Pergamon

Tetrahedron 58 (2002) 7503–7518

TETRAHEDRON

Ruthenium catalyzed ring rearrangement: a rapid entry to substituted aza- and oxacycles

Huib Ovaa,[a] Christian Stapper,[b] Gijs A. van der Marel,[a] Hermen S. Overkleeft,[a] Jacques H. van Boom[a] and Siegfried Blechert[b,*]

[a]*Gorlaeus Laboratories, Leiden Institute of Chemistry, P.O. Box 9502, 2300 RA Leiden, The Netherlands*
[b]*Institut für Chemie, Technische Universität Berlin, Strasse des 17, Juni 135, D-10623 Berlin, Germany*

Received 12 June 2002; revised 4 July 2002; accepted 5 July 2002

Abstract—A ring-closing metathesis (RCM) and a ring-opening metathesis (ROM) are combined in a domino process giving access to a variety of aza- and oxacyles, equipped with highly functionalized side chains, starting from readily accessible cyclopentenyl or cycloheptenyl ethers and amines. The role of different protective groups is examined as well as the influence of the relative configuration of stereocenters of the substrate molecules. Substituted 2,5-dihydro-furans and -pyrroles, 1,2,5,6-tetrahydropyranes and -pyridines as well as 2,3,4,7-tetrahydrooxepines are available via this methodology.

1. Introduction

A new method to convert enantiopure carbocycles into substituted heterocycles comprising a combination of ring-closing metathesis (RCM) and ring-opening metathesis (ROM) in a single ring rearrangement, has recently emerged.[1] In this reaction, the chirality embedded in the carbocyclic starting material is completely transferred into the product side chain. Carbocyclic olefins are frequently used precursors because the configuration of stereocenters can easily be controlled. The effectiveness of ROM–RCM was illustrated by the synthesis of different alkaloids and heterocycles.[2]

The behavior of higher substituted cycloolefins in ring rearrangement metathesis (RRM) reactions is of considerable interest (Scheme 1), since such substrates would give access to chiral heterocyclic systems with densely substituted side chains of defined stereochemistry. Therefore, the length of the side chains in the products can be controlled by the size of the carbocyclic starting material. The ring size of the heterocycle is dependent on the length of the side chain in the substrate molecule.

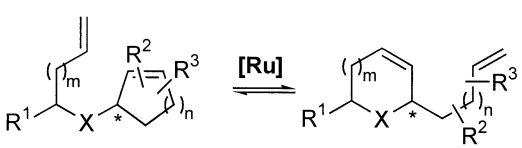
We herein report on the synthesis of chiral 1,2,5,6-tetrahydropyridines, 2,5-dihydro-1*H*-pyrroles, 1,2,5,6-tetrahydropyrans, 2,5-dihydro-1*H*-furans,[3] 2,5-dihydro-1*H*-pyrrol-2-ylmethyl-2,3,4,7-tetrahydrooxepines and 1,2,5,6-tetrahydropyridylmethyl-2,3,4,7-tetrahydrooxepines from cyclopentene and cycloheptene derived precursors via RRM.

2. Results and discussion

In a first study, protected *O*-allylcyclopentenetriols and *N*-allylcyclopentenediols (Scheme 2) were subjected to the olefin metathesis conditions. Palladium(0)-catalyzed allylic amination of allylic carbonate **2** (derived from racemic or enantiopure **1**[4]) with *N*-2-nitrobenzenesulfonyl *N*-allylamine using $[Pd_2(dba)_3]\cdot CHCl_3$ and Trost's ligand (*R*,*R*)-**8**[5] in the presence of 3 equiv. of NEt_3 afforded homogeneous **3** (e.e. >99.5%)[6] in 95% yield.

It has been shown that **2**, equipped with a bridging isopropylidene acetal, does not undergo a ring rearrangement probably for both steric and thermodynamic reasons: The starting material **3** would be transformed, via a strained tetracyclic intermediate, in a dioxolane product **17** that lacks a thermodynamically favorable [5,5]-*cis*-fused bicyclic system (Scheme 3).

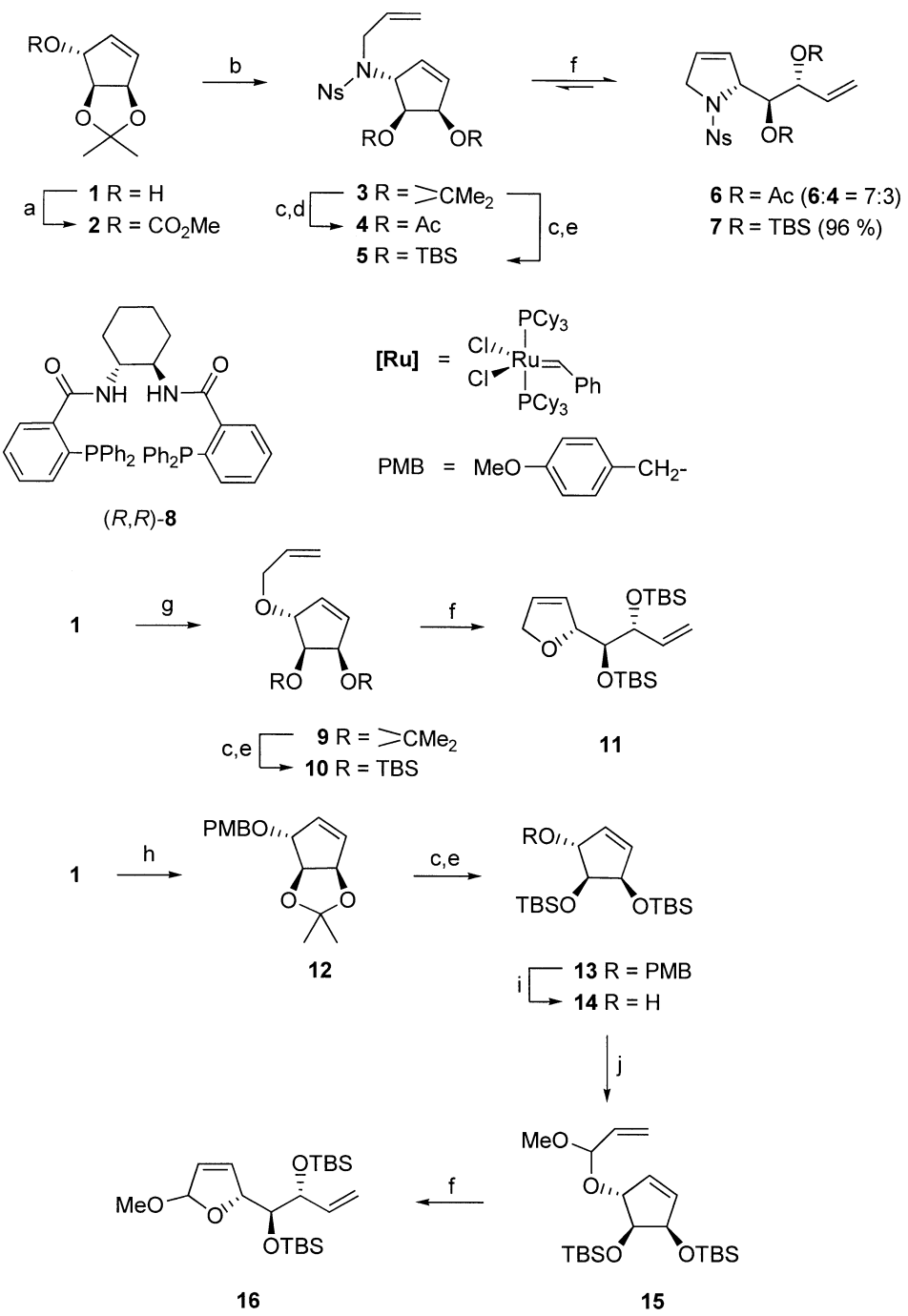
The latter barrier can be avoided by the use of acyclic



Scheme 1. ROM–RCM sequence.

Keywords: asymmetric synthesis; rearrangement; ruthenium; heterocycles.
* Corresponding author. Tel.: +49-30-31422255; fax: +49-30-31423619; e-mail: blechert@chem.tu-berlin.de

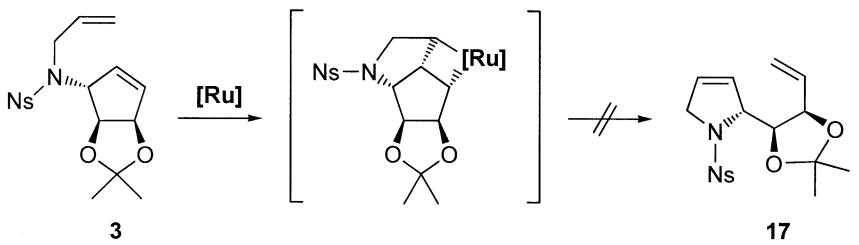
0040–4020/02/$ - see front matter
PII: S0040-4020(02)00832-3



Scheme 2. *Reagents and conditions*: (a) MeOCOCl, CH_2Cl_2/pyridine, 0°C, 97%; (b) $[Pd_2(dba)_3]\cdot CHCl_3$, (*R*,*R*)-**8**, *N*-nosyl-*N*-allylamine, NEt_3, THF, −10 to 0°C, 95%; (c) HOAc/H_2O, 100°C; (d) Ac_2O, pyridine, 99%; (e) TBSCl, imidazole, DMF, →**5**: 83%, →**10**: 82%, →**13**: 70%; (f) [Ru] (5 mol%), CH_2Cl_2, C_2H_4, →**11**: 100%, →**16**: 96%; (g) allyl bromide, NaH, DMF, 0°C, 95%; (h) *p*-$MeOC_6H_4CH_2Cl$, NaH, DMF, 0°C, 97%; (i) DDQ, CH_2Cl_2/H_2O, 0°C, 99%; (j) $Pd(OAc)_2$, dppp, 3-methoxyallene, NEt_3, CH_3CN, reflux, 97%.

protective groups. Deacetalization of **3** was followed by peracetylation giving **4** in 99% yield. Under ring rearrangement conditions, the dihydro-1*H*-pyrrole **6**, however, was found to be in an equilibrium with the starting diacetate **4** (**6**/**4**=7:3) as determined by ^1H NMR spectrum. In earlier studies, we have shown that bulky O-protective groups can shift the RRM equilibrium quantitatively to the product-side.[7] Therefore, the sterically more hindered TBDMS group was used. TBDMS ether **5** (83%) was obtained by a deacetalization and persilylation sequence. A 96% yield of dihydropyrrole **7** was obtained in the subsequent ring rearrangement step.

We next focused our attention to the synthesis of monocyclic oxacycles (i.e. ethers and acetals) via ring rearrangement. Cyclopentenylalcohol **1** was therefore alkylated with allyl bromide giving **9** (95%). In analogy to **3**, allyl ether **9** does not undergo ring rearrangement either. Moreover, when a solution of [Ru] catalyst and **9** was boiled under reflux in the absence of ethylene, a product resulting



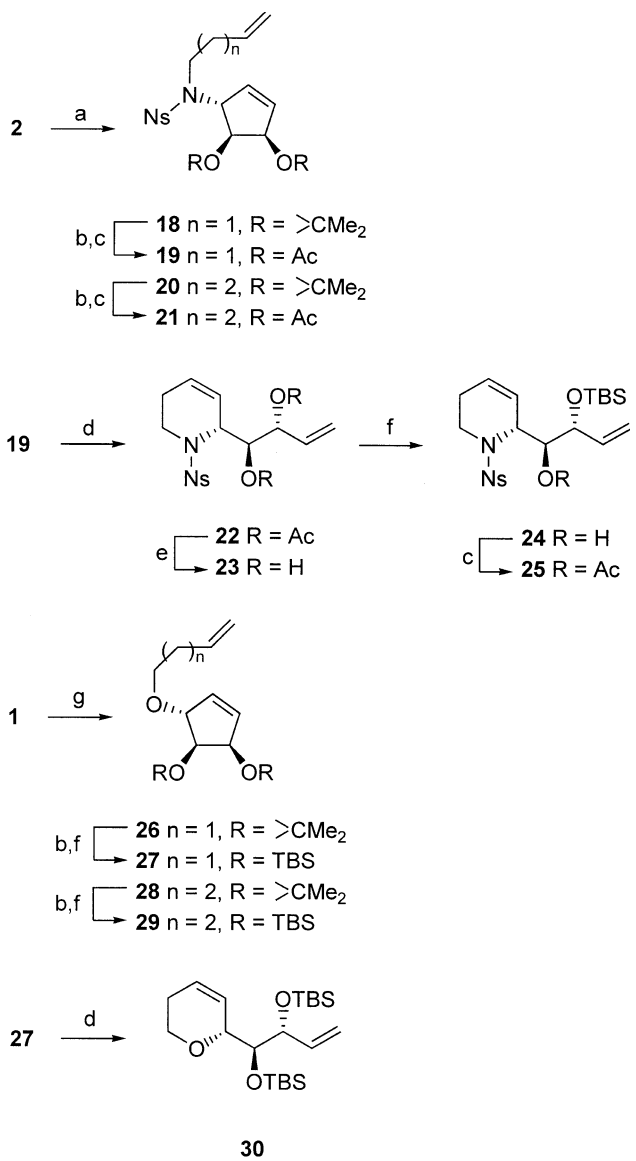
Scheme 3. Postulated tetracyclic [Ru]-intermediate.

from homodimerization by cross-metathesis (CM) was isolated as a single isomer in 26% yield (50% of **9** was reisolated). Deacetalization of **9** and persilylation of the resulting free diol afforded ether **10** (82%). Ring rearrangement of **10** gave the expected dihydrofuran **11** in quantitative yield.

The allylic acetal **15** was synthesized in order to obtain lactols by ring rearrangement. Protective group manipulations of **1** and subsequent palladium(II) catalyzed reaction of the resulting alcohol **14** with methoxyallene[8] afforded two diastereomers of acetal **15** in 97% yield. The ring rearrangement gave the acid labile[9] acetal **16** in 96% yield. This demonstrates the general applicability of substituted side chains in such RRM reactions.

The ease of formation of five-membered aza- and oxacycles, raised the question whether also six- or seven-membered rings could be obtained in this manner. For a pilot study (Scheme 4), the amines **19** and **21** and the ethers **27** and **29** were synthesized the same way as **4** and **9** from **2** and **1**, respectively. Ring rearrangement of **19** and **27** proceeded quantitatively to afford tetrahydropyridine **22** and tetrahydropyran **30**, respectively. In addition, we established that differentiation between the two acetate groups in **22**, which improves its synthetic potential, could easily be effected by a deprotection–silylation procedure to afford **24**. The identity of **24** was further established by reacetylation to **25**.

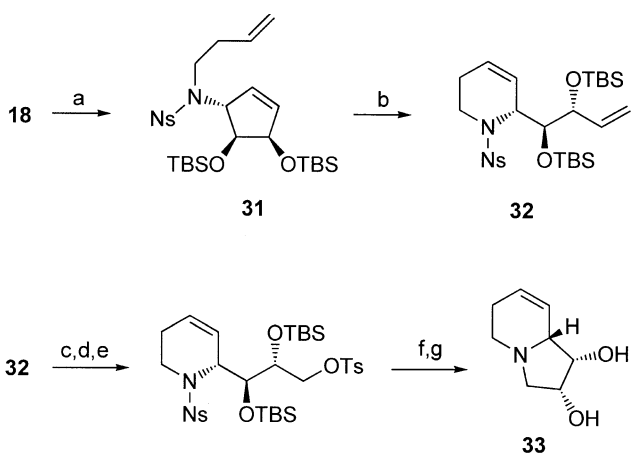
In the case of the pentenylamine **21** and of the pentenylether **29**, ring rearrangement under the olefin metathesis conditions failed. The equilibria are on the side of the starting materials. The ring strains of seven-membered heterocycles



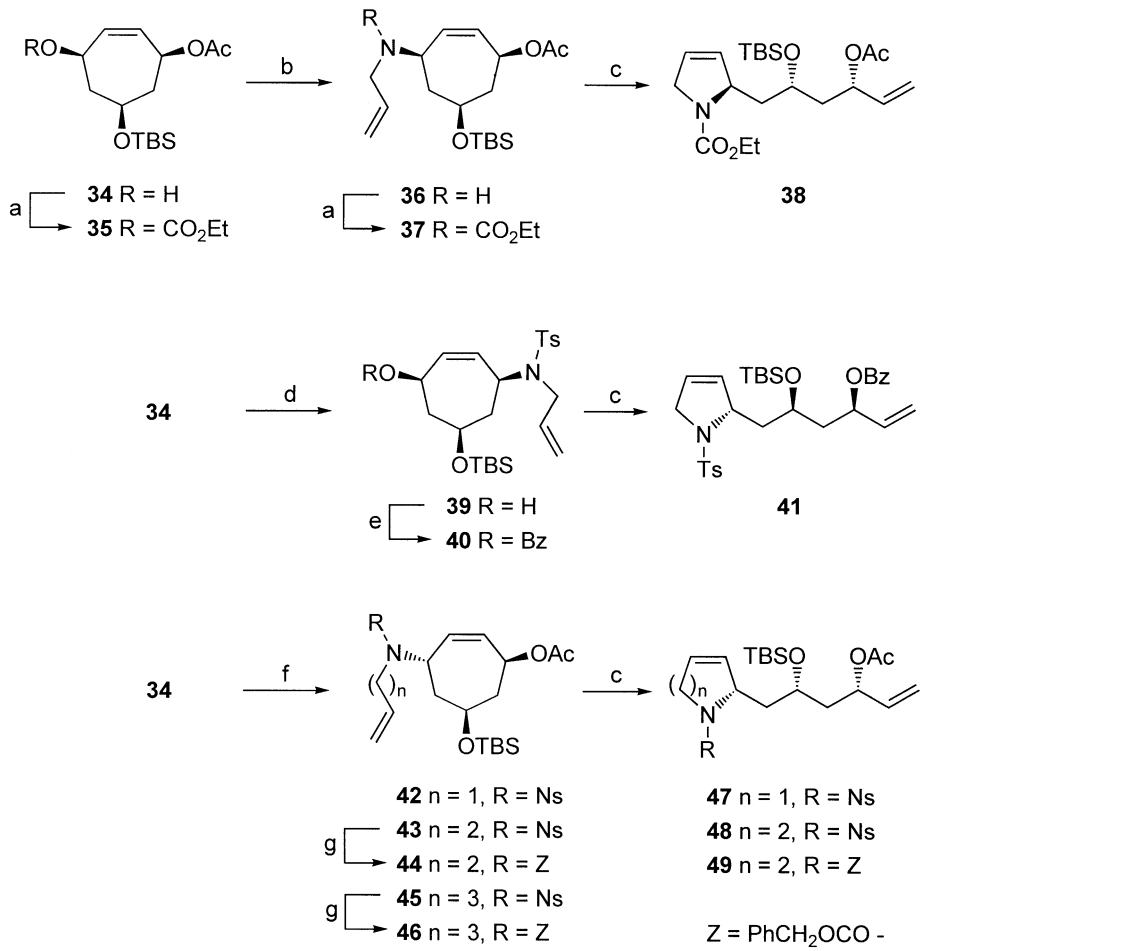
Scheme 4. *Reagents and conditions*: (a) $[Pd_2(dba)_3]\cdot CHCl_3$, (*R*,*R*)-**8**, *N*-nosyl-*N*-(but-3-enyl)-amine NEt_3, THF, −10 to 0°C, →**18**: 93%, or $[Pd_2(dba)_3]\cdot CHCl_3$, dppb, *N*-nosyl-*N*-(pent-4-enyl)-amine, NEt_3, THF, −10 to 0°C, →**20**: 100%; (b) $HOAc/H_2O$, 100°C; (c) Ac_2O, pyridine, →**19**: 99%, →**21**: 100%; (d) [Ru] (5 mol%), CH_2Cl_2, C_2H_4, →**22**: 100%, →**30**: 100%; (e) NaOMe, MeOH, 93%; (f) TBSCl, imidazole, DMF, →**24**: 95%, →**27**: 82%, →**29**: 87%; (g) but-3-enyl bromide, KH, DMPU/THF, 0°C, →**26**: 65%, or pent-4-enyl bromide, KH, DMPU/THF, 0°C, →**28**: 96%.

