First Highly Regio- and Diastereoselective [3+2] Cycloaddition of Chiral Nonracemic Alkenyl Fischer Carbene Complexes with Diazomethane Derivatives: Preparation and Synthetic Applications of Enantiomerically Pure Δ^2-Pyrazolines

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Abstract: The [3+2] cycloaddition of alkenyl Fischer carbene complexes **1** and **6** with diazomethane derivatives to give Δ^2-pyrazoline carbenes **2**, **4**, and **7** is described. The conversion of (−)-8-phenylmenthol-derived carbenes **6** into pyrazoline esters **9** through a one-pot cycloaddition–protection–oxidation is presented as an expeditious route to enantiomerically pure 3-alkoxycarbonyl-Δ^2-pyrazolines in good yields and in a highly regio- and diastereoselective manner. Pyrazolidines **13** were synthesized in excellent overall yields from **9** through pyrazolines **11** and **12**, the diastereoselective reduction of C=N bond being the key step. Azaprolines **16** and **17** were prepared in very good yields from epimeric *trans*-**13** or *cis*-**13** by oxidative deprotection of the silylated hydroxy group. In an alternative reaction, the pyrazolidine ring of **13** was reduced to obtain protected open-chain 2,4-diamino alcohols **19** with three chiral centers.

Keywords: amino alcohols · azaprolines · carbene complexes · cycloadditions · pyrazolines

Introduction

During the last three decades since their discovery in 1964,[1] Fischer carbene complexes have emerged as versatile synthons in organic synthesis.[2] Thus, thermal cyclopropanations[3] and Dötz benzannulations[4] as well as photoinduced reactions[5] and other cyclizations of diverse topological characteristics[6] occur on the metal–carbene carbon functionality, whereas the carbene ligand of α,β-unsaturated complexes is usually involved in [2+2][7] and [4+2][8] cycloadditions.

1,3-Dipolar cycloadditions are a powerful class of reactions for the preparation of functionalized five-membered heterocycles.[9] In the field of Fischer carbene complexes, the α,β-unsaturated derivatives have been scarcely used in [3+2] cycloadditions with 1,3-dipoles, in contrast with other type of cycloadditions (vide supra). In this regard, Fischer[10] reported the first [3+2] cycloaddition of this type between pentacarbonyl(ethoxy)phenylethynyltungsten and diazomethane obtaining the corresponding pyrazole derivative; the process was improved by Wulff and Chan[11] thirteen years later by the introduction of a bulky trimethylsilyl group on the diazomethane in order to prevent carbene–carbon olefination and thus obtaining pyrazole carbene complexes. More recently, (alkoxy)alkynyl carbenes have been shown to react with nitrones[12] and masked 1,3-dipoles[13] to give dihydroisoxazole and pyrrole or pyrazole carbene complexes respectively. On the other hand, only one case of participation of alkenyl Fischer carbenes in 1,3-dipolar cycloadditions has been reported so far,[14] which involves the reaction of an alkenyl carbene containing an *exo*-methylene double bond with trimethylsilyldiazomethane ($TMSCHN_2$) yielding spiropyrazoline derivatives.

There is a large number of Δ^2-pyrazolines described in the literature[15] due to their synthetic accessibility and important applications. Thus, Δ^2-pyrazolines are of interest for their biological activity (for example, as antiinflammatory agents)[16] and physical applications (for example, as optical brighteners)[17] as well as for their use as synthons in the preparation of several hetero- and carbocyclic derivatives; hence, procedures to obtain these systems as enantiomerically pure compounds in a regio- and diastereoselective way are of

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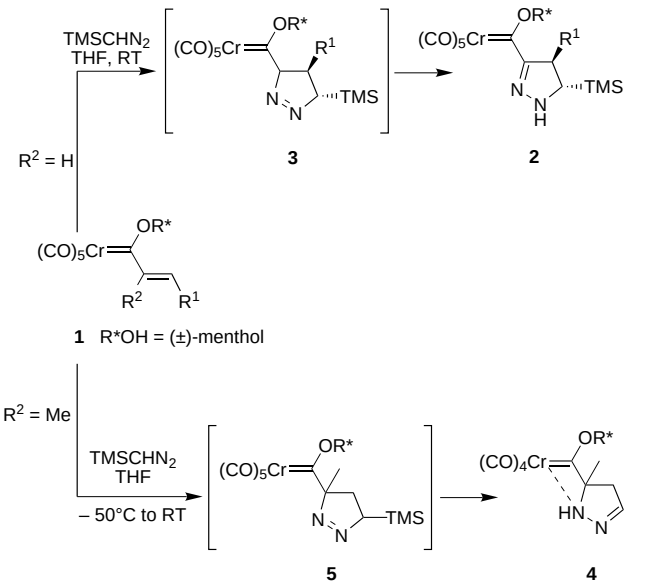
  0947-6539/99/0503-0883 $ 17.50+.50/0

great value. In this context, we present here the reaction of diazo compounds with alkenyl Fischer carbenes derived from chiral alcohols as an expedient synthesis of enantiomerically pure Δ^2-pyrazolines; the second part of this paper deals with the transformation of these compounds into several polyfunctionalized cyclic and open-chain derivatives.

Results and Discussion

[3+2] Cycloaddition of Fischer carbene complexes 1 and 6 with diazomethane derivatives: The first experiments were carried out with (±)-menthol-derived chromium carbenes **1**, which, after treatment with a slight excess of trimethylsilyldiazomethane in THF at room temperature for a few hours, gave Δ^2-pyrazoline carbene complexes **2** as single regioisomers in moderate yields; compounds **2** were detected as mixtures of diastereomers (diastereomeric ratio [dr] ≤ 3:1) with relative *trans* stereochemistry at the pyrazoline ring (Scheme 1, Table 1). The formation of **2** could be rationalized by assuming that the initially formed Δ^1-pyrazoline **3** undergoes a tautomerization to the thermodynamically more stable Δ^2-pyrazoline.[18] Carbene **1d** (R^2 = Me) was used in order to isolate the initial Δ^1-pyrazoline cycloadduct; however, only Δ^2-pyrazoline **4** could be obtained as a mixture of diastereomers (dr = 1:1) after chromatographic purification with silica gel (Scheme 1, Table 1, entry 4). A different compound was primarily formed in the reaction, as indicated by TLC, which should be the silylated Δ^1-pyrazoline **5**; this cycloadduct would lead to the final Δ^2-pyrazoline derivative by desilylation during chromatographic work-up.[19] The structure suggested for compound **4**, containing a tetracarbonyl unit, was supported by the observation in the ^{13}C NMR spectrum of six signals (two of them are duplicated) at δ = 232.1 (double), 231.1 (double), 220.5, 220.1 and 219.7, and 219.2 that were assigned to the four CO groups belonging to the two diastereomers, as well as two signals at 342.0 and 341.8 assigned to the carbene carbons.

Abstract in Spanish: *En este trabajo se describe por primera vez la cicloadición [3+2] de los alcoxi alquenil carbenos de Fischer **1** y **6** con diazocompuestos, que conduce a los correspondientes Δ²-pirazolinocarbenos **2**, **4** y **7**. Se presenta, asimismo, la transformación de los carbenos derivados de (−)-8-fenilmentol **6** en los ésteres pirazolínicos **9**, mediante una secuencia one-pot de cicloadición – protección – oxidación, lo que supone una ruta directa para la obtención de alcoxicarbonil-Δ²-pirazolinas con buenos rendimientos y de forma altamente regio- y diastereoselectiva. Las pirazolidinas **13** se sintetizaron, con excelentes rendimientos globales, a partir de **9** vía las pirazolinas **11** y **12**, siendo el paso clave de la secuencia la reducción diastereoselectiva del doble enlace C=N. Las azaprolinas **16** y **17** se prepararon, con elevados rendimientos, a partir de los epímeros trans-**13** o cis-**13** mediante desprotección oxidativa del grupo hidroxilo sililado. Por otra parte, el anillo pirazolidínico de los compuestos **13** fue reducido dando lugar a los 2,4-diaminoalcoholes protegidos de cadena abierta **19** que presentan tres centros estereogénicos.*



Scheme 1. [3+2] Cycloaddition of (±)-menthol-derived Fischer carbenes **1** and trimethylsilyldiazomethane.

Table 1. Synthesis of Δ^2-pyrazoline complexes **2** and **4**.

Entry	Carbene	R^1	R^2	Adduct	Time (h)	Yield (%)[a]	dr[b]
1	**1a**	Ph	H	**2a**	1	46	3:1
2	**1b**	2-furyl	H	**2b**	6	38	2:1
3	**1c**	*p*-anisyl	H	**2c**	6	40	2:1
4	**1d**	H	Me	**4**	4	72	1:1

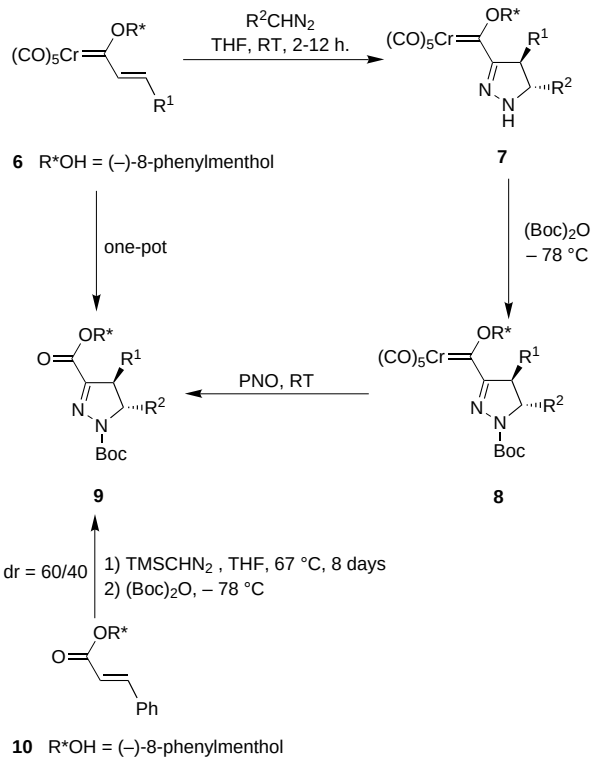
[a] Yield of isolated product after chromatographic purification; diastereomers not separated. [b] Determined by ^{1}H NMR from crude reaction mixture.

The lowering in the reaction rate observed when an electron-rich substituent is introduced in the carbene structure (Table 1, entry 1 vs. 2 and 3) can be rationalized in terms of the frontier molecular orbital theory, taking into account that the reaction is likely owing to the interaction between the LUMO of carbene complex and the HOMO of the dipole.

In view of the preliminary results and in order to improve the diastereoselectivity of the cycloaddition process, the use of (−)-8-phenylmenthol-derived carbenes **6** was considered, taking into account the excellent results obtained in addition reactions to alkenyl Fischer carbenes bearing this chiral auxiliary.[20] The reaction of carbenes **6** with several diazomethane derivatives under the conditions mentioned above led in a few hours to the corresponding Δ^2-pyrazoline carbenes **7** as the only diastereomer (dr > 95:5, by ^{1}H NMR of crude products) in moderate yields (Scheme 2, Table 2).[21]

Cycloadducts **7** were transformed into the corresponding *N*-Boc derivatives **8** by treatment with $(Boc)_2O$ at −78 °C. The metal pentacarbonyl moiety was removed from **8** by oxidation with pyridine *N*-oxide (PNO) at room temperature, giving Δ^2-pyrazoline esters **9** in good yield. The overall yields for the transformation of **6** into **9** were greatly improved by the one-pot procedure without isolation of derivatives **7** and **8** (Table 2, entry 2). On the other hand, pyrazoline esters **9** can also be prepared from the corresponding analogue esters of carbenes; thus, compound **9b** was obtained from *trans*-cinnamate **10** (R^1 = Ph) and trimethylsilyldiazomethane but

0947-6539/99/0503-0884 $ 17.50+.50/0 *Chem. Eur. J.* **1999**, *5*, No. 3



Scheme 2. [3+2] Cycloaddition of (−)-8-phenylmenthol-derived Fischer carbenes **6** and diazomethane derivatives.

Table 2. Synthesis of Δ^2-pyrazoline complexes **7** and **8** and esters **9**.

Entry	Carbene	R^1	R^2	**7** (%)[a]	**8** (%)[a]	**9** (%)[a]	**6** to **9** One-pot yield (%)[a]
1[b]	**6a**	Ph	H	**a** (≈29)[c]	–	**a**	79
2	**6a**	Ph	TMS	**b** (52)	**b** (60)	**b** (75)	73 (23)[d] (65)[e]
3	**6a**	Ph	Ph	**c** (40)	**c** (61)	**c** (83)	–
4	**6a**	Ph	CH=CH_2	**d** (47)	**d** (69)	**d** (86)	–
5	**6b**	2-furyl	TMS	**e** (53)	**e** (≈68)[c]	**e**	55
6	**6b**	2-furyl	Ph	**f** (42)	**f** (≈65)[c]	**f** (79)	–
7	**6b**	2-furyl	CH=CH_2	**g** (50)	**g** (72)	**g** (87)	–
8	**6b**	2-furyl	H	–	–	**h**	74[f]

[a] Yield of isolated product after chromatographic purification. [b] Reaction performed at −78 °C. [c] Compounds not characterized owing to partial oxidation. [d] Overall yield in the stepwise procedure. [e] Yield starting from **10**. [f] dr = 92:8; diastereomers not separated.

at higher temperature (67 °C), longer reaction time (8 days) and with much poorer diastereoselectivity (dr = 60:40) (Scheme 2, Table 2, entry 2). These results clearly show the rate and diastereoselectivity enhancement of the metal pentacarbonyl moiety over the oxygen atom in the cycloaddition process.[22]

The relative *trans* configuration in the Δ^2-pyrazoline ring of compounds **7–9** was established by ^{1}H NMR coupling constant analysis[23] as well as NOE experiments, and the absolute stereochemistry of stereogenic centers, as depicted in Scheme 2, was assigned on the basis of the X-ray analysis of compound **8b** (Figure 1).[24–25]

The asymmetric induction observed in the [3+2] cycloaddition process can be understood by assuming that in the reactive conformation of **6**, the chiral auxiliary phenyl group shields the double bond (*Re,Re*)-face by π,π-orbital overlapping, inducing the dipole to attack selectively from the (*Si,Si*)-face (Figure 2).

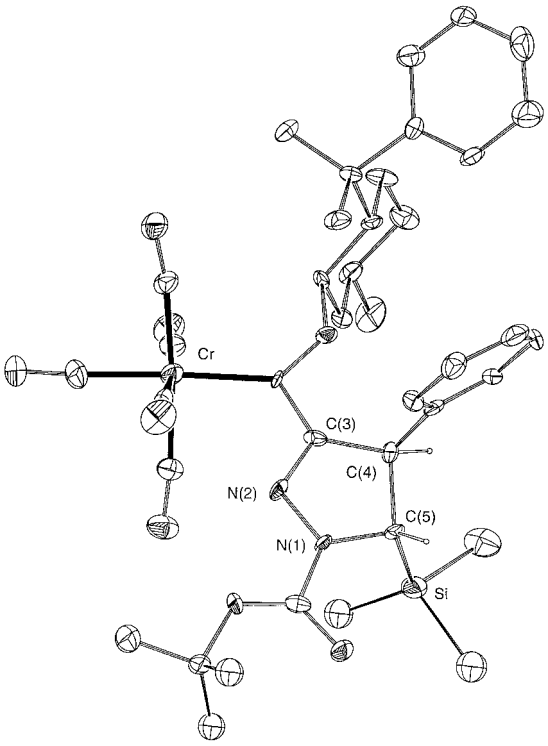


Figure 1. Crystal structure of **8b**.

Synthetic applications of Δ^2-pyrazoline esters 9: The use of pyrazoline derivatives, synthesized as diazoalkane/olefin cycloadducts, has typically been limited to the preparation of derivatized cyclopropanes or pyrazoles, obtained by nitrogen extrusion[26] or aromatization[27] of the initial adduct,

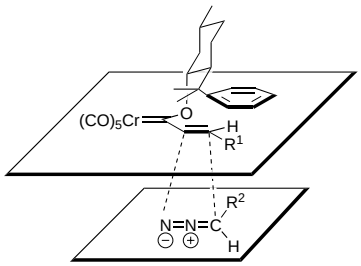
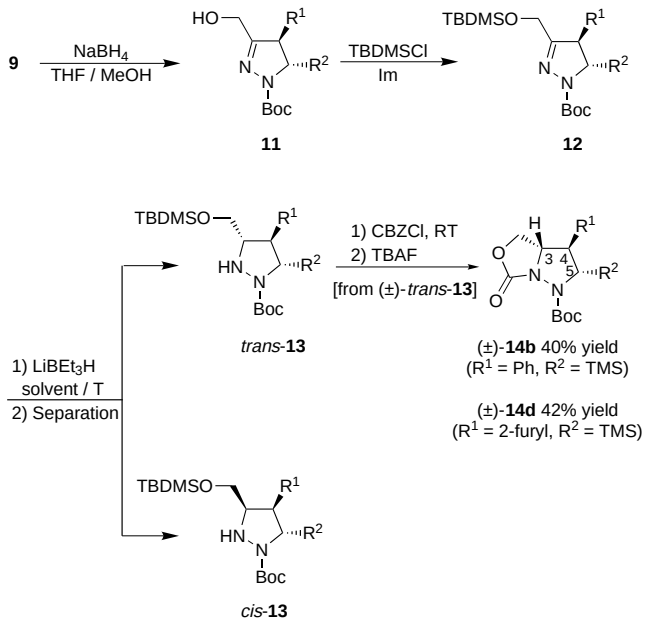


Figure 2. Posited reactive conformation of **6**, in which the chiral auxiliary phenyl group shields the (*Re,Re*)-face of the doble bond, inducing selective attack from the (*Si,Si*)-face.

respectively. However, the structure of 3-alkoxycarbonyl-Δ^2-pyrazolines **9** described in this paper suggests, in principle, their transformation into pyrazolidine-3-carboxylic acid derivatives (azaprolines) and diamino acids or alcohols basically by selective carbon–nitrogen double-bond reduction and further nitrogen–nitrogen single-bond hydrogenolysis. In this sense, several attempts at catalytic hydrogenation (Pd/C, black Pd, PtO_2, Raney Ni, Rh/Al_2O_3) of the C=N bond were unsuccessful; moreover, the presence of an electron-withdrawing group on N1 of **9** makes the use of complex hydrides

the method of choice for that purpose.[27b] Nevertheless, the treatment of Δ^2-pyrazoline esters **9** with different complex hydrides led always to the reduction of the ester group, the C=N bond remaining intact.[28] After optimization of the reaction, Δ^2-pyrazoline carbinols **11** were obtained in very good yields by reduction of **9** with $NaBH_4$ in THF/MeOH, with almost quantitative recovery of the chiral auxiliary, (−)-8-phenylmenthol, during the work-up (Scheme 3, Table 3).



