t), 46.0 (t), 37.3 (q, 2 C atoms), 36.5 (t, ?), 32.5 (t, ?), 31.1 (t, ?), 30.2 (d, ?), and 19.3 ppm (t).

Anal. Calcd for $C_{11}H_{19}NO$: C, 72.88; H, 10.57; N, 7.73. Found: C, 72.77; H, 10.59; N, 7.69.

Preparation of the Ammonium Salts 29 and 30. A solution of 186 mg (1.03 mmol) of the amino ketone **28** and 388 mg (2.73 mmol) of MeI in 3 mL of Et_2O was stirred at 25 °C for 48 h and then filtered to separate 312 mg (94%) of the methiodide **29** as a colorless solid, mp 206–210 °C dec. Recrystallization from EtOH–H_2O afforded the pure methiodide **29** as colorless plates: mp 206–209 °C dec; IR (KBr pellet) 1699 cm^{-1} (C=O); UV (95% EtOH) shoulder at 285 nm (ϵ 25) with end absorption (ϵ 10 700 at 218 nm); NMR (Me_2SO-d_6) δ 1.3–3.4 (22 H, m, aliphatic CH including a Me_3N^+ singlet at δ 3.07).

Anal. Calcd for $C_{12}H_{22}INO$: C, 44.59; H, 6.86; I, 39.26; N, 4.33. Found: C, 44.55; H, 6.88; I, 39.18; N, 4.35.

A mixture of 64.2 mg (0.199 mmol) of the methiodide **29**, 140 mg (0.604 mmol) of Ag_2O, and 1.5 mL of H_2O was stirred at 25 °C for 12 h and then filtered. The filtrate was concentrated under reduced pressure and the residual crude ammonium salt **30** was heated to 150 °C for 4 h in a sublimation apparatus at 20-mm pressure. The sublimate that was collected amounted to 13.5 mg (44%) of the ketol **19**, mp 233–240 °C dec, that was identified with the previously described sample by comparison of IR spectra.

Preparation of the Keto Selenide 27. Following previously described directions,[20] a solution of 2.34 g (7.50 mmol) of PhSeSePh in 100 mL of anhydrous MeOH was treated, portionwise, with 790 mg (20.9 mmol) of $NaBH_4$ and the resulting solution was stirred at 25 °C for 2.5 h. Then 1.73 g (10.0 mmol) of the chloro ketone **21** was added and the resulting solution was stirred while 10 mL of a MeOH solution containing 43.4 mmol of NaOMe was added dropwise during 2 min. The resulting mixture was stirred at 25 °C for 1.5 h and then concentrated under reduced pressure and partitioned between Et_2O and H_2O. The ethereal solution was dried and concentrated to leave 3.04 g of crude yellow liquid product containing (TLC, silica gel coating with an EtOAc–hexane eluent, 1:9 v/v) the selenide **27** (R_f 0.30) and a minor, unidentified impurity (R_f 0.65). Chromatography on silica gel with an EtOAc–hexane eluent (1:9 v/v) separated 2.54 g (87%) of the keto selenide **27** as a pale yellow liquid, n^{25}_D 1.6043. The selenide **27** crystallized on standing as yellow plates: mp 49.5–51 °C; IR (CCl_4) 1709 cm^{-1} (C=O); UV max (95% EtOH) 220 (ϵ 12 100) and 280 nm (ϵ 610); ^1H NMR (CCl_4) δ 6.9–7.7 (5 H, m, aryl CH) and 1.0–3.2 (13 H, m, aliphatic CH); mass spectrum *m/e* (rel intensity) 296 (M^+, 7), 294 (M^+, 22), 292 (M^+, 17), 291 (M^+, 5), 290 (M^+, 6), 157 (52), 137 (100), 109 (54), 95 (95), 93 (73), 81 (35), 77 (45), 67 (65), 55 (47), and 41 (45); ^{13}C NMR ($CDCl_3$, multiplicity in off-resonance decoupling) 210.0 (s, C=O), 137.8 (d, 2 C atoms), 128.4 (d, 3 C atoms), 125.4 (s), 53.9 (t), 46.2 (t), 45.6 (s), 40.1 (t), 39.1 (t), 31.4 (d), 30.8 (t), and 20.6 ppm (t).

Anal. Calcd for $C_{15}H_{18}OSe$: C, 61.43; H, 6.19. Found: C, 61.48; H, 6.28.