The amines **19** and **21** and the ethers **27** and **29** were synthesized the same way as **4** and **9** from **2** and **1**, respectively. Ring rearrangement of **19** and **27** proceeded quantitatively to afford tetrahydropyridine **22** and tetrahydropyran **30**, respectively. In addition, we established that differentiation between the two acetate groups in **22**, which improves its synthetic potential, could easily be effected by a deprotection–silylation procedure to afford **24**. The identity of **24** was further established by reacetylation to **25**.

In the case of the pentenylamine **21** and of the pentenylether **29**, ring rearrangement under the olefin metathesis conditions failed. The equilibria are on the side of the starting materials. The ring strains of seven-membered heterocycles



Scheme 5. Synthesis of indolizidine **33**. *Reagents and conditions*: (a) $HOAc/H_2O$, 80°C; TBSCl, imidazole, DMF, rt, 75%; (b) [Ru] (4 mol%), CH_2Cl_2, C_2H_4, rt, 100%; (c) $K_2OsO_4\cdot 2H_2O$, NMO, acetone/H_2O, rt, 80%; (d) $NaIO_4$, $MeOH/H_2O$, 0°C; $NaBH_4$ (aq.), 0°C, 99%; (e) TsCl, pyridine, DMAP, rt, 71%; (f) PhSH, K_2CO_3, DMF, 0°C; (g) TBAF, THF, rt (87% steps f and g).



Scheme 6. *Reagents and conditions*: (a) EtOCOCl, CH_2Cl_2/pyridine, 0°C to rt, →**35**: 92%, →**37**: 89%; (b) $[Pd_2(dba)_3]\cdot CHCl_3$, dppb, allylamine, THF, rt, 80%; (c) [Ru] (5 mol%), CH_2Cl_2, →**38**: 80%, →**41**: 92%, →**47**: 94%, →**48**: 86%, →**49**: 92%; (d) $[Pd_2(dba)_3]\cdot CHCl_3$, dppb, *N*-tosyl-*N*-allylamine, NaH, THF/DMF (3:1), 50°C, 82%; (e) benzoyl chloride, CH_2Cl_2, DMAP, rt, 91%; (f) *N*-nosyl-*N*-alkenylamine, PPh_3, DEAD, THF, 0°C to rt, →**42**: 93%, →**43**: 89%, →**45**: 74%; (g) PhSH, K_2CO_3, DMF, 70°C then benzyl chloroformate, 0°C, →**44**: 87%, →**46**: 78%.

are obviously much higher than those of the cyclopentene starting materials.

In one example the indolizidine **33** (Scheme 5) could be obtained in five steps from tetrahydropyridine **32**, the product of a quantitative RCM–ROM of **31** under influence of Grubbs-I catalyst and ethylene.[2a]

In order to enable the formation of larger heterocyclic ring systems, i.e. tetrahydroazepines or -oxepines, higher cycloolefins should be employed. An increase in free energy of the starting material should shift the equilibrium to the product side. In a further study, the ring size of the starting compounds was varied giving access to larger heterocycles and longer side chains. Besides substituted cyclohexenes, especially chiral substituted cycloheptenes were taken into account as interesting starting materials for natural product synthesis. We concentrated our investigations on the ring sizes accessible from cycloheptene precursors, on the influences of different N-protective groups and on different configurations of the stereocenters. In the current study, we restricted ourselves to *N*-heterocyclic systems. Compound **34** (Scheme 6) was considered as a suitable precursor because it can easily be prepared in both enantiomeric forms from tropone[10] according to literature protocols. Simple derivatizations of **34** should give, after ring rearrangement, access to a variety of heterocycles of different size and substitution pattern.

At first, the synthesis of dihydropyrrole derivatives with different configurations was examined. The amines **36**, **37**, **39**, **40** and **42** were stereoselectively prepared starting from **34** either by η^3-allyl-Pd(0) substitution of an allylic carbonate or acetate or by Mitsunobu reaction of an allylic alcohol. These substrates differ in the stereochemistry and N- and O-protecting groups. A complete protection of free alcohols or amines was necessary for the metathesis reaction. In a pilot study, ring rearrangements starting from the amine **36** or alcohol **39** proved to be abortive. Coordination of the amino or hydroxyl group to the catalyst may be responsible for the inhibition of the metathesis reaction.

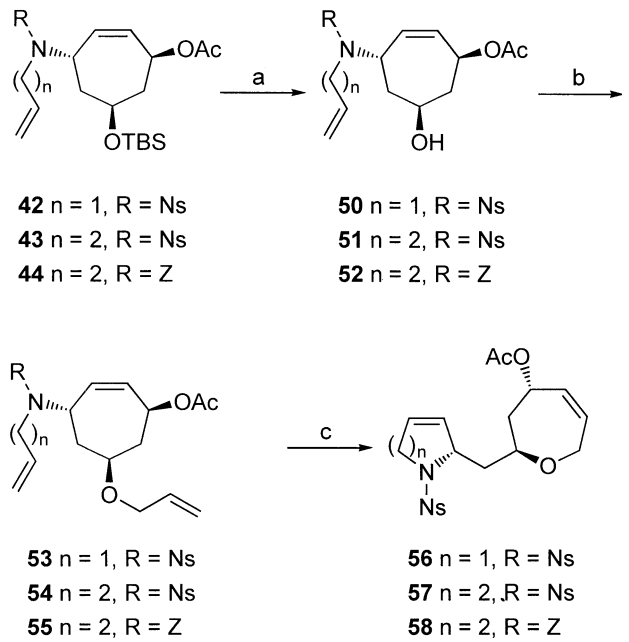
Ring rearrangement of the protected amines **37**, **40** and **42** gave the desired dihydropyrroles **38** (80%), **41** (92%) and **47** (94%). Tetrahydropyridines were also accessible via this method: the but-3-enylamines **43** and **44** gave the desired products **48** (86%) and **49** (92%). We found that the N-benzyloxycarbonyl protected amine **44** gave better yields than the N-nosyl protected derivative **43**, consistent with the results of former studies.[11] Compound **44** (87%) was easily prepared from **43** in a one-pot procedure with PhSH and

K_2CO_3 in DMF at 70°C[12] followed by addition of benzyl chloroformate at 0°C. Generally, it was established that RRM of cycloheptenylamines does not require the addition of ethylene, provided that reactions are carried out in boiling dichloromethane.

As outlined above, the synthesis of tetrahydroazepines from cycloheptene precursors was considered a promising goal. Thus, the pent-4-enylamines **45** and **46** were prepared and subjected to the olefin metathesis conditions, but the reaction failed. The rearrangement equilibrium is still on the side of the starting material.

In order to enable seven-membered ring formation to be productive in preparative terms via RRM strategy, it was decided to combine ring-rearrangement with RCM in order to provide an additional thermodynamic sink[13] (i.e. removal of ethylene liberated in this tandem process may shift the equilibrium in favor of the desired product). Therefore, allyloxy substituted cycloheptenylamines **53**–**55** (Scheme 7) were prepared from **42**–**44** by desilylation (→**50**–**52**) and subsequent O-allylation.[14] Subjecting **53**–**55** to Grubbs' catalyst [Ru] in boiling dichloromethane afforded substituted tetrahydrooxepines **56** (93%), **57** (74%) and **58** (92%).

In conclusion, it has been shown that derivatives of cyclopentenyl alcohol **1** and cycloheptenyl alcohol **34** can serve as a platform, capable of undergoing ruthenium catalyzed ring rearrangements to give five-, six- and seven-membered heterocycles. Furthermore, it was established that the equilibrium reached in this, in principle reversible reaction, is dependent on the choice of protecting groups. Substituted tetrahydrooxepines can be obtained provided the ring rearrangement is accompanied by an additional thermodynamic driving force (RCM). The method thus demonstrated gives access to an array of enantiopure, substituted heterocycles that cannot easily be obtained by other methods. The concept of tandem ring rearrangement is currently being extended to other ring sizes and substitution patterns for natural product synthesis.



Scheme 7. *Reagents and conditions*: (a) TBAF, THF, 0°C, →**50**: 85%, →**51**: 89%, →**52**: 88%; (b) allyl trichloroacetimidate, cat. CF_3SO_3H, CH_2Cl_2/cyclohexane (1:1), rt, →**53**: 52%, →**54**: 38%, →**55**: 37%; (c) [Ru] (5 mol%), CH_2Cl_2, reflux, →**56**: 93%, →**57**: 74%, →**58**: 92%.

3. Experimental

^1H NMR spectra (200, 400, 500 MHz) and ^{13}C NMR spectra (50, 100, 125 MHz) were recorded on either a BRUKER AC 200 or 400 or a BRUKER DRX 500 spectrometer. Mass spectra were obtained by electron impact (EI/CI) at 70 eV on a FINNIGAN MAT 95 SQ and IR spectra by attenuated total reflectance (ATR) on a NICOLET FT-IR 750 spectrometer. Optical rotations were determined on a PERKIN–ELMER 341 polarimeter using a 10 cm path length cell. Flash chromatography (FC) was performed on MERCK silica gel 60 (0.040–0.063 mm). MTBE=methyl *tert*-butyl ether. Chemicals were purchased from ALDRICH or MERCK and were used without further purification.

3.1. General procedures

*(A) Palladium catalyzed allylic aminations using the ligand (R,R)-**8***. The appropriate allylic carbonate (1 mmol), *N*-nosyl alkenylamine (1.3 mmol) and Et_3N (3 mmol) were dissolved in THF (5 mL) and cooled to −10°C. In a separate (Schlenk) flask $[Pd_2(dba)_3]\cdot CHCl_3$ (40 mg, 0.038 mmol) and ligand (*R*,*R*)-**8** (106 mg, 0.153 mmol) were dissolved in THF (4 mL) and stirred until the solution became red–orange (30 min). Quantities of this stock solution of catalyst (0.010 M in Pd) were added dropwise to the cooled reaction mixture by a syringe and were stirred overnight at 0°C, the reaction mixture was then allowed to warm slowly to rt. Reaction progress was monitored by ^1H NMR spectra of small aliquots that are taken from the reaction mixture and concentrated under reduced pressure. Upon completion, the reaction mixture was concentrated under reduced pressure and purified by FC (MTBE/hexane or (CH_2Cl_2).

*(B) Deacetalization of compounds **3**, **9**, **12**, **18**, **20**, **26** and **28***. Isopropylidene moieties were removed by dissolving 1 mmol of compound in acetic acid (4 mL) followed by slow addition of water (1 mL). The solution was heated to 80–100°C for 20–30 min. Reaction progress was monitored by TLC (MTBE). Upon completion, the reaction mixture was concentrated under high vacuum and directly used in the next step without further purification.

*(C) Acetylation to compounds **4**, **19**, **21**, **25***. Alcohols or diols (1 mmol) were dissolved in pyridine (2 mL) and acetic anhydride (1 mL) was added. Reactions were monitored by TLC (MTBE). Upon completion, toluene was added (5 mL) and the solution was concentrated under reduced pressure. This process was repeated twice. FC (MTBE–hexane) afforded the homogeneous acetylated compounds.

*(D) Mono- or bis-silylation to compounds **5**, **10**, **13**, **24**, **27**, and **29***. Alcohols or diols (1 mmol) and imidazole (10 equiv.) were dissolved in DMF (5 mL); *tert*-butyl dimethylsilanyl chloride (TBDMSCl, 2.2–2.3 mmol) was

added in one portion and the solution was stirred overnight. Reaction progress was monitored by TLC (MTBE–hexane). Heating the DMF solutions to 50°C, generally completes the reactions in one hour, without deterioration in yield. After completion, hexane and MTBE were added and the solution was poured into water and extracted twice with water. The organic layer was separated, dried ($MgSO_4$), filtered and concentrated under reduced pressure. FC (MTBE–hexane) gave the homogeneous target compounds.

*(E) RCM–ROM (ring rearrangement) of compounds **4**, **5**, **10**, **15**, **19**, **27** and **31**.* The substrate (1 mmol) was transferred into a BRAUN MB 150B glove box[15] and dissolved in dry CH_2Cl_2; ethylene gas (25 mL) was bubbled through the stirred solution slowly by a syringe and Grubbs' pre-catalyst $Cl_2(PCy_3)_2Ru{=}CHPh$ [Ru] 20–25 mg (4–5 mol%) was added. Reaction progress was monitored by NMR spectra of small aliquots that were taken from the reaction mixture and concentrated under reduced pressure. Typically, solutions were stirred overnight upon which ^1H NMR spectra revealed total transformation of all starting material. The solutions were taken out of the glove box,[15] concentrated and purified by FC (MTBE–hexane).

3.1.1. (−)-Carbonic acid (1*R*,4*R*,5*R*)-4,5-isopropylidenedioxycyclopent-2-enyl ester methyl ester [(−)-2]. Alcohol **1** (372.5 mg, 2.35 mmol) was dissolved in CH_2Cl_2 (10 mL) and pyridine (1 mL) and cooled to 0°C. Methyl chloroformate (270 μL, 3.5 mmol) was added. After 1 h, TLC analysis (MTBE) showed complete conversion to a less polar product. The mixture was poured into saturated NH_4Cl solution and extracted with MTBE. The organic phase was subsequently washed with water, dried ($MgSO_4$), filtered and concentrated. FC (15% MTBE in hexane) gave homogeneous carbonate **2** (495.6 mg, 97%). ^1H NMR (400 MHz): δ 6.14 (d, *J*=6 Hz, 1H), 5.90 (dd, *J*=6, 2 Hz, 1H), 5.50 (d, *J*=2 Hz, 1H), 5.24 (d, *J*=6 Hz, 1H), 4.61 (d, *J*=6 Hz, 1H), 3.78 (s, 3H), 1.30 (s, 3H), 1.28 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 155.1, 138.3, 130.6, 112.3, 86.3, 83.9, 83.0, 54.9, 27.2, 25.7; IR: ν 3066, 1749, 1257, 928, 867 cm^{-1}; HRMS: calcd for $C_9H_{11}O_5$ $[M-CH_3]^+$: 199.0606, found: 199.0607; $[\alpha]_D^{20}=-160.4°$ (*c* 1, $CHCl_3$).

3.1.2. *N*-Allyl-*N*-{(1*R*,4*R*,5*S*)-4,5-isopropylidenedioxycycopent-2-enyl)}-2-nitrobenzene sulfonamide (3). Pd catalyzed allylic amination of **2** using ligand (*R*,*R*)-**8** according to method A followed by purification by silica gel chromatography (0⟶5% MeOH in CH_2Cl_2) gave homogeneous compound **3**, 629 mg (95%). The e.e. was determined by chiral HPLC of the corresponding 4-methylbenzene sulfonamide and compared with the racemate (prepared with the dppb ligand, 70% yield). ^1H NMR (400 MHz, $CDCl_3$): δ 8.16 (m, 1H), 7.68 (m, 3H), 6.03 (dt, *J*=2, 6 Hz, 1H), 5.79 (m, 1H), 5.64 (dd, *J*=3, 9 Hz, 1H), 5.15 (m, 3H), 4.89 (d, *J*=2 Hz, 1H), 4.57 (d, *J*=8 Hz, 1H), 3.90 (tdd, *J*=2, 7, 16 Hz, 1H), 3.68 (dd, *J*=7, 16 Hz, 1H), 1.29, 1.30 (2s, 6H); ^{13}C NMR ($CDCl_3$): δ 147.8, 137.0, 134.3, 133.7, 131.7, 131.6, 130.5, 124.2, 118.7, 111.5, 84.3, 83.3, 69.8, 48.6, 27.2, 25.2; IR: ν 3084, 1543, 1372, 1164 cm^{-1}; HRMS: calcd for $C_{16}H_{17}N_2O_6S$ $[M-CH_3]^+$: 379.0807, found 379.0810.

For the determination of the e.e. of **3** the nosyl group was replaced by a tosyl group ((i) PhSH, K_2CO_3, DMF. (ii) TsCl, pyr.) in order to facilitate separation of the enantiomers on a Chiralcel OD Gold column (0.5% *i*PrOH in hexane, 0.9 mL/min, 218 nm).

3.1.3. *N*-Allyl-*N*-{(1*R*,4*R*,5*S*)-4,5-isopropylidenedioxycyclopent-2-enyl)}-(4-methylbenzene) sulfonamide. Compound **3** (85 mg, 0.22 mmol) was dissolved in DMF (2 mL). K_2CO_3 (61 mg, 0.5 mmol) was added followed by PhSH (300 μL, 1 M in DMF). The suspension was quickly heated using a heat gun until gas evolution occurred. After 5 min, the mixture was cooled and 1 M NaOH and Et_2O were added. The organic phase was separated and extracted with 0.1 M HCl. The aqueous phase was separated and immediately made basic by the addition of 1 M NaOH. The aqueous phase was extracted with Et_2O. This whole process was repeated on the combined aqueous phases. Combined organic phases were dried (Na_2SO_4), filtered and concentrated. The residue was dissolved in pyridine (1 mL), and tosyl chloride (65 mg, 0.34 mmol) was added. The mixture was heated to 50°C for 2 h after which MTBE and a saturated NH_4Cl solution were added. The organic phase was separated and washed with additional NH_4Cl solution and brine, then, it was separated, dried ($MgSO_4$), filtered and concentrated. The product (R_f=0.25 MTBE/hexane 1:4 v/v) was purified by FC (10⟶20% MTBE in hexane) to afford the homogeneous title compound (60 mg, 75%).

