Tetrahedron Vol 47, No 37, pp 7807-7820, 1991
Printed in Great Britain

0040-4020/91 $3 00+ 00

Synthetic Studies Towards Prismanes: 1,4-Bishomo-[6]-Prismane ("Garudane")

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(*Received in UK 3 July* 1991)

Key Words: Norbornenobenzoquinone; 2+2-photocycloaddition; Favorskii rearrangement; face-to-face dimer of norbornadiene.

Abstract:

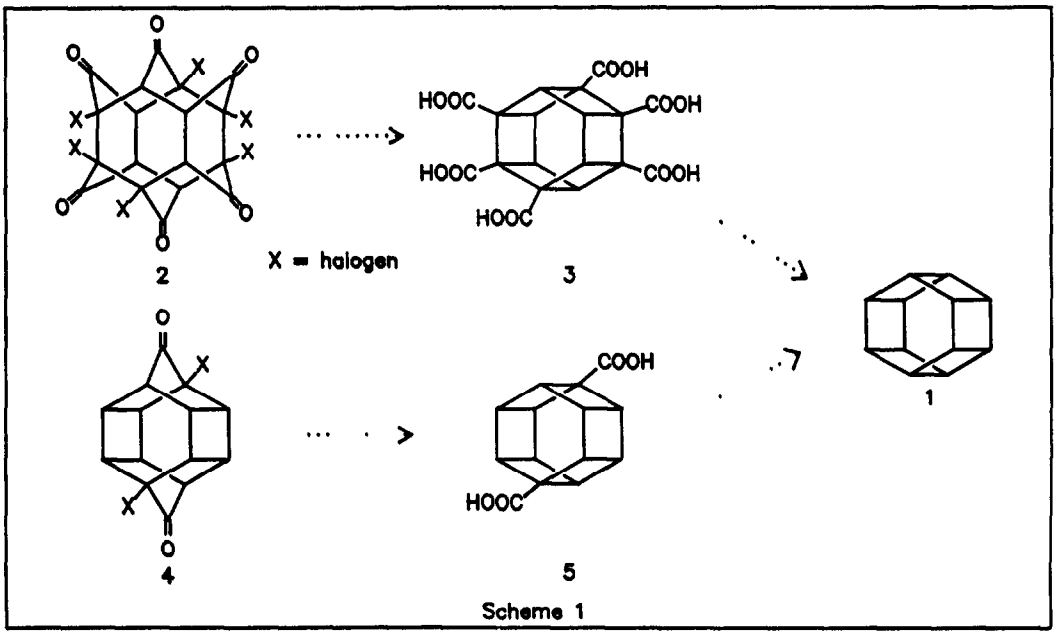
The first synthesis of 1,4-bishomohexaprismane 6, the true, face-to-face, heptacyclic dimer of norbornadiene is delineated. In the initial phase, the readily available norborneno-p-benzoquinone 13 was transformed into the bishomoseco[7]-prismane dione 11 in three steps involving stereoselective 4+2 cycloaddition, regio- and stereoselective Ti^{3+} reduction of the enedione moiety and intramolecular 2+2-photocycloaddition. The versatile dione 11 through Favorskii ring contraction technology and subsequent functional group interconversions delivered the target hydrocarbon 6. The new synthetic methodology outlined here opens up avenues for the synthesis of many novel polyhedranes, in particular [6]-, [7]- and [8]-prismanes.

Introduction

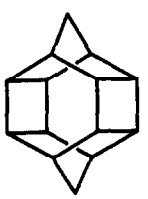
In the accompanying paper,[1] we have described a novel approach to [6]-prismane 1 in which a multiple cyclobutane forming intramolecular 2+2-photocycloaddition was assigned a pivotal role. However, as this strategy began to unfold, we encountered the failure of some key 2+2-photocycloadditions, and this forced us to simultaneously explore alternate avenues to 1. Quite obviously, the new tactic had to rely less on photochemical 2+2-cycloaddition step as the main cyclobutane generating stratagem. In this context, synthesis of [6]-prismane 1 *via* an asterane ring contraction route appeared to be an attractive and novel proposition as one does not have to surmount the enormous strain energy barriers encountered in the 2+2-photocycloaddition approaches.

On a conceptual level, a functionalised [6]-asterane like 2 could, in principle, eventuate in [6]-prismane through the intermediacy of [6]-prismane hexacarboxylic acid 3 obtained through six fold ring contraction stratagem, Scheme 1. However, [6]-asterane or its derivatives are not known and their synthesis itself poses substantial difficulties because of the steric interactions among the adjacent methylene groups. Also, the intermediate hexacarboxylic acid 3 has too many active sites and conversion of 3 to the hydrocarbon 1 could be a daunting task, fraught with complications. Therefore, from practical considerations tetranor-[6]-asterane 4 appeared to be a more realistic precursor to hexaprismane 1. Two fold ring contraction in 4 could deliver the diacid 5 which could then be converted to 1, Scheme 1. However, the ring system present in 4 has also remained unknown and before undertaking its synthesis, we considered

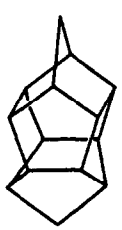
it important to develop a synthetic route towards its basic carbocyclic framework and aimed at the hydrocarbon 1,4-bishomohexaprismane 6 as the initial target. The first successful attainment of 6 (named "Garudane") is described in this report.[2]



Apart from being a potential precursor of 1, 1,4-bishomo-[6]-prismane 6 is an architecturally beautiful molecule of interest. It is the true face-to-face 2+2-dimer of norbornadiene and belongs to the D_{2h} point group. Ideally, 6 should be accessible through union of two norbornadiene moieties and indeed, several efforts in this direction have been made over the past three decades employing a variety of metal catalysts.[3] As many as seven novel dimers have been characterised, but the true face-to-face dimer 6 has remained elusive. In fact, the structure 6 has been repeatedly considered for one of the ubiquitous heptacyclic dimers of norbornadiene,[3a,b,k] but on incisive structural scrutiny, has always yielded to the alternative formulation 7 ("isogarudane").[3f,h,j,k] Understandably, the coalescence of two norbornadiene moieties to furnish 6 is disfavoured both on entropic as well as strain energy considerations[4] and hence the synthesis of this heptacyclic, $C_{14}H_{16}$ hydrocarbon constitutes an attractive and challenging proposition.



