Controlled Synthesis of Mono-*p*-[(2,3-epoxy)propyl]- and Mono-*p*-(2-oxoethyl)-tris-*p*-*tert*-butylcalix[4]arenes Crystal Structure Determination of an Epoxy Calix[4]arene

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Four new tri-*tert*-butylcalix[4]arenes bearing an epoxy or a carbaldehyde function at the upper rim have been prepared by a multi-step synthetic pathway involving initial selective allylation of tris-(*O*-benzoyl)-tri-*tert*-butylcalix[4]arene, followed by either *m*-CPBA oxidation or ozonolysis of the allyl group. The benzoylated epoxycalixarene was obtained as single crystals, analysis of which confirmed the formation of the epoxide group and the partial-cone conformation of the macrocyclic structure.

We have recently described the selective monochloromethylation[1] and monoformylation[2] of the tris-*p*-*tert*-butylcalix[4]arene tetrol at its upper rim. Most of the corresponding reductive amination or substitution compounds, with the exception of the monocyanomethyl analogue, are relatively unstable, which was notably evident upon attempted ES-MS analysis, where the unstable mono-*p*-quinone methide species was obtained as a result of elimination reactions.[3]

Such results diminished the synthetic interest in these functional groups for the building of stable, more elaborate structures, involving a calixarene platform[4] bearing free hydroxyl groups. For this reason, we have endeavoured to develop other approaches allowing the introduction of a single, stable, active ethylene or propylene group.

In the course of our investigations, we found that the allyl group should be a good candidate in our strategy, notably for the building of a (2,3-epoxy)propyl- or a 2-oxoethyl-containing calixarene. As far as we are aware, such functional groups have not previously been incorporated on a calixarene upper rim. Gutsche et al.[5] described attempts to synthesize tetra-*p*-(2-oxoethyl)- and tetra-*p*-(2,3-epoxy)propylcalix [4]arenes bearing *p*-toluenesulfonyl protecting groups at the lower rim: the former, prepared by ozonolysis of the tetra-*p*-allyl parent compound, was not isolated but was directly reduced to the corresponding alcohol, while the latter epoxide was not isolated.

In the present report, we describe successfully controlled syntheses of calix[4]arenes bearing the two aforementioned functionalities at the upper rim.

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Results and Discussion

Synthesis of Ligands

As starting material, we used the previously described tris(benzoyloxy)-tris-*p*-*tert*-butylcalix [4]arene **1**.[6] Introduction of the allyl group on **1** was achieved by employing a modified literature procedure,[7] which gave the mono-*O*-allyl ether **2** in 65% yield. The presence of the three benzoate groups in **2** resulted in a complex ^{1}H-NMR spectrum, hence for analytical purposes we hydrolysed these functions to give **3**. **2** was then heated at 200°C in *N*,*N*-diethylaniline to give the *p*-Claisen rearrangement product **4** in 70% yield. Despite this, the isolation of an analytically pure sample of **4** proved somewhat difficult; for this reason, the three benzoate groups were hydrolysed to give the calixarene tetrol species **6**, which could be fully characterized.

Compounds **4** and **6** were successfully converted into the corresponding oxiranes **5** and **7** and the aldehydes **8** and **9**, by treatment with *m*-CPBA and O_3, respectively.

The epoxidation reactions were simply carried out in $CHCl_3$ in the presence of an excess of oxidant with TLC monitoring; the purification process involved column chromatography on silica gel to give **5** and **7** in 75 and 68% yield, respectively.

The ozonolysis was performed according to the procedure of Anker et al.;[8] ozone was bubbled through CH_2Cl_2 solutions of **4** and **6** at −78°C until a light-blue coloration persisted. The resulting ozonides were then reduced with triethylamine at room temperature. The aldehydes **8** and **9** were obtained in a pure state after chromatography on silica gel in yields of 50 and 75%, respectively.

Analysis of Compounds

The presence of three bulky benzoate groups in compounds **1**, **2**, **4**, **5**, and **8** resulted in complex ^{1}H-NMR spec-

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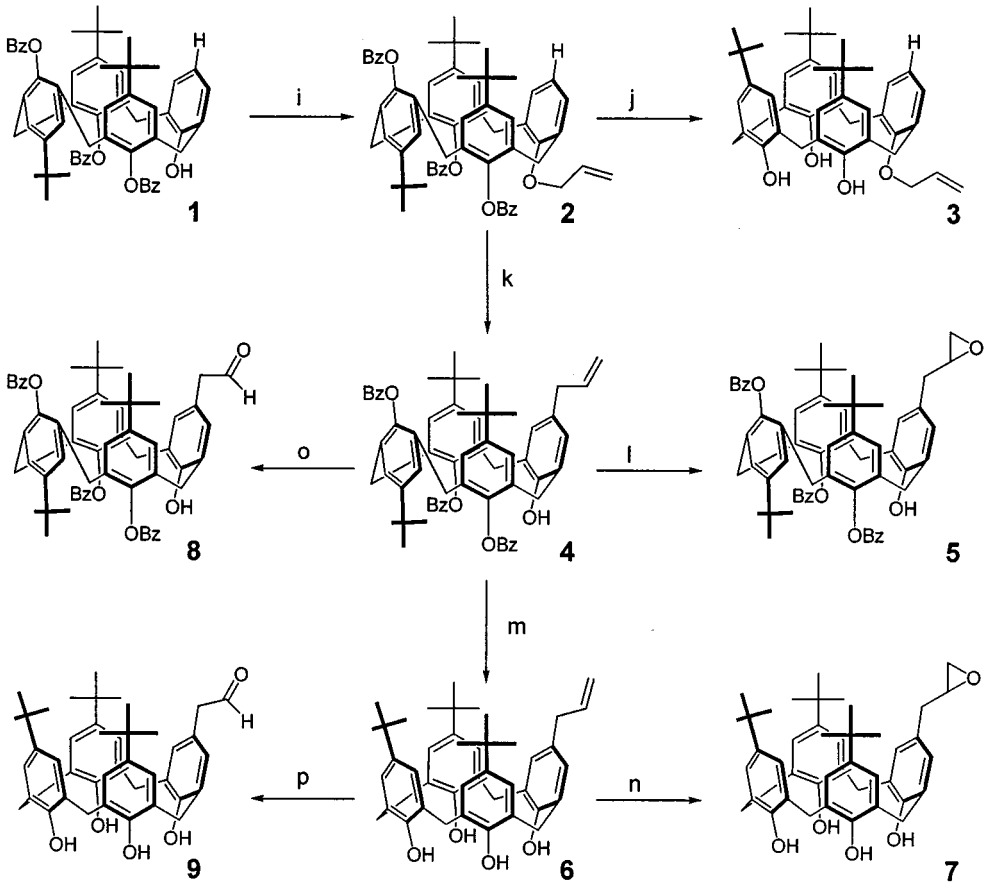

