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FEATURE ARTICLE

Control and applications of remote asymmetric induction using allylmetal reagents

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Treatment of hydroxy- and alkoxy-substituted allylstannanes with tin(IV) halides effects transmetallation and the stereoselective formation of allyltin trihalides. These react with aldehydes and imines derived from glyoxylates with useful levels of remote asymmetric induction. Aspects of this chemistry are discussed, together with the conversion of the products into tetrahydrofurans and dihydropyrans.

During a study of the chemistry of (*S*)-4-benzyloxypent-2-enylstannane **1**,[1] it was found that stereo- and regio-selective reactions in favour of the 1-substituted *syn*-(*Z*)-5-benzyloxyhex-3-en-1-ols **2** were achieved if the allylstannane was treated with tin(iv) chloride for a few minutes at −78 °C followed by addition of an aldehyde (Scheme 1).[2] This reaction attracted our interest because of its high level of 1,5-asymmetric induction. This review discusses the scope of remote asymmetric induction using allyltin reagents.

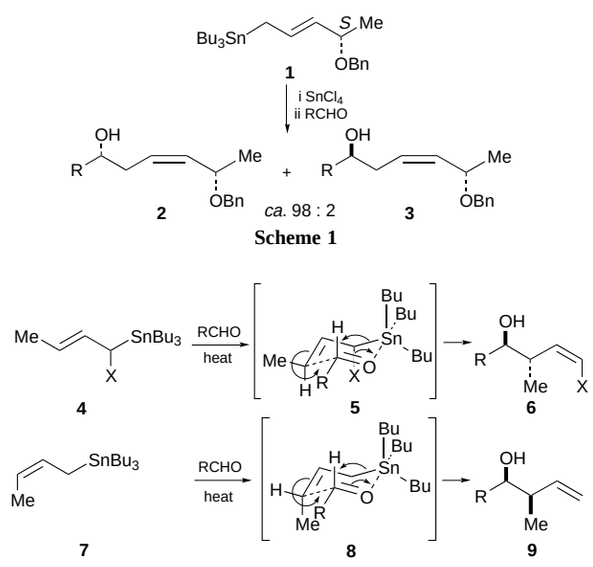
Background

At the onset of our work, it was known that allylstannanes react with aldehydes on heating and in the presence of Lewis acids.[3,4] The thermal reactions proceed stereo- and regio-selectively and are believed to involve six-membered, cyclic, chair-like, transition structures. For example, the *anti* and *syn* products **6** (X = H) and **9** are obtained from the (*E*)- and (*Z*)-but-2-enylstannanes **4** (X = H) and **7**, consistent with participation of the transition structures **5** and **8**.[5]

1-Substituted (*E*)-but-2-enylstannanes **4** (X = Me, OR) react with aldehydes on heating (Scheme 2) with excellent stereoselectivity in favour of the *anti*-(*Z*)-but-3-en-1-ols **6** (X = Me, OR).[6,7] The formation of *Z* double bonds in these reactions is consistent with participation of the transition structures **5** (X = Me, OR) in which the substituent next to tin is axial. This preference controls the facial selectivity of reactions of enantiomerically enriched 1-substituted but-2-enylstannanes with aldehydes.[8] Thus the (1*R*)- and (1*S*)-1-alkoxybut-2-enylstannanes **10** and **13** react with benzaldehyde to give the *anti* products **12** and **15** by selective attack on the *Si*- and *Re*-faces of the aldehyde, respectively (Scheme 3). Ozonolysis of these products gives rise to enantiomeric *anti*-aldol products, but the use of this reaction in synthesis is limited to aromatic and secondary aliphatic aldehydes because of the high temperatures required.[8]

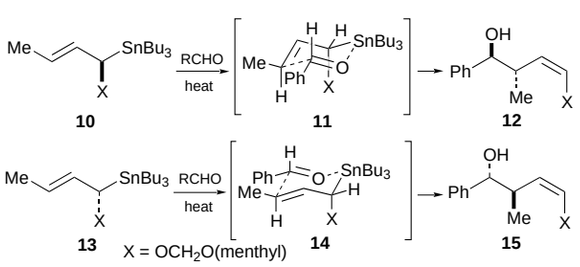
Two processes are involved in the Lewis acid promoted reactions of allylstannanes and aldehydes. Boron trifluoride–diethyl ether promotes the reaction at −78 °C, and leads to the formation of the *syn* product **9** from both the (*E*)- and (*Z*)-but-2-enylstannanes **4** (X = H) and **7**,[9] albeit less selectively from the (*Z*)-allylstannanes.[10] This stereoconvergence has been explained in terms of open-chain transition structures, the antiperiplanar arrangement of aldehyde and stannane being proposed by Yamamoto (Scheme 4),[9] although the *gauche* arrangement was suggested by Denmark.[11] In these reactions, the boron trifluoride–diethyl ether is accelerating the reaction by coordinating to the aldehyde.

Other Lewis acids react with the allylstannane to generate more reactive allylmetal reagents which then react with the aldehyde.[4] The transmetallation reactions normally involve SE′ processes so terminal allylstannanes give 1-substituted allylmetal reagents. These react with aldehydes to give linear products, but can be unstable with respect to 1,3-rearrangement to give terminal allyl metal reagents which react with aldehydes to give branched products.[12] For example, the 1-phenylprop-2-enyltin dichloride **18** is generated from the 3-phenylpropenylstannane **17** and butyltin trichloride (Scheme 5), and reacts with aldehydes to give the linear products **20**. On standing it isomerises to the 3-phenyl isomer **19** which gives the *anti* products **21** with aldehydes. Transition structures analogous to **5** are believed to be involved.[13]