6



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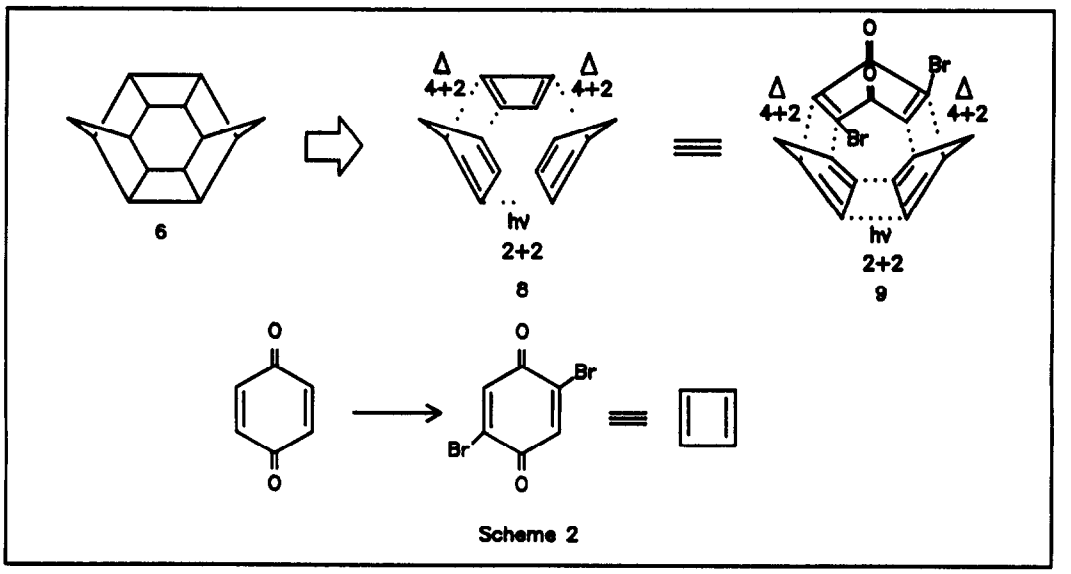
Synthetic Strategy

Among the various strategic options available for attaining 6, the one conceptualised in 8, Scheme 2, appealed to us the most. This involved a formal 2 x C_5 (1,3-cyclopentadiene) + C_4 (cyclobutadiene) union through thermal 4+2- and photochemical 2+2-cycloaddition processes. Imparting practical shape to this theme required deployment of a cyclobutadiene equivalent that could twice function as a 2π component in the 4+2-cycloaddition, control of stereochemistry to facilitate intramolecular 2+2-photocycloaddition and lastly, functional group adjustments to the hydrocarbon level. Synthetic logic and literature precedences[5] led to the identification of approach 9, the "2,5-dibromobenzoquinone between the two cyclopentadienes" as the stratagem for achieving 1,4-bishomo-[6]-prismane 6. The 2,5-dibromobenzoquinone was expected to function as the cyclobutadiene equivalent and we conceptualised the synthesis of our target molecule 6 by uniting the C_5 and C_6 fragments, step-by-step, as depicted in 9, Scheme 2.

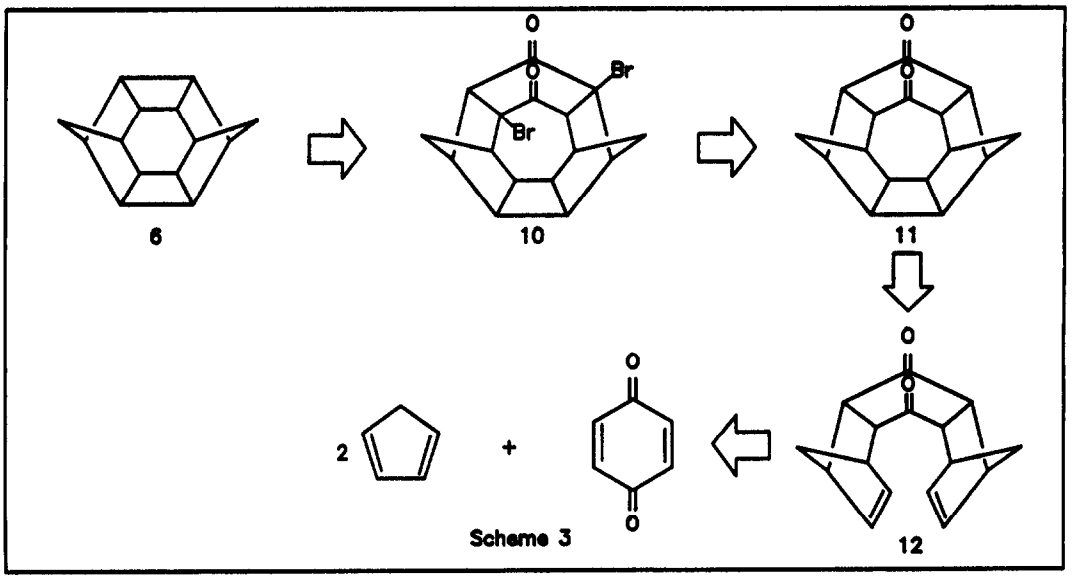


Scheme 2

To give practical expression to the theme 9, a retrosynthetic pathway was delineated as shown in Scheme 3. Its implementation required convenient access to the endo, syn, endo-adduct 12 of cyclopentadiene and p-benzoquinone, which could then be induced into a 2+2-intramolecular photocycloaddition to the key heptacyclic dione 11. Conversion of 11 to the target compound 6 could then be achieved through α-brominations to 10 and a stepwise or single shot double Favorskii ring contraction and functional group transformations.

Synthesis of "Garudane" 6

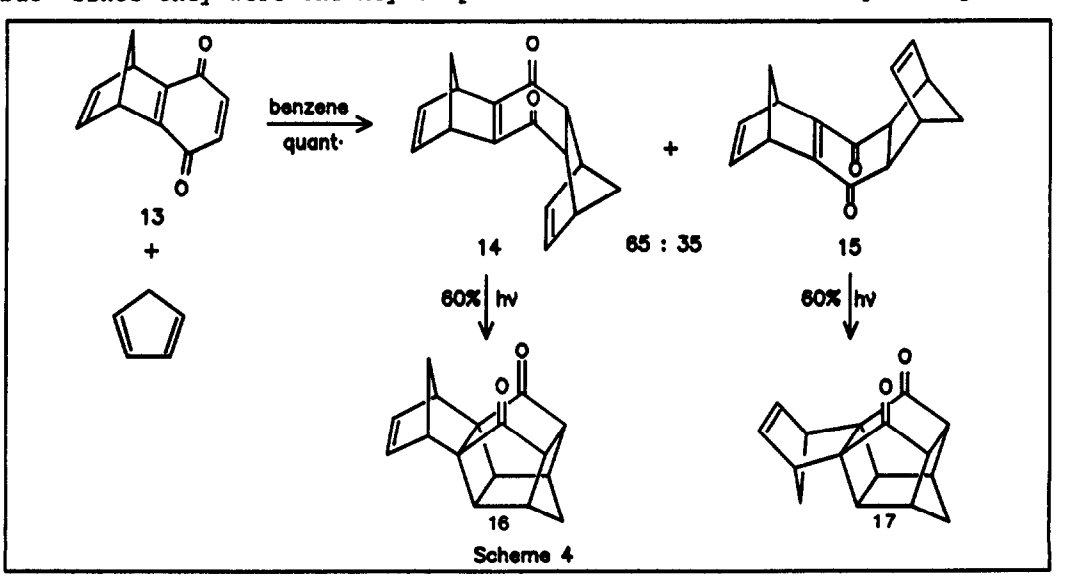
As indicated above, the synthesis of compound 12 with the right stereochemistry at all the centres was our primary objective towards attaining 6. The carbocyclic framework in 12 is basically a 2:1 adduct of cyclopentadiene and p-benzoquinone as envisaged in Scheme 3. However in practice, the 2:1 addition of cyclopentadiene to p-benzoquinone gives



Scheme 3

exclusively endo,anti,endo-adduct[6,7b] which is unserviceable in our context. Therefore, we adopted a more circuitous pathway to secure the endo,syn-endo-adduct 12. For this purpose, the readily available but previously overlooked tricyclic quinone 13[7] was selected as the starting point of our synthesis.

