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Enantioselective synthesis of (−)-(1*R*,2*R*)-1,2-dihydrochrysene-1,2-diol

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ABSTRACT

A general chiral building block containing the 1*R*,2*R*-*trans*-diol moiety was constructed utilizing the stereoselective Shi-epoxidation reaction on a tetralone scaffold assembled by a Negishi cross-coupling on *N*,*N*-diethylbenzamide. Further elaboration of this chiral building block into polycyclic aromatic compounds was demonstrated with the total synthesis of the precursor for the most carcinogenic metabolite of chrysene, (−)-(1*R*,2*R*)-1,2-dihydrochrysene-1,2-diol in 87% ee.

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs), either found naturally in coal tars and oil[1] or formed by incomplete combustion of organic materials, such as tobacco,[2] and fuel,[3] or in charred meat,[4] are all well-known pollutants in the environment. When digested by mammals or fish these compounds go through several enzymatic catalyzed oxidation steps forming different metabolites.[5] Initial enzymatic oxidation form epoxides, which undergo ring opening to *trans*-diols (Fig. 1). Further oxidation form metabolites that essentially bind covalently to DNA[6] and proteins[6a,7] in cells forming adducts, which leads to mutagenesis and cancer.[1b,8] Analysis of DNA adducts and protein adducts has a great potential as a new tool in environmental monitoring of oil contamination.[6a,b,7a] The presence in oil and the properties of chrysene, e.g., the toxicity of the metabolites formed in vivo, makes it an excellent starting point for the study of DNA and protein adduct formation. (1*R*,2*R*)-1,2-Dihydrochrysene-1,2-diol (**1**) has been found to be the precursor of the most carcinogenic chrysene metabolites formed.[9] It is believed that by subjecting fish (Atlantic cod) to chrysene metabolite **1**, instead of chrysene itself, higher amount of DNA and protein adducts will be formed in vivo, which will enable studies to a better understanding of the further metabolism of chrysene and other PAHs. Other PAHs can also form similar carcinogenic *trans*-dihydrodiols. Thus, a general method for making the desired enantiomers of *trans*-dihydrodiols in a few steps from a general chiral building block would be desirable as an alternative to the synthesis of the racemic compound, which was followed by separation of the two enantiomers as described by Harvey.[10] Here we report our search for such a general chiral building block that led to the first enantioselective synthesis of (−)-(1*R*,2*R*)-1,2-dihydrochrysene-1,2-diol (**1**) starting from readily available *N*,*N*-diethylbenzamide, where the chirality was installed utilizing the Shi-epoxidation reaction.[11]

It was envisioned that *trans*-dihydrodiols like **1** could be prepared from a general chiral building block by the two strategies outlined in the retrosynthetic analysis depicted in Scheme 1. The first approach includes an amide reduction,[12] a Wittig reaction[13] and a photocyclization reaction.[14] The double bond was envisioned to be introduced either before the amide reduction or after the photocyclization reaction. The second approach includes a directed *ortho* metalation (DoM) reaction,[15] a Suzuki–Miyaura cross-coupling reaction,[16] and a directed remote metalation (DreM) reaction[17] followed by a protection/cleavage protocol to generate the *trans*-dihydrodiol **1**. Other ring systems may be introduced by using other coupling partners in the Wittig reaction or Suzuki–Miyaura reaction.

2. Results and discussion

The total synthesis of (1*R*,2*R*)-1,2-dihydrochrysene-1,2-diol (**1**) began by coupling readily available *N*,*N*-diethylbenzamide **3** with ethyl-4-bromobutyrate utilizing a Negishi cross-coupling reaction.[18]

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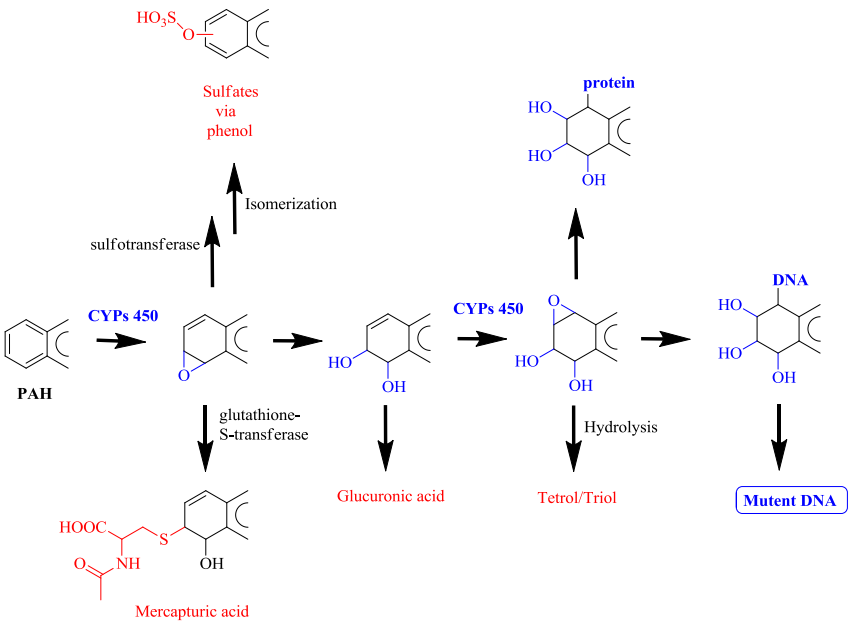
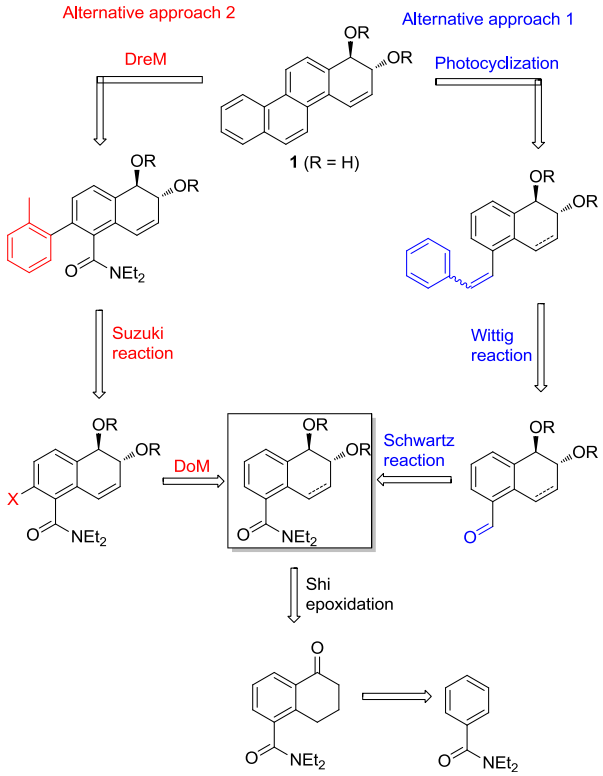


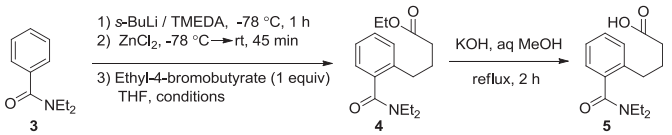
Fig. 1. Metabolism of polycyclic aromatic hydrocarbons.



Scheme 1. Retrosynthetic analysis for the formation of compound **1** from *N*,*N*-diethylbenzamide.

N,*N*-diethylbenzamide **3** was *ortho*-lithiated with *sec*-butyl lithium (*s*-BuLi),[15] followed by an in situ transmetalation with zinc chloride ($ZnCl_2$), and an in situ cross-coupling with ethyl-4-bromobutyrate.[18] Palladium catalysis was found not to promote the desired transformation (entries 1–3, Table 1). However, switching to a nickel catalyst improved matters. Different conditions were tested using $Ni(acac)_2/PPh_3$ as the catalyst.[19] At low temperature a significant amount of homocoupled benzamide and a low yield of the desired cross-coupling product was isolated (entries 4 and 5, Table 1).[20]

Table 1
Negishi cross-coupling reaction and ester hydrolysis



Entry	Catalyst (mol %)	Additive (mol %)	Temperature (°C)	Time (h)	Yield of **5** (%)
1	$Pd_2(dba)_3$	—	Reflux	19	nr
2	$Pd(dppf)Cl_2$ (5)	—	Reflux	19	nr
3	$Pd(dppf)Cl_2$ (5),	DIBALH (10)	Reflux	19	nr
4	$Ni(acac)_2$ (5)	PPh_3 (5)	0→rt	19	23[a]
5	$Ni(acac)_2$ (5)	PPh_3 (5)	50	2	40[b]
6	$Ni(acac)_2$ (5)	PPh_3 (5)	Reflux	2	67
7	$Ni(acac)_2$ (5)	PPh_3 (10)	Reflux	2	44
8	$NiCl_2(PCy_3)_2$ (2)	—	Reflux	2	61
9	$NiCl_2$(dppe) (5)	DIBALH (10)	Reflux	2	20[c]

[a] Homocoupling product of 40% was isolated.
[b] Homocoupling product observed by TLC but not isolated.
[c] Homocoupling product of 38% was isolated.

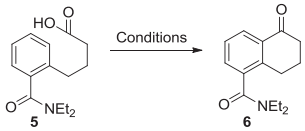
However, raising the temperature improved the reaction outcome, and the best result was obtained at reflux for 2 h giving product **5** in 67% isolated yield (entry 6, Table 1). At this temperature no traces of homocoupled benzamide were observed by TLC or ^1H NMR analysis. In all the reactions where the cross-coupling of ethyl-4-bromobutyrate and *N*,*N*-diethylbenzamide **3** occurred a small amount of unreacted benzamide **3** coeluted with the desired product **4** in the chromatographic purification. The ester **4** was, therefore, hydrolyzed with potassium hydroxide where the butanoic acid **5** was obtained in the respective yields shown in Table 1.

The amount of PPh_3 was found to have an effect on the reaction outcome. Adding 2 equiv of PPh_3 (10 mol %) compared to $Ni(acac)_2$ (5 mol %) resulted in a lower yield of compound **5** (entry 7, Table 1). Other nickel catalysts were also tested (entries 8 and 9, Table 1), but the reaction outcome did not improve.

