Regio- and Stereoselective Synthesis of Unsaturated Carbonyl Compounds Based on Ceric Ammonium Nitrate-Promoted Oxidative Addition of Trimethylsilyl Enol Ethers to Conjugated Dienes

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Received February 10, 1995

In the last decade, oxidative addition reactions of electrophilic carbon radicals to alkenes, promoted by one-electron metal oxidants, have received considerable attention in synthetic organic chemistry as a valuable tool in both intra- and intermolecular carbon–carbon bond formation.[1] In this respect, cerium(IV), frequently employed as ceric ammonium nitrate (CAN), has proved to be particularly effective in promoting the oxidative addition of enolizable carbonyl compounds to electron rich carbon–carbon double bonds.[2] The mechanism of this process is generally stated as follows: the carbonyl compound is first oxidized by CAN to generate an electrophilic α-oxoalkyl radical (eq 1), which attacks the alkene to give another carbon centered radical, now a nucleophilic species (eq 2) undergoing a fast oxidation by CAN to the final adduct (eq 3, Y is the metal ligand ONO_2 or other nucleophilic species present in the medium).

$$RCOCH_2R' + Ce^{4+} \rightarrow RCO\dot{C}HR' + Ce^{3+} + H^+ \quad (1)$$

$$RCO\dot{C}HR' + CH_2{=}CHR'' \rightarrow RCOCH(R')CH_2\dot{C}HR'' \quad (2)$$

$$RCOCH(R')CH_2\dot{C}HR'' + Ce^{4+} \rightarrow RCOCH(R')CH_2CHR''Y + Ce^{3+} \quad (3)$$

We have previously reported that CAN-promoted oxidative addition of carbonyl compounds to 1,3-butadiene leads to a 1:1 mixture of 4-(β-ketoalkyl)-substituted 3-nitroxy-1-butene and 1-nitroxy-2-butene.[2a] Although this process exhibits some interesting mechanistic aspects, its synthetic exploitation has been strongly limited by the lack of regioselectivity, by the low stability of the 1,2 adduct, and mostly by the difficulties met with the conversion or replacement of the allylic nitroxy group.[2b] Moreover, oxidation of simple ketones by CAN, generating α-ketoalkyl radicals, is a very slow process, and satisfactory yields of addition products can be obtained only when the carbonyl compound is used in considerable excess, in practice as the reaction solvent. It has also been reported that α-ketoalkyl radicals can be rapidly generated by CAN-promoted oxidation of trimethylsilyl enol ethers.[3] This procedure, which has been successfully exploited in both inter-[3] and intramolecular[4] carbon–carbon bond formation, could represent a substantial improvement with respect to the one above as the silyl enol ether can be used in stoichiometric amounts with respect to the oxidant in a variety of solvents, allowing the procedure to be extended to any enolizable carbonyl compounds. The possibility of widening the scope of the above process induced us to revisit the CAN-promoted oxidative addition of ketones to conjugated dienes making use of the parent silyl enol ethers. Since we expected that, in this case too, the reaction would have led to the same mixture of 1,2- and 1,4-nitroxy adducts, our principal aim was to increase the synthetic potentiality of the process by looking for a procedure that allows the conversion of the isomeric mixture into regio- and stereoselectively substituted unsaturated carbonyl derivatives. We have taken as a basis our recent finding according to which an allylic nitroxy group, like OCOR, OCO_2R, OR, OPO_2R, and other bad leaving groups, can be easily replaced by palladium(0)-catalyzed substitution reactions.[5] In this note we wish to report on a tandem procedure consisting in CAN-promoted oxidative addition of silyl enol ethers to conjugated dienes followed by palladium(0)-catalyzed alkylation of the resulting nitroxy adducts, as a valuable synthetic access to highly functionalized (*E*)-γ,δ-unsaturated carbonyl compounds.

Results and Discussion

Trimethylsilyl enol ether **1** was added to a red solution of CAN and 1,3-butadiene, (CAN:silyl enol ether, 1,3-butadiene, 1.1:0.75:2 molar ratio).[6] A rapid decoloration of the mixture was observed (5–15 min) and after workup, a crude product was obtained having spectroscopic characteristics consistent with a 1.2:1 mixture of nitroxy adducts **2** and **3** (Scheme 1). When the crude mixture was subjected to nucleophilic attack by sodium dimethyl malonate in THF at room temperature in the presence of catalytic amount of $Pd(PPh_3)_4$, a fast reaction occurred (1–10 min) to give the alkylated adducts **4** and **5** with high regioselectivity, attack at the primary allylic carbon accounting for at least 94%.

The structure of **4** was assigned on the basis of ^{1}H-NMR coupling constants and IR absorptions; in no case did GLC analysis allow us to detect *cis* stereoisomers, making this procedure suitable for the synthesis of (*E*)-6-alkyl-substituted γ,δ-unsaturated carbonyl compounds. Results are reported in Table 1.

Fairly good yields with respect to CAN are obtained except in the reaction of α-[(trimethylsilyl)oxy]styrene (entry 5 in Table 1) where a substantial amount of

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(1) Jasperse, C. P.; Curran, D. P.; Fevig, T. L. *Chem. Rev.* **1991**, *91*, 1237; Giese, B. *Radicals in Organic Synthesis: Formation of Carbon-Carbon Bonds*; Baldwin, J. E., Ed.; Pergamon Press: NY, 1986; Chap. 3, pp 89 and 182. Minisci, F. *Acc. Chem. Res.* **1975**, *8*, 165. Dessau, R. M.; Heiba, E. I. *J. Org.Chem.* **1974**, *39*, 3457. Vinogradov, M. G.; Pogosyan, M. S.; Shteinshneider, A. Ya.; Nikishin, G. I. *Izv. Akad. Nauk SSSR, Ser. Khim.* **1981**, 2077.

