Structure Characterization of the Products of the Reaction between Racemic 1,2,4-Butane Triol and Di-*tert*-butyltin Oxide

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The reaction of di-*tert*-butyltin oxide with racemic 1,2,4-butane triol, aiming at synthesizing a model compound mimicking the tetra-*tert*-butyldistannoxane derivative of erythromycine A, affords two novel compounds, **1** and **2**. Compound **1**, which cannot be isolated as a pure product, was characterized in situ in C_6D_6 solution by two-dimensional, multinuclear (^{1}H, ^{13}C, $^{119/117}$Sn) NMR and proven to exhibit the same structural organooxotin moiety as the tetra-*tert*-butyldistannoxane derivative of erythromycine A, with however the position of an exchangeable hydroxylic proton now being unambiguously defined. Compound **2**, isolated as a crystalline product, was characterized by X-ray diffraction analysis as the *RS*-isomer of a dimer generated from two monomeric units of opposite chirality obtained from 1:1 condensation of di-*tert*-butyltin oxide with racemic 1,2,4-butane triol; the hydroxylic protons of the OH groups of its carbon atoms C(1) and C(2) have been eliminated, giving rise to a five-membered cyclic 1,3,2 dioxastannolane-like pattern, where the oxygen of carbon C(1) of the ligand complexes the tin atom of a neighboring molecule, resulting in a centrosymmetric Sn_2O_2 core; the hydroxylic proton of the OH group of carbon atom C(4) of the ligand forms an intramolecular hydrogen bridge with the oxygen atom of C(2). The C_6D_6 solution structure of compound **2** is identical to that of the crystalline state, even though evidence is found for **2** to exist in solution as a mixture of **2**-*RS* and **2**-*RR*/*SS* dimers.

Introduction

Some time ago, the covalent structure and conformation of the tetra-*tert*-butyldistannoxane derivative of erythromycine A in deuterated benzene solution were described.[1] The covalent structure elucidation was achieved by combining two-dimensional (2D) gradient-enhanced (ge) ^{1}H−^{119}Sn heteronuclear multiple quantum correlation (HMQC) and heteronuclear multiple bond correlation (HMBC) spectroscopy, which enabled localizing the organotin moiety through $^nJ(^1\text{H}-^{119}\text{Sn})$ correlations. The conformational analysis was performed using restrained molecular dynamics (rMD) within the extensible systematic force field (esff), a generalized force field especially designed to address metal-containing functionalities in the conformational analysis of organic compounds. While the experimental distance restraints derived from the NOE data used for the rMD validated the proposed structure (Figure 1A), it remained somewhat cumbersome because the coordination of the tin atoms, which was implicitly admitted to be four-coordinate for the purpose of the force field calculation of the organic compound, was not in accordance with their rather low ^{119}Sn chemical shifts, which tended to indicate at least some degree of coordination extension from a fifth donor.[2] It was suggested by Grindley[3] that these low-frequency-shifted ^{119}Sn chemical shift values could be due to stabilizing interactions between the O(11) oxygen and one or both of the tin atoms, a coordination pattern that is illustrated in Figure 1B.[4] This structural pattern has the merit of accounting for all NMR (and other) data at hand, but suffers from the lack of literature support, as it is extremely uncommon. An alternative proposal by Grindley,[3] shown in Figure 1C,[4] reflects a well-known structural moiety for distannoxanes, but has the objection that the SIMPLE effect observed on the C(11) carbon,[1] which is, in the structure of Figure 1C, four bonds remote from the distannoxane proton, is rather large. A possible explanation to account for this is an equilibrium,[4] fast on the NMR time scale, between the

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(1) Martins, J. C.; Mercier, F.; Gielen, M.; Willem, R.; Biesemans, M. *J. Am. Chem. Soc.* **1999**, *121*, 3284.
(2) Grindley, T. B. *Adv. Carbohydr. Chem. Biochem.* **1998**, *53*, 17.
(3) Grindley, T. B. Personal communication.
(4) Martins, J. C.; Biesemans, M.; Willem, R. *Prog. NMR Spectrosc.* **2000**, *36*, 271.

