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Asymmetric *syn*-dihydroxylation of γ-substituted (2*R*)-*N*-(β,γ-enoyl)bornane-10,2-sultams

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Abstract

Various γ-substituted (2*R*)-*N*-(β,γ-enoyl)bornane-10,2-sultams have been examined in diastereoselective OsO_4 *syn*-dihydroxylation. In contrast to the C(α)-atom, the bornane-10,2-sultam auxiliary exerts a very poor influence on the C(β)-carbon. Spontaneous stereoselective hydrolysis of the minor diastereoisomer (3*S*,4*S*)-**5c** opens the way to enantiomerically pure building blocks.

1. Introduction

Oppolzer and Barras reported the diastereoselective OsO_4 *syn*-dihydroxylation of simple substituted α,β-alkenoyl-(2*R*)-bornane-10,2-sultams of type (−)-**1a**,**b** to the corresponding unstable diols (2*R*,3*S*)-**2a**,**b**.[1] We later showed that these diols could be isolated and fully characterized and we extended this methodology to synthetically more interesting carboxylic and aromatic β-substituted derivatives.[2] In continuing our studies on applications of sultam derivatives in stereocontrolled reactions[3] we have decided to use substrates with the target double bond distant from the inducing auxiliary, i.e. β,γ-alkenoyl sultams **3**. We also believed that any detrimental influence of the increased distance from bornanesultam to the double bond could be counterbalanced by introduction of the second chiral auxiliary into the molecule.

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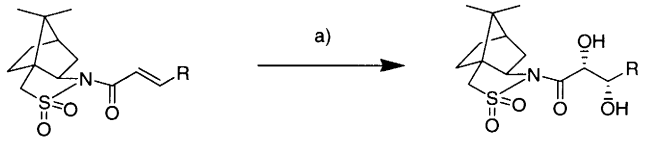
2. Results

Acylation of commercially available (2*R*)-bornane-10,2-sultam[4] by 3-butenoyl chloride[5] or 3-hexenoyl chloride[6] using classical conditions (NaH, toluene) gave exclusively the known conjugated derivatives (−)-**1a**,**b** (Scheme 1).[1,4] Although (−)-**3a** was earlier obtained under neutral conditions, by treatment of the free sultam with methyl 3-butenoate in the presence of $AlMe_3$[7] we preferred to use the conditions developed by Kociensky et al.[8] Thus, when the silylated auxiliary was treated with the corresponding alkenoyl chlorides, (−)-**3a**,**b** were obtained in 35 and 85% yield, respectively (Scheme 2). The unreported substrates (−)-**1c** and (−)-**3c**, possessing two prosthetic groups, were similarly obtained in 77 and 92% yield, respectively, using 1,6-hex-2*E*-[9a] and 1,6-hex-3*E*-endicarboxyloyl chloride.[10] Finally, the new analogues (−)-**1d** and (−)-**3d** were isolated in 62 and 52% yield, respectively, after equimolar addition of the corresponding mono-[9b] or diacid chlorides, followed by methanolysis.



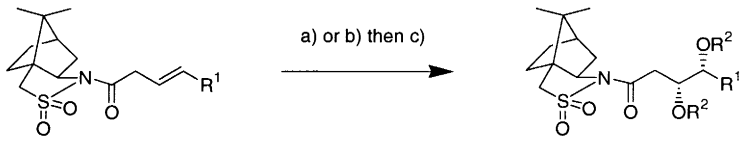
(-)-**1a** R= Me — (2*R*,3*S*)-**2a**

(-)-**1b** R= Pr — (2*R*,3*S*)-**2b**

(-)-**1c** R= $(CH_2)_2C(O)$(2*R*)-bornane-10,2-sultam — (2*R*,3*S*)-**2c**

(-)-**1d** R= $(CH_2)_2CO_2Me$ — (2*R*,3*S*)-**2d**

Scheme 1. Reaction conditions: (a) OsO_4/NMO, *t*-BuOH/DMF



(-)-**3a** R^1= H — (3*R*,4*R*)-**4a** R^2=H — (3*R*,4*R*)-**5a** R^2=isopropylidene

(-)-**3b** R^1= Et — (3*R*,4*R*)-**4b** R^2=H — (3*R*,4*R*)-**5b** R^2=isopropylidene

(-)-**3c** R^1= $CH_2C(O)$(2*R*)-bornane-10,2-sultam — (3*R*,4*R*)-**4c** R^2=H — (3*R*,4*R*)-**5c** R^2=isopropylidene

(-)-**3d** R^1= CH_2CO_2Me — (3*R*,4*R*)-**4d** R^2=H — (3*R*,4*R*)-**5d** R^2=isopropylidene

Scheme 2. Reaction conditions: (a) OsO_4/NMO, *t*-BuOH/DMF; (b) $RuCl_3/NaIO_4$, MeCN/AcOEt/H_2O, 0°C; (c) 2,2-dimethoxypropane, acetone, *p*TsOH, rt

As in our previous report,[2] the *syn*-dihydroxylation was carried out using either OsO_4 (*N*-methylmorpholine *N*-oxide monohydrate) or with the more reactive RuO_4 ($RuCl_3$, $NaIO_4$, MeCN:AcOEt 1:1).[11] The diastereoisomeric ratios were determined by ^1H NMR analyses and confirmed by HPLC and the absolute configurations were ascertained by chiroptical comparison of the corresponding γ-lactones.[12]

First of all, the OsO_4 *syn*-dihydroxylation of the conjugated olefin (−)-**1c** afforded at 0°C a 92:8 mixture of (2*R*,3*S*)-**2c**/(2*S*,3*R*)-**2c** in 90% yield. Two recrystallizations furnished pure (2*R*,3*S*)-**2c** (41% yield), a potential intermediate for a direct access to the (4*S*,5*R*)-(+)-L-Factor, a proposed autoregulator for anthracycline biosynthesis in streptomyces.[13] Hydrolyzed material of similar purity was obtained

from (−)-**2d**, suggesting that the second prosthetic group, separated by two methylene units, is too far away to sterically influence the approach.‡

When applied to the non-conjugated substrates (−)-**3a**,**b**, both oxidative methods provided chromatographically inseparable mixtures of diastereoisomers (3*R*,4*R*)-**4a**,**b**/(3*S*,4*S*)-**4a**,**b**; the poor diastereoselectivity observed could not be improved by temperature or metal counter ion modifications (see Table 1). In order to facilitate NMR spectra interpretations, and the purification procedure, **4a** was isolated in its dihydroxylic form, due to partial hydrolysis of the chiral auxiliary during the acetalization. Substrate (−)-**3c** allows the detailed study of the cumulative steric influence of both prosthetic groups on the C(β)-carbon.

Table 1
Asymmetric dihydroxylation of *N*-enoyl-(2*R*)-bornane-10,2-sultams (−)-**1c**, (−)-**3a–d** and diester (−)-**6**

Olefin	Method	Temperature [°C]	Time	Yield [%]	Diastereomeric ratio
1c	A	0	3 h	90[a]	92:8
3a	A	20	1 h	61[b]	57 : 43
	A	0	2 h	60[b]	56 : 44
	A	-20	20 h	70[b]	55 : 45
	B	0	2 min	62[b]	50 : 50
3b	A	-20	72 h	93[a]	60 : 40
	B	0	2 min	66[a]	58 : 42
3c	A	20	2 h	26[b]	>99:1
	A	-20	48 h	33[b]	>99:1
	A	0	24 h	39[b](68)[c]	>99:1(58:42)[c]
	B	0	30 min	11[b]	>99:1
3d	A	0	4 h	63[a]	56:44
6	A	0	3 h	95[a]	47:53

A) OsO_4/NMO, *t*-BuOH/DMF, B) $RuCl_3/NaIO_4$, MeCN/AcOEt/H_2O

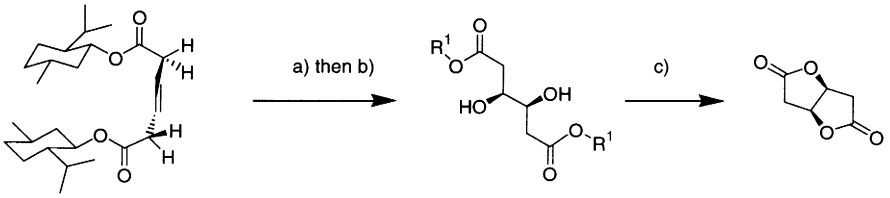
a) Yield and diastereomeric ratio given for diols **4** b) Yield and diastereomeric ratio given for isopropylidene acetals **5** c) Acetalisation performed prior to work-up of **4**. Also isolated as diacetate **5c''** (see exper. part).

Unexpectedly, we obtained, in this case, acetal (3*R*,4*R*)-**5c** as a pure diastereoisomer. Transesterification with $TiCl_4$/*i*PrOH to isopropylidene derivative of diester (3*R*,4*R*)-**8**,[14] followed by acidic treatment,

‡ Similarly, OsO_4 *syn*-dihydroxylation of (2*R*)-bornane-10,2-sultam *N*-hex-4*E*-en-1,6-dioic acid 1-yl-6-methyl ester gave at 0°C a 1:1 mixture of inseparable diastereoisomers.

afforded the enantiomerically pure (3*R*,4*R*)-dihydroxyadipic-γ,γ′-dilactone **9** in 42% overall yield. Because of the lower chemical yield obtained during this process, we decided to perform the acetalization directly on the reaction mixture, rather than after the aqueous work-up, and thus obtained at 0°C a 58:42 diastereoisomeric mixture in 68% yield.§ Interestingly, the minor diastereoisomer hydrolyzes selectively, probably due to a specific conformation of one of the generated hydroxyl groups. Alternatively, when the mono-(2*R*)-bornane-10,2-sultam analogue (−)-**3d** was oxidized with OsO_4 at 0°C, a similar 56:44 mixture of (3*R*,4*R*)-**4d**/(3*S*,4*S*)-**4d** was obtained in 63% yield, thus indicating a very low co-operative effect of both prosthetic groups.[15]

Finally, when a purely steric inducer was used, as in the reported but not fully characterized di-(*R*)-menthyl 1,6-diester (−)-**6**,[16] oxidation afforded diol **7** in 95% yield as a 47:53 inseparable mixture (Scheme 3).