Figure 1. Synthetic pathway. i) allyl bromide, NaH, DMF, THF, 80°C, 65%; j) KOH, H_2O, EtOH, reflux, 35%; k) $C_6H_5NEt_2$, 200°C, 70%; l) mCpBA, $CHCl_3$, r.t., 75%; m) KOH, H_2O, EtOH, reflux 90%; n) mCpBA, $CHCl_3$, r.t., 68%; o) O_3, CH_2Cl_2, −78°C, 50%; p) O_3, $CHCl_2$, −78°C, 75%

tra. Nevertheless, ^{13}C-DEPT experiments on the five compounds showed the presence of $ArCH_2Ar$ resonance signals at δ = ca. 38.0, indicating, according to the empirical rules of de Mendoza et al.,[9] that the cone conformation was not preserved.

We previously supposed the debutylated phenol in **1** to be inverted and we found that saponification resulted in the restoration of the cone conformation, as established by ^{13}C-NMR. This last point was verified with the pairs of compounds **2/3** and **4/6**. Oxidation of **6** into **7** and **9** was not accompanied by drastic conformational changes.

We considered that the debutylated phenol of **1**, which supports the chemical transformations, remains inverted in **2**, **4**, **5**, and **8**, the conformational changes being forbidden by the steric hindrance of the *tert*-butyl and benzoate groups. In order to verify this hypothesis, we attempted to obtain discrete crystals of these compounds. Single crystals of compound **5**, suitable for X-ray diffraction analysis, were obtained by liquid diffusion of hexane into a solution of **5** in $CHCl_3$.

This study confirmed the presence of the expected epoxide and benzoate groups. The asymmetric unit is composed of one molecule of calixarene and half a molecule of *n*-hexane. The latter is located in a specific position about the inversion centre. The cyclic tetramer is in the partial cone conformation; the benzoylated unit opposite the epoxide is inverted, contrary to our previous suggestions.[6] Considering the steric factors mentioned above, by analogy we suggest that the same conformation must be adopted in **1**, **2**, **4**, and **8**.