Scheme 3. Conversion of Δ^2-pyrazoline esters **9** into pyrazolidine derivatives **13** and bicyclic compounds **14**.

Further attempts to reduce the C=N bond of **11** failed, hence we decided to protect the hydroxy functionality to prevent the likely participation of the OH group in the reduction process. The reaction of **11** with *tert*-butyldimethylsilyl chloride (TBDMSCl) using imidazole (Im) as base gave rise to the pyrazoline silyl ethers **12** in quantitative yield.[29] The best results in the C=N reduction of **12** were achieved by using Superhydride ($LiBEt_3H$), which furnishes the desired pyrazolidines **13** in excellent yields as a mixture of diastereomers, *cis*-**13** and *trans*-**13**, that could be isolated by chromatographic separation (Scheme 3, Table 3).

The stereochemistry of **13** was assigned based on conventional ^1H and ^{13}C NMR data as well as HMBC, HMQC, and NOESY experiments. In this regard the conclusive data for the assignment of the stereochemistry of the new stereogenic center of **13b** and **13d** come from the NOESY spectra of bicyclic derivatives (±)-**14b** and (±)-**14d**, respectively, obtained by treatment of the pyrazolidine precursors (±)-**13** (prepared from (±)-menthol derivatives **2** following the same sequence) with benzyl chloroformate (CBZCl) and subsequent reaction with tetrabutylammonium fluoride (TBAF) to promote a tandem desilylation/cyclization process (Scheme 3). Thus, the cross-peak observed between hydrogens on C3 and C5 of the pyrazolidine ring of **14** clearly indicates a *cis* relative stereochemistry, as shown in Scheme 3; the X-ray structure of (±)-**14b** corroborates this assignment (Figure 3).[24,25]

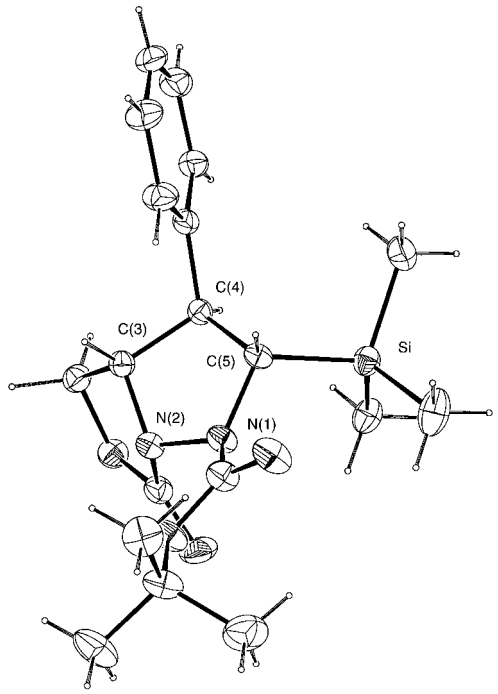


Figure 3. Crystal structure of **14b**.

As is listed in Table 3, the *cis*-**13** epimer was the only observed isomer in the reduction of the C=N bond of **12a** (entry 1) whereas *trans*-**13** was exclusively detected when the starting materials were **12b** and **12d** (entries 2 and 7); only the formation of *cis*-**13a** can be fully understood considering that the hydride attacks, as expected, from the opposite side to the R^1 substituent. A quick look at the solvent influence (entries 3–5) allows us to conclude that although the polarity and/or the complexing ability of the solvent seem to play a role in the asymmetric induction of the process, this is not drastic or decisive; in this sense, a decrease in the reaction temperature favors, but not strongly, the formation of *trans*-**13**

Table 3. Synthesis of Δ^2-pyrazolines **11** and **12** and pyrazolidines **13**.

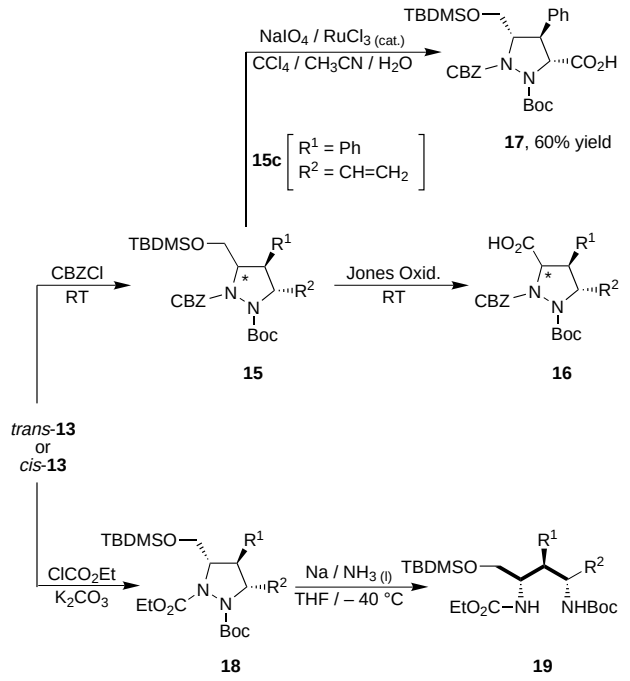
Entry	R^1	R^2	**11** (%)[a]	**12** (%)[a]	**13**	Solvent	*T*	*trans*-**13**/*cis*-**13**[b]	Yield (%)[a,c]
1	Ph	H	**a** (83)	**a** (quant.)	**a**	CH_2Cl_2	−78 °C to RT	< 5/95	85
2	Ph	TMS	**b** (81)	**b** (quant.)	**b**	CH_2Cl_2	−78 °C to RT	> 95/5	95
3	Ph	$CH{=}CH_2$	**c** (quant.)	**c** (96)	**c**	THF	RT	1/2	14/28
4					**c**	hexane	RT	1/1	35/37
5					**c**	CH_2Cl_2	RT	2/1	52/26
6					**c**	CH_2Cl_2	−78 °C to RT	4.7/1	82/17
7	2-furyl	TMS	**d** (76)	**d** (quant.)	**d**	CH_2Cl_2	−78 °C to RT	> 95/5	93

[a] Isolated yields. [b] By ^1H NMR (300 MHz) of crude mixtures. [c] Yields on the left refer to *trans*-**13** and those on the right refer to *cis*-**13**.

0947-6539/99/0503-0886 $ 17.50+.50/0 *Chem. Eur. J.* **1999**, *5*, No. 3

(entry 5 vs. 6). In view of these results and without a deeper study, it can be concluded that the stereochemical course of the reduction, far from being simple, must be influenced by both the reaction conditions (solvent and temperature) and the nature of the substituents R^1 and R^2, also taking into account that the orientation of the OTBDMS group during the reaction might play an important role in the stereochemical outcome.

Pyrazolidines **13** are fairly unstable and undergo slow oxidation in the air to the starting Δ^2-pyrazolines **12**; hence they must be stored at $-20\,^\circ C$ under an inert atmosphere after purification. This prompted us to protect the N2 in **13** prior to oxidation of the silyl ether moiety to the corresponding azaprolines. Compounds **13** were treated with benzyl chloroformate at room temperature to give protected derivatives **15** in almost quantitative yields (Scheme 4, Table 4). The



Scheme 4. Conversion of pyrazolidines **13** into protected pyrazolidines **15** and **18**, azaprolines **16** and **17** and protected diamino alcohols **19**.

Table 4. Synthesis of pyrazolidines **15** and **18**, azaprolines **16** and protected diamino alcohols **19**.

13	R^1	R^2	**15** (%)[a]	**16** (%)[a]	**18** (%)[a]	**19** (%)[a]
cis-**13a**	Ph	H	**a** (96)	**a** (97)		
trans-**13b**	Ph	TMS	**b** (92)	**b** (90)	**b** (85)	**b** (87)
trans-**13c**	Ph	$CH=CH_2$	**c** (quant.)	**c** (95)		
trans-**13d**	2-furyl	TMS	**d** (93)	**d** (63)	**d** (92)	**d** (84)

[a] Yields of isolated product.

reaction of **15** with Jones reagent (CrO_3/H^+) led, in very good yields, to azaprolines **16** through an oxidative deprotection of the *tert*-butyldimethylsilyl ether function. On the other hand, pyrazolidine **15c** (R^2 = vinyl) was converted into azaproline **17** (60% yield), analogue of **16**, by oxidative cleavage of the vinyl moiety with the sodium periodate/ruthenium trichloride system; compound **17** keeps the primary hydroxy group in its structure, which renders it useful for further transformations. It must be pointed out that azaprolines **16** and **17** have been prepared as free carboxylic acids containing orthogonally protected[30] amino groups; this facilitates their use in peptide synthesis with *N*-terminal amino acids or peptides.

The pyrazolidine ring of compounds **13** makes them potential precursors of 2,4-diamino alcohols by hydrogenolysis of the N–N bond; however, the *N*2-unprotected 2,4-diamino-*O*-silylated alcohols directly obtained by reductive opening of **13** were unstable to chromatographic purification. Consequently, we transformed the free amino group of **13** successfully into its ethyl carbamate derivative **18** by reaction with ethyl chloroformate (Scheme 4, Table 4). Treatment of **18** with sodium in liquid ammonia gave rise to protected 2,4-diamino alcohols **19** in good yields. The structure of compounds **19**, containing a γ-diamine and β-amino alcohol unit, allows them to be considered as potential chiral auxiliaries in organic synthesis.[31] Moreover, compounds **19** should also be, by oxidation of the carbinolic carbon, precursors of γ-aminobutyric acid (GABA) derivatives, present as neurotransmitters in mammalians.[32]

Conclusion

In summary, alkenyl Fischer carbenes derived from (–)-8-phenylmenthol have proved to be excellent precursors of enantiomerically pure 3-alkoxycarbonyl-Δ^2-pyrazolines in a one-pot procedure, the [3+2] cycloaddition between Fischer carbenes and diazoalkanes being the key step. This is the first example of this kind that employs chiral nonracemic alkenyl Fischer carbene complexes. The carbene–metal pentacarbonyl moiety has been found to play a decisive role on the reaction rate and diastereoselectivity. Further, 3-alkoxycarbonyl-Δ^2-pyrazolines have been demonstrated to be suitable synthons for the preparation of azaprolines, obtained as optimal starting materials for peptide synthesis, and 2,4-diamino alcohol derivatives which seem to be appropiate for further synthetic goals.

Experimental Section

General considerations: All reactions involving air-sensitive compounds were carried out under a N_2 atmosphere. All common reagents and solvents were obtained from commercial suppliers and used without any further purification unless otherwise indicated. Solvents were dried by standard methods. Hexane, ethyl acetate, and triethylamine were distilled before use. Diazocompounds[33] were prepared according to published procedures and were used in excess without previous titration. $TMSCHN_2$ ($(CH_3)_3SiCHN_2$) was used as a commercially available 2.0 M solution in hexane. TLC was performed on aluminum-backed plates coated with silica gel 60 with F_{254} indicator; the chromatograms were visualized under ultraviolet light and/or by staining with a Ce/Mo reagent (prepared by dissolving phosphomolybdic acid (2 g), cerium(IV) sulfate (1 g), and conc. sulfuric acid (10 mL) in H_2O (90 mL)) and subsequent heating. Flash column chromatography was carried out on silica gel 60, 230–240 mesh. The silica gel used in the purification process of cycloadducts **8** was previously deactivated by treatment with an aqueous solution saturated in potassium hydrogenphosphate and subsequently dried overnight at 120 °C. The enantiomeric purities were determined by chiral HPLC analysis using a Shimadzu instrument on a Chiralcel OD-H (Daicel) column (25 × 0.46 cm) and detection with photodiode array UV/vis detector. Optical

rotations were determined with a Perkin Elmer 241 polarimeter using a Na lamp; data are reported as follows: $[\alpha]_D^{T\,(^\circ C)}$ (concentration in g per 100 mL solvent). Melting points were obtained on a Büchi-Tottoli apparatus with open capillary tubes and are uncorrected. Routine NMR measurements were recorded on Bruker AC-200 or AC-300 spectrometers. ^{1}H NMR: splitting pattern abbreviations are: s, singlet; br s, broad singlet; d, doublet; t, triplet; q, quartet; m, multiplet. ^{13}C NMR: multiplicities were determined by DEPT; abbreviations are: q, CH_3; t, CH_2; d, CH; s, quaternary carbons. In the cases where a mixture of diastereomers was observed, the abbreviation min refers to the signals assigned to the minor diastereomer and the abbreviation maj to the signals belonging to the major one; in cases where neither is specified, either it was not possible to assign the signal to any diastereomer or the signal belongs to both of them. NOESY, HMQC, and HMBC experiments were carried out on a Bruker AMX-400 spectrometer. Standard pulse sequences were employed for the DEPT, HMQC, and HMBC experiments. FT-IR spectra were recorded with a Mattson 3000 FT-IR spectrometer. High-resolution mass spectra (HRMS) were obtained with a Finnigan Mat 95 mass spectrometer. Elemental analyses were carried out with a Perkin–Elmer 240 B microanalyzer.

General procedure for the synthesis of alkenyl carbene complexes 1a–d and 6a–b: The preparation of carbene complexes **1a–b** and **6a-b** has already been reported.[20b] Compound **1c** was prepared following that methodology, and complex **1d** was synthesized according to a slightly modified procedure: *t*BuLi (112.5 mmol, 1.5 M in pentane) was added through a syringe at $-78\,^\circ$C to a solution of 2-bromopropene (5 mL, 56.2 mmol) in Et_2O (175 mL). The resulting mixture was stirred at the same temperature for 90 min and then slowly added through a cannula to a suspension of $[Cr(CO)_6]$ (13.6 g, 62 mmol) in Et_2O (600 mL). The solution was then stirred at room temperature for an hour, till almost complete disappearance of $[Cr(CO)_6]$ was shown by FT-IR analysis. Solvents were removed under reduced pressure and the remaining solid dissolved in the minimum amount of degassed water (50 mL). The solution was cooled to $0\,^\circ$C and NMe_4Br (10.4 g, 67.5 mmol) was added portionwise and the resulting mixture stirred at the same temperature for 10 min. Water was then removed by means of a cannula, and the resulting orange solid was dried under reduced pressure and then dissolved in CH_2Cl_2 (500 mL). A solution of pivaloyl chloride (7 mL, 56.2 mmol) in CH_2Cl_2 (40 mL) was added at $-50\,^\circ$C to the reaction mixture and the resulting solution stirred at this temperature for 45 min. Finally, a solution of (±)-menthol (8.9 g, 56.2 mmol) in CH_2Cl_2 (40 mL) was added dropwise at $-50\,^\circ$C to the reaction mixture and then allowed to warm to room temperature overnight. Silica gel (10 g) was added to the reaction mixture and solvents were removed under reduced pressure. The resulting residue was purified by column chromatography using as eluent hexane/CH_2Cl_2: 95/5, yielding 2.70 g (12%) of carbene complex **1d** as an orange-red syrup.

Pentacarbonyl[1-((1*R,2*S**,5*R**)-menthyloxy)-*trans*-3-(4-methoxyphenyl)-2-propenylidene]chromium(0)** (**1c**): Complex **1c**, a red oil, was prepared following the standard procedure[20b] in 58% yield on a 15 mmol scale. $R_f = 0.23$ (hexane); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): $\delta =$ 7.95–7.65 (br s, 1H; CH), 7.61 (d, ^3J(H,H) = 8.6 Hz, 2H; 2 CH), 7.25–6.95 (br s, 1H; CH), 6.98 (d, ^3J(H,H) = 8.6 Hz, 2H; 2 CH), 5.07 (m, 1H; CH), 3.88 (s, 3H; CH_3), 2.22–0.85 (m, 9H), 1.04 (d, ^3J(H,H) = 6.6 Hz, 6H; 2 CH_3), 0.90 (d, ^3J(H,H) = 6.5 Hz, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 224.3$ (s), 217.1 (s), 162.0 (s), 131.1 (d), 126.9 (s), 114.5 (d), 91.1 (d), 55.2 (q), 48.1 (d), 42.0 (t), 33.9 (t), 31.0 (d), 26.4 (d), 23.8 (t), 21.9 (q), 21.5 (q), 16.9 (q); the signals corresponding to the carbene carbon and the CH of the double bond were not observed; FT-IR (neat): $\tilde{\nu} = 2054$ (C≡O), 1929 (C=O) cm^{-1}; MS (EI, 70 eV): m/z (%) = 492 (<5) [M^+], 464 (6), 380 (8), 352 (46), 214 (100); HRMS for $C_{25}H_{28}CrO_7$: calcd 492.1240; found 492.1234; anal. calcd for $C_{25}H_{28}CrO_7$: C 60.97, H 5.73; found C 61.13, H 5.71.

