

## Synthesis of Pyrano[3,2-*b*]indole Derivatives Based on Intramolecular Hetero-*Diels*–*Alder* of 2-Benzylidene-2,3-dihydro-1*H*-indol-3-ones

by Yann Davion<sup>a</sup>), Benoît Joseph<sup>a)1)</sup>, Valérie Bénéteau<sup>a</sup>), Jean-Michel Léger<sup>b</sup>), Christian Jarry<sup>b</sup>), and Jean-Yves Mèroux<sup>a)</sup>

<sup>a</sup>) Institut de Chimie Organique et Analytique, UMR-CNRS 6005, Université d'Orléans, BP 6759, F-45067 Orléans Cedex 2 (fax: (33)2-38-41-70-81; e-mail: jean-yves-meroux@univ-orleans.fr)

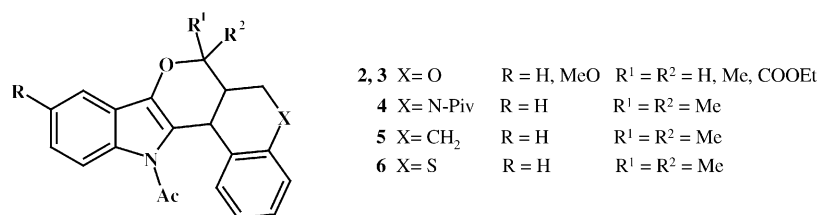
<sup>b</sup>) EA 2962, Pharmacochimie, Université Victor Segalen Bordeaux II, F-33076 Bordeaux Cedex

Pyrano[3,2-*b*]indole derivatives **2**–**6** were synthesized in good yields from 1-acetyl-2-benzylidene-2,3-dihydro-1*H*-indol-3-ones **8** and **13**–**15** by an intramolecular hetero-*Diels*–*Alder* reaction. The structures of compounds **2a**, **3a**, **4**, **5**, and **6** were unambiguously established by X-ray analysis. Compounds **4** and **5** were further aromatized to the corresponding derivatives **16** and **17**, respectively.

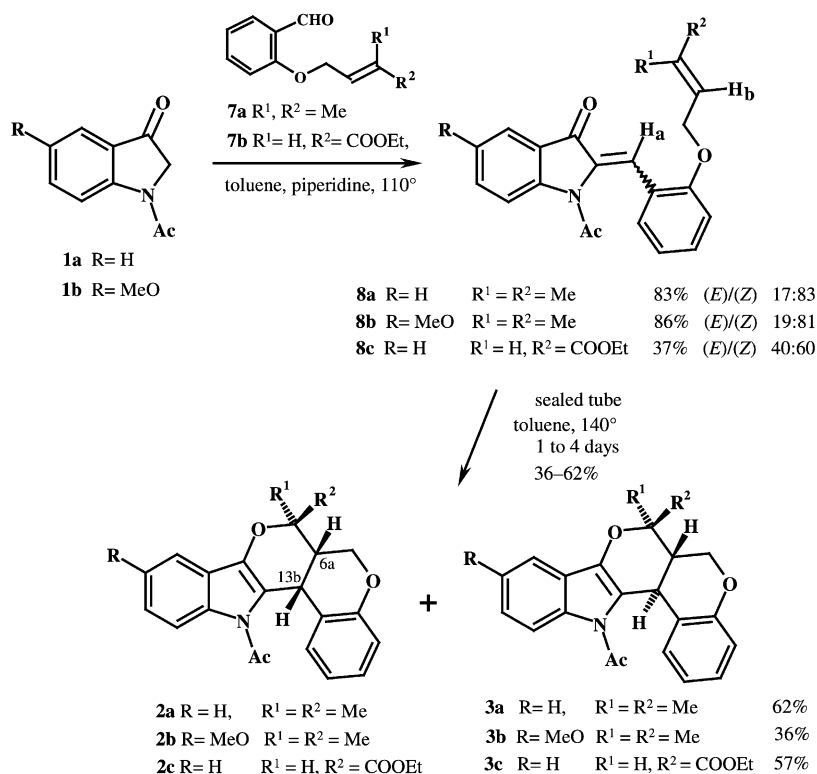
**1. Introduction.** – The hetero-*Diels*–*Alder* reaction has been developed in the last decade because of its elegant, economical, and stereocontrolled application in the synthesis of polycyclic skeletons of natural products [1]. Thus, *Tietze* and co-workers have performed hetero-*Diels*–*Alder* reactions of 1-oxa-1,3-butadiene as a powerful method for the synthesis of the pyran moiety [2]. By a similar approach, *Dehaen* and co-workers [3] have prepared in a diastereoselective manner polycyclic heterocycles with fused pyrano and thiopyrano rings. Under microwave irradiation conditions, *Raghunathan* and co-workers [4] have reported the synthesis of pyranoquinolinone by *Diels*–*Alder* methodology with a high degree of chemoselectivity. A limited number of benzylidenedihydroindol-2- or -3-ones have been reported to behave as dienophiles in *Diels*–*Alder* reactions. To the best of our knowledge, *Desimoni* and co-workers have described the preparation of pyrano[2,3-*b*]indole derivatives from benzylidenedihydroindol-2-one in good yields *via* this approach [5]. Among our research projects, the reactivity of 1-acetyl-2,3-dihydro-1*H*-indol-3-one (**1a**) was investigated in order to prepare new heterocyclic compounds through cycloaddition reactions [6]. Thus, we have already reported a convenient methodology for the preparation of pyrano[3,2-*b*]indole derivatives [7]. Following this preliminary communication, we herein describe the complete synthetic work with the corresponding structural analysis of the new pentacyclic derivatives **2**–**6**.

