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EFFICIENT SYNTHESIS OF 2-VINYLCYCLOBUTANONES BY THE REARRANGEMENT OF 1-METHOXY-1-CYCLOPROPYLCARBINOLS UNDER NEUTRAL CONDITIONS

Theodore Cohen* and Linda Brockunier
Chemistry Department, University of Pittsburgh, Pittsburgh, PA 15260, U.S.A.

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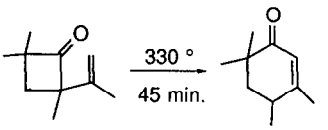
Abstract - A common synthesis of cyclobutanones involves the rearrangement of 1-alkoxy- or 1-(phenylthio)cyclopropylcarbinols under acidic conditions. We report that the synthetically useful 2-vinylcyclobutanones can be prepared in good yield in the absence of protonic acids by treating vinyl-1-(methoxycyclopropyl)carbinols with triflic anhydride in the presence of 2,6-di-*tert*-butyl-4-methylpyridine in methylene chloride. The product is formed before hydrolytic work-up, presumably via demethylation by triflate anion of a 1-methoxycyclobutyl cation. Acid induced destruction of product is thus avoided.

2-Vinylcyclobutanones undergo a variety of transformations, many of considerable potential value in synthesis. In addition to reactions involving the carbonyl or vinyl group individually, there are many in which both functional groups are significantly involved. Among those reactions reported before 1980, which were summarized in an earlier publication from this laboratory,[1] the most synthetically significant is the thermal 1,3-acyl group migration exemplified by eq. 1.[2] Recently, it has been found that photolysis via the triplet state yields mainly 1,2-acyl transfer products as exemplified by eq. 2.[3]



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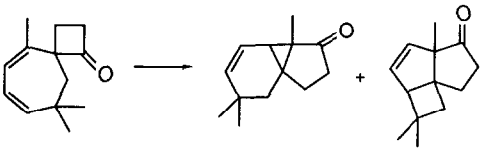

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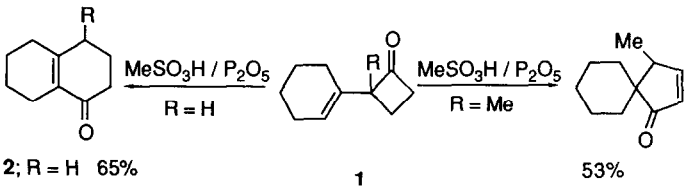
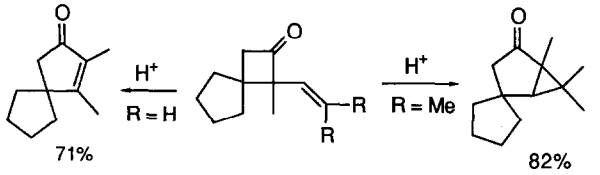


(3)

2; R = H 65% **1** 53% 8%

Of considerable interest are the acid catalysed ring expansions. In those cases in which the 3-position has neither a vinyl nor two alkyl substituents and in which the 3- and 4- positions are identically substituted (e.g. **1**) there are two modes of ring expansion depending on whether R = H or an alkyl group.[1,4] When R = H, acids lead to six-membered rings (eq. 3). When R = alkyl (**1**; R = Me), the product is mainly the 5-membered ring (eq. 3) although we will soon disclose a method for forcing these cases to provide six-membered rings as well.[4] In the more complex examples studied by Dreiding and co-workers,[5] cation stabilizing groups at the 3-position cause acid catalysed ring expansion to a 5-membered ring. The structure of the latter depends on the substitution pattern at the extremity of the vinyl system (eq. 4). When the cation-stabilizing substituent at the 3-position is a vinyl group, more complex products are observed.[5a] In certain cases, when the substituents at C3 and C4 are different, scrambling of these two carbon atoms in the cyclopentanone product can be detected (eq. 5).[5b]



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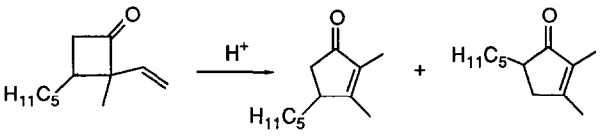
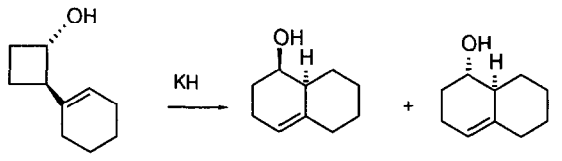


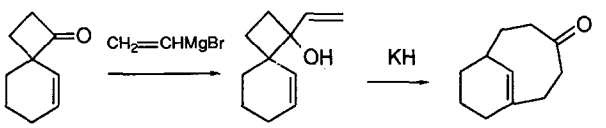
(5)

