pomer.[9] This transformation can also be accomplished quantitatively by chromatography of **5c,d** on Florisil at −50 °C.[10] The mechanism of the Florisil-promoted closure is unclear, but its stereochemistry is identical with that observed in the thermal closure. Assignment of the *endo*-D configuration to **7b** is supported by spectroscopy and chemical reactivity studies. η^4-Cyclopentadiene complexes of Rh(I) containing *exo*-H atoms have been shown to exhibit an anomalously low C–H stretching frequency (<2850 cm⁻¹) in their IR spectra;[11] this low-frequency band is observed for **7a** and **7b**.[9] Reaction of **7b** with $Ph_3C^+BF_4^-$ affords the rhodicinium cation **8b** in which D is retained;[12] this type of reaction is known to proceed by a net abstraction of the *exo*-H⁻.[14-16] Finally, reaction of cation **8a**[12] with BD_4^- affords exclusively the *exo*-D isotopomer **9**,[9] which does not exhibit a low-frequency C–H stretch in its IR spectrum and which reacts with $Ph_3C^+BF_4^-$ to regenerate **8a** with quantitative loss of deuterium.[17]

These data unambiguously define the stereochemistry of ring closure of **5d** to give **7b**. Closure cannot proceed by any pathway in which a plane of symmetry bisects the CHD group, thus excluding metallacyclohexadiene or metallabenzene intermediates. Accordingly, ring closure of **5c,d** must involve direct C–C bond formation from the puckered ligand and may best be viewed as the intraligand migratory insertion reaction shown in Scheme II. Addition of the Rh–C bond to the underside of the coordinated olefin requires that the CHD terminus rotate as shown to give *endo*-D isotopomer **7b**. This insertion mechanism also maintains bonding interaction between the Rh and the organic ligand, and presumably it has a lower activation barrier than a direct reductive elimination of two Rh–C bonds.

The demonstrable absence of a metallacyclohexadiene intermediate and the implicit inaccessibility of a metallabenzene species in this reaction suggest that such species may be mechanistic red herrings[18] en route to cyclopentadiene or (cyclopentadienyl)hydrido complexes in related systems.[3,5]

(9) **7a**: yellow crystals, mp 109-110 °C; ¹H NMR (C_6D_6) δ 7.11 (m, 2 H, $H_{4,7}$), 6.85 (m, 2 H, $H_{5,6}$), 6.13 (dt, $J_{HH} = J_{RhH} = 2.6$, H_2), 5.76 (br, 1 H, $H_{1/3}$), 5.63 (br, 1 H, $H_{1/3}$), 3.69 (ddd, 1 H, $J_{HH} = 2.7$, 1.4, $J_{RhH} = 1.5$, $H_{olefinic}$), 2.49 (ddd, 1 H, $J_{HH} = 12.4$, 1.3, $J_{RhH} = 4.6$, H_{exo}), 2.38 (ddd, 1 H, $J_{HH} = 12.4$, 2.6, $J_{RhH} = 2.6$, H_{endo}), 1.35 (s, 9 H, ¹Bu), 1.32 (s, 9 H, ¹Bu), 1.14 (s, 9 H, ¹Bu). **7b**: ¹H NMR (C_6D_6) identical except for δ 3.69 (dd, 1 H, $J_{HH} = J_{RhH} = 1.5$, $H_{olefinic}$), 2.49 (ddt, 1 H, $J_{HH} = J_{HD} = 1.5$, $J_{RhH} = 4.8$, H_{exo}); ²H{¹H} NMR (C_6H_6) δ 2.30 (s, 1 D, D_{endo}); IR (KBr) 2770 (m) cm⁻¹; νCH_{exo}. **9**: ¹H NMR (C_6D_6) identical except for δ 3.68 (dd, 1 H, $J_{HH} = 2.9$, $J_{RhH} = 1.8$, $H_{olefinic}$), 2.36 (ddt, 1 H, $J_{HH} = J_{RhH} = J_{HD} = 2.4$, H_{endo}); ²H{¹H} NMR (C_6H_6) δ 2.50 (s, 1 D, D_{exo}).