(2) (a) Baciocchi, E.; Ruzziconi, R. *J. Org.Chem.* **1986**, *51*, 1645. (b) Baciocchi, E.; Ruzziconi, R. *Gazz. Chim. Ital.* **1986**, *116*, 671. (c) Baciocchi, E.; Civitarese, G.; Ruzziconi, R. *Tetrahedron Lett.* **1987**, *28*, 5357.

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(6) Powdered calcium carbonate was also added in order to avoid extensive hydrolysis of the enol ether by the nitric acid produced in the oxidation processes.

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Scheme 1

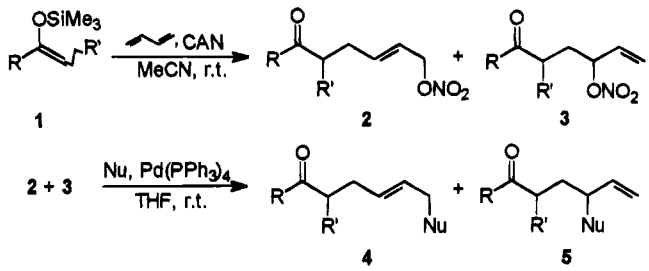
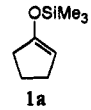
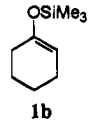
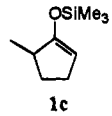
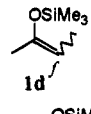
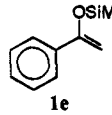
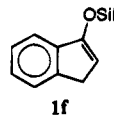
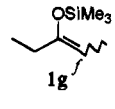
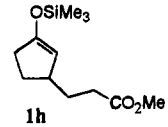


Table 1. Palladium(0)-Catalyzed Malonylation of the Nitroxy Adducts 2 + 3

Entry	Trimethylsilyl Enol Ether	Products (4+5) Overall Yield, %[b]	4:5 Molar Ratio[c]
1	 **1a**	**4a+5a** 62	93:7
2	 **1b**	**4b+5b**[d] 46	92:8
3	 **1c**	**4c**[e] + **5c**[d,e] 49	93:7
4	 **1d**[f]	**4d+5d**[d] 40	95:5
5	 **1e**	**4e+5e** 19	93:7
6	 **1f**	**4f+5f** 42	95:5
7	 **1g**[f]	**4g+5g**[d] 43	98:2
8	 **1h**	**4h+5h**[g] 32	> 99:1

[a] Nu = -CH(CO2Me). [b] Isolated yields with respect to CAN. [c] Determined by g.l.c. and ^{1}H-NMR. [d] Mixture of diastereoisomers. [e] 1.2:1 *trans:cis* mixture. [f] *Z:E* mixture. [g] Contaminated by less than 3% of stereoisomers.

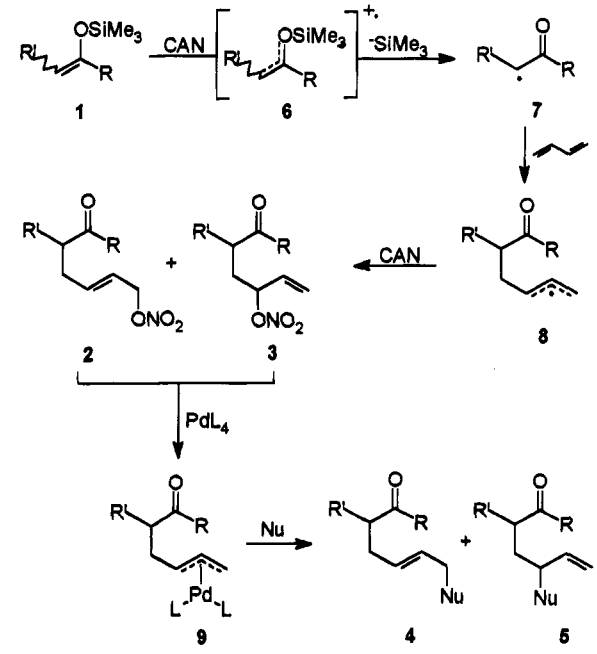
acetophenone was also recovered. This unsatisfactory result is certainly to be ascribed to the slow oxidation of 1-substituted [(trimethylsilyl)oxy]ethenes so that solvolysis of the enol ether, leading to the unreactive acetophenone, significantly competes.[3] Notably, since oxidation of the silyl enol ether takes place exclusively at the β-carbon involved in the enolic double bond, a synthetically relevant aspect of this process is that the attack at the α-carbon of an unsymmetrical ketone can be regioselectively controlled through the employment of the corresponding *kinetic* or *thermodynamic* silyl enol ether

Table 2.. Palladium(0)-Catalyzed Alkylation of the Adducts 2a+3a with Different Carbon Nucleophiles

entry	nucleophile	products **4**+**5**[a] (overall yield, %)[b]	4:5 molar ratio[c]
2	$MeCOC\bar{H}CO_2Me$	**4i**+**5i**[d] (74)	94:6
3	$MeC\bar{(}CO_2Et)_2$	**4l**+**5l** (63)	91:9
4	$MeCOC\bar{(}Me)SO_2Ph$	**4m**+**5m**[d] (30)	>99:1

[a] R, R' = $-(CH_2)_3-$ in Scheme 1. [b] Isolated yields with respect to CAN. [c] Determined by GLC and ^{1}H-NMR. [d] Diastereoisomeric mixture.