From butanoic acid **5**, tetralone **6** was prepared by an intramolecular Friedel–Crafts acylation reaction.[21] Transformation of butanoic acid **5** to its corresponding acyl chloride, followed by treatment with a catalytic amount of aluminum trichloride ($AlCl_3$)

resulted in only trace amounts of tetralone **6**, as observed by TLC analysis (entry 1, Table 2). Methane sulfonic acid (MsOH), known to directly transform carboxylic acids to tetralones,[22] did not promote the reaction in any way (entry 2, Table 2). However, with Eaton's reagent (7.7 wt % of P_2O_5 in MsOH)[23] at elevated temperatures tetralone **6** could be obtained in the respective yields shown in Table 2. The best overall conditions were found to be 100 °C for 2 h giving tetralone **6** in 61% isolated yield (entry 10, Table 2). Worth noting, 2 equiv of P_2O_5 was necessary in order to obtain this yield. When 1 equiv was used the yield of tetralone **6** decreased significantly (entries 13 and 14, respectively). It was also observed that with longer reaction time (entries 6 and 12, Table 2) the yield of tetralone **6** decreased, which might be explained by the conversion of amides to nitriles in the presence of drying agents such as diphosphor pentaoxide (P_2O_5).[24]

Table 2
Intramolecular Friedel–Crafts acylation of butanoic acid **5**



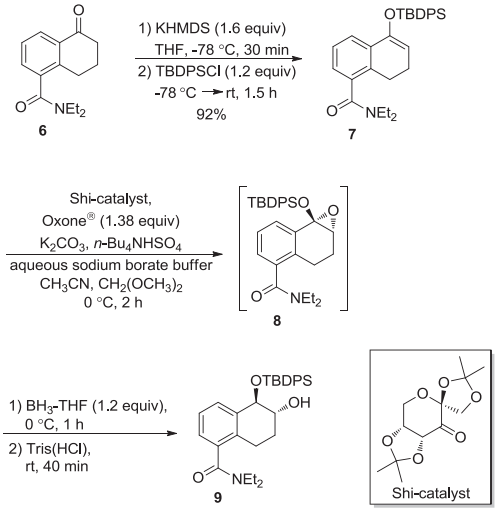
Entry	Reagent	Temperature (°C)	Time (h)	Yield (%)
1	$SOCl_2/AlCl_3$, $(CH_2)_2Cl_2$	75/85	2/19	Trace
2	MsOH	70	19	nr
3[a]	Eaton's reagent[b]	rt	19	nr
4	Eaton's reagent	60	6	26
5	Eaton's reagent	60	19	39
6	Eaton's reagent	60	72	30
7	Eaton's reagent	80	1.5	45
8	Eaton's reagent	80	4	52
9	Eaton's reagent	100	1.5	54
10	Eaton's reagent	100	2	61
11	Eaton's reagent	100	3	59
12	Eaton's reagent	100	67	13
13[c]	Eaton's reagent	100	1	37
14[c]	Eaton's reagent	100	3	31
15	Eaton's reagent	120	1.5	54

[a] P_2O_5 (2 equiv) was used if not otherwise specified.
[b] Eaton's reagent=7.7 wt % of P_2O_5 dissolved in MsOH.
[c] P_2O_5 (1 equiv).

From tetralone **6**, *tert*-butyldiphenylsilyl enol ether **7** was obtained in 92% yield by deprotonation with potassium hexamethyldisilazide (KHMDS), followed by in situ trapping of the formed enol with *tert*-butyldiphenylsilyl chloride (TBDPSCl).[25] With compound **7** in hand, the key step in the synthesis of target molecule **1**, namely the Shi-epoxidation reaction,[11,25] could be performed. Silyl enol ether **7** was first transformed to silyloxy epoxide **8**, followed by regio- and stereospecific addition of hydride to give *trans*-diol monosilyl ether **9**. This specific transformation of tetralones has been demonstrated to give *trans*-diols in high yields and high *enantiomeric excess*.[25]

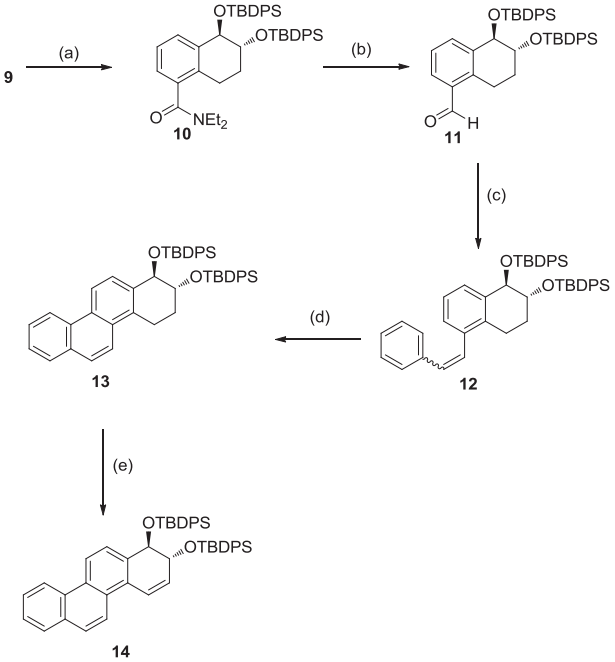
However, the Shi-epoxidation reaction is a rather sensitive reaction, and the outcome of the reaction depends on several factors,[11] especially the pH of the reaction mixture. Following literature procedures,[25] *trans*-diol monosilyl ether **9** was only obtained in 48% yield (entry 1, Table 3). However, the pH was measured to be only 9, while at ideal conditions the pH should be 10.5 or higher.[11] By increasing the amount of potassium carbonate from 5.8 equiv to 8 equiv, *trans*-diol monosilyl ether **9** was obtained in 70% isolated yield (entry 2, Table 3). In attempts to further increase the yield, the reaction was performed with 0.5 equiv of Shi catalyst, but the yield only increased slightly (entry 3, Table 3). The *enantiomeric excess* was shown to be 85% for the lower yielding reaction (entry 1, Table 3) and 83% for the higher yielding reactions (entries 2 and 3, Table 3), as evident from chiral HPLC analysis (Lux 3u Cellulose-2 column).

Table 3
Shi-epoxidation reaction



Entry	Shi catalyst (equiv)	K_2CO_3 (equiv)	Yield (%) of **9**	ee (%)
1	0.3	5.8	48	85
2	0.3	8.0	70	83
3	0.5	8.0	76	83

The free hydroxyl group within *trans*-diol monosilyl ether **9** was protected with TBDPSCl to afford *trans*-diol disilyl ether **10** in 94% isolated yield (Scheme 2). With both hydroxyl groups protected, amide **10** was reduced to aldehyde **11** using Schwartz reagent ($Cp_2Zr(H)Cl$)[12] resulting in the formation of product **11** in 87% yield. Substrate **11** was further subjected to a Wittig reaction[13] with benzyltriphenylphosphonium chloride and NaOH (50%-solution) in DCM, thus forming stilbene **12** in 98% yield as a ca. 2:3 mixture of *E*- and *Z*-isomers. The mixture of *E*- and *Z*-stilbene was further

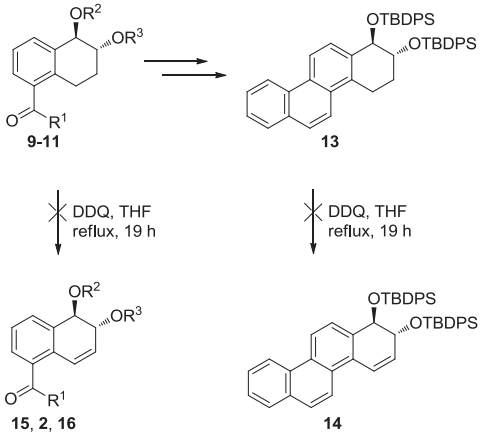


Scheme 2. Reagents and conditions: (a) (i) NaH (1.95 equiv), THF, 0 °C, 40 min; (ii) TBDPSCl (1.2 equiv), rt, 19 h, 94%; (b) $Cp_2Zr(H)Cl$ (1.5 equiv), THF, rt, 30 min, 87%; (c) benzyltriphenylphosphonium chloride, NaOH (50%-solution), DCM, rt, 30 min, 98%; (d) hν, I_2 (1.5 equiv), 1,2-epoxybutane (15 equiv), toluene, 1.5 h, 96%; (e) (i) NBS (1.5 equiv), AIBN (0.1 equiv), CCl_4, 65 °C, 2 h; (ii) *t*-BuOK (1.05 equiv), THF, 45 °C, 10 min, trace.

subjected to a Mallory photochemical cyclization reaction[14] to afford compound **13** in 96% isolated yield, as shown in Scheme 2.

From tetrahydrochrysene-1,2-diol **13** installation of the final double bond was attempted by utilizing the bromination/elimination strategy.[26] Unfortunately, the bromination reaction gave a range of products, which were inseparable by flash column chromatography. Subjecting the mixture to DBU resulted in formation of only trace amounts of the desired dihydrochrysene-1,2-diol **14** as evident by ^{1}H NMR analysis, along with a mixture of products, such as formation of mono-substituted chrysene with the loss of *tert*-butyldiphenylsilanol. Bromination of mono-substituted chrysene, along with bromination of the desired product **1**, due to the excess *N*-bromosuccinimide (NBS), may also occur. In spite of all efforts put into trying to separate these compounds, these products were not separable from one another by flash column chromatography on silica gel.

Installation of the double bond was also attempted by using DDQ, a reagent used by Harvey for the dehydrogenation of the benzo[*a*]anthracene-metabolite.[27] However, subjecting substrate **13** to DDQ only resulted in recovery of starting material. Introduction of the double bond was attempted at an earlier stage, but, as for substrate **13** DDQ was found not to promote the formation of the double bond in neither substrate **9**, **10** nor **11** (as indicated in Scheme 3).

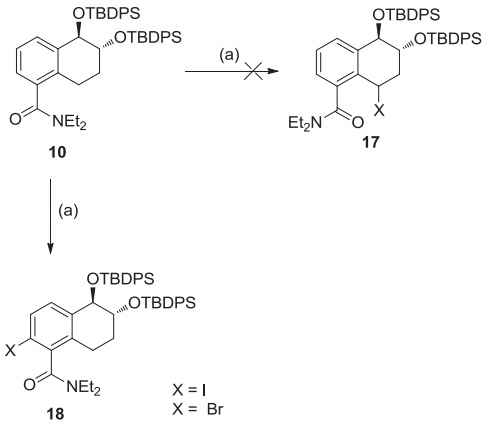


9 and **15** R^1 = NEt_2, R^2 = TBDPS, R^3 = H
10 and **2** R^1 = NEt_2, R^2 = R^3 = TBDPS
11 and **16** R^1 = H, R^2 = R^3 = TBDPS

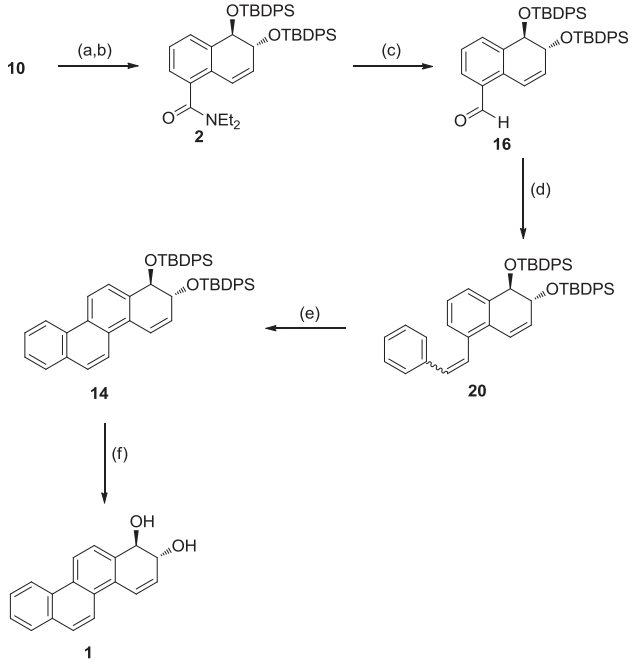
Scheme 3. Attempted introduction of double bond upon treatment with DDQ.