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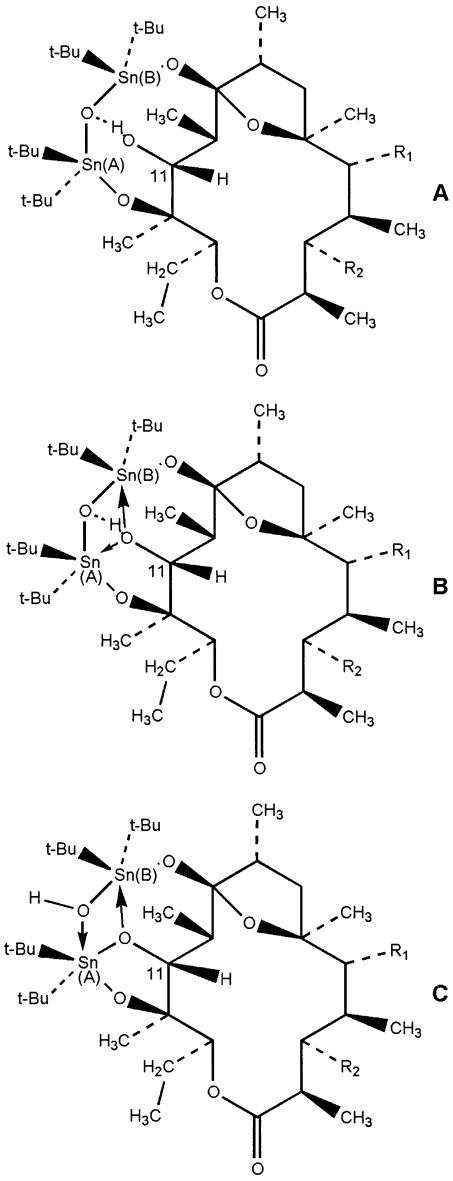


Figure 1. Possible structures for the tetra-*tert*-butyldistannoxane derivative of erythromycine A.

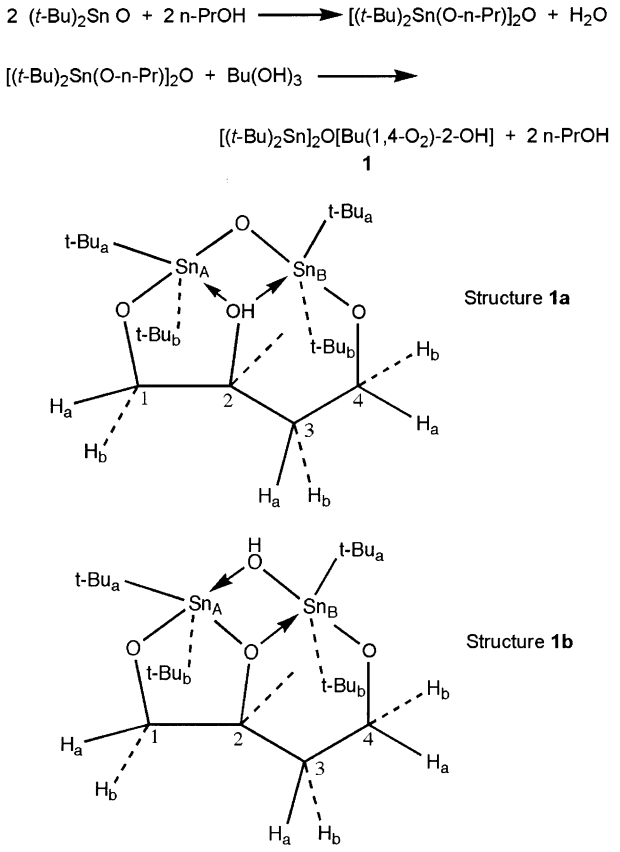
species B and C, which would represent two isomers, each corresponding to a potential well and separated by a low-energy barrier associated with a proton jump from one oxygen atom to the other.

Further investigation of this issue proved complex, mainly because of the difficulties experienced to separate spectral information arising from the organotin and the organic erythromycine A moieties.[1] Therefore, we thought of synthesizing a suitable model compound comprising the same organotin functionality and a simple organic moiety mimicking and substituting the functionality of the erythromycine A moiety involved in its tetra-*tert*-butyldistannoxane derivatization, which is of the 1,2,4-alkane triol type.

Results and Discussion

Synthesis. The reaction between racemic 1,2,4-butane triol and di-*tert*-butyltin oxide (Scheme 1) was carried out under the same conditions as used before with erythromycine A.[1] In Scheme 1 $Bu(OH)_3$ is a shortcut representing 1,2,4-butane triol, while [Bu(1,4-O_2)-2-OH] represents the corresponding residue doubly deprotonated in positions 1 and 4.

Scheme 1



The reaction was expected to give the analogue of the erythromycine A (ErySn) compound, with both structures depicted in Scheme 1. A ^{117}Sn spectrum of the crude reaction mixture indeed displayed two major resonances of equal intensity (75% of total integration) with chemical shifts at −238 and −288 ppm (assigned to compound **1**) very similar to the those of the ErySn compound (−234 and −294 ppm).[1,4,5] However, it also displayed two minor resonances of almost equal intensity (20% of total integration) at −220 and −221 ppm (assigned to compound **2**) and a small resonance (5%) at −84 ppm, arising from di-*tert*-butyltin oxide. Attempts to purify this crude mixture by crystallization were not really successful, as the crystals obtained were not those of the expected compound **1**, but instead were identified as the minor product **2**, the relative amount of which became more important during crystallization, paralleled by an increasing amount of di-*tert*-butyltin oxide. The remaining mother liquor containing compound **1** and di-*tert*-butyltin oxide was directly analyzed by NMR in solution.