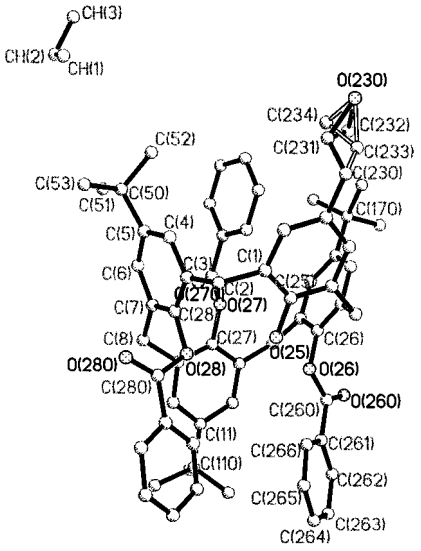

Figure 2. Numbering scheme of molecules in the asymmetric unit

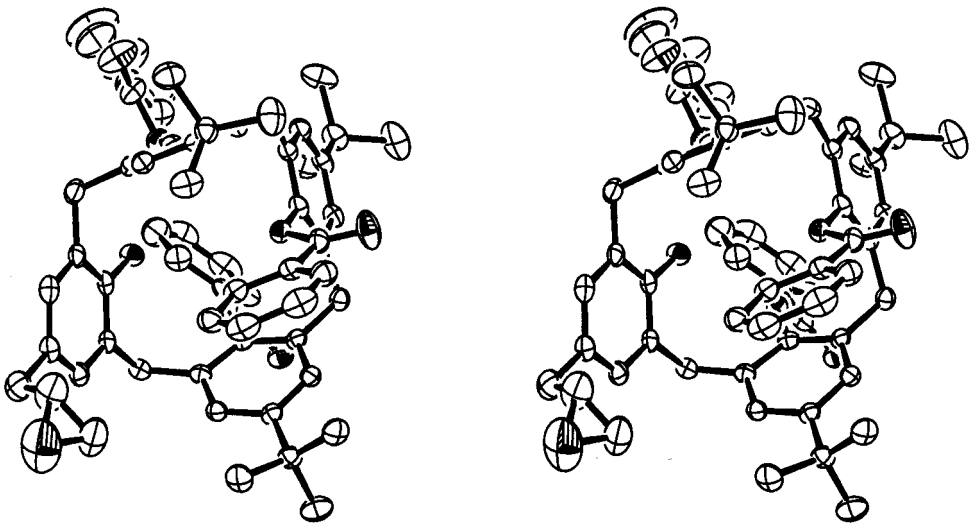

Figure 3. Stereoview of the encapsulation of the inverted benzoic unit

The angles between the phenyl rings and the mean plane defined by the methylene bridges amount to 108.79(8), 117.60(9), 107.19(8), and 134.14(1). The intramolecular O...O distances involving O(25), which is the unique free hydroxyl group, are O(25)...O(26) 3.007(1) Å and O(28)...O(25) 2.841(1) Å.

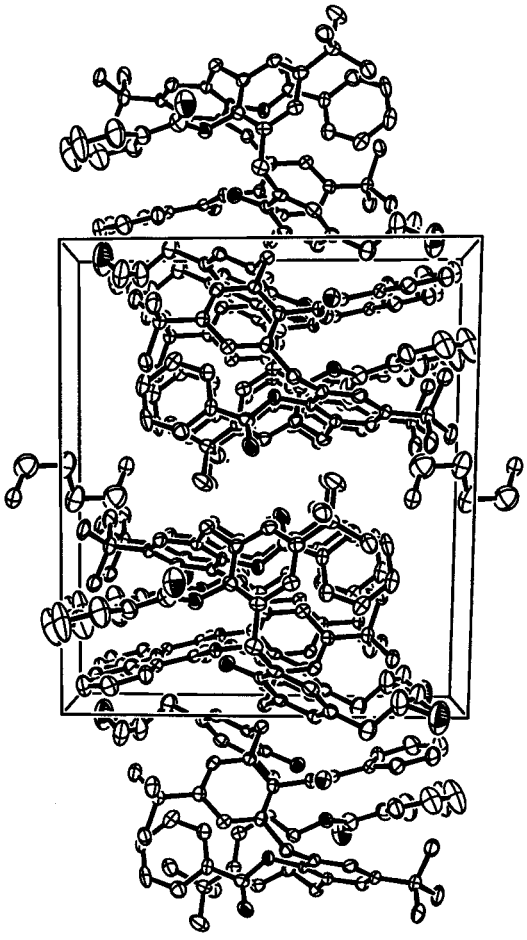

Figure 4. Packing along (100)

The three oxygen atoms O(260), O(270), and O(280) of the carbonyl groups are oriented *exo* to the calixarene, as could be expected with repulsion between the polar oxygens in the molecule. As shown in the stereoview (Figure 3), this geometry leads to an encapsulation of the inverted benzoate ring in the macrocycle cavity, with a mean distance of 4 Å from the two adjacent phenol rings. The *tert*-butyl group of this same phenolic unit occupies two positions, differing by a rotation of 60°, with occupancies of 75% and 25%.

A disorder found for the epoxide group shows that two different species are present in the solid state. These are the (*R*) and (*S*) enantiomers, contributing 65% and 35%, respectively: the position of the epoxide oxygen, O(230), remains unchanged in the two molecules, having an occupancy of 1, while the attached carbon atoms, C(231), C(232) then C(233) and C(234) have occupancy factors of 0.6 and 0.4, respectively. Similar situations have been found by Flippen et al. for the diglycidyl ether of bisphenol A,[10] and by Bocelli et al. for 2,2′-[1,3-phenylenebis(oxymethylene)]bis(oxirane).[11] Distances and angles in the epoxide rings (Table 1) are consistent with those found in other epoxide-containing molecules.[12][13] In the two enantiomers, the epoxide function is slightly oriented towards the calixarene cavity and the two positions are almost perpendicular (100(2)°). Figure 4 shows packing of the structure along (100), where slices of calixarenes with alternating cavity apertures can be seen. No specific interaction has been found with *n*-hexane. According to the proposal for classifi-

Table 1. Selected geometric parameters of epoxide groups [Å, °]

R enantiomer		*S* enantiomer	
O(230)−C(231)	1.487(8) Å	O(230)−C(233)	1.498(4) Å
O(230)−C(232)	1.407(4) Å	O(230)−C(234)	1.399(5) Å
C(231)−C(232)	1.392(1) Å	C(233)−C(234)	1.413(2) Å
C(231)−C(232)−O(230)	64.2(4)°	C(233)−C(234)−O(230)	64.4(7)°
C(232)−O(230)−C(231)	57.4(4)°	C(234)−O(230)−C(233)	58.3(7)°
O(230)−C(231)−C(232)	58.4(4)°	O(230)−C(233)−C(234)	57.4(6)

cation and nomenclature of host-guest type compounds given by Weber and Josel,[14] this compound can be defined as an intercalato-clathrate.

Conclusion

In summary, the selective introduction of a single epoxy or carbaldehyde group at the upper rim of an OH-protected or OH-free calix[4]arene platform has been achieved by a simple multi-step synthetic pathway involving initial selective allylation. X-ray analysis of the tris-benzoylated epoxy intermediate showed that the protective benzoylation reaction imposed a partial cone conformation on the macrocyclic platform, with inversion of the central benzoylated phenol unit. The four new active calixarene species described herein are currently being investigated with regard to the construction of more elaborate structures.

