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1,3-Dichloro-2-butene: a useful precursor for the 2-butene-1,3-dianion and its corresponding 1,3-dipolar synthon

Miguel Yus,* Beatriz Maciá and Cecilia Gómez

Departamento De Química Orgánica, Facultad De Ciencias, Universidad De Alicante, Apdo. 99, 03080 Alicante, Spain

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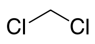
Dedicated to Professor Albert Padwa on occasion of his 65th birthday

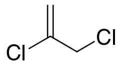
Abstract—The reaction of 1,3-dicloro-2-butene (**1**; 5:1 *Z*:*E*-mixture) with lithium powder and a catalytic amount of 4,4′-di-*tert*-butylbiphenyl (DTBB, 1% molar) in the presence of different electrophiles [EtCHO, Pr^{i}CHO, Bu^{t}CHO, c-C_6H_{11}CHO, Me_2CO, Et_2CO, $(CH_2)_4CO$, $(CH_2)_5CO$, $(c\text{-}C_3H_5)_2CO$, Me_3SiCl] in THF at temperatures ranging between −78 and −50°C gives, after hydrolysis with water, the corresponding products **2** in different *Z*:*E*-ratios depending on the electrophile used. Treatment of some diols **2** with hydrochloric acid gives dienic alcohols **3** or substituted dihydropyrans **4**, depending on the structure of the starting diol. Finally, the same dichlorinated starting material is transformed into the corresponding allylic amines derived from morpholine and benzyl methyl amine and submitted to the same DTBB-catalysed lithiation as above, so after reaction with different electrophiles [Bu^{t}CHO, c-C_6H_{11}CHO, Me_2CO, Et_2CO, $(CH_2)_4CO$, $(CH_2)_5CO$, Me_3SiCl] and final hydrolysis with water, compounds **7** are isolated having a *Z*-configuration. A mechanistic explanation for this behaviour is given. © 2003 Elsevier Science Ltd. All rights reserved.

1. Introduction

The use of carbanions in synthetic organic chemistry is of interest because in the reaction with carbon electrophiles a new carbon–carbon bond is formed and in many cases a new functionality is introduced (i.e. using carbonyl compounds as electrophiles) in the molecule at the same time.[1] Intermediates with carbanion character are in general organometallic compounds in which an alkali or alkaline earth cation is associated to the carbanionic centre.[2] In the case of organolithium compounds,[3] the corresponding polylithiated species[4] have been far less studied than the simple organolithium intermediates due to their instability even under very mild reaction conditions. These compounds, bearing more than one carbanionic centre, are interesting intermediates because reacting with electrophiles can introduce various electrophilic fragments at the same time leading to polyfunctionalised molecules in a direct manner. On the other hand, in the last few years we have been developing a lithiation methodology consisting in using an excess of lithium powder and a substoichiometric (catalytic) amount of an arene as electron carrier,[5,6] naphthalene and 4,4′-di-*tert*-butylbiphenyl (DTBB) being the most commonly used. The application of this procedure to some dichlorinated aliphatic (i.e. 1,1-,[7] 1,2-[8] or 1,3-disubstituted[9] compounds (**I**–**III**, respectively) or aromatic (**IV**[10])) materials under Barbier-type reaction conditions[11] allowed the simultaneous introduction of two equal electrophilic fragments in the molecule. In this paper we report the DTBB-catalysed lithiation of 1,3-dichloro-2-butene and the reaction with electrophiles in order to study both the stereochemistry of the reaction and the possibility to discriminate both carbon–chlorine bonds. In addition, we studied also the introduction of a nucleophile (an amine) and an electrophile (a carbonyl compound or a chlorosilane) in the mentioned C_4-unit.



I



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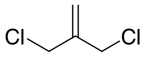

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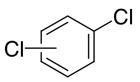

IV

2. Results and discussion

The reaction of commercially available 1,3-dichoro-2-butene (**1**; 5:1 *Z*:*E*) with an excess of lithium powder (1:7 molar ratio; theoretical 1:4) and a catalytic amount of DTBB (1:0.05 molar ratio; ca. 1 mol%) in the presence of different electrophiles [E=EtCHO, Pr^{i}CHO, Bu^{t}CHO, c-C_6H_{11}CHO, Me_2CO, Et_2CO, $(CH_2)_4CO$, $(CH_2)_5CO$, $(c\text{-}C_3H_5)_2CO$, Me_3SiCl] in THF at temperatures ranging between −78 and −50°C led, after hydrolysis with water, to the corresponding products **2** in moderate yields (Scheme 1 and Table 1).

Keywords: chlorine–lithium exchange; dilithium synthon; DTBB-catalysed lithiation; electrophilic substitution.

* Corresponding author. Tel.: +34965903548; fax: +34965903549; e-mail: yus@ua.es

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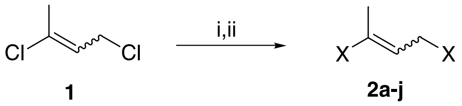


Scheme 1. *Reagents and conditions*: (i) Li powder, DTBB (1 mol%), E=EtCHO, Pr^{i}CHO, Bu^{t}CHO, *c*-C$_6$H$_{11}$CHO, Me$_2$CO, Et$_2$CO, (CH$_2$)$_4$CO, (CH$_2$)$_5$CO, (*c*-C$_3$H$_5$)$_2$CO, Me$_3$SiCl, THF −78 to −50°C; (ii) H$_2$O, −50°C to room temperature.

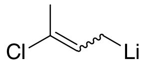
Table 1. Preparation of compounds **2**

Entry	Electrophile E	Product		
		No.	X	Yield (%)[a]
1	EtCHO	**2a**	EtCHOH	40[b,c]
2	Pr^{i}CHO	**2b**	Pr^{i}CHOH	18[b,c]
3	Bu^{t}CHO	**2c**	Bu^{t}CHOH	41[b,c]
4	*c*-C$_6$H$_{11}$CHO	**2d**	C$_6$H$_{11}$CHOH	56[b,c]
5	Me$_2$CO	**2e**	Me$_2$COH	52[c]
6	Et$_2$CO	**2f**	Et$_2$COH	40[c]
7	(CH$_2$)$_4$CO	**2g**	(CH$_2$)$_4$COH	57[d]
8	(CH$_2$)$_5$CO	**2h**	(CH$_2$)$_5$COH	12[c]
9	(*c*-C$_3$H$_5$)$_2$CO	**2i**	(*c*-C$_3$H$_5$)$_2$COH	59[c]
10	Me$_3$SiCl	**2j**	Me$_3$Si	64[e]

[a] Isolated yield after column chromatography (silica gel, hexane/ethyl acetate) based on the starting material **1**.
[b] A ca. 1:1 mixture of diastereomers (300 MHz ^{13}C NMR) was obtained.
[c] Only the *E*-diastereomer was isolated.
[d] A 1:28 *Z*:*E* mixture (300 MHz ^{1}H NMR) was obtained.
[e] A 6:1 *Z*:*E* mixture (300 MHz ^{1}H NMR) was obtained.

Concerning the stereochemistry of the reaction, when aldehydes were used as electrophiles a ca. 1:1 mixture of diastereomers **2a–d** was obtained (Table 1, entries 1–4 and footnotes b and c). In the case of ketones, the corresponding products **2** were isolated as *E*-diastereomers exclusively (**2e**,**f**,**h**,**i**) or as the very major product (**2g**) (Table 1, entries 5–9 and footnotes c and d).[12] Finally, the reaction with chlorotrimethylsilane gave the *Z*-compound as the main product (Table 1, entry 10, and footnote e).

From a mechanistic point of view, we think that the first process is the lithiation of the allylic carbon–chlorine bond giving an intermediate of type **V**. This intermediate can suffer *Z*/*E* isomerization by equilibration through the corresponding carbenoid **VI**. After reacting with the first molecule of the electrophile, a new intermediate **VII** is formed (X′=R^{1}R^{2}COLi, R^{1}R$^2_2$Si), which after lithiation gives the new functionalised organolithium compound[13] **VIII**. Last reaction with the electrophile present in the reaction medium gives the final products **2** with different stereochemistry depending on the electrophile used. In spite of the total conversion of the starting material **1**, the moderate yields obtained can be explained considering the high instability of intermediates of carbenoid type **VI**, which can suffer easily α-elimination to give carbenes even at very low temperatures.[13] When the reaction shown in Scheme 1 was carried out in two steps (Grignard-type conditions), that is performing the lithiation in the absence of the electrophile, only decomposition products were obtained. For this reason, we can rule out the formation of a dilithiated intermediate of type **IX**.



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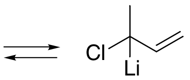
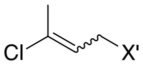
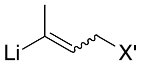


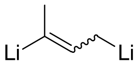
VI



VII

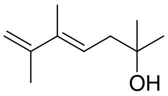


VIII

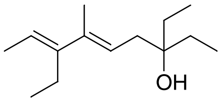


IX

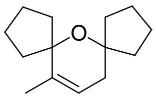
Some of diols **2**, resulting from the reaction with carbonyl compounds, were treated under acidic conditions (2 or 6 M HCl) in order to study the corresponding dehydration, the results being different depending also on the structure of the starting diol. Thus, whereas compounds **2e** or **2f** (both as the *E*-diastereomers) gave dienes **3e** and **3f**, respectively, the corresponding cyclopentanone **2g** (as a 1:28 *Z*:*E* mixture) and cyclohexanone **2h** (as the *E*-diastereomer) derivatives yielded the heterocycles **4g** and **4h**, respectively, in all cases with practically quantitative yields (>95%). It is worthy to note that for compounds **2g** and **2h** an isomerization of the major or unique *E*-diastereomer (through the corresponding allylic cation) had to occur in order to get the corresponding *Z*-isomer suitable for the observed cyclisation.