Pentacarbonyl[1-((1*R,2*S**,5*R**)-menthyloxy)-2-methyl-2-propenylidene]chromium(0)** (**1d**): $R_f = 0.37$ (hexane); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 5.25–4.33$ (m, 3H; CH+CH_2), 2.72–0.71 (m, 21H); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): $\delta = 351.8$ (s), 224.2 (s), 216.3 (s), 154.0 (s), 107.0 (t), 91.7 (d), 47.7 (d), 41.9 (t), 33.6 (t), 31.2 (d), 25.8 (d), 22.8 (t), 21.8 (q), 21.0 (q), 19.3 (q), 16.2 (q); FT-IR (neat): $\tilde{\nu} = 2062$ (C≡O), 1932 (C=O) cm^{-1}; MS (EI, 70 eV): m/z (%) = 400 (5) [M^+], 372 (10), 288 (16), 260 (86), 49 (100); HRMS for $C_{19}H_{24}CrO_6$: calcd 400.0978; found 400.0956; anal. calcd for $C_{19}H_{24}CrO_6$: C 57.00, H 6.04; found C 56.87, H 6.06.

General procedure for the cycloaddition of carbene complexes 1 and 6 with diazomethane derivatives: The corresponding diazocompound (1.5–2 equiv) was added through a syringe to a solution of the carbene complex (1 mmol) in THF (6 mL), and the resulting mixture stirred at RT (or, in the case of diazomethane, at $-78\,^\circ$C) till TLC analysis showed complete disappearance of the starting complex. Then SiO_2 (0.5 g) was added, and solvents removed under reduced pressure. The crude residue was purified by flash column chromatography with hexane/ethyl acetate 20:1 as eluent, yielding the corresponding cycloadducts **2** or **7** as red oils. In the case of carbene complex **1d**, the reaction with $TMSCHN_2$ was carried out at $-50\,^\circ$C and the solution allowed to warm to RT over 4 hours. Then SiO_2 (0.5 g) was added, and solvents were removed under reduced pressure. The crude residue was purified by flash column chromatography using hexane/ethyl acetate 5:1 as eluent, yielding the tetracarbonylic carbene **4** as a yellow-orange oil.

Pentacarbonyl[((4*R,5*S**)-4,5-dihydro-4-phenyl-5-trimethylsilyl-1*H*-pyrazol-3-yl)-((1*R**,2*S**,5*R**)-menthyloxy)methylidene]chromium(0)** (**2a**): Yield = 46% (3:1 mixture of diastereomers); $R_f = 0.30$ (hexane/ethyl acetate 20:1); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.67$ (br s, 1H; NH, maj), 7.60 (br s, 1H; NH, min), 7.29–7.19 (m, 3H; 3 CH), 7.03–6.98 (m, 2H; 2 CH), 4.84 (m, 1H; CH), 4.16–4.09 (m, 1H; CH), 3.55–3.46 (m, 1H; CH), 2.14–2.08 (m, 1H; CH), 1.74–0.37 (m, 17H), 0.12 (s, 9H; 3 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 309.4$ (s), 224.7 (s), 218.0 (s), 160.8 (s), 144.9 (s, min), 144.2 (s, maj), 128.9 (d, maj), 128.6 (d, min), 126.8 (d), 126.6 (d), 126.4 (d), 126.1 (d, maj), 90.1 (d, min), 89.7 (d, maj), 66.6 (d, maj), 65.6 (d, min), 50.8 (d, min), 49.7 (d, maj), 48.2 (d, min), 47.9 (d, maj), 43.5 (t, maj), 41.5 (t, min), 34.0 (t, maj), 33.9 (t, min), 30.8 (d, maj), 30.3 (d, min), 27.3 (d, min), 24.7 (t, min), 24.5 (d, maj), 22.7 (t, maj), 22.2 (q, min), 21.9 (q, maj), 21.7 (q, min), 18.1 (q, min), 16.0 (q, maj), −4.5 (q, maj), −4.6 (q, min); FT-IR (neat): $\tilde{\nu} = 3418$ (NH), 2050 (C≡O), 1931 (C=O), 1402 cm^{-1}; MS (EI, 70 eV): m/z (%) = 576 (<5) [M^+], 436 (<5), 95 (60), 44 (100); anal. calcd for $C_{28}H_{36}CrN_2O_6Si$: C 58.32, H 6.29, N 4.86; found C 58.41, H 6.27, N 4.87.

Pentacarbonyl[((4*S,5*S**)-4-(2-furyl)-4,5-dihydro-5-trimethylsilyl-1*H*-pyrazol-3-yl)-((1*R**,2*S**,5*R**)-menthyloxy)methylidene]chromium(0)** (**2b**): Yield = 38% (2:1 mixture of diastereomers); $R_f = 0.43$ (hexane/ethyl acetate 9/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.50$ (br s, 1H; NH), 7.27 (m, 1H; CH), 6.27 (m, 1H; CH), 5.91 (m, 1H; CH), 4.94 (m, 1H; CH), 4.25 (m, 1H; CH), 3.57 (m, 1H; CH), 2.26-0.63 (m, 18H), 0.10 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): $\delta = 311.3$ (s), 224.7 (s), 217.9 (s), 157.9 (s), 155.6 (s, min), 155.4 (s, maj), 141.2 (d, maj), 140.8 (d, min), 110.5 (d), 105.0 (d, min), 104.8 (d, maj), 90.5 (d, min), 89.9 (d, maj), 63.3 (d, maj), 62.4 (d, min), 48.2 (d, min), 48.0 (d, maj), 43.7 (d, min), 43.4 (t, maj), 42.9 (d, maj), 42.2 (t, min), 34.1 (t, min), 34.0 (t, maj), 30.8 (d, maj), 30.6 (d, min), 27.2 (d, min), 24.6 (d, maj), 22.9 (t), 22.1 (q, min), 22.0 (q, maj), 21.9 (q, maj), 21.8 (q, min), 18.0 (q, min), 16.3 (q, maj), −4.4 (q, min), −4.5 (q, maj); FT-IR (neat): $\tilde{\nu} = 3414$ (NH), 2060 (C≡O), 1933 (C=O), 1640 cm^{-1}; MS (EI, 70 eV): m/z (%) = 566 (<5) [M^+], 426 (<5), 119 (78), 49 (100); anal. calcd for $C_{26}H_{34}CrN_2O_7Si$: C 55.11, H 6.05, N 4.94; found C 55.19, H 6.03, N 4.96.

Pentacarbonyl[((4*R,5*S**)-4,5-dihydro-4-(4-methoxyphenyl)-5-trimethylsilyl-1*H*-pyrazol-3-yl)-((1*R**,2*S**,5*R**)-menthyloxy)methylidene]chromium(0)** (**2c**): Yield = 40% (2:1 mixture of diastereomers); $R_f = 0.41$ (hexane/ethyl acetate 9/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.54$ (br s, 1H; NH), 6.95-6.81 (m, 4H; 4 CH), 4.83 (m, 1H; CH), 4.08 (m, 1H; CH), 3.78 (s, 3H; CH_3), 3.41 (m, 1H; CH), 2.29–0.41 (m, 18H), 0.10 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): $\delta = 310.3$ (s, min), 310.1 (s, maj), 224.7 (s), 218.1 (s), 161.4 (s, min), 161.1 (s, maj), 158.4 (s, min), 158.3 (s, maj), 137.3 (s, min), 136.6 (s, maj), 127.8 (d, min), 127.3 (d, maj), 114.3 (d, maj), 114.0 (d, min), 90.1 (d, min), 89.9 (d, maj), 66.6 (d, maj), 65.6 (d, min), 55.3 (q, min), 55.2 (q, maj), 50.0 (d, min), 49.1 (d, maj), 48.3 (d, min), 48.0 (d, maj), 43.5 (t, maj), 41.7 (t, min), 34.0 (t), 30.8 (d, maj), 30.4 (d, min), 27.3 (d, min), 24.8 (t, min), 24.5 (d, maj), 23.0 (t, maj), 22.7 (q, maj), 22.2 (q, min), 21.9 (q, min), 21.8 (q, maj), 18.2 (q, min), 16.1 (q, maj), −4.4 (q, min), −4.5 (q, maj); FT-IR (neat): $\tilde{\nu} = 3420$ (NH), 3364 (NH), 2050 (C≡O), 1925 (C=O), 1611, 1512, 1404 cm^{-1}; anal. calcd for $C_{29}H_{38}CrN_2O_7Si$: C 57.41, H 6.31, N 4.62; found C 57.58, H 6.33, N 4.61.

Tetracarbonyl[(4,5-dihydro-5-methyl-1*H*-pyrazol-5-yl)-((1*R,2*S**,5*R**)-menthyloxy)methylidene]chromium(0)** (**4**): Yield = 72% (1:1 mixture of diastereomers); $R_f = 0.44$ (hexane/ethyl acetate 3/1); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS, both diastereomers): $\delta = 7.18$ (br s, 1H; NH), 5.59 (br s, 1H; CH), 4.98 (m, 1H; CH), 2.98–2.86 (m, 1H; CH_2), 2.69–2.59 (m, 1H;

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CH_2), 2.37–2.31 (m, 1H), 1.93–0.91 (m, 20H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C, both diastereomers): δ = 342.0 (s), 341.8 (s), 232.1 (s), 231.1 (s), 220.5 (s), 220.1 (s), 219.7 (s), 219.2 (s), 152.8 (d), 152.7 (d), 91.5 (d), 91.3 (d), 87.7 (s), 47.2 (d), 46.0 (t), 45.9 (t), 40.7 (t), 40.6 (t), 33.9 (t), 31.3 (d), 26.1 (d), 26.0 (d), 23.0 (t), 22.9 (t), 22.1 (q), 21.2 (q), 21.1 (q), 20.7 (q), 15.84 (q), 15.8 (q); FT-IR (neat): $\tilde{\nu}$ = 3169, 2016, 1919, 1852, 1304 cm^{-1}; MS (EI, 70 eV): *m/z* (%) = 414 (7) [M^+], 386 (12), 302 (100), 83 (81); anal. calcd for $C_{19}H_{26}CrN_2O_5$: C 55.07, H 6.32, N 6.76; found C 54.94, H 6.34, N 6.78.

Pentacarbonyl[((4*R*,5*S*)-4,5-dihydro-4-phenyl-5-trimethylsilyl-1*H*-pyrazol-3-yl)-((1*R*,2*S*,5*R*)-8-phenylmenthyloxy)methylidene]chromium(0) (**7b**): Yield = 52% (dr > 95/5); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.68 (br s, 1H; NH), 7.37–7.05 (m, 10H; 10 CH), 5.32 (m, 1H; CH), 4.20 (d, ^3J(H,H) = 5.4 Hz, 1H; CH), 3.54 (d, ^3J(H,H) = 5.4 Hz, 1H; CH), 2.08-1.95 (m, 2H), 1.53–1.49 (m, 2H), 1.29 (s, 6H; 2 CH_3), 1.43-0.71 (m, 4H), 0.90 (d, ^3J(H,H) = 6.5 Hz, 3H; CH_3), 0.15 (s, 9H; 3 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 309.5 (s), 224.6 (s), 218.1 (s), 161.1 (s), 150.7 (s), 144.6 (s), 129.3 (d), 127.6 (d), 127.1 (d), 126.4 (d), 125.8 (d), 125.2 (d), 90.0 (d), 67.8 (d), 50.7 (d), 49.6 (d), 45.8 (t), 40.8 (s), 33.9 (t), 30.6 (d), 29.7 (q), 26.5 (t), 21.8 (q), 20.8 (q), −4.6 (q); FT-IR (neat): $\tilde{\nu}$ = 3400 (NH), 2050 (C≡O), 1917 (C≡O) cm^{-1}; anal. calcd for $C_{34}H_{40}CrN_2O_6Si$: C 62.56, H 6.18, N 4.29; found C 62.63, H 6.17, N 4.30.

Pentacarbonyl[((4*S*,5*R*)-4,5-dihydro-4,5-diphenyl-1*H*-pyrazol-3-yl)-((1*R*,-2*S*,5*R*)-8-phenylmenthyloxy)methylidene]chromium (0) (**7c**): Yield = 40% (dr > 95/5); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.93 (br s, 1H; NH), 7.43–7.01 (m, 15H; 15 CH), 5.40 (m, 1H; CH), 4.82 (d, ^3J(H,H) = 4.1 Hz, 1H; CH), 4.17 (d, ^3J(H,H) = 4.1 Hz, 1H; CH), 2.32–0.65 (m, 8H), 1.30 (s, 6H; 2 CH_3), 0.87 (d, ^3J(H,H) = 6.5 Hz, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 316.5 (s), 224.6 (s), 217.9 (s), 160.3 (s), 150.5 (s), 142.1 (s), 141.0 (s), 129.42 (d), 129.37 (d), 128.9 (d), 128.5 (d), 127.6 (d), 127.5 (d), 126.8 (d), 125.7 (d), 125.3 (d), 91.1 (d), 77.0 (d), 57.5 (d), 50.6 (d), 45.2 (t), 40.7 (s), 33.8 (t), 30.6 (d), 29.8 (q), 26.5 (t), 21.7 (q), 20.8 (q); anal. calcd for $C_{37}H_{36}CrN_2O_6$: C 67.67, H 5.52, N 4.27; found C 67.82, H 5.54, N 4.28.

Pentacarbonyl[((4*S*,5*S*)-4,5-dihydro-4-phenyl-5-vinyl-1*H*-pyrazol-3-yl)-((1*R*,2*S*,5*R*)-8-phenylmenthyloxy)methylidene]chromium(0) (**7d**): Yield = 47% (dr > 95/5); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.43–7.04 (m, 11H; 10 CH + NH), 5.92 (m, 1H; CH), 5.43 (m, 1H; CH), 5.28–5.22 (m, 2H; CH_2), 4.28 (dd, ^3J(H,H) = 7.8 and 3.5 Hz, 1H; CH), 3.99 (d, ^3J(H,H) = 3.5 Hz, 1H; CH), 2.34–0.67 (m, 8H), 1.32 (s, 6H; 2 CH_3), 0.94 (d, ^3J(H,H) = 6.0 Hz, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 318.3 (s), 224.6 (s), 217.7 (s), 161.6 (s), 150.5 (s), 140.9 (s), 135.4 (d), 129.3 (d), 127.6 (d), 127.5 (d), 126.9 (d), 125.7 (d), 125.3 (d), 117.1 (t), 91.3 (d), 75.4 (d), 54.7 (d), 50.8 (d), 45.3 (t), 40.8 (s), 33.9 (t), 30.7 (d), 29.9 (q), 26.5 (t), 21.8 (q), 20.8 (q); FT-IR (neat): $\tilde{\nu}$ = 2052 (C≡O), 1927 (C≡O), 1713 cm^{-1}; anal. calcd for $C_{33}H_{34}CrN_2O_6$: C 65.34, H 5.65, N 4.62; found C 65.52, H 5.63, N 4.63.

Pentacarbonyl[((4*S*,5*S*)-4-(2-furyl)-4,5-dihydro-5-trimethylsilyl-1*H*-pyrazol-3-yl)-((1*R*,2*S*,5*R*)-8-phenylmenthyloxy)methylidene]chromium(0) (**7e**): Yield = 53% (dr > 95/5); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.64 (br s, 1H; NH), 7.31–7.19 (m, 6H; 6 CH), 6.28 (m, 1H; CH), 6.04 (d, ^3J(H,H) = 3.0 Hz, 1H; CH), 5.38 (m, 1H; CH), 4.35 (d, ^3J(H,H) = 6.7 Hz, 1H; CH), 3.64 (d, ^3J(H,H) = 6.7 Hz, 1H; CH), 2.31–2.05 (m, 4H), 1.64–0.72 (m, 4H), 1.37 (s, 3H; CH_3), 0.90 (d, ^3J(H,H) = 6.0 Hz, 3H; CH_3), 0.55 (s, 3H; CH_3), 0.14 (s, 9H; 3 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 309.5 (s), 224.6 (s), 218.0 (s), 158.1 (s), 155.7 (s), 150.9 (s), 141.3 (d), 127.8 (d), 125.7 (d), 125.3 (d), 110.9 (d), 105.3 (d), 90.3 (d), 64.6 (d), 51.0 (d), 45.6 (t), 42.6 (d), 41.0 (s), 34.0 (t), 30.7 (d), 30.3 (q), 26.7 (t), 21.7 (q), 20.9 (q), −4.5 (q); FT-IR (neat): $\tilde{\nu}$ = 3415 (NH), 2050 (C≡O), 1921 (C≡O), 1607, 1402 cm^{-1}; anal. calcd for $C_{32}H_{38}CrN_2O_7Si$: C 59.80, H 5.96, N 4.36; found C 59.88, H 5.98, N 4.37.

Pentacarbonyl[((4*S*,5*R*)-4-(2-furyl)-4,5-dihydro-5-phenyl-1*H*-pyrazol-3-yl)-((1*R*,2*S*,5*R*)-8-phenylmenthyloxy)methylidene]chromium(0) (**7f**): Yield = 42% (dr > 95/5); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.74 (br s, 1H; NH), 7.44–7.04 (m, 11H; 11 CH), 6.21 (m, 1H; CH), 6.03 (m, 1H; CH), 5.32 (m, 1H; CH), 4.80 (d, ^3J(H,H) = 4.5 Hz, 1H; CH), 4.25 (d, ^3J(H,H) = 4.5 Hz, 1H; CH), 2.02-0.55 (m, 8H), 1.25 (s, 3H; CH_3), 0.74 (d, ^3J(H,H) = 6.5 Hz, 3H; CH_3), 0.43 (s, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 317.4 (s), 224.6 (s), 217.7 (s), 157.2 (s), 153.4 (s), 150.6 (s), 141.9 (d), 140.2 (s), 129.34 (d), 129.3 (d), 128.5 (d), 127.8 (d), 125.6 (d), 125.4 (d), 110.9 (d), 106.1 (d), 91.2 (d), 73.9 (d), 50.9 (d), 50.2 (d), 45.1 (t), 40.9 (s), 33.8 (t), 30.6 (d), 30.2 (q), 26.7 (t), 21.7 (q), 20.9 (q); FT-IR (neat): $\tilde{\nu}$ = 3410 (NH), 2052 (C=O), 1927 (C=O), 1630 cm^{-1}; anal. calcd for $C_{35}H_{34}CrN_2O_7$: C 65.01, H 5.30, N 4.33; found C 64.88, H 5.31, N 4.31.

