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Four-directional synthesis of adamantane derivatives

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Dedicated to Professor Horst Kunz on the occasion of his 80th Birthday

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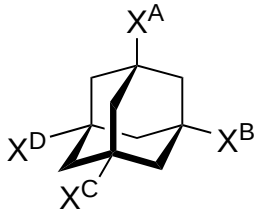
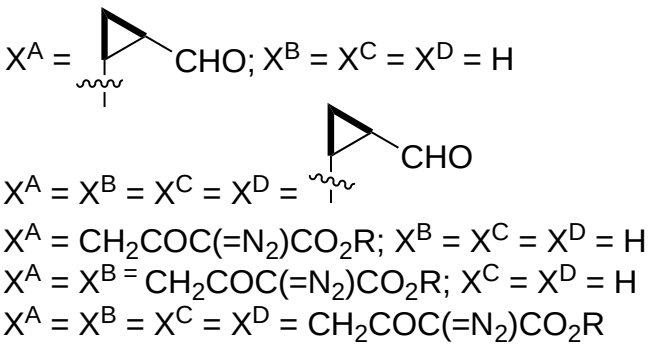
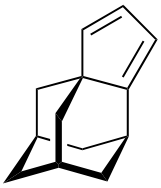
Abstract

1-Adamantanemethanol, 1,3-adamantanedimethanol and 1,3,5,7-adamantanetetramethanol were converted into adamantanes functionalized with one or four (2*R*,1*S*)-2-formyl-1-cyclopropyl residues using Charette enantioselective cyclopropanation reactions and with one, two or four 4-ethoxy- (or 4-*t*-butoxy)-3-diazo-2,4-dioxobutyl residues from aldehyde and diazo-acetate ester condensation reactions by 1-directional, 2-directional or 4-directional syntheses. The synthesis of adamantane fused to cyclopentadiene is also reported.



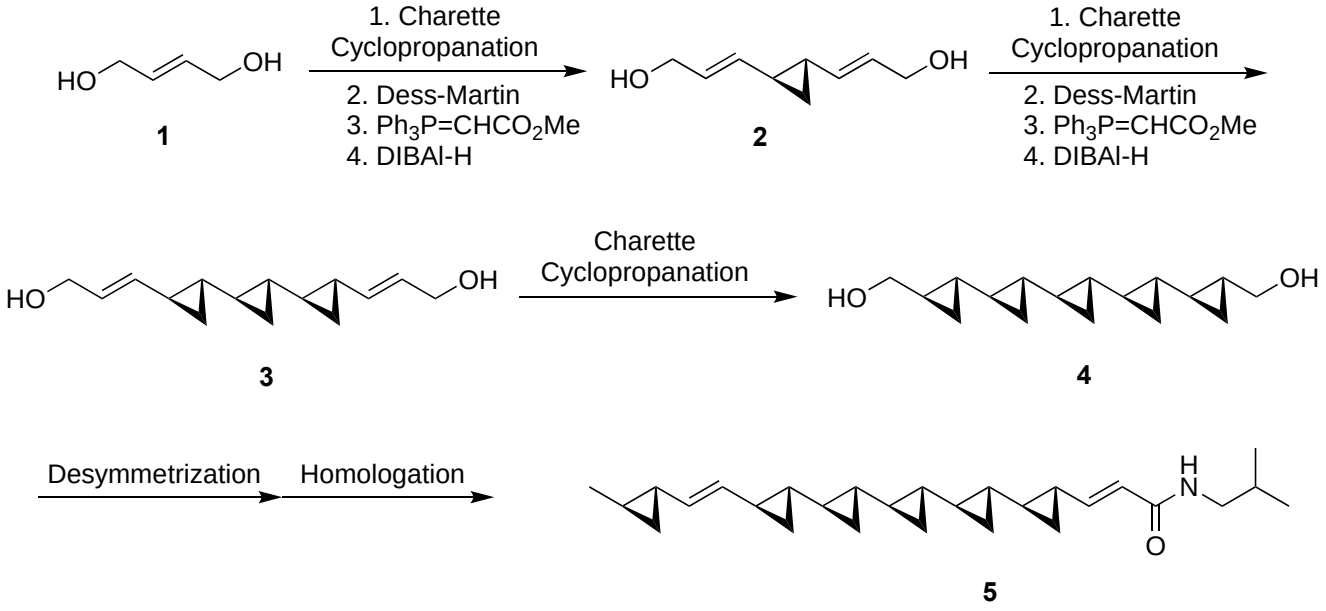




Keywords: Adamantane, 4-directional synthesis, enantioselective cyclopropanation, α-diazo-β-keto-esters

Introduction

Fuchs introduced the concept of the Intricacy Quotient (IQ) as a measure of the efficiency of natural product total synthesis.[1] One of the natural product examples highlighted in this study, was the total synthesis of the CETP inhibitor U-106305 (**5**) independently by Barrett and Charette.[2,3] This synthesis was scored at an IQ of 1.83 by Fuchs and the reason for this high value was due to the use of an iterative two-directional synthesis with late stage desymmetrization (Scheme 1) which, for example in the conversion of tercyclopropane **3** into quinquecyclopropane **4** generated two rings and controlled four stereocenters in an absolute sense. There is an added benefit with two-directional introduction of stereocenters by enantioselective synthesis and that is Horeau amplification of enantioselectivities.[4] It is clear, based on the Fuchs' analysis, that a total synthesis that depends on a four-directional synthesis is likely to score highly on the Fuchs IQ scale.

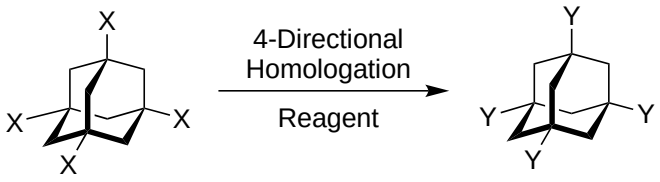


Scheme 1. Barrett and Charette two directional homologation in the total synthesis of U-106305 (**5**).

Four-directional transformations of adamantanes bearing identical tertiary substituents at C_1, C_3, C_5 and C_7 are well precedented. In a general sense, reaction of the adamantane derivative **6** with various reagents have been used to synthesize other adamantanes **7** bearing four identical substituents Y thereby conserving the symmetry. Most of these known transformations involve the construction of four carbon–heteroatom bonds or the quadruple derivatization of adamantanes functionalized by four identical tertiary aromatic rings. These are illustrated in Table 1 and the paragraph thereafter.

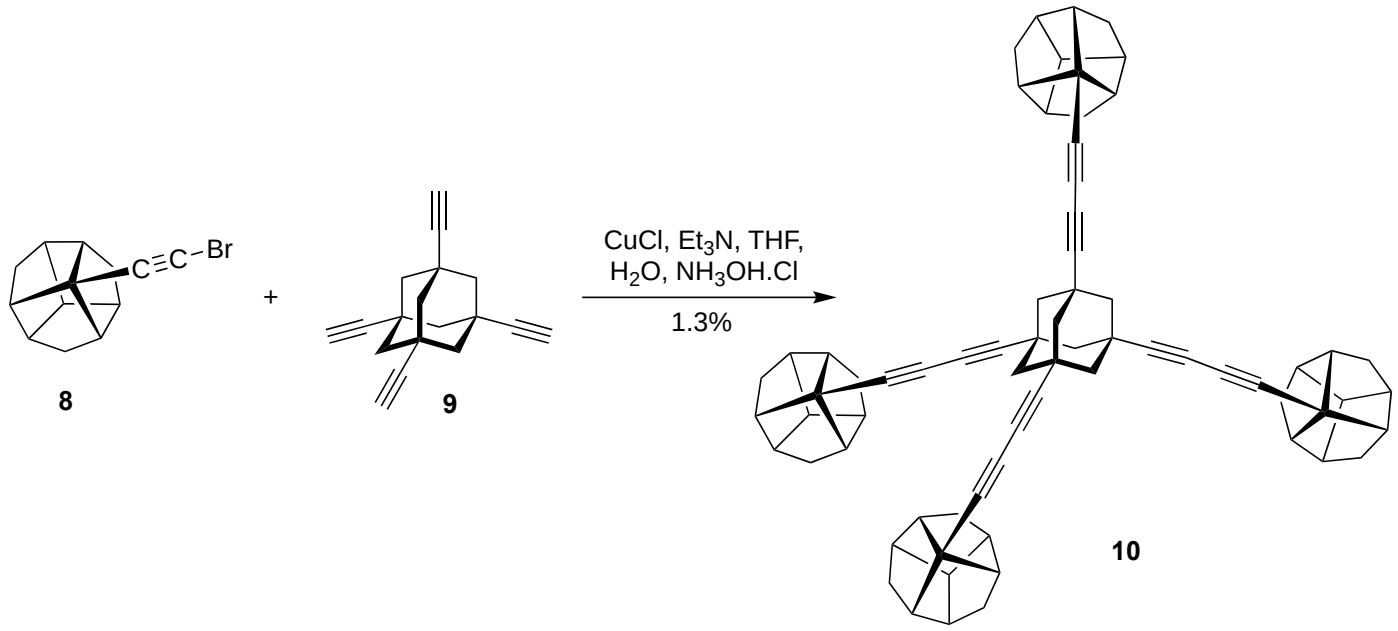
Tetra-aryl adamantanes **6** (X = Ph, 4-AcC_6H_4, 4-$O_2NC_6H_4$, 4-IC_6H_4 and 4-ethynylC_6H_4) have been converted into higher molecular weight adamantanes **7** by four-directional electrophilic aromatic substitution reactions, enantioselective reductions, aryl iodide to aryl nitrile conversions, nitroarene to aniline reductions, aniline to aryl azide conversions, Suzuki and Sonogashira coupling reactions and 3-component allene, aryl iodide and amine coupling reactions.[19-26] Of particular note in this chemistry are the application of four-directional syntheses to construct more complex adamantanes bearing nucleoside and nucleotide side chains[21] and the Naemura four-directional synthesis of the (+)-[1,3,5,7-tetrakis-trishomocubanylbuta-1,3-diynyl]adamantane derivative **10** (Scheme 2).[18]

Table 1. General four-directional synthesis of adamantane derivatives



6 **7**

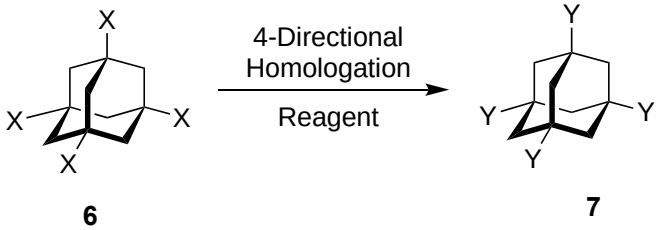
Reaction	Substituent X	Reagent	Substituent Y
Amide Synthesis[5-8]	CO_2H or COCl	R'R"NH	CONR'R"
Dendrimer Amide Synthesis[9]	CO_2H or COCl	R'R"NH	CONR'R'
Ester Synthesis[10-13]	COCl	R'OH or ArOH	CO_2R' or CO_2Ar
Ester Saponification[13,14]	CO_2Me	KOH, MeOH, H_2O, MeCN	CO_2H (90%)
Nitrile Alcoholysis[6]	CN	HCl, MeOH	CO_2Me (72%)
Nitrile Reduction[15]	CN	$Me_2S.BH_3$	CH_2NH_2 (98%)
Tetrazole Synthesis[16]	CN	NaN_3, $ZnCl_2$, DMF, Δ	5-Tetrazolyl (54%)
Arene Oxidative Degradation[13]	Ph	$RuCl_3$, $NaIO_4$, CCl_4, H_2O; $SOCl_2$; MeOH	CO_2Me (35%)
Alcohol Swern Oxidation[17]	CH_2OH	$(COCl)_2$, DMSO, Et_3N, CH_2Cl_2	CHO (55%)
4-Toluenesulfonylation[18]	CH_2OH	TsCl, pyridine	CH_2OTs
Cyanide Displacement[18]	CH_2OTs	NaCN, DMF, Δ	CH_2CN (77% from tetraol)
Cyanide Hydrolysis[18]	CH_2CN	H_2SO_4, H_2O, 120-130 °C	CH_2CO_2H (88%)
Amide Synthesis[18]	CH_2CO_2H	$SOCl_2$, Δ; PhH, Me_2N	CH_2CONMe_2 (93%)
Amide Reduction[18]	CH_2CONMe_2	$LiAlH_4$, THF, Δ	$CH_2CH_2NMe_2$ (84%)
Tertiary Amine Oxidation[18]	$CH_2CH_2NMe_2$	H_2O_2, MeOH, H_2O	$CH_2CH_2N(O)Me_2$
Cope Elimination[18]	$CH_2CH_2N(O)Me_2$	160-170 °C	$CH=CH_2$ (79% from tetraamine)
Alkene Bromination[18]	$CH=CH_2$	Br_2, CCl4	$CH(Br)CH_2Br$ (80%)
Acetylene Synthesis[18]	$CH(Br)CH_2Br$	KOH, triglyme, 160 °C, 30 mm	C≡CH = **9** (18%)



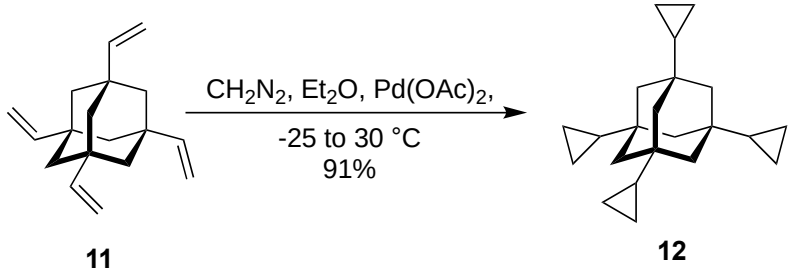
Scheme 2. Naemura four-directional synthesis of the adamantane derivative **10**.

There are fewer examples known for four-directional conversion of adamantanes **6** into adamantanes **7** by carbon-carbon bond construction at sp^3 centers. These are illustrated in Table 2. The de Meijere conversion of tetra-alkene **11** to tetracyclopropyl-adamantane **12** (91%) using diazomethane with a palladium catalyst (Scheme 3) is particularly relevant to this work.[17]

Table 2. Four-directional synthesis by carbon−carbon construction or change at sp^3 centers

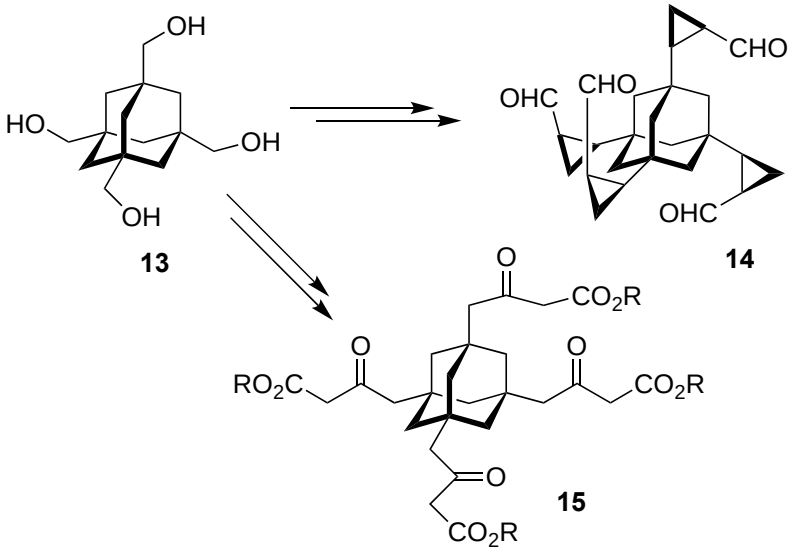


Reaction	Substituent X	Reagent	Substituent Y (%)
Bromide Photosubstitution[6]	Br	hν, NaCN, DMSO	CN (73%)
Wittig Reaction[17]	CHO	$Ph_3P=CH_2$	$CH=CH_2$ (82%)
Friedel Crafts Acylation[5]	COCl	PhH, $AlBr_3$	COPh (42%),
Friedel Crafts Alkylation[5]	Br	PhH, $AlBr_3$	Ph (77%),
Friedel Crafts Alkylation[27]	OH	$MeOC_6H_5$, TsOH	4-$MeOC_6H_5$ (68%)
Arene Oxidative Degradation[27]	4-$MeOC_6H_5$	$RuCl_3$, H_5IO_6; $SOCl_2$; MeOH	CO_2Me (42%)
Tertiary Alcohol Synthesis[28]	CO_2Me	PhLi, Et_2O, 0 °C	$C(OH)Ph_2$ (78%)



Scheme 3. de Meijere four-directional synthesis of tetracyclopropyl-adamantane **12**.

In this paper, four directional syntheses of the chiral tetra-cyclopropyl-tetra-aldehyde **14** and the tetra-β-keto-esters **15** from 1,3,5,7-tetra-hydroxymethyl-adamantane (**13**) are described (Scheme 4). In addition, the conversion of tetra-aldehyde **14** into the derived tetra-4-toluenesulfonylhydrazone and tetra-β-keto-esters **15** into the derived tetra-α-diazo-β-keto-esters as potential carbene precursors are outlined. Related transformations of adamantanes bearing one cyclopropane-carboxaldehyde residue and one and two α-diazo-β-keto-ester residues are described. Such studies may be relevant to the synthesis of diamondoid hydrocarbons.[29]



Scheme 4. Conversion of tetraol **13** into tetra-aldehyde **14** and tetra-β-keto-ester **15** (this work).

