Highly Diastereoselective Aziridination of Imines with Trimethylsilyldiazomethane. Subsequent Silyl Substitution with Electrophiles, Ring Opening, and Metalation of *C*-Silylaziridines—A Cornucopia of Highly Selective Transformations

Varinder K. Aggarwal,*,† Emma Alonso,† Marco Ferrara,† and Sharon E. Spey‡

Department of Chemistry, Bristol University, Cantock's Close, Bristol BS8 1TS, UK, and Department of Chemistry, University of Sheffield, Sheffield S3 7HF, UK

v.aggarwal@bristol.ac.uk.

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Treatment of a range of *N*-sulfonyl (Ts and SES) imines derived from aromatic, heteroaromatic, aliphatic, and unsaturated aldehydes with trimethylsilydiazomethane gave *C*-silylaziridines in good yield (32−83%) and with high diastereoselectivity in favor of the cis product (80:20−100:0). In contrast, an α-imino ester gave predominantly the *trans*-aziridine (89:11) in high yield (91%). The synthetic potential of *C*-silylaziridines was investigated. Treatment with F^- (tetrabutylammonium triphenyldifluorosilicate was used) in the presence of aldehydes gave the α-hydroxyaziridines in high yield and high diastereoselectivity (86:14−98:2) for the newly created stereogenic center. Complete retention of configuration was observed in the substitution of the silyl group with electrophiles in all cases. Trapping with deuterium (using $CDCl_3$ as electrophile) was also successful, but trapping with phosphate [using $ClP(O)(OPh)_2$] and acetate (using Ac_2O) was unsuccessful. In these latter cases ring opening by chloride and acetate, respectively, was observed. Further ring-opening reactions were effected using azide and thiolate nucleophiles and in all cases complete regioselectivity in favor of attack at the silyl-bearing carbon occurred. Complete regioselectivity was also observed in the carbonylative ring expansion using $Co_2(CO)_8$ to give a β-lactam. Treatment of *cis*-1-tosyl-2-phenyl/butyl-3-trimethylsilylaziridines with *n*-BuLi and subsequent quenching with MeI followed completely different pathways, depending on the 2-substituent. In the case of the 2-phenylaziridine, metalation was initiated α to the phenyl group and led finally to a fused tricyclic adduct with four stereogenic centers as a single diastereoisomer. In the case of the 2-butylaziridine, metalation occurred α to the silyl group and led to a trisubstituted silylaziridine, probably via an azirine intermediate.

Introduction

Aziridines are useful synthetic intermediates and, like epoxides, their chemistry is dominated by ring-opening reactions.[1−3] Thus, control in the regio- and stereoselectivity of the ring opening is of crucial importance. The regioselectivity can often be efficiently controlled in cases in which one ring carbon is either easily accessible (e.g., terminal aziridines) or if it bears a cation-stabilizing group (e.g., a phenyl or a vinyl substituent) or by coordination of the nucleophilic reagent to an appropriate group on one side of the aziridine.[1−3] We became interested in *C*-silylaziridines since a silicon atom appeared to be a substituent that could not only direct nucleophilic ring opening reactions but also promote electrophilic reactions by treatment with fluoride or with a strong base. Thus, *C*-silylaziridines seemed like highly versatile intermediates for use in synthesis. However, despite these seemingly attractive features, relatively few accounts have been reported on their synthesis. The thermal cycloaddition of azides to vinylsilanes followed by loss of nitrogen from the corresponding triazolines was first investigated by Adrianov[4] and later by Zanirato.[5−9] Lukevics has employed the reaction of vinylsilanes with nitrenes, which were generated by α-elimination of carbamates.[10]

Atkinson has reported the aziridination of vinylsilanes with acetoxyaminoquinazolinones,[11−13] and good diastereoselectivity has been achieved using a chiral aziridinating reagent (Scheme 1).[14,15] *C*-Silylaziridines have been synthesized from *vic*-haloamines, which were gen-

* Corresponding author.
† Bristol University.
‡ University of Sheffield.

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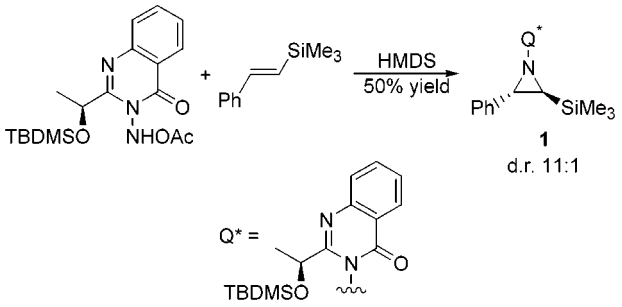
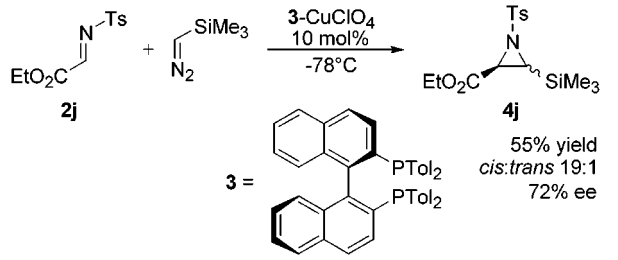
Scheme 1. Atkinson's Aziridination



Scheme 2. Jørgensen's Asymmetric Aziridination



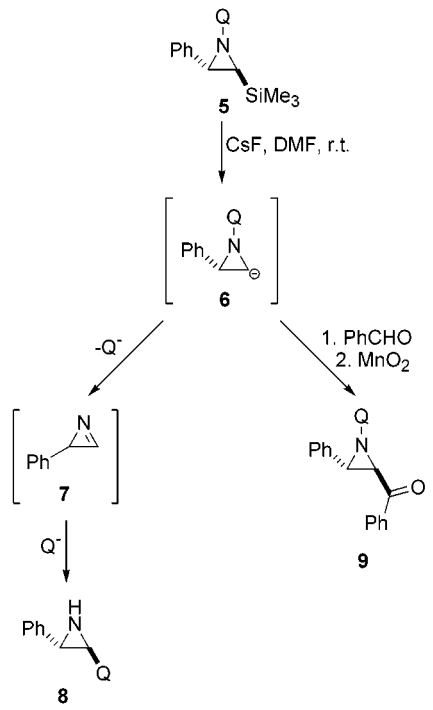
erated from vinylsilanes.[16−19] Recently Bassindale and Taylor explored several approaches to *C*-silylaziridines: the reaction between an α-chloro-α-silyl carbanion and a benzaldimine; the addition of bromoazide to vinylsilanes, followed by reduction of the 1-bromo-2-azide; and the photochemical or thermal reaction of organoazides and vinylsilanes.[20] Unfortunately, each of these strategies was shown to be applicable only to a limited range of substrates.

During the course of our work,[21] both Shioiri[22] and Jørgensen[23] reported the aziridination of imines with trimethylsilyldiazomethane (TMSD); in the latter case, moderate enantioselectivity was obtained using the α-imino ester **2j** in the presence of a chiral Lewis acid complex (Scheme 2).

