Department of Health, Education, and Welfare for a Graduate Professional Opportunities Program Fellowship (to S.S.H.) which helped make this work possible.

Registry No. *trans,trans*-2,2,8,8-tetramethylnona-3,6-dien-5-one, 73838-78-5; *trans,trans*-trideca-5,8-dien-7-one, 73838-79-6; *trans,trans*-1,5-diphenylpenta-1,4-dien-3-one, 35225-79-7; *trans,trans*-2,2,4,6,8,8-hexamethylnona-3,6-dien-5-one, 73838-80-9; *trans,trans*-1,5-bis(1-cyclohexenyl)penta-1,4-dien-3-one, 73838-81-0; *trans,trans*-2,8-dimethylnona-1,3,6,8-tetraen-5-one, 73838-82-1; 1,4-pentadien-3-one, 1890-28-4; *trans,trans*-1,5-dichloropenta-1,4-dien-3-one, 73838-83-2; benzophenone, 119-61-9; 2,2'-dinaphthyl ketone, 613-56-9; 2,2'-dithienyl ketone, 704-38-1; 3,3'-dinitrobenzophenone, 21222-05-9; *trans*-3,3-dimethyl-1-butenylmercuric chloride, 36525-02-7; *trans*-1-hexenylmercuric chloride, 50874-36-7; *trans*-2-phenylethenylmercuric chloride, 36525-03-8; *trans*-1,3,3-trimethyl-1-butenylmercuric chloride, 38010-69-4; *trans*-2-(1-cyclohexenyl)ethenylmercuric chloride, 56453-89-5; *trans*-3-methyl-1,3-butadienylmercuric chloride, 56453-81-7; ethenylmercuric chloride, 762-55-0; *trans*-2-chloroethenylmercuric chloride, 1190-78-9; phenylmercuric chloride, 100-56-1; 2-naphthylmercuric chloride, 39966-41-1; 2-thienylmercuric chloride, 5857-39-6; 3-nitrophenylmercuric chloride, 2865-17-0; CO, 630-08-0; bis(3,3-dimethyl-1-butynyl)mercury, 73838-84-3; 2,2,7,7-tetramethyl-3,5-octadiyne, 6130-98-9.

Acyclic Stereoselection. 9. Stereochemistry of the Addition of Lithium Enolates to α-Alkoxy Aldehydes[1]

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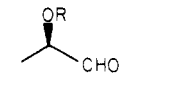
The stereochemistry of addition of lithium enolates derived from esters and ketones to the α-alkoxy aldehydes **1–5** has been investigated. In all cases, the predominant product is that predicted by application of Felkin's model for asymmetric induction and by assuming the alkoxy group to be the "large" group. The Cram cyclic model for asymmetric induction is *not* followed. Stereostructures have been assigned by a combination of conversion to products of known stereostructure, ^{13}C and ^{1}H NMR correlations, and single-crystal X-ray analysis.

Any program aimed at the total synthesis of macrolide antibiotics or polyether ionophores using stereoselective aldol condensations[1] must confront the problem of diastereoface selectivity in additions to chiral α-alkoxy aldehydes (relative asymmetric induction).[2] To examine this question, we have studied the additions of several lithium enolates to the α-alkoxy aldehydes **1–5**. The carbonyl compounds which have been utilized are ketones **6–9** and esters **10–13** (Chart I).

The preparation of α-alkoxy aldehydes was accomplished as follows. Aldehydes **1–3** were prepared in racemic form by ozonolysis of ethers **14–16**. The *R* enantiomer of **4** was prepared from D-mannitol by the method of Baer and Fischer.[3] Aldehyde **5**[4] was prepared in racemic form by the route outlined in Scheme I. Condensation of the known[5] dioxolanone **17** with propionaldehyde affords adduct **18** as a 70:30 mixture of diastereomers. After hydrolytic removal of the isopropylidine group, the major erythro[6] dihydroxy acid may be obtained by crystallization. The overall yield of crystalline **19**[7] is 30% from dioxolanone **17**. Although this synthesis of Bergel'son's



14, R = *t*-BuMe$_2$Si
15, R = $C_6H_5CH_2$-
16, R = $C_6H_5CH_2OCH_2$-

Chart I

1, R = *t*-BuMe$_2$Si
2, R = $C_6H_5CH_2$
3, R = $C_6H_5CH_2OCH_2$

4 **5**

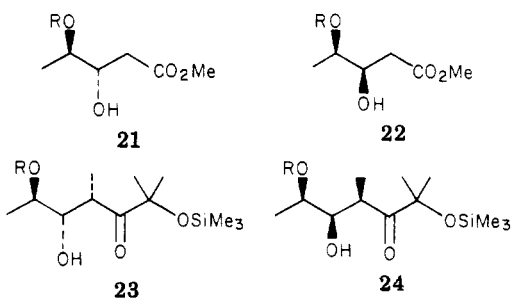
6, R = H
7, R = CH_3

8, R = H
9, R = CH_3

10, R = H
11, R = CH_3

12, R = H
13, R = CH_3

Chart II[a]



21 **22**

23 **24**

[a] **a**, R = *t*-BuMe$_2$Si; **b**, R = $C_6H_5CH_2$; **c**, R = $C_6H_5CH_2OCH_2$.

(1) For paper 8, see: C. H. Heathcock and M. C. Pirrung, *J. Org. Chem.*, **45**, 1727 (1980).
(2) P. A. Bartlett, *Tetrahedron*, **36**, 2 (1980).
(3) (a) E. Baer and H. O. L. Fischer, *J. Biol. Chem.*, **128**, 463 (1939); (b) E. Baer, *J. Am. Chem. Soc.*, **67**, 338 (1975); (c) D. Horton, J. B. Hughes, and J. K. Thomson, *J. Org. Chem.*, **33**, 728 (1968).
(4) J. Inananga, A. Takeda, N. Okukado, and M. Yamaquchi, *Mem. Fac. Sci., Kyushi Univ., Ser. C*, **9**(2), 295 (1975).
(5) M. Farines and J. Soulier, *Bull. Soc. Chim. Fr.*, 332 (1970).
(6) It has been convenient for us to have a stereostructural nomenclature which is invariant of the nature of R and R' (eq 2). We prefer the prefixes erythro and threo and use them in the following sense: when the backbone of the aldol is written in an extended (zigzag) manner and the α-alkyl and β-hydroxy substituents both extend toward the viewer or away from the viewer, this is the erythro diastereomer.

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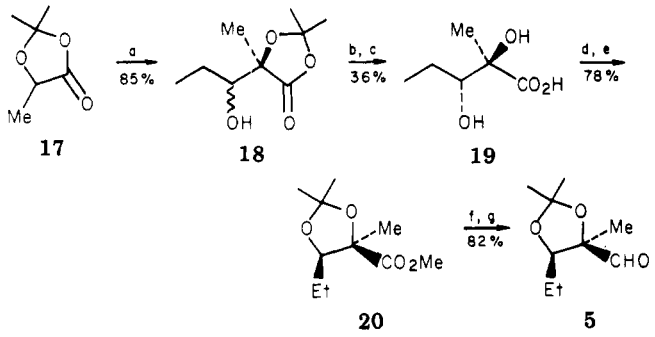
Scheme I[a]



17 18 19 20 5

[a] a, LDA, CH_3CH_2CHO, −78 °C; b, 4 M KOH, MeOH; c, fractional crystallization; d, MeOH, $ClCH_2CH_2Cl$, H_2SO_4, reflux 6 h; e, acetone, H_2SO_4, 20 °C, 2 h; f, LAH, Et_2O, 0 °C; g, PCC, CH_2Cl_2, 20 °C, 12 h.

Table I. Reaction of Aldehydes 1-3 with Ketone 9 and Ester 10

aldehyde	enolate precursor	product distribution, % 21	22	23	24
1	9			66	34
2	9			66	34
3	9			78	22
1	10	50	50		
2	10	50	50		
3	10	50	50		

Table II. ^{13}C NMR Chemical Shifts (ppm) of γ-Lactones

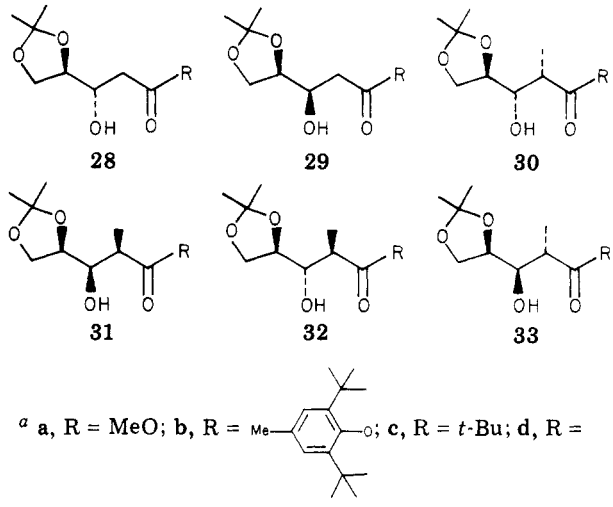
compd	C-2	C-3	C-4	C-5	C-2 methyl
25	43.8	80.1	80.3	17.9	12.4
26	43.3	75.1	78.3	13.7	12.9
43	43.2	73.1	84.6	60.0	12.5
44	39.1	70.1	86.9	60.9	8.3

acid is not stereospecific, it is a convenient method for preparing large amounts of this important intermediate and the derived dioxolane **20**, which have now been used in three macrolide total syntheses.[8] In fact, the overall yields (30% **19**, 24% **20**) are comparable to those obtainable by the other published procedures.[7,8b]

Results

Aldol condensations were carried out as previously described,[9] except that longer reaction times are required with certain combinations of reactants (see Experimental Section). Product mixtures were analyzed by ^{13}C NMR spectra of the crude products and in some cases by analytical high-pressure LC. Lactaldehyde ethers **1–3** were studied with methyl acetate (**10**) and the α-trimethylsiloxy ketone **9**.[9] In each case a mixture of two diastereomeric products was obtained, **21** and **22** (Chart II) from ester **10** and **23** and **24** from ketone **9**. Results are summarized in Table I. All three aldehydes show no diastereoselection with methyl acetate, equimolar mixtures of **21** and **22** being obtained in each case. Some selectivity is observed with the more sterically demanding enolate derived from ketone

Chart III[a]



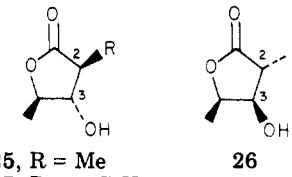
28 29 30 31 32 33

[a] a, R = MeO; b, R = ; c, R = *t*-Bu; d, R = $Me_2C(OH)$; e, R = $Me_2C(OSiMe_3)$.

Table III. Reaction of Aldehyde 4 with Ketones 6-9 and Esters 10-13

enolate precursor	product distribution, % 28	29	30	31	32	33
6	>95	<1				
7			85	15	0	0
8	66	34				
9			85	15	0	0
10	85	15				
11			60	0	40	0
12	66	34				
13			17	5	47	31

9. The **23**/**24** ratio is 2:1 for aldehydes **1** and **2** and about 3.5:1 for aldehyde **3**. Stereostructures were assigned to **23b** and **24b** and to **23c** and **24c** by oxidizing the mixtures with methanolic periodic acid[9] and subjecting the resulting acids to lithium/ammonia reduction to effect hydrogenolysis of the benzyl group. Acidification of the reduction products in each case afforded a separable mixture of lactones **25** and **26**. The major lactone was shown to have stereo-

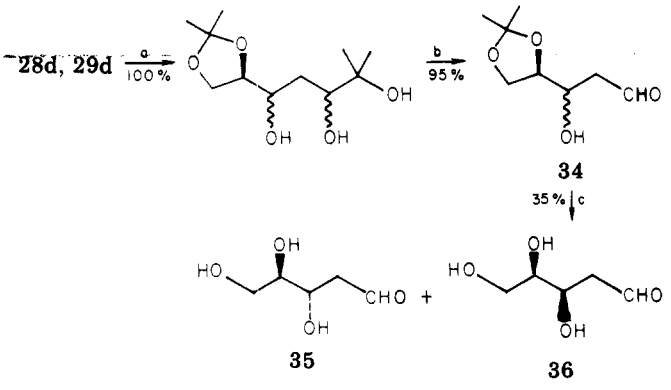


25, R = Me **26**
27, R = *n*-C_4H_9

structure **25** by comparison of its ^1H NMR spectrum with that of the known[10] lactone **27**. The most diagnostic feature in the spectrum of **25** is the resonance for the C-3 carbinol proton, which appears as a double doublet with J = 7.0 and 8.0 Hz. For lactone **27**, the relevant coupling constants are J = 7.0 and 8.5 Hz.[10] The ^{13}C NMR spectra of lactones **25** and **26** are also useful in confirming the assigned stereostructures; data are summarized in Table II. The relevant diagnostic resonance is that due to C-5. In the minor lactone **26** this carbon is shielded by 4.2 ppm by the *cis*-hydroxyl group at C-3. A similar shift is observed in the C-2 methyl resonances of lactones **43** and **44** (vide infra) and is precedented by the observation that the methyl resonance of *cis*-2-methylcyclopentanol is shifted 4.6 ppm upfield from the analogous resonance in *trans*-2-methylcyclopentanol.[11]

(7) L. D. Bergel'son, E. V. Dyatlovitskaya, M. Tichy, and V. V. Voronkova, *Izv. Akad. Nauk SSSR, Ser. Khim.*, **9**, 1612 (1962).
(8) (a) S. Masamune C. U. Kim, K. E. Wilson, G. O. Spessard, P. E. Georghiou, and G. S. Bates, *J. Am. Chem. Soc.*, **97**, 3512 (1975); (b) P. A. Grieco, Y. Ohfune, Y. Yokoyama, and W. Owens, *ibid.*, **101**, 4749 (1979); (c) J. Inanaga, T. Katsuki, S. Takimoto, S. Ouchida, A. Nakano, M. Aiga, N. Okukado, and M. Yamaguchi, Proceedings of the 21st Symposium on the Chemistry of Natural Products, Sapporo, Japan, 1978, 324.
(9) C. H. Heathcock, C. T. Buse, W. A. Kleschick, M. C. Pirrung, J. E. Sohn, and J. Lampe, *J. Org. Chem.*, **45**, 1066 (1980).
(10) M. Kinoshita, S. Aburaki, M. Wada, and S. Umezawa, *Bull. Chem. Soc. Jpn.*, **46**, 1279 (1973).

