Treatment of those experimental data that do not produce uniformly linear Ketelaar plots (eq 2) by eq 3–6 provides what appear to be reasonable results. The possibility cannot be overlooked, however, that the observed nonlinearities in those plots may be in part the result of deviations of the ether–carbon tetrachloride mixtures from ideal solutions laws.

Registry No. Diethyl ether/fluoranil complex (1:1), 112042-88-3; diethyl ether/chloranil complex (1:1), 112042-89-4; di-*n*-butyl ether/fluoranil complex (1:1), 112042-90-7; di-*n*-butyl ether/chloranil complex (1:1), 112042-91-8; di-*n*-butyl ether/ICl complex (1:1), 106531-92-4; di-*n*-butyl ether/I_2 complex (1:1), 41035-70-5; 1,4-dioxane/fluoranil complex (1:1), 112042-92-9; 1,4-dioxane/chloranil complex (1:1), 24134-39-2; 1,4-dioxane/ICl complex (1:1), 77570-05-9; 1,4-dioxane/I_2 complex (1:1), 2649-24-3; 1,1-dimethoxyethane/fluoranil complex (1:1), 112042-93-0; 1,1-dimethoxyethane/chloranil complex (1:1), 112042-94-1; 1,1-dimethoxyethane/ICl complex (1:1), 108472-77-1; 1,1-dimethoxyethane/I_2 complex (1:1), 108472-78-2; 1,3,5-trioxane/fluoranil complex (1:1), 112042-95-2; 1,3,5-trioxane/chloranil complex (1:1), 112042-96-3; 1,3,5-trioxane/ICl complex (1:1), 16787-68-1; 1,3,5-trioxane/I_2 complex (1:1), 16734-64-8; tetrahydrofuran/fluoranil complex (1:1), 112042-97-4; tetrahydrofuran/chloranil complex (1:1), 22999-73-1; tetrahydrofuran/ICl complex (1:1), 77570-07-1; tetrahydrofuran/I_2 complex (1:1), 2514-43-4; diethylene glycol dimethyl ester/fluoranil complex (1:1), 112042-98-5; diethylene glycol dimethyl ester/chloranil complex (1:1), 112042-99-6; diethylene glycol dimethyl ester/ICl complex (1:1), 106531-93-5; diethylene glycol dimethyl ester/I_2 complex (1:1), 108472-80-6; 1,2-dimethoxyethane/fluoranil complex (1:1), 112043-00-2; 1,2-dimethoxyethane/chloranil complex (1:1), 112043-01-3; 1,2-dimethoxyethane/ICl complex (1:1), 108472-79-3; 1,2-dimethoxyethane/I_2 complex (1:1), 17153-75-2; triethyl orthoformate/fluoranil complex (1:1), 112043-02-4; triethyl orthoformate/chloranil complex (1:1), 112043-03-5; triethyl orthoformate/I_2 complex (1:1), 112043-04-6; trimethyl orthoformate/fluoranil complex (1:1), 112043-05-7; trimethyl orthoformate/chloranil complex (1:1), 112043-06-8; trimethyl orthoformate/ICl complex (1:1), 108472-75-9; trimethyl orthoformate/I_2 complex (1:1), 108472-76-0; 18-crown-6/fluoranil complex (1:1), 