Scheme 2



(entries 3 and 4 in Table 1). The reaction with other nucleophiles gives similar results (Table 2) making this procedure of quite general applicability.

The overall process could be rationalized according to the suggested mechanism reported in Scheme 2. Oxidation of the silyl enol ether by CAN generates an electrophilic α-carbonylalkyl radical (**7**), probably through a transient radical cation (**6**). A fast addition of **7** to diene gives the carbonylallyl radical **8**, now a nucleophilic species, which is rapidly oxidized by CAN, by a ligand transfer process, to give the mixture of nitroxy adducts **2** and **3**. Palladium(0)-catalyzed alkylation of both **2** and **3** takes place through a common η^3 palladium complex **9** which undergoes nucleophilic attack almost exclusively at the less substituted allylic carbon.[7]

Less satisfactory results were obtained when we tried to extend the above procedure to alkyl substituted dienes. As to be expected, alkyl substituents around the conjugated carbon–carbon double bonds decrease the oxidation potential of the diene to such an extent that the reaction of the latter with CAN becomes faster than the generation of **7** from **1**; this makes the procedure applicable at most to monoalkyl substituted 1,3-butadienes. Thus, oxidative addition of **1a** to isoprene gives a complex mixture of regio- and stereoisomeric nitroxy adducts which, after reaction with sodium dimethyl malonate,

(7) Accordingly, in spite of a considerable loss of product, due to the instability of the 1,2-nitroxy adduct under chromatographic conditions, in a preliminary experiment the nitroxy adducts derived from **1a** were isolated by column chromatography and separately submitted to the attack by sodium dimethyl malonate. From both regioisomers, identical mixtures of **4a** and **5a** were obtained in a 92% yield.

Chart 1

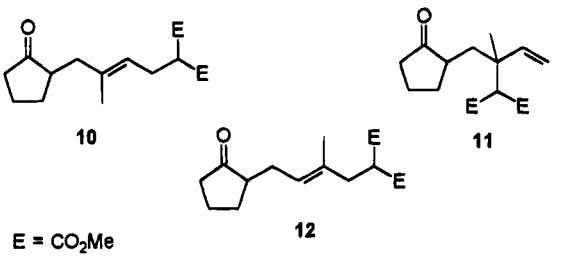
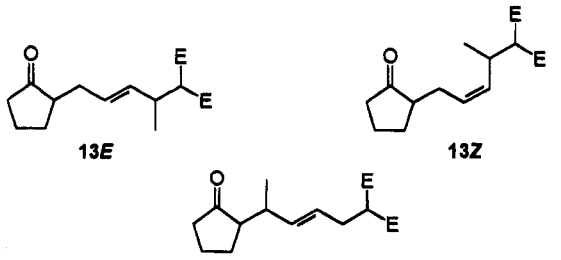


Chart 2



affords an inseparable mixture of alkylated products **10**–**12** in 65% overall yield.[8]

From ^{1}H NMR analysis of the crude mixture, a regioselectivity ratio of 3.8 in favor of the attack of **7** at C-1 of isoprene can be calculated (**10**+**11**/**12**) as expected for an electrophilic addition process.[9]

Oxidative addition of **1a** to piperylene followed by palladium-catalyzed alkylation with sodium dimethyl malonate afforded 20% of a 10:1 mixture of **13*E*** and **13*Z***, contaminated (*ca.* 1%) by the regioisomer **14** (Chart 2). Whereas the high regioselectivity observed in the attack of **7** at C-1 of piperylene is quite expected, being largely determined by the steric effect of the methyl group on C-4 (α effect),[9a] we have no explanation for the exclusive attack of the nucleophile at the methyl substituted allylic carbon in the palladium-catalyzed alkylation. On the other hand, the low yield of the process, probably due to the competing oxidation of piperylene by CAN,[10] makes any plausible hypothesis somewhat hazardous.

Experimental Section

^{1}H-NMR and ^{13}C-NMR spectra were recorded at 200 and 50 MHz, respectively, in $CDCl_3$ in the presence of TMS as an internal standard.

