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SECOND GENERATION α-ENONES FROM A PYRANOSIDIC α-ENONE*

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ABSTRACT

The Diels–Alder product from the reaction of methyl 2,3,6-trideoxy-α-D-*glycero*-hex-2-enopyranosid-4-ulose (**1b**) with *trans*-1-methoxy-3-*tert*-butyldimethylsilyloxy-1,3-butadiene is **3b** (93%). Reaction of **3b** with sodium borohydride causes reduction of the C-4 carbonyl group only, but, with lithium aluminum hydride, further reactions occur which can be rationalized by fragmentation brought about by hydride cleavage on the silicon–oxygen bond, with simultaneous ejection of the β-methoxyl group complexed to a trivalent aluminum species. The enone resulting from this fragmentation also reacts further with lithium aluminum hydride, and several products result. The behavior of postulated intermediates, which have been prepared separately and subjected to the reaction conditions, supports the proposed reaction mechanisms. The "second generation" enone (methyl 2,3,6-trideoxy-α-D-talopyranosido)-[3,2-*d*]-2-cyclohexenone (**10a**), arising from the first generation precursor **1b**, has been prepared by two routes.

INTRODUCTION

We reported recently that carbohydrate α-enones undergo Diels–Alder addition to butadiene with exclusive β-D-face stereoselectivity[1]. Although the addition products are formally oxa-*cis*-decalins, they gave no evidence of conformational mobility, and, as a consequence, they open the way for further stereocontrolled reactions. An interesting substrate for testing this notion would be an enone such as **10a**[2], the reactions of which should be as stereoselective as those of its monocyclic progenitor, the enosidulose **1**. Danishefsky's diene[3] (**2a**) has been devised for converting "first generation" α-enones into their "second generation" counterparts,

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*For a preliminary account of this work, see ref. 2.
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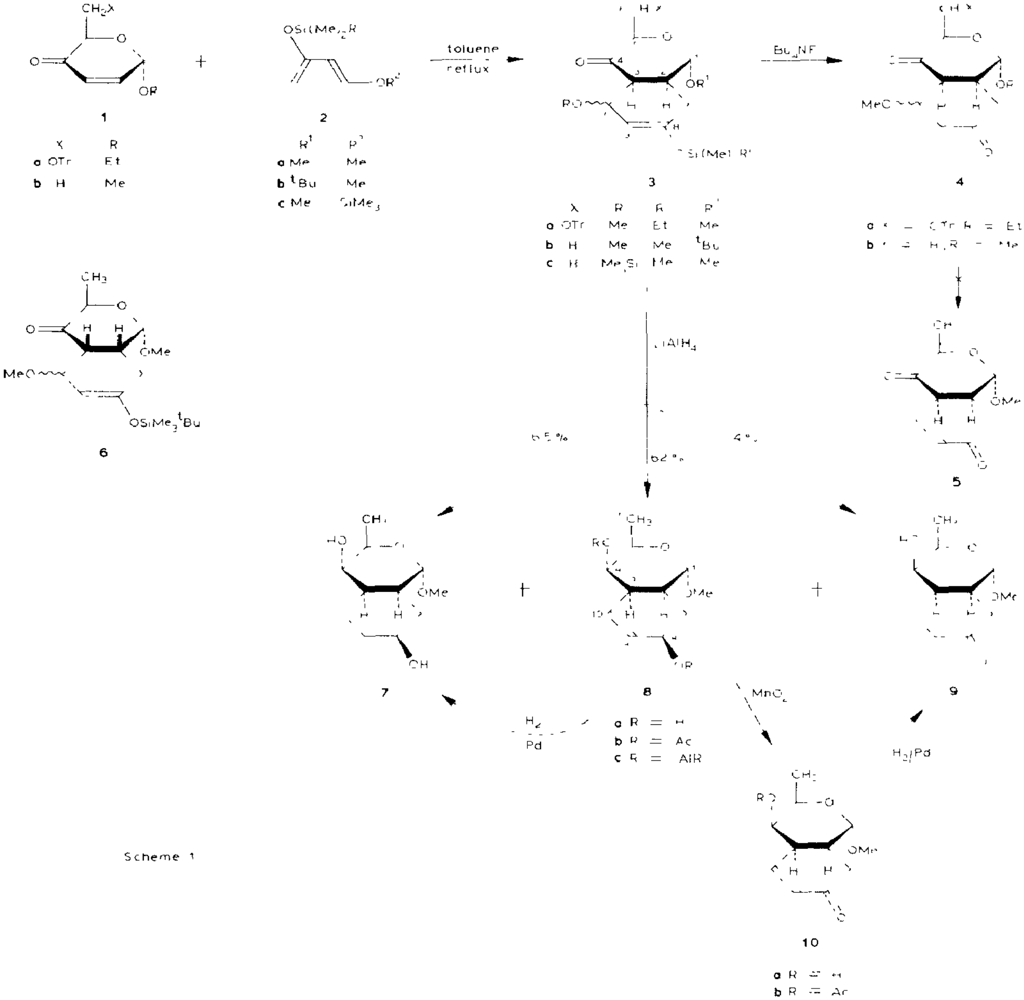
and it has been successfully applied to carbocyclic substrates[4]. We now report application of that methodology to **1**.