Scheme II[a]

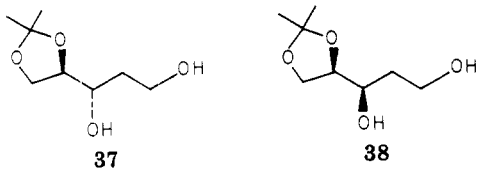


[a] a, $LiAlH_4$; b, $NaIO_4$, H_2O, EtOH, pH 6.0; c, 3:2 HOAc-H_2O.

Reactions of aldehyde 4 with all eight carbonyl compounds 6–13 were examined. The methyl ketones 6 and 8 and the acetates 10 and 12 give aldols 28 and 29 (Chart III). The ethyl carbonyl compounds 7, 9, 11, and 13 can each give rise to four diastereomeric adducts, 30–33. The product ratios which were observed in the eight reactions are summarized in Table III.

Stereostructures for adducts **28d** and **29d** (the trimethylsilyl group is lost in workup) were determined by conversion of the mixture into a 2:1 mixture of 2-deoxy-D-ribose (**35**) and 2-deoxy-D-lyxose (**36**) as is shown in Scheme II. A comparison mixture of **35** and **36** was prepared by addition of allylmagnesium bromide to **4**, followed by deprotection and ozonolysis of the resulting mixture of diastereomeric triols. The synthetic 2-deoxy-D-ribose was identified by comparison of its ^{13}C NMR spectrum with that published.[12] The overall yield for the three-step conversion outlined in Scheme II is 35%. Obviously, there is a danger that one of the diastereomers of the mixture of **28d** and **29d** may have reacted preferentially. However, since the ratio of **35** to **36** obtained was the same as the ratio of **28d** to **29d** we started with, we think that the structure proof is valid.

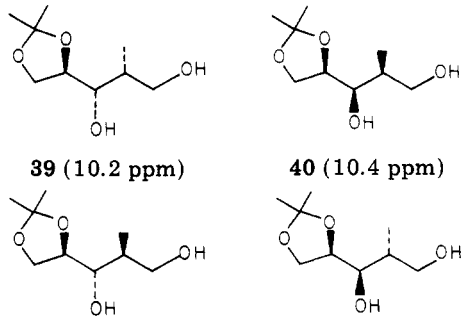
The mixture of adducts resulting from addition of esters **10** and **12** was reduced to a mixture of diols **37** and **38**,



37 **38**

which was compared by ^{13}C NMR with the 2:1 mixture of these diols produced by reduction of β-hydroxy aldehydes **34** (see Scheme II). Pinacolone (**6**) is the most selective reagent with aldehyde **4**; only a single crystalline aldol is produced. Although we have not rigorously proven its stereostructure, we tentatively assign it structure **28c** by analogy with the results obtained with the other reagents.

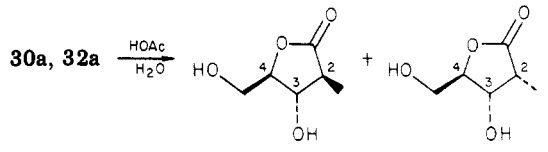
Stereostructural assignments for adducts **30–33** were more difficult. Fortunately, one reagent (ester **13**) gives all four possible products. This mixture of four β-hydroxy esters was separated by chromatography into threo (**32b**, **33b**) and erythro (**30b**, **31b**) fractions. Each fraction was then reduced to a mixture of diols, which show characteristic ^{13}C NMR chemical shifts for the C-4 methyl group (shown under appropriate structures). The 60:40 mixture of β-hydroxy esters (**30a** and **32a**) resulting from condensation of aldehyde **4** with methyl propionate was likewise reduced to give a 60:40 mixture of the 10.2 and 13.5-ppm diols (**39** and **41**). The stereostructures of aldols **30a** and



39 (10.2 ppm) **40** (10.4 ppm)

41 (13.5 ppm) **42** (14.2 ppm)

32a were rigorously established by conversion into the known[12] lactones **43** and **44**. Because the observed 2H, 3H coupling constants in **43** and **44** (8.9 and 5.9 Hz, respec-



43 **44**

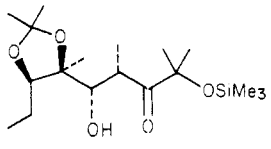
tively) are at variance with those reported for these lactones (2.6 and 7.1 Hz, respectively),[13] it is necessary to cite the other evidence in favor of the assigned stereostructures. First, the C-2 methyl resonances in the ^{13}C NMR spectra of aldols **30a** and **32a** occur at 10.1 and 14.0 ppm, respectively. We have previously shown[14] that this resonance in erythro aldols generally falls in the range 8–13 ppm, while in threo aldols it is generally in the range 13–18 ppm. Second, the ^{13}C NMR chemical shifts of the C-2 methyls of lactones **43** and **44** (Table II) clearly show that the methyl is cis to the C-3 hydroxyl in **44** and trans to it in **43**, thus confirming that **30a** is C-2, C-3 erythro and **32a** is C-2, C-3 threo. Third, the 2H, 3H coupling constants in the acetates of **43** and **44** agree in magnitude with the reported 2H, 3H coupling constants for the *p*-toluates of these lactones.[13]

With the stereostructures of **30a** and **32a** (and hence of diols **39** and **41**) rigorously established, it remains to confidently assign stereostructures to the 10.4- and 14.2-ppm diols. Three arguments are advanced in favor of the assigned structures. First, the ^{13}C NMR chemical shifts of the C-2 methyl groups in the four aldols resulting from ester **13** are as follows: **30b**, 9.1 ppm; **31b**, 9.1 ppm; **32b**, 14.6 ppm; **33b**, 12.5 ppm. We have previously shown that this resonance is of diagnostic value for assigning erythro or threo stereostructure to aldols,[14] with erythro aldols resonating at higher field than threo aldols. Although the normal ranges are 8–13 ppm for erythro and 13–18 ppm for threo aldols,[14] we have observed that 2,6-di-*tert*-butylaryl esters resonate about 1 ppm to higher field than methyl esters. By this criterion, the 47 and 31% products from ester **13** are C-2, C-3 threo, and the 17 and 5% products are C-2, C-3 erythro. Since the 47 and 17% products are related to diols **41** and **39**, the structures of which are rigorously defined (vide supra), then the 31% product must be the other threo isomer (**33b**) and the 5% isomer the other erythro isomer (**31b**). Second, esters such

(11) M. Christl, H. J. Reich, and J. D. Roberts, *J. Am. Chem. Soc.*, **93**, 3463 (1971).
(12) E. Breitmaier, G. Jung, and W. Voelter, *Chimia*, **26**, 136 (1972).
(13) J. J. K. Novák, *Collect. Czech. Chem. Commun.*, **39**, 869 (1974).
(14) C. H. Heathcock, M. C. Pirrung, and J. E. Sohn, *J. Org. Chem.*, **44**, 4294 (1979).

as **13** are known to be highly threo selective in their reactions with other aldehydes;[1] hence, the two major aldols should be **32b** and **33b**. Ketone **9** reacts with aldehyde **4** to give two major adducts in a 4.3:1 ratio along with 4% of a threo diastereomer. The mixture was converted into a mixture of β-hydroxy aldehydes (in the same manner as illustrated in Scheme II), which was reduced to give a 4:1 mixture of the 10.2- and 10.4-ppm diols. Since this reagent is known to be highly erythro selective,[9] these diols should be **39** and **40**. Since the stereostructure of **39** is rigorously established by its relationship to aldol **30a** and hence to lactone **43** (vide supra), the 10.4-ppm diol must be **40**.

The aldols obtained in a 6:1 ratio resulting from reaction of ethyl *tert*-butyl ketone with aldehyde **4** are assigned the erythro stereostructures **30c** and **31c**. These assignments were confirmed by the unambiguous synthesis of **30c**. Addition of *tert*-butyllithium to the 60:40 mixture of erythro and threo β-hydroxy esters **30a** and **32a** afforded aldols **30c** and **32c** in low yield. It should be noted that the minor isomer **31c** is an exception to our generalization that the α-methyl carbons of erythro aldols show ^{13}C NMR resonances in the range 8–13 ppm.[14] The analogous erythro isomer **31e** (13.7 ppm) is also an exception to this rule. It is possible that these two aldols exist in conformations which produce abnormal deshielding effects for some unknown reason. Aldehyde **5** reacts with ketone **9** to give two erythro adducts, **45** and **46**, in a ratio of 3:1.



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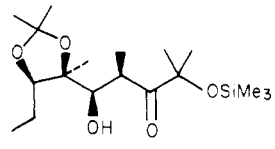

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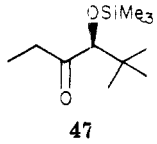
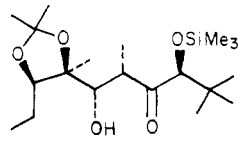
Reaction of aldehyde **5** with the racemic keto ether **47** was also examined.[15] A single crystalline diastereomer is produced, which was shown to have stereostructure **48** by

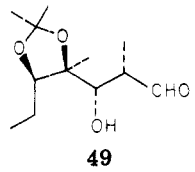


47



48

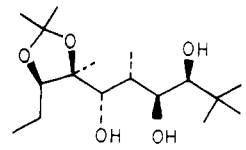
single-crystal X-ray analysis (Figure 1). Aldol **48** was shown to have the same relative stereochemistry at the relevant centers as the crystalline adduct **45**, the major product from the reaction of aldehyde **5** with ketone **9**. Reduction of **45** with lithium aluminum hydride gives a mixture of diols which is cleaved by sodium periodate in aqueous methanol to obtain β-hydroxy aldehyde **49**. The



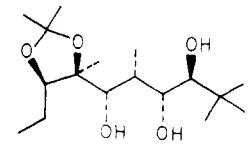
49

same aldehyde was prepared from aldol **48**. Reduction of **48** with lithium aluminum hydride, followed by desilylation with KF in methanol, affords a 5:1 mixture of triols **50** and **51**. Oxidation of the major diastereomer **50** affords aldehyde **49**.

(15) C. H. Heathcock, M. C. Pirrung, C. T. Buse, J. P. Hagen, S. D. Young, and J. E. Sohn, *J. Am. Chem. Soc.*, **101**, 7077 (1979). The preparation and further chemistry of **47** will be discussed in another paper. We introduce this one reaction at this time because it bears on the α-alkoxy aldehyde stereoselection question.

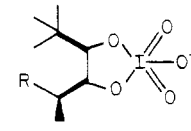


50



51

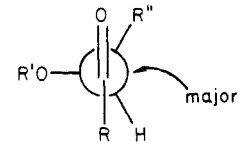
If aldol **48** is desilylated prior to reduction, the **50**/**51** ratio is 1:9. It is interesting that, while **50** undergoes rather smooth periodate oxidation to **49**, diastereomer **51** reacts slowly and gives **49** in poor yield. This is not unreasonable in view of the steric hindrance which must be associated with the cyclic periodate ester[16] derived from **51** in which two bulky groups are cis about the five-membered ring (**52**).



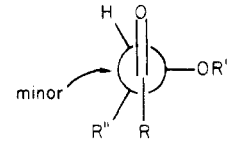
52

Discussion

In all cases studied, the major and minor products from the reaction of lithium enolates with α-alkoxy aldehydes are those predicted from attack as illustrated in structures **53** and **54**. Thus, the Cram "cyclic model" of asymmetric



53



54

induction[17] is *not* followed, as this would predict that the major product would be the other diastereomer in all cases. The transition state which is implied in structure **53** amounts to application of Felkin's model for asymmetric induction,[18] if one assumes that the alkoxy substituent is the "large" substituent on the asymmetric α-carbon. Felkin's model has recently received theoretical support from the work of Anh and Eisenstein,[19] who find a strong preference for transition states in which the entering nucleophile is antiperiplanar with one of the substituent bonds to the asymmetric carbon. Anh and Eisenstein argue that the "larger" substituent is the one which has the lowest energy $\sigma^*_{C_\alpha X}$ orbital. By this criterion, OR will always be "larger" than alkyl or aryl groups.

