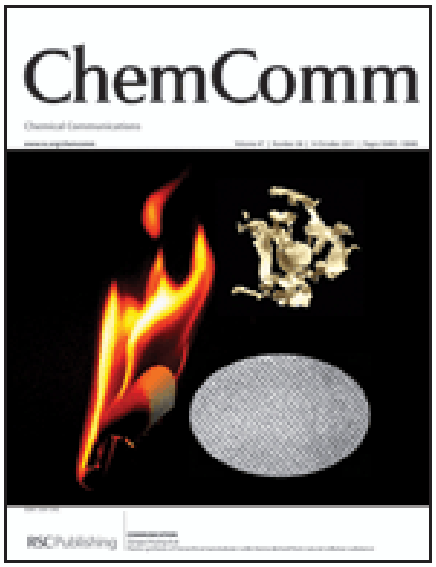

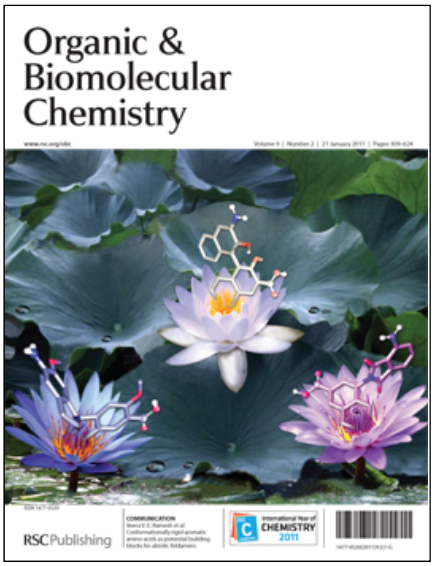

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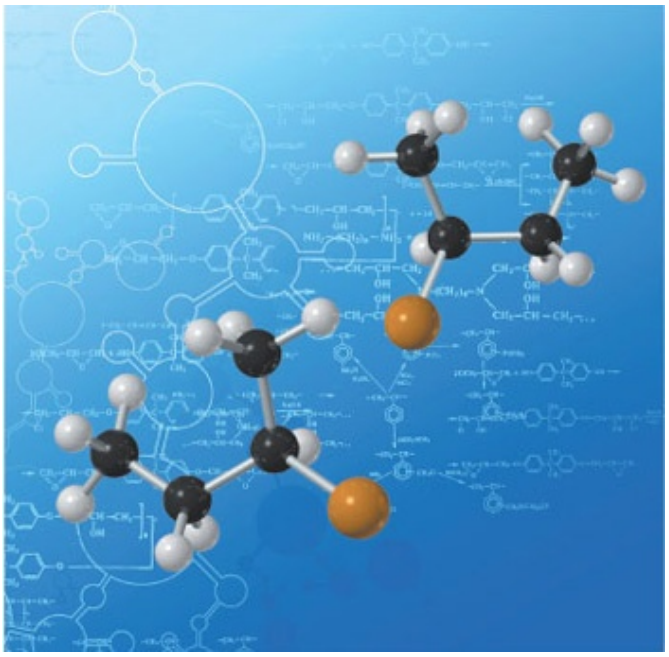

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PAPER

Polystyrene-supported TBD catalyzed ring-opening of *N*-tosylaziridines with silylated nucleophiles†‡

Satoru Matsukawa,* Takeru Harada and Shiori Yasuda

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Polystyrene-supported TBD (PS-TBD) catalyzes the ring-opening of *N*-tosylaziridines with silylated nucleophiles to give the corresponding products in high yields. PS-TBD was easily recovered and reused without significant loss of catalytic activity.

Introduction

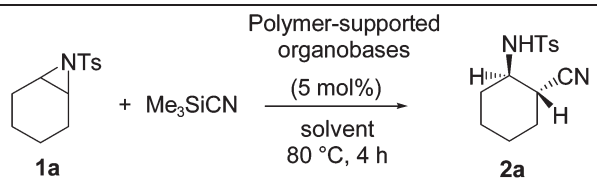
Aziridines are very useful intermediates for the synthesis of numerous nitrogen-containing biologically active compounds.[1] Therefore, nucleophilic ring-opening of aziridines by various approaches has been widely examined and developed.[2] Among these approaches, the ring-opening reaction using silylated nucleophiles, such as silyl cyanide, azide or halides, is important to produce highly functionalized compounds. Therefore, the catalytic ring-opening reaction with silylated nucleophiles using Lewis acids[3] and fluoride ions[4] has been developed to realize high yields and selectivities. Recently, Lewis base-catalyzed reactions have also been reported.[5] In search of a broadly applicable and environmentally friendly reaction, we used a polymer-supported organobase, 1,5,7-triazabicyclo[4,4,0]dec-5-ene polystyrene (PS-TBD) as a Lewis base catalyst.

Polymer-supported catalysts have attracted much attention in recent decades due to their inherent advantages in synthetic chemistry, *e.g.*, simplification of reaction procedures including easy recovery of the catalyst by filtration, application to automated systems, and recycling of catalyst.[6] PS-TBD is a polymer-supported organocatalyst, which consists of a highly basic guanidine moiety, TBD[7] anchored on polystyrene. It has been used to mediate the alkylation of phenols, amines, active methylene compounds and thiols, the esterification of carboxylic acids, the dehalogenation of organic halides and the high throughput synthesis of aryl triflates and aryl nonaflates.[8] PS-TBD also acts as a good catalyst for the Henry reaction and the addition of dialkyl phosphites to a variety of carbonyl compounds and imines.[9,10] Recently, Fringuelli *et al.* reported PS-TBD catalyzed ring-openings of epoxides, aldol-type condensations and Michael additions.[11] We have also reported cyanosilylation of aldehydes, ketones and imines catalyzed by PS-TBD.[12] In an effort to apply PS-TBD to other useful reactions, ring-opening of aziridines with various silylated nucleophiles were examined.