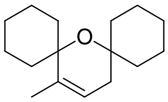
3e



3f



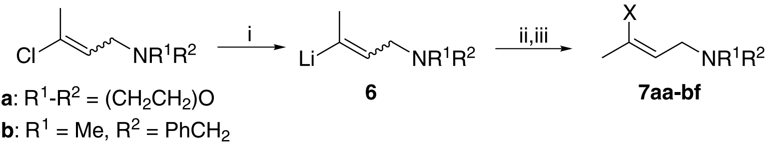
4g



4h

Since it was not possible to discriminate between both carbon–chlorine bonds in the lithiation/S$_E$ reaction of the starting material **1**, we decided to study first the introduction of a nucleophile and then an electrophile through the corresponding DTBB-catalysed lithiation. Thus, the treatment of 1,3-dichloro-2-butene (**1**; 5:1 *Z*:*E* mixture) with morpholine or benzyl methyl amine (in the second case in the presence of sodium hydride) in THF afforded the expected compounds **5a** (66%, 2.5:1 *Z*:*E* mixture) or **5b** (55%, 5:1 *Z*:*E* mixture), respectively. The lithiation of these materials **5** with lithium (1:7 molar ratio) and DTBB (1:0.05 molar ratio; 2.5 mol%) in THF at −78°C led to the corresponding chlorine–lithium exchange, so the organolithium intermediate **6** was formed. After reaction with the corresponding electrophile [Bu^{t}CHO, *c*-C$_6$H$_{11}$CHO, Me$_2$CO, Et$_2$CO, (CH$_2$)$_4$CO, (CH$_2$)$_5$CO, Me$_3$SiCl] and final hydrolysis with water, the expected products **7** were isolated (Scheme 2 and Table 2).

Concerning the stereochemistry of products **7**, we obtained in all cases the *Z*-diastereomer, except when using chlorotrimethylsilane and cyclopentanone as electrophile,



Scheme 2. *Reagents and conditions*: (i) Li powder, DTBB (2.5 mol%), THF, −78°C; (ii) E=$\mathrm{Bu^tCHO}$, c-$\mathrm{C_6H_{11}CHO}$, $\mathrm{Me_2CO}$, $\mathrm{Et_2CO}$, $\mathrm{(CH_2)_4CO}$, $\mathrm{(CH_2)_5CO}$, $\mathrm{Me_3SiCl}$, −78 to −50°C; (iii) $\mathrm{H_2O}$, −50°C to room temperature.

Table 2. Preparation of compounds **7**

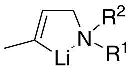
Entry	Starting material	Electrophile E	Product		
			No.	X	Yield (%)[a]
1	**5a**	$\mathrm{Bu^tCHO}$	**7aa**	$\mathrm{Bu^tCHOH}$	43
2	**5a**	c-$\mathrm{C_6H_{11}CHO}$	**7ab**	c-$\mathrm{C_6H_{11}CHOH}$	34
3	**5a**	$\mathrm{Me_2CO}$	**7ac**	$\mathrm{Me_2COH}$	30
4	**5a**	$\mathrm{Et_2CO}$	**7ad**	$\mathrm{Et_2COH}$	54
5	**5a**	$\mathrm{(CH_2)_4CO}$	**7ae**	$\mathrm{(CH_2)_4COH}$	50
6	**5a**	$\mathrm{(CH_2)_5CO}$	**7af**	$\mathrm{(CH_2)_5COH}$	14
7	**5a**	$\mathrm{Me_3SiCl}$	**7ag**	$\mathrm{Me_3Si}$	38[b]
8	**5b**	$\mathrm{Bu^tCHO}$	**7ba**	$\mathrm{Bu^tCHOH}$	84
9	**5b**	c-$\mathrm{C_6H_{11}CHO}$	**7bb**	c-$\mathrm{C_6H_{11}CHOH}$	40
10	**5b**	$\mathrm{Me_2CO}$	**7bc**	$\mathrm{Me_2COH}$	54
11	**5b**	$\mathrm{Et_2CO}$	**7bd**	$\mathrm{Et_2COH}$	60
12	**5b**	$\mathrm{(CH_2)_4CO}$	**7be**	$\mathrm{(CH_2)_4COH}$	45[c]
13	**5b**	$\mathrm{(CH_2)_5CO}$	**7bf**	$\mathrm{(CH_2)_5COH}$	51

[a] Isolated yield after column chromatography (silica gel, hexane/ethyl acetate) based on the starting material **5**; in all cases only the *Z*-diastereomer was obtained, unless otherwise stated.
[b] A 7:1 *Z*:*E* mixture was obtained.
[c] A 10:1 *Z*:*E* mixture was obtained.

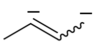
in which a small amount of the *E*-diastereomer was detected (Table 2, entries 7 and 12, and footnotes b and c, respectively). This result indicates that an isomerization should occur in some extension by inversion in the configuration of the sp^2-hybridised organolithium intermediate **6′**. This fact can be explained because the intermediate **6′** (which gave the final *Z*-products with retention in the configuration)[14] is stabilized a lot due to the intramolecular coordination of the lithium atom with the nitrogen atom (the so called CIPE: 'Complex Induced Proximity Effect').[15] On the other hand, curiously better yields for compounds **7** were obtained with chloro amine **5b** than **5a** (Table 2, entries 1–7 and 8–13).

3. Conclusion

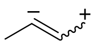
In conclusion, we report here the use of 1,3-dichloro-2-butene as the 1,3-dianionic synthon **X** (to give compounds **2**) or as the dipolar one **XI** (to give compounds **7**), taking advantage in both cases of a DTBB-catalysed lithiation under very mild reaction conditions.



6′



X



XI

4. Experimental

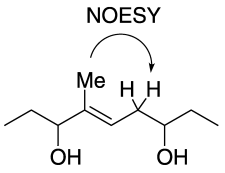
4.1. General

All reactions were carried out under an atmosphere of nitrogen in oven-dried glassware, except the preparation of the chloroamine **5a**. All reagents were commercially available (Acros, Aldrich) and were used without further purification. Commercially available anhydrous THF (99.9%, water content ≤0.006%, Acros) was used as solvent in all the lithiation reactions. IR spectra were measured (film) with a Nicolet Impact 400 D-FT Spectrometer. NMR spectra were recorded with a Bruker AC-300 or a Bruker ADVANCE DRX-500 using $\mathrm{CDCl_3}$ as the solvent. LRMS and HRMS were measured with Shimadzu GC/HS QP-5000 and Finingan MAT95 S spectrometers, respectively. The purity of volatile products and the chromatographic analyses (GLC) were determined with a flame ionization detector and a 30 m capillary column (0.32 mm diam., 0.25 μm film thickness), using nitrogen (2 mL/min) as carrier gas, T_{injector}=275°C, T_{detector}=300°C, T_{column}=60°C (3 min) and 60–270°C (15°C/min), P=40 kPa.

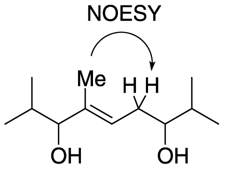
4.2. Preparation of compounds 2

To a cooled suspension of lithium (49 mg, 7 mmol) and DTBB (13 mg, 0.05 mmol) in THF (3 mL) at −78°C was slowly added (ca. 1.5 h) a solution of the corresponding electrophile (2.2 mmol) and 1,3-dichloro-2-butene (110 μL, 1 mmol) in THF (3 mL). The resulting mixture was stirred for 1.5 h allowing the temperature to rise to −50°C and then it was hydrolyzed with water (5 mL) allowing the temperature to rise to 20°C. The resulting mixture was extracted with ethyl acetate (3×10 mL). The organic layer was dried over anhydrous $\mathrm{MgSO_4}$ and evaporated (15 Torr). The resulting residue was then purified by flash chromatography (silica gel, hexane/ethyl acetate). Yield is given in Table 1 and physical, analytical and spectroscopic data follow.