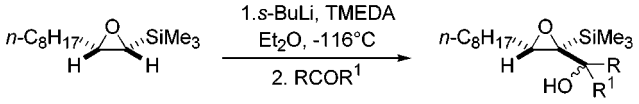
Even fewer reports have been published on the potential applications of *C*-silylaziridines in synthesis: the only examples are a series of papers by Atkinson on the generation of aziridinyl anions from aziridinyl silanes.[11−15]

Upon reaction of **5** with cesium fluoride in DMF, aziridine **8** was formed, probably via attack of the quinazolone anion on the intermediate azirine **7** (Scheme 3).[12] Performing the same reaction in the presence of potassium cyanide led to the 2-cyanoaziridine.[14,15] Carrying out the desilylation of **5** in the presence of benzaldehyde followed by oxidation gave the benzoylaziridine **9** (as the trans diastereoisomer exclusively) (Scheme 3).[12]

Scheme 3. Formation of Azirines from *C*-Silylaziridines



Scheme 4. Addition of Silicon-Stabilized Oxiranyl Anion to Carbonyl Compounds



In contrast to the very limited work on the chemistry of *C*-silylaziridines, a wider range of studies has been published on the related substrates, silyl epoxides. The generation of silicon-stabilized oxiranyl anions and their reactions with electrophiles have been shown to be successful, provided that the reaction conditions are carefully chosen to avoid side reactions of the unstable anions.[24] *cis*-Silyl epoxides undergo deprotonation more efficiently than the trans isomers, but the anion derived from the cis isomer can be configurationally unstable, whereas the trans isomer is configurationally stable.[24]

Molander has studied the addition of trimethylsilyl-substituted oxiranyl anions to carbonyl compounds (aldehydes/ketones) and found that the diastereoselectivity of the reaction is generally low with the exception of a few ketones that show high levels of diastereoselection (Scheme 4).[25]

α,*β*-Epoxysilanes have also been shown to undergo regioselective ring opening with nucleophiles.[26,27] Attack of nucleophiles occurs preferentially at the carbon bearing the silyl moiety (Scheme 5), although with hindered nucleophiles the steric shielding effect of the trialkylsilyl group can dominate over electronic factors, leading to *β*-selectivity.[28] The limited literature on the synthesis and applications of *C*-silylaziridines prompted our own in-

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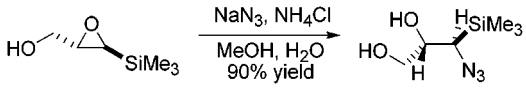
Scheme 5. Ring Opening of Silyl Epoxide



vestigation, and in this paper we report our results in full. In particular we describe a simple and general route to *C*-silylaziridines and further highly selective transformations that will make them useful intermediates in synthesis.

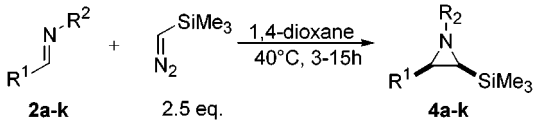
Results and Discussion

Synthesis of *C*-Silylaziridines. A potential route to aziridines is the reaction between a diazo compound and an imine.[23,29−39] This approach seemed particularly appealing for the synthesis of *C*-silylaziridines, because of the ease of synthesis of imines and especially because the required diazo compound TMSD[40] is a safe, stable, and commercially available compound. In our investigation, TMSD was found to react directly with imines without the need of any added Lewis acid or other metal catalyst that is normally required for such reaction. An excess of the diazo compound and moderate heating were required for the reaction to complete in a reasonably short time. Electron rich and electron deficient arylaldimines all gave good yields of aziridines, which were obtained with high *cis*-diastereoselectivity (Table 1, entries 1−4). A heteroaryl-subtituted imine could also be employed (Table 1, entry 5), but a vinyl group led to low yields, probably due to the sensitivity of the vinylaziridine, which underwent partial decomposition during purification and also possibly during the reaction itself (Table 1, entry 6). When the aliphatic enolizable imines **2f** and **2g** were employed, lower yields of the expected aziridines were observed, together with a substantial amount of the corresponding methyl ketoimines **11** (Table 1, entries 7 and 8). The *tert*-butyl-substituted starting material **2i** was the only unreactive imine, probably due to its steric hindrance (Table 1, entry 9). The more easily deprotectable trimethylsilylethanesulfonyl (SES) group[41] could also be employed and gave similarly high yield and diastereoselectivity to the tosyl group (compare entries 1 and 11, Table 1).

The α-imino ester **2j** showed a different reactivity from all the other imines: reaction with TMSD occurred at low temperature, affording a relatively stable intermediate together with a small amount of the expected aziridines **4j** (Scheme 6). Treatment of the reaction mixture with anhydrous silica gel was found to be the best way of converting this intermediate to the *C*-silylaziridines **4j** in terms of yield and diastereoselectivity.[42] A ratio of 89:11 in favor of the trans-product was obtained, with the cis-isomer being formed prior to the silica gel treatment (Table 1, entry 10).

Despite being unable to fully characterize the structure of the intermediate, we believe it is **10**, the product of a 1,3-dipolar cycloaddition between the diazo compound and the imine.[43] The observation of substantial gas evolution during the silica gel treatment is in agreement with initial formation of a cycloadduct followed by loss of nitrogen to give the aziridine. The conjugation with the ester substituent must lower the LUMO of the imine **2j** and alter the orbital coefficients and the charge distribution at both carbon and nitrogen relative to the other imines. This could account for the enhanced reactivity of imine **2j** and also for the [3 + 2] cycloaddition pathway now being favoured over the end-on addition.

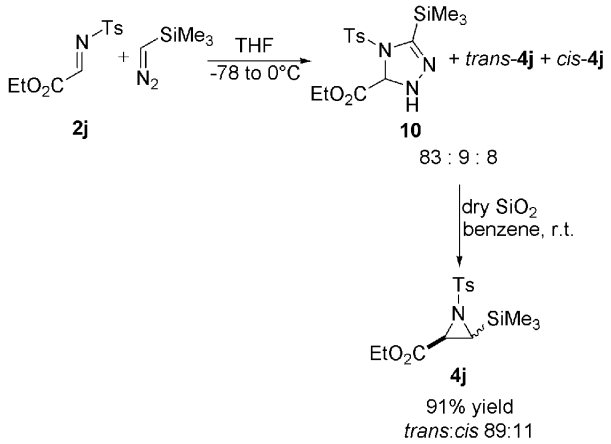
Table 1. Aziridination of Imines Using TMSD



entry	imine R1	imine R2		aziridine	yield (%)	cis:trans[a]
1	Ph	Ts	**2a**	**4a**	72	95:5
2	*p*-OMe-Ph	Ts	**2b**	**4b**	65	100:0
3	*p*-ClPh	Ts	**2c**	**4c**	64	91:9
4	*p*-NO_2Ph	Ts	**2d**	**4d**	83	94:6
5	3-pyridine	Ts	**2e**	**4e**	52	97:3
6	*E*-PhCH=CH	Ts	**2f**	**4f**	32[b]	100:0
7	*n*-Bu	Ts	**2g**	**4g**	53[c]	85:15
8	C_6H_{11}	Ts	**2h**	**4h**	40[c]	80:20
9	*t*-Bu	Ts	**2i**	**4i**	0	−
10[d]	CO_2Et	Ts	**2j**	**4j**	91	11:89
11	Ph	SES	**2k**	**4k**	72	96:4

[a] Determined by ^{1}H NMR of the crude reaction mixture. [b] 43% spectroscopic yield. [c] Obtained together with the corresponding methyl ketoimine (19% yield in entry 7 and 29% in entry 8). [d] Reaction carried out in THF with slow warming from −78 to 0 °C followed by treatment with anhydrous silica gel.

Scheme 6. Aziridination of Imine 2j Using TMSD



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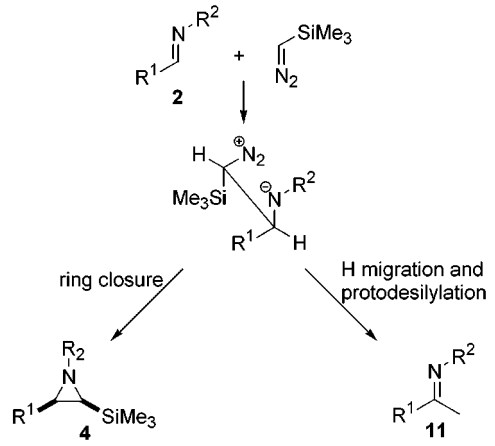
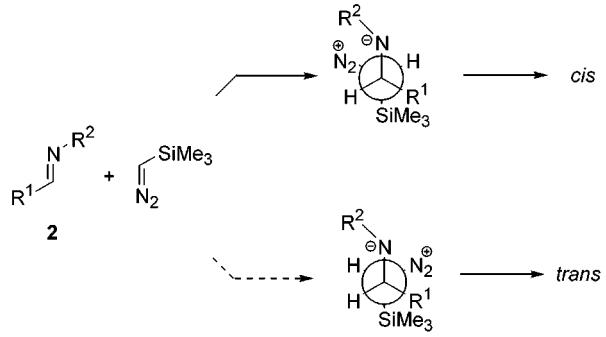
(42) Treatment of the reaction mixture with nonanhydrous silica gel afforded mainly the protodesilylated aziridine, while irradiation with a 254-nm lamp in a quartz vial or refluxing in benzene led to the aziridines **4j** in lower yield and trans-diastereoselectivity.