There are a number of other observations which deserve comment. First, the enhancement in stereoselectivity in going from aldehydes **1** or **2** to **3** in the reaction with ketone **9** is interesting. Still has recently noted excellent stereoselectivity in reactions of Grignard reagents with α-alkoxy ketones and reasonably rationalized his results in terms of the Cram cyclic model for asymmetric induction.[20] In Still's work, it was noted that α-benzyloxy gives higher chelation-controlled stereoselectivity than does α-[(benzyloxy)methoxy] (200/1 for the former, 100/1 for the latter). Still also noticed decreased stereoselectivity for α-tetrahydropyranyloxy. These results are in qualitative

(16) G. Dryhurst, "Periodate Oxidation of Diol and Other Functional Groups", Pergamon Press, Oxford, 1970, p 35.
(17) (a) D. J. Cram and K. R. Kopecky, *J. Am. Chem. Soc.*, **81**, 2737 (1959). (b) See also J. D. Morrison and H. S. Mosher, "Asymmetric Organic Reactions", Prentice-Hall, Englewood Cliffs, NJ, 1971, pp 87–108.
(18) M. Chêrest, H. Felkin, and N. Prudent, *Tetrahedron Lett.*, 2201 (1968).
(19) N. T. Anh and O. Eisenstein, *Nouv. J. Chim.*, **1**, 61 (1977).
(20) W. C. Still and J. H. McDonald, III, *Tetrahedron Lett.*, 1031 (1980).

agreement with our observations: the α-benzyloxy group gives more of the product which would result from a chelation-controlled addition. We think that a reasonable rationale for the results is that addition occurs by competing transition states, one in which the α-alkoxy group chelates a cation and a Felkin transition state in which alkoxy is the "large group". The (benzyloxy)methoxy group shows a slightly greater preference for the Felkin transition state because the inductive effect of the second oxygen renders the α-oxygen less basic. An obvious corollary of this hypothesis is that even more electron-withdrawing groups should favor the nonchelated transition state even more. Experiments to test this idea are underway.

One further trend emerges from the data collected in Tables I and III; enolates derived from ethyl carbonyl compounds usually show higher diastereoface selectivity than enolates derived from the analogous methyl carbonyl compounds. Thus, methyl propionate is generally more selective than methyl acetate, and ketone **9** is more selective than ketone **8**. There are exceptions to this generalization. While pinacolone gives only a single adduct with aldehyde **4**, ethyl *tert*-butyl ketone gives the two erythro adducts **30c** and **31c** in a ratio of 6:1. The other exceptions are the hindered aryl esters **12** and **13**, both of which give approximately 2:1 ratios of products derived from attack modes **53** and **54**.

Experimental Section

Unless otherwise noted, materials were obtained from commercial suppliers and were used without further purification. Ether, 1,2-dimethoxyethane (glyme), and tetrahydrofuran (THF) were distilled from $LiAlH_4$ or sodium/benzophenone immediately prior to use. All reactions involving organometallic reagents were conducted under a nitrogen atmosphere. Boiling points and melting points (Pyrex capillary) are uncorrected. IR spectra were determined with a Perkin-Elmer Model 297 infrared recording spectrophotometer. ^1H NMR were determined on the following spectrometers: Varian T-60, Varian EM-390, or UCB 180 (a superconducting, 180-MHz, FT instrument). ^{13}C NMR spectra were measured at 25.14 MHz with a Nicolet TT-23 spectrometer or at 45.28 MHz on the UCB 180. ^1H NMR chemical shifts are expressed in parts per million downfield from internal tetramethylsilane. For complex multiplets, m, the chemical shift given is the center of the multiplet. Significant ^1H NMR data are tabulated in the following order: number of protons, multiplicity (s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet), coupling constant(s) in hertz. Mass spectra were obtained with Atlas MS-112 and Consolidated 12-110B mass spectrometers. Mass spectral data are tabulated as *m/e* values (intensity expressed as percent of total ion current). Gas–liquid partition chromatography (GLC) was done with Varian Aerograph A-90P, 920, and 940 gas chromatographs. High-pressure liquid chromatography (LC) was done with a Waters Model ALC/GPC-244 liquid chromatograph (analytical) or a Waters PrepLC/System 500 (preparative). Porasil columns were used unless otherwise noted. Elemental analyses were performed by the Microanalytical Laboratory, operated by the College of Chemistry, University of California, Berkeley.

***O*-[(Benzyloxy)methyl]lactaldehyde (3).** Ether **16** (1.705 g, 7.75 mmol) was dissolved in 100 mL of CH_2Cl_2 and cooled to −70 °C, and methanol (0.65 mL, 16.1 mmol) was added. Ozone was passed through the solution at a rate of about 1 mmol/min until the blue color persisted. The excess ozone was removed by bubbling nitrogen through the solution, the solution was warmed, and dimethyl sulfide (0.65 mL, 8.9 mmol) was added. After the solution had been allowed to stand at room temperature for 2 h, the solvents were evaporated, the residue was passed through a short plug of silica, and the eluant was purified by preparative high-pressure LC (30% ether/hexane) to give 437 mg (29%) of the aldehyde **3**: ^1H NMR ($CDCl_3$) δ 1.33 (3 H, d, J = 7), 4.03 (1 H, dq, J = 1, 7), 4.60 (2 H, s), 4.80 (2 H, s), 7.23 (5 H, s), 9.67 (1 H, d, J = 1); IR (film) 2900, 1735, 1380, 1100, 1040 cm^{-1}. Satisfactory combustion analysis could not be obtained for this compound, and it gave no suitable molecular or fragment ions for exact mass spectrometric measurement.

(*tert*-Butyldimethylsilyl)lactaldehyde (1). By use of the procedure described above on a 19-mmol scale, the aldehyde was obtained in 47% yield after preparative high-pressure LC (10% ether/hexane, R_f 0.33): ^1H NMR ($CDCl_3$) δ 0.10 (6 H, s), 0.95 (9 H, s), 1.27 (3 H, d, J = 7), 4.00 (1 H, br q, J = 7), 9.66 (1 H, br s); IR (film) 2860, 2800, 1740, 1470, 1460, 1350, 1260, 1140, 1110, 1010, 840, 780 cm^{-1}; high-resolution mass spectrum on M − 15 ion, calcd for $C_8H_{17}O_2Si$ *m/e* 173.10078, found *m/e* 173.10090.

2-(Benzyloxy)propionaldehyde (2). By use of the procedure described above on a 13.2-mmol scale, a 35% yield of the known[10] aldehyde was obtained after preparative high-pressure LC (10% ether/hexane, R_f 0.19).

3-[(Trimethylsilyl)oxy]-3-methylbutan-2-one (8). To bis-[(trimethylsilyl)acetamide] (5.27 g, 25 mmol) was added 3-hydroxy-3-methylbutan-2-one (5.11 g, 50 mmol) under dry nitrogen. The mixture was heated to 100 °C with stirring for 12 h. The cooled mixture was taken up in hexanes and shaken with several portions of water. The layers were separated, the organic phase was dried over $MgSO_4$ and filtered, and the solvent was carefully removed in vacuo at 5–10 °C. The crude material was distilled (32 °C, 4 mmHg) to give the product: 4.70 g (54%); IR (film) 2950, 1720, 1380, 1355, 1255, 1200, 1180, 1135, 1040, 895, 845, 760 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.12 (9 H, s), 1.30 (6 H, s), 2.18 (3 H, s).

Anal. Calcd for $C_8H_{18}O_2Si$: C, 55.12; H, 10.41. Found: C, 54.86; H, 10.19.

2-Methyl-4-[(*tert*-butyldimethylsilyl)oxy]-2-pentene (14). In 25 mL of CH_2Cl_2 were dissolved *tert*-butyldimethylsilyl chloride (3.66 g, 24.2 mmol) and imidazole (1.90 g, 27.9 mmol). To this solution was added 2-methyl-4-hydroxy-2-pentene (2.0 g, 20 mmol) in 5 mL of CH_2Cl_2. After being allowed to stand at room temperature overnight, the reaction mixture was poured into H_2O, the layers were separated, and the aqueous phase was extracted with CH_2Cl_2. The combined organic phases were washed with 5% HCl, H_2O, and NaCl, dried, filtered, and evaporated to give 4.28 g (100%) of the silyl ether: ^1H NMR ($CDCl_3$) δ 0.00 (6 H, s), 0.85 (9 H, s), 1.10 (3 H, d, J = 7), 1.60 (3 H, s), 1.67 (3 H, s), 4.40 (1 H, m), 5.10 (1 H, br d, J = 8); IR (film) 2850, 1460, 1380, 1250, 1070, 1000, 900, 830, 770 cm^{-1}.

Anal. Calcd for $C_{12}H_{26}OSi$: C, 67.22; H, 12.13. Found: C, 67.02; H, 12.26.

2-Methyl-4-(benzyloxy)-2-pentene (15). In a 300-mL, three-necked, round-bottomed flask was placed NaH (7.40 g of a 50% oil dispersion, 154 mmol). This was washed twice with petroleum ether and covered with 80 mL of THF and 80 mL of DMF. The alcohol (13.35 g, 133 mmol) was added at 0 °C, and the solution was stirred at that temperature for 1 h. Benzyl bromide (17.0 mL, 143 mmol) was added, and the solution was stirred overnight. This solution was poured into a mixture of 200 mL of petroleum ether and 100 mL H_2O, and the layers were separated. The organic phase was washed with H_2O, 1% HCl, $NaHCO_3$, and NaCl, dried, filtered, evaporated, and distilled to give 18.2 g (72%) of material boiling at 78 °C (1 torr): ^1H NMR ($CDCl_3$) δ 1.20 (3 H, d, J = 7), 1.63 (3 H, s), 1.73 (3 H, s), 4.20 (1 H, m), 4.37 (1 H, d, J = 10), 4.57 (1 H, d, J = 10), 5.10 (1 H, br d, J = 8), 7.26 (5 H, s); IR (film) 3030, 2970, 1670, 1450, 1370, 1200, 1150, 1070, 1025, 840, 730, 645 cm^{-1}.

Anal. Calcd for $C_{13}H_{18}O$: C, 82.06; H, 9.53. Found: C, 82.10; H, 9.55.

2-Methyl-4-[(benzyloxy)methoxy]-2-pentene (16). In 10 mL of DMF were placed 2-methyl-4-hydroxy-2-pentene (3.0 g, 32 mmol), diisopropylethylamine (6.3 mL, 36.3 mmol), and benzyl chloromethyl ether (4.50 mL, 32.7 mmol). The solution was stirred at room temperature for 2 days and poured into a mixture of water and petroleum ether, and the layers were separated. The organic layer was washed with NH_4OH, H_2O, 5% HCl, H_2O, 5% NaOH, and NaCl. The solution was dried, filtered, evaporated, and Kugelrohr distilled (120 °C, 0.6 torr). This material was chromatogrqphed on silica gel (10% ether/hexane, R_f 0.21) to give 4.93 g (75%) of the ether: ^1H NMR ($CDCl_3$) δ 1.22 (3 H, d, J = 7), 1.66 (3 H, s), 1.72 (3 H, s), 4.55 (5 H, m), 5.0 (1 H, d, J = 9), 7.27 (5 H, s); IR (film) 2850, 1495, 1445, 1375, 1100, 1040, 1025 cm^{-1}.

Anal. Calcd for $C_{14}H_{20}O_2$: C, 76.32; H, 9.15. Found: C, 76.17; H, 8.92.

2,2,5-Trimethyl-5-(1-hydroxypropyl)-1,3-dioxolan-4-one (18). To a 3-L, three-necked round-bottomed flask fitted with a mechanical stirrer, a low-temperature thermometer, and a nitrogen inlet were added sequentially at −78 °C 150 mL (1.07 mol) of diisopropylamine, 800 mL of THF, and 705 mL (1.05 mol) of a 1.49 M solution of *n*-butyllithium in hexane. After the temperature of the LDA solution fell below −70 °C, 120 mL (0.945 mol) of **17** was added by a motor-driven syringe over the course of 1 h. The temperature of the solution was kept below −66 °C. After 30 min, 76.4 mL (1.06 mol) of propanal was added over a 20-min period. The temperature rose to −62 °C. After an additional 5 min, the reaction was quenched with 100 mL of saturated NH_4Cl. The phases were separated, and the water phase was extracted with Et_2O (2 × 1 volume). The organic phase was washed with 1.2 M HCl (2 × 500 mL), H_2O (200 mL), saturated $NaHCO_3$ (200 mL), and brine (500 mL). The ether solution was dried over $MgSO_4$, and the solvent was removed by aspirator to yield 150.9 g (85%) of a 70:30 mixture of diastereomers: IR (thin film) 3500, 3000, 2950, 1780, 1460 cm^{-1}; ^1H NMR ($CDCl_3$) erythro isomer δ 1.03 (3 H, br t, J = 7), 1.50 (3 H, s), 1.60 (6 H, s), 3.47 (1 H, br t, J = 7), 5.00 (1 H, br); threo isomer δ 1.03 (3 H, br t, J = 7), 1.40 (3 H, s), 1.60 (6 H, s), 3.47 (1 H, br t, J = 7), 5.00 (1 H, br). Preparative GLC (10-ft column, 8% Carbowax, 130 °C) afforded the analytical sample.

Anal. Calcd for $C_9H_{16}O_4$: C, 57.45; H, 8.51. Found: C, 57.16; H, 8.45.

(±)-*erythro*-2,3-Dihydroxy-2-methylpentanoic Acid (19). To a mixture of the diastereomeric dioxolanones **18** (128.37 g, 0.683 mol) was added 220 mL of a 4.65 M solution of KOH in MeOH over a 5-min period. After another 10 min, 25 g of solid NH_4Cl was added, and the MeOH was removed by evaporation at reduced pressure. The residue was dissolved in water and extracted with Et_2O (2 × 200 mL). The water phase was acidified with 82 mL of concentrated HCl and then extracted with ethyl acetate (8 × 250 mL). The organic phase was dried over $MgSO_4$. Filtration and solvent removal gave 93.1 g (92%) of crude acid. Two recrystallizations from ethyl acetate gave 25.6 g (25.3%, mp 153.5 °C) of pure erythro acid (lit.[7] mp 153.5–154.5 °C). The combined mother liquors eventually yielded another 11.9 g (9.9%) of erythro acid. The overall yield based on 3,3,5-trimethyl-2,4-dioxolanone (**17**) was 30%.