66339-22-8; 18-crown-6/chloranil complex (1:1), 112043-07-9; 18-crown-6/ICl complex (1:1), 106532-07-4; 18-crown-6/I_2 complex (1:1), 65324-94-9; 12-crown-4/fluoranil complex (1:1), 112043-08-0; 12-crown-4/chloranil complex (1:1), 112043-09-1; 12-crown-4/I_2 complex (1:1), 65324-92-7; 15-crown-5/fluoranil complex (1:1), 66403-47-2; 15-crown-5/chloranil complex (1:1), 112043-10-4; 15-crown-5/ICl complex (1:1), 106532-02-9; 15-crown-5/I_2 complex (1:1), 65324-93-8; toluene/fluoranil complex (1:1), 17284-54-7; toluene/chloranil complex (1:1), 2473-74-7; toluene/ICl complex (1:1), 6990-47-2; toluene/I_2 complex (1:1), 2605-02-9; diphenyl ether/fluoranil complex (1:1), 112043-11-5; diphenyl ether/chloranil complex (1:1), 112043-12-6; diphenyl ether/ICl complex (1:1), 108472-81-7; diphenyl ether/I_2 complex (1:1), 93119-16-5; anisole/fluoranil complex (1:1), 37437-54-0; anisole/chloranil complex (1:1), 3921-67-3; anisole/ICl complex (1:1), 62094-04-6; anisole/I_2 complex (1:1), 62093-94-1; dibenzyl ether/fluoroanil complex (1:1), 112043-13-7; dibenzyl ether/chloranil complex (1:1), 112043-14-8; dibenzyl ether/ICl complex (1:1), 108472-88-4; dibenzyl ether/I_2 complex (1:1), 108472-89-5; benzyl methyl ether/fluoranil complex (1:1), 112043-15-9; benzyl methyl ether/chloranil complex (1:1), 112043-16-0; benzyl methyl ether/ICl complex (1:1), 108472-90-8; benzyl methyl ether/I_2 complex (1:1), 108472-91-9; 1,4-dimethoxybenzene/fluoranil complex (1:1), 63023-07-4; 1,4-dimethoxybenzene/chloranil complex (1:1), 2200-23-9; 1,4-dimethoxybenzene/ICl complex (1:1), 108472-85-1; 1,4-dimethoxybenzene/I_2 complex (1:1), 62789-30-4; 1,3-dimethoxybenzene/fluoranil complex (1:1), 112043-17-1; 1,3-dimethoxybenzene/chloranil complex (1:1), 3921-68-4; 1,3-dimethoxybenzene/I_2 complex (1:1), 78717-51-8; 1,2-dimethoxybenzene/fluoranil complex (1:1), 63023-06-3; 1,2-dimethoxybenzene/chloranil complex (1:1), 84654-78-4; 1,2-dimethoxybenzene/ICl complex (1:1), 108472-86-2; 1,2-dimethoxybenzene/I_2 complex (1:1), 108472-87-3; 15-crown-5/fluoranil complex (2:1), 112043-18-2; 12-crown-4/fluoranil complex (2:1), 112043-19-3; trimethyl orthoformate/fluoranil complex (2:1), 112043-20-6; 1,2-dimethoxybenzene/fluoranil complex (2:1), 112043-21-7; 1,3-dimethoxybenzene/fluoranil complex (2:1), 112043-22-8; 1,2-dimethoxyethane/fluoranil complex (2:1), 112043-23-9; benzyl methyl ether/fluoranil complex (2:1), 112043-24-0.