(10) Chromatography on silica gel or alumina under identical conditions effects <5% ring closure.

(11) (a) *exo*- and *endo*-[Rh(η^5-C_5H_5)(η^4-C_5Me_5H)]: Moseley, K.; Kang, J. W.; Maitlis, P. M. *J. Chem. Soc. A* **1970**, 2875-2883. (b) Related examples: refs 14, 17, and Churchill, M. R.; Scholer, F. R. *Inorg. Chem.* **1969**, *8*, 1950-1955. Bird, P. H.; Churchill, M. R. *J. Chem. Soc., Chem. Commun.* **1967**, 777-778. Schrock, R. R.; Osborn, J. A. *Inorg. Chem.* **1970**, *9*, 2339-2343.

(12) **8a**: PF_6^- salt, orange crystals, mp 234-235 °C, structure confirmed by X-ray crystallography;[13] ¹H NMR (CD_3CN) δ 7.65 (m, 2 H, $H_{4,7}$), 7.44 (m, 2 H, $H_{5,6}$), 6.45 (dd, 2 H, $J_{HH} = 2.7$, $J_{RhH} = 0.7$, $H_{1,3}$), 5.81 (dt, 1 H, $J_{HH} = 2.7$, $J_{RhH} = 1.3$, H_2), 5.50 (d, 2 H, $J_{RhH} = 0.9$, CHC^1Bu), 1.43 (s, 18 H, ¹Bu), 1.40 (s, 9 H, ¹Bu). **8b**: ¹H NMR (CD_3CN) identical except δ 5.50 resonance half the intensity of that in **8a**; ²H{¹H} NMR (CH_3CN) δ 5.50 (s, 1 D, CDC^1Bu).

(13) Rheingold, A. L. Private communication.

(14) Khand, I. U.; Pauson, P. L.; Watts, W. E. *J. Chem. Soc. C* **1969**, 2024-2030. Efraty, A.; Maitlis, P. M. *J. Am. Chem. Soc.* **1967**, *89*, 3744-3750.

(15) **7a,b** can be oxidized to **8a,b** with *N*-bromosuccinimide or $CDCl_3$. Similar oxidation of *exo*-[Rh(η^5-C_5H_5)(η^4-C_5Me_5H)] is facile, but the *endo*-H isomer is not oxidized.[11a] Analogous oxidation of cyclopentadiene–cobalt complexes is less selective, depending on the oxidant.[16]

(16) O'Connor, J. M.; Johnson, J. A. *Synlett* **1989**, *1*, 57-59 and references therein.

(17) See ref 11a, and: White, C.; Maitlis, P. M. *J. Chem. Soc. A* **1971**, 3322-3326. Bailey, N. A.; Blunt, E. H.; Fairhurst, G.; White, C. *J. Chem. Soc., Dalton Trans.* **1980**, 829-836. Faller, J. W. *Inorg. Chem.* **1980**, *19*, 2857-2859. Whitesides, T. H.; Arhart, R. W. *J. Am. Chem. Soc.* **1971**, *93*, 5296-5298. Johnson, F. G.; Lewis, J.; Yarrow, D. J. *J. Chem. Soc., Dalton Trans.* **1972**, 2084-2089.

(18) We disagree with a reviewer's suggestion that use of the term "red herring" is inappropriate in this context. It seems to be a useful expression to describe a mechanistic side-trail that is irrelevant to the pathway of interest. See: Sayers, D. L. *The Five Red Herrings*; Harper & Row: New York.

General Strategy for the Systematic Synthesis of Oligosiloxanes. Silicone Dendrimers

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In view of the widespread use of silicones (polysiloxanes),[1] it is rather surprising that the literature documents virtually no *systematic* approaches to the synthesis of structurally defined oligosiloxanes. The availability of many of these compounds is necessitated in an ongoing project of our laboratories, and for this reason we have selected and modified a set of reactions to formulate a reliable general synthetic strategy as summarized in this paper. The validity of this strategy has been proven by the synthesis of a variety of oligosiloxanes and even silicone dendrimers (see later text) with discrete molecular weights of >10000. Several different modes of linear and branched elongation are delineated in the following text to illustrate this development. Most of the reactions proceed in high yield (>60%), unless otherwise specified.