Some particularly useful transformations are those of the alcohols derived by reduction of or addition of an organometallic to the keto function. If a vinyl group is not attached to the carbinol carbon atom, bases induce an oxyanion - accelerated [1,3]-sigmatropic rearrangement to a six-membered ring,[6-8] stereochemical control can be exerted by the presence or absence of a complexing agent for the metal counterion (eq. 6).[8b] Thermal rearrangement of the trimethylsilyl ethers of the cyanohydrins derived from the 2-vinylcyclobutanones give the same type of rearrangement.[9]



(6)

The addition of a vinylmetallic[3b,10,11] to or an alkynylmetallic[12] to a 2-vinylcyclobutanone provides a divinyl- or alkynylvinylcyclobutanol the potassium salts of which readily undergo an oxyanion accelerated [3,3]-sigmatropic rearrangement. One example of this powerful method for the construction of eight-membered rings is shown in eq. 7.[10,6b] Finally, the epoxyalcohol derivatives of 2-vinylcyclobutanones undergo base-induced fragmentation as shown in eq. 8.[13]



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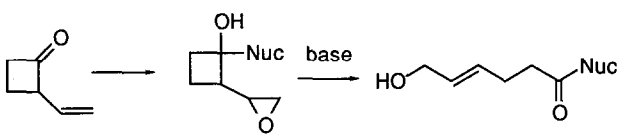

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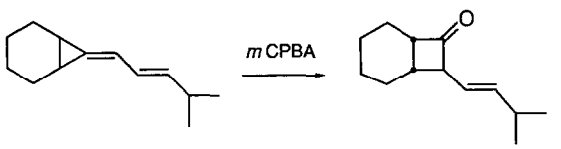
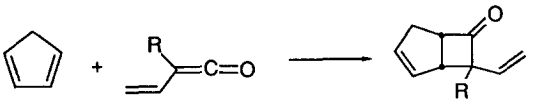


(9)

Aside from a newly introduced method involving peracid oxidation of allylidenecyclopropanes (e.g. eq. 9),[14] two major approaches to the preparation of 2-vinylcyclobutanones have been used. The first is the addition of vinylketenes to olefins (e.g. 10)[7,15,16] a process which is quite satisfactory in the case of conjugated dienes or strained monoolefins but which gives poor yields with ordinary olefins. However, even unactivated olefins give good yields when the vinylketene group is in the same molecule provided that the product is a bicycloheptanone.[17] The other approach which is related to the cyclobutanone synthesis pioneered by Wenkert[18] involves the acid catalyzed rearrangement of a vinylcyclopropylcarbinol bearing an electron donating group Y at that cyclopropyl carbon atom which is attached to the carbinol group (eq. 11). The first examples of this technique were those of Trost[19] in which Y was a phenylthio group as examplified by eq. 12. The cyclopropylcarbinol was derived either directly or indirectly from 1-lithio-1-phenylthiocyclopropane obtained by deprotonation of phenylthiocyclopropane. With very few exceptions, the lithio compound of only the unsubstituted

phenylthiocyclopropane was available.[20] Our own work[8a,21] involving rearrangements of analogous compounds in which Y = OCH_3 was prompted by this limitation as well as by the necessity when Y = SPh of experimenting with a variety of reaction conditions in order to obtain satisfactory yields.



(10)

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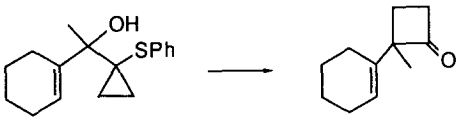
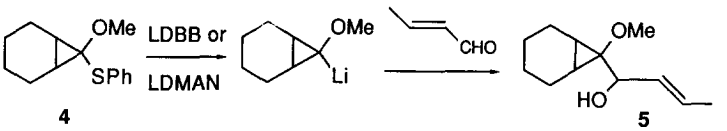
(11)



(12)