Pentacarbonyl[((4*S*,5*S*)-4-(2-furyl)-4,5-dihydro-5-vinyl-1*H*-pyrazol-3-yl)-((1*R*,2*S*,5*R*)-8-phenylmenthyloxy)methylidene]chromium(0) (**7g**): Yield = 50% (dr > 95/5); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.32–7.21 (m, 7H; NH + 6 CH), 6.31 (br s, 1H; CH), 6.14 (br s, 1H; CH), 5.92–5.79 (m, 1H; CH), 5.45 (m, 1H; CH), 5.28–5.24 (m, 2H; CH_2), 4.40 (br s, 1H; CH), 4.22 (br s, 1H; CH), 2.32–0.80 (m, 8H), 1.38 (s, 3H; CH_3), 0.92 (d, ^3J(H,H) = 6.0 Hz, 3H; CH_3), 0.56 (s, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 318.1 (s), 224.6 (s), 217.5 (s), 158.5 (s), 152.6 (s), 150.6 (s), 141.7 (d), 134.6 (d), 127.8 (d), 125.6 (d), 125.4 (d), 117.7 (t), 110.9 (d), 106.1 (d), 91.2 (d), 72.6 (d), 51.1 (d), 47.2 (d), 45.2 (t), 40.9 (s), 33.9 (t), 30.7 (d), 30.2 (q), 26.7 (t), 21.7 (q), 20.9 (q); FT-IR (neat): $\tilde{\nu}$ = 3402 (NH), 2054 (C≡O), 1927 (C≡O), 1599, 1422 cm^{-1}; anal. calcd for $C_{31}H_{32}CrN_2O_7$: C 62.41, H 5.41, N 4.70; found C 62.57, H 5.42, N 4.69.

General procedure for the protection of cycloadducts 7 with $(Boc)_2O$: A solution of the corresponding cycloadduct **7** (1 mmol) in CH_2Cl_2 (5 mL) was cooled to −78 °C, and $(Boc)_2O$ (0.45 g, 2 mmol), NEt_3 (0.14 mL, 1 mmol), and DMAP (0.12 g, 1 mmol) successively added. The resulting mixture was stirred at this temperature for 1–2 h, till TLC analysis showed complete disappearance of the starting material. Then, the solvent was removed under reduced pressure and the oily residue purified by flash column chromatography on deactivated silica gel with hexane/ethyl acetate 50/1 as eluent. Thus, oxidation of carbenes **8** to esters **9** was partially prevented and it was possible to isolate *N*-protected cycloadducts **8**, as violet syrups, in reasonable yields.

[((4*S*,5*R*)-1-*tert*-Butoxycarbonyl-4,5-dihydro-4-phenyl-5-trimethylsilyl-1-*H*-pyrazol-3-yl)-((1*R*,2*S*,5*R*)-8-phenylmenthyloxy)methylidene]pentacarbonylchromium(0) (**8b**): Violet syrup over 17 °C; we were able to crystallize it in hexane at −30 °C. Yield = 60%; ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.52–6.89 (m, 10H; 10 CH), 5.51 (m, 1H; CH), 4.16 (m, 1H; CH), 3.90 (m, 1H; CH), 2.62–0.25 (m, 17H), 1.62 (br s, 9H; 3 CH_3), 0.17 (br s, 9H; 3 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 325.1 (s), 225.2 (s), 217.1 (s), 162.8 (s), 151.4 (s), 150.3 (s), 142.8 (s), 129.5 (d), 127.7 (d), 127.5 (d), 126.4 (d), 125.7 (d), 125.4 (d), 92.1 (d), 82.7 (s), 64.2 (d), 51.4 (d), 50.7 (d), 45.1 (t), 40.8 (s), 33.8 (t), 30.6 (d), 29.8 (q), 28.1 (q), 26.5 (t), 21.7 (q), 20.9 (q), −2.9 (q); anal. calcd for $C_{39}H_{48}CrN_2O_8Si$: C 62.22, H 6.43, N 3.72; found C 62.01, H 6.54, N 3.69.

[((4*S*,5*R*)-1-*tert*-Butoxycarbonyl-4,5-dihydro-4,5-diphenyl-1*H*-pyrazol-3-yl)-((1*R*,2*S*,5*R*)-8-phenylmenthyloxy)methylidene]pentacarbonylchromium(0) (**8c**): Yield = 61%; ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.26–6.75 (m, 15H; 15 CH), 5.30 (m, 1H; CH), 4.93 (d, ^3J(H,H) = 3.5 Hz, 1H; CH), 3.90 (d, ^3J(H,H) = 3.5 Hz, 1H; CH), 2.09–0.42 (m, 11H; 2 CH + 3 CH_2 + CH_3), 1.23 (br s, 9H; 3 CH_3), 1.08 (s, 6H; 2 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 327.1 (s), 225.0 (s), 217.0 (s), 161.7 (s), 150.1 (s), 140.7 (s), 129.6 (d), 129.2 (d), 128.0 (d), 127.9 (d), 127.7 (d), 126.8 (d), 125.6 (d), 125.4 (d), 124.7 (d), 92.6 (d), 82.9 (s), 74.9 (d), 59.5 (d), 50.5 (d), 44.7 (t), 40.7 (s), 33.7 (t), 30.6 (d), 30.0 (q), 27.9 (q), 26.5 (t), 21.6 (q), 20.9 (q); the signals corresponding to two C (s) around δ = 140–150 were not observed; anal. calcd for $C_{42}H_{44}CrN_2O_8$: C 66.66, H 5.86, N 3.70; found C 66.51, H 5.84, N 3.69.

[((4*S*,5*S*)-1-*tert*-Butoxycarbonyl-4,5-dihydro-4-phenyl-5-vinyl-1*H*-pyrazol-3-yl)-((1*R*,2*S*,5*R*)-8-phenylmenthyloxy)methylidene]pentacarbonylchromium(0) (**8d**): Yield = 69%; ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.42–6.97 (m, 10H; 10 CH), 5.95–5.83 (m, 1H; CH), 5.50 (m, 1H; CH), 5.28–5.20 (m, 2H; CH_2), 4.65 (m, 1H; CH), 3.94 (d, ^3J(H,H) = 3.0 Hz, 1H; CH), 2.32–0.78 (m, 8H), 1.59 (s, 9H; 3 CH_3), 1.29 (s, 6H; 2 CH_3), 0.92 (d, ^3J(H,H) = 6.4 Hz, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 327.4 (s), 225.1 (s), 216.8 (s), 162.6 (s), 150.1 (s), 139.7 (s), 134.1 (d), 129.5 (d), 127.8 (d), 127.7 (d), 126.9 (d), 125.6 (d), 125.4 (d), 116.6 (t), 92.5 (d), 82.9 (s), 72.6 (d), 56.5 (d), 50.7 (d), 44.8 (t), 40.7 (s), 33.8 (t), 30.6 (d), 30.1 (q), 28.1 (q), 26.5 (t), 21.7 (q), 20.9 (q); the signal corresponding to one C (s) around δ = 145–150 was not observed; anal. calcd for $C_{38}H_{42}CrN_2O_8$: C 64.58, H 5.99, N 3.96; found C 64.73, H 6.01, N 3.97.

[((4*S*,5*S*)-1-*tert*-Butoxycarbonyl-4-(2-furyl)-4,5-dihydro-5-vinyl-1*H*-pyrazol-3-yl)-((1*R*,2*S*,5*R*)-8-phenylmenthyloxy)methylidene]pentacarbonylchromium(0) (**8g**): Yield = 72%; ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.32–7.17 (m, 6H; 6 CH), 6.34 (m, 1H; CH), 6.15 (d, ^3J(H,H) = 3.0 Hz, 1H; CH), 5.91–5.80 (m, 1H; CH), 5.54 (m, 1H; CH), 5.29–5.22 (m, 2H; CH_2), 4.77 (m, 1H; CH), 4.18 (d, ^3J(H,H) = 3.4 Hz, 1H; CH), 2.30–0.75

(m, 8H), 1.58 (s, 9H; 3 CH_3), 1.35 (s, 3H; CH_3), 0.91 (d, ^3J(H,H) = 6.0 Hz, 3H; CH_3), 0.57 (s, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 327.6 (s), 225.0 (s), 216.7 (s), 159.7 (s), 151.4 (s), 150.3 (s), 142.2 (d), 133.7 (d), 127.9 (d), 125.6 (d), 125.5 (d), 117.1 (t), 111.0 (d), 106.7 (d), 92.5 (d), 82.9 (s), 69.8 (d), 51.1 (d), 49.1 (d), 44.8 (t), 40.9 (s), 33.9 (t), 30.7 (d), 30.4 (q), 28.1 (q), 26.8 (t), 21.7 (q), 21.0 (q); the signal corresponding to one C (s) around δ = 144 was not observed; FT-IR (neat): $\tilde{\nu}$ = 2060 (C≡O), 1942 (C≡O), 1599 cm^{-1}; anal. calcd for $C_{36}H_{40}CrN_2O_9$: C 62.06, H 5.79, N 4.02; found C 61.88, H 5.77, N 4.03.

General procedure for the oxidation of cycloadducts 8 to the corresponding esters 9 with pyridine *N*-oxide: Pyridine *N*-oxide (PNO, 0.19 g, 2 mmol) was added at RT to a solution of carbene complex **8** (1 mmol) in THF (10 mL), and the resulting mixture stirred for 12–24 h, till TLC analysis showed complete disappearance of the starting complex. The solvent was then removed at reduced pressure and the organic residue, once redissolved in hexane/ethyl acetate 3/1 (20 mL), was exposed to sunlight until the organic layer turned completely colorless. The solution was then filtered through Celite and the solvents were removed under vacuum. The oily residue was purified by flash chromatography on silica gel, with hexane/ethyl acetate 50/1, 20/1, and 9/1 as eluent, yielding the corresponding esters **9** as colorless syrups.

(−)-(1*R*,2*S*,5*R*)-8-Phenylmenthyl 3-((4*R*,5*S*)-1-*tert*-butoxycarbonyl-4,5-dihydro-4-phenyl-5-trimethylsilyl-1*H*-pyrazole)carboxylate (9b): Yield = 75%; $[\alpha]_D^{25}$ = −16.0 (c = 1.04 in $CHCl_3$); R_f = 0.55 (hexane/ethyl acetate 9/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.39–7.22 (m, 10H; 10 CH), 4.84 (m, 1H; CH), 4.37 (d, ^3J(H,H) = 6.0 Hz, 1H; CH), 3.93 (d, ^3J(H,H) = 6.0 Hz, 1H; CH), 2.36–0.79 (m, 8H), 1.59 (s, 9H; 3 CH_3), 1.31 (s, 3H; CH_3), 1.23 (s, 3H; CH_3), 0.81 (d, ^3J(H,H) = 6.1 Hz, 3H; CH_3), 0.20 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 161.1 (s), 151.5 (s), 149.9 (s), 147.9 (s), 141.5 (s), 128.9 (d), 127.8 (d), 127.4 (d), 127.0 (d), 125.7 (d), 125.2 (d), 82.2 (s), 76.5 (d), 60.9 (d), 52.7 (d), 50.3 (d), 41.4 (t), 40.2 (s), 34.2 (t), 31.2 (d), 30.5 (q), 28.1 (q), 27.1 (t), 23.1 (q), 21.5 (q), −2.9 (q); FT-IR (neat): $\tilde{\nu}$ = 1703 (C≡O) cm^{-1}; MS (EI, 70 eV): m/z (%) = 576 (<5) [M^+], 561 (<5), 235 (95), 191 (82), 163 (100); HRMS for $C_{33}H_{45}N_2O_4Si$ [M − 15]: calcd 561.3149; found 561.3148; anal. calcd for $C_{34}H_{48}N_2O_4Si$: C 70.79, H 8.39, N 4.86; found C 70.86, H 8.41, N 4.84.

(−)-(1*R*,2*S*,5*R*)-8-Phenylmenthyl 3-((4*S*,5*R*)-1-*tert*-butoxycarbonyl-4,5-dihydro-4,5-diphenyl-1*H*-pyrazole)carboxylate (9c): Yield = 83%; $[\alpha]_D^{25}$ = −204.0 (c = 0.97 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.39–7.14 (m, 15H; 15 CH), 5.17 (m, 1H; CH), 4.84 (m, 1H; CH), 4.32 (d, ^3J(H,H) = 4.7 Hz, 1H; CH), 1.96–0.58 (m, 8H), 1.33 (br s, 9H; 3 CH_3), 1.29 (s, 3H; CH_3), 1.23 (s, 3H; CH_3), 0.79 (d, ^3J(H,H) = 6.4 Hz, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 160.9 (s), 150.8 (s), 150.0 (s), 146.9 (s), 141.2 (s), 139.4 (s), 129.2 (d), 129.0 (d), 128.0 (d), 127.8 (d), 127.1 (d), 125.7 (d), 125.3 (d), 124.9 (d), 82.4 (s), 76.5 (d), 72.8 (d), 60.6 (d), 50.3 (d), 41.5 (t), 40.2 (s), 34.2 (t), 31.2 (d), 29.7 (q), 27.8 (q), 27.1 (t), 24.1 (q), 21.6 (q); MS (EI, 70 eV): m/z (%) = 580 (<5) [M^+], 480 (28), 266 (100), 119 (78); HRMS for $C_{37}H_{44}N_2O_4$: calcd 580.3301; found 580.3309; anal. calcd for $C_{37}H_{44}N_2O_4$: C 76.52, H 7.64, N 4.82; found C 76.65, H 7.62, N 4.83.

(−)-(1*R*,2*S*,5*R*)-8-Phenylmenthyl 3-((4*S*,5*S*)-1-*tert*-butoxycarbonyl-4,5-dihydro-4-phenyl-5-vinyl-1*H*-pyrazole)carboxylate (9d): Yield = 86%; $[\alpha]_D^{25}$ = −103.5 (c = 0.95 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.36-7.13 (m, 10H; 10 CH), 5.99–5.87 (m, 1H; CH), 5.28–5.17 (m, 2H; CH_2), 4.85 (m, 1H; CH), 4.66 (m, 1H; CH), 4.16 (d, ^3J(H,H) = 4.7 Hz, 1H; CH), 1.99–0.70 (m, 8H), 1.54 (s, 9H; 3 CH_3), 1.26 (s, 3H; CH_3), 1.21 (s, 3H; CH_3), 0.81 (d, ^3J(H,H) = 6.5 Hz, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 160.8 (s), 150.8 (s), 150.1 (s), 147.0 (s), 138.8 (s), 135.0 (d), 129.0 (d), 127.8 (d), 127.1 (d), 125.6 (d), 125.1 (d), 116.6 (t), 82.4 (s), 76.3 (d), 71.0 (d), 57.3 (d), 50.2 (d), 41.4 (t), 40.0 (s), 34.2 (t), 31.2 (d), 28.8 (d), 28.0 (q), 27.0 (t), 24.6 (q), 21.6 (q); MS (EI, 70 eV): m/z (%) = 530 (<5) [M^+], 430 (16), 261 (45), 216 (80), 119 (100); HRMS for $C_{33}H_{42}N_2O_4$: calcd 530.3145; found 530.3177; anal. calcd for $C_{33}H_{42}N_2O_4$: C 74.69, H 7.98, N 5.28; found C 74.78, H 7.99, N 5.27.

(−)-(1*R*,2*S*,5*R*)-8-Phenylmenthyl 3-((4*S*,5*R*)-1-*tert*-butoxycarbonyl-4-(2-furyl)-4,5-dihydro-5-phenyl-1*H*-pyrazol-3-yl)carboxylate (9f): Yield = 79%; $[\alpha]_D^{25}$ = −132.4 (c = 0.82 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.35–7.06 (m, 11H; 11 CH), 6.28 (dd, ^3J(H,H) = 3.0 and 1.7 Hz, 1H; CH), 6.09 (d, ^3J(H,H) = 3.0 Hz, 1H; CH), 5.22 (d, ^3J(H,H) = 5.6 Hz, 1H; CH), 4.79 (m, 1H; CH), 4.39 (d, ^3J(H,H) = 5.6 Hz, 1H; CH), 2.21–0.66 (m, 23H), 0.75 (d, ^3J(H,H) = 6.5 Hz, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 160.7 (s), 150.7 (s), 150.0 (s), 143.6 (s), 142.5 (d), 140.6 (s), 128.9 (d), 128.6 (d), 127.8 (d), 125.7 (d), 125.3 (d), 125.0 (d), 110.7 (d), 107.1 (d), 82.5 (s), 76.7 (d), 69.6 (d), 53.8 (d), 50.3 (d), 41.4 (t), 40.2 (s), 34.3 (t), 31.3 (d), 29.5 (q), 27.8 (q), 27.1 (t), 24.4 (q), 21.6 (q); the signal corresponding to one C (s) around δ = 150 was not observed; MS (EI, 70 eV): m/z (%) = 570 (<5) [M^+], 470 (50), 301 (60), 256 (100); HRMS for $C_{35}H_{42}N_2O_5$: calcd 570.3094; found 570.3101; anal. calcd for $C_{35}H_{42}N_2O_5$: C 73.66, H 7.42, N 4.91; found C 73.71, H 7.44, N 4.93.

