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# CARBOCYCLIC RING EXPANSION REACTIONS VIA RADICAL CHAIN PROCESSES

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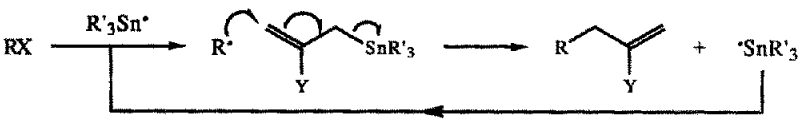
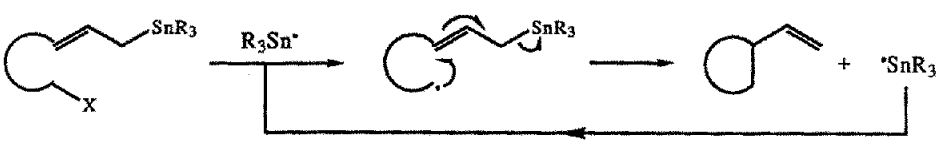
Abstract: A free radical mediated ring expansion of *cis*- and *trans*- α-alkylated-β-stannylcyclohexanones to provide efficient routes to *cis*- and *trans*-cyclononenones and cyclodecenones is described. The cis-/*trans*- relationship in the precursor was found to have significant bearing on the alkene geometry of the ring expanded product.

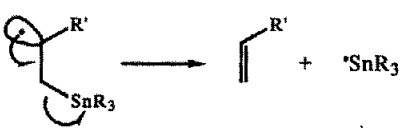
Recently the potential of allylic stannanes to provide efficient free radical pathways for intermolecular[1] C-C bond formation (Scheme 1) has been extended to intramolecular ring cyclisations[2] (Scheme 2). Crucial to these transformations and other related examples[3] is the rapid fragmentation of a trialkylstannane β- to a homolytically labile C-C bond, which provides both olefin product and chain carrying trialkylstannyl radical (Scheme 3). An alternative access to such β-stannyl radicals is the most




Scheme 1

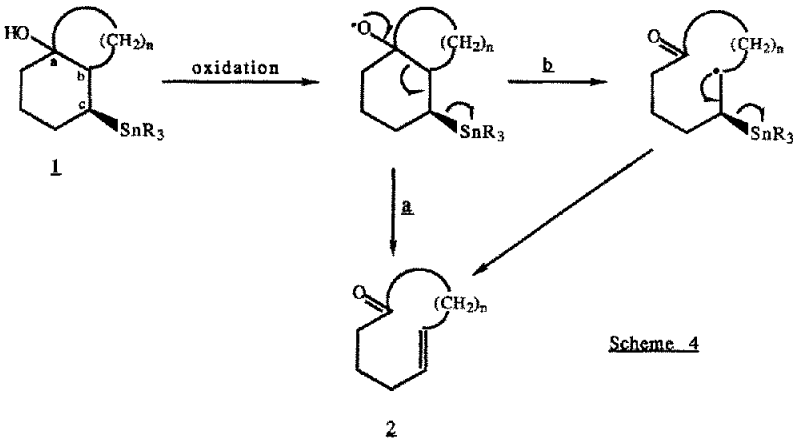



Scheme 2




Scheme 3

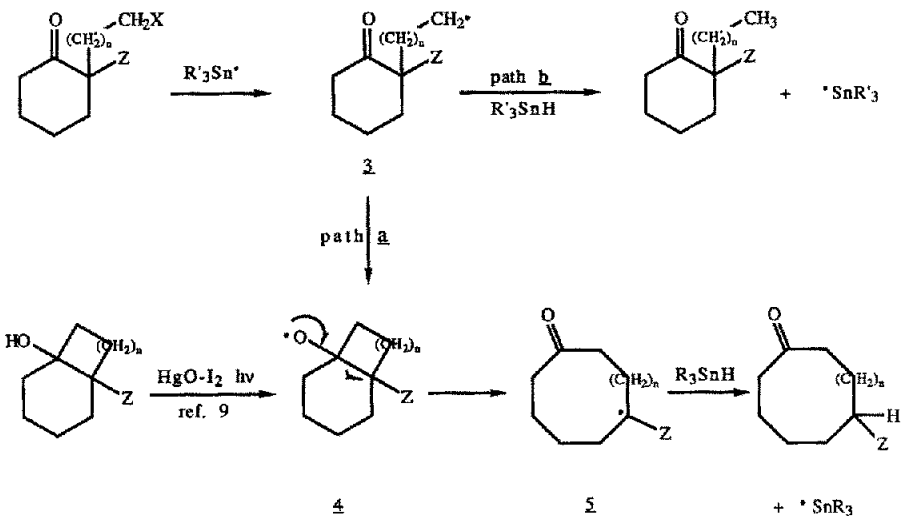
likely rationale of a new method for ring expansion of β- stannyl alcohols under oxidative conditions[4]. For example, the oxidation of β-stannyl alcohols by lead tetraacetate and heat or light[5] or by (diacetoxyiodo)benzene[6] provides an efficient means for ring expansion, most probably *via* free radical pathways (Scheme 4). An interesting feature of the conversion 1 to 2 was that the relative stereochemistry of the starting alcohol, i.e. *cis-/trans-* relationship at carbon b,c of 1 controlled the alkene geometry of the ring expanded product 2, i.e. *cis*-1 to *cis*-2 and *trans*-1 to *trans*-2. Such observations are consistent with a concerted fragmentation, path a (Scheme 4) as opposed to a stepwise version, path b.




1 2

Scheme 4

In a separate study Dowd[7], has improved an unoptimised method for ring expansion originally reported by Beckwith[8], demonstrating that α-(n-haloalkyl)-β-ketoesters undergo both ring expansion and subsequent reduction (Scheme 5, path a) and direct reduction (Scheme 5, path b) with trialkylstannanes *via* free radical pathways. As a facile ring opening of the alkoxy radical 4b to 5b is a likely mechanism of the efficient mercury(II) oxide-iodine irradiation-induced fragmentation-expansion of bicyclic alcohols to iodoketones reported by Suginome[9], then paramount to a successful ring expansion by Dowd's procedure is the ease of formation of the ring formed by attack of a terminal alkyl radical onto a ketone function, i.e. 3 to 4. Thus it was found[7] that efficient overall expansion before reduction occurred when n=0,2,3,≠1.

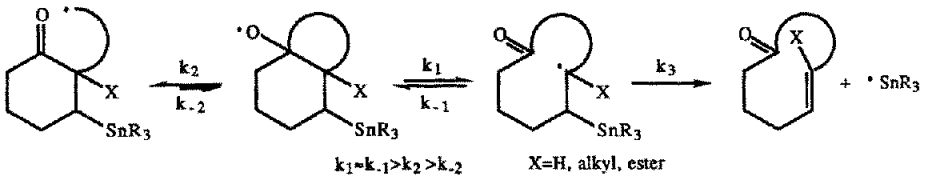



3

4 5

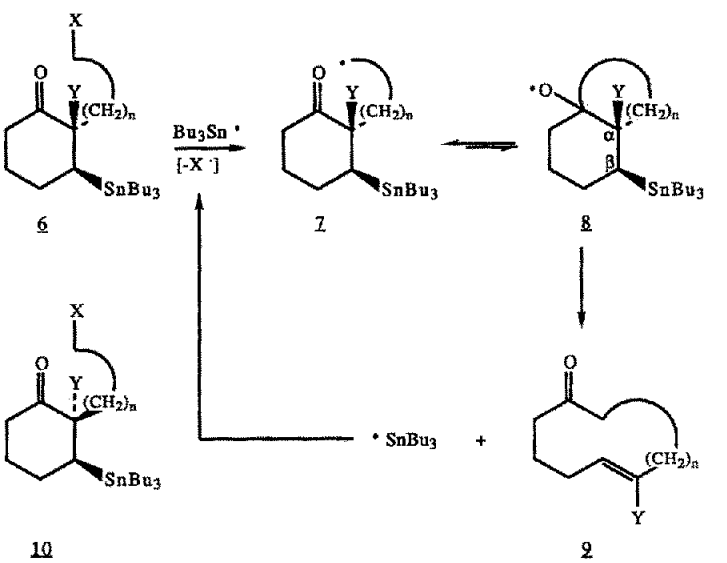
Scheme 5 for 3-5 a) $Z=CO_2R$
b) Z=H

In addition, the presence in the Dowd system of the ester function, e.g. 3a, appeared to promote the expansion pathway with respect to Beckwith's simpler system, e.g. 3b n=3, where reduction without expansion, path b, was predominant. From these observations an equilibrating set of alkyl and alkoxyl radicals can be formulated (Scheme 6) from which targetted positioning of a trialkylstannyl moiety could bias ring expansion, i.e. $k_3 > k_{-1} > k_2$.