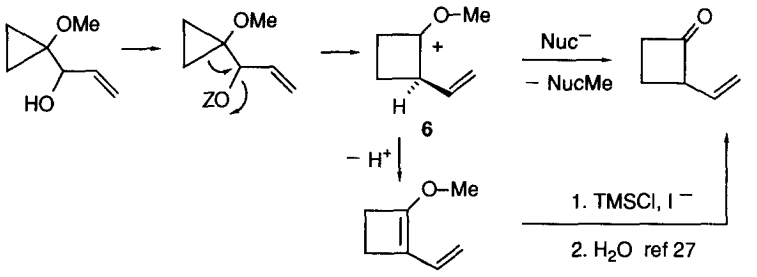
Reductive lithiation, using lithium 1-(dimethylamino)naphthalenide (LDMAN) or lithium p,p'-di-*tert*-butylbiphenylide (LDBB), of a 1-methoxy-1-phenylthiocyclopropane (e.g. **4**) yields a 1-methoxy-1-lithiocyclopropane[22] which is treated with an enal or enone to provide the substrate for the ring expansion (eq 13).[8a,21] The 1-methoxy-1-phenylthiocyclopropanes are available via several procedures.[1,23,24] Furthermore, Gadwood has recently devised a convenient procedure for preparation of the unsubstituted 1-ethoxy-1-lithiocyclopropane.[25] In our laboratory, the rearrangement of the crude cyclopropylvinylcarbinols in the presence of 5%[8a] or 10%[21] fluoroboric acid for ten minutes gives clean products. In every case in which a comparison has been performed.[3,9,21,25] the methoxycyclopropylvinylcarbinols have produced better yields of 2-vinylcyclobutanones than the phenylthio analogues and, very conveniently, uniform reaction conditions can be used.



4 5

(13)

Nevertheless, the acid conditions for the rearrangement can sometimes be detrimental in both these examples and in those of the phenylthio analogues. This is particularly so when functional groups which are particularly acid sensitive are present but, even in their absence, the structural features of the products make them somewhat vulnerable to acid induced rearrangements. These include the ring expansions discussed above as well as a prototropic shift to a conjugated enone.[26] We therefore sought a method for generating a cyclopropylcarbinyl cation under neutral conditions from alkoxycyclopropylvinylcarbinols such as **3** (Y = alkoxy) and **5** by converting the alcohol function into a good leaving group without the use of an acid. The conversion of the resulting carbocation **6** to the cyclobutanone could then take either of two routes both of which take advantage of the properties of the oxygen atom attached to the cyclopropane ring (eq 14).



(14)

A number of procedures gave less than satisfactory yields. These included formation of tosylates, benzenesulfonates, or mesylates either by treatment with the acid chloride in the presence of an appropriate amine or treatment of the lithium salt with the acid chloride in the presence or absence of tetramethylethylenediamine and/or iodide ion. The best of these

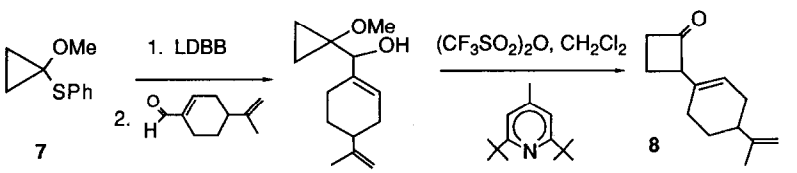
procedures (yields 30 - 73%) involved treatment with methanesulfonyl chloride in methylene chloride in the presence of triethylamine and sodium iodide. Treatment in acetonitrile with trimethylsilyl chloride and sodium iodide in the presence of various bases to scavange the protons gave good yields only in the cases of those products which are incapable of forming conjugated enones. The action of trifluoromethanesulfonic (triflic) anhydride[28] on the lithium salt also gave high yields in cases in which conjugated enones can not form but in other cases the yields were reduced.

Finally, the method which Stang[29] used to produce vinyl triflates was found to provide good yields in most cases. The procedure involves treatment of the alcohol with triflic anhydride in the presence of 2,6-di-*tert*.-butyl-4-methylpyridine (which is recoverable) in methylene chloride; the anhydride was found to form salts with all the other investigated amines including Hünig's base, diisopropylethylamine. It is of considerable interest that the ketone and not the enol ether is obtained directly thus obviating the need to perform the hydrolysis. That the ketone is not formed upon quenching the reaction is shown by its detection by NMR and IR spectroscopy in the concentrate of the unquenched reaction mixture. It thus appears likely that the triflate anion is executing a nucleophilic attack on the cation **6** (See top part of eq. 14). A major advantage, not originally contemplated, of the methoxy activating group thus becomes apparent; it can lead to product formation with innocuous methyl-oxygen bond cleavage leaving the important cyclopropyl-oxygen bond intact.

The results of the reductive lithiations and of the rearrangements are displayed in the table. The yields are uniformly good for the preparation of the alkoxycyclopropylvinylcarbinols using LDBB rather than LDMAN which was used in the previous work.[8a,21,22] When the reductive lithiations were performed with LDMAN the yields of alcohols were always somewhat lower, sharply lower in those examples in which the products are particularly acid sensitive since an acid wash is used to remove the by-product. Thus, as in the case of reductive lithiation of allyl phenyl sulfides,[30] LDBB is the reducing agent of choice as long as the product, as in the present case, is far more polar than the aromatic by-product and can be separated from the latter by means other than an acid wash.