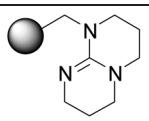
Results and discussion

Initially, the ring-opening reaction of *N*-tosylaziridine **1a** with trimethylsilyl cyanide was examined in the presence of 5 mol% of PS-TBD in DMF at room temperature. However, the reaction was very slow. Then the reaction was performed at elevated temperature. The desired product was obtained at 95% yield in 4 h at 80 °C. The product was obtained in low yield when other polymer-supported bases, such as PS-DIEA, PS-TPP, and

Table 1 Optimization of the reaction conditions



1a 2a

Entry	Base	Solvent	Yield (%)
1	 (PS-TBD)	DMF	95
2		DMF[a]	11
3		THF[b]	Trace
4		MeCN[c]	10
5		Toluene	Trace
6		SFC[d]	48
7	PS-DIEA[e]	DMF	15
8	PS-TPP[f]	DMF	Trace
9	PS-DMAP[g]	DMF	8

[a] At room temperature. [b] At 66 °C (reflux condition). [c] At 82 °C (reflux condition). [d] SFC: solvent free condition. [e] PS-DIEA: *N*,*N*-(Diisopropyl) aminomethyl polystyrene. [f] PS-TPP: Diphenylphosphinopolystyrene. [g] PS-DMAP: *N*-(Methyl polystyrene)-4-(methylamino)pyridine.

Department of Science Education, Faculty of Education, Ibaraki University, Ibaraki, 310-8512 Japan.
E-mail: smatsuka@mx.ibaraki.ac.jp; Fax: +81 29 228 8234

†Electronic supplementary information (ESI) available: Copies of ^{1}H and ^{13}C NMR Spectra of products **2a–2g**, **3a–3g**, **3a′**, **3a″**, **3c″**, **3e′**, **3e″** and **3g′**. See DOI: 10.1039/c2ob25435b

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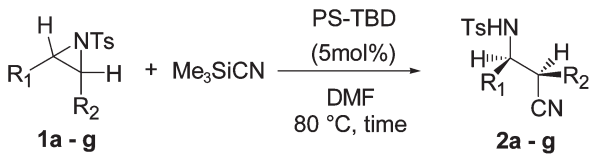
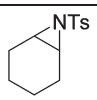
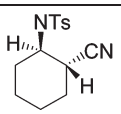
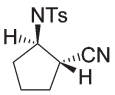
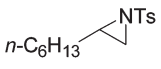
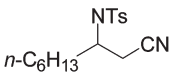
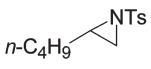
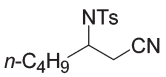
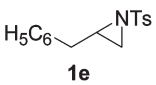
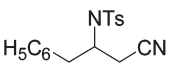
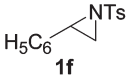
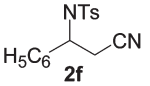
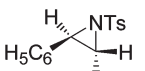
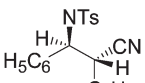
PS-DMAP were used (Table 1, entries 1 *vs.* 7–9). The reactions performed in THF, MeCN and toluene were inferior when compared with that performed in DMF. We also examined the reaction in SFC (solvent free condition), however, the yield was not satisfactory (Table 1, entry 6).

In order to clarify the scope of this reaction, several *N*-tosylaziridines were examined in the presence of 5 mol% PS-TBD (Table 2). High yields of the corresponding products were obtained for both 2-substituted aziridines and 2,3-disubstituted aziridines. In the case of 2-substituted aziridines, the reaction proceeded smoothly when 1 mol% of PS-TBD was used. Almost complete regioselectivity (>98 : 2) was observed when using both phenyl- and alkyl-substituted aziridines. Unfortunately, in the case of less reactive aziridine, 2,3-diphenylaziridine **1g**, the yield was unsatisfactory.

The TBD-catalyzed reaction was also applicable to other silylated nucleophiles, trimethylsilyl azide and halides (Table 3). The reaction proceeded smoothly at room temperature in high yields. High yields of the corresponding product were obtained using both 2-substituted aziridines and 2,3-disubstituted aziridines. 2,3-Diphenylaziridine also gave good results. High level of regioselectivity (>95 : 5) was observed when using alkyl-substituted aziridines as substrates. On the other hand, for phenyl-substituted aziridine **1f** with $TMSN_3$, the regioselectivity was not satisfactory. Although the reason is not clear, we consider the electronic effects as one possibility.

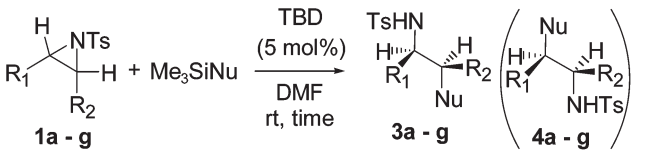
Table 2 PS-TBD catalyzed ring-opening of various aziridines with Me_3SiCN

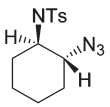
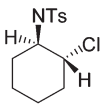
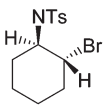
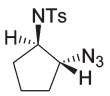
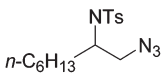
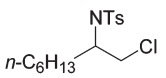
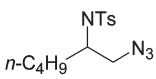
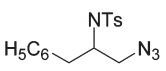
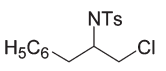
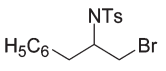
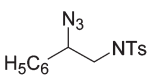
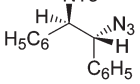
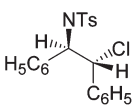


Entry	Aziridine	Product	Time	Yield[a] (%)
1	 **1a**	 **2a**	4 h	95
2	 **1b**	 **2b**	12 h	89
3	 **1c**	 **2c**	4 h	91
4[b]			12 h	85
5	 **1d**	 **2d**	4 h	95
6	 **1e**	 **2e**	4 h	95
7	 **1f**	 **2f**	4 h	94
8[c]	 **1g**	 **2g**	12 h	12

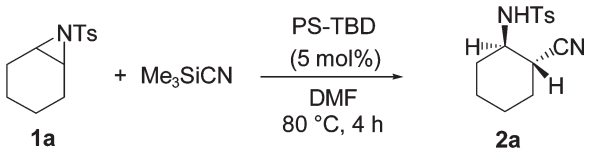
[a] Isolated yield. [b] 1 mol% of PS-TBD was used. [c] The reaction was carried out at 100 °C.