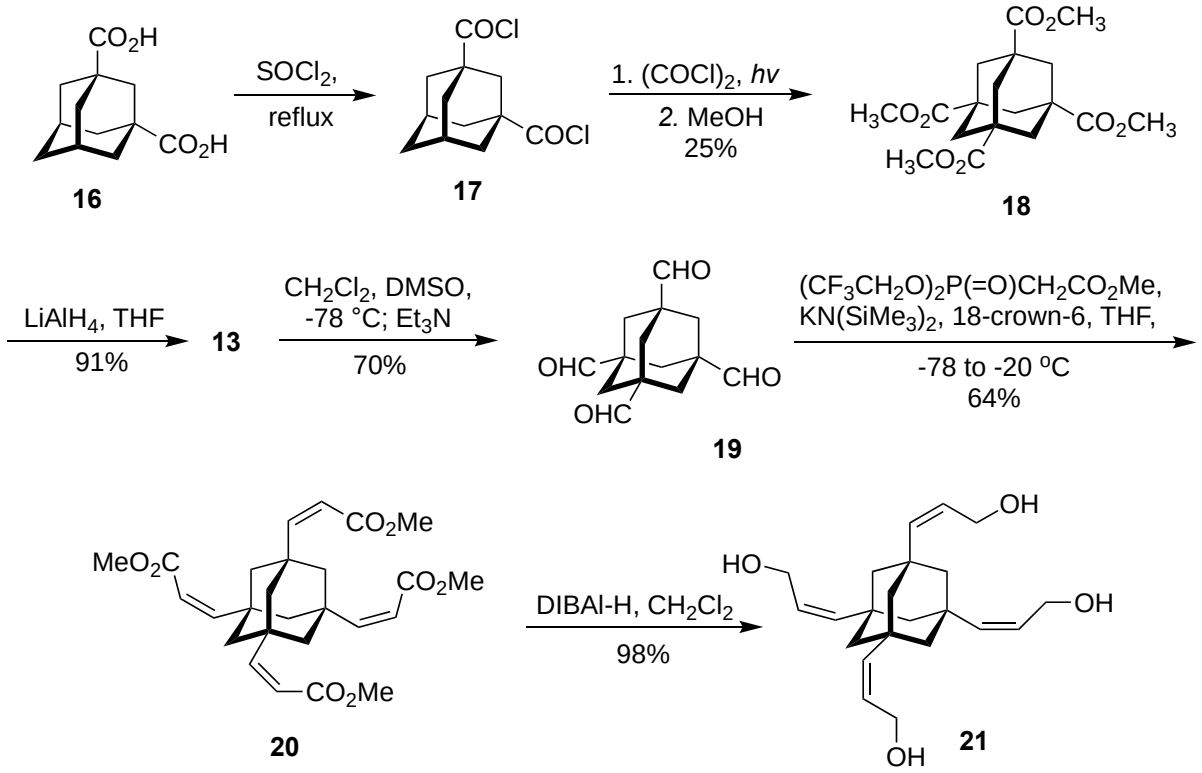
Results and Discussion

Four-directional homologation of 1,3,5,7-adamantanetetracarboxylic acid derivatives

Tetramethyl 1,3,5,7-adamantanetetracarboxylate (**18**) was synthesized from 1,3-adamantanedicarboxylic acid (**16**) by a modification of Bashir-Hashemi and Li's method.[30] Since dicarboxylic acid **16** is of low solubility in oxalyl chloride, the dicarboxylic acid **16** was first converted into the more soluble dichloride **17**[31] with thionyl chloride. This was dissolved in oxalyl chloride and irradiated at 20 °C using a medium pressure mercury-vapor lamp (450 Watts) in a quartz vessel to provide, on methanolysis, the tetra-ester **18** in variable yield (25% on a 10 g scale to 43% on a 2 g scale) depending on the efficiency of irradiation decreasing with scale. Reduction of

tetra-ester **18** using lithium aluminum hydride gave the corresponding tetraol **13** (91%). Attempted oxidation of the tetraol **13** to the corresponding tetra-aldehyde **19** was complicated due to its poor solubility in non-polar solvents. Nonetheless it was soluble in solvents such as MeOH, THF or DMSO. Dess-Martin oxidation of tetraol **13** (50 mg scale) in a mixed-solvent system (dichloromethane/DMSO, 2:1), which was necessary to dissolve the substrate, gave tetra-aldehyde **19** (45%, 40 mg scale) but this yield was not reproductible on a larger scale (32%, 80 mg scale). Swern oxidation of tetraol **13** in the same mixed-solvent system (dichloromethane/DMSO)[17] gave tetra-aldehyde **19** in a significantly better yield (70%, 1 g scale).

(*Z*)-Selective Horner-Emmons reaction of tetra-aldehyde **19** under Still-Gennari conditions[32] at −78 °C provided an inseparable mixture of the desired product **20** and the incomplete olefination products, however reaction at −20 °C gave the tetra-alkene **20** as the sole product in 64% yield. From ^{1}H NMR spectroscopy, the coupling constant between two olefinic protons was *J* 13.1 Hz, which is consistent with all four alkenes possessing the *cis* geometry.[33] Finally, DIBAl-H reduction of tetra-ester **20** gave the tetra-(*Z*)-allylic alcohol **21** in excellent yield (98%) (Scheme 5). The *cis*-geometry and constitution were unambiguously confirmed by a single crystal X-ray structure determination (see Supplementary Material: Appendix-1).

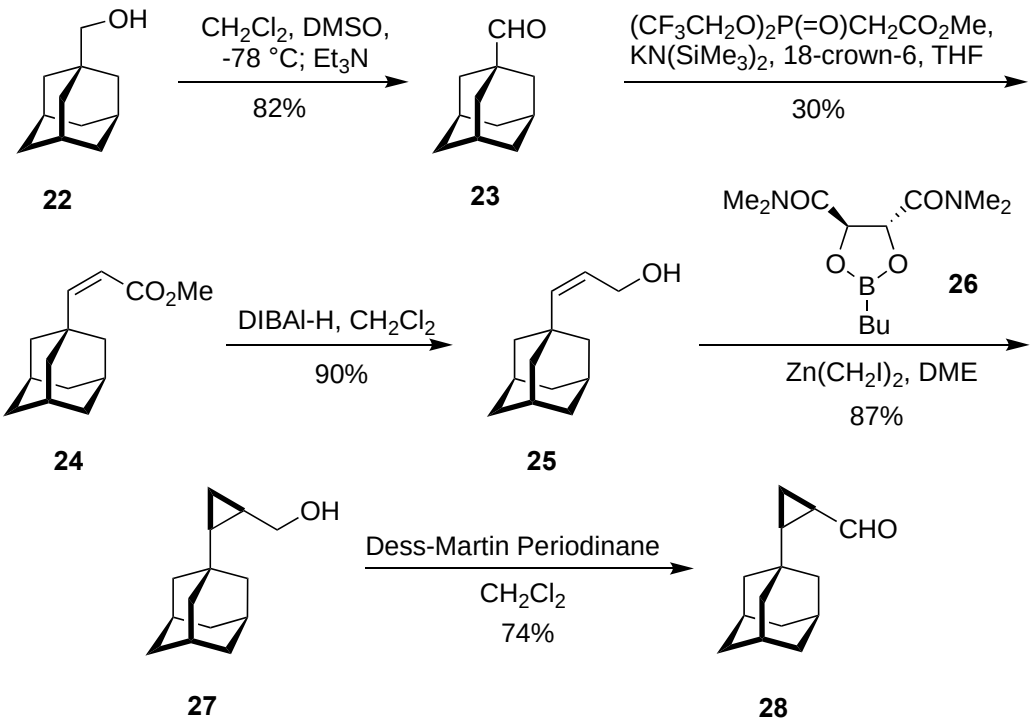


Scheme 5. Synthesis of tetraol **21** using photochemical substitution and (*Z*)-selective Horner-Emmons reaction.

The tetra-(*Z*)-allylic alcohol **21** was of low solubility and this caused significant problems in attempted tetra-cyclopropanation reactions. Prolonged reactions using samarium amalgam or samarium(II) iodide with diiodomethane or chloroiodomethane[34] failed to provide any identifiable cyclopropanated products. Additionally, the tetra-(*Z*)-allylic alcohol **21** was recovered unchanged on attempted tetra-cyclopropanation using the Charette's procedure.[35] Although, in this reaction, the tetra-(*Z*)-allylic alcohol **21** has very low solubility in the solvent CH_2Cl_2, it was anticipated that the intermediate zinc-alkoxide species formed from $Zn(CH_2I)_2$ and tetraol **21** would result in desymmetrization and enhanced solubility. This proved incorrect and the Charette reaction gave only unreacted starting material. Attempted transient desymmetrization of tetra-

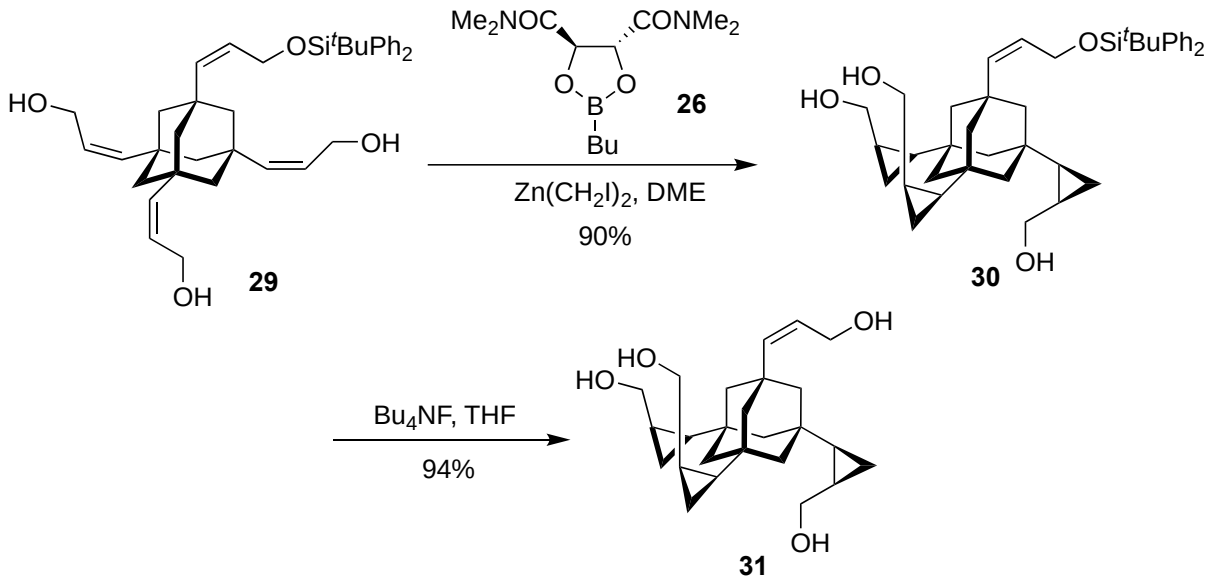
(*Z*)-allylic alcohol **21** by alkoxide exchange using trimethyl borate and subsequent Charette reaction also gave unreacted tetraol **21**.

Since direct cyclopropanation of tetra-*cis*-alkene **21** had failed to produce any desired tetra-cyclopropane, the corresponding reactions with allylic alcohol **25** were examined to underscore that the failure in the tetracyclopropanation reaction was solely due to poor solubility. Thus, Swern oxidation of commercially available 1-adamantanemethanol (**22**) gave rise to aldehyde **23** (82%). This product **23** was subject to the (*Z*)-selective Horner-Emmons olefination of aldehyde **23** under Still-Gennari conditions,[32] which provided the desired *cis*-olefin **24** in low but unoptimized yield (30%), owing to the low solubility of **23** in THF. DIBAl-H reduction of ester **24** gave allylic alcohol **25** (90%), which smoothly underwent Charette cyclopropanation to produce the cyclopropyl alcohol **27** (87%). Oxidation of alcohol **27** by Dess-Martin periodinane gave the corresponding aldehyde **28** (Scheme 6). These results clearly indicated that the failure in our attempted tetracyclopropanation of tetra-*cis*-alkene **21** under Charette conditions was only the result of low solubility.



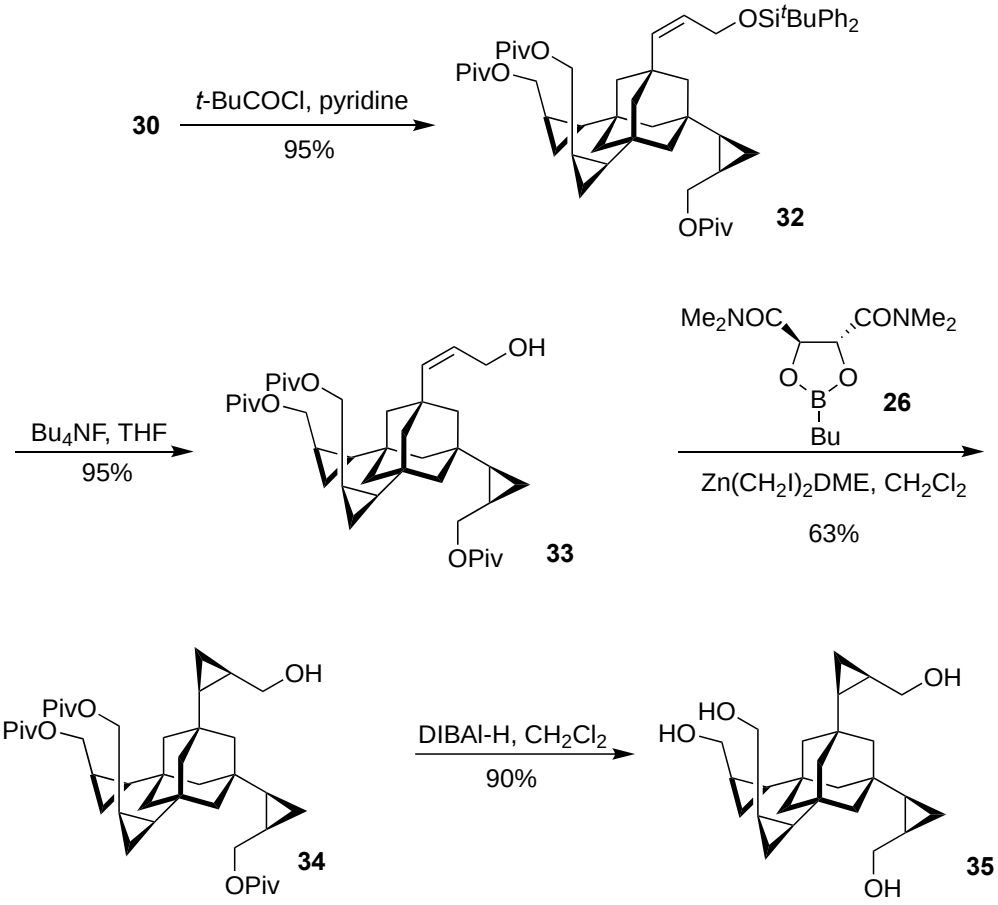
Scheme 6. Synthesis of cyclopropane **28** using (*Z*)-selective Horner-Emmons and Charette Cyclopropanation.

In order to overcome the reactivity issues with the four-directional approach, desymmetrization and a three-directional strategy was examined. Mono-protection of tetraol **21** with *t*-butyldiphenylsilyl chloride in pyridine at room temperature gave the mono-silyl derivative **29** (44%, 66% allowing for 33% recovered starting material). To our delight, triol **29** was soluble in dichloromethane and smoothly underwent triple Charette[35] cyclopropanation to produce tricyclopropane **30** (90%) and this was desilylated using tetra-*n*-butylammonium fluoride in THF to give the tetraol **31** (94%) (Scheme 7). Unfortunately, this tetraol **31** being insoluble in dichloromethane was inert to the Charette reagent.



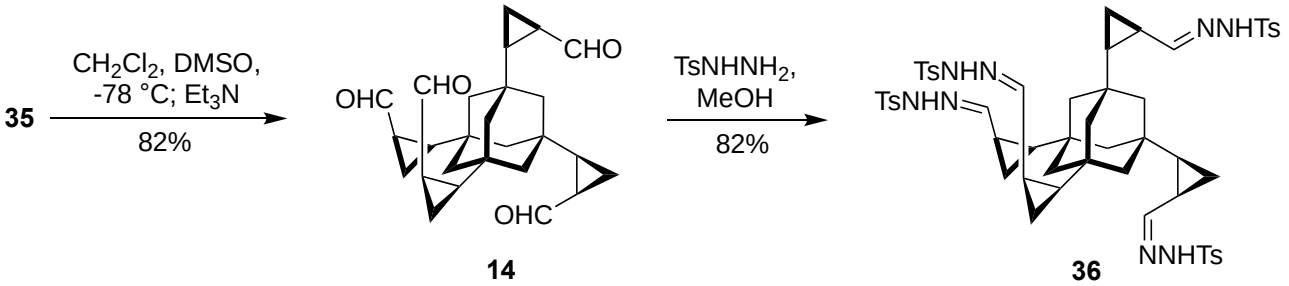
Scheme 7. Synthesis and three directional Charette enantioselective cyclopropanation of triol **29**.

This solubility problem associated with tetraol **31** was circumvented by triple pivaloylation. Thus, acylation of triol **30** with pivaloyl chloride in pyridine gave the triester **32** (95%), which was desilylated to give the allylic alcohol **33** (95%). Charette cyclopropanation of the dichloromethane soluble allylic alcohol **33** gave the tetra-cyclopropane **34** (63%). Finally, the key intermediate tetra-*syn*-cyclopropyl alcohol **35** (90%) was obtained by DIBAl-H reductive deacylation of the tri-pivaloate **34** (Scheme 8). The constitution of the tetra-*syn*-cyclopropyl alcohol **35** was confirmed by a single crystal X-ray structure determination (see Supplementary Material: Appendix-2). We were unable to define the absolute stereochemistry due to the lack of heavy atoms in the molecule. Perhaps unsurprisingly, the structure is disordered and actually shows an inversion of chirality in one of the four cyclopropyl arms. The figures in Appendix-2 show both diastereoisomers individually and overlapped, with the major diastereoisomer **35A** being *ca*. 64% occupancy, and the minor diastereoisomer **35B** *ca*. 36% occupancy and with each diastereoisomer possessing greater than 95% optical purity. Presumably, the final cyclopropanation reaction showed significantly lower diastereoselectivity than expected with the Charette chiral boronate **26** additive and/or recrystallization enhanced the percentage of the minor diastereoisomer. The ^{13}C NMR spectrum of the tetraol **35** did not show any duplication of any peaks.



Scheme 8. Completion of the synthesis of target tetra-*syn*-cyclopropyl alcohol **35**.

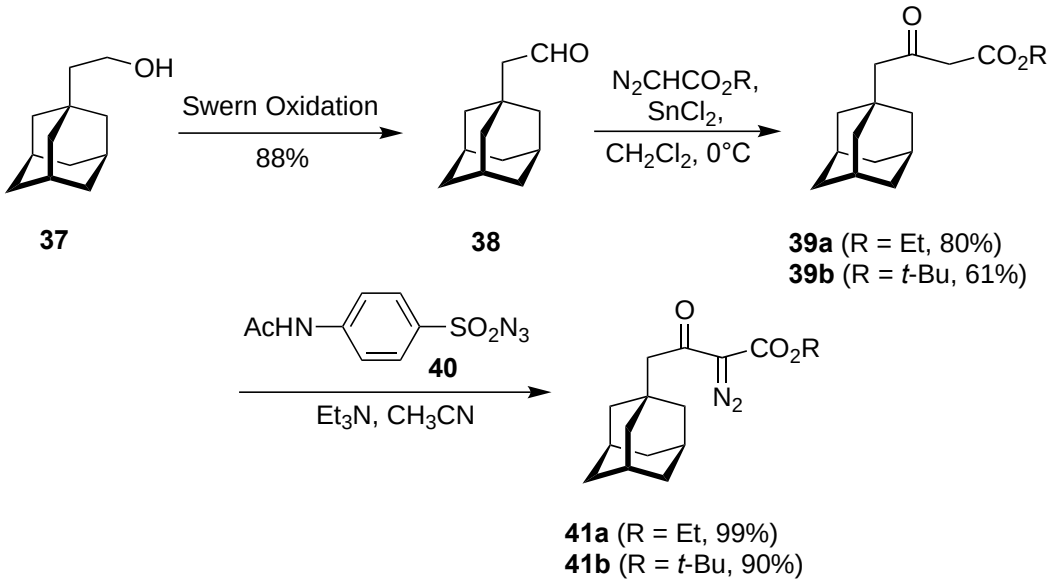
Swern oxidation of tetraol **35** was carried out in DMSO and dichloromethane solution due to poor solubility in dichloromethane alone. This gave the tetra-aldehyde **14** and subsequent condensation with *p*-toluenesulfonylhydrazine gave the derived tetra-tosylhydrazone **36** (82%) (Scheme 9). Attempts to generate tetra-carbene C–H insertion or fragmentation products from the tetra-tosylhydrazone **36** by conversion to the derived tetra-potassium salt, generated with either potassium *tert*-butoxide or potassium hexamethyldisilazide, and aprotic Bamford Stevens thermolysis at 138 °C or reaction with dirhodium tetraacetate in the presence of the phase transfer catalysts benzyltriethylammonium chloride or 18-crown-6[36] in dioxane or dichloromethane gave only intractable materials. Evidence for the formation of potassium salt from tetra-tosylhydrazone **36** was seen in the IR spectum with shifts of the sulfone stretches from 1332 and 1162 cm^{-1} to 1228 and 1126 cm^{-1} on reaction with the two bases.



Scheme 9. Synthesis of tetra-4-toluenesulfonylhydrazone **36**.