1. **Linear (Stepwise) Homologation of α-Hydropermethyloligosiloxane, $(MD_nM^H)^2$ (1).** Scheme I illustrates the use of two basic reactions, hydroxylation of **1**[3] and coupling with chlorodimethylsilane, and this homologation (**1** → **3**) is conveniently carried out without the isolation of **2**.[4] Reiterate application to MM^H (**4**) leads to homologous MD_nM^H (*n* = 1-8), many of which were isolated earlier from a mixture of several MD_nM^H components obtained by the transition-metal-catalyzed redistribution of **4**.[4]

2. **Branched Elongation.** Replacement of $ClSiMe_2H$ (used in the above linear coupling) by Cl_2SiMeH, Cl_2SiH_2, and Cl_3SiH in the reaction with MM^{OH} (**5**) leads to the synthesis of **6-8** (Scheme II), which can be transformed into the branched-chain compounds **9-11**, respectively.[4] In addition to **9-11**, which are symmetrically branched, unsymmetrically branched hydrooligosiloxanes can be prepared. Thus, for example, the two chlorine functionalities of Cl_2SiMeH react stepwise with **12** to afford **13**,

(1) For reviews of silicone, see for instance: (a) Stark, F. O.; Falender, J. R.; Wright, A. P. In *Comprehensive Organometallic Chemistry*, Wilkinson, G., Stone, F. G. A., Abel, E. W., Eds.; Pergamon Press: New York, 1982; Vol. 2, Chapter 9.3. (b) Kendrick, T. C.; Parbhoo, B.; White, J. W. In *The Chemistry of Organic Silicon Compounds*; Patai, S., Rappoport, S., Eds.; John Wiley and Sons Ltd.: Chichester, 1989; Part 2, Chapter 21.

(2) Descriptors M, D, T, and Q are conventionally used in silicone chemistry to denote Me_3Si-O-, $-O-SiMe_2-O-$
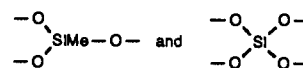
Superscripts on these descriptors denote a ligand or ligands substituting a Me or Me_2 ligands attached on M-T. See: Rochow, E. G. *An Introduction to the Chemistry of the Silicones*, 2nd ed.; Wiley: New York, 1951. Wilcock, D. F. *J. Am. Chem. Soc.* **1946**, *68*, 691.

(3) Barnes, G. H., Jr.; Daughenbaugh, N. E. *J. Org. Chem.* **1966**, *31*, 885.

(4) Representative experimental procedures, size-exclusive chromatographic results of **22** and **20A-C**, and physical properties of oligosiloxanes with pertinent references are found in the supplementary material.

Scheme I[a]

$$MD_nM^H \xrightarrow{a} MD_nM^{OH} \xrightarrow{b} MD_{n+1}M^H \quad MM^H$$
$$\quad 1 \qquad\qquad 2 \qquad\qquad 3 \qquad\quad 4$$
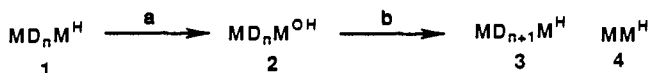
[a] Key: a, H_2O/dioxane, Pd/C; b, $ClSiMe_2H$, pyridine/C_6H_6.

Scheme II[a]

$$(MD)_2D^H \xleftarrow{a} MM^{OH} \xrightarrow{c} (MD)_3T^H$$
$$\quad 6 \qquad\qquad 5 \qquad\qquad 8$$

$$\downarrow d \qquad\qquad \downarrow b \qquad\qquad \downarrow e$$

$$(MD)_2D^{Cl} \qquad (MD)_2D^H{}_2 \qquad (MD)_3T^{Br}$$
$$\qquad\qquad\qquad\quad 7$$