Table 3 PS-TBD catalyzed ring-opening of aziridines with other silylated nucleophiles

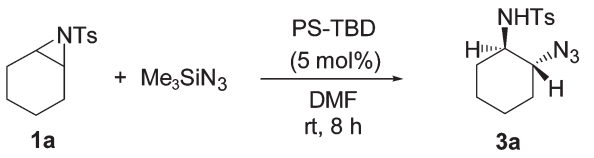


Entry	Aziridine	Nu	Product	Time	Yield[a,b] (%)
1	**1a**	N_3		8 h	94 (**3a**)
2		Cl		2 h	97 (**3a′**)
3		Br		2 h	97 (**3a″**)
4	**1b**	N_3		12 h	88 (**3b**)
5	**1c**	N_3		8 h	95 (**3c**)
6		Cl		2 h	90 (**3c′**)
7	**1d**	N_3		8 h	82 (**3d**)
8	**1e**	N_3		8 h	92 (**3e**)
9		Cl		1 h	98 (**3e′**)
10		Br		1 h	98 (**3e″**)
11	**1f**	N_3		12 h	97 (**3f**, **4f**)[c]
12[d]	**1g**	N_3		8 h	80 (**3g**)
13[d]	**1g**	Cl		12 h	75 (**3g′**)

[a] Isolated yield. [b] The product was obtained as **3a**–**g** unless otherwise noted. [c] Regioisomer ratio **3f** : **4f** = 22 : 78. [d] The reaction was carried out at 30 °C.



Runs	Yield (%)
1st	95
2nd	96
3rd	90
4th	91
5th	92



Runs	Yield (%)
1st	94
2nd	88
3rd	91
4th	92
5th	90

Scheme 1 Reuse of recovered PS-TBD.

The recovery and reuse of PS-TBD are illustrated for the reaction of *N*-tosylaziridine **1a** with trimethylsilyl cyanide in Scheme 1. After the reaction was completed, ethyl acetate was added to the reaction mixture and the catalyst was recovered by filtration. The recovered catalyst was washed, dried and then reused. The catalyst maintained its catalytic activity after four runs. The same result was observed in the reaction with trimethylsilyl azide.

Conclusions

In conclusion, we demonstrated that PS-TBD catalyze ring-opening reactions of aziridines with silylated nucleophiles. A broad range of silyl nucleophiles, including silyl cyanide, azide and halides, could be applied under mild conditions using 5 mol % PS-TBD. Furthermore, PS-TBD was easily recovered and reused without loss of activity after 4 runs. These reactions provide a simple and environmentally friendly route to the synthesis of precursor materials to highly functionalized β-amino acids, 1,2-diamines and 1,3-diamines.

Experimental

All reactions were performed under an argon atmosphere using oven-dried glassware. Flash column chromatography was performed using silica gel Wakogel C-200. Preparative thin-layer chromatography was carried out on silica gel Wakogel B-5F. Dehydrate DMF, THF, toluene and CH_3CN were purchased from Wako Chemical. Other commercially available reagents was used as received without further purification. The aziridines were prepared according to literature procedure.[13]

General procedure for PS-TBD catalyzed ring-opening of aziridines with silylated nucleophiles

To a solution of PS-TBD (0.05 mmol) in DMF (1 mL) was added aziridine (1.0 mmol) and silylated nucleophile (1.25 mmol) at room temperature or 80 °C. After the reaction was complete (as determined by TLC), EtOAc (5 ml) was added to the mixture and PS-TBD was separated by filtration. The filtrate was concentrated under vacuum and purified by column chromatography on silica gel (EtOAc–hexane = 1 : 3) to give the corresponding product. The recovered catalyst is reusable after washing (acetone and water) and drying *in vacuo*.

***N*-(2-Cyanocyclohexyl)-4-methylbenzenesulfonamide.[4] (2a).** IR (KBr, cm^{-1}) 3250, 2250, 1620; ^{1}H NMR (500 Hz, $CDCl_3$) δ 1.20–1.38 (m, 3H), 1.51–1.67 (m, 3H), 1.86–1.94 (m, 1H), 1.97–2.04 (m, 1H), 2.43 (s, 3H), 2.66 (brs, 1H), 3.35 (dq, J = 4.6, 8.0 Hz, 1H), 5.32 (d, J = 8.0 Hz, 1H), 7.32 (d, J = 8.5 Hz, 2H), 7.80 (d, J = 8.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.5, 22.6, 229, 27.1, 31.4, 34.4, 52.7, 120.2, 127.2, 129.8, 137.1, 143.9; HRMS (FAB): for $C_{14}H_{19}N_2O_2S$ $(M + H)^+$ calcd 279.1167, found 279.1169.

***N*-(2-Cyanocyclopentyl)-4-methylbenzenesulfonamide.[4] (2b).** IR (KBr, cm^{-1}) 3260, 2250, 1600; ^{1}H NMR (500 Hz, $CDCl_3$) δ 1.40–1.48 (m, 1H), 1.64–1.73 (m, 2H), 1.74–1.85 (m, 1H), 1.86–1.96 (m, 1H), 2.00–2.07 (m, 1H), 2.41 (s, 3H), 2.83 (dt, J = 6.0, 8.5 Hz, 1H), 3.69–3.75 (m, 1H), 5.71 (d, J = 7.0 Hz, 1H), 7.30 (d, J = 8.0 Hz, 2H), 7.77 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.4, 22.6, 28.9, 32.5, 35.6, 58.6, 121.1, 127.2, 129.9, 136.5, 144.0; HRMS (FAB): for $C_{13}H_{17}N_2O_2S$ $(M + H)^+$ calcd 265.1011, found 265.1021.