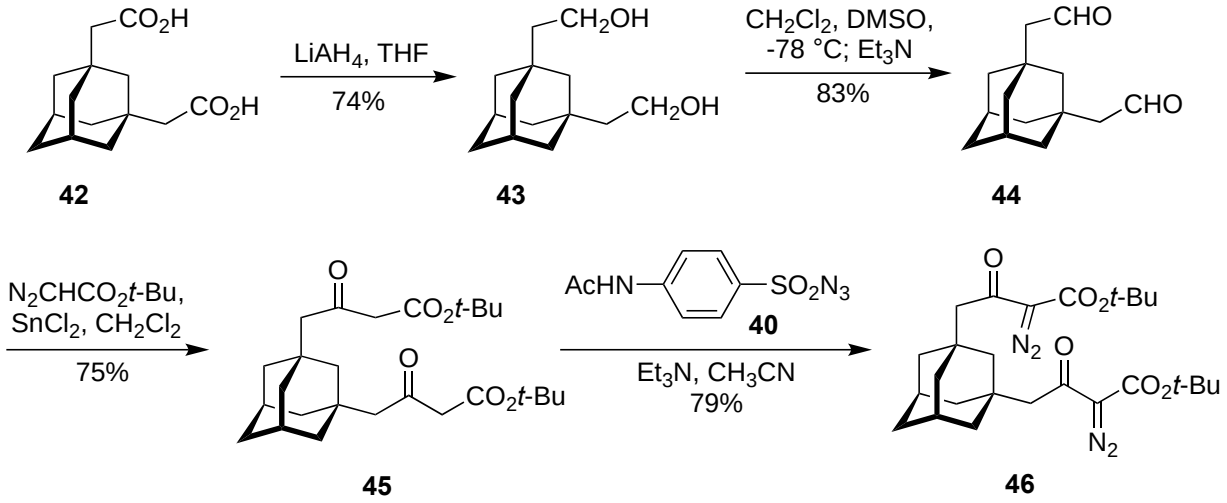
Four-directional homologation of 1,3,5,7-adamantanetetraacetic acid derivatives

In the light of the difficulties with the four-directional reactions to synthesize the adamantane derivatives **35** and **14**, studies on four-directional rhodium catalyzed C–H insertion reactions of adamantanes functionalized with four tertiary α-diazo-β-keto-ester units were carried out. Three model adamantane systems with one α-diazo-β-keto-ester unit and two α-diazo-β-keto-ester units were also synthesized. The known aldehyde **38** was synthesized from the commercially available alcohol **37** by Swern oxidation.[37] Interestingly, upon standing overnight at room temperature, the aldehyde **38** underwent hydration to give the corresponding geminal diol very easily. Therefore aldehyde **38** was used in the next step immediately following its purification. Treatment of freshly prepared aldehyde **38** with ethyl diazoacetate in the presence of a catalytic amount of tin(II) chloride[38] smoothly gave β-keto-ester **39a** as a 4:1 mixture of enol and keto tautomers. Finally, diazo transfer reaction of β-keto ester **39a** with 4-acetamidobenzenesulfonyl azide (**40**)[39] gave the α-diazo-β-keto-ester **41a** (99%). The aldehyde **38** was converted by the same method via β-keto-ester **39b** (61%) into the α-diazo-β-keto-ester **41b** (90%) (Scheme 10).



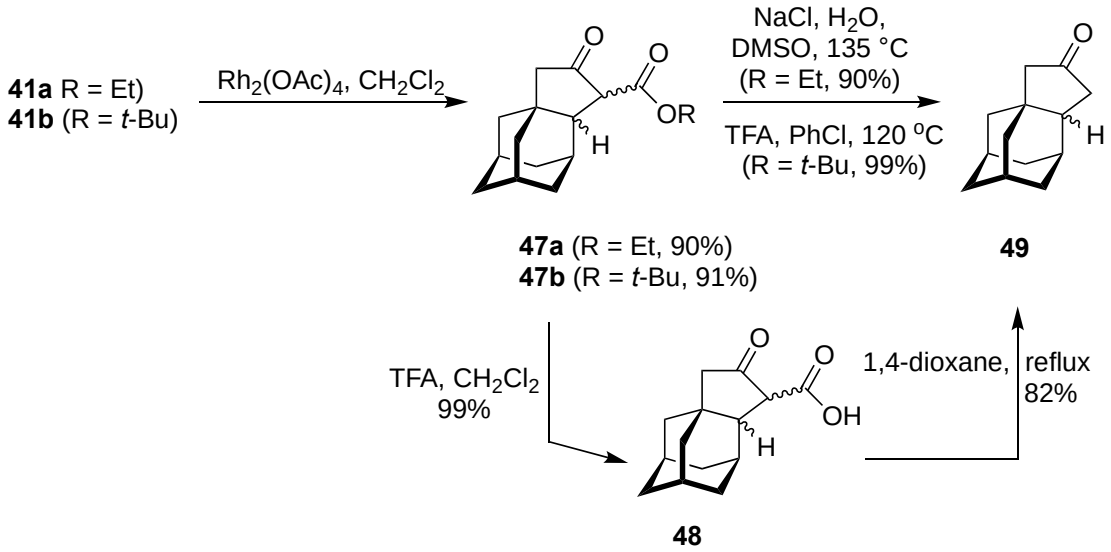
Scheme 10. Syntheses of α-diazo-β-keto-esters **41**.

The commercially available di-carboxylic acid **42** was reduced to the corresponding diol **43**[40] (74%) using lithium aluminum hydride. Swern oxidation of diol **43** gave dialdehyde **44**, which was allowed to react with *tert*-butyl diazoacetate in the presence of tin(II) chloride to give the di-β-keto ester **45** (75%). The diazo transfer reaction[39] was used again to convert di-β-keto ester **45** to the desired di-α-diazo-β-keto-ester **46** (Scheme 11).



Scheme 11. Synthesis of di-α-diazo-β-keto-ester **46**.

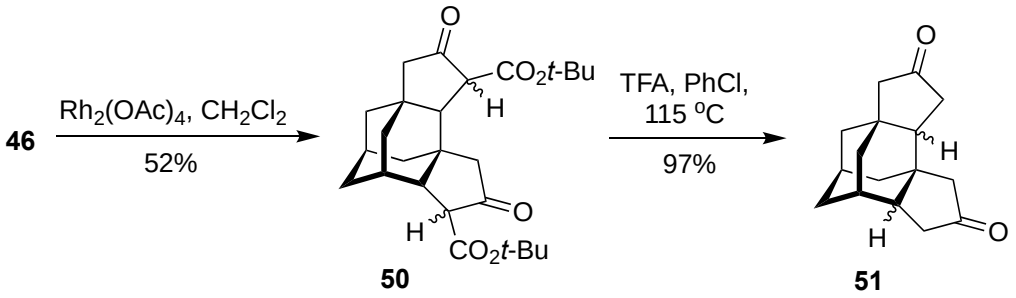
Dirhodium tetraacetate catalyzed carbene insertion of α-diazo-β-keto-esters **41a** and **41b** proceeded smoothly at room temperature to generate the cyclized products **47a** (90%) and **47b** (91%) both as single undetermined racemic stereoisomers. Respective Krapcho deethoxycarbonylation[41] and TFA catalyzed *t*-butyl ester cleavage and decarboxylation in chlorobenzene at 120 °C gave the same fused cyclopentanone **49**[42] (90 and 99% respectively). Alternatively, TFA catalyzed *t*-butyl ester cleavage in dichloromethane at room temperature gave the β-keto-carboxylic acid **48** (99%) and this smoothly gave the fused cyclopentanone **49** (82%) on reflux in 1,4-dioxane (Scheme 12).



Scheme 12. Rhodium catalyzed C–H insertion reactions of α-diazo-β-keto-esters **41** and synthesis of ketone **49**.

Double dirhodium tetraacetate catalyzed carbene insertion of di-α-diazo-β-keto-ester **46** gave the doubly cyclized product **50** (52%) along with minor unidentified by-products. Subsequent de-*t*-butylation and decarboxylation catalyzed by TFA in chlorobenzene at 115 °C proceeded smoothly and gave the di-cyclopentanone **51** (97%) as an unidentified racemic stereoisomer (Scheme 13). It should be noted that

there are many possible stereo- and regio-isomers arising from the double carbene insertion reaction of di-α-diazo-β-keto-ester **46**. For example, the final diketone **51** could either have the *syn*-**51** and/or the *anti*-**51** constitution and each of these could have the meso- and/or (±)-stereochemistry (**Figure 1**).



Scheme 13. Rhodium catalyzed C–H insertion reactions of α-diazo-β-keto-ester **46** and synthesis of dione **51**.

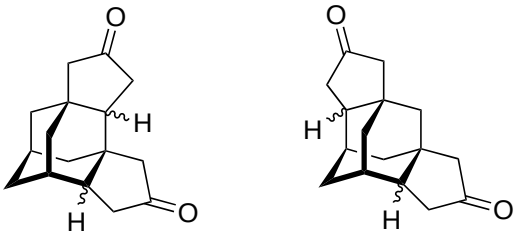
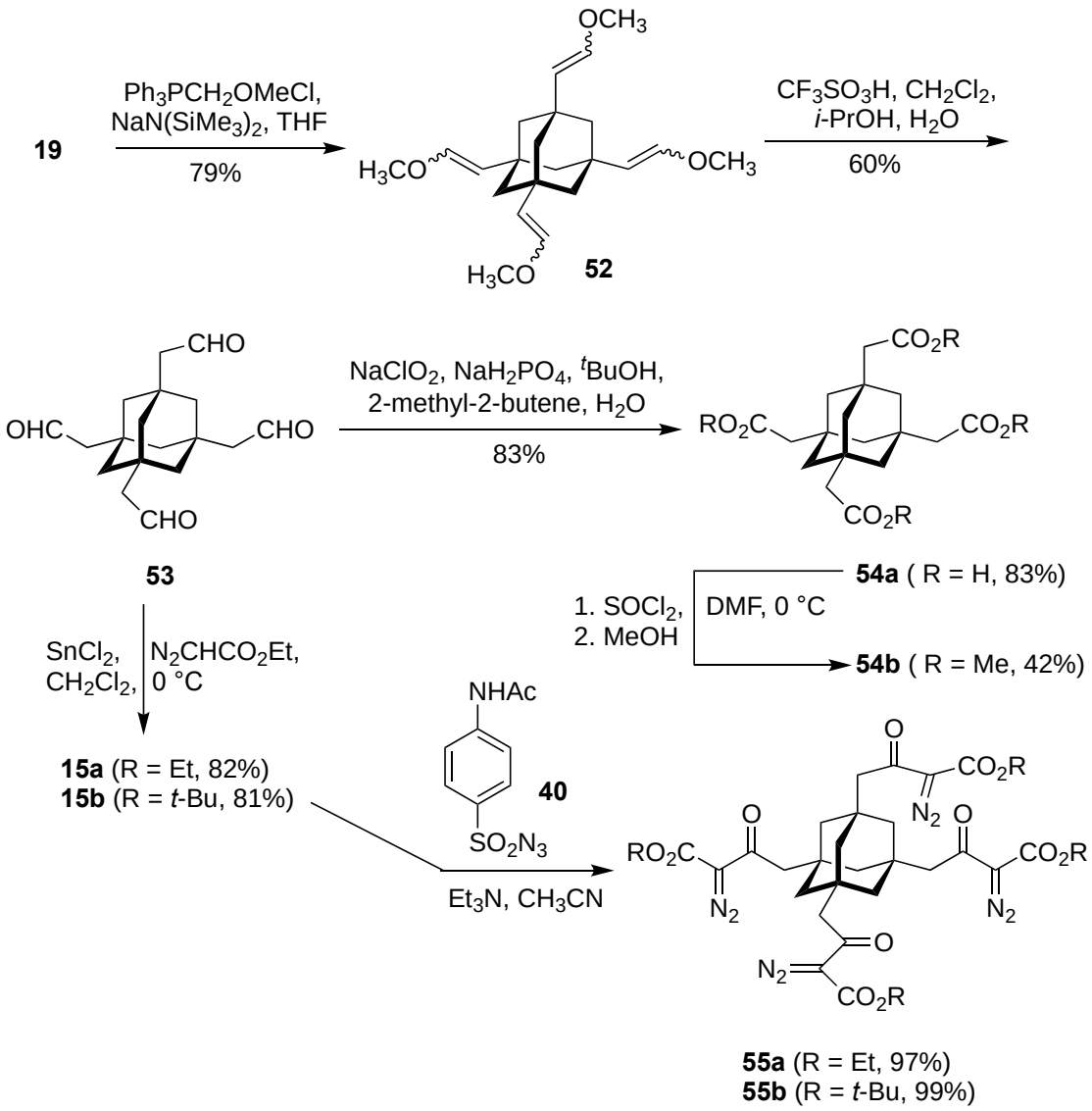


Figure 1. Possible isomers of ketone **51**.

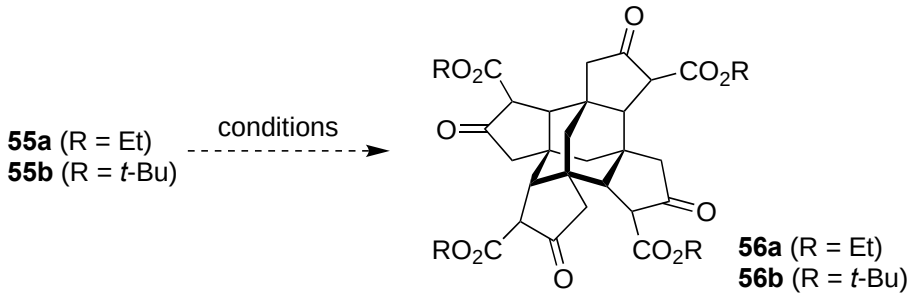
Wittig reaction[17] of tetra-aldehyde **19** with excess of methoxymethyl-triphenylphosphonium chloride and sodium hexamethyldisilazane gave tetra-enol ether **52** (79%) as a mixture of (*E*)- and (*Z*)-olefins. Hydrolysis using triflic acid in aqueous dichloromethane and *iso*-propanol gave the tetra-aldehyde **53** (60%). The yield of tetra-aldehyde **53** was inferior if the intermediate enol ether **52** was not isolated due to greater difficulty in purification. Pinnick oxidation[43] of tetra-aldehyde **53** smoothly gave the desired tetra-acid **54a** (83%), which was converted *via* the tetra-acyl chloride (IR 1802 cm^{-1}) into the tetramethyl ester **54b** (42%). Attempts to convert the tetra-acid **54a** *via* its derived tetra-acyl chloride or via its tetra-mixed anhydride with ethyl chloroformate to the derived tetra-diazo-ketone by reaction with diazomethane gave only intractable mixtures of products. In contrast tetra-aldehyde **53** was smoothly converted into the tetra-β-keto-ester **15a** (82%), which was obtained as a mixture of enol and keto-tautomers (ca 3 : 1), by reaction with ethyl diazoacetate in the presence of tin(II) chloride[38] and subsequently into the tetra-α-diazo-β-keto-ester **55a** (97%) by diazo transfer from 4-acetamidobenzenesulfonyl azide (**40**).[39] In the same way, the tetra-aldehyde **53** was readily converted into the tetra-β-keto-ester **15b** (81%), which was obtained as a mixture of enol and keto-tautomers (ca 4 : 1), and thence into the tetra-α-diazo-β-keto-ester **55b** (99%) (Scheme 14).



Scheme 14. Conversion of tetra-aldehyde **19** via tetra-aldehyde **53** into tetra-α-diazo-β-keto-esters **55a** and **55b**.

A range of catalysts were examined for the attempted quadruple C–H insertion reaction of tetra-α-diazo-β-keto-ester **55a**. Reactions using dirhodium tetraacetate in dilute solution (0.01 M) in dichloromethane at room temperature, copper sulfate or copper iodide in toluene at room temperature or reflux all were unsuccessful. In contrast, catalysis using dirhodium tetra-carboxylate (acetate, trifluoroacetate, perfluorobutyrate, octanoate) salts at reflux in toluene or trifluoromethylbenzene gave an isolable fraction by chromatography that may have contained carbene insertion products. For example, catalysis with dirhodium tetra-octanoate in toluene at reflux with slow addition of the tetra-α-diazo-β-keto-ester **55a** gave a complex product mixture that may have contained the tetra-β-keto-ester **56a**. The ^{1}H and ^{13}C NMR spectra of the product was complex presumably due to the presence of multiple isomers and the molecular ion could not be detected in the mass spectrum, although the IR spectrum was consistent with the presence of ester and keto-carbonyl groups (keto-ester **47a** at 1755 and 1724 cm^{-1} and tetra-β-keto-ester **56a** at 1753 and 1725 cm^{-1}). Attempted Krapcho deethoxycarbonylation[41] of the product mixture failed to produce identifiable products.

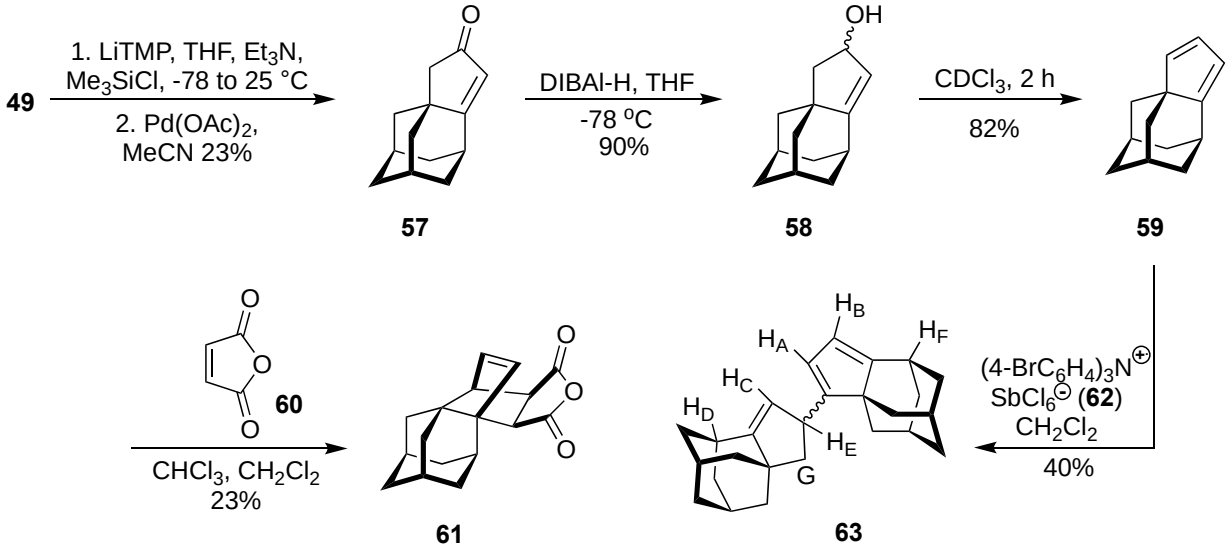
Reaction of the tetra-α-diazo-β-keto-ester **55b** with dirhodium tetra-octanoate in toluene (0.01M) at reflux with slow addition of the substrate gave a complex product mixture that may have contained the tetra-β-keto-ester **56b**. Again, this structural assignment was tentative since the ^{1}H and ^{13}C NMR spectra of the product was complex presumably due to the presence of multiple isomers and the molecular ion could not be detected in the mass spectrum, although the IR spectrum was consistent with the presence of an ester and keto-carbonyl groups (1747 and 1722 cm^{-1}) (Scheme 15). Attempted global de-*t*-butylation and decarboxylation catalyzed by TFA using the one step or two step methods in Scheme 12, failed to provide any isolable material although the *t*-butyl esters were cleaved.