Solution State Structure of 1. As already mentioned, the 1D ^{117}Sn spectrum of **1** displays two resonances of equal intensity at −238 and −288 ppm with unresolved $^2J(^{117}Sn-O-^{119/117}Sn)$ coupling satellites of 102 Hz, indicating the presence of a Sn−O−Sn moiety. The ^1H spectrum reveals very intense *tert*-butyl resonances in the 1.5−1.3 ppm region hiding the H(3) proton signals of the 1,2,4-butane triol moiety. A homonuclear

(5) Martins, J. C.; Kayser, F.; Verheyden, P.; Gielen, M.; Willem, R.; Biesemans, M. *J. Magn. Reson.* **1997**, *124*, 218.

Table 1. NMR Parameters for 1 in C_6D_6 Solution[a]

atom	^{1}H	^{13}C	^{119}Sn
C(1)H_a	3.32	69.6 [21]	
C(1)H_b	4.07 [64]		
C(2)H	3.88	79.2 [13, 10]	
C(3)H_a	1.56	38.8 [22, 14]	
C(3)H_b	1.25		
C(4)H_a	4.38 [53]	67.2 [34]	
C(4)H_b	4.21		
C(2)OH	1.12 [1.7, 3.9]		
C(*t*-Bu)Sn_A		38.4, 38.1	
C(*t*-Bu)Sn_B		40.2, 39.4	
CH_3(*t*-Bu)$_a$$Sn_A$	1.33 [96]	30.7	
CH_3(*t*-Bu)$_b$$Sn_A$	1.37 [97]	30.6	
CH_3(*t*-Bu)$_a$$Sn_B$	1.37 [101]	30.5	
CH_3(*t*-Bu)$_b$$Sn_B$	1.40 [98]	30.8	
Sn_A			−238{102}[b]
Sn_B			−288{102}[b]

[a] Chemical shifts in ppm, $^nJ(^1H-^{117}Sn)$ and $^nJ(^{13}C-^{119/117}Sn)$ coupling constants in Hz in brackets. The $^nJ(^1H-^{117}Sn)$ coupling constants are determined from 2D $^1H-^{117}Sn$ HMBC spectra. [b] $^2J(^{119}Sn-O-^{119/117}Sn)$.

2D DQF COSY[6] spectrum identified all proton resonances of **1** (Table 1). The ^{13}C NMR data, combined with $^1H-^{13}C$ HMQC[7] and $^1H-^{13}C$ HMBC[8] correlations, established the connectivity of the ^{13}C nuclei with the corresponding protons.

The assignment of the *tert*-butyl protons to the respective tin atoms A and B was accomplished through 2D $^1H-^{117}Sn$ HMQC and HMBC experiments.[5,9] The $^1H-^{117}Sn$ correlations observed in these spectra (detailed description available in the Supporting Information) unequivocally prove that the tin atom Sn_A is covalently bridging to C(1) and Sn_B to C(4) through an oxygen atom. In both cases, the $^3J(^1H-^{117}Sn)$ coupling constants are very unequal (a large one of 55−65 Hz and a small nonresolved one) for the two geminal protons, and consequently, since these coupling constants are dependent on the respective dihedral angles (Sn−O−C−H), this indicates that compound **1** has a very rigid structure in solution, with no (or at most limited) conformational averaging. The dihedral angles can be calculated from eq 1, established for deuterated compounds.[10,11]

$$^3J(^{119}Sn-^2H) = 9\cos(2\Psi) - 3\cos\Psi + 8.5 \quad (1)$$

The $^3J(^{119}Sn-^2H)$ coupling constants can be deduced from the measured $^3J(^1H-^{117}Sn)$ values, taking $\gamma(^1H)/\gamma(^2H) = 6.514$ and $\gamma(^{119}Sn)/\gamma(^{117}Sn) = 1.045$. As usual for Karplus-type equations, two mathematical solutions can be obtained, but since geminal protons are considered, we can assume that the projected HCH angle is about 120°, leaving only one possible combination (Figure 2) with values of 135° and 97° for the H(1) hydrogen atoms and 128° and 97° for the H(4) hydrogens.

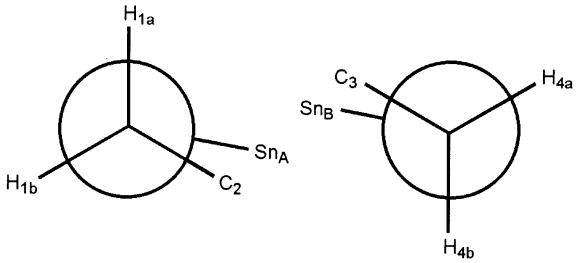


Figure 2. Approximate Newman projections of the conformation of compound **1** along the C(1)O and C(4)O bonds, respectively.

