Diastereofacial Selectivity in Atom Transfer Reactions of 5-Substituted (X) Adamant-2-yl Radicals: Nature of the Electronic Factor

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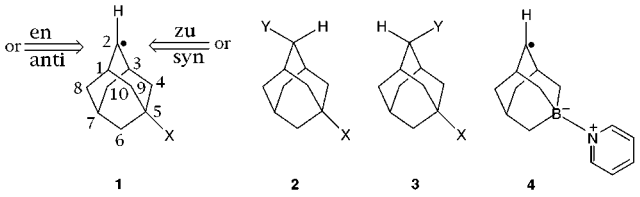
The diastereofacial selectivity in deuterium and halogen atom abstraction reactions of 5-fluoro- and 5-(trimethylstannyl)-2-adamantyl radicals has been investigated. Significant preferential *syn* (or *zu*) and *anti* (or *en*) face selectivity, respectively, is observed for these substituents of distinctly opposite electronic character. Although the observations are in accord with predictions from Cieplak's transition state hyperconjugation model, an alternative explanation can be advanced based on an early reactant-like TS model.

Introduction

The electronic effect of remote substituents on the diastereoselectivity of radical reactions has been investigated recently by the use of 5-substituted (X) adamant-2-yl radicals (**1**).[1,2] These model substrates are most



1 **2** **3** **4**

appropriate for this purpose since their rigid molecular frameworks ensure that ambiguities associated with conformational uncertainty are precluded. Moreover, the trigonal radical center can be electronically perturbed through distal modifications without introducing steric bias into the system. The first experiments by le Noble et al.[1] found that the 5-phenyl-2-adamantyl radical (**1**; X = C_6H_5) is captured by molecular bromine to give an *E*/*Z* mixture of bromides (**2** and **3**; X = C_6H_5 and Y = Br, respectively) in a ratio of 38:62, respectively; i.e., a dominant face preference is induced which is *antiperiplanar* to the more electron-rich vicinal C−C bonds flanking C2. Cieplak's transition-state hyperconjugation model[3] was invoked to explain the result. The basic premise of this model is that transition state (TS) stabilization is dominated by the hyperconjugative interaction between the antibonding molecular orbital (σ^*) of the developing bond and the anti-disposed best electron donor σ_{cc} bonds.

Subsequently, in connection with a product distribution study of the trimethylstannylation of *E* and *Z* isomers of 2,5-dihaloadamantanes (**2** and **3**; X = Y = halogens, respectively) we discovered that the 5-(trimethylstannyl)-adamant-2-yl radical (**1**; X = $SnMe_3$) appears to be captured by iodine atom abstraction and, as well, by the trimethylstannyl anion with essentially random stereochemistry.[2] On the basis of the dramatic effect of the (*E*)-5-Me_3Sn group (a strong σ-electron donor) on the stability and behavior of the adamant-2-yl carbocation as a consequence of double hyperconjugation[4] and, as well, the fact that the electrostatic field influence of Me_3Sn is practically zero ($\sigma_F \sim 0$),[5] we mounted a case for electrostatic rather than hyperconjugative effects as the origin of face selectivity in the case of radical capture.

More recently, le Noble et al.[6] have reported that a 5-boraadamant-2-yl radical (**4**) exhibits preferential *en* or *anti* face selectivity (65:35) in its deuterium atom abstraction reaction with *n*-Bu_3SnD. This directive effect by an apparent σ-electron donor substituent is diametrically opposite to that noted above for a modest σ-electron withdrawer (**1**; X = C_6H_5). Hence, it was concluded that Cieplak's transition state hyperconjugation model is corroborated.

The distinct facial preference of **4** appears to raise doubts about the aforementioned selectivity results for the tin radical species (**1**; X = $SnMe_3$) which had been initially expressed on the grounds that the radical was generated in a complex reaction and the product yields poor.[7] Although the latter criticism may be valid for the iodine atom abstraction (14−26% yield), it certainly does not hold for the trapping of **1** (X = $SnMe_3$) with Me_3Sn^- (56−78% yield). Moreover, we independently confirmed the latter result by direct trimethylstannylation of a mixture (*E*/*Z* = 40/60) of 2-bromo-5-(trimethylstannyl)-adamantane (**2** and **3**; X = $SnMe_3$ and Y = Br, respectively).[8] However, it is possible that the lack of π-facial selectivity in the nucleophilic capture of **1** (X = $SnMe_3$) by Me_3Sn^- (a supernucleophile) is a result of the coupling

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being at, or close to, the diffusion limit.[9] Under these circumstances stereochemistry will be lost irrespective of the electronic character of the substituent. On this point it is noteworthy that the nucleophilic capture of the 5-fluoroadamant-2-yl radical (**1**; X = F) by Me_3Sn^- also gave an unexpectedly low facial preference (Z/E = 56/44)[2] given the strong polar character of fluorine (σ_F = 0.40).