Scheme 15. Attempted syntheses of tetra-β-keto-esters **56**.

Synthesis of and Dimerization of Adamantanocyclopentadiene 59

Ketone **49** was synthesized by the methods in Scheme 12 and additionally by sequential reaction of 1-adamantaneacetic acid with thionyl chloride, diazomethane in diethyl ether and copper sulfate in toluene at reflux.[42] Conversion to the cyclopentenone **57** was carried out in modest yield (23% with 32% recovery of starting material) by enol silane formation with lithium 2,2,6,6-tetramethylpiperidide (LiTMP), trimethylsilyl chloride and triethylamine and Saegusa oxidation with palladium acetate. DIBAl-H reduction of the cyclopentenone **57** at −78 °C gave the allylic alcohol **58** (90%) and this delicate compound underwent complete dehydration, presumably DCl catalyzed, in deuterated chloroform over 2 hours during the recording of NMR spectra to produce diene **59** (82% isolated yield) (Scheme 16).



Scheme 16. Synthesis and reactions of cyclopentadiene derivative **59**.

Diene **59** underwent a Diels-Alder reaction with maleic anhydride (**60**) to produce the adduct **61** (23% unoptimized). Whilst diene **59** did not undergo dimerization by a self-Diels-Alder reaction on standing for 23 days, it did undergo an alternative dimerization reaction in the presence of tris(*p*-bromophenyl)aminium hexachloroantimonate (**62**), a known SET acceptor for mediating Diels-Alder reactions via diene cation radicals.[44] Of particular interest in this context is the known Diels-Alder rapid dimerization of 1,3-cyclohexadiene mediated by an SET pathway with aminium cation radical modulators, although 1,3-cyclohexadiene in known not to be normally reactive towards such self-Diels-Alder reactions below 200 °C. Attempted SET-Diels-Alder reaction of diene **59** gave an adduct that was assigned as dimer **63** (40%). Clearly a product this unexpected requires some further discussion with regard to its assignment.

The proposed structure **63** was elucidated based on the following key facts and explanations: (1) the dimer **63** has the molecular formula of $C_{26}H_{32}$ as confirmed by MS and high resolution MS; (2) there are three vinyl protons (δ 6.30, 5.93, 5.21 ppm) in the ^{1}H NMR spectrum; (3) there are three quaternary olefinic carbons (δ 162.2, 157.9 and 153.0 ppm) and three tertiary olefinic carbons (δ 123.9, 117.4, 114.6 ppm) in ^{13}C NMR and ^{13}C DEPT spectra (see Supplementary Material: Appendix-3); (4) there are two adjacent vinyl protons (δ 6.30 and 5.93 ppm), which are correlated to each other have the coupling constant of 1.9 Hz in the ^{1}H NMR and ^{1}H COSY spectra and this coupling constant is consistent with bonding B and not bonding A below (**Figure 2**); (5) there are three relatively low-field proton signals (δ 3.74 ppm, 2.98 ppm and 2.75 ppm) and these protons must be positioned next to a carbon-carbon double bond (H_D, H_E and H_F in the structure **63** in Scheme 16); (6) there is one proton (δ 3.72 ppm) next to a carbon-carbon double bond has the correlation with one vinyl proton and two protons in a CH_2 unit from the ^{1}H COSY and ^{1}H/^{13}C correlation spectra (see Appendix-3) (H_E in the structure **63** in Scheme 16); (7) the λ_{max} in the UV spectrum is at 262 nm (log ε) 262 (3.76) is inconsistent with the alkene and cyclopentadiene units being in conjugation since 1,4,5,5-tetramethylcyclopentadiene shows a λ_{max} of 258 nm[45] and if the third double bond was conjugated with the cyclopentadiene unit, the absorption maximum should be significantly red shifted. In spite of these considerations, the structural assignment for the dimer **63** must, in the absence of an X-ray crystallographic structure determination, be considered tentative.

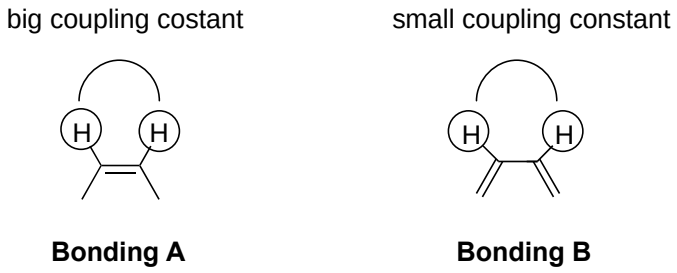


Figure 2. Vinyl coupling constants in the ^{1}H NMR relevant to the constitution of dimer **63**.

Conclusions

It is clear that not all transformations are readily amenable to four-directional synthesis of adamantane derivatives either for issues of low solubilities and/or the formation of multiple products. Nonetheless, (*Z*)-selective Horner-Emmons reaction of tetra-aldehyde **19** under Still-Gennari conditions, DIBAl-H reduction of

tetra-ester **20**, Wittig reaction of tetra-aldehyde **19** with methoxymethylenetriphenylphosphorane and subsequent Pinnick oxidation of the derived tetra-aldehyde **53**, Roskamp coupling of condensation of tetra-aldehyde **53** with both ethyl and *t*-butyl diazoacetate and conversions of the derived β-keto-esters **15a** and **15b** with 4-acetamidobenzenesulfonyl azide (**40**) to produce the α-diazo-β-keto-esters **55a** and **55b** all worked well in a four-directional sense. Although, three-directional Charette enantioselective cyclopropanation of triol **29** was successful, the equivalent four-directional reaction on tetraol **21** failed due to low solubility. Whilst one-directional rhodium catalyzed C–H insertion of the carbene derived from α-diazo-β-keto-esters **41a** and **41b** and two-directional rhodium catalyzed C–H insertion of the carbenes derived from the di-α-diazo-β-keto-ester **46** all gave adamantane-cyclopentanone annulation products **47a**, **47b** and **50** and thence **48**, **49**, **50** and **51**, related four-directional carbene reactions gave only intractable mixtures. The adamantane cyclopentadiene **59** underwent dimerization to the adduct **63** and not to the Diels-Alder product.

Experimental Section

General. Melting points were obtained on a hot stage melting point apparatus and are uncorrected. Infrared spectra were recorded as thin films on sodium chloride plates with absorptions reported in wavenumbers (cm^{-1}). ^1H NMR spectra were recorded at 300 MHz, 400 MHz and 500 MHz with chemical shifts (δ) quoted in parts per million (ppm) and referenced to the residual solvent peak, 7.27 for $CDCl_3$, 7.15 for C_6D_6, 3.34 for methanol-d_4, 2.52 for DMSO-d_6. ^{13}C NMR spectra were recorded at 75 MHz, 100 MHz and 125 MHz with chemical shifts (δ) quoted in parts per million (ppm) and referenced to the residual solvent peak, 77.0 for $CDCl_3$, 128.6 for C_6D_6, 49.9 for methanol-d_4, 39.7 for DMSO-d_6. Coupling constants (*J*) are quoted in Hertz (Hz) for both ^1H and ^{13}C NMR spectra.

All reactions were carried out in oven or flame-dried glassware under an inert atmosphere of nitrogen or argon. Reaction temperatures other than room temperature were recorded as bath temperatures unless otherwise stated. CH_2Cl_2, MeOH, pyridine and Et_3N were distilled from calcium hydride under a nitrogen atmosphere. Et_2O and THF were distilled from sodium benzophenone ketyl under a nitrogen atmosphere. PhMe was distilled from sodium under a nitrogen atmosphere. Column chromatography was performed on silica gel 60, particle size 20-63 μm or particle size 33-70 μm. TLC was performed on silica gel 60 F_{254} glass-backed plates with visualization under ultraviolet light 254 nm and/or by chemical staining using a potassium permanganate dip and drying with a heat gun.

Tetramethyl 1,3,5,7-Adamantanetetracarboxylate (18). 1,3-Adamantanedicarboxylic acid **16** (10.0 g, 44.6 mmol) and freshly distilled thionyl chloride (60 mL) were heated at reflux with vigorous stirring for 2 h and the excess thionyl chloride was removed *in vacuo*. The mixture was cooled to room temperature and dry PhH (50 mL) was added which was further removed *in vacuo* to give an off-white solid, which was stored under vacuum for 12 h to leave crude 1,3-adamantanedicarbonyl chloride **17** (11.7 g) as an off-white solid. This material showed spectroscopic data consistent with the reported values.[31] 1,3-Adamantanedicarbonyl chloride **17** (11.7 g, 44.6 mmol) in oxalyl chloride (130 mL) was irradiated at 20 °C by a medium pressure mercury-vapor lamp (450 Watts) immersed into a double-walled quartz well with inlet and outlet tubes for cooling. The reaction vessel constructed of glass was placed outside the immersion well with one vertical joint for the condenser. After 16 h of irradiation, the excess oxalyl chloride was removed on a rotary evaporator and the residue was stirred with dry MeOH (80 mL) at room temperature overnight. The mixture was concentrated *in vacuo*, the oily residue was dissolved in EtOAc (100 mL), washed with 5% aqueous Na_2CO_3 (30

mL) and brine (30 mL) and the organic layer was dried ($MgSO_4$), and concentrated *in vacuo*. The residue was triturated with the minimal amount of MeOH and the solid filtered off and dried under vacuum to give tetra-ester **18** (4.2 g; 25%, over 2 steps) as colorless crystals: mp 167 - 168 °C (hexanes : EtOAc, 5 : 1) (lit.[30] mp 168 - 170 °C); R_f 0.36 (hexanes : EtOAc, 2 : 1); IR (film) 1725, 1429, 1306 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 3.69 (s, 12H, OCH_3), 1.99 (s, 12H, CH_2); ^{13}C NMR (75 MHz, $CDCl_3$) δ 175.5, 52.1, 41.7, 38.5; MS (ES) *m/z* 369 ($M + H^+$); HRMS (ES) *m/z* calc for $C_{18}H_{25}O_8$ 369.1549, found: 369.1559.

1,3,5,7-Tetrakis(hydroxymethyl)adamantane (13).[18] Tetra-ester **18** (3.0 g, 8.15 mmol) in THF (40 mL) was added dropwise with stirring to a suspension of $LiAlH_4$ (1.24 g, 32.6 mmol) in THF (32 mL) at 0 °C under argon. The mixture was heated at reflux for 3 h, cooled and saturated aqueous Na_2SO_4 (2.43 mL) was added carefully to with stirring to quench the reaction. After 30 min, THF (40 mL), MeOH (40 mL) and silica gel (2.0 g) were added, and the mixture was filtered through a short pad of Celite. Rotary evaporation and flash chromatography (CH_2Cl_2 : MeOH, 10:1 to 8:1) to give tetraol **13** (1.90 g, 91%) as a white solid: mp 226 - 228 °C (MeOH) (lit.[18] mp 231 - 232 °C); R_f 0.36 (CH_2Cl_2 : MeOH, 4 : 1); IR (film) 3323 broad, 2919, 2851, 1576 cm^{-1}; ^1H NMR (300 MHz, MeOH-d_4) δ 3.26 (s, 8H, CH_2OH), 1.21 (s, 12H, CH_2); ^{13}C NMR (75 MHz, MeOH-d_4) δ 73.3, 41.5, 37.2; MS (EI) *m/z* 256 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{14}H_{24}O_4$ 256.1675, found: 256.1678.

1,3,5,7-Adamantanetetracarboxaldehyde (19).[17] Anhydrous DMSO (4.66 mL, 65.7 mmol) in CH_2Cl_2 (12 mL) was added over 10 min with vigorous stirring to oxalyl chloride (2.82 mL, 32.9 mmol) in CH_2Cl_2 (18 mL) at −78 °C. After 15 min, tetraol **13** (990 mg, 3.87 mmol) in anhydrous DMSO (15 mL) and CH_2Cl_2 (30 mL) was added dropwise over 10 min, and the reaction mixture was stirred at −78 °C for 1 h. Et_3N (22 mL) was added dropwise with stirring, the mixture was allowed to warm up to room temperature, H_2O (60 mL) was added and the two phases were separated. The organic layer was washed with 5% aqueous HCl (20 mL), H_2O (20 mL), 5% aqueous $NaHCO_3$ solution (40 mL) and brine (20 mL), dried ($MgSO_4$), concentrated *in vacuo* and the residue chromatographed (hexanes : EtOAc : MeOH, 1 : 1 : 0.02) to afford the tetra-aldehyde **19** (670 mg, 70%) as a white solid: R_f 0.26 (hexanes : EtOAc : MeOH, 1 : 1 : 0.2); mp 142 - 144 °C (EtOAc) (lit.[17] mp 143 - 145 °C); IR (film) 2935, 2856, 1719, 1449 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 9.51 (s, 4H, C*H*O), 1.79 (s, 12H, CH_2); ^{13}C NMR (75 MHz, $CDCl_3$) δ 201.8, 44.8, 33.7; MS (EI) *m/z* 248 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{14}H_{16}O_4$ 248.1049, found: 248.1054.

Tetramethyl 3,3',3'',3'''-(Adamantane-1,3,5,7-tetrayl)(2*Z*,2'*Z*,2''*Z*,2'''*Z*)-tetraacrylate (20). $KN(TMS)_2$ in PhMe (0.5 M; 4.26 mL, 2.13 mmol) was added dropwise with stirring to 18-crown-6 (2.80 g, 10.6 mmol) and bis(2,2,2-trifluoroethyl) (methoxycarbonylmethyl)phosphonate (762 mg, 2.40 mmol) in THF (3 mL) at −78 °C. After 30 min, tetra-aldehyde **19** (66 mg, 0.266 mmol) in THF (4 mL) was added and the mixture was allowed to warm up to −20 °C over 2.5 h, when reaction was quenched with saturated aqueous NH_4Cl (5 mL). The separated aqueous layer was extracted with EtOAc (3 x 8 mL) and the combined organic layers were washed with brine, dried ($MgSO_4$), concentrated *in vacuo* and the residue chromatographed (hexanes : EtOAc, 8 : 1) to give the tetra-ester **20** (80 mg, 64%) as a thick oil: R_f 0.57 (hexanes : EtOAc, 2 : 1); IR (film) 2951, 2920, 1726 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.85 (d, *J* 13.1 Hz, 4H, C*H*=CHCO$_2$Me), 5.70 (d, *J* 13.1 Hz, 4H, CH=C*H*CO$_2$Me), 3.72 (s, 12H, OCH_3), 1.97 (s, 12H, CH_2); ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.8, 153.6, 119.3, 51.4, 42.0, 37.8; MS (EI) *m/z* 472 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{26}H_{32}O_8$ 472.2097, found: 472.2101.

1,3,5,7-Tetra-(3-hydroxy-(1*Z*)-propenyl)adamantane (21). DIBAl-H in hexanes (1.0 M; 1.67 mL, 1.67 mmol) was added dropwise with stirring over 5 min to tetra-ester **20** (79 mg, 0.167 mmol) in CH_2Cl_2 (3 mL) at −78 °C.

After 1 h, reaction was carefully quenched by the dropwise addition of saturated aqueous NH_4Cl (0.30 mL), *i*-PrOH (5 mL), silica gel (0.2 g) and Celite (0.2 g). The mixture was allowed to warm to room temperature and filtered and the solids were washed with CH_2Cl_2/*i*-PrOH (2:1). Rotary evaporation of the combined filtrates and chromatography (CH_2Cl_2 : MeOH, 16 : 1 to 12 : 1) to give the tetra-allylic alcohol **21** (78 mg, 98%) as a solid. Colorless crystals of tetraol **21** were obtained by crystallization from MeOH/PhMe (1:1) at 4 °C: R_f 0.25 (CH_2Cl_2 : MeOH, 8 : 1); mp 114 - 116 °C (MeOH : toluene, 1 : 1); IR (film) 3556, 2922, 2851 cm^{-1}; ^1H NMR (300 MHz, MeOH-d_4) δ 5.41 (dt, *J* 12.4, 6.2 Hz, 4H, CH=C*H*CH_2OH), 5.22 (d, *J* 12.4 Hz, 4H, C*H*=CHCH_2OH), 4.30 (dd, *J* 6.2, 1.5 Hz, 8H, CH_2OH), 1.65 (s, 12H, CH_2); ^{13}C NMR (75 MHz, MeOH-d_4) δ 141.0, 131.2, 60.5, 48.2, 39.8; MS (CI, NH_3) *m/z* 378 (M + NH_4^+). Anal. calc for $C_{22}H_{32}O_4$: C, 76.44; H, 7.90. Found: C, 76.37; H, 8.03.

Methyl (*Z*)-3-(Adamantan-1-yl)acrylate (24). $KN(TMS)_2$ in PhMe (0.5 M; 7.32 mL, 3.66 mmol) was added dropwise with stirring to 18-crown-6 (4.83 g, 18.3 mmol) and bis(2,2,2-trifluoroethyl) (methoxycarbonylmethyl) phosphonate (1.28 g, 4.02 mmol) in THF (4 mL) at −78 °C. After 30 min, aldehyde **23** (300 mg, 1.83 mmol) in THF (10 mL) was added with stirring and, after further stirring at −78 °C for 1 h, 0 °C for 2 h and room temperature for 2 h, reaction was quenched with saturated aqueous NH_4Cl (20 mL). The separated aqueous layer was extracted with EtOAc (3 x 25 mL) and the combined organic layers were washed with brine (30 mL), dried ($MgSO_4$), concentrated *in vacuo* and the residue chromatographed (hexanes : EtOAc, 50 : 1) to give the methyl ester **24**[46] (116 mg, 30%) as a colorless oil: R_f 0.46 (hexanes : EtOAc, 15 : 1); IR (film) 2904, 2849, 1729, 1194 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.78 (d, *J* 13.2 Hz, 1H, C*H*=CHCO_2Me), 5.65 (d, *J* 13.2 Hz, 1H, CH=C*H*CO_2Me), 3.72 (s, 3H, OCH_3), 1.98 (s, 3H, adamantane methine), 1.86 (d, *J* 2.1 Hz, 6H, CH_2), 1.71 (s, 6H, CH_2); ^{13}C NMR (75 MHz, $CDCl_3$) δ 167.4, 155.1, 117.9, 51.3, 40.9, 36.6, 36.2, 28.5; MS (EI) *m/z* 220 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{14}H_{20}O_2$ 220.1463, found: 220.1462.

(*Z*)-3-(Adamantan-1-yl)prop-2-en-1-ol (25). DIBAl-H in hexanes (1.0 M; 1.16 mL, 1.16 mmol) was added dropwise with stirring to acrylate **24** (102 mg, 0.464 mmol) in CH_2Cl_2 (5 mL) at −78 °C. After 40 min, reaction was quenched with saturated aqueous NH_4Cl (2 mL) and 4 M aqueous HCl (1 mL). The separated aqueous layer was extracted with EtOAc (3 x 10 mL) and the combined organic layers were washed with saturated aqueous $NaHCO_3$ (20 mL) and brine (20 mL), dried ($MgSO_4$), concentrated *in vacuo* and the residue chromatographed (hexanes : EtOAc, 4 : 1) to give the allylic alcohol **25** (79 mg, 90%) as a colorless oil, which was used directly crude in the next step: R_f 0.58 (hexanes : EtOAc, 2 : 1); IR (film) 3560, 2920, 2854 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.35 (dt, *J* 12.3, 6.2 Hz, 1H, CH=C*H*CH_2OH), 5.17 (d, *J* 12.3 Hz, 1H, C*H*=CHCH_2OH), 4.33 (d, *J* 6.2 Hz, 2H, CH_2OH), 1.95 (s, 3H, adamantane methine), 1.84 (s, 1H, CH_2O*H*), 1.72 (s, 6H, CH_2), 1.68 (s, 6H, CH_2); ^{13}C NMR (75 MHz, $CDCl_3$) δ 142.0, 127.4, 59.5, 42.8, 36.6, 35.9, 28.5.