The reaction of the 6-*O*-tritylenosidulose **1a**[5] with Danishefsky's diene **2a**[2] in refluxing toluene gave a mixture of products (t.l.c.) which decomposed on attempted column chromatography on silica gel. On the assumption that this lability was due to the sensitive silyloxyalkene residue, the crude adduct was treated with tetrabutylammonium fluoride. Although this caused gross decomposition, a trace of the diketone **4a** could be isolated which confirmed the presence of **3a*** in the crude Diels–Alder product. Attempts at base-induced elimination of methanol from **4a** resulted in decomposition. On the other hand, the use of acidic conditions,



Scheme 1

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*The regiochemistry of Diels–Alder reactions involving Danishefsky's diene (*e.g.*, **1** + **2**→**3**) is well-precedented[3,4,6].

found successful by Danishefsky and co-workers[4,6], was precluded by the presence of acid-labile groups in the sugar moiety of **4a**.

Various changes were therefore made in the hope of obtaining a more amenable series of substrates. Thus, the 6-deoxy sugar **1b**[7] was treated with the more stable *tert*-butyldimethylsilyl analog **2b*** in refluxing toluene for 24 h. After chromatography, **3b** was obtained (93%). The material appeared homogeneous in t.l.c., but analytical h.p.l.c. (1% methanol in dichloromethane) revealed two components in the ratio 2.3:1. The 600-MHz, ^{1}H-n.m.r. spectrum showed two methoxy signals at δ 3.27 (major) and 3.30. There were also signals for two anomeric hydrogens at δ 4.70 and 4.34 (J 6.6 and 1 Hz, respectively). Although these parameters did not exclude the α-D-face adduct **6** *per se,* for each of the transformation products in which the C-4 carbonyl was reduced *(vide infra)* the resonance of H-1 was a singlet. As noted previously[1], this datum indicates that H-1 and H-2 are both equatorial, and shows that the Diels–Alder addition must have occurred from the β-D-face only.

Reaction of the adduct **3b** with tetrabutylammonium fluoride stopped at the β-methoxy ketone stage, **4b**, thereby failing to yield the α-enone **5**. Attempts to induce acid-catalysed removal of methanol from **4b** caused gross decomposition.

The above-mentioned attempts to convert **4b** into **5** were undoubtedly complicated by the fact that **5** is a vinylogous β-diketone and, therefore, would be exceedingly base-labile. In order to remove this difficulty, the carbonyl group of **3b** was reduced with lithium aluminum hydride, a previous study[1] on the less highly functionalized, annulated pyranosides having shown that a single configuration would be generated at C-4. However, a complex mixture containing a major and several minor products was obtained. Chromatography afforded the major product (62%) as a crystalline material whose elemental analysis was consistent with the formula **8a**. That the crude product was a mixture of isomers was revealed by the 600-MHz, ^{1}H-n.m.r. spectrum which showed two signals for anomeric methoxyl groups at δ 3.27 and 3.30 in the ratio 9:1. The minor product could be easily removed by fractional crystallization. The center of epimerism was evidently the C-8 allylic alcohol, since oxidation of the crude product with manganese dioxide gave a single enone, **10a**, the stereochemistry of which was established with the help of double irradiation experiments on the acetate **10b**. The signal for H-4 (δ 5.02) had a $w_{1/2}$ value of 6.0 Hz, indicative of an equatorial H-4. In the diacetate **8b**, the H-4 parameters were δ 4.90, $w_{1/2}$ 6.0 Hz. The structure of the major isomer was assumed to be **8a** with HO-8 (as well as HO-4) on the *endo*-face of the oxa-*cis*-decalin surface, as would be expected from the addition of hydrogen from the convex face.

