Thermal and Lewis Acid Catalyzed Intramolecular Ene Reactions of Allenylsilanes

Steven M. Weinreb,* Daniel T. Smith, Jian Jin

Department of Chemistry, The Pennsylvania State University, University Park, Pennsylvania 16802, USA Received 14 March 1997

Abstract: Intramolecular ene reactions of allenylsilanes can be effected with a variety of imines, aldehydes and alkenes as enophiles, forming five and six membered rings. These reactions are *cis* stereoselective in all cases studied, and appear to proceed via a concerted, pericyclic process. The cycloadditions all generally occur under mild thermal conditions and some involving imino enophiles can also be effected at lower temperatures using Lewis acid catalysis.

Key words: ene reaction, cycloaddition, pericyclic process, Lewis acid catalysis, stereoselective reactions

Introduction and Background

A few years ago we became interested in pursuing an approach to a total synthesis of the unique marine pentacyclic alkaloid papuamine (1, Scheme 1).¹ We conceived a synthetic strategy which would involve homocoupling of an appropriate derivative of the bicyclic homopropargyl amine 2, and thus considered potential methods for construction of this type of intermediate. We were particularly attracted to the extensive work of Danheiser and co-workers, who have convincingly demonstrated that carbon-carbon bonds can be efficiently generated via the combination of allenylsilanes with a variety of electrophiles.² For example, it was found that aldehydes react with allenylsilanes 3 in the presence of a Lewis acid to initially produce a silicon-stabilized vinyl cation 4 (Scheme 2).^{2b} In cases where R' is an alkyl group, intermediate 4 collapses directly to give a homopropargyl alcohol 6. In those situations where R'=H, an isolable chlorovinylsilane 5 is produced, which can be converted with fluoride to the terminal alkynol 6.



Scheme 1

A similar type of transformation could also be effected with electron-difficient imines.^{2c} Thus, the *N*-acyl imine derived from lactam **8** reacts with silyl allene **7** to produce vinyl cation **9**, which then produces homopropargyl amine derivative **10** and/or a rearrangement-cyclization product **11** (Scheme 3). We decided to investigate the possibility of using the type of Danheiser chemistry out-



Scheme 2

lined in Schemes 2 and 3, but in an intramolecular sense, for formation of the C-6,14 bond (papuamine numbering) and requisite functionality of papuamine intermediate **2**. Interestingly, no reports had previously appeared of any intramolecular cyclizations of this kind.



Scheme 3

To test the possibility of effecting the desired transformations, diastereomeric allenylsilane aldehydes **12** and **16** were prepared (Schemes 4, 5).¹ Conversion of aldehyde **12** to the *N*-benzyl imine and subsequent exposure to stannic chloride surprisingly led to formation of a single stereoisomeric amino silyl acetylene **14**, whose structure was confirmed by X-ray crystallography on the desilylated amino alkyne **15**. The fact that the product of this reaction was a silyl acetylene, rather than a simple terminal alkyne or a chlorovinylsilane (*cf* **5**), along with the high stereoselectivity of the process, made it evident that a Danheiser reaction of the kind shown in Schemes 2 and 3 was not in effect here. The most reasonable pathway for formation of **14** in fact appears to involve an imino-ene reaction.^{3–6} It is evident from inspection of models that imine conformation **13**, which leads to the observed product stereoisomer, is the only one properly disposed stereo-electronically for a concerted pericyclic ene reaction.







In order to confirm this mechanistic postulate, isomeric allenylsilane aldehyde **16** was also converted to the corresponding *N*-benzyl imine, which was treated with $SnCl_4$ to afford an amino silyl acetylene **18**. Once again, the structure of this cyclization product was established by X-ray analysis of the desilylated amino alkyne **19**. In this case only imine conformer **17** is aligned for a concerted ene reaction, and predicts the observed product stereochemistry. It might be noted that based upon work described in this paper (*vide infra*) it was subsequently found that the *N*-benzyl imines derived from aldehydes

12 and 16 can be cyclized to 14 and 18, respectively, by simply refluxing in toluene in the absence of any Lewis acid.

In view of the excellent stereospecificity of the novel ene reactions in Schemes 4 and 5, along with the mild conditions required for these transformations, we decided to explore the scope and synthetic potential of intramolecular allenylsilane ene reactions. In this paper are described studies on intramolecular allenylsilane ene reactions involving a variety of enophiles.

Imino Enophiles

In comparison with the large number of ene reactions employing alkenes³ and carbonyl compounds ⁴ as enophiles, few examples exist which involve imino enophiles.⁵ Scarcer yet are imino-ene reactions for which there is sufficient evidence to conclude that a concerted pericyclic mechanism is operative. Since the imino-ene reactions of **13** and **17** evidently belong to the category of pericyclic processes, we opted to initially explore such systems in more detail.

Two sets of simple substrates, prepared as outlined in Scheme 6, were examined first. Readily available aldehydes **20a** and **20b**⁷ were converted to propargyl alcohols **21a** and **21b** with ethynylmagnesium bromide, and then to acetates **22a** and **22b**, respectively, in high yields. Application of the Fleming/Terrett silyl cuprate methodology⁸ to propargyl acetates **22a** and **22b** afforded





allenylsilanes **23a** and **23b**, respectively. Mild acetal hydrolysis then provided the requisite allenylsilane aldehydes **24a** and **24b**.

Aldehyde 24a was first converted to the N-benzyl imine 25 and then treated with stannic chloride under conditions used for the imino-ene reactions shown in Schemes 4 and 5. We were pleased to find that a single imino-ene product 26 was produced here in 70% yield (Scheme 7). For characterization purposes, amino silvl acetylene 26 was desilylated to 27a and acetylated to form amide 27b. A ¹H NMR NOE experiment on acetamide 27b established that this series of compounds has the *cis* configuration shown. The stereoselective cyclization of allenylsilane imine 25 to this *cis* amino silyl acetylene 26 is again good evidence that a pericyclic process is operative here since the *trans* isomer is precluded for stereoelectronic reasons. At this point, it was also discovered that simply heating imine 25 in refluxing toluene effected a thermal ene reaction leading to 26 in a yield comparable to the Lewis acid catalyzed cyclization reaction.



The imine **28** was next prepared from homologous allenylsilane aldehyde **24b** (Scheme 8). Treatment of **28** with stannic chloride, however, to our surprise led to amino ketone **29a** rather than the anticipated silyl acetylene. The amino ketone was characterized as its acetamide derivative **29b**, whose configuration was shown to be *cis* by ¹H NMR decoupling ($J_{ab} = 4$ Hz). Although the ketone **29a** might have been produced via a stepwise, ionic cyclization of the Danheiser type (*cf* Scheme 1), the *cis* stereose-lectivity and chemical properties of authentic silyl acetylene (*vide infra*) led us to conclude that the ketone functionality is an artifact of the workup. If imine **28** is heated in refluxing mesitylene (165°C) the amino silyl acetylene expected from an imino-ene reaction is produced. Attempted chromatographic purification of the

crude material, however, led to amino ketone **29a**. On the other hand, if the crude silyl acetylene is immediately desilylated, a stable amino alkyne **30** can be isolated (65% yield from aldehyde **24b**). The *cis* stereochemistry of **30** was once again confirmed by ¹H NMR decoupling ($J_{ab} = 4$ Hz). It seems that in general the *cis* amino silyl acetylenes in cyclohexyl systems are hydrolytically less stable than those in cyclopentyl analogs, although at present we cannot satisfactorily rationalize this observation.^{9, 10}



Scheme 8

A system was also examined to determine if a more highly substituted allenylsilane would participate in these ene reactions, leading to formation of a quaternary carbon. Thus, commercially available oxo nitrile 31 was converted to propargyl alcohol 32a and then to acetate **32b** (Scheme 9). Addition of the silvl cuprate⁸ to **32b** yielded allenylsilane 33. DIBALH reduction of the nitrile functionality of 33 produced the desired allenylsilane aldehyde 34, which could be converted to an N-benzyl imine. Although Lewis acid promoted ene cyclizations of this imine failed, thermolysis led to a moderate yield of a single stereoisomeric amino silyl acetylene, tentatively formulated as 35. Although cyclization of the imine derived from allenylsilane aldehyde 34 did not proceed in high yield, cyclizations of trisubstituted allenes with other enophiles have proven to be more efficient (vide infra).

The possibility of producing a seven membered ring via this methodology was also briefly investigated. Allenyl-silane aldehyde **36** was prepared using the chemistry outlined in Scheme $6.^9$ However, the *N*-benzyl imine derived from **36**, upon treatment with stannic chloride afforded only the rearranged silyl acetylene **37** (Eq 1). Thermolysis of this imine up to 220 °C gave no discernible reaction.

One attempt was made to utilize an *O*-methyl oxime as an imino enophile (Eq 2). However, heating **38** only led to allenylsilane rearrangement product **39** and treatment with $SnCl_4$ gave decomposition products.





A fundamental mechanistic question pertaining to this methodology is whether the silyl substituent on the allene is actually required. To test this point, propargyl alcohol **21a** was converted by straightforward procedures¹⁰ to aldehyde allenes **40a/b** lacking the silyl group (Scheme 10). Compounds **40a/b** were then converted into the *N*-benzyl imines **41**. All attempts to cyclize these imines under the thermal or Lewis acid catalyzed conditions used for **25** gave no reaction. Under more forcing conditions, only decomposition was observed. It therefore

appears that the silyl group is, in fact, necessary to promote the ene cyclization. The most reasonable explanation for this phenomenon is that the imino-ene reaction transition state has dipolar character as indicated in structure **42**. Since there is positive charge accumulation at the central allene carbon, a β -silyl group tends to stabilize this charge and lowers the energy of the transition state relative to systems bearing hydrogen or alkyl substituents.



Scheme 10



Aldehyde Enophiles

Since a variety of allenylsilane aldehydes were in hand, we decided to investigate whether the ene cyclization methodology could be extended to these substrates. It had previously been reported by Snider that the simple allenyl aldehyde 40a undergoes cyclization at the central carbon of the allene on catalysis by Me_2AlCl to afford chlorocy-clohexenol **43** (Eq 3)¹¹ rather than an ene product. When we treated allenylsilane aldehyde 24a with titanium tetrachloride, a complex mixture of β -chlorovinylsilane stereoisomers 44 was formed (Scheme 11). Thus under these conditions, a Danheiser reaction of the type shown in Scheme 1 occurs. When substrate 24a is refluxed in xylene in the absence of a Lewis acid, however, the anticipated hydroxy silyl acetylene 45 resulting from an aldehyde-ene reaction is generated. The cis configuration of 45 could be deduced by ¹H NMR NOE methods. In the case of the homologous allenylsilane aldehyde 24b, treatment with TiCl₄ caused extensive decomposition, but on heating at 180°C in o-dichlorobenzene, followed by desilylation, cis hydroxy acetylene 46 was produced (Eq 4). The *cis* stereochemistry of **46** could be confirmed by ¹H NMR ($J_{ab} = 3.6$ Hz). Similarly, the trisubstituted allenylsilane aldehyde 34 could be successfully cyclized under thermal conditions to afford a good yield of cis hydroxy silyl acetylene 47 (Eq 5). The configuration of alcohol 47 was proven by ¹H NOE methodology.