Experimental Section

General Aspects: Melting points (°C, uncorrected values) were determined in capillaries on an Electrothermal 9100 apparatus. − ^{1}H- and ^{13}C-NMR spectra were recorded on Bruker AC 200, AM 300, or DRX 300 spectrometer (chemical shifts in δ units relative to TMS as internal standard, *J* in Hertz); ^{1}H resonance signals of the substituted phenol unit **A**, the two adjacent rings **B** and **D**, and the opposite ring **C** could be assigned in compounds **3**, **6**, **7**, and **9**. − Mass spectra (electrospray, ES) were recorded on a Platform Micromass apparatus at the Service Central d'Analyse du CNRS, Solaize. − Infrared spectra were recorded on a Mattson 5000 FT-IR apparatus ($\tilde{\nu}$ cm^{-1}). − UV spectra were recorded on a Shimadzu UV 2401 PC apparatus (λ_{max} in nm, ε in dm^3 mol^{-1} cm^{-1}). − Elemental analyses were performed at the Service Central de Microanalyse, Ecole Supérieure de Chimie, Montpellier. − Macherey−Nagel TLC plates were used for chromatographic analyses (SiO_2, Polygram SIL G/UV254, ref. 805021). − All commercially available materials were used without further purification unless otherwise specified.

Tri-*O*-benzoyl Mono-*O*-allylcalix[4]arene (2): A mixture of 1.0 g (1.1 mmol) of **1**, 0.18 g (7.8 mmol) of NaH, and 0.6 mL (7 mmol) of allyl bromide in 10 mL of DMF and 20 mL of THF was heated overnight at 80°C under N_2. After cooling to room temp., 1 mL of MeOH was added and the solvents were evaporated. The residue was triturated with MeOH to give 0.70 g of **2** (65%) as a white precipitate; m.p. 289−290°C. − IR (KBr): $\tilde{\nu}$ = 3080−2980 (CH), 1720 (C=O). − UV/vis (CH_2Cl_2): λ_{max} = 268 (7900), 277 (7700), 285.50 (sh, 5000). − ^{1}H NMR (200 MHz, $CDCl_3$, 25°C): δ = 0.81 (s, 18 H, 2 *Me*$_3$C), 0.87 (s, 9 H, 1 *Me*$_3$C), 3.58−4.43 (m, 10 H, ArC*H*$_2$Ar and ArOC*H*$_2$-), 5.24−5.33 (m, 2 H, C*H*$_2$=CH−), 6.00−6.17 (m, 1 H, CH$_2$C*H*=CH$_2$), 6.20−7.75 (m, 24 H, ArH). − ^{13}C NMR (75.3 MHz, $CDCl_3$, 25°C): δ = 31.29 (*Me*$_3$C), 34.09, 34.23 (Me$_3$*C*), 38.69, 38.86 (Ar*C*H$_2$Ar), 73.64 (O*C*H$_2$), 117.65 (*C*H$_2$=CH−), 123.76, 125.92, 126.25, 126.68, 128.15, 128.92, 130.44, 130.69, 131.12, 131.61, 132.99, 136.00 (C-3, C-5 of Ar, CH$_2$=*C*H−), 129.10, 132.72, 132.89, 133.38, 133.75, 134.20, 134.80, 146.16, 147.42, 147.54, 156.93 ($C_{i,o,p}$ of Ar), 164.58, 165.17 (C=O). − MS (ES, positive mode, CH_2Cl_2, *i*PrOH, HCOOH): *m/z* = 968.5 [M + Na]$^+$, 848.5 [M − (ArCOO) + H + Na]$^+$. − $C_{64}H_{64}O_7$·0.5 CH_2Cl_2 (987.68): calcd. C 78.44, H 6.63, O 11.34; found C 78.12, H 6.77, O 11.35.

Mono-*O*-allylcalix[4]arene (3): A mixture of 1.1 g (1.2 mmol) of **2** and 1.0 g (18 mmol) of KOH in 5 mL of H_2O and 25 mL of EtOH was heated at 80°C for 16 h. After cooling to room temp., the mixture was acidified to pH 2−3 with 1 M HCl. The resulting precipitate was collected, redissolved in CH_2Cl_2, and this solution was dried over Na_2SO_4. Chromatography (SiO_2, CH_2Cl_2/hexane, 3:2) furnished 0.25 g of **3** (35%) as a white powder; m.p. 288−289°C. − IR (KBr): $\tilde{\nu}$ = 3280 (OH), 2980 (CH), 1200 (C−O). − UV/vis (CH_2Cl_2): λ_{max} = 279.50 (10200), 283.50 (s, 10000). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.21 (s, 9 H, 1 *Me*$_3$C), 1.24 (s, 18 H, 2 *Me*$_3$C), 3.44, 4.27 (AB, J_{AB} = 13.6, 4 H, ArC*H*$_2$Ar), 3.47, 4.40 (AB, J_{AB} = 12.9, 4 H, ArC*H*$_2$Ar), 4.70 (d, *J* = 6.25, 2 H, ArOC*H*$_2$), 5.52, 5.67 (ABX, $^3J_{trans}$ = 17.3, $^3J_{cis}$ = 10.3, $^2J_{AB}$ = 1.1, 2 H, C*H*$_2$=CH−), 6.45 (m, $^3J_{trans}$ = 17.3, $^3J_{cis}$ = 10.3, ^3J = 6.25, 1 H, C*H*=CH$_2$); 6.91 (t, *J* = 7.5, 1 H, 4-H of Ar **A**), 7.01 (s, 2 H, 3-,5-H of Ar **C**), 7.037, 7.060 (AB, J_{AB} = 2.30, 4 H, 3-,5-H of Ar **B** and **D**), 7.12 (d, *J* = 7.5, 2 H, 3-,5-H of Ar **A**), 9.36 (s, 2 ArO*H*), 9.83 (s, 1 ArO*H*). − ^{13}C NMR (75.3 MHz, $CDCl_3$, 25°C): δ = 31.84, 31.92 (*Me*$_3$C), 32.45, 33.18 (ArCH$_2$Ar), 34.35 (Me$_3$*C*), 78.13 (OCH$_2$), 120.68 (CH=*C*H$_2$), 125.64, 126.10, 126.30, 126.62, 129.63 (C-3, C-5 of Ar), 129.46 (C-4 of Ar **A**), 132.76 (*C*H=CH$_2$), 127.93, 128.42, 128.53, 135.04, 143.57, 142.28, 147.45, 148.91, 151.79 (C-1, C-2, C-4 of Ar). − MS (ES, negative mode, $CHCl_3$, *i*PrOH, NH_4OH): *m/z* = 631.3 [M − H]$^-$. − $C_{43}H_{52}O_4$·0.1 CH_2Cl_2 (641.38): calcd. C 80.71, H 8.20, O 9.98; found C 80.63, H 8.31, O 9.81.