Another fraction contained the saturated hydroxy ketone **9** (3.3%), the relationship of which with **10a** was established by hydrogenating the double bond.

The third fraction afforded the saturated diol **7** (6.5%) which was identified by hydrogenation of the unsaturated counterpart **8a**.

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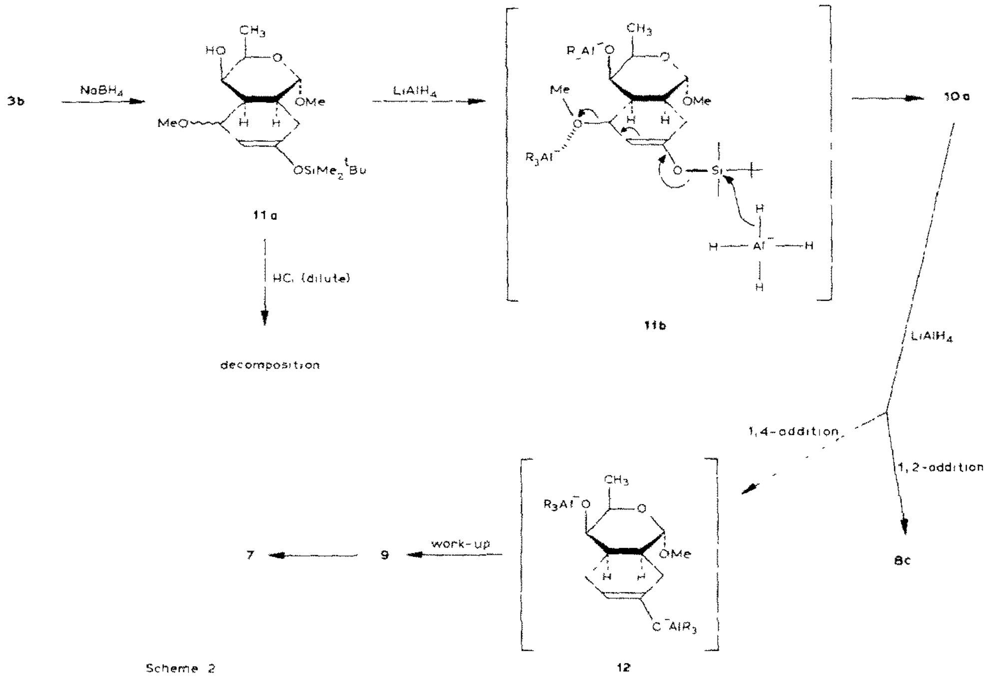
*We are grateful to Professor R. E. Ireland for details of the preparation of **2b**.