A similar procedure was used for the racemate, the enantiomers of which could be separated on a Chiralcel OD Gold column (0.5% *i*PrOH in hexane, 0.9 mL/min, 218 nm, ΔR_t=2 min.). The e.e. of the levorotatory title compound was determined to be higher than 95%. This compound had a retention time of ~20 min, whereas the enantiomer had a retention time of ~22 min. ^1H NMR (500 MHz, $CDCl_3$): δ 7.75 (d, *J*=7 Hz, 2H), 7.29 (d, *J*=7 Hz, 2H), 5.98 (m, 1H), 5.73 (m, 1H), 5.45 (m, 1H), 5.10 (m, 3H), 4.89 (s, 1H), 4.40 (d, *J*=8 Hz, 1H), 3.67 (dd, *J*=7, 16 Hz, 1H), 3.55 (dd, *J*=7, 16 Hz, 1H), 2.40 (s, 3H), 1.29, 1.30 (2s, 6H); ^{13}C NMR ($CDCl_3$): δ 143.4, 137.5, 136.2, 134.6, 129.6, 127.4, 117.9, 111.3, 84.3, 82.8, 69.8, 48.4, 27.2, 25.4, 21.5; $[\alpha]_D^{20}=-35.2°$ (*c* 1, $CHCl_3$).

3.1.4. Acetic acid (1*S*,2*R*,5*R*)-2-acetoxy-5-[allyl-(2-nitrobenzenesulfonyl)-amino]-cyclopent-3-enyl ester (4). Methods B and C with **3** gave **4** in 99% yield after FC (MTBE). ^1H NMR (500 MHz, $CDCl_3$): δ 8.04 (m, 1H), 7.67 (m, 3H), 5.96 (m, 2H), 5.71 (m, 1H), 5.61 (m, 1H), 5.19 (m, 2H), 5.09 (m, 2H), 3.81 (m, 2H), 1.98 (s, 3H), 1.94 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 170.0, 169.8, 147.8, 133.3, 136.1, 134.0, 133.8, 131.7, 131.4, 131.2, 124.4, 118.5, 72.8, 72.4, 65.5, 47.4, 20.6, 20.3; IR: ν 3080, 1743, 1543, 1371, 1242, 1165; HRMS: calcd for $C_{18}H_{20}N_2O_8S$ $[M]^+$: 424.0940, found: 424.0942.

3.1.5. *N*-Allyl-*N*-{(1*R*,4*R*,5*S*)-4,5-bis-(*tert*-butyl-dimethylsilanyloxy)-cyclopent-2-enyl}-2-nitrobenzene sulfonamide (5). Methods B and D with **3** (66.9 mg, 0.17 mmol) gave **5** (84 mg; 83%) after FC (10⟶50% MTBE in hexane). R_f=0.5 (MTBE/hexane 1/1). ^1H NMR (400 MHz, $CDCl_3$): δ 8.05 (m, 1H), 7.64 (m, 3H), 5.97 (dt, *J*=2, 6 Hz, 1H), 5.82 (m, 1H), 5.76 (dd, *J*=2, 7 Hz, 1H), 5.10 (m, 2H), 4.95 (m, 1H), 4.47 (dd, *J*=3, 8 Hz, 1H), 4.10

(t, J=6 Hz, 1H), 3.89 (m, 2H), 0.86, 0.90 (2s, 18H), 0.07, 0.06, 0.05, 0.04 (4s, 12H); ^{13}C NMR ($CDCl_3$): δ 135.3, 133.6, 133.3, 131.5, 131.4, 124.1, 117.9, 75.8, 73.8, 65.5, 47.7, 26.0, 25.8, 18.2, 17.9, −3.7, −4.0, −4.1; IR: ν 3081, 1546, 1361, 1167 cm^{-1}; HRMS: calcd for $C_{26}H_{44}N_2O_6SSi_2$ $[M]^+$: 568.2459, found: 568.2458.

3.1.6. Acetic acid (1*S*,2*R*)-2-acetoxy-1-[(*R*)-1-(2-nitrobenzenesulfonyl)-2,5-dihydro-1*H*-pyrrol-2-yl]-but-3-enyl ester (6). Method E with compound **4** gave after FC (MTBE) an inseparable mixture (180 mg, 100%) of **4** and product **6** (**4**/**6**=28:72). ^{1}H NMR (500 MHz, CD_2Cl_2): δ 7.96 (m, 1H), 7.68 (m, 2H), 7.61 (m, 1H), 5.01 (m, 1H), 5.86 (m, 1H), 5.74 (m, 1H), 5.31 (m, 3H), 5.16 (m, 1H), 5.04 (m, 1H), 4.36 (m, 1H), 4.09 (m, 1H), 2.06 (s, 3H), 2.04 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 170.1, 169.5, 149.0, 133.9, 132.2, 131.5, 130.6, 128.0, 126.6, 124.1, 119.9, 73.4, 72.5, 66.7, 55.8, 20.9, 20.7.

3.1.7. (*R*)-2-[(1*S*,2*R*)-1,2-Bis-(*tert*-butyl-dimethylsilanyloxy)-but-3-enyl]-1-(2-nitrobenzenesulfonyl)-2,5-dihydro-1*H*-pyrrole (7). Method E with **5** (330 mg, 0.58 mmol), gave **7** in 96% yield after FC (10⟶50% MTBE in hexane). R_f=0.35 (MTBE/hexane 1:1). ^{1}H NMR (400 MHz, CD_2Cl_2): δ 7.72 (m, 1H), 7.58 (m, 3H), 5.82 (m, 1H), 5.78 (m, 1H), 5.59 (m, 1H), 5.01 (m, 2H), 4.61 (m, 1H), 4.23 (m, 1H), 4.20 (m, 1H), 4.12 (dd, J=2, 5 Hz, 1H), 4.08 (m, 1H), 0.82, 0.80 (2s, 18H), 0.04 (s, 6H), 0.02, −0.04 (2s, 6H); ^{13}C NMR ($CDCl_3$): δ 137.8, 133.6, 131.5, 129.7, 128.5, 124.34, 124.27, 115.9, 78.5, 74.5, 70.4, 56.2, 25.95, 25.87, 18.2, 18.1, −4.3, −4.5, −4.6, −5.0; IR: ν 3078, 1544, 1372, 1349, 1162 cm^{-1}; HRMS: calcd for $C_{25}H_{41}N_2O_6SSi_2$ $[M-CH_3]^+$: 553.2223 found: 553.2222.

3.1.8. (3*R*,4*S*,5*R*)-3-Allyloxy-4,5-isopropylidenedioxy-cyclopent-1-ene (9). Compound **1** (0.87 g, 5.6 mmol) in DMF or THF (25 mL) was cooled to 0°C. Allyl bromide (720 mg, 6 mmol) was added followed by NaH (60% in mineral oil, 280 mg, 7 mmol). After 30 min, a few drops of MeOH were added. After 10 min, water (100 mL) and Et_2O (100 mL) were added. The organic phase was separated and washed with two portions of water then it was separated, dried ($MgSO_4$) and concentrated in vacuo. FC (10⟶50% MTBE in hexane) afforded homogeneous (volatile) **9** (1.05 g, 5.3 mmol, 95%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.04 (d, J=6 Hz, 1H), 5.94 (m, 2H), 5.26 (m, 3H), 4.56 (d, J=6 Hz, 1H), 4.48 (s, 1H), 4.12 (m, 1H), 4.05 (m, 1H), 1.43, 1.36 (2s, 6H); ^{13}C NMR ($CDCl_3$): δ 135.6, 134.3, 133.0, 117.3, 111.6, 88.0, 84.1, 83.1, 70.5, 27.2, 25.5.

3.1.9. (3*R*,4*S*,5*R*)-3-Allyloxy-4,5-bis-(*tert*-butyl-dimethylsilanyloxy)-cyclopent-1-ene (10). Compound **9** (117 mg, 0.62 mmol) was treated according to methods B and D to give after FC (0⟶10% MTBE in hexane) homogeneous **10** (195 mg, 82%). R_f=0.65 (MTBE/hexane 1/9 v/v). ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.97 (m, 3H), 5.32 (m, 1H), 5.18 (m, 1H), 4.53 (ddd, J=1, 3, 6 Hz, 1H), 4.45 (m, 1H), 4.09 (dt, J=1, 6 Hz, 2H), 3.86 (t, J=5 Hz, 1H), 0.92 (s, 9H), 0.88 (s, 9H), 0.14, 0.13, 0.10, 0.08 (4s, 12H); ^{13}C NMR ($CDCl_3$): δ 135.1, 134.6, 133.8, 116.7, 87.5, 78.8, 74.7, 71.2, 26.0, 18.3, −4.3, −4.4, −4.8; IR: ν 3096, 3077, 1547, 1373, 1253, 1171 cm^{-1}; MS (CI): m/z 407.3 $[M+Na]^+$. HRMS: calcd for $C_{20}H_{40}O_3Si_2$ $[M]^+$: 384.2516, found: 384.2515.

3.1.10. (+)-(*R*)-2-[(1*S*,2*R*)-1,2-Bis-(*tert*-butyl-dimethylsilanyloxy)-but-3-enyl]-2,5-dihydrofuran [(+)-11)]. Method E with compound **10** (390 mg) gave **11** (390 mg, 100%), after FC (0⟶15% MTBE in hexane) R_f=0.60 (MTBE/hexane 1/9 v/v). ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.89 (m, 1H), 5.75 (m, 1H), 5.85 (m, 1H), 5.19 (d, J=17 Hz, 1H), 5.10 (d, J=11 Hz, 1H), 4.90 (m, 1H), 4.62 (m, 2H), 4.18 (dt, J=1, 7.5 Hz, 1H), 3.55 (t, J=5 Hz, 1H), 0.79 (s, 9H), 0.72 (s, 9H), 0.16 (s, 3H), 0.08 (s, 6H), 0.05 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 139.3, 134.6, 127.5, 115.8, 86.9, 78.5, 75.3, 75.1, 26.0, 25.95, 18.25, 18.2, −4.1, −4.4, −4.8, −4.0; IR: ν 3078, 1253, 1130, 1079 cm^{-1}; MS (CI): m/z 407.2 $[M+Na]^+$; HRMS: calcd for $C_{19}H_{37}O_3Si_2$ $[M-CH_3]^+$: m/z 369.2281, found: 369.2287; $[\alpha]_D^{20}$=+61.4° (c 1, $CHCl_3$).

3.1.11. (3*R*,4*S*,5*R*)-3-(4-Methoxybenzyloxy)-4,5-(isopropylidenedioxy)-cyclopent-1-ene (12). Compound **1** (502 mg, 3.17 mmol), was dissolved in DMF (10 mL) and cooled to 0°C. NaH (60% in mineral oil, 200 mg, 5 mmol) was added followed by 4-methoxybenzyl chloride (0.39 mL, 3.8 mmol). After 1 h a few drops of MeOH were added and the solution was allowed to warm to rt over 30 min. Et_2O and water were added. The organic phase was separated and washed with two portions of water. The organic phase was separated, dried ($MgSO_4$), filtered and concentrated. FC (25% MTBE in hexane) afforded homogeneous **12** (856 mg (97%). ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.29 (d, J=7 Hz, 2H), 6.88 (d, J=7 Hz, 2H), 6.03 (m, 1H), 5.91 (m, 1H), 5.28 (m, 1H), 4.47 (m, 3H), 3.82 (m, 1H), 3.80 (s, 3H), 1.41 (s, 3H), 1.37 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 135.4, 133.1, 129.8, 129.3, 113.7, 109.0, 87.7, 84.1, 83.2, 71.2, 55.1, 27.1, 25.5; IR: ν 3062, 1612, 1513, 1369, 1247, 1027, 1048, 1036 cm^{-1}; HRMS: calcd for $C_{16}H_{20}O_4$ $[M]^+$: 276.1362, found: 276.1366.

3.1.12. (3*R*,4*S*,5*R*)-4,5-Bis-(*tert*-butyl-dimethylsilanyloxy)-3-(4-methoxybenzyloxy)-cyclopentene (13). Acetal **12** (0.83 g, 3 mmol) was dissolved in HOAc (4 mL), the solution was heated to 75°C and water (1 mL) was added. The resulting solution was kept at 75°C for 20 min after which toluene was added. Then, the solution was evaporated in vacuo and dried under high vacuum. Method D then gave the homogeneous **13** (0.99 g, 70%) after FC. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.29 (d, J=7 Hz, 2H), 6.90 (d, J=7 Hz, 2H), 5.96 (m, 2H), 4.54 (d, J=12 Hz, 1H), 4.52 (m, 3H), 4.04 (m, 1H), 3.85 (s, 3H), 0.95 (s, 9H), 0.89 (s, 9H), 0.11, 0.12, 0.09, 0.07 (4s, 12H); ^{13}C NMR ($CDCl_3$): δ 159.1, 134.7, 133.9, 130.7, 129.3, 113.7, 87.5, 78.9, 74.7, 71.9, 55.3, 26.0, 18.3, −4.3, −4.8; IR: ν 3061, 1613, 1514, 1361, 1249, 1156, 1125, 1083 cm^{-1}; HRMS: calcd for $C_{25}H_{44}O_4Si_2$ $[M]^+$: 464.2778, found: 464.2775.

3.1.13. (1*R*,4*R*,5*S*)-4,5-Bis-(*tert*-butyl-dimethylsilanyloxy)-cyclopent-2-enol (14). Compound **13** (196.3 mg, 0.425 mmol) was dissolved in CH_2Cl_2 (3 mL) and water was added (3 mL). This mixture was cooled to 0°C and DDQ (110 mg, 0.51 mmol) was added. After stirring vigorously for 20 min, the mixture was extracted with water and MTBE/hexane (1/1 v/v). The organic phase was

separated, dried ($MgSO_4$), filtered and concentrated. Purification by column chromatography (50→100% CH_2Cl_2 in hexanes) gave homogeneous **14** (144.2 mg, 99%) which was directly used in the next step. ^1H NMR (500 MHz, $CDCl_3$): δ 5.96 (m, 2H), 4.52 (m, 3H), 4.04 (m, 1H), 0.95 (s, 9H), 0.89 (s, 9H), 0.11, 0.12, 0.09, 0.07 (4s, 12H); HRMS: calcd for $C_{17}H_{36}O_3Si_2$ $[M]^+$: 344.2203, found: 344.2209.

3.1.14. (3*R*,4*S*,5*R*)-3,4-Bis-(*tert*-butyl-dimethylsilanyloxy)-5-(1-methoxy-allyloxy)-cyclopent-1-ene (15). Alcohol **14** (135 mg, 0.39 mmol) was dissolved in MeCN (3 mL) and Et_3N (1 mL); dppp (10 mg) and $Pd(OAc)_2$ (10 mg) were subsequently added. The solution was heated under reflux, and methoxyallene (0.150 mL) was added. The solution was refluxed for 1 h after which TLC indicated complete consumption of all starting materials. The mixture was cooled to rt and hexane was added. This mixture was poured into water. The organic layer was separated, dried (Na_2SO_4), filtered and concentrated. FC (10% MTBE–1% Et_3N in hexane) gave **15** (157 mg, 97%) as an inseparable mixture (1:1) of diastereomers. ^1H NMR (400 MHz, $CDCl_3$): δ 6.01 (m, 1H), 5.95 (m, 1H), 5.92 (m, 2H), 5.81 (m, 2H), 5.25–5.43 (m, 4H), 4.99 (m, 1H), 4.96 (m, 1H), 4.68 (m, 1H), 4.63 (m, 1H), 4.52 (m, 1H), 4.47 (m, 1H), 4.00 (t, J=5 Hz, 1H), 3.86 (t, J=5 Hz, 1H), 3.34 (s, 3H), 3.27 (s, 3H), 0.94 (s, 9H), 0.92 (s, 9H), 0.87 (s, 18H), 0.03–0.10 (5s, 24H); ^{13}C NMR ($CDCl_3$): δ 135.6, 135.2 (2C), 134.8, 134.4, 133.8, 118.7, 118.6, 103.7, 101.7, 86.2, 83.2, 79.1, 78.7, 74.6, 74.2, 52.8, 51.8, 26.0, 18.3, −4.2, −4.3, −4.8; HRMS: calcd for $C_{21}H_{42}O_4Si_2$ $[M]^+$: 414.2622, found: 414.2627.

3.1.15. (*R*)-2-[(1*S*,2*R*)-1,2-Bis-(*tert*-butyl-dimethylsilanyloxy)-but-3-enyl]-5-methoxy-2,5-dihydro-furan (16). Method E with **15** gave compound **16** (124 mg, 96%) as an inseparable mixture (1:1) of diastereomers after FC (10→50% MTBE in hexane containing 1% Et_3N), R_f=0.35 (MTBE/hexane/Et_3N 100/100/1 v/v/v). ^1H NMR (500 MHz, $CDCl_3$): δ 6.14 (m, 2H), 5.83 (m, 2H), 5.75 (m, 3H), 5.66 (m, 1H), 5.19 (m, 2H), 5.12 (m, 2H), 5.06 (m, 1H), 4.65 (m, 1H), 4.27 (m, 1H), 4.19 (m, 1H), 3.72 (dd, J=1, 5 Hz, 1H), 3.54 (dd, J=2, 3 Hz, 1H), 0.89 (s, 9H), 3.72 (s, 3H), 3.88 (s, 3H), 0.82 (s, 9H), 0.88 (s 18H), 0.08, 0.07, 0.06, 0.03, −0.04, −0.05, −0.06, −0.08 (8s, 24H); ^{13}C NMR ($CDCl_3$): δ 139.5, 138.3, 134.1, 132.9, 127.0, 126.6, 116.2, 116.1, 109.7, 109.0, 87.7, 86.2, 79.9, 78.8, 75.6, 75.0, 55.2, 53.6, 25.9, 25.85, 18.0; HRMS: calcd for $C_{21}H_{42}O_4Si_2$ $[M]^+$: 414.2622, found: 414.2622.