In an attempt to shed further light on the overall picture we report in this paper facial selectivity data for the 5-F- and 5-Me_3Sn-substituted 2-adamantyl radicals (**1**; X = F and $SnMe_3$, respectively) in their deuterium and halogen abstraction reactions with *n*-Bu_3SnD and various haloalkanes, respectively. These two strong σ-electron-withdrawing and -donating groups (F and $SnMe_3$, respectively) are of pronounced interest in the current context since they provide the most conspicuous examples of diastereoselectivity in the nucleophilic capture of 5-substituted (X) 2-adamantyl cations, the archetypal electron-deficient species of the probe substrate. The selectivity ratios for both substituents in this cation species are in excess of 9:1 but in diametrically opposite directions.[4,10]

Results and Discussion

Deuterium Transfer Reactions. *E*/*Z* mixtures of 2-bromo-5-fluoroadamantane (**2** and **3**; X = F and Br, 25/75, respectively) and 2-bromo-5-(trimethylstannyl)adamantane (**2** and **3**; X = $SnMe_3$ and Y = Br, 38/62, respectively) were treated with *n*-Bu_3SnD, and the deuterated product mixtures were examined by NMR spectroscopy. Unfortunately, the NMR analysis employed by le Noble et al.[6] to the reduction products from **4** cannot be applied to these mixtures. Furthermore, a possible analysis by ^{13}C NMR (125.763 MHz) was ruled out by the observation that 2-deutero substitution in adamantane does not differentiate the chemical shifts of the vicinally disposed carbon centers (C4,9 and C8,10). The lack of a pronounced differential three-bond $^2H/^1H$ isotopic shift (vicinal **W** versus "sickle" bond pathways) in 2-deuterioadamantane was somewhat surprising given that a vicinal shift is significant (−0.03 ppm) in the bicyclo[2.2.2]octane ring system.[11] However, we found that the ^1H-decoupled ^{19}F NMR spectrum (376.433 MHz) of a $CDCl_3$ solution of the fluoro deuterides (**2** and **3**; X = F and Y = D) showed two slightly overlapping singlets at δ (ppm) −130.686 and −130.704 (relative to external $C_6H_5CF_3$ set at −64.99 ppm) in the ratio of ca. 62:38, respectively. Application of a sine-bell function to the FID provided a singlet (−130.686 ppm) and a triplet (−130.706 ppm) with complete baseline separation in the ratio of 63:37, respectively. Since previous studies[4b,12] have revealed that five-bond long-range coupling constants ($^5J_{X-Y}$) are observed in the *E* (**2**) but not the *Z* (**3**) isomer (effective spin transmission requires the bridging ethano bonds to be in an antiperiplanar array with the C−X and C−Y bonds), the upfield triplet signal ($^5J_{D-F}$ = 0.61 Hz) was assigned to the *E* isomer (**2**; X = F and Y = D). The ^1H-decoupled ^2H NMR spectrum (76.773 MHz) of the same mixture revealed two overlapping singlets at δ (ppm) 1.636 and 1.613 ($CDCl_3$ set at 7.26 ppm) in the ratio of ca. 32:68, respectively. Under sine-bell conditions a doublet (1.643 ppm, $^5J_{D-F}$ = 0.70 Hz) and a singlet (1.613 ppm) emerged with almost baseline separation in the ratio of 35:65, respectively. The minor component located downfield is assigned to the *E* isomer because of the observed long-range coupling (see above).