((1*R*,2*S*)-2-(Adamantan-1-yl)cyclopropyl)methanol (27). CH_2Cl_2 (3 mL) and 1,2-dimethoxyethane (0.182 mL, 1.75 mmol) in a flame-dried flask were cooled to −15 °C and neat Et_2Zn (0.179 mL, 1.75 mmol) was added with stirring. CH_2I_2 (0.282 mL, 3.50 mmol) was added slowly with stirring keeping the internal temperature below −10 °C. After 10 min at −10 °C, dioxaborolane **26** (189 mg, 0.70 mmol) in CH_2Cl_2 (2 mL) was added slowly with stirring while maintaining the internal temperature below −5 °C. Allylic alcohol **25** (112 mg, 0.583 mmol) in CH_2Cl_2 (2 mL) was immediately added to the solution and the mixture allowed to reach and react further at room temperature. After 5 h, reaction was quenched with saturated aqueous NH_4Cl (10 mL), the separated aqueous layer was extracted with CH_2Cl_2 (3 x 10 mL), and the combined organic layers were washed with brine (20 mL), dried ($MgSO_4$), concentrated *in vacuo* and the residue chromatographed (hexanes : EtOAc, 7 : 1 → 6 : 1) to give the cyclopropane **27** (104 mg, 87%) as colorless needle crystals: mp 88 - 90 °C (hexanes : EtOAc, 2 :

1); R_f 0.57 (hexanes : EtOAc, 2 : 1); IR (film) 3271 broad, 2891, 2847, 1447 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 3.74 (m, 2H, C*H*$_2$OH), 1.94 (s, 3H, adamantane methine), 1.60-1.71 (m, 6H, adamantane methylene), 1.53 (s, 6H, adamantane methylene), 0.98-1.11 (m, 1H, C*H*CH$_2$OH), 0.59 (m, 2H, cyclopropane C*H*$_2$), 0.25 (m, 1H, cyclopropane C*H*); ^{13}C NMR (75 MHz, $CDCl_3$) δ 63.6, 43.2, 37.0, 32.3, 29.7, 28.8, 19.8, 4.5; MS (CI, NH_3) *m/z* 224 (M + NH_4^+); HRMS (CI, NH_3) *m/z* calc for $C_{14}H_{26}NO$ (M + NH_4^+) 224.2014, found: 224.2022.

(1*R*,2*S*)-2-(Adamantan-1-yl)cyclopropane-1-carboxaldehyde (28). Dess-Martin periodinane (268 mg, 0.631 mmol) was added with stirring to alcohol **27** (100 mg, 0.485 mmol) in CH_2Cl_2 (5 mL). After 1.2 h at room temperature, reaction was quenched with saturated aqueous $NaHCO_3$ (3 mL) and saturated aqueous $Na_2S_2O_3$ (3 mL). The mixture was extracted with CH_2Cl_2 (3 x 10 mL) and the combined organic extracts were washed with brine (20 mL), dried ($MgSO_4$), concentrated *in vacuo* and chromatographed (hexanes : EtOAc, 14 : 1) to afford the aldehyde **28** (71 mg, 72%) as a colorless oil: R_f 0.68 (hexanes : EtOAc, 4 : 1); IR (film) 2902, 2847, 1698 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 9.29 (d, *J* 7.2 Hz, 1H, C*H*O), 1.97 (s, 3H, adamantane methine), 1.59-1.76 (m, 6H, adamantane methylene), 1.53 (s, 6H, adamantane methylene), 1.16-1.35 (m, 4H, cyclopropane); ^{13}C NMR (75 MHz, $CDCl_3$) δ 200.9, 43.2, 38.0, 36.6, 32.4, 30.2, 28.5, 9.9; MS (EI) *m/z* 204 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{14}H_{20}O$ ($M^{+\cdot}$) 204.1514, found: 204.1521.

(2*Z*,2'*Z*,2''*Z*)-3,3',3''-(7-((*Z*)-3-((*tert*-Butyldiphenylsilyl)oxy)prop-1-en-1-yl)adamantane-1,3,5-triyl)tris(prop-2-en-1-ol) (29). DMAP (30 mg, 0.241 mmol) and ^{t}BuPh$_2$SiCl (0.173 mL, 0.663 mmol) were added with stirring to tetra-allylic alcohol **21** (217 mg, 0.603 mmol) in dry pyridine (5 mL). After 41 h at room temperature, reaction was quenched with saturated aqueous NH_4Cl (3 mL) and the aqueous layer was extracted with CH_2Cl_2/*i*-PrOH (4:1) (4 x 10 mL). The combined organic layers were dried ($MgSO_4$), concentrated *in vacuo*, and chromatographed (CH_2Cl_2 : MeOH, 16 : 1 to 12 : 1) to give recovered tetra-allylic alcohol **21** (71 mg, 33%) and the mono-silylated product **29** (160 mg, 44%) as a thick oil: R_f 0.48 (CH_2Cl_2 : MeOH, 8 : 1); IR (film) 3350, 2928, 2855 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.69 (d, *J* 7.2 Hz, 4H, Ar*H*), 7.42 (m, 6H, Ar*H*), 5.50 (dt, *J* 12.3, 5.8 Hz, 1H, CH=C*H*CH$_2$OSi), 5.39 (dt, *J* 12.2, 6.0 Hz, 3H, CH=C*H*CH$_2$OH), 5.15 (d, *J* 12.2 Hz, 3H, C*H*=CHCH$_2$OH), 5.10 (d, *J* 12.3 Hz, 1H, C*H*=CHCH$_2$OSi), 4.37 (d, *J* 6.0 Hz, 6H, CH=CHC*H*$_2$OH), 4.20 (d, *J* 5.8 Hz, 2H, CH=CHC*H*$_2$OSi), 1.73 (s, 3H, CH=CHCH$_2$O*H*), 1.52 (m, 6H, adamantane methylene), 1.44 (s, 6H, adamantane methylene), 1.05 (s, 9H, *tert*-butyl); ^{13}C NMR (75 MHz, $CDCl_3$) δ 140.0, 137.9, 135.6, 133.7, 129.7, 129.4, 128.4, 127.7, 60.9, 59.3, 46.0, 45.9, 37.6, 29.7, 26.7, 19.1; the product did not exhibit a molecular ion in the MS.

(*Z*)-*tert*-Butyldiphenyl((3-(3,5,7-tri-(1*R*,2*S*)-2-hydroxymethyl-1-cyclopropyl)-adamantan-1-yl)allyl)oxy)silane (30). CH_2Cl_2 (8 mL) and 1,2-dimethoxyethane (0.64 mL, 6.17 mmol) in a flame-dried flask were cooled to −15 °C and neat Et_2Zn (0.63 mL, 6.17 mmol) was added with stirring. CH_2I_2 (0.99 mL, 12.3 mmol) was added slowly with stirring keeping the internal temperature below −10 °C. After 10 min at −10 °C, dioxaborolane **26** (500 mg, 1.85 mmol) in CH_2Cl_2 (3 mL) was added slowly with stirring while maintaining the internal temperature below −5 °C. Allylic alcohol **29** (308 mg, 0.514 mmol) in CH_2Cl_2 (4 mL) was immediately added to the solution and the mixture allowed to reach and react further at room temperature. After 4 h, reaction was quenched with saturated aqueous NH_4Cl (8 mL) and the aqueous layer was extracted with CH_2Cl_2/MeOH (7:1) (4 x 10 mL). The combined organic layers were washed with brine (20 mL), dried ($MgSO_4$), concentrated *in vacuo*, and the residue chromatographed (hexanes : EtOAc : MeOH, 1 : 1 : 0.03 to 1 : 1 : 0.05) to give the tricyclopropane **30** (295 mg, 90%) as a colorless oil: R_f 0.40 (hexanes: EtOAc: MeOH, 1 : 1 : 0.2); $[\alpha]_D^{22}$ −15.3 (*c* 0.96, $CHCl_3$); IR (film) 3366 (br), 2928, 2895, 2855, 1427 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.70 (d, *J* 7.3 Hz, 4H, Ar*H*), 7.41 (m, 6H, Ar*H*), 5.48 (dt, *J* 12.4, 5.5 Hz, 1H, CH=C*H*CH$_2$OSi), 5.12 (d, *J* 12.4 Hz, 1H, C*H*=CHCH$_2$OSi), 4.37

(d, *J* 5.5 Hz, 2H, CH=CHC*H*$_2$OSi), 3.78 (dd, *J* 11.0, 7.5 Hz, 3H, C*H*$_2$OH), 3.50 (dd, *J* 11.0, 8.6 Hz, 3H, C*H*$_2$OH), 2.03 (s, 3H, CH$_2$O*H*), 1.24 (s, 6H, adamantane methylene), 1.17 (s, 6H, adamantane methylene), 1.05 (s, 9H, *tert*-butyl), 1.00 (m, 3H, cyclopropane methine), 0.55 (m, 6H, cyclopropane methylene), 0.16 (m, 3H, cyclopropane methine); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.8, 135.6, 133.8, 129.6, 128.8, 127.6, 63.3, 61.1, 46.9, 46.7, 37.8, 34.2, 28.9, 26.7, 19.2, 19.1, 4.6; MS (CI, NH_3) *m/z* 658 (M + NH_4^+). Anal. calc for $C_{41}H_{56}O_4Si$: C, 76.83; H, 8.81. Found: C, 76.77; H, 8.90.

1-((1*Z*)-3-Hydroxy-1-propenyl))-((3-(3,5,7-tri-(1*R*,2*S*)-2-hydroxymethyl-1-cyclopropyl)adamantane (31). Bu_4NF in THF (1.0 M; 0.233 mL, 0.233 mmol) was added with stirring to allylic alcohol **30** (136 mg, 0.212 mmol) in THF (3 mL) at room temperature. After 24 h, reaction was quenched with H_2O (2 mL) and the separated aqueous layer was extracted with CH_2Cl_2/*i*-PrOH (4:1) (4 x 5 mL). The combined organic layers were washed with brine (10 mL), dried ($MgSO_4$), concentrated *in vacuo*, and the residue chromatographed (hexanes : EtOAc : MeOH, 1 : 1 : 0.2) to give the free allylic alcohol **31** (79 mg, 94%) as a colorless oil: R_f 0.32 (CH_2Cl_2 : MeOH, 8 : 1); $[\alpha]_D^{22}$ −16.2 (*c* 1.03, MeOH); IR (film) 3345 (br), 2995, 2895 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.33 (dt, *J* 12.4, 6.0 Hz, 1H, CH=C*H*CH$_2$OH), 5.17 (d, *J* 12.4 Hz, 1H, C*H*=CHCH$_2$OH), 4.26 (dd, *J* 6.0, 1.4 Hz, 2H, CH=CHC*H*$_2$OH), 3.75-3.62 (m, 6H, cyclopropyl C*H*$_2$OH), 1.41 (s, 6H, adamantane methylene), 1.27 (s, 6H, adamantane methylene), 1.03 (m, 3H, cyclopropane), 0.67-0.60 (m, 6H, cyclopropane), 0.26 (m, 3H, cyclopropane); ^{13}C NMR (75 MHz, $CDCl_3$) δ 141.9, 130.6, 64.6, 60.7, 49.3, 40.1, 36.5, 31.0, 21.3, 6.4; the product did not exhibit a molecular ion in the MS.

(*Z*)-*tert*-Butyldiphenyl((3-(3,5,7-tri-(1*R*,2*S*)-2-(pivaloyloxymethyl)-1-cyclopropyl)-adamantan-1-yl)allyl)oxy)silane (32). Me_3CCOCl (0.233 mL, 1.89 mmol) was added with stirring to triol **30** (121 mg, 0.189 mmol) in dry pyridine (4 mL) at room temperature. After 2h, reaction was quenched with saturated aqueous NH_4Cl (4 mL) and the separated aqueous layer was extracted with CH_2Cl_2 (3 x 10 mL). The combined organic layers were washed with brine (15 mL), dried ($MgSO_4$), concentrated *in vacuo*, and the residue chromatographed (hexanes : EtOAc, 25 : 1 to 20 : 1) to give the tri-pivaloate **32** (160 mg, 95%) as a colorless thick oil: R_f 0.32 (hexanes : EtOAc, 10 : 1); $[\alpha]_D^{22}$ −24.5 (*c* 1.02, $CHCl_3$); IR (film) 3069, 2967, 2932, 1726 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.68 (d, *J* 7.1 Hz, 4H, Ar*H*), 7.39 (m, 6H, Ar*H*), 5.45 (dt, *J* 12.4, 5.6 Hz, 1H, CH=C*H*CH$_2$OSi), 5.05 (d, *J* 12.4 Hz, 1H, C*H*=CHCH$_2$OSi), 4.42-4.36 (m, 5H, CH=CHC*H*$_2$OSi and C*H*$_2$OPiv), 3.83 (dd, *J* 11.1, 9.0 Hz, 3H, C*H*$_2$OPiv), 1.24 (m, 12H, adamantane methylene), 1.21-1.16 (m, 30H, COC(C*H*$_3$)$_3$ and cyclopropane methine), 1.05 (s, 9H, SiC(C*H*$_3$)$_3$), 0.57 (m, 6H, cyclopropane methylene), 0.19 (m, 3H, cyclopropane methine); ^{13}C NMR (75 MHz, $CDCl_3$) δ 178.5, 138.4, 135.5, 133.7, 129.6, 128.8, 127.6, 65.6, 61.0, 46.9, 46.4, 38.6, 38.0, 34.2, 28.8, 27.3, 26.8, 19.1, 15.5, 4.7; the product did not exhibit a molecular ion in the MS.

1-((1*Z*)-3-Hydroxy-1-propenyl)-((3-(3,5,7-tri-(1*R*,2*S*)-2-(pivaloyloxymethyl)-1-cyclopropyl)adamantane (33). Bu_4NF in THF (1.0 M; 0.086 mL, 0.086 mmol) was added dropwise with stirring to silyl ether **32** (70 mg, 0.078 mmol) in THF (2 mL) at room temperature. After 16 h, reaction was quenched with H_2O (2 mL) and the separated aqueous layer was extracted with CH_2Cl_2 (3 x 6 mL). The combined organic layers were washed with brine, dried ($MgSO_4$), and concentrated *in vacuo*, and the residue chromatographed (hexanes : EtOAc, 7 : 1 to 4 : 1) to give the allylic alcohol **33** (49 mg, 95%) as a colorless thick oil: R_f 0.15 (hexanes : EtOAc, 4 : 1); $[\alpha]_D^{22}$ −31.2 (*c* 1.60, $CHCl_3$); IR (film) 3516 broad, 2971, 2906, 1726, 1480, 1283 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.39 (dt, *J* 12.3, 6.5 Hz, 1H, CH=C*H*CH$_2$OH), 5.17 (d, *J* 12.3 Hz, 1H, C*H*=CHCH$_2$OH), 4.44 (dd, *J* 11.5, 7.5 Hz, 3H, C*H*$_2$OPiv), 4.26 (d, *J* 6.5 Hz, 2H, CH=CHC*H*$_2$OH), 3.92 (dd, *J* 11.5, 8.9 Hz, 3H, C*H*$_2$OPiv), 1.35 (s, 6H, adamantane

methylene), 1.31-1.29 (m, 6H, adamantane methylene), 1.22 (s, 27H, $COC(CH_3)_3$), 1.11 (m, 3H, cyclopropane methine), 0.64 (m, 6H, cyclopropane methylene), 0.27 (m, 3H, cyclopropane methine); ^{13}C NMR (75 MHz, $CDCl_3$) δ 178.7, 140.3, 128.2, 65.7, 59.2, 47.3, 46.3, 38.7, 37.8, 34.3, 28.9, 27.3, 15.5, 4.7; the product did not exhibit a molecular ion in the MS.

1-((1*R*,2*S*)-2-(Hydroxymethyl)-1-cyclopropyl)-3,5,7-tri-((1*R*,2*S*)-2-(pivaloyloxymethyl)-1-cyclopropyl)adamantane (34). CH_2Cl_2 (4 mL) and 1,2-dimethoxyethane (0.196 mL, 1.89 mmol) in a flame-dried flask were cooled to −15 °C and neat Et_2Zn (0.193 mL, 1.89 mmol) was added with stirring. CH_2I_2 (0.304 mL, 3.77 mmol) was added slowly with stirring keeping the internal temperature below −10 °C. After 10 min at −10 °C, dioxaborolane ligand **26** (153 mg, 0.566 mmol) in CH_2Cl_2 (1 mL) was added slowly with stirring while maintaining the internal temperature below −5 °C. An aliquot (2 mL) of this cold solution was immediately added with stirring to allylic alcohol **33** (103 mg, 0.157 mmol) in CH_2Cl_2 (1 mL) at −10 °C and the mixture allowed to warm up to room temperature. After 5h, reaction was quenched with saturated aqueous NH_4Cl (2 mL) and the separated aqueous layer was extracted with CH_2Cl_2/MeOH (6:1) (4 x 5 mL). The combined organic layers were washed with brine (10 mL), dried ($MgSO_4$), concentrated *in vacuo*, and the residue chromatographed (hexanes : EtOAc, 15 : 1 to 12 : 1) to give the tetracyclopropyl adamantane **34** (66 mg, 63%) as a colorless oil: R_f 0.24 (hexanes: EtOAc, 4 : 1); $[\alpha]_D^{22}$ −25.3 (*c* 1.02, $CHCl_3$); IR (film) 3524 (br), 2969, 1726, 1152 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 4.40 (m, 3H, CH_2OPiv), 3.92 (m, 3H, CH_2OPiv), 3.82 (dd, *J* 10.8, 7.3 Hz, 1H, CH_2OH), 3.60 (dd, *J* 10.8, 7.9 Hz, 1H, CH_2OH), 1.39-1.09 (m, 42H, adamantane methylene and $COC(CH_3)_3$ and $CHCH_2OPiv$), 0.87 (m, 1H, $CHCH_2OH$), 0.64-0.60 (m, 8H, cyclopropane methylene), 0.27-0.21 (m, 4H, cyclopropane methine); ^{13}C NMR (75 MHz, $CDCl_3$) δ 178.6, 65.7, 63.3, 47.7, 46.6, 38.7, 34.3, 28.9, 27.3, 19.4, 15.5, 4.7; MS (CI, NH_3) *m/z* 686 ($M + NH_4^+$); HRMS (CI, NH_3) *m/z* calc for $C_{41}H_{68}NO_7$ ($M + NH_4^+$) 686.4996, found: 686.5004.