Scheme 7. Mechanism of Aziridination



Scheme 8. A Rationale for the *cis*-Diastereoselectivity of Aziridination



The mechanism for the formation of the remaining aziridines is believed to be nucleophilic attack of the diazo compound on the imine, leading to an intermediate betaine, which then affords the aziridine by ring closure and loss of nitrogen (Scheme 7).[38] Methyl ketoimine **11** formation probably derives from hydride migration in the betaine followed by protodesilylation.

The observed cis-diastereoselectivity can be explained by comparing the two possible transition states having the two developing charges in an electronically favored gauche arrangement. The one leading to the *trans*-aziridine is more congested, as it possesses three sterically demanding gauche interactions (Scheme 8). The complete reversal of diastereoselectivity in the case of imine **2j** is likely to be a consequence of the alternative mechanism for formation of the aziridine ([3 + 2] cycloaddition followed by loss of N_2), but the precise details of the process are not known at present.

The direct reaction between imines and diazo compounds is not general, but it seems to be particular to TMSD. In fact, ethyl diazoacetate was not reactive under the same reaction conditions, while phenyldiazomethane afforded a complex reaction mixture.

Substitution of the Silyl Group and Ring Opening. We first examined the substitution of the silyl group by generation of an aziridinyl anion with a fluoride source and trapping with an electrophile in situ. This in situ trapping was deemed necessary to prevent decomposition of the nonstabilized anion. Tetrabutylammonium triphenyldifluorosilicate (TBAT) was selected for desilylation, as it has been reported to act as a convenient source of anhydrous fluoride.[44]

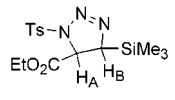
When *cis*-aziridine **4a** was treated with TBAT and benzaldehyde or valeraldehyde at 40 °C, the expected α-hydroxyaziridines *cis*-**12** and *cis*-**13** were obtained in good yield and high diastereoselectivity for the newly formed stereogenic center (Table 2, entries 1 and 2). No *trans*-aziridines were observed, showing that substitution occurred with complete retention of configuration at the silicon-bearing ring carbon. The corresponding SES-protected *cis*-aziridine **4k** gave *cis*-**14** in slightly lower diastereoselectivity (Table 2, entry 3). The selective desilylation at the ring carbon leaving the silicon-containing protecting group (SES) untouched is especially noteworthy. The *trans*-aziridine **4j** could also be employed: in this case, the reaction was performed at −78 °C[45] and allowed to warm to 0 °C, and under these conditions good yield and high diastereoselectivity were achieved (Table 2, entry 4). In contrast to all the other aziridines, which required heating to achieve substitution, *trans*-**4j** could be transformed at low temperature, which shows its enhanced reactivity.

The structures of the major adducts from entries 1 and 4 in Table 2 were determined by X-ray analysis, and the stereochemistry at the newly formed stereogenic center relative to the neighboring ring carbon was the same in both cases.

If the reactions proceed through aziridinyl anions, so that penta- and hexacoordinate silicon intermediates on the aziridines are excluded, the observed diastereoselectivity can be explained using the empirical model for reactions of chiral anions with aldehydes in the absence of the chelation control proposed by Bassindale and Taylor.[46] In this model, the large- and medium-sized groups need to be assigned. As the nitrogen is tetrahedral, the reactive conformation of the aziridine (Scheme 9) has the tosyl group pointing away from the incoming aldehydes and the lone pair toward it. Thus, this group is designated medium in size relative to the other ring carbon that has a substituent pointing toward the incoming aldehydes and is therefore designated large. This substituent (Ph or H) is bigger than the nitrogen lone pair, both in *cis*- and *trans*-aziridines.

Interestingly, Molander has instead reported a reversal in the diastereoselectivity for *cis*-epoxides relative to their trans isomers in the addition of carbonyl compounds to disubstituted oxiranyl anions (Scheme 10).[25] Furthermore, trisubstituted epoxides, which were expected to

(43) We were able to obtain ^{1}H NMR data of the crude reaction mixture that showed the two aziridines (minor components) and a new product that we believe is the [3 + 2] cycloadduct **10**. This new product, which is a [1,2,4]triazole, showed two doublets of equal intensity at 4.22 and 5.27 ppm (J = 7.6 Hz), which led us to the tentative assignment of cycloadduct **10**. [1,2,4]Triazoles have been reported to give aziridines upon gentle heating. See: Schwan, A. L.; Warkentin, J. *Can. J. Chem.* **1988**, *66*, 155. One of the referees suggested that the cycloadduct could be [1,2,3]triazole **26**, which then loses N_2 to give aziridine **4j**. However, the chemical shifts of the two protons (4.22 and 5.27) are more consistent with cycloadduct **10**, as H_B in **26** would be expected at much higher field, as it is attached to a carbon bearing a $SiMe_3$ group.



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(44) Pilcher, A. S.; DeShong, P. *J. Org. Chem.* **1996**, *61*, 6901.

(45) Treatment of *trans*-**4j** with TBAT at room temperature prior to the addition of benzaldehyde resulted in rapid and substantial decomposition.

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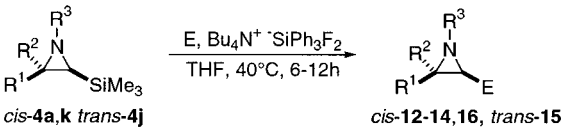
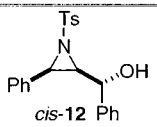
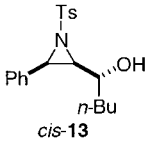
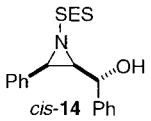
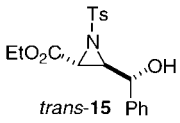
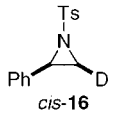
Table 2. Substitution of the Silyl Group

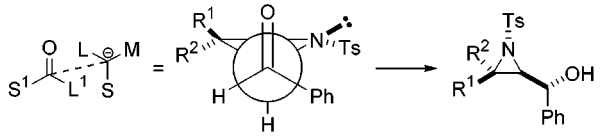


cis-**4a**,**k** *trans*-**4j** *cis*-**12**-**14**,**16**, *trans*-**15**

entry	*C*-silylaziridine				E	product	yield% (d.r.[a])
	R^1	R^2	R^3				
1	Ph	H	Ts	*cis*-**4a**	PhCHO	 *cis*-**12**	60 (98:2)
2	Ph	H	Ts	*cis*-**4a**	*n*-BuCHO	 *cis*-**13**	54 (92:8)
3	Ph	H	SES	*cis*-**4k**	PhCHO	 *cis*-**14**	64 (86:14)
4	H	CO_2Et	Ts	*trans*-**4j**	PhCHO	 *trans*-**15**	60[b] (98:2)
5	Ph	H	Ts	*cis*-**4a**	$CDCl_3$	 *cis*-**16**	84[c]

[a] Determined by ^1H NMR of the crude reaction mixture. [b] Reaction carried out with slow warming from −78 to 0 °C. [c] 88% D-incorporation.

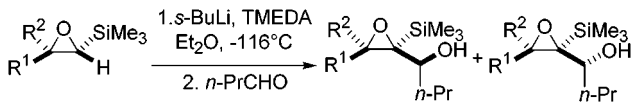
Scheme 9. A Rationale for the Diastereoselectivity in the Substitution of the Silyl Group



cis-**4a**: R^1 = Ph, R^2 = H — *cis*-**12**

trans-**4j**: R^1 = H, R^2 = CO_2Et — *trans*-**15**

Scheme 10. Diastereoselectivity in the Addition of Oxiranyl Anions to Aldehydes from Molander



R^1 = H, R^2 = n-C_8H_{17}	83% yield	2:1
R^1 = n-C_8H_{17}, R^2 = H	63% yield	1:1.3
R^1 = R^2 = -$(CH_2)_5$-	56% yield	2.4:1

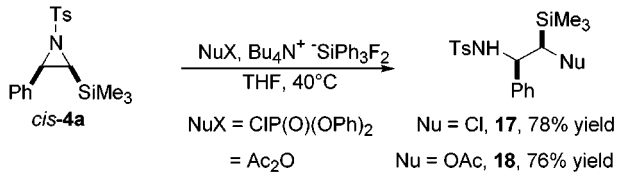
show similar diastereoselectivity to *trans*-disubstituted epoxides, instead showed similar diastereoselectivity to the cis isomers. In this case, no single model could be used to account for these fluctuating results. This could be due to the inadequacy of the model to predict the small energy differences involved in these poorly diastereoselective reactions, as it does not address the role of the counterion nor any aggregation phenomena. In contrast, our aziridinyl anions are likely to be monomeric, and this could account for the higher diastereoselectivity and the greater consistency of results in reactions of different substrates with different electrophiles.