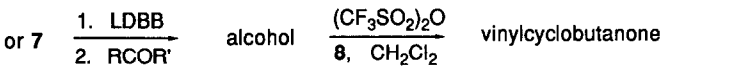
The rearrangements to 2-vinylcyclobutanones by the new method also give good yields (Table). In those cases in which acid sensitive groups are not present and in which comparisons with the earlier protonic rearrangements[8a,21] can be made, the yields using the two procedures are comparable. In the example shown in eq 15, in which the acid sensitive isopropenyl group is present, the product is formed in a greater yield (80% from **7**) than was possible previously[8a] under acid conditions (67% from **7**; previously, the crude alcohols were submitted directly to the rearrangement conditions.) A somewhat greater relative yield enhancement was observed in the production of 2-(2-furyl)cyclobutanone (67% for two steps as opposed to 54%) containing the acid sensitive furan ring. The alcohol derived from decadienal rearranges in satisfactory yield and, presumably, groups of even greater protonic acid sensitivity could be tolerated. A wide variety of cyclobutanones with unsaturated substituents at the 2-position should now become available by this new procedure.

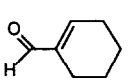
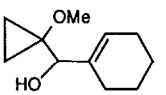
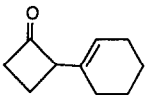
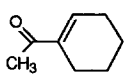
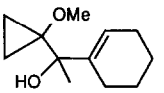
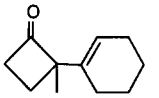
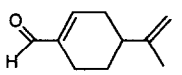
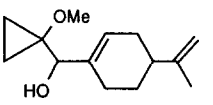
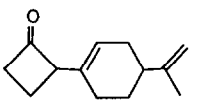
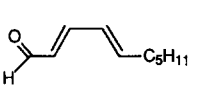
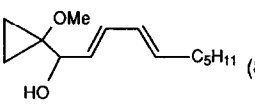
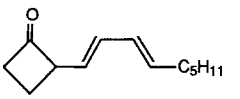
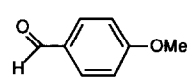
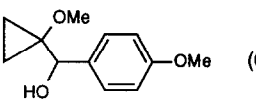
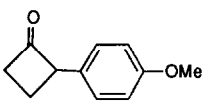
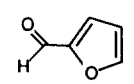
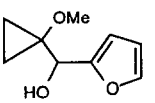
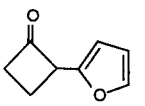
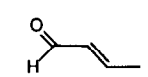
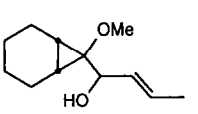
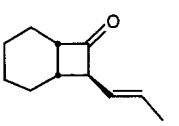
It should be noted that the standard conditions that gave good yields and short reaction times for most of the examples in the table were not satisfactory for three cases. These conditions involved adding the alcohol to a mixture of one molar equivalent of the anhydride and 1.5 molar equivalents of the amine. For the alcohols derived from furfural and 1-acetylcyclohexene, far better results were obtained by the use of two molar equivalents of the anhydride and amine. In the case of the alcohol derived from decadienal, adding an equimolar mixture of anhydride and amine to the alcohol (inverse addition) led to a yield improvement of from 49 to 67%. This latter procedure, which avoids an excess of amine at any time, was adopted when it was suspected that the intermediate 1-methoxycyclobutyl cation was losing the particularly acidic allylic proton to form an enol ether rather than being attacked by the triflate nucleophile.



7 **8** (15)

Table Rearrangement of Alkoxycyclopropylvinylcarbinols, Derived from 1-Methoxy-1-phenylthiocyclopropanes, to 2-Vinylcyclobutanones



4 or 7	RCOR'	alcohol	(yield, %)	vinylcyclobutanone	(yield, %)
7			(91)		(70)
7			(81)		(85)[b]
7			(89)		(90)
7			(87)		(67)
7			(68)[a]		(91)
7			(94)		(71)[b]
4			(92)		(92)

[a]After recrystallization. [b]Two equivalents of both triflic anhydride and of amine used.

EXPERIMENTAL

M.p.s were determined on a Thomas-Hoover Unimelt Capillary melting point apparatus and are uncorrected. Radial chromatography was performed on a Harrison Research Chromatotron. IR spectra were recorded on an IBM IR/32 FTIR spectrophotometer. ^{1}H NMR spectra were recorded on Bruker AF-300S and AF-300T spectrometers with TMS as an internal standard. Data are reported as follows: chemical shift, multiplicity (s: singlet, d: double, t: triplet, q: quartet, m: multiplet, br: broad), coupling constant, integration and assignment. Low resolution mass spectra were recorded on a LKB-9000 combined gas chromatograph-mass spectrometer. Exact mass spectra were obtained on a CH-5 double focussing Varian Mat mass spectrometer. Experiments were performed under argon.