The ^1H-decoupled ^{119}Sn NMR spectrum (186.502 MHz) of a $CDCl_3$ solution of the tin deuterides (**2** and **3**; X = $SnMe_3$ and Y = D) showed two overlapping singlets at δ (ppm) 0.080 and 0.048 (relative to external 1-(trimethylstannyl)adamantane[13] set at 0.00 ppm) in the ratio of ca. 58:42, respectively. Sine-bell conditions just separated them to give two singlets at 0.082 and 0.050 ppm in the same ratio. Deconvolution of the peaks gave a ratio of 59:41. Although no long-range coupling was resolved, the distinct broadening of the downfield signal strongly suggests the major product is the E isomer (**2**; X = $SnMe_3$ and Y = D). This assignment is corroborated by the observed downfield $^2H/^1H$ isotopic shift (0.06 ppm) on the ^{119}Sn chemical shift of 1-(trimethylstannyl)bicyclo[2.2.2]-octane[14] on 4-deutero substitution. Systematic studies have shown that through-three-bond substituent effects in the *E* isomer of 2,5- (or 1,4-) disubstituted adamantanes (**2**) parallel the corresponding effects in 1,4-disubstituted bicyclo[2.2.2]octanes.[4b,12] Similar effects are not observed in the *Z* isomer (**3**) of the former species because the obligatory stereoelectronic requirement of antiperiplanarity is structurally precluded. Unfortunately, the ^1H-decoupled ^2H NMR spectrum (76.773 MHz) of the tin deuteride mixture gave two overlapping signals at δ (ppm) 1.726 and 1.698 which could not be completely separated by sine-bell conditions (ca. ratio of 59:41, respectively).

Halogen Transfer Reactions. Recently, in connection with a study of polar substituent effects in the adamantane ring system as monitored by ^{19}F NMR we had occasion to synthesize 2-halo-5-fluoroadamantanes (**2** and **3**; X = F and Y = halogen).[12] The mixtures of chloro, bromo, and iodo compounds were prepared in good yields (>90%) by conversion of a mixture of *E*- and *Z*-5-fluoroadamantane-2-carboxylic acids (**2** and **3**; X = F and Y=COOH, 52:48, respectively) to the *O*-acyl-*N*-hydroxy-2-thiopyridone derivatives (Barton PTOC esters)[15] followed by their decomposition in the appropriate halogen atom source in the usual manner.[16] The diastereoselectivities (*E*/*Z*) for the capture of the 5-fluoroadamant-2-yl radical (**1**; X = F) which mediates the final step of the syntheses are presented in Table 1.

Unfortunately, we have been unable to similarly determine the diastereoselectivities of capture of the 5-(trimethylstannyl)adamant-2-yl radical (**1**; X = $SnMe_3$) because of our failure to date to synthesize the appropriate precursor tin carboxylic acids (**2** and **3**; X = $SnMe_3$

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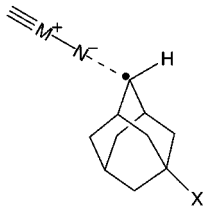
Table 1. Product Distribution in the Halogen Atom Capture of 5-Substituted (X) Adamant-2-yl Radicals (1)

X	atom source	% *E*	% *Z*	anal. method
F[a]	CCl_4	30	70	^{13}C NMR
		31	69	^{19}F NMR
		30	70	VPC
F[a]	$CF_3CHClBr$	25	75	^{13}C NMR
		26	74	^{19}F NMR
		25	75	VPC
F[a]	CF_3CH_2I	29	71	^{13}C NMR
		31	69	^{19}F NMR
		29	71	VPC
Br[a]	$CF_3CHClBr$	34	66	^{13}C NMR
		35	65	VPC
$SnMe_3$[b]	CCl_4	63	37	^{13}C NMR
		69	31	^{119}Sn NMR
		66	34	VPC

[a] Radical generated from carboxylic acids as precursor (see text). [b] Radical generated from alcohols as precursor (see text).