The 2D $^1H-^{117}Sn$ HMQC and HMBC experiments also draw attention to the proton resonance at 1.12 ppm, assigned to the alcohol proton at carbon C(2), which correlates with both tin atoms, revealing coupling constants of 1.7 and 3.9 Hz for Sn_A and Sn_B, respectively, which are very similar to those found for the Sn_A and Sn_B atoms of the ErySn derivative, 1.8 and 3.5 Hz, respectively.[4]

These similarities are confirmed independently by H/D isotope shifts in ^{13}C and ^{119}Sn secondary isotope multiplet of partially labeled entities (SIMPLE) spectra,[12] recorded for solutions containing unequal amounts of deuterated and nondeuterated **1**. The tin resonances of Sn_A and Sn_B have similar (large) isotope shifts of, respectively, 0.235 and 0.251 ppm (0.220 and 0.251 in ErySn). The carbon resonances of the quaternary carbon atoms of the *tert*-butyl groups on tin have isotope shifts between 0.027 and 0.031 ppm, values that are typical for three-bond effects.[13] The ^{13}C resonance of C(2), assumed to bear the underivatized OH function, displays only a small isotope shift of 0.015 ppm (0.023 ppm in ErySn), too small for a two-bond isotope shift that is expected to have magnitudes between 0.080 and 0.120 ppm.[13] This ^{13}C resonance also has a chemical shift value (79.2 ppm) that is not compatible with the chemical shift range for secondary alcohols. The small isotope effect on C(2) and the large isotope effect on both tin atoms and its *tert*-butyl groups indicate that the hydroxylic proton is closer to the tin atoms than to the C(2) atom.

All the above-mentioned arguments are compatible with two possible structures, **1a** and **1b** (Scheme 1), that are completely analogous to the ones previously proposed for the ErySn derivative (Figure 1, structure B or C).[4]

The structures **1a** and **1b**, differing only in the position of the hydroxylic proton, are drawn according to the information gathered from NOESY[14] cross-peaks, cross-checked with the dihedral angles calculated from the $^3J(^1H-^{117}Sn)$ coupling constants for H(1)$_b$ and H(4)$_a$, respectively. Examination of the cross-peaks indeed allows straightforward discrimination between the two *tert*-butyl groups on their respective tin atoms and between the geminal protons of the butane triol moiety (see Table 1 and Scheme 1). Most indicative however are the NOE cross-peaks between the hydroxylic proton

(6) Piantini, U.; Sørensen, O. W.; Ernst, R. R. *J. Am. Chem. Soc.* **1982**, *104*, 6800.
(7) Bax, A.; Griffey, R.; Hawkins, B. L. *J. Magn. Reson.* **1983**, *55*, 301.
(8) Bax, A.; Summers, M. F. *J. Am. Chem. Soc.* **1986**, *108*, 2093.
(9) Willem, R.; Bouhdid, A. Kayser, F.; Delmotte, A.; Gielen, M.; Martins, J. C.; Biesemans, M.; Mahieu, B.; Tiekink, E. R. T. *Organometallics* **1996**, *15*, 1920.
(10) Quintard, J. P.; Degueil-Castaing, M.; Barbe, B.; Pétraud, M. *J. Organomet. Chem.* **1982**, *234*, 41.
(11) Meurice, J.-C.; Duboudin, J.-G.; Ratier, M.; Pétraud, M.; Willem, R.; Biesemans, M. *Organometallics* **1999**, *18*, 1699.
(12) Christofides, J. C.; Davies, D. B. *J. Am. Chem. Soc.* **1983**, *105*, 5099.
(13) Hoffman, R. E.; Treitel, N.; Shabtai, E.; Benshafrut, R.: Rabinovitz, M. *J. Chem. Soc., Perkin Trans. 2* **2000**, 1007.
(14) Jeener, J.; Meier, B. H.; Bachmann, P.; Ernst, R. R. *J. Chem. Phys.* **1979**, *71*, 4546.

Table 2. NMR Parameters for 2 in C_6D_6 Solution[a]

	2-*RS*		**2**-*RR/SS*
^{119}Sn	−221.5 [189][b]		−222.7 [194][b]
^{1}H			
CH_3(*t*-Bu)	1.22 [107], 1.21 [105]		1.25 [107], 1.19 [105]
H(1)	3.05 and 3.64 [69]		3.06 and 3.64 [65]
H(2)		3.78	
H(3)		1.36 and 1.51	
H(4)		4.01	
C(4)OH	4.96 [16]		4.95 [16]
^{13}C			
CH_3(*t*-Bu)	30.9 [33,6], 30.6 [*c*, 6]		31.1 [30, 6]], 30.5 [*c*, 6]
C(*t*-Bu)	42.3 [575/549, 34], 41.0 [557/533, 33]		42.4 [579/553, 34], 41.0 [557/533, 33]
C(1)	71.48 [14]		71.55 [13]
C(2)		74.73 [14][d] 74.67 [15][d]	
C(3)		36.6[14]	
C(4)		63.0	

