(12) (a) T. Neilson, *Chem. Commun.*, 1139 (1969); (b) T. Neilson and E. S. Werstiuk, *Can. J. Chem.*, **49**, 3004 (1971).
(13) T. Mukaiyama and M. Hashimoto, *J. Am. Chem. Soc.*, **94**, 8528 (1972).
(14) H. Köster and W. Heidmann, *Angew. Chem., Int. Ed. Engl.*, **12**, 859 (1973).
(15) (a) N. J. Cusak, C. B. Reese, and J. H. Van Boom, *Tetrahedron Lett.*, 2209 (1973); (b) J. H. Van Boom, J. F. M. de Rooy, and C. B. Reese, *J. Chem. Soc., Perkin Trans.*, 2513 (1973).
(16) J. Smrt, *Collect. Czech. Chem. Commun.*, **38**, 3189 (1973).
(17) (a) K. K. Ogilvie and K. Kracker, *Can. J. Chem.*, **50**, 1211 (1972); (b) K. K. Ogilvie, *ibid.*, **51**, 3799 (1973); (c) K. K. Ogilvie, E. A. Thompson, M. A. Quilliam, and J. B. Westmore, *Tetrahedron Lett.*, 2865 (1974).
(18) W. S. Zielinski and J. Smrt, *Collect. Czech. Chem. Commun.*, **39**, 2483 (1974).
(19) T. Neilson and E. S. Werstiuk, *J. Am. Chem. Soc.*, **96**, 2295 (1974).
(20) (a) H. Koster and F. Cramer, *Justus Liebigs Ann. Chem.*, **766**, 6 (1972); (b) H. Köster and F. Cramer, *ibid.*, 946(1974); (c) M. M. Kabachnik, N. G. Timofeeva, M. V. Budanov, V. K. Potapov, Z. A. Shabarova, and M. A. Prokof'ev, *Zh. Obshch. Khim.*, **43**, 379 (1973).
(21) (a) A. Panet and H. G. Khorana, *J. Biol. Chem.*, **249**, 5213 (1974); (b) K. A. Agarwal, Y. A. Berlin, D. G. Kleid, V. D. Smirnov, and H. G. Khorana, *ibid.*, **250**, 5563 (1975).
(22) A. Myles, W. Hutzenlamb, G. Reitz, and W. Pfleiderer, *Chem. Ber.*, **108**, 2857 (1975).
(23) M. Rubinstein and A. Patchornik, *Tetrahedron*, **31**, 2107 (1975).
(24) (a) R. L. Letsinger and J. L. Finnan, *J. Am. Chem. Soc.*, **97**, 7197 (1975); (b) R. L. Letsinger and W. B. Lunsford, *ibid.*, **98**, 3655 (1976).
(25) (a) K. Itakura, N. Katagiri, C/ P. Bahl, R. H. Wightman, and S. A. Narang, *J. Am. Chem. Soc.*, **97**, 7327 (1975); (b) N. Katagiri, K. Itakura, and S. A. Narang, *ibid.*, **97**, 7332 (1975).
(26) J. H. Van Boom, P. M. J. Burges, R. Crea, W. C. M. M. Luyten, A. B. J. Vink, and C. B. Reese, *Tetrahedron*, **31**, 2953 (1975).
(27) M. Sekine and T. Hata, *Tetrahedron Lett.*, 1711 (1975).
(28) P. Cashion, K. Porter, T. Cadger, G. Sathe, T. Tranquilla, H. Notman, and E. Jay, *Tetrahedron Lett.*, 3769 (1976).
(29) (a) G. M. Tenner, H. G. Khorana, R. Markham, and E. H. Pol, *J. Am. Chem. Soc.*, **80**, 6223 (1958); (b) A. J. Turner and H. G. Khorana, *ibid.*, **81**, 4654 (1959); (c) H. Weimann and H. G. Khorana, *ibid.*, **84**, 419 (1962); (d) H. G. Khorana, *Pure Appl. Chem.*, **17**, 349 (1968); (e) K. L. Agarwal, A. Yamazaki, P. J. Cashion, and H. G. Khorana, *Angew. Chem., Int. Ed. Engl.*, **11**, 451 (1972).
(30) H. Koster, H. Blocker, R. Frank, S. Geussenheimer, and W. Kaiser, *Z. Physiol. Chem.*, **356**, 1585 (1975).
(31) (a) R. Lohrmann and H. G. Khorana, *J. Am. Chem. Soc.*, **86**, 4188 (1964); (b) *ibid.*, **88**, 829 (1966).
(32) E. S. Werstiuk and T. Neilson, *Can. J. Chem.*, **50**, 1283 (1970).
(33) J. Smrt, *Collect. Czech. Chem. Commun.*, **38**, 3642 (1973).
(34) (a) M. Ikehara, *Ann. N.Y. Acad. Sci.*, **255**, 71 (1975); (b) M. Ikehara, *Acc. Chem. Res.*, **7**, 92 (1974); (c) E. Ohtsuka, A. Hunda, H. Shigyo, S. Morioka, T. S. Ugiyama, and M. Ikehara, *Nucleic Acid Res.*, **1**, 223 (1974); (d) E. Ohtsuka, T. Sugiyama, and M. Ikehara, *Chem. Pharm. Bull.*, **23**, 2257 (1975).
(35) (a) F. Ramirez, J. F. Marecek, and I. Ugi, *J. Am. Chem. Soc.*, **97**, 3809 (1975); (b) J. S. Ricci, B. R. Davis, F. Ramirez, and J. Marecek, *ibid.*, **97**, 5457 (1975).
(36) (a) F. Ramirez, H. Okazaki, and J. F. Marecek, *Synthesis*, 637 (1975); (b) F. Ramirez, H. Okazaki, J. F. Marecek, and H. Tsuboi, *ibid.*, 819 (1976).
(37) (a) F. Ramirez, J. F. Marecek, and H. Okazaki, *J. Am. Chem. Soc.*, **97**, 7181 (1975); (b) *ibid.*, **98**, 5310 (1976).
(38) For discussions of applications of the oxyphosphorane concept to the synthesis of unsymmetrical phosphodiesters, see ref 39.
(39) (a) F. Ramirez and I. Ugi, *Bull. Soc. Chim. Fr.*, 453 (1974); (b) *Phosphorus Sulfur*, **1**, 231 (1976).
(40) F. Ramirez, P. V. Ioannou, J. F. Marecek, B. T. Golding, and G. H. Dodd, *Synthesis*, 769 (1976).
(41) (a) F. Ramirez, B. Hansen, and N. B. Desai, *J. Am. Chem. Soc.*, **84**, 4588 (1962); (b) P. Gillespie, F. Ramirez, I. Ugi, and D. Marquarding, *Angew. Chem.*, **85**, 99 (1973); *Angew. Chem. Int. Ed. Engl.*, **12**, 91 (1973); cf. p 110.
(42) F. Ramirez, P. V. Ioannou, J. F. Marecek, M. Nowakowski, B. T. Golding, and G. H. Dodd, *Synthesis*, 483 (1976).
(43) G. Stork and P. F. Hudrlik, *J. Am. Chem. Soc.*, **90**, 4462 (1968).
(44) E. J. Corey and A. Venkateswarlu, *J. Am. Chem. Soc.*, **94**, 6190 (1972).
(45) K. K. Ogilvie, K. L. Sadana, E. A. Thompson, M. A. Quilliam, and J. B. Westmore, *Tetrahedron Lett.*, 2861 (1974).
(46) H. G. Khorana, H. Schaller, G. Weimann, and B. Lerch, *J. Am. Chem. Soc.*, **85**, 3821 (1963).
(47) Thy = thymine; T = 2′-deoxythymidine. Except as noted, the internucleotide bond is 3′ → 5′ from left to right in the formulas, e.g., TpT. For nomenclature, see *J. Biol. Chem.*, **241**, 527 (1966). THF = tetrahydrofuran; DMF = dimethylformamide.
(48) (a) G. L. Eichorn et al., S. K. Dhar, Ed., "Metal Ions in Biological Systems", Plenum Press New York, N.Y., pp 43–65; (b) I. Sissoeff, J. Grisvard, and E. Guille, *Prog. Biophys. Mol. Biol.*, **31**, 165 (1976).
(49) J. C. Catlin and F. Cramer, *J. Org. Chem.*, **38**, 245 (1973).
(50) We are grateful to Mr. J. Finnan and Professor R. L. Letsinger of Northwestern University, Evanston, Ill., for the data on degradation of the oligonucleotides **8a** and **14a** by snake venom and spleen phosphodiesterases and for confirmation of the composition of crude salts **8a** and **14a**.
(51) C. Coutsogeorgopoulos and H. G. Khorana, *J. Am. Chem. Soc.*, **86**, 2926 (1964).
(52) To the limit of the resolution of silica gel plates designed for nano-TLC (60 F-254 HP-TLC plates Merck Cat. No. 5628) with CH_2Cl_2/CH_3OH 9/1 v/v as eluent.
(53) B. J. Hunt and W. Rigley, *Chem. Ind. (London)*, 1868 (1967).