In order to explore the cyclization in a system homologous to that in Eq 5, an appropriate substrate was prepared as outlined in Scheme 12. Oxo acetal 48^{12} was converted to propargyl alcohol 49a and then to acetate 49b. Silacupration of this propargyl acetate led to allenylsilane acetal 50, which could be hydrolyzed to aldehyde 51. Attempted cyclization of **51** with $SnCl_4$ led only to decomposition. However, upon thermolysis silvl acetylene alcohol 52 was formed in moderate yield as a single stereoisomer, shown to have the cis configuration by NMR analysis.



Alkene Enophiles

Some limited work has been previously reported on intramolecular-ene reactions involving allenes with alkenes as enophiles. For example, it was found that high temperature thermolysis of simple allene alkene 53 gave a mixture of the ene product 54 along with [2+2]cycloadducts 55 and 56 in unspecified yields (Eq 6).¹³ In more recent work, Normant and co-workers discovered that metallo-ene reactions can be effected with systems like 57.14 Thus, metallation of silyl acetylene 57, followed by treatment with zinc bromide gives allene 58, which cyclizes stereoselectively under mild conditions to



Scheme 12

afford ene product 59 (Eq 7). This species can then be trapped with various electrophiles to give products 60. To date, this methodology has apparently only been applied to formation of five membered rings.



SYNTHESIS

We have explored extensions of our silyl allene ene methodology using alkenes as the enophiles, and initially investigated approaches to five membered rings. Therefore aldehyde allenylsilane **24a** was combined with ylids **61a** and **61b** to afford α,β -unsaturated esters **62a** and **62b**, respectively (Scheme 13). Upon refluxing **62a** in mesitylene, a stereoselective cyclization occurred to produce a disubstituted cyclopentane system **63a** in 70% yield. An NOE experiment was used to confirm the structure of this cycloadduct.



Scheme 13

The more substituted unsaturated ester **62b** also underwent stereospecific thermal cyclization leading to an adduct which has been tentatively assigned structure **63b** on mechanistic grounds. It might be noted that Lewis acid catalysis of these allenylsilane alkene ene reactions was generally not effective.

Simple unactivated terminal, di-and trisubstituted alkenes can also participate in this type of intramolecular-ene process. Allenylsilane aldehyde **24a** reacted with the ylids derived from phosphonium salts **64a–c** to produce alkenes **65a–c**, respectively (Scheme 14). Thermolysis of allenylsilanes **65a–c** was stereoselective in all three cases, producing cycloadducts **66a–c**, respectively.



We next turned to a study of more highly substituted systems to determine if quaternary carbon centers can also be efficiently and stereoselectively generated via this ene chemistry. Substrate **70** was therefore prepared as described in Scheme 15. Oxo nitrile **31** was converted by a Wittig reaction to *exo* methylene compound **67**. Nitrile reduction of **67** led to aldehyde **68**, which on addition of acetylenemagnesium bromide and subsequent acetylation of alcohol **69a** provided propargyl acetate **69b**. Silacupration⁸ of **69b** yielded the derived allenysilane alkene **70**. Thermolysis of **70** then afforded the anticipated *gem*-dimethyl cycloadduct **71** in good yield.



Scheme 15

Another permutation which was investigated involved use of trisubstituted allenylsilanes in the ene cycloaddition with alkenes. Methylenation of aldehyde **34** provided substrate **72** for this purpose (Scheme 16). It was found that thermolysis of **72** led to a single cyclization product **73** in good yield.

 α,β -Unsaturated esters also proved useful as enophiles with trisubstituted allenes. Reaction of aldehyde **34** with ylids **61a** and **61b** produced conjugated alkenes **74a** and **74b**, respectively (Scheme 17). Heating **74a** in mesitylene led to a single cycloadduct **75a**. Interestingly, thermolysis of methyl-substituted system **74b** produced a 3:1 mixture of ene product **75b** along with hetero-Diels–Alder adduct **76**.¹⁵

In order to test the feasibility of a further extension this ene methodology to the construction of substituted cyclohexyl systems, α,β -unsaturated ester **77** was prepared by Wittig reaction of aldehyde **24b** (Scheme 18). Heating **77**





CO₂Me

Scheme 18

in a number of different solvents at various temperatures, as well as short contact thermolysis, was tried.⁹

36%

In the best case (trichlorobenzene, 215 °C, 1.5 days) only a 36% yield of the desired cycloadduct **78** could be isolated. Moreover, exposure of substrate **77** to several Lewis acids only provided traces of cycloadduct **78**. As a consequence of these disappointing results, no other cyclohexane-forming reactions of this type were attempted.

Conclusion

The work described here has demonstrated that allenylsilanes are efficient participants in a variety of intramolecular ene reactions. In all cases which have been examined, the cycloaddition reactions are stereoselective. In most substrates, the reactions proceed under mild thermal conditions, and in a few instances Lewis acid catalysis at low temperatures provides the same adducts. Imino-ene reactions of allenylsilanes yield *cis* amino silyl acetylenes in both five and six membered ring systems. Similarly, cyclizations of allenylsilane aldehydes under thermal conditions provide cis hydroxy silyl acetylenes. Allenylsilane-ene reactions with alkenic enophiles occurs thermally in five membered ring cases to stereoselectively afford 1,2-cis disubstituted cyclopentanes. We are currently examining extensions and applications of the methodology outlined here.¹⁶

Non-aqueous reactions were run under an atmosphere of Ar. Low-resolution electron impact mass spectra (EIMS) were obtained at 50–70 eV. Chemical ionization mass spectra (CIMS) were obtained using isobutane as the carrier gas. Flash chromatography was performed using EM Science silica gel 60 (25–40 mm). Analytical and preparative TLC were performed using EM Science silica gel 60 PF₂₅₄. THF was distilled from Na/benzophenone ketyl. CH₂Cl₂, benzene, toluene, Et₃N, and mesitylene were distilled from CaH₂.

Formation of Propargyl Alcohols; Typical Procedure:

To a solution of aldehyde **20a** (3.93 g, 26.9 mmol) in THF (125 mL) at 0°C was added ethynylmagnesium bromide (56.0 mL, 0.5 M in THF). The mixture was warmed to r.t. over 1 h, H₂O was added and the aqueous layer was extracted with Et₂O (3×30 mL). The combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo. The crude product was purified by flash chromatography (eluting with 40% EtOAc/hexanes) to give 4.58 g (99%) of oily alcohol **21a**.

¹H NMR (200 MHz, CDCl₃): δ = 4.37 (m, 2 H), 3.30 (s, 6 H), 2.44 (d, J = 2.2 Hz, 1 H), 2.00 (br s, 1 H), 1.80–1.40 (m, 6 H). ¹³C NMR (90 MHz, CDCl₃): δ = 104.3, 84.9, 72.7, 61.8, 52.6, 37.2,

31.9, 20.1.

IR (neat): $v = 3350, 2940, 2100 \text{ cm}^{-1}$.

CIMS: m/z = 171 (M⁺-H), 155, 141, 109.

21b: oil.

Prepared (4.67 g, 96%) from aldehyde 20b (5.21 g, 32.0 mmol) and ethynylmagnesium bromide (70.0 mL, 0.5 M in THF).

¹H NMR (200 MHz, CDCl₃): $\delta = 4.35$ (t, J = 5.6 Hz, 2 H), 3.28 (s, 6 H), 2.43 (d, J = 2.0 Hz, 1 H), 2.11 (br s, 1 H), 1.75–1.29 (m, 8 H).

H), 2.43 (d, J = 2.0 Hz, 1 H), 2.11 (br s, 1 H), 1.75–1.29 (m, 8 H). ¹³C NMR (90 MHz, CDCl₃): $\delta = 104.1$, 85.0, 72.4, 61.4, 52.3, 37.2, 32.0, 24.6, 24.0.

IR (neat): v = 3400 - 3200, 2920 cm⁻¹.

CIMS m/z (%) = 185 (M⁺+H, 0.7), 137 (30), 123 (100).

32a: oil.

Prepared (3.50 g, 94%) from commercially available (Aldrich) 5oxohexanenitrile (**31**, 3.00 g, 27.0 mmol) and ethynylmagnesium bromide (60.0 mL, 0.5 M in THF).

¹H NMR (200 MHz, CDCl₃): δ = 2.54 (s, 1 H), 2.44–2.36 (m, 2 H), 1.95–1.63 (m, 5 H), 1.46 (s, 3 H).

¹³C NMR (90 MHz, CDCl₃): δ = 207.1, 119.4, 86.7, 71.7, 41.6, 29.9, 20.6, 16.9.

IR (neat): v = 3440, 2981, 1372 cm⁻¹.

CIMS m/z (%) = 138 (M⁺+H, 46), 120 (100).

Anal. Calcd. for C₈H₁₁NO: C, 70.04; H, 8.08. Found: C, 69.95; H, 8.16.

49a: oil.

Prepared (770 mg, 89%) from oxo acetal **48** (750 mg, 4.30 mmol) and ethynylmagnesium bromide (14.0 mL, 0.5 M in THF).

¹H NMR (200 MHz, CDCl₃): δ = 4.38 (t, *J* = 4.9 Hz, 1 H), 3.31 (s, 6 H), 2.40 (s, 1 H), 2.32 (s, 1 H), 1.72–1.25 (m, 8 H), 1.44 (s, 3 H).

¹³C NMR (75 MHz, CDCl₃): δ = 104.3, 87.7, 71.2, 67.8, 52.5, 39.3, 32.3, 29.7, 24.6, 24.3.

IR (neat): $v = 3427, 3291, 2945, 1456, 1126 \text{ cm}^{-1}$.

CIMS m/z (%) = 200 (M⁺-H, 0.7), 169 (3), 151 (56), 75 (100). Anal. Calcd. for $C_{11}H_{20}O_3$: C, 65.97; H, 10.07. Found: C, 65.85; H, 10.09.