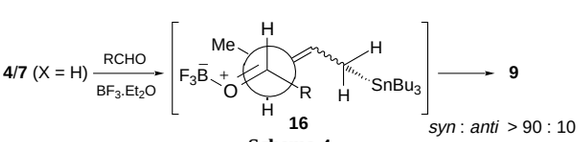


Scheme 1

Scheme 2



Scheme 3



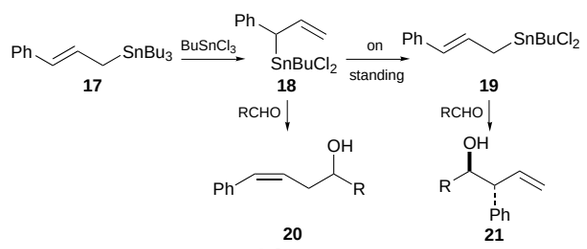
Scheme 4

Remote asymmetric induction in reactions of allylstannanes with aldehydes

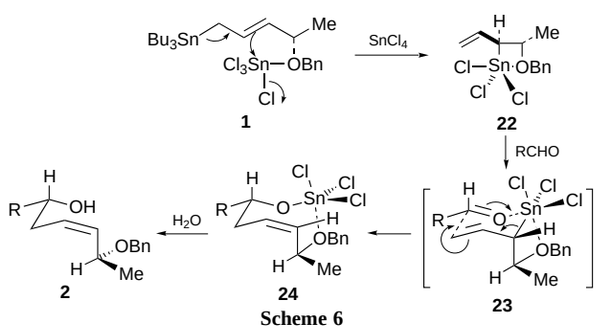
How can the regio- and stereo-selective formation of the 1,5-*syn* products **2** be explained? Since the tin(iv) halide is allowed to react with the stannane before the aldehyde is added, it is believed that transmetallation of the allylstannane is the first step.[14] This transmetallation is thought to involve delivery of the tin(iv) halide to the double bond of the allylstannane by the benzyloxy group to give the allyltin trichloride **22** which contains a four-membered oxastannane ring (Scheme 6). It is suggested that this transmetallation is stereoselective, with the isomer in which the vinyl and methyl groups are *trans*-disposed about the four-membered ring being preferred, perhaps due to kinetic control, although there may also be some equilibration of the *cis* and *trans* diastereoisomers under the reaction conditions. The allyltin trichloride **22** then reacts with the aldehyde *via* the transition structure **23** in which the group next to tin is axial, leading to the formation of the *cis* double bond in the product. Since the reaction between the tin(iv) chloride and an aldehyde is not reversible at −78 °C, this selectivity must be due to kinetic control. The initially formed product, before aqueous work-up, is the medium-ring dioxastannane **24**. Molecular modelling indicates that a *cis* double bond is more readily accommodated in the 8-membered ring of **24** than a *trans* double bond because of strain. If this strain is present in the transition structure **23**, it could account for the faster formation of the *cis* double bonded isomer **2**.[14]

The overall 1,5-asymmetric induction is therefore controlled by the stereoselectivity of the transmetallation step, and the preference of the group next to tin to be axial in the transition structure **23**. Coordination of the tin to the benzyloxy group is important in both of these steps. To investigate this coordination, the behaviour of the 4-*tert*-butyldimethylsilyloxypent-2-enylstannane **25** was investigated.[15]

With benzaldehyde three products, the 1,5-*anti*-(*E*)-alkenol **26**, the 1,5-*syn*-(*Z*)-isomer **27** and a minor component which was not fully characterised (ratio 60 : 30 : 10, respectively) were formed (Scheme 7). The formation of the *anti*-(*E*)-alkenol **26** is consistent with participation of the allyltin trichloride **28**, which has the opposite configuration at the tin-bearing carbon to that of the allyltin trichloride **22**, and which reacts with the aldehyde *via* the transition structure **29**. It may be that, in this case, the transmetallation is taking place by intermolecular attack of the tin(iv) chloride on the allylstannane mainly in the conformation in which the allylic hydrogen is in the plane of the double bond.



Scheme 5

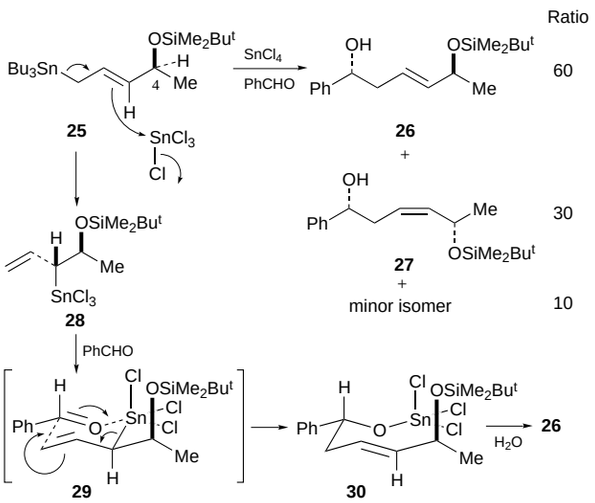


Scheme 6

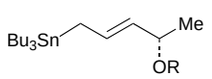
Approach of the tin(iv) chloride to the face away from the bulky silyloxy substituent,[16] would give the postulated intermediate **28**. The formation of the *trans* double bond in the products implies that the *tert*-butyldimethylsilyloxyethyl group adopts the equatorial position in the transition structure **29**. Perhaps, as no medium-ring strain is present, the bulky silyloxyethyl group is simply adopting the less hindered equatorial position.[15]

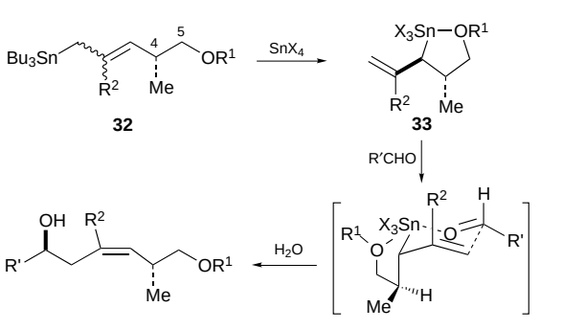
The scope of the tin(iv) halide-mediated reaction between alkoxy substituted allylstannanes and aldehydes has been widely investigated. The 4-(2-trimethylsilylethoxymethoxy)-, *p*-methoxybenzyloxy-, and hydroxy-pentenylstannanes **31** react with similar 1,5-induction to the 4-benzyloxypent-2-enylstannane **1**, although slightly reduced stereoselectivity is observed in reactions of the hydroxystannane **31** (R = H) with aliphatic aldehydes. Tin(iv) bromide leads to slightly better, and butyltin trichloride to similar, stereoselectivity, although the other Lewis acids investigated to date, $BF_3.Et_2O$, $TiCl_4$, $AlCl_3$, have proved less useful.