1,3,5,7-Tetra-((1*R*,2*S*)-2-(hydroxymethyl)-1-cyclopropyl)adamantane (35). DIBAl-H in hexanes (1.0 M; 0.706 mL, 0.706 mmol) was added dropwise with stirring over 5 min to tri-pivaloate **34** (63 mg, 0.094 mmol) in CH_2Cl_2 (3.5 mL) at −78 °C. After 1 h at −78 °C, saturated aqueous NH_4Cl (0.14 mL), *i*-PrOH (4 mL), silica gel (200 mg) and Celite (200 mg) were added. The mixture was allowed to warm to room temperature and filtered, and the solids were washed with CH_2Cl_2/MeOH (4:1). Rotary evaporation of the combined organic layers and chromatography (CH_2Cl_2 : MeOH, 16 : 1 to 12 : 1) gave the tetra-*syn*-cyclopropyl alcohol **35** (35 mg, 89%) as a viscous oil. Colorless crystals of tetra-*syn*-cyclopropyl alcohol **35** were obtained by crystallization from MeOH/PhMe/THF (1:1:1): mp 168 - 170 °C (MeOH : PhMe : THF, 1 : 1 : 1); R_f 0.32 (CH_2Cl_2 : MeOH, 8 : 1); $[\alpha]_D^{25}$ −17.6 (*c* 1.0, MeOH); IR (film) 3321 (br), 2894, 2360 cm^{-1}; ^1H NMR (300 MHz, MeOH-d_4) δ 3.72 (m, 8H, CH_2OH), 1.27 (s, 12H, adamantane methylene), 1.03 (m, 4H, cyclopropane methine), 0.70-0.63 (m, 8H, cyclopropane methylene), 0.29 (d, *J* 3.4 Hz, 4H, cyclopropane methine); ^{13}C NMR (75 MHz, MeOH-d_4) δ 64.6, 49.6, 36.6, 31.0, 21.2, 6.4; MS (CI, NH_3) *m/z* 434 ($M + NH_4^+$).

1,3,5,7-Tetra-((1*R*,2*S*)-2-(formyl)-1-cyclopropyl)adamantane (14). DMSO (32 µL, 0.448 mmol) was added slowly with vigorous stirring to $(COCl)_2$ (19 µL, 0.224 mmol) in CH_2Cl_2 (1 mL) at −78 °C. After a further 15 min at −78 °C, tetra-alcohol **35** (11 mg, 0.0264 mmol) in DMSO (0.3 mL) and CH_2Cl_2 (0.6 mL) was added slowly, and the reaction mixture was stirred at −78 °C for an additional 1 h. Et_3N (0.15 mL) was added dropwise, and the mixture was allowed to warm up to room temperature. H_2O (5 mL) and CH_2Cl_2 (5 mL) were added and the two phases were separated. The organic phase was washed with 5% aqueous HCl (2 mL), H_2O (2 mL), 5% aqueous $NaHCO_3$ (4 mL) and brine (4 mL), dried ($MgSO_4$), concentrated *in vacuo* and the residue chromatographed

(hexanes : EtOAc : MeOH, 1 : 1 : 0.04) to afford the tetra-aldehyde **14** (8 mg, 82%) as a white solid: mp 121 - 123 °C (hexanes : EtOAc, 1 : 2); R_f 0.35 (hexanes : EtOAc : MeOH, 1 : 1 : 0.2); $[\alpha]_D^{22}$ -73.1 (*c* 1.03, $CHCl_3$); IR (film) 2924, 2849, 1692 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 9.33 (d, *J* 6.1 Hz, 4H, C*H*O), 1.87-1.77 (m, 4H, cyclopropane), 1.33-1.10 (m, 12H, cyclopropane), 1.20 (s, 12H, adamantane methylene); ^{13}C NMR (75 MHz, $CDCl_3$) δ 200.0, 46.9, 36.5, 34.9, 29.6, 9.9; the product did not exhibit a molecular ion in the MS. Anal. calc for $C_{26}H_{32}O_4$: C, 76.44; H, 7.90. Found: C, 76.37; H, 8.03.

1,3,5,7-Tetra-((1*R*,2*S*)-2-(*N*-4-toluenesulfonylamino-iminomethyl)-1-cyclopropyl)adamantane (36). *p*-Toluenesulfonylhydrazine hydrochloride (42 mg, 0.225 mmol) was added with stirring to tetra-aldehyde **14** (23 mg, 0.056 mmol) in MeOH (3 mL) at room temperature. After 4.5 h, evaporation *in vacuo* and chromatography of the residue (hexanes : EtOAc : MeOH, 1 : 1 : 0.02) gave tetra-tosylhydrazone **36** (50 mg, 82%) as a white solid: mp 149 - 151 °C (hexanes : EtOAc, 1 : 2); R_f 0.31 (hexanes : EtOAc : MeOH, 1 : 1 : 0.2); $[\alpha]_D^{22}$ −154.7 (*c* 1.02, $CHCl_3$); IR (film) 3204, 2923, 2852, 1334, 1164 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 9.23-8.38 (m, 4H, CH=NN*H*Ts), 7.97-7.89 (m, 8H, Ar*H*), 7.35-7.28 (m, 8H, Ar*H*), 7.08-6.98 (m, 2H, C*H*=NNHTs), 6.61-6.48 (m, 2H, C*H*=NNHTs), 2.40 (s, 12H, ArCH_3), 1.59 (br s, 4H, cyclopropane methine), 1.27 (s, 8H, cyclopropane methylene), 1.12-0.75 (m, 16H, cyclopropane methine and adamantane methylene); the product did not exhibit a molecular ion in the MS.

1-Adamantyl)acetaldehyde 38. DMSO (1.60 mL, 22.5 mmol) in CH_2Cl_2 (2 mL) was added with vigorous stirring over 2 min to $(COCl)_2$ (0.263 mL, 3.06 mmol) in CH_2Cl_2 (7 mL) at −78 °C. After 15 min, 1-adamantaneethanol (**37**) (500 mg, 2.78 mmol) in CH_2Cl_2 (4 mL) was added slowly with stirring at −78 °C and, after a further 30 min, Et_3N (1.95 mL) was added dropwise, and the mixture was allowed to warm up to room temperature over 1 h. H_2O (15 mL) was added and the two phases were separated and the organic layer was washed with 5% aqueous HCl (10 mL), H_2O (10 mL), 5% aqueous $NaHCO_3$ (10 mL) and brine (10 mL), dried ($MgSO_4$), and concentrated *in vacuo*. The residue was chromatographed (hexanes : EtOAc, 30 : 1) to afford the aldehyde **38** (444 mg, 90%) as a colorless oil: R_f 0.44 (hexanes : EtOAc, 10 : 1); IR (film) 2902, 2848, 1720 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 9.87 (t, *J* 3.4 Hz, 1H, C*H*O), 2.12 (d, *J* 3.4 Hz, 2H, CH_2C*H*O), 1.98 (s, 3H, adamantane methine), 1.74-1.64 (m, 12H, adamantane methylene); ^{13}C NMR (100 MHz, $CDCl_3$) δ 203.8, 57.2, 42.7, 36.6, 33.3, 28.4; MS (EI) *m/z* 178 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{12}H_{18}O$ 178.1358, found: 178.1353. All spectroscopic data were consistent with the literature values.[37]

Ethyl 4-(Adamantan-1-yl)-3-oxobutanoate (39a).[47] Aldehyde **38** (89 mg, 0.50 mmol) in CH_2Cl_2 (2 mL) was added with stirring to anhydrous $SnCl_2$ (9.5 mg, 0.05 mmol) and ethyl diazoacetate (58 µL, 0.55 mmol) in CH_2Cl_2 (2 mL) at room temperature. After 1 h, the mixture was washed with brine (5 mL) and extracted with CH_2Cl_2 (3 x 10 mL). The organic extracts were dried ($MgSO_4$), concentrated *in vacuo* and the residue was chromatographed (hexanes : EtOAc, 40 : 1) to afford the β-keto ester **39a** (106 mg, 80%) (*ca.* 4 : 1 keto form and enol form) as a colorless oil: R_f 0.44 (hexanes : EtOAc, 10 : 1); IR (film) 2903, 2848, 1744, 1715, 1630 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): (keto form) δ 4.19 (q, *J* 7.1 Hz, 2H, $CO_2CH_2CH_3$), 3.41 (s, 2H, CH_2CO_2Et), 2.28 (s, 2H, $CH_2COCH_2CO_2Et$), 1.96 (s, 3H, adamantane methine), 1.65-1.64 (m, 12H, adamantane methylene), 1.29 (t, *J* 7.1 Hz, 3H, $CO_2CH_2CH_3$); (enol form) δ 12.10 (s, 1H, *H*OC=CH), 4.90 (s, 1H, HOC=C*H*), 4.19 (q, *J* 7.2 Hz, 2H, $CO_2CH_2CH_3$), 1.93 (s, 2H, CH_2C(OH)=CH), 1.72 (s, 3H, adamantane methine), 1.69-1.59 (m, 12H, adamantane methylene), 1.31 (t, *J* 7.2 Hz, 3H, $CO_2CH_2CH_3$); ^{13}C NMR (100 MHz, $CDCl_3$): (keto form) δ 202.4, 167.2, 61.3, 56.0, 51.9, 42.3, 36.8, 33.7, 28.5, 14.2; (enol form) δ 176.8, 172.6, 91.3, 59.9, 50.0, 42.6, 36.7, 33.4, 28.7, 14.3; MS (EI) *m/z* 264 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{16}H_{24}O_3$ 264.1725, found: 264.1717.

Ethyl 4-(Adamantan-1-yl)-2-diazo-3-oxobutanoate (41a). Et_3N (0.126 mL, 0.898 mmol) was added dropwise with stirring to β-keto ester **39a** (79 mg, 0.299 mmol) and 4-acetamidobenzenesulfonyl azide (**40**) (79 mg, 0.329 mmol) in dry MeCN (4 mL) at 0 °C. After stirring for 3 h at room temperature, the reaction mixture was concentrated *in vacuo* and the resultant solid was triturated with Et_2O and hexanes (1:1) (60 mL). The filtrate was concentrated *in vacuo* and the residue was chromatographed (hexanes : EtOAc, 30 : 1) to afford α-diazo-β-keto ester **41a** (86 mg, 99%) as a viscous oil: R_f 0.46 (hexanes : EtOAc, 10 : 1); IR (film) 2903, 2849, 2131, 1719, 1650 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 4.29 (q, *J* 7.2 Hz, 2H, $CO_2CH_2CH_3$), 2.71 (s, 2H, $CH_2COC{=}N_2$), 1.95 (s, 3H, adamantane methine), 1.67-1.66 (m, 12H, adamantane methylene), 1.34 (t, *J* 7.2 Hz, 3H, $CO_2CH_2CH_3$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.9, 161.5, 77.3, 61.3, 51.5, 42.4, 36.8, 34.7, 28.7, 14.4; MS (EI) *m/z* 290 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{16}H_{22}N_2O_3$ 290.1630, found: 290.1626.

***tert*-Butyl 4-(Adamantan-1-yl)-3-oxobutanoate (39b).** Aldehyde **38** (390 mg, 2.19 mmol) in CH_2Cl_2 (6 mL) was added with stirring to anhydrous $SnCl_2$ (42 mg, 0.22 mmol) and *tert*-butyl diazoacetate (0.333 mL, 2.41 mmol) in CH_2Cl_2 (6 mL) at room temperature. After 1.5 h, the mixture was washed with brine (15 mL) and extracted with CH_2Cl_2 (3 x 20 mL). The organic extracts were dried ($MgSO_4$), concentrated *in vacuo* and the residue was chromatographed (hexanes : EtOAc, 40 : 1) to afford the β-keto ester **39b** (390 mg, 61%) (ca. 6 : 4 keto form and enol form) as a colorless oil: R_f 0.41 (hexanes : EtOAc, 10 : 1); IR (film) 2902, 2848, 1739, 1714, 1637 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): (keto form) δ 3.24 (s, 2H, $CH_2CO_2C(CH_3)_3$), 2.19 (s, 2H, $CH_2COCH_2CO_2C(CH_3)_3$), 1.89 (s, 3H, adamantane methine), 1.64-1.52 (m, 12H, adamantane methylene), 1.40 (s, 9H, $CH_2CO_2C(CH_3)_3$); (enol form) δ 12.15 (s, 1H, *H*OC=CH), 4.73 (s, 1H, HOC=C*H*), 1.89 (s, 3H, adamantane methine), 1.83 (s, 2H, $CH_2C(OH){=}CH$), 1.61-1.52 (m, 12H, adamantane methylene), 1.43 (t, 9H, $CH_2CO_2C(CH_3)_3$); ^{13}C NMR (100 MHz, $CDCl_3$): (keto form) δ 202.9, 166.5, 81.7, 55.9, 53.1, 42.3, 36.7, 33.6, 28.5, 28.0; (enol form) δ 176.1, 172.6, 92.7, 80.6, 50.0, 42.6, 36.8, 33.3, 28.7, 28.3; MS (EI) *m/z* 292 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{18}H_{28}O_3$ 292.2038, found: 292.2034; Anal. Calc for $C_{18}H_{28}O_3$: C, 73.93; H, 9.65. Found: C, 74.01; H, 9.58.

***tert*-Butyl 4-(Adamantan-1-yl)-2-diazo-3-oxobutanoate (41b).** Et_3N (0.162 mL, 1.15 mmol) was added dropwise with stirring to β-keto ester **39b** (112 mg, 0.384 mmol) and 4-acetamidobenzenesulfonyl azide (**40**) (101 mg, 0.422 mmol) in dry MeCN (5 mL) at 0 °C and the mixture was allowed to warm up to room temperature. After 4 h, the reaction mixture was concentrated *in vacuo* and the resultant solid was triturated with Et_2O and hexanes (1:1), the filtrate was concentrated *in vacuo* and the residue chromatographed (hexanes : EtOAc, 40 : 1) to afford α-diazo-β-keto ester **41b** (109 mg, 90%) as a viscous oil: R_f 0.41 (hexanes : EtOAc, 10 : 1); IR (film) 2904, 2848, 2129, 1712, 1689, 1648 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.66 (s, 2H, $CH_2COC(N_2)$), 1.93 (s, 3H, adamantane methine), 1.66 (m, 12H, adamantane methylene), 1.52 (s, 9H, $C(CH_3)_3$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.0, 160.6, 82.9, 78.2, 51.3, 42.3, 36.7, 34.5, 28.7, 28.2; MS (EI) *m/z* 318 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{18}H_{26}N_2O_3$ 318.1943, found: 318.1942; Anal. Calc for $C_{18}H_{26}N_2O_3$: C, 67.90; H, 8.23; N, 8.80. Found: C, 68.01; H, 8.27; N, 8.74.

1,3-Di-(2-hydroxyethyl)adamantane (43).[40] $LiAlH_4$ (754 mg, 19.8 mmol) was added portionwise with stirring to di-acid **42** (1.0 g, 3.97 mmol) in THF (30 mL) at 0 °C and the mixture was allowed to warm up to room temperature. After 18 h, saturated aqueous Na_2SO_4 (1.50 mL) was added carefully to quench the reaction at 0 °C and the mixture was stirred for an additional 30 min, when THF (40 mL) and silica gel (2.0 g) were added. The mixture was filtered through a short pad of Celite, eluting with THF (60 mL). Rotary evaporation of the filtrate and chromatography of the residue (hexanes : EtOAc : MeOH, 1 : 1: 0.02 to 1 : 1: 0.0.5) gave diol **43**

(658 mg, 74%) as colorless needles: mp 112 - 113 °C (MeOH : CH_2Cl_2, 1 : 2) (lit.[40] mp 113 - 115 °C); R_f 0.39 (hexanes : EtOAc : MeOH, 1 : 1 : 0.02); IR (film) 3389 (br), 2899, 2359, 1644 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6) δ 4.19 (t, *J* 5.0 Hz, 2H, CH_2OH), 3.45 (td, *J* 7.6, 5.0 Hz, 4H, CH_2OH), 1.94 (m, 2H, adamantane methine), 1.55 (s, 2H, adamantane methylene), 1.46-1.36 (m, 8H, adamantane methylene and CH_2CH_2OH), 1.28-1.23 (m, 6H, adamantane methylene); ^{13}C NMR (100 MHz, DMSO-d_6) δ 56.4, 47.9, 46.8, 41.9, 36.3, 32.2, 28.6; MS (EI) *m/z* 224 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{14}H_{24}O_2$ 224.1776, found: 224.1773. All spectroscopic data were consistent with the literature values.[40]

2,2'-(Adamantane-1,3-diyl)diacetaldehyde (44). DMSO (0.47 mL, 6.61 mmol) in CH_2Cl_2 (2 mL) was added dropwise over 2 min with vigorous stirring to $(COCl)_2$ (0.284 mL, 3.30 mmol) in CH_2Cl_2 (2 mL) at −78 °C. After 10 min, diol **43** (500 mg, 2.78 mmol) in CH_2Cl_2 (4 mL) and anhydrous DMSO (2 mL) was added slowly with stirring at −78 °C. After 1 h, Et_3N (2.30 mL) was added dropwise with stirring, and the mixture was allowed to warm up to room temperature for 1 h. H_2O (15 mL) was added, the two phases were separated and the organic layer was washed with 5% aqueous HCl (10 mL), H_2O (10 mL), 5% aqueous $NaHCO_3$ (10 mL) and brine (10 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The residue was chromatographed (hexanes : EtOAc, 8 : 1) to afford the di-aldehyde **44** (150 mg, 83%) as a colorless oil: R_f 0.52 (hexanes : EtOAc, 2 : 1); IR (film) 2901, 2848, 1719 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 9.86 (t, *J* 3.1 Hz, 2H, CH_2CHO), 2.12 (d, *J* 3.1 Hz, 4H, CH_2CHO), 2.10 (m, 2H, adamantane methine), 1.69-1.58 (m, 12H, adamantane methylene); ^{13}C NMR (100 MHz, $CDCl_3$) δ 202.9, 56.6, 47.7, 41.7, 35.7, 33.9, 28.6; MS (EI) *m/z* 220 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{14}H_{20}O_2$ 220.1463, found: 220.1462.

Di-*tert*-butyl 4,4'-(Adamantane-1,3-diyl)bis(3-oxobutanoate) (45). Di-aldehyde **44** (148 mg, 0.673 mmol) in CH_2Cl_2 (2 mL) was added with stirring to anhydrous $SnCl_2$ (38 mg, 0.202 mmol) and *tert*-butyl diazoacetate (0.24 mL, 1.68 mmol) in CH_2Cl_2 (4 mL) at room temperature. After 1.5 h, the mixture was washed with brine (5 mL) and extracted with CH_2Cl_2 (3 x 10 mL), the organic extracts were dried ($MgSO_4$) and concentrated *in vacuo*. The resultant residue was chromatographed (hexanes : EtOAc, 12 : 1) to afford the di-β-keto ester **45** (225 mg, 75%) (*ca.* 2.5 : 1 keto : enol forms) as a viscous colorless oil: R_f 0.51 (hexanes : EtOAc, 4 : 1); IR (film) 2903, 1739, 1713, 1638 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): (keto form) δ 3.30 (s, 4H, $CH_2CO_2C(CH_3)_3$), 2.29 (s, 4H, $CH_2COCH_2CO_2C(CH_3)_3$), 2.05 (s, 2H, adamantane methine), 1.64-1.54 (m, 12H, adamantane methylene), 1.47 (s, 18H, $CH_2CO_2C(CH_3)_3$); (enol form) δ 12.21 (s, 2H, HOC=CH), 4.80 (s, 2H, HOC=CH), 2.05 (s, 2H, adamantane methine), 1.92 (s, 4H, $CH_2C(OH)=CH$), 1.64-1.54 (m, 12H, adamantane methylene), 1.50 (s, 9H, $CH_2CO_2C(CH_3)_3$); ^{13}C NMR (100 MHz, $CDCl_3$): (keto form) δ 202.6, 166.4, 81.8, 55.3, 53.0, 46.9, 41.3, 34.1, 28.7, 28.0; (enol form) δ 175.7, 172.6, 92.9, 80.7, 49.5, 47.5, 41.7, 35.8, 28.9, 28.4; MS (ES) *m/z* 471 (M + Na^+); HRMS (ES) *m/z* calc for $C_{26}H_{40}O_6Na$ 471.2723, found: 471.2715; Anal. Calc for $C_{26}H_{40}O_6$: C, 69.61; H, 8.99. Found: C, 69.56; H, 9.04.