Boron Compounds. 45.[1] 6-Deoxy-*O*-acyl-α-L-mannofuranoses via *O*-Ethylboranediyl Derivatives

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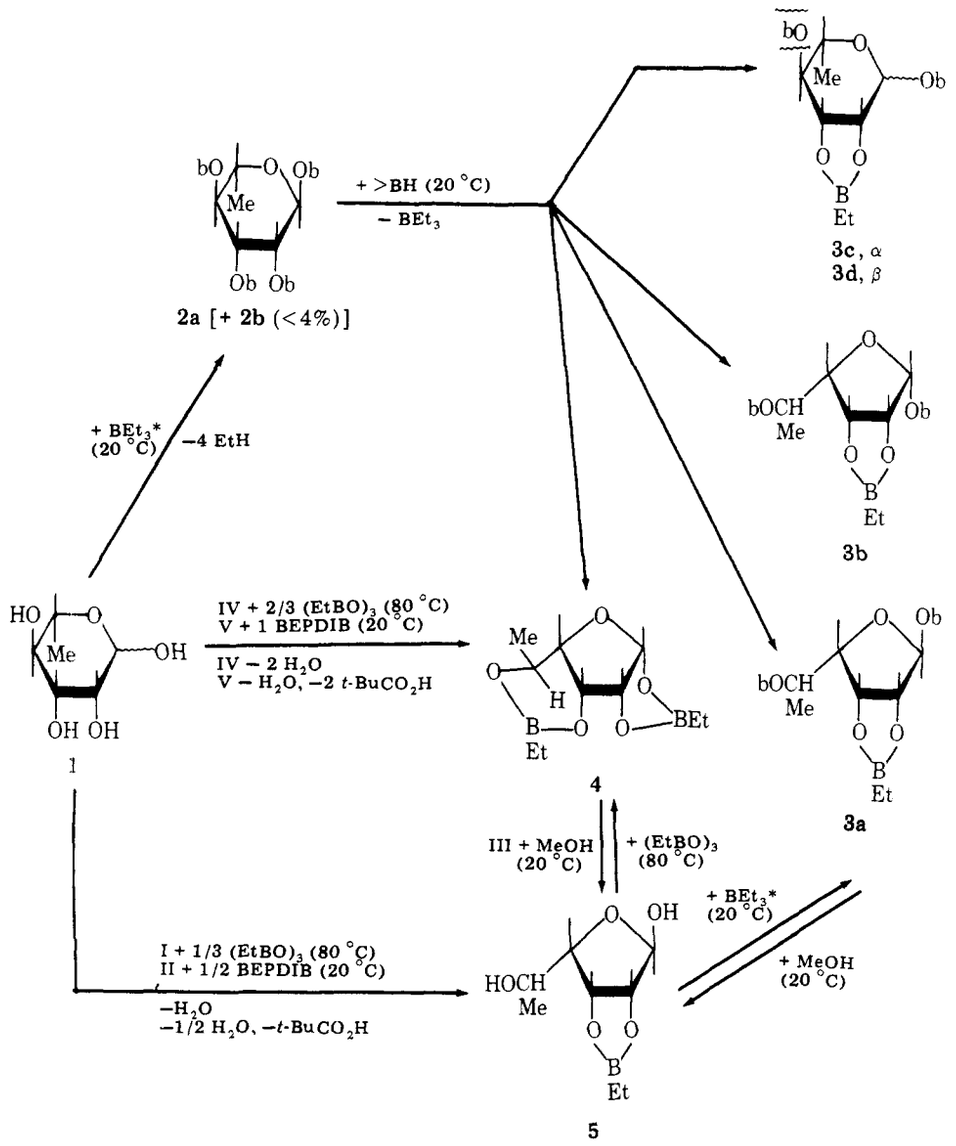
The O-diethylborylation of 6-deoxy-L-mannopyranose (L-rhamnose) (1) yields 6-deoxy-1,2,3,4-tetrakis-*O*-diethylboryl-α-L-mannopyranose (**2a**), which in the presence of >BH gives a mixture of four isomers **3a–d** and 6-deoxy-1,2:3,5-bis-*O*-ethylboranediyl-β-L-mannofuranose (**4**). Ethylboroxine or bis(ethylpivaloyloxy)diboroxane (BEPDIB) and **1** give over 90% yields of **4** or 6-deoxy-2,3-*O*-ethylboranediyl-α-L-mannofuranose (**5**), depending on the molar ratio used. A reversible trans-O-ethylboranediylation between **4** and **5** occurs on heating **5** or on heating a mixture of **1** and **4** in pyridine. The O-acetylation of **5** gives the 1,5-di-*O*-acetyl derivative **6**, which on deborylation and subsequent O-acylations lead to the boron-free derivatives **7** and **8a** or **8b**, respectively. Ethylboroxine and 6-deoxy-2,3-*O*-isopropylidene-L-mannofuranose (**9**) react to give the 1,5-ethylboranediyl derivative **10** in high yield. The hydride numbers (HZ) of 1 H_2O, **3a**, **4**, **5**, **7**, **8a**, and **9** were determined using propyldiborane(6).

Previous investigations[2–5] on the structures and properties of *O*-ethylboranediyl derivatives of some polyhydroxy compounds have shown that they are sometimes attractive alternatives to conventionally protected compounds for regioselective transformations to the O derivatives. The ease of introduction and removal of the *O*-ethylboranediyl protective group has been illustrated with xylitol,[2] D-mannitol,[3] dulcitol,[4] and several methyl glycosides.[5] In our previous publication with some methyl glycosides as model compounds, no ring isomerization could occur. The present study on the *O*-ethylboranediyl derivatives of 6-deoxy-L-mannopyranose (L-rhamnose) (1) shows that facile pyranose/furanose isomerizations and anomerizations can occur with the *O*-ethylboranediyl derivatives of the free monosaccharides.

Results and Discussion

A. The Indirect O-Ethylboranediylation of 1. The O-diethylborylation of the crystalline 6-deoxy-α-L-mannopyranose monohydrate[6] (1·H_2O) with activated triethylborane[7] at room temperature gives 6-deoxy-1,2,3,4-tetrakis-*O*-

Scheme I



b = BEt_2

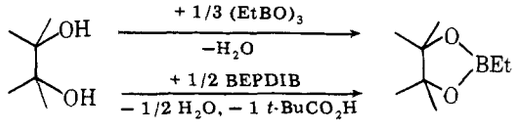
BEt_3* = activated triethylborane

diethylboryl-α-L-mannopyranose (**2a**) in 94% yield. Small amounts (<4%) of the corresponding β isomer (**2b**) can be detected by ^1H NMR measurements (see part E). No per-*O*-diethylborylated 6-deoxy-L-mannofuranoses are formed.

Addition of ethyldiborane(6)[8] to **2a** at room temperature causes the elimination of ca. 1 mol of triethylborane from this compound. However, a mixture of five isomers is obtained on distillation. 6-Deoxy-1,5-bis-*O*-diethylboryl-2,3-*O*-ethylboranediyl-α-L-mannofuranose (**3a**) is the major component (~60%). The other four isomers, which are obtained in equal ratios, include the β-rhamnofuranose derivative **3b**, the α,β-rhamnopyranoses **3c** and **3d**, and 6-deoxy-1,2:3,5-bis-*O*-ethylboranediyl-β-L-mannofuranose (**4**)[16a,b] (see Scheme I). The distilled mixture is obtained in about 70% yield. A residue remains after distillation, which must consist essentially of compounds with intermolecular *O*-ethylboranediyl groups.

The introduction of *O*-ethylboranediyl groups into several methyl glycosides[5] and polyalcohols[2-4] by per-O-diethylborylation and subsequent thermal or >BH-catalyzed triethylborane eliminations is, therefore, a useful alternative route; however, this indirect procedure is not suitable for free monosaccharides as mixtures of anomers and ring isomers are formed. A further disadvantage is that reduction of the carbonyl group can take place at temperature above 80 °C.