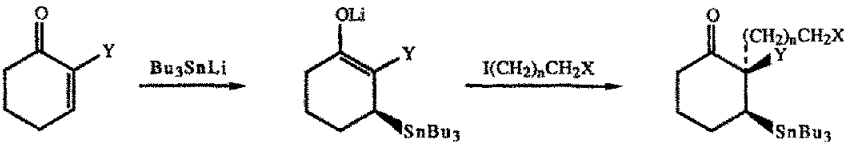

Scheme 6

Based upon these observations we argued that an α-(n-alkyl radical)-β-stannyl cyclic ketone, 7, should be an efficient precursor for a self promoted free radical chain ring expansion reaction (e.g. Scheme 7). As such a chain process would require only catalytic $Bu_3SnH$/AIBN for initiation, then the undesired direct reduction of 7 before expansion, a problem observed by Dowd[7], should be minimized. Additionally, as this process provides entry to a β-stannyl alkoxy radical with defined substituent stereochemistry at $C_\alpha$ and $C_\beta$ of 8, then the alkene geometry within 9 should be stereospecifically controlled providing a concerted fragmentation 8 to 9 occurs.



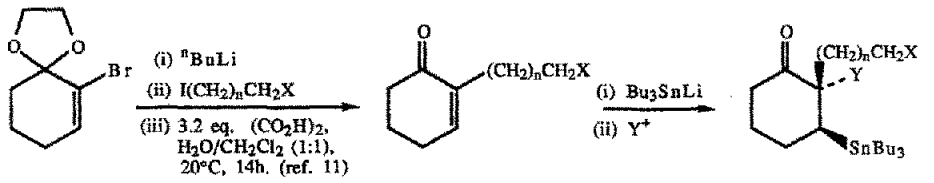

Scheme 7

Access to suitable precursors, 6, 10, to test these hypotheses was obtained by two methods, A, B. Firstly tributylstannyl lithium was added in Michael fashion to a 2-substituted cyclohexenone (1:1 THF:HMPA, -78°C, 0.5h) and the resultant enolate alkylated with a 1,n-di-iodide or a 1-iodo-n-phenylseleno alkane (-23°C to r.t., 14h. Method A, 35-60%)[10]. Secondly, tributylstannyl lithium was added in Michael fashion to a preformed α-(n-phenylselenoalkyl)-cyclohexenone (THF:HMPA, -23°C, 2h) and the resultant enolate protonated, deuterated or alkylated (Method B, 51-74%). The relative stereochemistries of the β-stannyl to α-radical precursor carbon chain, i.e. *trans-* from method A and *cis-* from method B, was assumed from kinetically controlled electrophilic attack of the derived enolates (i.e. *trans-* to the stannyl substituent). Observed values for the $^3J(^{119}Sn\text{-}^{13}C)$ coupling constant of the carbonyl carbon for *cis*-10 and *trans*-6 were in general consistent with literature values for related systems[6].




6 (*trans*-)

Method A



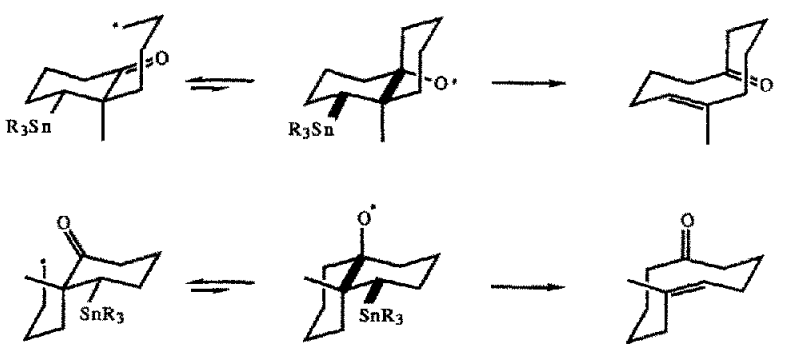

19

24 (n=2) X=SePh
25 (n=3) X=SePh

10 (*cis*-)

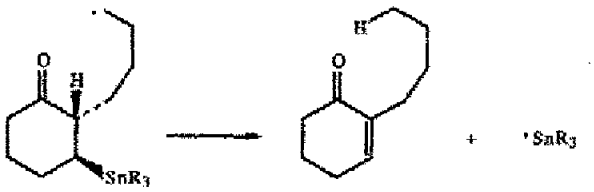
Method B

The results of radical initiated ring expansion of α-alkylradical-β-stannyl cyclic ketones are listed in Table 1. Clearly, efficient radical expansion was possible from both *cis*- and *trans*- substrates provided that the ketone was fully substituted at $C_\alpha$ (i.e. no hydrogen at $C_\alpha$) and that the initial ring formation, i.e. 7 to 8, was kinetically favoured. The relative stereochemistry of the substituents at $C_\alpha$ and $C_\beta$ was found to give extensive control of the alkene geometry as predicted. Thus *trans*- substrates gave *trans*-alkenes whereas *cis*- substrates gave *cis*- alkenes, as expected for trialkylstannyl radical expulsion *via* a concerted coplanar *anti*- elimination mechanism (Scheme 8), the only exception to this observation being the ring expansion of 6g in which a *cis*- seven membered ring alkene is produced from a *trans*-substrate. If the α-carbon bears hydrogen then reduction competes with expansion. This process was




Scheme 8

unaffected by a 10-fold increase in concentration and thus appears to be intramolecular as opposed to intermolecular (e.g. Scheme 9). If this hydrogen abstraction is disfavoured, i.e. by converting to deuterium (entry 2 vs. entry 1) or if the geometry for hydrogen abstraction is unsuitable, (i.e. entry 11; hydrogen abstraction *via* 5-endo-process, expansion *via* 5-exo-process; c.f. entry 8; hydrogen atom abstraction *via* 6-endo-process, expansion *via* 6-exo-process) then expansion, if possible, predominates. The competing intramolecular abstraction of an activated hydrogen atom by a 6-endo-type process has precedent elsewhere, e.g. Scheme 9[17].



Scheme 9

In conclusion, we have demonstrated that the ring expansion reactions *via* radical chain processes are in principal effective alternatives to the more classical 2-electron methods, e.g. Grob, Ireland Claisen and others[18].The effective control of alkene geometry from the $C_\alpha$, $C_\beta$ stereochemistry of the starting material, which can provide both *cis*- and *trans*- olefins is an attractive feature of this radically mediated ring expansion process. The scope of this type of reaction, i.e. variations in ring size of initial cyclic ketone, length and substitution of radical side chain, whilst maintaining effective ring expansion, and its application to acyclic systems are current objectives.

Table 1

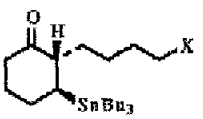
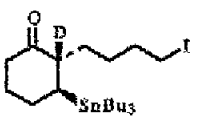
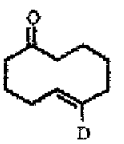
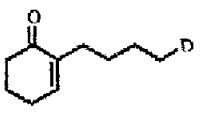
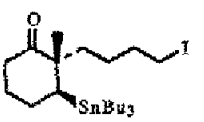
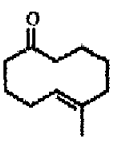
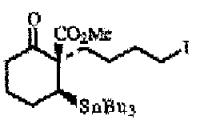
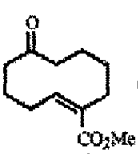
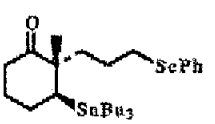
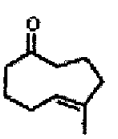
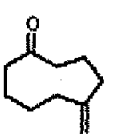
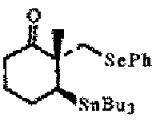
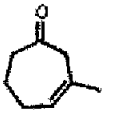
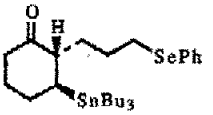
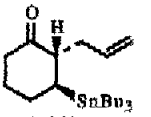
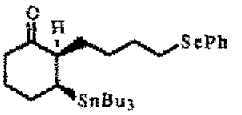
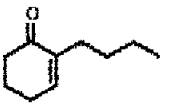
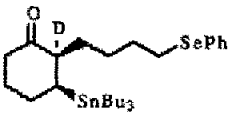
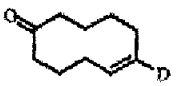
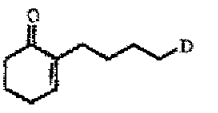
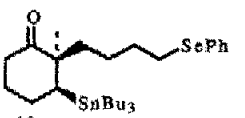
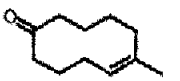
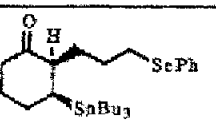
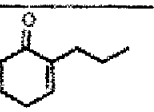
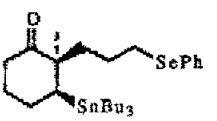
| Entry | Precursor | Product (% isolated) | Ref.[f] |
|---|---|---|---|
| 1. |  6a,b | a) X=I 26(47)[a] 27(36)<br>b) X=SePh 26(42)[a] 27(33) | Lit. 12 |
| 2. |  6c |  28(75)[a] |  29(10) Lit. 12 |
| 3. |  6d |  only<br>30(85)[a] | Lit. 13 |
| 4. |  6e |  only<br>31(72)[b] | - |
| 5. |  6f |  32[c](44)[d] |  33(36)[e] Lit. 14 |

Table 1 (contd.)

| Entry | Precursor | Product (% isolated) | Ref.[f] |
|---|---|---|---|
| 6. |  6g |  34(87)[b] only | Lit. 15 |
| 7. |  6h |  35(≈30) only | - |
| 8. |  10a |  27(86) only | - |
| 9. |  10h |  36(21)[b]  29(58) | Lit. 12 |
| 10[c]. |  10c |  37(89)[d] only | Lit. 13 |
| 11. |  10d |  38(87)[b]  39(4) | Lit. 16 |
| 12. |  10e |  40(87)[b] only | Lit. 14 |

Conditions: Initial; substrate (5mmolar in benzene), AIBN (0.2 mol. equiv.), $Bu_3SnH$ (0.1 mol. equiv.), reflux, 2-72h. Prolonged; add AIBN (0.2 mol. equiv.) every 12-24h.