Electrophiles other than aldehydes were also explored (such as ketones, imines, acyl halides, saturated, and α,β-unsaturated esters), but despite consumption of the starting aziridine, no useful products were observed. Curiously, the use of methyl iodide and benzyl bromide afforded the protodesilylated aziridine in good yield. Treatment of *cis*-**4a** with TBAT and $CDCl_3$ (optimum deuterium source) gave the deuterated *cis*-aziridine **16** in good yield (Table 2, entry 5). Alkyl halides acting as deuterium (or hydrogen) donors was unexpected, but they proved to be superior donors to D_2O.

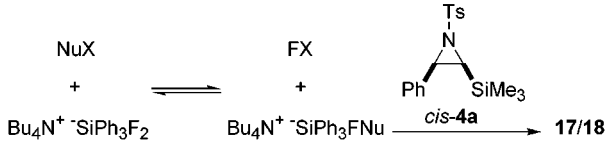
The substitution of the silyl group is a stereospecific reaction, since in all the cases examined complete retention of configuration was observed. This is a consequence of the intermediate aziridinyl anion being configurationally stable under the reaction conditions and being trapped by the electrophile as soon as it is formed. The limited reports that have appeared so far have shown that both *cis*- and *trans*-aziridinyl anions can be configurationally unstable as subsequent trapping with electrophiles often leads to cis and trans mixtures of aziridines.[24]

When we tried to employ acetic anhydride or diphenyl chlorophosphate as electrophiles in the fluoride-mediated substitution of the silyl group, ring opening of the

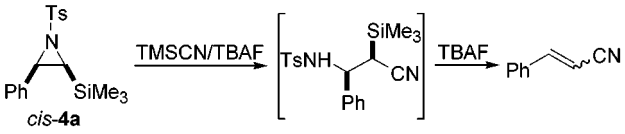
Scheme 11. TBAT-Promoted Ring Opening of Aziridine *cis*-4a



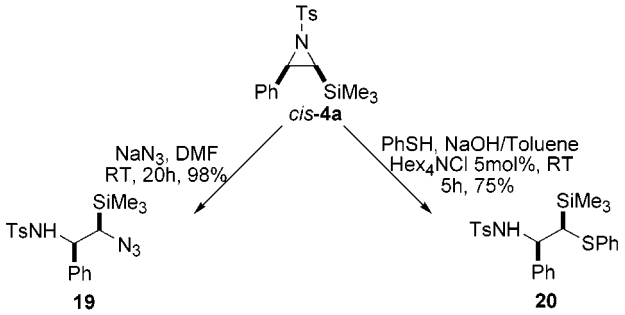
Scheme 12. Ring Opening of Aziridine via Hypervalent Silicate Intermediates



Scheme 13. Attempted Ring Opening of Aziridine *cis*-4a Using TMSCN/TBAF



Scheme 14. Ring Opening of Aziridine *cis*-4a



starting aziridine with acetate or chloride anions respectively was observed instead (Scheme 11). The ring-opened products **17** and **18**, obtained cleanly and in high yield, still bore the TMS group.

A possible explanation for this alternative reactivity is that TBAT, instead of cleaving the silicon−carbon bond in the aziridine, formed new hypervalent acetate and chlorosilicate derivatives, providing highly reactive nucleophilic agents (Scheme 12). Indeed, hypervalent intermediates, formed from the combination of TBAT (or TBAF) and $TMSN_3$ or TMSCN, have proven to be extremely effective sources of nucleophiles, even reacting with sugar tosylates and at neopentyl centers.[47,48] When tetrabutylammonium chloride was used in the place of TBAT/$ClP(O)(OPh)_2$, the ring-opening reaction proceeded much more slowly, in agreement with the lower nucleophilicity of chloride in this case compared to the proposed chlorosilicate.

Related ring-opening reactions of aziridines with trimethylsilyl compounds in the presence of TBAF have been recently reported by Dai, and they probably involve in situ formation of hypervalent silicates, too.[49] Attempted ring opening of *cis*-aziridine **4a** using TMSCN/TBAF under the conditions employed by Dai gave cinnamonitrile (predominantly trans) as the main product (Scheme 13). In this case, the ring-opened product probably underwent TBAF-promoted elimination before all the starting aziridine could be consumed.

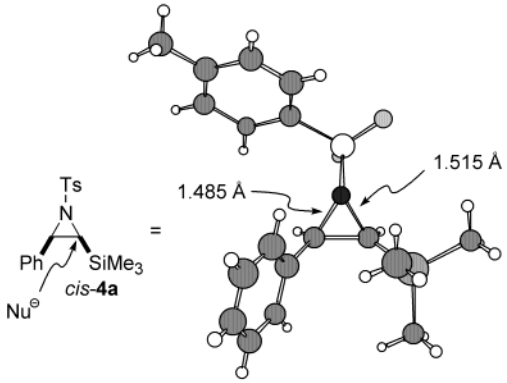


Figure 1. Lengthening of the silicon-bearing C−N bond in the *cis*-aziridine **4a**.

Ring opening of *cis*-aziridine **4a** with thiol and azide anion gave single regioisomeric products in high yield (Scheme 14) with exclusive attack at the silicon-bearing carbon. The structures of the ring-opened products **17** and **20** were unambiguously confirmed by X-ray analysis. The greater activation by a silicon over a phenyl group is especially noteworthy, considering the greater steric bulk of the silyl group and the electronic activation by the phenyl group. The regioselectivity in ring opening of the *C*-silylaziridine mirrors the regioselectivity observed in ring opening of epoxysilanes.[26,27]

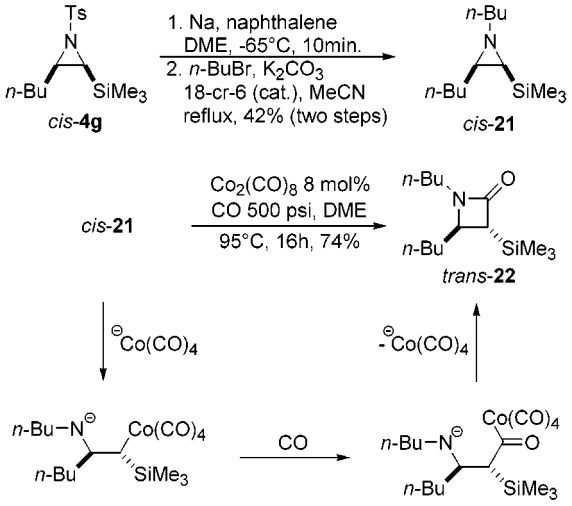
X-ray analysis of the *cis*-aziridine **4a** revealed that the two C−N bonds were significantly different in length: the (Me_3Si)C−N bond was 0.03 Å longer than the (Ph)C−N bond. A difference of this magnitude can easily account for the greater reactivity of the (Me_3Si)C−N bond (Figure 1).[50] Calculations on related α,*β*-epoxyalkylsilanes have indeed shown that an antibonding interaction between the oxygen 2p and the C−Si s orbital leads to a weakening of the C−O bond α to silicon and an enhanced electrophilicity of the α carbon.[51] An analogous phenomenon could account for the lengthening of the C−N bond α to silicon, leading to the same chemical behavior of *C*-silylaziridines.[52]

The regioselectivity and efficiency of the ring opening was then also exploited for the synthesis of a *β*-lactam. Alper has reported the carbonylative ring expansion of aziridines catalyzed by dicobalt octacarbonyl under CO pressure.[53] The reaction begins by nucleophilic ring opening of the aziridine by in situ generated tetracarbonylcobaltate anion, followed by CO insertion and final ring closure to *β*-lactam. The ring opening, and conse-

(47) Soli, E. D.; Manoso, A. S.; Patterson, M. C.; DeShong, P.; Favor, D. A.; Hirschmann, R.; Smith, A. B., III *J. Org. Chem.* **1999**, *64*, 3171.
(48) Soli, E. D.; DeShong, P. *J. Org. Chem.* **1999**, *64*, 9724.
(49) Wu, J.; Hou, X.-L.; Dai, L.-X. *J. Org. Chem.* **2000**, *65*, 1344.