Starting Materials. 1-Ethoxy-1-[(trimethylsilyl)oxy]cyclopropane, dimethyl malonate, diethyl methylmalonate, methyl acetoacetate, 1,3-butadiene, isoprene, piperylene mixture of *E* and *Z* stereoisomers) and tetrakis(triphenylphosphine)palladium(0) (Aldrich), of the highest grade of purity, were used as received. Ceric ammonium nitrate (Aldrich 99%) was dried by heating at 85 °C for 1 h. Acetonitrile (Carlo Erba RPE) was stirred with CaH_2 until no further hydrogen was evolved and then fractionally distilled. 3-(Phenylsulfonyl)-2-butanone was prepared by oxidation of the corresponding β-keto sulfide with potassium peroxymonosulfate (Oxone) in 95% ethanol at 0 °C and purified by column chromatography on silica gel (1:1 diethyl ether/petroleum ether as the eluent).[12] Trimethylsilyl enol ethers were prepared according to the general procedures described in the literature.[13] 1-[(Trimethylsilyl)oxy]-3-[2-(ethoxycarbonyl)ethyl]cyclopentene (99%, GLC) was prepared by copper-catalyzed conjugated addition of zinc homoenolate of ethyl propionate to cyclopenten-3-one according to the procedure described in the literature.[14] ^{1}H-NMR δ 4.58 (q, J = 1.9 Hz, 1 H), 4.12 (q, J = 7.0 Hz, 2 H), 2.6 (m, 1 H), 2.3 (m, 4 H), 2.17–1.95 (m, 1 H), 1.78–1.56 (m, 2 H), 1.53–1.32 (m, 1 H), 1.25 (t, J = 7.0 Hz, 3 H), 0.19 (s, 9 H).

General Oxidative Addition Procedure. A mixture of trimethylsilyl enol ether (12.0 mmol) and 1,3-diene (5.0 mL, 60.0 mmol) was added dropwise to a vigorously stirred suspension of CAN (18.0 mmol) and powdered calcium carbonate (63.0 mmol) in dry acetonitrile (70 mL) at room temperature. The mixture was allowed to react until complete reduction of CAN (iodometric titration). The solid was filtered on Celite and washed with chloroform (50 mL). The filtrate was poured into water, the organic phase was separated, and the aqueous phase was further extracted with chloroform (2 × 50 mL). The collected extracts were washed with water (50 mL) and dried with sodium sulfate, and the solvent was evaporated under vacuum (15 mmHg). The ^{1}H-NMR spectrum of the residual yellow oil showed, in all cases, a doublet at *ca.* δ 4.8 and a symmetric multiplet at δ 5.0–5.5 characteristic of the 1,4-nitroxy adducts, and a multiplet at δ 5.3 which was assigned to the 1,2-adduct. The presence of the ONO_2 group was further confirmed by the strong IR absorptions at *ca.* 1280 and 1630 cm^{-1} (symmetric and asymmetric stretching of N–O bonds, respectively). GC-MS analyses showed the nearly exclusive presence of 1,2- and 1,4-nitroxy adducts in *ca.* 1:1 molar ratio. Representatively, the adducts from the oxidative addition reaction of **1a** were isolated by column chromatography on silica gel (8:2 petroleum ether–diethyl ether as the eluent) and characterized as follows: **(*E*)-4-(2-oxocyclopentanyl)-2-buten-1-ol nitrate, 2a**: ^{1}H-NMR δ 5.92 (dtt, J = 15.3, 7.0, 1.2 Hz, 1 H), 5.62 (ddt, J = 15.3, 7.0, 1.2 Hz, 1 H), 4.82 (d, J = 7.0 Hz, 2 H), 2.62–2.46 (m, 1 H), 2.41–1.40 (m, 8 H); IR (neat) 2963–2882, 1735, 1627, 1434, 1278, 1156, 975, 862 cm^{-1}; MS, m/z (%) 199 (M$^+$, 1), 153 (4), 135 (6), 107 (8), 83 (15), 67 (44), 55 (100). Anal. Calcd for $C_9H_{13}NO_4$: C, 54.26; H, 6.58; N, 7.03. Found: C, 54.61; H, 6.93; N, 7.27. **4-(2-oxocyclopentanyl)-1-buten-3-ol nitrate, 3a** (1:1 mixture of diastereoisomers): ^{1}H-NMR δ 5.88–5.69 (m, 1 H), 5.56–5.34 (m, 3 H), 2.48–1.43 (m, 9 H); IR (neat) 3090, 2965–2880, 1734, 1624, 1406, 1273, 990, 863 cm^{-1}; MS m/z (%) 199 (M$^+$, 1), 153 (3), 135 (12), 107 (7), 83 (22), 69 (42), 55 (100). Anal. Calcd for $C_9H_{13}NO_4$: C, 54.26; H, 6.58; N, 7.03. Found: C, 54.38; H, 6.75; N, 7.31.

General Procedure for Palladium(0)-Catalyzed Alkylation. The above crude mixture and tetrakis(triphenylphosphine)palladium(0) (55 μmol) were stirred in anhydrous THF (10 mL) for 30 min at room temperature. In a separate flask, the carbon nucleophile was prepared by slow addition of the carbonyl compound (18 mmol) to a slurry of pentane-washed sodium hydride (10 mmol) in THF (20 mL) and stirred under nitrogen for 1 h. To the resulting clear solution the former was added in one portion, and the combined mixture was stirred at room temperature until disappearance of the nitrate adducts (GLC analysis, 5–10 min). The reaction mixture was poured into water (100 mL) and extracted with diethyl ether (3 × 50 mL). The collected ethereal extracts were washed with water and dried over sodium sulfate, and the solvent was evaporated at reduced pressure. Chromatography of the residual brown oil on silica gel (1:1 petroleum ether–diethyl ether as the eluent) allowed us to recover the mixture of alkylated products (**5**+**6**). In one experiment, the malonylated products derived from the reactions of **1a** were isolated by HPLC and characterized as

(8) The structures of **10** and **11** were assigned by comparison of ^{1}H-NMR of the crude mixture with those of dimethyl crotylmalonate and dimethyl 2-(2-methylallyl)malonate respectively, taken as models, the chemical shifts of the methyne proton at δ 3.39 and 3.58, respectively, were diagnostic.