Tri-*O*-benzoyl Mono-*p*-allylcalix[4]arene (4): A solution of 1.0 g (1.0 mmol) of **2** in 6 mL of *N*,*N*-diethylaniline was heated at 200°C under N_2 for 4 h. After cooling to room temp., the mixture was poured into 80 mL of 1 M HCl and the solution was stirred for 1 h. The precipitate thus formed was collected by filtration, redissolved in CH_2Cl_2, and the resulting solution was dried over Na_2SO_4. After evaporation of the solvent, the residue was chromatographed (SiO_2, CH_2Cl_2/hexane, 3:2) to give, after recrystallization from CH_2Cl_2/MeOH, 0.70 g of **4** (70%) as a white powder; m.p. 319−320°C. − IR (KBr): $\tilde{\nu}$ = 3520 (OH), 3070−2960 (CH), 1750 (C=O). − UV/vis (CH_2Cl_2): λ_{max} = 277 (9000). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.71 (s, 18 H, Me$_3$C), 0.81 (s, 9 H, Me$_3$C), 3.34 (d, *J* = 6.25, 2 H, C*H*$_2$CH=CH$_2$), 3.47, 4.10 (AB, J_{AB} = 13.6, 4 H, ArC*H*$_2$Ar), 3.80, 4.00 (AB, J_{AB} = 16.5, 4 H, ArC*H*$_2$Ar), 5.07−5.13 (m, 2 H, C*H*$_2$=CHCH$_2$), 5.91−6.06 (m, 1 H, CH$_2$=C*H*CH$_2$), 6.38 (s, 1 H, O*H*), 6.55−6.70 (m, 2 H of Ar and 4 H of Ph), 6.90−7.16 (m, 6 H, 3,5-H of Ar), 7.18−7.24 (m, 5 H, Ph), 7.53 (t, *J* = 7.3, 2 H, Ph), 8.02 (d, *J* = 7.4, 4 H, Ph). − ^{13}C NMR ($CDCl_3$, 75.33 MHz): δ = 31.08, 31.28 (*Me*$_3$C), 32.90, 32.97 (ArCH$_2$Ar), 34.11 (Me$_3$*C*), 39.23 (*C*H$_2$CH=CH$_2$), 115.54 (CH$_2$CH=*C*H$_2$), 126.10, 126.49, 126.98, 128.40 (C-3, C-5 of Ar), 138.66 (CH$_2$*C*H=CH$_2$), 128.63, 128.80, 129.77, 131.88, 132.03, 132.53, 133.02, 144.75, 146.36, 148.31, 148.94, 151.16 (C-1, C-2, C-4, C-6 of Ar and 1-Ph), 163.80, 165.24 (C=O). − MS (ES, positive mode; CH_2Cl_2, *i*PrOH, HCOOH): *m/z* = 967.5 [M + Na]$^+$. − $C_{64}H_{64}O_7$ (945.21): calcd. C 81.33, H 6.82, O 11.85; found C 81.05, H 6.96, O 11.33.

Mono-*p*-allylcalix[4]arene (6): A mixture of 1.2 g (1.27 mmol) of **4** and 1.6 g (28 mmol) of KOH in 20 mL of H_2O and 40 mL of EtOH was heated at 80°C for 14 h. After cooling to room temp., the mixture was acidified to pH 2−3 with 1 M HCl. The resulting precipitate was collected, redissolved in CH_2Cl_2, and this solution was dried over Na_2SO_4. After addition of MeOH, the CH_2Cl_2 was partially evaporated to give 0.72 g of **6** (90%) as a white powder; m.p. 286−288°C. − IR (KBr): $\tilde{\nu}$ = 3150 (OH), 2870−2962 (CH), 1200 (CO). − UV/vis (CH_2Cl_2): λ_{max} = 279.5 (10600), 286.0 (sh, 8500). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.22 (s, 9 H, *Me*$_3$C), 1.24 (s, 18 H, *Me*$_3$C), 3.20 (m, C*H*$_2$CH=CH$_2$), 3.50, 4.26 (AB, J_{AB} = 12, 8 H, ArC*H*$_2$Ar), 5.03−5.09 (m, 2 H, CH=C*H*$_2$), 5.85 (m,