Preparation of the Keto Acetate 39. A solution of 1.54 g (10.0 mmol) of the ketol **19** and 5 mL of Ac_2O in 10 mL of anhydrous pyridine was stirred for 25 °C for 176 h with additional 2.5-mL portions of Ac_2O being added after 42.5 and 151 h. The resulting mixture was partitioned between Et_2O and H_2O and the ethereal layer was washed with aqueous 1 M HCl and then dried and concentrated to leave 1.25 g of the crude acetate **39** as a yellow solid, mp 59.5–66 °C. Recrystallization from pentane separated 1.09 g (56%) of the pure keto acetate **39** as colorless plates: mp 65.5–67 °C; IR (CCl_4) 1737, 1730 (ester C=O), and 1713 cm^{-1} (C=O); UV (95% EtOH) shoulder at 250 nm (ϵ 45) with weak end absorption (ϵ 140 at 207 nm); NMR (CCl_4) δ 2.85 (2 H, br s, CH_2CO) and 1.1–2.8 (14 H, m, including a CH_3CO singlet at δ 1.93); mass spectrum *m/e* (rel intensity) 196 (M^+, 2), 136 (42), 111 (34), 108 (76), 97 (63), 95 (51), 94 (39), 93 (63), 92 (44), 82 (42), 79 (40), 67 (45), 55 (61), 53 (33), 43 (100), 41 (54), and 39 (55).

Anal. Calcd for $C_{11}H_{16}O_3$: C, 67.32; H, 8.22. Found: C, 67.36; H, 8.25.

Preparation of the Diketo Lactone 22. A solution of 1.54 g (10.0 mmol) of the ketol **19** and 1.28 g (10.1 mmol) of freshly distilled $(COCl)_2$ in 25 mL of $CHCl_3$ (alcohol free) was protected from moisture and stirred at 25 °C for 47 h. Evaporation of the volatile materials left a red-brown solid containing (TLC, silica gel coating with an EtOAc–hexane eluent, 2:3 v/v) the diketo lactone **22** (R_f 0.18) and three unidentified components (R_f 0.59, 0.33, and 0.05). The crude product was chromatographed on silica gel with EtOAc–hexane mixtures as the eluent to separate 856 mg of the product **22** as a tacky orange solid. Recrystallization from an Et_2O–$CHCl_3$ mixture separated 728 mg (35%) of the pure diketo lactone **22** (obtained as the enol **23**) as orange plates: mp 180.5–181.5 °C; IR ($CHCl_3$) 3490 (br, OH), 1788, 1777, 1768, 1760 (lactone C=O), 1687 (conjugated C=O), and 1621 cm^{-1} (C=C); UV max (CH_2CN) 270 (ϵ 7170) and 335 nm (ϵ 3260); ^1H NMR ($CDCl_3$) δ 7.91 (1 H, s, OH) and 1.0–3.0 (11 H, m, aliphatic CH); mass spectrum *m/e* (rel intensity) 208 (M^+, 4), 164 (45), 137 (74), 136 (100), 135 (21), 95 (22), 69 (34), 55 (30), 41 (54), and 39 (36); ^{13}C NMR ($CDCl_3$, multiplicity in off-resonance decoupling) 196.0 (s), 164.8 (s), 144.8 (s), 127.2 (s), 83.1 (s), 43.8 (t), 37.8 (t, 2 C atoms), 31.0 (t), 29.7 (d), and 21.3 ppm (t).

Anal. Calcd for $C_{11}H_{12}O_4$: C, 63.45; H, 5.81. Found: C, 63.50; H, 5.83.