$$\downarrow f \qquad\qquad \downarrow l \qquad\qquad \downarrow f$$

$$(MD)_2D^{OH} \qquad (MD)_2D^{(OH)}{}_2 \qquad (MD)_3T^{OH}$$

$$\downarrow g \qquad\qquad \downarrow g \qquad\qquad \downarrow g$$

$$(MD)_2TM^H \qquad (MD)_2Q(M^H)_2 \qquad (MD)_3QM^H$$
$$\quad 9 \qquad\qquad\qquad 10 \qquad\qquad\qquad 11$$
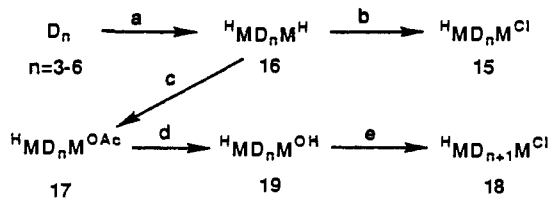
$$MDM^{OH} \xrightarrow{a} MD_2M^{H,Cl} \xrightarrow{h} MD_2D^HDM$$
$$\quad 12 \qquad\qquad\qquad 13$$

$$MD_2TDM \xleftarrow{g} MD_2D^{OH}DM \xleftarrow{l}$$
$$\quad M^H$$
$$\quad 14$$
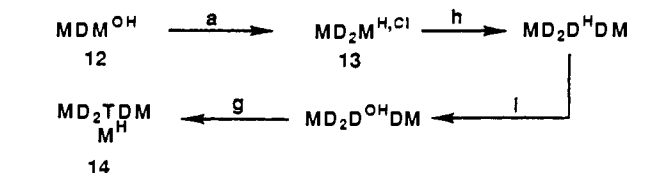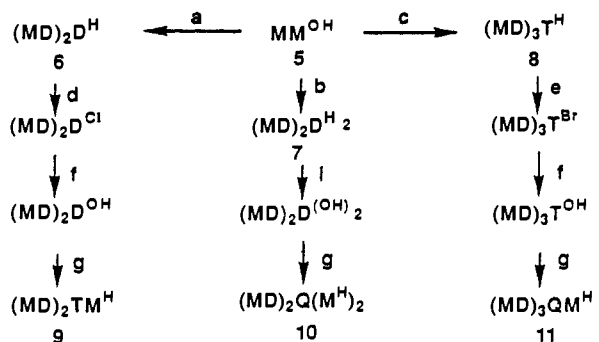
[a] Key: a, Cl_2SiMeH; b, Cl_2SiH_2; c, Cl_3SiH; d, CCl_4, $PdCl_2$; e, Br_2; f, $NaHCO_3$, H_2O; g, $ClSiMe_2H$; h, MM^{OH}; i, H_2O, Pd/C.

Scheme III[a]

$$D_n \xrightarrow{a} {}^HMD_nM^H \xrightarrow{b} {}^HMD_nM^{Cl}$$
$$n=3-6 \qquad\qquad 16 \qquad\qquad 15$$
$$\qquad\qquad\quad c \nearrow$$
$${}^HMD_nM^{OAc} \xrightarrow{d} {}^HMD_nM^{OH} \xrightarrow{e} {}^HMD_{n+1}M^{Cl}$$
$$\quad 17 \qquad\qquad\qquad 19 \qquad\qquad\qquad 18$$

[a] Key: a, $ClSiMe_2H$, silica gel, H_2O; b, 0.3 equiv of $(PhCOO)_2$, CCl_4; c, AcOH, Pd/C; d, H_2O; e, Cl_2SiMe_2.

which has a $M^{H,Cl}$ terminal capable of coupling with two different elongation units to provide **14** (Scheme II). A large number of new branched-chain hydrooligosiloxanes have been prepared and fully characterized.[4] 1D and 2D ^{29}Si NMR spectroscopy confirms the connectivity of these compounds indicated by the mode of synthesis.[5]