3.1.16. (−)-*N*-But-3-enyl-*N*-((1*R*,4*R*,5*S*)-4,5-isopropylidenedioxycyclopent-2-enyl)-2-nitrobenzene sulfonamide [(−)-18]. Carbonate **2** (1.50 g, 6.94 mmol) and *N*-(2-nitrobenzenesulfonyl)-*N*-but-3-enylamine (2.00 g, 7.80 mmol) were dissolved in THF (25 mL) and Et_3N (3 mL). This solution was degassed and cooled to −10°C. Ligand (*R*,*R*)-**8** (100 mg) and of $[Pd_2(dba_3)]\cdot CHCl_3$ (50 mg) were dissolved in a little THF and stirred for 1 h, after which this solution was slowly added to the mixture at −10°C. The mixture was stirred for 18 h at 0°C after which NMR analysis of a small sample showed that the reaction was complete. The solution was concentrated and purified by column chromatography (0→5% MeOH in CH_2Cl_2) to afford homogeneous **18**[2a] (72.54 g, 93%). ^1H NMR (400 MHz, $CDCl_3$): δ 8.08, (m, 1H), 7.67 (m, 2H), 7.58 (m, 1H), 6.02 (ddd, J=7, 4, 2 Hz, 1H), 5.65 (m, 2H), 5.20 (m, 1H), 5.04 (m, 1H), 5.01 (m, 1H), 4.81 (d, J=1 Hz, 1H), 4.51 (d, J=4 Hz, 1H), 3.36 (m, 1H), 2.99 (m, 1H), 2.26 (m, 2H), 1.36 (s, 3H), 1.24 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 148.0, 136.6, 134.1, 133.4, 133.6, 131.6, 131.5, 124.0, 117.4, 111.5, 84.1, 83.2, 70.5, 46.2, 34.9, 27.1, 25.4; IR: ν 3078, 1544, 1372, 1163 cm^{-1}; HRMS: calcd for $C_{17}H_{19}N_2O_6S$ $[M-CH_3]^+$: 379.0964, found: 379.0962; $[\alpha]_D^{20}=-33.3°$ (*c* 1, $CHCl_3$). Replacement of ligand (*R*,*R*)-**8** by the ligand dppb leads to the formation of racemic **18**.

3.1.17. Acetic acid (1*S*,2*R*,5*R*)-2-acetoxy-5-[allyl-(2-nitrobenzenesulfonyl)-amino]-cyclopent-3-enyl ester (19). Methods B and C with **18** gave **19** in 99% yield after FC (MTBE). ^1H NMR (500 MHz, $CDCl_3$): δ 8.04 (m, 1H), 7.67 (m, 3H), 5.96 (m, 2H), 5.71 (m, 1H), 5.61 (m, 1H), 5.19 (m, 2H), 5.09 (m, 2H), 3.81 (m, 2H), 1.98 (s, 3H), 1.94 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 170.0, 169.8, 147.8, 136.1, 134.0, 133.8, 133.3, 131.7, 131.4, 131.2, 124.4, 118.5, 72.8, 72.4, 65.5, 47.4, 20.6, 20.3; IR: ν 3080, 1743, 1543, 1371, 1242, 1165 cm^{-1}; HRMS: calcd for $C_{18}H_{20}N_2O_8S$ $[M]^+$: 424.0940, found: 424.0942.

For the determination of the e.e. of **18** the nosyl group was replaced by a tosyl group ((i) PhSH, K_2CO_3, DMF. (ii) TsCl, pyr.) in order to facilitate separation of the enantiomers on a Chiralcel OD Gold column (0.5% *i*PrOH in hexane, 0.9 mL/min, 218 nm).

3.1.18. *N*-But-3-enyl-*N*-[(1*R*,4*R*,5*S*)-4,5-isopropylidenedioxycyclopent-2-enyl] 4-methylbenzene sulfonamide. Compound **18** (90 mg, 0.23 mmol) was dissolved in DMF (2 mL). Thiophenol (300 μL, 1 M in DMF) and K_2CO_3 (61 mg, 0.5 mmol) were added and the mixture was heated to ~150°C. The reaction was allowed to stand for 5 min and extracted with 1 M NaOH and Et_2O. The organic phase was separated and extracted with 0.1 M HCl. The aqueous phase was separated and immediately made basic with 1 M NaOH and extracted with Et_2O. This process was repeated once and the combined organic phases were dried (Na_2SO_4), filtered and concentrated to give the free amine that was immediately used in the next step [^1H NMR (400 MHz, $CDCl_3$): δ 5.92 (m, 1H), 5.87 (m, 1H), 5.77 (m, 1H), 5.23 (d, J=5 Hz, 1H), 5.09 (m, 2H), 4.42 (d, J=5 Hz, 1H), 3.78 (s, 1H), 2.81 (m, 1H), 2.74 (m, 1H), 2.48 (m, 2H), 1.40 (s, 3H), 1.35 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 136.1, 134.8, 133.2, 116.6, 84.1, 83.2, 70.5, 46.9, 34.9, 27.3, 25.6]. The amine was dissolved in pyridine (1 mL) and tosyl chloride (60 mg, 0.31 mmol) was added. The solution was heated to 50°C for 2 h and concentrated under reduced pressure. MTBE and a saturated NH_4Cl solution were added. The organic phase was separated, dried ($MgSO_4$), filtered and concentrated. Column chromatography (CH_2Cl_2) gave the homogeneous title compound (67 mg, 78%). ^1H NMR (400 MHz, $CDCl_3$): δ 7.77 (d, J=7 Hz, 2H), 7.31 (d, J=7 Hz, 2H), 6.02 (m, 1H), 5.67 (m, 1H), 5.58 (m, 1H), 5.16 (d, J=4 Hz, 1H), 5.04 (m, 2H), 4.88 (s, 1H), 4.36 (d, J=4 Hz, 1H), 3.09 (m, 1H), 2.76 (m, 1H), 2.43 (s, 3H), 2.29 (m, 1H), 2.36 (m, 1H), 1.39 (s, 3H), 1.27 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 137.2, 135.9, 131.6, 129.6, 127.4, 117.1, 111.3, 84.2, 82.5, 70.3, 45.7, 35.4, 27.2, 25.3, 21.5.

An identical procedure was used for the preparation of a racemate from racemic **18**. Enantiomers of racemic **18** were separated on a CHIRALCEL OD Gold column (0.5% *i*PrOH in hexane). The difference in retention time was ca. 5 min. The racemate was compared with the 4-methyl-benzene sulfonamide described above. The e.e. was determined to be >99.5% (determined by comparison of the enantiopure compound with a mixture of the enantiopure compound and 0.5% of the racemate).

3.1.19. *N*-(2-Nitrobenzenesulfonyl)-*N*-pent-4-enyl amine. Nosylamine (2.0 g, 9.9 mmol) was dissolved in CH_2Cl_2 (10 mL) and Et_3N (2 mL). Di-*tert*-butyldicarbonate (2.15 g, 9.9 mmol) was added followed by a catalytic amount (1 mg) of DMAP. After 2 h additional CH_2Cl_2 was added and the mixture was poured into a saturated NH_4Cl solution. The organic phase was separated, dried ($MgSO_4$), filtered and concentrated under high vacuum. The product was sufficiently pure to use it directly in the subsequent Mitsunobu reaction. (If desired, it could be purified by dissolving in CH_2Cl_2 and extraction into 0.1 M NaOH followed by acidification with 1 M HCl to pH 6 and back-extraction into CH_2Cl_2. This process must be repeated three times on the aqueous phases to get a yield exceeding 90%.) The crude NsNHBoc was dissolved in THF (25 mL) and pent-4-enol (1.12 g, 13 mmol) was added, followed by PPh_3 (5 g, 20 mmol) and DEAD (2.61 g, 2.33 mL, 15 mmol). The solution was stirred overnight. CH_2Cl_2 was added and the organic phase was washed subsequently with 1 M NaOH and water, then it was dried ($MgSO_4$), filtered and concentrated. Et_2O (10 mL) and hexane (10 mL) were subsequently added to give white crystals which were filtered off and discarded. The filtrate was concentrated and the product could be used directly in the next step. [It could also be purified by column chromatography (CH_2Cl_2).] The crude product was dissolved in CH_2Cl_2 (5 mL), TFA (5 mL) was added and the solution was stirred for 4 h after which TLC (CH_2Cl_2) indicated complete consumption of all starting material into a polar compound. Column chromatography (CH_2Cl_2) afforded the homogeneous title compound in 89% yield over three steps based on nosylamine. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 (m, 1H), 7.87 (m, 1H), 7.75 (m, 2H), 5.70 (m, 1H), 5.38 (bt, 1H), 4.98 (m, 2H), 3.10 (m, 2H), 2.08 (m, 2H), 1.64 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 136.4, 133.4, 132.4, 130.4, 125.3, 115.2, 43.4, 30.3, 28.2.

3.1.20. *rac*-(1*R*,4*R*,5*S*)-*N*-(4,5-Isopropylidenedioxycyclopent-2-enyl)-*N*-pent-4-enyl-2-nitrobenzenesulfon-amide (20). The methyl carbonate **2** (268 mg, 1.24 mmol) was treated with *N*-nosyl-*N*-pent-4-enylamine (391 mg, 1.40 mmol) according to method A using the dppb ligand. Purification by column chromatography (25→0% hexane in CH_2Cl_2) gave racemic **20** (502 mg, 100%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 (m, 1H), 7.65 (m, 3H), 1.25, 1.36 (2s, 6H), 6.04 (dt, *J*=2, 6 Hz, 1H), 5.75 (m, 1H), 5.68 (dd, *J*=3, 9 Hz), 4.96–5.05 (m, 2H), 5.22 (m, 1H), 4.83 (d, *J*=2 Hz, 1H), 4.49 (d, *J*=8 Hz, 1H), 3.30 (m, 1H), 2.93 (m, 1H), 2.01 (m, 2H), 1.60 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 137.2, 136.7, 133.6, 131.6, 131.1, 124.1, 115.5, 111.6, 84.3, 83.3, 70.5, 46.4, 30.9, 29.7, 27.3, 25.5; IR: ν 3075, 1544, 1372, 1163 cm^{-1}; HRMS: calcd for $C_{16}H_{17}N_2O_6S$ $[M-CH_3]^+$ 393.1120, found: 393.1121.

3.1.21. *rac*-(1*R*,4*R*,5*S*)-*N*-[4,5-Bis-(*tert*-butyl-dimethylsilanyloxy)-cyclopent-2-enyl]-*N*-pent-4-enyl-2-nitrobenzenesulfonamide (21). Methods B and D with **20** (48.4 mg, 0.118 mmol) gave *rac*-**21** (70.0 mg, 99%) after FC (33% MTBE in hexane). ^{1}H NMR (500 MHz, CD_2Cl_2) δ 7.99 (m, 1H), 7.65 (m, 2H), 7.60 (m, 1H), 5.98 (td, *J*=2, 6 Hz, 1H), 5.75 (dd, *J*=2, 7 Hz, 1H), 5.72 (m, 1H), 4.97 (m, 2H), 4.88 (m, 1H), 4.48 (dd, *J*=3, 7 Hz, 1H), 4.01 (t, *J*=6 Hz, 1H), 3.22 (m, 1H), 3.13 (m, 1H), 1.98 (m, 2H), 1.70 (m, 1H), 1.56 (m, 1H), 0.89, 0.86 (2s), 0.07, 0.06, 0.05, 0.04 (4s, 12H).

3.1.22. (+)-Acetic acid (1*S*,2*R*)-2-acetoxy-{[(*R*)-1-(2-nitrobenzenesulfonyl)-1,2,5,6-tetrahydropyridin-2-yl]-methyl}-allyl ester [(+)-22]. Method E with **19** gave **22** (794 mg, 100%) after FC (MTBE). ^{1}H NMR (500 MHz, CD_2Cl_2): δ 7.99 (m, 1H), 7.66 (m, 2H), 7.57 (m, 1H), 5.97 (m, 1H), 5.84 (m, 1H), 5.72 (m, 1H), 5.46 (m, 2H), 5.39 (dd, *J*=2, 8 Hz, 1H),), 5.27 (dd, *J*=2, 8 Hz, 1H), 4.50 (m, 1H), 3.83 (dd, *J*=4, 14 Hz, 1H), 3.39 (ddd, *J*=6, 10, 14 Hz, 1H), 2.06 (s, 3H), 2.02 (s, 3H), 1.86 (m, 2H); ^{13}C NMR ($CDCl_3$): δ 170.3, 169.7, 148.0, 134.0, 133.5, 131.6, 131.0, 130.7, 128.2, 124.1, 122.8, 72.7, 72.4, 54.0, 39.0, 23.1, 21.5, 20.9, 20.7; IR: ν 3091, 3038, 1743, 1545, 1372, 1239, 1220, 1171 cm^{-1}; HRMS: calcd for $C_{19}H_{22}N_2O_8S$ $[M]^+$: 438.1097, found: 438.1099; $[\alpha]_D^{20}$=+243.7° (*c* 1, $CHCl_3$).

3.1.23. (1*S*,2*R*)-1-[(*R*)-1-(2-Nitrobenzenesulfonyl)-1,2,5,6-tetrahydropyridin-2-yl]-but-3-ene-1,2-diol (23). To a solution compound **22** (34.4 mg, 0.081 mmol) in MeOH (1 mL) was added a catalytic amount of NaOMe (~3 mg). After 30 min **22** was transformed into a polar product according to TLC (MTBE). Additional MeOH was added and the solution was neutralized by the addition of Amberlyst 15-H^+ resin until neutral pH, filtered and concentrated. FC (EtOAc) gave the homogeneous **23** (25.7 mg, 93%). ^{1}H NMR (500 MHz, CD_2Cl_2): δ 8.03 (m, 1H), 7.66 (m, 2H), 7.57 (m, 1H), 5.97 (m, 1H), 5.83 (m, 1H), 5.65 (m, 1H), 5.33 (m, 2H), 4.97 (m, 1H), 4.19 (m, 1H), 3.98 (m, 1H), 3.65 (m, 1H), 3.54 (m, 1H), 1.98 (m, 2H); ^{13}C NMR ($CDCl_3$): δ 148.0, 136.0, 133.8, 133.2, 131.7, 130.5, 127.7, 124.1, 124.0, 118.5, 75.5, 72.4, 54.9, 40.2, 23.0; IR: ν 3525, 3093, 1543, 1373, 1346, 1162 cm^{-1}; HRMS: calcd for $C_{15}H_{19}N_2O_8S$ $[MH]^+$: 355.0938, found: 355.0964.

3.1.24. (1*S*,2*R*)-2-(*tert*-Butyl-dimethylsilanyloxy)-1-[(*R*)-1-(2-nitrobenzenesulfonyl)-1,2,5,6-tetrahydropyridin-2-yl]-but-3-en-1-ol (24). Crude **23** was prepared from **22** (524.4 mg, 1.19 mmol) as described above (but not purified). Method D then gave after FC (MTBE) homogeneous **24** (590 mg, 95%) as a white foam. ^{1}H NMR (500 MHz, CD_2Cl_2): δ 8.11 (m, 1H), 7.64 (m, 2H), 7.60 (m, 1H), 5.87 (m, 1H), 5.84 (m, 1H), 5.68 (m, 1H), 5.27 (m, 2H), 4.29 (m, 1H), 4.24 (m, 1H), 4.00 (m, 1H), 3.64 (m, 1H), 3.29 (m, 1H), 2.57 (bs, 1H, OH), 2.19 (m, 1H), 1.94 (m, 1H), 0.92 (s, 9H), 0.08 (s, 3H), 0.05 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 147.9, 134.0, 136.5, 133.3, 131.4, 130.9, 127.2, 124.2, 123.9, 117.4, 75.5, 75.3, 55.7, 39.1, 25.8, 24.2, 18.1, −4.5, −4.8.

3.1.25. Acetic acid (1*S*,2*R*)-2-(*tert*-butyl-dimethylsilanyloxy)-1-[(*R*)-1-(2-nitrobenzenesulfonyl)-1,2,5,6-tetrahydropyridin-2-yl]-but-3-enyl ester (25). Acetylation of **24** (590 mg, 1.26 mmol) according to method C

gave homogeneous **25** (610 mg, 95%) after purification by FC (MTBE/hexane 1/1 v/v). ^{1}H NMR (500 MHz, CD_2Cl_2): δ 7.97 (m, 1H), 7.66 (m, 2H), 7.58 (m, 1H), 5.89 (m, 1H), 5.75 (m, 2H), 5.27 (m, 2H), 5.02 (m, 1H), 4.56 (m, 1H), 4.31 (m, 1H), 3.80 (m, 1H), 3.34 (m, H), 2.00 (s, 3H), 1.87 (m, 2H), 0.90 (s, 9H), 0.08 (s, 3H), 0.02 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 170.3, 147.9, 134.4, 137.0, 133.3, 131.5, 130.6, 127.2, 124.3, 123.9, 116.9, 75.2, 74.1, 54.2, 38.9, 25.7, 23.5, 20.7, 18.1, −4.6, −4.9.

3.1.26. (3*R*,4*S*,5*R*)-3-But-3-enyloxy-4,5-isopropylidenedioxycyclopentene (26). Compound **1** (164.7 mg, 1.06 mmol) was dissolved in THF (3 mL) and DMPU (1 mL) and cooled to 0°C. KH (35% slurry in oil, washed with *n*-pentane) was added (~1 equiv.), followed by but-3-enyl bromide (300 μL). This addition was repeated every 2 h (four times in total) while the solution was kept at 0°C. The mixture was allowed to warm to rt and stirred overnight. The mixture was extracted three times with Et_2O and water. The organic phase was separated, dried ($MgSO_4$), filtered and concentrated in vacuo. FC (10→20% EtOAc in PE) gave homogeneous **26** (136.5 mg, 65%). ^{1}H NMR ($CDCl_3$): δ 6.04 (m, 1H), 5.80 (m, 1H), 5.78 (m, 1H), 5.08 (m, 1H), 5.24 (d, *J*=6 Hz), 4.54 (d, *J*=6 Hz, 1H), 4.43 (s, 1H), 3.62 (m, 2H), 2.32 (m, 2H), 1.37, 1.41 (2s, 6H).