Formation and Decomposition of the Selenoxide 31. A cold (4 °C) solution of 171 mg (0.58 mmol) of the selenide **27** and 101 mg (0.58 mmol) of purified[19] *m*-$ClC_6H_4CO_3H$ in 12 mL of anhydrous furan was stirred at 4–5 °C for 30 min and then warmed to 25 °C and stirred for 2 h. During this warming the solution acquired a distinct yellow color at ~20 °C. After the reaction mixture had been partitioned between aqueous 10% Na_2CO_3 and CH_2Cl_2, the organic layer was washed with aqueous NaCl, dried, and concentrated. The residual yellow liquid (184 mg) contained (TLC, silica gel coating with an EtOAc–hexane eluent, 1:4 v/v) Ph_2Se_2 (R_f 0.72), the starting selenide **27** (R_f 0.52), the hydroxy selenide **32** (R_f 0.19), and a minor unknown component (R_f 0.04). Chromatography on silica gel with an EtOAc–hexane eluent (1:9 v/v) separated 31 mg of Ph_2Se_2, mp 59–61 °C (lit.[9] mp 60–62 °C, identified with an authentic sample by comparison of IR spectra and mixture melting point determination), 9.6 mg of the starting selenide **27** (IR and mass spectral analysis), and 78.5 mg (44%) of the hydroxy selenide **32** as a colorless solid, mp 94–96 °C. Recrystallization from a PhH–hexane mixture separated the pure hydroxy selenide **32** as colorless plates: mp 97–98 °C; IR (CCl_4) 3500 (br, assoc. OH) and 1700 cm^{-1} (C=O); UV max (95% EtOH) 227 (ε 8100) and 325 nm (ε 960); ^1H NMR ($CDCl_3$) δ 6.9–8.0 (5 H, m, aryl CH), 3.5–3.9 (1 H, m, COCHSe), and 1.0–3.3 (12 H, m, OH and aliphatic CH); mass spectrum *m/e* (rel intensity) 310 (M^+, 75), 308 (M^+, 39), 214 (61), 212 (34), 171 (59), 169 (45), 159 (53), 158 (71), 157 (100), 156 (56), 155 (83), 154 (61), 153 (50), 117 (44), 97 (77), 95 (34), 91 (42), 79 (40), 78 (55), 77 (81), 69 (39), 65 (44), 55 (62), 51 (51), 50 (44), 43 (75), 41 (55), and 39 (53); ^{13}C NMR ($CDCl_3$, multiplicity in off-resonance decoupling) 206.5 (s, C=O), 134.3 (d, 2 C atoms), 128.7 (d, 3 C atoms), 127.8 (s), 70.6 (s, COH), 66.1 (d, CHSe), 41.3 (t), 39.1 (t), 38.0 (t), 30.5 (t), 29.5 (d), and 19.5 ppm (t). Comparison of the position of the ^{13}C NMR signal for the substituted bridgehead carbon atom (70.6 ppm) with the position of the corresponding signals for the ketol **19** (70.6 ppm) and the keto selenide **27** (45.6 ppm) indicates that our product has the structure **32** and is not the isomeric α-hydroxy-β-phenylseleno ketone.

Anal. Calcd for $C_{15}H_{18}O_2Se$: C, 58.26; H, 5.87. Found: C, 58.33; H, 5.93.

In a similar experiment, 590 mg (2.01 mmol) of the selenide **27** was oxidized with 361 mg (2.09 mmol) of purified[19] *m*-$ClC_6H_4CO_3H$ in 50 mL of CH_2Cl_2 at 1–3 °C for 1 h and then 427 mg (2.67 mmol) of Br_2 was added to the cold solution. After the resulting solution had been warmed to 25 °C and stirred for 1 h, it was washed with aqueous 10% Na_2CO_3 and then dried and concentrated. The residual orange liquid (654 mg) contained (TLC, silica gel coating with an EtOAc–hexane eluent, 1:9 v/v) the bromo ketone **38** (R_f 0.34) and two minor unidentified components (R_f 0.78 and 0.44). Chromatography on silica gel with an EtOAc–hexane eluent (7:93 v/v) separated 240 mg (55%) of the bromo ketone **38**, mp 79–80.5 °C. Recrystallization from hexane afforded the pure bromo ketone **38** as colorless plates: mp 84.5–85.5 °C; IR (CCl_4) 1722 cm^{-1} (C=O); UV max (95% EtOH) 224 (ε 426) and 283 nm (ε 65); ^1H NMR (CCl_4) δ 2.8–3.2 (2 H, m, CH_2CO), 2.0–2.8 (6 H, m, aliphatic CH), and 0.7–2.0 (5 H, m, aliphatic CH); mass spectrum *m/e* (rel intensity) 218 (M^+, 2), 216 (M^+, 2), 137 (100), 109 (23), 95 (73), 93 (30), 67 (31), 65 (20), 55 (20), 41 (20), and 39 (25); ^{13}C NMR ($CHCl_3$, multiplicity in off-resonance decoupling) 206.9 (s), 62.3 (s), 58.0 (t), 45.1 (t), 44.5 (t, 2 C atoms), 32.0 (d), 30.0 (t), and 21.6 ppm (t).