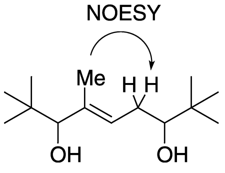
4.2.1. (*E*)-4-Methyl-4-nonene-3,7-diol (2a). Diastereomers mixture: t_r=9.6 min; ν (film) 3358 $\mathrm{cm^{-1}}$ (OH); δ_H 0.73–1.12 [12H, m, 2×$\mathrm{CH_2}$*$\mathrm{CH_3}$*)], 1.40–1.59 [8H, m, 2×*$\mathrm{CH_2}$*$\mathrm{CH_3}$)], 1.62 (6H, s, *$\mathrm{CH_3}$*C=CH), 2.10–2.42 (8H, m, 2×O*H*, *$\mathrm{CH_2}$*CH=C), 3.54–3.60 (2H, m, C*H*OHC$\mathrm{H_2}$-CH=C), 3.90–3.95 (2H, m, C*H*OHC=CH), 5.43 (2H, t, *J*=7.9 Hz, C=CH); δ_C 9.9, 10.0, 11.3, 11.6 ($\mathrm{CH_3}$), 27.4, 27.5, 29.5, 29.7, 34.9, 35.1 ($\mathrm{CH_2}$), 72.9, 73.0 (*C*HOHC$\mathrm{H_2}$-CH=C), 79.1, 79.3 (*C*HOHC=CH), 122.1, 122.7 (C=*C*H), 139.7, 139.8 (*C*=CH); *m*/*z* 154 ($\mathrm{M^+}$−$\mathrm{H_2O}$, 1%), 125 (7), 99 (8), 96 (68), 85 (75), 81 (100), 59 (45), 57 (32), 55 (22); HRMS: $\mathrm{M^+}$−$\mathrm{H_2O}$, found 154.1367. $\mathrm{C_{10}H_{18}O}$ requires 154.1367.



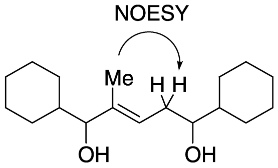
4.2.2. (*E*)-2,4,8-Trimethyl-4-nonene-3,7-diol (2b). Diastereomers mixture: t_r=10.7 min; ν (film) 3387 cm^{-1} (OH); δ_H 0.78–1.16 [24H, m, $2\times(CH_3)_2CH$], 1.62–1.81 [14H, m with a s at 1.62, $CH_3C{=}CH$, $2\times(CH_3)_2CH$, 2×OH], 2.16–2.35 (4H, m, CH_2), 3.39–3.43 (2H, m, $CHOHCH_2CH{=}C$), 3.59–3.64 (2H, m, $CHOHC{=}CH$), 5.43 (2H, t, *J*=6.7 Hz, $C{=}CH$); δ_C 17.4, 17.5, 18.5, 18.6, 18.8, 18.9 (CH_3), 31.0, 31.4 (CHCHOH), 32.4, 32.5 (CH_2), 33.1, 33.2 (CHCHOH), 76.4 ($CHOHCH_2$), 83.9, 84.0 ($CHOHC{=}CH$), 123.5, 123.7 ($C{=}CH$), 139.4, 139.5 ($C{=}CH$); *m/z* 182 (M^+-H_2O, 1%), 157 (10), 110 (16), 95 (51), 85 (100), 73 (29), 55 (28); HRMS: M^+-H_2O, found 182.1666 $C_{12}H_{22}O$ requires 182.1671.



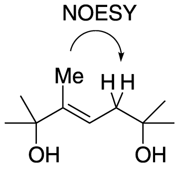
4.2.3. (*E*)-2,2,4,8,8-Pentamethyl-4-nonene-3,7-diol (2c). Diastereomers mixture: t_r=12.0 min; ν (film) 3420 cm^{-1} (OH); δ_H 0.92, 0.93 [36H, 2 s, $2\times C(CH_3)_3$], 1.67 (6H, s, $CH_3C{=}CH$), 2.02–2.07, 2.10–2.24 (4H, 2m, CH_2), 2.55 (4H, s, OH), 3.22–3.29 (2H, m, $CHOHCH_2$), 3.75 (2H, s, $CHOHC{=}CH$), 5.47 (2H, t, *J*=7.0 Hz, $C{=}CH$); δ_C 25.6, 25.7, 26.6, 26.7, 27.1, 26.9 [$C(CH_3)_3$,$CH_3C{=}CH$], 30.0, 30.1 (CH_2), 34.7, 35.4, 35.5 (CCHOH), 79.4, 84.8, 85.0 (CHOH), 125.7, 125.8 ($C{=}CH$), 138.8, 138.9 ($C{=}CH$); *m/z* 210 (M^+-H_2O, 1%), 109 (13), 87 (48), 86 (10), 85 (100), 84 (11), 69 (23), 57 (50), 55 (14), 45 (20), 43 (49), 41 (55); HRMS: M^+-H_2O, found 210.2005. $C_{14}H_{26}O$ requires 210.1984.



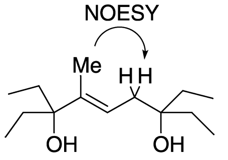
4.2.4. (*E*)-1,5-Dicyclohexyl-2-methyl-2-pentene-1,5-diol (2d). Diastereomers mixture: t_r=16.5 min; ν (film) 3409 (OH), 3050 cm^{-1} (=CH); δ_H 0.92–1.42, 1.68–1.87 (44H, 2m, 2×CH, 10×ring CH_2), 1.60 (6H, s, CH_3), 2.13–2.20 (4H, m, CH_2CHOH), 3.37 (2H, m, CH_2CHOH), 3.62 (2H, m, $CHOHC{=}CH$), 5.38 (2H, t, *J*=8.24 Hz, $C{=}CH$); δ_C 11.5, 11.5 (CH_3), 25.9, 26.1, 26.2, 26.3, 26.4, 26.5, 27.9, 28.2, 29.2, 29.6, 29.6, 32.4 (ring CH_2, CH_2CHOH), 40.4, 43.0, 43.2 (CHCHOH), 75.7, 75.8 (CH_2CHOH), 83.0 ($CHOHC{=}CH$), 123.8, 124.0, ($C{=}CH$), 139.1, 139.2 ($C{=}CH$); *m/z* 262 (M^+-H_2O, 1%), 150 (39), 135 (30), 121 (12), 95 (45), 85 (100), 84 (10), 83 (16), 81 (10), 67 (13), 55 (38); HRMS: M^+-H_2O, found 262.2254. $C_{18}H_{30}O$ requires 262.2297.



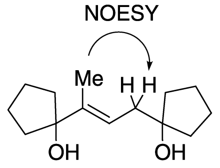
4.2.5. (*E*)-2,3,6-Trimethyl-3-heptene-2,6-diol (2e). t_r=8.5 min; ν (film) 3382 (OH), 1660 cm^{-1} (C=C); δ_H 1.21 [6H, s, $(CH_3)_2COHCH_2$], 1.33 [6H, s, $(CH_3)_2COHC{=}C$], 1.68 (3H, s, $CH_3C{=}C$), 2.20 (2H, d, *J*=8.2 Hz, CH_2), 5.67 (1H, t, *J*=8.2 Hz, $C{=}CH$); δ_C 13.0 ($CH_3C{=}C$), 29.1, 29.2 [$(CH_3)_2COH$], 41.6 (CH_2), 71.5, 73.6 (COH), 117.3 ($C{=}CH$), 144.1 ($C{=}CH$); *m/z* 139 (M^+-H_2O–Me, 3.5%), 121 (11), 99 (12), 96 (61), 81 (76), 79 (13), 59 (100), 55 (12), 43 (96), 41 (35); HRMS: M^+-H_2O, found 154.1362. $C_{10}H_{18}O$ requires 154.1358.

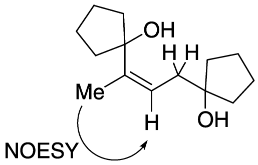


4.2.6. (*E*)-3,7-Diethyl-4-methyl-4-nonene-3,7-diol (2f). t_r=11.6 min; ν (film) 3428 cm^{-1} (OH); δ_H 0.77 [6H, t, *J*=7.6 Hz, $(CH_3CH_2)_2COHC{=}CH$], 0.87 [6H, t, *J*=7.3 Hz, $(CH_3CH_2)_2COHCH_2$], 1.46–1.67 [11H, m, $CH_3C{=}C$, 2× $(CH_3CH_2)_2COH$], 2.23 (2H, d, *J*=7.5 Hz, $CH_2CH{=}C$), 5.55 (1H, t, *J*=7.5 Hz, $C{=}CH$); δ_C 7.6, 7.9 (CH_3CH_2), 13.4 ($CH_3C{=}CH$), 31.0, 31.8 (CH_3CH_2), 36.7 ($CH_2CH{=}C$), 75.1, 78.5 (COH), 119.3 ($C{=}CH$), 139.9 ($C{=}CH$); *m/z* 199 (M^+–Et, 1%), 181 (6), 163 (12), 124 (80), 113 (37), 109 (43), 107 (10), 95 (58), 87 (76), 85 (12), 81 (10), 69 (29), 67 (21), 57 (100), 55 (26), 45 (93), 43 (64), 41 (60); HRMS: M^+-H_2O, found 210.1997. $C_{14}H_{26}O$ requires 210.1984.