3.1.27. (3*R*,4*S*,5*R*)-3-(But-3-enyloxy)-4,5-bis-(*tert*-butyldimethylsilanyloxy)-cyclopentene (27). Methods B and D with **26** (148 mg, 0.37 mmol) afforded after FC (0→5% EtOAc in PE) homogeneous **27** (122 mg, 82%) as an oil which was directly used in the next step (**27→30**). ^{1}H NMR (200 MHz, $CDCl_3$): δ 5.84 (m, 2H), 5.75 (m, 1H), 5.07 (m, 2H), 4.53 (ddd, *J*=2, 4, 5 Hz, 1H), 4.41 (m, 1H), 3.86 (t, *J*=5 Hz, 1H), 3.59 (m, 2H), 2.33 (m, 2H), 0.93 (s, 9H), 0.89 (s, 9H), 0.11, 0.10, 0.07, 0.06 (4s, 12H); ^{13}C NMR ($CDCl_3$): δ 135.2, 134.4, 133.9, 116.3, 87.7, 78.8, 74.6, 69.6, 34.6, 26.0, 18.3, −4.3 (2), −4.8 (4).

3.1.28. (3*R*,4*S*,5*R*)-3,4-Isopropylidenedioxy-5-(pent-4-enyloxy)-cyclopentene (28). Compound **1** (185 mg, 1.18 mmol) was dissolved in THF (3 mL) and DMPU (1 mL) and cooled to 0°C. 1.5 equiv. of KH (35 mass% slurry in mineral oil) and 210 μL of pent-4-enyl bromide were subsequently added. After 1 h, a similar quantity of KH was added and the solution was allowed to warm to rt and stirred overnight. Excess KH was destroyed with a few drops of MeOH and the mixture was stirred for 30 min. Water and Et_2O were added, the organic phase was separated and washed with an additional portion of water, then it was separated, dried ($MgSO_4$), filtered and concentrated. FC (10→20% EtOAc in PE) afforded homogeneous **28** (255 mg, 96%) as an oil. ^{1}H NMR (200 MHz, $CDCl_3$) δ 6.04 (d, *J*=4 Hz, 1H), 5.80 (dd, *J*=4, 7 Hz, 1H), 5.76 (m, 1H), 5.26 (d, *J*=6 Hz, 1H), 5.08 (m, 2H), 4.53 (d, *J*=6 Hz, 1H), 3.63 (m, 2H), 4.41 (s, 1H), 1.66 (m, 2H), 2.11 (m, 2H), 1.36, 1.41 (2s, 6H); ^{13}C NMR ($CDCl_3$) δ 137.9, 135.2, 133.1, 114.7, 111.4, 88.5, 84.0, 83.0, 68.8, 30.1, 28.8, 27.1, 25.4.

3.1.29. (3*R*,4*S*,5*R*)-3,4-Bis-(*tert*-butyl-dimethylsilanyloxy)-5-(pent-4′-enyloxy)-cyclopentene (29). Methods B and D with **28** (255 mg, 1.14 mmol) gave after FC (0→5% EtOAc in PE) homogeneous **29** (404 mg, 87%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 5.71–5.80 (m, 3H), 4.98 (m, 2H), 4.49 (ddd, *J*=1, 2.5, 5 Hz, 1H), 4.37 (dd, *J*=1, 5 Hz, 1H), 3.92 (t, *J*=5 Hz, 1H), 3.56 (dt, *J*=1, 6.5 Hz, 2H), 2.11 (m, 2H), 1.67 (m, 2H), 0.92 (s, 9H), 0.90 (s, 9H), 0.12, 0.10, 0.07, 0.06 (4s, 12H); ^{13}C NMR ($CDCl_3$) δ 138.3, 134.5, 134.9, 114.7, 87.7, 78.8, 74.7, 69.5, 30.3, 26.3, 26.0, 18.3, −4.3, −4.4, −4.8.

3.1.30. (+)-(*R*)-2-[(1*S*,2*R*)-1,2-Bis-(*tert*-butyl-dimethylsilanyloxy)-but-3-enyl]-2,5-dihydro-6*H*-pyrane [(+)-30]. Method E with **27** (117 mg, 0.291 mmol) gave **30** (117 mg, 100%) after FC (0→5% EtOAc in PE). ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.85 (m, 2H), 5.67 (m, 1H), 5.17 (m, 2H), 4.28 (m, 2H), 4.01 (m, 1H), 3.63 (m, 2H), 2.23 (m, 1H), 1.96 (m, 1H), 0.89 (s, 9H), 0.87 (s, 9H), 0.06 (s, 3H), 0.04 (s, 6H), 0.02 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 139.4, 128.5, 125.8, 116.0, 86.9, 74.3, 74.1, 63.3, 26.0, 25.9, 25.3, 18.3, 18.2, −3.8, −4.1, −4.4, −4.9; MS (CI): *m/z* 399.2 $[M+H]^+$, 421.2 $[M+Na]^+$; HRMS: calcd for $C_{21}H_{42}O_3Si_2$ $[M]^+$: 398.2673, found: 398.2673; $[\alpha]_D^{20}$=+40.9° (*c* 1, $CHCl_3$).

3.1.31. (−)-*N*-But-3′-enyl-*N*-((1*R*,4*R*,5*S*)-4,5-bis-(*tert*-butyl-dimethylsilanyloxy)-cyclopent-2-enyl) 2-nitrobenzene sulfonamide [(−)-31]. Compound **18** (78.0 mg, 0.197 mmol) was dissolved in HOAc (2 mL) and heated to 80°C, water (0.4 mL) was then added slowly. After 20 min, **18** had disappeared according to TLC analysis. Toluene (2 mL) was added and the solution was concentrated to yield the diol [^{1}H NMR (400 MHz, $CDCl_3$): δ 8.11 (m, 1H), 7.71 (m, 2H), 7.64 (m, 1H), 6.07 (m, 1H), 5.83 (dd, *J*=8, 2 Hz, 1H), 5.68 (m, 1H), 5.02 (m, 2H), 4.80 (m, 1H), 4.64 (d, *J*=5 Hz, 1H), 4.10 (t, *J*=5 Hz, 1H), 3.51 (br s, 1H), 3.25 (m, 2H), 3.01 (br s, 1H), 2.50 (m, 2H); ^{13}C NMR ($CDCl_3$): δ 148.4, 135.4, 134.1, 133.8, 133.1, 133.5, 131.9, 131.1, 124.2, 117.5, 74.1, 72.9, 69.5, 45.0, 35.2]. The diol was dissolved in DMF (3 mL), and imidazole (48 mg, 0.8 mmol) was added followed by TBDMSCl (89 mg, 0.59 mmol). The mixture was stirred overnight, or 1 h at 50°C on larger scales without deterioration in yield, after which the reaction was complete as judged by TLC. Hexane was added and the reaction mixture was washed twice with water, dried ($MgSO_4$), filtered and concentrated. FC (0→10% MTBE in hexane) afforded pure **31** (85.2 mg, 75%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.02 (m, 1H), 7.62 (m, 3H), 5.96 (m, 1H), 5.81 (m, 1H), 5.68 (m, 1H), 5.03 (m, 2H), 4.89 (m, 1H), 4.47 (m, 1H), 4.01 (m, 1H), 3.35 (m, 1H), 3.20 (m, 1H), 2.37 (m, 1H), 2.24 (m, 1H), 0.88 (s, 9H), 0.80 (s, 9H), 0.07 (s, 9H), 0.03 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 148.3, 134.8, 134.7, 134.4, 133.5, 133.3, 131.5, 131.2, 124.2, 117.2, 75.9, 73.7, 67.9, 44.8, 35.3, 26.0, 25.9, 18.2, 18.0, −4.8, −3.9, −3.8, −3.6; IR: ν 3077, 1546, 1371, 1252, 1167, 1117 cm^{-1}; HRMS: calcd for $C_{26}H_{43}N_2O_6SSi_2$ $[M-CH_3]^+$: 567.2380, found: 567.2385; $[\alpha]_D^{20}$=−71.2° (*c* 1, $CHCl_3$).

3.1.32. (+)-(*R*)-6-[(1*S*,2*R*)-1,2-Bis-(*tert*-butyl-dimethylsilanyl)oxy-but-3-enyl]-1-(2-nitrobenzenesulfonyl)-1,2,3,6-tetrahydropyridine [(+)-32].[2a] Compound **31** (245 mg) was treated according to method E. The solution was stirred overnight after which the reaction was complete as determined by NMR spectrum. The solution was concentrated and purified by FC (0→20% MTBE in hexane) to give **32** (245 mg, 100%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.91 (m, 1H), 7.62 (m, 2H), 7.51 (m, 1H), 5.94 (ddd, *J*=17,

10, 8 Hz, 1H), 5.77 (m, 1H), 5.67 (m, 1H), 5.22 (d, J=17 Hz, 1H), 5.10 (d, J=10 Hz, 1H), 4.50 (m, 1H), 4.35 (dd, J=2, 8 Hz, 1H), 3.87 (dd, J=2, 8 Hz, 1H), 3.97 (dd, J=14, 4 Hz, 1H), 3.41 (ddd, J=16, 10, 6 Hz, 1H), 1.82 (m, 2H), 0.91 (s, 9H), 0.89 (s, 9H), 0.09, 0.08, 0.06, 0.04 (4s, 12H); ^{13}C NMR ($CDCl_3$): δ 148.3, 134.5, 137.7, 133.3, 131.3, 130.4, 125.9, 125.6, 123.8, 116.5, 78.9, 76.6, 57.2, 40.2, 26.1, 22.9, 18.4, 18.3, −4.0, −4.4, −4.5, −4.6; HRMS: calcd for $C_{26}H_{43}N_2O_6SSi_2$ [M−CH_3]$^+$: 567.2380; found: 567.2388; $[\alpha]_D^{20}$=+189.4° (c 1, $CHCl_3$).

3.1.33. Preparation of 1,2,3,5,6,8a-hexahydroindolizidine-1,2-diol 33 from 32. Compound **32** (400 mg, 0.687 mmol) was dissolved in acetone (7.5 mL) and water (2.5 mL) was added. NMO (200 mg, 1.51 mmol) was added, followed by a catalytic amount of potassium osmate dihydrate (<1 mg). The solution was stirred for 2 days after which consumption of **32** was complete as judged by TLC. MTBE and brine were added, the organic phase was separated, washed with brine, dried ($MgSO_4$) and concentrated. FC (MTBE) gave 357 mg (80%) of the diol (3*R*,4*S*), bis-(*tert*-butyl-dimethylsilanyloxy)-4-[(*R*)-1-(2-nitrobenzenesulfonyl)-1,2,5,6-tetrahydropyridin-2-yl]-butane-1,2-diol as a single diastereomer. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.91 (d, J=8 Hz, 1H), 7.62 (m, 2H), 7.51 (d, J=8 Hz, 1H), 5.89 (m, 1H), 5.75 (m, 1H), 4.65 (m, 1H), 4.04 (m, 1H), 4.01 (m, 1H), 3.94 (m, 1H), 3.88 (m, 1H), 3.83 (m, 1H), 3.69 (m, 1H), 3.26 (m, 1H), 1.86 (m, 2H), 0.97 (s, 9H), 0.92 (s, 9H), 0.18, 0.17, 0.14, 0.11 (4s, 12H). ^{13}C NMR ($CDCl_3$): δ 148.0, 134.2, 133.4, 131.3, 130.2, 126.9, 124.7, 123.6, 77.7, 74.4, 72.6, 57.1, 63.8, 39.1, 26.0, 25.9, 22.7, 18.1, 18.0, −3.6, −4.0, −4.8, −5.3; IR: ν 3546, 3442, 1547 cm^{-1}. The diol (70 mg, 0.107 mmol) was dissolved in MeOH (5 mL), cooled to 0°C and 350 μL of $NaIO_4$ (0.5 M in water) were added slowly. After 30 min, $NaBH_4$ (19 mg) dissolved in water (250 μL) was added. After 3 min, excess $NaBH_4$ was destroyed by addition of acetone (50 μL). The mixture was poured into water and extracted with MTBE. The organic phase was dried ($MgSO_4$) and concentrated. FC (MTBE) gave 63 mg (99%) of (2*R*,3*S*)-2,3-bis-(*tert*-butyl-dimethylsilanyl)oxy-3-[(*R*)-1-(2-nitrobenzenesulfonyl)-1,2,5,6-tetrahydropyridin-2-yl]-propan-1-ol. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.93 (d, J=8 Hz, 1H), 7.65 (m, 2H), 7.54 (d, J=8 Hz, 1H), 5.81 (m, 2H), 4.49 (m, 1H), 4.00 (d, J=6 Hz, 1H), 3.97 (m, 1H), 3.93 (m, 1H), 3.77 (m, 1H), 3.67 (m, 1H), 3.33 (m, 1H), 1.84 (m, 2H), 0.93 (s, 9H), 0.91 (s, 9H), 0.15, 0.14 (2s, 6H), 0.11 (s, 6H). ^{13}C NMR ($CDCl_3$): δ 148.1, 133.9, 133.5, 131.5, 130.3, 126.4, 124.7, 123.9, 78.8, 74.9, 64.1, 56.9, 40.2, 26.0, 25.9, 22.9, 18.2, 18.1, −4.2, −4.3, −4.8, −4.9; IR: ν 3554, 3435, 1547 cm^{-1}; HRMS: calcd for $C_{26}H_{46}O_7SSi_2$ [MH$^+$]: 587.2643, found: 587.2649.

The alcohol was dissolved inn pyridine (3 mL), cooled to 0°C and tosyl chloride (95 mg, 0.5 mmol) was added, followed by a catalytic amount of DMAP. The solution was allowed to warm to rt and stirred overnight. MTBE was added, the mixture was subsequently washed with a saturated NH_4Cl solution and water. The organic phase was separated, dried ($MgSO_4$) and concentrated. FC (MTBE 0⟶20% in hexane) gave 161 mg (71%) of *p*-toluenesulfonic acid (2*R*,3*S*)-2,3-bis-(*tert*-butyl-dimethylsilanyl)oxy-3-[(*R*)-1-(2-nitrobenzenesulfonyl)-1,2,5,6-tetrahydropyridin-2-yl]-propyl ester. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.92 (d, J=8 Hz, 1H), 7.76 (d, J=8 Hz, 2H), 7.66 (m, 2H), 7.55 (d, J=8 Hz, 1H), 7.32 (d, J=8 Hz, 2H), 5.77 (m, 2H), 4.39 (m, 1H), 4.26 (dd, J=10, 3 Hz, 1H), 4.04 (dd, J=8, 3 Hz, 1H), 3.97 (d, J=5 Hz, 1H), 3.94 (m, 1H), 3.85 (dd, J=10, 8 Hz, 1H), 3.23 (m, 1H), 2.44 (s, 3H), 1.84 (m, 2H), 0.86 (s, 9H), 0.84 (s, 9H), 0.09, 0.08, 0.07, 0.04 (4s, 12H). ^{13}C NMR ($CDCl_3$): δ 144.7, 133.7, 133.6, 132.8, 131.6, 130.4, 129.7, 128.0, 127.0, 124.1, 123.7, 79.1, 72.5, 71.8, 56.6, 40.2, 25.8 (2×*t*Bu), 22.9, 21.6, 18.0 (2C), −4.5, −4.6, −4.8, −5.0; HRMS: calcd for $C_{29}H_{43}N_2O_9S_2Si_2$ [M−*t*Bu]: 683.1949, found: 683.1955.

The tosylate (30 mg, 0.04 mmol) was dissolved in DMF (2 mL) and cooled to 0°C, K_2CO_3 (100 mg, 1 mmol) was added, followed by slow addition of thiophenol (1.2 mL of a 0.05 M solution in DMF). After 30 min the mixture was concentrated. Column chromatography (0⟶10% MTBE in CH_2Cl_2) gave 15.4 mg (99%) of (1*S*,2*R*,8a*R*)-1,2-bis-(*tert*-butyl-dimethylsilanyl)oxy-1,2,3,5,6,8a-hexahydroindolizidine. ^{1}H NMR (500 MHz, C_6D_6): δ 5.88 (m, 1H), 5.67 (d, J=10 Hz, 1H), 4.08 (m, 1H), 3.70 (t, J=4 Hz, 1H), 3.52 (m, 1H), 3.28 (dd, J=8, 7 Hz, 1H), 2.92 (m, 1H), 2.87 (m, 1H), 2.79 (t, J=8 Hz, 1H), 1.98 (m, 2H), 1.03 (s, 9H), 0.97 (s, 9H), 0.18, 0.08, 0.07, 0.03 (4s, 12H). ^{13}C NMR (C_6D_6): δ 126.8, 126.3, 75.8, 73.8, 60.6, 58.3, 48.7, 26.0 (2×*t*Bu), 23.5, 18.3 (2C), −4.1, −4.6 (2C), −4.9; HRMS: calcd for $C_{20}H_{41}NO_2Si_2$ [M$^+$]: 383.2676, found: 383.2677.

The silyl ether (52.0 mg, 0.135 mmol) was dissolved in THF (8 mL), TBAF (6.4 mL, 0.05 M in THF) was added and the solution was stirred overnight. Chromatography over DOWEX-WX8-(H$^+$-form) with MeOH and then 0⟶25% ammonium hydroxide gave 20.0 mg (88%) of homogenous (+)-(1*S*,2*R*,8a*R*)-1,2,3,5,6,8a-hexahydroindolizidine-1,2-diol [(+)-**33**]. ^{1}H NMR (500 MHz, MeOD): δ 5.92 (m, 1H), 5.76 (dd, J=5, 1 Hz, 1H), 4.26 (dd, J=7, 4 Hz, 1H), 4.04 (t, J=2 Hz, 1H), 3.35 (m, 1H), 3.12 (dd, J=6, 3 Hz, 1H), 3.03 (m, 1H), 2.81 (m, 2H), 2.22 (m, 1H), 2.11 (m, 1H). ^{13}C NMR (MeOD): δ 126.8, 123.2, 71.9, 70.3, 62.3, 58.1, 47.8, 23.0; IR: ν 3278, 3034, 1661, 1598, 1138 cm^{-1}. HRMS: calcd for $C_8H_{13}NO_2$ [M$^+$]: 155.0946, found: 155.0948; $[\alpha]_D^{20}$=+45.9° (c 0.46, MeOH).