***N*-(2-Cyanooctyl)-4-methylbenzenesulfonamide.[4] (2c).** IR (neat, cm^{-1}) 3310, 2250, 1600; ^{1}H NMR (500 Hz, $CDCl_3$) δ 0.81 (t, J = 7.5 Hz, 3H), 1.07–1.20 (m, 8H), 1.47–1.58 (m, 2H), 2.41 (s, 3H), 2.54 (dd, J = 3.5, 16.5 Hz, 1H), 2.64 (dd, J = 6.0, 16.5 Hz, 1H), 3.38–3.41 (m, 1H), 4.83 (d, J = 8.0 Hz, 1H), 7.31 (d, J = 8.0 Hz, 2H), 7.75 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.0, 21.5, 22.4, 25.0, 25.2, 28.4, 31.4, 33.9, 50.0, 116.7, 127.0, 129.9, 137.0, 144.0; HRMS (FAB): for $C_{16}H_{25}N_2O_2S$ $(M + H)^+$ calcd 308.1558, found 308.1552.

***N*-(2-Cyanohexyl)-4-methylbenzenesulfonamide.[4] (2d).** IR (neat, cm^{-1}) 3270, 2240, 1600; ^{1}H NMR (500 Hz, $CDCl_3$) δ 0.82 (t, J = 7.5 Hz, 3H), 1.08–1.24 (m, 4H), 1.47–1.58 (m, 2H), 2.41 (s, 3H), 2.55 (dd, J = 4.0, 16.5 Hz, 1H), 2.65 (dd, J = 6.0, 16.5 Hz, 1H), 3.38–3.42 (m, 1H), 4.80–4.83 (m, 1H), 7.31 (d, J = 8.0 Hz, 2H), 7.75 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.1, 21.7, 25.1, 28.8, 31.4, 33.4, 50.5, 116.6, 127.2, 129.8, 137.5, 143.9; Anal. Found: C, 60.12; H 7.28; N 9.79. Calcd for $C_{14}H_{20}N_2O_2S$: C, 59.97; H 7.19; N 9.99%.

***N*-(2-Cyano-1-benzylethyl)-4-methylbenzenesulfonamide.[5a] (2e).** IR (KBr, cm^{-1}) 3270, 2250, 1600; ^{1}H NMR (500 Hz, $CDCl_3$) δ 2.42 (s, 3H), 2.54 (dd, J = 4.0, 14.0 Hz, 1H), 2.64 (dd, J = 6.0, 14.0 Hz, 1H), 2.74 (dd, J = 8.0, 4.0 Hz, 1H), 2.88 (dd, J = 7.5, 14.0 Hz, 1H), 3.57–3.64 (m, 1H), 4.82–4.88 (m, 1H), 6.97 (d, J = 7.6 Hz, 2H), 7.18–7.20 (m, 5H), 7.53 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.5, 24.1, 39.7, 51.3, 116.7, 126.9, 127.3, 128.9, 129.0, 129.8, 135.0, 136.3, 143.8.;

HRMS (FAB): for $C_{17}H_{19}N_2O_2S$ $(M + H)^+$ calcd 315.1167, found 315.1166.

***N*-(2-Cyano-1-phenylethyl)-4-methylbenzenesulfonamide.[4] (2f).** IR (KBr, cm^{-1}) 3280, 2250, 1590; ^1H NMR (500 Hz, $CDCl_3$) δ 2.39 (s, 3H), 2.87 (dd, J = 7.0, 17.0 Hz, 1H), 2.93 (dd, J = 5.0, 17.0 Hz, 1H), 4.55 (dt, J = 5.5, 7.0 Hz, 1H), 5.16 (d, J = 8.5 Hz, 1H), 7.10 (d, J = 8.0 Hz, 2H), 7.20–7.28 (m, 5H), 7.65 (d, J = 8.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.5, 26.2, 54.1, 116.3, 126.2, 127.1, 129.0, 129.2, 129.8, 136.4, 144.1; HRMS (FAB): for $C_{16}H_{17}N_2O_2S$ $(M + H)^+$ calcd 301.1011, found 301.1003.

***N*-(2-Cyano-1,2-diphenylethyl)-4-methylbenzenesulfonamide.[5a] (2g).** IR (KBr, cm^{-1}) 3270, 2960, 2100, 1600; ^1H NMR (500 Hz, $CDCl_3$) δ 2.44 (s, 3H), 4.27 (s, 1H), 4.98 (br, 1H), 7.02 (d, J = 7.6 Hz, 2H), 7.07–7.13 (m, 3H), 7.25–7.42 (m, 7H), 7.81 (d, J = 7.6 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.4, 70.1, 126.4, 127.3, 127.4, 127.7, 128.1, 128.4, 129.3, 135.4, 136.9, 137.0, 142.9; Anal. Found: C, 69.90; H 5.20; N 7.79. Calcd for $C_{22}H_{20}N_2O_2S$: C, 70.19; H 5.35; N 7.44%.

***N*-(2-Azidocyclohexyl)-4-methylbenzenesulfonamide.[4] (3a).** IR (KBr, cm^{-1}) 3300, 2940, 2090, 1600; ^1H NMR (500 Hz, $CDCl_3$) δ 1.12–1.33 (m, 4H), 1.54–1.68 (m, 2H), 1.92–2.00 (m, 2H), 2.39 (s, 3H), 2.91–2.95 (m, 1H), 3.07–3.10 (m, 1H), 5.29 (d, J = 8.0 Hz, 1H), 7.28 (d, J = 8.0 Hz, 2H), 7.78 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.5, 23.6, 23.8, 30.2, 32.4, 56.7, 63.5, 127.0, 129.5, 137.5, 143.3; HRMS (FAB): for $C_{13}H_{19}N_4O_2S$ $(M + H)^+$ calcd 295.1229, found 295.1235.