Footnotes: a: *E*/*Z* isomer ratio greater than 95:5; b: *Z*/*E* isomer ratio greater than 95:5; c: *cis*-/*trans*-precursor ratio *ca.* 90:10; d: *Z*/*E* isomer ratio *ca.* 90:10; e: Ratio after 14h reaction. The exomethylene isomer predominates in prolonged reactions; f: References to ring expanded products.

## EXPERIMENTAL SECTION

Infrared (IR) spectra were obtained using a Perkin-Elmer 681 spectrometer. Nuclear magnetic resonance spectra were obtained using a Varian Gemini 200, a Bruker AM 250, a Bruker WH 300 or a Bruker AM 500 machine and were run in $CDCl_3$. Chemical shifts are quoted in parts per million ($\delta$ p.p.m.) using chloroform as an internal reference. Coupling constants ($J$) are given to the nearest 0.5Hz. Mass spectra were recorded on a V.G. Micromass 16F (ACE - alternative E.I./C.I.), a V.G. Micromass 30F (E.I./C.I.) or a V.G. Micromass ZAB IF (E.I./D.C.I./F.I./F.D.). Microanalyses were performed in the Dyson Perrins Laboratory.

Bulb to bulb distillation refers to distillation at reduced pressure using a horizontal Kugelrohr apparatus, the temperature quoted being that of the heating bath.

All solvents were distilled before use; tetrahydrofuran (THF) was distilled from sodium/benzophenone ketyl, hexamethylphosphoric triamide (HMPA) from calcium hydride. 'Petrol' refers to that fraction of light petroleum boiling between 30-40°C. 6-bromo-1,4-dioxaspiro[4,5]dec-6-ene 19 was prepared by the method of Smith *et al*,[11] 2-methylcyclohexenone 13 was produced by the method of Warnhoff *et al*,[19] and 2-carbomethoxycyclohexenone 14 was produced by the method of Reich *et al*.[20] Other starting materials were used as obtained from commercial sources.

***General procedure for the preparation of the 1-halo-n-phenylselenoalkanes 15-18.*** Sodium borohydride (1.1 equiv.) was added in portions to a stirred solution of diphenyl diselenide (0.5 equiv.) in ethanol (≈2ml/mmol of diphenyl diselenide) at 0°C. The colourless solution was stirred for 0.5h at this temperature then added dropwise to a cooled (0°C), stirred solution of the appropriate 1,n-dihalide (4-20 equiv.) in ethanol (same volume as above). The mixture was stirred overnight at room temperature. The ethanol was removed *in vacuo* then the residue was dissolved in a mixture of equal volumes of 10% aqueous sodium carbonate and ether. The aqueous layer was thoroughly extracted with ether then the combined organic portions were washed with brine, dried (magnesium sulphate) and concentrated *in vacuo* . Further purification was carried out as detailed below.

***Bromo-phenylselenomethane*[21] 15.** The standard procedure was followed using diphenyl diselenide (5.0g, 0.016mol) and dibromomethane (45ml, 0.64mol). The crude product was subjected to bulb to bulb distillation and the bromophenylselenomethane[21] 15 collected (2.60g, 33%; b.p. 130°C/0.02mm Hg) as a pale yellow oil. $\nu_{max.}$ (thin film) 3060 (m), 2960 (w), 1580 (s), 1480 (s), 1440 (s), 1165 (s), 1090 (m), 1070 (m), 1025 (s), 1000 (m), 775 (m), 735 (s), 690 (s), 620 (s); $\delta_H$ (200 MHz) 4.76 (2H, s), 7.27-7.34 (3H, m), 7.50-7.62 (2H, m); *m/z* (E.I.) 252 ($M^+$, $^{80}Se^{81}Br$, 12%), 250 (15), 248 (8), 171 (76), 169 (44), 167 (20), 157 (13), 91 (100), 77 (27), 65 (14), 51 (33). The residue from the distillation consisted of di-(phenylseleno)-methane[21] 16 (3.45g, 66%), also a yellow oil. $\nu_{max.}$ (thin film) 3070 (m), 3000 (m), 2930 (m), 1580 (s), 1475 (s), 1440 (s), 1135 (s), 1070 (s), 1020 (s), 1000 (s), 730 (s), 690 (s); $\delta_H$ (200 MHz) 4.25 (2H, s), 7.32-7.42 (6H, m), 7.58-7.70 (4H, m); *m/z* (E.I.) 328 ($M^+$, $^{80}Se_2$, 22%), 326 (22), 324 (14), 171 (74), 169 (45), 167 (21), 157 (12), 91 (100), 77 (25), 65 (15), 51 (25).

***1-Iodo-3-phenylselenopropane 17*** . The standard procedure with diphenyl diselenide (1.0g, 3.21mmol) and di-iodopropane (3.0ml, 26mmol) gave a crude product containing excess di-iodide which was removed by bulb to bulb distillation (≈80°C/0.02mm Hg). The residue was further purified by flash column chromatography (10:1 petrol: ether) to yield the product 17 as a pale yellow oil (2.04g, 96%). This material contained less than 5% of the diselenide by inspection of the integral ratios in the NMR spectrum. $\nu_{max.}$ (thin film) 3060 (m), 2960 (m), 1575 (s), 1475 (s), 1435 (s), 1280 (m), 1200 (s), 1070 (m), 1020 (s), 1000 (m), 730 (s), 690 (s), 670 (m); $\delta_H$ (200 MHz) 2.08-2.28 (2H, m), 3.01 (2H, t, $J$ 8.0Hz), 3.30 (2H, t, $J$ 6.5Hz), 7.20-7.34 (3H, m), 7.47-7.58 (2H, m); *m/z* (E.I.) 326 ($M^+$, $^{80}Se$, 26%), 324 (14), 296 (33), 199 (43), 197 (24), 169 (100), 157 (28), 155 (17), 127 (23), 91 (26), 77 (20), 65 (5), 51 (13).

***1-Iodo-4-phenylselenobutane 18*** . The standard procedure with diphenyl diselenide (1.0g, 3.21mmol) and di-iodobutane (2.5ml, 19mmol) afforded a crude product which was rendered free of di-iodide by bulb to bulb distillation (≈100°C/0.02mm Hg). The residue was passed through a plug of silica (10:1 petrol: ether eluant) to provide the selenide 18 (1.89g, 87%) as a pale yellow oil. This material was contaminated by ≈25% di-(phenylseleno)-butane. $\nu_{max.}$ (thin film) 3070 (m), 3005 (m), 2940 (m), 1580 (m), 1475 (s), 1440 (s), 1260 (m), 1165 (m), 1075 (m), 1000 (m), 690 (s); $\delta_H$ (200 MHz) 1.74-2.07 (4H, m), 2.92 (2H, t, $J$ 8.0Hz), 3.18 (2H, t, $J$ 7.0Hz), 7.18-7.34 (3H, m), 7.42-7.57 (2H, m); *m/z* (E.I.) 370 ($M^+$, $^{80}Se_2$, diselenide, 5%), 368 (diselenide, 5), 340 ($M^+$, $^{80}Se$, 12), 338 (6), 234 (9), 213 (100), 211 (54), 183 (40), 171 (27), 169 (14), 157 (42), 91 (33), 77 (45), 55 (88).

***General procedure for generation and alkylation of the vinyl anion*[11].** A solution of the bromoketal 19 in dry THF (≈10ml/mmol of 19) was cooled to -78°C under argon. $^{n}$Butyl lithium (1.25 equiv. of a 1.3M solution in hexanes) was added and the resultant mixture stirred for 1h at -78°C. The electrophile was added and the mixture allowed to come up to room temperature overnight. In cases where alkylation was more difficult the mixture was warmed to -23°C and HMPA (5-12 equiv.) was added after addition of the electrophile. The mixture was quenched with saturated ammonium chloride solution and the aqueous layer extracted thoroughly with ether. The organic layer was then washed with brine, dried (sodium sulphate) and concentrated *in vacuo* to yield the crude alkylated ketals. Flash column chromatography (10:1-15:1 petrol: ether) afforded the pure compounds as colourless oils.

***6-Deutero-1,4-dioxaspiro[4,5]dec-6-ene* 20.** The anion derived from the bromoketal 19 (2.0g, 9.13mmol) was quenched with deuterium oxide (1ml, ≈55mmol) at -78°C then allowed to warm up to room temperature over 1h. The work-up described in the general procedure afforded spectroscopically pure 20 (1.12g, 87%). $\nu_{max.}$ (thin film) 3020 (m), 2940 (s), 2880 (s), 2840 (m), 1640 (m), 1455 (m), 1440 (m), 1365 (m), 1260 (m), 1175 (s), 1115 (s), 1075 (s), 1030 (s), 945 (s), 890 (m), 840 (m); $\delta_H$(200 MHz) 1.71-1.86 (4H, m), 1.96-2.12 (2H, m), 3.92-4.05 (4H, m), 5.92-6.03 (1H, m); *m/z* (E.I.) 141 ($M^+$, 21%), 113 (100), 69 (44), 55 (14).