and Y═COOH). Our attempts to obtain a selectivity result for the tin radical species (**1**; X = $SnMe_3$) by treating a mixture of the tin alcohols (**2** and **3**; X = $SnMe_3$ and Y═OH, 60:40, respectively) with oxalyl chloride followed by addition to a benzene solution containing CCl_4 and *N*-hydroxypyridine-2-thione sodium salt[17] was met with limited success. The desired chloro−tin product (**2** and **3**; X = $SnMe_3$ and Y = Cl) was obtained in only poor yield (19%), and several attempts failed to improve it. The diastereoselectivity (*E*/*Z*) of chlorine atom capture from this experiment is given in Table 1. It is pertinent to note that the generation and capture of the fluoro radical (**1**; X = F) in the same manner also led to relatively low product yields (46%) but, nevertheless, provided a selectivity result for chlorine atom capture (*E*:*Z* = 29:71, VPC) identical to that determined using the fluoro carboxylic acids as the radical precursor (see Table 1). The selectivity of capture of the 5-bromoadamant-2-yl radical (**1**; X = Br) listed in Table 1 was obtained from a mixture of the bromo carboxylic acids (**2** and **3**; X = Br and Y═COOH, *E*:*Z* = 74:26, respectively) in the same manner indicated above for the fluoro radical (**1**; X = F). The latter acids were available from our failed attempts to synthesize the corresponding tin compounds (**2** and **3**; X = $SnMe_3$ and Y = COOH; see above).

Transition-State Model. Although the preferential *syn* (or *zu*) and *anti* (or *en*) face selectivity induced by 5-fluoro- and 5-(trimethylstannyl)-substitution in the 2-adamantyl radical (**1**; X = H), respectively (see above), is clearly in accord with expectations from the Cieplak model,[3] there is an alternative equally plausible explanation based on an early reactant-like TS model. A considerable body of stereoselectivity data of atom transfer reactions involving acyclic radicals is available which is consistent with this supposition.[18] Moreover, strong corroboration is provided by recent high-level ab initio calculated transition states for hydrogen abstraction by alkyl radicals (1°, 2°, and 3°) from stannane and trimethylstannane.[19] Within this framework the diastereomeric transition states for capture of **1** are depicted by structures **5** and **6** where ≡M−N represents the deuterium or halogen atom source (M = C or Sn; N = D, Cl, Br, or I). The 2-adamantyl radical (**1**; X = H) has been shown to be planar,[20] and ab initio high-level calculations (UHF/6-31G*) suggest that this is also the case for the 5-F- and 5-Me_3Sn-substituted derivatives as well.



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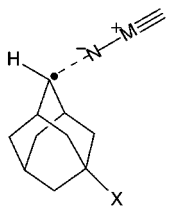

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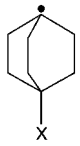
However, some degree of pyramidalization of the radical center is to be expected in the TS structures (**5** and **6**). There are two possible factors which may be envisaged to operate to differentiate the energies of **5** and **6**: (i) The first factor is radical stabilization due to spin delocalization of the unpaired electron by double hyperconjugation. The possible importance of this mechanism has recently been revealed by the discovery that 4-fluoro- and 4-trimethylstannyl-substitution stabilizes (0.81−1.15 kcal/mol[21] and 2.58−3.04 kcal/mol,[13] respectively) the bicyclo[2.2.2]oct-1-yl radical (**7**, X = H) by enhanced delocalization of the unpaired electron.[22]



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Given that on stereoelectronic grounds (antiperiplanarity of participating orbitals) similar effects should be at play in the *E* but not the *Z* species of **1** (X = H), both F and Me_3Sn would be expected to stabilize **5** relative to **6** and, therefore, induce preferential *anti* (or *en*) face selectivity in atom transfer reactions. The selectivity is expected to be more pronounced for the latter substituent. (ii) The second factor is the electrostatic field of the remote substituent which interacts with the polar bonds of the atom transfer agent ($\equiv M^{\delta+}-N^{\delta-}$). Unfortunately, existing theory is not good enough to be able to confidently predict the relative stability of **5** and **6** as a consequence of this Coulombic interaction. However, because of the polarity of the $M^{\delta+}-N^{\delta-}$ bond it seems not unreasonable to view the atom transfer agents as nucleophilic-like species, and therefore, preferential *syn* (or *zu*) face selectivity is to be expected in line with electrostatically controlled nucleophilic additions to *para*-substituted 5-phenyl-2-adamantanones.[23] This Coulombic factor will be important for strongly polar substituents (e.g. F, $\sigma_F = 0.40$)[24] but not for the Me_3Sn group ($\sigma_F \sim 0$).[5] Thus, the preferential *syn* (or *zu*) and *anti* (or *en*) face selectivity observed for **1** (X = F and $SnMe_3$,

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respectively) is comprehensible in terms of a predominant electrostatic field and double hyperconjugative influence for F and Me_3Sn, respectively.