***N*-(2-Chlorocyclohexyl)-4-methylbenzenesulfonamide.[4] (3a′).** IR (KBr, cm^{-1}) 3270, 2860, 1920, 1600; ^1H NMR (500 Hz, $CDCl_3$) δ 1.22–1.28 (m, 3H), 1.55–1.67 (m, 3H), 2.10–2.15 (m, 2H), 2.39 (s, 3H), 3.05–3.10 (m, 1H), 3.66–3.69 (m, 1H), 5.20 (d, J = 6.0 Hz, 1H), 7.26 (d, J = 8.0 Hz, 2H), 7.75 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.5, 23.4, 24.3, 32.4, 34.9, 58.7, 62.1, 127.3, 129.6, 137.2, 143.4; HRMS (FAB): for $C_{13}H_{19}ClNO_2S$ $(M + H)^+$ calcd 288.0825, found 288.0833.

***N*-(2-Bromocyclohexyl)-4-methylbenzenesulfonamide.[4] (3a″).** IR (KBr, cm^{-1}) 3270, 2870, 1900, 1610; ^1H NMR (500 Hz, $CDCl_3$) δ 1.23–1.30 (m, 3H), 1.58–1.64 (m, 2H), 1.71–1.79 (m, 1H), 2.18–2.28 (m, 2H), 2.40 (s, 3H), 3.14–3.19 (m, 1H), 3.80–3.88 (m, 1H), 5.11 (d, J = 5.5 Hz, 1H), 7.28 (d, J = 8.0 Hz, 2H), 7.76 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.5, 23.4, 25.3, 32.8, 35.7, 55.0, 58.6, 127.3, 129.6, 137.1, 143.5; HRMS (FAB): for $C_{13}H_{19}BrNO_2S$ $(M + H)^+$ calcd 332.0320, found 332.0323.

***N*-(2-Azidocyclopentyl)-4-methylbenzenesulfonamide.[4] (3b).** IR (KBr, cm^{-1}) 3260, 2960, 2100, 1600; ^1H NMR (500 Hz, $CDCl_3$) δ 1.31–1.39 (m, 1H), 1.51–1.65 (m, 3H), 1.81–1.92 (m, 2H), 2.40 (s, 3H), 3.36 (dt, J = 5.0, 7.0 Hz, 1H), 3.65–3.71 (m, 1H), 5.54 (d, J = 8.0 Hz, 1H), 7.28 (d, J = 8.0 Hz, 2H), 7.76 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 20.8, 21.5, 26.9, 29.0, 30.8, 59.7, 66.9, 126.7, 129.6, 137.0, 143.5; HRMS (FAB): for $C_{12}H_{17}N_4O_2S$ $(M + H)^+$ calcd 281.1072, found 281.1075.

***N*-(2-Azidooctyl)-4-methylbenzenesulfonamide.[4] (3c).** IR (neat, cm^{-1}) 3280, 2940, 2100, 1600; ^1H NMR (500 Hz, $CDCl_3$) δ 0.82 (t, J = 7.0 Hz, 3H), 1.10–1.50 (m, 10H), 2.41 (s, 3H), 3.26–3.30 (m, 3H), 4.80 (d, J = 7.0 Hz, 1H), 7.28 (d, J = 8.0 Hz, 2H), 7.74 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.0, 21.5, 22.4, 25.3, 28.8, 31.6, 32.6, 53.2, 55.0, 127.0, 129.7, 137.7, 143.6; HRMS (FAB): for $C_{15}H_{25}N_4O_2S$ $(M + H)^+$ calcd 325.1698, found 325.1698.

***N*-(2-Chlorooctyl)-4-methylbenzenesulfonamide.[4] (3c′).** IR (neat, cm^{-1}) 3280, 2840, 1610; ^1H NMR (500 Hz, $CDCl_3$) δ 0.81 (t, J = 7.5 Hz, 3H), 1.10–1.25 (m, 8H), 1.39–1.47 (m, 1H), 1.51–1.57 (m, 1H), 2.40 (s, 3H), 3.40–3.52 (m, 3H), 4.91 (d, J = 8.5 Hz, m, 1H), 7.28 (d, J = 8.0 Hz, 2H), 7.75 (d, J = 8.0 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.0, 21.5, 22.4, 225, 25.2, 28.7, 31.4, 32.3, 48.1, 53.8, 127.0, 129.7, 137.8, 143.6; HRMS (FAB): for $C_{15}H_{25}ClNO_2S$ $(M + H)^+$ calcd 318.1295, found 318.1301.

***N*-(2-Azidobutyl)-4-methylbenzenesulfonamide.[4] (3d).** IR (neat, cm^{-1}) 3280, 2100, 1600; ^1H NMR (500 Hz, $CDCl_3$) δ 0.74 (t, J = 7.0 Hz, 3H), 1.04–1.50 (m, 6H), 2.40 (s, 3H), 3.24–3.29 (m, 3H), 5.00 (brs, 1H), 7.28 (d, J = 8.0 Hz, 2H), 7.74 (d, J = 8.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.7, 21.5, 22.1, 27.5, 32.2, 53.2, 54.9, 126.9, 129.6, 137.6, 143.4; HRMS (FAB): for $C_{13}H_{21}N_4O_2S$ $(M + H)^+$ calcd 297.1385, found 297.1386.