Di-*tert*-butyl 4,4'-(Adamantane-1,3-diyl)bis(2-diazo-3-oxobutanoate (46). Et_3N (0.395 mL, 2.81 mmol) was added dropwise with stirring to di-β-keto ester **45** (210 mg, 0.469 mmol) and 4-acetamidobenzenesulfonyl azide (**40**) (248 mg, 1.03 mmol) in dry MeCN (12 mL) at 0 °C and the mixture was allowed to warm up to room temperature. After 4 h, the mixture was concentrated *in vacuo* and the resultant solid was triturated with Et_2O and hexanes (1:1) (80 mL). The mixture was filtered, the filtrate was concentrated *in vacuo* and the residue chromatographed (hexanes : EtOAc, 20 : 1) to afford di-α-diazo-β-keto ester **46** (184 mg, 79%) as a viscous colorless oil: R_f 0.60 (hexanes : EtOAc, 4 : 1); IR (film) 2904, 2129, 1712, 1648 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.65 (s, 4H, $CH_2COC(N_2)$), 1.97 (m, 2H, adamantane methine), 1.61-1.54 (m, 12H, adamantane methylene),

1.49 (s, 18H, C(C*H*$_3$)$_3$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.8, 160.5, 83.0, 78.2, 51.0, 47.2, 41.4, 35.9, 35.1, 29.0, 28.3; MS (ES) *m/z* 471 (M + Na^+); HRMS (ES) *m/z* calc for $C_{26}H_{40}O_6Na$ 471.2723, found: 471.2715.

Ethyl 2-Oxodecahydro-3a,7:5,9-dimethanocyclopenta[8]annulene-1-carboxylate (47a). $Rh_2(OAc)_4$ (1.8 mg, 4.1 μmol) was added with stirring to α-diazo-β-keto ester **41a** (60 mg, 0.21 mmol) in CH_2Cl_2 (5 mL) at room temperature. After 1.5 h, the solvent was removed *in vacuo* and the residue was chromatographed (hexanes : EtOAc, 25 : 1) to afford β-keto ester **47a** (49 mg, 90%) as a viscous oil containing a single diastereoisomer: R_f 0.27 (hexanes : EtOAc, 10 : 1); IR (film) 2905, 2852, 1755, 1724 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.19 (q, *J* 7.2 Hz, 2H, COC*H*$_2$CH$_3$), 3.29 (d, *J* 12.9 Hz, 1H, C*H*CO_2Et), 2.52 (dd, *J* 12.9, 1.6 Hz, 1H, COCH(CO_2Et)C*H*), 2.07 (s, 2H, C*H*$_2$COCHCO_2Et), 2.02-1.64 (m, 11H, adamantane methylene and methine), 1.49 (s, 2H, adamantane methine), 1.27 (t, *J* 7.2 Hz, 3H, COCH$_2$C*H*$_3$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 211.1, 169.7, 61.3, 55.8, 53.2, 51.2, 43.0, 38.3, 37.9, 37.0, 35.8, 29.8, 29.1, 28.5, 27.9, 14.2; MS (EI) *m/z* 262 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{16}H_{22}O_3$ 262.1569, found: 262.1566.

tert-Butyl 2-Oxodecahydro-3a,7:5,9-dimethanocyclopenta[8]annulene-1-carboxylate (47b). $Rh_2(OAc)_4$ (14.5 mg, 0.033 mmol) was added with stirring to α-diazo-β-keto ester **41b** (208 mg, 0.654 mmol) in CH_2Cl_2 (10 mL) at room temperature. After 1.5 h, the solvent was removed *in vacuo* and the residue chromatographed (hexanes : EtOAc, 30 : 1) to afford β-ketoester **47b** (173 mg, 91%) as a colorless viscous oil: R_f 0.34 (hexanes : EtOAc, 10 : 1); IR (film) 2906, 2852, 1752, 1722 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.18 (d, *J* 12.9 Hz, 1H, COC*H*CO_2C(CH_3)$_3$), 2.46 (d, *J* 12.8 Hz, 1H, COCH(CO_2C(CH_3)$_3$)C*H*), 2.06-1.67 (m, 13H, adamantane methylene and methine), 2.03 (s, 2H, C*H*$_2$COCH), 1.45 (s, 9H, C(C*H*$_3$)$_3$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 211.4, 168.9, 81.5, 56.7, 53.1, 51.2, 42.9, 38.3, 37.9, 37.0, 35.6, 29.7, 29.1, 28.5, 28.0, 27.8; MS (EI) *m/z* 290 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{18}H_{26}O_3$ 290.1882, found: 290.1881; Anal. Calc for $C_{18}H_{26}O_3$: C, 74.45; H, 9.02. Found: C, 74.55; H, 8.99.

2-Oxodecahydro-3a,7:5,9-dimethanocyclopenta[8]annulene-1-carboxylic Acid (48). CF_3CO_2H (0.3 mL) was added with stirring to *tert*-butyl ester **47b** (20 mg, 0.069 mmol) in CH_2Cl_2 (3 mL) at room temperature. After 3 h, volatile materials were removed *in vacuo* and the residue was dried under vacuum for 4 h to leave the β-keto acid **48** (16 mg, 99%) as a white solid: mp 118 - 120 °C (CH_2Cl_2); R_f 0.39 (hexanes : EtOAc : MeOH, 1 : 1 : 0.2); IR (film) 2906, 2852, 1752, 1702 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.54 (br s, 1H, CO_2*H*), 3.34 (d, *J* 13.0 Hz, 1H, C*H*CO_2H), 2.51 (d, *J* 13.0 Hz, 1H, CH(CO_2H)C*H*), 2.17-2.07 (m, 4H, C*H*$_2$COCHCO_2H and adamantane), 1.98-1.68 (m, 9H, adamantane), 1.51 (s, 2H, adamantane); ^{13}C NMR (100 MHz, $CDCl_3$) δ 211.4, 174.3, 55.3, 53.1, 51.1, 42.9, 38.2, 37.9, 37.0, 35.8, 29.6, 29.1, 28.5, 27.8; MS (EI) *m/z* 234 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{14}H_{18}O_3$ 234.1256, found: 234.1254.

Octahydro-3a,7:5,9-dimethanocyclopenta[8]annulen-2(3*H*)-one (49).[42] **From β–keto-ethyl ester 47a.** β–Ketoester **47a** (46 mg, 0.176 mmol) and NaCl (20 mg, 0.351 mmol) in DMSO (6 mL) and H_2O (0.095 mL, 5.27 mmol) was stirred at 130 - 140 °C for 1.5 h. The solution was cooled to room temperature, diluted with Et_2O (50 mL) and washed with H_2O (2 x 15 mL) and brine (15 mL). The organic extracts were dried ($MgSO_4$), concentrated *in vacuo* and the residue was chromatographed (hexanes : EtOAc, 25 : 1) to afford cyclopentanone **49** (30 mg, 90%). **From β–keto-*tert*-butyl ester 47b.** CF_3CO_2H (0.3 mL) was added with stirring to *tert*-butyl ester **47b** (20 mg, 0.069 mmol) in dry PhCl (5 mL) at room temperature. The mixture was subsequently stirred at 120 °C for 3 h, after which the solvent was removed *in vacuo*. The crude material was dried under vacuum for 3 h to afford the cyclopentanone **49** (13 mg, 100%). **From β–keto-acid 48.** β–Keto-acid

48 (18 mg, 0.077 mmol) in 1,4-dioxane (5 mL) was heated under reflux for 3 h, and the solvent was removed *in vacuo*. The residue was chromatographed (hexanes : EtOAc, 20 : 1) to afford the cyclopentanone **49** (12 mg, 82%). The cyclopentanone **49** in these experiments was obtained as colorless crystals: mp 73 - 75 °C (EtOAc) (lit.[48] mp 74 - 76 °C); R_f 0.22 (hexanes : EtOAc, 15 : 1); IR (film) 2903, 2851, 1744, 1452 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.31(m, 1H, C*H*$_2$C=O), 2.16 (m, 2H, C*H*$_2$C=O), 2.07 (m, 1H, C*H*$_2$C=O), 1.99-1.40 (m, 14H, adamantane methine and methylene); ^{13}C NMR (75 MHz, $CDCl_3$) δ 219.1, 53.8, 47.3, 43.1, 39.6, 38.6, 37.5, 37.1, 36.9, 29.5, 29.2, 29.1, 27.9; MS (EI) *m/z* 190 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{13}H_{18}O$ ($M^{+\cdot}$) 190.1358, found: 190.1358. Anal. Calc for $C_{13}H_{18}O$: C, 82.06; H, 9.53. Found: C, 82.14; H, 9.63.

Di-*tert*-butyl 2,9-Dioxododecahydro-3a,7:5,10a-dimethanodicyclopenta[*a*,*c*][8]annulene-1,8-dicarboxylate (50). $Rh_2(OAc)_4$ (17 mg, 0.038 mmol) was added with stirring to di-α-diazo-β-keto ester **46** (126 mg, 0.252 mmol) in CH_2Cl_2 (6 mL) at room temperature. After 1 h, the solvent was removed *in vacuo* and the residue chromatographed (hexanes : EtOAc, 10 : 1 to 8 : 1) to give diester **50** (57 mg, 52%) as a colorless viscous oil: R_f 0.25 (hexanes : EtOAc, 4 : 1); IR (film) 2913, 2859, 1753, 1720 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.34-3.13 (m, 2H, C*H*CO$_2$C(CH$_3$)$_3$), 2.77-2.45 (m, 2H, C*H*CHCO$_2$C(CH$_3$)$_3$), 2.31-1.61 (m, 14H, C*H*$_2$C=O and adamantane), 1.48-1.45 (m, 18H, CO$_2$C(C*H*$_3$)$_3$); MS (EI) *m/z* 444 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{26}H_{36}O_6$ 444.2512, found: 444.2514.

Octahydro-3a,7:5,10a-dimethanodicyclopenta[*a*,*c*][8]annulene-2,9(3*H*,10*H*)-dione (51). CF_3CO_2H (0.5 mL) was added with stirring to di-*tert*-butyl ester **50** (28 mg, 0.063 mmol) in dry PhCl (5 mL) at room temperature. The mixture was stirred at 115 °C for 3 h, cooled and the solvent was removed *in vacuo*. The residue was chromatographed (hexanes : EtOAc, 4 : 1) to afford the di-ketone **51** (15 mg, 97%) as a colorless oil: R_f 0.24 (hexanes : EtOAc, 2 : 1); IR (film) 2910, 2856, 1740 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.4-2.1 (m, C*H*$_2$C=O), 2.1-1.3 (m, adamantane methine and methylene); ^{13}C NMR (75 MHz, $CDCl_3$) δ 217, 53.8, 53.3, 53.0, 51.5, 50.2, 48.8, 47.4, 47.2, 47.144.8, 44.4, 43.1, 39.7, 39.6, 39.4, 39.2, 39.1, 39.0, 38.9, 38.2, 38.0, 37.9, 37.8, 37.2, 36.9, 36.8, 36.535.8, 35.4, 30.5, 30.3, 29.8, 29.7, 29.4, 29.2; MS (EI) *m/z* 244 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{16}H_{120}O_2$ 244.1463, found: 244.1464; Anal. Calc for $C_{16}H_{20}O_2$: C, 78.65; H, 8.25. Found: C, 78.55; H, 8.37.

1,3,5,7-Tetra-(2-methoxyethenyl)adamantane (52). $NaN(SiMe_3)_2$ in THF (1.0 M; 6.05 mL, 6.05 mmol) was added with stirring to Ph_3PCH_2OMeCl (2.21 g, 6.45 mmol) in THF (10 mL) at −78 °C. After 1 h, tetra-aldehyde **19** (200 mg, 0.806 mmol) in THF (10 mL) was added dropwise with stirring to the red solution and the mixture allowed to warm up to room temperature. After 16 h, saturated aqueous NH_4Cl (10 mL) was added and the mixture was extracted with EtOAc (3 x 20 mL). The combined organic layers were washed with brine (20 mL), dried ($MgSO_4$), concentrated *in vacuo* and the residue chromatographed (hexanes : EtOAc, 30 : 1 to 15 : 1) to give the tetra-enol ether **53** (ca. 1 : 1 (*E*)-olefin : (*Z*)-olefin isomers) (230 mg, 80%) as a colorless oil: R_f 0.62 (hexanes : EtOAc, 4 : 1); IR (film) 3019, 2930, 2901, 2849, 1656, 1449 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 6.22 (d, *J* 12.9 Hz, 2H, (*E*)-isomer CH=C*H*OCH$_3$), 5.71-5.67 (m, 2H, (*Z*)-isomer CH=C*H*OCH$_3$), 4.72 (d, *J* 12.9 Hz, 2H, (*E*)-isomer C*H*=CHOCH$_3$), 4.05 (d, *J* 7.0 Hz, 2H, (*Z*)-isomer C*H*=CHOCH$_3$), 3.53 (s, 6H, (*Z*)-isomer CH=CHOC*H*$_3$), 3.49 (s, 6H, (*E*)-isomer CH=CHOC*H*$_3$), 1.72-1.69 (m, 6H, (*Z*)-isomer adamantane methylene), 1.52 (s, 6H, (*E*)-isomer adamantane methylene); ^{13}C NMR (75 MHz, $CDCl_3$) δ complex due to mixtures of geometric isomers 145.6-144.7 (multiple peaks, *C*H=CH(OMe), 116.4-114.5 (multiple peaks, CH=*C*H(OMe), 59.7, 55.8, 47.8-46.0 (multiple peaks), 35.8, 34.4 (the peaks in the ^1H and ^{13}C NMR spectra for the *E*- and *Z*- CH=CHOMe units were consistent with those in the spectra reported for the isolated *E*- and *Z*- isomers of 1-(2-methoxyethenyl)-1-methylcyclohexane[49]); the product did not exhibit a molecular ion in the MS. Anal. Calc for $C_{22}H_{32}O_4$: C, 73.30; H, 8.95. Found: C, 73.34; H, 8.96.

2,2',2'',2'''-(Adamantane-1,3,5,7-tetrayl)tetraacetaldehyde (53). CF_3CO_2H (41 mg, 0.275 mmol) in solvent CH_2Cl_2, *i*-PrOH and H_2O (60:20:1; (5 mL) was added dropwise with stirring to tetra-enol ether **52** (23 mg, 0.064 mmol) at room temperature. After 16 h, saturated aqueous $NaHCO_3$ (8 mL) was added and the mixture was extracted with CH_2Cl_2 (3 x 15 mL). The combined organic layers were dried ($MgSO_4$), concentrated *in vacuo* and the residue chromatographed (hexanes : EtOAc : MeOH, 1 : 1 : 0.2) to afford tetra-aldehyde **53** (11.5 mg, 60%) as colorless crystals: mp 124 - 126 °C (EtOAc); R_f 0.24 (hexanes : EtOAc : MeOH, 1 : 1 : 0.2); IR (film) 2923, 2850, 1713 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 9.83 (t, *J* 2.6 Hz, 4H, C*H*O), 2.28 (d, *J* 2.6 Hz, 8H, CH_2CHO), 1.56 (s, 12H, adamantane methylene); ^{13}C NMR (100 MHz, $CDCl_3$) δ 201.6, 55.4, 45.6, 34.8; MS (EI) *m/z* 304 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{18}H_{24}O_4$ ($M^{+\cdot}$) 304.1675, found: 304.1683; Anal. Calc for $C_{18}H_{24}O_4$: C, 71.03; H, 7.95. Found: C, 70.98; H, 7.93.

2,2',2'',2'''-(Adamantane-1,3,5,7-tetrayl)tetraacetic Acid (54a).[13] $NaClO_2$ (308 mg, 2.74 mmol) and $NaH_2PO_4{\cdot}H_2O$ (378 mg, 2.74 mmol) in H_2O (2.8 mL) were added slowly with stirring to *t*-BuOH (11.2 mL), 2-methyl-2-butene (2.8 mL) and tetra-aldehyde **53** (52 mg, 0.171 mmol) in the dark at room temperature. After overnight stirring, the mixture was acidified to pH 1-2 and extracted with EtOAc (5 x 15 mL). The combined organic layers were back extracted into saturated aqueous $NaHCO_3$ (70 mL). This solution was reacidified to pH 1-2 using 4 M HCl and extracted with EtOAc (4 x 40 mL). These combined organic extracts were dried ($MgSO_4$), concentrated *in vacuo* and the residue further dried under vacuum overnight to afford the tetra-acid **54a** (52 mg, 83%) as a white solid, which was used directly in the subsequent step without further purification: ^1H NMR (400 MHz, DMSO-d_6) δ 11.96 (*br* s, 4H, CO_2H), 2.01 (s, 8H, CH_2CO_2H), 1.32 (s, 12H, adamantane methylene); ^{13}C NMR (100 MHz, DMSO-d_6) δ 172.8, 47.7, 45.6, 34.2.

Tetramethyl 2,2',2'',2'''-(Adamantane-1,3,5,7-tetrayl)tetraacetate (54b). $SOCl_2$ (35 µL, 0.47 mmol) was added slowly with stirring to tetra-acid **54a** (29 mg, 0.079 mmol) and DMF (1.2 µL, 0.016 mmol) in CH_2Cl_2 (3 mL) at 0 °C. After stirring overnight at room temperature, all volatile materials were removed *in vacuo* and the crude tetra-acid chloride was allowed to dry under vacuum for an additional 4 h and was used in the subsequent step without any further purification. MeOH (6 mL) was added with stirring to crude tetra-acid chloride at room temperature overnight, during which time the original cloudy mixture became a clear solution. The MeOH and HCl were removed *in vacuo*, the residue was dissolved in EtOAc (20 mL), washed with H_2O (5 mL), 5% aqueous Na_2CO_3 (5 mL) and brine (10 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The residue was chromatographed (hexanes : EtOAc, 4 : 1) to afford tetra-methyl ester **54b** (14 mg, 42% over two steps) as colorless crystals: mp 80 - 82 °C (hexanes : EtOAc, 1 : 1); R_f 0.31 (hexanes : EtOAc, 2 : 1); IR (film) 2951, 2924, 2851, 1732, 1438 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.65 (s, 12H, CO_2CH_3), 2.17 (s, 8H, C$H_2CO_2CH_3$), 1.40 (s, 12H, adamantane methylene); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.6, 51.2, 47.1, 45.2, 34.3; MS (EI) *m/z* 424 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{22}H_{32}O_8$ 424.2097, found: 424.2083.