Scheme 3. (a) OsO_4/NMO, *t*-BuOH/DMF; (b) $TiCl_4$, *i*PrOH; (c) 2N HCl, THF/H_2O

The X-ray structure analysis of substrate (−)-**3c** shows several interesting features and is characterized by a crystallographic disorder around one of the sultam SO_2 moieties, due to two possible conformations of the five membered ring (Fig. 1). This substrate thus manifests the correlation that we found earlier between the S–N–C=O dihedral angle and the degree of pyramidalization of the N atom.[17] For one sultam moiety (S–N–C=O=161.2(6)°), the pyramidalization of the N atom is of 0.19(1) Å, while for the second unit the N is either more planar (S–N–C=O=170(1)°, Δ*h*N=0.13(2)) or remarkably pyramidalized (S–N–C=O=143(1)°; Δ*h*N=0.31(5) Å). This analysis also suggests that the conformations of the C(O) and C(β) atoms are very similar to the conjugated α,β-enoyl derivatives.[4,18]

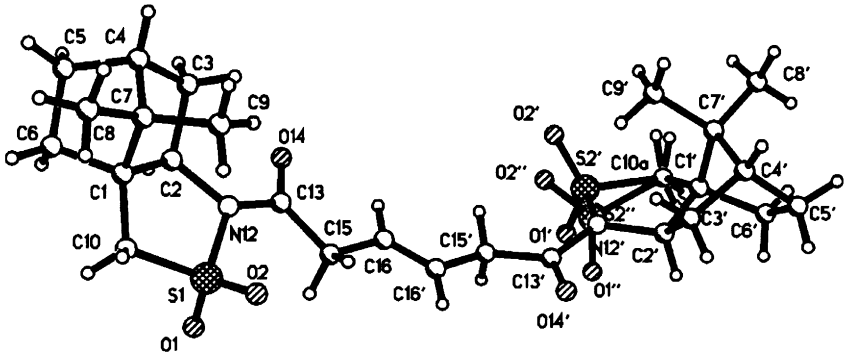


Fig. 1. X-Ray structure of compound (−)-**3c** with arbitrary numbering

Indeed, the C(O) moiety remains *anti*-periplanar to the SO_2 group and the C(α)–C(β) bond is *syn*-periplanar to the C(O) function, thus projecting the C(β)=C(γ) double bond in a thermodynamically

§ This is the only case where traces of free sultam were observed and attracted our attention, thus precluding hydrolytic artefacts in all other examples reported.

favoured *anti*-periplanar direction with respect to the C(O)–C(α) bond. As a consequence, the C(β)-*re* face is slightly more accessible, hypothetically due to the steric and/or electrostatic interactions[19] of both *pseudo*-axial S=O(1)/S=O(1′) groups, on the convex C(β)-*si* face of the transition state.

This is even more visible from the X-ray structure analysis of product **5c**, which shows the same features (Fig. 2). However, one should admit that in relation to the low selectivities obtained, the proposed course of reaction is only speculation and can be influenced by reaction conditions (Table 2).

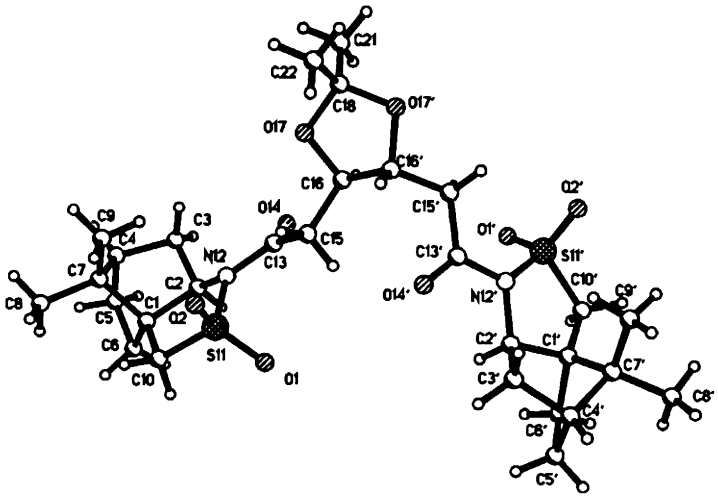


Fig. 2. X-Ray structure of compound **5c** showing its (3*R*,4*R*) configuration and arbitrary numbering

Table 2
Selected bond lengths [Å] and dihedral angles [°] for (−)-**3c** and (3*R*,4*R*)-**5c**

	3c	**3c'**	**3c''**	**5c**	**5c'**
S=O(1)	1.413(6)	1.40(2)	1.40(2)	1.427(5)	1.442(6)
S=O(2)	1.424(7)	1.39(1)	1.40(2)	1.423(5)	1.397(6)
S-N	1.684(6)	1.70(1)	1.71(1)	1.682(6)	1.678(5)
N-C(2)	1.466(9)	1.468(8)	1.46(a)	1.491(8)	1.485(8)
S-C(10)	1.765(8)	1.79(1)	1.81(a)	1.780(7)	1.785(7)
N-C(13)	1.400(9)	1.390(9)	1.39(a)	1.383(8)	1.383(8)
O(1)=S-N-C(2)	99.8(6)	105(2)	82(1)	102.6(5)	101.2(5)
O(2)=S-N-C(2)	-129.8(5)	-119.7(13)	-149(2)	-128.1(5)	-128.9(5)
O(1)=S-N-lone pair	-159(2)	a)	a)	-155.4(4)	-158.1(4)
S-N-C(2)-C(3)	144.0(6)	135(1)	158(1)	144.2(6)	142.4(5)
S-N-C(11)=O(3)	161.2(6)	170(1)	143(1)	155.4(6)	166.9(5)
ΔhN	0.19(1)	0.13(2)	0.31(5)	0.214(5)	0.184(5)

a) Not significant, due to high esd's.

3. Conclusions

In contrast to the strong influence exerted on the C(α)-carbon, as evidenced for example by the diastereoselective OsO_4 *syn*-dihydroxylation of (−)-**1c**, the bornane-10,2-sultam auxiliary exerts a very poor influence on the C(β)-carbon, as formerly pointed out by Curran et al.[20,21] for the thermal C(β) cyclohexyl radical addition to α,β-enoyl derivatives. In the absence of electronic conjugation, this poor diastereoselectivity mainly results from the lack of steric influence from the auxiliary.

However, by recrystallization of (2*R*,3*S*)-**2c**, and due to a fortuitous stereoselective spontaneous hydrolysis of the minor diastereoisomer (3*S*,4*S*)-**5c**, this methodology allows some enantiomerically pure building blocks to be obtained.

4. Experimental

All reactions with acid chlorides were carried out under argon atmosphere with anhydrous solvents dried according to standard laboratory methods. ^{1}H and ^{13}C NMR spectra were measured on Bruker AM-500 (500 and 125 MHz) and Varian Gemini (200 and 50 MHz) spectrometers using residual $CHCl_3$ as internal reference. Mass spectra were carried out with an AMD-604 Intectra instrument. Optical rotations were measured on a JASCO DIP-360 polarimeter with a thermally jacketed 10 cm cell. Infrared spectra were recorded on a Perkin–Elmer 1640 FT-IR. Melting points were determined with Kofler hot stage apparatus and are uncorrected. Flash chromatography was performed according to Still et al.[22] on silica gel (Kieselgel-60, Merck, 200–400 mesh). TLC was performed on Merck aluminum plates (Kieselgel 60 F_{254}) and compounds were visualized with a solution of MoO_3 and $Ce_2(SO_4)_3$ in 15% H_2SO_4.

*4.1. X-Ray structure determination of (−)-**3c** and (3*R*,4*R*)-**5c***

Suitable crystals were grown from hexane/AcOEt soln. The measurements were run on a Nonius MACH3 diffractometer using Express software, without absorption corrections. Table 3 shows details of the data collection and refinement. In the final steps of the least-squares procedure, all but Me group H-atoms were kept fixed at their calculated positions. The structures were solved by the SHELXS86[23] and refined with the SHELXL93[24] programs. The known configuration of the asymmetric centers of the sultam unit has been confirmed by the Flack parameter refinement.[25] Lists of the fractional atomic coordinates, isotropic thermal parameters, and bond lengths and angles have been deposited at the Cambridge Crystallographic Data Centre as supplementary material ((−)-**3c** reg. no. CCDC 134661 and (3*R*,4*R*)-**5c** reg. no. CCDC 134660).

4.2. General procedure for N-*acylation according to Ref. 11*

(2*R*)-Bornane-10,2-sultam (4.9 g, 23 mmol) was dissolved in dry benzene (60 ml) and MeCN (10 ml). TMSCl (14 ml, 110 mmol) was added at rt and the reaction mixture was cooled to 0°C. A soln of Et_3N (3.8 ml, 26 mmol) in benzene (20 ml) was added, the cooling bath was removed and stirring was continued for 1.5 h. Solvents were evaporated and the product was separated from $Et_3N{\cdot}HCl$ by dissolving in dry toluene and filtration. The mixture of silylated sultam, the corresponding enoyl chloride (92 mmol) and anhyd. $CuCl_2$ (309 mg, 2.3 mmol) in dry benzene (25 ml) was refluxed for 18 h. After filtration, washing with satd aq. $NaHCO_3$, extraction of water phase (3×AcOEt), drying over anhyd. $MgSO_4$ and evaporation of solvents, the residue was purified by column chromatography.