B. The Direct Routes to the *O*-Ethylboranediyl Derivatives of 1. The *O*-ethylboranediyl derivatives of monosaccharides are best prepared by direct routes from the free



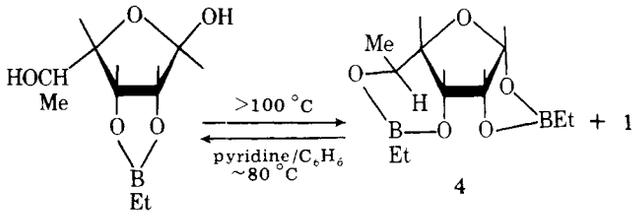
sugars with reagents such as ethylboroxine or bis(ethylpivaloyloxy)diboroxane (BEPDIB).[3-5] Water is formed on reaction of ethyl boroxine with polyhydroxy compounds, whereas pivalic acid and water are formed when BEPDIB is used (see Scheme I).

The presence of water no doubt facilitates anomerization and ring isomerization and hence pure products are generally not obtained. We have found that in certain cases water elimination can occur to give unsaturated derivatives on reaction with ethylboroxine.[17] This observation was not made with BEPDIB. The latter reagent is, however, not as readily accessible as ethylboroxine. The choice of the best reagent,

therefore, depends on the particular substrate.

6-Deoxy-2,3-O-ethylboranediyl-α-L-mannofuranose (**5**) can be prepared in three ways (see Scheme I). The reaction of anhydrous **1** with ethylboroxine in the molar ratio 1:0.33 gives **5** in 95% yield (route I). **5** is also obtained in 98% yield by reaction of 0.5 mol of bis(ethylpivaloyloxy)diboroxane (BEPDIB) with 1 mol of **1** at room temperature (route II).[16a,b] Route III involves treatment of **4** with methanol at room temperature. Partial deboronation and an intramolecular transesterification occur to give **5** in 99% yield.[16a,b]

The viscous liquid **5** disproportionates during vacuum distillation to give **4** and **1**, which is obtained as residue. Heating **1** and **4** to 80 °C in the presence of pyridine as solvent



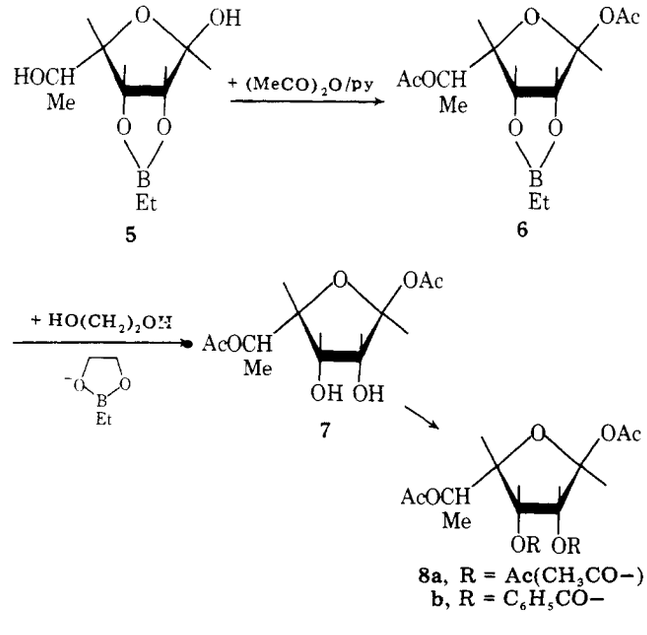
gives **5** in 98% yield. In contrast, the 6-deoxy-2,3-O-isopropylidene-α-L-mannofuranose (**9**)[9,10] can be vacuum distilled without any disproportionation[10] occurring.

5 reacts with activated triethylborane[7,11] at room temperature to give **3a**. This colorless liquid with bp 92–95 °C (10^{-3} Torr) can be selectively de-O-diethylborylated by addition of methanol at room temperature. **5** is obtained in 98% yield.

Isomerically pure **4** can be isolated as vacuum distillable liquid using the three routes IV–VI (see Scheme I). Reaction of **1** with ethylboroxine in the molar ratio 1:≥0.67 (route IV) gives **4** in 92% yield, and in 96% yield by reaction of **1** with BEPDIB in the molar ratio 1:≥1 (route V). It may also be prepared in 92% yield by reaction of **5** with ethylboroxine (route VI).

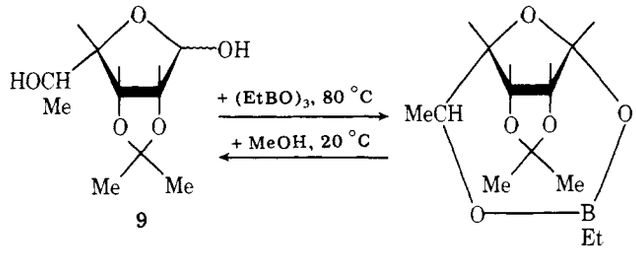
C. Regioselective O-Acylation of 1. O-Acetylation of **5** by normal simple procedure gives the vacuum distillable 6-deoxy-1,5-di-O-acetyl-2,3-O-ethylboranediyl-α-L-mannofuranose (**6**) in 93% yield (see Scheme II).[16a,b] The total deboronation of **6** requires several treatments with hot ethane-1,2-diol. Crystalline 6-deoxy-1,5-di-O-acetyl-α-L-mannofuranose (**7**) is obtained in 75% yield. Further O-acetylation

Scheme II



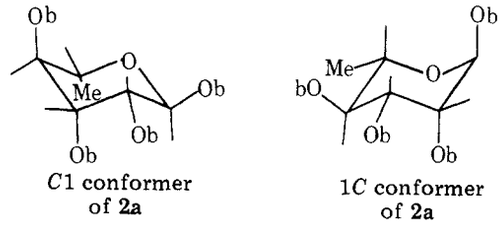
yields tetra-O-acetyl-6-deoxy-α-L-mannofuranose (**8a**). **7** can also be O-benzoylated to give pure 6-deoxy-1,5-di-O-acetyl-2,3-di-O-benzoyl-α-L-mannofuranose (**8b**) in 69% yield.

D. 6-Deoxy-2,3-O-isopropylidene-L-mannose (9) with Ethylboroxine. Reaction of 6-deoxy-2,3-O-isopropylidene-L-mannofuranose (**9**)[9,10] with ethylboroxine gives 6-deoxy-1,5-O-ethylboranediyl-2,3-O-isopropylidene-β-L-mannofuranose (**10**) as a vacuum distillable product. The facile deboronation of **10** under mild conditions with methanol at room temperature gives **9** in 96% yield. Although several structures



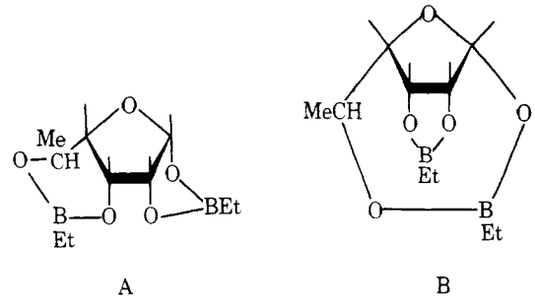
are possible, it is evident that **10** has the proposed structure with a seven-membered ring. A quantitative intramolecular transesterification of the 2,3-O-isopropylidene group can be ruled out under the mild, neutral conditions of methanolysis.

E. Determination of the Structures of 2, 3a, 4, 5 and 10. Structure of 2a. The ^1H NMR spectrum of **2a** shows that it is contaminated with <4% of the β isomer **2b**. It is fully consistent with the pyranose assignment because $J_{3,4}$ = 9 Hz and not 3.5–5 Hz as for furanose forms. The H^1H^2 coupling con-



stant (1 Hz) rules out an axial–axial relationship and a C1 conformation. The observed H^4H^5 coupling constant (9 Hz) clearly demonstrates an axial–axial coupling constant as required by the 1C conformation. The coupling constants are very similar to those found for methyl 6-deoxy-2,3,4-tri-O-acetyl-α-L-mannopyranoside,[12] which also adopts the 1C conformation.

Structure of 4. The combination of the B, B_C, and H^+ determinations of **4** show that this derivative contains two O-ethylboranediyl rings and no free hydroxy groups. In the ^{13}C NMR spectrum the C^1 signal lies at δ = 105 ppm, which is in the characteristic range for the furanose forms of monosaccharides.[26] **4** can, therefore, only have either structure A or B.