It is noteworthy that the selectivity induced by bromine (Z/E = 65/35 (VPC); see Table 1) for bromine atom transfer is significantly lower than that for fluorine (Z/E = 75/25 (VPC); see Table 1) even though its *syn* (or *zu*) directing polar field effect is slightly larger (σ_F = 0.40 (F), 0.44 (Br)).[24] However, bromine is more effective than fluorine at radical stabilization by double hyperconjugative electron delocalization. This is evident from through-three-bond stabilization of **7** by 4-Br (1.61−2.21 kcal/mol)[21] versus 4-F (0.81−1.15 kcal/mol)[21] substitution. Consequently, the net result of Coulombic (favors **6**) and delocalization (favors **5**) influences on facial selectivity for Br will be less than that for F. The selectivity result is also explicable in terms of the Cieplak model[3] since there is evidence in the neutral ground state from ^{19}F NMR chemical shifts[4b,12] that F is more effective than Br at reducing the electron donor capabilities of the proximate vicinal C−C bonds.

Finally, we should mention that an attempt to carry out ab initio high-level TS calculations (B3LYP/6-31G*) on **5** and **6** (≡M−N = Me_3SnH; X = F and $SnMe_3$) was not feasible as the number of basis functions generated by Me_3SnH and **1** (X = F and $SnMe_3$) proved too formidable.[25]

Experimental Section

Compounds. Mixtures of (*E*)- and (*Z*)-2-bromo-5-fluoroadamantane (**2** and **3**; X = F and Y = Br, respectively)[12] and (*E*)- and (*Z*)-5-(trimethylstannyl)admantan-2-ol (**2** and **3**, X = $SnMe_3$ and Y = OH, respectively)[4] were prepared by literature procedures. The tin−alcohol mixture was converted to the corresponding bromo−tin compounds as described below. It should be noted, however, that our initial attempts to prepare the latter derivatives were fraught with difficulty. Although the replacement of OH with Br on treatment with $(C_6H_5)_3P/CBr_4$ proceeded smoothly, the isolation and purification of the product was a problem. It was found that even after chromatography (basic alumina, hexane as eluent) the bromo−tin compounds decomposed on standing to give predominantly (*E*)- and (*Z*)-1,4-dibromoadamantanes (**2** and **3**; X = Y = Br, respectively, readily identified by the availability of authentic samples)[26] together with a minor amount of 7-methylenebicyclo-[3.3.1]non-2-ene. The latter fragmentation product[4a] highlights the sensitivity of the compounds to solvolysis even in the presence of trace amounts of water. Because the mixture of $(C_6H_5)_3P/CBr_4$ is known to be always contaminated by dibromotriphenylphosphine,[27] we reasoned that this strong electrophile is probably responsible for the reaction which leads to the formation of 1,4-dibromoadamantanes. We finally managed to successfully eliminate the problem by treating the crude reaction mixture with phenyltrimethylsilane during workup. The latter compound readily reacts with $(C_6H_5)_3PBr_2$ to form innocuous products (C_6H_5Br and Me_3SiBr) which are readily removed by evaporation in vacuo.

(*E*)- and (*Z*)-2-Bromo-5-(trimethylstannyl)adamantane (2 and 3; X = $SnMe_3$ and Y = Br, Respectively). A solution of tetrabromomethane (346 mg, 1.04 mmol, 1.1 equiv) in dry tetrahydrofuran (5 mL) was added dropwise[28] over 3 min to a well-stirred solution of a mixture (E/Z = 60/40)[4] of the tin alcohols (**2** and **3**; X = $SnMe_3$ and Y = OH; 300 mg, 0.95 mmol), triphenylphosphine (274 mg, 1.04 mmol, 1.1 equiv), and triethylamine (145 μL, 1 equiv) in dry tetrahydrofuran (5 mL) under N_2. After 5 min a distinct yellow precipitate appeared, and the resulting mixture was allowed to stir at room temperature until VPC analysis indicated that the reaction was complete (2 h). The mixture was then frit filtered, and the separated supernatant was evaporated in vacuo to dryness. The crude residue was immediately dissolved in dry dichloromethane (ca. 10 mL), and phenyltrimethylsilane (ca. 1 mL) was added to the solution. After the solution was allowed to stir overnight at room temperature, evaporation in vacuo afforded a crude reaction mixture which gave a colorless oil (220 mg, 61%) after chromatography on neutral alumina (hexane as eluent). An analysis by ^{13}C NMR indicated a mixture of the desired title compounds (E/Z = 38/62). The ratio was confirmed by VPC. The spectra were assigned by the additivity of substituent effects on the adamantane ring.[29]