Table 3
Crystal data and structure refinement of (−)-**3c** and (3*R*,4*R*)-**5c**

		(-)-**3c**	(3*R*,4*R*)-**5c**
Empirical formula		$C_{26}H_{38}N_2O_6S_2$	$C_{29}H_{44}N_2O_8S_2$
Formula weight		538.70	620.78
Crystal system		orthorhombic	orthorhombic
Space group		$P2_12_12_1$	$C222_1$
Unit cell dimensions	*a* [Å]	7.602(2)	12.983(3)
	b [Å]	16.669(3)	21.320(4)
	c [Å]	21.270(4)	23.299(5)
Volume [Å^3]		2695.3(10)	6449.1(24)
Z		4	8
Density calc. [Mg m^{-3}]		1.328	1.279
Absorption coeff [mm^{-1}]		0.241	1.923
F(000)		1152	2656
Crystal size [mm]		0.62x0.21x0.07	0.63x0.35x0.28
θ-Range [°]		3.10 to 74.1	3.79 to 60.73
Index ranges		0≤h≤9, 0≤k≤20, 0≤l≤26	0≤h≤14, 0≤k≤23, -26≤l≤0
Reflex. collected		1865	2111
Independent reflex.		1865 [*R*(int)=0.0000]	2111 [*R*(int)=0.0000]
Refinement method		Full-matrix least-squaare on F^2	
Data/restraints/parameters		1865/8/354	2107/0/416
Goodness of fit on F^2		1.049	0.959
Final *R* indices ($I>3\tau(I)$)		R_1=0.0616, wR_2=0.1403	R_1=0.0482, wR_2=0.1305
R indice (all data)		R_1=0.0720, wR_2=0.1503	R_1=0.0505, wR_2=0.1347
Absolute structure parameter		-0.8(2)	0.00
Extinction coeff.		0.052(4)	0.00010(4)
Largest diff. peak and hole [eÅ^{-3}]		0.232 and –0.255	0.498 and –0.236

4.3. *General procedure for the OsO_4 catalyzed* syn*-dihydroxylation of olefins* ***1,3***

The olefin and twofold excess of *N*-methylmorpholine *N*-oxide were dissolved in a mixture of *tert*-BuOH and DMF (1:1, 0.1 mmol/ml). OsO_4 (0.3 equiv., 0.05 M solution in *tert*-BuOH) was added and the reaction was followed by disappearance of the starting material on TLC (hexane–AcOEt). The reaction was quenched by addition of a satd aq. $NaHSO_3$ soln and extracted 4 times with AcOEt. The combined organic extracts were dried over anhyd. $MgSO_4$, evaporated (DMF on an oil pump, 60°C) and purified by

SiO_2 column chromatography (hexane–AcOEt). For details concerning yields, temperature and reaction times see Table 1.

4.4. General procedure for the acetalization of diols **3a** and **3c**

The crude diol was dissolved in a mixture of 2,2-dimethoxypropane and acetone (1:1, 0.1 mmol/ml). A catalytic amount of *p*TsOH was added, the reaction mixture was stirred at rt and followed by disappearance of the starting material on TLC (hexane:AcOEt 7:3, ~1–2 h). Aq. $NaHCO_3$ was added to the mixture, which was then extracted 3 times with CH_2Cl_2, dried over anhyd. $MgSO_4$ and purified by column chromatography (hexane:AcOEt 9:1→4:1).

4.5. N,N′-*[(2′′E)-Hex-2′′-enedioyl]-bis-(2R)-bornane-10,2-sultam (−)-**1c***

According to the general method (benzene replaced by toluene), from 782 mg (3.63 mmol) of sultam and 328 mg (1.81 mmol) of (2*E*)-hex-2-enedioyl dichloride, after column chromatography (hexane:AcOEt 9:1→7:3) 755 mg (77% yield) of white solid was obtained. Recrystallized from hexane/AcOEt (53%). White crystals, mp 218°C; $[\alpha]_D=-109.4$ (c 1.01, $CHCl_3$); ν_{max} (KBr, cm^{-1}) 3014, 2958, 2885, 1690, 1676, 1637, 1393, 1330, 1285, 1213, 1134, 1115, 1071, 989, 776, 734, 535; δ_H (500 MHz, $CDCl_3$) 7.05 (dt, $J_{2'',3''}$=15.1 Hz, $J_{3'',4''A}=J_{3'',4''B}$=7.1 Hz, 1H, 3′′-H), 6.59 (dt, $J_{2'',3''}$=15.1 Hz, $J_{2'',4''A}=J_{2'',4''B}$=1.5 Hz, 1H, 2′′-H), 3.92 (dd, $J_{2,3A}$=5.1 Hz, $J_{2,3B}$=7.6 Hz, 1H, 2-H), 3.86 (dd, $J_{2',3'A}$=4.9 Hz, $J_{2',3'B}$=7.8 Hz, 1H, 2′-H), 3.49 (d_{AB}, J_{AB}=13.8 Hz, 1H, 10-H_A), 3.48 (d_{AB}, J_{AB}=13.8 Hz, 1H, 10′-H_A), 3.42 (d_{AB}, J_{AB}=13.8 Hz, 2H, 10-H_B, 10′-H_B), 2.90 (t, *J*=7.5 Hz, 1H, 5′′-H_A), 2.89 (t, *J*=7.1 Hz, 1H, 5′′-H_B), 2.65–2.59 (m, 2H, 4′′-H), 2.17–2.03 (m, 4H, 3-H, 3′-H), 1.96–1.84 (m, 6H, 4-H, 4′-H, 5-H, 5′-H), 1.45–1.31 (m, 4H, 6-H, 6′-H), 1.17 (s, 3H, 8-H), 1.15 (s, 3H, 8′-H), 0.97 (s, 3H, 9-H), 0.96 (s, 3H, 9-H); δ_C (125 MHz, $CDCl_3$) 170.2 (C-1′′), 163.7 (C-6′′), 147.9 (C-2′′), 121.9 (C-3′′), 65.2 (C-2), 65.1 (C-2′), 53.1 (C-10), 52.8 (C-10′), 48.5 (C-1), 48.4 (C-1′), 47.8 (C-7), 47.7 (C-7′), 44.7 (C-4), 44.6 (C-4′), 38.5 (C-3), 38.4 (C-3′), 33.7 (C-5′′), 32.84 (C-6), 32.80 (C-6′), 27.0 (C-4′′), 26.5 (C-5), 26.4 (C-5′), 20.8 (C-8, C-8′), 19.9 (C-9), 19.8 (C-9′); m/z (EI-MS) 538 (M^+); m/z (EI-HR) calculated for $C_{26}H_{38}O_6N_2S_2$ (M^+) 538.21710, found 538.21374. Anal. calcd for $C_{26}H_{38}O_6N_2S_2$: C, 57.97; H, 7.11; N, 5.20; S, 11.20. Found: C, 57.77; H, 7.17; N, 5.14; S, 11.16.

4.6. N-*[(2E)-Hex-2-en-6-carbomethoxy-1-oyl](2R)-bornane-10,2-sultam (−)-**1d***

Isolated in 62% yield from (2*R*)-bornane-10,2-sultam and 1,6-hex-2*E*-endicarboxyloyl chloride according to the general procedure. Mp: 78–79°C (hexane/Et_2O); $[\alpha]_D^{20}=-90.8$ (c=0.6, $CHCl_3$); IR (film): 2957, 2886, 1724, 1697, 1660, 1437, 1330, 1273, 1215, 1135; δ_H (200 MHz): 6.96 (dt, *J*=15.7, 6.6 Hz, 1H), 5.87 (dt, *J*=15.7, 1.6 Hz, 1H), 3.86 (t, *J*=7 Hz, 1H), 3.72 (s, 3H), 3.47, (dAB, *J*=13.6, 32 Hz, 2H), 2.90, t, *J*=7.4 Hz, 2H), 2.56 (q, *J*=7.7 Hz, 2H), 2.08 (m, 2H), 1.90 (m, 3H), 1.38 (m, 2H), 1.48 (s, 3H), 0.97 (s, 3H); δ_C (50 MHz): 170.3 (*C*O_2Me), 166.7 (C-1′), 146.7 (C-3′), 121.9 (C-2′), 65.2 (C-2), 52.9 (C-10), 51.4 (CO_2*Me*), 48.5 (C-1), 47.7 (C-7), 44.6 (C-4), 38.4 (C-3), 33.5 (C-5′), 32.8 (C-6), 26.6 (C-4′), 26.4 (C-5), 20.8 (C-8), 19.8 (C-9); (MS): 355 (M^+, 26), 324 (15), 216 (18), 214 (20), 143 (64), 141 (100), 135 (50), 134 (37), 113 (31), 111 (50), 109 (50), 108 (20), 93 (24), 81 (30), 71 (42), 55 (27), 41 (31). Anal. calcd for $C_{17}H_{25}NO_5S$: C, 57.44; H, 7.09; N, 3.94; S, 9.02. Found: C, 57.25; H, 7.27; N, 3.75; S, 9.09.