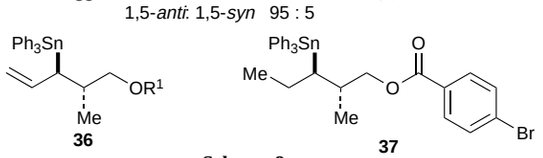
The 5-substituted pent-2-enylstannanes **32** (R^1 = Bn, PMB, SEM, H; R^2 = H) also react with aldehydes with useful levels of 1,5-induction after treatment with tin(iv) chloride or bromide (Scheme 8).[17,18] In this case the major product (*ca*. 95 : 5) is the



Scheme 7







Scheme 8

1,5-*anti*-(*Z*) stereoisomer **35** (R^2 = H). This is consistent with participation of the corresponding allyltin trihalide **33** (R^2 = H) which reacts with the aldehyde *via* the transition structure **34**. The formation of the *cis* double bond implies that the group next to tin is axial, so determining the facial selectivity of the reaction with the aldehyde and the configuration of the hydroxy bearing chiral centre in the product.

In the 5-substituted series, the *tert*-butyldimethylsilyl group has less effect on the overall selectivity, the stannane **32** (R^1 = $SiMe_2Bu^t$) giving the 1,5-*anti* product **35** (R^1 = $SiMe_2Bu^t$), albeit with reduced stereoselectivity (*ca.* 80 : 20).[15] An alkyl group at C(2) in the allylstannane, or the geometry of the double bond, have little effect. Thus both the (*E*)- and (*Z*)-2-methylpentenylstannanes **32** (R^2 = Me) give the 1,5-*anti*-(*Z*) products **35** (R^2 = Me) containing less than 2% of their *syn* diastereoisomers.[19]

In this series, the intermediate allyltin trichlorides **33** (R^2 = H; X = Cl) have been trapped by phenyllithium. Addition of phenyllithium to the allyltin trichloride from the benzyloxystannane **32** (R^1 = Bn; R^2 = H) gave the internal triphenylstannane **36** (R^1 = Bn) with excellent stereoselectivity (95 : 5) and similar stereoselectivity was observed for the hydroxy- and *tert*-butyldimethylsilyloxy-stannanes **32** (R^1 = H, $SiMe_2Bu^t$; R^2 = H). The structures of the major trapping products were established by X-ray diffraction of the *p*-bromobenzoate **37** which was prepared from the hydroxystannane **36** (R^1 = H) by reduction using diimide and esterification.[20]

This work is of interest since not only does it confirm the configurations originally assigned to the allyltin chlorides **33** on mechanistic grounds, but it also provides the regioisomeric triphenylallylstannanes **36** for transmetallation studies.

Transmetallation of allylstannanes with chiral centres at the 5- and 6-positions generates allyltin trihalides which react with aldehydes with 1,6- and 1,7-induction. In practice better stereoselectivities were observed with hydroxy substituted allylstannanes using tin(iv) bromide rather than tin(iv) chloride as the Lewis acid, although 1,6-induction was also observed for a 5-methoxyallylstannane. Thus the 5-hydroxy- and 5-methoxyhex-2-enyl and the 6-hydroxy-5-methylhex-2-enylstannanes **38** (R^1 = H, Me)[21] and **41**[22] were transmetallated with tin(iv) bromide to give allyltin tribromides, which reacted with aldehydes to give the 1,6-*syn* and the 1,6-*anti* products **40** (R^1 = H, Me) and **43**, respectively, with useful levels of 1,6-asymmetric induction (Scheme 9). Similarly the 6-hydroxyhept-2-enylstannane **44** gave the 1,7-*syn* products **46** with *ca.* 90 : 10 stereoselectivity.[23]

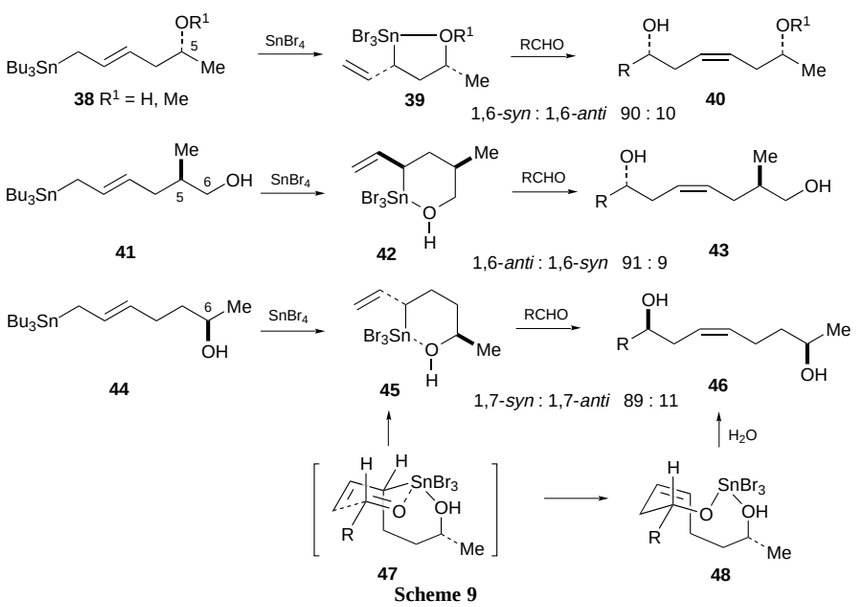
The stereoselectivities of these reactions are consistent with transmetallation giving the allyltin tribromides **39** (R^1 = H, Me), **42** and **45**, which react with aldehydes *via* six-membered, chair-like transition states in which the group next to tin is axial, *e.g.* **47** for the reaction of the allyltin tribromide **45**. The transmetallations are believed to generate allyltin tribromide in which the vinyl and methyl groups are both equatorial, as in the six-membered cyclic intermediates **42** and **45**, or pseudo-equatorial, as in the five-membered ring intermediate **39** (*cf.* also **33**), *i.e.* the more stable intermediates are believed to be involved, albeit formed kinetically.