3.1.34. (+)-(1*S*,3*R*,5*R*)-3-(*tert*-Butyl-dimethylsilanyloxy)-5-ethoxycarbonyloxy-cyclohept-6-enyl acetate [(+)-35). To a solution of compound **34** (300 mg, 1.00 mmol, prepared starting from tropone according to Ref. 10) in CH_2Cl_2 (10 mL) was added ethyl chloroformate (220 mg, 2.00 mmol), then pyridine (160 mg, 2.00 mmol) was added dropwise at 0°C. The solution was allowed to warm to rt and stirred for 18 h. MTBE (20 mL) and water (10 mL) were added and the phases separated. The aqueous phase was extracted with MTBE (3×10 mL), the combined organic phases were washed with water (10 mL) and brine (10 mL), dried over $MgSO_4$ and concentrated in vacuo. The residue was purified by FC (cyclohexane/MTBE 20:1) giving **35** (343 mg, 92%) as a colorless oil. R_f=0.58 (cyclohexane/MTBE 10:1). ^{1}H NMR (200 MHz, $CDCl_3$): δ 5.57–5.78 (m, 2H), 5.20–5.30 (m, 1H), 5.06–5.19 (m, 1H), 4.22 (q, J=7 Hz, 2H), 3.88–4.04 (m, 1H), 1.97–2.10 (m, 2H), 2.02 (s, 3H), 1.60–1.94 (m, 2H), 1.32 (t, J=7 Hz, 3H), 0.97 (s, 9H), 0.08 (s, 6H); ^{13}C NMR ($CDCl_3$): δ 169.9,

154.2, 131.8, 131.3, 72.4, 68.6, 68.1, 64.0, 41.9, 41.85, 25.6, 21.1, 17.9, 14.1, 4.9; IR: ν 1744, 1371, 1262, 1239, 1095, 1029, 837, 777 cm^{-1}; MS (100°C): *m/z* (%) 373 (<1) [MH^+], 241 (7), 223 (100), 161 (25), 109 (53); HRMS: calcd for $C_{18}H_{33}O_6Si$ [MH^+]: 373.2046, found: 373.2049. Anal. calcd for $C_{18}H_{33}O_6Si$: C, 58.06%; H, 8.60%. Found: C, 57.95%; H, 8.56%; $[\alpha]_D^{20}=+0.86°$ (*c* 1.05, $CHCl_3$).

3.1.35. (−)-(1*S*,3*R*,5*R*)-3-(*tert*-Butyl-dimethylsilanyloxy)-5-*N*-allylamino-cyclohept-6-enyl acetate [(−)-36]. To a solution of carbonate **35** (300 mg, 0.80 mmol) and allylamine (183 mg, 4.0 mmol) in THF (10 mL) were added under an N_2 atmosphere $[Pd_2(dba)_3]\cdot CHCl_3$ (21 mg, 0.020 mmol, 2.5 mol%) and dppb (34 mg, 0.080 mmol, 10 mol%) as solids. The solution was stirred for 2 h at rt, then diluted with MTBE (20 mL) and washed with water (3×10 mL). The aqueous phases were back extracted with MTBE (10 mL). The combined organic phases were then washed with brine (10 mL), dried over $MgSO_4$ and the solvent was evaporated in vacuo. FC [cyclohexane/MTBE 4:1 (3% NEt_3)] afforded **36** (306 mg, 80%) as a colorless oil. R_f=0.41 [cyclohexane/MTBE 4:1 (5% NEt_3)]; ^1H NMR (200 MHz, $CDCl_3$): δ 5.68–5.98 (m, 2H), 5.50–5.61 (m, 1H), 5.30–5.43 (m, 1H), 5.01–5.22 (m, 2H), 4.12–4.29 (m, 1H), 3.49–3.62 (m, 1H), 3.12–3.34 (m, 2H), 2.00–2.16 (m, 1H), 2.03 (s, 3H), 1.74–1.94 (m, 3H), 0.98 (br s, 1H), 0.86 (s, 9H), 0.03, 0.04 (2s, 6H); ^{13}C NMR ($CDCl_3$): δ 170.2, 136.8, 135.6, 132.3, 115.8, 69.1, 65.6, 50.8, 49.7, 42.0, 41.8, 25.7, 21.3, 18.0, −4.8, −4.75; IR: ν 3078, 1739, 1369, 1241, 1075, 1024, 836, 775 cm^{-1}; MS (70°C): *m/z* (%)=339 (<1) [M^+], 279 (30), 222 (34), 148 (40), 117 (41), 75 (100), HR-MS: calcd for $C_{18}H_{33}NO_3Si$ [M^+]: 339.2230, found 339.2224. Anal. calcd for $C_{18}H_{33}NO_3Si$: C, 63.72%, H, 9.73%; N, 4.13%. Found C, 63.71%, H, 9.83%, N, 4.39%. $[\alpha]_D^{20}=-45.6°$ (*c* 0.56, $CHCl_3$).

3.1.36. (−)-Acetic acid (1*S*,3*R*,5*R*)-3-(*tert*-butyl-dimethylsilanyloxy)-5-(*N*-allyl-*N*-ethoxycarbonyl-amino)-cyclohept-6-enyl ester [(−)-37). To a solution of amine **36** (300 mg, 0.88 mmol) in CH_2Cl_2 (10 mL) were sequentially added ethyl chloroformate (110 mg, 1.0 mmol) and pyridine (200 mg, 2.5 mmol) under N_2 atmosphere. The solution was stirred for 12 h, diluted with MTBE (20 mL) and washed with water (3×10 mL). The aqueous phases were extracted with MTBE (10 mL), the combined organic phases were washed with brine (10 mL), dried over $MgSO_4$ and concentrated in vacuo. The residue was purified by FC (cyclohexane/MTBE 4:1) giving **37** (321 mg, 89%) as a colorless oil. R_f=0.69 (cyclohexane/MTBE 1:1); ^1H NMR (500 MHz, $CDCl_3$): (rotameric mixture) δ 5.75–5.95 (m, 1H), 5.54–5.74 (m, 2H), 5.29–5.40 (m, 1H), 5.07–5.24 (m, 2H), 4.65–4.83 (m, 1H), 4.06–4.30 (m, 3H), 3.82–4.03 (m, 1H), 3.62–3.75 (m, 1H), 2.00–2.48 (m, 2H), 2.05 (s, 3H), 1.76–1.94 (m, 2H), 1.25 (t, *J*=7 Hz, 3H), 0.86 (s, 9H), 0.03 (s, 6H); ^{13}C NMR ($CDCl_3$): (rotameric mixture) δ 170.3, 156.0, 135.6, 135.1, 132.0, 116.6, 68.7, 65.0, 61.4, 51.9, 51.4, 48.5, 42.5, 42.2, 41.9, 25.8, 21.4, 18.0, 14.7, −4.7, −4.8; IR: ν 3080, 1740, 1701, 1369, 1240, 1078, 1023, 836, 775 cm^{-1}; MS (105°C): *m/z* (%) 411 (<1) [M^+], 354 (100), 294 (53), 220 (51), 117 (74); HRMS: calcd for $C_{21}H_{37}NO_5Si$ [M^+]: 411.2441, found: 411.2442. Anal. calcd for $C_{21}H_{37}NO_5Si$: C, 61.31%; H, 9.00%; N, 3.41%. Found: C, 60.62%; H, 8.45%; N, 3.71%; $[\alpha]_D^{20}=-59°$ (*c* 0.70, $CHCl_3$).

3.1.37. (+)-(2*R*)-*N*-Ethoxycarbonyl-2-[(2*S*,4*S*)-4-acetoxy-2-(*tert*-butyl-dimethylsilanyloxy)-hex-5-enyl]-2,5-dihydro-1*H*-pyrrole [(−)-38]. A solution of **37** (20 mg, 0.05 mmol) and [Ru] (2 mg, 5 mol%) in dry CH_2Cl_2 (5 mL) was refluxed under N_2 atmosphere for 12 h. The solution was concentrated in vacuo, the residue was purified by FC (cyclohexane/MTBE 3:1) affording **38** (16 mg, 80%) as a brown oil. R_f=0.33 (cyclohexane/MTBE 3:1). ^1H NMR (500 MHz, $CDCl_3$): δ 5.68–5.85 (m, 3H), 5.30–5.39 (m, 1H), 5.12–5.30 (m, 2H), 4.40–4.56 (m, 1H), 3.98–4.30 (m, 4H), 3.73–3.97 (m, 1H), 2.00–2.22 (m, 1H), 2.05 (s, 3H), 1.81–1.94 (m, 1H), 1.71–1.82 (m, 1H), 1.57–1.66 (m, 1H), 1.76–1.94 (m, 2H), 1.20–1.35 (m, 3H), 0.88 (s, 9H), 0.06 (s, 6H); ^{13}C NMR ($CDCl_3$): (rotameric mixture) δ 170.2, 155.0, 154.8, 136.7, 136.4, 131.2, 130.8, 124.8, 124.4, 117.2, 116.8, 72.1, 72.0, 67.7, 67.4, 62.9, 62.2, 61.2, 60.9, 53.5, 53.0, 43.0, 42.6, 42.4, 42.1, 25.9, 21.3, 18.0, 14.9, −4.1, −4.4; IR: ν 3082, 1742, 1704, 1415, 1381, 1237, 1108, 837, 774 cm^{-1}; MS (70°C): *m/z* (%) 411 (<1) [M^+], 294 (3), 140 (100), 117 (5), 68 (23). HRMS: calcd for $C_{21}H_{37}O_5NSi$ [M^+]: 411.2441, found: 411.2450. Anal. calcd for $C_{21}H_{37}NO_5Si$: C, 61.31%; H, 9.00%; N, 3.41%. Found: C, 60.94%; H, 8.98%; N, 3.60%; $[\alpha]_D^{20}=+14.4°$ (*c* 0.50, $CHCl_3$).

3.1.38. (−)-(1*R*,3*R*,5*S*)-5-(*N*-Allyl-*N*-(4-methylbenzene-sulfonyl)-amino)-3-(*tert*-butyl-dimethylsilanyloxy)-cyclohept-6-enol [(−)-39]. Dry THF (15 mL) was added to acetate **34** (610 mg, 2.03 mmol), *N*-allyl-*N*-tosylamide (500 mg, 2.37 mmol) and NaH (60% suspension in mineral oil, 90 mg, 2.25 mmol). DMF (4–5 mL) was then added to the suspension until the solution became clear. Under N_2 atmosphere $[Pd_2(dba)_3]\cdot CHCl_3$ (52 mg, 0.051 mmol, 2.5 mol%) and dppb (90 mg, 0.21 mmol, 10 mol%) were added as solids. The solution was stirred for 30 min at 50°C. After addition of water (50 mL) the solution was extracted with MTBE (3×20 mL). The combined organic phases were washed with brine (20 mL), dried over $MgSO_4$ and concentrated in vacuo. The residue was purified by FC (cyclohexane/MTBE 3:1) affording **39** (755 mg, 82%) as yellow oil. R_f=0.27 (cyclohexane/MTBE 3:1). ^1H NMR (200 MHz, $CDCl_3$): δ 7.64–7.72 (m, 2H), 7.21–7.31 (m, 2H), 5.89–6.10 (m, 1H), 5.57–5.70 (m, 1H), 5.38–5.50 (m, 1H), 5.24–5.36 (m, 1H), 5.08–5.17 (m, 1H), 4.74–4.80 (m, 1H), 4.02–4.22 (m, 4H), 3.90–4.02 (m, 1H), 2.20–2.60 (m, 3H), 2.40 (s, 3H), 1.70–1.84 (m, 1H), 0.84 (s, 9H), 0.05 (s, 6H); ^{13}C NMR ($CDCl_3$): δ 143.0, 137.7, 136.3, 131.5, 129.5, 128.0, 126.2, 116.5, 72.6, 67.9, 62.3, 47.7, 41.5, 34.7, 25.6, 21.4, 17.8, −5.2, −5.3; IR: ν 3488, 3081, 3035, 1598, 1338, 1255, 1159, 1091, 1025, 837, 712, 662; MS (210°C): *m/z* (%) 433 (2) [M^+-H_2O], 394 (21), 183 (100), 91 (88); HRMS: calcd for $C_{23}H_{35}NO_3SSi$ [M^+-H_2O): 433.2107, found: 433.2101. Anal. calcd for $C_{23}H_{37}NO_4SSi$: C, 61.20%; H, 8.20%; N, 3.14%. Found: C, 61.28%; H, 8.00%; N, 3.11%; $[\alpha]_D^{20}=-103°$ (*c* 0.47, $CHCl_3$).

3.1.39. (+)-(1*R*,3*R*,5*S*)-5-(*N*-Allyl-*N*-(4-methylbenzene-sulfonyl)-amino)-3-(*tert*-butyl-dimethylsilanyloxy)-cyclohept-6-enyl benzoate [(−)-40]. To a solution of alcohol **39** (220 mg, 0.49 mmol) and DMAP (500 mg, 4.09 mmol) in CH_2Cl_2 (20 mL) was added benzoyl chloride

(140 mg, 0.1 mmol) and stirred at rt for 15 h. The solution was concentrated in vacuo. FC of the residue (cyclohexane/CH_2Cl_2 1:1) yielded **40** (247 mg, 91%) as a white solid. R_f=0.30 (cyclohexane/MTBE 4:1). ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.90–7.97 (m, 2H), 7.65–7.74 (m, 2H), 7.25–7.56 (m, 5H), 5.78–5.92 (m, 1H), 5.52–5.75 (m, 1H), 5.30–5.37 (m, 1H), 5.10–5.12 (m, 1H), 4.82–5.03 (m, 3H), 3.96–4.12 (m, 1H), 3.66–3.96 (m, 2H), 2.40–2.58 (m, 1H), 2.46 (s, 3H), 2.20–2.36 (m, 2H), 2.00–2.14 (m, 1H), 0.78 (s, 9H), 0.00, 0.01 (2s, 6H); ^{13}C NMR ($CDCl_3$): δ 165.1, 143.4, 137.2, 135.1, 133.0, 130.6, 129.9, 129.7, 129.4, 128.3, 127.4, 127.2, 116.4, 74.8, 68.4, 58.6, 47.7, 40.8, 37.4, 25.6, 21.5, 17.9, −4.9; IR: ν 3068, 3027, 1720, 1346, 1271, 1163, 1091, 1027, 837, 712 cm^{-1}; MS (190°C): *m/z* (%) 498 (7) [$M^+-C_4H_9$], 433 (63), 302 (51), 278 (45), 146 (86), 105 (100); HRMS: calcd for $C_{26}H_{32}NO_5SSi$ [$M^+-C_4H_9$]: 498.1770, found: 498.1769. Anal. calcd for $C_{30}H_{41}NO_5SSi$: C, 64.86%; H, 7.39%; N, 2.52%. Found: C, 65.34%; H, 7.45%; N, 2.62%; $[\alpha]_D^{20}$=+54° (*c* 0.51, $CHCl_3$).

3.1.40. (−)-(2*S*)-*N*-(4-Methylbenzenesulfonyl)-2-[(2*R*,4*R*)-4-benzoyloxy-2-(*tert*-butyl-dimethylsilanyloxy)-hex-5-enyl]-2,5-dihydro-1*H*-pyrrole [(−)-41]. Compound **40** (12 mg, 0.022 mmol) and [Ru] (1 mg, 5 mol%) in dry CH_2Cl_2 (2 mL) were refluxed under N_2 atmosphere for 12 h. The solution was concentrated in vacuo, the residue was purified by FC (cyclohexane/MTBE 3:1) affording **41** (11 mg, 92%) as a brown oil. R_f=0.19 (cyclohexane/MTBE 4:1). ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.97–8.06 (m, 2H), 7.60–7.70 (m, 2H), 7.36–7.56 (m, 3H), 7.16–7.28 (m, 2H), 5.66–5.97 (m, 3H), 5.40–5.50 (m, 1H), 4.90–5.20 (m, 3H), 4.08–4.24 (m, 1H), 3.82–4.06 (m, 2H), 2.22–2.56 (m, 2H), 2.39 (s, 3H), 1.94–2.12 (m, 1H), 1.70–1.98 (m, 1H), 0.86 (s, 9H), 0.03 (s, 6H); ^{13}C NMR ($CDCl_3$): δ 165.9, 143.4, 134.8, 134.6, 132.9, 130.4, 129.7, 128.3, 127.5, 127.45, 125.9, 116.4, 73.2, 69.6, 69.2, 56.2, 40.5, 36.7, 25.8, 21.5, 18.1, −4.6, −4.7; IR: ν 3071, 3031, 1718, 1350, 1273, 1164, 1092, 1069, 836, 711, 667 cm^{-1}; MS (180°C): *m/z* (%) 498 (11) [$M^+-C_4H_9$], 222 (100), 179 (25), 105 (95), 91 (27). HRMS: calcd for $C_{26}H_{32}NO_5SSi$ [$M^+-C_4H_9$]: 498.1770, found: 498.1773; $[\alpha]_D^{20}$=−119° (*c* 0.50, $CHCl_3$).

3.1.41. (−)-(1*S*,3*S*,5*S*)-5-(*N*-Allyl-*N*-(2-nitrobenzenesulfonyl)-amino)-3-(*tert*-butyl-dimethylsilanyloxy)-cyclohept-6-enyl acetate [(−)-42]. Compound **34** (2.60 g, 8.71 mmol), *N*-allyl-*N*-nosylamide (2.74 g, 11.3 mmol) and PPh_3 (5.71 g, 21.8 mmol) were dissolved in dry THF (60 mL); DEAD (3.03 g, 17.4 mmol) was added dropwise at 0°C. After stirring at rt for 18 h, the solution was concentrated in vacuo and the residue was purified by FC (cyclohexane/MTBE 4:1) yielding **42** (4.25 g, 93%) as light yellow oil. R_f=0.53 (cyclohexane/MTBE 1:1). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.00–8.03 (m, 1H), 7.61–7.70 (m, 3H), 5.76–5.87 (m, 1H), 5.60–5.65 (m, 1H), 5.49–5.55 (m, 1H), 5.24–5.30 (m, 1H), 5.15–5.23 (m, 1H), 5.05–5.10 (m, 1H), 4.82–4.88 (m, 1H), 4.18–4.25 (m, 1H), 3.97–4.05 (m, 1H), 3.77–3.86 (m, 1H), 1.97–2.20 (m, 3H), 2.04 (s, 3H), 1.78–1.88 (m, 1H), 0.85 (s, 9H), 0.02 (s, 6H); ^{13}C NMR ($CDCl_3$): δ 170.2, 148.1, 135.6, 134.7, 133.9, 133.6, 133.2, 131.7, 131.5, 124.3, 118.1, 68.3, 64.6, 53.3, 48.1, 42.2, 42.1, 25.8, 21.3, 18.1, −4.8; IR: ν 3092, 3027, 1740, 1545, 1371, 1242, 1165, 1087, 1024, 837, 777 cm^{-1}; MS (200°C): *m/z* (%) 509 (1) [M^+-CH_3], 467 (51), 186 (96), 147 (100); HRMS: calcd for $C_{23}H_{33}N_2O_7SSi$ [M^+-CH_3]: 509.1778, found: 509.1772. Anal. calcd for $C_{24}H_{36}N_2O_7SSi$: C, 54.96%; H, 6.87%; N, 5.34%. Found: C, 55.12%; H, 6.74%; N, 5.41%; $[\alpha]_D^{20}$=−31° (*c* 0.46, $CHCl_3$).