$CH_2CH{=}CH_2$), 6.87 (br. s, 2 H, 3-,5-H of Ar **A**), 7.00−7.20 (m, 6 H, 3-,5-H of Ar **B**, **C**, **D**), 10.25, 10.30 (2 s, 4 ArO*H*). − ^{13}C NMR (75.3 MHz, $CDCl_3$): δ = 31.37, 31.40, 31.42 (Me_3C), 32.17, 32.25, 32.50 ($ArCH_2Ar$), 34.01 (Me_3C), 39.37 ($ArCH_2CH{=}CH_2$), 115.63 ($CH{=}CH_2$), 137.5 ($CH{=}CH_2$), 125.71, 125.88, 125.96, 126.02, 128.81, 128.97, 129.03 (C-3, C-5 of Ar), 127.35, 127.40, 127.66, 127.86, 128.18, 128.42, 128.54, 133.40, 144.44, 144.46, 144.52, 146.40, 146.69, 147.21 (C-1, C-2, C-4, C-6 of Ar). − MS (ES, negative mode; CH_2Cl_2, *i*PrOH, NH_4OH): *m/z* = 631.6 $[M - H]^-$. − $C_{43}H_{52}O_4$·0.6 CH_2Cl_2 (683.85): calcd. C 76.58, H 7.84, O 9.36; found C 76.32, H 7.91, O 9.86.

Tri-*O*-benzoyl Mono-*p*-(epoxypropyl)calix[4]arene (5): A dried solution of 0.23 g (ca. 0.76 mmol) of *m*-CPBA in 20 mL of $CHCl_3$ was added dropwise under N_2 to a solution of 0.23 g (0.2 mmol) of **4** in 10 mL of $CHCl_3$. The mixture was stirred at room temp. until **4** had been completely consumed (TLC monitoring; SiO_2, CH_2Cl_2). The solvent was then evaporated to dryness and the residue was chromatographed (SiO_2, CH_2Cl_2) to give 0.17 g of **5** (75%) as a white powder; m.p. 314−315°C. − IR (KBr): ṽ = 3040 (OH), 3030−2970 (CH), 1750 (C=O). − UV/vis (CH_2Cl_2): λ_{max} = 277 (8400). − ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.71 (s, 18 H, Me_3C), 0.80 (s, 9 H, Me_3C), 2.50−3.00 [ABd + ABd, 4 H, $CH_2CH(O)CH_2$ and $CH_2CH(O)CH_2$], 3.12 [m, 1 H, $CH_2CH(O)CH_2$], 3.48, 4.09 (AB, J_{AB} = 13.7, 4 H, $ArCH_2Ar$), 3.79, 4.00 (AB, J_{AB} = 16.5, 4 H, $ArCH_2Ar$), 6.45 (s, 1 H, OH), 6.60−6.66 (m, 6 H, 3-,5-H of Ar and Ph), 6.90 (s, 2 H, 3-,5-H of Ar), 6.96 (d, *J* = 1.8, 2 H, 3-,5-H of Ar), 7.05 (s, 2 H, 3-,5-H of Ar), 7.15−8.10 (m, 11 H, Ph). − ^{13}C NMR (50.3 MHz, $CDCl_3$): δ = 30.74, 30.93 (Me_3C), 32.67, 38.85 ($ArCH_2Ar$), 33.78 (Me_3C), 37.99 [$CH_2CH(O)CH_2$], 46.84 [$CH_2CH(O)CH_2$], 52.97 [$CH_2CH(O)CH_2$], 125.82, 126.13, 126.63, 128.02, 128.31, 129.07, 129.40, 129.85, 130.08, 130.25, 130.34, 130.80, 132.74, 133.16, 133.73 (C-3, C-5 of Ar and C-2 to C-6 of Ph), 128.43, 131.53, 132.20, 144.45, 146.01, 148.00, 148.65, 151.41 (C-1, C-2, C-4, C-6 of Ar and 1-Ph), 163.48, 164.88 (*C*=O). − MS (ES, positive mode; acetone *i*PrOH): *m/z* = 983.6 $[M + Na]^+$, 863.6 $[M - (ArCOO) + H + Na]^+$, 999.6 $[M + K]^+$ or $[M' + Na]^+$, 1015.6 $[M' + K]^+$ (M′ as mass of the corresponding diol). − $C_{64}H_{64}O_8$ (961.85): calcd. C 79.97, H 6.71, O 13.31; found C 79.96, H 6.92, O 13.34.