4.7. N,N′-[(2′′R,3′′S)-2′′,3′′-Dihydroxyhexanedioyl]-bis-(2R)-bornane-10,2-sultam (2R,3S)-**2c**

Twice recrystallized single diastereoisomer (41% yield). Colorless crystals, mp 178–181°C (hexane/Et_2O); $[\alpha]_D=-116.0$ (c 1.01, $CHCl_3$); ν_{max} (KBr, cm^{-1}) 3544, 3500, 2960, 2882, 1695, 1679, 1456, 1328, 1220, 1137, 1067, 990, 776, 540; δ_H (500 MHz, $CDCl_3$) 4.47 (dd, $J_{2'',3''}=2.4$ Hz, $J_{2'',OH}=8.5$ Hz, 1H, 2′′-H), 4.14 (ddt, $J_{2'',3''}=2.4$ Hz, $J_{3'',OH}=J_{3'',4''A}=4.5$ Hz, $J_{3'',4''B}=8.6$ Hz, 1H, 3′′-H), 3.92 (dd, $J_{2,3A}=5.0$ Hz, $J_{2,3B}=7.8$ Hz, 1H, 2-H), 3.86 (dd, $J_{2',3'A}=4.9$ Hz, $J_{2',3'B}=7.7$ Hz, 1H, 2′-H), 3.51 (d_{AB}, $J_{AB}=13.8$ Hz, 1H, 10-H_A), 3.48 (d_{AB}, $J_{AB}=13.8$ Hz, 1H, 10-H_B), 3.45 (d_{AB}, $J_{AB}=13.8$ Hz, 1H, 10′-H_A), 3.42 (d_{AB}, $J_{AB}=13.8$ Hz, 1H, 10′-H_B), 2.97–2.86 (m, 2H, 5′′-H), 2.82 (d, $J=4.5$ Hz, 1H, OH), 2.76–2.69 (m, 1H, OH), 2.24–1.98 (m, 5H, 3-H, 3′-H, 4′′-H_A), 1.97–1.84 (m, 7H, 4-H, 4′-H, 4′′-H_B, 5-H, 5′-H), 1.49–1.30 (m, 4H, 6-H, 6′-H), 1.15 (s, 6H, 8-H, 8′-H), 0.97 (s, 3H, 9-H), 0.96 (s, 3H, 9′-H); δ_C (125 MHz, $CDCl_3$) 171.8 (C-1′′), 171.6 (C-6′′), 72.3 (C-2′′), 69.8 (C-3′′), 65.3 (C-2), 65.2 (C-2′), 52.9 (C-10), 52.8 (C-10′), 49.1 (C-1), 48.4 (C-1′), 47.9 (C-7), 47.7 (C-7′), 44.7 (C-4), 44.6 (C-4′), 38.4 (C-3), 38.1 (C-3′), 32.8 (C-6, C-6′), 31.9 (C-5′′), 27.6 (C-4′′), 26.5 (C-5), 26.4 (C-5′), 20.9 (C-8), 20.8 (C-8′), 19.9 (C-9), 19.8 (C-9′); m/z (LSI-MS) 595 $(M+Na)^+$, 573 $(M+H)^+$; m/z (LSI-MS, HR) calcd for $C_{26}H_{41}O_8N_2S_2$ $(M+H)^+$ 573.23041, found 573.22997. Anal. calcd for $C_{26}H_{40}O_8N_2S_2$: C, 54.52; H, 7.04; N, 4.89; S, 11.20. Found: C, 54.46; H, 7.22; N, 4.95; S, 11.27.

4.8. (2R)-N-(But-3-enoyl)-bornane-10,2-sultam (−)-**3a**

Isolated in 35% yield from sultam and 3-butenoyl chloride, after column chromatography (hexane:AcOEt 9:1→8:2) followed by recrystallization. White crystals, mp 67–69°C (hexane); $[\alpha]_D=-105.9$ (c 0.51, $CHCl_3$); ν_{max} (KBr, cm^{-1}) 2942, 2883, 1693, 1330, 1268, 1233, 1209, 1127, 1062, 988, 924, 814, 786, 759, 534; δ_H (200 MHz, $CDCl_3$) 5.97 (ddt, $J_{2A',3'}=J_{3',4B'}=6.7$ Hz, $J_{2B',3'}=9.8$, $J_{3',4A'}=17.5$ Hz, 1H, 3′-H), 5.29–5.23 (m, 1H, 4′-H_A), 5.22–5.16 (m, 1H, 4′-H_B), 3.88 (dd, $J_{2,3A}=5.4$ Hz, $J_{2,3B}=7.2$ Hz, 1H, 2-H), 3.58–3.50 (m, 2H, 2′-H_A, 2′-H_B), 3.55 (d_{AB}, $J_{AB}=13.8$ Hz, 1H, 10-H_A), 3.45 (d_{AB}, $J_{AB}=13.8$ Hz, 1H, 10-H_B), 2.19–2.02 (m, 2H, 3-H_A, 3-H_B), 2.00–1.83 (m, 3H, 4-H, 6-H_A, 6-H_B), 1.49–1.31 (m, 2H, 5-H_A, 5-H_B), 1.17 (s, 3H, 8-Me), 0.99 (s, 3H, 9-Me); δ_C (50 MHz, $CDCl_3$) 169.8 (C-1′), 129.4 (C-3′), 119.3 (C-4′), 65.2 (C-2), 52.9 (C-10), 48.5 (C-1), 47.8 (C-7), 44.6 (C-4), 40.0 (C-2′), 38.4 (C-3), 32.8 (C-6), 26.4 (C-5), 20.8 (C-8), 19.9 (C-9); m/z (EI-MS) 283 (M^+), 242 $(M-CH_2CHCH_2)^+$; m/z (HR-EI) calcd for $C_{14}H_{21}NO_3S$ (M^+) 283.1241, found 283.1242. Anal. calcd for $C_{14}H_{21}NO_3S$: C, 59.34; H, 7.47; N, 4.94; S, 11.32. Found: C, 59.08; H, 7.22; N, 4.85; S, 11.43.

4.9. (2R)-N-[(3′E)-Hex-3′-enoyl]bornane-10,2-sultam (−)-**3b**

Isolated in 85% yield from 2.08 g (9.67 mmol) of sultam and 3.22 g (24.3 mmol) of (3*E*)-hex-3-enoyl chloride, after column chromatography (hexane:AcOEt 9:1). Colorless oil; $[\alpha]_D=-102.6$ (c 1.57, $CHCl_3$); ν_{max} (film, cm^{-1}) 2961, 2883, 1703, 1456, 1375, 1329, 1217, 1134, 1061, 969, 776, 537; δ_H (200 MHz, $CDCl_3$) 5.75–5.45 (m, 2H, 3′H, 4′H), 3.86 (d, $J_{2,3A}=5.3$ Hz, $J_{23B}=7.3$ Hz, 1H, 2-H); 3.51 (d_{AB}, $J_{AB}=13.9$ Hz, 1H, 10-H_A), 3.50–3.41 (m, 2H, 2′-H_A, 2′-H_B), 3.42 (d_{AB}, $J_{AB}=13.9$ Hz, 1H, 10-H_B), 2.14–1.97 (m, 4H, 3-H_A, 3-H_B, 5′-H_A, 5′-H_B), 1.98–1.80 (m, 3H, 4-H, 6-H_A, 6-H_B), 1.48–1.28 (m, 2H, 5-H_A, 5-H_B), 1.15 (s, 3H, 8-Me), 0.98 (t, $J_{5A,6}=J_{5B,6}=7.4$ Hz, 3H, 6-Me), 0.97 (s, 3H, 9-Me); δ_C (50 MHz, $CDCl_3$) 170.5 (C-1′), 137.2 (C-3′), 119.7 (C-4′), 65.2 (C-2), 52.9 (C-10), 48.5 (C-1), 47.8 (C-7), 44.6 (C-4), 39.1 (C-2′), 38.4 (C-3), 32.8 (C-6), 26.4 (C-5), 25.5 (C-5′), 20.8 (C-8), 19.9 (C-9), 13.4 (C-6′); m/z (EI-MS) 311 (M^+), 296 $(M-CH_3)^+$; m/z (HR-EI) calcd for $C_{16}H_{25}NO_3S$ (M^+) 311.1555, found 311.1556. Anal. calcd for $C_{16}H_{25}NO_3S$: C, 61.70; H, 8.09; N, 4.50; S, 10.30. Found: C, 61.47; H, 8.17; N, 4.38, S, 10.11.

4.10. N,N′-*[(3′*E*)-Hex-3′-enedioyl]-bis-(2*R*)-bornane-10,2-sultam (−)-**3c**

Isolated in 67% yield from 5.0 g (23.25 mmol) of sultam and 1.99 g (11 mmol) of (3*E*)-hex-3-enedioyl dichloride (*trans*-β-hydromuconic acid chloride), after recrystallization. White crystals, mp 237–239°C (hexane/AcOEt); $[\alpha]_D=-122.0$ (c 1.15, $CHCl_3$); ν_{max} (film, cm^{-1}) 2960, 2885, 1683, 1042, 1334, 1282, 1213, 1134, 1057, 982, 812, 771, 536, 493; δ_H (200 MHz, $CDCl_3$) 5.77 (ddd, J_1=1.6 Hz, J_2=3.7 Hz, J_3=5.3 Hz, 2H, 3′-H×2), 3.85 (dd, $J_{2,3A}$=5.3 Hz, $J_{2,3B}$=7.3 Hz, 2H, 2-H×2), 3.54–3.48 (m, 4H, 2′-H_A, 2′-H_B×2), 3.51 ($d_{AB,}$ J_{AB}=13.8 Hz, 10-H_A), 3.42 ($d_{AB,}$ J_{AB}=13.8 Hz, 10-H_B), 2.03–2.15 (m, 4H, 3-$H_{A,}$ 3-H_B×2), 2.00–1.80 (m, 6H, 4-H, 6-H_A, 6-H_B), 1.44–1.31 (m, 4H, 5-$H_{A,}$ 5-H_B), 1.15 (s, 3H, 8-Me), 0.97 (s, 3H, 9-Me); δ_C (50 MHz, $CDCl_3$) 169.6 (C-1′×2), 125.8 (C-3′×2), 65.2 (C-2), 52.9 (C-10×2), 48.5 (C-1×2), 47.8 (C-7×2), 44.7 (C-4×2), 38.9 (C-2′×2), 38.4 (C-3×2), 32.8 (C-6×2), 26.4 (C-5×2), 20.8 (C-8), 29.9 (C-9); m/z (EI-MS) 538 (M^+); m/z (HR-EI) calcd for $C_{26}H_{38}N_2O_6S_2$ (M^+) 538.2171, found 538.2183. Anal. calcd for $C_{26}H_{38}N_2O_6S_2$: C, 57.97; H, 7.11; N, 5.20; S, 11.90. Found: C, 57.95; H, 7.29; N, 5.41; S, 11.61.