Methyl (±)-*erythro*-2,3-*O*-Isopropylidine-2,3-dihyroxy-2-methylpentanoate (20). To 25.6 g (0.173 mol) of (±) erythro acid **19** were added 52 mL of 1,2-dichloroethane, 21 mL of methanol, and 0.52 mL of H_2SO_4.[21] The mixture was refluxed overnight and then cooled and concentrated by using a rotary evaporator. The residue was partitioned between saturated $NaHCO_3$ and ethyl acetate. The water phase was washed with ethyl acetate (2 × 200 mL) and the combined organic fractions were dried over $MgSO_4$. Removal of solvent gave 25 g (89%) of the known methyl ester.

To 3.16 g (19.5 mmol) of the dihydroxy ester were added 20 mL of acetone and 0.05 mL of H_2SO_4. After the mixture was stirred for 3 h, 5 mL of saturated $NaHCO_3$ was added to the mixture, and the acetone was removed in vacuo. The water phase was extracted with ether (3 × 50 mL), and the ether phase was dried over $MgSO_4$. Removal of solvent gave 3.5 g (88%) of the known[4] acetonide **20**.

(±)-*erythro*-2,3-*O*-Isopropylidine-2,3-dihydroxy-2-methylpentanal (5). The acetonide ester **20** was converted to its corresponding alcohol by a literature procedure employing $LiAlH_4$ as the reductant.[4] To 2.0 g (11.5 mmol) of this alcohol in 20 mL of CH_2Cl_2 was added 3.72 g (17.24 mmol) of pyridinium chlorochromate. After 15 h of being stirred, the black-brown mixture was diluted with 1 volume of ether and 1 volume of pentane. The mixture was filtered through a short plug of silica gel (15 g, 60–200 mesh) topped with sand. The black residue was extracted several times with small portions of ether. Removal of solvent gave the known[4] aldehyde (1.78 g, 90%). The NMR spectrum was unchanged upon distillation [bp 90–95 °C (60 torr)]. Preparative GLC (5 ft × $^1/_4$ in. column, 8% SE-30 on Chrom G 60/80 at 125 °C, flow rate 60 mL/min; t_R = 3.75 min) gave the analytical sample: ^1H NMR ($CDCl_3$) δ 9.6 (1 H, s), 3.8 (1 H, t, J = 7), 3.8 (1 H, t, J = 7), 1.59 (3 H, s), 1.49 (3 H, s), 1.30 (3 H, s), 1.5 (2 H, m), 1.00 (3 H, t, J = 6).

Anal. Calcd for $C_9H_{16}O_3$: C, 62.77; H, 9.36. Found: C, 61.57; H, 9.42.

Repeated attempts to obtain satisfactory combustion analysis were unsuccessful. Low results for carbon were consistently obtained (59.32–61.57%). The authors who originally reported aldehyde **5**[4] also do not give analytical values.

2,6-Di-*tert*-butyl-4-methylphenyl Propionate (13). In a 50-mL, three-necked, round-bottomed flask under nitrogen was placed 2,6-di-*tert*-butyl-4-methylphenol (2.60 g, 11.8 mmol). Tetrahydrofuran (12 mL) was added, and the solution was cooled to 0 °C. A solution of *n*-BuLi (1.5 M in hexane, 7.90 mL, 11.85 mmol) was added at this temperature, and after the solution had returned to 0 °C, propionyl chloride (1.54 mL, 17.7 mmol) was added. The solution was stirred overnight, poured into NH_4Cl solution, and extracted with ether. The combined organic phases were washed with $NaHCO_3$ and NaCl, dried ($MgSO_4$), filtered, and evaporated. Kugelrohr distillation (120 °C, 0.5 torr) gave 3.12 g of ester **13** (96%). Analysis by GLC (10-ft column, 8% SE-30, 130 °C) showed a single peak with a retention time of 13 min: ^1H NMR ($CDCl_3$) δ 1.00 (18 H, s), 2.28 (3 H, s), 2.63 (2 H, q, J = 7), 7.03 (2 H, s); IR (thin film) 3070, 2950, 2870, 1760, 1600, 1480, 1460, 1420, 1395, 1360, 1345, 1270, 1220, 1220, 1185, 1145, 1110, 1075, 980, 890, 860, 800 cm^{-1}.

Anal. Calcd for $C_{18}H_{28}O_2$: C, 78.21; H, 10.21. Found: C, 78.34; H, 10.15.

The known[22] **12** was prepared in the same manner in 94% yield.

General Procedure for Aldol Condensations. Preparation of (6*R*)-2,4-Dimethyl-5-hydroxy-6,7-*O*-isopropylidine-2-[(trimethylsilyl)oxy]-3-heptanones 30e and 31e. To a solution of 0.55 mL (3.9 mmol) of diisopropylamine in 10 mL of dry THF at 0 °C was added 2.6 mL (3.9 mmol) of a 1.5 M solution of *n*-butyllithium in hexane. After 10 min the solution was cooled to −70 °C, and 0.66 g (3.5 mmol) of 2-methyl-2-(trimethylsiloxy)-3-pentanone (**9**) was added over 3 min. After the mixture was stirred at −70 °C for 2 h, 0.46 g (3.5 mmol) of (*R*)-glyceraldehyde acetonide was added, and the mixture was stirred 20 min and quenched with 10 mL of saturated $NaHCO_3$. After warming to room temperature, the reaction mixture was extracted two times with ether. The ether layers were combined, dried (Na_2SO_4), and evaporated to give 0.83 g (75%) of a mixture of **30e** (78%), **31e** (18%), and 4% or a threo diastereomer as a pale yellow oil: IR (thin film) 3500, 1705, 1460, 1380, 1370, 1250, 1200, 1040, 1060, 950, 940 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.23 (9 H, s), 1.0–1.3 (3 H, mixture of doublets), 1.3–1.6 (12 H, unresolved singlets, 3.0–4.2 (4 H, m); ^{13}C NMR ($CDCl_3$) δ 2.1, 10.7, 13.7 (minor), 25.1, 26.3, 26.6, 27.0, 27.4, 39.8, 43.1 (minor), 66.0 (minor), 67.1, 71.6 (minor), 72.7, 75.2, 76.7 (minor), 80.3, 108.9, 219.6.

Anal. Calcd for $C_{15}H_{30}O_5Si$: C, 56.57; H, 9.49. Found: C, 56.45; H, 9.35.

Methyl 3-Hydroxy-4-[(*tert*-butyldimethylsilyl)oxy]pentanoates 21a and 22a. An aldol reaction under standard conditions gave a 1:1 mixture of diastereomers in a 67% yield after column chromatography (10% ether/hexane, R_f 0.12): IR (film) 3500, 1740, 1440, 1250, 1080, 835, 775 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.10 (6 H, s), 0.90 (9 H, s), 1.13 and 1.20 (3 H total, d, J = 7), 2.50 (2 H, m), 3.66 (3 H, s), 3.80 (3 H, m); ^{13}C NMR δ 172.9, 172.4, 72.3, 71.7, 70.8, 70.2, 51.2, 37.5, 36.7, 25.5, 19.0, 18.8, −4.7, −5.1; high-resolution mass spectrum on the M − 15 ion, calcd for $C_{11}H_{23}O_4Si$ m/e 247.13695, found m/e 247.1370.

Methyl 3-Hydroxy-4-(benzyloxy)pentanoates 21b and 22b. Aldol reaction under standard conditions gave a 1:1 mixture of diastereomers in 41% yield after chromatography (30% ether/hexane, R_f 0.12): IR (film) 3450, 1735, 1440, 1285, 1080, 700 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.18 (3 H, d, J = 7), 2.50 (2 H, m), 3.60 (3 H, s), 4.45 (2 H, m), 7.23 (5 H, s); ^{13}C NMR δ 128.2, 127.6 77.0, 76.5, 70.9, 51.5, 37.6, 37.0, 15.0; high-resolution mass spectrum calcd for $C_{13}H_{18}O_4$ m/e 238.1205, found m/e 238.1204.

(21) R. O. Clinton and S. C. Laskowski, *J. Am. Chem. Soc.*, **70**, 3135 (1948).

(22) A. Volod'kin, D. Rasuleva, V. Ershov, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 178 (1972).

Methyl 3-Hydroxy-4-[(benzyloxy)methoxy]pentanoates 21c and 22c. An aldol reaction under standard conditions gave a 1:1 mixture of diastereomers in 61% yield after chromatography (30% ether/hexane, R_f 0.13): IR (film) 3500, 1740, 1440, 1265, 1160, 1100, 1040 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.17 and 1.20 (3 H, d, J = 7), 2.50 (2 H, m), 3.60 (3 H, s), 4.53 (2 H, s), 4.72 (2 H, s), 7.25 (5 H, s); ^{13}C NMR δ 128.2, 127.6, 127.5, 93.4, 76.1, 75.7, 70.9, 69.5, 51.4, 37.5, 36.8, 15.6. Satisfactory analytical data could not be obtained for this compound, and it showed no suitable ions for exact mass spectrometric measurement.

2,4-Dimethyl-2-[(trimethylsilyl)oxy]-5-hydroxy-6-[(*tert*-butyldimethylsilyl)oxy]-3-heptanones 23a and 24a. Aldol reaction under standard conditions gave a 2:1 mixture of diastereomers in 41% yield after chromatography (10% ether/hexane): IR (film) 3500, 1700, 1460, 1375, 1255, 1200, 1090, 1040, 900, 840, 780 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.10 (6 H, s), 0.20 (9 H, s), 0.90 (9 H, s), 1.15 (6 H, m), 1.30 (3 H, s), 1.34 (3 H, s), 3.50 (2 H, m); ^{13}C NMR δ 76.0, 75.1 (minor), 70.3 (minor), 68.5, 42.6 (minor), 39.6, 27.5, 25.8, 20.7 (minor), 14.6, 12.2 (minor), 11.1, 2.3, −4.2, −4.9.

Anal. Calcd for $C_{18}H_{40}O_4Si_2$: C, 57.39; H, 10.70. Found: C, 57.35; H, 10.96.

2,4-Dimethyl-2-[(trimethylsilyl)oxy]-5-hydroxy-6-(benzyloxy)-3-heptanones 23b and 24b. An aldol reaction under standard conditions gave a mixture of diastereomers in 51% yield after chromatography (10% ether/hexane, R_f 0.19): IR (film) 3500, 1705, 1455, 1380, 1255, 1200, 1040, 900, 840 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.16 (9 H, s), 1.02 and 1.05 (3 H, d, J = 7), 1.20 (3 H, d, J = 7), 1.27 (3 H, s), 1.33 (3 H, s), 3.3–3.7 (3 H, m), 4.40 (2 H, m), 7.23 (5 H, s); ^{13}C NMR δ 220.1, 217.4 (minor), 138.4, 128.1, 127.5, 127.3, 76.0, 74.9, 74.5, 74.0, 70.7 (minor), 70.3, 41.9 (minor), 39.7, 27.8 (minor), 27.5, 27.4, 27.3, 15.8 (minor), 15.2, 12.4 (minor), 11.1, 2.0; high-resolution mass spectrum on M − 33 ion calcd for $C_{18}H_{27}O_3Si$ m/e 319.1729, found m/e 319.1720.

2,4-Dimethyl-2-[(trimethylsilyl)oxy]-5-hydroxy-6-[(benzyloxy)methoxy]-3-heptanones 23c and 24c. An aldol reaction under standard conditions gave a 4:1 mixture of diastereomers after chromatography (30% ether/hexane, R_f 0.31): IR (film) 3500, 1700, 1450, 1380, 1250, 1200, 1040, 910 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.17 (9 H, s), 1.0–1.2 (12 H, m), 3.40–3.7 (3 H, m), 4.50–4.80 (4 H, m), 7.27 (5 H, s); ^{13}C NMR major isomer δ 128.3, 127.7, 92.9, 74.7, 73.4, 69.6, 39.8, 27.7, 27.4, 15.8, 11.6, 2.2; minor isomer δ 128.4, 127.8, 127.7, 94.0, 75.9, 74.8, 69.8, 41.7, 29.7, 28.1, 27.8, 27.5, 17.1, 11.3, 2.4.

Anal. Calcd for $C_{20}H_{34}O_5Si$: C, 62.79; H, 8.96. Found: C, 62.56; H, 8.88.

(4*R*)-Methyl 2,4-*O*-Isopropylidene-3,4,5-trihydroxypentanoates 28a and 29a. The crude aldol was isolated in 74% yield on a 5-mmol scale. An analytical sample was prepared by column chromatography on silica gel, eluting with 40% ether in hexanes (R_p 0.39): IR (film) 3450, 2990, 2940, 1725, 1440, 1375, 1260, 1210, 1060, 850 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.30 (3 H, s), 1.40 (3 H, s), 2.50 (2 H, s), 3.10 (1 H, Br), 3.95 (4 H, m); ^{13}C NMR ($CDCl_3$) δ 25.0, 26.3 (minor), 26.5, 37.6, 38.1 (minor), 51.1, 65.5 (minor), 66.2; 77.7, 109.5.

Anal. Calcd for $C_9H_{16}O_5$: C, 52.94; H, 7.90. Found: C, 52.99; H, 7.81.