***N*-(2-Azido-1-benzylethyl)-4-methylbenzenesulfonamide.[6] (3e).** IR (neat, cm^{-1}) 3270, 2090, 1600; ^1H NMR (500 Hz, $CDCl_3$) δ 2.39 (s, 3H), 2.68 (dd, J = 7.0, 14.0 Hz, 1H), 2.75 (dd, J = 7.5, 14.0 Hz, 1H), 3.28 (dd, J = 4.0, 12.0 Hz, 1H), 3.31 (dd, J = 6.5, 12.0 Hz, 1H), 3.45–3.54 (m, 1H), 4.92 (d, J = 8.0 Hz, 1H), 6.98 (d, J = 8.5 Hz, 2H), 7.10–7.35 (m, 5H), 7.60 (d, J = 8.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.5, 38.4, 53.7, 54.3, 126.8, 127.2, 128.6, 128.7, 129.1, 129.6, 136.1, 136.7, 143.4; HRMS (FAB): for $C_{16}H_{19}N_4O_2S$ $(M + H)^+$ calcd 331.1229, found 331.1236.

***N*-(2-Chloro-1-benzylethyl)-4-methylbenzenesulfonamide.[6] (3e′).** IR (neat, cm^{-1}) 3270, 2890, 1600; ^1H NMR (500 Hz, $CDCl_3$) δ 2.40 (s, 3H), 2.75 (dd, J = 6.5, 13.5 Hz, 1H), 2.87 (dd, J = 7.5, 13.5 Hz, 1H), 3.43 (dd, J = 5.5, 11.5 Hz, 1H), 3.47 (dd, J = 3.0, 11.5 Hz, 1H), 3.64–3.71 (m, 1H), 4.88 (d, J = 7.0 Hz, 1H), 7.03 (d, J = 7.5 Hz, 2H), 7.17–7.22 (m, 5H), 7.61 (d, J = 8.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.5, 38.2, 46.8, 55.1, 126.9, 127.0, 128.7, 128.8, 129.1, 129.7, 136.1, 137.2, 143.5; HRMS (FAB): for $C_{16}H_{19}ClNO_2S$ $(M + H)^+$ calcd 324.0825, found 324.0830.

***N*-(2-Bromo-1-benzylethyl)-4-methylbenzenesulfonamide.[6] (3e″).** IR (neat, cm^{-1}) 3250, 2850, 1590; ^1H NMR (500 Hz, $CDCl_3$) δ 2.39 (s, 3H), 2.73 (dd, J = 5.5, 14.0 Hz, 1H), 2.87 (dd, J = 8.0, 14.0 Hz, 1H), 3.31 (dd, J = 5.5, 11.0 Hz, 1H), 3.34 (dd, J = 5.0, 11.0 Hz, 1H), 3.57–3.62 (m, 1H), 5.02 (d, J = 8.0 Hz, 1H), 7.01–7.08 (m, 2H), 7.15–7.22 (m, 5H), 7.62 (d, J = 8.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.4, 37.4, 41.1, 54.6, 126.9, 127.0, 128.6, 129.1, 129.5, 129.8, 136.0, 137.1, 143.4; HRMS (FAB): for $C_{16}H_{19}BrNO_2S$ $(M + H)^+$ calcd 368.0320, found 368.0318.

***N*-(2-Azido-1-phenylethyl)-4-methylbenzenesulfonamide.[4] (3f).** IR (KBr, cm^{-1}) 3280, 2100, 1590 (mixture of **3f** and **4f**);

^{1}H NMR (500 Hz, $CDCl_3$) δ 2.37 (s, 3H), 3.53 (d, J = 6.5 Hz, 1H), 4.47 (dd, J = 6.0, 16.5 Hz, 1H), 5.62 (d, J = 8.0 Hz, 1H), 7.10 (d, J = 8.0 Hz, 2H), 7.18–7.38 (m, 5H), 7.60 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.4, 55.9, 57.1, 126.7, 127.0, 128.1, 128.6, 129.4, 137.0, 137.5, 143.4; HRMS (FAB): for $C_{15}H_{17}N_4O_2S$ $(M + H)^+$ calcd 317.1072, found 317.1075 (mixture of **3f** and **4f**).

***N*-(2-Azido-2-phenylethyl)-4-methylbenzenesulfonamide.[4] (4f).** IR (KBr, cm^{-1}) 3280, 2100, 1590 (mixture of **3f** and **4f**); ^{1}H NMR (400 Hz, $CDCl_3$) δ 2.43 (s, 3H), 3.06 (ddd, J = 5.0, 8.0, 13.5 Hz, 1H), 3.21 (ddd, J = 5.0, 7.5, 13.5 Hz, 1H), 4.60 (dd, J = 5.5, 9.0 Hz, 1H), 5.11 (dd, J = 5.5, 7.5 Hz, 1H), 7.18 (d, J = 8.0 Hz, 2H), 7.18–7.38 (m, 5H), 7.72 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.5, 48.0, 65.4, 126.9, 127.0, 128.9, 129.0, 129.8, 136.2, 136.7, 143.7.

***N*-(2-Azido-1,2-diphenylethyl)-4-methylbenzenesulfonamide.[5e] (3g).** IR (KBr, cm^{-1}) 3270, 2960, 2100, 1600; ^{1}H NMR (400 Hz, $CDCl_3$) δ 2.31 (s, 3H), 4.48–4.51 (m, 1H), 4.69 (d, J = 6.5 Hz, 1H), 5.53 (brs, 1H), 6.94 (d, J = 7.0 Hz, 2H), 7.01 (d, J = 8.0 Hz, 2H), 7.05–7.15 (m, 5H), 7.20–7.24 (m, 3H), 7.38 (d, J = 8.0 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.4, 62.3, 70.2, 126.9, 127.4, 127.5, 127.8, 128.1, 128.6, 129.2, 135.4, 136.9, 137.0, 143.0; HRMS (FAB): for $C_{21}H_{21}N_4O_2S$ $(M + H)^+$ calcd 393.1385, found 393.1377.