***6-(4-Iodobutyl)-1,4-dioxaspiro[4,5]dec-6-ene* 21.** The anion derived from the bromoketal 19 (500mg, 2.28mmol) was quenched with di-iodobutane (0.9ml, 6.82mmol) and allowed up to room temperature over 14h. The usual work-up and flash column chromatography (10:1 petrol: ether) gave pure 21 (724mg, 99%). $\nu_{max.}$ (thin film) 2940 (s), 2880 (s), 2840 (m), 1675 (w), 1455 (m), 1440 (m), 1210 (m), 1175 (s), 1115 (s), 1070 (s), 1025 (s), 945 (s); $\delta_H$(200 MHz) 1.45-1.66 (4H, m), 1.75-1.92 (4H, m), 1.96-2.13 (4H, m), 3.19 (2H, t, *J* 8.0Hz), 3.99 (4H, s), 5.70 (1H, brs); *m/z* (ACE, $NH_3$) 323 ($MH^+$, 100%), 294 (45), 267 (10), 195 (9), 167 (28), 151 (9), 125 (22), 99 (37).

***6-(3-Phenylselenopropyl)-1,4-dioxaspiro[4,5]dec-6-ene* 22.** The anion derived from the bromoketal 19 (300mg, 1.37mmol) was quenched with 1-iodo-3-phenylselenopropane 17 (490mg, 1.51mmol) and allowed to warm up to room temperature over 14h. Work-up and flash column chromatography (15:1 petrol: ether) gave pure 22 (320mg, 69%). (Found: C, 60.26; H, 6.20. $C_{17}H_{22}O_2Se$ requires C, 60.53; H, 6.57%); $\nu_{max.}$ (thin film) 3060 (m), 2950 (s), 2920 (s), 2875 (s), 1670 (s), 1580 (s), 1475 (s), 1435 (s), 1380 (m), 1170 (s), 1110 (s), 1070 (s), 1020 (s), 940 (s), 735 (s), 690 (s); $\delta_H$ (250 MHz) 1.69-1.80 (4H, m), 1.82-2.03 (2H, m), 2.12-2.23 (4H, m), 2.98 (2H, t, *J* 6.5Hz), 4.02 (4H, s), 5.69-5.75 (1H, m), 7.23-7.33 (3H, m), 7.47-7.58 (2H, m); *m/z* (ACE, $NH_3$) 339 ($MH^+$, $^{80}$Se, 41%), 337 (22), 295 (45), 293 (24), 267 (65), 221 (94), 219 (100), 137 (35), 99 (26).

***6-(4-Phenylselenobutyl)-1,4-dioxaspiro[4,5]dec-6-ene* 23.** Sodium borohydride (68mg, 1.70mmol) was added in portions to a solution of diphenyl diselenide (266mg, 0.85mmol) in ethanol (20ml) cooled to 0°C. The colourless solution was stirred for 0.5h at 0°C then a solution of the iodide 21 (500mg, 1.55mmol) in ethanol (2ml) was added rapidly. The solution was warmed to room temperature and stirred for 2h. Most of the solvent was removed *in vacuo* then the mixture was partitioned between 1:1 petrol: ether and aqueous sodium carbonate (10%). The organic layer was washed with brine then dried (sodium sulphate) and concentrated *in vacuo*. The crude product was purified by flash column chromatography (15:1 petrol: ether) to give the pure selenide 23 as a colourless oil (520mg, 96%). (Found: C, 61.34; H, 7.02. $C_{18}H_{24}O_2Se$ requires C, 61.53; H, 6.88%); $\nu_{max.}$ (thin film) 3060 (w), 2940 (m), 2880 (m), 1580 (m), 1480 (m), 1435 (m), 1170 (m), 1115 (m), 1020 (m), 945 (m); $\delta_H$ (250 MHz) 1.45-1.64 (2H, m), 1.66-1.78 (6H, m), 1.98-2.08 (4H, m), 2.93 (2H, t, *J* 7.5Hz), 3.99 (4H, s), 5.65-5.70 (1H, m), 7.21-7.29 (3H, m), 7.45-7.52 (2H, m); *m/z* (C.I., $NH_3$) 353 ($MH^+$, $^{80}$Se, 100%), 351 (66), 307 (18), 305 (9), 99 (12).

***General procedure for the hydrolysis of the alkylated ketals* 20-23.** A solution of oxalic acid (3.2 equiv.) in water (10ml/mmol of ketal) was added to a stirred solution of the ketal in dichloromethane (10ml/mmol) at room temperature. The mixture was stirred as rapidly as possible until the hydrolysis was found to be complete by t.l.c. analysis (2-14h). The aqueous layer was extracted with ether and the extracts combined with the organic layer. The combined extracts were washed with saturated sodium hydrogen carbonate solution, brine then dried (magnesium sulphate) and concentrated *in vacuo*. The ketones thus obtained required no further purification except for purposes of characterisation in which case small samples were subjected to p.l.c.

***2-Deuterocyclohex-2-enone* 12.** Hydrolysis of the ketal 20 (1.12g, 7.94mmol) gave the pure ketone 12 (728mg, 95%) as a colourless, volatile oil. $\nu_{max.}$ (thin film) 3030 (w), 2940 (m), 2870 (m),

1680 (s), 1605 (m), 1430 (m), 1360 (m), 1235 (m), 1170 (m), 1135 (m), 970 (m), 750 (m), 705 (m), 670 (m); $\delta_H$ (200 MHz) 1.92-2.09 (2H, m), 2.26-2.46 (4H, m), 6.96-7.03 (1H, m); *m/z* (E.I.) 97 ($M^+$, 25%), 69 (100), 55 (14).

***2-(3-Phenylselenopropyl)-cyclohex-2-enone*** 24 . Hydrolysis of the ketal 22 (180mg, 0.53mmol) afforded the ketone 24 (153mg, 98%) as a colourless oil. (Found: C, 61.45; H, 6.27. $C_{15}H_{18}OSe$ requires C, 61.43; H, 6.19%); $\nu_{max.}$ (thin film) 3060 (m), 2930 (s), 2860 (m), 1670 (s), 1580 (m), 1480 (m), 1435 (m), 1375 (m), 1170 (m), 1025 (m), 905 (m), 735 (s), 690 (s); $\delta_H$ (250 MHz) 1.65-1.71 (2H, m), 1.82-1.96 (2H, m), 2.15-2.20 (4H, m), 2.32 (2H, t, *J* 6.5Hz), 2.82 (2H, t, *J* 6.5Hz), 6.63 (1H, t, *J* 4.0Hz), 7.12-7.23 (3H, m), 7.35-7.44 (2H, m); *m/z* (E.I.) 294 ($M^+$, $^{80}Se$, 12%), 292 (7), 157 (9), 137 (100), 95 (9), 91 (10), 81 (12), 79 (13), 77 (14), 67 (17).

***2-(4-Phenylselenobutyl)-cyclohex-2-enone*** 25. Hydrolysis of the ketal 23 (500mg, 1.42mmol) afforded the ketone 25 (468mg, 100%) as a colourless oil. (Found: C, 62.48; H, 6.71. $C_{16}H_{20}OSe$ requires C, 62.54; H, 6.56%); $\nu_{max.}$ (thin film) 3060 (m), 2930 (s), 2860 (m), 1670 (s), 1580 (m), 1480 (m), 1435 (m), 1380 (m), 1175 (m), 1020 (m), 910 (m), 735 (s), 690 (m); $\delta_H$ (250 MHz) 1.43-1.58 (2H, m), 1.63-1.77 (2H, m), 1.92-2.03 (2H, m), 2.18 (2H, t, *J* 7.5Hz), 2.28-2.36 (2H, m), 2.40 (2H, t, *J* 8.0Hz), 2.91 (2H, t, *J* 8.0Hz), 6.68 (1H, t, *J* 4.0Hz), 7.21-7.30 (3H, m), 7.44-7.53 (2H, m); *m/z* (C.I., $NH_3$) 326 ($MNH_4^+$, $^{80}Se$, 40%), 324 (20), 309 ($MH^+$, $^{80}Se$, 100), 307 (50), 305 (20), 151 (61).

***General procedure for the preparation of the trans- substrates 6a-h.*** To a stirred solution of di-isopropylamine (1.5 equiv.) in anhydrous THF (≈2ml/mmol of enone) at 0°C under argon was added $^n$butyl lithium (1.05 equiv. of a 1.60M solution in hexanes). The mixture was stirred for 20min at this temperature then tributyltin hydride (1.0 equiv.) was added and the mixture stirred for a further 20min. The yellow solution was cooled to -78°C whereupon the relevant enone (11-14) was added dropwise as a solution in THF (≈0.5ml/mmol). The mixture was stirred at this temperature until no starting enone remained by t.l.c. analysis (10-30min) then warmed to -23°C. HMPA (12 equiv.) was added and the resulting mixture stirred for 10min. The alkylating agent was added dropwise and the mixture kept at -23°C for a further 4h before being allowed to warm up to room temperature overnight. The mixture was quenched with saturated ammonium chloride solution and the aqueous layer extracted with ether (x5). The combined organic portions were washed with brine then dried (magnesium sulphate), filtered and concentrated *in vacuo* . The crude products were subjected to flash column chromatography (20:1 petrol: ether then gradient elution to 5:1 petrol: ether). Material obtained in this way contained trace amounts of closely running impurities; absolute purity, for the purposes of characterisation, was obtained by p.l.c.