(50) From a correlation of bond length with reactivity, Kirby has formulated a simple rule: "The longer the bond, in a given system, the faster it breaks": Edwards, M. R.; Jones, P. G.; Kirby, A. J. *J. Am. Chem. Soc.* **1986**, *108*, 7067.
(51) Fristad, W. E.; Bailey, T. R.; Paquette, L. A.; Gleiter, R.; Böhm, M. C. *J. Am. Chem. Soc.* **1979**, *101*, 4420.
(52) Another possible explanation to account for ring opening α to silicon is that the nucleophile initially attacks silicon, followed by 1,2-rearrangement. However, in reactions of Me_2CuLi with (*Z*)-1-phenyldimethylsilyl-1,2-epoxyoctane, none of the phenyl-migrated ring-opened products was observed, discounting this explanation: Hudrlik, P. F.; Ma, D.; Bhamidipati, R. S.; Hudrlik, A. M. *J. Org. Chem.* **1996**, *61*, 8655.
(53) Piotti, M. E.; Alper, H. *J. Am. Chem. Soc.* **1996**, *118*, 111.

Scheme 15. Conversion of *cis*-Aziridine 4g to *trans*-β-Lactam 22



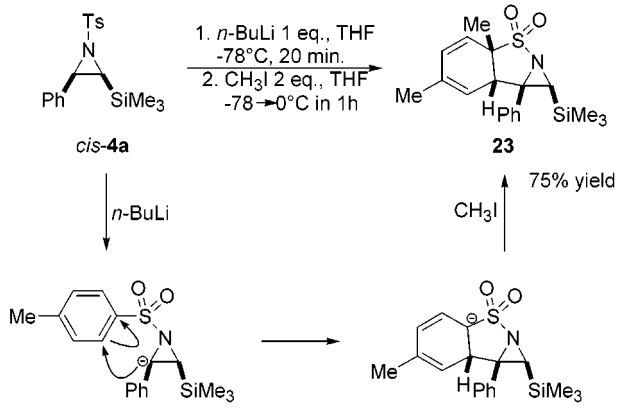
quently the CO insertion, occurs preferentially on the ring carbon displaying the higher electrophilic character or the lower steric hindrance.[54] When the *cis*-aziridine **4a** was subjected to the established carbonylation conditions [$Co_2(CO)_8$, CO, DME], it was recovered untouched, while only $TsNH_2$ was obtained at the end of the reaction when the preformed nucleophilic reagent $Na^+Co(CO)_4^-$ was used as catalyst. As *N*-alkyl-aziridines work especially well in the carbonylation reaction,[53,54] we decided to employ this type of electron-donating (instead of electron-withdrawing) nitrogen substituent.

Deprotection of *cis*-**4g** could be carried out using sodium naphthalenide to provide the corresponding NH aziridine,[55] which was then alkylated to give cis-**21** (Scheme 15). Attempts at desulfonylation using magnesium in methanol under ultrasonic conditions to give the unprotected aziridine were unsuccessful.[56] *cis*-**21** was then employed in the carbonylation reaction and in this case the *trans*-β-lactam **22** could be obtained as a single diastereo- and regioisomer in good yield. The nucleophilic ring opening of the cis starting material resulted in inversion of configuration, thus leading to the *trans*-β-lactam. The exclusive formation of the 3-TMS-substituted β-lactam **22** is a consequence of the completely regioselective ring opening of the aziridine, which, again, occurred exclusively at the silicon-bearing carbon.

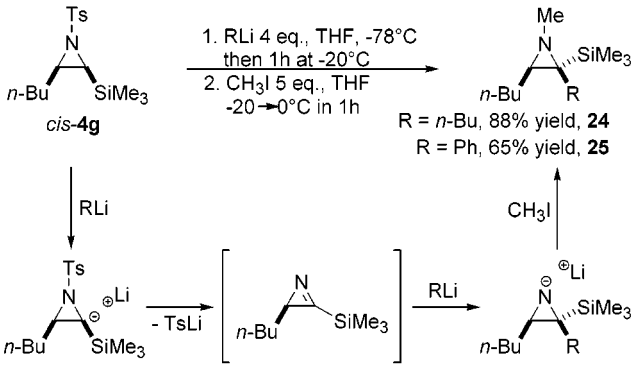
Metalation of *C*-Silylaziridines. We finally explored the possibility of generating aziridinyl anions by deprotonation of *C*-silylaziridines.

Metalation of the phenyl-substituted *cis*-aziridine **4a** followed by quenching with MeI afforded the tricyclic aziridine **23** as a single distereoisomer (Scheme 16). Treatment with *n*-BuLi resulted in metalation of the benzylic position, rather than the position α to the silicon, and the benzylic anion then intramolecularly attacked the tosyl group ortho to the sulfonyl group. The corresponding anion was then quenched with MeI, giving **23** as a single diastereoisomer, whose structure was confirmed by X-ray analysis. An analogous but much lower yielding reaction using 1-tosyl-2-phenylaziridine was

Scheme 16. Metalation of Phenyl-Substituted Aziridine *cis*-4a



Scheme 17. Metalation of Alkyl-Substituted Aziridine *cis*-4g

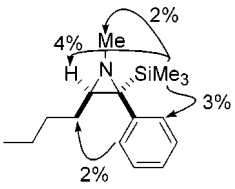


reported by Schaumann.[57] It should also be noted that the generation of an oxiranyl anion from 2-phenyl-3-trimethylsilylepoxide and its reaction with an electrophile were reported to occur α to the phenyl, suggesting that it is a more powerful anion-stabilizing group than the trimethylsilyl group.[58]

A different path was followed in the metalation of the alkyl-substituted cis-aziridine **4g**. In this case, treatment with an excess of an organolithium followed by quenching with MeI afforded the trisubstituted aziridines **24** and **25** (Scheme 17). The formation of the observed products can be explained if the metalation, this time α to the silicon, is followed by rapid elimination of TsLi to give an azirine.[59] The 1,2-elimination of TsLi from a metalated *N*-Ts aziridine to form a stable azirine has previously been reported by Davis.[60] In our case the azirine could not be isolated[61] but was instead trapped by excess organolithium with complete diastereoselectivity.

The stereochemistry of the product, unambiguously assigned for **25** by ^1H NOE experiments (Figure 2), is the result of the attack of the alkyllithium from the same side as the *n*-butyl azirine substituent. The stereochemical outcome of the reaction is surprising, as attack of organometallic reagents on 2*H*-azirines generally occur

(54) Davoli, P.; Forni, A.; Moretti, I.; Prati, F.; Torre, G. *Tetrahedron* **2001**, *57*, 1801.
(55) Bergmeier, S. C.; Seth, P. P. *Tetrahedron Lett.* **1999**, *40*, 6181.
(56) Alonso, D. A.; Andersson, P. G. *J. Org. Chem.* **1998**, *63*, 9455.
(57) Breternitz, H.-J.; Schaumann, E.; Adiwidjaja, G. *Tetrahedron Lett.* **1991**, *32*, 1299.
(58) Eisch, J. J.; Galle, J. E. *J. Organomet. Chem.* **1988**, *341*, 293.
(59) For a review on the synthesis and application of 2*H*-azirines, see: Palacios, F.; Ochoa de Retana, A. M.; Martinez de Marigorta, E.; Manuel De los Santos, J. *Eur. J. Org. Chem.* **2001**, 2401.
(60) Davis, F. A.; Liang, C.-H.; Liu, H. *J. Org. Chem.* **1997**, *62*, 3796.
(61) Attempts to use LDA under different conditions to avoid subsequent addition of the base to the azirine and aid its isolation were unsuccessful and gave a complex reaction mixture.