Anal. Calcd for $C_9H_{13}BrO$: C, 49.79; H, 6.04; Br, 36.81. Found: C, 49.80; H, 6.04; Br, 36.75.

Vapor-Phase Pyrolysis Studies. A. With the Keto Acetate 39. A solution of 1.55 g (7.90 mmol) of the acetate **39** in 10 mL of CH_2Cl_2 and 40 mL of pentane was added, dropwise during 2.5 h, to the top of a 20-cm vertical glass column packed with glass helices and surrounded by an oven heated to 580–600 °C. During this addition a slow stream of N_2 was passed through the column and the effluent solvent and volatile pyrolysis products were collected in traps cooled with a dry ice–*i*-PrOH mixture. After the effluent liquid had been concentrated, an aliquot of the crude pyrolysate (910 mg of red liquid) was mixed with a known weight of *n*-$C_8H_{17}Ph$ (an internal standard) for GLC analysis (silicone DC-710 on Chromosorb P, apparatus calibrated with known mixtures). The material contained the keto olefin **41** (retention time 18.6 min, 42% yield), the dienone **40** (22.9 min, 16% yield), *n*-$C_8H_{17}Ph$ (54.0 min), and a series of minor unidentified components (1.3, 1.5, 1.7, 2.0, 2.1, 2.6, 3.3, 4.3, 5.4, 6.9, 9.4, 11.4, 14.4, and 15.0 min). A collected (GLC) sample of the keto olefin **41** was obtained as a colorless liquid: $n^{25}D$ 1.5047; IR (CCl_4) 1729 (C=O), 1650 (C=C), and 897 cm^{-1} (C=CH_2); UV max (95% EtOH) 283 nm (ε 239); NMR (CCl_4) δ 4.6–5.1 (2 H, m, vinyl CH), 2.6–2.9 (1 H, m, CHCO), and 1.4–2.6 (9 H, m, aliphatic CH); mass spectrum *m/e* (rel intensity) 136 (M^+, 12), 93 (25), 92 (100), 91 (24), 79 (37), 77 (16), 41 (15), and 39 (20).

Anal. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88. Found: C, 79.35; H, 8.90.

A collected (GLC) sample of the dienone **40** was obtained as a colorless liquid: $n^{25}D$ 1.4995; IR (CCl_4) 1671 (C=O), 1639 (C=C), and 924 cm^{-1} (CH=CH_2); UV max (95% EtOH) 237 nm (ε 9830); NMR ($CDCl_3$ at 100 MHz) δ 5.9 (1 H, m, vinyl CH), 1.9–2.7 (8 H, m, aliphatic CH including a CH_3 singlet at δ 1.98), and a pattern characteristic of a —CH=CH_2 group with signals (total 3 H) at δ 5.82 (d of d of d, *J* = 6.9, 10.8, and 18.6 Hz), 5.08 (d of d of d, *J* = 1.4, 1.5, and 18.6 Hz), and 5.06 (d of d of d, *J* = 1.5, 1.6, and 10.8 Hz); mass spectrum *m/e* (rel intensity) 136 (M^+, 11), 107 (14), 94 (30), 93 (34), 82 (100), 79 (17), 77 (14), 54 (32), 53 (16), 44 (20), 41 (29), and 39 (40).

Anal. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88. Found: C, 79.29; H, 8.92.

B. With the Keto Lactone 22. A solution of 217 mg (1.04 mmol) of the lactone **22** in 10 mL of CH_2Cl_2 was added, dropwise during 50 min, to the previously described pyrolysis apparatus with the oven heated to 600–620 °C. The crude liquid pyrolysate was 172 mg of red liquid. After an aliquot of this crude product had been mixed with *n*-$C_8H_{17}Ph$ (an internal standard), GLC analysis (silicone DC 710 on Chromosorb P, apparatus calibrated with known mixtures) indicated the presence of the enone **49** (retention time 18.5 min, 9% yield), the enone **41** (23.8 min, 8% yield), the dienone **40** (31.5 min, 7% yield), *n*-$C_8H_{17}Ph$ (76.2 min), and a number of minor, unidentified materials (1.1, 1.2, 1.7, 2.0, 2.6, 3.2, 4.4, 5.5, 6.6, 7.5, 8.4, 9.1, 13.4, and 35.3 min). Collected (GLC) samples of ketones **40** and **41** were identified with previously described samples by comparison of IR and mass spectra and GLC retention times. A collected (GLC) sample of the enone **49** was identified with a subsequently described sample by comparison of IR and mass spectra and GLC retention times.