4.11. N-*[(3′*E*)-5-(Methoxycarbonyl)pent-3′-enoyl]-(2*R*)-bornane-10,2-sultam (−)-**3d**

According to the Kocienski method (benzene replaced by toluene), from free sultam (2.360 g, 11.01 mmol) and (3*E*)-hex-3-enedioyl dichloride (*trans*-β-hydromuconic acid chloride, 2.449 g, 13.529 mmol), after 3 h at reflux and work-up (brine, extraction AcOEt, drying over $MgSO_4$) the residue was dissolved in MeOH (10 ml), concd HCl was added (6 drops) and the mixture was stirred for 18 h at rt. After evaporation of reagents, AcOEt was added, followed by water, extraction of water phase with AcOEt and drying over anhyd. $MgSO_4$. After purification by column chromatography (hexane:AcOEt 9:1→7:3), 2.032 g (52% yield) of monoester was obtained and 1.189 g (20%) of disultam derivative (−)-**3c**. Monoester was distilled (bulb-to-bulb). Colorless oil (bp 110–120°C/0.1 mm); $[\alpha]_D=-90.6$ (c 1.30, $CHCl_3$); ν_{max} (film, cm^{-1}) 2958, 2887, 1739, 1696, 1376, 1330, 1215, 1165, 1135, 1061, 984, 723, 538; δ_H (200 MHz, $CDCl_3$) 5.78–5.70 (m, 2H, 3′-H, 4′-H), 3.86 (dd, $J_{2,3A}$=5.3 Hz, $J_{2,3B}$=7.4 Hz, 1H, 2-H), 3.68 (s, 3H, CO_2*Me*), 3.54–3.49 (m, 2H, 2′-H), 3.52 ($d_{AB,}$ J_{AB}=13.8 Hz, 1H, 10-H_A), 3.43 ($d_{AB,}$ J_{AB}=13.8 Hz, 1H, 10-H_B), 3.13–3.08 (m, 2H, 5′-H), 2.15–2.02 (m, 2H, 3-H), 2.00–1.84 (m, 3H, 4-H, 6-H), 1.46–1.29 (m, 2H, 5-H), 1.15 (s, 3H, 8-H), 0.97 (s, 3H, 9-H); δ_C (50 MHz, $CDCl_3$) 171.8 (*C*OOMe), 169.7 (C-1′), 126.6 (C-3′), 125.0 (C-4′), 65.2 (C-2), 52.9 (C-10), 51.8 (COO*Me*), 48.5 (C-1), 47.8 (C-7), 44.6 (C-4), 38.8 (C-3), 38.3 (C-2′), 37.8 (C-5′), 32.8 (C-6), 26.4 (C-5), 20.8 (C-8), 19.9 (C-9); m/z (EI-MS) 355 (M^+); m/z (HR-EI) calcd for $C_{17}H_{25}O_5NS$ (M^+) 355.14534, found 355.14653. Anal. calcd for $C_{17}H_{25}O_5NS$: C, 57.44; H, 7.09; N, 3.94; S, 9.02. Found: C, 57.49; H, 7.09; N, 3.97; S, 9.15.

*4.12. (2*R*)-*N*-[(3′*RS*,4′*RS*)-3′,4′-*O*-Isopropylidenebutanoyl]bornane-10,2-sultam **5a***

Colorless crystals, mp 111–112°C (hexane–AcOEt); ν_{max} (KBr, cm^{-1}) 3440, 2960, 1686, 1382, 1326, 1218, 1136, 1079, 1024, 840, 779, 536; m/z (EI) 342 $(M-CH_3)^+$; m/z (HR-EI) calcd for $C_{16}H_{24}NO_5S$ $(M-CH_3)^+$ 342.13752, found 342.13754. Anal. calcd for $C_{17}H_{27}NO_5S$: C, 57.12; H, 7.61; N, 3.92; S, 8.97. Found: C, 57.04; H, 7.77; N, 3.91; S, 9.10.

4.12.1. Major diastereoisomer (deduced)

δ_H (200 MHz, $CDCl_3$) 4.63–4.48 (m, 3′-H), 4.18 (dd, $J_{3',4A'}$=6.0 Hz, $J_{4A',4B'}$=8.4 Hz, 4′-H_A), 3.92–3.82 (m, 2-H), 3.67 (dd, $J_{3',4B'}$=6.3 Hz, $J_{4A',4B'}$=8.4 Hz, 4′-H_B), 3.57 (d_{AB}, J_{AB}=13.9 Hz, 10-H_A), 3.42 ($d_{AB,}$ J_{AB}=13.9 Hz, 10-H_B), 3.22 (dd_{AB}, $J_{2A',3'}$=6.5 Hz, J_{AB}=16.7 Hz, 2′-H_A), 2.97–2.79 (m, 2′-H_B), 2.23–1.99 (m, 3-H_A, 3-H_B), 1.97–1.80 (m, 4-H, 6-H_A, 6-H_B), 1.54–1.22 (m, 5-H_A, 5-H_B), 1.42

(s, Me), 1.35 (s, Me), 1.16 (s, 8-Me), 0.97 (s, 9-Me); δ_C (50 MHz, $CDCl_3$) 169.1 (C-1′), 109.2 (*C*Me_2), 71.8 (C-3′), 69.3 (C-4′), 65.1 (C-2), 52.9 (C-10), 48.5 (C-1), 47.8 (C-7), 44.7 (C-4), 40.2 (C-2′), 38.4 (C-3), 32.8 (C-6), 26.8 (Me), 26.4 (C-5), 25.5 (Me) 20.8 (C-8), 19.9 (C-9).

4.12.2. Minor diastereoisomer (deduced)

δ_H (200 MHz, $CDCl_3$) 4.63–4.48 (m, 3′-H), 4.17 (dd, $J_{3',4A'}$=6.0 Hz, $J_{4A',4B'}$=8.4 Hz, 4′-H_A), 3.92–3.82 (m, 2-H), 3.65 (dd, $J_{3',4B'}$=6.4 Hz, $J_{4A',4B'}$=8.4 Hz, 4′-H_B), 3.57 ($d_{AB,}$ J_{AB}=13.9 Hz, 10-H_A), 3.42 ($d_{AB,}$ J_{AB}=13.9 Hz, 10-H_B), 3.20 ($dd_{AB,}$ $J_{2A',3'}$=6.2 Hz, J_{AB}=16.7 Hz, 2′-H_A), 2.97–2.79 (m, 2′-H_B), 2.23–1.99 (m, 3-H_A, 3-H_B), 1.97–1.80 (m, 4-H, 6-H_A, 6-H_B), 1.54–1.22 (m, 5-H_A, 5-H_B), 1.41 (s, Me), 1.35 (s, Me), 1.15 (s, 8-Me), 0.97 (s, 9-Me); δ_C (50 MHz, $CDCl_3$) 168.8 (C-1′), 109.2 (*C*Me_2), 71.7 (C-3′), 69.2 (C-4′), 65.1 (C-2), 52.8 (C-10), 48.5 (C-1), 47.8 (C-7), 44.6 (C-4), 40.1 (C-2′), 38.3 (C-3), 32.8 (C-6), 26.8 (Me), 26.4 (C-5), 25.5 (Me) 20.8 (C-8), 19.9 (C-9).

*4.13. (2*R*)-*N*-[(3′*RS*,4′*RS*)-3′,4′-Dihydroxyhexanoyl]bornane-10,2-sultam* ***4b***

Colorless oil; ν_{max} (film, cm^{-1}) 3620, 3457, 2976, 2896, 1769, 1602, 1392, 1238, 1046, 877, 685; m/z (LSI-MS) 368 $(M+Na)^+$, 346 $(M+H)^+$; m/z (LSI-MS, HR) calcd for $C_{16}H_{28}NO_5S$ $(M+H)^+$ 346.16648, found 346.16717.

4.13.1. Major diastereoisomer (deduced)

δ_H (500 MHz, $CDCl_3$) 4.01–3.94 (m, 3′H), 3.89 (dd, $J_{2,3A}$=4.9 Hz, $J_{2,3B}$=7.8 Hz, 2-H), 3.52 ($d_{AB,}$ J_{AB}=13.8 Hz, 10-H_A), 3.45 ($d_{AB,}$ J_{AB}=13.8 Hz, 10-H_B), 2.44–3.37 (m, 4′-H), 3.25 (d, $J_{3',OH}$=4.8 Hz, OH), 2.99 ($dd_{AB,}$ $J_{2'A,3'}$=8.7 Hz, J_{AB}=16.5 Hz, 2′-H_A), 2.91 (dd_{AB}, $J_{2'B,3'}$=3.7 Hz, J_{AB}=16.5 Hz, 2′-H_B), 2.37 (d, $J_{4',OH}$=5.4 Hz, OH), 2.24–2.14 (m, 1H, 3-H_A), 2.08 ($dd_{AB,}$ $J_{2,3'B}$=7.8 Hz, J_{AB}=13.9 Hz, 1H, 3-H_B), 1.97–1.81 (m, 4-H, 6-H_A, 6-H_B), 1.64–1.55 (m, 5′-H_A), 1.56–1.50 (m, 5′-H_B), 1.16 (s, 8-Me), 0.99 (t, $J_{5,6}$=7.4 Hz, 6′-Me), 0.98 (s, 9-Me); δ_C (125 MHz, $CDCl_3$) 171.3 (C-1′), 75.0 (C-3′), 70.5 (C-4′), 65.2 (C-2), 52.9 (C-10), 48.5 (C-1), 47.8 (C-7), 44.7 (C-4), 39.3 (C-2′), 38.5 (C-3), 32.9 (C-6), 26.4 (C-5′), 26.2 (C-5), 20.9 (C-8), 19.9 (C-9), 10.0 (C-6′).