Tri-*O*-benzoyl Mono-*p*-(2-oxoethyl)calix[4]arene (8): A solution of 0.20 g (0.2 mmol) of **4** in 20 mL of dry CH_2Cl_2 was cooled to −78°C in a three-necked flask. O_2 was bubbled through the solution for 3 min. (1 L min^{-1}; 3 L), and then O_3 was bubbled for 10 min (0.20 mmol min^{-1}; 2.0 mmol). The pale-blue solution was then purged with O_2 and 0.05 mL (0.4 mmol) of NEt_3 was added. The resulting solution was stirred at room temp. for 2 h and then the solvents were evaporated to dryness. The residue was redissolved in 20 mL CH_2Cl_2 and the resulting solution was washed with 20 mL of H_2O. The organic phase was dried over Na_2SO_4, concentrated, and then chromatographed (SiO_2, CH_2Cl_2) to give 0.1 g of **8** (50%) as a white powder; m.p. 327−328°C. − IR (KBr): ṽ = 3500 (OH), 3080−2960 (CH), 1740 (vs, C=O of ester and aldehyde). − UV/vis (CH_2Cl_2): λ_{max} = 277.00 (8900). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.72 (s, 18 H, Me_3C), 0.82 (s, 9 H, Me_3C), 3.50, 4.09 (AB, J_{AB} = 13.8, 4 H, $ArCH_2Ar$), 3.80, 3.99 (AB, J_{AB} = 16.3, 4 H, $ArCH_2Ar$), 3.61 (d, *J* = 2.2, 2 H, CH_2CHO), 6.56 (s, 1 H, OH), 6.63−6.66 (m, 4 H of Ph and 2 H of Ar), 6.91 (s, 2 H, 3-,5-H of Ar), 6.95 (d, *J* = 2.6, 2 H, 3-,5-H of Ar), 7.03 (s, 2 H, 3-,5-H of Ar), 7.19−7.26 (m, 5 H, Ph), 7.55 (t, *J* = 7.35, 2 H, Ph), 8.00 (d, *J* = 8.3, 4 H, Ph), 9.74 (t, *J* = 2.2, CHO). − ^{13}C NMR (75.3 MHz, $CDCl_3$): δ = 29.56, 29.76 (Me_3C), 31.58, 37.67 ($ArCH_2Ar$), 32.63, 32.68 (Me_3C), 48.69 (CH_2CHO), 124.80, 124.92, 125.49, 126.85, 127.92, 128.81, 128.87, 129.14, 131.73, 132.03 (C-3, C-5 of Ar and C-2 to C-6 of Ph), 121.83, 127.26, 127.71, 128.18, 130.03, 131.02, 131.63, 143.33, 144.84, 146.84, 147.58, 150.96 (C-1, C-2, C-4, C-6 of Ar and 1-Ph), 162.26, 163.61 (*C*=O), 198.32 (*C*H=O). − MS (ES, positive mode; CH_2Cl_2, Pr^{i}OH, HCOOH): *m/z* = 969.6 $[M + Na]^+$.

Mono-*p*-(epoxypropyl)calix[4]arene (7): A solution of 0.6 g (ca. 2.0 mmol) of *m*-CPBA in 20 mL of $CHCl_3$ was added dropwise under N_2 to a solution of 0.3 g (0.48 mmol) of **6** in 20 mL of $CHCl_3$. The resulting mixture was stirred at room temp. until **6** had been completely consumed (TLC monitoring; SiO_2, CH_2Cl_2). EtOH was then added and the CH_2Cl_2 was partially evaporated to give 0.21 g of **7** (68%) as a white powder; m.p. 304°C. − IR (KBr): ṽ = 3164 (OH), 2870−2960 (CH), 1200 (C−O). − UV/vis (CH_2Cl_2): λ_{max} = 279.5 (17000), 286.5 (sh, 13000). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.21 (s, 9 H, Me_3C), 1.22 (s, 18 H, Me_3C), 2.50−2.80 (ABd + ABd, 4 H, $CH_2CH(O)CH_2$ and $CH_2CH(O)CH_2$), 3.05 (m, 1 H, $CH_2CH(O)CH_2$), 3.50, 4.26 (AB, J_{AB} = 13.5, 8 H, $ArCH_2Ar$), 6.94 (s, 2 H, 3-,5-H of Ar **A**), 7.04 (s, 2 H, 3-,5-H of Ar **C**), 7.05−7.08 (AB, J_{AB} = 2.2, 4 H, 3-,5-H of Ar **B** and **D**), 10.27 (s, 1 H, OH), 10.31 (s, 3 H, OH). − ^{13}C NMR (75.3 MHz, $CDCl_3$): δ = 31.45, 31.50 (Me_3C), 32.30, 32.58 ($ArCH_2Ar$), 34.05, 34.12 (Me_3C), 38.08 ($CH_2CH(O)CH_2$), 46.96 ($CH_2CH(O)CH_2$), 52.56 ($CH_2CH(O)CH_2$), 125.78, 125.95, 126.14, 129.59 (C-3, C-5 of Ar), 127.38, 127.72, 127.94, 128.68, 130.65, 144.54, 144.56, 146.45, 146.73, 147.83 (C-1, C-2, C-4, C-6 of Ar). − $C_{43}H_{52}O_5$, 0.25 CH_2Cl_2 (670.123): calcd. C 77.52, H 7.90, O 11.94; found C 77.31, H 8.14, O 12.02. − MS (ES, negative mode; CH_2Cl_2, MeCN, NH_4OH): *m/z* = 647.5 $[M - H]^-$.