(4*R*)-2,6-Di-*tert*-butyl-4-methylphenyl 4,5-*O*-Isopropylidene-3,4,5-hydroxypentanoates 28b and 29b. The crude product was obtained in 72% yield on a 5-mmol scale. An analytical sample was prepared by chromatography on silica gel with 40% ether in hexanes as the eluant (R_f 0.27): IR (film) 3450, 2950, 2910, 1740, 1500, 1365, 1150, 860 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.30 (18 H, s), 1.35 (3 H, s), 1.40 (3 H, s), 2.25 (3 H, s), 2.90 (2 H, m), 3.40 (1 H, br), 3.95 (4 H, m); ^{13}C NMR ($CDCl_3$) δ 20.9, 24.7, 25.8 (minor), 26.3, 31.0, 38.9, 64.9 (minor), 66.5, 66.8 (minor), 68.5, 109.0, 126.5, 172.9.

Anal. Calcd for $C_{23}H_{36}O_5$: C, 70.38; H, 9.24. Found: C, 70.70; H, 9.50.

(6*R*)-6,7-*O*-Isopropylidene-5,6,7-trihydroxy-2,2-dimethylheptan-3-ones 28c and 29c. The crude product was obtained in 87% yield on a 5-mmol scale. An analytical sample (mp 54–55 °C) was prepared by recrystallization from pentane. ^{13}C NMR spectroscopy showed that both the crude and crystalline products were a single diastereomer: IR (film) 3450, 2970, 2920, 2880, 1690, 1465, 1370, 1210, 1060, 860 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.12 (9 H, s), 1.35 (3 H, s), 1.45 (3 H, s), 2.85 (2 H, m), 3.40 (1 H, br), 4.00 (4 H, m); ^{13}C NMR ($CDCl_3$) δ 25.2, 26.3, 26.7, 39.7, 67.2, 69.6, 77.7.

Anal. Calcd for $C_{12}H_{22}O_4$: C, 62.60; H, 9.63. Found: C, 62.72; H, 9.64.

(6*R*)-6,7-*O*-Isopropylidene-2,5,6,7-tetrahydroxy-2-methylheptan-3-ones 28d and 29d. The general procedure was followed, the crude product was treated with 0.5% methanolic HCl (10 mL) for 1 h, the mixture was neutralized with saturated aqueous $NaHCO_3$ and extracted with ether, the extract was dried over anhydrous $MgSO_4$ and filtered, and the solvent was removed in vacuo to give a 77% yield on a 5-mmol scale. An analytical sample was prepared by column chromatography on silica gel with 3% CH_3OH in $CHCl_3$ as the eluant: IR (film) 3430, 2990, 1710, 1370, 1215, 1155, 1060, 970, 850 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.30 (6 H, s), 1.35 (3 H, s), 1.40 (3 H, s), 2.80 (2 H, m), 3.20 (1 H, br), 4.00 (4 H, m); ^{13}C NMR ($CDCl_3$) δ 25.1, 26.3, 26.7, 39.3 (minor), 39.4, 65.5 (minor), 66.8, 68.1 (minor), 69.1, 76.4 (minor), 76.5, 77.3, 109.6, 215.1.

Anal. Calcd for $C_{11}H_{20}O_5$: C, 56.88; H, 8.68. Found: C, 56.65; H, 8.43.

(3*S*,4*R*)-Methyl 4,5-*O*-Isopropylidene-3,4,5-trihydroxy-2-methylpentanoates 30a and 32a. The crude aldol was obtained in 87% yield on a 5-mmol scale. An analytical sample was prepared by column chromatography on silica gel with 50% ether in hexane as the eluant (R_f 0.34): IR (film) 3470, 2990, 2950, 2880, 1725, 1460, 1435, 1380, 1370, 1255, 1210, 1060, 850, 760 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.30 (3 H, s), 1.45 (3 H, s), 2.80 (2 H, m), 3.80 (3 H, s), 4.00 (4 H, m); ^{13}C NMR ($CDCl_3$) δ 10.4, 14.5 (minor), 25.2, 25.9 (minor), 26.2, 41.1, 51.7, 66.8 (minor), 67.1, 72.4, 74.6, 75.0 (minor), 75.4.

Anal. Calcd for $C_{10}H_{18}O_5$: C, 55.03; H, 8.31. Found: C, 55.21; H, 8.15.

(5*R*)-2,6-Di-*tert*-butyl-4-methylphenyl 4,5-*O*-Isopropylidine-3,4,5-trihydroxy-2-methylpentanoates 30b, 31b, 32b, and 33b. Aldol condensations under standard conditions gave 100% yields of crude product. The ^{13}C NMR spectrum of the crude product showed two threo adducts (C-2 methyl shifts of 14.6 and 12.5 ppm) and a single erythro resonance (9.1 ppm). Integration of the ^{13}C NMR resonances gave values of 46 and 32% for the two threo adducts and 22% for the erythro products. The mixture was chromatographed on silica gel (30% ether/hexane) to obtain a threo fraction and an erythro fraction. The threo fraction (R_f 0.26) showed the two diastereomers to be present in a ratio of 2:1: ^{13}C NMR ($CDCl_3$) δ 175.6, 141.9, 134.3, 127.0, 126.8, 76.4 (minor), 75.4, 71.3, 67.6, 65.9 (minor), 44.3 (minor), 42.1, 31.3, 26.6, 26.0, 25.3, 25.1, 21.2, 14.6, 12.5 (minor). This fraction slowly crystallized. Recrystallization from hexane provided one nearly pure threo diastereomer (**32b**), mp 70–72 °C.

Anal. Calcd for $C_{24}H_{38}O_5$: C, 70.90; H, 9.42. Found: C, 71.05; H, 9.52.

The erythro fraction was contaminated with the threo adducts. This material was chromatographed again to obtain a fraction which contained only erythro material: ^{13}C NMR ($CDCl_3$) δ 127.2, 127.0, 74.7, 72.0, 67.8, 41.8, 35.2, 31.4, 31.3, 26.9, 25.3, 21.3, 9.1. This fraction was shown to be a 3:1 mixture of both erythro diastereomers **30b** and **31b** by reduction to a 3:1 mixture of diols **39** and **40** (vide infra).

(6*R*)-6,7-*O*-Isopropylidine-5,6,7-trihydroxy-2,2,4-trimethylheptan-3-ones 30c and 31c. The two aldols were obtained in a ratio of 6:1 in 43% yield on a 5-mmol scale: ^{13}C NMR ($CDCl_3$) δ 10.4, 15.5 (minor), 25.1, 25.8, 26.7, 39., 43.9, 45.0 (minor), 66.1, 67.4, 71.9 (minor), 72.9, 74.0 (minor), 74.8, 109.1, 221.8.

The two diastereomers were separated by chromatography on silica gel with 40% ether in hexanes as the eluant.

(5*S*,6*R*)-6,7-*O*-Isopropylidene-5,6,7-trihydroxy-2,2,4-trimethylheptan-3-one (30c): R_f 0.16; IR (film) 3500, 2960, 2880, 1690, 1480, 1375, 1260, 1220, 1065, 900, 850 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.12 (3 H, d, J = 7), 1.15 (9 H, s), 1.35 (3 H, s), 1.40 (3 H, s), 3.45 (1 H, dq, J = 7, 1), 3.55 (2 H, m), 3.9–4.1 (3 H, m); ^{13}C NMR ($CDCl_3$) δ 10.4, 25.7, 25.8, 26.8 39.2, 45.0, 67.4, 72.9, 74.78, 109.1.

Anal. Calcd for $C_{13}H_{24}O_4$: C, 63.91; H, 9.90. Found: C, 63.83; H, 9.79.

(4*R*,5*R*,6*R*)-6,7-*O*-Isopropylidene-5,6,7-trihydroxy-2,2,4-trimethylheptan-3-one (31c): R_f 0.27; mp: 81–82 °C; IR ($CHCl_3$) 3500, 2900, 1795, 1375, 1040, 850 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.17

(9 H, s), 1.22 (3 H, d, J = 7), 1.31 (3 H, s), 1.44 (3 H, s), 2.22 (1 H, d, J = 8), 3.10–3.21 (1 H, dq, J = 7, 1), 3.66 (1 H, dd, J = 8, 1), 3.75–4.05 (3 H, m).

Anal. Calcd for $C_{13}H_{24}O_4$: C, 63.91; H, 9.90. Found: C, 64.01; H, 10.16.

(3*SR*,4*RS*)-3,5-Dimethyl-4-hydroxy-4,5-dihydrofuran-2-(3*H*)-ones 25 and 26. (a) From Aldols 23b and 24b. A 2:1 mixture of the aldols (326 mg, 0.93 mmol) was dissolved in 3 mL of methanol, and a solution of periodic acid (0.84 g, 3.68 mmol) in 2 mL of water was added. After being stirred overnight, the reaction mixture was poured into a mixture of water and ether, and the layers were separated. Ether extraction, followed by washing with NaCl, drying ($MgSO_4$), filtration, and evaporation gave 220 mg (100%) of the β-hydroxy acid, which solidified on standing: IR (film) 3450–2500, 1710, 1450, 1210, 1100, 1065, 985, 740 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.0–1.3 (6 H, m), 2.7 (1 H, m), 3.40 (1 H, q, J = 7), 3.85 (1 H, dd, J = 5, 7), 4.33 (1 H, d, J = 12), 4.53 (1 H, d, J = 12), 7.23 (5 H, s). Recrystallization from hexane–ether gave one of the diastereomers in pure form; mp 87–88 °C.

Anal. Calcd for $C_{13}H_{18}O_4$: C, 65.53; H, 7.61. Found: C, 65.33; H, 7.49.

Anhydrous ammonia (10 mL) was distilled into a 50-mL, round-bottomed flask. The flask was cooled to −78 °C, and lithium wire (0.03 g, 5.14 mmol) was added. After the mixture was stirred for 30 min, 2-methyl-3-hydroxy-4-(benzyloxy)pentanoic acid (220 mg, 0.93 mmol) was added in 2 mL of THF. The resulting solution was stirred for 1 h and the ammonia allowed to evaporate. Ether and water were added, and the reaction mixture was acidified with 2 mL of concentrated HCl. The solution was saturated with salt, the layers were separated, and the aqueous layer was extracted with ether. Drying ($MgSO_4$), filtration, and evaporation gave 98 mg (82%) of a 2:1 mixture of lactones, which were separated by preparative GLC (10-ft column, 8% SE-30, 180 °C).

For the major isomer (t_R = 3.4 min, **25**): IR (film) 3450, 1760, 1455, 1390, 1380, 1320, 1240, 1190, 1065, 1040, 965, 915 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.26 (3 H, d, J = 7), 1.45 (3 H, d, J = 6), 2.55 (1 H, dq, J = 7, 7), 2.80 (1 H, br s), 3.60 (1 H, dd, J = 7, 8), 4.13 (1 H, dq, J = 8, 6); ^{13}C NMR ($CDCl_3$) δ 80.4, 80.2, 43.8, 17.9, 12.4.

Anal. Calcd for $C_6H_{10}O_3$: C, 55.37; H, 7.74. Found: C, 55.21; H, 7.87.

For the minor isomer (t_R = 4.0 min, **26**): IR (film) 3450, 1760, 1455, 1380, 1190, 1055, 845 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.23 (3 H, d, J = 7), 1.30 (3 H, d, J = 6), 2.50 (1 H, dq, J = 5, 7), 4.00 (1 H, t, J = 5), 4.50 (1 H, dq, J = 5, 6); ^{13}C NMR ($CDCl_3$) δ 78.3, 75.1, 43.3, 12.9, 12.7.

Anal. Calcd for $C_6H_{10}O_3$: C, 55.37; H, 7.74. Found: C, 55.05; H, 7.81.

(b) From Aldols 23c and 24c. A 4:1 mixture of aldols **23c** and **24c** was cleaved in the foregoing manner with periodic acid. The crude mixture of acids, analytically pure, was obtained in 63% yield: IR (film) 3400–2500, 1710, 1460, 1390, 1180, 1110, 1040, 1035, 740, 705 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.23 (3 H, d, J = 7), 1.27 (3 H, d, J = 7), 2.72 (1 H, dq, J = 2, 7), 3.80 (2 H, m), 4.53 (2 H, s), 4.65 (1 H, d, J = 6), 4.75 (1 H, d, J = 6), 7.23 (5 H, s).

Anal. Calcd for $C_{14}H_{20}O_5$: C, 62.67; H, 7.51. Found: C, 62.76; H, 7.56.

When the benzyl group was hydrogenolyzed and the resulting dihydroxy acid lactonized as described in part a, lactones **25** and **26** were obtained in quantitative yield. Analysis of this mixture by ^1H NMR and GLC showed it to be >90% **25** and <10% **26**.

(6*R*)-6,7-*O*-Isopropylidene-5,6,7-trihydroxy-2,2,4-trimethylheptan-3-ones 30c and 32c. To a solution of esters **30a** and **32a**, as crude aldol products (1.00 g, 4.58 mmol), in THF (18 mL) at −78 °C was added *tert*-butyllithium (4.82 mL, 9.16 mmol, as a 1.9 M solution in pentane) in one portion. The mixture was allowed to warm to 0 °C with stirring and was then quenched with saturated aqueous $NaHCO_3$ (5 mL). The layers were separated, and the aqueous phase was extracted with ether (3 × 25 mL). The combined organic phases were dried over anhydrous $MgSO_4$, filtered, and concentrated in vacuo. The diastereomers were separated by chromatography on silica gel (35 g) with 40% ether in hexanes to give 140 mg (13%) of **30c** (R_f 0.16) and 62 mg (5.5%) of **32c** (R_f 0.36).

(4*S*,5*S*,6*R*)-6,7-*O*-Isopropylidene-5,6,7-trihydroxy-2,2,4-trimethylheptan-3-one (30c). The IR, ^1H NMR, and ^{13}C NMR spectra of this material were identical with those of the major component prepared by condensation of ethyl *tert*-butyl ketone with aldehyde **4** (vide supra).