3.1.42. (−)-(1*S*,3*S*,5*S*)-5-(*N*-But-3-enyl-*N*-(2-nitrobenzenesulfonyl)-amino)-3-(*tert*-butyl-dimethylsilanyloxy)-cyclohept-6-enyl acetate [(−)-43]. Compound **34** (1.79 g, 5.95 mmol), *N*-but-3-enyl-*N*-nosylamide (2.00 g, 7.75 mmol) and PPh_3 (3.10 g, 11.8 mmol) were dissolved in dry THF (60 mL); DEAD (1.80 g, 10.3 mmol) were added dropwise at 0°C. After stirring at rt for 18 h, the solution was concentrated in vacuo and the residue was purified by FC (cyclohexane/MTBE 4:1) yielding **43** (2.80 g, 89%) as light yellow oil. R_f=0.54 (cyclohexane/MTBE 1:1). ^{1}H NMR (200 MHz, $CDCl_3$): δ 8.02–8.11 (m, 1H), 7.58–7.72 (m, 3H), 5.52–5.84 (m, 3H), 5.24–5.36 (m, 1H), 5.00–5.13 (m, 2H), 4.74–4.87 (m, 1H), 4.17–4.30 (m, 1H), 3.18–3.48 (m), 1.96–2.58 (m, 5H), 2.05 (s, 3H), 1.76–1.94 (m, 1H), 0.84 (s, 9H), 0.02 (s, 6H); ^{13}C NMR ($CDCl_3$): δ 170.1, 148.1, 134.4, 133.8, 133.5, 133.45, 131.6, 131.2, 124.1, 117.2, 68.1, 64.4, 52.8, 45.0, 42.2, 41.9, 35.5, 25.7, 21.2, 18.0, −4.9; IR: ν 3078, 1739, 1546, 1372, 1240, 1164, 1085, 1023, 837, 777 cm^{-1}; MS (210°C): *m/z* (%) 481 (12) [$M^+-C_4H_9$], 421 (17), 186 (86), 161 (46), 91 (70), 75 (100); HRMS: calcd for $C_{21}H_{29}N_2O_7SSi$ [$M^+-C_4H_9$]: 481.1465, found: 481.1461. Anal. calcd for $C_{25}H_{38}N_2O_7SSi$: C, 55.76%; H, 7.06%; N, 5.20%. Found: C, 55.11%; H, 7.18%; N, 5.67%; $[\alpha]_D^{20}$=−26° (*c* 0.90, $CHCl_3$).

3.1.43. (−)-(1*S*,3*S*,5*S*)-5-(*N*-But-3-enyl-*N*-benzyloxycarbonyl-amino)-3-(*tert*-butyl-dimethylsilanyloxy)-cyclohept-6-enyl acetate [(−)-44]. To a suspension of **43** (380 mg, 0.71 mmol) and K_2CO_3 (450 mg, 3.26 mmol) in dry DMF (10 mL) was added PhSH (150 mg, 1.36 mmol). The solution was stirred for 1 h at 70°C, then cooled to 0°C. Under vigorous stirring benzyl chloroformate (250 mg, 1.47 mmol) was added. After 2 h, water (20 mL) and MTBE (20 mL) were added, the organic phase was separated and the aqueous phase was extracted twice with MTBE (10 mL). The combined organic phases were washed with brine (20 mL), dried over $MgSO_4$ and concentrated in vacuo. The residue was purified by FC (cyclohexane/MTBE 5:1) giving **44** (301 mg, 87%) as a pale yellow oil. R_f=0.46 (cyclohexane/MTBE 3:1). ^{1}H NMR (200 MHz, $CDCl_3$): (rotameric mixture) δ 7.20–7.39 (m, 5H), 5.49–5.90 (m, 3H), 5.24–5.44 (m, 1H), 4.94–5.18 (m, 4H), 4.48–4.70 (m, 1H), 4.10–4.30 (m, 1H), 3.12–3.46 (m, 2H), 1.72–2.53 (m, 6H), 2.06 (s, 3H), 0.86 (s, 9H), 0.04 (s, 6H); ^{13}C NMR ($CDCl_3$): (rotameric mixture) δ 170.2, 155.6, 136.8, 135.8, 135.2, 131.5, 128.4, 127.8, 127.7, 116.7, 68.6, 66.9, 65.0, 52.7, 52.0, 46.6, 42.7, 42.5, 41.7, 34.1, 33.5, 25.7, 21.3, 17.9, −4.8, −4.9; IR: ν 3067, 3033, 1737, 1701, 1239, 1072, 1022, 1004, 910, 836, 775, 698 cm^{-1}; MS (190°C): *m/z* (%) 430 (37) [$M^+-C_4H_9$], 386 (18), 91 (100); HRMS: calcd for $C_{23}H_{32}NO_5Si$ [$M^+-C_4H_9$]: 430.2050, found: 430.2053. Anal. calcd for $C_{27}H_{41}N_2O_5Si$: C, 66.53%; H, 8.42%; N, 2.87%. Found: C, 66.17%; H, 8.23%; N, 3.11%; $[\alpha]_D^{20}$=−60° (*c* 0.76, $CHCl_3$).

3.1.44. (−)-(1*S*,3*S*,5*S*)-5-(*N*-Pent-4-enyl-*N*-(2-nitrobenzenesulfonyl)-amino)-3-(*tert*-butyldimethyl-silanyloxy)-cyclohept-6-enyl acetate [(−)-45]. To a solution of **34**

(300 mg, 1.0 mmol), PPh_3 (524 mg, 2.00 mmol) and *N*-pent-4-enyl-*N*-nosylamide (405 mg, 1.49 mmol) in dry THF (10 mL) was added dropwise at 0°C DEAD (300 mg, 1.70 mmol). After stirring at rt for 18 h, the solution was concentrated in vacuo and the residue was purified by FC (cyclohexane/MTBE 4:1) to afford **45** (408 mg, 74%) as light yellow oil. R_f=0.57 (cyclohexane/MTBE 1:1). ^{1}H NMR (200 MHz, $CDCl_3$): δ 8.00–8.08 (m, 1H), 7.56–7.72 (m, 3H), 5.48–5.85 (m, 3H), 4.92–5.05 (m, 2H), 4.72–4.82 (m, 1H), 4.12–4.30 (m, 1H), 3.10–3.40 (m, 2H), 1.60–2.26 (m, 8H), 2.05 (s, 3H), 0.84 (s, 9H), 0.04 (s, 6H); ^{13}C NMR ($CDCl_3$): δ 170.1, 148.0, 137.2, 134.3, 133.7, 133.5, 133.4, 131.5, 131.0, 124.1, 115.2, 68.0, 64.4, 52.7, 45.2, 42.1, 41.8, 31.0, 30.2, 25.7, 21.1, 17.9, −5.0; IR: ν 3077, 1739, 1546, 1372, 1240, 1164, 1085, 1023, 837, 777 cm^{-1}; MS (220°C): *m*/*z* (%) 537 (1) [M^+-CH_3], 495 (9), 361 (100); HRMS: calcd. for $C_{25}H_{37}N_2O_7SSi$ [M^+-CH_3]: 537.2091, found: 537.2087. Anal. calcd for $C_{26}H_{40}N_2O_7SSi$: C, 56.52%; H, 7.25%; N, 5.07%. Found: C, 55.81%; H, 7.43%; N, 5.27%; $[\alpha]_D^{20}$=−24.8° (*c* 0.40, $CHCl_3$).

3.1.45. (−)-(1*S*,3*S*,5*S*)-5-(*N*-Pent-4-enyl-*N*-benzyloxycarbonyl-amino)-3-(*tert*-butyl-dimethylsilanyloxy)-cyclohept-6-enyl acetate [(−)-46]. To a suspension of **45** (165 mg, 0.30 mmol) and K_2CO_3 (200 mg, 1.53 mmol) in dry DMF (5 mL) was added PhSH (65 mg, 0.60 mmol). The solution was stirred for 1 h at 70°C, then cooled to 0°C. Under vigorous stirring benzyl chloroformate (110 mg, 0.65 mmol) was added. After 2 h water (20 mL) and MTBE (20 mL) were added, the organic phase was separated and the aqueous phase was extracted twice with MTBE (10 mL). The combined organic phases were washed with brine (20 mL), dried over $MgSO_4$ and concentrated in vacuo. The residue was purified by FC (cyclohexane/MTBE 5:1) to give **46** (117 mg, 78%) as a pale yellow oil. R_f=0.36 (cyclohexane/MTBE 4:1). ^{1}H NMR (200 MHz, $CDCl_3$): (rotameric mixture) δ 7.22–7.40 (m, 5H), 5.46–5.92 (m, 3H), 5.24–5.42 (m, 1H), 4.90–5.16 (m, 4H), 4.44–4.68 (m, 1H), 4.09–4.30 (m, 1H), 3.06–3.37 (m, 2H), 1.48–2.52 (m, 8H), 2.07 (s, 3H), 0.86 (s, 9H), 0.02 (s, 6H); ^{13}C NMR ($CDCl_3$): (rotameric mixture) δ 170.3, 155.6, 136.8, 136.0, 135.2, 131.6, 128.5, 127.9, 127.8, 115.1, 68.7, 67.1, 65.1, 52.7, 46.6, 42.7, 42.5, 41.8, 31.2, 25.8, 21.4, 18.0, −4.7, −4.8; IR: ν 3069, 3032, 1737, 1702, 1240, 1076, 1022, 1004, 910, 837, 775, 698 cm^{-1}; MS (130°C): *m*/*z* (%) 444 (10) [$M^+-C_4H_9$], 250 (7), 117 (9), 91 (100); HRMS: calcd for $C_{24}H_{34}NO_5Si$ [$M^+-C_4H_9$]: 444.2206, found: 444.2209. Anal. calcd for $C_{28}H_{43}NO_5Si$: C, 67.07%; H, 8.58%; N, 2.79%. Found: C, 66.92%; H, 8.35%; N, 2.95%; $[\alpha]_D^{20}$=−62.4° (*c* 0.47, $CHCl_3$).

3.2. General procedure for the preparation of 47–49 from 42–44

The acetate **42**, **43** or **44** (0.10 mmol) and [Ru] (5 mol.%) in dry CH_2Cl_2 (2 mL) were refluxed under N_2 atmosphere. The solution was concentrated in vacuo, the residue was purified by FC (cyclohexane/MTBE 3:1) to give the products **47**, **48** or **49**.

3.2.1. (+)-(2*S*)-*N*-(2-Nitrobenzenesulfonyl)-2-[(2*S*,4*S*)-4-acetoxy-2-(*tert*-butyl-dimethylsilanyloxy)-hex-5-enyl]-2,5-dihydro-1*H*-pyrrole [(+)-47]. Compound **42** (92 mg, 0.18 mmol) and [Ru] (7 mg, 5 mol%) afforded after 3 h **47** (87 mg, 94%) as a light brown oil. R_f=0.28 (cyclohexane/MTBE 1:1). ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.82–7.93 (m, 1H), 7.55–7.70 (m, 3H), 5.66–5.87 (m, 3H), 5.12–5.38 (m, 3H), 4.63–4.77 (m, 1H), 4.10–4.36 (m, 2H), 3.93–4.06 (m, 1H), 2.12–2.26 (m, 1H), 2.06 (s, 3H), 1.59–2.00 (m, 3H), 0.89 (s, 9H), 0.05, 0.07 (s, 6H); ^{13}C NMR ($CDCl_3$): δ 170.1, 148.7, 136.4, 133.5, 132.1, 131.6, 131.0, 129.8, 124.2, 123.9, 116.8, 71.5, 67.3, 65.8, 54.9, 43.8, 42.1, 25.8, 21.1, 17.9, −4.35, −4.4; IR: ν 3091, 1738, 1547, 1372, 1361, 1239, 1171, 1092, 836, 776 cm^{-1}; MS (210°C): *m*/*z* (%) 524 (39) [MH^+], 411 (74), 407 (30), 253 (100), 186 (70); HRMS: calcd for $C_{24}H_{37}N_2O_7SSi$ [MH^+]: 525.2091, found: 525.2101. Anal. calcd for $C_{24}H_{36}N_2O_7SSi$: C, 54.96%; H, 6.87%; N, 5.34%. Found: C, 54.87%; H, 6.71%; N, 5.49%; $[\alpha]_D^{20}$=+130° (*c* 0.43, $CHCl_3$).

3.2.2. (+)-(2*S*)-*N*-(2-Nitrobenzenesulfonyl)-2-[(2*S*,4*S*)-4-acetoxy-2-(*tert*-butyl-dimethylsilanyloxy)-hex-5-enyl]-1,2,5,6-tetrahydropyridine [(+)-48]. Compound **43** (54 mg, 0.10 mmol) and [Ru] (5 mg, 5 mol%) afforded after 12 h **48** (46 mg, 86%) as a brown oil. R_f=0.31 (cyclohexane/MTBE 1:1). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.95–8.00 (m, 1H), 7.54–7.67 (m, 3H), 5.62–5.83 (m, 3H), 5.31–5.39 (m, 1H), 5.22–5.27 (m, 1H), 5.15–5.20 (m, 1H), 4.45–4.53 (m, 1H), 3.95–4.02 (m, 1H), 3.85–4.94 (m, 1H), 3.17–3.26 (m, 1H), 1.60–2.15 (m, 6H), 2.09 (s, 3H), 0.93 (s, 9H), 0.12, 0.15 (s, 6H); ^{13}C NMR ($CDCl_3$): δ 170.4, 148.7, 136.5, 134.4, 133.3, 131.5, 130.4, 128.6, 124.5, 124.0, 116.8, 71.5, 66.8, 52.2, 42.4, 42.2, 38.4, 26.0, 23.4, 21.2, 18.1, −4.35, −4.4; IR: ν 3092, 3035, 1738, 1547, 1372, 1359, 1239, 1170, 1104, 837, 777 cm^{-1}; MS (180°C): *m*/*z* (%) 481 (<1) [$M^+-C_4H_9$], 267 (100), 186 (52), 117 (19); HRMS: calcd for $C_{21}H_{29}N_2O_7SSi$ [$M^+-C_4H_9$]: 481.1465, found: 481.1467. Anal. calcd for $C_{25}H_{38}N_2O_7SSi$: C, 55.76%; H, 7.06%; N, 5.20%. Found: C, 55.41%; H, 7.16%; N, 5.26%; $[\alpha]_D^{20}$=+116° (*c* 0.46, $CHCl_3$).

3.2.3. (+)-(2*S*)-*N*-Benzyloxycarbonyl-2-[(2*S*,4*S*)-4-acetoxy-2-(*tert*-butyl-dimethylsilanyloxy)-hex-5-enyl]-1,2,5,6-tetrahydropyridine [(+)-49]. Compound **44** (98 mg, 0.20 mmol) and [Ru] (10 mg, 5 mol%) afforded after 6 h **49** (90 mg; 92%) as a brown oil. R_f=0.33 (cyclohexane/MTBE 3:1). ^{1}H NMR (200 MHz, $CDCl_3$): (rotameric mixture) δ 7.26–7.40 (m, 5H), 5.63–5.85 (m, 3H), 5.33–5.40 (m, 1H), 5.09–5.26 (m, 4H), 4.45–4.65 (m, 1H), 4.05–4.24 (m, 1H), 3.85–3.92 (m, 1H), 2.85–2.97 (m, 1H), 2.17–2.30 (m, 1H), 1.66–2.06 (m, 5H), 2.00 (s, 3H), 0.92 (s, 9H), 0.09 (s, 6H); ^{13}C NMR ($CDCl_3$): (rotameric mixture) δ 169.7, 155.2, 137.1, 136.7, 128.4, 127.9, 127.9, 116.7, 71.8, 66.5, 67.0, 50.2, 42.3, 42.1, 37.3, 25.7, 24.9, 20.9, 18.0, −4.2, −4.4; IR: ν 3090, 3067, 3033, 1740, 1700, 1428, 1242, 1093, 1024, 837, 776, 698 cm^{-1}; MS (150°C): *m*/*z* (%) 430 (3) [$M^+-C_4H_9$], 117 (14), 91 (100); HRMS: calcd for $C_{23}H_{32}NO_5Si$ [$M^+-C_4H_9$]: 430.2050, found: 430.2048. Anal. calcd for $C_{27}H_{41}NO_5Si$: C, 66.53%; H, 8.42%; N, 2.87%. Found: C, 66.33%; H, 8.66%; N, 3.17%; $[\alpha]_D^{20}$=+98° (*c* 1.13, $CHCl_3$).

3.3. General procedure for the preparation of 50–52 from 42–44

To a solution of the TBDMS ether **42**, **43** or **44** (50 mmol) in

dry THF (5 mL) was added TBAF solution (1.0 mL, 1 M in THF) dropwise at 0°C and stirred for 1 h at 0°C. Water (10 mL) was added and the solution was extracted with MTBE (3×10 mL). The combined organic layers were washed with brine (15 mL), dried over $MgSO_4$ and concentrated in vacuo. The residue was purified by FC (cyclohexane/MTBE 1:1 [**50**, **51**] or 2:1 [**52**]) to give **50**–**52**.

3.3.1. (−)-(1*S*,3*S*,5*S*)-5-(*N*-Allyl-*N*-(2-nitrobenzenesulfonyl)-amino)-3-hydroxycyclohept-6-enyl acetate [(−)-50]. Compound **42** (360 mg, 0.69 mmol) gave **50** (240 mg, 85%) as a pale yellow oil. R_f=0.14 (cyclohexane/MTBE 1:2). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.03–8.09 (m, 1H), 7.60–7.72 (m, 3H), 5.75–5.84 (m, 1H), 5.64–5.68 (m, 1H), 5.55–5.62 (m, 1H), 5.23–5.30 (m, 1H), 5.14–5.23 (m, 1H), 5.04–5.10 (m, 1H), 4.89–4.94 (m, 1H), 4.22–4.30 (m, 1H), 3.94–3.99 (m, 1H), 3.79–3.88 (m, 1H), 1.98–2.40 (m, 4H), 2.03 (s, 3H), 1.80–1.91 (m, 1H); ^{13}C NMR ($CDCl_3$): δ 170.3, 147.9, 135.2, 134.4, 133.8, 133.7, 133.6, 132.0, 131.6, 124.3, 118.4, 68.4, 64.2, 52.9, 47.9, 42.3, 40.3, 21.4; IR: ν 3528, 3092, 3025, 1730, 1543, 1372, 1347, 1242, 1163, 1025, 852, 741 cm^{-1}; MS (190°C): *m/z* (%) 410 (3) [M$^+$], 224 (27), 186 (100), 164 (94); HRMS: calcd for $C_{18}H_{22}N_2O_7S$ [M$^+$]: 410.1148, found: 410.1151. Anal. calcd for $C_{18}H_{22}N_2O_7S$: C, 52.81%; H, 5.38%; N, 6.85%. Found: C, 52.66%; H, 5.39%; N, 6.97%; $[\alpha]_D^{20}$=−50.1° (*c* 0.66, $CHCl_3$).