3. Preparation of α-Hydro-ω-chlorooligosiloxane ($^HMD_nM^{Cl}$) Units for Block Elongation. Obviously the homologation reactions shown in Schemes I and II can be, and indeed have been more efficiently executed with the use of a $^HMD_nM^{Cl}$ unit (**15**) than with $HSiMe_2Cl$. The synthesis of this block unit uses, as starting material, readily available D_n cyclic oligomers ($n = 3–6$) that have now been found to undergo ring opening with 2 equiv of $ClSiMe_2H$ and 1 equiv of water in the presence of silica gel to provide, in good yield, the $^HMD_nM^H$ products (**16**) as exemplified at the end of this paper.[4,6] All of the earlier procedures led to a mixture of several ring-opened oligosiloxanes.[4,7] The products **16** can be functionalized in the two ways shown in Scheme III: (1) benzoyl peroxide with CCl_4 and (2) acetic acid with Pd/C to provide $^HMD_nM^{Cl}$ (**15**) and $^HMD_nM^{OAc}$ (**17**), respectively. Both conversions involve partial functionalization of the two M^H; ac-

Scheme IV
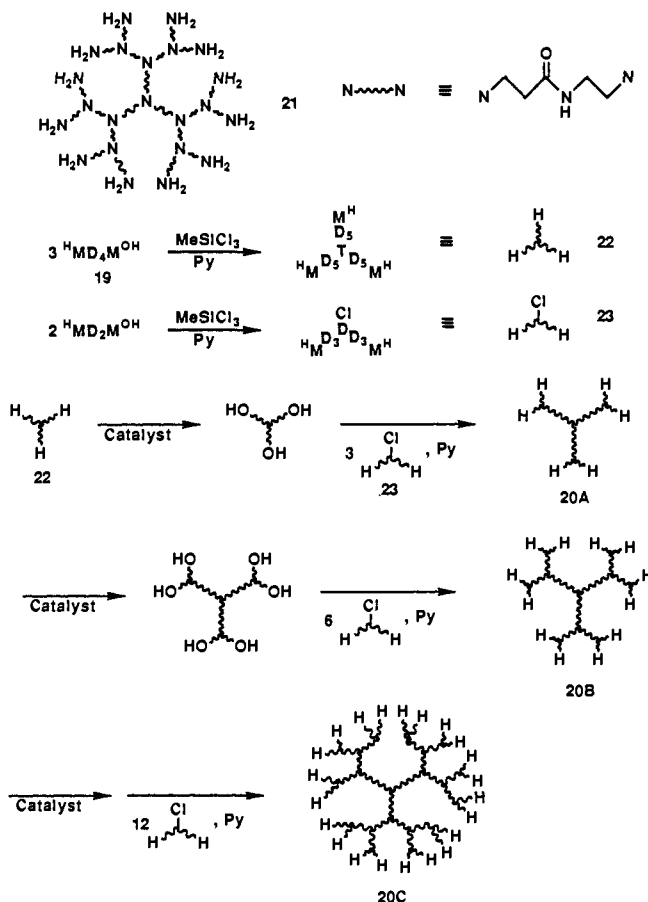
cordingly, the yields range between 25 and 50% and further work is required for improvement. α-Hydro-ω-acetoxyl oligomers (**17**) are also converted into $^HMD_{n+1}M^{Cl}$ (**18**) as indicated, and the intermediate **19** ($n = 4$) serves as a key building unit for the construction of dendrimers.

4. Synthesis of Silicone Dendrimers, Multibranched Polysiloxanes with Terminal Silicon Hydrogens for Further Modification. With the availability of various core and elongation units and also with the reliable coupling methodology, one can envision the construction of sizeable polysiloxanes whose structures are preselected and defined. Illustrated in Scheme IV are silicone dendrimers (**20A–C**),[4] structurally analogous to the starburst dendrimers that have been prepared recently with NH_3, CH_2= $CHCO_2CH_3$, and $NH_2CH_2CH_2NH_2$ through stepwise couplings[8,9] (see **21** in Scheme IV for the structure of the third-generation dendrimer). The synthesis of silicone dendrimers uses the core unit (**22**) and the elongation unit (**23**), both of which are prepared through the coupling of Cl_3SiMe with 3 equiv of $^HMD_4M^{OH}$ (**19**) and 2 equiv of $^HMD_2M^{OH}$, respectively. Coupling of **22** and **23** proceeds smoothly to provide the silicone dendrimer (**20A**) of the first generation. Repetition of this elongation leads to those of

(5) Will be discussed in a later publication.