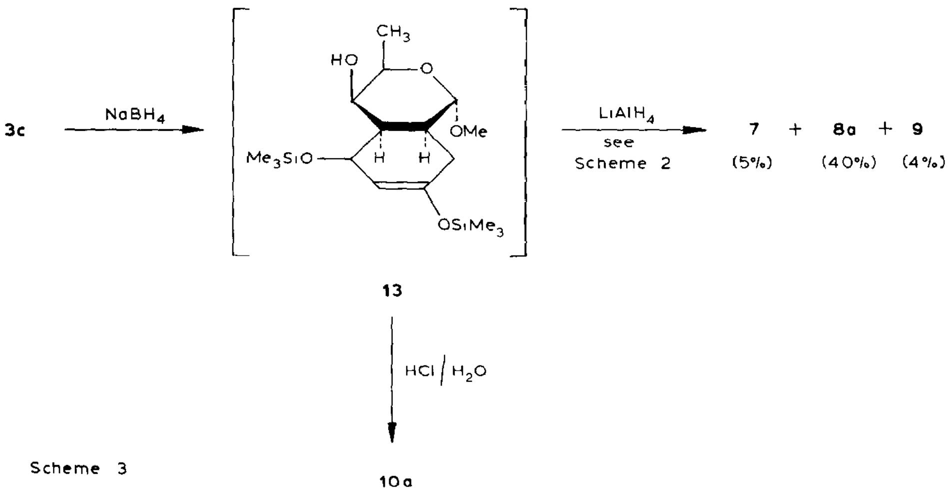


Scheme 2

Mechanism. — The formation of **7**, **8a**, and **9** in the reduction of **3b** with lithium aluminum hydride was puzzling. If the enone **10a** were an intermediate, then **8a** and **9** could arise, respectively, by 1,2- and 1,4-additions of hydride. A mechanism whereby **10a** could arise from **3b**, shown in Scheme 2, requires the intermediacy of **11a**. It is suggested (*a*) that the methoxyl of **11a** becomes a good leaving-group because of complexation with trivalent aluminum, and (*b*) that cleavage of the silicon–oxygen bond is induced by hydride ion. Both processes have precedents as separate events in the literature, the former in the synthesis of cedrol by Stork and Clark[8], and the latter in the work of Beely *et al.*[9]. Operation of both events in tandem would cause the fragmentation depicted by the arrows in **11b**, and subsequent 1,4-addition of hydride to **10a** would afford the enolic complex **12**, a portion of which survives until work-up, when hydrolysis leads to **9**. The portion of **12** which ketonises is reduced further to the saturated diol **7**.

It was established that treatment of **10a** with lithium aluminum hydride under the reaction conditions did, in fact, give **7**, **8a**, and **9**, as required by the mechanistic suggestions above. In order to test the more speculative fragmentation, a reliable supply of **11a** was needed, and this was obtained by reducing **3b** with sodium borohydride. Indeed, treatment of **11a** with lithium aluminum hydride in tetrahydrofuran for 18 h gave **7**, **8a**, and **9**, in yields of 5, 40, and 4%, respectively, after isolation.

The desired "second generation" enone **10a** had been obtained by oxidation of diol **8a** with manganese dioxide. This oxidation could also be carried out smoothly with pyridinium dichromate, which is further evidence for the extremely hindered nature of HO-4, as noted previously for similar systems[1]. A more direct route to **10a** was required, but attempts to expose the enone moiety of **11a**, by treatment with dilute hydrochloric acid, led to decomposition, probably because the conditions for cleaving the *tert*-butyldimethylsilyl ether were too severe.



Scheme 3

It was the lability of the trimethylsilyl group in **3a** during chromatography that prompted the preparation of the more stable analog **3b**; presumably, a bis-trimethylsilylated system would be sufficiently labile, so that the α-enone would be readily exposed. Accordingly, the enone **1b** was treated with the bis(trimethylsilyloxy)diene **2c*** at room temperature until the reaction was complete (2 days as judged by t.l.c.), presumably with the formation of **3c**. A solution of sodium borohydride in 2-propanol was then added. After 4 h, t.l.c. revealed a more polar product, presumably **13**, and the solution was brought to pH 3 by the addition of 0.1M hydrochloric acid and processed after storage at room temperature for 8 h. There were then several components, but 30% of **10a** was isolated by chromatography. Clearly the route to **10a** *via* **8a** is preferable.

EXPERIMENTAL

General. — Melting points were determined in capillary tubes, using a Büchi Model 510 apparatus, and are uncorrected. Elemental analyses were performed either by Guelph Chemical Labs. (Guelph, Ontario) or by Dr. F. Kasler (Department of Chemistry, University of Maryland). ^{1}H-N.m.r. spectra were recorded for solutions in $CDCl_3$ (internal Me_4Si), unless otherwise stated, with one of the follow-

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*We are grateful to Professor T. R. Kelly for releasing details for preparation of **2c** prior to publication (ref. 10).

ing spectrometers: Varian EM-360, XL-100, XL-200, HR-220, XL-360, or Bruker WH-400. Coupling constants were measured directly from the spectra or calculated from the peak listings. I.r. spectra for films or solutions were recorded with either a Beckman IR-10 or a Perkin–Elmer 298 spectrometer. Low-resolution mass spectra were obtained with a Hitachi/Perkin–Elmer RMH-2 instrument, and high-resolution mass spectra were obtained with a VG 7070F instrument. Optical rotations were determined with a Perkin–Elmer 241 polarimeter. T.l.c. was performed on Silica Gel HF-254 (0.2-mm layers) containing a fluorescent indicator (Merck, 5539), with detection by u.v. (254 nm) or charring with sulfuric acid. Column chromatography was effected on silica gel (Merck 70–230 mesh A.S.T.M. or 230–400 mesh A.S.T.M.).