(−)-(1*R*,2*S*,5*R*)-8-Phenylmenthyl 3-((4*S*,5*S*)-1-*tert*-butoxycarbonyl-4-(2-furyl)-4,5-dihydro-5-vinyl-1*H*-pyrazole)carboxylate (9g): Yield = 87%; $[\alpha]_D^{25}$ = −61.9 (c = 1.18 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.26 (d, ^3J(H,H) = 1.7 Hz, 1H; CH), 7.19–6.93 (m, 5H; 5 CH), 6.24 (dd, ^3J(H,H) = 3.4 and 1.7 Hz, 1H; CH), 6.08 (d, ^3J(H,H) = 3.4 Hz, 1H; CH), 5.88–5.76 (m, 1H; CH), 5.21–5.13 (m, 2H; CH_2), 4.80 (m, 1H; CH), 4.70 (m, 1H; CH), 4.23 (d, ^3J(H,H) = 5.2 Hz, 1H; CH), 2.21–0.68 (m, 8H), 1.45 (s, 9H; 3 CH_3), 1.22 (s, 3H; CH_3), 1.20 (s, 3H; CH_3), 0.75 (d, ^3J(H,H) = 6.5 Hz, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 160.7 (s), 150.8 (s), 150.4 (s), 150.2 (s), 143.9 (s), 142.4 (d), 134.6 (d), 127.8 (d), 125.7 (d), 125.2 (d), 117.0 (t), 110.7 (d), 107.0 (d), 82.5 (s), 76.5 (d), 68.0 (d), 50.5 (d), 50.3 (d), 41.4 (t), 40.1 (s), 34.3 (t), 31.3 (d), 28.7 (q), 28.1 (q), 27.0 (t), 24.9 (q), 21.6 (q); MS (EI, 70 eV): m/z (%) = 520 (<5) [M^+], 420 (16), 251 (24), 206 (92), 119 (100); HRMS for $C_{31}H_{40}N_2O_5$: calcd 520.2937; found 520.2960; anal. calcd for $C_{31}H_{40}N_2O_5$: C 71.51, H 7.74, N 5.38; found C 71.47, H 7.77, N 5.39.

General procedure for the one-pot synthesis of esters 9 from carbene complexes 6: The corresponding diazocompound (1.5–2 equiv) was added with a syringe to a solution of the carbene complex **6** (1 mmol) in THF (6 mL), and the resulting mixture stirred at RT (in the case of diazomethane at −78 °C) till TLC analysis showed complete disappearance of the starting complex. Then the reaction was cooled to −78 °C, and $(Boc)_2O$ (0.45 g, 2 mmol), NEt_3 (0.14 mL, 1 mmol), and DMAP (0.12 g, 1 mmol) were successively added. The resulting mixture was stirred at this temperature for 1–2 h, till TLC analysis showed complete disappearance of complex **7**. Pyridine *N*-oxide (0.19 g, 2 mmol) was added to the violet solution of carbene complex **8** and the resulting mixture allowed to warm to RT and stirred for an additional 12–24 h, till TLC analysis showed complete disappearance of carbene complex **8**. The solvent was removed at reduced pressure and the organic residue, once redissolved in hexane/ethyl acetate 3/1 (20 mL), exposed to sunlight until the organic layer turned completely colorless. The solution was then filtered through Celite and the solvents were removed under vacuum. The oily residue was purified by flash chromatography on silica gel, with hexane/ethyl acetate 50/1, 20/1, and 9/1 as eluents, yielding the corresponding esters **9**, greatly improving the overall yield respect to the stepwise procedure.

(−)-(1*R*,2*S*,5*R*)-8-Phenylmenthyl 3-((4*S*)-1-*tert*-butoxycarbonyl-4,5-dihydro-4-phenyl-1*H*-pyrazole)carboxylate (9a): White solid; m.p. = 157–161 °C (hexane); yield = 79% (dr > 95/5); $[\alpha]_D^{25}$ = −133.0 (c = 0.99 in $CHCl_3$); R_f = 0.22 (hexane/ethyl acetate 9/1); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.33–7.09 (m, 10H; 10 CH), 4.86 (m, 1H; CH), 4.47 (dd, ^2J(H,H) = 11.7 Hz, ^3J(H,H) = 5.3 Hz, 1H; CH_2), 4.31 (dd, ^2J(H,H) = 11.7 Hz, ^3J(H,H) = 10.8 Hz, 1H; CH_2), 3.94 (dd, ^3J(H,H) = 10.8 and 5.3 Hz, 1H; CH), 2.11–0.72 (m, 8H), 1.57 (s, 9H; 3 CH_3), 1.26 (s, 3H; CH_3), 1.24 (s, 3H; CH_3), 0.80 (d, ^3J(H,H) = 5.8 Hz, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 160.7 (s), 151.4 (s), 150.4 (s), 148.3 (s), 139.8 (s), 128.9 (d), 127.8 (d), 127.6 (d), 127.1 (d), 125.6 (d), 124.9 (d), 82.4 (s), 75.9 (d), 56.1 (t), 50.2 (d), 49.7 (d), 41.4 (t), 40.0 (s), 34.2 (t), 31.2 (d), 28.1 (q), 26.9 (t), 25.2 (q), 21.6 (q); the signal corresponding to one C (q) around δ = 30 was not observed; FT-IR (film): $\tilde{\nu}$ = 1742 (C≡O), 1705 (C≡O), 1148 cm^{-1}; MS (EI, 70 eV): m/z (%) = 504 (<5) [M^+], 190 (80), 119 (100); HRMS for $C_{31}H_{40}N_2O_4$: calcd 504.2988; found 504.2984; anal. calcd for $C_{31}H_{40}N_2O_4$: C 73.78, H 7.99, N 5.55; found C 73.85, H 8.01, N 5.56.

(+)-(1*R*,2*S*,5*R*)-8-Phenylmenthyl 3-((4*S*,5*S*)-1-*tert*-butoxycarbonyl-4-(2-furyl)-4,5-dihydro-5-trimethylsilyl-1*H*-pyrazole)carboxylate (9e): Colorless syrup; yield = 55% (dr > 95/5); $[\alpha]_D^{25}$ = +6.3 (c = 1.05 in $CHCl_3$); R_f = 0.61 (hexane/ethyl acetate 9/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.33–7.17 (m, 6H; 6 CH), 6.32 (dd, ^3J(H,H) = 3.0 and 1.8 Hz, 1H; CH), 6.13 (d, ^3J(H,H) = 3.0 Hz, 1H; CH), 4.83 (m, 1H; CH), 4.49 (d, ^3J(H,H) = 7.5 Hz, 1H; CH), 3.95 (d, ^3J(H,H) = 7.5 Hz, 1H; CH), 2.01–0.81 (m, 8H), 1.56 (s, 9H; 3 CH_3), 1.31 (s, 6H; 2 CH_3), 0.83 (d, ^3J(H,H) = 6.2 Hz, 3H; CH_3), 0.17 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 161.1 (s), 152.6 (s), 151.6 (s), 150.0 (s), 144.7 (s), 142.0 (d), 127.8 (d), 125.8 (d),

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125.3 (d), 110.6 (d), 106.4 (d), 82.3 (s), 76.7 (d), 57.5 (d), 50.4 (d), 46.1 (d), 41.4 (t), 40.3 (s), 34.3 (t), 31.2 (d), 30.4 (q), 28.1 (q), 27.2 (t), 23.5 (q), 21.6 (q), −2.8 (q); FT-IR (neat): $\tilde{\nu}$ = 1703 (C=O), 1438 cm^{-1}; MS (EI, 70 eV): *m*/*z* (%) = 566 (<5) [M^+], 327 (46), 181 (96), 153 (100); HRMS for $C_{32}H_{46}N_2O_5Si$: calcd 566.3176; found 566.3176; anal. calcd for $C_{32}H_{46}N_2O_5Si$: C 67.81, H 8.18, N 4.94; found C 67.90, H 8.16, N 4.95.

(−)-(1*R*,2*S*,5*R*)-8-Phenylmenthyl 3-((4*S*)-1-*tert*-butoxycarbonyl-4-(2-furyl)-4,5-dihydro-1*H*-pyrazole)carboxylate (9h): White solid; m.p. = 49–51 °C (pentane); yield = 74% (dr = 92/8); $[\alpha]_D^{25} = -65.6$ (*c* = 1.31 in $CHCl_3$); R_f = 0.12 (hexane/ethyl acetate 9/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS, major diastereomer): δ = 7.33–7.08 (m, 6H; 6 CH), 6.32 (dd, ^3J(H,H) = 3.2 and 1.8 Hz, 1H; CH), 6.16 (d, ^3J(H,H) = 3.2 Hz, 1H; CH), 4.92 (m, 1H; CH), 4.60 (dd, ^2J(H,H) = 11.9 Hz, ^3J(H,H) = 6.8 Hz, 1H; CH_2), 4.17 (dd, ^2J(H,H) = 11.9 Hz, ^3J(H,H) = 11.3 Hz, 1H; CH_2), 4.04 (dd, ^3J(H,H) = 11.3 and 6.8 Hz, 1H; CH), 2.12–0.78 (m, 8H), 1.57 (s, 9H; 3 CH_3), 1.35 (s, 3H; CH_3), 1.27 (s, 3H; CH_3), 0.85 (d, ^3J(H,H) = 6.2 Hz, 3H; CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C, major diastereomer): δ = 160.5 (s), 151.0 (s), 150.3 (s), 144.9 (s), 142.0 (d), 127.7 (d), 125.5 (d), 124.8 (d), 110.5 (d), 106.7 (d), 82.3 (s), 75.9 (d), 52.8 (t), 50.2 (d), 42.9 (d), 41.3 (t), 39.9 (s), 34.2 (t), 31.1 (d), 28.0 (q), 27.7 (q), 26.8 (t), 25.4 (q), 21.5 (q); the signal corresponding to one C (s) around δ = 150 was not observed; FT-IR (film): $\tilde{\nu}$ = 1705 (C=O), 1152 cm^{-1}; MS (EI, 70 eV): *m*/*z* (%) = 494 (<5) [M^+], 438 (10), 180 (74), 119 (100); HRMS for $C_{29}H_{38}N_2O_5$: calcd 494.2781; found 494.2781; anal. calcd for $C_{29}H_{38}N_2O_5$: C 70.42, H 7.74, N 5.66; found C 70.55, H 7.72, N 5.67.

Synthesis of cycloadduct 9b starting from cinnamate 10: $TMSCHN_2$ (2.0 M in hexanes, 0.6 mL, 1.2 mmol) was added through a syringe to a solution of cinnamate **10** (0.36 g, 1 mmol) in THF (6 mL) and the resulting mixture stirred over 8 days at 67 °C, till TLC analysis showed complete disappearance of the dipolarophile. The reaction was then cooled to −78 °C and $(Boc)_2O$ (0.45 g, 2 mmol), NEt_3 (0.14 mL, 1 mmol), and DMAP (0.12 g, 1 mmol) were successively added. The solution was allowed to warm to RT and then stirred for 2 h. Solvents were then removed under vacuum and the oily residue purified by flash chromatography on silica gel, with hexane/ethyl acetate 50/1, 20/1 and 9/1 as eluent, yielding the corresponding ester **9b** (0.37 g, 65%) as a mixture of diastereomers (dr = 60/40), that could not be chromatographically separated.

(1*R*,2*S*,5*R*)-8-Phenylmenthyl 3-((4*S*,5*R*)-1-*tert*-butoxycarbonyl-4,5-dihydro-4-phenyl-5-trimethylsilyl-1*H*-pyrazole)carboxylate (9b): Obtained as the minor diastereomer in the reaction of cinnamate **10**; R_f = 0.55 (hexane/ethyl acetate 9/1); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.46–7.08 (m, 10H; 10 CH), 4.84 (m, 1H; CH), 3.84 (m, 2H; 2 CH), 2.35–0.71 (m, 17H), 1.63 (s, 9H; 3 CH_3), 0.22 (s, 9H; 3 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 160.5 (s), 152.0 (s), 151.0 (s), 147.8 (s), 142.0 (s), 128.8 (d), 127.9 (d), 127.6 (d), 127.3 (d), 125.8 (d), 125.7 (d), 82.3 (s), 75.9 (d), 60.8 (d), 52.7 (d), 50.3 (d), 40.5 (t), 39.8 (s), 34.3 (t), 31.0 (d), 30.7 (q), 28.2 (q), 26.6 (t), 23.4 (q), 21.6 (q), −2.5 (q).

General procedure for the reduction of esters 9 to alcohols 11: $NaBH_4$ (0.45 g, 12 mmol) was added at 0 °C to a solution of the corresponding ester **9** (1 mmol) in THF/MeOH (15 mL, 1/1) and the resulting mixture was stirred at RT. After 12 h, more $NaBH_4$ (0.30 g, 8 mmol) was added and stirring continued for a further 4 h, till TLC analysis showed complete disappearance of the starting material. The reaction was then carefully hydrolyzed at 0 °C with 3 N NaOH (10 mL) and the solvents were removed under vacuum. The aqueous phase was extracted with ethyl acetate (3 × 15 mL) and the combined organic layers dried over Na_2SO_4. After concentration under reduced pressure, the oily residue was purified by flash chromatography on silica gel, with hexane/ethyl acetate 9/1, 5/1 and 3/1 as eluents, yielding the corresponding alcohols **11** as colorless syrups. The chiral auxiliary used in the cycloaddition step was almost quantitatively recovered during the purification process.

(−)-(4*S*)-1-*tert*-Butoxycarbonyl-4,5-dihydro-3-hydroxymethyl-4-phenyl-1-*H*-pyrazole (11a): Yield = 83%; $[\alpha]_D^{21} = -210.6$ (*c* = 0.85 in $CHCl_3$); R_f = 0.16 (hexane/ethyl acetate 20/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.32–7.11 (m, 5H; 5 CH), 4.38 (dd, ^2J(H, H) = 11.8 Hz, ^3J(H,H) = 6.5 Hz, 1H; CH_2), 4.27 (d, ^2J(H, H) = 14.3 Hz, 1H; CH_2), 4.17 (dd, ^2J(H, H) = 11.8 Hz, ^3J(H,H) = 10.9 Hz, 1H; CH_2), 4.00 (d, ^2J(H,H) = 14.3 Hz, 1H; CH_2), 3.79 (dd, ^3J(H,H) = 10.9 and 6.5 Hz, 1H; CH), 1.47 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 159.7 (s), 151.9 (s), 138.6 (s), 128.8 (d), 127.3 (d), 127.2 (d), 81.2 (s), 57.7 (t), 54.0 (t), 50.6 (d), 28.0 (q); FT-IR (neat): $\tilde{\nu}$ = 3414 (OH), 1696 (C=O), 1163 cm^{-1}; MS (EI, 70 eV): *m*/*z* (%) = 276 (12) [M^+], 217 (16), 176 (82), 147 (46), 57 (100); anal. calcd for $C_{15}H_{20}N_2O_3$: C 65.20, H 7.29, N 10.14; found C 65.28, H 7.27, N 10.17.

(−)-(4*R*,5*S*)-1-*tert*-Butoxycarbonyl-4,5-dihydro-3-hydroxymethyl-4-phenyl-5-trimethylsilyl-1*H*-pyrazole (11b): Yield = 81%; $[\alpha]_D^{25} = -86.0$ (*c* = 0.79 in $CHCl_3$); R_f = 0.65 (hexane/ethyl acetate 1/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.40–7.12 (m, 5H; 5 CH), 4.30–4.07 (ABq, ^2J(H,H) = 14.9 Hz, 2H; CH_2), 4.13 (d, ^3J(H,H) = 6.7 Hz, 1H; CH), 3.80 (d, ^3J(H,H) = 6.7 Hz, 1H; CH), 2.50 (brs, 1H; OH), 1.57 (s, 9H; 3 CH_3), 0.14 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 159.0 (s), 152.4 (s), 140.4 (s), 129.2 (d), 127.6 (d), 127.2 (d), 81.4 (s), 58.7 (t), 58.4 (d), 54.2 (d), 28.3 (q), −3.0 (q); FT-IR (neat): $\tilde{\nu}$ = 3418 (OH), 1694 (C=O) cm^{-1}; MS (EI, 70 eV): *m*/*z* (%) = 348 (<5) [M^+], 235 (57), 191 (68), 149 (100); HRMS for $C_{18}H_{28}N_2O_3Si$: calcd 348.1869; found 348.1869; anal. calcd for $C_{18}H_{28}N_2O_3Si$: C 62.03, H 8.10, N 8.04; found C 61.92, H 8.12, N 8.01.

(−)-(4*S*,5*S*)-1-*tert*-Butoxycarbonyl-4,5-dihydro-3-hydroxymethyl-4-phenyl-5-vinyl-1*H*-pyrazole (11c): Yield = quant.; $[\alpha]_D^{18} = -168.0$ (*c* = 1.68 in $CHCl_3$); R_f = 0.37 (hexane/ethyl acetate 1/1); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.38–7.26 (m, 3H; 3 CH), 7.14 (d, ^3J(H,H) = 6.5 Hz, 2H; 2 CH), 5.89 (ddd, ^3J(H,H) = 16.7, 10.2, and 7.2 Hz, 1H; CH), 5.17 (m, 2H; CH_2), 4.61 (dd, ^3J(H,H) = 6.6 and 5.6 Hz, 1H; CH), 4.32 (d, ^2J(H,H) = 15.1 Hz, 1H; CH_2), 4.16 (d, ^2J(H,H) = 15.1 Hz, 1H; CH_2), 4.01 (d, ^3J(H,H) = 5.1 Hz, 1H; CH), 2.22 (brs, 1H; OH), 1.50 (s, 9H; 3 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 158.0 (s), 151.9 (s), 137.8 (s), 135.7 (d), 129.3 (d), 127.9 (d), 127.4 (d), 116.2 (t), 81.6 (s), 69.6 (d), 58.8 (d), 58.7 (t), 28.2 (q); FT-IR (neat): $\tilde{\nu}$ = 3425 (OH), 1703 (C=O), 1393, 1367, 1165 cm^{-1}; MS (EI, 70 eV): *m*/*z* (%) = 302 (13) [M^+], 243 (15), 202 (58), 57 (100); anal. calcd for $C_{17}H_{22}N_2O_3$: C 67.53, H 7.33, N 9.26; found C 67.61, H 7.31, N 9.29.