69a: oil.

Prepared (2.66 g, 71%) from alkene aldehyde **68** (3.02 g, 21.9 mmol) and ethynylmagnesium bromide (50.0 mL, 0.5 M in THF).

¹H NMR (200 MHz, CDCl₃): δ = 4.70 (d, *J* = 5.5 Hz, 2 H), 4.38 (dt, *J* = 2.1, 6.1 Hz, 1 H), 2.44 (d, *J* = 2.1 Hz, 1 H), 2.08–1.95 (m, 2 H), 1.72–1.48 (m, 4 H), 1.69 (s, 3 H).

¹³C NMR (90 MHz, CDCl₃): δ = 143.8, 108.7, 83.4, 71.4, 60.6, 35.7, 35.5, 21.3, 20.7.

IR (neat): v = 3345, 3303, 3074, 2941, 1649 cm⁻¹.

CIMS: *m*/*z* (%) = 139 (M⁺+H, 7.6), 121 (44), 93 (66), 81 (100).

Anal. Calcd. for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 78.23; H, 10.28.

Typical Procedure for Preparing Propargyl Acetates:

To a solution of alcohol **21a** (3.00 g, 17.4 mmol) in CH_2Cl_2 (100 mL) at 0 °C was added Et_3N (2.40 mL, 17.4 mmol), a catalytic amount of DMAP and Ac_2O (1.60 mL, 17.4 mmol). The mixture was warmed to r.t. over 16 h and quenched with sat. aq NaHCO₃ solution (50 mL). The aqueous layer was extracted with CH_2Cl_2 (3 × 20 mL) and the combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo. The crude product was purified by flash chromatography eluting with 30% EtOAc/hexanes to give 3.42 g (92%) of acetate **22a** as an oil.

¹H NMR (200 MHz, CDCl₃): $\delta = 5.33$ (dt, J = 2.2, 6.5 Hz, 1 H), 4.34 (t, J = 5.3 Hz, 1 H), 3.29 (s, 6 H), 2.43 (d, J = 2.2 Hz, 1 H), 2.05 (s, 3 H), 1.82–1.42 (m, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 169.1, 103.7, 80.7, 73.4, 63.0, 52.1, 33.9, 31.5, 20.4, 19.6.

IR (neat): $v = 3260, 2100, 1730 \text{ cm}^{-1}$.

EIMS m/z = 213 (M⁺-H, 0.1), 141, 75.

HRMS m/z calcd. for C₁₁H₁₇O₄ (M⁺-H) 213.1127, found 213.1109.

22b: oil.

Using Et_3N (5.60 mL, 40.0 mmol), and Ac_2O (3.80 mL, 40.0 mmol), alcohol **21b** (6.80 g, 36.6 mmol) was converted to propargyl acetate **22b** (6.70 g, 81%).

¹H NMR (200 MHz, $CDCl_3$): $\delta = 5.32$ (dt, J = 2.1, 6.6 Hz, 1 H), 4.33 (t, J = 5.7 Hz, 1 H), 3.27 (s, 6 H), 2.41 (d, J = 2.1 Hz, 1 H), 2.04, (s, 3 H), 1.72–1.26 (m, 8 H).

¹³C NMR (90 MHz, CDCl₃): δ = 169.1, 103.8, 80.8, 73.3, 63.1, 52.0, 34.0, 31.8, 24.3, 20.2.

IR (neat): $v = 3260, 2110, 1730 \text{ cm}^{-1}$.

EIMS *m*/*z* (%) = 228 (M⁺, 0.03), 155 (11), 105 (22), 105 (100).

HRMS m/z calcd. for C₁₂H₁₉O₄ 227.1283 (M⁺-H), found 227.1282.

32b: oil.

Using Et_3N (3.80 mL, 27.0 mmol), and Ac_2O (2.80 mL, 27.0 mmol), alcohol **32a** (3.50 g, 25.3 mmol) was converted to propargyl acetate **32b** (2.90 g, 65%).

¹H NMR (200 MHz, CDCl₃): δ = 2.56 (s, 1 H), 2.39 (t, *J* = 6.6 Hz, 2 H), 2.00 (s, 3 H), 1.92–1.87 (m, 4 H), 1.67 (s, 3 H).

¹³C NMR (90 MHz, CDCl₃): δ = 119.3, 82.8, 74.0, 73.5, 53.5, 40.3, 26.4, 21.7, 20.5, 16.9.

IR (neat): v = 3275, 2942, 2246, 1743, 1370, 1243 cm⁻¹.

CIMS m/z (%) = 180 (M⁺+1, 8), 120 (100).

Anal. Calcd. for $C_{10}H_{13}NO_2$: C, 67.02; H, 7.31; N, 7.82. Found: C, 67.05; H, 7.34; N, 7.86.

49b: oil.

Using Et_3N (1.20 mL, 8.00 mmol), and Ac_2O (0.80 mL, 8.00 mmol), alcohol **49a** (1.34 g, 6.70 mmol) was converted to propargyl acetate **49b** (940 mg, 58% yield from ketone **48**).

¹H NMR (200 MHz, $CDCl_3$): $\delta = 4.34$ (t, J = 6.2 Hz, 1 H), 3.31 (s, 6 H), 2.54 (s, 1 H), 2.00 (s, 3 H), 1.63 (s, 3 H), 1.98–1.22 (m, 8 H).

¹³C NMR (90 MHz, CDCl₃): δ = 169.2, 104.4, 83.8, 74.7, 73.2, 52.6, 41.2, 32.4, 26.4, 24.4, 23.9, 21.8.

IR (neat): $v = 3270, 2947, 2117, 1746, 1369 \text{ cm}^{-1}$.

CIMS m/z (%) = 243 (M⁺+H, 0.5), 151 (100).

Anal. Calcd. for $C_{13}H_{22}O_4$: C, 64.44; H, 9.15. Found: C, 64.45; H, 9.14.

69b: oil.

Using Et₃N (2.80 mL, 20.0 mmol), and Ac₂O (1.90 mL, 20.0 mmol), alcohol **69a** (2.22 g, 16.1 mmol) was converted to propargyl acetate **69b** (1.37 g, 47% yield from nitrile **67**).

¹H NMR (200 MHz, CDCl₃): $\delta = 5.36$ (td, J = 2.2, 6.4 Hz, 1 H), 4.70 (d, J = 7.4 Hz, 2 H), 2.43 (d, J = 2.2 Hz, 1 H), 2.06 (s, 3 H), 2.03–1.94 (m, 2 H), 1.80–1.51 (m, 4 H), 1.68 (s, 3 H).

¹³C NMR (90 MHz, CDCl₃): δ = 168.2, 143.4, 108.9, 79.6, 71.9, 62.0, 35.5, 32.4, 21.1, 20.6, 19.3.

IR (neat): v = 3293, 3074, 2939, 1743, 1649, 1373 cm⁻¹.

CIMS m/z (%) = 139 (M⁺+H, 49), 121 (100).

Allenylsilanes; Typical Procedure:

To a mixture of Li wire (1.10 g, 156 mg atoms) and THF (20 mL) at 0° C was added dimethylphenylsilyl chloride (4.03 mL, 26.0 mmol). The mixture was warmed to r.t. over 16 h and the red solution was added to a slurry of CuCN (1.16 g, 13.0 mmol) in THF (40 mL) at 0° C. The mixture was stirred for 30 min, cooled to -78° C and used immediately.

To a solution of propargyl acetate **22a** (2.83 g, 13.0 mmol) in THF (75 mL) at -90° C was slowly added the silyl cuprate reagent (13.0 mmol based on CuCN). After stirring the mixture for 1 h at -90° C, a solution of 10% NH₄OH in sat. aq NH₄Cl was added. The mixture was warmed to r.t. and filtered through Celite. The product was extracted with Et₂O (3 × 10 mL) and the combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo. The crude product was purified by flash chromatography (eluting with hexanes, then 5% EtOAc/hexanes) to give 3.20 g (85%) of oily allenylsilane **23a**.

¹H NMR (200 MHz, CDCl₃): δ = 7.59–7.26 (m, 5 H), 5.06 (dt, *J* = 3.7, 6.9 Hz, 1 H), 4.82 (q, *J* = 6.9 Hz, 1 H), 4.35 (t, *J* = 5.4 Hz, 1 H), 3.29 (s, 3 H), 2.05–1.93 (m, 2 H), 0.33 (s, 6 H). ¹³C NMR (90 MHz, CDCl₃): δ = 211.0, 138.3, 133.5, 128.8, 127.6,

¹³C NMR (90 MHz, CDCl₃): δ = 211.0, 138.3, 133.5, 128.8, 127.6, 104.1, 83.4, 81.0, 52.2, 52.1, 31.7, 27.4, 24.5, -2.4.

IR (neat): $v = 3050, 2940, 1930 \text{ cm}^{-1}$.

EIMS m/z (%) = 290 (M⁺, 0.1), 135 (9), 84 (100).

HRMS m/z calcd. for $C_{17}H_{26}O_2Si$ 290.1702 (M⁺), found 290.1708.

23b: oil.

Allenylsilane **23b** (900 mg, 76%) was prepared from propargyl acetate **22b** (900 mg, 3.90 mmol), Li wire (552 mg, 80.0 mg atoms), dimethylphenylsilyl chloride (1.30 mL, 8.00 mmol), and CuCN (358 mg, 4.00 mmol).

¹H NMR (200 MHz, CDCl₃): δ = 7.60–7.27 (m, 5 H), 5.05 (dt, *J* = 3.8, 6.9 Hz, 1 H), 4.82 (q, *J* = 6.9 Hz, 1 H), 4.34 (t, *J* = 5.6 Hz, 1 H), 3.29

(s, 6 H), 2.00–1.89 (m, 2 H), 1.60–1.26 (m, 6 H), 0.31 (s, 6 H). ¹³C NMR (90 MHz, CDCl₃): δ = 211.0, 138.4, 133.5, 128.5, 137.6,

104.2, 83.6, 80.9, 52.3, 52.2, 32.1, 29.3, 27.6, 24.0, -2.4.

IR (neat): v = 2940, 1930 cm⁻¹.

EIMS m/z (%) = 304 (M⁺, 0.5), 135 (100).

HRMS m/z calcd. for C₁₈H₂₈O₂Si 304.1858 (M⁺), found 304.1852.

33: oil

Allenylsilane **33** (3.04 g, 74%) was prepared from propargyl acetate **32b** (2.90 g, 16.2 mmol), Li wire (2.23 g, 324 mg atoms), dimethylphenylsilyl chloride (5.40 mL, 32.4 mmol), and CuCN (1.45 g, 16.2 mmol).