(*E*)-2-Bromo-5-(trimethylstannyl)adamantane (2; X = $SnMe_3$ and Y = Br). ^{13}C NMR ($CDCl_3$, relative to Me_4Si): δ 37.21 (C1,3), 64.59 (C2), 43.22 (C4,9), 26.12 (C5), 42.32 (C6), 28.30 (C7), 31.75 (C8,10), −12.89 ($SnMe_3$; $^1J_{C-Sn}$ = 285.12, 300.67 Hz). ^{119}Sn NMR ($CDCl_3$, relative to Me_4Sn): δ 0.86.

(*Z*)-2-Bromo-5-(trimethylstannyl)adamantane (3; X = $SnMe_3$ and Y = Br). ^{13}C NMR ($CDCl_3$, relative to Me_4Si): δ 36.74 (C1,3), 64.40 (C2), 35.90 (C4,9), 26.89 (C5), 42.32 (C6), 27.59 (C7), 38.78 (C8,10), −12.99 ($SnMe_3$; $^1J_{C-Sn}$ = 285.12, 300.67 Hz). ^{119}Sn NMR ($CDCl_3$, relative to Me_4Sn): δ −1.64.

(*E*)- and (*Z*)-1,4-Bis(trimethylstannyl)adamantane (2; X = Y = $SnMe_3$, Respectively). A solution of (trimethylstannyl)lithium (ca. 1.43 mmol) in anhydrous THF (6 mL) prepared in the standard way[30] was added dropwise to a solution of the E/Z bromo−tin mixture (**2** and **3**; X = $SnMe_3$ and Y = Br; 180 mg, 0.48 mmol) in anhydrous THF (2 mL) at 0 °C under a nitrogen atmosphere. A standard workup afforded the title compounds as a white solid (140 mg, 63%). An analysis by ^{13}C and ^{119}Sn NMR indicated a 50/50 mixture of the E/Z isomers. This was confirmed by VPC. An attempt to separate these mixtures by HPLC (silica gel/hexane) was not successful. The ^{13}C NMR spectra were assigned by additivity methodology.[29]

(*E*)-1,4-Bis(trimethylstannyl)adamantane (2; X = Y = $SnMe_3$). ^{13}C NMR ($CDCl_3$, relative to Me_4Si): δ 28.07 (C1), 45.20 (C2,9), 32.94 (C3,5), 40.11 (C4), 36.61 (C6,10), 29.46 (C7), 42.49 (C8), −12.95 (C1−$SnMe_3$), −9.50 (C4−$SnMe_3$). ^{119}Sn NMR ($CDCl_3$, relative to Me_4Sn): δ −8.66 (C1−$SnMe_3$), −15.11 (C4−$SnMe_3$).

(*Z*)-1,4-Bis(trimethylstannyl)adamantane (3; X = Y = $SnMe_3$). ^{13}C NMR ($CDCl_3$, relative to Me_4Si): δ 28.47 (C1), 40.76 (C2,9), 32.76 (C3,5), 40.11 (C4), 40.89 (C6,10), 29.08 (C7), 42.49 (C8), −12.95 (C1−$SnMe_3$), −9.50 (C4−$SnMe_3$). ^{119}Sn NMR ($CDCl_3$, relative to Me_4Sn): δ −5.76 (C1−$SnMe_3$), −13.42 (C4−$SnMe_3$).