***trans-2-(4-Iodobutyl)-3-tributylstannylcyclohexanone*** 6a . The above procedure produced the pure stannane 6a (1.61g, 55%) as a colourless oil from cyclohex-2-enone 11 (500 mg, 5.21mmol) and di-iodobutane (2.75ml, 21mmol). (Found: C, 46.61; H, 8.00. $C_{22}H_{43}IOSn$ requires C, 46.43; H, 7.61%); $\nu_{max.}$ (thin film) 2960 (s), 2930 (s), 2860 (s), 1710 (s), 1470-1410 (m), 1380 (m), 1170 (m), 1075 (m), 875 (m); $\delta_H$ (200 MHz) 0.70-1.05 (15H, m), 1.08-2.22 (23H, m), 2.29-2.49 (3H, m), 3.17 (2H, t, *J* 7.5Hz); $\delta_C$ (50.3 MHz, DEPT) CH: 34.31, 54.53, $CH_2$: 16.54, 19.10, 27.56, 28.97(3), 30.47, 32.61, 33.89, 42.99, $CH_3$: 13.68; *m/z* (D.C.I., $NH_3$) 571 ($MH^+$, $^{120}Sn$, 16%), 569 (16), 513 (25), 511 (20), 509 (11), 385 (20), 378 (16), 361 (23), 308 (100), 306 (77), 304 (49), 291 (44), 289 (34), 287 (22), 153 (59), 135 (49), 81 (16), 67 (16), 55 (21).

***trans-2-(4-Phenylselenobutyl)-3-tributylstannylcyclohexanone*** 6b . From cyclohex-2-enone 11 (75mg, 0.78mmol) and 1-iodo-4-phenylselenobutane 18 (290mg, 0.85mmol) the stannane 6b was produced as a colourless oil (255mg, 54%). (Found: C, 56.20; H, 8.17. $C_{28}H_{48}OSeSn$ requires C, 56.21; H, 8.09%); $\nu_{max.}$ (thin film) 3060 (w), 2960 (s), 2920 (s), 2850 (s), 1710 (s), 1580 (w), 1480-1400 (m), 1225 (m), 1075 (m), 1020 (m), 965 (m), 735 (m), 690 (m), 670-640 (w); $\delta_H$ (200 MHz) 0.78-1.05 (15H, m), 1.18-2.03 (22H, m), 2.10-2.23 (1H, m), 2.30-2.53 (3H, m), 2.89 (2H, t, *J* 8.0Hz), 7.20-7.30 (3H, m), 7.42-7.53 (2H, m); *m/z* (F.D.) Calc. see 6f; Found. 600 ($M^+$, $^{80}Se^{120}Sn$, 100%), 599 (58), 598 (85), 597 (62), 596 (77), 595 (27), 594 (35).

***trans-2-Deutero-2-(4-iodobutyl)-3-tributylstannylcyclohexanone*** 6c. From 2-deuterocyclohex-2-enone 12 (500mg, 5.15mmol) and di-iodobutane (2.75ml, 21mmol) the stannane 6c was obtained as a colourless oil (1.39g, 48%). (Found: C, 46.21; H(D), 8.06. $C_{22}H_{42}DIOSn$ requires C, 46.34; H(D), 7.60%); $\nu_{max.}$ (thin film) 2960 (s), 2920 (s), 2860 (s), 1705 (s), 1475-1410 (m), 1375 (m), 1250 (m), 1170 (m), 1075 (m), 870 (m); $\delta_H$ (200 MHz) 0.70-1.05 (15H, m), 1.09-2.24 (23H, m), 2.33-2.45 (2H, m), 3.20 (2H, t, *J* 8.0Hz); *m/z* (F.I.) 571 ($M^+$, $^{120}Sn$, 71%), 569 (51), 567 (45), 514 (set to 100), 512 (51), 510 (35).

***trans*-2-(4-Iodobutyl)-2-methyl-3-tributylstannylcyclohexanone** **6d**. From 2-methylcyclohex-2-enone 13 (500mg, 4.55mmol) and di-iodobutane (2.75ml, 21mmol) was obtained the pure stannane 6d as a colourless oil (1.60g, 60%). (Found: C, 47.09; H, 8.20. $C_{23}H_{45}IOSn$ requires C, 47.37; H, 7.78%); $\nu_{max.}$ (thin film) 2960 (s), 2920 (s), 2860 (s), 1705 (s), 1480-1410 (m), 1380 (m), 1075 (w), 870 (w); $\delta_H$ (200 MHz) 0.82-0.97 (15H, m), 1.13 (3H, s), 1.22-1.68 (16H, m), 1.72-2.05 (7H, m), 2.25-2.51 (2H, m), 3.19 (2H, td, *J* 8.0, 3.0Hz); *m/z* (D.C.I., $NH_3$) 602 ($MNH_4^+$, $^{120}Sn$, 50%), 600 (39), 598 (22), 457 (34), 455 (28), 453 (14), 308 (66), 306 (50), 304 (24), 184 (52), 167 (27), 149 (100).

***trans*-2-Carbomethoxy-2-(4-iodobutyl)-3-tributylstannylcyclohexanone** **6e**. Using 2-carbomethoxycyclohex-2-enone 14 (500mg, 3.25mmol) and di-iodobutane (1.29ml, 9.78mmol), this reaction required a longer reaction time than the others (24h) in order to obtain acceptable yields of alkylated material. Even so, flash column chromatography (20:1-5:1 petrol: ether) afforded material which was contaminated with a closely running impurity (possibly the *cis*- compound) which had to be removed on a second column (20:1 petrol: ether). This yielded the pure stannane 6e (35-40% yield) as a colourless oil. (Found: C, 45.68; H, 7.36. $C_{24}H_{45}IO_3Sn$ requires C, 45.96; H, 7.23%); $\nu_{max.}$ (thin film) 2960 (s), 2920 (s), 2860 (s), 1730 (m), 1710 (s), 1470-1410 (m), 1375 (m), 1280-1130 (m), 1080 (m); $\delta_H$ (200 MHz) 0.74-0.99 (15H, m), 1.12-1.59 (16H, m), 1.64-1.88 (6H, m), 2.04-2.18 (1H, m), 2.34-2.55 (2H, m), 3.17 (2H, td, *J* 8.0, 4.0Hz), 3.72 (3H, s); $\delta_C$ (50.3 MHz) 9.77, 10.91, 13.75, 26.53, 26.99, 27.95, 28.92, 29.66, 30.51, 31.36, 34.49, 42.56, 53.07, 64.15, 174.77, 208.69 ($^3J$ ($^{119}Sn$-$^{13}C$) 38Hz); *m/z* (F.I.) 628 ($M^+$, $^{120}Sn$, 85%), 626 (74), 624 (44), 571 (set to 100), 569 (79), 567 (55).

***trans*-2-Methyl-2-(3-phenylselenopropyl)-3-tributylstannylcyclohexanone** **6f**. The usual procedure produced pure 6f (270mg, 50%) as a colourless oil from 2-methylcyclohex-2-enone 13 (250mg, 2.27mmol) and 1-iodo-3-phenylselenopropane 17 (810mg, 2.48mmol). (Found: C, 56.10; H, 8.30. $C_{28}H_{48}OSeSn$ requires C, 56.21; H, 8.09%); $\nu_{max.}$ (thin film) 3080 (w), 2960 (s), 2930 (s), 2860 (s), 1705 (s), 1580 (m), 1480-1410 (m), 1375 (m), 1245 (w), 1070 (m), 1025 (m), 735 (s), 690 (s); $\delta_H$ (200 MHz) 0.76-0.97 (15H, m), 1.05 (3H, s), 1.18-2.04 (21H, m), 2.24-2.43 (2H, m), 2.88 (2H, t, *J* 8.0Hz), 7.14-7.28 (3H, m), 7.39-7.51 (2H, m); $\delta_C$ (50.3 MHz) 9.81, 13.63, 17.45, 24.46, 25.10, 25.73, 27.64, 29.55, 30.51, 38.15, 39.11, 39.30, 52.10, 127.01, 129.24, 131.02, 132.74, 215.61 ($^3J$ ($^{119}Sn$-$^{13}C$) 32Hz); *m/z* (F.I.) Calc. 600 ($M^+$, $^{80}Se^{120}Sn$, 91%), 599 (51), 598 (100), 597 (56), 596 (74), 595 (28), 594 (31); Found. 600 ($M^+$, $^{80}Se^{120}Sn$, 93), 599 (67), 598 (100), 597 (66), 596 (60), 595 (20), 594 (40).