The stereoselectivities of reactions with aldehydes of allylstannanes with nitrogen- and sulfur-containing functional groups have been investigated and found to parallel the reactions of their oxygen analogues. For example, treatment of the 4-aminopent-2-enylstannane **49** with tin(iv) bromide followed by the addition of an aldehyde gave the 1,5-*syn* products **51** with excellent stereoselectivity,[24] and the 5-benzylthiopent-2-enylstannane **52** similarly gave the 1,5-*anti* products **54**, with *ca.* 90 : 10 selectivity (Scheme 10).[25] The allyltin tribromides **50** and **53** are believed to be involved.

Rather different selectivity was observed for 5-acyloxyallylstannanes. The 5-acetoxypent-2-enylstannane **55** (R = Me) gave a mixture of products in which the *anti*-(*E*)-isomer **56** was the major component (Scheme 11).[26] The formation of this product is consistent with participation of the 7-membered ring containing allyltin trichloride **58** which reacts with the aldehyde *via* the transition structure **59**. Perhaps there is enough flexibility to accommodate an incipient *trans* double bond in this transitional structure so that the group next to tin can be equatorial. The use of different acyloxystannanes **55** (R = Ph, Bu^t, OMe, *etc*), failed to improve the selectivity to reliably useful levels.[26] The allylstannane **60** also gives rise to *E* double bonds in products from reactions with aldehydes, albeit with only low 1,8-*syn/anti* selectivity.[27]

Remote asymmetric induction in reactions of allylstannanes and imines

Allylstannanes react with imines in the presence of strong Lewis acids,[28] but preliminary investigations showed that allyltin trichlorides did not react at −78 °C with *N*-alkyl and *N*-aryl imines prepared from benzaldehyde. However, the more



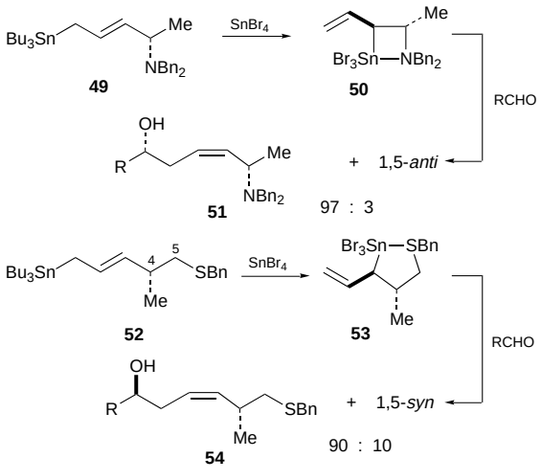
Scheme 9

electrophilic *N*-ethoxycarbonyl imine **61** and the chiral imine **63** prepared from butyl glyoxylate reacted efficiently with propenyltin trichloride to give the homoallylic amine derivatives **62** and **64**; (ratio 93 : 7, Scheme 12).[29] Of interest is the facial selectivity observed with the chiral imine **63** which is the opposite of that observed for an allylborane.[30]

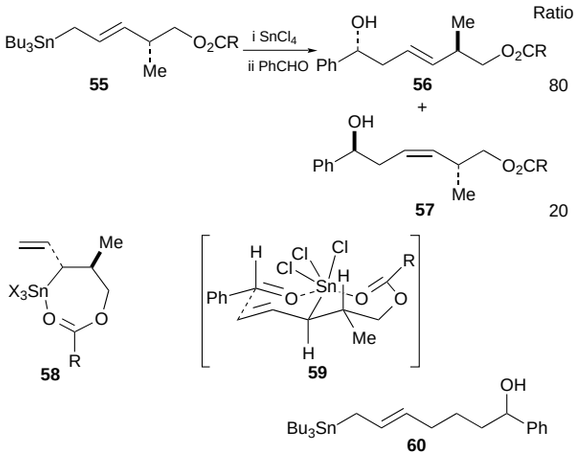
The imine **63** reacted with the allyltin trichloride **22** (Scheme 13) generated from the 4-benzyloxypent-2-enylstannane **1** with effective 1,5-induction in favour of the 1,5-*anti* isomer **66** (selectivity 90 : 10) even though this had involved attack of the allyltin trichloride on the less reactive face of the imine, *cf.* the facial stereoselectivity observed during the reaction of the imine **63** with propenyltin trichloride. With the enantiomeric imine *ent*-**63**, the formation of the 1,5-*anti* product was matched with the facial preference of the imine, and the major product was the 2*R* epimer **68**, selectivity 96 : 4. In both cases, all products isolated from the reactions between the imines **63** and *ent*-**63** were (*E*)-alkenes, in contrast to the selective formation of (*Z*)-alkenols in reactions with aldehydes.[29] The preference for formation of 1,5-*anti* products was maintained for the achiral *N*-arylthio, *N*-benzhydryl and *N*-dimethylbenzyl imines **70**–**72**, which gave the 1,5-*anti* products **73**–**75**, in *ca*. 90 : 10 stereoselectivity.[31]

The mechanisms of these reactions are not clear, although it is supposed that the allyltin trichloride **22** is involved since its formation takes place before addition of the electrophile. By analogy with the boron trifluoride–diethyl ether-promoted reactions of allylstannanes and aldehydes, which give (*E*)-alkenes,[32] perhaps the reaction between the allyltin trichloride **22** and imines involves an open-chain process. The transition structure **76** shows one possible orientation of the allyltin trichloride and the matched imine *ent*-**63** leading to the major product **68**. However, the cyclic transition structure **77** is also consistent with the observed stereoselectivity. In this case, the group on nitrogen, which must be axial if the nitrogen is to be coordinated to the tin, forces the group next to tin into the equatorial position to avoid severe 1,3-diaxial interactions, compare **23** and **77**.[29]