C. With the Sulfoxide 50. A solution of 275 mg (1.05 mmol) of the sulfoxide **50** in 10 mL of CH_2Cl_2 was added, dropwise during 45 min, to the previously described pyrolysis apparatus with the oven heated to 400–420 °C. An aliquot of the crude pyrolysate (511 mg of red liquid) was mixed with *n*-$C_8H_{17}Ph$ for GLC analysis (silicone DC 710 on Chromosorb P). The crude product contained PhSH (retention time 5.5 min), the enone **41** (19.4 min, 3% yield), the enone **49** (15.3 min, 13% yield), an unidentified component [or mixture of components, IR (CCl_4) 1717 cm^{-1}, 29.8 min, ~10% yield], *n*-$C_8H_{17}Ph$ (59.8 min), and a number of minor unidentified components (1.5, 2.0, 2.3, 4.3, 9.8, and 11.7 min). Collected (GLC) samples of PhSH and the enone **41** were identified with authentic samples by comparison of IR and mass spectra and GLC retention times. A collected (GLC) sample of the enone **49** was obtained as a colorless liquid: IR (CCl_4) 1726 (C=O) and 1650 cm^{-1} (weak, C=C); NMR ($CDCl_3$, obtained at 100 MHz) δ 6.07 (1 H, d of d of q, *J* = 7.1, 1.9, and ~1.7 Hz, vinyl CH), 2.7–3.0 (2 H, m, bridgehead CH), 2.16 (2 H, d, *J* = 2.9 Hz, CH_2CO), and 1.1–2.1 [7 H, m, aliphatic CH including a CH_3 doublet (*J* = ~1.7 Hz) at δ 1.82]; mass spectrum *m/e* (rel intensity) 136 (M^+, 12), 94 (75), 93 (12), 91 (14), 79 (100), 77 (16), 41 (11), and 39 (14); calcd for $C_9H_{12}O$, 136.0888; found, 136.0908 [lit.[14a] IR 1715 cm^{-1}; NMR δ 6.02 (d of q, *J* = ~2 and ~6.5 Hz), 2.84 (br, 2 H), and 1.62 (d, *J* = ~2 Hz)].

To obtain an authentic sample of the enone **49** a mixture of 204 mg (1.5 mmol) of the enone **41**, 160 mg of 5% Pd/C catalyst, 2 mL of H_2O, and 18 mL of DME was refluxed for a total of 268 h with the reaction being stopped periodically to examine the progress of the isomerization. After the mixture had been filtered and then partitioned between Et_2O and aqueous NaCl, and organic solution was dried and concentrated. The crude liquid product (834 mg) contained (GLC with added internal standard) the enone **49** (26% yield) and the starting enone **41** (27% recovery). Collected (GLC) samples of both enones **41** and **49** were identified with previously described samples by comparison of IR and mass spectra and GLC retention times. The collected sample of enone **49** exhibited a UV maximum (95% EtOH) at 295 nm (ε 47) [lit.[14a] UV 294 nm (ε 153)].

Degradation of the Keto Olefin 41. To the mixture obtained from 3.9 mg of OsO_4 and 30.9 mg (0.227 mmol) of the keto olefin **41** in 0.75 mL of purified dioxane and 0.25 mL of H_2O was added, portionwise and with stirring during 35 min, 102 mg (0.477 mmol) of $NaIO_4$. After the resulting suspension had been stirred at 25 °C for 3 h, it was partitioned between H_2O and CH_2Cl_2. The organic layer was dried over Na_2SO_4, concentrated, redissolved in an Et_2O–PhH mixture (1:1 v/v), filtered through alumina, and again concentrated to leave 30.7 mg of the crude diketone **46**. Recrystallization from a PhH–hexane mixture afforded 20.8 mg (66%) of the pure diketone **46** as colorless plates: mp 195.5–196.5 °C (lit. mp 188–190,[21] 191,[22] 190–191 °C[23]); IR (CCl_4) 1742 and 1721 cm^{-1} (C=O) [lit.[21] IR (CCl_4) 1745 and 1720 cm^{-1}]; UV max (cyclohexane) 298 (ε 103), 307 (ε 103), 318 (ε 101), and 329 nm (ε 73) [lit.[21] UV max (cyclohexane) 300 (ε 100), 320 (ε 100), and 330 nm (ε 75)]; mass spectrum *m/e* (rel intensity) 138 (M^+, 73), 110 (12), 109 (11), 95 (16), 82 (11), 81 (17), 68 (37), 67 (83), 55 (100), 41 (19), and 39 (18).