Regioselective Acylation of Terpene Hydrocarbons via Allyl- and Benzyltin Derivatives

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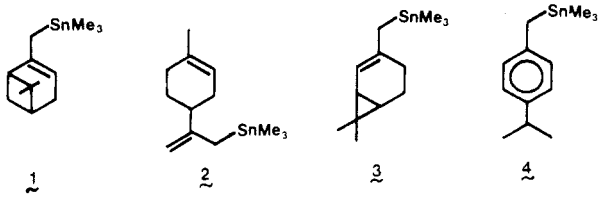
Regioselective acylation of allyl- and benzylstannane derivatives derived from unsaturated terpene hydrocarbons are realized by a rhodium-catalyzed coupling with acyl halides. Mono- and sesquiterpenoid ketones which play an important role in the fragrance industry can be obtained by a three-step process.

Allyl- and benzylstannanes **1**–**4** (Scheme I) can be readily obtained[1] from terpene hydrocarbons (α-pinene, limonene, 2-carene, *p*-cymene, respectively) by metalation with an *n*-butyllithium–tetramethylethylenediamine complex[2] followed by trapping with trimethyltin chloride. These stannanes are versatile reagents that show high reactivity toward electrophilic species[3] and are useful precursors for the introduction of a variety of functional groups.[4]

Scheme I

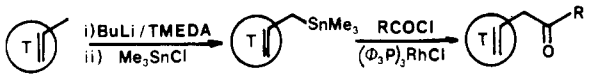


1 2 3 4

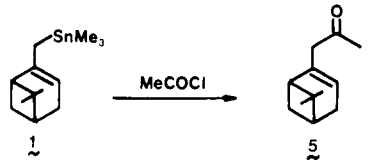
(1) Andrianome, M.; Delmond, B. *Tetrahedron Lett.* **1985**, *26*, 6341.
(2) (a) Crawford, R. J.; Erman, W. F.; Broadus, C. D. *J. Am. Chem. Soc.* **1972**, *94*, 4298. (b) Wilson, S. R.; Philips, L. R.; Natalie, K. J. *J. Am. Chem. Soc.* **1979**, *101*, 3340.

0022-3263/88/1953-0542$01.50/0

Scheme II

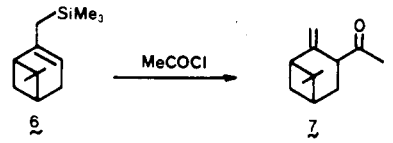


Scheme III



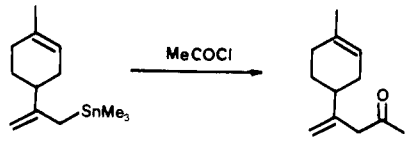
1 5

Scheme IV



6 7

Scheme V



2 8

We have been exploring the use of these intermediates in the synthesis of terpene derivatives[5] not readily obtained by traditional methods.

In this manuscript we extend the work of Migita[6] and Stille[7] to the acylation of 1–4 with acid chlorides in the presence of chlorotris(triphenylphosphine)rhodium[6] as illustrated in Scheme II.

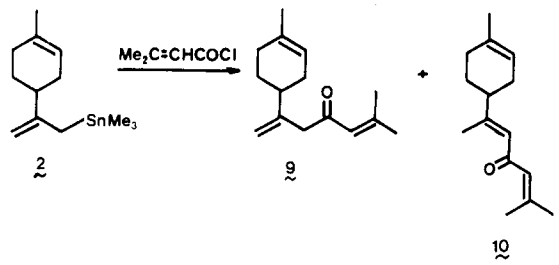
The resulting ketones are not easily prepared by conventional techniques and are compounds useful in the aroma industry.

Results

Acylation of α-Pinene. The reaction of acetyl chloride with 10-(trimethylstannyl)-α-pinene (1) gave 10-acetyl-α-pinene (5) in 74% yield (Scheme III). In contrast, reactions of α-pinene directly with acetic anhydride[8] or β-pinene with acetyl hexachloroantimonate[9] produce 5 in poor yield, often accompanied by rearrangement products.

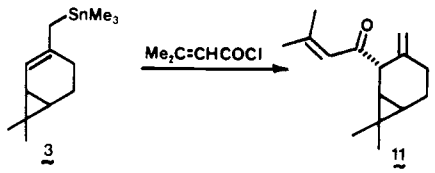
Pillot[10] has reported that the $AlCl_3$-catalyzed reaction of 10-(trimethylsilyl)-α-pinene (6) with acetyl chloride gave 3-acetyl-β-pinene (7) (Scheme IV). Thus allylsilanes and allylstannanes are complementary reagents permitting the selective synthesis of β,γ-unsaturated ketones 5 or 7 with either the α-pinene or β-pinene structure.

Scheme VI



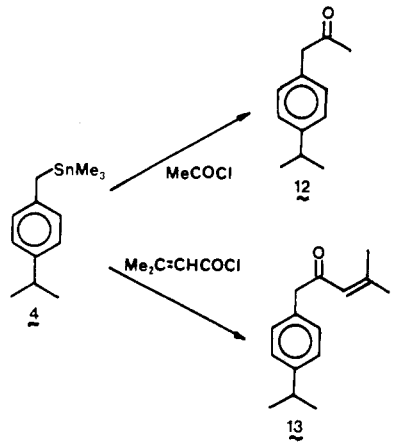
2 9 10

Scheme VII



3 11

Scheme VIII



4 12 13

Acylation of Limonene. Acylation with acetyl chloride of 10-(trimethylstannyl)limonene (2) gave the exclusive formation of 10-acetyllimonene (8) in 62% yield (Scheme V).