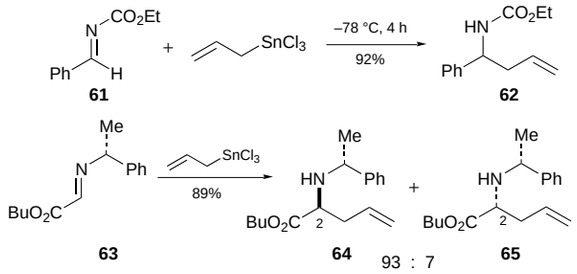
Of interest is the stereoselectivity of the reaction between the 4-*tert*-butyldimethylsilyloxypent-2-enylstannane **25** and imines. The achiral imines **70**–**72** react to give more of the 1,5-*syn* products **78**–**80** (Scheme 14), although the stereoselectivity, being *ca*. 75 : 25, is less than with the benzyloxystannane **1**.[15] The 1,5-*syn* products **81** and **82** are also preferred in reactions with the chiral imines **63** and *ent*-**63** (Scheme 15). This stereoselectivity is consistent with participation of the allyltin trichloride **28** which has the (*R*)-configuration at the tin bearing



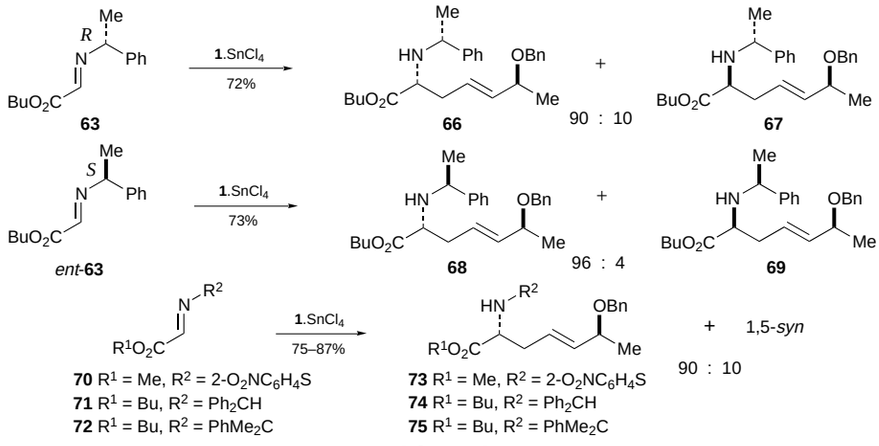
Scheme 10



Scheme 11



Scheme 12



70 R^1 = Me, R^2 = 2-$O_2NC_6H_4S$
71 R^1 = Bu, R^2 = Ph_2CH
72 R^1 = Bu, R^2 = $PhMe_2C$

73 R^1 = Me, R^2 = 2-$O_2NC_6H_4S$
74 R^1 = Bu, R^2 = Ph_2CH
75 R^1 = Bu, R^2 = $PhMe_2C$

Scheme 13

carbon. This prefers to approach the *Si* face of the imine, giving rise to the 1,5-*syn* product (see transition structure **83**).[15]

The allyltin trichloride generated from the 5-benzyloxypent-2-enylstannane **32** (R^1 = Bn; R^2 = H) reacts with the achiral imines **70** and **71** with useful 1,5-induction in favour of the 1,5-*syn* products **84** and **85** (Scheme 16).[31] With the matched (*R*)-imine **63** this selectivity is enhanced, but it is significantly reduced in reaction with the mismatched (*S*)-imine *ent*-**63**.[29] The formation of these 1,5-*syn* products is consistent with participation of the allyltin trichloride **33** (R^1 = Bn; R^2 = H; X = Cl) which reacts with the imine through either an open-chain or cyclic transition structure analogous to **76** or **77**.

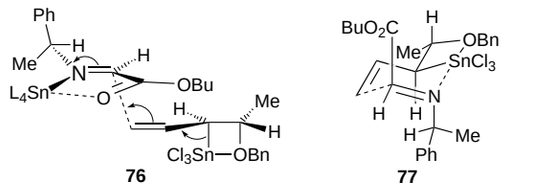
Aspects of the chemistry of the products

The 4-benzyloxypent-2-enylstannane **1** reacts with chiral 3-alkoxy aldehydes with selectivity controlled by the stannane, not by the aldehyde, *e.g.* the 1,5-*syn* products **91** and **93** were the dominant products from the 3-alkoxybutanals **90** and **92** (Scheme 17), although some matching and mismatching was observed with 2-alkoxy aldehydes.[33] Since remote chiral centres in the aldehyde do not affect the 1,5-*syn*-stereoselectivity, it is possible to use repetitively the remote induction of alkoxystannanes to synthesize open-chain polyols.

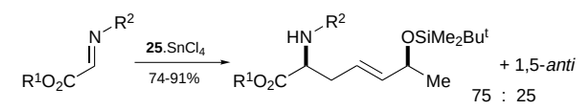
The 4-benzyloxyocta-2,7-dienylstannane **94** gave the 1,5-*syn* product **95** with 2-methylpropanal (*syn* : *anti* selectivity = 95 : 5) (Scheme 18). Protection and hydroboration–oxidation gave the aldehyde **96**, which reacted with the pent-2-enylstannane **1** to give the all-*syn* product **97**. Selective hydrogenation and hydrogenolysis gave the 15-methylhexadeca-2,6,10,14-tetraol **98** containing less than 5% of any other diastereoisomer. The aldehyde **96** was also treated with the stannane **94** to give the 1,5-*syn* product **99** which was protected and taken through to the corresponding aldehyde which gave the hexaol derivative **100** on treatment with the pent-2-enylstannane **1**.[34]