Utilization of the amide functionality within substrate **10** as a directing group was attempted in order to introduce a halogen in the more acidic benzylic position.[28] Neither LDA nor *n*-BuLi promoted the desired transformation and with *s*-BuLi the *ortho*-metalated product was formed instead of the desired compound **17** (Scheme 4). This may indicate that the amide group in this particular compound is a stronger directing group toward deprotonation in the *ortho*-position rather than the more acidic benzylic position. The relative large protecting groups on both hydroxyl groups may also affect the regioselectivity of the metalation reaction.

Since both treatment with DDQ and the metalation strategy failed, substrate **10** was subjected to the more typical bromination,[26] followed by an elimination reaction. Fortunately, the bromination/elimination strategy was more successful compared to tetrahydrochrysene-1,2-diol **13** and benzyl bromide **17** (X=Br) was obtained in 67% isolated yield (Scheme 5). In addition 26% of substrate **10** could be recovered from the reaction mixture. From benzyl bromide **17** (X=Br) an elimination reaction was performed.



Scheme 4. Reagents and conditions: (a) (i) *s*-BuLi (1.2 equiv), TMEDA (1.2 equiv), THF, −78 °C, 10–20 min; (ii) I_2 (1.2 equiv), −78 °C to rt, 1.5 h, 83% of **18** (X=I).



Scheme 5. Reagents and conditions: (a) NBS (1.2 equiv), AIBN (0.1 equiv), CCl_4, 65 °C, 4 h, 67%; (b) DBU (1.2 equiv), THF, reflux, 3 days, 73%; (c) $Cp_2Zr(H)Cl$ (1.2 equiv), THF, rt, 30 min, 76%; (d) benzyltriphenylphosphonium chloride, NaOH (50%-solution), DCM, rt, 20 min, 99%; (e) hν, I_2 (cat.), Et_2O/DCM (35:1), 3 h, 28%; (f) TBAF (2.6 equiv), THF, rt, 3 h, 76%.

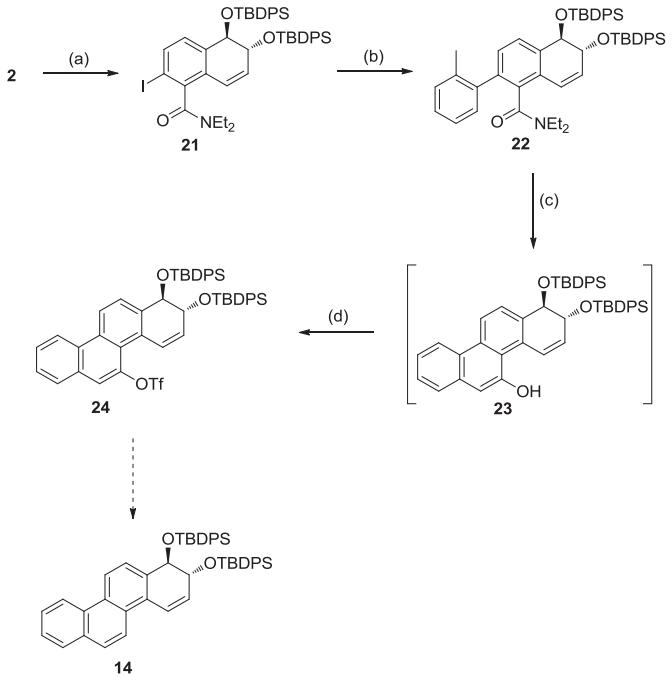
Using DBU the reaction reached completion after 3 days giving the desired compound **2** in 73% yield, while with *t*-BuOK the reaction was finished after only 1 h and compound **2** was obtained in 66% isolated yield.

Amide **2** was reduced to aldehyde **16** (76% yield) using Schwartz reagent,[12] and further subjected to a Wittig reaction[13] to afford a ca. 2:3 mixture of *E*- and *Z*-stilbene **20** in 96% yield. The *E*- and *Z*-stilbene was further subjected to a Mallory photochemical cyclization reaction as previously described.[14] Unfortunately, the reaction gave a mixture of products and only trace amounts of the desired product were detected by ^{1}H NMR analysis. GC–MS analysis of the product mixture detected one major product with a mass of 864 Da, indicating that iodine had been added to the compound after cyclization.

Since stoichiometric amount of iodine was found to be a problem, the photochemical transformation was tested with a catalytic amount of iodine,[29] and the desired compound **14** was finally obtained in 28% isolated yield. With compound **14** in hand, the final deprotection with tetrabutylammonium fluoride (TBAF) went

smoothly, resulting in the isolation of (−)-(1*R*,2*R*)-1,2-dihydrochrysene-1,2-diol (**1**) in 76% yield. The product was found to have 87% ee as measured by chiral HPLC (Lux 3u Cellulose-2 column) and the optical rotation was found to be $[\alpha]_D^{20}$ −85.4 (*c* 0.58, acetone/DMSO 4:1) (lit.[21] $[\alpha]_D^{23}$ −105 (*c* 0.37, THF)). The spectroscopic data obtained for compound **1** were in full accordance with data reported in the literature.[10a–d,30]

The synthesis of target compound **1** was also attempted utilizing the directed *ortho* metalation (DoM)[15] and directed remote metalation (DreM)[17] strategy, outlined in Scheme 1. Amide **2** was *ortho* lithiated with *s*-BuLi, followed by in situ trapping of the formed lithiated species with iodine to afford product **21** in 78% yield (Scheme 6). The *ortho*-metalated product **21** was further subjected to a Suzuki–Miyaura cross-coupling reaction[16] with *o*-tolylboronic acid forming biphenyl **22** in 97% isolated yield. From biphenyl **22** a directed remote metalation reaction with LDA was conducted and the transformation went quantitatively as observed by TLC analysis. However, when subjecting the cyclized product **23** to 2,6-lutidine and triflic anhydride[17] only a 7% yield of product **24** could be isolated. DreM product **23** suffers from rapid oxidation as observed by a rapid color change on the TLC plate. The product was kept under nitrogen as much as possible during work-up procedures. However, due to steric hindrance between 2,6-lutidine and the compound itself, protection with triflic anhydride did not go to completion and upon purification most of compound **23** was lost. A change to pyridine (stirred overnight) as base resulted in mostly an aromatization of product **24**, with the loss of *tert*-butyldiphenylsilanol, and only trace amounts of the desired product **24** were observed by TLC and ^{1}H NMR analysis.



Scheme 6. Reagents and conditions: (a) (i) *s*-BuLi (1.06 equiv), TMEDA (1.06 equiv), THF, −78 °C, 1 h; (ii) I_2 (1.5 equiv), −78 °C to rt, 5 h, 78%; (b) *o*-tolylboronic acid (1.5 equiv), $PdCl_2$dppf (5 mol %), Na_2CO_3 (2 M), DME, reflux, 19 h, 97%; (c) LDA (2.5 equiv), THF, 0 °C, 1 h, quant.; (d) 2,6-lutidine (1.1 equiv), Tf_2O (1.1 equiv), DCM, 0 °C to rt, 2 h, 7%.

3. Conclusion

An enantioselective synthesis of (−)-(1*R*,2*R*)-1,2-dihydrochrysene-1,2-diol (**1**) has been achieved, starting from readily available *N*,*N*-diethylbenzamide. The chirality (*trans*-diol) within the structure was formed by a Shi-epoxidation reaction. From the two strategies outlined in Scheme 1 the best approach was found to be alternative 1, utilizing amide reduction, a Wittig reaction, and a photochemical cyclization reaction. The analytical data of target molecule **1** were in full accordance with data reported in the literature. Compound **1** is now undergoing biological studies in order to shed light on the further fate of the metabolite in vivo.

4. Experimental

4.1. General

Tetrahydrofuran (THF) was distilled under nitrogen atmosphere from Na/benzophenone. *N*,*N*,*N*′,*N*′-tetramethylethylenediamine (TMEDA) was distilled and stored over potassium hydroxide (KOH). Glove box was used when necessary. All reactions were carried out under nitrogen atmosphere if not otherwise specified. The photochemical reactions were performed by using a Photochemical Reactor Ltd. equipped with a 400 W medium pressure Mercury-lamp in a 350 mL quartz immersion well reactor fitted with a no. 3408 Pyrex glass filter sleeve. TLC was performed on Merck silica gel 60 F_{254} plates, using UV light at 254 nm and 5% alcoholic molybdophosphoric acid for detection. Normalsil 60, 40–63 μm silica gel was used for flash chromatography. ^{1}H NMR and ^{13}C NMR were recorded on a Varian Mercury 300 MHz, all at room temperature. Chloroform-d_1 was used as solvent, unless otherwise specified. Chemical shifts were reported in parts per million (ppm) compared to TMS (δ 0, singlet, for ^{1}H NMR), or for ^{13}C resonance signal to $CDCl_3$ (δ 77.0, triplet). The splitting pattern was recorded as a singlet, s; doublet, d; triplet, t; double doublet, dd; double triplet, dt; quartet, q; multiplet, m; broad, br. IR was recorded on a Perkin Elmer FT-IR spectrometer, version 3.02.01. Melting points were determined on a Stuart Scientific melting point apparatus SMP3. *Enantiomeric excess* (ee) was determined using chiral Ultimate 300 HPLC with a Lux 3u Cellulose-2 column (150×4.60 mm, Phenomex Inc.), RS pump, Autosampler and a Diode Array detector at 220 nm.

4.2. Synthesis of ethyl 4-(2-(*N*,*N*′-diethylcarbamoyl)phenyl) butanoate (4)

N,*N*-Siethylbenzamide (1.68 g, 9.48 mmol) in THF (10 mL) was added to a solution of *s*-BuLi (8.4 mL, 10.42 mmol, 1.4 M solution in cyclohexane), TMEDA (1.56 mL, 10.41 mmol), and THF (14 mL) at −78 °C. After stirring for 1 h, a solution of $ZnCl_2$ (1.43 g, 10.45 mmol, pre-dried under vacuum) in THF (10 mL) was added and the mixture was allowed to warm to room temperature over a period of 45 min.