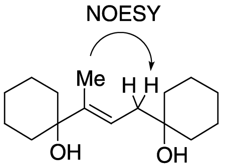
4.2.7. (*Z*/*E*)-1-[3-(1-Hydroxycyclopentyl)-2-butenyl]-1-cyclopentanol (2g). Mixture (*Z*/*E*): 1/28: t_r (*Z*)=12.6 min; t_r (*E*)=13.2 min; ν (film) 3387 (OH), 3047 cm^{-1} (=CH); δ_H 1.64–1.86 (38H, m, 8×ring CH_2, CH_3), 2.31 [2H, d, *J*=7.3 Hz, CH_2 (*E*)], 2.44 [2H, d, *J*=7.3 Hz, CH_2 (*Z*)], 2.64 (4H, br s, 2×OH), 5.53 [1H, t, *J*=7.3 Hz, $C{=}CH$ (*Z*)], 5.66 [1H, t, *J*=7.3 Hz, $C{=}CH$ (*E*)]; δ_C 13.4, 14.2 (CH_3), 23.0, 23.5, 23.6, 23.7 [$(CH_2)_4COHC{=}CH$)], 39.1, 39.2, 39.3, 39.7 [$(CH_2)_4COHCH_2$], 82.4, 82.5, 84.8 (COH), 122.8, 125.6 ($C{=}CH$), 141.6, 145.3 ($C{=}CH$); *m/z* (*Z*) 206 (M^+, 1%), 145 (12), 123 (10), 122 (100), 107 (73), 93 (38), 91 (22), 85 (55), 79 (26), 77 (15), 67 (39), 57 (11), 55 (26); HRMS: M^+-H_2O, found 206.1650. $C_{14}H_{22}O$ requires 206.1671; *m/z* (*E*) 206 (M^+, 1%), 145 (10), 123 (10), 122 (100), 107 (77), 105 (13), 93 (43), 91 (27), 85 (63), 79 (28), 77 (17), 67 (43), 57 (12), 55 (24); HRMS: M^+-H_2O, found, 206.1634. $C_{14}H_{22}O$ requires, 206.1671.





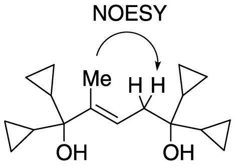
4.2.8. (*E*)-1-[3-(1-Hydroxycyclohexyl)-2-butenyl]-1-cyclohexanol (2h).

t_r=14.5 min; ν (film) 3372 cm^{-1} (OH); δ_H 1.22–1.69 (23H, m, 10×ring CH_2, CH_3), 2.21 (2H, d, *J*=7.5 Hz, $CH_2CH{=}C$), 5.67 (1H, t, *J*=7.5 Hz, C=CH); δ_C 12.9 (CH_3), 22.1, 22.2, 25.6, 25.8, 35.9, 37.4, 40.7 (ring CH_2, $CH_2CH{=}C$), 72.0, 74.3 (*C*OH), 117.5 (C=*C*H), 144.6 (*C*=CH); *m/z* 234 (M^+-H_2O, 1%), 221 (55), 137 (10), 136 (100), 108 (13), 107 (54), 105 (12), 99 (65), 93 (29), 91 (32), 81 (94), 80 (10), 79 (50), 78 (12), 77 (29), 69 (10), 67 (22), 65 (14), 57 (16), 55 (59), 53 (21), 43 (40), 42 (13), 41 (70); HRMS: M^+-H_2O, found 234.1994. $C_{16}H_{26}O$ requires 234.1984.



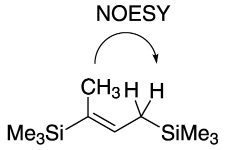
4.2.9. (*E*)-1,1,5,5-Tetracyclopropyl-2-methyl-2-pentene-1,5-diol (2i).

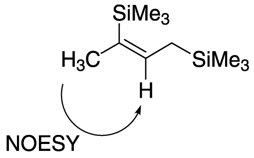
t_r=15.1 min; ν (film) 3482 (OH), 3084 cm^{-1} (=CH); δ_H 0.24–0.56, 0.79–0.99 (20H, 2m, 4×ring CH, 8×ring CH_2), 1.80 (3H, s, CH_3), 2.38 (2H, d, *J*=7.5 Hz, $CH_2CH{=}C$), 5.85 (1H, t, *J*=7.5 Hz, C=CH); δ_C 0.7, 1.7 (ring CH_2), 18.3, 18.4, 18.6 (CH_3, ring CH), 40.5 (CH_2-CH=C), 71.0, 73.8 (*C*OH), 118.1 (C=*C*H), 143.2 (*C*=CH); *m/z* 258 (M^+-H_2O, 1%), 148 (20), 133 (14), 120 (38), 111 (54), 105 (28), 91 (20), 79 (11), 77 (10), 69 (95), 55 (31), 53 (12), 43 (21), 41 (100); HRMS: M^+-H_2O, found 258.1992. $C_{18}H_{26}O$ requires 258.1984.



4.2.10. (*Z*/*E*)-1,3-Bis(trimethylsilyl)-2-butene (2j).[16]

Mixture (*Z*/*E*): 6/1: t_r (*Z*)=6.7 min; t_r (*E*)=6.9 min; ν (film) 1609 (C=C), 837 cm^{-1} (Si–C); δ_H 0.00–0.14 [36H, m, $(CH_3)_3Si$], 1.62, 1.62 [5H, s and d, *J*=7.3 Hz, $CH_3C{=}CH$, CH_2 (*Z*)], 1.75 [5H, br s, $CH_3C{=}CH$, CH_2 (*E*)], 5.81 [1H, t, *J*=7.3 Hz, C=CH (*Z*)], 6.00 [1H, t, *J*=6.8 Hz, C=CH (*E*)]; δ_C −2.1, −2.0, −1.9, −1.5 (CH_3Si), 14.2, 20.4, 22.7 ($CH_3C{=}CH$), 24.6 (CH_2), 131.6, 132.8 (C=*C*H), 135.2, 138.1 (*C*=CH); *m/z* (*Z*) 200 (M^+, 5%), 112 (56), 97 (30), 74 (14), 73 (100), 56 (12), 45 (42), 43 (16); HRMS: M^+, found M^+, 200.1396, $C_{10}H_{24}Si_2$ requires 200.1416); *m/z* (*E*) 200 (M^+, 3%), 112 (35), 97 (20), 74 (10), 73 (100), 45 (23), 43 (10); HRMS: M^+, found 200.1387. $C_{10}H_{24}Si_2$ requires 200.1416.



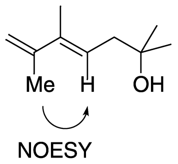


4.3. Acidic treatment of diols 2. Isolation of compounds 3 and 4

To a solution of the corresponding diol (0.5 mmol) in ether (3 mL) was added HCl 2 M (3 mL) for the diol **2d** or HCl 6 M (3 mL) for the other. The mixture was stirred between 12 and 72 h. The resulting mixture was extracted with ether (3×10 mL). The organic layer was dried over anhydrous $MgSO_4$ and evaporated (15 Torr). The resulting residue was then purified by flash chromatography (silica gel, hexane/ethyl acetate). Yield is given in the text and physical, analytical and spectroscopic data follow.

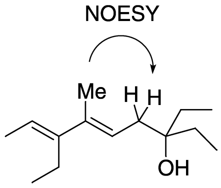
4.3.1. (4*E*)-2,5,6-Trimethyl-4,6-heptadien-2-ol (3e).

t_r=7.5 min; ν (film) 3412 (OH), 3093 cm^{-1} (=CH); δ_H 1.25 [6H, s, $(CH_3)_2C$], 1.84 (3H, s, $CH_3C{=}CH$), 1.94 (3H, s, $CH_3C{=}CH_2$), 2.35 (2H, d, *J*=7.7 Hz, $CH_2CH{=}C$), 4.98 (2H, d, *J*=29.9 Hz, $CH_2{=}C$), 5.71 (1H, t, *J*=7.7 Hz, C=CH); δ_C 13.9 ($CH_3C{=}CH$), 20.9 ($CH_3C{=}CH_2$), 29.2 [$(CH_3)_2C$], 42.6 ($CH_2CH{=}C$), 71.6 (COH), 111.7 ($CH_2{=}C$), 122.9 (C=*C*H), 137.7 (*C*=CH), 144.6 ($CH_2{=}C$); *m/z* 139 (M^+, 1%), 96 (30), 81 (35), 59 (100), 43 (54), 41 (26); HRMS: M^+, found 139.1104. $C_9H_{15}O$ requires 139.1123.



4.3.2. (5*E*,7*E*)-3,7-Diethyl-6-methyl-5,7-nonadien-3-ol (3f).

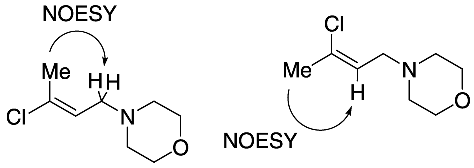
t_r=10.4 min; ν (film) 3400 cm^{-1} (OH); δ_H 0.86–0.98, 1.46–1.53 [13H, 2m, $(CH_3CH_2)_2C$, $CH_3CH_2C{=}CH$], 1.70 (3H, d, *J*=6.7 Hz, $CH_3CH{=}C$), 1.77 (3H, s, CH_3-C=CH), 2.24–2.29 (4H, m, $CH_2CH{=}C$, $CH_2C{=}CH$), 5.53 (2H, t, *J*=6.7 Hz, 2×C=CH); δ_C 7.9 [$(CH_3CH_2)_2C$], 13.5, 13.6, 14.7 ($CH_3C{=}CH$, $CH_3CH{=}C$, CH_3CH_2-C=CH), 20.5 ($CH_3CH_2C{=}CH$), 31.1, 37.3 [$(CH_3CH_2)_2C$, $CH_2CH{=}C$], 75.3 (COH), 119.3, 119.9 (C=*C*H), 138.0 ($CH_3C{=}CH$), 144.4 ($CH_3CH{=}C$); *m/z* 210 (M^+, 1%), 196 (12), 195 (85), 181 (34), 163 (34), 141 (14), 125 (11), 123 (32), 109 (51), 97 (49), 95 (23), 83 (19), 81 (15), 69 (25), 67 (18), 57 (100), 55 (38), 53 (10); HRMS: M^+, found 210.1990. $C_{14}H_{26}O$ requires 210.1984.