The organostannyl group controls the acylation on C10 carbon whereas direct acylation of limonene with acetyl chloride in the presence of tin tetrachloride[11] occurs at both C6 and C10 to give, after dehydrochloration, a complex mixture of α,β- and β,γ-unsaturated ketones.

Acylation of the stannanes 1–4 with senecioyl chloride offers the potential of introducing an additional isoprene unit and the formation of sesquiterpene ketones. We illustrate this methodology by the synthesis of the atlantones 9 and 10 from limonene.[12]

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(12) Atlantones, isolated from essential oils of the Cedrus species,[13] are natural compounds useful for the aroma industry. Numerous syntheses of these compounds have been reported. α-Atlantone: (a) Alexander, J.; Rao, G. S. K. *Indian J. Chem.* **1973**, *11*, 859. (b) Babler, J. H.; Olsen, D. O.; Arnold, W. H. *J. Org. Chem.* **1974**, *39*, 1656. (c) Plattier, H.; Teisseire, P. *Recherches* **1974**, *19*, 153. (d) Malanco, F. L.; Maldonado, L. A. *Synth. Commun.* **1976**, *6*, 515. (e) Cookson, R. C.; Parsons, P. J. *J. Chem. Soc., Chem. Commun.* **1978**, 822. (f) Dauphin, G. *Synthesis* **1979**, 799. (g) Motoyoshiya, J.; Miyajima, M.; Hirakawa, K.; Kakurai, T. *J. Org. Chem.* **1985**, *50*, 1326. β-Atlantone: (h) Crawford, R. C.; Erman, W. F.; Broadus, C. D. *J. Am. Chem. Soc.* **1972**, *94*, 4298. (i) Mehta, G.; Reddy, A. V. *Tetrahedron Lett.* **1979**, 2625. (j) Rousseau, G.; Drouin, J. *Tetrahedron* **1983**, *39*, 2307.
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The rhodium-catalyzed acylation of 10-(trimethylstannyl)limonene (2) with senecioyl chloride proceeded as described earlier to afford a 62% yield of a 75:25 mixture of β-atlantone (9) and α-atlantone (10) (Scheme VI).

Again this reaction proceeded with good regioselectivity, whereas direct reaction of limonene with senecioyl chloride under classical reaction conditions[14] affords a complex mixture of unsaturated ketones.

Acylation of 2-Carene. Acylation of 10-(trimethylstannyl)-2-carene (3) with senecioyl chloride resulted in total allylic transposition with the formation of 2-senecioyl-3(10)-carene (11) in 54% yield (Scheme VII).

To our knowledge this compound has never been described in the literature. Its structural assignment was supported by its ^{1}H NMR spectrum which exhibited a multiplet signal ($W_{1/2}$ = 5 Hz) at δ 4.86 consistent with the presence of a methylene double bond and a signal at δ 3.44 corresponding to the H-2α proton.

Acylation of *p*-Cymene. The selective transfer of a benzyl group from benzylstannanes has been previously reported by Stille.[7,15] Consequently we have extended our study to benzyltin derivatives in the terpene series. Thus 7-(trimethylstannyl)-*p*-cymene (4) when allowed to react with acetyl and senecioyl chlorides in the presence of chlorotris(triphenylphosphine)rhodium gave 7-acetyl-*p*-cymene (12) (72%) and 7-senecioyl-*p*-cymene (13) (53%) (Scheme VIII), respectively.

To our knowledge these two compounds have not been reported. In comparison the acylation of *p*-cymene with acid chlorides in the presence of aluminum chloride[16] occurs on the aromatic nucleus to give alkylphenones.