1-Lithio-1-methoxycyclopropane. A mixture of 4,4'-di-*tert*-butylbiphenyl (DBB, 3.27 g, 12.3 mmol) and lithium foil (≅ 85 mg, ≅ 12.2 mmol, cut into 5-10 mg pieces) in 31 ml of THF was stirred (glass-coated stirring bar) for 5 h at 0°. The dark blue-green reaction mixture was cooled to -78° and 1-methoxy-1-(phenylthio)cyclopropane[8a] (**7**, 706 mg, 3.92 mmol) in 6 ml of THF was added. When the addition was complete the color changed from dark blue-green to brown-red. Hence, this color change can be used as a "titration" indicating when the LDBB is consumed. The reaction mixture was used immediately.

4-Methoxyphenyl(1-methoxycycloprop-1-yl)methanol. To a solution of the reductive lithiation product from 2.04 mmol of **7** in 15 ml of THF at -78° was added *p*-anisaldehyde (0.30 ml. 2.5 mmol), and the mixture was stirred for 10 min. The reaction was quenched with 10% aq NH_4Cl and partitioned between ether and water. The organic layer was washed twice with water to remove lithium thiophenoxide and once with sat aq NaCl . The organic layer was dried ($MgSO_4$), filtered, and concentrated. The residue was purified by radial chromatography (65% CH_2Cl_2 / 15% EtOAc in hexanes: R_f =0.24). The product was recrystallized from hexanes to give 425 mg (68%) of the title compound as a white solid. M.p. 48-50°C; IR (neat) 3335, 2944, 2836, 1610, 1512, 1462, 1248, 1177, 1036, 982 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 7.31 (d, J = 8.7 Hz, 2H, aromatic ortho to OCH_3), 6.87 (d, J = 8.7 Hz, 2H, aromatic meta to OCH_3), 4.95 (d, J=2.5 Hz, 1H, C<u>H</u>OH), 3.80 (s, 3H, *p*-OCH_3), 3.35 (s, 1H , OCH_3), 2.47 (d, J = 2.5 Hz, 1H, CHO<u>H</u>), 0.81- 0.63 (m, 3H, cyclopropyl), 0.48-0.46 (m, 1H, cyclopropyl). MS *m/z* 208 (M^+); exact mass: calc for $C_{12}H_{16}$: 208.1099; found: 208.1099.

4-(2-Propenyl)cyclohexene-1-yl(1-methoxycycloprop-1-yl)methanol. From **7** (3.92 mmol) and (S)-(-)-perillaldehyde (0.95 ml, 6.1 mmol) in 37 ml of THF was obtained after radial chromatography (15% EtOAc in hexanes: R_f = 0.21) 778 mg (89% yield) of the alcohol as a mixture of diastereomers. IR (neat) 3446, 2930, 2838, 1437, 1068, 887 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 5.82 (br s, 1H, -C=C<u>H</u>), 4.71 (m, 2H, C=C<u>H</u>$_2$), 4.13 (br s, 1H, C<u>H</u>OH), 4.00 (br s 1H, C<u>H</u>OH), 3.344 (s, 3H, OC<u>H</u>$_3$), 3.338 (s, 3H, OC<u>H</u>$_3$) 2.22-1.81 (m, 7H, alicyclic and O<u>H</u>), 1.74 (s, 3H, C<u>H</u>$_3$), 1.45 (m, 1H, alicyclic), 0.85-0.58 (m, 4H, cyclopropyl). MS *m/z* 222 (M^+); exact mass: calc for $C_{14}H_{22}O_2$: 222.1620; found: 222.1620.

Cyclohexene-1-yl(1-methoxycycloprop-1-yl)-1-ethanol. From **7** (1.80 mmol) and 1-acetyl-1-cyclohexene (0.31 ml, 2.4 mmol) in 15 ml of THF was obtained, after radial chromatography, (40% CH_2Cl_2, 5% EtOAc in hexanes: R_f = 0.23) 284 mg (81%) of the title compound as a colorless oil. IR (neat) 3460, 2930, 2834, 1449, 1244, 1075 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 5.89-5.87 (m, 1H, vinyl), 3.28 (s, 3H, OCH_3), 2.25-2.00 (m, 4H, allylic), 1.99 (s, 1H, CHO<u>H</u>), 1.70-1.50 (m, 4H, alicyclic), 1.21 (s, 3H, CH_3), 0.90 - 0.70 (m, 4H, cyclopropyl). MS *m/z* 196 (M^+); exact mass: calc for $C_{12}H_{20}O_2$: 196.143; found: 196.1463.

