

the complete connectivity pattern.²⁰ This technique of spectral assignment requires no knowledge of the biosynthetic distribution of label since it depends exclusively on increasing the level of ¹³C in the molecule. However, intact biosynthetic units can still be identified because there is a much higher level of coupled signals between carbons comprising them if multiply ¹³C-labeled precursors are used.²¹ Bacher, Floss, and co-workers recently demonstrated²² the utility of double-quantum coherence NMR for biosyntheses employing [U-¹³C₆]glucose as a precursor.²³

Incorporations¹⁸ of sodium [1-¹³C]acetate, sodium [2-¹³C]-acetate, and [methyl-¹³C]methionine followed by ¹³C NMR analysis showed that the main portion of mevinolin (**1**) consists of a polyketide chain of nine intact acetate units with a methionine-derived methyl group at C-6 (Figure 1). Interestingly, the α-methylbutyryl side chain is constructed in an analogous fashion. Recent methods to detect oxygen-18²⁴ or deuterium^{13a,25} by isotope shifts induced in ¹³C NMR provide mechanistic information by limiting possible intermediate oxidation states and revealing precursor bonds to oxygen or hydrogen that remain intact in the product. Administration¹⁸ of sodium [1-¹³C,¹⁸O₂]acetate^{24b} to cultures of *A. terreus* followed by both normal and SEFT ¹³C NMR analysis^{24b-c} of the resulting mevinolin (**1**) showed extensive labeling of the doubly bonded oxygen at C-1' (isotope shift 0.038 ppm). Even though ¹³C incorporation was high (2-7-fold peak enhancement), the amount of oxygen-18 at other expected sites such as C-11, C-13, and C-15 was less than 5% of the carbon labeling. We are currently investigating the problem of solvent-exchange during biosynthesis. Incorporation of sodium [1-¹³C,²H₃]acetate and ¹³C NMR examination of the β-isotope shifts²⁵ in mevinolin (**1**) indicated high ²H retention at all expected sites except C-3 and C-6 (Table I). Since the β-isotope shifts may be upfield, downfield, or possibly zero,^{25f} there is a small chance that these carbons bear deuterium, but most probably the biogenesis of **1** results in hydrogen loss at these positions. The presence of species bearing three deuteriums at C-4' and at the C-2 methyl identifies these carbons as starter units of the polyketide chains. These observations were confirmed by ²H NMR of mevinolin (**1**) derived from sodium [²H₃]acetate. Our results support biogenesis of **1** either by intramolecular Diels-Alder cyclization of a C-18 polyunsaturated acid or by the more likely mechanism of intramolecular anionic condensations of a partially reduced C-18 polyketide. Work is in progress to elucidate the biochemical details of the formation of mevinolin (**1**) and compactin (**2**).

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Registry No. **1**, 75330-75-5; acetic acid, 64-19-7; L-methionine, 63-68-3.

Supplementary Material Available: Listing of ¹H NMR data of **1** and conditions for incorporation experiments (1 page). Ordering information is given on any current masthead page.

First Synthesis of Stannacyclobutanes

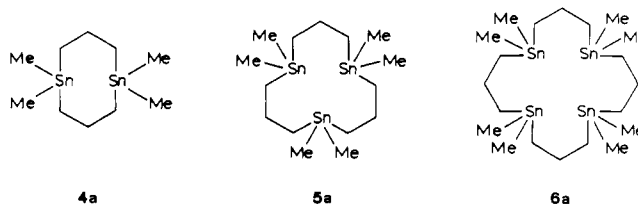
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Stannacyclobutanes were hitherto unknown, although their synthesis has been attempted and claimed repeatedly.^{1,2} This is all the more remarkable as 1,3-distannacyclobutanes³ and cyclooctastannanes⁴ have been prepared, and germacyclobutanes are well-known.^{1b} The direct and preparatively useful access to the 1,3-di-Grignard reagent of propane (**2a**)⁵ and of its 2,2-dimethyl derivative **2b**⁶ from the corresponding dibromides opens a new approach to metallacyclobutanes. We here report the synthesis of 1,1-dimethylstannacyclobutane (**1a**) and 1,1,3,3-tetramethylstannacyclobutane (**1b**).

When a stoichiometric amount of dichlorodimethylstannane (**3**) was added to **2a** at room temperature and the reaction mixture was hydrolyzed and subjected to GC-MS, none of the expected **1a** but only its cyclic oligomers **4a** (dimer), **5a** (trimer), and **6a** (tetramer), formed in about 70% total yield, could be observed.