3.3.2. (−)-(1*S*,3*S*,5*S*)-5-(*N*-(But-3-enyl)-*N*-(2-nitrobenzenesulfonyl)-amino)-3-hydroxycyclohept-6-enyl acetate [(−)-51]. Compound **43** (270 mg, 0.50 mmol) gave **51** (190 mg, 89%) as a pale yellow oil. R_f=0.14 (cyclohexane/MTBE 1:1). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.05–8.11 (m, 1H), 7.58–7.72 (m, 3H), 5.57–5.74 (m, 3H), 5.27–5.34 (m, 1H), 5.00–5.08 (m, 2H), 4.85–4.91 (m, 1H), 4.24–4.33 (m, 1H), 3.23–3.38 (m, 2H), 1.98–2.45 (m, 6H), 2.04 (s, 3H), 1.83–1.94 (m, 1H); ^{13}C NMR ($CDCl_3$): δ 170.3, 148.1, 134.4, 134.2, 133.2, 133.8, 133.4, 131.9, 131.4, 124.3, 117.5, 68.3, 64.2, 52.6, 44.9, 42.2, 40.3, 35.5, 21.3; IR: ν 3524, 3075, 1730, 1543, 1372, 1347, 1239, 1161, 1025, 852, 740 cm^{-1}; MS (190°C): *m/z* (%) 383 (100) [M$^+$−C_3H_5], 347 (49), 186 (66), 109 (98); HRMS: calcd for $C_{16}H_{19}N_2O_7S$ [M$^+$−C_3H_5]: 383.0913, found: 383.0913; $[\alpha]_D^{20}$=−58.7° (*c* 0.62, $CHCl_3$).

3.3.3. (−)-(1*S*,3*S*,5*S*)-5-(*N*-(But-4-enyl)-*N*-benzyloxycarbonyl-amino)-3-hydroxycyclohept-6-enyl acetate [(−)-52]. Compound **44** (152 mg, 0.31 mmol) gave **52** (102 mg, 88%) as a pale yellow oil. R_f=0.24 (cyclohexane/MTBE 1:1). ^{1}H NMR (200 MHz, $CDCl_3$): (rotameric mixture) δ 7.21–7.37 (m, 5H), 5.50–5.88 (m, 3H), 5.24–5.39 (m, 1H), 4.92–5.16 (m, 4H), 4.52–4.91 (m, 1H), 4.17–4.32 (m, 1H), 3.06–3.42 (m, 2H), 2.10–2.43 (m, 5H), 2.04 (s, 3H), 1.78–2.06 (m, 2H); ^{13}C NMR ($CDCl_3$): (rotameric mixture) δ 170.1, 155.8, 136.5, 135.8, 135.0, 132.3, 131.4, 128.4, 127.9, 127.7, 116.7, 68.6, 67.0, 64.5, 51.6, 46.5, 45.0, 41.9, 41.8, 40.3, 34.4, 33.5, 21.1; IR: ν 3448, 3067, 3032, 1732, 1696, 1418, 1239, 1021, 970, 698 cm^{-1}; MS (170°C): *m/z* (%) 373 (1) [M$^+$], 332 (15), 143 (30), 138 (22), 91 (100); HRMS: calcd for $C_{21}H_{27}NO_5$ [M$^+$]: 373.1889, found: 373.1889; $[\alpha]_D^{20}$=−78.2° (*c* 0.62, $CHCl_3$).

3.4. General procedure for the preparation of 53–55 from 50–52

To a solution of **50**, **51** or **52** (0.20 mmol) in cyclohexane/CH_2Cl_2 (1:1, 2 mL) at 0°C allyl trichloroacetamidate (1.0 mmol) and one drop of trifluormethane sulfonic acid were added and the solution was stirred at rt for 1 day. The solvents were distilled off and the residue was purified by FC (cyclohexane/MTBE 1:1) to give **53**, **54** or **55**.

3.4.1. (−)-(1*S*,3*S*,5*S*)-3-Allyloxy-5-(*N*-allyl-*N*-(2-nitrobenzenesulfonyl)-amino)-cyclohept-6-enyl acetate [(−)-53]. Compound **50** (87 mg, 0.21 mmol) gave **53** (49 mg, 52%) as pale yellow oil. R_f=0.27 (cyclohexane/MTBE 1:1). ^{1}H NMR (200 MHz, $CDCl_3$): δ 8.00–8.09 (m, 1H), 7.54–7.73 (m, 3H), 5.48–5.94 (m, 4H), 4.98–5.36 (m, 5H), 4.68–4.85 (m, 1H), 3.76–4.06 (m, 5H), 1.70–2.38 (m, 4H), 2.02 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 170.3, 147.9, 135.3, 134.6, 134.5, 133.5, 133.4, 133.0, 131.7, 131.6, 124.1, 118.2, 116.8, 70.4, 69.1, 68.3, 53.2, 47.8, 38.7, 37.5, 21.1; IR: ν 3081, 3023, 1732, 1544, 1371, 1242, 1165, 1025, 852, 742 cm^{-1}; MS (140°C): *m/z* (%) 450 (<1) [M$^+$], 333 (98), 264 (28), 204 (79), 186 (100), 146 (78), 120 (57), 91 (80); HRMS: calcd for $C_{21}H_{26}N_2O_7S$ [M$^+$]: 450.1461, found: 450.1463; $[\alpha]_D^{20}$=−21° (*c* 0.89, $CHCl_3$).

3.4.2. (−)-(1*S*,3*S*,5*S*)-3-Allyloxy-5-(*N*-(but-3-enyl)-*N*-(2-nitrobenzenesulfonyl)-amino)-cyclohept-6-enyl acetate [(−)-54]. Compound **51** (120 mg, 0.28 mmol) afforded **54** (50 mg, 38%) as pale brown oil. R_f=0.22 (cyclohexane/MTBE 1:1). ^{1}H NMR (200 MHz, $CDCl_3$): δ 8.00–8.09 (m, 1H), 7.54–7.73 (m, 3H), 5.53–5.92 (m, 4H), 4.99–5.39 (m, 5H), 4.68–4.80 (m, 1H), 3.76–4.00 (m, 3H), 3.26–3.38 (m, 2H), 1.70–2.50 (m, 6H), 2.05 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 170.3, 148.0, 134.6, 134.4, 133.7, 133.5, 133.3, 131.7, 131.5, 131.45, 124.1, 117.3, 116.9, 70.3, 69.1, 68.3, 53.9, 44.8, 38.7, 37.5, 35.5, 21.2; IR: ν 3080, 1732, 1542, 1373, 1240, 1165, 1026, 852, 741 cm^{-1}; MS (200°C): *m/z* (%) 423 (5) [M$^+$−C_3H_5], 209 (100), 109 (55); HRMS: calcd for $C_{19}H_{23}N_2O_7S$ [M$^+$−C_3H_5]: 423.1226, found: 423.1221; $[\alpha]_D^{20}$=−21.4° (*c* 0.83, $CHCl_3$).

3.4.3. (−)-(1*S*,3*S*,5*S*)-3-Allyloxy-5-(*N*-(but-3-enyl)-*N*-benzyloxycarbonyl-amino)-cyclohept-6-enyl acetate [(−)-55]. Compound **52** (100 mg, 0.32 mmol) gave **55** (49 mg, 37%) as pale brown oil. R_f=0.52 (cyclohexane/MTBE 1:1). ^{1}H NMR (200 MHz, $CDCl_3$): (rotameric mixture) δ 7.20–7.40 (m, 5H), 5.52–6.00 (m, 4H), 4.92–5.48 (m, 7H), 4.40–4.79 (m, 1H), 3.78–4.11 (m, 3H), 3.12–3.36 (m, 2H), 1.80–2.46 (m, 6H), 2.06 (s, 3H); ^{13}C NMR ($CDCl_3$): (rotameric mixture) δ 170.2, 155.7, 136.7, 135.4, 135.2, 134.8, 131.9, 128.4, 127.9, 127.8, 127.6, 116.7, 116.65, 71.1, 69.2, 68.7, 67.0, 52.8, 46.3, 38.5, 38.1, 34.2, 33.6, 21.2; IR: ν 3065, 3031, 1734, 1696, 1415, 1237, 1022, 916, 697 cm^{-1}; MS (170°C): *m/z* (%) 372 (2) [M$^+$−C_3H_5], 354 (2), 312 (4), 109 (8), 91 (100); HRMS: calcd for $C_{21}H_{26}NO_5$ [M$^+$−C_3H_5]: 372.1811, found: 372.1815; $[\alpha]_D^{20}$=−57.5° (*c* 0.48, $CHCl_3$).

3.5. General procedure for the preparation of 56–58 from 53–55

Compounds **53**, **54** or **55** (0.11 mmol) and [Ru] (5 mol%)

were refluxed in dry CH_2Cl_2 (2 mL) under N_2 atmosphere. The solution was concentrated in vacuo, the residue was purified by FC (cyclohexane/MTBE 3:1) to give *56*, **57** or **58**.

3.5.1. (+)-(2*S*,4*S*)-2-[(2*S*)-(*N*-(2-Nitrobenzenesulfonyl)-2,5-dihydro-1*H*-pyrrol-2-ylmethyl)]-2,3,4,7-tetrahydrooxepin-4-yl acetate [(+)-56]. Compound **53** (49 mg, 0.11 mmol) and [Ru] (5 mg, 5 mol%) gave after 8 h **56** (42 mg, 93%) as a light brown oil. R_f=0.17 (cyclohexane/MTBE 1:1). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.87–7.92 (m, 1H), 7.57–7.73 (m, 3H), 5.58–5.87 (m, 5H), 4.80–4.89 (m, 1H), 4.00–4.38 (m, 5H), 2.14–2.25 (m, 1H), 2.07 (s, 3H), 1.87–2.00 (m, 3H); ^{13}C NMR ($CDCl_3$): δ 170.4, 148.8, 133.6, 132.0, 131.6, 131.4, 131.1, 130.6, 129.9, 124.3, 124.1, 73.1, 69.4, 67.9, 66.0, 55.2, 42.8, 40.4, 21.4; IR: ν 3096, 3026, 1730, 1544, 1371, 1355, 1242, 1168, 1127, 1095, 1028, 852, 743, 654 cm^{-1}; MS (220°C): *m/z* (%) 423 (<1) [MH$^+$], 363 (25), 253 (94), 236 (26), 186 (100); HRMS: calcd for $C_{19}H_{23}N_2O_7S$ [MH$^+$]: 423.1226, found: 423.1227; $[\alpha]_D^{20}$=+139° (*c* 1.07, $CHCl_3$).

3.5.2. (+)-(2*S*,4*S*)-2-[(2*S*)-(*N*-(2-Nitrobenzenesulfonyl)-1,2,5,6-tetrahydropyrid-2-ylmethyl)]-2,3,4,7-tetrahydrooxepin-4-yl acetate [(+)-57]. Compound **54** (48 mg, 0.11 mmol) and [Ru] (5 mg, 5 mol%) gave after 1 day **57** (35 mg, 74%) as a brown oil. R_f=0.11 (cyclohexane/MTBE 1:1). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.97–8.01 (m, 1H), 7.54–7.70 (m, 3H), 5.62–5.77 (m, 5H), 4.60–4.66 (m, 1H), 4.25–4.32 (m, 1H), 4.10–4.18 (m, 1H), 3.86–4.03 (m, 2H), 3.20–3.30 (m, 1H), 1.80–2.20 (m, 5H), 2.05 (s, 3H), 1.62–1.73 (m, 1H); ^{13}C NMR ($CDCl_3$): δ 170.4, 148.2, 134.2, 133.3, 131.4, 130.9, 130.4, 130.2, 128.6, 124.5, 123.9, 72.0, 69.5, 68.5, 51.9, 41.4, 40.5, 38.4, 23.3, 21.4; IR: ν 3093, 3032, 2924, 2853, 1730, 1543, 1371, 1355, 1242, 1162, 1125, 1109, 1028, 852, 745, 676 cm^{-1}; MS (190°C): *m/z* (%) 437 (<1) [MH$^+$], 377 (28), 267 (55), 186 (100), 95 (41); HRMS: calcd for $C_{20}H_{25}N_2O_7S$ [MH$^+$]: 437.1382, found: 437.1388; $[\alpha]_D^{20}$=+150° (*c* 0.2, $CHCl_3$).

3.5.3. (+)-(2*S*,4*S*)-2-[(2*S*)-(*N*-benzyloxycarbonyl-1,2,5,6-tetrahydropyrid-2-ylmethyl)]-2,3,4,7-tetrahydrooxepin-4-yl acetate [(+)-58]. Compound **55** (22 mg, 0.053 mmol) and [Ru] (2 mg, 5 mol%) gave after 12 h **58** (19 mg, 92%) as a brown oil. R_f=0.40 (cyclohexane/MTBE 1:1). ^{1}H NMR (500 MHz, $CDCl_3$): (rotameric mixture) δ 7.26–7.39 (m, 5H), 5.45–5.83 (m, 5H), 5.10–5.23 (m, 2H), 4.56–4.80 (m, 1H), 3.42–4.43 (m, 3H), 3.69–3.75 (m, 2H), 2.84–2.98 (m, 1H), 1.78–2.35 (m, 4H), 2.04 (s, 3H), 1.57–1.66 (m, 1H); ^{13}C NMR ($CDCl_3$): (rotameric mixture) δ 170.4, 155.8, 155.4, 137.0, 136.7, 130.8, 130.4, 129.7, 129.2, 128.5, 127.8, 128.1, 125.4, 124.8, 73.1, 72.7, 69.8, 69.5, 69.3, 68.3, 67.3, 67.0, 50.1, 50.0, 41.0, 40.9, 40.8, 40.7, 37.4, 37.0, 25.1, 24.6, 21.4; IR: ν 3064, 3031, 1734, 1695, 1420, 1238, 1095, 1026, 698 cm^{-1}; MS (160°C): *m/z* (%) 386 (<1) [MH$^+$], 216 (40), 172 (49), 166 (20), 91 (100); HRMS: calcd for $C_{22}H_{28}NO_5$ [MH$^+$]: 386.1967, found: 386.1970; $[\alpha]_D^{20}$=+99° (*c* 0.39, $CHCl_3$).

Acknowledgments

This work was financially supported by the Netherlands Foundation for Chemical Research (NWO-CW) and the Fonds der Chemischen Industrie.

References

1. For recent reviews see: (a) Trnka, T. M.; Grubbs, R. H. *Acc. Chem. Res.* **2001**, *34*, 18. (b) Fürstner, A. *Angew. Chem. Int. Ed. Engl.* **2000**, *39*, 3013. (c) Blechert, S. *Pure Appl. Chem.* **1999**, *71*(8), 1393.
2. (a) Ovaa, H.; Stragies, R.; van der Marel, G. A.; van Boom, J. H.; Blechert, S. *Chem. Commun.* **2000**, 1501. (b) Voigtmann, U.; Blechert, S. *Org. Lett.* **2000**, *2*, 3971. (c) Voigtmann, U.; Blechert, S. *Synthesis* **2000**, *6*, 893. (d) Stragies, R.; Blechert, S. *J. Am. Chem. Soc.* **2000**, *122*, 9584. (e) Buschmann, N.; Rückert, A.; Blechert, S. *J. Org. Chem.* **2002**, *67*, 4325.
3. Adams, J. A.; Gair-Ford, J.; Stamatos, P. J.; Hoveyda, A. H. *J. Org. Chem.* **1999**, *64*, 9690.
4. Ovaa, H.; Codee, J. D. C.; Lastdrager, B.; Overkleeft, H. S.; van der Marel, G. A.; van Boom, J. H. *Tetrahedron Lett.* **1998**, *39*, 7987.
5. For a review on asymmetric transition metal catalyzed allylic alkylations see: Trost, B. M.; van Vranken, D. L. *Chem. Rev.* **1996**, *96*, 395.
6. For determination of the enantiomeric excess the nosyl group was replaced by a tosyl group ((i) PhSH, K_2CO_3, DMF. (ii) TsCl, pyridine) in order to facilitate separation of the enantiomers on a Chiralcel OD Gold column (0.5% *i*PrOH in hexane, 0.9 mL/min, 218 nm).
7. Stragies, R.; Blechert, S. *Tetrahedron* **1999**, *55*, 8179.
8. (a) Rutjes, F. P. J. T.; Kooistra, T. M.; Hiemstra, H.; Schoemaker, H. E. *Synlett* **1998**, 192. (b) Ovaa, H.; Leeuwenburgh, M. A.; van der Marel, G. A.; van Boom, J. H. *Tetrahedron Lett.* **1998**, *39*, 3025.
9. 2-Methoxy-2,5-dihydrofuran **16** rearranges to afford a tetrahydrofuran with loss of methanol under the influence of silica gel. Solutions of **16** must therefore be kept basic (little Et_3N) during work-up and purification by column chromatography in order to prevent this elimination reaction.
10. Johnson, C. R.; Golebiowski, A.; Steensma, D. H. *J. Am. Chem. Soc.* **1992**, *114*, 9414.
11. Stragies, R.; Blechert, S. *J. Am. Chem. Soc.* **2000**, *122*, 9584.
12. For the deprotection protocol see: Fukuyama, T.; Joe, C.-K.; Cheung, M. *Tetrahedron Lett.* **1995**, *52*, 1922.
13. Zuercher, W. J.; Hashimoto, M.; Grubbs, R. H. *J. Am. Chem. Soc.* **1996**, *118*, 6634.
14. Wessel, H.-P.; Iversen, T.; Bundle, D. R. *J. Chem. Soc., Perkin Trans. 1* **1985**, 2247.
15. Instead of working in a glove box, Schlenk technique may also be used. Solid Grubbs catalyst [Ru] can be handled in air.