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(10) This is in line with the substantial lower oxidation potential of piperylene (IP = −8.78 eV) with respect to those of 1,3-butadiene and isoprene (IP = −9.07 and −9.04 eV, respectively).[11]

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follows: **Methyl (*E*)-2-(methoxycarbonyl)-6-(2-oxocyclopentanyl)-4-hexenoate (4a)**: ^{1}H-NMR δ 5.48 (dt, J = 14.9, 6.0 Hz, 1 H), 5.40 (dt, J = 14.9, 6.0, 1 H), 3.73 (s, 6 H); 3.40 (t, J = 7.5 Hz, 1 H), 2.58 (dd, J = 7.5, 6.0 Hz, 2 H), 2.5–1.4 (m, 9 H); IR (neat) 2955, 2875, 1734, 1653, 1436, 1234, 1155, 975 cm^{-1}; MS m/z (%) 268 (M^+, 1), 237 (2), 228 (16), 205 (35), 185 (100), 153 (32), 136 (40), 132 (52), 84 (86), 55 (46). Anal. Calcd for $C_{14}H_{20}O_5$: C, 62.67; H, 7.51. Found: C, 62.51; H, 7.72. **Methyl 2-(methoxycarbonyl)-4-(2-oxocyclopentanyl)-3-vinylbutanoate (5a)** (1:1 mixture of diastereoisomer): ^{1}H NMR δ 5.90–5.65 (m, 1 H), 5.20–5.08 (m, 2 H), 3.70 (s, 3 H), 3.69 (s, 3 H), 3.38 (m, 1 H), 2.7–1.4 (m, 10 H); IR (neat) 3075, 2960–2860, 1737, 1643, 907 cm^{-1}; MS m/z (%) 250 (2), 236 (7), 205 (27), 185 (98), 121 (100), 84 (90), 55 (65). Anal. Calcd for $C_{14}H_{20}O_5$: C, 62.67; H, 7.51. Found: C, 62.13; H, 7.66.

In all other cases, the products were identified in the mixture by spectroscopic and analytical data. The **4/5** molar ratios were determined by typical ^{1}H NMR absorptions of the olefinic protons and confirmed by GLC analysis.

Product from 1b. Methyl (*E*)-2-(methoxycarbonyl)-6-(2-oxocyclohexanyl)-4-hexenoate (4b): ^{1}H-NMR δ 5.50 (dt, J = 15.3 and 6.0 Hz, 1 H), 5.38 (dt, J = 15.3 and 6.0 Hz, 1 H), 3.72 (s, 6 H), 3.41 (t, J = 7.5 Hz, 1 H), 2.58 (t, J = 7.6 Hz, 2 H), 2.5–1.2 (m, 11 H); IR ($CHCl_3$) 3035, 1749, 1730, 1705, 1653, 1436, 1158, 974 cm^{-1}; MS m/z (%) 282 (M^+, 3), 250 (2), 219 (16), 185 (46), 150 (32), 132 (70), 106 (54), 98 (100), 55 (40). **Methyl 2-(methoxycarbonyl)-4-(2-oxocyclohexanyl)-3-vinylbutanoate (5b)**: ^{1}H-NMR (partial data) δ 5.95–5.70 (m, 1 H), 5.05–5.20 (m, 2 H), 3.42 (m, 1 H); MS m/z (%) 281 (4), 207 (7), 185 (41), 150 (25), 121 (19), 98 (100) 55 (24). Anal. (mixture). Calcd for $C_{15}H_{22}O_5$: C, 63.81; H, 7.85. Found: C, 63.72; H, 8.01.

Products from 1c. Methyl (*E*)-2-(methoxycarbonyl)-6-(2-oxo-3-methylcyclopentanyl)-4-hexenoate (4c) (1.4:1 mixture of trans and cis isomers): ^{1}H-NMR δ 5.43 (m, 2 H), 3.72 (s, 6 H), 3.41 two partially superimposed triplets, J = 7.5 Hz, 1H); 2.6 (m, 2 H) 2.5–1.3 (m, 8 H), 1.10 and 1.05 (two doublets J = 6.2 and 7.1 Hz, respectively, for complexive 3 H); IR (neat) 2957, 2872, 1751, 1734, 1635, 1436, 1233, 1158, 975 cm; MS m/z (%) (major stereoisomer) 282 (M^+, 3), 219 (10), 185 (26), 132 (17), 125 (18), 98 (100), 69 (7), 55 (18); (minor stereoisomer) 282 (M^+, 4), 250 (4), 219 (24), 185 (74), 150 (31), 132 (39), 125 (25), 98 (100), 69 (12), 55 (22). **Methyl 2-(methoxycarbonyl)-4-(2-oxo-3-methylcyclopentanyl)-3-vinylbutanoate (5c)** (mixture of stereoisomers): ^{1}H-NMR (partial data) δ 5.95–5.75 (m,1 H), 5.25–5.1 (m, 2 H), 3.35 (m, 1 H); MS m/z (%) 218 (37), 185 (92), 132 (27), 121 (51), 98 (100). Anal.(mixture). Calcd for $C_{15}H_{22}O_5$: C, 63.81; H, 7.85. Found: C, 63.55; H, 8.00.