25

Figure 2. Observed NOE enhancements in the aziridine **25** (selective irradiation of the 3-substituents was not possible).

on the less hindered face.[59] However, in one example from Davis, addition of methylmagnesium bromide occurred from the more hindered face of a 2*H*-azirine-2-carboxylate ester, although in this case chelation of the organometallic reagent to the ester group could account for the observed selectivity.[60]

Conclusions

In this paper we have presented an efficient, simple, and general synthesis of *C*-silylaziridines based on the direct reaction between TMSD and *N*-sulfonyl (Ts and SES) imines. Upon treatment with an anhydrous source of fluoride, the *C*-silylaziridines undergo stereospecific substitution of the silyl group with electrophiles (aldehydes and $CDCl_3$), which in the case of aldehydes is also highly diastereoselective for the newly created stereogenic center. Complete regioselectivity was observed in the nucleophilic ring-opening reaction of the aziridines with attack occurring at the silyl-bearing carbon. A lengthening of the $(Me_3Si)C-N$ bond relative to the (Ph)C−N bond was observed in the X-ray structure of an aziridine, and this accounts for the observed selectivity in the ring-opening reactions. *C*-Silylaziridines could also be converted into β-lactams using $Co_2(CO)_8$ again with complete regio- and stereoselectivity. Deprotonation of the *C*-silylaziridines and trapping with electrophiles was also highly efficient but followed completely different pathways, depending on the substituents on the ring. In the case of the 2-phenylaziridine, metalation adjacent to the phenyl group occurred followed by addition to the arylsulfonyl group to give a fused tricyclic adduct that was trapped by MeI. In the case of the 2-butylaziridine, metalation adjacent to the silyl group occurred, followed by elimination of TsLi to give an azirine intermediate. The base (*n*-BuLi or PhLi) added to the azirine, and trapping with MeI furnished the trisubstituted *N*-Me aziridine. Contrary to expectation, the base added syn to the butyl group.

The numerous applications in which *C*-silylaziridines have been successfully employed, based on silyl substitution, ring-opening reactions, and generation of aziridinyl anions, demonstrate the versatility and high potential of these compounds in synthetic organic chemistry.

Experimental Section

General Methods. See Supporting Information for details of the instrumentation employed. IR spectra were recorded using an ATR sampling accessory, unless otherwise specified. ^1H NMR chemical shifts (δ_H) are quoted in parts per million (ppm), referenced to TMS. ^{13}C NMR chemical shifts (δ_C) are quoted in parts per million (ppm), referenced to the appropriate residual solvent peak and assigned as + or − for CH/CH_3 and C/CH_2. The carbonylation reaction was run in a stainless steel autoclave.

Imines **2a**−**d**,[62] **2e**,[63] **2f**,[62] **2g,h**,[64] **2i**,[62] **2j,**[65] and **2k**[62,66] were prepared according to literature procedures. Characterizations of compounds **4a**−**d**, **4f**−**i**, **4k**, *cis*-**12**-**14**, *cis*-**16**, **19**, **20**, and **23** and the procedures for their syntheses, described in a preliminary account,[21] are reported in the Supporting Information. TMSD and TBAT were purchased from Aldrich; the concentration of TMSD was determined by ^1H NMR using 1,4-dimethoxybenzene as an internal standard.

Representative Procedure for the Aziridination of Imines Using TMSD. To a solution of *N*-tosylbenzaldimine (**2a**) (259.3 mg, 1.0 mmol) in 1,4-dioxane (5 mL) was added a 1.8 M solution of TMSD in hexanes (1.39 mL, 2.5 equiv). After being stirred for 7 h at 40 °C, the solvent was removed and the crude mixture was purified by flash chromatography on silica gel (eluent petroleum ether/ethyl acetate 20:1) to afford *trans*-**4a** (12.4 mg, 4%) and *cis*-**4a** (236.3 mg, 68%).

3-[(2*R,3*S**)-1-[(4-Methylphenyl)sulfonyl]-3-(1,1,1-trimethylsilyl)aziridin-2-yl]pyridine (cis-4e):** colorless oil; eluent petroleum ether/ethyl acetate 2:1, $R_f = 0.21$; ^1H NMR (270 MHz, $CDCl_3$) δ −0.29 (9H, s), 2.29 (1H, d, $J = 8.4$ Hz), 2.45 (3H, s), 4.00 (1H, d, $J = 8.4$ Hz), 7.20 (1H, dd, $J = 8.1$, 5.1 Hz), 7.36 (2H, d, $J = 8.2$ Hz), 7.53 (1H, m), 7.90 (2H, d, $J = 8.2$ Hz), 8.50 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ −2.3 (+), 21.8 (+), 37.7 (+), 42.7 (+), 123.1 (+), 128.3 (+), 129.8 (+), 131.3 (−), 134.9 (−), 135.2 (+), 144.8 (−), 149.0 (+), 149.1 (+); IR ν_{max}/cm^{-1} (neat) 2900, 1590, 1315, 1240, 1135; MS *m*/*z* (CI with NH_3) 347 ([M + H]$^+$, 100), 191 (60), 91 (75); HRMS found [M + H]$^+$ 347.1262, $C_{17}H_{23}N_2O_2SSi$ requires 347.1249.

3-[(2*R,3*R**)-1-[(4-Methylphenyl)sulfonyl]-3-(1,1,1-trimethylsilyl)aziridin-2-yl]pyridine *(trans*-4e):** eluent petroleum ether/ethyl acetate 2:1, $R_f = 0.20$; ^1H NMR (270 MHz, $CDCl_3$, selection of signals) δ 2.10 (1H, d, $J = 6.1$ Hz), 3.70 (1H, d, $J = 6.1$ Hz).

Aziridination of Imine 2j Using TMSD. To a solution of the α-imino ester **2j** (638.2 mg, 2.5 mmol) in THF (5 mL) cooled to −78 °C was added a 1.74 M solution of TMSD in hexanes (4 mL, 7.2 mmol, 2.5 equiv). The reaction mixture was warmed to 0 °C during 12 h and the solvent was removed. ^1H NMR analysis of the crude reaction mixture showed the two aziridines (minor components) and the following selection of signals: ^1H NMR (250 MHz, $CDCl_3$) δ 0.00 (9H, s), 1.09 (3H, t, $J = 7.2$ Hz), 2.32 (3H, s), 3.96 (2H, m), 4.22 (1H, d, $J = 7.6$ Hz), 5.27 (1H, d, $J = 7.6$ Hz). The doublets at 4.22 and 5.27 ppm were shown to couple together by selective irradiation. HRMS was also performed: found 369.1179, $C_{15}H_{23}N_3O_4SSi$ requires 369.1194. The reaction mixture was dissolved in benzene (20 mL) and then added dropwise to anhydrous silica gel in benzene (20 mL) in the presence of 4 Å molecular sieves via a cannula. After stirring for 1 h at room temperature, the solvent was removed and the crude mixture was purified by flash chromatography on silica gel (eluent petroleum ether/ethyl acetate 10:1) to afford *cis*-**4j** (85.5 mg, 10%) and *trans*-**4j** (691.5 mg, 81%).

Ethyl (2*R,3*S**)-1-[(4-methylphenyl)sulfonyl]-3-(1,1,1-trimethylsilyl)aziridine-2-carboxylate (*cis*-4j):**[23] colorless liquid; ^1H NMR (400 MHz, $CDCl_3$) δ 0.00 (9H, s), 1.26 (3H, m), 2.12 (1H, d, $J = 8.7$ Hz), 2.44 (3H, s), 3.43 (1H, d, $J = 8.7$ Hz), 4.17 (2H, m), 7.33 (2H, d, $J = 8.1$ Hz), 7.83 (2H, d, $J = 8.1$ Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ −2.4 (+), 14.0 (+), 21.6 (+), 35.6 (+), 40.4 (+), 61.8 (−), 128.2 (+), 129.6 (+), 134.4 (−), 144.9 (−), 167.1 (−).

Ethyl (2*R,3*R**)-1-[(4-methylphenyl)sulfonyl]-3-(1,1,1-trimethylsilyl)aziridine-2-carboxylate *(trans*-4j):**[23] colorless liquid; ^1H NMR (400 MHz, $CDCl_3$) δ 0.26 (9H, s), 1.23 (3H, m), 2.32 (1H, d, $J = 6.0$ Hz), 2.44 (3H, s), 3.22 (1H, d, $J = 8.7$ Hz), 4.17 (2H, m), 7.33 (2H, d, $J = 8.1$ Hz), 7.86 (2H, d,

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J = 8.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ −1.5 (+), 14.0 (+), 21.6 (+), 39.4 (+), 41.1 (+), 61.8 (−), 127.7 (+), 129.6 (+), 136.2 (−), 144.4 (−), 167.8 (−).