*(Methyl 2,3,6-trideoxy-α-*D-lyxo-*hexopyranosid-4-ulo)-[3,2-*d]*-3-*(R,S)*-methoxyl-1-(*tert*-butyldimethylsiloxy)cyclohexene* (**3b**). — A solution of methyl 2,3,6-trideoxy-α-D-*glycero*-hex-2-enopyranosid-4-ulose[6] (1.46 g, 10.3 mmol) and Danishefsky's diene (**2b**; 2.73 g, 12.7 mmol) in dry toluene (50 mL) was boiled under reflux under argon for 24 h. T.l.c. [light petroleum (b.p. 35–60°)–ethyl acetate, 7:3] revealed a major and a minor product. Evaporation of the solvent gave a viscous liquid which, on column chromatography, afforded a yellow oil (3.4 g, 93%) that was further purified by sublimation at 60°/0.44 mmHg to give **3b**, R_F 0.6 (light petroleum–ethyl acetate, 7:3); ν_{max}^{film} 1725 (carbonyl) and 1660 cm^{-1} (enol). ^{1}H-N.m.r. data (600 MHz): **3b** [10(*S*) configuration, major isomer], δ 0.10 (s, 6 H, Me_2Si), 0.90 (s, 9 H, Me_3C), 1.25 (d, 3 H, $J_{5,6}$ 6.0 Hz, H-6,6,6), 2.13 (ddd, 1 H, $J_{2,7}$ 3.75, $J_{7,7}$ 18 Hz, H-7*exo*), 2.25 (ddd, 1 H, $J_{2,7}$ 7.2 Hz, H-7*endo*), 2.47 (ddd, 1 H, $J_{1,2}$ 6.6, $J_{2,3}$ 5.5 Hz, H-2), 2.86 (t, 1 H, $J_{3,10}$ 5.5 Hz, H-3), 3.27 (s, 3 H, OMe), 3.50 (s, 3 H, OMe), 4.05 (m, 1 H, $J_{9,10}$ 4.5 Hz, H-10), 4.24 (q, 1 H, H-5), 4.70 (d, 1 H, $J_{1,2}$ 6.0 Hz, H-1), and 5.18 (dt, 1 H, $J_{9,11}$ 4.5 Hz, H-9); **3b** [10(*R*) configuration, minor isomer]: δ 0.10 (s, 6 H, Me_2Si), 0.90 (s, 9 H, Me_3C), 1.25 (d, 3 H, $J_{5,6}$ 6.0 Hz, 3 H-6), 1.98 (dd, 1 H, $J_{2,7}$ 6.5, $J_{7,7}$ 15 Hz, H-7*exo*), 2.09 (dd, 1 H, $J_{2,7}$ 11.0 Hz, H-7*endo*), 2.76 (dddd, 1 H, $J_{1,2}$ 1 Hz, $J_{2,3}$ 5 Hz, H-2), 3.22 (d, 1 H, $J_{9,10}$ 2 Hz, H-3), 3.30 (s, 3 H, OMe), 3.50 (s, 3 H, OMe), 4.27 (q, 1 H, H-5), 4.34 (dd, 1 H, $J_{9,10}$ 5 Hz, H-10), 4.59 (d, 1 H, $J_{1,2}$ 1 Hz, H-1), and 5.05 (d, 1 H, H-9).

Anal. Calc. for $C_{18}H_{32}O_4Si$: C, 60.64; H, 9.05. Found: C, 60.45; H, 9.35.

*(Methyl 2,3,6-trideoxy-α-*D-lyxo-*hexopyranosid-4-ulo)-[3,2*d]*-3-*(R,S)*-methoxycyclohexanone* (**4b**). — To a solution of **3b** (356.08 mg, 1 mmol) in dry tetrahydrofuran (10 mL) was added tetrabutylammonium fluoride (3 mL, 0.5M), and the mixture was stirred at room temperature for 1 h. Ether (25 mL) was added and the solution was passed through a short column of silica gel. Evaporation of the solvent and column chromatography of the residue on silica gel, using light petroleum (b.p. 35–60°)–ethyl acetate (7:3), gave **4b** as an oil (150 mg, 62%), R_F 0.60 (ethyl acetate–light petroleum, 3:7). ^{1}H-N.m.r. data ($CDCl_3$, 600 MHz): δ 1.33 (d, 3 H, $J_{5,6}$ 6.0 Hz, CH_3), 2.40 (dd, 2 H, $J_{2,7}$ 5.2 $J_{7,7'}$ 15.6 Hz, H-7,7'), 2.61 (d, 2 H, $J_{9,10}$ 3.0 Hz, H-9,9'), 2.97 (m, 1 H, H-2), 3.30 (s, 3 H, OMe aglycon), 3.40 (br, 1