(4*R*,5*R*,6*R*)-6,7-*O*-Isopropylidene-5,6,7-trihydroxy-2,2,4-trimethylheptan-3-one (32c): IR (film) 3490, 2950, 1700, 1480, 1460, 1370, 1220, 1060 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.12 (9 H, s), 1.2–1.4 (9 H, m), 3.4 (2 H, m), 3.6 (4 H, m); ^{13}C NMR ($CDCl_3$) δ 15.9, 25.2, 26.0, 26.6, 39.9, 67.6, 76.5, 78.0, 109.2.

Anal. Calcd for $C_{13}H_{29}O_4$: C, 63.91; H, 9.90. Found: C, 64.05; H, 9.96.

2-Deoxy-D-ribose (35) and 2-Deoxy-D-lyxose (36). (a) Aldol Route. To a suspension of lithium aluminum hydride (245 mg, 6.5 mmol) in THF (25 mL), under nitrogen, was added a solution of ketones **28d** and **29d** (500 mg, 2.15 mmol) in THF (10 mL), and the mixture was stirred for 1 h at room temperature. The reaction was quenched with water (0.24 mL), 15% aqueous NaOH (0.24 mL), and water (0.75 mL), and the resulting suspension was stirred for an additional 2 h. To this was added anhydrous $MgSO_4$, and the mixture shaken and filtered through a sintered-glass frit. The filter cake was washed with ether, and the combined filtrates were concentrated in vacuo to give 504 mg (100%) of analytically pure material: IR (film) 3420, 2980, 2940, 2880, 1370, 1215, 1065, 910 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.19 (3 H, s), 1.12 (3 H, s), 1.35 (3 H, s), 1.42 (3 H, s), 1.8–1.9 (2 H, m), 2.1–2.8 (3 H, br), 3.5–4.1 (5 H, m).

Anal. Calcd for $C_{11}H_{22}O_5$: C, 56.39; H, 9.47. Found: C, 56.04; H, 9.55.

To a solution of this triol mixture (1.00 g, 4.30 mmol) in 25 mL of absolute ethanol was added a solution of $NaIO_4$ (913 mg, 4.30 mmol) in water (38 mL) containing enough saturated $NaHCO_3$ solution to raise the pH to 6.0. This was stirred for 1 h at room temperature. Most of the ethanol was removed in vacuo and the aqueous residue extracted with chloroform (2 × 75 mL). The combined extracts were dried over anhydrous $MgSO_4$, filtered, and concentrated in vacuo to give 710 mg of aldehydes **34** (95%). An analytical sample was prepared by chromatography on silica gel (10% CH_3OH in $CHCl_3$, R_f 0.42): IR (film) 3420, 2980, 2940, 1720, 1370, 1215, 1060, 850, 755 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.25 (3 H, s), 1.35 (3 H, s), 2.4–2.7 (2 H, m), 3.8–4.0 (4 H, m), 9.80 (1 H, m).

Anal. Calcd for $C_8H_{14}O_4$: C, 55.16; H, 8.10. Found: C, 55.43; H, 8.06.

To a 50-mL, round-bottomed flask containing 60% (v/v) aqueous acetic acid (20 mL) was added aldehyde **34** (500 mg, 2.9 mmol), and the mixture was stirred for 12 h at room temperature. The solvent was removed in vacuo to give a dark yellow syrup. This was chromatographed on silica gel (16 g) with 20% CH_3OH in $CHCl_3$ to give 138 mg (35%) of a mixture of **35** and **36** as a colorless syrup: ^1H NMR (D_2O) δ 1.5–2.5 (2 H, m), 3.4–4.3 (4 H, m), 5.1 (0.75 H, dd, J = 3, 5), 5.5 (0.25 H, m); ^{13}C NMR (D_2O) δ 36.5, 37.8, 39.1 (minor) 41.4, 43.8 (minor), 64.2, 65.2, 65.4, 67.2, 68.4, 69.1, 69.8, 70.0, 70.6, 72.4, 72.8, 73.6, 73.8, 87.8, 88.4, 94.2, 96.3, 96.6 (minor), 100.7; $[\alpha]^{20}_D$ +34° (equilibrium, c 0.5, H_2O).

(b) Grignard Route. To a 100-mL three-necked round-bottomed flask equipped with a reflux condenser, nitrogen inlet, and dropping funnel was added Mg turnings (748 mg, 31 mmol) and the flask flame dried. After this had cooled, ether (25 mL) was added and the dropping funnel charged with a solution of allyl bromide (4.125 g, 2.951 mL, 34 mmol) in ether (12 mL). A small crystal of iodine was added to the flask, and the allyl bromide solution was added at such a rate as to maintain a gentle reflux. When the addition was complete, the solution was allowed to stir for an additional 20 min, followed by dropwise addition of aldehyde **4** (4.0 g, 31 mmol) in ether (12 mL). When the addition was complete, saturated NH_4Cl solution (20 mL) was added dropwise, and the resulting mixture was allowed to stir for 1 h. The layers were separated, and the aqueous phase was extracted with ether (2 × 70 mL). The combined organic fractions were washed with brine, dried over anhydrous $MgSO_4$, and filtered. The solvent was removed in vacuo to give 3.18 g (59%) of crude product. An analytical sample was prepared by chromatography on silica gel with 50% ether in hexanes as the eluant (R_f 0.32): IR (capillary film) 3080, 2990, 2950, 2900, 1640, 1370, 1220, 1065, 915, 855 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.35 (3 H, s), 1.45 (3 H, s), 2.0–2.3 (2 H, m), 3.5–4.0 (4 H, m), 5.1 (2 H, m), 5.6–6.0 (1 H, m); ^{13}C NMR ($CDCl_3$) δ 26.2, 26.5, 37.6, 38.7 (minor), 65.3, 65.9 (minor), 70.6, 71.5 (minor), 78.1, 78.5 (minor), 117.6 (minor), 118.0, 134.0.

Anal. Calcd for $C_9H_{16}O_3$: C, 62.77; H, 9.36. Found: C, 62.72; H, 9.22.

To a 25-mL, round-bottomed flask were added 410 mg (2.4 mmol) of the foregoing alcohol and 10 mL of aqueous acetic acid. The solution was stirred at room temperature for 6 h. The solvent was removed in vacuo, and the crude product crystallized on standing overnight. This material was twice recrystallized from ethyl acetate to give 170 mg (54%) of extremely hygroscopic white crystals: mp 37–38 °C; IR (Nujol mull) 3300, 2920, 1640, 1460, 1060, 1030, 920, 870 cm^{-1}; ^1H NMR (Me_2SO-d_6) δ 1.9–2.6 (2 H, m), 3.1–3.6 (4 H, m), 4.1–4.5 (3 H, m), 4.8–5.2 (2 H, m), 5.6–6.1 (1 H, m); ^{13}C NMR (D_2O) δ 39.3, 39.8 (minor), 65.3, 65.6 (minor), 73.6 (minor), 74.0, 46.4 (minor), 76.9, 120.4, 137.8.

Anal. Calcd for $C_6H_{12}O_3$: C, 54.33; H, 9.15. Found: C, 54.39; H, 9.16.

Ozone was bubbled through a solution of 1.20 g (9.1 mmol) of this alkene in 30 mL of CH_3OH at a rate of 0.25 mmol min^{-1} at −78 °C. After 45 min, a light blue color had developed, and the residual ozone was removed by bubbling oxygen through the cooled solution for 15 min. To this was added dimethyl sulfide (5 mL), and the mixture was allowed to warm to room temperature with stirring. The solvents were removed in vacuo, and the crude material was chromatographed on silica gel (85 g) with 11% CH_3OH in $CHCl_3$ to give 778 mg of a mixture of **35** and **36** (64%): IR (thin film) 3350, 2940, 1650, 1070 cm^{-1}; ^{1}NMR (D_2O) δ 1.5–2.5 (2 H, m), 3.4–4.3 (4 H, m), 5.1 (0.75 H, dd, J = 3, 5), 5.5 (0.25 H, m); ^{13}C NMR (D_2O) δ 36.4, 37.8, 41.5, 43.8, 43.9, 65.3, 65.5, 67.3, 67.7, 68.7, 69.2, 70.0, 70.2, 70.4, 70.7, 72.4, 72.9, 73.4, 73.6, 73.8, 73.9, 88.0, 88.5, 94.3, 96.6, 96.8, 100.8.

(2*R*)-1,2-*O*-Isopropylidinepentane-1,2,3,5-tetraols 37 and 38. (a) From Esters 28a and 29a. To a suspension of lithium aluminum hydride (260 mg, 6.9 mmol) in THF (35 mL) under N_2 was added a mixture of esters **28a** and **29a** (700 mg, 3.43 mmol) in THF (15 mL), and the mixture was allowed to stir for 2 h at room temperature. The reaction was quenched by the addition of water (0.26 mL), 15% aqueous NaOH (0.26 mL), and water (0.78 mL), and the resulting suspension was allowed to stir for an additional 2 h. To this mixture was added anhydrous $MgSO_4$, and the mixture was shaken and filtered through a sintered-glass frit. The solvents were removed in vacuo to give 479 mg (79.3%) of product. An analytical sample was prepared by chromatography on silica gel with 10% CH_3OH in $CHCl_3$ as the eluant (R_f 0.31): IR (film) 3400, 2940, 1445, 1370, 1220, 1150, 1060, 870 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.30 (3 H, s), 1.40 (3 H, s), 1.75 (2 H, m), 2.9 (1 H, br), 3.2 (1 H, br), 3.8–4.0 (4 H, m); ^{13}C NMR ($CDCl_3$) δ 25.0, 26.0 (minor), 59.6 (minor), 60.3, 65.6, 70.8, 78.3, 78.8 (minor), 109.0, 109.3 (minor).

Anal. Calcd for $C_8H_{16}O_4$: C, 54.53; H, 9.15. Found: C, 54.27; H, 9.22.

(b) From Aldehyde 34. To a suspension of lithium aluminum hydride (184 mg, 4.84 mmol) in THF (10 mL) under nitrogen was added aldehyde **34** (422 mg, 2.42 mmol) in THF (5 mL). The mixture was stirred for 1 h, quenched with water (0.2 mL), 15% aqueous NaOH (0.2 mL), and water (0.6 mL), and allowed to stir for an additional hour. To this was added anhydrous $MgSO_4$, the mixture was shaken and filtered through a sintered-glass frit, the filter cake was washed with ether, and the combined filtrates were concentrated in vacuo to give 312 mg of a mixture of **37** and **38** (73%): IR (film) 3400, 2940, 1445, 1370, 1220, 1150, 1060, 870 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.30 (3 H, s), 1.40 (3 H, s), 1.75 (2 H, m), 2.9 (1 H, br), 3.2 (1 H, br), 3.8–4.0 (4 H, m); ^{13}C NMR ($CDCl_3$) δ 25.1, 25.8 (minor), 26.4, 34.3, 34.8 (minor), 59.8 (minor), 60.5, 65.6, 70.9, 78.31, 78.83 (minor), 109.07, 109.4 (minor).

(2*R*,3*S*,4*S*)-1,2-*O*-Isopropylidine-4-methylpentane-1,2,3,5-tetraol (41) and (2*R*,3*R*,4*R*)-1,2-*O*-Isopropylidine-4-methylpentane-1,2,3,5-tetraol (42). The 2:1 mixture of adducts **32b** and **33b** (397 mg, 0.987 mmol) purified chromatographically as previously described (vide supra) was dissolved in 3 mL of THF and the solution slowly added to a solution of $LiAlH_4$ (49 mg, 1.29 mmol) in 5 mL of THF. The solution was heated at reflux for 14 h, cooled, and quenched by the addition of 0.40 mL of H_2O, 0.40 mL of 15% NaOH, and 1.20 mL of H_2O. The resulting solution was dried ($MgSO_4$), filtered, and evaporated to give a 2:1 mixture of diols **41** and **42**. This material was chromatographed on silica gel with ether as eluant to give three fractions. Fraction 1 (59 mg, 32%, R_f 0.33) was pure **41**: ^1H NMR ($CDCl_3$) δ 0.95 (3 H, d, J = 7), 1.35 (3 H, s), 1.40 (3 H, s), 1.70 (1 H, m), 3.0–4.0 (7 H, m); ^{13}C NMR ($CDCl_3$) δ 76.8, 75.6, 66.5, 65.1, 36.8, 26.4, 25.2, 13.5.

Anal. Calcd for $C_9H_{18}O_4$: C, 56.82; H, 9.54. Found: C, 57.19; H, 9.44.

Fraction 2 (50 mg, 27%) was a mixture. Fraction 3 (25 mg, 13%, R_f 0.24) was pure minor product **42**: ^1H NMR ($CDCl_3$) δ 0.97 (3 H, d, J = 7), 1.40 (3 H, s), 1.47 (3 H, s), 1.80 (1 H, m), 3.3–4.3 (8 H, m); ^{13}C NMR ($CDCl_3$) δ 75.5, 66.9, 66.4, 65.9, 38.5, 26.4, 25.2, 14.2.