Coupling of Aziridine *trans*-4j with Benzaldehyde. To a solution of TBAT (35.3 mg, 0.065 mmol, 1 equiv) and benzaldehyde (20 μL, 0.20 mmol, 3 equiv) in THF (0.5 mL) cooled to −78 °C was added *cis*-**4j** (22.3 mg, 0.065 mmol) in THF (0.5 mL). The reaction mixture was warmed to 0 °C over 3 h and saturated NH_4Cl solution was added (2 mL). The solvent was removed under reduced pressure and the reaction mixture was extracted with ethyl acetate (3×). The combined organic extracts were washed with saturated NaCl solution, dried with anhydrous Na_2SO_4, and evaporated. The crude mixture was purified by flash chromatography on silica gel (eluent petroleum ether/ethyl acetate 4:1) to afford major (13.9 mg, 59%) and minor (0.3 mg, 1%) diastereoisomers of *trans*-**15**.

Ethyl (2*R,3*R**)-3-[(*R**)-1-hydroxy-1-phenylmethyl]-1-[(4-methylphenyl)sulfonyl]aziridine-2-carboxylate (*trans*-15, major diastereoisomer):** white solid; eluent petroleum ether/ethyl acetate 3:1, R_f = 0.33; mp 87−89 °C (from petroleum ether/ethyl acetate); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.18 (3H, t, J = 7.1 Hz), 2.45 (3H, s), 3.43 (1H, dd, J = 8.4, 3.9 Hz), 3.56 (1H, br d, J = 3.3 Hz), 3.66 (1H, d, J = 3.9 Hz), 4.11 (2H, q, J = 7.1 Hz), 5.09 (1H, dd, J = 8.4, 3.3 Hz), 7.18−7.46 (7H, m), 7.86 (2H, d, J = 8.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.8 (+), 21.6 (+), 42.7 (+), 53.7 (+), 62.1 (−), 71.5 (+), 125.9 (+), 127.5 (+), 128.4 (+), 128.7 (+), 129.8 (+), 136.3 (−), 139.2 (−), 144.9 (−), 165.9 (−); IR ν_{max}/cm^{-1} 3509, 1749, 1315, 1161; MS m/z (CI with NH_3) 376 ([M + H]$^+$, 4), 155 (100), 91 (67); HRMS found [M + H]$^+$ 376.1212, $C_{19}H_{22}NO_5S$ requires 376.1219. Anal. Calcd for $C_{19}H_{21}NO_5S$: C, 60.78; H, 5.64; N, 3.73. Found: C, 60.98; H, 5.99; N, 3.74.

Ethyl (2*R,3*R**)-3-[(*S**)-1-hydroxy-1-phenylmethyl]-1-[(4-methylphenyl)sulfonyl]aziridine-2-carboxylate (*trans*-15, minor diastereoisomer):** ^{1}H NMR (400 MHz, $CDCl_3$, selection of signals) δ 3.18 (1H, dd, J = 5.4, 1.8 Hz), 3.85 (1H, d, J = 1.8 Hz), 5.43 (1H, br d, J = 8.3 Hz), 7.74 (2H, d, J = 8.3 Hz).

Representative Procedure for the TBAT-Promoted Ring Opening of Aziridine *cis*-4a. A solution of *cis*-**4a** (34.6 mg, 0.10 mmol), TBAT (54.0 mg, 0.10 mmol, 1 equiv), and diphenyl chlorophosphate (62 μL, 0.30 mmol, 3 equiv) in THF (1 mL) was stirred for 20 h at 40 °C. The solvent was evaporated and the crude mixture was purified by flash chromatography on silica gel (eluent petroleum ether/ethyl acetate 15:1) to afford **17** (31.2 mg, 78%).

***N*1-[(1*R**,2S*)-2-Chloro-1-phenyl-2-(1,1,1-trimethylsilyl)-ethyl]-4-methyl-1-benzenesulfonamide (17):** white solid; eluent petroleum ether/ethyl acetate 5:1, R_f = 0.37; ^{1}H NMR (250 MHz, $CDCl_3$) δ 0.00 (9H, s), 2.23 (3H, s), 3.32 (1H, d, J = 5.8 Hz), 4.69 (1H, dd, J = 7.0, 5.8 Hz), 5.32 (1H, br d, J = 7.0 Hz), 6.88−6.95 (3H, m), 6.98−7.08 (2H, m), 7.02 (2H, d, J = 7.9 Hz), 7.33 (2H, d, J = 7.9 Hz); ^{13}C NMR (63 MHz, $CDCl_3$) δ −2.8 (+), 21.4 (+), 56.9 (+), 59.8 (+), 127.0 (+), 127.3 (+), 127.8 (+), 128.1 (+), 129.0 (+), 137.4 (−), 138.3 (−), 142.9 (−); IR ν_{max}/cm^{-1} 3377, 3323, 3034, 2959, 1600, 1253, 1161, 1091; MS m/z (CI with NH_3) 399 ([M + NH_4]$^+$, 6), 346 (55), 260 (92), 244 (100), 190 (76), 91 (42), 73 (51); HRMS found [M + NH_4]$^+$ 399.1316, $C_{18}H_{28}N_2O_2ClSSi$ requires 399.1329.

(1*R,2*R**)-2-[(4-Methylphenyl)sulfonyl]amino-2-phenyl-1-(1,1,1-trimethylsilyl)ethyl acetate (18):** white solid; eluent petroleum ether/ethyl acetate 3:1, R_f = 0.43; mp 140−142 °C (from petroleum ether/ethyl acetate); ^{1}H NMR (250 MHz, $CDCl_3$) δ 0.00 (9H, s), 2.17 (3H, s), 2.48 (3H, s), 4.80 (1H, t, J = 9.0 Hz), 5.13 (1H, d, J = 9.2 Hz), 5.50 (1H, br d, J = 8.2 Hz), 7.16−7.34 (7H, m), 7.59 (2H, d, J = 8.2 Hz); ^{13}C NMR (63 MHz, $CDCl_3$) δ 3.3 (+), 20.8 (+), 21.4 (+), 60.4 (+), 70.5 (+), 126.8 (+), 127.4 (+), 128.0 (+), 128.5 (+), 129.1 (+), 137.7 (−), 138.2 (−), 142.6 (−), 171.9 (−); IR ν_{max}/cm^{-1} 3371, 3283, 3033, 2958, 1725, 1599, 1253, 1160; MS m/z (CI with NH_3) 423 ([M + NH_4]$^+$, 6), 356 (50), 260 (69), 244 (100), 190 (59), 106 (43); HRMS found [M + NH_4]$^+$ 423.1763, $C_{20}H_{31}N_2O_4SSi$ requires 423.1774. Anal. Calcd for $C_{20}H_{27}NO_4SSi$: C, 59.23; H, 6.71; N, 3.45. Found: C, 59.03; H, 6.60; N, 3.24.

Deprotection of Aziridine *cis*-4g. According to the procedure of Bergmeier,[55] finely divided sodium metal (73.0 mg, 3.18 mmol, 20 equiv) and naphthalene (447.8 mg, 3.49 mmol, 22 mmol) were dissolved in DME (3.2 mL). The reaction was stirred for 2 h, to provide a dark green solution. A solution of *cis*-**4g** (46.2 mg, 0.142 mmol) in DME (0.6 mL) was cooled to −65 °C. The sodium naphthalenide solution was added dropwise to the reaction via a syringe, until a dark green color persisted for 5 min. The reaction was quenched at −65 °C with one drop of water (which discharged the green color), and the reaction was diluted with diethyl ether to provide a cloudy solution that was dried ($MgSO_4$), filtered, and concentrated to give crude (2*R**,3*S**)-2-butyl-3-(1,1,1-trimethylsilyl)aziridine (care should be exercised while isolating the product, which is somewhat volatile), which was used in the next step without further purification: ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.10 (9H, s), 0.91 (3H, t, J = 7.1 Hz), 1.00 (1H, d, J = 7.0 Hz), 1.20−1.53 (6H, m), 2.13−2.18 (1H, m); MS m/z (EI) 171 (M$^+$, 1), 142 (55), 128 (87), 100 (100), 98 (57), 73 (59), 59 (50).