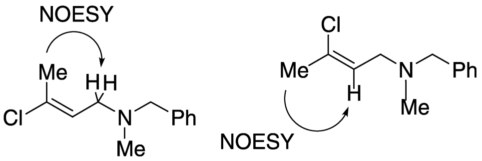
4.3.3. 12-Methyl-6-oxadispiro[4.1.4.3]tetradec-12-ene (4g). t_r=10.7 min; ν (film) 3047 cm^{-1} (=CH); δ_H 0.83–0.97 [8H, m, (C*H*$_2$)$_4$CCH$_2$], 1.33 (3H, s, CH$_3$), 1.54–1.89 [8H, m, (C*H*$_2$)$_4$CC=CH], 2.31 (2H, t, *J*=7.3 Hz, C*H*$_2$-CH=C), 5.54 (1H, br s, C=CH); δ_C 14.2 (CH$_3$), 23.8, 23.9, 32.2, 32.3 (ring CH$_2$), 39.7 (*C*H$_2$CH=C), 82.3 [(CH$_2$)$_4$-*C*C=CH], 91.4 [(CH$_2$)$_4$*C*CH$_2$], 122.9 (C=*C*H), 150.4 (*C*=CH); *m/z* 206 (M$^+$, 13%), 192 (15), 191 (100), 173 (24), 149 (17), 131 (11), 121 (18), 111 (18), 107 (28), 95 (26), 93 (33), 91 (20), 81 (13), 79 (27), 77 (14), 67 (23), 55 (21); HRMS: M$^+$, found 206.1660. $C_{14}H_{22}O$ requires 206.1671.

4.3.4. 14-Methyl-7-oxadispiro[5.1.5.3]hexadec-14-ene (4h). t_r=12.2 min; ν (film) 3043 cm^{-1} (=CH); δ_H 1.27–1.33, 1.54–1.78 (23H, 2m, 10×ring CH$_2$, CH$_3$), 1.97 (2H, br d, C*H*$_2$CH=C), 5.76 (1H, br s, C=CH); δ_C 22.5, 23.2, 24.1, 25.1, 25.7, 35.4, 36.0, 38.3, 39.2 (ring CH$_2$), 27.8 (CH$_3$), 83.0, 84.5 (*C*C=CH, *C*CH$_2$CH=C), 118.6 (C=*C*H), 142.7 (*C*=CH); *m/z* 234 (M$^+$, 3%), 220 (16), 219 (100), 135 (28), 125 (12), 121 (31), 109 (29), 107 (13), 95 (26), 93 (21), 91 (16), 81 (24), 79 (25), 77 (11), 67 (19), 55 (25); HRMS: M$^+$, found 234.2021. $C_{16}H_{26}O$ requires 234.1984.

4.3.5. Preparation of (*Z*/*E*)-2-chloro-4-morpholino-2-butene (5a). To a solution of 1,3-dichloro-2-butene (1.12 mL, 10 mmol) in THF (30 mL) was added morpholine (1.76 mL, 20 mmol). After 24 h stirring at room temperature the reaction mixture was hydrolyzed with water (25 mL), neutralized with 4 M NaOH and extracted with ethyl acetate (3×30 mL). The organic layer was dried over anhydrous MgSO$_4$ and evaporated (15 Torr). The resulting residue was then purified by flash chromatography (silica gel, hexane/ethyl acetate) to give the title compound in 66% yield as a 5/2 *Z*/*E* mixture; t_r (*Z*)=8.8 min; t_r (*E*)=8.9 min; ν (film) 1665 (C=C), 1119 cm^{-1} (C–O–C)); δ_H 2.08 [3H, s, CH$_3$ (*Z*)], 2.06 [3H, s, CH$_3$ (*E*)], 2.43 [4H, br s, N(C*H*$_2$CH$_2$)$_2$O (*Z*)], 2.44 [4H, br s, N(C*H*$_2$CH$_2$)$_2$O (*E*)], 2.95 [2H, d, *J*=7.5 Hz, C*H*$_2$CH=C (*E*)], 3.10 [2H, d, *J*=6.4 Hz, C*H*$_2$CH=C (*Z*)], 3.65 [8H, t, *J*=4.3 Hz, N(CH$_2$C*H*$_2$)$_2$O], 5.56 [1H, t, *J*=6.4 Hz, C=CH (*Z*)], 5.67 [1H, t, *J*=7.5 Hz, C=CH (*E*)]; δ_C 20.4, 25.4 (CH$_3$), 52.7, 55.6, 56.0 [*C*H$_2$CH=C, N(*C*H$_2$CH$_2$)$_2$O], 66.0 [N(CH$_2$*C*H$_2$)$_2$O], 121.5, 123.3 (C=*C*H), 132.0, 132.1 (*C*=CH); *m/z* (*Z*) 175 (M$^+$, 21%), 140 (68), 112 (17), 110 (87), 100 (46), 91 (32), 89 (100), 87 (67), 86 (39), 82 (32), 57 (19), 56 (51), 55 (15), 54 (14), 53 (72), 51 (10); HRMS: M$^+$, found 175.0785. $C_8H_{14}ONCl$ requires 175.0764; *m/z* (*E*) 175 (M$^+$, 30%), 174 (10), 140 (62), 112 (14), 110 (100), 100 (43), 91 (31), 89 (98), 87 (27), 86 (28), 82 (29), 56 (33), 55 (12), 54 (12), 53 (59); HRMS: M$^+$, found 175.0776. $C_8H_{14}ONCl$ requires 175.0764.



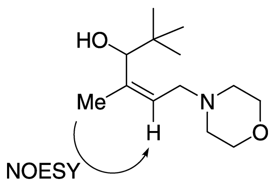
4.3.6. Preparation of (*Z*/*E*)-*N*-benzyl-*N*-methyl-3-chloro-2-buten-1-amine (5b).[17] Benzyl methyl amine (1.33 mL, 11 mmol) was added dropwise to a suspension of sodium hydride (280 mg, 11 mmol) in THF (50 mL) at 0°C. The mixture was refluxed for 2 h. Then, 1,3-dichloro-2-butene (1.12 mL, 10 mmol) was added to the resulting mixture maintaining the reflux for 16 additional hours. After cooling it to ambient temperature it was hydrolyzed with water (20 mL), neutralized with 4 M NaOH and extracted with ethyl acetate (3×30 mL). The organic layer was dried over anhydrous MgSO$_4$ and evaporated (15 Torr). The resulting residue was then purified by flash chromatography (silica gel, hexane/ethyl acetate) to give the title compound in 55% yield as a 5/1 *Z*/*E* mixture; t_r (*Z*)=9.6 min; t_r (*E*)=9.7 min; ν (film) 3028 cm^1 (=CH); δ_H 1.96 [3H, s, C*H*$_3$C=CH (*E*)], 2.07 [3H, s, C*H*$_3$C=CH (*Z*)], 1.99 [3H, s, CH$_3$N (*E*)], 2.12 [3H, s, CH$_3$N(*Z*)], 2.95 [2H, d, *J*=7.3 Hz, C=CHC*H*$_2$ (*E*)], 3.15 [2H, d, *J*=6.6 Hz, C=CHC*H*$_2$ (*Z*)], 3.43 [2H, s, CH$_2$Ar (*E*)], 3.46 [2H, s, CH$_2$Ar (*Z*)], 5.59 [1H, t, *J*=6.6 Hz, C=CH (*Z*)], 5.74 [1H, t, *J*=7.3 Hz, C=CH (*E*)], 7.17–7.28 (10H, m, ArH); δ_C 21.0, 26.0 (*C*H$_3$C=CH), 41.7, 41.9 (CH$_3$N), 55.2, 54.4 (C=CH*C*H$_2$), 61.3, 61.6 (CH$_2$Ar), 123.0, 124.6, 126.7, 126.8, 127.9, 128.0, 128.4, 128.7 (C=*C*H, ArCH), 131.9, 132.0 (*C*=CH), 138.5, 138.7 (ArC); *m/z* (*Z*) 209 (M$^+$, 7%), 174 (20), 134 (17), 132 (12), 121 (23), 120 (23), 92 (13), 91 (100), 89 (15), 65 (16), 53 (17); HRMS: M$^+$, found 209.0970. $C_{12}H_{16}NCl$ requires 209.1779; *m/z* (*E*) 209 (M$^+$, 14%), 208 (12), 174 (29), 134 (21), 132 (19), 120 (11), 118 (12), 92 (12), 91 (100), 89 (16), 65 (15), 53 (15); HRMS: M$^+$, found 209.0951. $C_{12}H_{16}NCl$ requires 209.0971.