(2*R*,3*S*)-1,2-*O*-Isopropylidine-4-methylpentane-1,2,3,5-tetraols 39 and 40. To a stirred solution of 0.20 g (5.3 mmol) of lithium aluminum hydride in 10 mL of ether was added 1.7 g (5.3 mmol) of a solution of aldols **30e** (78%) and **31e** (18%) in 4 mL of ether. After 2 h at room temperature, the reaction was quenched with, successively, 0.2 mL of H_2O, 0.2 mL of 15% NaOH, and 0.6 mL of H_2O. The resultant slurry was stirred 2 h and filtered. The salts were washed two times with ether, and the filtrate was evaporated to give 1.36 g of a nearly colorless thick oil. The product was a mixture of triols and trimethylsiloxy diols as indicated by TLC [R_f (ether) 0.57 and 0.22]. The crude mixture was dissolved in 10 mL of methanol to which 100 mg of K_2CO_3 had been added. After 2 h at room temperature, the reaction product showed a single spot on TLC at R_f 0.22 (ether). The methanol was evaporated, and the residue was taken up in ether and filtered. Evaporation of the ether gave 1.23 g of (2*R*)-4,6-dimethyl-1,2-*O*-isopropylideneheptane-1,2,3,5,6-pentaol as a colorless very thick oil which was used in the following reaction without further purification.

To a stirred 0 °C solution of 3.2 g (15 mmol) of $NaIO_4$ in 75 mL of H_2O was added a 0 °C solution of 1.23 g (5.0 mmol) of the triol in 30 mL of ethanol. After being stirred 15 min at 0 °C, the reaction mixture was diluted with 100 mL of H_2O and extracted five times with 65 mL of $CHCl_3$. The $CHCl_3$ layers were combined, dried (Na_2SO_4), and evaporated to give 0.77 g (4.1 mmol) of (2*R*,4*R*)-4,5-*O*-isopropylidine-3,4,5-trihydroxy-2-methylpentanal as a colorless oil which showed a single spot by TLC (ether); R_f 0.65.

The crude aldehyde (0.77 g, 4.1 mmol) in 4 mL of ether was added to a stirred solution of 0.16 g (4.1 mmol) of lithium aluminum hydride in 15 mL of ether. After being stirred for 50 min at room temperature, the reaction mixture was quenched by addition of, successively, 0.16 mL of H_2O, 0.16 mL of 15% NaOH, and 0.48 mL of H_2O. The resultant slurry was stirred 45 min and filtered. The salts were washed two times with ether, and the filtrate was evaporated to give 0.69 g (3.6 mmol) of **39** (78%) and **40** (18%) as a colorless liquid. A 69% yield of tetraol was obtained, based on the aldols **30e** and **31e**: IR (thin film) 3400, 1380, 1370, 1260, 1220, 1160, 1060, 1040, 990, 860 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.96 (3 H, d, J = 8), 1.34 (3 H, s), 1.40 (3 H, s), 1.85 (1 H, m), 3.3–4.1 (6 H, m); ^{13}C NMR ($CDCl_3$) δ 10.2, 10.4 (minor), 25.1, 26.5, 36.7, 37.9 (minor), 65.3 (minor), 66.2, 66.8, 72.8 (minor), 73.7, 76.3, 77.2 (minor), 108.9, 109.4 (minor).

Anal. Calcd for $C_9H_{18}O_4$: C, 56.82; H, 9.54. Found: C, 56.56; H, 9.62.

(2*R*,3*S*)-1,2-*O*-Isopropylidene-4-methylpentane-1,2,3,5-tetraols 39 and 41. To a stirred solution of 0.085 g (2.2 mmol) of lithium aluminum hydride in 8 mL of ether was added a solution of 0.43 g (2.0 mmol) of aldols **30a** (60%) and **32a** (40%) in 2 mL of ether. After the mixture was stirred for 23 h at room temperature, the reaction was quenched with, successively, 85 μL of H_2O, 85 μL of 15% NaOH, and 255 μL of H_2O. The resultant slurry was stirred 2 h and filtered. The salts were washed two times with ether, and the filtrate was evaporated to give 0.32 g (85%) of diols **39** (60%) and **41** (40%) as a colorless oil. An analytical sample was prepared by chromatography on silica gel, eluted with ether: IR (thin film) 3400, 1380, 1370, 1260, 1220, 1160, 1060, 860, 850 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.89 (3 H, d, J = 7), 0.94 (3 H, d, J = 7), 1.32 (3 H, s), 1.37 (3 H, s), 1.8 (1 H, m), 3.4–4.2 (complex m); ^{13}C NMR ($CDCl_3$) δ 10.2, 13.4 (minor), 25.1, 26.3 (minor), 26.5, 36.7, 65.2 (minor), 66.4, 66.8, 73.9, 75.5 (minor), 76.3, 76.7 (minor), 109.1.

Anal. Calcd for $C_9H_{18}O_4$: C, 56.82; H, 9.54. Found: C, 56.69; H, 9.64.

(3*S*,4*R*)-3-Hydroxy-4-(hydroxymethyl)-2-methyldihydro-1(2*H*)-furanones 43 and 44. The aldols **30e** (60%) and **31e**

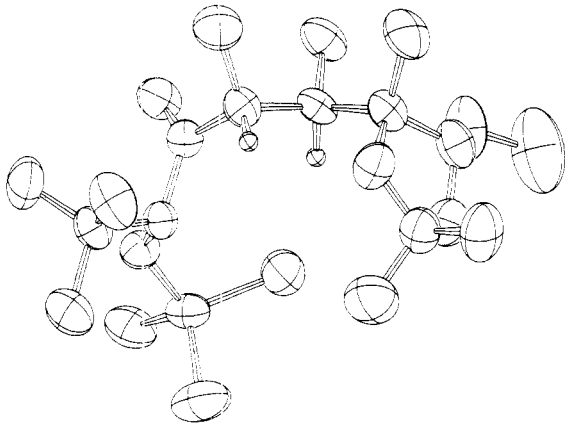


Figure 1. Perspective view of the molecular structure of aldol **48**. For clarity, hydrogens are shown only on C-5 and C-6.

(40%) (1.02 g, 4.7 mmol) were dissolved in 20 mL of 60% aqueous acetic acid, and the mixture was stirred at room temperature overnight. The solvents were removed (bath temperature 40–70 °C) in vacuo to give 0.6 of **43** (60%) and **44** (40%) as a yellow oil. The product was purified by chromatography on silica gel, eluted with ethyl acetate to give 0.2 g (30%) of pure **43** and **44** as a colorless oil: ^{1}H NMR (180 MHz, $CDCl_3$) δ 1.04 (3 H, d, J = 7.1, minor), 1.14 (3 H, d, J = 7.36), 2.56 (1 H, dq, J = 7.36, 8.85), 2.80 (1 H, dq, J = 5.94, 7.10, minor), 3.4–4.3 (series of complex multiplets); ^{13}C NMR (Me_2SO-d_6) δ 8.3 (minor), 12.5, 39.1 (minor), 43.2, 60.0, 60.9 (minor), 70.1 (minor), 73.1, 84.6, 86.9 (minor), 177.1, 179.2 (minor).

(3*S*,4*R*)-3-Acetoxy-4-(acetoxymethyl)-2-methyldihydro-1(2*H*)-furanone. To a solution of 0.20 g (1.4 mmol) of diol lactones **43** (60%) and **44** (40%) in 10 mL of pyridine was added 2.0 mL of acetic anhydride, and the mixture was warmed to 40 °C for 1 h. The reaction mixture was poured into H_2O and extracted two times with ether. The ether layers was combined, washed one time with water, dried ($MgSO_4$), and evaporated to give 0.23 g (71%) of the diacetate. The product was purifed by chromatography on silica gel, eluted with 50% ether in hexanes to yield 0.20 g (62%) of the pure diacetate (60:40) as a colorless oil: IR (thin film) 1780 (br), 1760 (br), 1380, 1230 (br), 1180, 1060 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.24 (3 H, d, J = 8), 1.36 (3 H, d, J = 7), 2.06 (3 H, s), 2.10 (3 H, s), 2.8 (1 H, m), 4.2–4.6 (m), 4.98 (1 H, dd, J = 4.8, 5.7), 5.32 (1 H, dd, J = 6.9, 1.2); ^{13}C NMR ($CDCl_3$) δ 8.5 (minor), 13.6, 20.4, 37.4 (minor), 41.3, 62.9 (minor), 63.0, 72.6 (minor), 76.1, 79.5, 80.4 (minor), 170.0, 170.1 (minor).

Anal. Calcd for $C_{10}H_{14}O_6$: C, 52.17; H, 6.13. Found: C, 51.95; H, 6.17.

6,7-*O*-Isopropylidine-5,6,7-trihydroxy-2,4,6-trimethyl-2-[(trimethylsilyl)oxy]-3-nonanones 45 and 46. To 1.75 mL of a 0.633 M solution of LDA at −70 °C was added over 5 min 0.221 mL (1 mmol) of ketone **9**. After 30 min, aldehyde **5** (177 μL, 1.0 mmol) was added over a 3-min period. After an additional 15 min, 1 mL of saturated $NaHCO_3$ was added. The mixture was diluted with brine and then extracted with Et_2O (3 × 10 mL). The organic phase was dried over $MgSO_4$. Filtration and solvent removal gave 302 mg of an oil containing a 3:1 mixture of diastereomers (assayed by ^{13}C NMR). Preparative TLC (SiO_2, eluant 30% Et_2O/hexane) gave **45** (R_f 0.38). Crystallization from hexane gave pure **45**: mp 79–80 °C; IR (1% in $CHCl_3$) 3520, 1690, 1435, 1360, 1250, 1200, 1140 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.7–4.0 (2 H, m), 3.65 (1 H, dd, J = 8, 4.5), 2.90 (1 H, d, J = 3), 1.6–1.9 (2 H, m), 1.36 (3 H, s), 1.33 (6 H, s), 1.32 (3 H, s), 1.31 (3 H, s), 1.18 (3 H, d, J = 7), 1.03 (3 H, t, J = 7), 0.2 (9 H, s); ^{13}C NMR ($CDCl_3$) δ 221.5, 106.9, 87.9, 82.7, 80.5, 70.9, 39.3, 28.4, 28.1, 27.9, 26.5, 22.0, 12.0, 11.7, 2.3.

Anal. Calcd for $C_{18}H_{36}O_5Si$: C, 60.01; H, 9.99. Found: C, 59.89; H, 9.88.

Pure diastereomer **46** (R_f 0.44) was not obtained.

7,8-*O*-Isopropylidine-6,7,8-trihydroxy-2,2,5,7-tetramethyl-3-[(trimethylsilyl)oxy]-4-decanone (48). To 52 mL of a 0.4 M solution of LDA in THF was added at −70 °C over a 5-min period 4.38 mL (3.83 g, 17.7 mmol) of 2,2-dimethyl-3-[(trimethylsilyl)oxy]-4-hexanone. After the mixture was stirred for 2 h, 3.13 mL (17.7 mmol) of the aldehyde **5** was added. After 25 min, 20 mL of saturated $NaHCO_3$ was added. The mixture was diluted with brine and then extracted with Et_2O (3 × 50 mL). The ether phase was washed with 220 mL of 10% HCl and then dried over $MgSO_4$. Solvent removal in vacuo gave an oil (6.1 g) from which 2.1 g (31%) of a single aldol crystallized. The remaining oil, which consisted mostly of uncondensed starting material, was subjected to column chromotography (120 g of silica gel, 10% Et_2O–hexane) to give 1.212 g of a forerun fraction (R_f 0.46), the product (0.9 g, 13%, R_f 0.17), and a third component (0.3 g, R_f 0.12) which was a mixture of aldehyde **5** and product **48**: mp 81.5–82.5 (hexane). The total yield of purified **48** was 44%: IR (1% in $CDCl_3$) 3500, 1700, 1685, 1455, 1370, 1250, 1100, 840 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.80 (1 H, s), 3.70 (1 H, m), 3.55 (1 H, m), 2.95 (1 H, d, J = 2), 1.65 (2 H, m), 1.40 (3 H, s), 1.37 (3 H, s), 1.30 (3 H, s), 1.15 (3 H, d, J = 7), 1.00 (3 H, t, J = 7), 0.95 (9 H, s), 0.15 (9 H, s); ^{13}C NMR ($CDCl_3$) δ 219.5, 107.0, 88.4, 85.3, 82.7, 69.1, 42.2, 36.0, 28.5, 26.8, 26.4, 21.9, 21.1, 11.7, 11.0, 0.38.

Anal. Calcd for $C_{20}H_{40}O_5Si$: C, 61.79; H, 10.38. Found: C, 62.10; H, 10.17.

Desilylation of Aldol 48. To 257 mg (0.662 mmol) of silyloxy ketone **48** was added 4 mL of MeOH and 150 mg (1.6 mmol) of KF·2H_2O. The mixture was stirred overnight at room temperature, and the methanol was then removed in vacuo. The residue was taken up in ether and filtered. After solvent removal the filtrate gave 205 mg (98%) of product. Recrystallization from hexane gave white needles: mp 122.5–123 °C; IR (1% in $CHCl_3$) 3480, 1690, 1650, 1450, 1370, 1090, 1000 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 4.00 (1 H, s), 3.67 (1 H, m), 3.65 (1 H, m), 3.2 (1 H, quintet, J = 6), 2.15 (1 H, d, J = 13), 1.70 (1 H, m), 1.70 (2 H, m), 1.30 (6 H, s), 1.30 (3 H, s), 1.15 (3 H, d, J = 7), 1.05 (3 H, t, J = 7), 1.00 (9 H, s).

Anal. Calcd for $C_{17}H_{32}O_5$: C, 64.5; H, 10.2. Found: C, 64.22; H, 9.95.