Cycohexene-1-yl(1-methoxycycloprop-1-yl)methanol. From **7** (1.41 mmol) and cyclohexene-1-carboxaldehyde[31] (0.24 g, 2.3 mmol) in 14 ml of THF was obtained, after radial chromatography, (10% EtOAc in hexanes: R_f=0.13) 233 mg (91%) of the title compound as a pale yellow oil. IR (neat) 3440, 2930, 2857, 1449, 1221, 1032 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 5.8 (m, 1H, vinyl), 4.05 (br s, 1H, C<u>H</u>OH), 3.34 (s, 3H, OCH_3), 2.20-2.00 (m, 4H, allylic), 1.88 (d, J = 3.8 Hz, 1H, CHO<u>H</u>), 1.70-1.55 (m, 5H, alicyclic), 0.85-0.60 (m, 4H, cyclopropyl). MS *m/z* 182 (M^+); exact mass: calc for $C_{11}H_{18}O_2$: 182.1307; found: 182.1308.

2-Furyl(1-methoxycycloprop-1-yl)methanol. From **7** (1.43 mmol) and 2-furfural (0.22 ml, 2.7 mmol) in 15 ml of THF was obtained, after radial chromatography, (15% EtOAc in hexanes: R_f = 0.11) 226 mg (94%) of the title compound as a yellow oil. IR (neat) 3422, 1225, 1146, 1065, 1013, 739 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 7.37 (br s, 1H, 5-furyl H), 6.35 (m, 2H, 3 -and 4-furyl H), 4.84 (d, J = 5.0 Hz, 1H, C<u>H</u>OH), 3.29 (s, 3H, OCH_3), 2.48 (d, J = 5.0 Hz, 1H, CHO<u>H</u>), 0.90-0.60 (m, 4H, cyclopropyl). MS *m/z* 168 (M^+); exact mass: calc for $C_9H_{12}O_3$: 168.0786; found: 168.0787.

7-Methoxybicyclo[4.1.0] heptane-7-yl(1-trans-propenyl)methanol. To 17 ml of a solution of LDBB (0.4 M, 6.63 mmol), prepared as above, was added a solution of 471 mg (2.01 mmol) of 7-methoxy-7-(phenylthio)bicyclo[4.1.0] heptane[8a] in 3 ml of THF at -78°. Crotonaldehyde (0.28 ml, 3.4 mmol) in 1 ml of THF was added and after 10 min the product was worked up in the usual way. Radial chromatography (40% CH_2Cl_2, 10% EtOAc in hexanes: R_f = 0.28) provided 363 mg (92%) of the title compound as a colorless oil. IR (neat) 3439, 3014, 2870, 1450, 1100 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 5.90-5.70 (m, 2H, vinyl), 4.22 (dd, J = 5.1, 5.1 Hz, 2H, vinyl), 3.37 (s, 3H, OCH_3), 2.05-1.10 (m, 10H, cyclohexyl and OH), 1.76 (d, J = 4.4 Hz, 3H, C=C-C<u>H</u>$_3$).

***trans,trans*-1,3-Nonadiene-1-yl(1-methoxycycloprop-1-yl)methanol.** From **7** (2.60 mmol) and *trans,trans*-2,4-decadienal (0.50 ml, 2.8 mmol) in 17 ml of THF was obtained, after radial chromatography (20% CH_2Cl_2, 10% EtOAc in hexanes; R_f = 0.21),507 mg (87%) of the title compound as a colorless oil. IR (neat) 3430, 2957, 2928, 2857, 1110, 990 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 6.27 (dd, J = 15.2, 10.4 Hz, 1H, -CH=C<u>H</u>-CH=CH-C_5H_{11}), 6.02 (dd, J = 15.1, 10.4, 1H, -CH=CH-C<u>H</u>=CH-C_5H_{11}), 5.71 (dt, J = 15.1, 7.2 Hz, 1H, -CH=C<u>H</u>-C_5H_{11}), 5.49 (dd, J = 15.2, 6.7 Hz, 1H, -C<u>H</u>=CH-CH=CH-C_5H_{11}), 4.35 (d, J = 6.7 Hz, 1H, -C<u>H</u>OH), 3.36 (s, 3H, OCH_3), 2.19 (br s, 1H, CHO<u>H</u>), 2.07 (m 2H, allylic), 1.45-1.20 (m, 6H, aliphatic), 0.88 (t, J = 6.7 Hz, 3H, -CH_2C<u>H</u>$_3$), 0.81-0.56 (m, 4H, cyclopropyl); irradiation of the peak at δ 5.71 caused the dd at 6.02 to change to a d, J= 9.9 Hz. MS *m/z* 224 (M^+); exact mass: calc for $C_{14}H_{24}O_2$: 224 1776; found: 224.1776.

Trifluoromethanesulfonic anhydride. Prepared by distillation of trifluoromethanesulfonic acid from phosphorous pentoxide.[32,33] The crude $(CF_3SO_2)_2O$ is then redistilled from P_2O_5, stored over a small amount of P_2O_5, and freshly distilled before each use.