¹H NMR (200 MHz, CDCl₃): δ = 7.59–7.51 (m, 2 H), 7.40–7.35 (m, 3 H), 5.61–5.02 (m, 1 H), 2.22 (t, *J* = 7.6 Hz, 2 H), 2.05–1.94 (m, 2 H), 1.73–1.65 (m, 2 H), 1.61 (d, *J* = 4.0 Hz, 3 H), 0.34 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 209.5, 138.5, 133.7, 129.2, 127.8, 119.6, 90.5, 82.1, 31.7, 23.4, 18.0, 16.5, -2.1. IR (neat): ν = 3068, 2955, 2246, 1943, 1427 cm⁻¹. CIMS m/z (%) = 256 (M⁺+H, 40), 194 (100), 135 (27).

50: oil.

Allenylsilane **50** (2.26 g, 91%) was prepared from propargyl acetate **49b** (1.89 g, 7.80 mmol), Li wire (1.09 mg, 156 mg atoms), dimethylphenylsilyl chloride (2.60 mL, 15.6 mmol), and CuCN (699 mg, 7.80 mmol).

¹H NMR (200 MHz, CDCl₃): δ = 7.61–7.53 (m, 2 H), 7.45–7.32 (m, 3 H), 5.04–4.95 (m, 1 H), 4.32 (t, *J* = 5.3 Hz, 1 H), 3.30 (s, 6 H), 1.98–1.88 (m, 2 H), 1.63 (d, *J* = 4.1 Hz, 3 H), 1.62–1.52 (m, 2 H), 1.41–1.23 (m, 4 H), 0.32 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 210.0, 139.0, 133.6, 128.9, 127.6, 104.5, 92.2, 80.6, 52.5, 52.4, 33.0, 32.3, 27.5, 24.4, 18.0, -2.1.

IN (neat): v = 2945, 1942, 1427, 1363, 1246 cm⁻¹.

CIMS m/z (%) = 317 (M⁺-H, 0.5), 135 (56), 75 (100).

70: oil.

Allenylsilane **70** (1.05 g, 73%) was prepared from propargyl acetate **69b** (1.00 g, 5.60 mmol), Li wire (759 mg, 110 mg atoms), dimethylphenylsilyl chloride (1.80 mL, 11.0 mmol), and CuCN (497 mg, 5.50 mmol).

¹H NMR (200 MHz, CDCl₃): δ = 7.59–7.43 (m, 2 H), 7.41–7.34 (m, 2 H), 5.06 (dt, *J* = 3.3, 6.5 Hz, 1 H), 4.85 (q, *J* = 6.9 Hz, 1 H), 4.69 (d, *J* = 6.9 Hz, 2 H), 2.05–1.86 (m, 4 H), 1.68 (s, 3 H), 1.56–1.38 (m, 2 H), 0.32 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 209.7, 144.2, 137.2, 132.1, 127.5, 126.2, 108.3, 82.2, 79.6, 35.8, 26.1, 25.9, 20.8, -3.8.

IR (neat): v = 3050, 2934, 1938, 1649, 1427, 1374, 1248, 1113 cm⁻¹. EIMS m/z (%) = 256 (M⁺, 0.6), 135 (100).

Hydrolysis of Acetals to Aldehydes; Typical Procedure:

To a solution of allenylsilane acetal **23a** (1.42 g, 4.90 mmol) in acetone (50 mL) were added catalytic amounts of PPTS and H₂O. The solution was refluxed for 2 h, and sat. aq NaHCO₃ (10 mL) was added. The aqueous layer was extracted with Et₂O (3×10 mL) and the combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo to give 1.19 g (100%) of aldehyde **24a** as an oil. No further purification was needed for the next step.

¹H NMR (200 MHz, $CDCl_3$): $\delta = 9.75$ (t, J = 1.3 Hz, 1 H), 7.59–7.36 (m, 5 H), 5.10 (dt, J = 3.7, 6.9 Hz, 1 H), 4.80 (q, J = 6.9 Hz, 1 H), 2.40 (td, J = 1.3, 7.3 Hz, 2 H), 2.09–1.93 (m, 2 H), 0.34 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 211.0, 202.4, 138.4, 133.6, 129.1, 127.8, 82.9, 81.6, 43.2, 27.1, 21.9, -2.3.

IR (neat): $v = 3050, 2700, 1930, 1715 \text{ cm}^{-1}$.

EIMS *m*/*z* (%) = 244 (M⁺, 2), 229 (13), 215 (7), 135 (100).

HRMS m/z calcd. for C₁₅H₂₀OSi 244.1283 (M⁺), found 244.1282.

24b: oil.

Acetal **23b** (879 mg, 2.90 mmol) was hydrolyzed to give aldehyde **24b** (746 mg, 100%).

¹H NMR (200 MHz, $CDCl_3$): $\delta = 9.76$ (t, J = 1.8 Hz, 1 H), 7.66–7.25 (m, 5 H), 5.06 (dt, J = 3.7, 6.9 Hz, 1 H), 4.81 (q, J = 6.9 Hz, 1 H), 2.38 (dt, J = 1.7, 7.2 Hz, 2 H), 2.04–1.91 (m, 2 H), 1.72–1.52 (m, 2 H), 1.49–1.27 (m, 2 H), 0.32 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 211.0, 202.3, 138.4, 133.5, 129.0,

127.6, 83.3, 81.2, 43.5, 28.9, 27.3, 21.4, -2.3.

IR (neat): $v = 3030, 2700, 1930, 1715 \text{ cm}^{-1}$. EIMS m/z (%) = 258 (M⁺, 1), 243 (6), 215 (5), 135 (100).

HRMS m/z calcd. for C₁₆H₂₂OSi 258.1440 (M⁺), found 258.1424.

51: oil.

Acetal **50** (2.28 g, 7.20 mmol) was hydrolyzed to give aldehyde **51** (1.90 g, 98%).

¹H NMR (200 MHz, CDCl₃): δ = 9.78 (t, *J* = 1.1 Hz, 1 H), 7.61–7.52 (m, 2 H), 7.43–7.35 (m, 3 H), 5.06–4.97 (m, 1 H), 2.39 (td, *J* = 1.1, 9.0 Hz, 2 H), 1.99–1.87 (m, 2 H), 1.67 (d, *J* = 4.5 Hz, 3 H), 1.69–1.30 (m, 4 H), 0.31 (s, 6 H).

¹³C NMR (75 MHz, CDCl₃): δ = 209.8, 202.2, 138.8, 133.6, 128.9, 127.6, 91.7, 80.9, 43.6, 32.6, 27.0, 21.7, 17.9, -2.2.

IR (neat): v = 2935, 2717, 1924, 1726 cm⁻¹.

CIMS m/z (%) = 271 (M⁺-H, 10), 203 (39), 135 (72), 75 (100).

Lewis Acid Promoted Cyclization of Allenylsilane Imine 25:

To a solution of allenylsilane aldehyde **24a** (112 mg, 0.46 mmol) in anhyd benzene (3 mL) at r.t. was added dropwise anhyd benzylamine (53 μ L, 0.49 mmol) in the presence of 4Å molecular sieves (0.5 g). The mixture was stirred for 70 min at r.t. and used for the next step immediately without purification.

¹H NMR (200 MHz, d_6 -benzene) δ = 0.4 (s, 6 H), 1.50–1.72 (m, 2 H), 1.85–2.04 (m, 2 H), 2.02–2.20 (m, 2 H), 4.46 (s, 2 H), 4.74–4.90 (m, 1 H), 5.13–5.22 (m, 1 H), 7.05–7.65 (m, 11 H).

To the crude *N*-benzyl imine **25** and 4 Å molecular sieves (0.5 g) in anhyd benzene (3 mL) at 5°C was added anhyd SnCl_4 (1.15 mL, 1.15 mmol, 1.0 M solution in CH_2Cl_2). The mixture was warmed to r.t. and was stirred for 12 h. Aqueous NaOH solution (5 mL, 15%) was added at 0°C and the mixture was stirred for 10 min. The mixture was extracted with Et_2O (3 × 10 mL). The combined organic layers were washed with sat. aq NaHCO₃ solution and brine, dried (MgSO₄) and concentrated in vacuo. The residue was purified by preparative TLC, developing with EtOAc/hexanes (1:4), to produce silyl acetylene **26** as a yellow oil (105 mg, 69%).

¹H NMR (360 MHz, CDCl₃): $\delta = 0.46$ (s, 6 H), 1.50–2.10 (m, 6 H), 3.06–3.11 (m, 1 H), 3.14–3.19 (m, 1 H), 3.81 (d, J = 12.8 Hz, 1 H), 3.90 (d, J = 12.8 Hz, 1 H), 7.26–7.69 (m, 10 H).

¹³C NMR (90 MHz, CDCl₃): δ = -0.6, 21.4, 30.8, 31.0, 35.5, 52.2, 61.4, 86.0, 109.1, 126.8, 127.7, 127.8, 128.1, 128.3, 129.2, 129.3, 133.0, 133.5, 137.4, 140.3.

IR (neat): $v = 3300, 2940, 2160 \text{ cm}^{-1}$.

EIMS m/z (%) = 333 (M⁺, 6), 198 (33), 135 (37), 91 (100). HRMS m/z calcd. for C₂₂H₂₇NSi 333.1913 (M⁺), found 333.1901.

Desilylation of Silyl Acetylene 26:

To a solution of silyl acetylene **26** (60 mg, 0.18 mmol) in anhyd THF (2 mL) at 0°C was added tetrabutylammonium fluoride (0.27 mL, 0.27 mmol, 1.0 M solution in THF). The solution was warmed to r.t. and stirred for 2 h. Sat. aq NaHCO₃ solution (5 mL) was added and the mixture was stirred for 10 min. The mixture was extracted with Et₂O (3 × 10 mL). The combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo. The residue was purified by preparative TLC, developing with EtOAc/hexanes (1:4), to produce terminal alkyne **27a** as a yellow oil (34 mg, 96%).

¹H NMR (360 MHz, CDCl₃): $\delta = 1.50-1.65$ (m, 2 H), 1.75–1.95 (m, 4 H), 2.09 (br s, 1 H), 2.18 (d, J = 2.6 Hz, 1 H), 2.94–2.99 (m, 1 H), 3.09–3.15 (m, 1 H), 3.77 (d, J = 13.0 Hz, 1 H), 3.88 (d, J = 13.0 Hz, 1 H), 7.23–7.39 (m, 5 H).