Conclusion

In summary, the rhodium-catalyzed coupling of acid chlorides with terpene allyl- and benzylstannanes provides a convenient regioselective method for the synthesis of terpenic ketones which are very useful compounds for the aroma industry.[17,18] This three-step procedure from terpene hydrocarbons represents an improvement in comparison to the earlier acylation reactions.

Experimental Section

Infrared spectra were obtained with a UNICAM SP 200 spectrophotometer. ^{1}H NMR spectra were recorded at 90 MHz on a BRUKER WH 90 spectrometer using $CDCl_3$ as solvent. Chemical shifts are reported as δ values in parts per million from internal tetramethylsilane. Mass spectra were measured on a Micromass 16F instrument. Elemental microanalyses were performed by Service Central de Microanalyses du CNRS, F-69630 Vernaison, France. Column chromatography was performed with MERCK silica gel 60, 70–230 mesh ASTM.

Solvents were freshly distilled from drying agent in a nitrogen atmosphere. Dichloromethane was distilled from calcium hydride before use.

α-Pinene, limonene, 2-carene, *p*-cymene, and chlorotris(triphenylphosphine)rhodium were obtained from Fluka. *n*-Butyllithium in hexane was from Aldrich Chemical CO. and its activity was determined by titration.[19] Trimethylstannyl chloride was a generous gift of Schering–France.

All reactions were carried out in an atmosphere of dry nitrogen.

Preparation of Terpene Allyl- and Benzylstannanes. 10-(Trimethylstannyl)-α-pinene (1). To a stirred solution of 1.5 M *n*-butyllithium in hexane (15 mL, 0.022 mol) was added TMEDA (2.56 g, 0.022 mol). The resulting solution was stirred at room temperature for 15 min, at which time α-pinene (6 g, 0.044 mol) was added. The reaction mixture was heated at reflux for 8 h and then cooled to room temperature. A solution of trimethylstannyl chloride (5.73 g, 0.029 mol) in hexane (11 mL) was added dropwise with stirring. After 4 h the insoluble salts were removed by filtration. The filtrate solvent was poured into a saturated aqueous NH_4Cl solution and extracted with ether. The organic layers were washed with H_2O, dried ($MgSO_4$), and evaporated under reduced pressure. The crude product was distilled to give 3.9 g (59%) of 10-(trimethylstannyl)-α-pinene (1): bp 60 °C (0.6 mm); MS, *m/z* (relative intensity) 300 (M^+, 4), 165 (100); ^{1}H NMR ($CDCl_3$) δ 0.13 (9 H, s), 0.91 (3 H, s), 1.33 (3 H, s), 5.06 (1 H, m). Anal. Calcd for $C_{13}H_{24}Sn$: C, 52.17; H, 8.03; Sn, 39.80. Found: C, 52.10; H, 8.08; Sn, 40.07.

10-(Trimethylstannyl)limonene (2). To a stirred solution of 1.5 M *n*-butyllithium in hexane (30 mL, 0.044 mol) was added TMEDA (5.11 g, 0.044 mol). The resulting solution was stirred at room temperature for 15 min, at which time limonene (12 g, 0.088 mol) was added. The reaction mixture was stirred at room temperature for 4 h. To the solution cooled at 0 °C was added trimethylstannyl chloride (11.5 g, 0.06 mol) in hexane (22 mL).

The reaction mixture was allowed to warm to room temperature and worked up as in the experiment above. The crude product was distilled to give 7.4 g (56%) of 10-(trimethylstannyl)limonene (2): bp 72 °C (0.4 mm); MS, *m/z* (relative intensity) 300 (M^+, 5), 165 (100); ^{1}H NMR ($CDCl_3$) δ 0.00 (9 H, s), 1.61 (3 H, br s), 4.55 and 4.62 (2 H, m), 5.40 (1 H, m). Anal. Calcd for $C_{13}H_{24}Sn$: C, 52.17; H, 8.03; Sn, 39.80. Found: C, 52.21; H, 7.98; Sn, 39.74.