As both of these possible structures contain one five-membered 1,3,2-dioxaborolane ring and one larger boron ring (a 6- and a 7-ring, respectively, for A and B), it is not possible

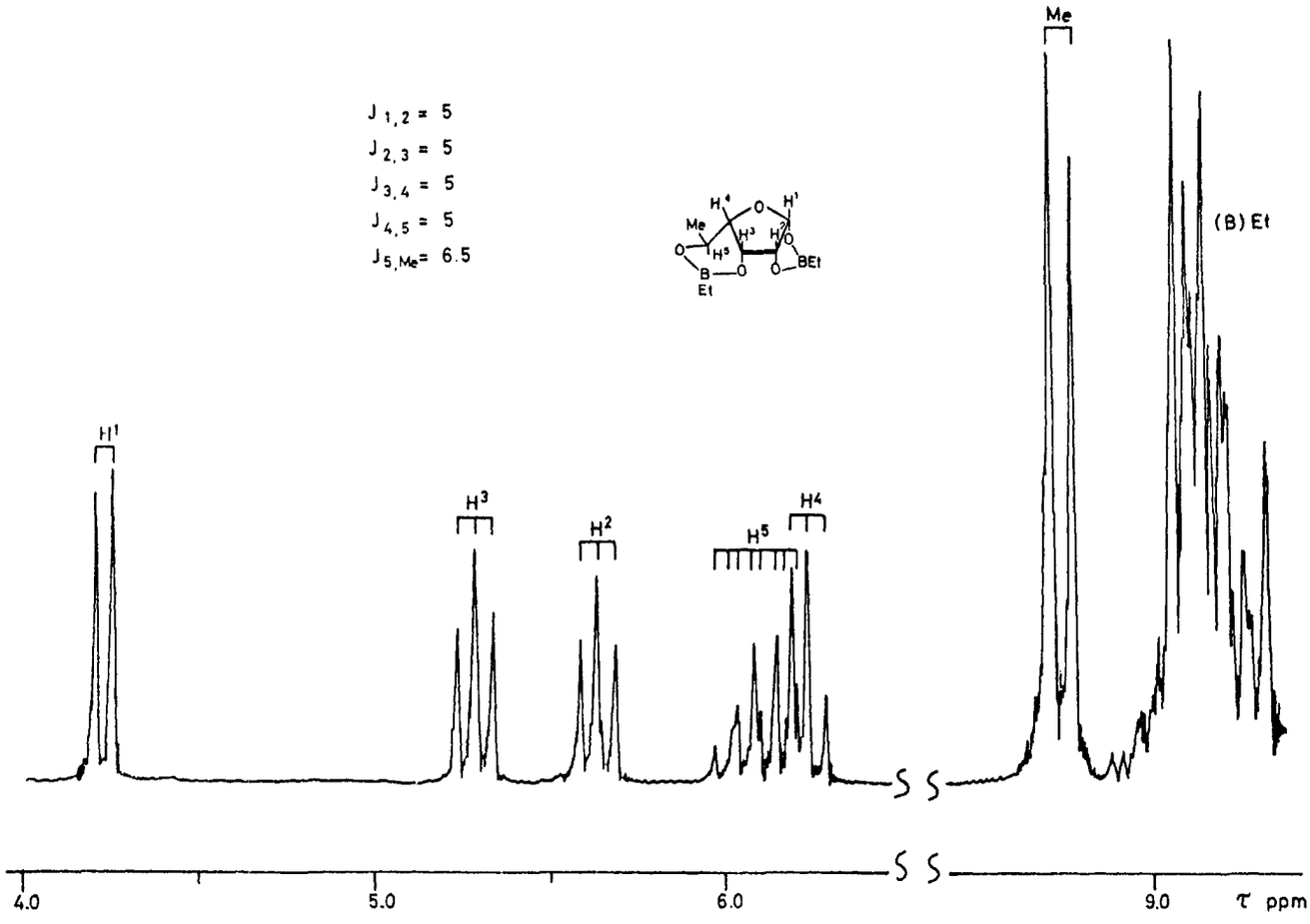


Figure 1. The 100-MHz ^{1}H NMR spectrum of 6-deoxy-1,2:3,5-bis-*O*-ethylboranediyl-β-L-mannofuranose (4) in CCl_4.

to differentiate between these alternatives using ^{11}B NMR, because only the boron in a five-membered ring gives rise to a signal at $\delta \sim 34.5$[13] and the six and higher membered rings have signals at $\delta \sim 31$. The structure was ascertained by comparing the ^{1}H NMR spectra of **4** (Figure 1) and **10.** As the ^{1}H NMR spectra of **9** and **5** are very similar, one would expect the spectrum of **10** to bear a close resemblance to that of its bisboron analogue (B), as both contain a seven-membered boron ring. This is, however, not the case (see Experimental Section, parts C and E). The correct structure, therefore, is A.

Structures of 5 and 3a. The presence of two hydroxy groups in **5** was confirmed gas volumetrically by reaction with activated triethylborane[7,11] to give **3a.** The B and B_C values are also in accord with a mono-*O*-ethylboranediyl derivative of **1.**

In the ^{1}H NMR spectrum of **5** in Me_2SO-d_6 a low-field doublet is observed at τ 3.60 ppm with $J_{1,OH}$ = 4.5 Hz. As this signal is indicative of a free anomeric hydroxy group,[14] possible structures containing a 1,2-*O*-ethylboranediyl group can be ruled out. The characteristic coupling constants in the ^{1}H NMR spectrum of **5** are always found when a 1,3,2-dioxaborolane ring is fused to a furanose sugar ring with C^2 and C^3.[17]

The ^{1}H NMR spectrum bears a close resemblance to those of 2,3-*O*-isopropylidene-L-erythrose[15] and 5-aldo-D-lyxofuranose 2,3-*O*-carbonate,[15] in which the only type of fused ring system possible is one that contains two five-membered rings. These ^{1}H NMR spectra, in turn, bear a strong similarity in general spectral characteristics to those of D-mannofuranose 2,3-carbonate,[15] 2,3-*O*-ethylboranediyl-α-D-mannofuranose,[16] 6-deoxy-2,3-*O*-isopropylidene-L-mannofuranose,[15] 2,3-*O*-ethylboranediyl-α-D-lyxofuranose,[17] and D-lyxofuranose 2,3-carbonate.[18]

Thus, the kind of bicyclic structure which is present in all of these compounds, i.e., a five-membered ring fused to the furanose form of the sugar ring, must be substantially more stable than the form in which the five-membered ring is fused to a pyranose sugar ring. Although the assignment of peaks to H^1 and H^3 in the ^{1}H NMR spectrum of **5** is unproblematic, H^4 and H^5 give rise to a rather complex overlapping multiplet. It is convenient to convert **5** to **3a,** as its spectrum allows an unequivocal assignment to be made of all the protons (see Figure 2). The O-diethylborylation to **3a** causes a downfield shift of the signals for H^1 and H^5 and hence they are separated from other signals.

The ^{13}C NMR spectrum of **5** is also consistent with the furanose assignment. The signals at δ 80.0, 83.3, and 85.6 fall in a range which is characteristic for ethylboranediylfuranose derivatives of sugars.[17] The absence of notable peaks, beside the seven signals observed, provides further evidence for a relatively high degree of purity of **5.**

The ^{11}B NMR spectrum of **3a** confirms the presence of a five-membered 1,3,2-dioxaborolane ring,[13] higher membered rings having signals at $\delta \sim 30$.

Structure of 10. Proof for the structural assignment is given by the fact that the high yield deboronation of **10** gives **9.**

The ^{1}H NMR spectrum of **10** shows some interesting features. The signal assigned to H^3 is observed as a triplet of doublets at τ 5.35. The additional splitting is due to long-range coupling between H^3 and H^5 ($J_{3,5}$ = 1.5 Hz). The four bonds involved must, therefore, be in the so-called "W conformation" [19] with $\angle H^4H^5 \sim 90°$.

F. Hydride Values (HZ)[20] of 1·H_2O, 3a, 4, 5, 7, 8a, and 9. The 6-deoxy-L-mannose derivatives were further characterized by their so-called hydride numbers (HZ). The HZ of a compound is the number of >BH equivalents consumed, per

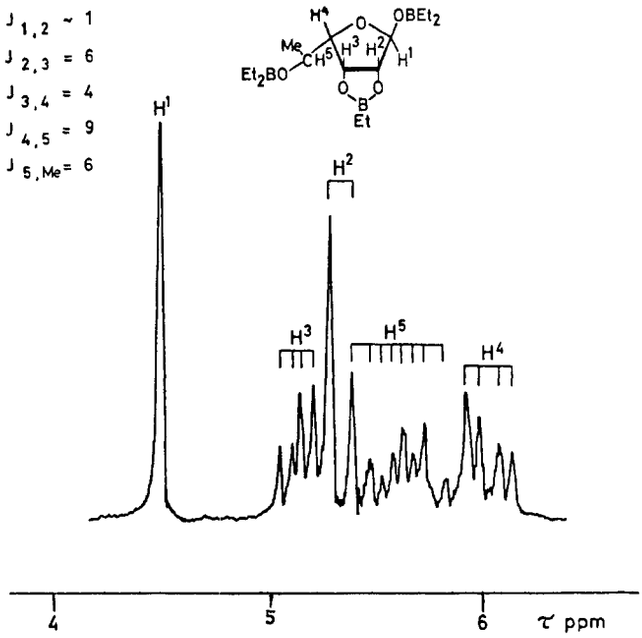


Figure 2. Ring proton region in the 60-MHz ^1H NMR spectrum of 6-deoxy-1,5-bis-O-diethylboryl-2,3-O-ethylboranediyl-α-L-mannofuranose (**3a**) in CCl_4.