¹³C NMR (90 MHz, CDCl₃): δ = 21.3, 30.6, 30.9, 34.2, 52.2, 61.2, 71.6, 84.6, 126.8, 128.2, 128.3, 140.4.

IR (neat): $v = 3280, 2940, 2090 \text{ cm}^{-1}$.

EIMS m/z (%) = 199 (M⁺, 15), 170 (17), 91 (100).

HRMS m/z calcd. for C₁₄H₁₇N 199.1361 (M⁺), found 199.1364.

Thermal Cyclization of Imine 25:

To a solution of aldehyde **24a** (114 mg, 0.47 mmol) in anhyd toluene (3 mL) at r.t. was added dropwise anhyd benzylamine (54 μ L, 0.49 mmol) in the presence of 4 Å molecular sieves (0.5 g). After stirring for 70 min at r.t., the mixture was gently refluxed at 110 °C for 16 h. The mixture was cooled to r.t. and filtered. The precipitate was washed with benzene (5 mL) and EtOAc (20 mL). The combined filtrates were concentrated in vacuo to produce crude cyclization product **26**.

Following the above desilylation procedure, the crude material (156 mg, 0.47 mmol) was converted to amino alkyne **27a** (65 mg, 70% from aldehyde **24a**) having spectral data identical to those from the Lewis acid mediated reaction.

Preparation of Acetamide 27b:

To a solution of amino alkyne **27a** (14 mg, 0.070 mmol) and a catalytic amount of DMAP in pyridine (1.5 mL) at 0° C was added drop-

¹H NMR (200 MHz, CDCl₃): δ = 1.29–1.97 (m, 6 H), 2.04 (s, 3 H), 2.10 (d, *J* = 2.5 Hz, 1 H), 3.20–3.32 (m, 1 H), 4.15 (d, *J* = 16.4 Hz, 0.2 H), 4.74 (d, *J* = 1.8 Hz, 1.6 H), 4.80–4.93 (m, 1 H), 5.37 (d, *J* = 16.4 Hz, 0.2 H), 7.15–7.39 (m, 5 H).

IR (neat): v = 3300 - 3200, 2960, 2100, 1640 cm⁻¹.

EIMS m/z (%) = 241 (M⁺, 20), 150 (25), 91 (100).

Preparation of Amide 29b:

To a solution of aldehyde **24b** (144 mg, 0.56 mmol) in anhyd benzene (2 mL) at r.t. was added dropwise anhyd benzylamine (64 μ L, 0.59 mmol) in the presence of 4Å molecular sieves (0.5 g). The mixture was stirred for 70 min at r.t. and was used immediately without purification.

¹H NMR (200 MHz, d_6 -benzene): $\delta = 0.4$ (s, 6 H), 1.20–1.57 (m, 4 H), 1.76–1.96 (m, 2 H), 1.98–2.12 (m, 2 H), 4.41 (s, 2 H), 4.67–4.80 (m, 1 H), 5.10–5.22 (m, 1 H), 7.08–7.62 (m, 11 H).

To a solution of the above crude imine in anhyd benzene (3 mL) at 5°C was added anhyd SnCl₄ (1.12 mL, 1.12 mmol, 1.0 M solution in CH₂Cl₂). The mixture was warmed to r.t. and stirred for 12 h. To this was added aq NaOH (15%, 5 mL) at 0°C and the mixture was stirred for 15 min. The aqueous layer was extracted with EtOAc (3×10 mL). The combined organic layers were washed with sat. aq NaHCO₃ and brine, dried (MgSO₄) and concentrated in vacuo. The crude product **29a** was used directly in the next step without purification.

¹H NMR (200 MHz, CDCl₃): $\delta = 0.97-1.83$ (m, 6 H), 2.05 (s, 3 H), 2.06–2.35 (m, 2 H), 2.55 (dt, J = 4.6, 10.4 Hz, 1 H), 3.07–3.15 (m, 1 H), 3.60 (d, J = 13.5 Hz, 1 H), 3.85 (d, J = 13.5 Hz, 1 H), 7.10–7.50 (m, 5 H).

To a solution of the above crude product in pyridine (2 mL) at 0 °C was added a catalytic amount of DMAP, followed by the dropwise addition of Ac₂O (121 µL, 1.28 mmol). The ice bath was removed and the mixture was stirred for 2 h. Sat. aq NaHCO₃ solution (5 mL) was added and the mixture was stirred for 10 min. The aqueous layer was extracted with EtOAc (3 × 10 mL). The combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo. The residue was purified by preparative TLC, developing with EtOAc/hexanes (1:1), to produce white solid acetamide **29b** (61 mg, 40% from aldehyde **24b**).

mp 95–97°C.

¹H NMR (360 MHz, $CDCl_3$): $\delta = 1.10-1.55$ (m, 4 H), 1.70-1.88 (m, 2 H), 1.99 (s, 3 H), 2.07 (s, 3 H), 2.10-2.25 (m, 2 H), 3.44-3.54 (m, 1 H), 4.44 (dt, J = 4.1, 13.2 Hz, 1 H), 4.54 (d, J = 18.9 Hz, 1 H), 5.00 (d, J = 18.6 Hz, 1 H), 7.11-7.36 (m, 5 H).

(d, J = 18.6 Hz, 1 H), 7.11–7.36 (m, 5 H). ¹³C NMR (90 MHz, CDCl₃): $\delta = 21.5$, 22.7, 25.1, 26.0, 28.2, 30.2, 48.9, 49.9, 55.9, 125.3, 126.7, 128.7, 139.4, 172.0, 212.1.

IR (neat): v = 2920, 1700, 1640 cm⁻¹.

EIMS m/z (%) = 273 (M⁺, 7), 230 (52), 146 (23), 106 (24), 91(100). HRMS m/z calcd. for C₁₇H₂₃NO₂ 273.1729 (M⁺), found 273.1734.

Preparation of Amino Acetylene 30:

To a solution of aldehyde **24b** (69 mg, 0.27 mmol) in anhyd mesitylene (2 mL) at r.t. was added dropwise anhyd benzylamine (31 μ L, 0.28 mmol) in the presence of 4 Å molecular sieves (0.4 g). After stirring for 70 min at r.t., the mixture was gently refluxed at 165 °C for 16 h. The mixture was cooled to r.t. and filtered. The precipitate was washed with benzene (5 mL) and EtOAc (20 mL). The combined filtrates were concentrated in vacuo to produce the crude silyl acetylene. To a solution of the above silyl acetylene (94 mg, 0.27 mmol) in anhyd THF (3 mL) under Ar at 0 °C was added tetrabutylammonium fluoride (0.40 mL, 0.40 mmol, 1.0 M solution in THF). The solution was warmed to r.t. and stirred for 2 h. To this was added sat. aq NaHCO₃ (5 mL) and the mixture was stirred for 10 min. The mixture was extracted with Et₂O (3 × 10 mL). The combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo. The residue was purified by flash chromatography, developing with EtOAc/hexanes (1:2.5), to produce amino acetylene **30** as a colorless oil (37 mg, 65% from aldehyde **24b**).

¹H NMR (300 MHz, CDCl₃): δ = 1.15–1.98 (m, 9 H), 2.11 (d, *J* = 2.5 Hz, 1 H), 2.54 (ddd, *J* = 3.6, 3.7, 11.0 Hz, 1 H), 3.09 (m, 1 H), 3.75 (d, *J* = 13.1 Hz, 1 H), 3.90 (d, *J* = 13.1 Hz, 1 H), 7.24–7.60 (m, 5 H). ¹³C NMR (50 MHz, CDCl₃): δ = 21.6, 24.8, 29.2, 29.9, 32.3, 50.0, 56.3, 71.6, 84.3, 126.8, 128.1, 128.3, 140.5.

IR (neat): $v = 3280, 2920, 2100 \text{ cm}^{-1}$.

EIMS m/z (%) = 213 (M⁺, 13), 137 (46), 91 (100). HRMS m/z calcd. for C₁₅H₁₉N 213.1517 (M⁺), found 213.1508.

Reduction of Nitrile 33 to Aldehyde 34:

To a solution of nitrile **33** (1.00 g, 3.90 mmol) in toluene (20 mL) at -78 °C was added DIBALH (4.70 mL, 1.0 M in hexanes). After 3 h, a saturated solution of Rochelle salts (30 mL) was added and the mixture was extracted with Et₂O (3 × 20 mL). The combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo. The crude product was purified by flash chromatography (eluting with 10% EtOAc/hexanes) to give 680 mg (67%) of pure oily aldehyde **34**.

¹H NMR (200 MHz, $CDCl_3$): $\delta = 9.72$ (t, J = 1.7 Hz, 1 H), 7.59–7.51 (m, 2 H), 7.39–7.30 (m, 3 H), 5.08–5.03 (m, 1 H), 2.40 (td, J = 1.7, 7.2 Hz, 2 H), 2.01–1.95 (m, 2 H), 1.71–1.63 (m, 2 H), 1.68 (d, J = 3.6 Hz, 3 H), 0.34 (s, 6 H).

¹³C NMR (75 MHz, CDCl₃): δ = 209.8, 202.4, 138.8, 133.6, 129.0, 127.7, 91.4, 81.2, 43.3, 32.3, 20.0, 17.9, -2.1.

IR (neat): v = 2954, 2716, 1942, 1726, 1366, 1247, 1113 cm⁻¹. HRMS m/z calcd. for C₁₆H₂₂OSi 258.1419 (M⁺), found 258.1423.

Formation of Amino Silyl Acetylene 35:

To a solution of aldehyde **34** (100 mg, 0.39 mmol) in mesitylene (1 mL) was added benzylamine (42 μ L, 0.39 mmol). After 1 h, the mixture was transferred to a sealed tube, heated at 250 °C for 24 h and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with 5% EtOAc/hexanes) to give 34 mg (25%) of oily amino silyl acetylene **35** as a single stereoisomer.

¹H NMR (300 MHz, $CDCl_3$): $\delta = 7.67-7.61$ (m, 2 H), 7.39-7.29 (m, 3 H), 3.90 (d, J = 2.2 Hz, 2 H), 2.71 (t, J = 7.4 Hz, 1 H), 2.11-1.55 (m, 6 H), 1.37 (s, 3 H), 0.41 (s, 6 H).

¹³C NMR (75 MHz, CDCl₃): δ = 140.9, 137.7, 133.6, 129.2, 128.2, 127.9, 127.8, 126.6, 113.5, 84.8, 67.3, 51.9, 43.3, 39.9, 31.2, 26.3, 20.6, -0.49.

IR (neat): v = 2960, 2156, 1454, 1249, 1116 cm⁻¹. CIMS m/z (%) = 348 (M⁺+H, 100).