[a] Chemical shifts in ppm, $^{n}J(^{1}H-^{119}Sn)$ and $^{n}J(^{13}C-^{119/119}Sn)$ coupling constants in Hz in brackets. The $^{n}J(^{1}H-^{119}Sn)$ coupling constants are determined from 2D $^{1}H-^{119}Sn$ HMBC spectra. [b] $^{2}J(^{119}Sn-O-^{119/117}Sn)$. [c] Not visible because of overlap. [d] Not attributable to **2**-*RS* or **2**-*RR/SS*.

and all the *tert*-butyl groups, while cross-peaks with protons of the carbon chain of the butane triol moiety are completely absent. This observation is definitely in favor of structure **1b**, since for structure **1a** cross-peaks with at least one or two protons of the butane triol moiety should be observed.

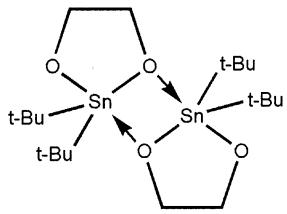
Solution State Structure of 2. Compound **2**, originally a byproduct in the synthesis described, is actually the only one obtained as a pure crystalline product amenable to a solid state structure determination by X-ray diffraction (see below). No equivalent of **2** was observed in the case of the erythromycine A derivative.

The ^{119}Sn spectrum of **2** displays two resonances at −221.5 and −222.7 ppm with, respectively, $^{2}J(^{119}Sn-O-^{119/117}Sn)$ coupling satellites of 189 and 194 Hz.

In the ^{13}C spectrum, the resonances from the butane triol moiety occur pairwise with a small difference in chemical shift. From the integration of the ^{1}H spectrum, giving 18 *tert*-butyl protons for 8 other protons, it is clear that **2** consists of a structural unit with tin and butane triol in a molar ratio of 1:1. The presence of $^{2}J(^{119}Sn-O-^{119/117}Sn)$ coupling satellites implies that the structure is dimeric in nature. The presence of two slightly different ^{119}Sn resonances with different $^{2}J(^{119}Sn-O-^{119/117}Sn)$ coupling constants and the pairwise occurrence of the ^{13}C resonances belonging to the butane triol moiety indicate the existence of two diastereoisomers, i.e., **2**-*RR/SS (dl mixture)* and **2**-*RS (meso derivative)*, present in solution in an approximate ratio of 0.9:1, as assessed from the ^{119}Sn resonance areas (assignment see below).

The hydroxylic proton signals at 4.95 and 4.96 ppm were used as a starting point to establish the entire ^{1}H connectivity pattern of the butane triol moiety from a 2D DQF COSY spectrum. The corresponding ^{13}C resonances were identified from the $^{1}H-^{13}C$ HMQC experiment. The assignment of the ^{1}H, ^{13}C, and ^{119}Sn chemical shifts and coupling constants is summarized in Table 2.

Only the H(1) resonance at 3.64 ppm exhibits resolved tin satellites in the 1D ^{1}H spectrum. The existence of



2,2-*t*-butyl-1,3,2-dioxastannolane

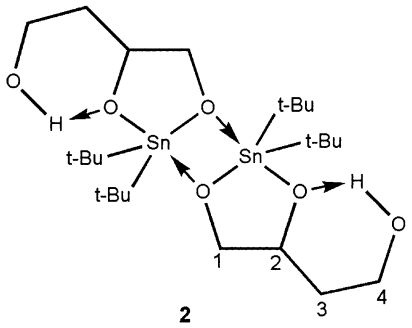


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Figure 3. Solution structure of compound **2** and of 2,2-di-*tert*-butyl-1,3,2-dioxastannolane.