Products from 1d. Methyl (*E*)-2-(methoxycarbonyl)-7-methyl-8-oxo-4-nonenoate (4d): ^{1}H-NMR δ 5.54–5.33 (sym m, 2 H), 3.73 (s, 6 H), 3.41 (t, J = 7.5 Hz, 1 H), 2.62–2.42 (m, 3 H), 2.3 (m, 1 H), 2.12 (s, 3 H), 2.0 (m, 1 H), 1.06 (d, J = 7.6 Hz, 3 H); IR (neat) 2955, 1750, 1734, 1710, 1635, 1554, 1436, 1157, 975 cm^{-1}; MS m/z (%) 213 ($M^+ - CH_3CO$, 1), 185 (4), 153 (1), 132 (10), 125 (5), 81 (22), 43 (100). **Methyl 2-(methoxycarbonyl)-5-methyl-6-oxo-3-vinyloctanoate (5d)**: ^{1}H NMR (partial data) δ 5.95–5.70 (m, 1 H), 5.00–5.20 (m, 2 H), 3.5 (m, 1 H); MS m/z (%) 223 (0.5), 185 (12), 153 (3), 121 (14), 81 (24), 43 (100). Anal. (mixture). Calcd for $C_{13}H_{20}O_5$: C, 60.92; H, 7.86. Found: C, 71.15; H, 8.02.

Products from 1e. Methyl (*E*)-2-(methoxycarbonyl)-8-oxo-8-phenyl-4-octenoate (4e): ^{1}H-NMR δ 8.0–7.9 (m, 2 H), 7.6–7.4 (m, 3 H), 5.63 (dt, J = 15.0 and 6.4 Hz, 1 H), 5.46 (dt, J = 15.0 and 6.4 Hz, 1 H), 3.72 (s, 6 H), 3.42 (t, J = 7.1 Hz, 1 H), 3.02 (t, J = 7.1 Hz, 2 H), 2.59 (t, J = 7.1 Hz, 2 H), 2.43 (q, J = 7.1 Hz, 2 H); IR ($CHCl_3$) 2998–2848, 1749, 1732, 1684, 1598, 1436, 1270, 1159, 971, 690 cm^{-1}; MS m/z (%) 273 ($M^+ - OCH_3$, 1), 241 (4), 173 (9), 132 (5), 105 (100), 77 (35).

Methyl 2-(methoxycarbonyl)-6-oxo-6-phenyl-3-vinylhexanoate (5e): ^{1}H NMR (partial data) δ 5.95–5.75 (m, 1 H), 5.10–5.25 (m, 2 H), 3.44 (d, J = 7.1 Hz, 1 H); MS m/z (%) 241 (1), 227 (2), 172 (13), 121 (25), 105 (100), 77 (30). Anal. (mixture). Calcd for $C_{17}H_{20}O_5$: C, 67.09; H, 6.62. Found: C, 67.23; H, 6.78.

Products from 1f. Methyl (*E*)-2-(methoxycarbonyl)-6-(1-oxo-2-indanyl)-4-hexenoate (4f): ^{1}H-NMR δ 7.88–7.30 (m, 4 H), 5.51 (m, 2 H), 3.71 (s, 3 H), 3.70 (s, 3 H), 3.40 (t, J = 7.4 Hz, 1 H), 3.33–3.14 (m, 1 H), 2.87–2.10 (m, 6 H); IR (neat) 2951, 2846, 1750, 1734, 1709, 1653, 1608, 1434, 1152, 974 cm^{-1}; MS m/z (%) 316 (M^+, 2), 253 (5), 185 (16), 169 (7), 132 (100), 77 (6), 59 (7). Anal. Calcd for $C_{18}H_{20}O_5$: C, 68.34; H, 6.37. Found: C, 68.59; H, 6.51.

Products from 1g. Methyl (*E*)-2-(methoxycarbonyl)-7-methyl-8-oxo-4-decenoate (4g): ^{1}H-NMR δ 5.42 (m, 2H), 3.72 (s, 6 H), 3.40 (t, J = 7.3 Hz, 1 H), 2.6–1.8 (m, 8 H), 1.05 (d, J = 7.2 Hz, 3 H), 1.03 (t, 7.2 Hz, 3 H); IR (neat) 2955, 1752, 1735, 1710, 1628, 1436, 1234, 975 cm^{-1}; MS m/z (%) 270 (M^+, 1), 239 (2), 213 (13), 185 (24), 149 (15), 138 (31), 121 (40), 81 (60), 57 (98). **Methyl 2-(methoxycarbonyl)-5-methyl-6-oxo-3-vinyloctanoate (5g)**: ^{1}H NMR (partial data) δ 5.95–5.70 (m, 1 H), 5.20–5.05 (m, 2 H), 3.5 (m, 1 H); MS m/z (%) 245 (3), 193 (22), 185 (100), 121 (42), 81 (64), 57 (82); MS m/z (%) 270 (M^+, 1), 239 (2), 213 (13), 185 (24), 149 (15), 138 (31), 121 (40), 81 (60), 57 (98). Anal. (mixture). Calcd for $C_{14}H_{22}O_5$: C, 62.20; H, 8.20. Found: C, 62.41; H, 8.45.