Isomerization of the Dienone 40. A mixture of 17.1 mg (0.126 mmol) of the dienone **40**, 24 mg of 5% Pd on C, 0.4 mL of H_2O, and 3.6 mL of DME was refluxed for 78 h, at which time isomerization of **40** was practically complete [TLC analysis on silica gel with an EtOAc–hexane eluent (1:4 v/v); **40**, R_f 0.47; **42**, R_f 0.57]. The mixture was diluted with Et_2O, filtered, washed with aqueous NaCl, dried, and concentrated to leave 31.1 mg of crude liquid product. After an aliquot of the crude product had been mixed with a known weight of $PhCH_2CH_2Ph$ (an internal standard), GLC analysis (silicone DC-710 on Chromosorb P, apparatus calibrated with a known mixture) indicated the presence of the phenol **42** (retention time 30.2 min, 30% yield), $PhCH_2CH_2Ph$ (81.1 min), and a number of minor unidentified byproducts. A collected (GLC) sample of the phenol **42** was obtained as a colorless solid, mp 50–51 °C (lit. mp 51,[24] 52–54,[25] 54,[26] 55 °C[27]), that was identified with an authentic sample (Aldrich Chemical Co.) by comparison of IR and mass spectra and GLC retention times. The sample was clearly different from the isomeric phenol **43**.

Following a previously described procedure,[12] 5.04 g (31.1 mmol) of isosafrole (**45**) was added, dropwise and with stirring during 30 min, to a refluxing dispersion of 4.66 g (202 mg-atom) of Na in 35 mL of xylene. Then 45 mL of anhydrous EtOH was added, dropwise and with stirring during 4 h, and the resulting mixture was steam-distilled to remove volatile neutral components. The residual aqueous solution was acidified and extracted with CH_2Cl_2. The organic extract was dried and concentrated and the dark residual liquid (3.38 g) was distilled to separate 1.69 g of colorless liquid, bp 106–109 °C (8 mm), that contained [TLC on silica gel coating, EtOAc–hexane eluent (3:17 v/v)] the phenol **43** (R_f 0.41) and a component believed to be phenol **44** (R_f 0.36). Chromatography on silica gel with an EtOAc–hexane eluent separated early fractions containing 1.04 g (25%) of the phenol **43** as a colorless liquid: $n^{25}D$ 1.5199 [lit. bp 110 (10 mm),[12] 117–118 °C (11 mm)[28]]; IR (CCl_4) 3590 and 3380 cm^{-1} (OH); NMR (CCl_4) δ 6.2–7.4 (5 H, m, OH and aryl CH), 2.43 (2 H, t, J = 7 Hz, benzylic CH_2), 1.2–2.1 (2 H, m, CH_2), and 0.85 (3 H, t, J = 7 Hz, CH_3); mass spectrum m/e (rel intensity) 136 (M^+, 39), 121 (16), 108 (43), 107 (100), 77 (21), and 39 (13).

Later chromatographic fractions contained 462 mg (11%) of a component believed to be phenol **44** as a colorless liquid: $n^{25}D$ 1.5748; IR (CCl_4) 3590, 3400 (OH), and 965 cm^{-1} (*trans*-CH=CH); NMR (CCl_4) δ 6.5–7.4 (7 H, m, OH, vinyl and aryl CH) and 1.78 (3 H, d, J = 5 Hz, CH_3); mass spectrum m/e (rel intensity) 134 (M^+, 100), 133 (71), 107 (30), 105 (28), 91 (22), 77 (24), 51 (20), 40 (25), and 39 (22).

Anal. Calcd for $C_9H_{10}O$: C, 80.56; H, 7.51. Found: C, 80.31; H, 7.71.