(6) Yoshino, K.; Kawamata, A. (Kao Corp.) Japanese patent application, 1989.

(7) For the ring opening of D_n, see: (a) Brown, P. L. (Dow Corning Corp.) U.S. Patent 3162662, 1964. (b) Bennett, E. W. (Union Carbide Corp.) U.S. Patent 3624851, 1972. (c) Frey, V. (Wacker Chemie) Ger. Offen. DE 2630744, 1976.

(8) (a) Tomalia, D. A.; Baker, H.; Dewald, J.; Hall, M.; Kallos, G.; Martin, S.; Roeck, J.; Ryder, J.; Smith, P. *Polym. J.* (*Tokyo*) **1985**, *17*, 117. (b) Tomalia, D. A.; Baker, H.; Dewald, J.; Hall, M.; Kallos, G.; Martin, S.; Roeck, J.; Ryder, J.; Smith, P. *Macromolecules* **1986**, *19*, 2466. (c) Tomalia, D. A.; Berry, V.; Hall, M.; Hedstrand, D. M. *Macromolecules* **1987**, *20*, 1164. (d) Hall, H.; Padias, A.; McConnell, R.; Tomalia, D. A. *J. Org. Chem.* **1987**, *52*, 5305. (e) Tomalia, D. A.; Hall, M.; Hedstrand, D. M. *J. Am. Chem. Soc.* **1987**, *109*, 1601. (f) Naylor, A. M.; Goddard, W. A., III; Kiefer, G. E.; Tomalia, D. A. *J. Am. Chem. Soc.* **1989**, *111*, 2339. (g) For a review, see: Tomalia, D. A.; Naylor, A. M. N.; Goddard, W. A., III. *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 138.

(9) For "Arborols", see: (a) Newkome, G. R.; Yao, Z.-q.; Baker, G. R.; Gupta, V. K. *J. Org. Chem.* **1985**, *50*, 2003. (b) Newkome, G. R.; Yao, Z.-q.; Baker, G. R.; Gupta, V. K.; Russo, P. S.; Saunders, M. J. *J. Am. Chem. Soc.* **1986**, *108*, 849. (c) Newkome, G. R.; Baker, G. R.; Saunders, M. J.; Russo, P. S.; Gupta, V. K.; Yao, Z.-q.; Miller, J. E.; Bouillion, K. *J. Chem. Soc., Chem. Commun.* **1986**, 752.

the second and third generations without problem (**20B,C**). Compounds **22** and **20A–C** show ^{1}H, ^{13}C, and ^{29}Si NMR spectra consistent with the expected structures and have the retention volumes that correspond to their respective molecular weights on size-exclusion chromatography.[4,10] These values are corroborated with mass spectral data (FD) of **22**, **20A**, and **20B** that exhibit their M$^+$ and (M – 15)$^+$ peaks but the molecular weight of **20C** is apparently too large to be determined with this spectrometry. From the retention volume of **20C** in the chromatography, its molecular weight is estimated to be 14790, in excellent agreement with the calculated value of 15073 (with ^{28}Si).[4] Note that the "surfaces" of these silicone dendrimers are "coated" with SiH groups that are readily amenable to functional group transformation to modify physical properties of the polymers.[11]

Synthesis of ^{H}MD$_4$H^H. To a mixture of 500 g (1.70 mmol) of D$_4$, 304 g (16.9 mol) of water, and 50.1 g of silica gel was added dropwise 480 g (5.07 mol) of Me$_2$SiHCl over 2 h. After the mixture was stirred for 4 h, the silica gel was filtered off and low-boiling side products were removed on a rotary evaporator. The residue was diluted with 500 mL of benzene. The water layer was separated and the organic layer washed with 500 mL of water, 500 mL of 1% NaHCO$_3$ solution twice, and finally 500 mL of water twice. Distillation provided 341 g (47% yield and 78% based on the consumed D$_4$) of ^{H}MD$_4$M^H, bp 81 °C (0.1 Torr), as a colorless oil and 199 g of recovered D$_4$.