Products from 1h. *trans*-2-[5,5-Bis(ethoxycarbonyl)-2-penten-1-yl]-3-[2-(ethoxycarbonyl)ethyl]cyclopentanone (4h): ^{1}H-NMR δ 5.54–5.34 (m, 2 H), 4.16 (q, J = 7.1 Hz, 2 H), 3.73 (s, 6 H), 3.40 (t, J = 7.5 Hz, 1 H), 2.1 (m, 2 H), 2.48–1.40 (m, 12 H), 1.28 (t, J = 7.1 Hz, 3 H); ^{13}C-NMR δ 217.8, 172.8, 168.8, 129.7, 127.9, 60.0, 54.2, 52.0, 51.3, 39.7, 37.4, 31.5, 31.4, 30.1, 29.1, 26.3, 13.9; IR (neat) 2985–2876, 1734, 1653, 1163, 1029, 975 cm^{-1}; MS m/z (%) 368 (M^+, 2), 323 (4), 305 (2), 259 (17), 236 (52), 203 (47) 83 (94), 55 (100). Anal. Calcd for $C_{19}H_{28}O_7$: C, 61.94; H, 7.66. Found: C, 62.11; H, 7.83.

Alkylation Products of 2a+3a with Methyl Acetoacetate. (*E*)-3-(methoxycarbonyl)-7-(2-oxocyclopentanyl)-5-hepten-2-one (4i): ^{1}H-NMR δ 5.47 (dt, J = 15.2, 5.9 Hz, 1 H), 5.39 (dt, J = 15.2, 5.9 Hz, 1 H), 3.73 (s, 3 H), 3.49 (t, J = 7.3 Hz, 1 H), 2.54 (t, J = 5.9 Hz, 2 H), 2.4–1.4 (m, 9 H), 2.22 (s, 3 H); MS m/z (%) 210 ($M^+ - CH_2CO$, 6), 178 (5), 169 (40), 136 (52), 84 (61), 55 (24), 43 (100).

3-(Methoxycarbonyl)-5-(2-oxocyclopentanyl)-4-vinyl-2-pentanone (5i): ^{1}H NMR (partial data) δ 5.95–5.75 (m, 1 H), 5.06–5.22 (m, 2 H), 2.24 (s, 3 H); MS m/z (%) 221 (1), 168 (7), 127 (36), 121 (8), 84 (35), 55 (30), 43 (100); IR (neat) 2957, 2878, 1738, 1715, 1646, 1434, 1358, 1154, 974 cm^{-1}. Anal. (mixture). Calcd for $C_{14}H_{20}O_4$: C, 66.44; H, 7.99. Found: C, 66.31; H, 8.10.

Alkylation Products of 2a+3a with Diethyl Methylmalonate. Ethyl (*E*)-2-(ethoxycarbonyl)-2-methyl-6-(2-oxocyclopentanyl)-4-hexenoate (4l): ^{1}H-NMR δ 5.46 (dt, J = 14.9, 6.0 Hz, 1 H), 5.35 (dt, J = 14.9, 6.0 Hz, 1 H), 4.17 (q, J = 7.2 Hz, 4 H), 2.55 (d, 6.7 Hz, 2 H), 2.5–1.4 (m, 9 H), 1.47 (s, 3 H), 1.25 (t, J = 7.2 Hz, 6 H); IR ($CHCl_3$) 2979–2876, 1734, 1653, 1449, 1243, 1109, 975 cm^{-1}; MS m/z (%) 265 ($M^+ - OEt$, 5), 227 (100), 191 (14), 174 (85), 153 (73), 128 (51), 79 (32), 55 (20). Anal. (mixture). Calcd for $C_{17}H_{26}O_5$: C, 65.78; H, 8.44. Found: C, 65.83; H, 8.49.

Alkylation Products of 2a+3a with 3-(Phenylsulfonyl)-2-butanone. (*E*)-3-methyl-7-(2-oxocyclopentanyl)-3-(phenylsulfonyl)-5-hepten-2-one (4m): ^{1}H-NMR δ 7.8–7.5 (m, 5 H), 5.50 (dt, J = 14.9, 6.5 Hz, 1 H), 5.13 (dt, J = 14.9, 5.8 Hz, 1 H), 2.98 (dd, J = 14.3, 6.5 Hz, 1 H), 2.5–1.6 (m, 10 H), 2.46 (s, 3 H), 1.50 and 1.48 two singlets for complexive 3 H; IR ($CHCl_3$) 3065, 2961–2877, 1734, 1709, 1584, 1305, 1147, 973 cm^{-1}; MS m/z (%) 207 ($M^+ - C_6H_5SO_2$, 1), 164 (21), 121 (16), 81 (100), 77 (46), 55 (55), 43 (21). Anal. Calcd for $C_{19}H_{24}O_4S$: C, 65.49; H, 6.94. Found: C, 65.57; H, 7.11.