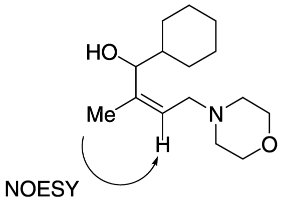
4.4. Preparation of compounds 7

To a cooled suspension of lithium (49 mg, 7 mmol) and DTBB (13 mg, 0.05 mmol) in THF (5 mL) at −78°C was added the corresponding chloroamine **5a** or **5b** (1 mmol). The mixture was stirred for 3 h at the same temperature. Then, was added the corresponding electrophile (1.1 mmol). The resulting mixture was stirred for 3 additional hours. allowing the temperature to rise to −50°C and then it was hydrolyzed with water (5 mL) allowing the temperature to rise to 20°C. The resulting mixture was extracted with ethyl acetate (3×10 mL). The organic layer was dried over anhydrous MgSO$_4$ and evaporated (15 Torr). The resulting residue was then purified by flash chromatography (silica gel, hexane/ethyl acetate). Yield is given in Table 2 and physical, analytical and spectroscopic data follow.

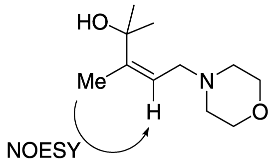
4.4.1. (*Z*)-2,2,4-Trimethyl-6-morpholino-4-hexen-3-ol (7aa). t_r=12.0 min; ν (film) 3443 cm^{-1} (OH); δ_H 0.95 [9H, s, $(CH_3)_3C$], 1.81 (3H, s, $C\mathit{H}_3C{=}CH$), 2.43–2.56, 2.86–2.93, 3.03–3.09 [8H, 3m, $N(CH_2CH_2)_2O$], 3.73 (2H, d, *J*=6.7 Hz, $C\mathit{H}_2CH{=}C$), 3.88 (1H, br s, OH), 4.07 (1H, s, $C\mathit{H}OH$), 5.45 (1H, t, *J*=6.7 Hz, $C{=}CH$); δ_C 22.0, 26.8 [$\mathit{C}H_3C{=}CH$, $(\mathit{C}H_3)_3C$], 55.9, 60.2 [$\mathit{C}H_2CH{=}C$, $N(\mathit{C}H_2CH_2)_2O$], 66.7 [$N(CH_2\mathit{C}H_2)_2O$], 78.5 (COH), 124.1 ($C{=}\mathit{C}H$), 141.4 ($\mathit{C}{=}CH$); *m*/*z* 227 (M$^+$, 13%), 170 (20), 140 (27), 125 (12), 107 (10), 100 (12), 97 (10), 88 (90), 86 (14), 84 (14), 83 (100), 82 (12), 57 (36), 56 (15), 55 (27); HRMS: M$^+$, found 209.1758. $C_{13}H_{23}ON$ requires 209.1779.



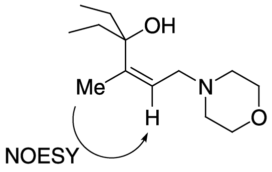
4.4.2. (*Z*)-1-Cyclohexyl-2-methyl-4-morpholino-2-buten-1-ol (7ab). t_r=14.7 min; ν (film) 3437 (OH), 3047 cm^{-1} (C=C); δ_H 0.88–1.19, 1.44–1.55, 1.68–1.80 (13H, 3m with a s at 1.69, 5×ring CH_2, CH_3), 2.00 (1H, d, *J*=7.7 Hz, ring CH), 2.48 [4H, t, *J*=4.8 Hz, $N(C\mathit{H}_2CH_2)_2O$], 2.96 (2H, d, *J*=6.9 Hz, $C\mathit{H}_2CH{=}C$), 3.45 (1H, br s, OH), 3.71 [4H, t, *J*=4.8 Hz, $N(CH_2C\mathit{H}_2)_2O$], 4.04 (1H, d, *J*=7.7 Hz, $C\mathit{H}OH$), 5.42 (1H, t, *J*=6.9 Hz, $C{=}CH$); δ_C 19.9 (CH_3), 26.0, 26.2, 26.4, 29.0, 29.4 (ring CH_2), 41.4 ($\mathit{C}HCHOH$), 53.3, 55.2 ($\mathit{C}H_2CH{=}C$, $N(\mathit{C}H_2CH_2)_2O$], 66.8 [$N(CH_2\mathit{C}H_2)_2O$], 75.7 (COH), 123.1 ($C{=}\mathit{C}H$), 142.4 ($\mathit{C}{=}CH$); *m*/*z* 253 (M$^+$, 1%), 170 (31), 166 (37), 151 (26), 140 (22), 100 (32), 88 (90), 87 (48), 86 (28), 84 (18), 83 (100), 82 (11), 81 (12), 57 (27), 56 (20), 55 (62); HRMS: M$^+-H_2O$, found 235.1921. $C_{15}H_{25}ON$ requires 235.1936.



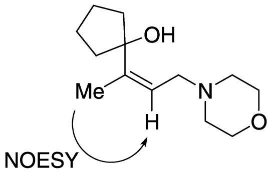
4.4.3. (*Z*)-2,3-Dimethyl-5-morpholino-3-penten-2-ol (7ac). t_r=10.9 min; ν (film) 3419 cm^{-1} (OH); δ_H 1.32 [6H, s, $(C\mathit{H}_3)_2COH$], 1.74 (3H, s, $C\mathit{H}_3C{=}CH$), 2.57 [4H, br s, $N(C\mathit{H}_2CH_2)_2O$], 3.06 (2H, br s, $C\mathit{H}_2CH{=}C$), 3.73 [4H, br s, $N(CH_2C\mathit{H}_2)_2O$], 5.24 (1H, t, *J*=5.8 Hz, $C{=}CH$); δ_C 23.4 ($\mathit{C}H_3C{=}CH$), 29.4 [$(\mathit{C}H_3)_2COH$)], 52.6, 55.4 [$\mathit{C}H_2CH{=}C$, $N(\mathit{C}H_2CH_2)_2O$], 66.5 [N $(CH_2\mathit{C}H_2)_2O$], 73.7 (COH), 117.2 ($C{=}\mathit{C}H$), 149.9 ($\mathit{C}{=}CH$); *m*/*z* 199 (M$^+$, 1%), 181 (16), 138 (12), 100 (14), 97 (20), 87 (11), 86 (15), 57 (13), 56 (21), 55 (19), 44 (10), 43 (100), 42 (21), 41 (31); HRMS: M$^+$, found 119.1570. $C_{11}H_{21}O_2N$ requires 199.1572.



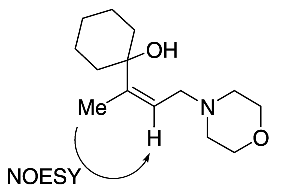
4.4.4. (*Z*)-3-Ethyl-4-methyl-6-morpholino-4-hexen-3-ol (7ad). t_r=12.0 min; ν (film) 3200 cm^{-1} (OH); δ_H 0.86 (6H, t, *J*=7.4 Hz, 2×$C\mathit{H}_3CH_2$), 1.38–1.69 (7H, m with a s at 1.62, 2×$CH_3C\mathit{H}_2$, $C\mathit{H}_3C{=}CH$), 2.54 [4H, br s, $N(C\mathit{H}_2CH_2)_2O$], 2.96 (2H, d, *J*=6.8 Hz, $C\mathit{H}_2CH{=}C$), 3.70 [4H, t, *J*=4.5 Hz, $N(CH_2C\mathit{H}_2)_2O$], 5.47 (1H, t, *J*=6.8 Hz, $C{=}CH$); δ_C 7.7 ($\mathit{C}H_3C{=}CH$), 22.7 ($\mathit{C}H_3CH_2$), 33.5 ($CH_3\mathit{C}H_2$), 52.6, 55.3 [$C{=}CH\mathit{C}H_2$, $N(\mathit{C}H_2CH_2)_2O$], 66.6 [$N(CH_2\mathit{C}H_2)_2O$], 79.9 (COH), 121.9 ($C{=}\mathit{C}H$), 146.0 ($\mathit{C}{=}CH$); *m*/*z* 227 (M$^+$, 2%), 209 (25), 198 (46), 194 (49), 140 (28), 138 (11), 123 (11), 122 (11), 113 (11), 112 (19), 111 (100), 100 (22), 95 (10), 88 (43), 87 (16), 86 (22), 83 (19), 57 (46), 56 (18), 55 (33); HRMS: M$^+$, found 227.1894. $C_{13}H_{25}O_2N$ requires 227.1885.