A second round bottomed flask containing $Ni(acac)_2$ (124 mg, 0.48 mmol, 5 mol %) and Ph_3P (128 mg, 0.49 mmol, 5 mol %) in THF (15 mL) was heated to reflux before ethyl-4-bromobutyrate (1.4 mL, 9.69 mmol) was added. After stirring the resulting reaction mixture for 10 min, the arylzinc chloride was added slowly over a period of 15 min and the mixture was stirred at reflux for 2 h. After allowing the mixture to cool down, it was quenched with saturated NH_4Cl (50 mL) and extracted with Et_2O (3×70 mL). The organic layer was dried over $MgSO_4$, filtered, and concentrated to give a yellow oil. The crude product was purified by flash column chromatography (petroleum ether/EtOAc 1:1) to afford a ca. 9:1 mixture of product **4** and benzamide **3** (2.04 g) as a light yellow oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.38 (s, 5H, benzamide **3**), 7.30–7.14 (m, 4H), 4.12 (q, *J*=7.1 Hz, 2H), 3.79 (app. s, 1H), 3.58 (app. s, 2H, benzamide **3**), 3.35 (app. s, 1H), 3.48 (q, *J*=7.0 Hz, 2H), 2.66–2.58 (br m, 2H), 2.33 (t, *J*=7.4 Hz, 2H), 1.99–1.92 (m, 2H), 1.28–1.22 (m, 6H), 1.11 (app. s, 3H, benzamide **3**), 1.04 (t, *J*=7.0 Hz, 3H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 173.2 (*C*OOEt), 170.5 (*C*ON), 137.5 (*C*), 136.8 (*C*), 129.3 (*C*H), 128.6 (*C*H), 126.0 (*C*H), 125.5 (*C*H), 60.1 (OCH_2CH_3), 42.7 (NCH_2), 38.5

(NCH_2), 33.8 (CH_2), 32.1 (CH_2), 25.8 (CH_2), 14.2 (NCH_2CH_3), 13.8 (OCH_2CH_3), 12.6 (NCH_2CH_3).

4.3. 4-(2-(*N*,*N*′-Diethylcarbamoyl)phenyl)butanoic acid (5)

To a solution of phenylbutanoate **4** (2.04 g) in MeOH (65 mL) and water (5 mL) was added KOH (0.79 g, 14.15 mmol). The reaction mixture was heated at reflux for 2 h, before concentrated in vacuo. The yellow residue was dissolved in water (50 mL), added 2 M aqueous NaOH-solution (2 mL) and extracted with Et_2O (2×60 mL). The water layer was adjusted to pH 0 by the addition of 6 M HCl (4 mL) and extracted a second time with Et_2O (3×60 mL). The latter organic layer was dried over $MgSO_4$, filtered, and concentrated to afford 1.68 g (67% from benzamide **3**) of product **5** as a light yellow oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 9.65 (br s, 1H, O*H*), 7.38–7.14 (m, 4H), 3.79 (app. s, 1H), 3.37 (app. s, 1H), 3.12 (q, *J*=6.9 Hz, 2H), 2.66 (app. s, 1H), 2.58 (app. s, 1H), 2.35 (t, *J*=7.2 Hz, 2H), 1.94 (app. hep, *J*=7.3 Hz, 2H), 1.25 (t, *J*=7.5 Hz, 3H), 1.04 (t, *J*=7.5 Hz, 3H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 178.0 (*C*OOH), 170.9 (*C*ON), 137.4 (*C*), 136.5 (*C*), 129.5 (*C*H), 128.8 (*C*H), 126.1 (*C*H), 125.6 (*C*H), 42.9 (NCH_2), 38.8 (NCH_2), 33.6 (CH_2), 32.0 (CH_2), 25.1 (CH_2), 13.8 (NCH_2CH_3), 12.6 (NCH_2CH_3); IR (KBr) 2974 (m), 2936 (m), 1731 (s), 1630 (m), 1591 (s), 1498 (w), 1460 (m), 1439 (m), 1383 (w), 1364 (w), 1292 (w), 1220 (w), 1150 (w), 1117 (w), 1085 (w), 946 (w), 752 (w); mass spectrometry *m*/*z* (relative intensity %) 286.1 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{15}H_{21}O_3N$+Na: 286.1414, found 286.1412.

4.4. *N*,*N*′-Diethyl-5-oxo-5,6,7,8-tetrahydronaphthalene-1-carboxamide (6)

To butanoic acid **5** (300 mg, 1.141 mmol) was added Eaton's reagent (7.7 wt % P_2O_5 in MsOH, 6.2 mL) and the resulting reaction mixture was quickly warmed to 100 °C and stirred for 2 h. The dark brown mixture was then cooled to room temperature and poured into ice (40 mL). After the ice had melted the yellow aqueous solution was extracted with CH_2Cl_2 (3×60 mL). The organic layer was washed with saturated $NaHCO_3$-solution (1×100 mL), dried over $MgSO_4$, filtered, and concentrated in vacuo to give a dark brown oil. The crude product was purified by flash column chromatography (petroleum ether/EtOAc 1:1) to afford 170 mg (61%) of product **6** as a white solid. Mp 96.1–96.6 °C (Et_2O); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 8.09–8.06 (m, 1H), 7.39–7.23 (m, 2H), 3.76 (app. s, 1H), 3.43 (app. s, 1H), 3.14 (q, *J*=7.2 Hz, 2H), 3.06 (app. s, 1H), 2.73 (app. s, 1H), 2.67 (t, *J*=6.6 Hz, 2H), 2.15 (app. d, *J*=6.9 Hz, 2H), 1.28 (dt, *J*=0.8, 7.2 Hz, 3H), 1.06 (dt, *J*=0.8, 7.5 Hz, 3H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 197.7 (*C*O), 169.5 (*C*ON), 140.4 (*C*), 137.0 (*C*), 133.1 (*C*), 130.2 (*C*H), 127.6 (*C*H), 126.6 (*C*H), 42.7 (NCH_2), 39.0 (NCH_2), 38.9 (CH_2), 26.4 (CH_2), 22.7 (CH_2), 14.1 (NCH_2CH_3), 12.9 (NCH_2CH_3); IR (KBr) 2981 (w), 2943 (m), 2874 (w), 1683 (s), 1624 (s), 1584 (m), 1478 (m), 1457 (m), 1432 (m), 1366 (w), 1327 (w), 1296 (m), 1278 (s), 1215 (m), 1192 (w), 1131 (m), 1088 (m), 950 (w), 905 (w), 829 (m), 802 (m), 736 (w), 669 (w), 548 (w); mass spectrum *m*/*z* (relative intensity %) 268.1 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{15}H_{19}O_2N$+Na: 268.1308, found 268.1309.

4.5. 5-((*tert*-Butyldiphenylsilyl)oxy)-*N*,*N*-diethyl-7,8-dihydronaphthalene-1-carboxamide (7)

A solution of KHMDS (213 mg, 1.07 mmol) in THF (3 mL) was added drop wise to a stirred solution of tetralone **6** (161 mg, 0.66 mmol) in THF (8 mL) at −78 °C. The brown solution was stirred for 35 min before TBDPSCl (0.2 mL, 0.77 mmol) was added drop wise. After stirring for 5 min at −78 °C, the flask was removed from the cooling bath and allowed to warm to room temperature. The mixture was stirred at room temperature for 1 h, and concentrated in vacuo. The brown oil was dissolved in pentane (30 mL) and filtered through Celite. The yellow filtrate was concentrated and purified by flash column chromatography (petroleum ether/EtOAc 2:1) to afford 292 mg (92%) of product **7** as a fluffy white foamy oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.78 (app. d, *J*=6.8 Hz, 3H), 7.72 (app. d, *J*=6.3 Hz, 2H), 7.41 (app. s, 6H), 7.30 (t, *J*=7.7 Hz, 1H), 7.10 (dd, *J*=1.0, 7.6 Hz, 1H), 4.79 (t, *J*=4.7 Hz, 1H), 3.78–3.71 (m, 1H), 3.43–3.37 (m, 1H), 3.16 (q, *J*=7.1 Hz, 2H), 2.73–2.65 (m, 1H), 2.51–2.43 (m, 1H), 2.10–1.99 (m, 2H), 1.25 (t, *J*=7.1 Hz, 3H), 1.10 (app. s, 9H), 1.04 (t, *J*=7.1 Hz, 3H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 170.6 (*C*O), 147.4 (*C*), 135.4 (*C*H×4), 133.9 (*C*), 133.0 (*C*), 132.9 (*C*), 132.3 (*C*), 129.8 (*C*H×2), 127.7 (*C*H×4), 126.3 (*C*H), 124.6 (*C*H), 122.0 (*C*H), 106.3 (*C*H=), 42.7 (NCH_2), 38.7 (NCH_2), 26.6 (CH_3×3), 24.6 (CH_2), 21.6 (CH_2), 19.5 (*C*), 14.1 (NCH_2CH_3), 12.9 (NCH_2CH_3); IR (KBr) 3072 (w), 2891 (w), 2932 (m), 2858 (w), 1635 (s), 1473 (w), 1428 (m), 1362 (w), 1344 (w), 1286 (w), 1255 (m), 1220 (w), 1196 (w), 1149 (m), 1113 (m), 955 (w), 921 (w), 823 (w), 736 (w), 701 (m); mass spectrum *m*/*z* (relative intensity %) 506.3 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{31}H_{37}O_2N_1Si_1$+Na: 506.2491, found 506.2492.

4.6. *trans*-(5*R*,6*R*)-5-((*tert*-Butyldiphenylsilyl)oxy)-*N*,*N*-diethyl-6-hydroxy-5,6,7,8-tetrahydronaphthalene-1-carboxamide (9)[25]

Oxone® (519 mg, 0.844 mmol, 1.38 equiv) in aqueous EDTA solution (4.9 mL), and K_2CO_3 (674 mg, 4.88 mmol, 8 equiv) in water (4.9 mL) were added simultaneously (syringe pump, 0.053 mL/min) over a period of 90 min to a precooled mixture of silyl enol ether **7** (295 mg, 0.61 mmol), Shi catalyst (51 mg, 0.197 mmol, 0.3 equiv), tetrabutylammonium bisulfate (5 mg, 0.015 mmol, 0.04 equiv), acetonitrile (3.7 mL), DME (7.4 mL), and aqueous sodium borate–EDTA solution (7.4 mL) at 0 °C. After stirring for an additional 30 min at 0 °C, the reaction mixture was diluted with ice-cold pentane (70 mL), and ice-cold water (40 mL). The aqueous layer was extracted with ice-cold pentane (2×70 mL). The organic layer was washed with brine (1×150 mL), dried over $MgSO_4$, filtered, and concentrated in vacuo to give a transparent oil.

To a precooled solution of crude product in THF (12 mL) was added borane–tetrahydrofuran complex solution (0.91 mL, 0.91 mmol, 1 M in THF) at 0 °C. The reaction mixture was stirred at 0 °C for 90 min, before septum was removed and the mixture diluted with Et_2O (10 mL). An aqueous 1 M solution of tris(hydroxymethyl)aminomethane hydrochloride (10 mL) was added slowly, and the solution was warmed to room temperature and stirred for 30 min. Water (10 mL) was added, and the aqueous layer extracted with Et_2O (3×30 mL). The organic layer was washed with brine (1×75 mL), dried over $MgSO_4$, filtered, and concentrated in vacuo. The crude product was purified by flash column chromatography (petroleum ether/EtOAc 1:1) to afford 215 mg (70%) of product **9** as a fluffy white foamy oil. 83% ee measured by a Lux 3u Cellulose-2 HPLC column (10% *i*-PrOH in hexane, 218 nm, 1.0 mL/min) t_R 8.9 (minor), t_R 18.9 (major); $[\alpha]_D^{20}$ −113.8 (*c* 0.21, acetone); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.75–7.62 (m, 4H), 7.47–7.37 (m, 6H), 7.21–7.04 (m, 3H), 4.61 (app. d, *J*=8.5 Hz, 1H), 4.02 (app. s, 1H), 3.77 (app. s, 1H), 3.36–2.89 (m, 4H), 2.58–2.53 (m, 1H), 2.23–2.18 (m, 1H), 1.93 (app. s, 1H), 1.83–1.74 (m, 1H), 1.26–1.22 (br m, 4H), 1.07 (s, 9H), 0.99–0.95 (br m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 170.5 (*C*O), 137.5 (*C*), 136.3 (*C*H), 136.2 (*C*H), 135.9 (*C*H), 135.7 (*C*H), 134.2 (*C*), 133.0 (*C*), 132.4 (*C*), 132.2 (*C*), 129.9 (*C*H), 129.8 (*C*H), 127.9 (*C*H×2), 127.6 (*C*H×2), 125.9 (*C*H), 125.8 (*C*H),124.5 (*C*H), 75.1 (*C*H–OSi), 71.2 (*C*H–OSi), 42.5 (NCH_2), 38.6 (NCH_2), 27.1 (CH_3×3), 26.2 (CH_2), 22.6 (CH_2), 19.5 (*C*), 13.9 (NCH_2CH_3), 12.8 (NCH_2CH_3); IR (KBr) 3393 (br, w), 3070 (w), 2932 (m), 2857 (m), 1614 (s), 1460 (w), 1427 (s), 1292 (w), 1217 (w), 1110 (s), 1069 (br s), 853(w), 821 (w), 788 (w), 741 (w), 703 (m), 609 (w); mass spectrum *m*/*z* (relative intensity %) 524.3 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{31}H_{39}O_3NSi$+Na: 524.2591, found 524.2591.