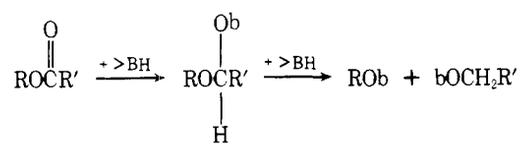
mole of compound, on reaction with an excess of propyldiborane(6) at 130 °C. This HZ consists of the two parts HZ_{gas} and HZ_{red}:

$$HZ_{gas} = \frac{\text{mol of } H_2 \text{ evolved}}{\text{mol of compd}} \text{ (O-dipropylborylation)}$$

$$HZ_{red} = \frac{\text{mol of BH reducing}}{\text{mol of compd}} \text{ (hydroboration)}$$

The values found using propyldiboranes(6), having hydride contents of 10–15‰ H^-, at 130 °C for ca. 3 h are listed in Table I. It is evident from the HZ_{red} values listed in Table I that all the compounds are quantitatively reduced to derivatives of 6-deoxy-L-mannitol.

The O-acyl containing derivatives **7** and **8a** have HZ_{red} = 5 and 9, respectively. This shows that, in addition to the sugar reduction, each O-acyl function reacts with exactly two >BH equivalents.



This method can be used to accurately determine O-acyl groups in a molecule and to deacylate O-acyl derivatives preparatively.[20]

G. Comparison of O-Ethylboranediyl with O-Isopropylidene Derivatives. At first, there appears to be close analogy between O-isopropylidene and O-ethylboranediyl derivatives. A closer critical comparison, however, reveals notable differences between these protective groups. Thus, for example, treatment of **1** with a 50- to 100-fold excess of acetone only results in the formation of 6-deoxy-2,3-O-isopropylidene-L-mannofuranose (**9**) in 50–68% yield.[9,10,21] The O-ethylboranediyl analogue **5**, on the other hand, is obtained in >95% yield by stoichiometric reaction of **1** with either BEPDIB or ethylboroxine. Addition of more BEPDIB or ethylboroxine immediately results in formation of the compound **4**. Yields of **4** and **5** are excellent, whereas only a moderate yield (65%) of **9** is obtained. This fact clearly demonstrates the versatility of the O-ethylboranediyl protective group, which is also capable of forming both intra- and intermolecular[2,16] linkages in yield of over 90%.

Table I. Hydride Numbers (HZ)[20] of the 6-Deoxy-L-mannose Derivatives (See Table II)

Compd	Registry no.	HZ_{gas}	HZ_{red}	HZ
1·H_2O	3615-41-6	6	1	7
3a	62930-51-2	0	1	1
4	62930-52-3	0	1	1
5	62930-53-4	2	1	3
7	62930-54-5	2	5	7
8a	62930-55-6	0	9	9
9	4926-05-0	2	1	3

Table II. Hydride Numbers (HZ)[20] of O-Derivatives of 6-Deoxy-L-mannose (1)

Compd no.	mg	mmol	>BH(H_2), mmol	$>BH_{red}$, mmol	$>BH_{total}$, mmol	HZ_{obsd}
1·H_2O	179.2	0.98	6.0	0.93	6.93	7.07
3a	300.3	0.89	0	0.93	0.93	1.04
4	260.5	1.09	0	1.13	1.13	1.04
5	315.2	1.56	3.2	1.69	4.89	3.13
7	403.9	1.73	3.48	9.0	12.48	7.21
8a	357.1	1.075	0	9.9	9.9	9.21
9	202.1	0.99	2.16	1.0	3.16	3.13

A further, possibly more important, factor is that the O-ethylboranediyl group can be removed under mild, neutral conditions. Whereas both 1,5-di-O-benzoyl-[10] and 1,5-di-O-methyl-2,3-O-isopropylidene-L-rhamnofuranose[22] can be prepared, the removal of the O-isopropylidene protective group requires acidic conditions and hence the 1,5-O-derivatives are not obtained. Instead, the labile O^1 substituents are lost and one obtains 5-O-benzoyl-[10] and 5-O-methyl-L-rhamnofuranose.[22] As O-acetyl groups are less stable toward acids than either O-benzoyl or O-methyl groups, it is noteworthy that 1,5-di-O-acetyl-α-L-rhamnofuranose (**7**) is obtained in good yield. This demonstrates the advantage of having a protective group, which can be removed under mild conditions.

Experimental Section

General. All experiments were carried out in dry, deoxygenated solvents under an atmosphere of argon.

Analyses. The purity of **4** and **6** was determined gas chromatographically[23] with a Carlo Erba (50-m column, OV 101). The ^1H NMR[24] and mass spectra[25] were obtained using the Varian A-60 or HA-100 and Varian MAT CH5 spectrometers, respectively. ^{13}C NMR spectra[26] were recorded at 25.2 MHz using a Varian XL-100-15 spectrometer with Me_4Si as an internal standard (deshielding $\delta > 0$). ^{11}B NMR spectra[26] were obtained with the latter instrument at 32.1 MHz with Et_2O–BF_3 as an external standard (deshielding $\delta > 0$). Optical rotations were measured using a OLD 5 from Carl Zeiss. Boron was determined by flame photometry of methanol solutions with a M4QIII. The B_C values were obtained using anhydrous trimethylamine N-oxide in boiling benzene.[27] C,H analyses were carried out by Dornis and Kolbe, Mülheim-Ruhr. The hydroxy groups were determined using activated triethylborane.[7,13]

Reagents. 6-Deoxy-L-mannose (**1**) was obtained from the monohydrate (Senn Chemicals, Switzerland) (found HZ = 7.1, see Table II) by dehydration in vacuo at 100 °C. 6-Deoxy-2,3-O-isopropylidene-L-mannose (**9**) was prepared by the acid-catalyzed condensation of **1** with acetone.[10,21] Triethylborane,[28] diethylboryl pivalate,[7] bis(ethylpivaloyloxy)diboroxane,[7,29] and ethylboroxine[30] have been synthesized in our pilot plant and laboratory, respectively.

Preparation. A. Ethylboroxine (from triethylborane and diboron trioxide). Triethylborane (147 g, 1.5 mol) was added to anhydrous diboron trioxide (70 g, 1 mol) in an autoclave and the mixture was heated, with rolling, to 250 °C for 5 h. The autoclave was allowed to cool to room temperature and the contents were siphoned out by means of argon pressure. After distilling off the triethylborane in

vacuo, bp <25 °C (12 Torr), ethylboroxine (160 g, 95%) was obtained as a colorless liquid: bp 55 °C (12 Torr); ^{1}H NMR (60 MHz, neat) τ 9.16 (m).

Anal. Calcd for $C_6H_{15}B_3O_3$ (168.0): B, 19.3; B_C, 6.43. Found: B, 19.0; B_C, 6.39.

B. 6-Deoxy-1,2,3,4-tetrakis-*O*-diethylboryl-α-L-mannopyranose (2a). From 1·H$_2$O with Activated Triethylborane. Triethylborane (64.4 g, 0.66 mol), activated by 0.5 mL of diethylboryl pivalate, is added dropwise (3 h) to 1·H$_2$O (20 g, 0.11 mol) in heptane (100 mL). Ethane (14.9 nL) is evolved. The heptane is removed in vacuo to give **2a** (47 g, 98%) as colorless liquid residue: MS (70 eV) no M$^+$, found *m/e* 407 (B_4, rel intensity ~1), 351 (B_3, 15), 253 (B_2, 17), 209 (B_2, 42), 83 (B_0, 100); ^{1}H NMR (100 MHz, neat) τ 4.70 (d, $J_{1,2}$ ~ 1 Hz, H^1), 5.35 (dd, $J_{2,3}$ = 2.5, $J_{3,4}$ = 9 Hz, H^3), [5.65 (t, $J_{3,4}$ = 9, $J_{4,5}$ = 9 Hz, H^4), 5.69 (dd, $J_{1,2}$ = 1, $J_{2,3}$ = 2.5 Hz, H^2)], 6.08 (dq, $J_{4,5}$ = 9, $J_{5,Me}$ = 6 Hz, H^5), 8.85 (d, $J_{5,Me}$ = 6 Hz, CMe), 9.13 (m, BEt) in the ratio 1:1:2:1:3:40, small signal at 4.95 (br s, H^1 of **2b**).