The 1,5-*syn*-alkenols **2** were converted stereoselectively into the all-*syn* epoxides **101** using $VO(acac)_2$ and *tert*-butyl hydroperoxide (Scheme 19).[35] The regioselectivity of hydride reduction of these epoxides was dependent upon the reducing agent. The 1,4- and 1,3-diols **102** and **103** were obtained as a mixture (33 : 67) using diisobutylaluminium hydride, but lithium aluminium hydride gave predominantly (99 : 1), and Red-Al† gave exclusively, the 1,4-diol **102**. Treatment of the 1,4-diol **102** (R = Ph) with lithium diisopropylamide and toluene-*p*-sulfonyl chloride gave the 2,5-*trans*-disubstituted tetrahydrofuran **104** by selective tosylation and displacement of the benzylic hydroxy group, but this sequence gave mixtures of products from other 1,4-diols **102** (R ≠ Ar).[36]

A synthesis of *cis*-2,5-disubstituted tetrahydrofurans, was developed from the alkenols **2**.[36] Treatment with toluene-*p*-sulfonyl chloride in pyridine gave the toluene-*p*-sulfonates **105**, which were oxidised stereoselectively using osmium tetraoxide (Scheme 20). The intermediate diols **106** were not isolated. Instead they cyclised *in situ* to give tetrahydrofurans,

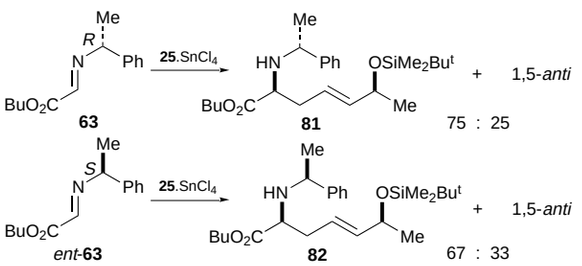


76 **77**

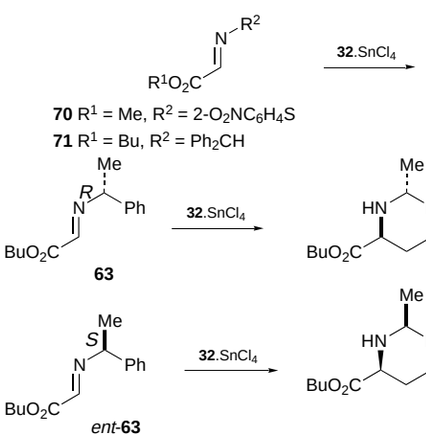


70 R^1 = Me, R^2 = 2-$O_2NC_6H_4S$ **78** R^1 = Me, R^2 = 2-$O_2NC_6H_4S$
71 R^1 = Bu, R^2 = Ph_2CH **79** R^1 = Bu, R^2 = Ph_2CH
72 R^1 = Bu, R^2 = $PhMe_2C$ **80** R^1 = Bu, R^2 = $PhMe_2C$

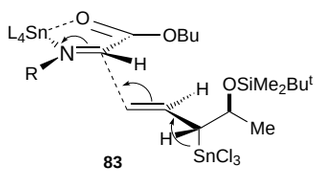
Scheme 14



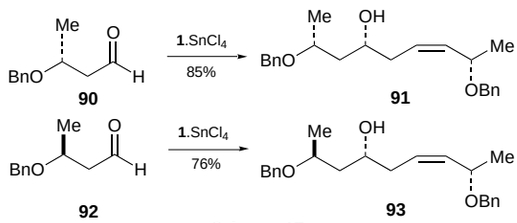
Scheme 15



Scheme 16



83



Scheme 17

e.g. **107** and **109** (ratio 85 : 15) and **108** and **110** (ratio 95 : 5). The stereoselectivity of formation of these tetrahydrofurans is consistent with the diastereofacial selectivity of oxidation of the alkenyl tosylates being controlled by the allylic benzyloxy group, and, for the 5-isopropyltetrahydrofuran **107**, was confirmed by NMR (NOE) studies on the ketone **111**.

This synthesis of tetrahydrofurans **107**–**110** involves three steps from the starting aldehyde, namely reaction with the allylstannane, tosylation and oxidation–cyclisation. This three step sequence was used to give polycyclic tetrahydrofurans. The major tetrahydrofuranyl-2-carboxylate **108** was taken through to the allylstannane **112**. Treatment with tin(iv) bromide and an aldehyde (Scheme 21) proceeded with useful levels (⩽ 90 : 10) of 1,5-induction to give the 1,5-*syn* products **113** (R = Ph, Pr^i, CO_2Bu), the allylic tetrahydrofuranyl chiral centre controlling the 1,5-induction. Tosylation and oxidation of the 2-hydroxyhexenyltetrahydrofuran **113** (R = Pr^i) then gave the bis(tetrahydrofuran) **114** (23%) together with a minor isomer, ratio 87 : 13.[36] As an alternative strategy, the tetrahydrofuranyl-2-carboxylate **108** was converted by protection and reduction into the aldehyde **115** (Scheme 22). This was treated under the usual conditions with stannane **1** and tin(iv) chloride to give the 1,5-*syn* product **116** (74%, no minor isomer being detected by HPLC). Tosylation and oxidation with osmium tetraoxide gave the diol **117** and a minor isomer (85 : 15). Treatment with sodium hydride instigated cyclisation to the bis(tetrahydrofuran) **118**.[36]