4.7. (5*R*,6*R*)-5,6-Bis((*tert*-butyldiphenylsilyl)oxy)-*N*,*N*-diethyl-5,6,7,8-tetrahydronaphthalene-1-carboxamide (10)

To a suspension of sodium hydride (56 mg, 1.40 mmol) in THF (4 mL) was added *trans*-diol monosilyl ether **9** (365 mg, 0.728 mmol) in THF (9 mL) at 0 °C. The reaction mixture was warmed to room temperature, and stirred for 30 min before TBDPSCl (0.23 mL, 0.886 mmol) was added drop wise. After stirring overnight (19 h), the reaction mixture was quenched with saturated NH_4Cl (15 mL) and extracted with Et_2O (3×30 mL). The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The crude product was purified by flash column chromatography (petroleum ether/EtOAc 2:1) to afford 508 mg (94%) of product **10** as fluffy white foamy oil as a ca. 2:3 mixture of rotamers. $[\alpha]_D^{20}$ −45.1 (*c* 0.26, acetone); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.59–7.19 (m, 20H), 7.04 (t, *J*=7.4 Hz, 1H), 6.92 (t, *J*=7.5 Hz, 1H—major rotamer), 6.84 (t, *J*=7.3 Hz, 1H—minor rotamer), 6.51 (d, *J*=7.5 Hz, 1H—major rotamer), 6.32 (d, *J*=7.3 Hz, 1H—minor rotamer), 4.45 (app. d, *J*=2.3 Hz, 1H), 4.28 (app. s, 1H), 3.91–3.72 (m, 2H), 3.49–2.71 (m, 3H), 2.57–231 (m, 1H), 1.87–1.82 (m, 2H), 1.29–1.24 (m, 3H), 1.11–1.02 (m, 3H—minor rotamer), 0.94 (t, *J*=6.9 Hz, 3H—major rotamer), 0.84 (s, 9H), 0.82 (s, 9H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 170.9 (*C*O), 136.6 (*C*), 136.3 (*C*), 135.9 (*C*H×2), 135.8 (*C*H×2), 135.7 (*C*H×2), 135.5 (*C*H×2), 133.8 (*C*), 133.7 (*C*), 133.5 (*C*), 132.9 (*C*), 131.7 (*C*—major rotamer), 131.5 (*C*—minor rotamer), 129.6 (*C*H), 129.5(3) (*C*H), 129.5(0) (*C*H), 129.3 (*C*H), 127.5 (*C*H×4), 127.4 (*C*H×4), 127.3 (*C*H—major rotamer), 127.1 (*C*H—minor rotamer), 125.3 (*C*H), 124.5 (*C*H), 71.7 (*C*H—OSi—minor rotamer), 71.4 (*C*H—OSi—major rotamer), 70.3 (*C*H—OSi—major rotamer), 67.9 (*C*H—OSi—minor rotamer), 42.7 (N*C*H$_2$—minor rotamer), 42.4 (N*C*H$_2$—major rotamer), 38.7 (N*C*H$_2$—minor rotamer), 38.5 (N*C*H$_2$—major rotamer), 26.7 (*C*H$_3$x6), 24.1 (*C*H$_2$—minor rotamer), 23.5 (*C*H$_2$—major rotamer), 21.1 (*C*H$_2$—minor rotamer), 20.4 (*C*H$_2$—major rotamer), 19.1 (*C*), 14.0 (NCH$_2$*C*H$_3$), 12.8 (NCH$_2$*C*H$_3$); IR (KBr) 3071 (w), 2931 (m), 2857 (m), 1637 (s), 1590 (w), 1473 (w), 1460 (w), 1427 (m), 1290 (w), 1221 (w), 1111 (s), 1080 (br m), 1008 (w), 822 (w), 740 (w), 701 (s), 609 (w); mass spectrum *m*/*z* (relative intensity %) 762.4 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{47}H_{57}O_3N_1Si_2$+Na: 762.3775, found 762.3777.

4.8. (5*R*,6*R*)-5,6-Bis((*tert*-butyldiphenylsilyl)oxy)-5,6,7,8-tetrahydronaphthalene-1-carbaldehyde (11)

Amide **10** (282 mg, 0.38 mmol) in THF (4 mL) was added to a suspension of $Cp_2Zr(H)Cl$ (148 mg, 0.57 mmol) in THF (2 mL) at room temperature. After 30 min of stirring the yellow solution was concentrated in vacuo and the orange residue was purified by flash column chromatography (petroleum ether/EtOAc 4:1) to afford 221 mg (87%) of product **11** as a fluffy white foamy oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.33 (s, 1H), 7.69 (d, *J*=6.4 Hz, 1H), 7.53–7.17 (m, 20H), 7.02 (t, *J*=7.6 Hz, 1H), 6.61 (d, *J*=6.7 Hz, 1H), 4.49 (app. d, *J*=2.8 Hz, 1H), 4.32 (s, 1H), 3.48–3.23 (m, 2H), 2.41–2.31 (m, 1H), 1.95–1.90 (m, 1H), 0.84 (s, 9H), 0.81 (s, 9H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 193.1 (*C*O), 140.0 (*C*), 137.4 (*C*H), 137.2 (*C*), 135.8 (*C*H×4), 135.6 (*C*H×2), 135.5 (*C*H×2), 133.9 (*C*), 133.6 (*C*), 133.4 (*C*×2), 133.3 (*C*), 132.2 (*C*H), 129.7 (*C*H), 129.6 (*C*H), 129.5 (*C*H), 129.4 (*C*H), 127.7 (*C*H×2), 127.6 (*C*H×2), 127.5 (*C*H×2), 127.3 (*C*H×2), 125.5 (*C*H), 71.5 (*C*H—OSi), 69.7 (*C*H—OSi), 26.7 (*C*H$_3$×6), 23.4 (*C*H$_2$), 21.2 (*C*H$_2$), 19.2 (C×2); IR (KBr) 3071 (w), 2931 (m), 2857 (m), 1698 (m), 1590 (w), 1472 (w), 1427 (m), 1184 (w), 1113 (s), 1079 (br s), 1008 (w), 822 (w), 740 (w), 701 (s), 610 (w); mass spectrum *m*/*z* (relative intensity %) 691.3 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{43}H_{48}O_3Si_2$+Na: 691.3040, found 691.3039.

4.9. (((1*R*,2*R*)-5-Styryl-1,2,3,4-tetrahydronaphthalene-1,2-diyl)bis(oxy))bis(*tert*-butyldiphenylsilane) (12)

To a solution of aldehyde **11** (179 mg, 0.27 mmol) in CH_2Cl_2 (8 mL) was added benzyltriphenylphosphonium chloride (146 mg, 0.38 mmol) and a 50%-solution of NaOH (0.8 mL). The yellow reaction mixture was stirred at room temperature for 2.5 h. Water (20 mL) was added and the water layer was extracted with CH_2Cl_2 (3×20 mL). The organic layer was washed with brine (40 mL), dried over $MgSO_4$, filtered, and concentrated in vacuo. The crude product was purified by flash column chromatography (2% EtOAc in petroleum ether) to afford 195 mg (98%) of product **12** as a fluffy white foamy oil as ca. 2:1 mixture of *Z* and *E* isomers. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.56–7.18 (m, 25H), 7.02–6.88 (m, 2H), 6.76–6.59 (m, 2H), 6.45 (d, *J*=7.6 Hz, 1H—minor isomer), 6.36 (d, *J*=7.6 Hz, 1H—major isomer), 4.50 (app. s, 1H), 4.30 (app. s, 1H), 3.08–2.76 (m, 2H), 2.41–2.31 (m, 1H), 1.89–1.84 (m, 1H), 0.85 (s, 9H), 0.84 (s, 9H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 137.0 (*C*), 136.6 (*C*), 136.0 (*C*H), 135.9 (*C*H×2), 135.8 (*C*H×2), 135.6 (*C*H×2), 135.2 (*C*), 134.1 (*C*), 134.0 (*C*), 133.9 (*C*), 133.8(4) (*C*), 133.8(0) (*C*), 131.3 (*C*), 130.7 (*C*H), 130.2 (*C*H), 129.9 (*C*H), 129.8 (*C*), 129.5 (*C*H×2), 129.4 (*C*H), 129.3 (*C*H), 129.0 (*C*H×2), 128.7 (*C*H), 128.1 (*C*H), 128.0 (*C*H×2), 127.5(4) (*C*H×2), 127.5(1) (*C*H), 127.4 (*C*H×2), 127.2 (*C*H×2), 126.9 (*C*H), 126.6 (*C*), 126.5 (*C*H), 125.3 (*C*), 125.1 (*C*H), 124.7 (*C*), 72.0 (*C*H—OSi—minor isomer), 71.9 (*C*H—OSi—major isomer), 70.4 (*C*H—OSi—major isomer), 70.2 (*C*H—OSi—minor isomer), 26.8 (*C*H$_3$×3), 26.7 (*C*H$_3$×3), 24.0 (*C*H$_2$), 22.0 (*C*H$_2$), 19.2 (3) (*C*×2—major isomer), 19.2 (0) (*C*×2—minor isomer); IR (KBr) 3070 (m), 2930 (s), 2857 (m), 1660 (w), 1589 (w), 1472 (m), 1427 (s), 1390 (w), 1362 (w), 1189 (w), 1112 (s), 1075 (br, s), 1007 (m), 910 (w), 858 (w), 822 (m), 790 (w), 738 (m), 701 (s), 610 (m); mass spectrum *m*/*z* (relative intensity %) 765.4 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{50}H_{54}O_2Si_2$+Na: 765.3560, found 765.3562.