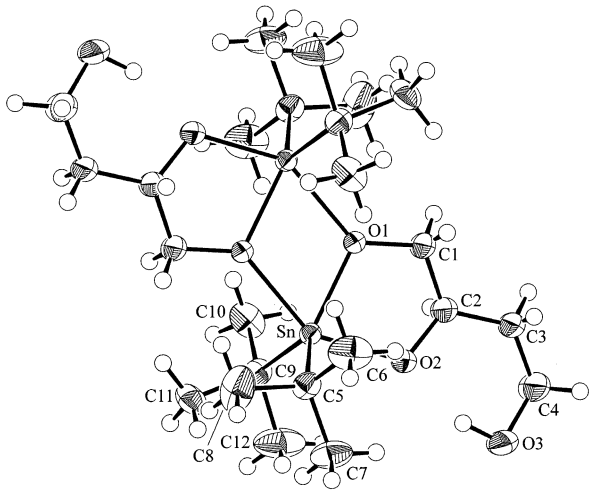


Figure 4. Molecular structure and crystallographic numbering scheme for the **2**-*RS* isomer. Selected geometric parameters [Å, deg]: Sn−O1 2.083(2), Sn−O2 2.059(3), Sn−C5 2.180(4), Sn−C9 2.172(4), Sn−O1′ 2.238(2), O1−Sn−O2 79.36(9), O1−Sn−C5 122.60(13), O1−Sn−C9 117.35-(13), O1−Sn−O1′ 67.85(10), O2−Sn−C5 96.39(13), O2−Sn−C9 99.77(13), O2−Sn−O1′ 147.11(9), C5−Sn−C9 119.74(16), C5−Sn−O1′ 98.98(12), C9−Sn−O1′ 97.52(12), Sn−O1−Sn′ 112.15(10), Sn−O1−C1 113.7(2), Sn−O1′−C1′ 133.7(2), Sn−O2−C2 114.4(2). Primed atoms are related by a crystallographic center of inversion at 0, 0, 1/2.

$^{n}J(^{1}H-^{119}Sn)$ couplings with the proton resonances of the carbon chain was demonstrated from a 2D $^{1}H-^{119}$-Sn HMQC experiment,[5,9] but the splittings are unresolved and/or obscured by homonuclear J_{HH} coupling patterns. Apart from the latter correlations both ^{119}Sn resonances also display a correlation with a coupling constant of 16 Hz and another unresolved one with the OH proton on C(4). The former large coupling constant can only be explained by the existence of a hydrogen bond between the C(4) hydroxyl proton and the oxygen atom O(2) (see **2** in Figure 3 and Figure 4), thus creating a two-bond coupling pathway, instead of a six-bond

coupling pathway in an open chain derivative. The dimeric nature of the solution structure is confirmed by the fact that both ^{119}Sn chemical shifts in solution are identical to that in the solid state, for which a detailed molecular structure was determined by X-ray crystallography (see below).

Moreover, the ^{119}Sn chemical shifts of **2** perfectly match the chemical shifts obtained for 2,2-di-*tert*-butyl-1,3,2-dioxastannolane,[15a] which is dimeric with a ladder structure, the tin atom being part of a five-membered ring, as in **2** (Figure 3).

Solid State Structure of 2. The solid state ^{117}Sn spectrum displays a broad (810 ppm) anisotropy pattern with an isotropic chemical shift at −222 ppm. This agrees with the data found in solution and in the solid state for 2,2-di-*tert*-butyl-1,3,2-dioxastannolane.[15a] The IR spectrum displays a strong and sharp absorption at 3330 cm^{-1}, characteristic for an OH group involved in a hydrogen bond.

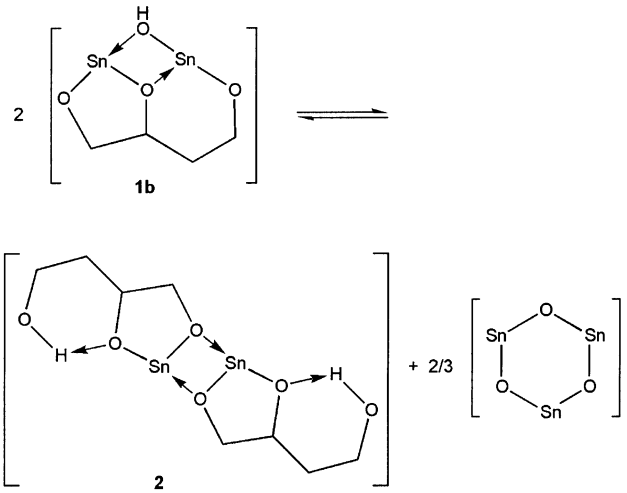
An X-ray analysis of the **2**-*RS* isomer shows that the centrosymmetric and dimeric molecule (Figure 4) exists exclusively as the *RS*-isomer; no evidence for different crystalline forms was apparent. The doubly deprotonated 1,2,4-butane triol ligand chelates one tin atom via the deprotonated O1 and O2 oxygen atoms and simultaneously bridges a centrosymmetrically related tin atom via the O1 atom so that this ligand is tridentate, bridging two tin centers. The remaining positions in the tin atom geometry are occupied by the *tert*-butyl groups so that the coordination is distorted trigonal bipyramidal. There are intramolecular hydrogen bonding interactions involving the noncoordinating O3 atom and the coordinated O2 atom so that H···O2 is 1.80 Å, O2···O3 is 2.703(5) Å, and the angle subtended at H is 160°.

The structural pattern reported here for the **2**-*RS* isomer is relatively rare in the crystallographic literature for organotins, there being only two examples, the aforementioned 2,2-di-*tert*-butyl-1,3,2-dioxastannolane[15b] and methyl 4,6-*O*-benzylidene-2,3-*O*-dibutylstannylene-α-D-glucopyranoside.[16]

Solution Chemistry. The rearrangement of compound **1** into compound **2** and di-*tert*-butyltin oxide can formally be explained by the reaction given in Scheme 2, where the *tert*-butyl groups have been omitted for clarity. The reaction in Scheme 2 is an equilibrium, as evidenced by a ^{119}Sn NMR experiment on a sample containing a mixture of **1**, **2**, and di-*tert*-butyltin oxide in solution to which pure crystals of **2**-*RS* have been added: this resulted in a drastic increase of the ^{119}Sn resonance intensity of **1** at the expense of the di-*tert*-butyltin oxide resonance.