Anal. Calcd. for $C_{22}H_{48}B_4O_5$ (435.9): B, 9.92; B_C, 6.6. Found: B, 9.95; B_C, 6.41.

With Ethyldiborane(6) (elimination of triethylborane). A mixture of **2a** (16.3 g, 37.4 mmol) and ethyldiborane (2 g, 25.56‰ H$^-$, 52.1 mmol) is stirred for 3 h at room temperature. All volatile components are then removed in vacuo and further distillation yielded a mixture (8.8 g) with bp 90 °C (10^{-3} Torr) consisting of ~60% **3a**, 10% **4**, and equal amounts of three further isomers **3b–d** (^{1}H NMR). Viscous residue (3.9 g) remained after the distillation: ^{1}H NMR (100 MHz, CCl_4) τ 4.24 (d, $J_{1,2}$ = 5 Hz, H^1 of **4**), 4.38 (br s, H^1 **3a**), 4.50 (br s, H^1 **3b**), 4.70 (br s, H^1 **3d**), 4.99 (br s, H^1 **3c**), 5.2–6.3 (m), 8.77 (d, $J_{5,Me}$ = 6 Hz, CMe), 9.10 (m, BEt) in the ratio 0.1:0.1:0.6:0.1:0.1:5:3.3:23.7.

C. *O*-Ethylboron Derivatives 3a, 4, and 5. 6-Deoxy-1,5-bis-*O*-diethylboryl-2,3-*O*-ethylboranediyl-α-L-mannofuranose (3a). From 5 with Activated Triethylborane. Triethylborane (10.5 g, 107 mmol), which was activated by 0.1 mL of diethylboryl pivalate, was added dropwise (40 min) to **5** (5.7 g, 28.2 mmol) in heptane (20 mL). Ethane (1.3 nL) was evolved. The excess triethylborane and heptane were removed in vacuo and the residue was distilled to give colorless **3a** (8.4 g, 88%): bp 92–95 °C (10^{-3} Torr); $[\alpha]^{20}_D$ −1.8° (*c* 4, CCl_4); ^{1}H NMR (100 MHz, CCl_4) (Figure 2) τ 4.53 (s, $J_{1,2}$ = 1 Hz, H^1), 5.17 (dd, $J_{2,3}$ = 6, $J_{3,4}$ = 4 Hz, H^3), 5.36 (d, $J_{2,3}$ = 6 Hz, H^2), 5.65 (dq, $J_{4,5}$ = 9, $J_{5,Me}$ = 6 Hz, H^5), 6.06 (dd, $J_{3,4}$ = 4, $J_{4,5}$ = 9 Hz, H^4), 8.76 (d, $J_{5,Me}$ = 6 Hz, C^5_{Me}), 9.10 (m, BEt) in the ratio 1:1:1:1:1:3:25; ^{11}B NMR (CH_3CN) δ 35.2 ± 1 (half-width ~ 750 Hz), 54.1 ± 1 ppm (half-width ~ 600 Hz) in the ratio 1:2.

Anal. Calcd for $C_{16}H_{33}B_3O_5$ (337.8): B, 9.60; B_C, 5.33. Found: B, 9.45; B_C, 5.20; HZ^{20} = 1.04.

With Methanol. Methanol (5 mL) is added dropwise in 3 min to a solution of **3a** (3.4 g, 10.1 mmol) in hexane (20 mL). After removal of the volatile components in vacuo (12 Torr) **5** (2 g, 98%) was obtained as residue.

6-Deoxy-1,2:3,5-bis-*O*-ethylboranediyl-β-L-mannofuranose (4). Route IV (1 and ethylboroxine in the ratio 3:2). Ethylboroxine (5.3 g, 31.5 mmol) was added to a stirred suspension of **1** (4.1 g, 25 mmol) in benzene (25 mL) and the benzene/water azeotrope was distilled off. The remaining benzene was removed in vacuo and **4** (5.4 g, 92%), bp 76–78 °C (10^{-3} Torr), was obtained.

Route V (1 and BEPDIB in the ratio 1:1). A solution of BEPDIB (7.4 g, 24.8 mmol) in benzene (15 mL) was added dropwise to a stirred solution of **1** (4.1 g, 25 mmol) in pyridine (10 mL) in 10 min at room temperature. The volatile components were removed in vacuo and after distillation of the residue colorless **4** (5.7 g, 96%) 99% pure (GLC) was obtained: bp 77–78 °C (10^{-3} Torr); $[\alpha]^{20}_D$ −10.2° (*c* 2.9, CCl_4).

Route VI (5 and ethylboroxine). Ethylboroxine (3 g, 20.2 mmol) was added to **5** (4.4 g, 21.8 mmol) in benzene (20 mL) and the benzene/water azeotrope was distilled off. After removal of the remaining benzene in vacuo, **4** (4.8 g, 92%) was obtained; bp 75 °C (10^{-3} Torr); MS (70 eV) M$^+$ 240 (B_2, rel intensity ~1), 167 (B_2, 17), 140 (B_1, 32), 111 (B_1, 100); ^{1}H NMR (100 MHz, CCl_4) (Figure 1) τ 4.24 (d, $J_{1,2}$ = 5 Hz, H^1), 5.30 (t, $J_{1,2}$ = 5, $J_{2,3}$ = 5 Hz, H^3), 5.65 (t, $J_{2,3}$ = 5, $J_{3,4}$ = 5 Hz, H^2), 6.09 (oct, $J_{4,5}$ = 5, $J_{5,Me}$ = 6.5 Hz, H^5), 6.25 (t, $J_{3,4}$ = 5, $J_{4,5}$ = 5 Hz, H^4), 8.73 (d, $J_{5,Me}$ = 6.5 Hz, Me), 9.1 (m, BEt) in the ratio 1:1:1:1:3:10; ^{13}C NMR (Me_2SO-d_6) δ 105.0 (C^1), 68.3 (C^2), 80.7 (C^3), 78.7 (C^4), 66.9 (C^5), 20.7 (CH_3), 2.9 (BCH_2CH_3), 7.73 and 7.47 (BCH_2CH_3).

Anal. Calcd for $C_{10}H_{18}B_2O_5$ (239.9): B, 9.01; B_C, 3.00. Found: B, 8.90; B_C, 2.97; HZ^{20} = 1.04.

6-Deoxy-2,3-*O*-ethylboranediyl-α-L-mannofuranose (5). Route I (1 and ethylboroxine in the ratio 3:1). Ethylboroxine (7.1 g, 42.3 mmol) was added to a stirred suspension of **1** (20.8 g, 126.7 mmol) in benzene (70 mL) and the benzene/water azeotropic mixture was distilled off. The remaining benzene was removed in vacuo, leaving **5** (24.4 g, 95%) as residue.

Route II (1 and BEPDIB in the ratio 2:1). A solution of BEPDIB (4.9 g, 16.4 mmol) in benzene (20 mL) was added dropwise to a stirred solution of **1** (5.4 g, 32.8 mmol) in pyridine (20 mL) at room temperature. The reaction mixture was concentrated in vacuo to give **5** (6.4 g, 98%) as residue, $[\alpha]^{20}_D$ 4.7° (*c* 7, Me_2SO).

Route III (5 from 4 with methanol). Three portions of a methanol/hexane mixture (~10 mL, 1:1 mixture) were added to **4** (3.6 g, 15 mmol) and after stirring for 10 min at room temperature the dimethoxyethylborane, methanol, and hexane mixtures (6.5 g with 1.23% B, 5.8 g with 0.68% B, and 6.6 g with 0.53% B) were removed in vacuo (12 Torr). **5** (3 g, 99%) was obtained as a residue: ^{1}H NMR (100 MHz, Me_2SO-d_6) τ 3.60 (d, $J_{1,OH}$ = 4.5 Hz, C^{1}OH), 4.83 (d, $J_{1,OH}$ = 4.5 Hz, H^1), 5.07 (dd, $J_{2,3}$ = 6, $J_{3,4}$ = 4 Hz, H^3), 5.39 (d, $J_{2,3}$ = 6 Hz, H^2), 5.4–6.4 (m, H^{4}H^5, C^5_{OH}), 8.83 (d, $J_{5,Me}$ = 5.5 Hz, C^5_{Me}), 9.1 (m, BEt) in the ratio 1:1:2:3:3:5; ^{13}C NMR (Me_2SO-d_6) δ 21.2 (Me), 63.3, 80.0, 83.3, 85.6, 100.7 (C^1), 7.6 (BCH_2CH_3), 1.7 (BCH_2CH_3).