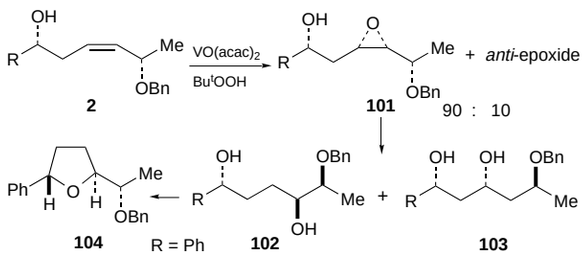
This synthesis of tetrahydrofurans is limited to products prepared from 4-alkoxyalkenylstannanes, since the alkoxy group is important in controlling the stereoselectivity of the oxidation using osmium tetraoxide as well as the reaction of the allylstannane with the aldehyde. However, another route to 2,5-*cis*-substituted tetrahydrofurans has been developed which is applicable to products prepared from 5-alkoxyalkenylstannanes. Epoxidation of the *anti*-alkenol **35** (R^1 = Bn, R^2 = H, R′ = Pr^i) using $VO(acac)_2$ and Bu^tOOH gave the *syn* epoxide **119** (Scheme 23). Treatment of this with diphenyldiselenide and sodium borohydride in ethanol gave a mixture of the dihydroxyselenides **120** and **121** corresponding to nonregioselective opening of the epoxide ring by sodium phenylselenide.[37] This mixture was not separated; rather it was treated with perchloric acid which gave the tetrahydrofuran **123** *via* the selenonium ion **122**. Reduction using tributyltin hydride gave the tetrahydrofuran **124**.[38]

Functionalised aldehydes were used in syntheses of dihydropyrans.[39,40] The tin(iv) chloride-promoted reaction of the 4-alkoxypent-2-enylstannane **31** (R = SEM) with toluene-*p*-sulfonyloxyacetaldehyde gave the 1,5-*syn* adduct **125** (Scheme 24). Treatment of this with anhydrous potassium carbonate gave the *syn* epoxide **126** which, on deprotection with trifluoroacetic acid, was converted into the 2,6-*cis*-disubstituted dihydropyran **127** containing *ca*. 20% of its 2,6-*trans* epimer. Conversely, the *anti* epoxide **129** was available *via* treatment of the 1,5-*syn* product **128**, prepared from stannane **31** (R = SEM) and benzoyloxyacetaldehyde, with mesyl chloride and triethylamine followed by saponification and cyclisation using potassium carbonate. Deprotection of this epoxide gave the 2,6-*trans*-disubstituted dihydropyran **130** containing *ca*. 20% of its 2,6-*cis* epimer.[39,40]

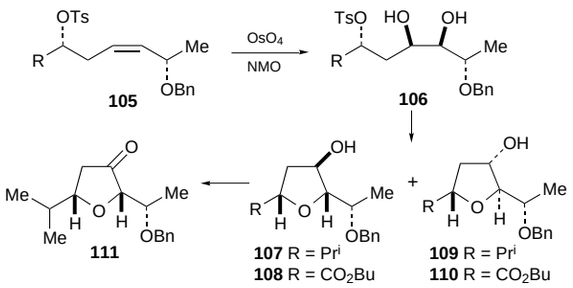
Remote asymmetric induction using other allylmetal reagents

Although allylstannanes are useful in synthesis, there is often a problem in removing unwanted tin-containing residues from the products and so it was of interest to see whether the intermediate allyltin trihalides, important for remote induction, could be generated stereoselectively from starting materials other than allylstannanes.

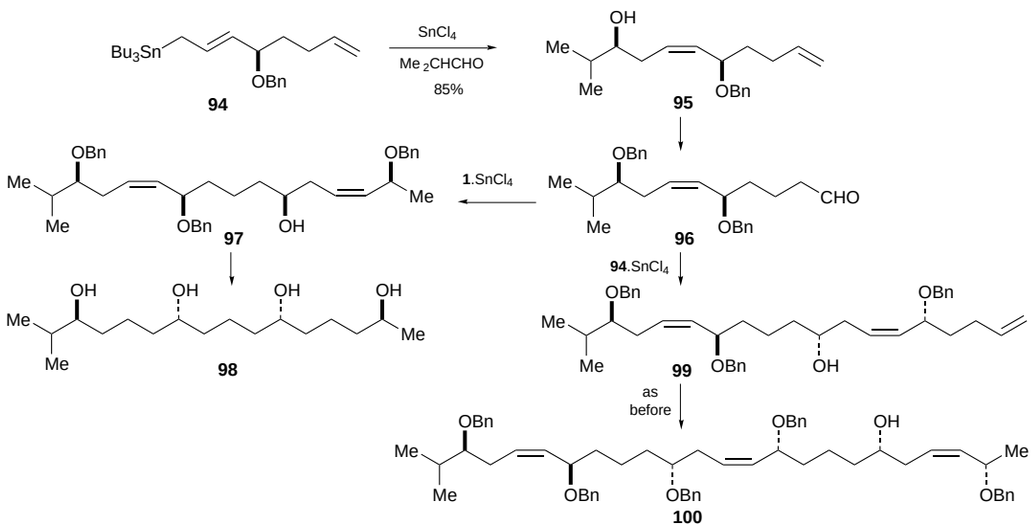
Stannous fluoride promotes reactions between 3-iodopropene and aldehydes, perhaps by formation of allyltin trihalides which