The observation of a single diastereomer, **2**-*RS*, in the crystalline state, in contrast with the mixture of two diastereomers, **2**-*RR*/*SS* and **2**-*RS*, in solution indicates selective crystallization of the **2**-*RS* isomer from a mother liquor containing both isomers, **2**-*RR*/*SS* and **2**-*RS*. This phenomenon, known as *crystallization-induced asymmetric transformation*,[17] is interpreted by

Scheme 2



an equilibrium between the dimeric structure and short-lived *R* and *S* monomers in equal amounts, resulting in recombination from **2**-*RR*/*SS* into **2**-*RS* and vice versa. Similar monomer−dimer equilibria have been described.[18] Further evidence relies on the relative intensities of 1:0.6 of the ^{119}Sn resonances immediately after dissolution of the sample evolving to 1:0.9 after 24 h equilibration. Hence one resonance is growing in time at the expense of the other, which assigns the high- and low-frequency ^{119}Sn resonances to **2**-*RS* and **2**-*RR*/*SS*, respectively.

Conclusion

Compound **1**, aimed to be a model compound for the earlier described tetra-*tert*-butyldistannoxane derivative of erythromycine A,[1] was analyzed in solution using a similar NMR strategy as before. The structure analysis proved **1** to show the same peculiar structural pattern as for the ErySn compound, with the exact position of a hydroxylic proton now being elucidated in favor of structure **1b**, implying that the hydroxylic proton of the O(2) oxygen has been transferred to the distannoxane oxygen.

Compound **2**, obtained in solution as a mixture of two dimeric diastereoisomers, **2**-*RS* and **2**-*RR*/*SS*, exhibits a ladder structure with a strong hydrogen bond resulting in a $^2J(^1\mathrm{H}-^{119}\mathrm{Sn})$ coupling constant of 16 Hz, never mentioned before for SnO→H*O* moieties. In the crystalline state **2** exists only as the **2**-*RS* isomer as the result of a monomer−dimer equilibrium enabling the racemic **2**-*RR*/*S* and **2**-*RS* species to crystallize as pure **2**-*RS* by a crystallization-induced asymmetric transformation.

Experimental Section

Synthesis. A suspension of 1.673 g (6.721 mmol) of di-*tert*-butyltin oxide[19] in a mixture of 56 mL of *n*-propanol and 136 mL of benzene is heated at reflux for 2−3 h in a Dean−Stark apparatus with distillation of the ternary and subsequent binary azeotropes to ca. 50% of the initial volume.[20] The

(15) (a) Grindley, T. B.; Wasylishen, R. E.; Thangarasa, R.; Power, W. P.; Curtis, R. D. *Can. J. Chem.* **1992**, *70*, 205. (b) Bates, P. A.; Hursthouse, M. B.; Davies, A. G.; Slater, S. D. *J. Organomet. Chem.* **1989**, *363*, 45.

(16) Cameron, T. S.; Bakshi, P. K.; Thangarasa, R.; Grindley, T. B. *Can. J. Chem.* **1992**, *70*, 1623.

(17) Eliel, E. L.; Wilen, S. H. *Stereochemistry of Organic Compounds*; J. Wiley & Sons Inc.: New York, 1994; Chapter 7, p 316.

(18) (a) Grindley, T. B.; Thangarasa, R. *J. Am. Chem. Soc.* **1990**, *112*, 1364. (b) Luchinat, C.; Roelens, S. *J. Org. Chem.* **1987**, *52*, 4444.

(19) Puff, H.; Schuh, W.; Sievers, R.; Wald, W.; Zimmer, R. *J. Organomet. Chem.* **1984**, *260*, 271.

(20) Davies, A. G.; Kleinschmidt, D. C.; Palan, P. R.; Visishtha, S. C. *J. Chem. Soc. C* **1971**, 3972.

remaining solution is allowed to cool to room temperature, after which 0.357 g (3.36 mmol) of dried racemic 1,2,4-butane triol in 56 mL of benzene is added. After the solution is stirred overnight at room temperature, the solvent is slowly evaporated, leaving a white solid. This solid was partially soluble in light petroleum ether. The insoluble fraction could be crystallized from benzene, giving a pure compound **2** (different from the expected **1**), which was characterized by X-ray diffraction in the solid state and NMR analysis in solution. Mp: 221−225 °C. Anal. Found: 7.76 H, 42.25 C, 34.62 Sn. Calcd: 7.78 H, 42.77 C, 35.22 Sn. The soluble fraction turned out to be a mixture of **1** and di-*tert*-butyltin oxide, which could not be further purified and was analyzed as such in solution by different NMR techniques.