Products from the Oxidative Addition of 1a to Isoprene and Alkylation with Sodium Dimethyl Malonate. Methyl 2-(methoxycarbonyl)-5-methyl-6-(2-oxocyclopentanyl)-4-hexenoate (11): ^{1}H-NMR δ 5.10 (broad t, J = 7.2 Hz, 1 H), 3.73 (s, 6 H), 3.39 (t, J = 7.5 Hz, 1 H), 2.62 (t, J = 7.4 Hz, 2 H), 2.50 (m, 1 H), 1.61 (broad s, 3H), 2.4–1.4 (m, 8 H); ^{13}C-NMR δ 216.2, 169.1, 136.2, 121.0, 52.1, 51.4, 47.1, 39.5, 37.8, 28.8, 27.2, 20.2, 15.5; MS m/z (%) 282 (M^+, 23), 264 (13), 219 (39), 199 (100), 167 (36), 139 (58), 107 (52), 79 (72), 55 (34). **Methyl 2-(methoxycarbonyl)-4-methyl-6-(2-oxocyclopentanyl)-4-hexenoate (12)** (partial data from the mixture): ^{1}H-NMR δ 5.17 (broad t, J = 7.8 Hz, 1 H), 3.72 (s, 6 H), 3.57 (t, J = 7.4 Hz, 1 H), 2.58 d, J = 7.4 Hz, broad s after irradiation at δ 3.57, 2 H), 1.60 (s, 3 H); ^{13}C-NMR δ 136.2, 124.3, 50.2, 48.8, 38.3, 26.5, 20.6; MS (from GLC-MS analysis) m/z (%) 282 (M^+, 19), 264 (12), 219 (45), 199 (100), 167 (31) 139 (43), 107 (41), 79 (49), 55 (24). **Methyl 2-(methoxycarbonyl)-3-methyl-4-(2-oxocyclopentanyl)-3-vinylbutanoate (13)**: partial data (mixture of diastereoisomers) δ 5.95–5.8 (m, 1 H), 5.2–5.0 (m, 2 H), 3.70 (s, 3 H), 3.69 (s, 3 H), 3.45 (s, 1 H), 1.29 (s, 3 H). MS (from GLC-MS

analysis) m/z (%) 251 (M^+ − OMe, 1), 219 (33), 199 (14), 185 (77), 150 (100), 127 (89), 79 (38), 55 (34). Anal. (mixture). Calcd for $C_{15}H_{22}O_5$: C, 63.81; H, 7.85. Found: C, 63.40; H, 7.97.

Products from the Oxidative Addition of 1a to Piperylene and Alkylation with Sodium Dimethyl Malonate. Methyl 2-(methoxycarbonyl)-3-methyl-6-(2-oxocyclopentanyl)-4-hexenoate (14). 14*E* (1.4:1 mixture of diastereoisomers): δ 5.44 (m, 2H), 3.74, 3.71, and 3.70 (three singlets in 2.8:1:1 integral ratio for complexive 6 H), 3.28 (d, J = 9.0 Hz, 1 H), 2.91 (broad sext, J = 8 Hz, 1 H), 2.73−2.60 (m, 1 H), 2.51−1.4 (m; 8 H), 1.07 (d, J = 6.6 Hz, 3 H); MS (from GLC-MS analysis) m/z (%) 219 (7), 199 (17), 167 (4), 150 (19), 135 (53), 125 (29), 91 (46) 79 (100), 55 (62). **14*Z*** (partial data): δ 3.48 (d, J = 7.9 Hz, 1 H), 1.22 (d, J = 6.6 Hz, 3 H); MS (from GLC-MS analysis of the mixture) m/z (%) 235 (5), 199 (13), 167 (4), 135 (32), 107 (30), 79 (100), 59 (62), 55 (28).

Methyl 2-(methoxycarbonyl)-6-(2-oxocyclopentanyl)-4-heptenoate (15): δ 3.39 (t, J = 7.2 Hz, 1H), 0.91 (d, J = 6.8 Hz, 3 H); MS (from GLC-MS analysis of the mixture) m/z (%) 199 (29), 135 (100), 84 (79), 67 (50), 55 (45). Anal. (mixture). Calcd for $C_{15}H_{22}O_5$: C, 63.81; H, 7.85. Found: C, 64.15; H, 8.11.

Acknowledgment. Thanks are due to the Italian National Research Council (CNR) and the Ministero dell'Università e della Ricerca Scientifica e Tecnologica (MURST) for financial support.

JO9502716

Additions and Corrections

Vol. 58, 1993

Wendell L. Dilling. Bishomocubane Chemistry. 14. Molecular Mechanics Calculations on Bishomocubyl Systems.

Page 5338, column 2, line 5, program[19,33,34] should read program[18,33,34]. Line 11, workers.[20,21] should read workers.[19,21].

Page 5339, Figure 1. Compound **4**, SE value should be 93.90.

JO954008G

Vol. 59, 1994

Suresh Das,* J. S. Dileep Kumar, K. George Thomas, K. Shivaramayya, and M. V. George. Photocatalyzed Multiple Additions of Amines to α,β-Unsaturated Esters and Nitriles.

Page 629, Table 1, sensitizer (30−40 μM) should read sensitizer (0.3−0.4 mM).

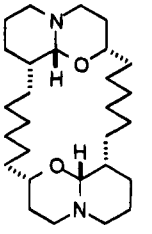
Page 630, Table 2, sensitizer (10^{-4} M) should read sensitizer (0.3−0.4 mM).

Pages 633−634, Experimental Section. Anthraquinone (30−40 μM) should read anthraquinone (0.3−0.4 mM) throughout.

JO954001Z

Thomas R. Hoye,* Jeffrey T. North, and Lelitia J. Yao . Conformational Considerations in 1-Oxaquinolizidines Related to the Xestospongin/Araguspongine Family: Reassignment of Stereostructures for Araguspongines B and E.

Page 6904, column 2. Corrected structure for araguspongine B (**6**).



newly proposed structure for Araguspongine B

6

JO954007O