**Results and Discussion.** – First, we investigated the synthesis of pyrano[3,2-*b*]indole derivatives **2** and **3** (*Scheme 1*). Aldol condensation of 1-acetyl-2,3-dihydro-1*H*-indol-3-one (**1a**) or 1-acetyl-2,3-dihydro-5-methoxy-1*H*-indol-3-one (**1b**) and 2-[(3-methylbut-2-enyl)oxy]benzaldehyde (**7a**) [8] or ethyl (*E*)-4-(2-formylphenoxy)but-2-enoate

<sup>1)</sup> Present address: Laboratoire de Chimie Organique 1, Université Claude Bernard – Lyon 1, UMR-CNRS 5622, CPE - Bâtiment 308, 43 Boulevard du 11 Novembre 1918, F-69622 Villeurbanne Cedex



(**7b**) [9], respectively, gave compounds **8a–8c** in good yields (except **8c**) as (*E*)/(*Z*) diastereoisomer mixtures [10]. The intramolecular *Diels–Alder* reaction was first carried out with derivative **8a** ((*E*)/(*Z*) ratio 17:83). The reaction was performed in a sealed tube in toluene at 140° for 3 days to afford, after a chromatographic separation, the *cis*- and *trans*-pyrano[3,2-*b*]indole derivatives **2a** and **3a**, respectively, in 62% overall yield.

Scheme 1. Synthesis of Compounds **2** and **3**

The cyclization gave predominantly the *cis*-product (*cis*/*trans* ratio 76:24) [10]. The ratio did not exactly match the (*E*)/(*Z*) ratio of the starting heterodiene due to a partial isomerization of the mixture during the cyclization reaction. The *cis*-configuration of **2a** was supported by the coupling constant  $J(6a,13b) = 4.4$  Hz (*trans*-isomer **3a**:

$J(6a,13b) = 12.0$  Hz) consistent with a *trans*-diaxial relationship and 2D-NOESY experiments (connectivities were observed between H–C(6a) and H–C(13b)). In addition, X-ray crystal-structure analyses of **2a** and **3a** were performed (Figs. 1 and 2), and the *cis*- and *trans*-configurations, respectively, were unambiguously established.