Anal. Calcd for $C_8H_{15}BO_5$ (202.0): B, 5.35; B_C, 1.78; H$^+$, 0.99. Found: B, 5.26; B_C, 1.80; H$^+$, 1.05; HZ^{20} = 3.1.

Pyrolysis of 5 to 1 and 4 (conversion ~43%). 1a (4.8 g, 23.8 mmol) was heated to 130 °C (bath temp) in vacuo (10^{-3} Torr) and a mixture of **5** and **4**, 2.6 g with 0.57% H$^+$, 57% **5**, and 43% **4** conversion (^{1}H NMR) with bp 58–65 °C (10^{-3} Torr), distilled over. Crude **1** (1.0 g, 51% with 2.25% H$^+$) was obtained as a residue.

5 from 1 and 4. A mixture of **1** (1.2 g, 7.1 mmol) and **4** (1.7 g, 7.1 mmol) was dissolved in a benzene (10 mL)/pyridine (5 mL) mixture by heating to 80 °C for 10 min. The solvents were removed in vacuo, leaving **5** (2.8 g, 98%) as residue (^{1}H NMR).

D. O-Acylation of 5. 6-Deoxy-1,5-di-*O*-acetyl-2,3-*O*-ethylboranediyl-α-L-mannofuranose (6). Acetic anhydride (20 mL) was added dropwise in 40 min to a stirred solution of **5** (5.8 g, 28.7 mmol) in pyridine (20 mL) at 0 °C. The mixture was stirred for 20 min at room temperature and concentrated in vacuo. Distillation yielded 89% (GLC) **6** (7.6 g, 93%): bp 106 °C (10^{-3} Torr); $[\alpha]^{20}_D$ 59.2° (*c* 2.3, CCl_4); ^{1}H NMR (100 MHz, CCl_4) τ 3.93 (s, $J_{1,2}$ ~ 1 Hz, H^1), 5.0 (m, $J_{4,5}$ = 7.5, $J_{5,Me}$ = 6 Hz, H^5), 5.12 (dd, $J_{2,3}$ = 6, $J_{3,4}$ = 4 Hz, H^3), 5.28 (d, $J_{2,3}$ = 6 Hz, H^2) 6.00 (dd, $J_{4,5}$ = 7.5, $J_{3,4}$ = 4 Hz, H^4), 7.99 (s, C^{5}OAc), 8.03 (s, C^{1}OAc), 8.72 (d, $J_{5,Me}$ = 6 Hz, C^{5}Me), 9.15 (m, BEt) in the ratio 1:2:1:1:6:3:5.

Anal. Calcd for $C_{12}H_{19}BO_7$ (286.1): B_C, 1.26. Found: B_C, 1.21.

6-Deoxy-1,5-di-*O*-acetyl-α-L-mannofuranose (7). 7 from 6 with Ethane-1,2-diol. Ethane-1,2-diol (ca. 5 mL) was added twice to **6** (1.7 g, 5.9 mmol) and the mixture was evaporated to dryness in vacuo (10^{-3} Torr). Crude **4** (1.1 g, 75%), mp 85 °C, was obtained. Pure **7** is obtained after recrystallization from ethanol: mp 127 °C; $[\alpha]^{20}_D$ −80° (*c* 1, Me_2SO); ^{1}H NMR (60 MHz, Me_2SO-d_6) τ 4.09 (d, $J_{1,2}$ = 2 Hz, H^1), 4.8–5.1 (m), 5.9 (m), 6.3–6.7 (m), 7.95 (s, OAc), 8.02 (s, OAc), 8.81 (d, $J_{5,Me}$ = 6.5 Hz) in the ratio 1:2:3:1:3:3:3.

Anal. Calcd for $C_{10}H_{16}O_7$ (248.2): C, 48.39; H, 6.50; H$^+$, 0.81. Found: C, 48.42; H, 6.47; H$^+$, 0.83; HZ^{20} = 7.2.

6-Deoxytetra-*O*-acetyl-α-L-mannofuranose (8a). From 4 with Acetic Anhydride. Acetic anhydride (5 mL) was added dropwise to **7** (0.5 g, 2 mmol) in pyridine (5 mL) at room temperature. The mixture was left overnight and the pyridine and acetic anhydride were removed in vacuo (10^{-3} Torr). The residue was crystallized by dissolving in ethanol (3 mL) and cooling to 0 °C and pure (GLC) **8a** (0.4 g, 60%) was obtained by filtration and drying in vacuo: mp 53 °C, $[\alpha]^{20}_D$ −101.7° (*c* 0.7, C_2H_5OH); MS (70 eV) no M$^+$, found *m/e* 273 (rel intensity 2), 245 (2), 170 (7), 157 (3), 143 (8), 43 (100); ^{1}H NMR (100 MHz, $CDCl_3$) τ 3.77 (d, $J_{1,2}$ = 3.5 Hz, H^1), 4.38 (dd, $J_{2,3}$ = 5, $J_{3,4}$ = 4 Hz, H^3), 4.63 (dd, $J_{1,2}$ = 3.5, $J_{2,3}$ = 5 Hz, H^2), 4.86 (dq, $J_{4,5}$ = 9, $J_{5,Me}$ = 6 Hz, H^5), 5.75 (dd, $J_{3,4}$ = 4, $J_{4,5}$ = 9 Hz, H^4), 7.91 (s, OAc), 7.95 (s, 2 OAc), 8.03 (s, OAc), 8.68 (d, $J_{5,Me}$ = 6 Hz, C^5_{Me}) in the ratio 1:1:1:1:9:3:3.

Anal. Calcd for $C_{14}H_{20}O_9$ (332.3): C, 50.60; H, 6.07. Found: C, 50.90; H, 6.13; HZ^{20} = 9.2.

6-Deoxy-1,5-di-*O*-acetyl-2,3-di-*O*-benzoyl-α-L-mannofuranose (8b). From 7 with Benzoyl Chloride. Benzoyl chloride (2.4 g, 16.8 mmol) was added dropwise in 15 min to a stirred solution of **7** (1.9 g, 7.66 mmol) in pyridine (5 mL) at 0 °C. The mixture was then stirred for 2 h at room temperature. Water (20 mL) was added and the product was extracted with diethyl ether (two 20-mL portions). Pure needles of **8b** (2.4 g, 69%) were obtained after filtration and vacuum drying: mp 158 °C, $[\alpha]^{20}_D$ −41.8° (*c* 1.6, $CHCl_3$); ^{1}H NMR (100 MHz, $CDCl_3$) τ [2.13 (m), 2.65 (m), COPh], 3.54 (d, $J_{1,2}$ = 2.5 Hz, H^1), 3.97 (dd, $J_{2,3}$ = 5.5, $J_{3,4}$ = 4.5 Hz, H^3), 4.29 (dd, $J_{1,2}$ = 2.5, $J_{2,3}$ = 5.5 Hz, H^2), 4.72 (dq, $J_{4,5}$ = 8.5, $J_{5,Me}$ = 6 Hz, H^5), 5.44 (dd, $J_{3,4}$ = 4.5, $J_{4,5}$ = 8.5 Hz, H^4), 7.88 (s, C^{1}OAc), 8.20 (s, C^{5}OAc), 8.60 (d, $J_{5,Me}$ = 6 Hz, CMe) in the ratio [4:6] 1:1:1:1:1:3:3:3.

Anal. Calcd for $C_{24}H_{24}O_9$ (456.4): C, 63.15; H, 5.30. Found: C, 63.30; H, 5.05.