Supplementary Material Available: Representative experimental procedures, size-exclusion chromatographic results, and physical properties of oligosiloxanes with pertinent references (16 pages). Ordering information is given on any current masthead page.

(10) *Steric Exclusion Liquid Chromatography of Polymers*; Janca, J., Ed.; Chromatography Series; Marcel Dekker: New York, 1984; Vol. 25.

(11) The work at M.I.T. was supported by a grant from the National Science Foundation (CHE-8706760-03). The mass spectra were provided by the facilities supported by the National Institutes of Health (Grant RR 00317, Professor K. Biemann) from the Biotechnology Resources Branch, Division of Research Resources.

Pimaricin. Stereochemistry and Synthesis of Its Aglycon (Pimarolide) Methyl Ester[†]

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Pimaricin (**1**) is a representative antifungal polyenemacrolide of significant physiological activity and practical utility.[1] Its correct gross structure was documented in 1977,[2] but the entire stereochemistry of its aglycon, pimarolide, remained unknown until the completion of this work mainly because **1** and its derivatives fail to crystallize in a form suitable for X-ray analysis. We degraded the antibiotic to the major fragment **7** (of unknown stereochemistry) through a pimarolide derivative (**4**) (Scheme I). Reagent-controlled syntheses[3] of a set of diastereomers possible for the structure of **7** unambiguously established its stereochemistry,[4] and subsequently **7** was converted into the pimarolide methyl

[†] This work was initiated at M.I.T. and completed at I.F.R., Kao. A.J.D. participated in an exchange program between the two institutions.

(1) For reviews, see: (a) Omura, S. *Macrolide Antibiotics, Chemistry, Biology and Practice*; Academic Press: New York, 1984; Chapters 9–12, and references quoted therein. (b) Bolard, J. *Biochim. Biophys. Acta* **1986**, *864*, 257.

(2) Ceder, O.; Hansson, B. *Tetrahedron* **1977**, *33*, 2703.

(3) Masamune, S.; Choy, W.; Petersen, J. S.; Sita, L. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 1.

ester **4b**. These accomplishments summarized below represent the first synthesis of a polyenemacrolide aglycon without prior knowledge of its stereochemistry and also provide synthetic proof for the correctness of the stereostructure disclosed for **1** by Lancelin and Beau[5] during the preparation of this manuscript. The set of NMR techniques employed in their study is indeed powerful.

Degradation of 1 to 7. The degradation pathway from **1** to **7** via **2–6** outlined in Scheme I[6] is patterned after that developed in our laboratory in conjunction with the synthesis of amphoterolide B.[7,8] Two comments are appropriate. (1) The normally problematic step of cleaving the mycosamyl moiety (step b) proceeded well through oxidative deglycosidation of **2** with DDQ[7a] to provide tetraenone **3**, and this method appears generally applicable to many other polyenemacrolides. (2) Reduction of **3** with NaBH$_4$ (step c)[8a] led to the exclusive formation of a single tetraenol (**4**). The 15R configuration was assigned to **4** through the observation of a negative Cotton effect in the CD spectrum of the *p*-nitrobenzoate derivative **4a**.[9,10] That both the MOM ether of **4** ($J_{14,15}$ 2.8, $J_{14',15}$ 8.0, $J_{15,16}$ 7.0 Hz) and **2** ($J_{14,15}$ 2.5, $J_{14',15}$ 8.0, $J_{15,16}$ 7.5 Hz) show very similar coupling patterns for H$_{14}$, H$_{14'}$, H$_{15}$, and H$_{16}$ confirms the 15R assignment of **1**.[10]