7,8-*O*-Isopropylidine-2,2,5,7-tetramethyldecane-3,4,6,7,8-pentaols 50 and 51. Method a. To 51 mg (1.35 mmol) of $LiAlH_4$ in 4 mL of dry Et_2O at −70 °C was added 261 mg (0.673 mmol) of silyloxy ketone **48** in 1 mL of Et_2O. When the addition was complete, the bath was removed and the reaction allowed to warm to room temperature. After a total reaction time of 45 min, 50 μL of H_2O, 50 μL of 15% NaOH, and 150 μL of H_2O were sequentially added. After the mixture was stirred for 5 min, $MgSO_4$ was added, the mixture was filtered, and the residue was washed with several portions of $CHCl_3$. Solvent removal gave an oil which was stirred overnight with 3 mL off MeOH and 130 mg (1.4 mmol) of KF·H_2O. Solvent removal in vacuo gave an oil which was taken up in ether, filtered, and reduced in vacuo to give a 3:1 mixture of triols (206 mg, 96%), the major isomer **50** being the less polar (R_f 0.21, 0.13; 20% ethyl acetate–hexane). At length, the major isomer was induced to crystallize from $CHCl_3$: mp 116.5–117.5 °C; IR (1% in $CHCl_3$) 3500, 1450, 1375, 1365, 1180, 1100 cm^{-1}; ^{1}H NMR (acetone-d_6) δ 4.15 (1 H, m), 3.75 (1 H, m), 3.55 (3 H, m), 3.20 (2 H, m), 2.70 (1 H, m), 1.65 (2 H, m), 1.30 (3 H, s), 1.25 (6 H, s), 1.00 (3 H, d, J = 7), 1.00 (3 H, t, J = 7), 0.90 (9 H, s); ^{13}C NMR (acetone-d_6) δ 105.3, 87.2, 75.7, 71.2, 67.9, 37.0, 26.9, 25.3, 25.2, 24.6, 20.8, 19.4, 11.1, 10.3.

Anal. Calcd. for $C_{17}H_{34}O_5$: C, 64.1; H, 10.77. Found: C, 64.09; H, 10.9.

Method b. To 110 mg (2.9 mmol) of $LiAlH_4$ in 6 mL of dry Et_2O at room temperature was added 304 mg (0.962 mmol) of dihydroxy ketone **14** in 1 mL of Et_2O. After the mixture was stirred for 0.5 h, 0.11 mL of H_2O, 0.11 mL of 15% NaOH, and 0.35 mL of H_2O were sequentially added to the mixture. The mixture was stirred 10 min, $MgSO_4$ was added, and the mixture was filtered and then reduced in vacuo to yield 304 mg (99%) of the more polar isomer **51** (R_f 0.13). The less polar isomer was not detected by ^{13}C NMR (acetone-d_6) δ 87.1, 77.6, 75.0, 34.0, 27.3, 26.1, 25.5, 24.8, 21.0, 18.8.

(2*SR*,3*SR*,4*SR*,5*SR*)-4,5-*O*-Isopropylidine-3,4,5-trihydroxy-2-methylheptanal (49). Method A. To a solution of triol **50** (0.775 g, 2.44 mmol) in 18 mL of ethanol at 0 °C was added 36.6 mL (7.32 mmol) of a precooled 0.2 M solution of $NaIO_4$ in H_2O. After 1 h of rapid stirring at 0 °C a copious white precipitate had appeared. One volume of H_2O was added to the mixture. The aqueous phase was extracted with $CHCl_3$ (6 × 30 mL). The combined organic phases were dried over $MgSO_4$. Filtration

followed by solvent removal in vacuo gave 417 mg (84%) of aldehyde **49**: IR (thin film) 3460, 1715 cm^{-1}; ^1H NMR ($CDCl_3$) δ 9.5 (1 H, d, J = 2), 4.03 (1 H, t, J = 5), 3.6 (1 H, dd, J = 9, 5), 2.8 (1 H, m), 1.75 (3 H, m), 1.34 (6 H, s), 1.30 (3 H, s), 1.15 (3 H, d, J = 7), 1.03 (3 H, t, J = 7); ^{13}C NMR ($CDCl_3$) δ 203.0, 107.2, 86.8 (m), 92.4, 70.5, 48.6, 28.2, 26.2, 22.1, 19.5, 11.9, 10.1; mass spectrum m/e (relative intensity) 215 (0.56), 197 (0.12), 157 (1.66), 143 (6.75).

Method B. To a solution of $LiAlH_4$ (18 mg, 0.47 mmol) in 5 mL of ether was added aldol **45** (56 mg, 0.156 mmol) in 1 mL of ether. After the mixture was stirred for 1 h at room temperature, 0.2 mL of H_2O, 0.2 mL of 15% NaOH, and 0.6 mL of H_2O were added sequentially to the mixture. After the precipitate turned white, the solution was filtered off and the residue washed several times with $CHCl_3$. The filtrate was concentrated to an oil, and 5 mL of CH_3OH and a catalytic quantity of K_2CO_3 were added. The mixture was refluxed for 0.5 h and cooled, and the solvent was removed in vacuo, giving 44 mg (98%) of desilylated triol. This triol was treated with $NaIO_4$ as in part A to give an aldehyde identical with that obtained by cleavage of triol **50** by ^1H NMR, ^{13}C NMR, and TLC.

Crystal Structure of Aldol 48. Crystallographic Data Collection. Two crystals of aldol **48**, both with approximate dimensions 0.7 × 0.4 × 0.4 mm were mounted on a glass fiber with epoxy cement such that the longest crystal dimension was approximately parallel to the fiber axis. The first crystal decomposed significantly after about half of the data set, and the remaining data were collected on the second crystal.

Unit cell parameters and the orientation matrix were determined on a Syntex $P2_1$ four-circle diffractometer equipped with a graphite monochromator (Bragg 2θ angle 12.2°) and using Mo Kα radiation at a takeoff angle of 6.75°. Fifteen reflections whose 2θ values ranged from 8.86 to 18.12° were machine centered and used in least-squares refinement of the lattice parameters and orientation matrix. The unit cell parameters obtained were a = 9.050 (2) Å,[23] b = 11.538 (3) Å, c = 13.741 (3) Å, α = 109.95 (2)°, β = 100.41 (2)°, γ = 108.68 (2)°, and V = 1207.9 (5) Å^3. The calculated density of 1.07 g cm^{-3} for 2 formula units per unit cell agrees with the experimental density of 1.08 g cm^{-3} measured by the flotation method using a mixture of $ZnCl_2$ and H_2O. ω scans of several low 2θ angle reflections gave peak widths at half-height of less than 0.13°, indicating a satisfactory mosaic spread for the crystal.

Axial photographs indicated that the crystal belonged to the triclinic system. Intensity data for zero and upper levels were collected at a rapid scan rate and the intensities examined carefully for systematic absences. No systematic absences were observed, which is consistent with space group $P1$ or $P\bar{1}$ (No. 1 or 2).[24] Our initial choice of $P\bar{1}$ was confirmed by successful refinement in that space group.

Intensity data were collected by using θ–2θ scans with the X-ray source and monochromator settings identical with those used for determination of the unit cell parameters. A variable scan rate of from 3.91 to 29.3° per minute was used, and a scan width of 2.0° was sufficient to collect all of the peak intensity. Stationary background counts were measured at the beginning and at the end of each scan with a total background to scan time ratio of 1.0. A constant decrease was observed in the intensities of three standard reflections (030, 005, and 200) monitored every 97 reflections, and a linear decomposition correction was applied. From a total of 4272 reflections collected in a complete hemisphere of data (our 2θ = 50°), 2721 were accepted as statistically above background on the basis that F was greater than $5\sigma(F)$. Lorentz and polarization corrections were made in the usual way.

Solution and Refinement of the Structure. Computations were performed by using standard programs;[25] all computations were carried out on the CDC Cyber 74 system. For structure factor calculations the scattering factors were taken from Cromer and Waber's tabulation.[26] The scattering factor(s) for all atoms except hydrogen were corrected for the real and imaginary anomalous despersion components.[26] The agreement factors are defined in the usual way as shown in eq 1 and 2. In all least-squares

$$R = (\Sigma||F_o| - |F_c||)/(\Sigma|F_o|) \quad (1)$$

$$R_w = \Sigma(|F_o| - |F_c|)w^{1/2}/\Sigma(|F_o|)w^{1/2} \quad (2)$$

refinements, the quantity minimized was $\Sigma(|F_o| - |F_c|)^2$. A weighting scheme based on counting statistics, $w = 2.7/[\sigma(F)^2 + 0.0004F^2]$, was employed for calculating R_w and in least-squares refinement.

The silicon position was determined from a sharpened Patterson function. The coordinates of the oxygen, carbon, and hydroxy hydrogen atoms were located from difference Fourier maps. The positions of the remaining hydrogens were calculated by using the riding mode of the SHELX-76 program. A total of 247 parameters were varied, including a scale factor, the coordinates, the anisotropic thermal parameters for all nonhydrogen atoms, and the isotropic temperature factors for the hydrogens. However, only one overall temperature factor was varied when hydrogens occurred in chemically similar groups (i.e., hydrogens in the *tert*-butyl group). The full-matrix, least-squares refinement converged with R = 0.067 and R_w = 0.071. The final positional and thermal parameters, a list of bond lengths, and a list of bond angles are available in Tables IV, V, VI, and VII in the supplementary material.[27]

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Registry No. (±)-**1**, 74262-56-9; (±)-**2**, 41954-96-5; (±)-**3**, 74310-50-2; **4**, 15186-48-8; DL-**5**, 72523-81-0; **6**, 75-97-8; **7**, 564-04-5; **8**, 55816-60-9; **9**, 72507-50-7; **10**, 79-20-9; **11**, 554-12-1; **12**, 29311-34-0; **13**, 72959-50-3; (±)-**14**, 74262-57-0; (±)-**15**, 74262-58-1; (±)-**16**, 74262-59-2; (±)-**17**, 74262-60-5; DL-*erythro*-**18**, 74262-61-6; DL-*threo*-**18**, 74262-62-7; DL-**19**, 56709-62-7; DL-**20**, 74310-51-3; DL-**21a**, 74262-63-8; DL-**21b**, 74262-64-9; DL-**21c**, 74262-65-0; DL-**22a**, 74262-66-1; DL-**22b**, 74262-67-2; DL-**22c**, 74262-68-3; DL-**23a**, 74262-69-4; DL-**23b**, 74262-70-7; DL-**23c**, 74262-71-8; DL-**24a**, 74262-72-9; DL-**24b**, 74262-73-0; DL-**24c**, 74262-74-1; DL-**25**, 74262-75-2; DL-**26**, 74262-76-3; DL-**28a**, 74262-77-4; DL-**28b**, 74262-78-5; (±)-**28c**, 74262-79-6; (±)-**28d**, 74262-80-9; DL-**29a**, 74262-81-0; DL-**29b**, 74262-82-1; (±)-**29c**, 74262-83-2; (±)-**29d**, 74262-83-2; DL-**30a**, 74262-84-3; DL-**30b**, 74262-85-4; DL-**30c**, 74262-86-5; DL-**30e**, 74262-87-6; DL-**31b**, 74262-88-7; DL-**31c**, 74262-89-8; DL-**31e**, 74262-90-1; DL-**32a**, 74262-91-2; DL-**32b**, 74262-92-3; DL-**32c**, 74262-93-4; DL-**33b**, 74262-94-5; **34**, 74310-52-4; DL-**35**, 18546-36-6; DL-**36**, 40156-57-8; DL-**37**, 74262-95-6; DL-**38**, 74262-96-7; (±)-**39**, 74262-97-8; DL-**40**, 74310-53-5; DL-**41**, 74310-54-6; (±)-**42**, 74310-55-7; DL-**43**, 74262-98-9; DL-**44**, 74262-99-0; DL-**45**, 72507-48-3; DL-**46**, 72523-88-7; (±)-**48**, 72507-49-4; desilylated (±)-**48**, 74263-00-6; DL-**49**, 74263-01-7; (±)-**50**, 74263-02-8; (±)-**51**, 74310-56-8; 3-hydroxy-3-methylbutan-2-one, 115-22-0; *tert*-butyldimethylsilyl chloride, 18162-48-6; (±)-2-methyl-4-hydroxy-2-pentene, 53177-37-0; benzyl bromide, 100-39-0; propanal, 123-38-6; 2,6-di-*tert*-butyl-4-methylphenol, 128-37-0; propionyl chloride, 79-03-8; (*R*)-glyceraldehyde acetonide, 15186-48-8; 2-methyl-3-hydroxy-4-(benzyloxy)-pentanoic acid, 74263-03-9; allyl bromide, 106-95-6; 4,6-dimethyl-1,2-*O*-isopropylideneheptane-1,2,3,5,6-pentaol, 74282-43-2; 4,5-*O*-isopropylidene-3,4,5-trihydroxy-2-methylpentanal, 74263-04-0; 2,2-dimethyl-3-[(trimethylsilyl)oxy]-4-hexanone, 74263-05-1.

Supplementary Material Available: Structure with numbering scheme of aldol **48**, tables of atomic coordinates and thermal parameters (Tables IV and V), and tables of bond lengths and bond angles (Tables VI and VII) (6 pages). Ordering information is given on any current masthead page.

(23) Numbers in parentheses here and in the supplementary material tables indicate estimated standard deviations in the least signficant digit(s).

(24) "International Tables for X-ray Crystallography", Vol. I, Kynoch Press, Birmingham, England, 1952.

(25) The programs utilized were Sheldrick's SHELX-76, Johnson's ORTEP, Main, Germain, and Woolfoon's MULTAN, and Zalkin's FORDAP.

(26) "International Tables for X-ray Crystallography", Vol. IV, Kynoch Press, Birmingham, England, 1974, pp 99–101, 149–150.

(27) See the paragraph at the end of the paper regarding supplementary material.