***trans*-2-Methyl-2-(phenylselenomethyl)-3-tributylstannylcyclohexanone** **6g**. Obtained from 2-methylcyclohex-2-enone 13 (110mg, 1.0mmol) and bromophenylselenomethane 15 (280mg, 1.12mmol) as a colourless oil (288mg, 50%) after flash column chromatography (20:1-15:1 petrol: ether). (Found: C, 54.88; H, 7.57. $C_{26}H_{44}OSeSn$ requires C, 54.77; H, 7.78%); $\nu_{max.}$ (thin film) 3060 (w), 2960 (s), 2930 (s), 2860 (s), 1705 (s), 1580 (m), 1480-1410 (s), 1375 (m), 1070 (m), 1025 (m), 875 (m), 740 (s), 690 (s), 670 (m); $\delta_H$ (200 MHz) 0.74-0.99 (15H, m), 1.20-1.64 and 1.74-2.16 (17H, m), 1.28 (3H, s), 2.26-2.58 (2H, m), 2.98 and 3.11 (2H, ABq, *J* 12Hz), 7.17-7.34 (3H, m), 7.49-7.60 (2H, m); *m/z* (E.I.) Calc. for $M^+$-$^n$Bu· 515 ($^{80}Se^{120}Sn$, 91%), 514 (46), 513 (100), 512 (53), 511 (75), 510 (27), 509 (31); Found. 515 (89), 514 (46), 513 (100), 512 (54), 511 (78), 510 (29), 509 (32) [and 389 (46), 345 (75), 291 (95), 235 (65), 177 (76), 77 (57), 67 (47), 55 (89)].

***trans*-2-(3-Phenylselenopropyl)-3-tributylstannylcyclohexanone** **6h**. The usual procedure with cyclohex-2-enone 11 (150mg, 1.56mmol) and 1-iodo-3-phenylselenopropane 17 (560mg, 1.72mmol) produced pure 6h (496mg, 56%) as a colourless oil. (Found: C, 55.84; H, 8.30. $C_{27}H_{46}OSeSn$ requires C, 55.50; H, 7.93 %); $\nu_{max.}$ (thin film) 3070 (w), 2960 (s), 2920 (s), 2860 (s), 1705 (s), 1580 (m), 1470-1410 (m), 1375 (m), 1245 (m), 1075 (m), 1025 (m), 735 (m), 690 (s); $\delta_H$ (200 MHz) 0.82-0.97 (15H, m), 1.20-2.03 (20H, m), 2.10-2.18 (1H, m), 2.29-2.47 (3H, m), 2.81-2.99 (2H, m), 7.18-7.32 (3H, m), 7.41-7.53 (2H, m); $\delta_C$ (50.3 MHz) 9.46, 14.02, 27.50, 28.03, 28.46, 29.09, 30.31, 31.58, 32.79. 34.22, 42.58, 54.11, 126.42, 128.80, 130.38, 132.23, 213.16 ($^3J$ ($^{119}Sn$-$^{13}C$) 45Hz); *m/z* (F.D.) Calc. 586 (91%), 584 ($M^+$,100), 582 (74) and 529 ( $M^+$-$^n$Bu·,91), 527 (100), 525 (75); Found. 584 (14), 580 (11), 529 ($M^+$-$^n$Bu·, $^{80}Se^{120}Sn$, 74), 527 (set to 100), 526 (57), 525 (74).

***General procedure for the preparation of the cis- substrates 10a-e*** . Tributyl stannyl lithium (1.0 equiv.) was produced at 0°C as previously described. The solution was cooled to -78°C and the 2-substituted enone (24 or 25) was added as a solution in THF (≈0.5ml/mmol). The mixture was warmed to -23°C and HMPA (12.0 equiv.) was added. Stirring was continued at -23°C until 1,4-addition

was judged to be complete by t.l.c. analysis (up to 2h). The electrophile (water, deuterium oxide or methyl iodide) was added at -23°C, the mixture warmed up to room temperature over 1h (electrophile=water, deuterium oxide) or 14h (electrophile=methyl iodide), then quenched with saturated ammonium chloride solution. The same extractive work-up described above was used to furnish the crude alkylated compounds. The compounds were rendered pure by flash column chromatography.

***cis*-2-(4-Phenylselenobutyl)-3-tributylstannylcyclohexanone** **10a**. Obtained as a colourless oil (85mg, 51%) from enone **25** (100mg, 0.33mmol) and water (1.0ml, 55.6mmol) after flash column chromatography (15:1-5:1 petrol: ether). (Found: C, 56.30; H, 8.38. $C_{28}H_{48}OSeSn$ requires C, 56.21; H, 8.09%); $\nu_{max.}$ (thin film) 3060 (w), 2950 (s), 2920 (s), 2860 (s), 1702 (s), 1580 (m), 1480-1410 (m), 1375 (m), 1250 (m), 1145 (m), 1075 (m), 1020 (m), 735 (m), 690 (s), 670 (w); $\delta_H$ (200 MHz) 0.75-0.97 (15H, m), 1.16-1.96 (22H, m), 2.03-2.32 (2H, m), 2.41-2.50 (2H, m), 2.87 (2H, t, *J* 7.0Hz), 7.22-7.30 (3H, m), 7.42-7.55 (2H, m); *m/z* (C.I., $NH_3$) 618 ($MNH_4^+$, $^{80}Se^{120}Sn$, 29%), 617 (22), 616 (28), 615 (34), 614 (31), 601 (71), 600 (51), 599 (theoretical $MH^+$, 100), 598 (55), 597 (86), 596 (55), 595 (49).

***cis*-2-Deutero-2-(4-phenylselenobutyl)-3-tributylstannylcyclohexanone** **10b**. Following the usual method the pure deuterated compound **10b** was obtained as a colourless oil (75mg, 62% based on recovered starting enone, 38mg) from the enone **25** (100mg, 0.33mmol) and deuterium oxide (1.0ml, 55.4mmol). (Found: C, 55.87; H(D), 8.12. $C_{28}H_{47}DOSeSn$ requires C, 56.11; H(D), 8.07%); $\nu_{max.}$ (thin film) 3070 (w), 2960 (s), 2920 (s), 2860 (s), 1705 (s), 1580 (m), 1480-1410 (m), 1375 (m), 1335 (m), 1075 (m), 1025 (m), 735 (s), 690 (s), 670 (m); $\delta_H$ (200 MHz) 0.67-0.97 (15H, m), 1.05-1.55 (15H, m), 1.57-2.04 (8H, m), 2.06-2.51 (2H, m), 2.88 (2H, t, *J* 7.0Hz), 7.20-7.33 (3H, m), 7.42-7.53 (2H, m); *m/z* (F.D.) Calc. base peak for $d_1$=599; Found. 602 (70%), 601 (87), 600 (70), 599 (set to 100), 598 (83), 597 (61).

***cis*-2-Methyl-2-(4-phenylselenobutyl)-3-tributylstannylcyclohexanone** **10c**. The standard procedure was followed and the stannane obtained as a colourless oil (120mg, 60%) from enone **25** (100mg, 0.33mmol) and methyl iodide (0.11ml, 1.77mmol). (Found: C, 56.52; H, 8.61. $C_{29}H_{50}OSeSn$ requires C, 56.88; H, 8.23%); $\nu_{max.}$ (thin film) 3070 (w), 2960 (s), 2925 (s), 2855 (s), 1702 (s), 1580 (m), 1480-1420 (m), 1375 (m), 1075 (m), 1025 (m), 910 (m), 735 (s), 690 (m), 670-650 (w); $\delta_H$ (500 MHz) 0.76-0.93 (15H, m), 1.00 (3H, s), 1.08 ($CH_3$- group in *trans*- isomer; integrates as ≈10% of $CH_3$- group in *cis*- compound), 1.28-1.36 (8H, m), 1.41-1.53 (8H, m), 1.66-1.76 (4H, m), 1.84-2.04 (2H, m), 2.08-2.15 (1H, m), 2.37-2.47 (1H, m), 2.50 (1H, dt, *J* 9.0, 5.5Hz), 2.89 (2H, "q", *J* 7.5Hz), 7.20-7.32 (3H, m), 7.41-7.56 (2H, m); $\delta_C$ (50.3 MHz) 9.28, 10.26, 13.70, 22.87, 24.01, 27.16, 29.17, 30.03, 30.49, 31.17, 37.77, 42.87, 52.61, 54.90, 126.88, 128.88, 130.32, 132.61, 216.62 ($^3J(^{119}Sn\text{-}^{13}C)$ 29Hz); *m/z* (F.D.) 616 (63%), 615 (43), 614 ($M^+$, $^{80}Se^{120}Sn$, 93), 613 (46), 612 (100), 611 (45), 610 (55).

***cis*-2-(3-Phenylselenopropyl)-3-tributylstannylcyclohexanone** **10d**. Use of the above protocol with enone **24** (100mg, 0.34mmol) and water (1.0ml, 55.6mmol) afforded the pure material as a colourless oil (120mg, 60%). (Found: C, 55.83; H, 8.40. $C_{27}H_{46}OSeSn$ requires C, 55.50; H, 7.93%); $\nu_{max.}$ (thin film) 3070 (w), 2960 (s), 2920 (s), 2860 (s), 1710 (s), 1580 (m), 1480-1410 (m), 1375 (m), 1075 (m), 1020 (m), 735 (s), 690 (s), 665 (m); $\delta_H$ (200 MHz) 0.76-0.97 (15H, m), 1.17-1.71 (16H, m), 1.76-2.07 (5H, m), 2.13-2.32 (1H, m), 2.33-2.58 (2H, m), 2.89 (2H, t, *J* 8.0Hz), 7.21-7.30 (3H, m), 7.44-7.53 (2H, m); $\delta_C$ (50.3 MHz) 9.31, 13.64, 26.76, 27.51, 27.80, 28.38, 29.42, 30.98, 31.56, 33.01, 40.29, 54.62, 126.94, 129.08, 130.40, 132.72, 214.28 ($^3J(^{119}Sn\text{-}^{13}C)$ 29Hz); *m/z* (ACE, $NH_3$) 587 ($MH^+$, $^{80}Se^{120}Sn$, 40%), 585 (46), 584 (27), 583 (35), 527 (27), 308 (100), 295 (72), 279 (61), 137 (67).