Tetraethyl 4,4',4'',4'''-(adamantane-1,3,5,7-tetrayl)tetrakis(3-oxobutanoate) (15a). Tetra-aldehyde **53** (238 mg, 0.78 mmol) in CH_2Cl_2 (6 mL) was added with stirring to anhydrous $SnCl_2$ (60 mg, 0.31 mmol) and ethyl diazoacetate (0.362 mL, 3.44 mmol) in CH_2Cl_2 (10 mL) at 0 °C and the mixture allowed to warm up to room temperature. After 2 h, the mixture was washed with brine (15 mL) and extracted with CH_2Cl_2 (3 x 20 mL). The organic extracts were dried ($MgSO_4$), concentrated *in vacuo* and the residue was chromatographed (hexanes : EtOAc, 2 : 1) to afford the tetra-β-keto ester **15a** (417 mg, 82%) (3 : 1 keto : enol forms) as a colorless oil: R_f 0.46 (hexanes : EtOAc, 1 : 1); IR (film) 2983, 2905, 1744, 1714, 1633 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): (all keto

form) δ 4.17 (q, *J* 7.2 Hz, 8H, $CO_2CH_2CH_3$), 3.36 (m, 8H, CH_2CO_2Et), 2.34 (m, 8H, $CH_2COCH_2CO_2Et$), 1.46-1.38 (m, 12H, adamantane methylene), 1.26 (t, *J* 7.2 Hz, 12H, $CO_2CH_2CH_3$); (all enol form) δ 12.06 (s, 4H, *H*OC=CH), 4.86 (m, 4H, HOC=C*H*), 4.17 (q, *J* 7.2 Hz, 8H, $CO_2CH_2CH_3$), 1.97 (m, 8H, $CH_2C(OH)=CH$), 1.46-1.38 (m, 12H, adamantane methylene), 1.26 (t, *J* 7.2 Hz, 12H, $CO_2CH_2CH_3$); ^{13}C NMR (100 MHz, $CDCl_3$): (all keto form) δ 201.5, 166.9, 61.3, 54.1, 51.3, 44.6, 34.9, 14.1; (all enol form) δ 175.6, 172.4, 91.7, 59.9, 48.5, 45.3, 34.7, 14.2; MS (EI) *m/z* 648 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{34}H_{48}O_{12}$ 648.3146, found: 648.3145; Anal. Calc for $C_{34}H_{48}O_{12}$: C, 62.95; H, 7.46. Found: C, 63.02; H, 7.52.

Tetraethyl 4,4',4'',4'''-(adamantane-1,3,5,7-tetrayl)tetrakis(2-diazo-3-oxobutanoate) (55a). Et_3N (1.04 mL, 7.44 mmol) was added dropwise with stirring to tetra-β-ketoester **15a** (402 mg, 0.62 mmol) and 4-acetamidobenzenesulfonyl azide (**40**) (655 mg, 2.73 mmol) in dry MeCN (15 mL) at 0 °C and the mixture allowed to warm up to room temperature. After 3 h, the reaction mixture was concentrated *in vacuo* and the resultant solid was triturated with Et_2O and hexanes (1:1) (100 mL). The mixture was filtered, the filtrate was concentrated *in vacuo* and the residue was chromatographed (hexanes : EtOAc, 2 : 1) to afford the tetra-diazo-ester **55a** (450 mg, 97%) as a viscous oil: R_f 0.51 (hexanes : EtOAc, 1 : 1); IR (film) 2133, 1714, 1649, 1300 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.23 (q, *J* 7.2 Hz, 8H, $CO_2CH_2CH_3$), 2.68 (s, 8H, $CH_2COC=N_2$), 1.45 (s, 12H, adamantane methylene), 1.28 (t, *J* 7.2 Hz, 12H, $CO_2CH_2CH_3$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.8, 161.2, 77.2, 61.2, 50.1, 45.2, 35.9, 14.2; MS (ES) *m/z* 775 (M + Na^+); HRMS (ES) *m/z* calc for $C_{34}H_{40}N_8O_{12}Na$ 775.2663, found: 775.2654.

Tetra-*tert*-butyl 4,4',4'',4'''-(Adamantane-1,3,5,7-tetrayl)tetrakis(3-oxobutanoate) (**15b.)** Tetra-aldehyde **53** (30 mg, 0.099 mmol) in CH_2Cl_2 (3 mL) was added with stirring to anhydrous $SnCl_2$ (7.5 mg, 0.040 mmol) and *tert*-butyl diazoacetate (0.060 mL, 0.43 mmol) in CH_2Cl_2 (2 mL) at 0 °C and the mixture was allowed to warm up to room temperature. After 2 h, the reaction was quenched with brine (10 mL) and the mixture was extracted with CH_2Cl_2 (3 x 15 mL). The organic extracts were dried ($MgSO_4$), concentrated *in vacuo* and the residue was chromatographed (hexanes : EtOAc, 4 : 1) to afford the tetra-β-keto ester **15b** (61 mg, 81%) (ca. 4 : 1 keto : enol forms) as a colorless oil: R_f 0.41 (hexanes : EtOAc, 2 : 1); IR (film) 2978, 2932, 1738, 1714, 1638 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): (all keto form) δ 3.26 (s, 8H, $CH_2CO_2{}^t$Bu), 2.33 (s, 8H, $CH_2COCH_2CO_2{}^t$Bu), 1.48 (s, 12H, adamantane methylene), 1.45 (s, 36H, $C(CH_3)_3$); (enol form) δ 12.19 (s, 4H, C(O*H*)=$CHCO_2{}^t$Bu), 4.77 (s, 4H, C(OH)=*CH*$CO_2{}^t$Bu), 1.94 (s, 8H, $CH_2C(OH)=CHCO_2{}^t$Bu), 1.48 (s, 12H, adamantane methylene), 1.45 (s, 36H, $C(CH_3)_3$); ^{13}C NMR (100 MHz, $CDCl_3$): (keto form) δ 202.0, 166.2, 81.8, 52.6, 48.6, 44.7, 34.7, 28.0; (enol form) δ 174.9, 172.4, 93.1, 81.9, 54.2, 45.2, 34.9, 28.3; MS (ES) *m/z* 783 (M + Na^+); HRMS (ES) *m/z* calc for $C_{42}H_{64}O_{12}Na$ 783.4295, found: 783.4293; Anal. Calc for $C_{42}H_{64}O_{12}$: C, 66.29; H, 8.48. Found: C, 66.33; H, 8.38.

Tetra-*tert*-butyl 4,4',4'',4'''-(Adamantane-1,3,5,7-tetrayl)tetrakis(2-diazo-3-oxobutanoate) (55b). Et_3N (0.255 mL, 1.82 mmol) was added dropwise with stirring to tetra-β-keto ester **15b** (115 mg, 0.151 mmol) and 4-acetamidobenzenesulfonyl azide (**40**) (160 mg, 0.666 mmol) in dry MeCN (10 mL) at 0 °C was added and the mixture was allowed to warm up to room temperature. After stirring overnight, the reaction mixture was concentrated *in vacuo* and the resultant solid was triturated with Et_2O and hexanes (1:1) (80 mL), the mixture was filtered, and the filtrate was concentrated *in vacuo*. The residue was chromatographed (hexanes : EtOAc, 4 : 1) to afford tetra-diazo-*tert*-butyl ester **55b** (130 mg, 99%) as a viscous oil: R_f 0.57 (hexanes : EtOAc, 2 : 1); IR (film) 2979, 2930, 2130, 1712, 1645, 1310 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.67 (s, 8H, $CH_2C(O)C=N_2$), 1.48 (s, 36H, *tert*-butyl), 1.46 (s, 12H, adamantane methylene); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.2, 160.4, 82.9,

78.0, 50.2, 45.2, 35.9, 28.2; MS (ES) *m/z* 887 (M + Na^+); HRMS (ES) *m/z* calc for $C_{42}H_{56}N_8O_{12}Na$ 887.3915, found: 887.3923; Anal. Calc for $C_{42}H_{56}N_8O_{12}$: C, 58.32; H, 6.53; N, 12.96. Found: C, 58.42; H, 6.47; N, 12.86.

2-(1-Adamantane)acetyl chloride.[50] Freshly distilled $SOCl_2$ (12 mL) was added to 2-(1-adamantane)acetic acid (1.50 g, 7.73 mmol) in a flame-dried flask. The mixture was heated to reflux with vigorous stirring for 5 h, when the excess thionyl chloride was removed *in vacuo*. PhH (15 mL) was added and was subsequently removed *in vacuo* to leave a light yellow oil, which was stored under vacuum overnight to leave crude 2-(1-adamantane)acetyl chloride (1.65 g, 99%) as a light yellow oil: IR (film) 2904, 2850, 1797, 1451 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 2.70 (s, 2H, C*H*$_2$COCl), 1.99 (s, 3H, adamantane methine), 1.74-1.67 (m, 12H, adamantane methylene); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.9, 60.7, 41.6, 36.4, 34.0, 28.3.

1-Diazo-3-(1-adamantyl)-2-propanone.[48] *N*-Nitroso-*N*-methyl urea (3.0 g, 28.6 mmol) was added in small portions with stirring to aqueous KOH (50%; 8 mL) and Et_2O (20 mL) at 0 °C. After 15 min, the bright yellow ethereal solution of CH_2N_2 was carefully decanted and maintained at 0 °C. 2-(1-Adamantane)acetyl chloride (1.5 g, 7.04 mmol) in Et_2O (10 mL) was added dropwise with stirring to the ice-cold CH_2N_2 solution. After 2 h at 0 °C and room temperature overnight, removal of solvent *in vacuo* left the title diazo-ketone (1.54 g, quantitative yield) as a yellow oil: R_f 0.42 (hexanes : EtOAc, 4 : 1); IR (film) 2902, 2847, 2099, 1631, 1354 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.19 (s, 1H, COC*H*N_2), 2.05 (s, 2H, C*H*$_2$CO), 1.97 (s, 3H, adamantane methine), 1.63 (s, 12H, adamantane methylene); MS (CI, NH_3) *m/z* 219 (M + H^+); HRMS (CI, NH_3) *m/z* calc for $C_{13}H_{19}N_2O$ (M + H^+) 219.1497, found: 219.1496.

Octahydro-3a,7:5,9-dimethanocyclopenta[8]annulen-2(3*H*)-one (49).[48] **1-Diazo-3-(1-adamantyl)-2-propanone** 1-(3-Diazo-2-oxo-1-propyl)-adamantane[48] (1.55 g, 7.11 mmol) in PhMe (40 mL) was added over 5 h *via* syringe pump to toluene (160 mL) containing $CuSO_4$ (320 mg, 2.0 mmol) at reflux. The mixture was subsequently heated under reflux for an additional 2 h, cooled down to room temperature and filtered. The filtrate was sequentially washed with H_2O (50 mL), 5 M aqueous NaOH (50 mL), H_2O (50 mL) and brine (50 mL), dried ($MgSO_4$) filtered and evaporation *in vacuo*. The residual thick light brown oil was chromatographed (hexanes : EtOAc, 50 : 1) to give the cyclopentanone **49** (632 mg, 47% over 3 steps), which was identical with the material previously prepared.[48]

4,5,6,7,8,9-Hexahydro-3a,7:5,9-dimethanocyclopenta[8]annulen-2(3*H*)-one (57). Me_3SiCl (3.74 mL, 29.2 mmol) and cyclopentanone **49** (554 mg, 2.92 mmol) in THF (6 mL) were added sequentially dropwise with stirring to lithium 2,2,6,6-tetramethylpiperidide (13.1 mmol), prepared from 2,2,6,6-tetramethylpiperidine (2.46 mL, 14.6 mmol) and *n*-BuLi (1.6 M in hexanes, 8.2 mL, 13.1 mmol) in THF (5 mL), at −78 °C. After a further 20 min at −78 °C, Et_3N (6.3 mL) was added, and the mixture was allowed to warm to room temperature during a period of 1 h. Et_2O (50 mL) was added, and the organic solution was washed with H_2O (20 mL) and brine (20 mL), dried ($MgSO_4$), concentrated *in vacuo* and the remaining tetramethylpiperidine removed under vacuum. $Pd(OAc)_2$ (643 mg, 2.86 mmol) was added to residue of silyl enol ethers in dry MeCN (10 mL) and the mixture stirred overnight at room temperature. The mixture was filtered through a short pad of Celite, eluting with Et_2O and the organic phase was washed with saturated aqueous NH_4Cl (10 mL), dried ($MgSO_4$), concentrated *in vacuo* and the residue chromatographed (hexanes : EtOAc, 15 : 1 to 10 : 1) to afford the cyclopentenone **57** (125 mg, 23%) and recovered starting material **49** (178 mg, 32%). The enone **57** was obtained as a colorless oil: R_f 0.29 (hexanes : EtOAc, 4 : 1); IR (film) 2917, 2851, 1703, 1626 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.73 (s, 1H, COC*H*=C), 3.06 (s, 2H, C*H*$_2$CO), 2.10-2.01 (m, 7H, adamantane methine and

methylene), 1.84-1.82 (m, 4H, adamantane methylene), 1.66 (m, 2H, adamantane methylene); ^{13}C NMR (75 MHz, $CDCl_3$) δ 208.5, 192.3, 121.5, 49.4, 45.2, 43.3, 38.2, 35.7, 35.2, 28.7; MS (EI) *m/z* 188 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{13}H_{16}O$ ($M^{+\cdot}$) 188.1201, found: 188.1201.

2,3,4,5,6,7,8,9-Octahydro-3a,7:5,9-dimethanocyclopenta[8]annulen-2-ol (58). DIBAl-H in hexanes (1.0 M; 0.59 mL, 0.59 mmol) was added dropwise with stirring to cyclopentenone **57** (55 mg, 0.29 mmol) in dry THF (5 mL) at −78 °C. After a further 30 min at −78 °C, saturated aqueous NH_4Cl (0.16 mL), Et_2O (10 mL), and silica gel (200 mg) were added and the mixture was stirred vigorously and allowed to warm up to room temperature. The mixture was filtered through a short pad of anhydrous $MgSO_4$ and the solids were leached with EtOAc. The combined organic phases were rotary evaporated and the residue chromatographed (hexanes : EtOAc, 8 : 1) to give the cyclopentenol **58** (50 mg, 90%) as a colorless oil: R_f 0.28 (hexanes : EtOAc, 4 : 1); IR (film) 3331 broad, 2902, 2847, 1666 cm^{-1}; ^{1}H NMR (400 MHz, C_6D_6) δ 5.25 (d, *J* 2.0 Hz, 1H, C*H*=C), 4.83 (ddd, *J* 7.8, 3.9, 2.0 Hz, 1H, C*H*OH), 2.61 (m, 1H, CH_2CHOH), 2.31 (m, 1H, CH_2CHOH), 1.91 (dd, *J* 14.1, 7.8 Hz, 1H, CH=CC*H*), 1.86-1.37 (m, 12H, adamantane); ^{13}C NMR (100 MHz, C_6D_6) δ 157.4, 118.0, 76.3, 48.4, 46.9, 46.3, 46.2, 38.7, 36.7, 33.9, 30.2, 30.0, 29.8; the product did not exhibit a molecular ion in the MS.

4,5,6,7,8,9-Hexahydro-3a,7:5,9-dimethanocyclopenta[8]annulene (59). Allylic alcohol **58** (48 mg, 0.25 mmol) was dissolved in $CDCl_3$ (2 mL). After 2 h, $CDCl_3$ was carefully removed *in vacuo* and the residue was chromatographed (hexanes only) to afford adamantanocyclopentadiene **59** (40 mg, 89%) as a colorless and volatile oil: R_f 0.76 (hexanes : EtOAc, 15 : 1); IR (film) 2914, 2848 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.41 (d, *J* 5.0 Hz, 1H, CH=C*H*CH=C), 6.30 (d, *J* 5.0 Hz, 1H, C*H*=CHCH=C), 5.82 (s, 1H, CH=CHC*H*=C), 3.06 (apparent s, 1H, CH=CHCH=CC*H*), 2.15 (apparent d, *J* 12.0 Hz, 2H, adamantane), 2.01 (apparent s, 2H, adamantane), 1.93 (apparent d, *J* 12.0 Hz, 2H, adamantane), 1.78 (apparent s, 2H, adamantane), 1.51 (apparent d, *J* 11.5 Hz, 2H, adamantane), 1.12 (apparent d, *J* 11.5 Hz, 2H, adamantane); ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.6, 142.7, 130.0, 113.8, 53.0, 41.2, 39.3, 36.1, 33.8, 28.1; MS (EI) *m/z* 172 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{13}H_{16}$ ($M^{+\cdot}$) 172.1252, found: 172.1253.

(±)-(3a*R*,3b*R*,4*S*,6*R*,8*S*,9a*R*,10*S*,10a*R*)-4,5,6,7,8,9,10,10a-Octahydro-1*H*-3b,10-etheno-4,8:6,9a-dimethanocycloocta[3,4]cyclopenta[1,2-*c*]furan-1,3(3a*H*)-dione (61). Diene **59** (15 mg, 0.087 mmol) and maleic anhydride (**60**) (11 mg, 0.13 mmol) in CH_2Cl_2 (0.5 mL) and $CHCl_3$ (1 mL) were allowed to stand for 21 h at room temperature. $CHCl_3$ and CH_2Cl_2 were removed *in vacuo* and the residue was chromatographed (hexanes : Et_2O) to give the Diels-Alder adduct **61** (5 mg, 23%) as a light yellow oil; R_f 0.40 (hexanes : EtOAc, 4:1); IR (film) 2912, 2854, 2359, 1856, 1776 cm^{-1}; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 6.25 (d, J 5.7 Hz, 1H), 6.15 (dd, J 5.7, 2.8 Hz, 1H), 3.91 (d, J 7.7 Hz, 1H), 3.70 (dd, J 7.6, 4.5 Hz, 1H), 3.10 (m, 1H), 2.55 (s, 1H), 2.21-2.17 (m, 1H), 2.06-2.02 (m, 2H), 1.90-1.62 (m, 6H), 1.34-1.26 (m, 3H); ^{13}C NMR: (75 MHz, $CDCl_3$) δ 172.3, 171.8, 138.8, 133.1, 63.1, 61.3, 53.5, 47.8, 46.4, 38.2, 35.1, 33.7, 31.9, 29.7, 28.4, 28.2, 27.8; MS (EI) *m/z* 270 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{17}H_{18}O_3$ ($M^{+\cdot}$) 270.1256, found 270.1256.

(2,3,4,5,6,7,8,9-Octahydro-3a,7:5,9-dimethanocyclopenta[8]annulen-2-yl) 3-(4,5,6,7,8,9-hexahydro-3a,7:5,9-dimethanocyclopenta[8]annulene) (63). Tris(*p*-bromophenyl)aminium hexachloroantimonate (**62**) (57 mg, 0.070 mmol) was added with stirring to adamantanocyclopentadiene **59** (120 mg, 0.70 mmol) in CH_2Cl_2 (3.5 mL) at 0 °C. After 2.5 h, reaction was quenched with excess methanolic sodium methoxide and the mixture was diluted with excess CH_2Cl_2. The organic phase was washed with H_2O (3 x 10 mL) and brine (10 mL), dried ($MgSO_4$), concentrated *in vacuo* and the residue chromatographed (hexanes only) to give the substituted

cyclopentadiene dimer **63** (48 mg, 40%) as a colorless oil: R_f 0.78 (hexanes : EtOAc, 15 : 1); IR (film) 2904, 2846, 1445 cm^{-1}; UV-Vis (hexanes) λ_{max} (log ε) 262 (3.76) nm; ^1H NMR (500 MHz, C_6D_6) δ 6.30 (m, 1H, H_A), 5.93 (d, *J* 1.9 Hz, 1H, H_B), 5.21 (d, *J* 2.0 Hz, 1H, H_C), 3.72 (m, 1H, H_E), 2.98 (m, 1H, H_F), 2.75 (m, 1H, H_D), 2.10-1.20 (m, 26H, adamantane and H_G); ^{13}C NMR (125 MHz, C_6D_6) δ 162.2, 157.9, 153.0, 123.9, 117.4, 114.6, 53.3, 47.3, 47.1, 46.4, 45.9, 41.9, 41.5, 41.4, 40.4, 39.8, 39.5, 38.7, 37.0, 36.5, 34.2, 34.1, 30.39, 30.36, 28.74, 28.70; MS (EI) *m/z* 344 ($M^{+\cdot}$); HRMS (EI) *m/z* calc for $C_{26}H_{32}$ ($M^{+\cdot}$) 344.2504, found: 344.2503.

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Supplementary Material

Copies of the single crystal X-ray crystallographic structures of tetraol **21** and tetra-((hydroxymethyl)-cyclopropyl)-adamantane **35**, their CIF files and NMR spectra for the dimer **63** are provided in the Supplementary Material.

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