(*E*)- and (*Z*)-2-Chloro-5-(trimethylstannyl)adamantane (2 and 3; X = $SnMe_3$ and Y = Cl, Respectively). By use of the procedure of Crich and Fortt[17] for converting 1-adamantanol to 1-chloroadamantane, freshly distilled oxalyl chloride (0.83 mL, 9.49 mmol, 10 equiv) was added to a solution of (*E*)- and (*Z*)-5-(trimethylstannyl)adamantan-2-ol (**2** and **3**; X = $SnMe_3$ and Y = OH; 300 mg, 0.95 mmol) in dry benzene (5 mL) under N_2, and the resulting yellow solution was allowed to stir at room-temperature overnight. The solvent and excess oxalyl chloride were evaporated in vacuo, and the residue was taken up in a solvent mixture of benzene (5 mL) and CCl_4 (2 mL). This solution was then added dropwise over 10 min to a suspension of 2-mercaptopyridine *N*-oxide sodium salt (142 mg, 0.95 mmol) in dry benzene (5 mL) containing CCl_4 (2 mL) at reflux. The mixture developed a bright yellow-green color which eventually dissipated after further reflux and irradiation (300-W lamp) for 1 h. The solution was then frit filtered and

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evaporated to dryness. A white solid (60 mg, 19%) was obtained after chromatography on silica gel (hexane as eluent). An analysis by ^{13}C NMR indicated a 63/37 mixture of the title *E*/*Z* isomers, respectively (spectra assigned by additivity methodology).[29] This was confirmed by VPC (*E*/*Z* = 66/34) and ^{119}Sn NMR (*E*/*Z* = 69/31).

(*E*)-2-Chloro-5-(trimethylstannyl)adamantane (2; X = $SnMe_3$ and Y = Cl). ^{13}C NMR ($CDCl_3$, relative to Me_4Si): δ 36.53 (C1,3), 68.63 (C2), 42.59 (C4,9), 26.75 (C5), 42.03 (C6), 28.17 (C7), 31.02 (C8,10), −12.90 ($SnMe_3$). ^{119}Sn NMR ($CDCl_3$, relative to Me_4Sn): δ 0.57.

(*Z*)-2-Chloro-5-(trimethylstannyl)adamantane (3; X = $SnMe_3$ and Y = Cl). ^{13}C NMR ($CDCl_3$, relative to Me_4Si): δ 36.20 (C1,3), 68.58 (C2), 35.17 (C4,9), 27.34 (C5), 42.10 (C6), 27.49 (C7), 38.18 (C8,10), −13.00 ($SnMe_3$). ^{119}Sn NMR ($CDCl_3$, relative to Me_4Sn): δ −1.64.

General Procedure for *n*-Bu_3SnD Reduction of 2 and 3 (X = F or $SnMe_3$ and Y = Br) and 1-Bromo-4-(trimethylstannyl)bicyclo[2.2.2]octane.[13] In a Pyrex test tube fitted with a side arm was added 2-bromoadamantane (40 mg, 292 mmol; sample available from another study),[26] freshly prepared *n*-Bu_3SnD (ca. 1 mL; n-Bu_3SnCl + $LiAlD_4$), and a few crystals of AIBN. The resulting well-stirred solution was then irradiated (300-W lamp) from a distance of 10 cm until reduction was complete (ca. 30−40 min.) monitored by VPC. The deuterated sample was carefully distilled out of the test tube in vacuo (0.1 mm) into a cold trap (liquid N_2). ^{13}C NMR ($CDCl_3$, relative to Me_4Si): δ 28.29 (C1,3), 37.34 (C2; J_{C-D} = 19.3 Hz), 37.77 (C4,6,8,9,10), 28.39 (C5,7). ^2H NMR ($CDCl_3$, set at 7.26 ppm): δ 1.765 (J_{H-D} = 1.5 Hz).

The workup procedure for the reduction of the bromo−tin compounds (**2** and **3**; X = $SnMe_3$ and Y = Br) was modified by adding iodomethane (2 mL) to destroy excess n-Bu_3SnD. This allowed the deutero tin derivative to be isolated by careful distillation (kugelrohr) as white crystals without contamination by n-Bu_3SnD.

(*E*)- and (*Z*)-2-Deuterio-5-fluoroadamantane (2 and 3; X = F and Y = D. ^{13}C NMR ($CDCl_3$, relative to Me_4Si): δ 31.43 (C1,3; J_{C-F} = 9.53 Hz), 35.49 (C2; J_{C-F} = 2.0 Hz, J_{C-D} = 19.42 Hz), 42.79 (C4,6,9; J_{C-F} = 17.05 Hz), 92.54 (C5, J_{C-F} = 183.37), 31.53 (C7, J_{C-F} = 9.67 Hz), 35.89 (C8,10).