Scheme 19

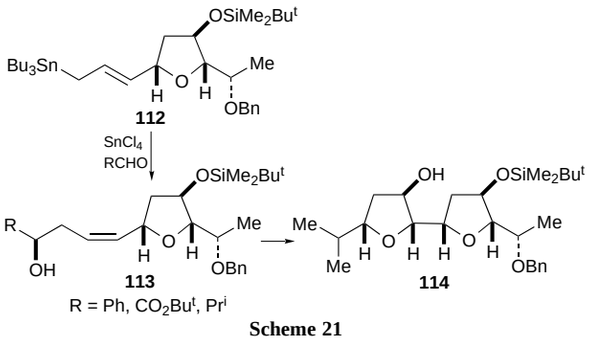


Scheme 20

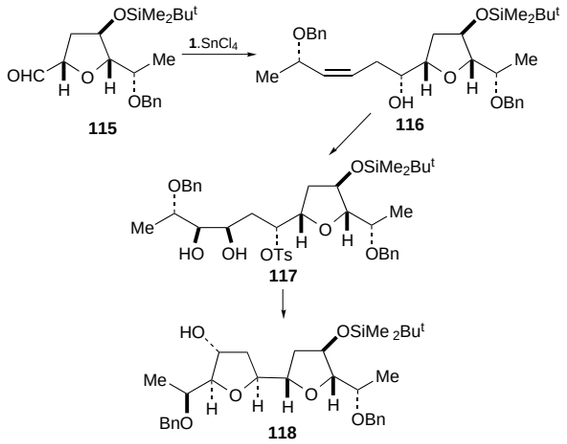


Scheme 18

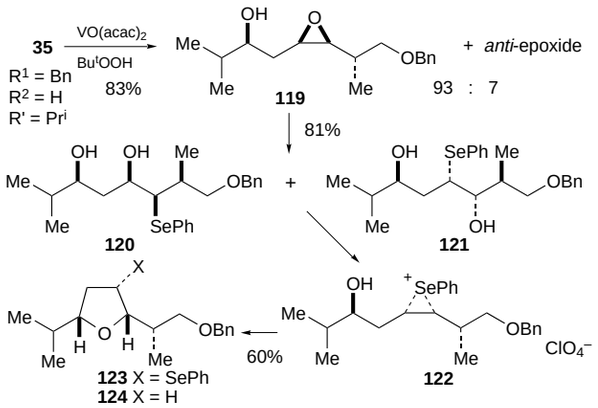
then react with the aldehyde.[41] However, treatment of either the allylic iodide or bromide **131** (X = I, Br) with stannous fluoride, chloride or triflate in the presence of benzaldehyde gave low yields of mixtures of products containing mainly the branched alkenols **132**.[42] The use of metallic tin with the iodide was similarly unsuccessful. However, some success was attained with allylsilanes. The (*Z*)- and (*E*)-pent-2-enylsilanes **134** and **135** were prepared from the aldehyde **133** (Scheme 25). Treatment of the (*Z*)-isomer **134** with tin(iv) chloride at −78 °C for 1–2 h generated an intermediate, perhaps the allyltin trihalide **33** (X = Cl, R^1 = Bn, R^2 = H), which reacted with benzaldehyde to give the 1,5-*anti* and 1,5- *syn* products **35** (R′ = Ph, R^1 = Bn, R^2 = H) and **136** (R′ = Ph), ratio 85 : 15. The (*E*)-allylsilane **135** similarly gave the 1,5-*anti* and 1,5-*syn* products **35** (R′ = Ph, Pr^i, Et, R^1 = Bn, R^2 = H) and **136** (R′ = Ph, Pr^i, Et), but with slightly reduced selectivity (1,5-*anti* : 1,5-*syn* = *ca*. 75 : 25).[43] Attempts to improve the 1,5-induction of allylsilanes to the levels observed with allylstannanes have not yet proved successful.



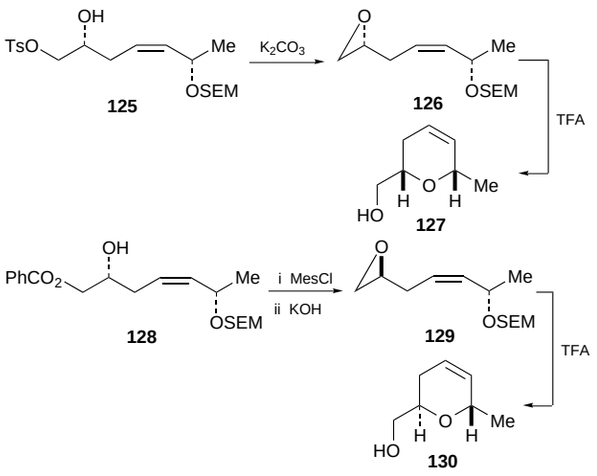
Scheme 21



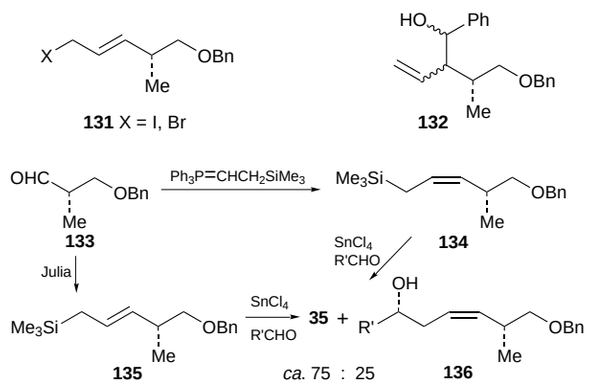
Scheme 22



Scheme 23



Scheme 24

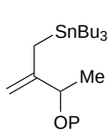


Scheme 25

Summary and conclusions

The work outlined in this article shows that 4-, 5- and 6-substituted alkenylstannanes, after transmetallation with tin(iv) halides, react with aldehydes and imines with useful levels of 1,5-, 1,6- and 1,7-asymmetric induction.

Recently, a complementary approach to remote induction using allylstannanes has been introduced based on the chemistry of 2-(substituted-alkyl)propenylstannanes. For example, stereodivergent approaches to 1,4-asymmetric induction were developed based on the chemistry of 2-(1-substituted ethyl)propenylstannanes **137** (P = Me, Ac) and related compounds.[44–47] Advances in this area are expected.



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Footnote

† A 3.4 m solution of sodium bis(2-methoxyethoxy)aluminium hydride in toluene.

E. J. Thomas studied at Cambridge University, carrying out research for his PhD under the supervision of Dr I. Fleming. He spent two years in the Dyson Perrins Laboratory, Oxford, as a post-doctoral research assistant working under the supervision of Dr G. H. Whitham, then moved to King's College, London as a University Lecturer in Organic Chemistry. After six years he returned to Oxford as a University Lecturer and Fellow of Exeter College. In 1988 he was appointed Professor of Organic Chemistry at the University of Manchester. His research interests are concerned with synthetic organic chemistry including both synthetic methodology and the synthesis of complex natural products. He was awarded a Hickinbottom Fellowship by the RSC in 1982, a Pfizer Academic Award in 1986 and was an RSC Tilden Lecturer in 1995/96.

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