Although **1a** had also been formed, it escaped direct observation with the exception of a singlet in the ¹H NMR spectrum when the reaction was performed in dioxane-*d*₈ (δ 0.39, ²J_{SnH} = 52, 54 Hz); due to its characteristic low-field position (cf. **1b**), this signal must be assigned to the methyl groups of **1a**. Attempts to isolate **1a** were thwarted by its high volatility, which prevented its separation from the ether, and by its instability, as it did not survive the conditions of GC-MS. Compelling evidence for the presence of **1a** was obtained when the reaction mixture was subjected to distillation at room temperature under reduced pressure. The distillate was treated with a ca. 10-fold excess of **2a**, followed by H₂O (or D₂O) to give **7**⁷ (or **7-d**₂, respectively, Scheme I). Under

(20) Most assignments were confirmed by selective homonuclear (¹³C) decoupling experiments.

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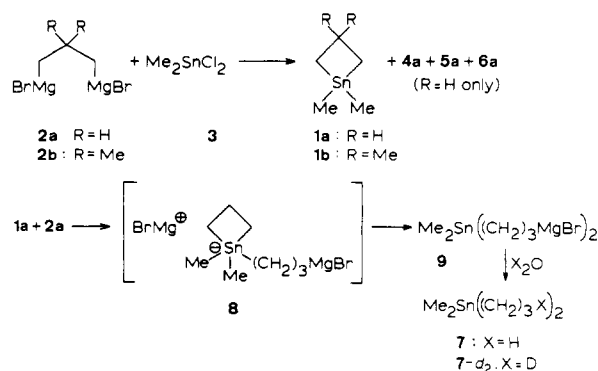
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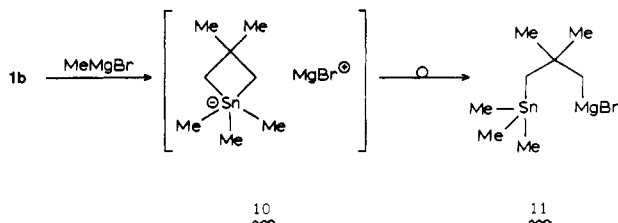
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Scheme I



Scheme II



these conditions, 4a, 5a, and 6a are not volatile; moreover, they are inert toward 2a. Therefore, the formation of 7 can be explained only by the reaction of 1a with 2a; via the intermediate ate complex 8 the di-Grignard reagent 9 is formed, which with D_2O gives 7-d₂. An analogous ring opening of 1,3-distannacyclobutanes with methylolithium has been observed by Seyferth and Lefferts.^{3b}

More success was achieved in our efforts to directly identify and isolate 1b, the 3,3-dimethyl derivative of 1a. It was formed in 48% yield in the stoichiometric reaction of 2b with 3 in diethyl ether (Scheme I). The yield was determined as follows: after 0.5 h at 25 °C, the volatile compounds were distilled in vacuo from the reaction mixture into a solution of methylmagnesium bromide in diethyl ether; presumably, 1b reacted via the ate complex 10 to give 11 (Scheme II), which on hydrolysis gave (trimethylstannyl)neopentane (12), independently synthesized from neopentylmagnesium bromide and chlorotrimethylstannane; deuterolysis of 11 gave 12-d₁.

The isolation of 1b was achieved in the following way. First, the diethyl ether was removed from 2b by addition of the high-boiling polyether bis(2-n-butoxyethoxy)methane and distillation of all low-boiling material in vacuo (a similar treatment of 2a would lead to considerable decomposition due to β -hydride elimination⁵). To the remaining solution, 3 was added at room temperature, and after 0.5 h, 1b was distilled in vacuo out of the reaction mixture into a liquid nitrogen trap. A colorless liquid of practically pure 1b was thus obtained (5% isolated yield) and characterized by its spectral data.⁸

The properties of 1b convincingly demonstrate its monomeric structure. Typical is its high volatility, in contrast to that of 4a, and the fact that its molecular ion can be observed in the mass spectrum on electron impact ionization (70 eV), though with low intensity (1%). All other cyclic dimethyltin compounds reported

here showed no detectable molecular ion under this condition, the highest mass ions observed being $[\text{M} - \text{CH}_3]^+$ or even smaller fragment ions. We believe this to be a consequence of the rapid cleavage of an endocyclic Sn-C bond in 1b⁺ under relief of ring strain; the structure of the observed ion is therefore probably $\text{Me}_2^+\text{SnCH}_2\text{CH}_2\text{CH}_2$.

Similarly unique and characteristic are the ¹H and ¹³C NMR resonances of the 1-methyl groups of 1b. They occur at much lower field (in dioxane-d₈: δ (¹H) 0.39 (²J_{SnH} = 53.1, 55.6 Hz); δ (¹³C) 15.4) than those of the strain-free oligomers in CDCl_3 : (4a) δ (¹H) 0.02 (²J_{SnH} = 48–50 Hz); δ (¹³C) –11.8. Qualitatively, these low-field shifts can be understood as a consequence of the presumably rather small $\text{CH}_2\text{-Sn-CH}_2$ bond angle, imposed by the geometry of the four-membered ring. This increases the p character of the endocyclic bonds of the tin atom and in turn the s character and thus the electronegativity in its exocyclic bonds toward the methyl groups. The increased values of ²J_{SnH} for the methyl groups of 1b may also reflect this effect.