H, H-3), 3.51 (s, 3 H, OMe), 4.31 (q, 1 H, H-10), 4.50 (q, 1 H, $J_{5,6}$ 11.00 Hz, H-5), and 4.54 (s, 1 H, H-1).

Reduction of **3b** *with lithium aluminum hydride.* — To a slurry of lithium aluminum hydride (1.05 g, 27.7 mmol) in dry tetrahydrofuran (100 mL) at 0° under argon stirred for 1 h, a solution of **3b** (2.5 g, 7 mmol) in dry tetrahydrofuran (20 mL) was added by a syringe. The mixture was stirred at 0° for 1 h and then for 40 h at room temperature. The excess of lithium aluminum hydride was decomposed with hydrated sodium sulfate, insoluble material was collected and washed with ether (200 mL), and the combined filtrate and washings were concentrated to a syrup (1.5 g). T.l.c. (0.5:9.5 methanol–chloroform) revealed one major and a number of minor products which were fractionated by column chromatography (methanol–chloroform, 1.5:98.5) to give **9** (60 mg, 4%), **8a** (930 mg, 62%), and **7** (98 mg, 6.5%), with R_F values 0.37, 0.18, and 0.11, respectively.

(Methyl 2,3,6-trideoxy-α-D-talopyranosido)-[2,3-*c*]-cyclohexanol (**7**) had m.p. 175–177° (from dichloromethane), $[\alpha]_D^{20}$ +71° (*c* 0.1, chloroform); $\nu_{max}^{CHCl_3}$ 3400 cm^{-1} (hydroxyl). ^{1}H-N.m.r. data (200 MHz): δ 1.20 (d, 3 H, CH_3), 1.40–2.0 (m, 8 H, H-2,3,7,7,9,9,10,10), 3.33 (s, 3 H, OMe), 3.40–3.70 (m, 2 H, H-4,8), 3.93 (q, 1 H, $J_{5,6}$ 10 Hz, H-5), and 4.45 (s, 1 H, H-1).

Anal. Calc. for $C_{11}H_{20}O_4$: C, 61.87; H, 9.32. Found: C, 61.88; H, 9.38.

(Methyl 2,3,6-trideoxy-α-D-talopyranosido)-[3,2-*d*]-(*R*)-cyclohex-2-enol (**8a**) had m.p. 80–81° [from chloroform–light petroleum (b.p. 35–60°)], $[\alpha]_D^{20}$ +145° (*c* 0.1, chloroform), R_F 0.175; $\nu_{max}^{CHCl_3}$ 3400 cm^{-1} (hydroxyl). ^{1}H-N.m.r. data (200 MHz): δ 1.25 (d, 3 H, $J_{5,6}$ 7.0 Hz, CH_3), 1.70–1.90 (m, 5 H, H-2,7,7 and 2 OH), 2.49 (m, 1 H, H-3), 3.35 (s, 3 H, OMe), 3.49 (br, 1 H, H-4), 4.0 (q, 1 H, H-5), 4.35 (m, 1 H, H-8), 4.50 (s, 1 H, H-1), 5.6 (m, 1 H, H-9), and 6.0 (dd, 1 H, $J_{9,10}$ 10 Hz, H-10).

Anal. Calc. for $C_{11}H_{18}O_4$: C, 61.66; H, 8.47. Found: C, 61.40; H, 8.70.