4.10. (((1*R*,2*R*)-1,2,3,4-Tetrahydrochrysene-1,2-diyl)bis(oxy))bis(*tert*-butyldiphenylsilane) (13)

To a solution of stilbene **12** (173 mg, 0.23 mmol) in degassed toluene (350 mL) were added iodine (68 mg, 0.27 mmol) and 1,2-epoxybutane (7 mL). The pink mixture was irradiated for 1.5 h before concentrated to a volume of 50 mL. The residue was washed with 10% aqueous sodium thiosulfate solution (20 mL) and brine (20 mL), dried over $MgSO_4$, filtered, and concentrated in vacuo. The crude product was purified by flash column chromatography (5% EtOAc in petroleum ether) to afford 166 mg (96%) of product **13** as a fluffy white foamy oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 8.63 (d, *J*=7.9 Hz, 1H), 8.29 (d, *J*=8.5 Hz, 1H), 8.08 (d, *J*=9.2 Hz, 1H), 7.90 (d, *J*=7.4 Hz, 1H), 7.80 (d, *J*=9.2 Hz, 1H), 7.63–7.49 (m, 4H), 7.42–7.12 (m, 18H), 6.82 (d, *J*=8.5 Hz, 1H), 4.69 (app. d, *J*=1.9 Hz, 1H), 4.39 (app. s, 1H), 3.35–3.32 (m, 2H), 2.51–2.47 (m, 1H), 2.06–2.01 (m, 1H), 0.86 (s, 9H), 0.79 (s, 9H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 135.9 (*C*H×2), 136.0 (*C*H×2), 135.6(2) (*C*H×2), 135.6(0) (*C*H×2), 134.1 (*C*), 134.0 (*C*), 133.8(2) (*C*), 133.8(0) (*C*), 133.7 (*C*), 133.2 (*C*), 131.6 (*C*), 130.7 (*C*), 130.1 (*C*H), 129.6 (*C*H), 129.5 (*C*H), 129.4 (*C*H×2), 129.3 (*C*H), 128.4 (*C*H), 127.6 (*C*H×2), 127.5 (*C*H×2), 127.4 (*C*H×2), 127.2 (*C*H×2), 126.4 (*C*H), 126.2 (*C*H), 123.0 (*C*H), 122.5 (*C*H), 120.1 (*C*H), 72.1 (*C*H—OSi), 70.4 (*C*H—OSi), 26.8 (*C*H$_3$×3), 26.7 (*C*H$_3$×3), 24.1 (*C*H$_2$), 21.4 (*C*H$_2$), 19.3 (*C*), 19.2 (*C*); IR (KBr) 3070 (m), 2930 (s), 2857 (m), 1589 (w), 1471 (m), 1427 (m), 1390 (w), 1361 (m), 1189 (w), 1112 (s), 1085 (br, s), 1068 (br, s), 1007 (m), 908 (m), 841 (m), 822 (m), 790 (w), 771 (w), 739 (m), 701 (s), 610 (m); mass spectrum *m*/*z* (relative intensity %) 763.3 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{50}H_{52}O_2Si_2$+Na: 763.3404, found 763.3406.

4.11. (((1*R*,2*R*)-1,2-Dihydrochrysene-1,2-diyl)bis(oxy))bis(*tert*-butyldiphenylsilane) (14)

To a solution of compound **13** (399 mg, 0.54 mmol) in CCl_4 (10 mL) were added *N*-bromosuccinimide (NBS, 144 mg, 0.81 mmol) and azobisisobutyronitrile (AIBN, 12 mg, 0.06 mmol). The solution was quickly warmed to reflux, stirred for 2 h before it was allowed to cool down. Succinimide was filtered off, and the filtrate was diluted in CH_2Cl_2 (100 mL), washed with brine (70 mL), dried over $MgSO_4$, filtered, and concentrated to a yellow oil. The crude product was purified by flash column chromatography (2% EtOAc in petroleum ether) to afford an intractable mixture of products.

To a solution of this product mixture and benzyl bromide (306 mg) in THF (5 mL) was added DBU (3.6 mL, 0.54 mmol) at room temperature. The solution was stirred for 1 h and quenched with saturated NH_4Cl (10 mL). The aqueous layer was extracted with Et_2O (3×15 mL), washed with brine (30 mL), dried over $MgSO_4$, filtered, and concentrated. The crude product was purified by flash column chromatography (5% EtOAc in petroleum ether) to afford an intractable mixture of products.

4.12. (5*R*,6*R*)-5,6-Bis((*tert*-butyldiphenylsilyl)oxy)-*N*,*N*-diethyl-5,6-dihydronaphthalene-1-carboxamide (2)

NBS (53 mg, 0.299 mmol) and AIBN (3 mg, 0.012 mmol) were added to a solution of amide **10** (188 mg, 0.254 mmol) in CCl_4 (7 mL). The reaction mixture was heated to 65 °C, stirred for 4 h, and cooled down before *N*-succinimine was filtered of. The filtrate was diluted in CH_2Cl_2 (50 mL), washed with brine (1×30 mL), dried over $MgSO_4$, filtered, and concentrated. The crude product was purified by flash column chromatography (petroleum ether/EtOAc 4:1) to afford 136 mg (67%) of the benzyl bromide **17** as a yellow oil.

DBU (0.035 mL, 0.231 mmol) was added to a solution of the benzyl bromide **17** (136 mg, 0.166 mmol) in THF (4 mL) at room temperature. The reaction mixture was heated to reflux, and stirred for 67 h, cooled down, quenched with saturated NH_4Cl (15 mL), and extracted with Et_2O (3×30 mL). The organic layer was dried over $MgSO_4$, filtered, and concentrated. The crude product was purified by flash column chromatography (petroleum ether/EtOAc 3:1) to afford 92 mg (73%) of product **2** as a fluffy white foamy oil as a ca. 3:2 mixture of rotamers. $[\alpha]_D^{20}$ −169.8 (*c* 0.43, acetone); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.52–7.22 (m, 20H), 7.12 (d, *J*=7.5 Hz, 1H), 6.96 (t, *J*=7.3 Hz, 1H), 6.59 (d, *J*=9.4 Hz, 1H, H-7—major rotamer), 6.52 (d, *J*=7.7 Hz, 1H, H-4), 6.46 (d, *J*=7.5 Hz, 1H, H-7—minor rotamer), 5.94–5.82 (m, 1H, H-3), 4.61 (app. s, 1H, H-1), 4.31 (dd, *J*=1.8, 4.8 Hz, 1H, H-2), 3.82–3.72 (m, 1H), 3.53–3.39 (m, 1H), 3.21 (app. d, *J*=6.2 Hz, 2H—minor rotamer), 3.05 (app. d, *J*=7.0 Hz, 2H—major rotamer), 1.30 (t, *J*=7.0 Hz, 3H), 1.05–1.01 (br m, 3H—minor rotamer), 0.97–0.92 (br m, 3H—major rotamer), 0.86 (s, 9H—minor rotamer), 0.83 (s, 9H—major rotamer), 0.80 (s, 9H—major rotamer), 0.77 (s, 9H—minor rotamer); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 170.1 (*C*O), 135.7 (*C*Hx6), 135.6 (*C*H×2), 135.4 (*C*), 135.1 (*C*), 134.3 (*C*), 133.9 (*C*), 133.7 (*C*), 133.3 (*C*), 130.2 (*C*H, C-4—major rotamer), 130.0 (*C*H, C-4—minor rotamer), 129.6 (*C*H×2), 129.4 (*C*), 129.3 (*C*), 128.9 (*C*H, C-3—major rotamer), 128.7 (*C*H, C-3—minor rotamer), 128.6 (*C*), 127.6 (*C*Hx6), 127.5 (*C*H×2), 127.3 (*C*H×2), 127.0 (*C*H), 125.8 (*C*H), 125.7, 125.5 (*C*H, C-7—major rotamer), 125.0 (*C*H, C-7—minor rotamer), 73.0 (*C*H–OSi—minor rotamer), 72.6 (*C*H–OSi—major rotamer), 68.7 (*C*H–OSi—minor rotamer), 68.3 (*C*H–OSi—major rotamer), 42.9 (N*C*H$_2$), 39.0 (N*C*H$_2$), 26.6 (*C*H$_3$x6), 19.2 (*C*), 19.0 (*C*), 14.0 (NCH$_2$*C*H$_3$), 13.1 (NCH$_2$*C*H$_3$); IR (KBr) 3071 (w), 3048 (w), 2961 (m), 2931 (m), 2857 (m), 1634 (s), 1589 (w), 1473 (m), 1462 (m), 1428 (s), 1381 (w), 1362 (m), 1290 (w), 1216 (w), 1112 (s), 1073 (br s), 1007 (w), 910 (w), 887 (w), 822 (m), 771 (w), 738 (m), 701 (s), 610 (m), 504 (m); mass spectrum *m*/*z* (relative intensity %) 760.4 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{47}H_{55}O_3N_1Si_2$+Na: 760.3618, found 760.3617.

4.13. (5*R*,6*R*)-5,6-Bis((*tert*-butyldiphenylsilyl)oxy)-5,6-dihydronaphthalene-1-carbaldehyde (16)

Amide **2** (1.976 g, 2.68 mmol) in THF (50 mL) was added to a suspension of Schwartz' reagent ($Cp_2Zr(H)Cl$, 834 mg, 3.23 mmol) in THF (21 mL) at room temperature. After 20 min of stirring, silica was added to the yellow solution and stirred for 3 min before it was concentrated in vacuo and purified by flash column chromatography (petroleum ether/EtOAc 10:1) to afford 1.356 g (76%) of product **16** as a fluffy white foamy oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.23 (s, 1H), 7.59 (dd, *J*=1.4, 7.8 Hz, 1H), 7.52 (d, *J*=9.9 Hz, 1H), 7.47–7.18 (m, 19H), 7.13 (d, *J*=7.1 Hz, 1H), 6.97 (t, *J*=7.6 Hz, 1H), 6.61 (d, *J*=7.4 Hz, 1H), 5.94 (ddd, *J*=1.2, 5.5, 9.9 Hz, 1H), 4.60 (app. q, *J*=1.2 Hz, 1H), 4.27 (dd, *J*=2.4,5.5 Hz, 1H), 0.76 (s, 9H), 0.73 (s, 9H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 192.3 (*C*HO), 136.0 (*C*), 135.8 (*C*H×2), 135.6 (*C*H×6), 135.4 (*C*H), 133.9 (*C*), 133.7 (*C*), 133.6 (*C*), 133.5 (*C*), 133.4 (*C*), 131.7 (*C*H), 131.1 (*C*H), 130.7 (*C*), 129.7 (*C*H×2), 129.6 (*C*H), 129.4 (*C*H), 127.7 (*C*H×2), 127.6 (*C*H×2), 127.5 (*C*H×2), 127.3 (*C*H×2), 127.0 (*C*H), 123.7 (*C*H), 72.8 (*C*H–OSi), 67.9 (*C*H–OSi), 26.7 (*C*H$_3$×3), 26.6 (*C*H$_3$×3), 19.2 (*C*), 19.1 (*C*); IR (KBr) 3070 (w), 2930 (m), 2856 (m), 1697 (m), 1590 (w), 1569 (w), 1471 (w), 1427 (m), 1390 (w), 1361 (w), 1195 (w), 1112 (s), 1074 (br s), 886 (w), 821 (w), 780 (w), 739 (m), 701 (s), 611 (w); mass spectrum *m*/*z* (relative intensity %) 689.3 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{43}H_{46}O_3Si_2$+Na: 689.2883, found 689.2885.