Preparation of β -Chlorovinylsilane Alcohols 44:

To a solution of aldehyde **24a** (79 mg, 0.32 mmol) in anhyd CH₂Cl₂ (2 mL) at $-78 \,^{\circ}$ C was added anhyd TiCl₄ (0.5 mL, 0.5 mmol, 1.0 M solution in CH₂Cl₂). After the solution had been stirred at $-78 \,^{\circ}$ C for 2 h, sat. aq NaHCO₃ (5 mL) was added at $-78 \,^{\circ}$ C. After stirring at 0 $^{\circ}$ C for 30 min, the mixture was extracted with CH₂Cl₂ (3 × 10 mL). The combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo. The residue was purified by flash chromatography, eluting with EtOAc/hexanes (1:5), to produce a complex mixture of stereoisomeric β -chlorovinylsilane alcohols **44** as a colorless oil (29 mg, 32%).

¹H NMR (200 MHz, CDCl₃): $\delta = 0.40$ (s, 6 H), 1.11 (br d, J = 2.3 Hz, 1 H), 1.31–1.95 (m, 6 H), 2.61–2.76 (m, 1 H), 4.13–4.24 (m, 1 H), 5.94 (s, 1 H), 7.28–7.71 (m, 5 H).

IR (neat): v = 3600-3300, 2950, 1600, 1250, 700 cm⁻¹.

CIMS m/z (%) = 281 (M⁺+H, 1), 263 (M⁺-OH, 7), 245 (M⁺-Cl, 22), 227 (28), 93 (100).

Preparation of Silyl Acetylene Alcohol 45:

A solution of aldehyde **24a** (110 mg, 0.45 mmol) in anhyd *p*-xylene (3 mL) was gently refluxed at 140° C for 16 h. The mixture was cooled to r.t. and filtered. The precipitate was washed with benzene (5 mL) and EtOAc (20 mL). The combined filtrates were concentrated in vacuo. The residue was purified by flash chromatography, elut-

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ing with EtOAc/hexanes (1:9), to produce alcohol 45 as a colorless oil (56 mg, 51 %).

¹H NMR (200 MHz, CDCl₃): δ = 0.40 (s, 6 H), 1.73–2.03 (m, 6 H), 2.06 (br d, J = 2.3 Hz, 1 H), 2.67–2.78 (m, 1 H), 4.15–4.20 (m, 1 H), 7.27-7.67 (m. 5 H).

¹³C NMR (50 MHz, CDCl₃): $\delta = -0.7$, 22.4, 30.2, 33.0, 39.4, 74.0, 86.6, 107.9, 127.9, 129.4, 133.5, 137.1.

IR (neat): v = 3600 - 3300, 2950, 2170 cm⁻¹.

EIMS m/z (%) = 244 (M⁺, 2), 243 (M⁺-H, 3), 229 (23), 161 (64), 135 (100).

HRMS m/z calcd. for C₁₅H₂₀OSi 244.1283 (M⁺), found 244.1282.

Preparation of Acetylene Alcohol 46:

A solution of aldehyde 24b (149 mg, 0.58 mmol) in anhyd o-dichlorobenzene (5 mL) was gently refluxed at 180 °C for 16 h. The mixture was cooled to r.t. and filtered. The flask was washed with benzene (5 mL) and EtOAc (20 mL). The combined filtrates were concentrated in vacuo to produce the crude hydroxy silyl acetylene.

To a solution of the above silvl acetylene (149 mg, 0.58 mmol) in THF (5 mL) under Ar at 0 °C was added tetrabutylammonium fluoride (0.90 mL, 0.90 mmol, 1.0 M solution in THF). The solution was warmed to r.t. and stirred for 2 h. Sat. aq NaHCO₃ solution (10 mL) was added and the mixture was stirred for 10 min. The mixture was extracted with Et₂O (3×15 mL). The combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo. The residue was purified by flash chromatography, eluting with EtOAc/ hexanes (1:9), to produce hydroxy alkyne 46 as a colorless oil (35 mg, 49% from aldehyde 24b)

¹H NMR (200 MHz, CDCl₃): δ =1.12–1.93 (m, 9 H), 2.13 (d, J = 2.5 Hz, 1 H), 2.76–2.84 (m, 1 H), 3.60–3.72 (m, 1 H).

¹³C NMR (50 MHz, CDCl₃): δ = 22.1, 22.6, 28.6, 31.2, 35.6, 69.6, 71.7, 84.3.

IR (neat) 3400–3200, 2940, 2100 cm⁻¹.

EIMS m/z (%) = 124 (M⁺, 4), 107 (5), 57 (100).

Cyclization of Aldehyde 34:

A solution of allenylsilane aldehyde 34 (75 mg, 0.29 mmol) in mesitylene (4 mL) was sealed in a tube, heated in a sand bath at 300 °C for 14 h and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with 5% EtOAc/hexanes) to give cyclopentanol derivative 47 (50 mg, 67%) as an oil.

¹H NMR (300 MHz, CDCl₃): δ = 7.67–7.60 (m, 2 H), 7.41–7.35 (m, 3 H), 3.71 (q, J = 5.4 Hz, 1 H), 2.16–1.59 (m, 6 H), 1.28 (s, 3 H), 0.45

(s, 6 H). ¹³C NMR (75 MHz, CDCl₃): δ = 137.3, 133.5, 129.4, 127.9, 111.9, 86.2, 80.2, 45.2, 27.4, 31.8, 24.4, 20.4, -0.6.

IR (neat): v = 3472, 2965, 2158, 1249, 1116 cm⁻¹.

EIMS *m*/*z* (%) = 258 (M⁺, 1.8), 243 (15), 161 (18), 135 (100).

HRMS m/z calcd. for C₁₆H₂₂OSi 258.1440 (M⁺), found 258.1419.

Cyclization of Aldehyde 51:

A solution of aldehyde 51 (140 mg, 0.51 mmol) in mesitylene (4 mL) was sealed in a tube and heated at 300°C for 24 h and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with 5% EtOAc/hexanes) to give alkynyl cyclohexanol 52 (57 mg, 41%) as an oil.

¹H NMR (300 MHz, CDCl₃): δ = 7.68–7.62 (m, 2 H), 7.41–7.37 (m, 3 H), 3.23-3.11 (m, 1 H), 1.97-1.53 (m, 6 H), 1.39 (s, 3 H), 1.38-1.22 (m, 2 H), 0.42 (s, 6 H). ¹³C NMR (75 MHz, CDCl₃): δ = 137.5, 133.6, 129.3, 127.9, 111.5,

86.9, 76.3, 41.2, 38.3, 32.6, 26.6, 24.8, 22.5, -0.5. IR (neat): v = 3455, 2932, 2162, 1448, 1115 cm⁻¹.

EIMS m/z (%) = 272 (M⁺, 5), 257 (16), 135 (100). HRMS m/z calcd. for C₁₇H₂₄Si 272.1596 (M⁺), found 272.1614.

Formation of α,β -Unsaturated Esters, Typical Procedure:

A solution of aldehyde 24a (137 mg, 0.56 mmol) and phosphonium ylid 61a (386 mg, 1.12 mmol) in CH₂Cl₂ (10 mL) was refluxed for 17 h and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with 25% EtOAc/hexanes) to give 60 mg (58%) of pure oily ester 62a.

¹H NMR (200 MHz, CDCl₃): δ = 7.60–7.23 (m, 5 H), 6.93 (dt, *J* = 6.5, 15 Hz, 1 H), 5.81 (d, J = 15 Hz, 1 H), 5.08 (dt, J = 3.7, 6.9 Hz, 1 H), 4.79 (q, J = 6.9 Hz, 1H), 3.71 (s, 3 H), 2.39–1.85 (m, 4 H), 1.65–1.45 (m, 2 H), 0.31 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 211.1, 166.9, 149.2, 138.8, 133.7, 129.1, 127.8, 121.0, 83.2, 81.5, 51.4, 31.6, 27.9, 27.2, -2.2.

IR (neat): v = 2951, 1938, 1725, 1657 cm⁻¹.

EIMS m/z (%) = 300 (M⁺, 5.6), 135 (100).

62b: oil.

Prepared (90 mg, 86%) from aldehyde 24a (78.0 mg, 0.32 mmol) and phosphonium ylid 61b (232 mg, 0.64 mmol).

¹H NMR (200MHz, CDCl₃): $\tilde{\delta}$ = 7.59–7.52 (m, 2 H), 7.39–7.23 (m, 3 H), 6.74 (tq, J = 1.4, 7.5 Hz, 1 H), 5.07 (dt, J = 3.7, 6.8 Hz, 1 H), 4.82 (q, J = 6.8 Hz, 1 H), 4.19 (q, J = 7.1 Hz, 2 H), 2.22-2.11 (m, 2 H),1.27 (t, J = 7.2 Hz, 3 H), 0.33 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 211.0, 168.2, 141.8, 139.6, 138.5, 133.6, 129.0, 127.7, 83.3, 81.3, 60.3, 28.4, 28.1, 27.4, 14.2, 12.3, -2.3. IR (neat): v = 2934, 1938, 1711, 1649 cm⁻¹

CIMS m/z (%) = 329 (M⁺+H, 72), 251 (38), 135 (100).

HRMS m/z calcd. for C₂₀H₂₈O₂Si 328.1858 (M⁺), found 328.1857.

74a: oil.

Prepared (367 mg, 73%) from aldehyde 34 (400 mg, 1.60 mmol) and ylid 61a (688 mg, 2.00 mmol).

¹H NMR (200 MHz, CDCl₃): δ7.61–7.52 (m, 2 H), 7.43–7.32 (m, 3 H), 6.96 (dt, J = 7.0, 15.8 Hz, 1 H), 5.80 (dt, J = 1.5, 15.9 Hz, 1 H), 5.03-4.98 (m, 1 H), 3.72 (s, 3 H), 2.20-2.05 (m, 2 H), 1.95-1.82 (m, 2 H), 1.62 (d, J = 4.0 Hz, 3 H), 1.61–1.45 (m, 2 H), 0.29 (s, 6 H). ¹³C NMR (75 MHz, CDCl₂): δ = 209.8, 167.1, 149.3, 139.8, 133.6, 129.0, 127.7, 120.9, 91.7, 81.1, 51.3, 32.4, 31.7, 25.9, 18.0, -2.1.

IR (neat): v = 2951, 1942, 1726, 1657 cm⁻¹

CIMS m/z (%) = 315 (M⁺+H, 21), 237 (30), 149 (61), 135 (100).