4.13.2. Minor diastereoisomer (deduced)

δ_H (500 MHz, $CDCl_3$) 4.01–3.94 (m, 3′H), 3.88 (dd, $J_{2,3A}$=5.1 Hz, $J_{2,3B}$=7.8 Hz, 2-H), 3.51 ($d_{AB,}$ J_{AB}=13.9 Hz, 10-H_A), 3.44 ($d_{AB,}$ J_{AB}=13.9 Hz, 10-H_B), 2.44–3.37 (m, 4′-H), 3.21 (d, $J_{3',OH}$=5.4 Hz, OH), 2.96 (d, $J_{2',3'}$=6.1 Hz, 2′-H), 2.31 (d, $J_{4',OH}$=5.1 Hz, OH), 2.24–2.14 (m, 3-H_A), 2.08 ($dd_{AB,}$ $J_{2,3B}$=7.8 Hz, J_{AB}=13.9 Hz, 3-H_B), 1.97–1.81 (m, 4-H, 6-H_A, 6-H_B), 1.64–1.55 (m, 5′-H_A), 1.56–1.50 (m, 5′-H_B), 1.16 (s, 8-Me), 0.99 (t, $J_{5,6}$=7.4 Hz, 6′-Me), 0.98 (s, 9-Me); δ_C (125 MHz, $CDCl_3$) 171.2 (C-1′), 75.0 (C-3′), 70.4 (C-4′), 65.2 (C-2), 52.9 (C-10), 48.5 (C-1), 47.8 (C-7), 44.6 (C-4), 39.2 (C-2′), 38.3 (C-3), 32.9 (C-6), 26.4 (C-5′), 26.2 (C-5), 20.8 (C-8), 19.9 (C-9), 10.0 (C-6′).

*4.14. (2*R*)-*N,N*-[(3′*R*,4′*R*)-3′,4′-*O*-Isopropylidenehexanedioyl]-bis-bornane-10,2-sultam (3*R*,4*R*)-***5c*** (major diastereoisomer)*

Preparation: after the typical osmylation procedure (from 200 mg, 0.371 mmol of olefin **3c**), the reaction mixture was diluted with 4 ml of acetone. *p*TsOH (20 mg) was added followed by 2-methoxypropene (1.0 ml) and stirring was continued for 16 h at rt. Et_2O, then aq. $NaHSO_3$ were added, the aq. phase was extracted 3 times with Et_2O and dried over anhyd. $MgSO_4$. After removal of solvents (for DMF oil pump, 60°C) diastereomeric products were separated by column chromatography (hexane:EtOAc 9:1–7:3) to give 90 and 65 mg (58:42) of acetals, overall yield 68%. Colorless crystals, mp 225–227°C (methanol);

$[\alpha]_D$=−78.7 (c 0.7, $CHCl_3$); ν_{max} (KBr, cm^{-1}) 2960, 1689, 1395, 1336, 1291, 1201, 1136, 1070, 989, 541; δ_H (500 MHz, $CDCl_3$) 4.27–4.36 (m, 2H, 3′-H×2), 3.88 (dd, $J_{2,3A}$=4.9 Hz, $J_{2,3B}$=7.8 Hz, 2H, 2-H×2), 3.49 ($d_{AB,}$ J_{AB}=13.8 Hz, 2H, 10-H_A×2), 3.42 ($d_{AB,}$ J_{AB}=13.8 Hz, 2H, 10-H_B×2), 3.13 ($dd_{AB,}$ $J_{2'A,3'}$=7.3 Hz, J_{AB}=16.4 Hz, 2H, 2′-H_A, 5′-H_A), 2.99 ($dd_{AB,}$ $J_{2'B,3'}$=4.0 Hz, J_{AB}=16.4 Hz, 2H, 2′-H_B, 5′-H_B), 2.26–2.15 (m, 2H, 3-H_A×2), 2.07 ($dd_{AB,}$ $J_{2,3B}$=7.8 Hz, J_{AB}=13.9 Hz, 2H, 3-H_B×2), 1.96–1.80 (m, 6H, 4-H×2, 6-H_A×2, 6-H_B×2), 1.48–1.30 (m, 4H, 5-H_A×2, 5-H_B×2), 1.38 (s, 6H, 2×Me), 1.16 (s, 6H, 8-Me), 0.96 (s, 6H, 9-Me); δ_C (125 MHz, $CDCl_3$) 168.7 (C-1′), 109.9 (*C*Me_2), 76.8 (C-3′), 65.3 (C-2), 53.0 (C-10), 48.5 (C-1), 47.8 (C-7), 44.7 (C-4), 39.5 (C-2′), 38.5 (C-3), 32.8 (C-6), 27.5 (C*Me*$_2$), 26.4 (C-5), 20.8 (C-8), 19.9 (C-9); m/z (EI) 597 $(M-CH_3)^+$, 537 $(M-O_2CMe_2)^+$; m/z (HR-EI) calcd for $C_{28}H_{41}N_2O_8S_2$ $(M-CH_3)^+$ 597.23044, found 597.23024. Anal. calcd for $C_{29}H_{44}N_2O_8S_2$: C, 56.84; H, 7.24; N, 4.57; S, 10.47. Found: C, 56.88; H, 7.46; N, 4.49; S, 10.42.

*4.15. (2*R*)*-N,N-*[(3′*S*,4′*S*)-3′,4′*-O-*Isopropylidenehexanedioyl]-bis-bornane-10,2-sultam (3*S*,4*S*)-**5c** (minor diastereoisomer)*

Colorless crystals, mp 217°C (hexane/AcOEt); $[\alpha]_D$=−117.8 (c 0.54, $CHCl_3$); ν_{max} (KBr, cm^{-1}) 2972, 2918, 1701, 1459, 1392, 1327, 1234, 1136, 1087, 981, 778, 617, 536; δ_H (200 MHz, $CDCl_3$) 4.21–4.34 (m, 2H, 3′-H×2), 3.84 (dd, $J_{2,3A}$=5.0 Hz, $J_{2,3B}$=7.8 Hz, 2H, 2-H×2), 3.50 ($d_{AB,}$ J_{AB}=13.7 Hz, 2H, 10-H_A×2), 3.41 ($d_{AB,}$ J_{AB}=13.7 Hz, 2H, 10-H_B×2), 3.13–3.00 (m, 4H, 2′-H×2, 5′-H×2), 2.25–2.10 (m, 2H, 3-H_A×2), 2.05 ($dd_{AB,}$ $J_{2,3B}$=7.7 Hz, J_{AB}=13.7 Hz, 2H, 3-H_B×2), 1.97–1.78 (m, 6H, 4-H×2, 6-H_A×2, 6-H_B×2), 1.49–1.24 (m, 4H, 5-H_A×2, 5-H_B×2), 1.39 (s, 6H, 2×Me), 1.15 (s, 6H, 8-Me×2), 0.96 (s, 6H, 9-Me×2); δ_C (50 MHz, $CDCl_3$) 168.7 (C-1′), 109.4 (*C*Me_2), 76.2 (C-3′), 65.1 (C-2), 52.8 (C-10), 48.5 (C-1), 47.8 (C-7), 44.6 (C-4), 39.4 (C-2′), 38.3 (C-3), 32.8 (C-6), 27.1 (C*Me*$_2$), 26.5 (C-5), 20.8 (C-8), 19.9 (C-9); m/z (LSI-MS) 635 $(M+Na)^+$, 613 $(M+H)^+$; m/z (LSI-MS, HR) calcd for $C_{29}H_{45}N_2O_8S_2$ $(M+H)^+$ 613.26174, found 613.25811. Anal. calcd for $C_{29}H_{44}N_2O_8S_2$: C, 56.84; H, 7.24; N, 4.57; S, 10.47. Found: C, 56.63; H, 7.45; N, 4.40; S, 10.57.

*4.16. (2*R*)*-N,N-*[3′*R,*4′*R-O-*Diacetoxyhexanedioyl]-bis-bornane-10,2-sultam (3*R,*4*R*)-**5c′′** (major diastereoisomer)*

After the typical osmylation procedure (from 166 mg, 0.308 mmol of olefin **3c**), the reaction mixture was diluted with CH_2Cl_2 (5.0 ml). Ac_2O (0.5 ml) and a catalytical amount of DMAP were added and stirring was continued for 16 h at rt. AcOEt and aq. $NaHSO_3$ were added, the aq. phase was extracted 3 times with AcOEt and dried over anhyd. $MgSO_4$. After removal of solvents (for DMF oil pump, 60°C) diastereomeric products were separated by column chromatography (hexane:AcOEt 9:1–7:3) to give 104 and 80 mg (57:43) of acetates, overall yield 91% prior to recrystallization. Colorless crystals, mp 143–146°C (hexane/Et_2O); $[\alpha]_D$=−98.1 (c 0.96, $CHCl_3$); ν_{max} (KBr, cm^{-1}) 2963, 2885, 1755, 1693, 1374, 1329, 1217, 1137, 1065, 1029, 989, 779, 539; δ_H (200 MHz, $CDCl_3$) 5.59 (dt, $J_{2'A,3'}$=$J_{3',4'}$=6.9 Hz, $J_{2'B,3'}$=2.4 Hz, 2H, 3′-H×2), 3.87 (dd, $J_{2,3A}$=5.5 Hz, $J_{2,3B}$=7.2 Hz, 2H, 2-H×2), 3.49 ($d_{AB,}$ J_{AB}=13.9 Hz, 2H, 10-H_A×2), 3.41 ($d_{AB,}$ J_{AB}=13.9 Hz, 2H, 10-H_B×2), 3.20–2.90 (m, 4H, 2′-H, 5′-H), 2.22–1.96 (m, 4H, 3-H×2), 2.08 (s, 6H, Ac×2), 1.92–1.78 (m, 6H, 4-H×2, 6-H×2), 1.49–1.20 (m, 4H, 5H×2), 1.13 (s, 6H, 8-H×2), 0.96 (s, 6H, 9-H×2); δ_C (50 MHz, $CDCl_3$) 170.1 (*C*OAc), 167.4 (C-1′), 69.1 (C-3′), 65.2 (C-2), 52.8 (C-10), 48.4 (C-1), 47.7 (C-7), 44.6 (C-4), 38.2 (C-3), 36.0 (C-2′), 32.7 (C-6), 26.4 (C-5), 20.8 (Ac), 20.7 (C-8), 19.8 (C-9); m/z (LSI-MS) 679 $(M+Na)^+$, 657 $(M+H)^+$; m/z (LSI-MS, HR) calcd for $C_{30}H_{45}N_2O_{10}S_2$ $(M+H)^+$ 657.25156, found 657.25071.