In view of the reported instability of stannacyclopentanes,² it was not surprising that 1b was not stable at room temperature. With air, it reacted immediately under formation of a white precipitate of unknown composition (cf. the slow reaction of stannacyclopentanes with oxygen²). In solution 1a and 1b polymerized; 4–6 were not formed from 1. The rate of polymerization of 1b was strongly solvent dependent: at room temperature, $t_{1/2} \approx 30$ days in toluene-d₈ while in ethereal solvents such as dioxane-d₈, $t_{1/2} \approx 2$ days. Preliminary NMR results suggest that in the latter case, the solvent is also consumed to a certain extent, which indicates its active participation in the polymerization process.

Registry No. 1a, 85443-02-3; 1b, 85443-03-4; 2a, 62934-64-9; 2b, 83528-98-7; 3, 753-73-1; 4a, 85443-04-5; 5a, 85443-05-6; 6a, 85443-06-7; 7, 56535-52-5; 7-d₂, 85443-07-8; 9, 85452-92-2; 11, 85443-08-9; 12, 55204-72-3; 12-d₁, 85443-09-0; MeMgBr, 75-16-1.

Oxygenation of Chloroalkenes by Superoxide in Aprotic Media

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Although primary and secondary haloalkanes are readily oxidized by superoxide ion (O_2^-) in aprotic media via an $\text{S}_\text{N}2$ mechanism,^{1–4} simple alkenes are unreactive.^{5–7} In a recent study of polychloro hydrocarbons,⁸ we observed that chloroethene and trichloroethene also did not react at significant rates with O_2^- in dimethyl sulfoxide. However, we now report that *cis*-1,2-dichloroethene, trichloroethene, and tetrachloroethene among others are rapidly oxygenated by O_2^- in dimethylformamide (DMF) or acetonitrile.

The extent of the reaction of electrogenerated O_2^- with chloroalkenes has been determined by cyclic voltammetry of O_2 in the presence of excess substrate.⁸ The overall reaction and product stoichiometries for the degradation of the chloroalkene substrates

(7) 7: ¹H NMR (90 MHz, CDCl_3) δ 0.00 (s, ²J_{SnH} = 49.0, 51.0 Hz, 6 H, SnMe), 0.82 (t, ³J_{HH} = 8.0 Hz, ²J_{SnH} = 50 Hz, 4 H, SnCH₂), 1.04 (t, ³J_{HH} = 7.0 Hz, 6 H, Me), 1.35–1.75 (m, 4 H, CH₂CH₂Me); mass spectrum, *m/z* 236 (1) [M^+ , calcd for $\text{C}_8\text{H}_{20}\text{Sn}$ 236.0586, obsd 236.0589], 221 (6) [$\text{M} - \text{Me}]^+$, 193 (75), 151 (100).

(8) 1b: ¹H NMR (90 MHz, dioxane-d₈) δ 0.39 (s, ²J_{SnH} = 53.1, 55.6 Hz, 6 H, SnMe), 1.13 (s, 6 H, CMe), 1.54 (s, ²J_{SnH} = 52 Hz, 4 H, CH₂); ¹H NMR (250 MHz, toluene-d₈) δ 0.25 (s, ²J_{SnH} = 54 Hz, 6 H, SnMe), 1.25 (s, 6 H, CMe), 1.65 (s, ²J_{SnH} = 52 Hz, 4 H, CH₂); ¹³C NMR (62.89 MHz, dioxane-d₈) δ 15.4 (q, ¹J_{CH} = 126 Hz, SnMe), 34.5 (t, ¹J_{CH} = 125 Hz, SnCH₂), 35.6 (q, ¹J_{CH} = 125 Hz, CMe), 40.3 (s, CMe); ¹³C NMR (62.89 MHz, toluene-d₈) δ –6.5 (q, ¹J_{CH} = 129 Hz, SnMe), 34.0 (t, ¹J_{CH} = 132 Hz, SnCH₂), 35.6 (q, ¹J_{CH} = 132 Hz, CMe), 40.2 (s, CMe); mass spectrum, *m/z* 220 (1) [M^+ , calcd for $\text{C}_7\text{H}_{16}\text{Sn}$ 220.0273, obsd 220.0263], 205 (6) [$\text{M} - \text{Me}]^+$, 150 (61), 135 (100).

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