2-(p-Methoxyphenyl)cyclobutanone.[21,34] To the alcohol (69 mg, 0.33 mmol) and 2,6-di-*tert*-butyl-4-methylpyridine (102 mg, 0.497 mmol) in 3.3 ml of dry CH_2Cl_2, at -78° was added $(CF_3SO_2)_2O$ (56 µl, 0.33 mmol). It was later found that the reaction is much faster and usually gives improved yields if the alcohol is added to the other components, although this does not appear to apply to those cases in which two equivalents of anhydride and amine are used. The mixture was stirred for 5 h and the reaction was quenched with 10% $NaHCO_3$. The mixture was partitioned between CH_2Cl_2 and 10% $NaHCO_3$ and the organic phase was washed with sat aq NaCl. The residue from the dried (Na_2SO_4) organic layer was purified by radial chromatography (10% EtOAc in hexanes: $R_f = 0.18$) to give 53 mg (91%) of the title compound as a pale yellow oil. IR (neat) 3002, 2961, 2838, 1779, 1612 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 7.17 (d, J = 8.3 Hz, 2H, aromatic), 6.88 (d, J = 8.3 Hz, 2H, aromatic), 4.48 (t, J = 9.3 Hz, 1H, COC<u>H</u>), 3.84 (s, 3H, OC<u>H</u>$_3$), 3.27-3.15 (m, 1H, COC<u>H</u>$_2$), 3.07-2.96 (m, 1H, COC<u>H</u>$_2$), 2.58-2.46 (ddd, J = 21.2, 10.6, 4.9 Hz, 1H, C<u>H</u>$_2$CH$_2$CO), 2.24-2.12 (m, 1H, -C<u>H</u>$_2$CH$_2$CO).

2-(4-(2-Propenyl)cyclohexen-1-yl)cyclobutanone.[8a] The alcohol (45 mg, 0.20 mmol) in 1.0 ml of CH_2Cl_2 was added dropwise to a mixture of 2,6-di-*tert*-butyl-4-methylpyridine (62 mg, 0.30 mmol) and $(CF_3SO_2)_2O$ (34 µl, 0.20 mmol) at -78° and the mixture was stirred for 1 h. The reaction was quenched by adding 10% $NaHCO_3$ and worked up as usual. Radial chromatography (4% EtOAc in hexanes: $R_f = 0.19$) gave 34 mg (90%) of the title compound as a pale yellow oil. IR (neat) 2924, 2840, 1780, 1646, 1437, 1073 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 5.58 (m, 1H, -C=C<u>H</u>), 4.71 (m, 2H, -C=C<u>H</u>$_2$), 3.88 (br t, J = 7.6 Hz, 1H, COC<u>H</u>), 3.10-2.83 (m, 2H, COC<u>H</u>$_2$), 2.25-1.77 (m, 8H, alicyclic), 1.73 (s, 3H, CH_3), 1.45 (m, 1H, alicyclic).

2-(Cyclohexen-1-yl)-2-methylcyclobutanone.[34] To the corresponding alcohol (30 mg, 0.153 mmol) and 2,6-di-*tert*.-butyl-4-methylpyridine (63 mg, 0.31 mmol) in 1.5 ml of CH_2Cl_2 at ambient temperature (23°) was added $(CF_3SO_2)_2O$ (52 µl, 0.31 mmol) and the mixture was stirred for 2 h. In this particular case, the reaction was far slower if it was performed at -78 °C and/or only one equivalent of anhydride was employed. The reaction was quenched by pouring it into sat aq $NaHCO_3$. The usual work up and radial chromatography (5% EtOAc in hexanes: $R_f = 0.33$) gave 21 mg (85%) of the title compound as a pale yellow oil. IR (neat) 2928, 2859, 1777, 1449, 1055, 1034 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 5.58 (m, 1H, vinyl), 2.98 (m, 2H, COC<u>H</u>$_2$), 2.25-1.50 (m, 10H, alicyclic), 1.29 (s, 3H, CH_3).

2-(Cyclohexen-1-yl)cyclobutanone.[34] The corresponding alcohol (49 mg, 0.27 mmol) in 1.5 ml of CH_2Cl_2 was added dropwise to a mixture of 2,6,-di-*tert*-butyl-4-methylpyridine (82 mg, 0.40 mmol) and $(CF_3SO_2)_2O$ (45 µl, 0.27 mmol) in 1.0 ml of CH_2Cl_2 at 0° and the mixture was stirred for 30 min. The reaction was quenched with 10% $NaHCO_3$; work-up and radial chromatography (5% EtOAc in hexanes: $R_f = 0.22$) gave 28 mg (70%) of the title compound as a yellow oil. IR (neat) 2930, 1782, 1657 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 5.56 (m, 1H, vinyl), 3.85 (br t, J = 9.3 Hz, 1H, COC<u>H</u>), 3.06-2.87 (m, 2H, COC<u>H</u>$_2$), 2.20-1.85 (m, 6H alicyclic), 1.68-1.52 (m, 4H, alicyclic).