Synthesis of 7. ^{1}H NMR spectral comparison between the pimarolide derivative **4** and the amphoterolide B methyl ester as well as between a pair of their respective degradation products strongly suggests that the pyran moieties [C(9)–C(13) in **1**] of both antibiotics possess the same stereochemistry. Thus, a synthetic intermediate (**8**) representing the C(9)–C(15) fragment and used in our amphoterolide B synthesis[7b,11] served as starting material and was converted into aldehyde **12** via **9–11** as shown in Scheme II.[12–14] Two different reagent-controlled reactions were used to prepare the two possible configurations at C(7) in **7**. (1) The asymmetric aldol reaction of aldehyde **12** with the enolate derived from 3-ethylpentyl ethanethioate and chiral (*R,R*)-dimethylborolanyl triflate[15] provided a 1:8 mixture of **13a** and **13b**, while the use of (*S,S*)-dimethylborolanyl triflate reversed the product ratio (10:1 of **13a** and **13b**). Silylation of **13a** and **13b** followed by NaBH$_4$ reduction[16] and oxidation afforded the aldehydes **14a** and **14b**, respectively. (2) Asymmetric allylboration[17] of **12** with chiral (*S*)-*B*-allyl-2-(trimethylsilyl)borolane led to the predominant formation of diastereomer **15** (9.5:1), which was then transformed to **14a**. The stereochemical outcome of the aldol reaction and allylboration are governed by the rule of double

(4) Notable examples of establishing stereochemistry through this methodology include Kishi's palytoxin quoted in ref 3 and Schreiber's mycoticin A and B (Schreiber, S. L.; Goulet, M. T. *J. Am. Chem. Soc.* **1987**, *109*, 8120).

(5) Lancelin, J.-M.; Beau, J.-M. *J. Am. Chem. Soc.* **1990**, *112*, 4060. Also see: Lancelin, J.-M.; Paquet, F.; Beau, J.-M. *Tetrahedron. Lett.* **1988**, *29*, 2827.

(6) For **2**, see: Oppong, I.; Pauls, H. W.; Liang, D.; Fraser-Reid, B. *J. Chem. Soc., Chem. Commun.* **1986**, 1241.

(7) (a) Kennedy, R. M.; Abiko, A.; Masamune, S. *Tetrahedron Lett.* **1988**, *29*, 447. (b) Kennedy, R. M.; Abiko, A.; Takemasa, T.; Okumoto, H.; Masamune, S. *Ibid.* **1988**, *29*, 451. (c) Masamune, S. *N.Y. Acad. Sci.* **1988**, *544*, 168.

(8) (a) Nicolaou, K. C.; Chakraborty, T. K.; Ogawa, Y.; Daines, R. A.; Simpkins, N. S.; Furst, G. T. *J. Am. Chem. Soc.* **1988**, *110*, 4660. (b) Nicolaou, K. C.; Daines, R. A.; Chakrabory, T. K.; Ogaway, Y. *Ibid.* **1988**, *110*, 4685.

(9) For a review on CD, see: Harada, N.; Nakanishi, K. *Circular Dichroic Spectroscopy - Exciton Coupling in Organic Stereochemistry*; University Science Books: Mill Valley, CA, 1983.

(10) We thank Prof. N. Harada, Tohoku University, for the CD spectrum of **4a** and Dr. K. Furihata, Tokyo University, for the 500-MHz ^{1}H NMR spectra of several compounds prepared in this work.

(11) Boschelli, D.; Ellingboe, J. W.; Masamune, S. *Tetrahedron Lett.* **1984**, *25*, 3395.

(12) For step a, reaction 3, see: Bal, B. S.; Childers, W. E., Jr.; Pinnick, H. W. *Tetrahedron* **1981**, *27*, 2091.

(13) For step a, reaction 4, see: Brooks, D. W.; Lu, L. D.; Masamune, S. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 72.

(14) For step c, reaction 4, see: Abiko, A.; Roberts, J. C.; Takemasa, T.; Masamune, S. *Tetrahedron Lett.* **1986**, *27*, 4537.

(15) (a) Masamune, S.; Sato, T.; Kim, B.-M.; Wollmann, T. *J. Am. Chem. Soc.* **1986**, *108*, 8279. (b) Short, R. P.; Masamune, S. *Tetrahedron Lett.* **1987**, *28*, 2841.

(16) Liu, H. J.; Bukownik, R. P.; Pednecker, P. R. *Synth. Commun.* **1981**, *11*, 599.

(17) Short, R. P.; Masamune, S. *J. Am. Chem. Soc.* **1989**, *111*, 1892.