***N*-(2-Chloro-1,2-diphenylethyl)-4-methylbenzenesulfonamide (3g′).** IR (KBr, cm^{-1}) 3250, 2960, 2880, 1600; ^{1}H NMR (400 Hz, $CDCl_3$) δ 2.32 (s, 3H), 4.72 (t, J = 6.5 Hz, 1H), 5.00 (d, J = 6.5 Hz, 1H), 5.39 (d, J = 6.0 Hz, 1H), 6.90 (d, J = 7.0 Hz, 2H), 7.02–7.06 (m, 4H), 7.08–7.15 (m, 2H), 7.16–7.21 (m, 4H), 7.38 (d, J = 7.0 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.5, 63.8, 66.8, 127.1, 127.9, 1280, 128.3, 128.7, 129.2, 136.5, 136.9, 136.9, 143.2.; HRMS (FAB): for $C_{21}H_{21}ClNO_2S$ $(M + H)^+$ calcd 386.0982, found 386.0988.

Notes and references

1 (*a*) J. B. Sweeny, *Chem. Soc. Rev.*, 2002, **31**, 247–258; (*b*) A. Padwa, W. H. Pearson, B. N. Lian and S. C. Bergmeier, in *Comprehensive Heterocyclic Chemistry II*, ed. A. R. Katritzky, C. W. Rees and E. F. V. Scriven, Pergamon, New York, 1996, vol. 1a; (*c*) D. Tanner, *Angew. Chem., Int. Ed. Engl.*, 1994, **33**, 599–619; (*d*) A. Padwa and A. D. Woolhouse, in *Comprehensive Heterocyclic Chemistry*, ed. W. Lwowski, Pergamon, Oxford, 1984, vol. 7.

2 A recent review, see: (*a*) X. E. Hu, *Tetrahedron*, 2004, **60**, 2701–2743; (*b*) I. D. G. Watson, L. Yu and A. K. Yudin, *Acc. Chem. Res.*, 2006, **39**, 194–206; (*c*) *Aziridine and Epoxide in Organc Synthesis*, ed. A. K. Yudin, Wiley-VCH, Weinheim, 2006; (*d*) G. S. Singh, M. D'hooghe and N. D. Kimpe, *Chem. Rev.*, 2007, **107**, 2080–2135; (*e*) P. Lu, *Tetrahedron*, 2010, **66**, 2549–2560.

3 (*a*) S. Matsubara, T. Kodama and K. Utimoto, *Tetrahedron Lett.*, 1990, **31**, 6379–6380; (*b*) H. M. I. Osborn and J. B. Sweeney, *Synlett*, 1994, 145–147; (*c*) W.-H. Leung, M. T. Yu, M. C. Wu and L.-L. Yeung, *Tetrahedron Lett.*, 1996, **37**, 891–892; (*d*) D. Ferraris, W. J. Drury III, C. Cox and J. Lectka, *J. Org. Chem.*, 1998, **63**, 4568–4571; (*e*) Z. Li, M. Fernandez and E. N. Jacobsen, *Org. Lett.*, 1999, **1**, 1611–1613; (*f*) M. Chandrasekhar, G. Sekar and V. K. Singh, *Tetrahedron Lett.*, 2000, **41**, 4677–4679; (*g*) S.-H. Shin, E. Y. Han, C. S. Park, W. K. Lee and H.-J. Ha, *Tetrahedron: Asymmetry*, 2000, **11**, 3293–3295; (*h*) M. A. Reddy, L. R. Reddy, N. Bhanumathi and K. R. Rao, *Chem. Lett.*, 2001, 246–247; (*i*) M. Chandrasekhar, G. Sekar and V. K. Singh, *Tetrahedron Lett.*, 2000, **41**, 10079–10083; (*j*) J. S. Yadav, B. V. S. Reddy, G. M. Kumar and V. S. R. Murhty, *Synth. Commun.*, 2002, **32**, 1797–1802; (*k*) T. Mita, I. Fujimori, R. Wada, J. Wen, M. Kanai and M. Shibasaki, *J. Am. Chem. Soc.*, 2005, **127**, 11252–11253; (*l*) Y. Fukuta, T. Mita, N. Fukuda, M. Kanai and M. Shibasaki, *J. Am. Chem. Soc.*, 2006, **128**, 6312–6313; (*m*) I. Fujimori, T. Mita, K. Maki, M. Shiro, A. Sato, S. Furusho, M. Kanai and M. Shibasaki, *J. Am. Chem. Soc.*, 2006, **128**, 16438–16439; (*n*) E. B. Rowland, G. B. Rowland, E. Rivera-Otero and J. C. Antilla, *J. Am. Chem. Soc.*, 2007, **129**, 12084–12085; (*o*) R. Yu, Y. Yamashita and S. Kobayashi, *Adv. Synth. Catal.*, 2009, **351**, 157–162; (*p*) B. Wu, J. C. Gallucci, J. R. Parquette and T. V. RajanBabu, *Angew. Chem., Int. Ed.*, 2009, **48**, 1126–1129; (*q*) Y. Hayashi, T. Kumamoto, M. Kawahata, K. Yamaguchi and T. Ishikawa, *Tetrahedron*, 2010, **66**, 3836–3841; (*r*) M. Bera, S. Pratihar and S. Roy, *J. Org. Chem.*, 2011, **76**, 1475–1478.

4 J. Wu, X.-L. Hou and L.-X. Dai, *J. Org. Chem.*, 2000, **65**, 1344–1348.

5 (*a*) S. Minakata, Y. Okada, Y. Oderaotoshi and M. Komatsu, *Org. Lett.*, 2005, **7**, 3509–3512; (*b*) J. Wu, X. Sun and H.-G. Xia, *Eur. J. Org. Chem.*, 2005, 4769–4772; (*c*) J. Wu, X. Sun, Y. Shengqing and W. Sun, *Tetrahedron Lett.*, 2006, **47**, 4813–4816; (*d*) J. Wu, X. Sun and W. Sun, *Org. Biomol. Chem.*, 2006, **4**, 4231–4234; (*e*) S. Matsukawa and K. Tsukamoto, *Org. Biomol. Chem.*, 2009, **7**, 3792–3796.