10-(Trimethylstannyl)-2-carene (3). A 1.5 M *n*-butyllithium solution in hexane (12.3 mL, 0.0184 mol) was added to TMEDA (2.1 g, 0.0184 mol) at room temperature with stirring. After 15 min, 2-carene (5 g, 0.037 mol) was added and the resulting solution was stirred for 48 h and then cooled at 0 °C. To this solution was added trimethylstannyl chloride (4.8 g, 0.024 mol). The reaction mixture was warmed to room temperature where it was maintained for 2 h. The predescribed workup, followed by distillation, gave 2.58 g (47%) of 10-(trimethylstannyl)-2-carene (3): bp 67 °C (0.2 mm); MS, *m/z* (relative intensity) 300 (M^+, 7), 165 (100); ^{1}H NMR ($CDCl_3$) δ 0.06 (9 H, s), 0.85 (3 H, s), 1.05 (3 H, s), 5.35 (1 H, m). Anal. Calcd for $C_{13}H_{24}Sn$: C, 52.17; H, 8.03; Sn, 39.80. Found: C, 52.09; H, 8.05; Sn, 39.41.

7-(Trimethylstannyl)-*p*-cymene (4). To a stirred solution of 1.5 M *n*-butyllithium in hexane (25 mL, 0.0373 mol) was added TMEDA (4.33 g, 0.0373 mol). The resulting complex was stirred for 15 min; then *p*-cymene (10 g, 0.0746 mol) was added. The solution was stirred for 48 h at room temperature and cooled at 0 °C. A solution of trimethylstannyl chloride (9.7 g, 0.049 mol) in hexane (20 mL) was added. The reaction mixture was allowed to warm to room temperature and maintained for 2 h. Further workup as in the experiments above gave 8.06 g (72%) of 7-(trimethylstannyl)-*p*-cymene (4): bp 73 °C (0.2 mm); MS, *m/z* (relative intensity) 298 (M^+, 8), 165 (100); ^{1}H NMR ($CDCl_3$) δ 0.03 (9 H, s), 1.20 (6 H, d), 2.30 (2 H, s), 2.80 (1 H, m), 7.00 (4 H, m). Anal. Calcd for $C_{13}H_{22}Sn$: C, 52.52; H, 7.41; Sn, 40.07. Found: C, 52.47; H, 7.39; Sn, 40.18.

Acylation of Terpene Allyl- and Benzylstannanes. Acylation of 10-(Trimethylstannyl)-α-pinene (1) with Acetyl Chloride. A solution of 2 g (6.7 mmol) of 10-(trimethylstannyl)-α-pinene and 0.79 g (10 mmol) of acetyl chloride in 4 mL of dichloromethane was heated (60 °C) for 48 h in a sealed tube in the presence of 0.062 g (0.067 mmol) of chlorotris(triphenylphosphine)rhodium. After 16 h, the reaction mixture was hydrolyzed with a saturated aqueous NH_4Cl solution and extracted with ether. The organic layers were washed with H_2O and dried ($MgSO_4$). The solvents were removed by evaporation under reduced pressure. The crude product was purified by liquid chromatography on silica gel. Elution with 1:1 petroleum ether/benzene gave 880 mg (74%) of 10-acetyl-α-pinene[9] (5): IR (neat) 1715 cm^{-1} (CO); MS, *m/z* (relative intensity) 178 (M^+, 5), 43 (100); ^{1}H NMR ($CDCl_3$) δ 0.75 (3 H, s), 1.17 (3 H, s), 2.02 (3 H, s), 2.97 (2 H, br s), 5.28 (1 H, m).

Acylation of 10-(Trimethylstannyl)limonene (2). With Acetyl Chloride. A solution of 2.73 g (9.1 mmol) of 10-(trimethylstannyl)limonene (2) and 1.07 g (13.7 mmol) of acetyl chloride in 5 mL of dichloromethane was allowed to react in the

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presence of 0.127 g (0.137 mmol) of chlorotris(triphenylphosphine)rhodium in a sealed tube at 60 °C. The predescribed workup, followed by purification by liquid chromatography on silica gel with 7:3 petroleum ether/benzene as an eluent, gave 1.02 g (62%) of 10-acetyllimonene[9] (8): IR (neat) 1715 cm^{-1} (CO); MS, m/z (relative intensity) 178 (M^+, 2), 43 (100); ^1H NMR ($CDCl_3$) δ 1.64 (3 H, br s), 2.10 (3 H, s), 3.16 (2 H, s), 4.88 and 5.00 (2 H, m), 5.37 (1 H, m).