Diels-Alder reaction of the quinone 13 with cyclopentadiene furnished the desired endo,syn-adduct 14 and the undesired endo,anti-adduct 15 in a ratio of 65:35 (^{1}H NMR), respectively, in quantitative yield, Scheme 4. Formation of both the adducts has been previously observed by Cookson,[7b] but since they were the key compounds in our scheme of things, they were

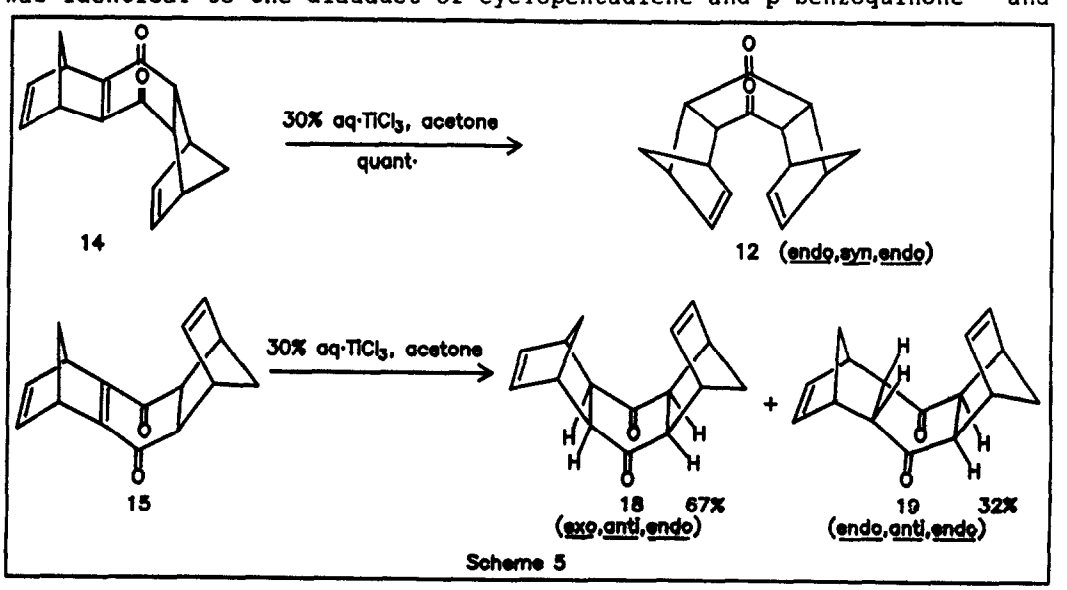


Scheme 4

fully characterised on the basis of ^{1}H and ^{13}C NMR spectra and also through 2+2-photocycloaddition to the corresponding cage systems 16 and 17, respectively, Scheme 4.[8]

Conversion of 14 to the intermediate 12 in Scheme 3 required regio- and stereoselective reduction of the enedione moiety in 14 without disturbing the isolated olefinic bonds. In this connection McMurry's procedure for the reduction of enediones using 30% aq.$TiCl_3$ came very handy.[9] In the context of 14 it was expected that the enedione moiety in it would be stereoselectively reduced, in view of the known predilection of the norbornene systems towards exo-face reactivity, leading to the formation of the required endo,syn,endo-adduct 12. Thus treatment of 14 with 30% aq.$TiCl_3$ in acetone solvent furnished 12 in quantitative yield, Scheme 5. Absence of UV absorption and shift of carbonyl absorption to 1700 cm^{-1} in the IR spectrum indicated the reduction of enedione moiety. Further, the ^{1}H NMR spectrum exhibited only four sets of signals at δ 5.94 (-HC=CH-), 3.4, 3.24 and 1.31 ($-CH_2-$), and the ^{13}C NMR spectrum showed 5 lines at δ 209.8, 136.9, 54.0, 47.0 and 43.9 consonant with the four fold symmetrical structure of 12.

The reduction of enedione 15 with 30% aq.$TiCl_3$ was also studied in order to gain access to the other 2:1 adducts of cyclopentadiene and p-benzoquinone. The two products 18 and 19 were obtained in a 2:1 ratio, respectively, Scheme 5. The less polar major product 18 arising from endo-face reduction was assigned the exo,anti,endo-stereochemistry. The ^{1}H and ^{13}C NMR spectra of 18 indicated the presence of only one vertical symmetry plane along the methylenes (vide experimental). The presence of a highly shielded proton appearing at δ 0.55 (J=10Hz) in the ^{1}H NMR spectrum can arise only from the exo,anti,endo-stereochemistry wherein one of the methylene protons is proximal to the norbornene moiety. The more polar endo,anti,endo-adduct 19, arising from the reduction from exo-face, was identical to the diadduct of cyclopentadiene and p-benzoquinone[7b] and

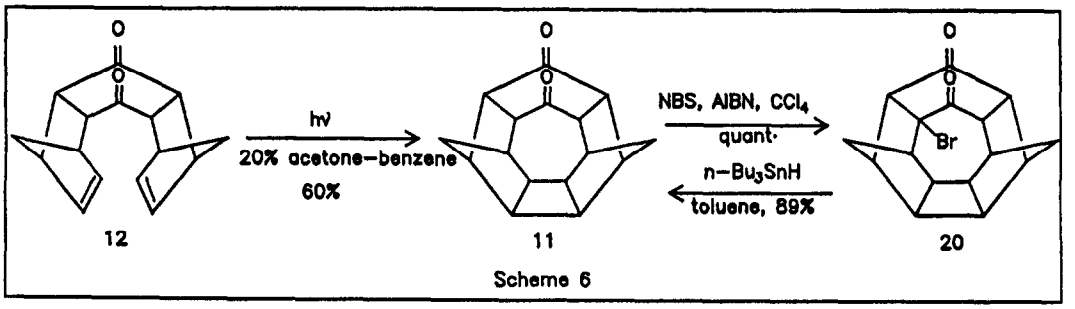


Scheme 5

its ^1H NMR and 5 line ^{13}C NMR indicated the presence of four fold symmetry in accordance with its structure. Thus, the reduction of 15 takes place from both the endo- and exo-faces. The endo-face reduction in this case takes place because the exo-face is partially hindered by the norbornene moiety. Thus, through Ti^{+3} reduction, two hitherto unknown diastereomeric 2:1 adducts of cyclopentadiene and p-benzoquinone 12 and 18 were obtained.