Registry No.—**3**, 66921-72-0; **4**, 17348-81-1; **5**, 1123-09-7; **6**, 66921-73-1; **8**, 66921-74-2; **9**, 66921-75-3; **19**, 20498-02-6; **20**, 66921-76-4; **21**, 66921-77-5; **23**, 66921-78-6; **24**, 66921-79-7; **25**, 66921-80-0; **26**, 66921-81-1; **27**, 66921-82-2; **28**, 66921-83-3; **29**, 67011-17-0; **30**, 66921-84-4; **32**, 66921-85-5; **37**, 66921-86-6; **38**, 66077-98-3; **39**, 66921-87-7; **40**, 66921-88-8; **41**, 66921-89-9; **42**, 698-71-5; **43**, 621-27-2; **44**, 66921-90-2; **45**, 120-58-1; **46**, 66921-91-3; **49**, 53922-17-1; **50** isomer I, 66921-92-4; **50** isomer II, 67009-05-6; ethyl acetoacetate, 141-97-9; 2-cyclohexenone, 930-68-7; cycloheptanone, 1121-66-0; diphenyl diselenide, 1666-13-3.

References and Notes

(1) This research has been supported by Public Health Service Grant R01-GM-20197 from the National Institute of General Medical Science. The execution of this research was also assisted by Institutional Research Grants from the National Science Foundation for the purchase of a mass spectrometer and a Fourier transform NMR spectrometer.