*4.17. (2*R*)-*N,N*-[3′*S*,4′*S*-O-Diacetoxyhexanedioyl]-bis-bornane-10,2-sultam (3*S*,4*S*)-**5c′′** (minor diastereoisomer)*

Colorless crystals, mp 117–120°C (hexane/Et_2O); $[\alpha]_D$=−90.1 (c 0.45, $CHCl_3$); ν_{max} (KBr, cm^{-1}) 2961, 2886, 1747, 1693, 1374, 1330, 1222, 1136, 1061, 1039, 989, 779, 613, 537; δ_H (200 MHz, $CDCl_3$) 5.64 (m, 2H, 3′-H×2), 3.83 (dd, $J_{2,3A}$=4.9 Hz, $J_{2,3B}$=5.7 Hz, 2H, 2-H×2), 3.50 (d_{AB}, J_{AB}=13.9 Hz, 2H, 10-H_A×2), 3.41 ($d_{AB,}$ J_{AB}=13.9 Hz, 2H, 10-H_B×2), 3.06 ($dd_{AB,}$ J_{AB}=16.4 Hz, $J_{2'A,3'}$=5.6 Hz, 2H, 2′-H_A×2), 2.93 ($dd_{AB,}$ J_{AB}=16.4 Hz, $J_{2'B,3'}$=7.2 Hz, 2H, 2′-H_B×2), 2.28–1.85 (m, 10H, 3-H×2, 4-H×2, 6-H×2), 2.07 (s, 6H, Ac×2), 1.48–1.20 (m, 4H, 5H×2), 1.16 (s, 6H, 8-H×2), 0.96 (s, 6H, 9-H×2); δ_C (50 MHz, $CDCl_3$) 169.9 (*C*OAc), 167.5 (C-1′), 68.9 (C-3′), 65.1 (C-2), 52.8 (C-10), 48.5 (C-1), 47.7 (C-7), 44.5 (C-4), 37.9 (C-3), 36.4 (C-2′), 32.8 (C-6), 26.4 (C-5), 20.6 (Ac), 20.5 (C-8), 19.9 (C-9); m/z (LSI-MS) 679 $(M+Na)^+$, 657 $(M+H)^+$; m/z (LSI-MS, HR) calcd for $C_{30}H_{45}N_2O_{10}S_2$ $(M+H)^+$ 657.25156, found 657.24985.

4.18. N-*[(3′*RS*, 4′*RS*)-3′,4′-Dihydroxy-5-(methoxycarbonyl)pentanoyl]-(2*R*)-bornane-10,2-sultam* ***4d***

Colorless crystals, mp 125–128°C (hexane/Et_2O); ν_{max} (KBr, cm^{-1}) 3525, 3009, 2969, 1719, 1684, 1398, 1325, 1288, 1197, 1136, 1067, 994, 781, 762, 538; m/z (LSI-MS) 412 $(M+Na)^+$, 390 $(M+H)^+$; m/z (LSI-MS, HR) calcd for $C_{17}H_{28}O_7NS$ $(M+H)^+$ 390.15865, found 390.15685; Anal. calcd for $C_{17}H_{27}O_7NS$: C, 52.43; H, 6.98; N, 3.60; S, 8.23. Found: C, 52.44; H, 7.15; N, 3.39; S, 8.17.

4.18.1. Major diastereoisomer

δ_H (500 MHz, $CDCl_3$) 4.08–3.96 (m, 3′-H, 4′-H), 3.89 (dd, $J_{2,3A}$=4.9 Hz, $J_{2,3B}$=7.2 Hz, 2-H), 3.71 (s, OMe), 3.52 ($d_{AB,}$ J_{AB}=13.9 Hz, 10-H_A), 3.46 ($d_{AB,}$ J_{AB}=13.9 Hz, 10-H_B), 3.28 (brs, OH), 3.12–2.80 (m, 2′-H), 2.67 ($dd_{AB,}$ J_{AB}=16.1 Hz, $J_{4',5'A}$=8.7 Hz, 5′-H_A), 2.57 ($dd_{AB,}$ J_{AB}=16.1 Hz, $J_{4',5'B}$=9.3 Hz, 5′-H_B), 2.25–2.13 (m, 3-H_A), 2.11–2.03 (m, 3-H_B), 1.98–1.85 (m, 4-H, 5-H), 1.49–1.27 (m, 6-H), 1.16 (s, 8-H), 0.98 (s, 9-H); δ_C (125 MHz, $CDCl_3$) 172.7 (CO_2Me), 170.8 (C-1′), 70.1 (C-3′), 69.9 (C-4′), 65.2 (C-2), 52.9 (C-10), 51.8 (OMe), 48.5 (C-1), 47.7 (C-7), 44.7 (C-4), 39.1 (C-3), 38.4 (C-2′), 37.9 (C-5′), 32.8 (C-6), 26.4 (C-5), 20.8 (C-8), 19.81 (C-9).

4.18.2. Minor diastereoisomer (remaining signals)

δ_H (500 MHz, $CDCl_3$) 3.87 (dd, $J_{2,3A}$=4.8 Hz, $J_{2,3B}$=7.4 Hz, 2-H), 3.51 ($d_{AB,}$ J_{AB}=13.8 Hz, 10-H_A), 3.45 ($d_{AB,}$ J_{AB}=13.8 Hz, 10-H_B), 2.65 ($dd_{AB,}$ J_{AB}=16.2 Hz, $J_{4',5'A}$=8.5 Hz, 5′-H_A), 2.58 ($dd_{AB,}$ J_{AB}=16.2 Hz, $J_{4',5'A}$=9.7 Hz, 5′-H_B), 1.15 (s, 8-H); δ_C (125 MHz, $CDCl_3$) 170.7 (CO_2Me), 70.0 (C-3′), 69.8 (C-4′), 52.8 (C-10), 48.48 (C-1), 44.6 (C-4), 38.3 (C-2′), 37.8 (C-5′), 26.3 (C-5), 20.7 (C-8), 19.80 (C-9).

*4.19. [(3′*E*)-Hex-3′-enedioyl]-1,6-bis-(1*R*,2*S*,5*R*)-menthol (hexene-(3′*E*)-dioic acid di-1-(−)-menthyl ester (−)-**6**)*

A mixture of commercially available *trans*-β-hydromuconic acid (1.387 g, 9.623 mmol) in dry benzene (50 ml), (−)-menthol (3.308 g, 2.2 equiv., 21.17 mmol) and concd H_2SO_4 (8 drops) was heated at 100°C (bath) under a Dean–Stark trap during 36 h. The cold mixture was diluted with ether (50 ml), washed with satd $NaHCO_3$, NaCl, dried over $MgSO_4$ and purified by column chromatography (hexane:AcOEt 95:5) to afford, after recrystallization, 92% of diester **6**. White crystals (MeOH/H_2O), mp 38–40°C; $[\alpha]_D$=−85.4 (c 1.36, $CHCl_3$); ν_{max} (KBr, cm^{-1}) 2953, 2871, 1725, 1453, 1387, 1275, 1163, 983, 843; δ_H (200 MHz, $CDCl_3$) 5.69 (ddd, $J_{2A',3'}$=1.6 Hz, $J_{2B',3'}$=3.8 Hz, $J_{3',4'}$=5.4 Hz, 2H, 3′-H, 4′-H), 4.68 (dt, $J_{1,2}$=$J_{1,6A}$=10.9 Hz, $J_{1,6B}$=4.4 Hz, 2H, 1-H×2), 3.04–3.09 (m, 4H, 2-H′, 5-H′), 1.92–2.04 (m, 2H,

2-H×2), 1.85 (dq, J_q=7.0 Hz, $J_{2,8}$=2.7 Hz, 2H, C*H*Me$_2$×2), 1.60–1.75 (m, 4H, 6-H×2), 1.29–1.58 (m, 4H, 3-H×2), 0.80–1.18 (m, 6H, 5-H×2, 4-H×2), 0.90 (d, *J*=7.0 Hz, 6H, Me×2), 0.89 (d, *J*=7.0 Hz, 6H, Me×2), 0.75 (d, *J*=7.0 Hz, 6H, Me×2); δ_C (50 MHz, $CDCl_3$) 171.1 (C-1′×2), 126.0 (C-3′, C-4′), 74.5 (C-1×2), 47.0 (C-2×2), 40.9 (C-2′, C-5′), 38.2 (C-6×2), 34.2 (C-3×2), 31.4 (*C*HMe$_2$×2), 26.3 (C-5×2), 23.5 (C-4×2), 22.0 (Me×2), 20.7 (Me×2), 16.4 (Me×2); m/z (LSI-MS) 421 $(M+H)^+$; m/z (LSI-MS, HR) calcd for $C_{26}H_{45}O_4$ $(M+H)^+$ 421.33179, found 421.33191. Anal. calcd for $C_{26}H_{44}O_4$: C, 74.24; H, 10.54. Found: C, 73.87; H, 10.76.