***cis*-2-Methyl-2-(3-phenylselenopropyl)-3-tributylstannylcyclohexanone** **10e**. Obtained as a colourless oil (150mg, 74%) from enone **24** (100mg, 0.34mmol) and methyl iodide (0.11ml, 1.77mmol) after flash column chromatography (20:1 petrol: ether). (Found: C, 56.19; H, 8.29. $C_{28}H_{48}OSeSn$ requires C, 56.21; H, 8.09%); $\nu_{max.}$ (thin film) 3060 (w), 2970 (s), 2920 (s), 2850 (s), 1700 (s), 1580 (m), 1490-1410 (m), 1375 (m), 1230 (m), 1150 (m), 1075 (m), 1020 (m), 735 (s), 690 (s), 670 (m); $\delta_H$ (200 MHz) 0.82-1.04 (15H, m), 0.96 (3H, s), 1.16-2.55 (23H, m), 2.87 (2H, t, *J* 6.5Hz), 7.19-7.30 (3H, m), 7.41-7.51 (2H, m); *m/z* (E.I.) 541 ($M^+$-$^n$Bu·, $^{78}Se^{120}Sn$, 7%), 291 (30), 269 (100), 235 (22), 213 (56), 177 (34), 153 (26), 121 (12), 91 (12), 77 (19), 57 (53).

***General procedure for the ring expansion reaction.*** The tin containing substrate (**6a-h** and **10a-e**) was dissolved in sodium dried benzene (200ml/mmol) and the solution degassed with argon. Azobisisobutyronitrile (AIBN, 0.2 equiv.) and tributyltin hydride (0.1 equiv.) were added and the mixture

heated at reflux under a nitrogen atmosphere. The reaction was monitored by t.l.c. and refluxing continued until the starting material was consumed, more AIBN and tributyltin hydride being added every 12h in slow reactions. The mixture was cooled to room temperature and the benzene removed *in vacuo* as its azeotrope with carbon tetrachloride. The crude product was subjected to flash column chromatography (≈10:1 petrol: ether). At this stage the product was contaminated with small amounts of tin containing residues, these were removed either by p.l.c. or bulb to bulb distillation depending on the scale of the reaction. The pure products were all volatile oils with characteristic odours.

***Ring expansion reaction of 6a*** . The reaction was complete after 2h at reflux (1.32mmol scale). Flash column chromatography (8:1 petrol: ether and again with 20:1 petrol: ether) gave tin-free material consisting of an inseparable mixture of *E-cyclodec-5-enone*[12] 26 (47%) and *2-butylcyclohex-2-enone*[22] 27 (36%). For 26 and 27 $\nu_{max.}$ (thin film) 3030 (w), 2930 (s), 2860 (m), 1710 (s), 1675 (s), 1440 (m), 1170 (m), 990 (m); for 26 $\delta_H$ (500 MHz) 1.64 (2H, brm), 1.77 (2H, brm), 1.93 (2H, brm), 2.23 (4H, brm), 2.39 (2H, brm), 2.51 (2H, brm), 5.15 (1H, dt, *J* 15Hz, 7.5Hz), 5.34 (1H, dt, *J* 15Hz, 7.5Hz), irradiation at 1.93 caused partial collapse of the multiplet at 5.15 whilst that at 5.34 collapsed to a doublet, *J* 15Hz; for 27 $\delta_H$ (500 MHz) 0.90 (3H, t, *J* 7.5Hz), 1.26-1.39 (4H, m), 1.97 (2H, quintet, *J* 7.5Hz), 2.19 (2H, td, *J* 8.5, 1.5Hz), 2.32-2.36 (2H, m), 2.41-2.45 (2H, m), 6.71 (1H, t, *J* 5.0Hz); for 26 and 27 *m/z* (ACE, E.I.) 152 ($M^+$, 79%), 137 (31), 134 (57), 123 (77), 119 (26), 109 (70), 95 (74), 91 (31), 81 (81), 79 (63), 67 (100), 55 (76), 53 (86).

***Ring expansion reaction of 6b***. This reaction was complete after 24h (0.1mmol scale). The product composition was effectively the same as that obtained from the iodide 6a . The ring expanded product 26 was produced in 42% yield and the reduced material 27 in 33% yield. Data as given above.

***Ring expansion reaction of 6c***. This was complete after 24h at reflux (1.31 mmol scale). Successive flash column chromatography with 15:1 then 20:1 petrol: ether gave clean product consisting of an inseparable mixture of *E-6-deuterocyclodec-5-enone*[12] 28 (75%) and *2-(4-deuterobutyl)-cyclohex-2-enone* 29 (10%). For 28 and 29 $\nu_{max.}$ (thin film) 3020 (w), 2930 (s), 2850 (m), 1710 (s), 1675 (m), 1440 (m), 1360 (m), 1170 (m), 1120 (m), 1100 (m), 905 (m), 850 (m), 760 (w); for 28 $\delta_H$ (200 MHz) 1.54-2.07 (6H, m), 2.10-2.32 (4H, m), 2.33-2.58 (4H, m), 5.08-5.21 (1H, m); for 29 $\delta_H$ (200 MHz) 0.81-0.96 (2H, m), 1.22-1.43 (4H, m), 1.91-2.05 (2H, m), 2.11-2.25 (2H, m), 2.28-2.45 (4H, m), 6.70 (1H, t, *J* 4.5Hz); $\delta_D$ (38.4 MHz) 0.82 (1D, s), 5.32 (8D, s); $\delta_C$ (50.3 MHz, DEPT) for 28 CD: 130.83, CO: 213.06, CH: 134.41, $CH_2$: 22.12, 27.94, 28.73, 32.96, 34.02, 42.80, 45.45; for 29 only see CH: 145.03, $CH_2$: 22.28, 23.17, 25.98, 29.26, 30.71, 38.52; *m/z* (E.I) 153 ($M^+$, 47%), 135 (79), 124 (21), 120 (15), 110 (31), 96 (43), 93 (36), 84 (61), 81 (83), 68 (92), 55 (100).

***Ring expansion reaction of 6d*** . This reaction required heating at reflux for 40h (1.71mmol scale). The crude material was subjected to flash column chromatography (20:1 petrol: ether) then bulb to bulb distillation (120-130°C/14mm Hg). *E-6-Methylcyclodec-5-enone*[13] 30 was obtained as a fragrant, colourless oil (85%). $\nu_{max}$ (thin film) 3060 (w), 2950 (s), 2930 (s), 2860 (s), 1705 (s), 1625 (m), 1480-1400 (m), 1390-1320 (m), 1170 (m), 1100 (m), 965 (w), 880 (w), 815 (w), 765 (w), 735 (w); $\delta_H$ (200 MHz) 1.51-2.50 (2H, m), 1.71 (3H, s), 1.74-1.91 (2H, m), 1.97-2.20 (8H, m), 2.33-2.45 (2H, m), 4.91-5.03 (1H, m); $\delta_C$ (50.3 MHz) 16.07, 22.42, 25.44, 28.46(2), 40.12, 42.42, 43.32, 129.37, 134.68, 212.99; *m/z* (ACE, E.I.) 166 ($M^+$, 25%), 148 (45), 137 (81), 133 (46), 124 (100), 119 (36), 109 (92), 105 (37), 95 (76), 93 (82), 91 (94), 81 (74), 79 (85), 67 (96), 55 (87).

***Ring expansion reaction of 6e*** . This reaction was complete after 50h at reflux (0.40mmol scale). Flash column chromatography (20:1 petrol: ether) then p.l.c. (5:1 petrol: ether) afforded pure *Z-6-carbomethoxycyclodec-5-enone* 31 as a colourless oil (72%). (Found: C, 68.71; H, 8.71. $C_{12}H_{18}O_3$ requires C, 68.55; H, 8.63%); $\nu_{max.}$ (thin film) 2990 (m), 2930 (s), 2860 (m), 1680-1750 (s), 1645 (w), 1440 (s), 1380 (m), 1235 (s), 1195 (s), 1165 (m), 1125 (m), 1095 (s), 1020 (m), 815 (m), 785 (m); $\delta_H$ (200 MHz) 1.54-1.68 (2H, m), 1.71-1.88 (2H, m), 2.04-2.20 (2H, m), 2.25-2.38 (4H, m), 2.40-2.54 (4H, m), 3.81 (3H, s), 5.59 (1H, t, *J* 9.0Hz); *m/z* (ACE, $NH_3$) 228 ($MNH_4^+$, 45%), 211 ($MH^+$, 100), 193 (70), 179 (12), 135 (20).