Returning back to Scheme 3, we now carried out the key 2+2-photocycloaddition. On irradiation through vycor filter and using acetone as sensitizer, 12 readily underwent the projected intramolecular 2+2-photoclosure to afford the heptacyclic dione 11, a 1,4-bishomo-11-seco-[7]-prismane derivative in 60% yield, Scheme 6. This photoclosure gave the ultimate proof of the endo,syn,endo-stereochemistry of its precursor 12 and thereby of the endo,syn-adduct 14. The 5 line ^{13}C NMR spectrum of 11, which was devoid of olefinic carbons and exhibited resonances at δ 210.8, 55.1, 46.8, 43.9 and 39.4, affirmed the structure of heptacyclo[7.6.1.-$0^{2,8}.0^{3,7}.0^{4,13}.0^{6,12}.0^{10,15}$]hexadecane-11,14-dione 11, which was further unequivocally established through X-ray crystal structure determination.[10] The novel dione 11 is a remarkably versatile polycycle, accessible in only three steps from the quinone 13 and is potentially serviceable for further elaboration to [7]- and [8]-prismane analogues.

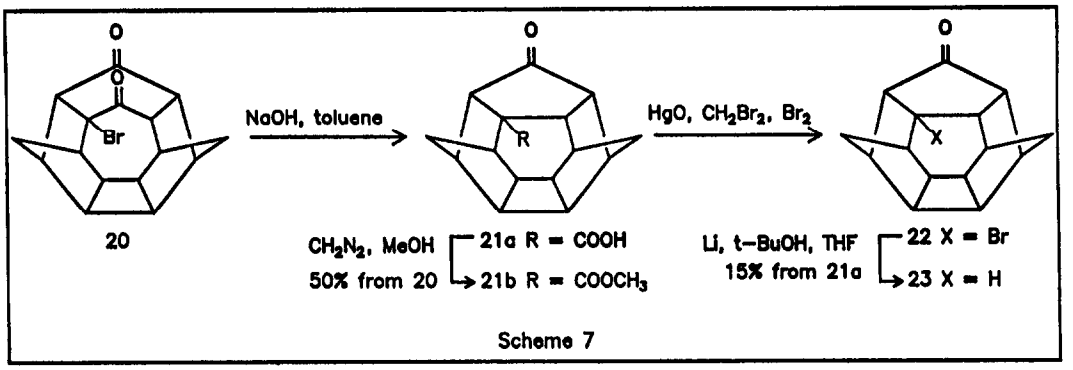
Further elaboration of the dione 11 to 6 required two ring contractions of the 1,4-cyclohexane dione ring *via* Favorskii rearrangement. Therefore, conversion of 11 to the dibromo compound 10 as indicated in Scheme 3, was attempted. Reaction of 11 with N-bromosuccinimide in the presence of AIBN led to facile bridge-head substitution and the α-bromodione 20 was obtained in high yield, Scheme 6. The 16 line ^{13}C NMR spectrum with C12 at δ 73.8 (-$\underline{C}$-Br) indicated the loss of symmetry in the molecule due to a bromine substitution. In order to ensure that no skeletal rearrangement had occurred during bromination, 20 was subjected to reductive dehalogenation with tri-n-butyltin hydride and the heptacyclic dione 11 was obtained, confirming the structure as 20.



Scheme 6

To test the feasibility of ring contraction and subsequent functional group manipulations, 20 was first transformed to the ring contracted ketone 23 through steps summarised in Scheme 7.

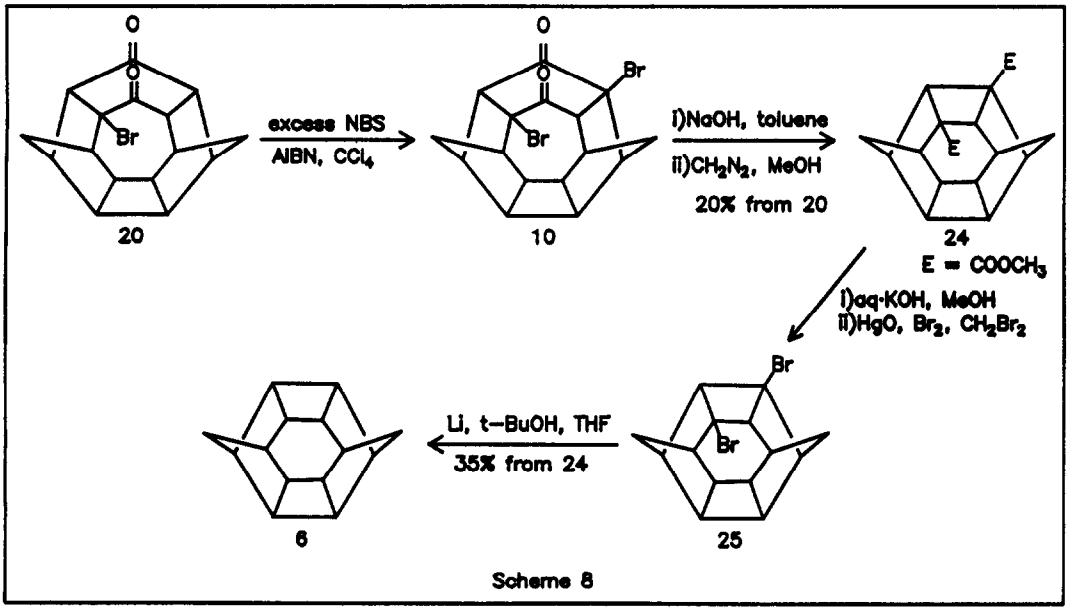
With the acquisition of 23, having served as a dress rehearsal for 6, we now ventured to effect two Favorskii ring contractions. Reaction of α-bromodione 20 with excess of NBS for prolonged period furnished a mixture of bromides in which the dibromide 10 predominated (~50%). The major



Scheme 7

viscous compound from chromatographic separation was treated with powdered NaOH in refluxing toluene[11] to effect Favorskii ring contraction and the resulting material esterified with diazomethane. To our delight, a single-shot double Favorskii ring contraction occurred, albeit in a rather low yield of 20% from 20 and the heptacyclic 1,4-bishomo-[6]-prismane diester **24** was realised, Scheme 8. The structure of **24** with C_2 symmetry rests secured on its diagnostic ^1H NMR spectrum with ester protons appearing at δ 3.68 and 9 line ^{13}C NMR spectrum with resonances at δ 177.6, 52.1, 45.3, 42.1, 41.8, 39.5, 36.1, 32.9 and 32.4. An X-ray crystal structure determination of **24** unambiguously established its structural formulation.[4]

Assured of the attainment of 1,4-bishomohexaprismane framework **24**, conversion to the hydrocarbon **6** was effected routinely. The ester moiety in **24** was hydrolysed and the resulting crude diacid was subjected to the



Scheme 8

modified Hunsdiecker reaction[12] to furnish the dibromo compound 25 which was used directly for the next step. Exposure of 25 to lithium - t-BuOH in THF[13] furnished the prized target molecule 6# in 35% yield, Scheme 8.