74b: oil.

Prepared (179 mg, 67%) from aldehyde 34 (200 mg, 0.78 mmol) and ylid 61b (362 mg, 1.00 mmol).

¹H NMR (200 MHz, CDCl₃): δ = 7.65–7.58 (m, 2 H), 7.48–7.38 (m, 3 H), 7.76 (t, J = 7.5 Hz, 1 H), 5.09–4.99 (m, 1 H), 4.19 (q, J = 7.2 Hz, 2 H), 2.20-2.08 (m, 2 H), 1.97-1.85 (m, 2 H), 1.78 (s, 3 H), 1.62 (d, J = 3.6 Hz, 3 H), 1.58–1.39 (m, 2 H), 1.26 (t, J = 7.2 Hz, 3 H), 0.30

(s, 6 H). ¹³C NMR (90 MHz, CDCl₃): $\delta = 209.9$, 168.2, 141.9, 138.9, 133.6, 128.9, 127.7, 91.9, 81.0, 60.3, 32.7, 28.3, 26.5, 18.0, 14.3, 12.3, -2.1. IR (neat): v = 2934, 1942, 1710, 1649 cm⁻¹

HRMS *m/z* calcd. for C₂₁H₃₀O₂Si 342.2015 (M⁺), found 342.1990.

77: oil.

Prepared (460 mg, 40%) from aldehyde 24b (950 mg, 3.70 mmol) and ylid 61a (1.72 g, 5.00 mmol).

¹H NMR (200 MHz, CDCl₃): δ = 7.59–7.52 (m, 2 H), 7.40–7.35 (m, 3 H), 6.96 (dt, J = 6.9, 15.9 Hz, 1 H), 5.81 (d, J = 15.9 Hz, 1 H), 5.09-5.02 (m, 1 H), 4.79 (q, J = 6.9 Hz, 1 H), 3.71 (s, 3 H), 2.21–2.09 (m, 2 H), 2.03-1.89 (m, 2 H), 1.48-1.28 (m, 4 H), 0.31 (s, 6 H).

Typical Wittig Reaction of Aldehydes:

To a mixture of methyltriphenylphosphonium bromide (64a, 1.70 g, 4.80 mmol) in THF (100 mL) at 0°C was added BuLi (1.92 mL, 2.5 M in hexanes). After 1h, a solution of aldehyde 24a (1.19 g, 4.90 mmol) in THF (5 mL) was slowly added. The mixture was warmed to r.t. over 24 h and H₂O (50 mL) was added. The aqueous layer was extracted with Et₂O (3×20 mL) and the combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo. The crude product was purified by flash chromatography eluting with 30% EtOAc/hexanes to give alkene 65a (850 mg, 72%) as an oil.

¹H NMR (200 MHz, CDCl₃): δ = 7.75–7.69 (m, 2 H), 7.54–7.47 (m, 3 H), 6.03–5.90 (m, 1 H), 5.24 (dt, J = 2.0, 3.6 Hz, 1 H), 5.21–5.10 (m, 2 H), 5.01 (q, J = 4.0 Hz, 1 H), 2.30–2.12 (m, 4 H), 1.71–1.60 (m, 2 H), 0.56 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 211.2, 138.5, 133.8, 133.6, 129.0, 127.7, 114.5, 83.7, 81.1, 32.2, 28.8, 27.2, -2.2.

IR (neat): v = 2068, 3049, 2360, 1938 cm⁻¹. CIMS m/z (%) = 243 (M⁺+H, 2.4), 227 (9.8), 135 (100).

65b: oil.

Aldehyde 24a (325 mg, 1.30 mmol), ethyltriphenylphosphonium bromide (64b, 557 mg, 1.50 mmol) and BuLi (0.60 mL, 2.5 M in hexanes) gave an inseparable mixture of alkene E/Z isomers 65b (200 mg, 60%).

¹H NMR (200 MHz, CDCl₂): $\delta = 7.63 - 7.58$ (m, 2 H), 7.43 - 7.38 (m, 3 H), 5.56-5.32 (m, 2 H), 5.09-5.01 (m, 1 H), 4.90-4.78 (m, 1 H), 2.11-1.88 (m, 4 H), 1.65-1.58 (m, 3 H), 1.51-1.36 (m, 2 H), 0.32 (s, 6 H).

IR (neat): v = 2930, 1938, 1427, 1248 cm⁻¹.

EIMS m/z (%) = 256 (M⁺, 0.8), 135 (100).

HRMS m/z calcd. for C17H24Si 256.1647 (M⁺), found 256.1634.

65c: oil.

Aldehyde 24a (130 mg, 0.53 mmol), BuLi (0.25 mL, 2.5 M in hexanes), and *i*-propyltriphenylphosphonium iodide (64c, 276 mg, 0.64 mmol) gave trisubstituted alkene 65c (84.0 mg, 59%).

¹H NMR (200 MHz, CDCl₃): δ = 7.61–7.53 (m, 2 H), 7.41–7.32 (m, 3 H), 5.12–4.97 (m, 2 H), 4.83 (q, J = 6.9 Hz, 1 H), 2.02–1.85 (m, 4 H), 1.66 (s, 3 H), 1.57 (s, 3 H), 1.46-1.30 (m, 2 H), 0.32 (s, 6 H).

¹³C NMR (75 MHz, CDCl₃): δ = 211.2, 133.7, 129.6, 129.0, 127.9,

127.7, 124.4, 83.9, 80.9, 29.8, 27.6, 27.5, 25.7, 17.6, -2.2.

IR (neat): v = 2927, 1938, 1428, 1248, 1113 cm⁻¹.

CIMS m/z (%) = 271 (M⁺+H, 3.3), 135 (100).

HRMS m/z calcd. for C₁₈H₂₆Si 270.1804 (M⁺), found 270.1820.

67: oil.

5-Oxohexanenitrile (31, 3.00 g, 27.0 mmol), BuLi (12.0 mL, 2.5 M in hexanes), and methyltriphenylphosphonium bromide (64a, 10.7 g, 30.0 mmol) gave disubstituted alkene 67 (1.75 g, 60%).

¹H NMR (200 MHz, CDCl₃): δ = 4.75 (d, J = 12.9 Hz, 2 H), 2.30 (t, J = 7.3 Hz, 2 H), 2.13 (t, J = 7.5 Hz, 2 H), 1.89–1.72 (m, 2 H), 1.68

(s, 3 H). ¹³C NMR (90 MHz, CDCl₃): δ =143.0, 119.4, 111.5, 36.2, 23.0, 21.8, 16.2.

IR (neat): v = 3076, 2939, 2246, 1650 cm⁻¹.

CIMS m/z (%) = 110 (M⁺+H, 100).

Anal. Calcd. for C₇H₁₁N: C, 77.01; H, 10.16; N, 12.83. Found: C, 76.87; H, 10.07; N, 12.55.

72: oil.

Aldehyde 34 (410 mg, 1.80 mmol), BuLi (0.70 mL, 2.5 M in hexanes), and methyltriphenylphosphonium bromide (642 mg, 1.80 mmol) gave alkene 72 (275 mg, 67%).

¹H NMR (200 MHz, CDCl₃): δ = 7.61–7.55 (m, 2 H), 7.40–7.35 (m, 3 H), 5.92–5.19 (m, 1 H), 5.06–4.89 (m, 2 H), 2.10–1.85 (m, 4 H), 1.61 (d, J = 4.0 Hz, 3 H), 1.56–1.33 (m, 2 H), 0.30 (s, 6 H).

¹³C NMR (75 MHz, CDCl₃): δ = 138.3, 133.6, 129.5, 128.9, 127.9, 114.8, 107.5, 88.1, 81.1, 38.1, 33.6, 27.0, 24.3, 23.5, -0.9.

IR (neat): $v = 3069, 2932, 1942, 1640, 1114 \text{ cm}^{-1}$

HRMS m/z calcd. for C₁₇H₂₄Si 256.1647 (M⁺), found 256.1647.

Cyclization of α , β -Unsaturated Ester 62a:

A solution of α,β -unsaturated ester 62a (100 mg, 0.3 mmol) in mesitylene (5 mL) was refluxed for 17 h and the mixture was concentrated in vacuo. The crude product was purified by preparative TLC (eluting with 10% EtOAc/hexanes) to give 70 mg (70%) of pure silyl acetylene 63a as an oil.

¹H NMR (200 MHz, CDCl₃): δ = 7.69–7.61 (m, 2 H), 7.42–7.34 (m, 3 H), 3.65 (s, 3 H), 2.95 (m, 1 H), 2.68 (m, 1 H), 2.40 (m, 2 H), 2.00-1.74 (m, 4 H), 1.68–1.35 (m, 2 H), 0.39 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 173.6, 133.9, 129.4, 128.0, 110.2, 85.2, 51.5, 39.6, 36.8, 35.3, 32.9, 30.5, 23.1, -0.30.

IR (neat): v = 2955, 2163, 1738, 1428 cm⁻¹

CIMS *m*/*z* (%) = 300 (M⁺-H, 100), 285 (33), 269 (7), 223 (76).

HRMS m/z calcd. for C₁₈H₂₄O₂Si 300.1546 (M⁺), found 300.1515.

Cyclization of α,β -Unsaturated Ester 62b:

A solution of α,β -unsaturated ester **62b** (85.0 mg, 0.26 mmol) in mesitylene (5 mL) was refluxed for 22 h and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with 5% EtOAc/hexanes) to give oily cyclopentane 63b (58 mg, 68%).

¹H NMR (360 MHz, CDCl₃): δ = 7.69–7.63 (m, 2 H), 7.40–7.35 (m, 3 H), 4.13 (dq, J = 2.2, 8.1 Hz, 2 H), 3.08–3.02 (m, 1 H), 2.70 (dq, J = 7.3, 14.0 Hz, 1 H), 1.91–1.79 (m, 6 H), 1.28–1.20 (m, 6 H), 0.39 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 176.7, 138.2, 133.6, 129.1, 127.7, 110.6, 84.9, 60.0, 46.6, 42.3, 34.7, 33.3, 28.1, 22.9, 17.3, 14.2, -0.6. IR (neat): v = 2959, 2164, 1731, 1428, 1249 cm⁻¹

HRMS m/z calcd. for C₂₀H₂₈O₂Si 328.1858 (M⁺), found 328.1860.

Cyclization of Allene Alkene 65a:

A mixture of allene 65a (100 mg, 0.41 mmol) and 4Å molecular sieves in anhyd mesitylene (4 mL) was stirred at r.t. for 1h. The mixture was then heated at reflux for 15 h and filtered through Celite. The solvent was removed under reduced pressure using a Kugelrohr apparatus. The product was purified by preparative TLC eluting with 15% EtOAc/hexanes to give alkyne 66a (62 mg, 62%) as an oil.