***Ring expansion reaction of 6f***. Reaction complete after 14h at reflux (0.5 mmol scale). Flash column chromatography (20:1 petrol: ether) gave a mixture of two isomers, which were separable by p.l.c. (10:1 petrol: ether), *E-5-methylcyclonon-5-enone*[14] 32 (44%) and *5-methylenecyclononanone*[14] 33 (36%). Longer reaction times led to the predominance of the exomethylene isomer. For 32 $\nu_{max.}$ (thin film) 2930 (s), 2860 (m), 1695 (m), 1480-1415 (m), 1390-1370 (m), 1340 (m), 1160 (m), 1115 (m); $\delta_H$ (200 MHz) 1.37 (3H, s), 1.72-1.96 (4H, m), 2.00-2.26 (4H, m), 2.30-2.42 (4H, m), 5.51 (1H, t,

*J* 8.0Hz); *m/z* (C.I., $NH_3$) 170 ($MNH_4^+$, 22%), 153 ($MH^+$, 73), 135 (100), 124 (13), 109 (16), 95 (17) 91 (16), 81 (17), 79 (6), 69 (8), 58 (11). For 33 $\nu_{max.}$ (thin film) 2960 (s), 2930 (s), 2860 (m), 1705 (m), 1670 (w), 1630 (m), 1480-1410 (m), 1340 (m), 1310 (w), 1245 (w), 1075 (m), 965 (m), 885 (m); $\delta_H$ (200 MHz) 1.36-2.06 (10H, m), 2.09-2.19 (2H, m), 2.25-2.31 (1H, m), 2.33-2.39 (1H, m), 4.71 (1H, d, *J* 1.5Hz), 4.93 (1H, d, *J* 1.5Hz); *m/z* (E.I.) 152 ($M^+$, 9%), 136 (6), 124 (8), 120 (5), 110 (13), 106 (10), 96 (16), 92 (100), 80 (22), 70 (46), 68 (14), 66 (13), 56 (37).

***Ring expansion reaction of 6g***. Reaction complete after 24h at reflux (0.18 mmol scale). The crude material was subjected to purification by p.l.c. (3:1 petrol: ether). The product, a colourless oil, was identified as *Z-3-methylcyclohept-3-enone*[15] 34 (87%). $\nu_{max.}$ (thin film) 2960 (m), 2930 (s), 2860 (m), 1710 (m), 1480-1420 (m), 1380 (m), 1290 (w), 1260 (m), 1115 (w), 1020 (w), 800 (w); $\delta_H$ (300 MHz) 1.78 (3H, d, *J* 1.5Hz), 1.94 (2H, quintet, *J* 6.0Hz), 2.21-2.30 (2H, m), 2.52-2.58 (2H, m), 3.20 (2H, s), 5.52 (1H, dt, *J* 5.0, 1.5Hz); nOe expt: irradiation of the doublet at 1.78 caused a 12% enhancement of the signal at 5.52; *m/z* (C.I., $NH_3$) 142 ($MNH_4^+$, 53%), 125 ($MH^+$, 100), 109 (5), 99 (19), 97 (3).

***Attempted ring expansion of 6h***. Prolonged reaction times in a number of solvents and a variety of initiators led in all cases to decomposition products, no ring expanded products were observed. The only isolable material was *trans-2-allyl-3-tributylstannylcyclohexanone* 35 obtained in variable yield (≈30%). (Found: C, 59.10; H, 9.24. $C_{21}H_{40}OSn$ requires C, 59.04; H, 9.44%); $\nu_{max.}$ (thin film) 3080 (w), 2960 (s), 2920 (s), 2865 (s), 1710 (s), 1640 (m), 1470-1410 (m), 1375 (m), 1340 (m), 1310 (w), 1070 (m), 1020 (m), 1000 (m), 910 (m), 735 (m); $\delta_H$ (200 MHz) 0.82-0.95 (15H, m), 1.22-1.84 (16H, m), 1.87-2.22 (3H, m), 2.29-2.61 (3H, m), 4.91-5.05 (2H, m), 5.71-5.95 (1H, m); *m/z* (E.I.) 427 (18%), 425 (13), 423 (7), 371 ($M^+$-$^n$Bu$^\cdot$, $^{80}Se^{120}Sn$, 75), 369 (58), 367 (34), 291 (28), 235 (55), 177 (100), 121 (53), 93 (19), 79 (28), 67 (41), 55 (49).

***Attempted ring expansion reaction of 10a***. The starting material was consumed after 4h at reflux (0.05mmol scale), however, flash column chromatography (20:1 petrol: ether) afforded only *2-butylcyclohex-2-enone*[22] 27 (86%). Data as above.

***Ring expansion reaction of 10b***. This was complete after 2h at reflux (0.12mmol scale). The crude product was purified by p.l.c. (10:1 petrol: ether) to afford, most probably, *Z-6-deuterocyclodec-5-enone*[12] 36 (21%) and *2-(4-deuterobutyl)-cyclohex-2-enone* 29 (58%). For 29 and 36 $\nu_{max.}$ (thin film) 3020 (w), 2930 (s), 2860 (m), 1710 (m), 1675 (s), 1470-1410 (m), 1380 (m), 1175 (m), 1100 (m), 980 (m), 910 (m), 800 (w); for 29 NMR data given above; for 36 the only distinct resonance for this compound was 5.09-5.25 (1H, m), the others being broad and of low intensity being masked by those of the reduced material 29; *m/z* (C.I., $NH_3$) 171 ($MNH_4^+$, 14%), 154 ($MH^+$, 100), 137 (34), 125 (9), 111 (10), 105 (10), 105 (10), 95 (8), 91 (7), 82 (11), 58 (4).

***Ring expansion reaction of 10c***. This reaction was complete after 40h at reflux (0.16mmol scale). The crude product was purified by flash column chromatography (20:1 petrol: ether) then p.l.c. (5:1 petrol: ether) to give *Z-6-methylcyclodec-5-enone*[13] 37 (89%). This material was contaminated with ≈10% of the *E*- isomer as judged by the integral ratios of the olefinic protons in the NMR spectrum. $\nu_{max.}$ (thin film) 3040 (w), 2930 (s), 2860 (s), 1705 (s), 1625 (m), 1470-1405 (m), 1375 (m), 1250 (m), 1200 (m), 1130 (m), 1010 (m), 970 (m), 800 (m); $\delta_H$ (200 MHz) 1.55-1.87 (6H, m), 1.65 (3H, s), 1.96-2.16 (4H, m), 2.29-2.37 (2H, m), 2.46-2.53 (2H, m), 4.91-5.03 ("0.1"H, m, -C<u>H</u>= in *E*- isomer), 5.16 (1H, t, *J* 8.5Hz); *m/z* (E.I.) 166 ($M^+$, 7%), 148 (100), 133 (43), 124 (21), 119 (23), 108 (49), 105 (34), 97 (18), 95 (38), 93 (92), 91 (30), 81 (50), 79 (51), 67 (56), 55 (60), 53 (32).

***Ring expansion reaction of 10d***. After 48h at reflux (0.15mmol scale) t.l.c. showed no starting material remaining. The crude product was subjected to purification by flash column chromatography (20:1 petrol: ether) and the ring expanded material *Z-cyclonon-5-enone*[16] 38 obtained in 87% yield. $\nu_{max.}$ (thin film) 3010 (m), 2970 (s), 2930 (s), 2870 (m), 1705 (s), 1470-1410 (m), 1355 (m), 1250 (m), 1205 (m), 1120 (m), 715 (m), 615 (m); $\delta_H$ (250 MHz) 1.84-1.96 (4H, m), 2.07-2.18 (4H, m), 2.44 (4H, t, *J* 6.5Hz), 5.40-5.55 (2H, m) irradiation of the signal at 2.13 caused the multiplet at 5.40-5.55 to collapse to a sharp singlet, no other peaks corresponding to the *trans*- compound were observed; *m/z* (E.I.) 138 ($M^+$, 8%), 120 (68), 109 (13), 95 (28), 82 (46), 79 (35), 67 (72), 55 (100), 54 (93). A small amount of *2-propylcyclohex-2-enone*[23] 39 (4%) was also observed. $\delta_H$ (250 MHz) 0.92 (3H, t, *J* 8.0Hz), 1.23-1.50 (2H, m), 1.98 (2H, quintet, *J* 7.5Hz), 2.15 (2H, td, *J* 8.0, 1.0Hz), 2.29-2.45 (4H, m), 6.70 (1H, t, *J* 5.0Hz).

***Ring expansion of 10e***. The reaction was complete after 24h (0.17mmol scale). Mixture subjected to p.l.c. (5:1 petrol: ether) and *Z-methylcyclonon-5-enone*[14] 40 obtained as a colourless oil (87%). $\nu_{max.}$ (thin film) 3040 (w), 2960 (s), 2930 (s), 2860 (m), 1705 (s), 1470-1400 (m), 1355 (m),

1235 (m), 1105 (m), 885 (m); $\delta_H$ (250 MHz) 1.70 (3H, s), 1.83-1.98 (4H, m), 2.05-2.12 (4H, m), 2.33-2.43 (4H, m), 5.23 (1H, t, *J* 8.5Hz); *m/z* (C.I., $NH_3$) 170 ($MNH_4^+$, 9%), 153 ($MH^+$), 135 (100), 134 (12).

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