(−)-(4*S*,5*S*)-1-*tert*-Butoxycarbonyl-4-(2-furyl)-4,5-dihydro-3-hydroxymethyl-5-trimethylsilyl-1*H*-pyrazole (11d): Yield = 76%; $[\alpha]_D^{26} = -106.1$ (*c* = 1.03 in $CHCl_3$); R_f = 0.30 (hexane/ethyl acetate 2/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.24 (m, 1H; CH), 6.20 (dd, ^3J(H,H) = 3.1 and 1.8 Hz, 1H; CH), 6.04 (d, ^3J(H,H) = 3.1 Hz, 1H; CH), 4.28 (d, ^2J(H,H) = 14.3 Hz, 1H; CH_2), 4.26 (d, ^3J(H,H) = 7.9 Hz, 1H; CH), 4.10 (brs, 1H; OH), 4.04 (d, ^2J(H,H) = 14.3 Hz, 1H; CH_2), 3.71 (d, ^3J(H,H) = 7.9 Hz, 1H; CH), 1.42 (s, 9H; 3 CH_3), 0.01 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 156.4 (s), 152.2 (s), 151.6 (s), 142.0 (d), 110.2 (d), 106.3 (d), 81.0 (s), 57.8 (t), 53.9 (d), 47.0 (d), 27.9 (q), −3.3 (q); FT-IR (neat): $\tilde{\nu}$ = 3403 (OH), 1694 (C=O) cm^{-1}; MS (EI, 70 eV): *m*/*z* (%) = 338 (<5) [M^+], 267 (17), 181 (79), 139 (96), 73 (89), 57 (100); anal. calcd for $C_{16}H_{26}N_2O_4Si$: C 56.78, H 7.74, N 8.28; found C 56.69, H 7.72, N 8.31.

General procedure for the protection of alcohols 11 as silyl ethers 12: TBDMSCl (0.23 g, 1.5 mmol) and imidazole (0.14 g, 2 mmol) were successively added at RT to a solution of the corresponding alcohol **11** (1 mmol) in CH_2Cl_2 (5 mL) and the resulting mixture stirred at RT for 1–2 h, till TLC analysis showed complete disappearance of the starting material. The reaction was hydrolyzed with NaOH 3 N (5 mL) and the organic residue extracted with CH_2Cl_2 (3 × 5 mL). The combined organic layers were dried over Na_2SO_4 and solvents removed under vacuum. The oily residue was purified by flash chromatography on silica gel, using as eluent hexane/ethyl acetate 50/1, 20/1 and 9/1, yielding the corresponding silyl ethers **12** as colorless syrups.

(−)-(4*S*)-1-*tert*-Butoxycarbonyl-3-*tert*-butyldimethylsilyloxymethyl-4,5-dihydro-4-phenyl-1*H*-pyrazole (12a): Yield = quant.; $[\alpha]_D^{23} = -155.3$ (*c* = 1.01 in $CHCl_3$); R_f = 0.18 (hexane/ethyl acetate 9/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.27–7.08 (m, 5H; 5 CH), 4.35 (dd, ^2J(H,H) = 11.7 Hz, ^3J(H,H) = 6.6 Hz, 1H; CH_2), 4.33 (d, ^2J(H,H) = 12.8 Hz, 1H; CH_2), 4.17 (dd, ^2J(H,H) = 11.7 Hz, ^3J(H,H) = 10.7 Hz, 1H; CH_2), 3.99 (d, ^2J(H,H) = 12.8 Hz, 1H; CH_2), 3.77 (dd, ^3J(H,H) = 10.7 and 6.6 Hz, 1H; CH), 1.48 (s, 9H; 3 CH_3), 0.76 (s, 9H; 3 CH_3), −0.15 (s, 3H; CH_3), −0.19 (s, 3H; CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 158.9 (s), 151.8 (s), 138.8 (s), 128.6 (d), 127.3 (d), 127.2 (d), 80.8 (s), 58.5 (t), 53.8 (t), 50.4 (d), 28.0 (q), 25.3 (q), 17.7 (s), −6.1 (q), −6.2 (q); FT-IR (neat): $\tilde{\nu}$ = 1730, 1696, 1456, 1433 cm^{-1}; MS (EI, 70 eV): *m*/*z* (%) = 390 (<5) [M^+], 333 (13), 277 (100), 233 (41); anal. calcd for $C_{21}H_{34}N_2O_3Si$: C 64.58, H 8.77, N 7.17; found C 64.49, H 8.79, N 7.19.

(−)-(4*R*,5*S*)-1-*tert*-Butoxycarbonyl-3-*tert*-butyldimethylsilyloxymethyl-4,5-dihydro-4-phenyl-5-trimethylsilyl-1*H*-pyrazole (12b): Yield = quant.;

$[\alpha]_D^{25} = -49.6$ ($c = 0.98$ in $CHCl_3$); $R_f = 0.69$ (hexane/ethyl acetate 3/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.29-7.09$ (m, 5H; 5 CH), 4.35 (d, ^2J(H,H) = 12.8 Hz, 1H; CH_2), 4.22 (d, ^3J(H,H) = 5.2 Hz, 1H; CH), 4.00 (d, ^2J(H,H) = 12.8 Hz, 1H; CH_2), 3.76 (d, ^3J(H,H) = 5.2 Hz, 1H; CH), 1.54 (s, 9H; 3 CH_3), 0.84 (s, 9H; 3 CH_3), 0.12 (s, 9H; 3 CH_3), −0.06 (s, 3H; CH_3), −0.10 (s, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 159.1$ (s), 152.1 (s), 140.5 (s), 128.7 (d), 127.15 (d), 127.1 (d), 80.8 (s), 58.6 (t), 57.7 (d), 53.3 (d), 28.1 (q), 25.4 (q), 17.8 (s), −3.2 (q), −5.9 (q), −6.1 (q); FT-IR (neat): $\tilde{\nu} = 1694$ (C=O) cm^{-1}; MS (EI, 70 eV): m/z (%) = 462 (<5) [M^+], 405 (21), 349 (100), 235 (70), 206 (88), 191 (82); anal. calcd for $C_{24}H_{42}N_2O_3Si_2$: C 62.29, H 9.15, N 6.05; found C 62.34, H 9.13, N 6.07.

(−)-(4*S*,5*S*)-1-*tert*-Butoxycarbonyl-3-*tert*-butyldimethylsilyloxymethyl-4,5-dihydro-4-phenyl-5-vinyl-1*H*-pyrazole (12c): Yield = 96%; $[\alpha]_D^{18} = -137.0$ ($c = 1.36$ in $CHCl_3$); $R_f = 0.56$ (hexane/ethyl acetate 3/1); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.36-7.25$ (m, 3H; 3 CH), 7.12 (d, ^3J(H,H) = 7.0 Hz, 2H; 2 CH), 5.89 (ddd, ^3J(H,H) = 16.8, 10.2 and 7.2 Hz, 1H; CH), 5.18 (m, 2H; CH_2), 4.57 (dd, ^3J(H,H) = 7.2 and 5.0 Hz, 1H; CH), 4.40 (d, ^2J(H,H) = 13.1 Hz, 1H; CH_2), 4.12 (d, ^2J(H,H) = 13.1 Hz, 1H; CH_2), 4.06 (d, ^3J(H,H) = 5.0 Hz, 1H; CH), 1.50 (s, 9H; 3 CH_3), 0.81 (s, 9H; 3 CH_3), −0.08 (s, 3H; CH_3), −0.11 (s, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 158.2$ (s), 151.9 (s), 138.2 (s), 135.9 (d), 128.9 (d), 127.6 (d), 127.6 (d), 115.8 (t), 81.3 (s), 69.1 (d), 59.0 (t), 58.4 (d), 28.2 (q), 25.6 (q), 18.0 (s), −5.7 (q), −5.8 (q); FT-IR (neat): $\tilde{\nu} = 1730$, 1703, 1365, 1169 cm^{-1}; MS (EI, 70 eV): m/z (%) = 416 (<5) [M^+], 303 (100), 259 (47); anal. calcd for $C_{23}H_{36}N_2O_3Si$: C 66.31, H 8.71, N 6.72; found C 66.37, H 8.73, N 6.70.

(−)-(4*S*,5*S*)-1-*tert*-Butoxycarbonyl-3-*tert*-butyldimethylsilyloxymethyl-4-(2-furyl)-4,5-dihydro-5-trimethylsilyl-1*H*-pyrazole (12d): Yield = quant.; $[\alpha]_D^{27} = -32.7$ ($c = 0.51$ in $CHCl_3$); $R_f = 0.41$ (hexane/ethyl acetate 9/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.24$ (m, 1H; CH), 6.22 (m, 1H; CH), 6.01 (d, ^3J(H,H) = 3.1 Hz, 1H; CH), 4.32 (d, ^2J(H,H) = 12.7 Hz, 1H; CH_2), 4.28 (d, ^3J(H,H) = 7.6 Hz, 1H; CH), 4.07 (d, ^2J(H,H) = 12.7 Hz, 1H; CH_2), 3.72 (d, ^3J(H,H) = 7.6 Hz, 1H; CH), 1.46 (s, 9H; 3 CH_3), 0.79 (s, 9H; 3 CH_3), 0.04 (s, 9H; 3 CH_3), −0.08 (s, 3H; CH_3), −0.09 (s, 3H; CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): $\delta = 155.6$ (s), 152.13 (s), 152.10 (s), 141.8 (d), 110.2 (d), 106.1 (d), 80.7 (s), 58.8 (t), 54.1 (d), 46.5 (d), 28.0 (q), 25.3 (q), 17.8 (s), −3.2 (q), −5.9 (q), −6.1 (q); FT-IR (neat): $\tilde{\nu} = 1696$ (C=O), 1433, 1366, 1252 cm^{-1}; MS (EI, 70 eV): m/z (%) = 452 (<5) [M^+], 395 (10), 339 (100), 181 (53), 73 (69); anal. calcd for $C_{22}H_{40}N_2O_4Si_2$: C 58.37, H 8.90, N 6.19; found C 58.25, H 8.92, N 6.21.

General procedure for the reduction of silyl ethers 12 to pyrazolidines *trans*/*cis*-13: A solution of Superhydride (1.0 M in THF, 2.5 mL, 2.5 mmol) was added dropwise to a solution of the corresponding silyl ether **12** (1 mmol) in the solvent (50 mL) and temperature conditions indicated in Table 3. The resulting mixture was stirred for 12 h, till TLC analysis showed complete disappearance of the starting material (the reduction product was visualized by staining with a Ce/Mo reagent followed by heating). The reaction was then hydrolyzed with 3 N NaOH (5 mL) and the organic residue extracted with ethyl acetate (3 × 15 mL). The combined organic layers were dried over Na_2SO_4 and solvents removed under vacuum. The oily residue was purified by flash chromatography on silica gel, with hexane/ethyl acetate 20/1, 9/1 and 5/1 as eluents, yielding the corresponding diastereomerically pure pyrazolidines **13** as colorless syrups. Although pyrazolidines **13** can be manipulated in the air, they are moderately unstable and slowly oxidize to silyl ethers **12**. In order to prevent their oxidation, they have to be stored under nitrogen at −20 °C. MS spectra and elemental analyses of pyrazolidines **13** could not be recorded because of their decomposition.

(−)-(3*R*,4*S*)-1-*tert*-Butoxycarbonyl-3-*tert*-butyldimethylsilyloxymethyl-4-phenylpyrazolidine (*cis*-13a): Yield = 85% (*trans*-**13a**/*cis*-**13a** < 5/95; Table 3, entry 1); $[\alpha]_D^{23} = -61.8$ ($c = 0.82$ in $CHCl_3$); $R_f = 0.36$ (hexane/ethyl acetate 3/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.36-7.17$ (m, 5H; 5 CH), 4.30 (br s, 1H; NH), 3.91 (dd, ^2J(H,H) = 10.3 Hz, ^3J(H,H) = 7.1 Hz, 1H; CH_2), 3.72 (dd, ^2J(H,H) = 10.3 Hz, ^3J(H,H) = 4.0 Hz, 1H; CH_2), 3.67 (ddd, ^3J(H,H) = 7.1, 5.6 and 4.0 Hz, 1H; CH), 3.56 (ddd, ^3J(H,H) = 6.5, 5.6, and 5.2 Hz, 1H; CH), 3.46 (dd, ^2J(H,H) = 10.1 Hz, ^3J(H,H) = 5.2 Hz, 1H; CH_2), 3.12 (dd, ^2J(H,H) = 10.1 Hz, ^3J(H,H) = 6.5 Hz, 1H; CH_2), 1.52 (s, 9H; 3 CH_3), 0.83 (s, 9H; 3 CH_3), −0.09 (s, 6H; 2 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): $\delta = 154.7$ (s), 138.1 (s), 128.3 (d), 128.0 (d), 126.9 (d), 80.3 (s), 63.5 (d), 60.0 (t), 52.1 (t), 46.9 (d), 28.3 (q), 25.7 (q), 18.0 (s), −5.8 (q); FT-IR (neat): $\tilde{\nu} = 3240$ (NH), 1713 (C=O), 1697, 1127 cm^{-1}.

(+)-(3*S*,4*R*,5*S*)-1-*tert*-Butoxycarbonyl-3-*tert*-butyldimethylsilyloxymethyl-4-phenyl-5-trimethylsilylpyrazolidine (*trans*-13b): Yield = 95% (*trans*-**13b**/*cis*-**13b** > 95/5; Table 3, entry 2); $[\alpha]_D^{25} = +12.9$ ($c = 0.28$ in $CHCl_3$); $R_f = 0.59$ (hexane/ethyl acetate 3/1); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.32-7.18$ (m, 5H; 5 CH), 4.29 (br s, 1H; NH), 3.90 (d, ^3J(H,H) = 10.5 Hz, 1H; CH_2), 3.67 (d, ^3J(H,H) = 9.4 Hz, 1H; CH), 3.48–3.41 (m, 2H), 2.94 (m, 1H; CH), 1.52 (s, 9H; 3 CH_3), 0.91 (s, 9H; 3 CH_3), 0.06 (s, 3H; CH_3), 0.04 (s, 3H; CH_3), −0.01 (s, 9H; 3 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 156.9$ (s), 141.1 (s), 128.7 (d), 127.9 (d), 126.7 (d), 80.2 (s), 69.4 (d), 58.1 (d), 57.7 (t), 50.9 (d), 28.4 (q), 25.7 (q), 18.2 (s), −2.8 (q), −5.6 (q), −5.7 (q); FT-IR (neat): $\tilde{\nu} = 3420$ (NH), 1688 (C=O) cm^{-1}.

(−)-(3*R*,4*S*,5*S*)-1-*tert*-Butoxycarbonyl-3-*tert*-butyldimethylsilyloxymethyl-4-phenyl-5-vinylpyrazolidine (*cis*-13c): Yield = 37% (*trans*-**13c**/*cis*-**13c** = 50/50; Table 3, entry 4); $[\alpha]_D^{24} = -74.8$ ($c = 1.32$ in $CHCl_3$); $R_f = 0.19$ (hexane/ethyl acetate 3/1); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.37-7.16$ (m, 5H; 5 CH), 5.93 (ddd, ^3J(H,H) = 17.1, 10.1 and 6.6 Hz, 1H; CH), 5.20 (m, 2H; CH_2), 4.62 (m, 1H; CH), 3.67–3.62 (m, 1H; CH), 3.48–3.36 (m, 2H; CH + CH_2), 3.22 (dd, ^2J(H,H) = 10.0 Hz, ^3J(H,H) = 5.9 Hz, 1H; CH_2), 1.50 (s, 9H; 3 CH_3), 0.82 (s, 9H; 3 CH_3), −0.08 (s, 3H; CH_3), −0.09 (s, 3H; CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): $\delta = 153.7$ (s), 137.4 (s), 137.2 (d), 128.4 (d), 128.1 (d), 127.0 (d), 115.5 (t), 80.4 (s), 65.4 (d), 61.7 (d), 60.9 (t), 54.0 (d), 28.4 (q), 25.8 (q), 18.1 (s), −5.7 (q); FT-IR (neat): $\tilde{\nu} =$ 3237 (NH), 1707 (C=O), 1366, 1130 cm^{-1}.

(−)-(3*S*,4*S*,5*S*)-1-*tert*-Butoxycarbonyl-3-*tert*-butyldimethylsilyloxymethyl-4-phenyl-5-vinylpyrazolidine (*trans*-13c): Yield = 82% (*trans*-**13c**/cis-**13c** = 82/18; Table 3, entry 6); $[\alpha]_D^{24} = -4.5$ ($c = 1.21$ in $CHCl_3$); $R_f = 0.43$ (hexane/ethyl acetate 3/1); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.37-7.19$ (m, 5H; 5 CH), 5.78 (ddd, ^3J(H,H) = 16.9, 10.2 and 6.7 Hz, 1H; CH), 5.05–4.97 (m, 2H; CH_2), 4.41 (dd, ^3J(H,H) = 6.7 and 6.7 Hz, 1H; CH), 3.86 (d, ^2J(H,H) = 10.7 Hz, 1H; CH_2), 3.42 (d, ^2J(H,H) = 10.7 Hz, 1H; CH_2), 3.26–3.24 (m, 2H; 2 CH), 1.48 (s, 9H; 3 CH_3), 0.90 (s, 9H; 3 CH_3), 0.03 (s, 3H; CH_3), 0.02 (s, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 155.3$ (s), 138.0 (s), 137.2 (d), 128.7 (d), 128.1 (d), 127.2 (d), 115.1 (t), 80.4 (s), 69.9 (d), 67.0 (d), 57.4 (t), 55.3 (d), 28.3 (q), 25.7 (q), 18.1 (s), −5.6 (q), −5.7 (q); FT-IR (neat): $\tilde{\nu} = 1713$ (C=O), 1366, 1121 cm^{-1}.