¹H NMR (200 MHz, CDCl₃): δ = 7.68–7.62 (m, 2 H), 7.41–7.30 (m, 3 H), 2.82–2.72, (m, 1 H), 2.30–2.19 (m, 1 H), 2.15–1.60 (m, 6 H), 1.09 (d, J = 8.0 Hz, 3 H), 0.37 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 133.6, 129.4, 128.9, 127.4, 84.0, 80.0, 38.0, 36.9, 34.9, 33.8, 23.3, 17.0, -0.2.

IR (neat): v = 3055, 3040, 2950, 2160 cm⁻¹.

CIMS m/z (%) = 243 (M⁺+H, 40), 227 (98), 165 (100), 135 (89).

Cyclization of Disubstituted Alkenes 65b:

A solution of a mixture of E/Z alkenes 65b (100 mg, 0.39 mmol) in oDCB (5 mL) was refluxed for 3 d and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with hexanes) to give oily alkyne 66b (62 mg, 62%).

¹H NMR (200 MHz, CDCl₃): δ = 7.69–7.63 (m, 2 H), 7.41–7.35 (m, 3 H), 2.90–2.81 (m, 1 H), 1.91–1.35 (m, 9 H), 0.91 (t, J = 7.4 Hz, 3 H), 0.34 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 138.1, 133.7, 129.1, 127.7, 111.4, 84.0, 45.7, 35.4, 33.0, 30.2, 24.8, 23.1, 23.1, 13.1, -0.44.

IR (neat): v = 2958, 2161, 1428, 1248, 1114 cm⁻¹

EIMS m/z (%) = 256 (M⁺, 8.4), 241 (100), 135 (36).

HRMS *m/z* calcd. for C₁₇H₂₄Si 256.1647 (M⁺), found 256.1631.

Cyclization of Trisubstituted Alkene 65c:

A solution of allene 65c (125 mg, 0.46 mmol) in trichlorobenzene (4 mL) was refluxed at 215 °C for 3 d and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with hexanes) to give oily isopropyl cyclopentane 66c (44 mg, 35%).

¹H NMR (200 MHz, CDCl₃): δ = 7.70–7.62 (m, 2 H), 7.41–7.32 (m, 3 H), 2.94–2.33 (m, 1 H), 1.92–1.25 (m, 8 H), 0.94 (d, J = 6.5 Hz, 3 H), 0.89 (d, J = 6.6 Hz, 3 H), 0.33 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 138.1, 133.7, 129.1, 127.7, 111.2, 83.9, 52.7, 34.9, 33.3, 30.8, 28.7, 22.9, 22.2, 21.9, -0.44.

IR (neat): v = 2958, 2161, 1248, 1115 cm⁻¹

EIMS m/z (%) = 270 (M⁺, 7.3), 255 (50), 135 (100).

HRMS *m/z* calcd. for C₁₈H₂₆Si 270.1804 (M⁺), found 270.1825.

Cyclization of Allene Alkene 70:

A solution of allene 70 (95.0 mg, 0.37 mmol) in mesitylene (4 mL) was sealed in a tube and heated in a sand bath at 300 °C for 2 d and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with 2% EtOAc/hexanes) to give alkyne 71 (70 mg, 75%) as an oil.

¹H NMR (200 MHz, CDCl₃): δ = 7.69–7.62 (m, 2 H), 7.41–7.33 (m, 3 H), 2.39-2.21 (m, 1 H), 1.84-1.29 (m, 6 H), 1.04 (s, 3 H), 0.96 (s, 3 H), 0.34 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 136.5, 132.1, 127.6, 126.2, 109.6, 82.2, 41.7, 40.9, 38.6, 30.1, 26.4, 21.8, 20.4, -1.9.

IR (neat): $v = 2958, 2164, 1428, 1248, 1115 \text{ cm}^{-1}$. EIMS m/z (%) = 256 (M⁺, 22), 241 (59), 135 (100).

HRMS *m/z* calcd. for C₁₇H₂₄Si 256.1647 (M⁺), found 256.1670.

Cyclization of Alkene 72:

A solution of alkene **72** (140 mg, 0.55 mmol) in mesitylene (4 mL) was sealed in a tube and heated in a sand bath at 310° C for 1.5 d and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with 2% EtOAc/hexanes) to give oily cyclopentane **73** (100 mg, 71%).

¹H NMR (200 MHz, CDCl₃): δ = 7.69–7.64 (m, 2 H), 7.41–7.34 (m, 3 H), 2.04–1.91 (m, 1 H), 1.85–1.35 (m, 6 H), 1.22 (s, 3 H), 1.01 (d, *J* = 6.0 Hz, 3 H), 0.32 (s, 6 H).

IR (neat): v = 2959, 2154, 1428, 1248, 1115 cm⁻¹.

Cyclization of Ester 74a:

A solution of α , β -unsaturated ester **74a** (100 mg, 0.39 mmol) in mesitylene (4 mL) was sealed in a tube and heated at 270 °C for 24 h and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with 10% EtOAc/hexanes) to give oily cyclopentane **75a** (64 mg, 64%).

¹H NMR (300 MHz, CDCl₃): δ = 7.65–7.59 (m, 2 H), 7.41–7.32 (m, 3 H), 3.69 (s, 3 H), 2.63 (dd, *J* = 4.9, 13.5 Hz, 1 H), 2.38 (dd, *J* = 9.2, 13.5 Hz, 1 H), 2.04–1.41 (m, 6 H), 1.28 (s, 3 H), 0.39 (s, 3 H).

¹³C NMR (75 MHz, CDCl₃): δ = 174.2, 131.6, 129.2, 128.5, 127.8, 113.2, 84.7, 51.6, 46.7, 43.0, 41.5, 36.3, 30.8, 25.8, 21.6, -0.5. IR (neat): *ν* = 2960, 2158, 1740, 1657, 1428, 1249 cm⁻¹.

HRMS m/z calcd. for C₁₉H₂₆O₂Si 314.1702 (M⁺), found 314.1705.

Cyclization of Ester 74b:

A solution of α , β -unsaturated ester **74b** (100 mg, 0.29 mmol) in mesitylene (4 mL) was sealed in a tube and heated at 250°C for 16 h and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with 2% EtOAc/hexanes) to give 53 mg (53%) of cyclopentane **75b** and bicycle **76** (18 mg, 18%), both as oils. Data for **75b**:

¹H NMR (200 MHz, CDCl₃): δ = 7.70–7.62 (m, 2 H), 7.41–7.32 (m, 3 H), 4.10 (qd, *J* = 3.2, 7.6 Hz, 2 H), 2.78–2.59 (m, 1 H), 2.04–1.33 (m, 6 H), 1.27–1.11 (m, 6 H), 1.18 (s, 3 H), 0.35 (s, 6 H).

¹³C NMR (90 MHz, CDCl₃): δ = 177.1, 138.0, 133.7, 129.1, 127.7, 113.9, 84.3, 60.0, 52.0, 43.0, 42.4, 41.7, 29.2, 26.8, 21.3, 17.1, 14.1, -0.4.

IR (neat): v = 2963, 2157, 1732, 1448, 1249 cm⁻¹.

HRMS m/z calcd. for $C_{21}H_{30}O_2Si$ 342.2015 (M⁺), found 342.2026. Data for **76**:

¹H NMR (200 MHz, CDCl₃): δ = 7.61–7.55 (m, 2 H), 7.39–7.20 (m, 3 H), 4.03 (qd, *J* = 3.2, 7.6 Hz, 2 H), 3.48 (br s, 1 H), 3.24–3.12 (m, 1 H), 1.98–1.48 (m, 6 H), 1.37 (bs, 1 H), 1.13 (t, *J* = 7.6 Hz, 3 H), 0.35 (s, 3 H), 0.23 (s, 3 H).

¹³C NMR (75 MHz, CDCl₃): δ = 176.8, 139.3, 133.8, 133.5, 131.2, 128.8, 127.7, 121.1, 60.4, 51.0, 47.4, 42.3, 30.7, 21.3, 19.2, 16.0, 14.1, -1.6.

IR (neat): v = 2934, 1724, 1447, 1374, 1111 cm⁻¹.

CIMS m/z (%) = 343 (M⁺+H, 18), 256 (100), 135 (66).

Cyclization of Allene 77:

A solution of allene **77** (100 mg, 0.32 mg) in 1,2,4-trichlorobenzene (4 mL) was refluxed for 1.5 d and concentrated in vacuo. The crude product was purified by preparative TLC (eluting with 10% EtOAc/hexanes) to give 36 mg (36%) of alkynyl cyclohexane **78** as an oil.

¹H NMR (200 MHz, $CDCl_3$): $\delta = 7.68-7.54$ (m, 2 H), 7.39–7.30 (m, 3 H), 3.69 (s, 3 H), 2.89–2.82 (m, 1 H), 2.49 (dd, J = 7.8, 15.9 Hz, 1 H), 2.30 (dd, J = 7.8, 15.9 Hz, 1 H), 2.05–1.20 (m, 9 H), 0.39 (s, 6 H).

Reduction of Nitrile 67:

To a solution of nitrile **67** (1.75 g, 16.1 mmol) in CH₂Cl₂ (100 mL) at -78 °C was added DIBALH (28.9 mL, 1.0 M in hexanes). After 2 h, a solution of 5% aq. HCl (50 mL) was added and the reaction was extracted with CH₂Cl₂ (3 × 40 mL). The combined organic layers were washed with brine, dried (MgSO₄) and concentrated in vacuo to give 1.80 g of crude aldehyde **68** as an oil. No further purification was required for the next step.

- ¹H NMR (200 MHz, $CDCl_3$): $\delta = 9.80$ (t, J = 1.7 Hz, 1 H), 4.70 (d, J = 7.5 Hz, 2 H), 2.40 (td, J = 1.6 Hz, 7.3 Hz, 2 H), 2.01 (t, J = 7.5 Hz, 2 H), 1.82–1.70 (m, 2 H), 1.67 (s, 3 H).
- ¹³C NMR (90 MHz, CDCl₃): *δ* = 202.2, 144.5, 110.6, 43.0, 36.8, 21.9, 19.7.
- IR (neat): v = 3074, 2938, 2718, 1726, 1649 cm⁻¹.
- CIMS m/z (%) = 113 (M⁺+H, 23), 95 (100).

We are indebted to the National Institutes of Health (CA-34303) for financial support of this research.

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