Conventional treatment of **8a** (50 mg, 0.23 mmol) with pyridine and acetic anhydride gave the diacetate **8b**, in the form of colorless needles, m.p. 60–61° (from pentane), $[\alpha]_D^{20}$ −40° (*c* 0.1, chloroform); ν_{max}^{Nujol} 1740 cm^{-1} (carbonyl). ^{1}H-N.m.r. data (100 MHz): δ 1.15 (d, 3 H, $J_{5,6}$ 6.0 Hz, CH_3), 2.04–2.09 (m, 8 H, H-7,7 and 2 OAc), 3.36 (s, 3 H, OMe), 4.0 (q, 1 H, $J_{5,6}$ 12.0 Hz, H-5), 4.40 (s, 1 H, H-1), 4.90 (b, 1 H, $w_{1/2}$ 6.0 Hz, H-4), 5.30 (m, 1 H, H-8), and 5.68 (br, 2 H, H-9,10).

Anal. Calc. for $C_{15}H_{22}O_6$: C, 60.39; H, 7.43. Found: C, 60.39; H, 7.70.

(Methyl 2,3,6-trideoxy-β-D-talopyranosido)-[2,3-*c*]-cyclohexanone (**9**) had m.p. 90–92° [from chloroform–light petroleum (b.p. 35–60°)], $[\alpha]_D^{20}$ +78° (*c* 1, chloroform); $\nu_{max}^{CHCl_3}$ 3700 and 3060 (hydroxyl), 1700 cm^{-1} (carbonyl). ^{1}H-N.m.r. data (60 MHz): δ 1.25 (d, 3 H, $J_{5,6}$ 7.0 Hz, CH_3), 1.53–3.26 (m, 8 H, H-2,3,7,7,9,9,10,10), 3.36 (s, 3 H, OMe), 3.73 (m, 1 H, unresolved, H-4), 4.0 (q, 1 H, H-5), and 4.4 (s, 1 H, H-1).

Anal. Calc. for $C_{11}H_{18}O_4$: C, 61.68; H, 8.41. Found: C, 61.11; H, 8.58.

*(Methyl 2,3,6-trideoxy-α-D-talopyranosido)-[3,2-*d*]-2-cyclohexenone* (**10a**) *and its acetate* (**10b**). — (*a*) To a solution of **8a** (200 mg, 0.93 mmol) in

dichloromethane (100 mL) was added manganese dioxide (2.0 g), and the mixture was stirred overnight at room temperature, filtered (Celite), and concentrated. Column chromatography of the residue (170 mg), using light petroleum (b.p. 35–60°)–ethyl acetate (7:3), gave **10a** (150 mg, 75.8%), m.p. 103° [from ether–light petroleum (b.p. 35–60°)], $[\alpha]_D^{20}$ −7° (*c* 1, chloroform), R_F 0.70 (5:95 methanol–chloroform); ν_{max}^{Nujol} 3600–3200 (hydroxyl) and 1660 cm^{-1} (conjugated carbonyl). ^{1}H-N.m.r. data (200 MHz): δ 1.35 (d, 3 H, $J_{5,6}$ 6.0 Hz, CH_3), 1.52 (bs, 1 H, OH), 2.35 (dd, 2 H, H-7,7′), 2.80–2.90 (m, 2 H, H-2,3), 3.40 (s, 3 H, OMe), 3.66 (b, 1 H, $w_{1/2}$ 8 Hz, H-4), 4.05 (q, 1 H, $J_{5,6}$ 12.0 Hz, H-5), 4.40 (s, 1 H, H-1), 6.20 (d, 1 H, $J_{9,10}$ 10.0 Hz, H-9), and 6.85 (dd, 1 H, $J_{9,10}$ 10, $J_{3,10}$ 6.0 Hz, H-10).

Anal. Calc. for $C_{11}H_{16}O_4$: C, 62.25; H, 7.60. Found: C, 62.52; H, 7.84.

(*b*) A mixture of **1b** (0.2 g, 1.4 mmol) and **2c** (0.74 g, 2.3 mmol) was stirred at room temperature for 2 days and then heated overnight at 50°. T.l.c. revealed the absence of **1b** and the presence of a faster-moving compound which was presumed to be adduct **3c**. When the adduct was stirred with sodium borohydride (52 mg, 1.3 mmol) in 2-propanol (3 mL) for 4 h at room temperature, it disappeared (t.l.c.), and the solution was then brought to pH 3 by the addition of 0.1M hydrochloric acid and stirred for 8 h. Neutralization with solid $NaHCO_3$, addition of water, extraction with ethyl acetate, drying (Na_2SO_4), filtration, and solvent removal then gave a liquid which showed four components in t.l.c. with R_F values 0.74, 0.49, 0.38, and 0.29. Column chromatography, using light petroleum and then ether, separated all the components. The compound with R_F 0.49 was identical to **10a** described in (*a*).