2-(2-Furyl)cyclobutanone.[8a] To the corresponding alcohol (100 mg, 0.61 mmol) and 2,6-di-*tert*-butyl-4-methylpyridine (250 mg, 1.2 mmol) in 3.5 ml of CH_2Cl_2 at -78° was added $(CF_3SO_2)_2O$ (205 µl, 1.2 mmol) and the mixture was stirred for 2 h. The reaction was quenched by pouring it into sat aq $NaHCO_3$. After normal work up, radial chromatography (50% CH_2Cl_2, 1% EtOAc in hexanes: $R_f = 0.38$) gave 60 mg (72%) of the title compound as a yellow oil. IR (neat) 2969, 1788, 1505, 1150, 1078 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 7.35 (d, J = 1.9 Hz, 1H, 5-furyl H), 6.32 (dd, J = 3.1, 1.9 Hz, 1H, 4-furyl H), 6.15 (d, J = 3.1 Hz, 1H, 3-furyl H), 4.52 (t, J = 9.1 Hz, 1H, COC<u>H</u>), 3.27-3.06 (m, 2H, C<u>H</u>$_2$CO), 2.53-2.41 (ddd J = 21.1, 10.7, 5.9 Hz, 1H, C<u>H</u>$_2$CH$_2$CO), 2.34-2.21 (m, 1H, C<u>H</u>$_2$CH$_2$CO).

8-(1-*trans*-Propenyl)bicyclo[4.2.0]octan-7-one.[14] The corresponding alcohol (69 mg, 0.35 mmol) in 1 ml of CH_2Cl_2 was added dropwise to a mixture of 2,6-di-*tert*.-butyl-4-methylpyridine (111 mg, 0.541 mmol) and $(CF_3SO_2)_2O$ (62 µl, 0.37 mmol) at -78° and stirred for 2.25 h. The reaction was quenched with 10% $NaHCO_3$ and worked up as usual. Radial chromatography (5% EtOAc in hexanes $R_f = 0.34$) gave 53 mg (93%) of the title compound as a colorless oil. IR (neat) 2932, 2361, 1771, 1450, 965 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 5.60-5.40 (m 2H, vinyl), 3.62 (ddd, J = 6.0, 6.0, 2.2,Hz, 1H, COC<u>H</u>-CH=CH$_3$), 3.21 (ddt, J = 8.4, 7.5, 2.2 Hz, 1H, CO-C<u>H</u>), 2.29 (m, 1H, COCHC<u>H</u>), 1.97-1.33 (m, 8H, alicyclic) 1.68 (dd, J = 6.0, 1.2 Hz, 3H, CH_3).

2-(*trans,trans*-1,3-Nonene-1-yl)cyclobutanone. To the alcohol (70 mg. 0.31 mmol) at -78° in 1.0 ml of CH_2Cl_2 was added dropwise a mixture of 2,6-di-*tert*-butyl-4-methylpyridine (65 mg, 0.32 mmol) and $(CF_3SO_2)_2O$ (52 µl, 0.31 mmol) in 2.0 ml of CH_2Cl_2 and the mixture was stirred for 0.5 h. The reaction was quenched by pouring it into sat aq $NaHCO_3$ and after normal workup radial chromatography (5% EtOAc in hexanes: $R_f = 0.36$) gave 40 mg (67%) of the ketone as a colorless oil. IR (neat) 2928, 2856, 1783, 1069 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 6.15-5.95 (m, 2H, -C=C<u>H</u>-C<u>H</u>=CH-C$_5$H$_{11}$), 5.67 (dt, J = 14.3, 7.1 Hz, 1H, -HC=CH-CH=C<u>H</u>-C$_5$H$_{11}$), 5.55 (dd, J = 15.0, 6.9 Hz, 1H, C<u>H</u>=CH-CH=CH-C$_5$H$_{11}$), 3.98 (m, 1H, COC<u>H</u>), 3.15-2.90 (m, 2H,COC<u>H</u>$_2$), 2.30 (ddd, J = 21.0, 10.6, 5.2 Hz, 1H, COCH$_2$C<u>H</u>$_2$), 2.06 (m, 2H, allylic), 1.91 (m, 1H, COCH$_2$C<u>H</u>$_2$), 1.42-1.20 (m, 6H, aliphatic), 0.88 (t, J = 6.6 Hz, 3H, C<u>H</u>$_3$).

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