(+)-(3*S*,4*S*,5*S*)-1-*tert*-Butoxycarbonyl-3-*tert*-butyldimethylsilyloxymethyl-4-(2-furyl)-5-trimethylsilylpyrazolidine (*trans*-13d): Yield = 93% (*trans*-**13d**/cis-**13d** > 95/5; Table 3, entry 7); $[\alpha]_D^{21} = +36.0$ ($c = 0.84$ in $CHCl_3$); $R_f = 0.55$ (hexane/ethyl acetate 3/1); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.29$ (d, ^3J(H,H) = 1.9 Hz, 1H; CH), 6.26 (dd, ^3J(H,H) = 3.1 and 1.9 Hz, 1H; CH), 6.04 (d, ^3J(H,H) = 3.1 Hz, 1H; CH), 4.35–4.05 (br s, 1H; NH), 3.95 (dd, ^2J(H,H) = 10.5 Hz, ^3J(H,H) = 2.4 Hz, 1H; CH_2), 3.67 (d, ^3J(H,H) = 9.8 Hz, 1H; CH), 3.65 (dd, ^2J(H,H) = 10.5 Hz, ^3J(H,H) = 1.3 Hz, 1H; CH_2), 3.54 (dd, ^3J(H,H) = 9.8 and 9.6 Hz, 1H; CH), 3.02 (ddd, ^3J(H,H) = 9.6, 2.4 and 1.3 Hz, 1H; CH), 1.47 (s, 9H; 3 CH_3), 0.87 (s, 9H; 3 CH_3), 0.05–0.02 (m, 15H; 5 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): $\delta =$ 156.9 (s), 153.6 (s), 141.6 (d), 110.0 (d), 105.9 (d), 80.2 (s), 65.4 (d), 58.0 (t), 54.0 (d), 43.7 (d), 28.3 (q), 25.7 (q), 18.2 (s), −3.0 (q), −5.7 (q), −5.8 (q); FT-IR (neat): $\tilde{\nu} = 1692$ (C=O), 1468, 1366, 1252, 1167, 1117 cm^{-1}.

General procedure for the synthesis of bicyclic compounds 14: Aqueous saturated K_2CO_3 (12 mL) and CBZCl (0.26 mL, 1.8 mmol) were sequentially added to a solution of the corresponding pyrazolidine **13** (1 mmol) in CH_3CN (2 mL) at room temperature. The resulting mixture was stirred at room temperature for a 1–2 h period, until complete disappearance of the starting material was detected by TLC monitoring (Ce/Mo staining solution). Once the reaction is completed, the organic layer is extracted with ethyl acetate (3 × 15 mL), dried over Na_2SO_4, and filtered. Solvents were evaporated and the residue was dissolved in dry THF (3 mL) and TBAF (1.5 equiv, 1.36 mL, 1.1 M in THF) was added by means of a syringe at 0 °C. The reaction was stirred at 0 °C for 1.5–2 h till TLC monitoring showed completed disappearance of the CBZ-protected pyrazolidine. Solvents were then evaporated under vacuum and the residue was hydrolyzed with saturated NH_4Cl (10 mL) and extracted with Et_2O (3 × 15 mL). The combined organic layers were dried (Na_2SO_4), filtered and vacuum-evaporated, and the residue was purified by flash chromatography over silica gel using hexane/ethyl acetate 20/1 and 9/1 as eluents. Bicyclic carbamates **14** were obtained in the yields described in Scheme 3.

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Bicyclic carbamate (±)-14b obtained starting from (±)-*trans*-13b: White solid; m.p. 130–132 °C (hexane); yield = 40 %; R_f = 0.38 (hexane/ethyl acetate 3/1); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.40–7.24 (m, 5H; 5 CH), 4.49 (dd, ^2J(H,H) = 9.4 Hz, ^3J(H,H) = 6.4 Hz, 1H; CH_2), 4.21 (dd, ^2J(H,H) = 9.4 Hz, ^3J(H,H) = 1.0 Hz, 1H; CH_2), 3.76 (ddd, ^3J(H,H) = 9.4, 6.4, and 1.0 Hz, 1H; CH), 3.73 (d, ^3J(H,H) = 11.3 Hz, 1H; CH), 3.12 (dd, ^3J(H,H) = 11.3 and 9.4 Hz, 1H; CH), 1.55 (s, 9H; 3 CH_3), 0.01 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 160.0 (s), 157.1 (s), 136.8 (s), 129.3 (d), 128.1 (d), 127.9 (d), 82.2 (s), 65.1 (t), 64.6 (d), 58.8 (d), 53.9 (d), 28.2 (c), −2.7 (c); anal. calcd for $C_{19}H_{28}N_2O_4Si$: C 60.61, H 7.50, N 7.44; found C 60.66, H 7.52, N 7.40.

Bicyclic carbamate (±)-14d obtained starting from (±)-*trans*-13d: Colorless syrup; yield = 42 %; R_f = 0.54 (hexane/ethyl acetate 3/1); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.39 (m, 1H; CH), 6.34 (m, 1H; CH), 6.21 (m, 1H; CH), 4.57 (dd, ^2J(H,H) = 9.1 Hz, ^3J(H,H) = 5.2 Hz, 1H; CH_2), 4.35 (d, ^2J(H,H) = 9.1 Hz, 1H; CH_2), 3.93–3.73 (dd, ^3J(H,H) = 6.6 and 5.2 Hz, 1H; CH), 3.76 (d, ^3J(H,H) = 9.5 Hz, 1H; CH), 3.27 (dd, ^3J(H,H) = 9.5 and 6.3 Hz, 1H; CH), 1.54 (s, 9H; 3 CH_3), 0.07 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 159.8 (s), 157.0 (s), 149.9 (s), 142.5 (d), 110.3 (d), 107.4 (d), 82.1 (s), 65.2 (t), 61.5 (d), 55.0 (d), 46.6 (d), 28.0 (c), −3.0 (c); anal. calcd for $C_{17}H_{26}N_2O_5Si$: C 55.71, H 7.15, N 7.64; found C 55.68, H 7.17, N 7.67.

General procedure for the synthesis of pyrazolidines 15 by treatment of 13 with benzyl chloroformate: Aqueous saturated K_2CO_3 (12 mL) and CBZCl (0.26 mL, 1.8 mmol) were sequentially added to a solution of the corresponding pyrazolidine **13** (1 mmol) in CH_3CN (2 mL) at room temperature. The resulting mixture was stirred at room temperature for 1–2 h, until complete disappearance of the starting material was detected by TLC monitoring (both starting material **13** and product **15** can be visualized by using a Ce/Mo staining solution). Once the reaction is completed, the organic layer is extracted with ethyl acetate (3 × 15 mL), dried over Na_2SO_4, and filtered. Solvents were evaporated and the residue was purified by flash cromatography over silica gel with hexane/ethyl acetate 20/1, 9/1, and 5/1 as eluents. Protected pyrazolidines **15** were obtained in the yields described in Table 4, and they proved to be perfectly air-stable.

(−)-[(3*R*,4*S*)-2-Benzyloxycarbonyl-1-(*tert*-butoxycarbonyl)-3-*tert*-butyldimethylsilyloxymethyl-4-phenylpyrazolidine (15a): Colorless syrup; yield = 96 %; R_f = 0.15 (hexane/ethyl acetate 9/1); $[\alpha]_D^{27} = -9.5$ (c = 0.82 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.41–7.24 (m, 10H; 10 CH), 5.31 (d, ^2J(H,H) = 12.3 Hz, 1H; CH_2), 5.19 (d, ^2J(H,H) = 12.3 Hz, 1H; CH_2), 4.52 (m, 1H; CH), 4.17–4.08 (m, 1H), 3.87–3.70 (m, 2H), 3.60 (m, 2H), 1.46 (s, 9H; 3 CH_3), 0.79 (s, 9H; 3 CH_3), −0.06 (s, 3H; CH_3), −0.10 (s, 3H; CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 157.4 (s), 155.4 (s), 135.9 (s), 135.8 (s), 128.33 (d), 128.27 (d), 127.9 (d), 127.8 (d), 127.1 (d), 81.1 (s), 67.9 (t), 63.6 (d), 61.5 (t), 51.1 (t), 46.6 (d), 28.0 (c), 25.7 (c), 18.1 (s), −5.9 (c), −6.0 (c); IR (neat): $\tilde{\nu}$ = 1703 (C=O), 1701 (C=O), 1366, 1344, 1256, 1163 cm^{-1}; MS (70 eV, EI): m/z (%) = 526 (< 5) [M^+], 426 (55), 369 (29), 91 (100); anal. calcd for $C_{29}H_{42}N_2O_5Si$: C 66.13, H 8.04, N 5.32; found C 66.18, H 8.01, N 5.29.

(−)-[(3*S*,4*R*,5*S*)-1-Benzyloxycarbonyl-2-(*tert*-butoxycarbonyl)-5-*tert*-butyldimethylsilyloxymethyl-4-phenyl-3-trimethylsilylpyrazolidine (15b): Colorless syrup; yield = 92 %; R_f = 0.47 (hexane/ethyl acetate 9/1); $[\alpha]_D^{24} = -14.4$ (c = 1.40 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.40–7.24 (m, 10H; 10 CH), 5.34 (d, ^2J(H,H) = 12.4 Hz, 1H; CH_2), 5.20 (d, ^2J(H,H) = 12.4 Hz, 1H; CH_2), 4.18 (ddd, ^3J(H,H) = 6.3, 4.8 and 4.5 Hz, 1H; CH), 3.91 (dd, ^2J(H,H) = 10.0 Hz, ^3J(H,H) = 4.8 Hz, 1H; CH_2), 3.54 (dd, ^2J(H,H) = 10.0 Hz, ^3J(H,H) = 6.3 Hz, 1H; CH_2), 3.34 (dd, ^3J(H,H) = 11.3 and 4.5 Hz, 1H; CH), 2.85 (d, ^3J(H,H) = 11.3 Hz, 1H; CH), 1.43 (s, 9H; 3 CH_3), 0.80 (s, 9H; 3 CH_3), 0.01 (s, 3H; CH_3), −0.02 (s, 3H; CH_3), −0.06 (s, 9H; 3 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 156.4 (s), 156.1 (s), 140.7 (s), 136.3 (s), 128.4 (d), 128.2 (d), 127.9 (d), 127.6 (d), 126.8 (d), 80.8 (s), 69.7 (d), 64.2 (t), 60.1 (d), 54.0 (d), 27.8 (c), 25.6 (c), 18.0 (s), −0.5 (c), −5.7 (c); IR (neat): $\tilde{\nu}$ = 1707 (C=O), 1252 cm^{-1}; MS (70 eV, EI): m/z (%) = 598 (< 5) [M^+], 541 (< 5), 498 (42), 91 (100); anal. calcd for $C_{32}H_{50}N_2O_5Si_2$: C 64.17, H 8.41, N 4.68; found C 64.33, H 8.28, N 4.79.

(−)-[(3*S*,4*S*,5*S*)-1-Benzyloxycarbonyl-2-(*tert*-butoxycarbonyl)-5-*tert*-butyldimethylsilyloxymethyl-4-phenyl-3-vinylpyrazolidine (15c): Colorless syrup; yield = quant.; R_f = 0.30 (hexane/ethyl acetate 9/1); $[\alpha]_D^{22} = -17.8$ (c = 0.76 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.36–7.10 (m, 10H; 10 CH), 5.97 (m, 1H; CH), 5.27-5.05 (m, 4H; 2 CH_2), 4.35-3.66 (m, 4H), 3.41 (m, 1H), 1.41 (s, 9H; 3 CH_3), 0.83 (s, 9H; 3 CH_3), 0.02 (s, 3H; CH_3), −0.01 (s, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 154.9 (s), 153.8 (s), 140.1 (s), 135.9 (d), 135.4 (s), 128.7 (d), 128.3 (d), 128.0 (d), 127.6 (d), 127.0 (d), 115.8 (t), 81.5 (s), 70.0 (d), 67.7 (t), 67.3 (d), 62.8 (t), 55.9 (d), 28.0 (c), 25.7 (c), 18.0 (s), −5.6 (c); IR (neat): $\tilde{\nu}$ = 1711 (C=O), 1142 cm^{-1}; MS (70 eV, EI): m/z (%) = 552 (< 5) [M^+], 452 (51), 303 (35), 91 (100); anal. calcd for $C_{31}H_{44}N_2O_5Si$: C 67.36, H 8.02, N 5.07; found C 67.35, H 7.98, N 5.09.

(−)-[(3*S*,4*S*,5*S*)-1-Benzyloxycarbonyl-2-(*tert*-butoxycarbonyl)-5-*tert*-butyldimethylsilyloxymethyl-4-(2-furyl)-3-trimethylsilylpyrazolidine (15d): White solid; m.p. = 64–67 °C (pentane); yield = 93 %; R_f = 0.65 (hexane/ethyl acetate 3/1); $[\alpha]_D^{22} = -26.8$ (c = 1.30 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.47–7.26 (m, 6H; 6 CH), 6.30 (dd, ^3J(H,H) = 3.1 and 1.9 Hz, 1H; CH), 6.12 (dd, ^3J(H,H) = 3.1 Hz, 1H; CH), 5.32–5.19 (m, 2H), 4.25 (m, 1H), 3.93 (m, 1H), 3.60–3.49 (m, 2H), 2.98 (d, ^3J(H,H) = 11.6 Hz, 1H), 1.43 (s, 9H; 3 CH_3), 0.88 (s, 9H; 3 CH_3), 0.06 (s, 3H; CH_3), 0.04 (s, 9H; 3 CH_3), 0.02 (s, 3H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 156.5 (s), 156.1 (s), 152.6 (s), 141.2 (d), 136.3 (s), 128.3 (d), 127.9 (d), 127.7 (d), 110.3 (d), 107.0 (d), 81.1 (s), 67.3 (t), 66.2 (d), 63.8 (t), 56.7 (d), 46.4 (d), 27.9 (c), 25.7 (c), 18.2 (s), −1.0 (c), −5.5 (c), −5.6 (c); IR (film): $\tilde{\nu}$ = 1705 (C=O), 1393, 1252 cm^{-1}; MS (70 eV, EI): m/z (%) = 588 (6) [M^+], 517 (9), 488 (82), 91 (100); anal. calcd for $C_{30}H_{48}N_2O_6Si_2$: C 61.19, H 8.22, N 4.76; found C 61.23, H 8.19, N 4.75.

General procedure for the synthesis of azaprolines 16 by one-pot deprotection-oxidation of pyrazolidines 15: Jones reagent (CrO_3/H$^+$, 2 mL, excess) was added dropwise to a solution of the corresponding pyrazolidine **15** (0.15 mmol) at 0 °C until the orange color persisted. The resulting mixture was stirred at room temperature for half an hour; then TLC monitoring indicated complete consumption of **15**, so the deprotected alcohol was presumably formed. Stirring was continued until disappearance of the deprotected alcohol was observed by TLC (4 to 10 h) (Compounds **15**, **16**, and the deprotected alcohol intermediate can be monitored by using a Ce/Mo staining solution). Isopropyl alcohol (3 mL) was then added and solvents were evaporated at low pressure. Ethyl acetate (20 mL) was added to the residue; the resulting suspension was filtered through a pad of Celite and solvents were evaporated under vacuum. The residue was purified by flash cromatography over silica gel, with hexane/ethyl acetate 3/1 and hexane/ethyl acetate/formic acid 20/12/1 as sequential eluents to obtain azaprolines **15** in the yields shown in Table 4.

(−)-3-[(3*R*,4*S*)-2-Benzyloxycarbonyl-1-(*tert*-butoxycarbonyl)-4-phenylpyrazolidine] carboxylic acid (16a): Colorless syrup; yield = 97 %; R_f = 0.18 (hexane/ethyl acetate/formic acid 20/12/1); $[\alpha]_D^{28} = -36.3$ (c = 0.53 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 8.25–7.91 (br s, 1H, COO*H*), 7.42–7.11 (m, 10H; 10 CH), 5.32–5.06 (m, 3H; CH + CH_2), 4.25–3.61 (m, 3H; CH + CH_2), 1.42 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 172.5 (s), 156.4 (s), 156.3 (s), 135.4 (s), 134.2 (s), 128.7 (d), 128.4 (d), 128.2 (d), 127.9 (d), 127.8 (d), 82.6 (s), 68.4 (t), 63.8 (d), 52.0 (d), 48.6 (d), 27.9 (c); IR (neat): $\tilde{\nu}$ = 3350–2600 (OH), 1740 (C=O), 1724 (C=O), 1713 (C=O), 1155 cm^{-1}; MS (70 eV, EI): m/z (%) = 426 (< 5) [M^+], 382 (27), 191 (21), 147 (25), 108 (27), 91 (84), 41 (100); anal. calcd for $C_{23}H_{26}N_2O_6$: C 64.78, H 6.14, N 6.57; found C 64.75, H 6.18, N 6.62.

(−)-3-[(3*S*,4*R*,5*S*)-2-Benzyloxycarbonyl-1-(*tert*-butoxycarbonyl)-4-phenyl-5-trimethylsilyl pyrazolidine]carboxylic acid (16b): White solid; m.p. 140–143 °C ($CHCl_3$); yield = 90 %; R_f = 0.32 (hexane/ethyl acetate/formic acid: 20/12/1); $[\alpha]_D^{29} = -30.1$ (c = 1.05 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 8.65 (br s, 1H, COO*H*), 7.40–7.24 (m, 10H; 10 CH), 5.40 (d, ^2J(H,H) = 12.3 Hz, 1H; CH_2), 5.20 (d, ^2J(H,H) = 12.3 Hz, 1H; CH_2), 4.62 (d, ^3J(H,H) = 7.6 Hz, 1H; CH), 3.59 (dd, ^3J(H,H) = 11.5 and 7.6 Hz, 1H; CH), 2.87 (d, ^3J(H,H) = 11.5 Hz, 1H; CH), 1.40 (s, 9H; 3 CH_3), −0.08 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 173.2 (s), 156.7 (s), 155.8 (s), 137.5 (s), 135.7 (s), 128.9 (d), 128.4 (d), 128.2 (d), 127.9 (d), 82.5 (s), 69.2 (d), 68.2 (t), 60.6 (d), 54.9 (d), 27.6 (c), −0.6 (c); IR (neat): $\tilde{\nu}$ = 3300-2500 (OH), 1723 (C=O), 1713 (C=O) cm^{-1}; MS (70 eV, EI): m/z (%) = 498 (< 5) [M^+], 398 (19), 263 (20), 145 (23), 91 (100); anal. calcd for $C_{26}H_{34}N_2O_6Si$: C 62.63, H 6.87, N 5.62; found C 62.68, H 6.92, N 5.65.