Garudane 6 is a highly volatile, waxy solid, which readily sublimes at 100°C, mp. 180°C (rapid heating in a sealed capillary). The HRMS exhibited molecular ion peak at 184.12558. The 3 line ^{1}H NMR spectrum with resonances at δ 2.38 (cyclobutyl protons), 2.0 (bridgehead protons) and 1.2 (dd, J=1.3Hz, methylene protons) in a 2:1:1 ratio, respectively, and 3 line ^{13}C NMR spectrum with resonances at δ 43.0, 36.3 and 33.5 were in accordance with its symmetry and structural formulation.

In short, we have accomplished the <u>first</u> synthesis of heptacyclic $C_{14}H_{16}$ hydrocarbon, 1,4-bishomo-[6]-prismane 6, the face-to-face dimer of norbornadiene, through a novel approach from the readily available starting materials like cyclopentadiene and p-benzoquinone. The flexible strategy delineated here offers scope for further amplification to functionalised derivatives of 6 as well as [7]- and [8]-prismane homo- and secologues.

Experimental

For a description of general procedures, see Ref.1.

1,4-Dihydro-1,4-methanonaphthalene-5,8-dione (2,3-norbornenobenzoquinone) (13):[7] It was prepared according to literature procedure from cyclopentadiene and p-benzoquinone. mp.: 66°C (Lit.[7] 66°C); IR: 3250, 3000, 2950, 2850, 1640, 1580, 1305, 720 cm^{-1}; ^{1}H NMR: δ 6.84 (2H, dd, J_1=J_2= 2Hz, -H<u>C</u>=C<u>H</u>-), 6.56 (2H, s, -C(O)-H<u>C</u>=C<u>H</u>-C(O)-), 4.08 (2H, m, -H<u>C</u>-), 2.28 (2H, m, -C<u>H</u>$_2$-); ^{13}C NMR: δ 184.1(s), 160.8(s), 142.6(d), 135.8(d), 73.8(t), 48.4(d);

Reaction of 2,3-norbornenobenzoquinone 13 with cyclopentadiene:[7b,8] Excess cyclopentadiene (8 g, 0.12 mol) was added to a solution of the quinone 13 (10 g, 0.058 mol) in benzene (30 mL) and the reaction mixture stirred at ~ 25°C for 30 min. Removal of solvent under vacuum gave a residual solid, which on washing with cold hexane to remove excess cyclopentadiene, gave a mixture (65:35, *estimated by ^{1}H NMR spectrum*) of the <u>endo</u>, <u>syn</u>-adduct 14 and <u>endo</u>, <u>anti</u>- adduct 15 , in quantitative yield (lit.[7b] reports a 80:20 ratio of 14 and 15, respectively, based on separation by column chromatography and fractional crystallisation). A small amount of the product mixture (1 g) was chromatographed on a silica gel (50 g) column. Elution with 5% ethyl acetate- hexane gave the <u>endo</u>, <u>anti</u> - adduct, 1α, 4α, 10aα, 5β, 8β, 8aα -hexahydro-1,4·5,8-dimethanoanthracene-9,10 dione 15 and was recrystallised from dichloromethane - hexane to furnish bright yellow crystals. mp.: 153-155°C (Lit.[7b] 153°C); IR: 2975, 1640, 1280, 730, 690 cm^{-1}; ^{1}H NMR: δ 6.76 (2H, dd, J_1 = J_2 = 2Hz, norbornadienyl -H<u>C</u>=C<u>H</u>-), 6.0 (2H, dd, J_1 = J_2 = 2Hz, norbornenyl -H<u>C</u>=C<u>H</u>-), 3.92(2H, dd, J_1 = J_2 = 2Hz, -HC=CH-C<u>H</u>-CH=CH-), 3.48 (2H, br s, -C(O)-C<u>H</u>-), 3.15 (2H, dd, J_1 = J_2 = 2Hz, -H<u>C</u>-HC=CH-), 2.1 (2H, ABq, J_1 = J_2 = 7Hz, norbornadienyl -C<u>H</u>$_2$),

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#We christened this long-sought hydrocarbon "Garudane" as the protruding bridges ('Wings') in 6 are reminiscent of "Garuda" (Sanskrit), the Hindu mythological demi-god, part-man, part-bird.[14]

1.48 (2H, ABq, $J_1 = J_2 = 9Hz$, norbornenyl-C<u>H</u>$_2$); ^{13}C NMR: δ 195.6, 167.1, 142.5, 134.9, 73.7, 51.1, 49.4, 48.8,48.4. Further elution of the column with the same solvent mixture and recrystallisation from dichloromethane-hexane gave the required <u>endo</u>, <u>syn</u>-adduct, 1α, 4α, 10aβ, 5α, 8α, 8aβ-hexahydro-1,4:5,8-dimethanoanthracene-9,10-dione 14 as bright yellow crystals. mp.: 155°C (Lit.[7b] 152-154°C); IR: 3050, 2975, 1640, 1280, 710 cm^{-1}; ^1H NMR: δ 6.78 (2H, dd, $J_1 = J_2 = 2Hz$, norbornadienyl-HC=C<u>H</u>-), 5.79 (2H, dd, $J_1 = J_2 = 2Hz$, norbornenyl-<u>H</u>C = C<u>H</u>-), 3.98 (2H, dd, $J_1 = J_2 = 2Hz$, -HC=CH-C<u>H</u>-CH=CH-), 3.46 (2H, br s, -C(O)-C<u>H</u>-), 3.26 (2H, m, -<u>H</u>C-HC=CH-), 2.18 (2H, m, norbornadienyl-C<u>H</u>$_2$), 1.46 (2H, m, norbornenyl-C<u>H</u>$_2$); ^{13}C NMR: δ 195.6, 166.9, 142.7, 134.5, 72.3, 50.5, 48.7, 48.2 (2C);

Irradiation of the <u>endo</u>, <u>syn</u>-adduct 14: <u>anti</u>-Heptacyclo[10.2.1.1^{5,8}.0^{2,11}.0^{4,9}.0^{2,6}.0^{7,11}]hexadec-13-ene-3,10-dione (16):[7b,8] A solution of the enedione 14 (50 mg, 0.2 mmol) in hexane (125 mL) was purged with a slow stream of nitrogen and irradiated for 4h, using pyrex filter. The solvent was removed under vacuum and the residue charged on a silica gel (10 g) column. Elution with 10% ethyl acetate - hexane furnished the photolysed product 16 (30 mg, 60%) and was recrystallised from dichloromethane-hexane. mp.: 140 - 142°C (Lit.[7b] 125-133°C); IR: 3025, 2950, 1740, 1230, 730 cm^{-1}; ^1H NMR: δ 6.36 (2H, dd, $J_1 = J_2 = 2Hz$, -<u>H</u>C=C<u>H</u>-), 3.0-2.76 (4H, m), 2.69 (2H, m), 2.50 (2H, dd, $J_1 = J_2 = 2Hz$), 1.94 (2H, ABq with st. $J_1 = J_2 = 12Hz$, norbornenyl -C<u>H</u>$_2$), 1.67 and 1.4 (2H, ABq with st., J = 9Hz, -C<u>H</u>$_2$-); ^{13}C NMR: δ 213.8, 136.8, 62.2, 55.9, 50.9, 44.1, 41.9, 41.2, 39.3.