To a solution of **10a** (60 mg, 0.28 mmol) in dichloromethane (5 mL) were added pyridine (0.1 mL), acetic anhydride (0.2 mL), and *N,N*-dimethylaminopyridine (4 mg). The mixture was stirred at room temperature overnight and then worked-up in the usual way. Column chromatography of the solid product, using light petroleum (b.p. 35–60°)–ethyl acetate (7:3), gave **10b** (40 mg, 66%), m.p. 82–83° (from pentane), R_F 0.46 (ethyl acetate–light petroleum, 1:3); ν_{max}^{Nujol} 1750 (ester C=O) and 1660 cm^{-1} (conjugated C=O). ^{1}H-N.m.r. data (200 MHz): δ 1.14 (d, 3 H, $J_{5,6}$ 6.0 Hz, CH_3), 2.0 (s, 3 H, OAc), 2.35 (dd, 2 H, H-7,7), 2.8–3.0 (m, 2 H, H-2,3), 3.37 (s, 3 H, OMe), 4.10 (q, 1 H, $J_{5,6}$ 12.0 Hz, H-5), 4.50 (s, 1 H, H-1), 5.02 (br, 1 H, $w_{1/2}$ 6.0 Hz, H-4), 6.09 (d, 1 H, $J_{9,10}$ 10.0 Hz, H-9), and 6.80 (dd, 1 H, $J_{9,10}$ 10, $J_{3,10}$ 6.0 Hz, H-10).

Anal. Calc. for $C_{13}H_{18}O_5$: C, 61.40; H, 7.13. Found: C, 61.52; H, 7.11.

ACKNOWLEDGMENTS

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REFERENCES

1 J. L. Primeau, R. C. Anderson, and B. Fraser-Reid, *J. Am. Chem. Soc.*, 105 (1983) 5874–5879.

2 B. Fraser-Reid, M. A. Rahman, D. R. Kelly, and R. M. Srivastava, *J. Org. Chem.*, 49 (1984) 1835–1837.

3 S. Danishefsky and T. Kitahara, *J. Am. Chem. Soc.*, 96 (1974) 7807–7808.

4 S. Danishefsky, T. Kitahara, C. F. Yan, and J. Morris, *J. Am. Chem. Soc.*, 101 (1979) 6996–7000; S. Danishefsky, C. F. Yan, R. K. Singh, R. B. Garmel, P. M. McCurry, N. Fritsch, and J. Clardy, *ibid.*, 101 (1979) 7001–7008; S. Danishefsky, T. Harayama, and R. K. Singh, *ibid.*, 101 (1979) 7008–7012; S. Danishefsky, M. Hirama, N. Fritsch, and J. Clardy, *ibid.*, 101 (1979) 7013–7018; S. Danishefsky and F. J. Walker, *ibid.*, 101 (1979) 7018–7020; S. Danishefsky, M. Hirama, K. Gombatz, T. Harayama, E. Berman, and P. F. Schuda, *ibid.*, 101 (1979) 7020–7031; S. Danishefsky, P. F. Schuda, T. Kitahara, and S. Etheredge, *ibid.*, 99 (1977) 6066–6075.

5 B. Fraser-Reid, A. McLean, E. W. Usherwood, and M. B. Yunker, *Can. J. Chem.*, 48 (1970) 2877–2884.

6 S. Danishefsky, J. Morris, and L. A. Clizbe, *Heterocycles*, 15 (1981) 1205–1207.

7 B. Fraser-Reid, D. R. Kelly, D. B. Tulshian, and P. S. Ravi, *J. Carbohydr. Chem.*, 2 (1983) 105–114.

8 G. Stork and F. H. Clarke, *J. Am. Chem. Soc.*, 83 (1961) 3114–3125.

9 N. R. A. Beeley, G. Cremer, A. Dorlhene, B. Mompom, C. Pascad, and E. T. H. Dau, *Chem. Commun.*, (1983) 1046–1048.

10 T. R. Kelly, J. Vaya, and L. Anathasubramanian, *J. Am. Chem. Soc.*, 102 (1980) 5983–5984.