*4.20. [(3′*RS*, 4′*RS*)-3′,4′-Dihydroxyhexanedioyl]-1,6-bis-(1*R*,2*S*,5*R*)-menthol **7***

Colorless crystals, mp 105–107°C (hexane/Et_2O); ν_{max} (KBr, cm^{-1}) 3542, 3427, 2957, 2867, 1728, 1457, 1388, 1261, 1171, 1102, 985, 661; δ_H (200 MHz, $CDCl_3$) 4.72 (dt, $J_{1,2}$=$J_{1.6A}$=10.7 Hz, $J_{1,6B}$=4.3 Hz, 2H, 1-H×2), 4.03–3.90 (m, 2H, 3′-H, 4′-H), 3.33–3.23 (m, 2H, OH×2), 2.73–2.47 (m, 4H, 2′-H, 5′-H), 2.07–1.92 (m, 2H, 2-H×2), 1.86 (dq, J_q=7.0 Hz, $J_{2,8}$=2.7 Hz, 2H, C*H*Me$_2$), 1.77–1.60 (m, 4H, 6-H×2), 1.59–1.25 (m, 4H, 3-H×2), 1.18–0.81 (m, 6H, 4-H, 5-H×2), 0.91 (d, *J*=7.0 Hz, 6H, Me×2), 0.89 (d, *J*=7.0 Hz, 6H, Me×2), 0.76 (d, *J*=6.8 Hz, 6H, Me×2); δ_C (50 MHz, $CDCl_3$) 172.32 (C-1′), 172.28 (C-6′), 74.9 (C-1×2), 70.0 (C-3′), 69.9 (C-4′), 46.9 (C-2×2), 40.84 (C-2′), 40. 77 (C-5′), 38.2 (C-6×2), 34.2 (C-3×2), 31.4 (*C*HMe$_2$×2), 26.3 (C-5×2), 23.4 (C-4×2), 22.0 (Me×2), 20.7 (Me×2), 16.3 (Me×2); m/z (LSI-MS) 477 $(M+Na)^+$, 455 $(M+H)^+$; m/z (LSI-MS, HR) calcd for $C_{26}H_{47}O_6$ $(M+H)^+$ 455.33725, found 455.33731. Anal. calcd for $C_{26}H_{46}O_6$: C, 68.69; H, 10.20. Found: C, 68.70; H, 10.41.

*4.21. Diester (3*R*,4*R*)-**8***

Diol (3*R*,4*R*)-**5c** (136 mg, 0.222 mmol) was dissolved in dry *i*-PrOH (20 ml), $TiCl_4$ (1.0 ml, 3.5 mmol) was added and the reaction mixture was refluxed for 20 h (bath 120°C). Into the pre-cooled (0°C) reaction mixture 1N HCl (5 ml) was added, after 10 min stirring at rt the mixture was diluted with CH_2Cl_2, washed with satd $NaHCO_3$, extracted with CH_2Cl_2 (3×) and dried over $MgSO_4$. Diisopropyl ester was purified by column chromatography to give 59 mg (88% yield) of the isopropylidene derivative of diester (3*R*,4*R*)-**8** as a colorless oil.

*4.22. (3*R*,4*R*)-Dihydroxyadipic-γ,γ′-dilactone **9***

To the isopropylidene protected diester **8** (42 mg, 0.139 mmol) in THF:H_2O 4:1 (5 ml) was added 3 ml of 2N HCl and the reaction mixture was stirred at rt for 16 h. Solvents were evaporated and the residue purified by crystallization from hexane/AcOEt to give 9.5 mg (48%) of bislactone, mp 122–123°C; $[\alpha]_D$=143.0 (c=0.8, H_2O). Lit: mp 122–123°C,[12f] 125–126°C;[12g] $[\alpha]_D$[19]=143.0 (c=0.785, H_2O[12f]); 145.0 (c=1.0, H_2O[12g]).

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References

1. Oppolzer, W.; Barras, J.-P. *Helv. Chim. Acta* **1987**, *70*, 1666.

2. Raczko, J.; Achmatowicz, M.; Jezewski, A.; Chapuis, C.; Urbanczyk-Lipkowska, Z.; Jurczak, J. *Helv. Chim. Acta* **1998**, *81*, 1264.
3. Chapuis, C.; Rzepecki, P.; Bauer, T.; Jurczak, J. *Helv. Chim. Acta* **1995**, *78*, 145; Bauer, T.; Chapuis, C.; Kiegiel, J.; Krajewski, J. W.; Piechota, K.; Urbanczyk-Lipkowska, Z.; Jurczak, J. *ibid*. **1996**, *79*, 1059; Raczko, J.; Achmatowicz, M.; Jezewski, A.; Chapuis, C.; Urbanczyk-Lipkowska, Z.; Jurczak, J. *ibid*. **1998**, *81*, 1264; Bauer, T.; Chapuis, C.; Jezewski, A.; Kozak, J.; Jurczak, J. *Tetrahedron: Asymmetry* **1996**, *7*, 1391.
4. Oppolzer, W.; Chapuis, C.; Bernardinelli, G. *Helv. Chim. Acta* **1984**, *67*, 1397.
5. Vogel, J. *J. Chem. Soc*. **1948**, 661; MacKenzie, B. D.; Angelo, M. M.; Wolinsky, J. *J. Org. Chem*. **1979**, *44*, 4042.
6. Feldhues, M.; Schaefer, H. J. *Tetrahedron* **1985**, *41*, 4213; Schmith, A. B.; Toder, B. H.; Branca, S. J. *J. Chem. Soc*. **1984**, *106*, 3995; Hertenstein, U.; Hünig, S.; Reichelt, H.; Schaller, R. *Chem. Ber*. **1982**, *115*, 261.
7. Oppolzer, W.; Moretti, R.; Thomi, S. *Tetrahedron Lett.* **1989**, *30*, 5603; Schroeer, J.; Welzel, P. *Tetrahedron* **1994**, *50*, 6839.
8. Thom, C.; Kocienski, P. *Synthesis* **1992**, 582; Ward, R. S.; Pelter, A.; Goubet, D.; Pritchard, M. C. *Tetrahedron: Asymmetry* **1995**, *6*, 469.
9. (a) Elvidge, J. A.; Linstead, R. P.; Smith, J. F. *J. Chem. Soc*. **1953**, 708; (b) Winterfeldt, E. *Chem. Ber*. **1963**, *96*, 3349.
10. Bienaymé, H. *Tetrahedron Lett.* **1994**, *35*, 6867; Ahmad, R.; Sondheimer, F.; Weedon, B. C. L.; Woods, R. J. *J. Chem. Soc*. **1952**, 4089; Evans, G. L.; Gray, H. W.; Jacobson, H. W. *J. Am. Chem. Soc*. **1950**, *72*, 2727.
11. (a) Shing, T. K. M.; Tam, E. K. W.; Tai, V. W. F.; Chung, I. H. F.; Jiang, Q. *Chem. Eur. J*. **1996**, *2*, 50; (b) Lee, A. W.; Chan, W. H.; Yuen, W. H.; Xia, P. F.; Wong, W. Y. *Tetrahedron: Asymmetry* **1999**, *10*, 1421.
12. For the chiroptical properties of (+)-(3*R*)-hydroxybutyrolactone, see: (a) Suzuki, T.; Idogaki, H.; Kasai, N.; *Tetrahedron: Asymmetry* **1996**, *7*, 3109; (b) Seebach, D.; Eberle, M. *Synthesis* **1986**, 37; (c) Tanaka, A.; Yamashita, K. *Synthesis* **1987**, 570. (−)-(4*S*)-Ethyl-(3*S*)-hydroxybutyrolactone: (d) Wang, Z. M.; Zhang, X. L.; Sharpless, K. B. *Tetrahedron Lett.* **1992**, *33*, 6407; (e) Ghosh, A. *J. Med. Chem*. **1994**, 1177. (+)-(3*R*,4*R*)-Dihydroxyadipic γ,γ′-dilactone: (f) Posternak, T.; Susz, J. P. *Helv. Chim. Acta* **1956**, *39*, 2032; for a puzzling report, see: (g) Edwards, J. M.; Jackman, L. M. *Aust. J. Chem*. **1965**, *18*, 1227.
13. Pougny, J. R. *Tetrahedron Lett.* **1984**, *25*, 2363; Gräfe, U.; Eritt, I. *J. Antibiot.* **1983**, *36*, 1592.
14. Burns, C. J.; Martin, C. A.; Sharpless, K. B. *J. Org. Chem*. **1989**, *54*, 2826.
15. Tolbert, L. M.; Ali, M. B. *J. Am. Chem. Soc*. **1981**, *103*, 2104; *ibid*. **1982**, *104*, 1742; *ibid*. *106*, 3806; *ibid*. **1985**, *107*, 4589.
16. Hilditch, T. P. *J. Chem. Soc*. **1909**, *95*, 1570.
17. Chapuis, C.; de Saint-Laumer, J.-Y.; Marty, M. *Helv. Chim. Acta* **1997**, *80*, 146; Bernardinelli, G.; Chapuis, C.; Kingma, A. J.; Wills, M. *ibid*. **1997**, *80*, 1607.
18. Curran, D. P.; Kim, B. H.; Daugherty, J.; Heffner, T. A. *Tetrahedron Lett.* **1988**, *29*, 3555.
19. Kim, K. S.; Kim, B. H.; Park, W. M.; Cho, S. J.; Mhin, B. J. *J. Am. Chem. Soc*. **1993**, *115*, 7472.
20. Kim, B. H.; Curran, D. P. *Tetrahedron* **1993**, *49*, 293.
21. For a 66:33 mixture, see: Porter, N. A.; Giese, B.; Curran, D. P. *Acc. Chem. Res*. **1991**, *24*, 296, for a 47:53 mixture during the C-β alkyl radical addition to a C-α unsubstituted oxime ether derived from camphersultam, see: Miyabe, H.; Fujii, K.; Naito, T. *Org. Lett.* **1999**, *1*, 569.
22. Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem*. **1978**, *43*, 2939.
23. Sheldrick, G. M. SHELX86, 'Program for the Solution of Crystal Structures', University of Göttingen, Germany, 1985.
24. Sheldrick, G. M. SHELX93, 'Program for the Refinement of Crystal Structures', University of Göttingen, Germany, 1993.
25. Flack, H. D. *Acta Crystallogr., Sect. C* **1983**, *39*, 876.