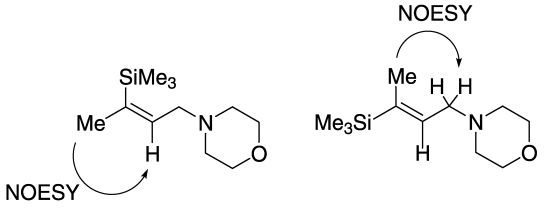
4.4.5. (*Z*)-1-[1-Methyl-3-morpholino-1-propenyl]-1-cyclopentanol (7ae). t_r=12.0 min; ν (film) 3417 cm^{-1} (OH); δ_H 1.64–1.89 (11H, m with a s at 1.73, 4×ring CH_2, CH_3), 2.48 [4H, br s, $N(C\mathit{H}_2CH_2)_2O$], 3.03 (2H, d, *J*=6.1 Hz, $C\mathit{H}_2CH{=}C$), 3.73 [4H, t, *J*=4.9 Hz, $N(CH_2C\mathit{H}_2)_2O$], 5.64 (1H, t, *J*=6.1 Hz, $C{=}CH$); δ_C 13.6 (CH_3), 23.5, 38.3 (ring CH_2), 53.6, 56.4 [$C{=}CH\mathit{C}H_2$, $N(\mathit{C}H_2CH_2)_2O$], 66.9 [$N(CH_2\mathit{C}H_2)_2O$], 84.8 (COH), 118.8 ($C{=}\mathit{C}H$), 143.0 ($\mathit{C}{=}CH$); *m*/*z* 225 (M$^+$, 3%), 208 (14), 207 (74), 206 (14), 192 (24), 140 (36), 138 (49), 121 (28), 112 (18), 110 (29), 109 (27), 108 (16), 100 (41), 96 (13), 95 (28), 94 (11), 93 (23), 88 (38), 87 (100), 86 (58), 83 (12), 82 (27), 81 (14), 79 (17), 77 (11), 69 (13), 67 (17), 57 (54), 56 (31), 55 (42), 54 (13), 53 (16); HRMS: M$^+$, found 225.1718. $C_{13}H_{23}O_2N$ requires 225.1729.



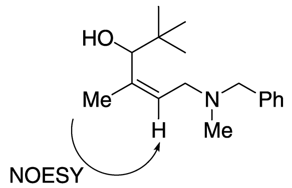
4.4.6. (*Z*)-1-[1-Methyl-3-morpholino-1-propenyl]-1-cyclohexanol (7af). t_r=13.9 min; ν (film) 3411 (OH), 3031 cm^{-1} (C=C); δ_H 0.88–1.80 (13H, m with a s at 1.74, 5×ring CH_2, CH_3), 2.53 [4H, br s, $N(C\mathit{H}_2CH_2)_2O$], 3.02 (2H, d, *J*=6.4 Hz, $C\mathit{H}_2CH{=}C$), 3.70 [4H, br s, $N(CH_2C\mathit{H}_2)_2O$], 5.25 (1H, t, *J*=6.4 Hz, $C{=}CH$); δ_C 25.6 (CH_3), 21.2, 23.1, 35.8 (ring CH_2), 52.7 [$N(\mathit{C}H_2CH_2)_2O$], 55.7, 66.7 [$\mathit{C}\mathrm{H_2CH{=}C}$, $\mathrm{N(CH_2}\mathit{C}\mathrm{H_2)_2O}$], 74.6 (COH), 118.3 (C=*C*H), 149.5 (*C*=CH); *m*/*z* 239 ($\mathrm{M^+}$, 13%), 222 (12), 221 (70), 206 (26), 196 (30), 182 (13), 152 (26), 140 (79), 138 (61), 137 (18), 136 (14), 135 (47), 134 (33), 124 (14), 123 (42), 121 (10), 119 (20), 112 (37), 110 (28), 109 (86), 107 (19), 106 (12), 105 (14), 100 (65), 98 (11), 97 (12), 96 (28), 95 (35), 94 (15), 93 (29), 88 (100), 87 (93), 86 (79), 83 (19), 82 (32), 81 (36), 80 (11), 79 (28), 77 (16), 71 (12), 69 (23), 68 (12), 67 (25), 57 (57), 56 (49), 55 (73), 54 (20), 53 (27); HRMS: $\mathrm{M^+}$, found 239.1899. $\mathrm{C_{14}H_{25}O_2N}$ requires 239.1885.



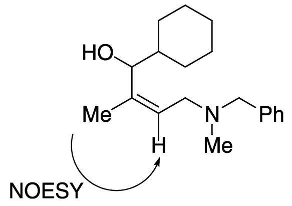
4.4.7. (*E*)-Trimethyl[1-methyl-3-morpholino-1-propenyl]silane (7ag). Mixture *Z*/*E*: 7/1: t_r (*Z*)=9.9 min; t_r (*E*)=10.0 min; ν (film) 844 $\mathrm{cm^{-1}}$ (Si–C); δ_H 0.04 [9H, s, $\mathrm{(CH_3)_3}$ Si (*E*)], 0.14 [9H, s, $\mathrm{(CH_3)_3}$ Si (*Z*)], 1.68 [3H, s, $\mathrm{C}\mathit{H}_3\mathrm{C{=}CH}$ (*E*)], 1.78 [3H, s, $\mathrm{C}\mathit{H}_3\mathrm{C{=}CH}$ (*Z*)], 2.45 [8H, br d, *J*=4.5 Hz, $\mathrm{N(C}\mathit{H}_2\mathrm{CH_2)_2O}$], 3.02 (4H, m, $\mathrm{C}\mathit{H}_2\mathrm{CH{=}C}$), 3.71 [8H, br d, *J*=4.5 Hz, $\mathrm{N(CH_2C}\mathit{H}_2\mathrm{)_2O}$], 5.99 [1H, t, *J*=3.5 Hz, C=CH (*E*)], 6.04 [1H, t, *J*=3.5 Hz, C=CH (*Z*)]; δ_C −0.1, −2.2 [$\mathrm{(CH_3)_3Si}$], 24.8, 29.6 ($\mathrm{CH_3C{=}CH}$), 53.6, 59.4 [$\mathit{C}\mathrm{H_2{-}CH{=}C}$, $\mathrm{N(}\mathit{C}\mathrm{H_2CH_2)_2O}$], 67.0 [$\mathrm{N(CH_2}\mathit{C}\mathrm{H_2)_2O}$], 134.4, 138.4 (C=*C*H), 140.3, 140.9 (*C*=CH); *m*/*z* (*Z*) 213 ($\mathrm{M^+}$, 13%), 198 (12), 141 (10), 140 (100), 110 (16), 100 (64), 87 (89), 86 (27), 85 (12), 82 (11), 73 (66), 59 (23), 57 (11), 56 (19); HRMS: $\mathrm{M^+}$, found 213.1557. $\mathrm{C_{11}H_{23}ONSi}$ requires 213.1549; *m*/*z* (*E*) 213 ($\mathrm{M^+}$, 7%), 145 (23), 140 (18), 100 (52), 87 (100), 86 (33), 73 (39), 59 (15), 57 (25), 56 (13); HRMS: $\mathrm{M^+}$, found 213.1543. $\mathrm{C_{11}H_{23}ONSi}$ requires 213.1549.



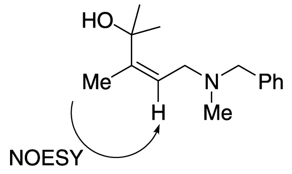
4.4.8. (*Z*)-6-(*N*-Benzyl-*N*-methylamino)-2,2,4-trimethyl-4-hexen-3-ol (7ba). t_r=13.5 min; ν (film) 3420 (OH), 3029 $\mathrm{cm^{-1}}$ (=CH); δ_H 0.92 [9H, s, $\mathrm{(CH_3)_3C}$], 1.81 (3H, s, $\mathrm{C}\mathit{H}_3\mathrm{C{=}CH}$), 2.16 (3H, s, $\mathrm{CH_3N}$), 2.85–2.92, 3.03–3.09 (2H, 2m, $\mathrm{C}\mathit{H}_2\mathrm{CH{=}C}$), 3.48 (2H, m, $\mathrm{CH_2Ar}$), 3.81 (1H, br s, OH), 4.03 (1H, s, C*H*OH), 5.52 (1H, t, *J*=6.5 Hz, C=CH), 7.23–7.31 (5H, m, ArH); δ_C 22.1, 26.9 [$\mathit{C}\mathrm{H_3C{=}CH}$, $\mathrm{(}\mathit{C}\mathrm{H_3)_3C}$], 36.8 [$\mathrm{(CH_3)_3}\mathit{C}$], 41.2 ($\mathrm{CH_3N}$), 54.5 ($\mathit{C}\mathrm{H_2{-}CH{=}C}$), 61.8 ($\mathit{C}\mathrm{H_2Ar}$), 78.6 (CHOH), 125.4, 127.0, 128.2, 129.1 (C=*C*H, ArCH), 138.3, 141.1 (*C*=CH, ArC); *m*/*z* 261 ($\mathrm{M^+}$, 4%), 204 (30), 122 (12), 121 (35), 120 (46), 92 (10), 91 (100), 57 (14); HRMS: $\mathrm{M^+}$, found 261.2086. $\mathrm{C_{17}H_{27}ON}$ requires 261.2093.