Irradiation of the <u>endo</u>,<u>anti</u>-adduct 15: <u>syn</u>-Heptacyclo[10.2.1.1^{5,8}.0^{2,11}.0^{4,9}.0^{7,11}]hexadec-13-ene-3,10-dione (17):[7b,8] A solution of the enedione 15 (50 mg, 0.2 mmol) in hexane (125 mL) was purged with a slow stream of nitrogen and irradiated for 3h, using pyrex filter. The solvent was removed under vacuum and the residue was chromatographed on a silica gel (10 g) column. Elution with 5% ethyl acetate-hexane furnished the heptacyclic compound 17 (30 mg, 60%) and was recrystallised from dichloromethane-hexane. mp.: 153°C (Lit.[7b] 153°C); IR: 3075, 2975, 1730, 720 cm^{-1}; ^1H NMR: δ 6.2 (2H, dd, $J_1 = J_2 = 2Hz$, -<u>H</u>C=C<u>H</u>-), 3.0 - 2.6 (6H, m), 2.52 (2H, br s), 1.97 (2H, m, norbornenyl -C<u>H</u>$_2$), 1.8 (1H, ½ ABq, J = 9Hz, >C<$^{H}_{H}$), 1.55 (1H, ½ ABq with st., J = 9Hz, >C<$^{H}_{H}$); ^{13}C NMR: δ 217.6, 137.7, 62.3, 53.8, 44.2, 43.0, 40.4, 39.9, 38.1.

Reduction of the enedione 14 with aq.TiCl$_3$: In a 25 mL two necked RB flask equipped with a nitrogen inlet and addition funnel was placed the enedione 14 (100 mg, 0.42 mmol) and acetone (5 mL). To this vigorously stirred solution, 30% aq.TiCl$_3$ was added dropwise until a pale purple colour persisted.[9] The reaction mixture was poured into water (20 mL), saturated with NaCl and extracted with ethyl acetate (3 x 20 mL). The combined organic extract was washed with 10% $NaHCO_3$, water and dried. Removal of solvent and filtration through a silica gel (5 g) column using 30% ethyl acetate-hexane as the eluent furnished the <u>endo</u>, <u>syn</u>, <u>endo</u>-adduct , 1α,4α,4aβ,10aβ,5α,8α,8aβ,9aβ-octahydro-1,4:5,8- dimethanoanthracene-9,10-dione, 12 (100 mg), in quantitative yield and was recrystallised from dichloromethane-hexane. mp.: 184°C (decomp.); IR. 3050, 3000, 2925,

1700, 1250, 720 cm^{-1}; ^1H NMR: δ 5.94 (4H, dd, $J_1 = J_2 = 2Hz$, -HC=CH-), 3.4 (4H, s, -C(O)-CH-), 3.24 (4H, s with st., -HC=CH-CH-), 1.39 and 1.23 (4H, ABq with st., J = 10Hz, $-CH_2-$); ^{13}C NMR: δ 209.8, 136.9, 54.0, 47.0, 43.9. Anal. Calcd. for $C_{16}H_{16}O_2$: C, 79.97; H, 6.71. Found: C, 79.90; H, 6.67. For large scale preparations the reaction was done on the stereoisomeric mixture of enedione 14 and 15 and the products were separated on silica gel column.

Reduction of enedione 15 with aq.$TiCl_3$: In a 25 mL two necked RB flask equipped with a nitrogen inlet and addition funnel was placed the enedione 15 (50 mg, 0.21 mmol) and acetone (5 mL). To this vigorously stirred solution, 30% aq.$TiCl_3$ was added dropwise until a pale purple colour persisted.[9] The reaction mixture was poured into water (15 mL), saturated with NaCl and extracted with ethyl acetate (3 x 15 mL). The combined organic extract was washed with 10% $NaHCO_3$, water and dried. Removal of solvent gave a crude material which on tlc examination (30% ethyl acetate-hexane) indicated the presence of two products. The material was charged on a silica gel (10 g) column. Elution with 15% ethyl acetate-hexane furnished the exo, anti, endo - adduct, 1α,4α,4aα,10aα,5β,8β,8aα,9aα-octahydro-1,4:5,8-dimethano-anthracene-9,10-dione 18 (34 mg, 67%) which was recrystallised from dichloromethane-hexane. mp.: 184-185°C; IR: 3050, 2975, 1700, 1245, 900, 700 cm^{-1}; ^1H NMR: δ 6.14 (2H, dd, $J_1 = J_2 = 2Hz$), 6.09 (2H, dd, $J_1 = J_2 = 2Hz$), 3.56 (2H, s with st.-C(O)-CH-), 3.38 (2H, dd, $J_1 = J_2 = 2Hz$, -HC=CH-CH-), 3.24 (2H, dd, $J_1 = J_2 = 2Hz$, -HC=CH-CH-), 2.66 (2H, s with st.,-C(O)-CH-), 1.56 - 1.08 (3H, m), 0.55 (1H, ½ ABq, J = 10Hz, >C<H H); ^{13}C NMR: δ 209.7, 137.1, 136.6, 55.1, 52.3, 47.2 (2C), 43.5, 42.9. Anal. Calcd. for $C_{16}H_{16}O_2$: C, 79.97; H, 6.71. Found: C, 79.86; H, 6.82. Further elution of the column gave the endo, anti, endo-adduct, 1α,4α,4aβ,10aα,5β,8β,8aα,9aβ-octahydro-1,4:5,8-dimethanoanthracene-9,10-dione 19 (16 mg, 32%) and was recrystallised from dichloromethane-hexane. mp.: 155-156°C (Lit.[6a] 155°C); IR: 3050, 2975, 2950, 1695, 1240, 1195, 700 cm^{-1}; ^1H NMR: δ 6.17 (4H, dd, $J_1 = J_2 = 2Hz$, -HC=CH-), 3.34 (4H, br s, -HC=CH-CH-), 2.87 (4H, br s, -C(O)-CH-), 1.46 (2H, ½ ABq with st. J = 9Hz, >C<H H), 1.28 (2H, ½ ABq, J = 9Hz, >C<H H) ; ^{13}C NMR: δ 212.8, 136.5, 53.1, 49.6, 48.2.