NMR Experiments. Samples were prepared by dissolving ca. 20 mg of material in 0.5 mL of C_6D_6. NMR experiments were performed at 303 K on a Bruker AMX500 or an Avance DRX250 instrument. Chemical shifts were referenced to the residual solvent peak and converted to the standard Me_4Si scale by adding 7.15 and 128.0 ppm for ^1H and ^{13}C, respectively. For ^{119}Sn (recorded on the AMX500 spectrometer), external referencing with $\Xi = 37.290665$ MHz and for ^{117}Sn (recorded on the Avance DRX250 spectrometer) with $\Xi = 35.632295$ MHz was used.[21] On the latter instrument ^{117}Sn spectra instead of the more common ^{119}Sn spectra were recorded to overcome a local radio interference problem.[22] This has no influence on the chemical shifts reported, since $^{117}Sn/^{119}Sn$ isotopic effects are known to be negligible.[23] All 1D spectra, including ^{13}C DEPT spectra and gradient pulsed proton detected 2D $^1H-^{13}C$ HMQC[7] and HMBC[8] correlation spectra as well as the 2D ^1H NOESY[14] and DQF COSY[6] spectra, were acquired using the pulse sequences of the Bruker program library. 2D $^1H-^{117}Sn$ HMQC and HMBC experiments were performed as previously described.[5,9]

X-ray Diffraction. Data (3784) were collected for a colorless crystal ($0.07 \times 0.32 \times 0.47$ mm^3) of the **2**-*RS* isomer at 173 K employing graphite-monochromatized Mo Kα radiation, $\lambda = 0.71069$ Å, on a Rigaku AFC7R diffractometer ($\theta_{max} = 27.5°$). Corrections were made for Lorentz and polarization effects,[24] and for absorption using an empirical procedure (DIFABS[25]). Crystal data for **2**-*RS* isomer: $C_{12}H_{26}O_2Sn$, fw = 337.0, monoclinic, space group = $P2_1/n$, $a = 8.651(2)$ Å, $b = 10.996(4)$ Å, $c = 16.040(5)$ Å, $\beta = 104.98(3)°$, V, = 1473.9(8) Å^3, $Z = 2$ (dimers), $D_{calcd} = 1.519$ g cm^{-3}, $F(000) = 688$, $\mu = 17.26$ cm^{-1}, no. of obs data with $I \geq 2.0\sigma(I) = 2616$.

The structure was solved by heavy-atom methods[26] and refined by a full-matrix least-squares procedure based on F^2.[27] Non-hydrogen atoms were refined anisotropically, and hydrogen atoms were included in the model in their calculated positions; the O-*H* atom was located from a difference map. The C(9)-bound methyl groups were found to be disordered and so were modeled over two positions with the major component having 0.59(1) site occupancy (from refinement). The refinement was continued until convergence with the application of a weighting scheme of the form $w = 1/[\sigma^2(F_o)^2 + (0.042P)^2 + 1.4826P]$ where $P = (F_o^2 + 2F_c^2)/3$. Final R, R_w (obs data) 0.030, 0.077 and R, R_w (all data) = 0.048, 0.085 and $\rho_{max} = 0.78$ e Å^{-3}. The numbering scheme, shown in Figure 4, was drawn with ORTEP[28] with 50% displacement ellipsoids.

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Supporting Information Available: A crystallographic file in CIF format of **2**-*RS* and details of the $^1H-^{117}Sn$ correlations of **1** in solution. This material is available free of charge via the Internet at http://pubs.acs.org.

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(21) Davies, A. G.; Harrison, P. G.; Kennedy, J. D.; Mitchell, T. N.; Puddephatt, R. J.; Mc. Farlane, W. *J. Chem. Soc. C* **1969**, 1136.
(22) Harrison, P. G. In *Chemistry of Tin*; Harrison, P. G., Ed.; Blackie & Son Limited: Glasgow, 1989; Chapter 3, p 113.
(23) Mc Farlane, H. C. E.; Mc Farlane, W.; Turner, C. *J. Mol. Phys.* **1979**, *37*, 1639.
(24) *teXsan*: Structure Analysis Software; Molecular Structure Corp.: The Woodlands, TX, 1997.
(25) Walker, N.; Stuart, D. *Acta Crystallogr. Sect. A* **1983**, *39*, 158.
(26) Sheldrick, G. M. *SHELXL97*, Program for crystal structure refinement; University of Göttingen: Germany, 1997.
(27) Beurskens, P. T.; Admiraal, G.; Beurskens, G.; Bosman, W. P.; García-Granda, S.; Smits, J. M. M.; Smykalla, C. *The DIRDIF program system*; Technical Report of the Crystallography Laboratory; University of Nijmegen, 1992.
(28) Johnson, C. K. *ORTEP*; Report ORNL-5138; Oak Ridge National Laboratory: Oak Ridge, TN, 1976.