4.4.9. (*Z*)-4-(*N*-Benzyl-*N*-methylamino)-1-cyclohexyl-2-methyl-2-buten-1-ol (7bb). t_r=15.8 min; ν (film) 3504 $\mathrm{cm^{-1}}$ (OH); δ_H 1.13–1.27, 1.36–1.47, 1.66–1.72, 2.00–2.05 (14H, 4m with a s at 1.72, 5×ring $\mathrm{CH_2}$, ring CH, $\mathrm{C}\mathit{H}_3\mathrm{C{=}CH}$), 2.15 (3H, s, $\mathrm{CH_3N}$), 2.96 (2H, d, *J*=9.7 Hz, $\mathrm{C}\mathit{H}_2\mathrm{CH{=}C}$), 3.48 (2H, m, $\mathrm{CH_2Ar}$), 3.96 (2H, d, *J*=8.1 Hz, C*HOH*), 5.47 (1H, t, *J*=9.7 Hz, C=CH), 7.21–7.31 (5H, m, ArH); δ_C 19.9 ($\mathit{C}\mathrm{H_3C{=}CH}$), 25.9, 26.2, 26.4, 29.2, 29.3 (ring $\mathrm{CH_2}$), 41.2, 41.7 (ring CH, $\mathrm{CH_3N}$), 53.67 ($\mathit{C}\mathrm{H_2{-}CH{=}C}$), 61.8 ($\mathit{C}\mathrm{H_2Ar}$), 75.4 (CHOH), 124.0, 127.1, 128.2, 129.2 (C=*C*H, ArCH), 138.1, 142.3 (*C*=CH, ArC),); *m*/*z* 287 ($\mathrm{M^+}$, 1%), 204 (14), 166 (27), 151 (19), 122 (100), 120 (16), 91 (98), 83 (51), 55 (23) HRMS: $\mathrm{M^+}$, found 287.2204. $\mathrm{C_{19}H_{29}ON}$ requires 287.2249.

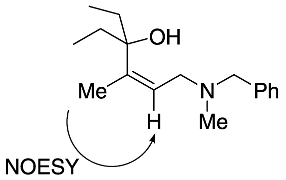


4.4.10. (*Z*)-5-(*N*-Benzyl-*N*-methylamino)-2,3-dimethyl-3-penten-2-ol (7bc). t_r=12.3 min; ν (film) 3388 (OH), 3063 $\mathrm{cm^{-1}}$ (C=C); δ_H 1.34 [6H, s, $\mathrm{(CH_3)_2C}$], 1.75 (3H, s, $\mathrm{C}\mathit{H}_3\mathrm{C{=}CH}$), 2.11 (3H, s, $\mathrm{CH_3N}$), 3.09 (2H, d, *J*=6.0 Hz, $\mathrm{C}\mathit{H}_2\mathrm{CH{=}C}$), 3.56 (2H, s, $\mathrm{CH_2Ar}$), 5.31 (1H, t, *J*=6.0 Hz, C=CH), 7.24–7.34 (5H, m, ArH); δ_C 23.3, 29.5 [$\mathit{C}\mathrm{H_3{-}C{=}CH}$, $\mathrm{(}\mathit{C}\mathrm{H_3)_2C}$], 40.3 ($\mathrm{CH_3N}$), 54.9 ($\mathit{C}\mathrm{H_2CH{=}C}$), 60.8 ($\mathit{C}\mathrm{H_2Ar}$), 73.5 (COH), 118.6, 127.1, 128.3, 129.0 (C=*C*H, ArCH), 137.3, 149.1 (*C*=CH, ArC); *m*/*z* 233 ($\mathrm{M^+}$, 1%), 215 (39), 174 (11), 172 (21), 124 (10), 124 (22), 120 (18), 97 (13), 91 (100), 65 (11); HRMS: $\mathrm{M^+}$, found 233.1756. $\mathrm{C_{15}H_{23}ON}$ requires 233.1780.

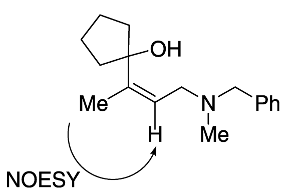


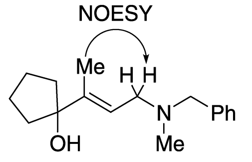
4.4.11. (*Z*)-6-(*N*-Benzyl-*N*-methylamino)-3-ethyl-4-methyl-4-hexen-3-ol (7bd). t_r=13.9 min; ν (film) 3166 (OH), 3030 $\mathrm{cm^{-1}}$ (=CH); δ_H 0.88 (6H, t, *J*=7.4 Hz, 2×$\mathrm{C}\mathit{H}_3\mathrm{CH_2}$, 1.49–1.67 (7H, m with a s at 1.63, 2×$\mathrm{CH_3C}\mathit{H}_2$, $\mathrm{C}\mathit{H}_3\mathrm{C{=}CH}$), 2.07 (3H, s, $\mathrm{CH_3N}$), 3.05 (2H, d, *J*=6.4 Hz, $\mathrm{C}\mathit{H}_2\mathrm{CH{=}C}$), 3.56 (2H, s, $\mathrm{CH_2Ar}$), 5.53 (1H, t, *J*=6.4 Hz, C=CH), 7.23–7.31 (5H, m, ArH); δ_C 7.8 ($\mathit{C}\mathrm{H_3CH_2}$), 22.9 ($\mathit{C}\mathrm{H_3C{=}CH}$), 33.6 ($\mathrm{CH_3}\mathit{C}\mathrm{H_2}$), 40.0

(CH$_3$N), 55.0, 61.4 (*C*H$_2$CH=C, *C*H$_2$Ar), 79.8 (COH), 123.0, 127.0, 128.1, 128.2, 129.0, 129.1 (C=*C*H, ArCH), 137.4, 145.9 (*C*=CH, ArC); *m/z* 261 (M$^+$, 1%), 243 (29), 232 (22), 228 (28), 174 (12), 122 (25), 120 (19), 111 (32), 91 (100), 57 (12), 55 (11); HRMS: M$^+$, found 261.2062. $C_{17}H_{27}ON$ requires 261.2093.

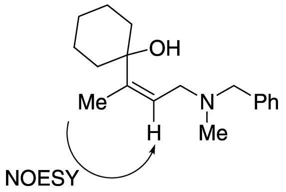


4.4.12. (*Z*/*E*)-1-[3-(*N*-Benzyl-*N*-methylamino)-1-methyl-1-propenyl]-1-cyclopentanol (7be). Mixture *Z*/*E*: 10/1: t_r (*Z*)=14.5 min; t_r (*E*)=14.7 min; ν (film) 3415 (OH), 3030 cm^{-1} (=CH); δ_H 1.36–1.92 (22H, m with a s at 1.76, 4×ring CH$_2$, C*H*$_3$C=CH), 2.12 [3H, s, CH$_3$N (Z)], 2.16 [3H, s, CH$_3$N (E)], 2.95 [2H, d, *J*=6.4 Hz, C*H*$_2$CH=C (*E*)], 3.07 [2H, d, *J*=6.3 Hz, C*H*$_2$CH=C (*Z*)], 3.47 [2H, s, CH$_2$Ar (*E*)], 3.56 [2H, s, CH$_2$Ar (*Z*)], 5.42 [1H, t, *J*=6.3 Hz, C=CH (Z)], 5.58 [1H, t, *J*=6.4 Hz, C=CH (E)], 7.23–7.34 (10H, m, 5ArH); δ_C 23.1 (*C*H$_3$C=CH), 24.0, 39.2 (ring CH$_2$), 40.6 (CH$_3$N), 54.8, 60.9 (*C*H$_2$CH=C, CH$_2$Ar), 83.7 (COH), 120.7, 127.1, 128.22, 129.2 (C=*C*H, ArCH), 137.2, 147.5 (*C*=CH, ArC),); *m/z* (*Z*) 259 (M$^+$, 1%), 241 (34), 172 (16), 150 (19), 134 (13), 122 (18), 121 (34), 120 (48), 92 (12), 91 (100), 65 (11), 55 (11); HRMS: M$^+$, found 259.1892. $C_{17}H_{25}ON$ requires 259.1936; *m/z* (*E*) 259 (M$^+$, 2%), 241 (11), 174 (11), 146 (21), 134 (14), 121 (36), 120 (55), 92 (13), 91 (100), 65 (10); HRMS: M$^+$, found 259.1889. $C_{17}H_{25}ON$ requires 259.1936.





4.4.13. (*Z*)-1-[3-(*N*-Benzyl-*N*-methylamino)-1-methyl-1-propenyl]-1-cyclohexanol (7bf). t_r=15.2 min; ν (film) 3400 (OH) 3031 cm^{-1} (=CH); δ_H 1.12–1.87 (13H, m with a s at 1.76, 5×ring CH$_2$, C*H*$_3$C=CH), 2.10 (3H, s, CH$_3$N), 3.08 (2H, d, *J*=6.5 Hz, C*H*$_2$CH=C), 3.56 (2H, s, CH$_2$Ar), 5.33 (1H, t, *J*=6.5 Hz, C=CH), 7.24–7.34 (5H, m, ArH); δ_C 23.1 (*C*H$_3$C=CH), 21.3, 25.8, 35.9, (ring CH$_2$), 40.6 (CH$_3$N), 55.1, 60.7 (*C*H$_2$CH=C, *C*H$_2$Ar), 74.4 (COH), 119.4, 127.0, 128.2, 128.9 (C=*C*H, ArCH), 137.5, 149.4 (*C*=CH, ArC),); *m/z* 273 (M$^+$, 2%), 255 (26), 182 (18), 174 (12), 172 (14), 164 (12), 146 (12), 134 (14), 122 (24), 121 (18), 109 (13), 92 (10), 91 (100), 55 (11); HRMS: M$^+$, found 273.2082. $C_{18}H_{27}ON$ requires 273.2093.



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involving double ketyl SN2′ addition to the double bond with displacement of halide that could explain the formation of the obtained products. We thank the referee for this observation.

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