Heptacyclo[7.6.1.$0^{2,8}$.$0^{3,7}$.$0^{4,13}$.$0^{6,12}$.$0^{10,15}$]hexadecane-11,14-dione (11): A solution of the endo, syn, endo - adduct 12 (1.2 g, 5 mmol) in 20% acetone-benzene (125 mL) was purged with a slow stream of nitrogen and irradiated for 4h using vycor filter. The solvent was evaporated off and residue charged on a silica gel (25 g) column. Elution with 40% ethyl acetate-hexane furnished the heptacyclic dione 11 (725 mg, 60%) which was recrystallised from dichloromethane-hexane. mp.: 247-248°C; IR: 2950, 1680, 1240, 920 cm^{-1}; ^1H NMR: δ 3.08 (4H, br s), 2.84 (4H, br s), 2.68 (4H, br s), 1.55 (4H, ABq with st., $J_1 = J_2 = 10Hz$, $-CH_2-$); ^{13}C NMR: δ 210.8(s), 55.1(d), 46.8(d), 43.9(t), 39.4(d). Anal. Calcd. for $C_6H_{16}O_2$: C, 79.97; H, 6.71. Found: C, 80.06; H, 6.76.

12-Bromoheptacyclo[7.6.1.$0^{2,8}$.$0^{3,7}$.$0^{4,13}$.$0^{6,12}$.$0^{10,15}$]hexadecane-11,14-dione (20): A mixture of dione 11 (900 mg, 3.75 mmol), N-bromosuccinimide (1 g, 5.6 mmol), AIBN (15 mg) in carbontetrachloride (30 mL) was

refluxed for 5h. The reaction mixture was cooled and succinimide filtered off and washed with carbontetrachloride (25 mL). The combined organic layer was washed with water and dried. Removal of solvent gave a crude material which was chromatographed on a silica gel (50 g) column. Elution with 30% ethyl acetate-hexane furnished the bromo-compound **20** (730 mg, 100% based on starting material recovery) and was recrystallised from dichloromethane-hexane. mp.: 184-185°C; IR: 2950, 1690, 1250, 720 cm^{-1}; ^1H NMR: δ 3.78 (1H, br s), 3.4-2.24 (10H, series of m), 1.76-1.32 (4H, m, -C<u>H</u>$_2$-); ^{13}C NMR: δ 207.5, 202.7, 73.8, 69.1, 56.6, 54.8, 52.6, 47.3, 47.0, 46.5, 43.6, 43.3, 39.6, 39.4, 39.2, 37.8. Anal. Calcd. for $C_{16}H_{15}O_2Br$: C, 60.21; H, 4.74. Found: C, 60.28; H, 4.69. Further elution of the column afforded the unreacted starting dione **11** (350 mg).

Reductive debromination of 20: To a solution of the bromo compound **20** (12 mg, 0.037 mmol) in toluene (5 mL) was added tri-n-butyltin hydride (12 mg, 0.041 mmol) and a catalytic amount of AIBN. The reaction mixture was refluxed for 3h, cooled and diluted with ether (15 mL). The organic layer was washed with saturated solution of KF, water and dried. Removal of solvent and filtration through a silica gel (2 g) column, using 50% ethyl acetate-hexane as the eluent furnished the heptacyclic dione **11** (8 mg, 89%) which was recrystallised from dichloromethane-hexane. mp.: 246°C; ^1H NMR was found identical to that of heptacyclic dione **11**.

Heptacyclo[7.5.1.0^{2,8}.0^{3,7}.0^{4,13}.0^{6,12}.0^{10,14}]pentadecan-11-one-13-carboxylic acid methyl ester (21b): A suspension of powdered NaOH (160 mg, 4 mmol) in toluene (10 mL) was refluxed for 30 min and traces of water in NaOH azeotropically removed using a Dean Stark apparatus. The RB flask was cooled to ~ 25°C and the bromo compound **20** (40 mg, 0.125 mmol) in toluene (5 mL) was added and the mixture refluxed for 10h.[11] The flask was cooled, diluted with water (10 mL) and acidified to ~ pH 5 with dil.HCl. The organic layer was separated and the aqueous layer extracted with ethyl acetate (3 x 15 mL). The combined organic layer was washed with water and dried. Removal of solvent furnished the crude acid **21a** (20 mg) which was dissolved in methanol (4 mL) and esterified at 0°C with an ethereal solution of diazomethane. The solvent was evaporated off and the residue chromatographed on a silica gel (5 g) column. Elution with 20% ethyl acetate-hexane furnished the ring contracted ester **21b** (17 mg, 50%) and was recrystallised from dichloromethane-hexane. mp.: 95°C; IR: 2923, 1715, 1225, 1040, 720 cm^{-1}; ^1H NMR: δ 3.68 (3H, s, -C(O)-OC<u>H</u>$_3$), 3.08 (1H, m), 3.0-2.2 (10H, series of m), 1.8-1.28 (4H, m, -C<u>H</u>$_2$-); ^{13}C NMR: δ 216.6, 178.0, 66.2, 61.9, 52.5, 51.9, 45.5, 44.8, 43.3, 43.2, 42.6, 40.1, 38.8, 38.6, 38.4, 34.0, 33.9. Anal. Calcd. for $C_{17}H_{18}O_3$: C, 75.53; H, 6.71. Found. C, 75.32, H, 6.77. For the subsequent steps the reaction was repeated on 350 mg scale and the crude acid **21a** was directly used without purification.

Heptacyclo[7.5.1.0^{2,8}.0^{3,7}.0^{4,13}.0^{6,12}.0^{10,14}]pentadecan-11-one(23) : The crude acid **21a** obtained above (170 mg, 0.62 mmol) was dissolved in dibromomethane (5 mL) and red mercuric oxide (250 mg, 0.15 mmol) was added and the mixture refluxed for 1h. Then 5 drops of bromine was added and

the reaction mixture refluxed further for 2h[12]. It was then diluted with dichloromethane (20 mL) and washed successively with water and dried. Removal of solvent gave the crude bromo compound 22 (185 mg) which was filtered through a silica gel column and used directly for the next step. IR: 2925, 1720, 1450, 1220, 790 cm^{-1}.