(2) J. A. Bertrand, D. Cheung, A. D. Hammerich, H. O. House, W. T. Reichle, D. Vanderveer, and E. J. Zaiko, *J. Org. Chem.*, **42**, 1600 (1977).
(3) W. A. Ayer and W. I. Taylor, *J. Chem. Soc.*, 2227 (1955).
(4) For reviews and recent examples, see (a) G. L. Buchanan, *Chem. Soc. Rev.*, **3**, 41 (1974); (b) G. Köbrich, *Angew. Chem., Int. Ed. Engl.*, **12**, 464 (1973); (c) R. Keese, *ibid.*, **14**, 528 (1975); (d) K. B. Becker, *Helv. Chim. Acta*, **60**, 68, 81, 94 (1977).
(5) (a) A. Marchesini, S. Bradamante, R. Fusco, and G. Pagani, *Tetrahedron Lett.*, 671 (1971); (b) A. Marchesini, U. M. Pagnoni, and A. Pinetti, *ibid.*, 4299 (1973); (c) B. Gioia, A. Marchesini, G. D. Andreeti, G. Bocelli, and P. Sgarabotto, *J. Chem. Soc., Perkin Trans. 1*, 410 (1977); (d) G. L. Buchanan and G. Jamieson, *Tetrahedron*, **28**, 1123, 1129 (1972); (e) A. F. Cameron and G. Jamieson, *J. Chem. Soc. B*, 1581 (1971); (f) B. G. Cordiner, M. R. Vegar, and R. J. Wells, *Tetrahedron Lett.*, 2285 (1970); (g) J. R. Hargreaves, P. W. Hickmott, and B. J. Hopkins, *J. Chem. Soc. C*, 592 (1969); (h) W. Carruthers and M. Qureshi, *ibid.*, 2238 (1970).
(6) (a) P. E. Eaton, *Acc. Chem. Res.*, **1**, 50 (1968); (b) R. Bonneau, P. Fornier de Violet, and J. Joussot-Dubien, *Nouv. J. Chim.*, **1**, 31 (1977); (c) for a recent discussion of related systems, see E. Dunkelblum, H. Hart, and M. Suzuki *J. Am. Chem. Soc.*, **99**, 5074 (1977); M. Suzuki, H. Hart, E. Dunkelblum, and W. Li, *ibid.*, **99**, 5083 (1977).
(7) For recent discussions, see: (a) C. E. Dykstra, *J. Am. Chem. Soc.*, **98**, 7182 (1976); (b) M. C. Bruni, J. P. Daudey, J. Langlet, J. P. Malrieu, and F. Momicchioli, *ibid.*, **99**, 3587 (1977).
(8) W. D. K. Macrosson, J. Martin, W. Parker, and A. B. Penrose, *J. Chem. Soc. C*, 2323 (1968).
(9) H. J. Reich, J. M. Renga, and I. L. Reich, *J. Am. Chem. Soc.*, **97**, 5434 (1975).
(10) (a) H. J. Reich, S. Wollowitz, J. E. Trend, F. Chow, and D. F. Wendelborn, *J. Org. Chem.*, **43**, 1697 (1978); (b) H. J. Reich and J. E. Trend, *ibid.*, **41**, 2503 (1976).
(11) (a) H. J. Reich and J. M. Renga, *J. Org. Chem.*, **40**, 3313 (1975); (b) H. J. Reich, J. M. Renga, and J. E. Trend, *Tetrahedron Lett.*, 2217 (1976).
(12) G. M. Strunz and A. S. Court, *J. Am. Chem. Soc.*, **95**, 3000 (1973).
(13) (a) G. M. Ksander and J. E. McMurry, *Tetrahedron Lett.*, 4691 (1976); (b) G. M. Ksander, J. E. McMurry, and M. Johnson, *J. Org. Chem.*, **42**, 1180 (1977).
(14) (a) I. Alfaro, W. Ashton, K. L. Rabone, and N. A. J. Rogers, *Tetrahedron*, **30**, 559 (1974); (b) for a recent review of sulfoxide pyrolysis to form olefins, see S. Oae and N. Furukawa, *ibid.*, **33**, 2359 (1977); (c) for the isolation of sulfenic acids from the pyrolysis of sulfoxides, see F. A. Davis, S. G. Yocklovich, and G. S. Baker, *Tetrahedron Lett.*, 97 (1978).
(15) All melting points are corrected and all boiling points are uncorrected. Unless otherwise stated $MgSO_4$ was employed as a drying agent. The IR spectra were determined with a Perkin-Elmer Model 257 infrared recording spectrophotometer fitted with a grating. The UV spectra were determined with a Cary Model 14 or a Perkin-Elmer Model 202 recording spectrophotometer. The proton NMR spectra were determined at 60 MHz with a Varian Model A-60 or Model T-60-A NMR spectrometer and the ^{13}C NMR spectra were determined at 25 MHz with a JEOL Fourier transform spectrometer, Model PFT-100. The chemical shift values are expressed in δ values (ppm) relative to a Me_4Si internal standard. The mass spectra were obtained with an Hitachi (Perkin-Elmer) Model RMU-7 mass spectrometer. All reactions involving strong bases or reactive organometallic intermediates were performed under a nitrogen atmosphere.
(16) E. C. Horning, M. O. Denekas, and R. E. Field, "Organic Syntheses", Collect. Vol. III, Wiley, New York, N.Y., 1955, p 317.
(17) (a) E. Knoevenagel and E. Reinecki, *Ber. Dtsch. Chem. Ges.*, **32**, 418 (1899); (b) J. P. Morizur, B. Furth, and J. Kossanyi, *Bull. Soc. Chim. Fr.*, 1422 (1967).
(18) Dr. J. S. Roberts (University of Stirling, personal communication) redetermined the melting point of the previously described sample (ref 8) and also provided us with copies of ^1H NMR and IR spectra of this sample. From comparison of these spectra with the spectra of our sample, we conclude that the two samples are the same.
(19) N. N. Schwartz and J. H. Blumberg, *J. Org. Chem.*, **29**, 1976 (1964).
(20) K. B. Sharpless and R. F. Lauer, *J. Am. Chem. Soc.*, **95**, 2697 (1973).
(21) H. Gerlach and W. Müller, *Angew. Chem., Int. Ed. Engl.*, **11**, 1030 (1972).
(22) K. Mori, Y. Nakahara, and M. Matsui, *Tetrahedron*, **28**, 3217 (1972).
(23) P. D. Bartlett and G. F. Woods, *J. Am. Chem. Soc.*, **62**, 2933 (1940).
(24) G. T. Morgan and A. E. J. Pettet, *J. Chem. Soc.*, 418 (1934).
(25) E. C. Horning, M. G. Horning, and G. N. Walker, *J. Am. Chem. Soc.*, **71**, 169 (1949).
(26) G. Baddeley, *J. Chem. Soc.*, 330 (1944).
(27) O. Kruber and A. Schmitt, *Ber. Dtsch. Chem. Ges.*, **64**, 2270 (1931).
(28) S. G. Cousin and F. Lions, *J. Proc. Roy. Soc. N.S.W.*, **70**, 413 (1937).