6 Recent reviews, see: (*a*) C. A. McNamara, M. J. Dixon and M. Bradley, *Chem. Rev.*, 2002, **102**, 3275–3300; (*b*) M. Benaglia, A. Puglisi and F. Cozzi, *Chem. Rev.*, 2003, **103**, 3401–3429; (*c*) F. Cozzi, *Adv. Synth. Catal.*, 2006, **348**, 1367–1390; (*d*) W. J. Sommer and M. Weck, *Coord. Chem. Rev.*, 2007, **251**, 860–873; (*e*) C. K. Kwong, R. Huang, M. Zhang and P. H. Toy, *Chem.–Eur. J.*, 2007, **13**, 2369–2376; (*f*) M. R. Buchmeiser, *Chem. Rev.*, 2009, **109**, 303–321; (*g*) Z. Wang, G. Chen and K. Ding, *Chem. Rev.*, 2009, **109**, 322–359; (*h*) S. Ikegami and H. Hamamoto, *Chem. Rev.*, 2009, **109**, 583–593; (*i*) J. Lu and P. H. Toy, *Chem. Rev.*, 2009, **109**, 815–838; (*j*) T. E. Kristensen and T. Hansen, *Eur. J. Org. Chem.*, 2010, 3179–3204.

7 TBD-catalyzed reactions, see: (*a*) D. Simoni, M. Rossi, R. Rondanin, A. Mazzali, R. Baruchello, C. Malagutti, M. Roberti and F. P. Invidata, *Org. Lett.*, 2000, **2**, 3765–3768; (*b*) D. Simoni, R. Rondanin, M. Morini, R. Baruchello and F. P. Invidata, *Tetrahedron Lett.*, 2000, **41**, 1607–1610; (*c*) R. Ballini, D. Fiorini, R. Maggi, P. Righi, G. Sartori and R. Sartorio, *Green Chem.*, 2003, **5**, 396–398; (*d*) W. Ye, J. Xu, C.-T. Tan and C.-H. Tan, *Tetrahedron Lett.*, 2005, **46**, 6875–6878; (*e*) R. C. Pratt, B. G. G. Lohmeijer, D. A. Long, R. A. Waymouth and J. A. Hedric, *J. Am. Chem. Soc.*, 2006, **129**, 4556–4557; (*f*) Z. Jiang, Y. Zhang, W. Ye and C.-H. Tan, *Tetrahedron Lett.*, 2007, **48**, 51–54; (*g*) C. Sabot, K. A. Kumar, S. Meunier and C. Mioskowski, *Tetrahedron Lett.*, 2007, **48**, 3863–3866; (*h*) C. Sabot, K. A. Kumar, C. Antheaume and C. Mioskowski, *J. Org. Chem.*, 2007, **72**, 5001–5004; (*i*) C. Ghobril, C. Sabot, C. Mioskowski and R. Baati, *Eur. J. Org. Chem.*, 2008, 4104–4108; (*j*) O. Mahe, D. Frath, I. Dez, F. Marsais, V. Levacher and J.-F. Briere, *Org. Biomol. Chem.*, 2009, **7**, 3648–3651; (*k*) F. Saliu and B. Rindone, *Tetrahedron Lett.*, 2010, **51**, 6301–6304; (*l*) I. Cota, F. Medina, J. E. Sueiras and D. Tichit, *Tetrahedron Lett.*, 2011, **52**, 385–387.

8 (*a*) M. Tomoi, Y. Kato and H. Kakiuchi, *Makromol. Chem.*, 1984, **185**, 2117–2124; (*b*) K. Iijima, W. Fukuda and M. Tomoi, *J. Macromol. Sci., Pure Appl. Chem.*, 1992, **A29**, 249–261; (*c*) Y. Tamura, W. Fukuda and M. Tomoi, *Synth. Commun.*, 1994, **24**, 2907–2914; (*d*) X. Xu, R. Mohan and M. M. Morrissey, *Tetrahedron Lett.*, 1997, **38**, 7337–7340; (*e*) S. Boisnard, J. Chastanet and J. Zhu, *Tetrahedron Lett.*, 1999, **40**, 7469–7472.

9 (*a*) D. Simoni, R. Rondanin, M. Morini, R. Baruchello and F. P. Invidiata, *Tetrahedron Lett.*, 2000, **41**, 1607–1610. PS-TBD as ligand in Cu-catalyzed 1,3-dipolar cycloaddition reaction, see: (*b*) C. Coelho, P. Diz, O. Caamano and E. Sotelo, *Adv. Synth. Catal.*, 2010, **352**, 1179–1192.

10 Silica-supported TBD catalyzed reactions have also been reported, see: (*a*) Y. V. S. Rao, D. E. De Vos and P. A. Jacobs, *Angew. Chem., Int. Ed. Engl.*, 1997, **36**, 2661–2663; (*b*) R. Ballini, G. Bosica, D. Fiorini, M. Raimondo, P. Righi, G. Sartori and R. Sartorio, *Tetrahedron Lett.*, 2002, **43**, 8445–8447; (*c*) R. Ballini, D. Fiorini, R. Maggi, C. Oro, A. Palmieri and G. Sartori, *Synlett*, 2006, 1849–1850; (*d*) R. Srivastava, *J. Mol. Catal. A: Chem.*, 2007, **264**, 146–152.

11 (*a*) F. Fringuelli, F. Pizzo, C. Vittoriani and L. Vaccaro, *Chem. Commun.*, 2004, 2756–2757; (*b*) F. Fringuelli, F. Pizzo, C. Vittoriani and L. Vaccaro, *Eur. J. Org. Chem.*, 2006, 1231–1236; (*c*) D. Lanari, R. Balini, A. Palmieri, F. Pizzo and L. Vaccaro, *Eur. J. Org. Chem.*, 2011, 2874–2884.

12 S. Matsukawa and S. Fujikawa, *Tetrahedron Lett.*, 2012, **53**, 1075–1077.

13 V. V. Thakur and A. Sudalai, *Tetrahedron Lett.*, 2003, **44**, 989–992.