In a 25 mL three necked RB flask equipped with a nitrogen inlet and condenser was placed the above obtained bromo compound 22 (180 mg), THF (8 mL) and t-BuOH (0.1 mL). Lithium metal (15 mg, 0.002 g atom) was added to it as small pieces and the reaction mixture refluxed for 3h.[13] The unreacted lithium was filtered off and THF removed under reduced pressure. The residue was diluted with water (10 mL), acidified with dil.HCl and extracted with ether (3 x 15 mL). The ethereal extract was washed with water and dried. Removal of solvent gave a crude viscous material (120 mg). IR: 3400 (br), 2900, 1700, 720 cm^{-1}; To a suspension of pyridinium chlorochromate (150 mg, 0.69 mmol) and molecular sieves (4 A°, 150 mg) in dichloromethane (5mL) was added the above obtained crude mixture (120 mg) at 0°C. The reaction mixture was stirred further for 2h at ~ 25°C, diluted with ether and filtered through a short column of florisil. Removal of solvent gave a crude material (80 mg) which was charged on a silica gel (5 g) column. Elution with 5% ethyl acetate-hexane furnished the pure heptacyclic ketone 23 (35 mg, 15% from 21a) and was recrystallised from hexane. mp.: 123-5°C; IR: 2900, 1710, 720, cm^{-1}; ^1H NMR: δ 2.8-2.0 (12H, m), 1.45 (4H, ABq with st., $J_1 = J_2 = 8Hz$, $-C\underline{H}_2-$); ^{13}C NMR: δ 219.9, 62.1, 45.6, 43.4, 38.9, 38.1, 35.1, 34.4. Anal. Calcd. for $C_{15}H_{16}O$: C, 84.87; H, 7.60. Found: C, 84.72; H, 7.53.

Bromination of 20: A mixture of the bromo dione 20 (600 mg, 1.88 mmol), excess N-bromosuccinimide (600 mg, 3.3 mmol), AIBN (10 mg) andcarbontetrachloride (30 mL) was refluxed for 8h. The reaction mixture was cooled and succinimide filtered off and washed with carbontetrachloride (20 mL). The combined organic layer was washed with water and dried. Removal of solvent gave a viscous material which on tlc examination (25% ethyl acetate-hexane) indicated a complex mixture in which the spot slightly less polar than the starting material was predominant apart from unreacted starting material. The material was charged on a silica gel (30 g) column. Elution with 20% ethyl acetate-hexane gave the minor products first and further elution gave the major dibromo product 10 (240 mg) as a viscous liquid. This was used directly for the next step. IR: 2925, 1690, 720 cm^{-1}; Continued elution of the column gave the starting bromodione 20 (340 mg).

Heptacyclo[9.3.0.0^{2,5}.0^{3,13}.0^{4,8}.0^{6,10}.0^{9,12}]tetradecane-2,4-dicarboxylic acid dimethyl ester (24): A suspension of powdered NaOH (2 g, 0.05 mol) in toluene (20 mL) was refluxed for 45 min and traces of water in NaOH azeotropically removed using a Dean Stark apparatus. The RB flask was cooled to ~ 25°C and the dibromodione mixture 10 (240 mg, 0.6 mmol) in toluene (5 mL) was added and the mixture refluxed for 8h. The reaction mixture was cooled, diluted with water (15 mL) and acidified to ~ pH 5. The organic layer was separated and the aqueous layer extracted with ethyl acetate (3 x 15 mL). The combined organic layer was washed with water and

dried. Removal of solvent gave 220 mg of a crude material which was dissolved in methanol (5 mL) and esterified with an ethereal solution of diazomethane at 0°C. Removal of solvent and tlc examination (15% ethyl acetate-hexane) of the residue indicated the presence of at least four products. The residue was charged on a silica gel (20 g) column. Elution with 10% ethyl acetate-hexane furnished first the required ring contracted diester **24** (38 mg, 20% from 20). mp.: 93-96°C; IR: 2925, 1710, 1225 cm^{-1}; ^1H NMR: δ 3.68 (6H, s, -C(O)-OC<u>H</u>$_3$), 2.96 (2H, d, J = 8Hz, -<u>H</u>C-C(O)-OCH$_3$), 2.46 (4H, br s with st., cyclobutyl -C<u>H</u>), 2.26 (4H, br , -C<u>H</u>-), 1.57 and 1.24 (4H, ABq with st., J = 10Hz, -C<u>H</u>$_2$-); ^{13}C NMR: δ 177.6, 52.1, 45.3, 42.1, 41.8, 39.5, 36.1, 32.9, 32.4. HRMS: M^+ Calcd. for $C_{18}H_{20}O_4$: 300.1362. Found: 300.1367. Further elution of the column gave some intractable products.

2,4-Dibromoheptacyclo[9.3.0.0^{2,5}.0^{3,13}.0^{4,8}.0^{6,10}.0^{9,12}]tetradecane (25): The heptacyclic diester **24** (33 mg, 0.11 mmol) was dissolved in methanol (5 mL) and KOH (20 mg, 0.35 mmol) in water (1 mL) was added and the mixture refluxed for 2h. Methanol was removed under vacuum and the residue diluted with water (5 mL) and acidified with dil.HCl. The aqueous layer was extracted with ethyl acetate (2 x 10 mL) and the combined organic extract washed with water and dried. Removal of solvent gave 30 mg of the crude diacid which was directly used for the next step.

To the above obtained crude diacid (30 mg) in dibromomethane (5 mL), red mercuric oxide (80 mg, 0.36 mmol) was added and the mixture refluxed for 1h. Then, bromine (2 drops) was added and refluxed further for 2h.[12] The reaction mixture was diluted with dichloromethane (15 mL) and washed with water and dried. Removal of solvent and filtration through a small alumina (4 g) pad gave the dibromide 25 (23 mg) as a viscous material and was used for the next step without further purification. IR: 2925, 1440, 1230, 1010, 820, 730 cm^{-1}; ^1H NMR: δ 3.37 (2H, d, J = 6Hz), 2.6-2.2 (8H, m), 1.89 and 1.29 (4H, ABq, J = 10Hz, -C<u>H</u>$_2$-).

Heptacyclo[9.3.0.0^{2,5}.0^{3,13}.0^{4,8}.0^{6,10}.0^{9,12}]tetradecane('Garudane') (6): In a 25 mL three necked RB flask fitted with a nitrogen inlet and condenser was placed the dibromo compound 25 (23 mg, 0.067 mmol), THF (5 mL) and t-BuOH (0.05 mL). Lithium metal (10 mg, 0.0014 g atom) was added to it as small pieces and the reaction mixture refluxed for 3h.[13] Unreacted lithium was filtered and THF removed under vacuum. The residue was diluted with water (8 mL) and extracted with pentane (3 x 8 mL). Removal of solvent gave the crude hydrocarbon which was charged on a silica gel (5 g) column. Elution with pentane furnished the target molecule 'Garudane' **6** (7 mg, 35% from **24**) and was sublimed at ~ 100°C. mp.: 180°C (sealed tube, rapid heating); IR: 2900 cm^{-1}; ^1H NMR· δ 2.38 (8H, br s with st., cyclobutyl-C<u>H</u>), 2.00 (4H, br s, -C<u>H</u>-), 1.2 (4H, dd, J_1 = J_2 = 1.3Hz, -C<u>H</u>$_2$-); ^{13}C NMR: δ 43.0, 36.3, 33.5. HRMS: M^+ Calcd. for $C_{16}H_{16}$: 184.12528. Found: 184.12558.

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