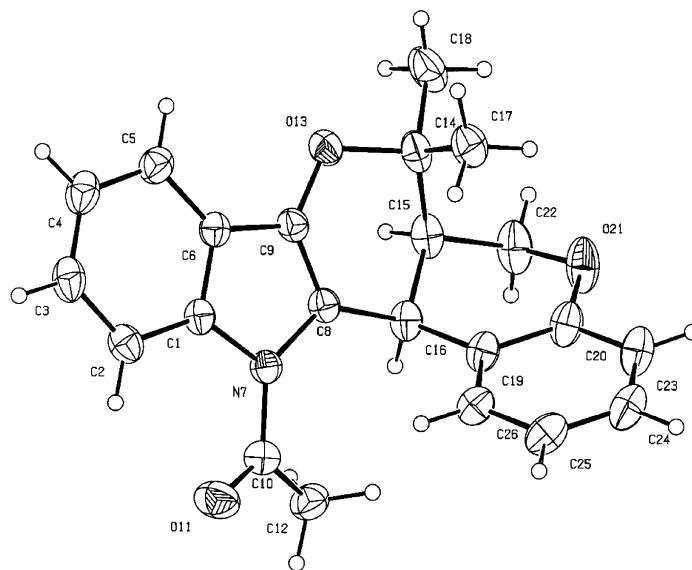


Fig. 1. ORTEP Drawing of the crystal structure of compound **2a** with atom numbering (ellipsoids at 50% probability)

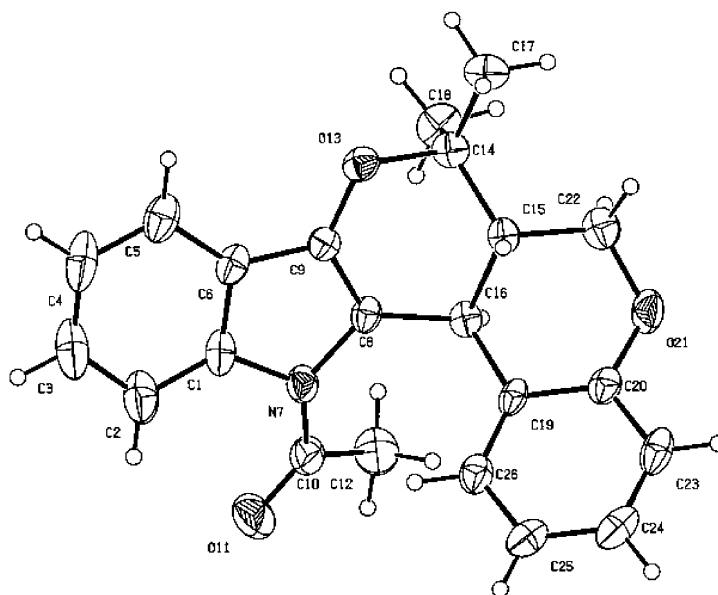


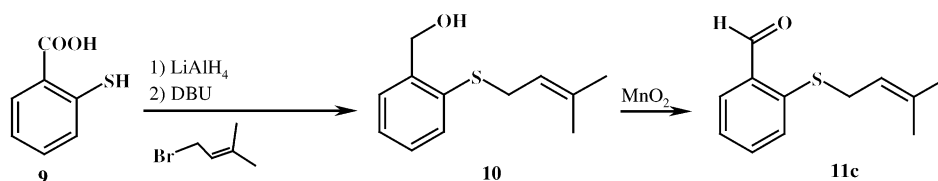
Fig. 2. ORTEP Drawing of the crystal structure of compound **3a** with atom numbering (ellipsoids at 50% probability)

All attempts to improve the yield of the intramolecular cyclization and the diastereoselectivity failed. Addition of a *Lewis* acid into the medium accelerates the reaction but decreases the yield (15–23%) by degradation of the starting material. In addition, no ene product was obtained in our different attempts at intramolecular cyclization.

The intramolecular-cyclization conditions (sealed tube, 140°, 3 days, toluene) were applied to the derivatives **8b** ((*E*)/(*Z*) ratio 19:81) and **8c** ((*E*)/(*Z*) ratio 40:60). The first one gave **2b** (*cis* isomer,  $J(6a,13b) = 5.4$  Hz) and **3b** (*trans*-isomer,  $J(6a,13b) = 10.7$  Hz) in moderate yield (36%) with a *cis/trans* diastereoisomer ratio of 69:31. Similarly from **8c**, compounds **2c** (*cis*-isomer,  $J(6a,13b) = 4.7$  and  $J(6a,7) = 11.3$  Hz) and **3c** (*trans*-isomer  $J(6a,13b) = 9.8$  and  $J(6a,7) = 10.3$  Hz) were obtained in 57% yield (*cis/trans* ratio 63:37). For the compounds **2c** and **3c**, the *trans*-configuration, observed in compound **8c** between the H-atoms H<sub>b</sub> and H<sub>c</sub>, was also conserved *i.e.*, between H–C(6a) and H–C(7)).