(*E*)- and (*Z*)-2-Deuterio-5-(trimethylstannyl)adamantane (2 and 3; X = $SnMe_3$ and Y = D. ^{13}C NMR ($CDCl_3$, relative to Me_4Si): δ 29.04 (C1,3; J_{C-Sn} = 50.1 Hz), 37.41 (C2; J_{C-D} = 19.29 Hz), 42.12 (C4,6,9; J_{C-Sn} = 11.5 Hz), 28.16 (C5), 29.14 (C7, J_{C-Sn} = 49.90 Hz), 37.84 (C8,10), −13.13 ($SnMe_3$; J_{C-Sn} = 277.60, 290.54 Hz).

1-Deuterio-4-(trimethylstannyl)bicyclo[2.2.2]octane. ^{13}C NMR ($CDCl_3$, relative to Me_4Si): δ 23.51 (C1, J_{C-D} = 20.64 Hz), 27.32 (C2, J_{C-Sn} = 52.7, 55.3 Hz), 30.13 (C3), 21.73 (C4), −12.65 ($SnMe_3$, J_{C-Sn} = 283.83, 296.36 Hz). ^2H NMR ($CDCl_3$, set at 7.26 ppm): δ 1.450. ^{119}Sn NMR ($CDCl_3$, relative to 1-(trimethylstannyl)bicyclo[2.2.2]octane):[14] δ 0.206 (external), 0.06 (internal).

(*E*)- and (*Z*)-1,4-Dibromoadamantane (2 and 3; X = Y = Br, Respectively). 5-Bromoadamant-2-one[31] was converted to a mixture of (*E*)- and (*Z*)-5-bromoadamantane-2-carboxylic acids (*E*/*Z* = 74/26; **2** and **3**, X = Br and Y = COOH, respectively) following procedures recently outlined for the corresponding fluoro acids (**2** and **3**; X = F and Y = COOH).[12] The mixture of bromo acids was characterized by ^{13}C NMR. Assignments followed readily by application of additivity methodology.[29] *E* isomer (**2**, X = Br and Y = COOH): ^{13}C NMR ($CDCl_3$, relative to Me_4Si) δ 33.43 (C1,3), 47.80 (C2), 49.24 (C4,9), 63.78 (C5), 48.88 (C6), 31.50 (C7), 31.67 (C8,10), 179.85 (COOH). *Z* isomer (**3**; X = Br and Y = COOH): ^{13}C NMR ($CDCl_3$, relative to Me_4Si) δ 33.56 (C1,3), 47.60 (C2), 45.21 (C4,9), 64.23 (C5), 48.88 (C6), 31.50 (C7), 35.92 (C8,10), 179.79 (COOH).

Following procedures recently described for the preparation of 1-bromo-3-chloroadamantane from 3-chloroadamantane-1-carboxylic acid,[16] a mixture of the bromo acids (**2** and **3**; X = Br and Y = COOH; 100 mg, 0.39 mmol; *E*/*Z* = 74/26) was converted to the Barton PTOC esters[15] which were dissolved in halothane ($CF_3CHBrCl$, 15 mL) and the solution irradiated (300-W lamp) under N_2 at reflux temperature for 40 min. A standard workup[16] by column chromatography (basic alumina; hexane as eluent) provided the title compounds as a white solid (75 mg, 66%). The availability of authentic samples of the (*E*)- and (*Z*)-1,4-dibromoadamantanes (**2** and **3**; X = Y = Br, respectively)[26] facilitated the analysis. The ^{13}C NMR analysis indicated a 66/34 (*Z*/*E*) mixture which was confirmed by VPC (*Z*/*E* = 65/35). *E* isomer (**2**; X = Y = Br): ^{13}C NMR ($CDCl_3$, relative to Me_4Si) δ 61.86 (C1), 49.43 (C2,9), 39.72 (C3,5), 59.13 (C4), 29.78 (C6,10), 31.54 (C7), 49.35 (C8). *Z* isomer (**3**; X = Y = Br): ^{13}C NMR ($CDCl_3$, relative to Me_4Si) δ 63.13 (C1), 42.98 (C2,9), 40.35 (C3,5), 58.91 (C4), 36.59 (C6,10), 30.79 (C7), 49.24 (C8).

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Supporting Information Available: High-field deuterium, fluorine, and tin NMR spectra of the deuterated mixtures (**2** and **3**; X = F or $SnMe_3$, Y = D) (10 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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