With Senecioyl Chloride. A solution of 2 g (6.7 mmol) of 10-(trimethylstannyl)limonene (2) and 1.19 g (10 mmol) of senecioyl chloride in 4 mL of dichloromethane are heated (60 °C) for 16 h in a sealed tube in the presence of 0.062 g (0.067 mmol) of rhodium complex. The reaction mixture was worked up as in the experiments above. The crude product obtained after removing the solvent was purified by liquid chromatography on silica gel.

Elution with 6:4 petroleum ether/benzene gave 680 mg (47%) of β-atlantone (9):[12,13] IR (neat) 1685 cm^{-1} (CO); MS, m/z (relative intensity) 218 (M^+, 3), 83 (100); ^1H NMR ($CDCl_3$) δ 1.62 (3 H, br s), 1.81 (3 H, br s), 2.10 (3 H, br s), 3.10 (2 H, br s), 4.80 and 4.90 (2 H, m), 5.30 (1 H, m), 6.00 (1 H, m).

Further elution with 4:6 petroleum ether/benzene gave 220 mg (15%) of α-atlantone (10):[12,13] IR (neat) 1685 cm^{-1} (CO); MS, m/z (relative intensity) 218 (M^+, 14), 83 (100); ^1H NMR ($CDCl_3$) δ 1.62 (3 H, br s), 1.85 (3 H, br s), 2.13 (6 H, br s), 5.36 (1 H, m), 5.97 (2 H, m).

Acylation of 10-(Trimethylstannyl)-2-carene (3) with Senecioyl Chloride. A solution of 1.5 g (5 mmol) of 10-(trimethylstannyl)-2-carene (3) and 0.89 g (7.5 mmol) of senecioyl chloride in 3 mL of dichloromethane was allowed to react in the presence of 0.047 g (0.05 mmol) of rhodium complex in a sealed tube at 60 °C for 24 h.

The reaction mixture was worked up as previously described and was purified by liquid chromatography on silica gel with 2:3 petroleum ether/benzene as an eluent to give 560 mg (51%) of 2-α-senecioyl-3(10)-carene (11): IR (neat) 1685 cm^{-1} (CO); MS, m/z (relative intensity) 218 (M^+, 3), 83 (100); ^1H NMR ($CDCl_3$) δ 0.95 (3 H, s), 1.02 (3 H, s), 1.88 (3 H, br s), 2.11 (3 H, br s), 3.44 (1 H, br s), 4.86 (2 H, m), 6.22 (1 H, m). Anal. Calcd for $C_{15}H_{22}O$: C, 82.57; H, 10.10. Found: C, 82.47; H, 10.19.

Acylation of 7-(Trimethylstannyl)-p-cymene (4). The reactions were conducted in the same fashion as with the allylstannanes. A solution of 0.0106 mol of acid chloride (acetyl or senecioyl chloride) and 0.0067 mol of 7-(trimethylstannyl)-p-cymene (4) in 5 mL of dichloromethane in the presence of 0.067 mmol of chlorotris(triphenylphosphine)rhodium is heated (60 °C) in a sealed tube for 48 h. The solution was cooled to room temperature, poured into a saturated aqueous NH_4Cl solution, and extracted with ether. The organic layer was washed with H_2O and dried ($MgSO_4$). The solvents were removed by evaporation and the crude product was purified by liquid chromatography on silica gel with 4:6 petroleum ether/benzene as an eluent.