The crude deprotected aziridine, butyl bromide (23 μL, 0.213 mmol, 1.5 equiv), and 18-crown-6 (3.8 mg, 0.014 mmol, 0.1 equiv) were dissolved in CH_3CN (2 mL). K_2CO_3 (29.4 mg, 0.213 mmol, 1.5 equiv) was added and the reaction mixture was refluxed for 2 days. The solvent was evaporated, water was added, and the resulting mixture was extracted with CH_2Cl_2 (3×). The combined organic extracts were washed with saturated NaCl solution, dried with anhydrous Na_2SO_4, and evaporated. The crude mixture was purified by flash chromatography on silica gel (eluent petroleum ether to remove naphthalene and then petroleum ether/ethyl acetate 30:1 + 0.5% NEt_3) to afford *cis*-**21** (13.6 mg, 42%).

(2*R,3*S**)-1,2-Dibutyl-3-(1,1,1-trimethylsilyl)aziridine (*cis*-21):** colorless liquid; eluent petroleum ether/ethyl acetate 20:1 + 0.5% NEt_3, R_f = 0.35; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.06 (9H, s), 0.27 (1H, d, J = 7.0 Hz), 0.88 (3H, t, J = 7.3 Hz), 0.89 (3H, t, J = 7.2 Hz), 1.23−1.57 (11H, m), 1.77 (1H, ddd, J = 11.2, 9.6, 5.4 Hz), 2.65 (1H, ddd, J = 11.2, 9.5, 5.9 Hz); ^{13}C NMR (63 MHz, $CDCl_3$) δ −1.1 (+), 14.1 (+), 20.6 (−), 22.7 (−), 30.6 (−), 31.7 (−), 32.2 (−), 35.0 (+), 45.7 (+), 64.6 (−); IR ($CDCl_3$) ν_{max}/cm^{-1} 2959, 1249; MS m/z (CI, NH_3) 228 ([M + H]$^+$, 9), 84 (100), 73 (100); HRMS found [M + H]$^+$ 228.2143, $C_{13}H_{30}NSi$ requires 228.2148. Anal. Calcd for $C_{13}H_{29}NSi$: C, 68.64; H, 12.85; N, 6.16. Found: C, 69.00; H, 13.28; N, 5.75.

Carbonylation of Aziridine *cis*-21. According to the procedure of Alper,[53] *cis*-**21** (146.1 mg, 0.64 mmol), dry and O_2-free DME (10 mL), and $Co_2(CO)_8$ (17.6 mg, 0.051 mmol, 0.08 equiv) were placed in a stainless steel autoclave equipped with a stirring bar. The autoclave was purged three times with carbon monoxide and was then charged with 500 psi of carbon monoxide. The reaction was stirred at 95 °C for 16 h and the autoclave was then opened and left in contact with air for a few hours to induce decomposition of the catalyst. Addition of a small amount of ether accelerates the process. A precipitate was formed and the mixture was filtered through a short column packed with silica gel, using ether as eluent. The crude mixture was purified by flash chromatography on silica gel (eluent petroleum ether/ethyl acetate 10:1) to afford *trans*-**22** (120.6 mg, 74%).

(3*R,4*R**)-1,4-Dibutyl-3-(1,1,1-trimethylsilyl)azetidin-2-one (*trans*-22):** pale brown oil; eluent petroleum ether/ethyl acetate 10:1, R_f = 0.21; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.11 (9H, s), 0.91 (3H, t, J = 7.1 Hz), 0.91 (3H, t, J = 7.3 Hz), 1.15−1.42 (7H, m), 1.42−1.56 (2H, m), 1.83 (1H, m), 2.30 (1H, d, J = 2.0 Hz), 2.91 (1H, m), 3.30 (1H, ddd, J = 8.8, 4.3, 2.0 Hz), 3.35 (1H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ −2.6 (+), 13.6 (+), 13.9 (+), 20.3 (−), 22.7 (−), 28.0 (−), 30.5 (−), 33.6 (−), 39.9 (−), 47.1 (+), 53.1 (+), 169.2 (−); IR ν_{max}/cm^{-1} 1730, 1248; MS m/z (CI, NH_3) 256 ([M + H]$^+$, 16), 141 ([$C_4H_9NCHC_4H_9$]$^+$, 10), 86 (70), 84 (100); HRMS found [M + H]$^+$ 256.2097, $C_{14}H_{30}NOSi$ requires 256.2097. Anal. Calcd for $C_{14}H_{29}NOSi$: C, 65.82; H, 11.44; N, 5.49. Found: C, 66.24; H, 11.81; N, 5.21.

Representative Procedure for the Metalation of Alkyl-Substituted Aziridine *cis*-4g. To a solution of *cis*-**4g** (32.6 mg, 0.10 mmol) in THF (1.5 mL) at −78 °C was added dropwise

a 1.49 M solution of *n*-BuLi in hexanes (269 μL, 0.40 mmol, 4 equiv). After stirring of the resulting yellow solution for 1 h at −20 °C, MeI (31 μL, 0.50 mmol, 5 equiv) was added. The mixture was allowed to reach 0 °C within 1 h and saturated NH_4Cl solution was added (2 mL). The organic solvent was removed and the reaction mixture was extracted with diethyl ether (4×). The combined organic extracts were washed with saturated NaCl solution, dried with anhydrous Na_2SO_4, and evaporated. The crude mixture was purified by flash chromatography on silica gel (eluent petroleum ether/ethyl acetate 10:1 + 0.5% NEt_3) to afford **24** (21.3 mg, 88%).

(2*R,3*R**)-2,3-Dibutyl-1-methyl-2-(1,1,1-trimethylsilyl)-aziridine** (**24**)**:** colorless liquid; eluent petroleum ether/ethyl acetate 4:1 + 0.5% NEt_3, R_f = 0.45; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.06 (9H, s), 0.91 (6H, m), 1.21−1.50 (12H, m), 1.58−1.65 (1H, m), 2.44 (3H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ −0.5 (+), 14.1 (+), 14.1 (+), 22.7 (−), 23.2 (−), 29.0 (−), 30.6 (−), 31.1 (−), 31.4 (−), 38.0 (−), 39.4 (+), 54.2 (+); IR ($CDCl_3$) ν_{max}/cm^{-1} 1265; MS *m*/*z* (EI) 241 (M^+, 2), 86 (69), 84 (100), 73 (64); HRMS (CI, NH_3) found $[M + H]^+$ 242.2292, $C_{14}H_{32}NSi$ requires 242.2304.

(2*R,3*R**)-3-Butyl-1-methyl-2-phenyl-2-(1,1,1-trimethylsilyl)aziridine** (**25**)**:** colorless liquid; eluent petroleum ether/ethyl acetate 13:1 + 0.5% NEt_3, R_f = 0.13; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.07 (9H, s), 0.77−0.84 (1H, m), 0.86 (3H, t, J = 7.3 Hz), 1.28 (2H, m), 1.35−1.49 (3H, m), 1.78 (1H, dd, J = 8.1, 3.7 Hz), 2.78 (3H, s), 7.10−7.14 (3H, m), 7.21−7.24 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ −0.3 (+), 14.2 (+), 22.9 (−), 30.5 (−), 31.1 (−), 44.3 (+), 45.3 (−), 50.2 (+), 125.4 (+), 127.6 (+), 129.5 (+), 142.1 (−); IR ($CDCl_3$) ν_{max}/cm^{-1} 1600, 1251; MS *m*/*z* (EI) 261 (M + , 3), 84 (100); HRMS found 261.1899, $C_{16}H_{27}NSi$ requires 261.1913.

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Supporting Information Available: Characterizations of compounds **4a**−**d**, **4f**−**i**, **4k**, *cis*-**12**−**14**, *cis*-**16**, **19**, **20,** and **23** and the procedures for their syntheses; X-ray structures and crystallographic data for compounds *cis*-**4a**, *cis*-**12**, *trans*-**15**, **17**, **20,** and **23**.This material is available free of charge via the Internet at http://pubs.acs.org.

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