(+)-3-[(3*S*,4*S*,5*S*)-2-Benzyloxycarbonyl-1-(*tert*-butoxycarbonyl)-4-phenyl-5-vinylpyrazolidine]carboxylic acid (16c): Colorless syrup; yield = 95 %; R_f = 0.30 (hexane/ethyl acetate/formic acid: 20/12/1); $[\alpha]_D^{17} = +8.8$ (c = 0.93 in EtOH); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 9.80–8.90 (br s,

1H, COO*H*), 7.36–7.15 (m, 10H; 10 CH), 6.18–5.82 (m, 1H; CH), 5.41–5.03 (m, 4H; 2 CH_2), 4.71–4.31 (m, 2H; 2 CH), 3.80–3.68 (m, 1H; CH), 1.37 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 173.2 (s), 155.4 (s), 155.3 (s), 140.0 (s), 135.5 (s), 135.2 (d), 128.9 (d), 128.3 (d), 127.9 (d), 127.5 (d), 126.8 (d), 117.1 (t), 82.5 (s), 69.8 (d), 68.2 (t), 66.3 (d), 56.4 (d), 27.8 (c); IR (neat): $\tilde{\nu}$ = 3400–2700 (OH), 1730 (C=O), 1707 (C=O), 1154 cm^{-1}; MS (70 eV, EI): *m*/*z* (%) = 452 (<5) [M^+], 408 (17), 217 (15), 108 (60), 91 (100); anal. calcd for $C_{25}H_{28}N_2O_6$: C 66.36, H 6.24, N 6.19; found C 66.33, H 6.20, N 6.23.

(+)-3-[(3*S*,4*S*,5*S*)-2-Benzyloxycarbonyl-1-(*tert*-butoxycarbonyl)-4-(2-furyl)-5-trimethylsilyl pyrazolidine]carboxylic acid (16d): Colorless syrup; yield = 63%; R_f = 0.45 (hexane/ethyl acetate/formic acid 20/12/1); $[\alpha]_D^{22}$ = +5.4 (*c* = 0.90 in MeOH); ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.38–7.28 (m, 6H; 6 CH), 6.31 (m, 1H; CH), 6.27 (m, 1H; CH), 5.43 (d, ^2J(H,H) = 12.5 Hz, 1H; CH_2), 5.16 (d, ^2J(H,H) = 12.5 Hz, 1H; CH_2), 4.70 (m, 1H; CH), 3.78 (m, 1H; CH), 2.99 (d, ^3J(H,H) = 11.3 Hz, 1H; CH), 1.38 (s, 9H; 3 CH_3), 0.00 (s, 9H; 3 CH_3); ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 156.7 (s), 156.1 (s), 149.2 (s), 142.2 (d), 135.6 (s), 128.5 (d), 128.3 (d), 127.9 (d), 110.6 (d), 108.8 (d), 82.8 (s), 68.3 (t), 57.5 (d), 47.8 (d), 27.7 (c), −1.3 (c) (The *C*OOH signal around δ = 173 and another signal for a C (d) around δ = 70 were not detected); IR (neat): $\tilde{\nu}$ = 3500–2700 (OH), 1717 (C=O), 1152 cm^{-1}; MS (70 eV, EI): *m*/*z* (%) = 488 (<5) [M^+], 388 (37), 253 (36), 91 (100); anal. calcd for $C_{24}H_{32}N_2O_7Si$: C 59.00, H 6.60, N 5.73; found C 59.04, H 6.63, N 5.77.

Synthesis of (−)-3-[(3*R*,4*R*,5*S*)-1-benzyloxycarbonyl-2-(*tert*-butoxycarbonyl)-5-(*tert*-butyldimethylsilyloxymethyl)-4-phenylpyrazolidine]carboxylic acid (17) by oxidation of pyrazolidine 15c: $NaIO_4$ (130 mg, 0.608 mmol) and $RuCl_3$ (0.7 mg, 0.02 equiv) were added to a solution of pyrazolidine **15c** (82 mg, 0.148 mmol) in $CCl_4/CH_3CN/H_2O$ (0.3/0.3/0.45 mL). The resulting mixture was stirred at room temperature for 2.5 h, until disappearance of the starting material was monitored by TLC (both **15c** and **17** can be visualized by using a Ce/Mo staining solution). The organic phase was extracted with CH_2Cl_2 (4 × 5 mL), dried over Na_2SO_4, and filtered through Celite. Solvents were evaporated under vacuum and the residue was purified by flash cromatography over SiO_2, by means of hexane/ethyl acetate 3/1 and hexane/ethyl acetate/formic acid 40/12/1 as sequential eluents, to furnish azaproline **17** (51 mg, 60%) as a spectroscopically pure white solid. M.p. = 173–5 °C; R_f = 0.56 (hexane/ethyl acetate/formic acid 20/12/1); $[\alpha]_D^{24}$ = −50.6 (*c* = 0.66 in EtOH); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.35–7.11 (m, 5H; 5 CH), 5.27–5.17 (m, 2H; CH_2), 4.61 (m, 1H), 4.24 (m, 1H), 3.03–2.94 (m, 3H), 1.47 (s, 9H; 3 CH_3), 0.92 (s, 9H; 3 CH_3), 0.08 (s, 6H; 2 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 174.4 (s), 157.0 (s), 152.1 (s), 140.9 (s), 135.4 (s), 129.1 (d), 128.4 (d), 128.2 (d), 128.1 (d), 127.4 (d), 126.5 (d), 82.4 (s), 68.6 (d), 68.3 (t), 65.9 (d), 62.5 (t), 51.8 (d), 27.9 (c), 25.7 (c), 18.1 (s), −5.6 (c); IR (film): $\tilde{\nu}$ = 1738 (C=O), 1728 (C=O), 1711 (C=O), 1154 cm^{-1}; MS (70 eV, EI): *m*/*z* (%) = 570 (<5) [M^+], 470 (12), 413 (15), 367 (13), 256 (22), 203 (15), 91 (100); anal. calcd for $C_{30}H_{42}N_2O_7Si$: C 63.13, H 7.42, N 4.91; found C 63.18, H 7.45, N 4.91.

General procedure for the protection of pyrazolidines 13 with ethyl chloroformate: Aqueous saturated K_2CO_3 (1.5 mL) and $ClCO_2Et$ (39 μL, 0.4 mmol) were sequentially added to a solution of pyrazolidine **13** in CH_3CN (2 mL) at room temperature. The resulting mixture was stirred at room temperature for 1–2 h, until complete disappearance of the starting material was detected by TLC monitoring (both starting material **13** and product **18** can be visualized by using a Ce/Mo staining solution). Once the reaction was completed, the organic layer was extracted with ethyl acetate (3 × 5 mL), dried over Na_2SO_4, and filtered. Solvents were evaporated and the residue was purified by flash cromatography over silica gel with hexane/ethyl acetate 20/1, 9/1, and 5/1 as eluent. Protected pyrazolidines **18** were obtained as colorless syrups in the yields described in Table 4.

(−)-(3*S*,4*R*,5*S*)-1-[(*tert*-Butoxycarbonyl)amino]-3-(*tert*-butyldimethylsilyloxymethyl)-2-(ethoxycarbonyl)-4-phenyl-5-trimethylsilylpyrazolidine (18b): Yield = 85%; R_f = 0.16 (hexane/ethyl acetate 20/1); $[\alpha]_D^{30}$ = −15.6 (*c* = 1.43 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.30–7.10 (m, 5H; 5 CH), 4.33–4.12 (m, 3H; CH_2 + CH), 3.89 (dd, ^2J(H,H) = 9.5 Hz, ^3J(H,H) = 4.7 Hz, 1H; CH_2), 3.51 (dd, ^2J(H,H) = 9.5 Hz, ^3J(H,H) = 9.1 Hz, 1H; CH_2), 3.31 (dd, ^3J(H,H) = 11.3 and 6.4 Hz, 1H; CH), 2.83 (d, 1H, ^3J(H,H) = 11.3 Hz; CH), 1.46 (s, 9H; 3 CH_3), 1.30 (t, ^3J(H,H) = 7.1 Hz, 3H; CH_3), 0.84 (s, 9H; 3 CH_3), −0.00 (s, 6H; 2 CH_3), −0.10 (s, 9H; 3 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 156.6 (s), 156.1 (s), 140.9 (s), 128.5 (d), 128.1 (d), 126.8 (d), 80.8 (s), 69.5 (d), 64.3 (t), 61.8 (t), 60.0 (d), 54.1 (d), 28.0 (c), 25.7 (c), 18.1 (s), 14.6 (c), −0.5 (c), −5.6 (c); IR (neat): $\tilde{\nu}$ = 1705 (C=O) cm^{-1}; MS (70 eV, EI): *m*/*z* (%) = 536 (<5) [M^+], 479 (10), 465 (18), 436 (100), 317 (46); anal. calcd for $C_{27}H_{48}N_2O_5Si_2$: C 60.41, H 8.99, N 5.21; found C 60.42, H 8.98, N 5.24.

(−)-(3*S*,4*S*,5*S*)-1-[(*tert*-Butoxycarbonyl)amino]-3-(*tert*-butyldimethylsilyloxymethyl)-2-(ethoxycarbonyl)-4-(2-furyl)-5-trimethylsilylpyrazolidine (18d): Yield = 92%; R_f = 0.53 (hexane/ethyl acetate 5/1); $[\alpha]_D^{29}$ = −99.6 (*c* = 0.90 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.28 (d, ^3J(H,H) = 1.9 Hz, 1H; CH), 6.25 (dd, ^3J(H,H) = 3.0 and 1.9 Hz, 1H; CH), 6.07 (d, ^3J(H,H) = 3.0 Hz, 1H; CH), 4.26–4.12 (m, 3H; CH_2 + CH), 3.88 (dd, ^2J(H,H) = 10.2 Hz, ^3J(H,H) = 4.4 Hz, 1H; CH_2), 3.55–3.43 (m, 2H), 2.91 (d, ^3J(H,H) = 11.1 Hz, 1H; CH), 1.43 (s, 9H; 3 CH_3), 1.23 (t, ^3J(H,H) = 7.1 Hz, 3H; CH_3), 0.84 (s, 9H; 3 CH_3), 0.02 (s, 3H; CH_3), −0.01 (s, 3H; CH_3), −0.02 (s, 9H; CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 156.4 (s), 156.3 (s), 152.7 (s), 141.2 (d), 110.2 (d), 106.9 (d), 80.8 (s), 66.1 (d), 63.8 (t), 61.8 (t), 46.4 (d), 28.0 (c), 25.7 (c), 18.1 (s), 14.6 (c), −1.1 (c), −5.5 (c); IR (neat): $\tilde{\nu}$ = 1732 (C=O), 1705 (C=O) cm^{-1}; MS (70 eV, EI): *m*/*z* (%) = 526 (8) [M^+], 469 (13), 455 (27), 426 (100); anal. calcd for $C_{25}H_{46}N_2O_6Si_2$: C 57.00, H 8.80, N 5.32; found C 57.22, H 8.74, N 5.21.

General procedure for the synthesis of 2,4-diamino alcohols 19 by N−N reduction of pyrazolidines 18: NH_3 was bubbled into a solution of pyrazolidine **18** (0.2 mmol) in THF (10 mL) at −70 °C, until aproximately 10 mL were condensed. Excess Na was added and the solution turned dark blue. The resulting mixture was stirred at −40 °C for 1 h. Then the reaction was quenched by careful addition of solid NH_4Cl, and NH_3 was allowed to evaporate slowly. The residue was diluted with AcOEt (15 mL) and filtered, and the solvents were evaporated in a rotary evaporator. The resulting residue was purified by flash chromatography over SiO_2, with hexane/ethyl acetate/NEt_3 20/1/1 as eluent, to give 2,4-diamino alcohols **19** as spectroscopically pure, colorless syrups. Yields are shown in Table 4.

(−)-(2*S*,3*R*,4*S*)-4-[(*tert*-Butoxycarbonyl)amino]-*O*-(*tert*-butyldimethylsilyl)-2-[(ethoxycarbonyl)amino]-3-phenyl-4-trimethylsilyl-1-butanol (19b): Yield = 87%; R_f = 0.26 (hexane/ethyl acetate/triethylamine 20/1/1); $[\alpha]_D^{27}$ = −1.4 (*c* = 1.20 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.28–7.13 (m, 5H; 5 CH), 5.22 (d, ^3J(H,H) = 9.5 Hz, 1H, NH), 4.76 (d, ^3J(H,H) = 10.6 Hz, 1H, NH), 4.10 (c, ^3J(H,H) = 7.1 Hz, 2H; CH_2), 4.15–4.05 (m, 1H; CH), 3.72-3.62 (m, 1H; CH_2), 3.67 (dd, ^3J(H,H) = 10.6 and 10.0 Hz, 1H; CH_2), 3.44 (dd, ^2J(H,H) = 10.0 Hz, ^3J(H,H) = 5.9 Hz, 1H; CH_2), 3.18 (dd, ^3J(H,H) = 10.0 and 5.9 Hz, 1H; CH), 1.45 (s, 9H; 3 CH_3), 1.23 (t, ^3J(H,H) = 7.1 Hz, 3H; CH_3), 0.85 (s, 9H; 3 CH_3), −0.02 (s, 3H; CH_3), −0.05 (s, 3H; CH_3), −0.24 (s, 9H; 3 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 156.6 (s), 156.1 (s), 140.2 (s), 128.9 (d), 128.3 (d), 127.0 (d), 79.2 (s), 62.6 (t), 60.6 (t), 54.3 (d), 47.3 (d), 42.5 (d), 28.3 (c), 25.7 (c), 18.0 (s), 14.6 (c), −2.8 (c), −5.6 (c); IR (neat): $\tilde{\nu}$ = 3437 (NH), 3333 (NH), 1713 (C=O), 1697 (C=O), 1516, 1507 cm^{-1}; MS (70 eV, EI): *m*/*z* (%) = 538 (<5) [M^+], 523 (<5), 481 (10), 425 (35), 392 (57), 246 (100), 146 (88), 73 (93); anal. calcd for $C_{27}H_{50}N_2O_5Si_2$: C 60.18, H 9.35, N 5.20; found C 60.15, H 9.35, N 5.24.

(−)-(2*S*,3*S*,4*S*)-4-[(*tert*-Butoxycarbonyl)amino]-*O*-(*tert*-butyldimethylsilyl)-2-[(ethoxycarbonyl)amino]-3-(2-furyl)-4-trimethylsilyl-1-butanol (19d): Yield = 84%; R_f = 0.43 (hexane/ethyl acetate/triethylamine 20/1/1); $[\alpha]_D^{26}$ = −19.6 (*c* = 1.38 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.30 (m, 1H; CH), 6.26 (m, 1H; CH), 6.05 (d, ^3J(H,H) = 2.7 Hz, 1H; CH), 5.11 (d, ^3J(H,H) = 9.0 Hz, 1H, NH), 4.63 (d, ^3J(H,H) = 10.6 Hz, 1H, NH), 4.11–4.08 (m, 3H; CH + CH_2), 3.70 (dd, ^2J(H,H) = 10.2 Hz, ^3J(H,H) = 4.4 Hz, 1H; CH_2), 3.61 (dd, ^3J(H,H) = 10.6 and 8.7 Hz, 1H; CH), 3.35 (dd, ^2J(H,H) = 10.2 Hz, ^3J(H,H) = 5.7 Hz, 1H; CH_2), 3.26 (dd, ^3J(H,H) = 8.7 and 5.8 Hz, 1H; CH), 1.43 (s, 9H; 3 CH_3), 1.23 (t, ^3J(H,H) = 7.1 Hz, 3H; CH_3), 0.83 (s, 9H; 3 CH_3), −0.03 (s, 3H; CH_3), −0.06 (s, 3H; CH_3), −0.16 (s, 9H; 3 CH_3); ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C): δ = 156.5 (s), 156.0 (s), 153.0 (s), 141.3 (d), 110.3 (d), 108.3 (d), 79.2 (s), 62.3 (t), 60.6 (t), 52.7 (d), 42.4 (d), 40.9 (d), 28.3 (c), 25.7 (c), 18.0 (s), 14.6 (c), −3.3 (c), −5.65 (c), −5.7 (c); IR (neat): $\tilde{\nu}$ = 3443 (NH), 3439 (NH), 1715 (C=O), 1701 (C=O), 1508, 1250, 1173 cm^{-1}; MS (70 eV, EI): *m*/*z* (%) = 528 (<5) [M^+], 513 (<5), 471 (10), 415 (21), 382 (39), 246 (84), 146 (100); anal. calcd for $C_{25}H_{48}N_2O_6Si_2$: C 56.78, H 9.15, N 5.30; found C 56.69, H 9.10, N 5.32.

0947-6539/99/0503-0894 $ 17.50+.50/0 *Chem. Eur. J.* **1999**, *5*, No. 3

Acknowledgments

We are grateful for the financial support received from the Dirección General de Investigación Científica y Técnica (DGICYT, PB92-1005). F.F-M. is indebted to the Ministerio de Educación y Ciencia (Spain) for a predoctoral fellowship.

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Received: 30 July 1998 [F1274]

0947-6539/99/0503-0896 $ 17.50+.50/0