With Acetyl Chloride: 850 mg (72%) of 7-acetyl-p-cymene (12) was obtained; MS, m/z (relative intensity) 176 (M^+, 21), 133 (100); ^1H NMR ($CDCl_3$) δ 1.18 (6 H, d), 2.05 (3 H, s), 3.55 (2 H, s), 7.05 (4 H, s). Anal. Calcd for $C_{12}H_{16}O$: C, 81.82; H, 9.09. Found: C, 82.03; H, 9.11.

With Senecioyl Chloride: 500 mg (53%) of 7-senecioyl-p-cymene (13) was obtained; MS, m/z (relative intensity) 216 (M^+, 3), 83 (100); ^1H NMR ($CDCl_3$) δ 1.24 (6 H, d), 1.40 (3 H, br s), 2.15 (3 H, br s), 2.82 (1 H, m), 3.66 (2 H, s), 6.08 (1 H, m), 7.13 (4 H, s). Anal. Calcd for $C_{15}H_{20}O$: C, 83.33; H, 9.26. Found: C, 83.51; H, 9.15.

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Registry No. 1, 105760-49-4; 2, 112069-27-9; 3, 100692-36-2; 4, 105631-51-4; 5, 64615-27-6; 8, 112069-28-0; 9, 38331-79-2; 10, 112137-48-1; 11, 112069-29-1; 12, 7306-39-0; 13, 112069-30-4; α-pinene, 80-56-8; limonene, 5989-27-5; 2-carene, 554-61-0; p-cymene, 99-87-6.

Ozonization of Cholesterol in Nonparticipating Solvents[1]

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Reaction of ozone with cholesterol (or cholesterol 3β-acetate) in dilute CCl_4 or hexane solutions gave the heretofore undescribed isomeric 1,2,4-trioxolane ozonides 5,7α-epidioxy-5α-*B*-homo-6-oxacholestan-3β-ol and 5,7β-epidioxy-5β-*B*-homo-6-oxacholestan-3β-ol (or their 3β-acetates). Structures are supported by proton and carbon spectra and by Zn/acetic acid reduction to 3β-hydroxy(or 3β-acetoxy)-5-oxo-5,6-secocholestan-6-al. At higher cholesterol concentrations oxidized dimeric and oligomeric products are formed at the expense of 1,2,4-trioxolane ozonides. The major dimer 6ξ-(cholest-5′-en-3′β-yloxy)-5,6ξ-epidioxy-5ξ-5,6-secocholestane-3β,5-diol formed monoesters and was reduced by Zn/acetic acid to equivalent amounts of 3β-hydroxy-5-oxo-5,6-secocholestan-6-al and cholesterol. Also formed from cholesterol were dimeric ozonides 6ξ-(5′,7′α-epidioxy-5′α-*B*′-homo-6′-oxacholestan-3′β-yloxy)-5,6ξ-epidioxy-5ξ-5,6-secocholestane-3β,5-diol and 6ξ-(5′,7′β-epidioxy-5′β-*B*′-homo-6′-oxacholestan-3′β-yloxy)-5,6ξ-epidioxy-5ξ-5,6-secocholestane-3β,5-diol and dimeric epoxides 5,6ξ-epidioxy-6ξ-(5′,6′α-epoxy-5′α-cholestan-3′β-yloxy)-5ξ-5,6-secocholestane-3β,5-diol and 5,6ξ-epidioxy-6ξ-(5′,6′β-epoxy-5′β-cholestan-3′β-yloxy)-5ξ-5,6-secocholestane-3β,5-diol. Oligomeric 1,2,4-trioxolane ozonide isomers were also formed. Ozone thus reacts with cholesterol in two ways, by epoxidation and putatively by carbonyl oxide formation, with subsequent carbonyl oxide cyclization to 1,2,4-trioxolane ozonides or interception of cholesterol, cholesterol epoxides, and cholesterol ozonides (as alcohols) to yield dimeric and oligomeric species.

The reaction of ozone (O_3) with cholesterol (1a) (Chart I) and with cholesterol 3β-acetate (1b) in nonparticipating solvents for form 5,6-secosterols has received attention from 1905, but only poorly characterized putative ozonides,

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