4.14. (((1*R*,2*R*)-5-Styryl-1,2-dihydronaphthalene-1,2-diyl)bis(oxy))bis(*tert*-butyldiphenylsilane) (20)

To a solution of aldehyde **16** (1.326 g, 1.99 mmol) in CH_2Cl_2 (50 mL) were added benzyltriphenylphosphonium chloride (1.084 g, 2.80 mmol) and a 50% aqueous NaOH-solution (5 mL). The orange reaction mixture was stirred at room temperature for 20 min (until the mixture turned yellow). Water (90 mL) was added and the water layer was extracted with CH_2Cl_2 (3×150 mL). The organic layer was washed with brine (25 mL), dried over $MgSO_4$, filtered, and concentrated. The crude product was purified by flash column chromatography (2% EtOAc in petroleum ether) to afford 1.462 g (99%) of product **20** as a transparent oil as a ca. 2:3 mixture of *Z* and *E* isomers. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.48–7.40 (m, 8H), 7.37–7.12 (m, 15H), 7.09–7.01 (m, 3H), 6.95–6.84 (m, 2H), 6.76–6.57 (m, 2H), 6.45 (d, *J*=7.3 Hz, 1H—minor isomer), 6.37 (d, *J*=7.3 Hz, 1H—major isomer), 5.76–5.65 (m, 1H), 4.59–4.58 (m, 1H—minor isomer), 4.56–4.55 (m, 1H—major isomer), 4.24–4.21 (m, 1H), 0.78 (s, 9H—major isomer), 0.77 (s, 9H—minor isomer), 0.75 (s, 9H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 137.6 (*C*), 136.7 (*C*), 135.9 (*C*H×2—major), 135.8 (*C*H×2—minor), 135.7 (3) (*C*H×2—major), 135.7 (1) (*C*H×2—minor isomer), 135.7 (0) (*C*H×2), 135.3 (*C*—minor), 135.2 (*C*—major), 134.7 (*C*), 134.2(0) (*C*—minor), 134.2(0) (*C*—major), 133.9 (*C*H—major), 133.8(5) (*C*H—minor), 133.8(0) (*C*—major), 133.7 (*C*—minor) 131.4 (*C*H), 131.0 (*C*H), 130.3 (*C*), 130.0 (*C*), 129.7 (*C*H—minor), 129.6 (*C*H), 129.5 (*C*H—major), 129.4 (*C*H—major), 129.3 (*C*H—minor), 129.2(4) (*C*H—minor), 129.2(0) (*C*H—major), 129.1(1) (*C*H×2), 129.1(0) (*C*H), 128.7 (*C*H—major), 128.6 (*C*H—minor), 128.1 (*C*H), 127.6 (*C*H×4), 127.4 (*C*H—major), 127.3(5) (*C*H×2), 127.3(0) (*C*H×2—major), 127.2 (*C*H×2—minor), 127.1 (*C*H—minor), 127.0(4) (*C*H), 127.0(0) (*C*H), 126.5 (*C*H), 126.3 (*C*H—major), 126.2 (*C*H—minor), 125.7 (*C*H—major), 125.4 (*C*H—minor), 73.5 (*C*H–OSi—minor), 73.3 (*C*H–OSi—major), 68.7 (*C*H–OSi—minor), 68.5 (*C*H–OSi—major), 26.7(2) (*C*H$_3$×6—minor), 26.7(0) (*C*H$_3$×6,—minor), 19.2 (*C*×2—minor), 19.1 (*C*×2—major); IR (KBr) 3069 (w), 2930 (m), 2856 (m), 1472 (w), 1427 (m), 1361 (w), 1112 (s), 1075 (br, s), 888

(w), 822 (w), 769 (m), 739 (m), 701 (s), 611 (w); mass spectrum *m*/*z* (relative intensity %) 763.3 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{50}H_{52}O_2Si_2$+Na: 763.3404, found 763.3407.

4.15. (((1*R*,2*R*)-1,2-Dihydrochrysene-1,2-diyl)bis(oxy))bis(*tert*-butyldiphenylsilane) (14)

Air was bubbled through a solution of stilbene **20** (84 mg, 0.113 mmol) in Et_2O (245 mL) and CH_2Cl_2 (7 mL) for 5 min. A catalytic amount of iodine (2 mg) was added to the solution and the reaction mixture was irradiated for 3 h before washing with 10% aqueous sodium thiosulfate solution (1×100 mL) and brine (1×250 mL), dried over $MgSO_4$, filtered, and concentrated. The crude product was purified by flash column chromatography (2% EtOAc in petroleum ether) to afford 23 mg (28%) of product **14** as a fluffy white foamy oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 8.62 (d, *J*=7.8 Hz, 1H), 8.35 (d, *J*=8.4 Hz, 1H), 8.11 (d, *J*=9.3 Hz, 1H), 7.9 (dd, *J*=1.8, 7.8 Hz, 1H), 7.78 (d, *J*=9.3 Hz, 1H), 7.69–7.08 (m, 23H), 6.95 (d, *J*=8.4 Hz, 1H), 5.96 (dd, *J*=5.4, 9.8 Hz, 1H), 4.87 (app. s, 1H), 4.42 (dd, *J*=2.2, 5.4 Hz, 1H), 0.82 (s, 9H), 0.81 (s, 9H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 135.9 (*C*H×2), 135.7(4) (*C*H×2), 135.7(1) (*C*H×2), 135.7(0) (*C*H×2), 135.3 (*C*), 134.2 (*C*), 134.0 (*C*), 133.9 (*C*), 133.6 (*C*), 133.3 (*C*), 131.5 (*C*), 130.6 (*C*), 130.5 (*C*), 129.6(1) (*C*H), 129.6(0) (*C*H), 129.4 (*C*H), 129.3 (*C*H), 128.7 (*C*H), 128.5 (*C*), 128.4 (*C*H), 128.0 (*C*H), 127.6 (*C*H×4), 127.3 (*C*H×2), 127.2 (CH×2), 126.8 (CH), 126.6 (CH), 126.5 (CH), 124.6 (CH), 122.9 (CH), 121.7(3) (CH), 121.7(0) (CH), 73.7 (CH–OSi), 68.7 (CH–OSi), 26.7(2) (CH_3×3), 26.7(0) (CH_3×3), 19.3 (C), 19.1 (C); IR (KBr) 3071 (w), 3049 (w), 2930 (m), 2857 (m), 1718 (w), 1589 (w), 1472 (m), 1428 (m), 1389 (w), 1361 (w), 1190 (w), 1112 (s), 1074 (s), 999 (w), 908 (m), 891 (w), 822 (m), 751 (m), 736 (m), 701 (s), 611 (m), 506 (m); mass spectrum *m*/*z* (relative intensity %) 761.3 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{50}H_{50}O_2Si_2$+Na: 761.3247, found 761.3249.

4.16. (−)-(1*R*,2*R*)-1,2-Dihydrochrysene-1,2-diol (1)

To a solution of protected 1,2-dihydrochrysene-1,2-diol **14** (23 mg, 0.031 mmol) in THF (2.5 mL) was added TBAF (0.08 mL, 0.08 mmol, 1 M in THF) at 0 °C. The reaction mixture was warmed to room temperature and stirred for 3 h before water (8 mL) was added. The mixture was extracted with Et_2O (3×10 mL). The organic layer was dried over $MgSO_4$, filtered, and concentrated. The crude product was purified by flash column chromatography (petroleum ether/EtOAc 1:2) to afford 6 mg (76%) of product **1** as a white solid. 87% ee measured by a Lux 3u Cellulose-2 HPLC column (10% *i*-PrOH in hexane, 254 nm, 0,5 mL/min) t_R 27.2 (minor), t_R 33.1 (major); $[\alpha]_D^{20}$ −85.4 (*c* 0.58, acetone/DMSO 4:1) (lit.[2a] $[\alpha]_D^{23}$ −105 (*c* 0.37, THF)); ^{1}H NMR (acetone-d_6/DMSO-d_6 4:1, 300 MHz): δ 8.83 (d, *J*=8.2 Hz, 1H), 8.78 (d, *J*=8.6 Hz, 1H), 8.20 (d, *J*=9.2 Hz, 1H), 8.00 (d, *J*=8.6 Hz, 1H), 7.97 (dd, *J*=1.6, 7.7 Hz, 1H), 7.86 (d, *J*=9.2 Hz, 1H), 7.72–7.60 (m, 2H), 7.32 (dd, *J*=2.5, 10.2 Hz, 1H), 6.20 (dd, *J*=2.2, 10.2 Hz, 1H), 5.47 (br s, 1H, O*H*), 5.07 (br s, 1H, O*H*), 4.84 (d, *J*=11.5 Hz, 1H), 4.45 (d, *J*=11.5 Hz, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 137.9 (*C*), 135.1 (*C*H), 132.1 (*C*), 131.0 (*C*), 130.2 (*C*), 129.1(4) (*C*), 129.1(0) (*C*H), 128.0 (*C*), 127.8 (*C*H), 127.6 (*C*H), 127.3 (*C*H), 124.7 (*C*H), 123.6 (*C*H), 122.5 (*C*H), 122.4 (*C*H), 75.6 (*C*HOH), 73.3 (*C*HOH). The spectroscopic data for (−)-(1*R*,2*R*)-1,2-dihydrochrysene-1,2-diol (**1**) were in full accordance with the data reported in the literature.