Mono-*p*-(2-oxoethyl)calix[4]arene (9): A solution of 0.70 g (1.1 mmol) of **6** in 160 mL of dry CH_2Cl_2 was cooled to −78°C in a three-necked flask. O_2 was bubbled through the solution for 3 min. (1 L min^{-1}; 3 L), and then O_3 was bubbled for 20 min. (0.20 mmol min^{-1}; 4.0 mmol). The pale-blue solution was then purged with O_2 and 0.3 mL (2.2 mmol) of NEt_3 was added. The resulting solution was stirred at room temp. for 2 h and then the solvents were evaporated to dryness. The residue was taken up in a mixture of 25 mL of EtOH and 25 mL of H_2O and acidified to pH 2 with 1 M HCl. The insoluble material was collected by filtration, redissolved in 50 mL of CH_2Cl_2, then chromatographed (SiO_2, CH_2Cl_2) to give the aldehyde as a glassy material. Precipitation from $CHCl_3$/MeOH afforded 0.52 g of **9** (75%) as a white powder; m.p. 304−305°C. − IR (KBr): ṽ = 3157 (OH), 1726 (C=O). − UV/vis (CH_2Cl_2): λ_{max} = 279.5 (11000), 286.0 (sh, 9000). − ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.21 (s, 9 H, Me_3C), 1.24 (s, 18 H, Me_3C), 3.40−3.50 (br. 1/2 AB + d, *J* = 2.6, 6 H, $ArCH_2Ar$ and CH_2CHO), 4.10−4.25 (br. 1/2 AB, 4 H, $ArCH_2Ar$), 6.92 (s, 2 H, 3-,5-H of Ar **A**), 7.00−7.11 (m, 6 H, 3-,5-H of Ar **B**, **C** and **D**), 9.65 (t, *J* = 2.6, 1 H, CH_2CHO), 10.32 (s,br., 4 OH). − ^{13}C NMR (75.3 MHz, $CDCl_3$): δ = 31.43, 31.48 (Me_3C), 32.28, 32.55 ($ArCH_2Ar$), 34.12 (Me_3C), 49.80 (CH_2CHO), 125.71, 125.95, 126.27, 130.18 (C-3, C-5 of Ar), 125.08, 127.10, 127.62, 128.05, 129.28, 144.58, 144.70, 146.39, 146.65, 148.60 (C-1, C-2, C-4, C-6 of Ar), 199.74 (CHO). − MS (ES, negative mode; CH_2Cl_2, MeCN, NH_4OH): *m/z* = 633.3 $[M - H]^-$. − $C_{42}H_{50}O_5$·0.5 $CHCl_3$ + 0.5 H_2O (703.56): calcd. C 72.55, H 7.38, O 12.51; found C 72.63, H 7.44, O 12.63.

X-ray Crystallographic Study of Epoxide 5: $C_{128}H_{128}O_{16}$, C_6H_{14}, crystal system triclinic, space group *P*-1 with *a* = 10.548(5) Å, *b* = 14.921(5) Å, *c* = 17.680(9) Å, α = 87.97(3)°, β = 76.10(3)°, γ = 84.53(3)°, *V* = 2688(1) Å^3, D_{calcd} = 1.240 g/cm^3 and *Z* = 1. The data were collected at 123 K by X-ray diffraction on an Enraf−-Nonius Kappa-CCD diffractometer. A full sphere of data was col-

Table 2. Crystal data and structure refinement of **5**

Empirical formula	$C_{128}H_{128}O_{16}$, C_6H_{14}
M_r	2008.48
Space group	*P*-1
a [Å]	10.548(5)
b [Å]	14.921(5)
c [Å]	17.680(9)
α [°]	87.97(3)
β [°]	76.10(3)
γ [°]	84.53(3)
V [Å^3]	2688(1)
Z	1
D_x [mg·m^{-3}]	1.240
D_m	not measured
T [K]	123
Crystal size, plates [mm]	0.50 × 0.50 × 0.2
Colour	Colourless
Enraf−Nonius Kappa-CCD diffractometer	
Extinction correction:	None
Absorption correction	none
Measured reflections	16933
Independent reflections	9344
Reflections with $I>2\sigma(I)$	4713
R_{int}	0
θ_{max} [°]	27.71
Index of ranges	0−13, ±17, ±22
$(\Delta/\sigma)_{max}$	< 0.05
$\Delta\rho_{min}$ [Å^3]	−0.40 e
$\Delta\rho_{max}$ [Å^3]	0.66 e
$WR(F^2)$	0.1528
S	0.991
Parameters	724
H atoms riding	
Mo-K_α radiation	λ = 0.7107 Å

lected by φ axis rotation with 1.0° increments over 180°, with 35 s exposures per frame. Dezingering was accomplished by measuring each frame twice. θ, ω, and κ axes were positioned at 0° throughout all the data collection. The crystal to detector distance was 30 mm. Data were analysed using Kappa-CCD software.[15] Cell dimensions were refined with HKL Scalepack.[16] Data reduction was performed with Denzo.[16] The structure was solved with SIR-92[17] and refined by full-matrix least-squares on F^2 with all measured reflections using SHELX-97.[18] All nonhydrogen atoms were given anisotropic displacement parameters. All hydrogen atoms were located at their theoretical position and refined as a riding model. U_{iso} values were fixed such that they amounted to 1.2 U_{eq} of their parent atom, and to 1.5 U_{eq} for methyl groups. The final electron density difference map showed a maximum of 0.66 e·Å^{-3} and a minimum of −0.40 eÅ^{-3}. Final values were $R = 0.0686$ and $S = 0.991$ for 724 parameters and 9344 contributing reflections. PLATON[19] was used to analyse intra- and intermolecular interactions. Molecular graphics were drawn with MAXUS[20] and ORTEP.[21]

Crystallographic data (excluding structure factors) have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. 103122. Copies of the data can be obtained free of charge on application to the CCDC, 12 Union Road, Cambridge CB2 1EZ, U.K. [Fax: (internat.) +44 (0)1223 336033; E-mail: deposit@ccdc.cam.ac.uk]. For other details, see Table 2.

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