E. *O*-Ethylboranediyl Derivative (10) of 6-Deoxy-2,3-isopropylidene-L-mannofuranose (9). 6-Deoxy-1,5-*O*-ethylboranediyl-2,3-*O*-isopropylidene-β-L-mannofuranose (10) from 9 and Ethylboroxine. Ethylboroxine (5 g, 16.7 mmol) was added to **9** (2.9 g, 14.2 mmol) in toluene (20 mL) and the azeotropic mixture of water/toluene was distilled off. The remaining toluene was removed in vacuo (10^{-3} Torr) and the residue was distilled to give **10** (2.6 g, 77%): bp 68 °C (10^{-3} Torr), $[\alpha]^{20}_D$ 39.7° (*c* 3.7, CCl_4); 0.8 g residue; MS (70 eV) M^+ 242 (B_1, rel intensity ~ 1), 227 (B_1, 16), 138 (B_1, 37), 111 (B_1, 100); ^1H NMR (100 MHz, CCl_4) τ 4.99 (br s, half-width = 2.5 Hz, H^1), 5.35 (ddd, $J_{2,3}$ = 7.5, $J_{3,4}$ = 3.5, $J_{3,5}$ = 1.5 Hz, H^3), 5.73 (dd, $J_{1,2}$ = 1.5, $J_{2,3}$ = 7.5, H^2), 5.75 (dq, $J_{3,5}$ = 1.5, $J_{5,Me}$ = 7, H^5), 6.00 (d, $J_{3,4}$ = 3.5 Hz, H^4), 8.55 (s, CMe), 8.65 (d, $J_{5,Me}$ = 7 Hz, $C^5{}_{Me}$), 8.70 (s, CMe), 9.16–9.34 (m, BEt) in the ratio 1:1:2:1:9:5.

Anal. Calcd for $C_{11}H_{19}BO_5$ (242.0): B, 4.47. Found: B, 4.38.

9 from 10 with Methanol. Two 5-mL portions of methanol were added to **10** (1.8 g, 7.4 mmol) and the dimethoxyethylborane/methanol mixture was removed in vacuo (0.1 Torr), leaving **9** (1.45 g, 96%) as residue: mp (from ether/hexane) 87 °C, $[\alpha]^{20}_D$ 17.8° (*c* 2.9, H_2O); found HZ^{20} = 3.19.

F. Determinations of Hydride Numbers (HZ). The hydride numbers (HZ) were obtained by heating the compounds, listed in Table II, to 130 °C for ~3 h with an excess of propyldiborane(6) having 11–15‰ H^-.[20] The volume of hydrogen, evolved after each determination, was measured after cooling to room temperature, and the excess >BH remaining after reaction was then determined volumetrically by addition of 2-ethylhexanol.

Registry No.—2a, 62930-56-7; **3b,** 62930-57-8; **3c,** 62930-58-9; **3d,** 62930-59-0; **6,** 62930-60-3; **8b,** 62930-61-4; **10,** 62962-24-7; ethylboroxine, 3043-60-5; triethylborane, 97-94-9; diboron trioxide, 1303-86-2; ethyldiborane, 12081-54-8; dimethoxyethylborane, 7318-82-3; ethane-1,2-diol, 107-21-1; benzoyl chloride, 98-88-4.

References and Notes

(1) Part 44: L. A. Hagelee and R. Köster, *Synth. Inorg. Met.-Org. Chem.*, **7**, 53 (1977).
(2) W. V. Dahlhoff and R. Köster, *Justus Liebigs Ann. Chem.*, 1926 (1975).
(3) W. V. Dahlhoff, W. Schüßler, and R. Köster, *Justus Liebigs Ann. Chem.*, 387 (1976).
(4) W. V. Dahlhoff and R. Köster, *J. Org. Chem.*, **41**, 2316 (1976).
(5) R. Köster and W. V. Dahlhoff, *Justus Liebigs Ann. Chem.*, 1925 (1976).
(6) R. C. G. Killean, J. L. Lawrence, and V. C. Sharma, *Acta Crystallogr., Sect. B*, **27**, 1707 (1971).
(7) R. Köster, H. Bellut, and W. Fenzl, *Justus Liebigs Ann. Chem.*, 54 (1974).
(8) R. Köster and P. Binger, *Inorg. Synth.*, **15**, 141 (1974).
(9) E. Fischer, *Ber.*, **28**, 1145 (1895).
(10) B. R. Baker and K. Hewson, *J. Org. Chem.*, **22**, 966 (1957).
(11) R. Köster, K.-L. Amen, and W. V. Dahlhoff, *Justus Liebigs Ann. Chem.*, 752 (1975).
(12) E. Hemmer and S. Liaaen-Jensen, *Acta Chem. Scand.*, **24**, 3019 (1970).
(13) W. V. Dahlhoff and R. Köster, *Justus Liebigs Ann. Chem.*, 1625 (1975).
(14) B. Casu and M. Reggiani, *Tetrahedron*, **22**, 3069 (1966).
(15) A. S. Perlin, *Can. J. Chem.*, **42**, 1365 (1964).
(16) (a) R. Köster and W. V. Dahlhoff, *ACS Symp. Ser.*, **39**, 1 (1976); (b) R. Köster, IMEBORON III, München-Ettal, 1976, IUPAC Proceedings, in press.
(17) W. V. Dahlhoff and R. Köster, unpublished results.
(18) A. S. Perlin, *Can. J. Chem.*, **44**, 539 (1966).
(19) R. L. Whistler and J. N. BeMiller, *Methods Carbohydr. Chem.*, **6**, 530 (1972).
(20) HZ (hydridzahl) = hydride number, determined with propyldiborane(6) at 130 °C; R. Köster and W. Schüßler, unpublished results.
(21) J. N. Baxter and A. S. Perlin, *Can. J. Chem.*, **38**, 2217 (1960).
(22) K. Freudenberg and A. Wolf, *Ber.*, **59**, 836 (1926).
(23) G. Schomburg and F. Sagheb, Max-Planck-Institut für Kohlenforschung, Mülheim-Ruhr.
(24) E. G. Hoffmann and G. Schroth, Max-Planck-Institut für Kohlenforschung, Mülheim-Ruhr.
(25) D. Henneberg, Max-Planck-Institut für Kohlenforschung, Mülheim-Ruhr.
(26) R. Mynott, Max-Planck-Institut für Kohlenforschung, Mülheim-Ruhr.
(27) R. Köster and Y. Morita, *Justus Liebigs Ann. Chem.*, **704**, 70 (1967).
(28) R. Köster, P. Binger, and W. V. Dahlhoff, *Synth. Inorg. Met.-Org. Chem.*, **3**, 359 (1973).
(29) R. Köster and A.-A. Pourzal, *Synthesis*, 674 (1973).
(30) R. Köster, *Justus Liebigs Ann. Chem.*, **618**, 31 (1958), using the method for the preparation of methyl boroxine, described by J. Goubeau and H. Keller, *Z. Anorg. Allg. Chem.*, **267**, 16 (1951).

Diterpenes from *Dolabella californica*

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Fourteen diterpenes have been isolated from the digestive gland of the opisthobranch mollusc *Dolabella californica*. Twelve of the diterpenes have been related through a series of chemical conversions to a compound whose structure was previously determined by x-ray analysis. The structure of the remaining compound was determined by analysis of spectroscopic data. The configurations of ten of the new diterpenes were determined by the LIS method. The compounds are all based on the dolabellane skeleton, which contains an 11-membered ring fused to a five-membered ring.

We have previously shown[1] that the digestive gland of the sea hare *Aplysia californica* contained a variety of interesting halogenated metabolites which were found to be of dietary origin.[2] Two collections of *Dolbella californica* (Sterns),[3] a related anaspidean opisthobranch mollusc, have yielded a number of diterpenes, all of which have the same novel carbon skeleton. One of the diterpenes was shown by x-ray analysis[4] to have the structure **2** and was named 10-acetoxy-18-hydroxy-2,7-dolabelladiene. We wish to report the structural determinations of the remaining diterpenes isolated from the digestive gland of *D. californica*.

The two collections of *D. californica* were made at Isla Espiritu Santo in April 1975 and March 1976. The acetone extracts of the digestive glands were chromatographed on Florisil. Rechromatography of selected fractions on silica gel gave 6 compounds from the first collection and 12 compounds from the second collection, four compounds being found in both collections. Details of the composition of the two collections, together with the molecular formulas and melting points, are shown in Table I.

An initial examination of the molecular formulas, infrared spectra, and ^1H NMR spectra (Table II) revealed that we had isolated a series of very similar compounds which differed primarily in the numbers and positions of acetate and hydroxyl groups. By reduction of the acetates to alcohols using lithium aluminum hydride in ether, we were able to relate each compound to one of four alcohols. The diacetate **1** and monoacetate **2** were both converted to the diol **3**; the triacetate **4**, three diacetates **5–7**, and a monoacetate **8** were all reduced to triol **9**; the diacetate **10** and two monoacetates **11** and **12** were related to an isomeric triol **13**; the remaining compound was an alcohol **14**.

The monoacetate **2** was the major crystalline constituent of the first collection. The molecular formula $C_{22}H_{36}O_3$, to-