4.17. (5*R*,6*R*)-5,6-Bis((*tert*-butyldiphenylsilyl)oxy)-*N*,*N*-diethyl-2-iodo-5,6-dihydronaphthalene-1-carboxamide (21)

To a solution of amide **2** (182 mg, 0.247 mmol) and TMEDA (0.04 mL, 0.267 mmol) in THF (4 mL) was added *s*-BuLi (0.29 mL, 0.261 mmol) drop wise at −78 °C. The yellow solution was stirred for 45 min before I_2 in THF (0.437 M, 0.85 mL, 0.372 mmol) was introduced. The orange solution was warmed to room temperature overnight (20 h), quenched with sodium thiosulfate (10 mL), and extracted with Et_2O (3×20 mL). The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The crude product was purified by flash column chromatography (petroleum ether/EtOAc 5:1) to afford 167 mg (78%) of product **21** as a fluffy white foamy oil as a ca. 3:2 mixture of rotamers. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.55–7.20 (m, 21H), 6.56 (d, *J*=9.7 Hz, 1H—major rotamer), 6.47 (d, *J*=9.8 Hz, 1H—minor rotamer), 6.12 (app. t, *J*=7.8 Hz, 1H), 5.97 (dd, *J*=9.7, 5.4 Hz, 1H—major rotamer), 5.84 (dd, *J*=9.8, 5.3 Hz, 1H—minor rotamer), 4.58 (app. s, 1H—minor rotamer), 4.54 (app. s, 1H—major rotamer), 4.32 (dd, *J*=5.4, 2.5 Hz, 1H—major rotamer), 4.29 (dd, 5.3, 2.4 Hz, 1H—minor rotamer), 3.93–3.73 (m, 2H—minor rotamer), 3.52–3.36 (m, 2H—major rotamer), 3.19 (q, *J*=7.2 Hz, 2H—minor rotamer), 3.08–3.00 (m, 2H—major rotamer), 1.34 (t, *J*=7.2 Hz, 3H—minor rotamer), 1.33 (t, *J*=7.1 Hz, 3H—major rotamer), 1.06 (t, *J*=7.2 Hz, 3H—minor rotamer), 1.02 (t, *J*=7.1 Hz, 3H—major rotamer), 0.86 (s, 9H—minor rotamer), 0.83 (s, 9H—major rotamer), 0.79 (s, 9H—major rotamer), 0.77 (s, 9H—minor rotamer); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 168.9 (*C*O), 139.3 (*C*), 139.2 (*C*), 137.4 (*C*H), 137.2 (*C*H), 135.8 (*C*H), 135.7(4) (*C*H), 135.7(1) (*C*H), 135.7(0) (*C*H), 135.6 (*C*H), 135.6(0) (*C*H), 135.5 (*C*H), 135.4 (*C*), 135.0 (*C*), 133.7 (*C*), 133.6 (*C*), 133.5(3) (*C*), 133.5(0) (*C*), 133.4(2) (*C*), 133.4(0) (*C*), 133.4(0) (*C*), 133.0 (*C*), 131.2 (*C*H), 131.0 (*C*H), 130.7 (*C*), 130.4 (*C*), 129.7 (*C*H), 129.6(3) (*C*H), 129.6(0) (*C*H), 129.3 (*C*H), 127.6(2) (*C*H), 127.6(0) (*C*H), 127.5 (*C*H), 127.4 (*C*H), 137.3 (*C*H), 125.8 (*C*H), 125.2 (*C*H), 92.9 (*C*–I—major rotamer), 92.8 (*C*–I—minor rotamer), 72.6 (*C*H–OSi—minor rotamer), 72.2 (*C*H–OSi—major rotamer), 68.4 (*C*H–OSi—minor rotamer), 68.0 (*C*H–OSi—major rotamer), 42.9 (N*C*H$_2$—major rotamer), 42.8 (N*C*H$_2$—minor rotamer), 39.0 (1) (N*C*H$_2$—major rotamer), 39.0 (0) (N*C*H$_2$—minor rotamer), 26.8 (*C*H$_3$×3—minor rotamer), 26.6 (*C*H$_3$×3—major rotamer), 26.6(0) (*C*H$_3$×3—major rotamer), 26.5 (*C*H$_3$×3—minor rotamer), 19.2 (*C*—minor rotamer), 19.1 (*C*—major rotamer), 19.0(4) (*C*—minor rotamer), 19.0(1) (*C*—major rotamer), 13.8 (NCH$_2$*C*H$_3$), 12.5 (NCH$_2$*C*H$_3$); IR (KBr) 3070 (w), 3048 (w), 2960 (m), 2931 (m), 2894 (m), 2857 (m), 1641 (s), 1589 (w), 1560 (w), 1473 (m), 1460 (m), 1428 (m), 1389 (w), 1362 (w), 1314 (w), 1283 (m), 1212 (w), 1188 (w), 1112 (s), 1073 (br s), 1007 (w), 890 (m), 823 (m), 741 (m), 701 (s), 660 (w), 611 (m), 505 (m); mass spectrum *m*/*z* (relative intensity %) 864.3 $[M]^+$ (100); HRMS (ESI) calcd for $C_{50}H_{52}O_2Si_2$: 864.2767, found 864.2767.

4.18. (5*R*,6*R*)-5,6-Bis((*tert*-butyldiphenylsilyl)oxy)-*N*,*N*-diethyl-2-(*o*-tolyl)-5,6-dihydronaphthalene-1-carboxamide (22)

All solution was degassed prior to use. A solution of **21** (740 mg, 0.857 mmol) and Pd(dppf)Cl_2 (35 mg, 0.04 mmol) in DME (15 mL) was stirred at room temperature for 7 min. *o*-Tolylboronic acid in DME (10 mL) was introduced, followed by sodium carbonate solution (2 M, 2.4 mL, 4.8 mmol). The orange solution was warmed to reflux and stirred overnight (19 h). After allowing the black reaction mixture to cool down, it was quenched with water (30 mL) and extracted with Et_2O (3×40 mL). The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The crude product was purified by flash column chromatography (petroleum ether/EtOAc 5:1) to afford 685 mg (97%) of product **22** as a fluffy white foamy oil as a mixture of rotamers. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.55–7.02 (m, 23H), 6.92–6.65 (m, 2H), 6.57–6.39 (m, 2H), 6.00–5.77 (br m, 1H), 4.73–4.62 (br m, 1H), 4.42–4.37 (m, 1H), 3.81–3.68 (m, 1H), 3.31–2.62 (br m, 3H), 2.17 (s, 3H—minor rotamer), 2.15 (s, 3H—major rotamer), 0.89 (s, 9H—minor rotamer), 0.86 (app. s, overlapping signal, 3H), 0.80 (s, 9H—minor rotamer), 0.64 (app. s, 3H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 168.5, 135.9 (*C*H×2—minor rotamer), 135.8 (*C*H×2—minor rotamer),

135.7 (*C*H×2—major rotamer), 135.6 (*C*H×2—major rotamer), 134.4 (*C*), 133.8 (*C*), 133.8 (*C*×6), 131.4 (*C*H—minor rotamer), 130.8 (*C*H—major rotamer), 129.9 (*C*H), 129.7 (*C*H), 129.6(4) (*C*H), 129.6(0) (*C*H), 129.5 (*C*H), 129.2 (*C*H), 128.7 (*C*H), 128.6 (*C*×2), 127.9 (*C*H), 127.6 (*C*H×4), 127.5 (*C*H×2), 127.3 (*C*H×2), 126.9 (*C*H), 126.3 (*C*H), 125.9 (*C*H), 125.4 (*C*H), 124.4 (*C*H), 120.2 (*C*H), 114.9 (*C*H), 73.1 (*C*H—OSi—minor rotamer), 72.6 (*C*H—OSi—major rotamer), 69.0 (*C*H—OSi—minor rotamer), 68.6 (*C*H—OSi—major rotamer), 42.6 (NCH_2—major rotamer), 42.2 (NCH_2—minor rotamer), 37.7 (NCH_2), 26.8 (CH_3×3—minor rotamer), 26.7 (CH_3×3—major rotamer), 26.6 (CH_3×3), 20.2 (*C*H$_3$, br), 19.2(3) (*C*—major rotamer), 19.2(0) (*C*—minor rotamer), 13.7 (NCH_2CH_3), 11.6 (NCH_2CH_3); IR (KBr) 3049 (w), 2931 (m), 2857 (m), 1637 (s), 1473 (m), 1428 (m), 1383 (w), 1362 (w), 1283 (w), 1112 (s), 1073 (br s), 892 (m), 822 (m), 741 (m), 701 (s), 611 (m), 506 (m); mass spectrum *m*/*z* (relative intensity %) 828.3 $[M]^+$ (100); HRMS (ESI) calcd for $C_{50}H_{52}O_2Si_2$: 828.4268, found 828.4267.

4.19. (1*R*,2*R*)-1,2-Bis((*tert*-butyldiphenylsilyl)oxy)-1,2-dihydrochrysen-5-yl trifluoromethanesulfonate (24)

To a precooled solution of diisopropylamine (0.28 mL, 2.0 mmol) in THF (2 mL) was added *n*-BuLi (1.3 M, 1.54 mL, 2.0 mmol) at −10 °C. After stirring for 15 min, biphenyl **22** (663 mg, 0.801 mmol) in THF (3 mL) was added. The black reaction mixture was stirred for 1 h before quenched with saturated NH_4Cl (10 mL). The layers were separated and the water layer extracted with Et_2O (3×15 mL). The organic layer was kept under nitrogen atmosphere as much as possible, dried over $MgSO_4$, filtered, and concentrated in vacuo. The yellow/orange oil was dissolved in CH_2Cl_2 (10 mL) and cooled to 0 °C before 2,6-lutidine (0.11 mL, 0.95 mmol) was added. After stirring for 5 min, triflic anhydride (0.16 mL, 0.95 mmol) was added slowly and the red reaction mixture was stirred for 45 min at 0 °C and 1 h at room temperature. Water (10 mL) was added to the reaction mixture and extracted with CH_2Cl_2 (3×15 mL). The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The crude product was purified by flash column chromatography twice (petroleum ether/EtOAc 5:1) and then petroleum ether to give 50 mg (7%) of product **24** as a transparent oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 8.54 (d, *J*=8.1 Hz, 1H), 8.27 (d, *J*=8.4 Hz, 1H), 7.88 (d, *J*=7.2 Hz, 1H), 7.76 (s, 1H), 7.66–7.19 (m, 21H), 7.08 (d, *J*=7.2 Hz, 2H), 6.87 (d, *J*=8.4 Hz, 1H), 6.08 (dd, *J*=5.4, 9.9 Hz, 1H), 4.8 (app. s, 1H), 4.40 (dd, *J*=5.4, 2.4 Hz, 1H), 0.84 (s, 9H), 0.79 (s, 9H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 145.1 (*C*), 135.8(2) (*C*H×2), 135.8(0) (*C*H×2), 135.7 (*C*H×2), 135.6 (*C*H×2), 133.9 (*C*), 133.8 (*C*), 133.7 (*C*), 133.5 (*C*), 133.1 (*C*), 130.1 (*C*H), 130.0 (*C*), 129.9 (*C*), 129.6(2) (*C*H), 129.6(2) (*C*H), 129.6(0) (*C*H), 129.2 (*C*H), 128.5(2) (*C*H), 128.5(1) (*C*H), 128.2 (*C*), 128.0 (*C*H), 127.6(2) (*C*H×2), 127.6(0) (*C*H×3), 127.5 (*C*H×2), 127.2 (*C*H×2), 126.9 (*C*H), 123.0 (*C*H), 121.8 (*C*H), 121.7 (*C*), 120.0 (*C*H), 73.8 (*C*H—OSi), 67.6 (*C*H—OSi), 26.7 (CH_3×3), 26.6 (CH_3×3), 19.2 (*C*), 19.0 (*C*); IR (KBr) 3072 (m), 2858 (m), 2930 (s), 1590 (w), 1472 (m), 1427 (s), 1362 (w), 1244 (m), 1213 (s), 1141 (m), 1112 (s), 1078 (m), 1007 (w), 973 (w), 898 (m), 869 (w), 846 (w), 821 (m), 808 (m), 756 (m), 739 (m), 701 (s), 612 (m), 506 (m), 459 (m); mass spectrum *m*/*z* (relative intensity %) 909.3 $[M+Na]^+$ (100); HRMS (ESI) calcd for $C_{51}H_{49}F_3O_5SSi_2$: 909.2689, found 909.2687.

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Supplementary data

^{1}H NMR and ^{13}C NMR spectra of all new compounds and HPLC chromatogram for compounds **10** and **1**. Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.tet.2014.10.016. These data include MOL files and InChiKeys of the most important compounds described in this article.

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