On the basis of these successful results, we investigated the intramolecular hetero-*Diels–Alder* reaction of substituted 1-acetyl-2-benzylidene-2,3-dihydro-1*H*-indol-3-ones (**13**, **14**, and **15** obtained from **1a** and *tert*-butyl *N*-(2-formylphenyl)-*N*-(3-methylbut-2-enyl)carbamate (**11a**), 2-(4-methylpent-3-enyl)benzaldehyde (**11b**) [11], or 2-[(3-methylbut-2-enyl)sulfanyl]benzaldehyde (**11c**) [12], respectively, in the presence of piperidine in 78–80% yield as a mixture of diastereoisomers (**13**: (*E*)/(*Z*) 49:51; **14**: (*E*)/(*Z*) 7:93; **15**: (*E*)/(*Z*) 21:79). It should be noted that starting material **11c** was prepared from 2-sulfanylbenzoic acid (**9**) [13] by a reduction/alkylation sequence, followed by MnO<sub>2</sub> oxidation (Scheme 2). Alkylation [14] [15] with 1-bromo-3-methylbut-2-ene must be performed on the 2-sulfanylbenzyl alcohol rather than 2-sulfanylbenzaldehyde in order to prevent dimerization.

Scheme 2. Preparation of Sulfonyl-Substituted Benzaldehyde **11c**



Hetero-*Diels–Alder* reactions were performed on **13–15** in a sealed tube (140°, 24 h) to afford exclusively the *cis*-diastereoisomers **4–6**, respectively, in 86, 71, and 57% yield (Scheme 3).

The structures were again deduced from the  $^1\text{H}$ -NMR coupling constants of the ring H-atoms H–C(6a) and H–C(13b) (**4**:  $J(6a,13b) = 7.0$  and **5**:  $J(6a,13b) = 6.3$  Hz) and 2D-NOESY experiments. X-Ray crystal-structure analyses were also performed for compounds **4–6** (see Fig. 3 for compound **4**) indicating *inter alia* the *cis*-configuration.

In all cases studied, the *cis*-annulated products were predominantly or exclusively obtained from benzylidenedihydroindol-2-ones. As already described by Tietze *et al.* [12], under kinetic control, the *endo*-transition state **A**, leading to the *cis*-adduct, is energetically more favorable than the *exo*-transition state **B**. The presence of a heteroatom ( $\text{X} = \text{O}$ ,  $\text{N–Piv}$ ,  $\text{S}$ ) instead of a  $\text{CH}_2$  group in the chain adjacent to the aryl

Reaction scheme for the synthesis of **13**, **14**, and **15** from **1a** and 2a:

**1a** (N-acetylindolin-3-one) reacts with 2a (2-(2-methyl-3-oxoprop-1-en-1-yl)benzaldehyde) in the presence of toluene, piperidine, and 110°C to yield **13**, **14**, and **15**.

Reaction conditions: toluene, piperidine, 110°C

Products and yields:

- 13** X= N-Piv 78% (*E*)/(*Z*) 49:51
- 14** X= CH<sub>2</sub> 80% (*E*)/(*Z*) 7:93
- 15** X= S 78% (*E*)/(*Z*) 21:79

Reaction scheme for the synthesis of **4**, **5**, and **6** from **13**, **14**, and **15**:

**13**, **14**, and **15** are cyclized in a sealed tube in toluene at 140°C for 24 h to yield **4**, **5**, and **6**.

Reaction conditions: sealed tube, toluene, 140°C, 24 h

Products and yields:

- 4** X= N-Piv 86%
- 5** X= CH<sub>2</sub> 71%
- 6** X= S 57%

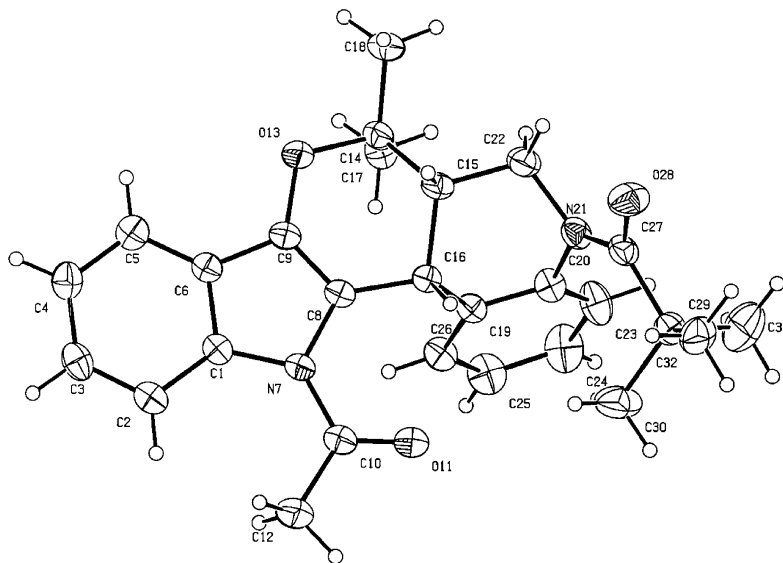


Fig. 3. ORTEP Drawing of the crystal structure of compound **4** with atom numbering (ellipsoids at 50% probability)

moiety has no product-determining influence on the conformation of the transition state (Fig. 4).

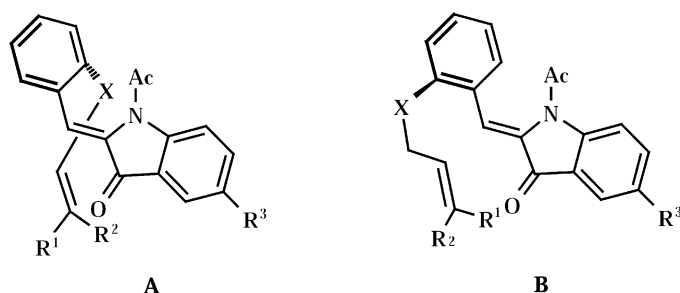
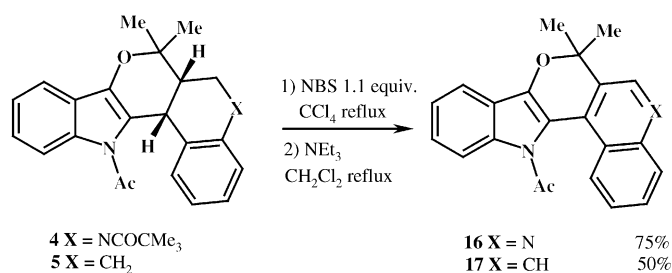


Fig. 4. endo- and exo-Transition states **A** and **B**, respectively

When compound **4** was treated with *N*-bromosuccinimide (NBS; 1.1 equiv.), followed by reflux in basic medium, a satisfying 75% yield of the corresponding aromatized derivative **16** was obtained. Similarly, the same conditions applied to **5** afforded derivative **17** in 50% yield (Scheme 4).

Scheme 4. Aromatization



In this study, new intramolecular *Diels–Alder* adducts **2–6** have been obtained from judiciously prepared substituted benzylidene-2,3-dihydro-1*H*-indol-3-ones. The method described is useful to synthesize polycyclic derivatives with potential pharmaceutical properties.

#### Experimental Part

**General.** All reactions requiring anhydrous conditions were conducted in flame-dried apparatus. Petroleum ether (b.p. 40–60°) was used as chromatographic eluent. 2-[(3-methylbut-2-enyl)oxy]benzaldehyde (**7a**) [8], ethyl 4-(2-formylphenoxy)but-2-enoate (**7b**) [9], and 2-(4-methylpent-3-enyl)benzaldehyde (**11b**) [11] were prepared in good yields according to literature procedures. TLC: on precoated silica-gel plates (Merck 60F<sub>254</sub>); visualization with an UV lamp. Flash chromatography (FC): on a column with flash silica gel 60 Merck (40–63 μm) as the stationary phase. M.p.: Büchi capillary instrument; uncorrected. IR Spectra: Perkin-Elmer FTIR paragon 1000 spectrometer. NMR Spectra: at 300 K in CDCl<sub>3</sub>, with Bruker Avance DPX-250 spectrometer; chemical shifts in ppm relative to Me<sub>4</sub>Si (TMS). MS: Perkin-Elmer SCIEX API-300; ion-spray methodology.

1. *Diels–Alder Reactions: Typical Procedure.* In a sealed tube, a soln. of **8** (1.0 mmol) or **13–15** (1.0 mmol) in toluene (10 ml) was stirred at 140° for 3 or 4 d for **8** and 24 h for **13–15**. After cooling, toluene was removed *in vacuo*, the crude residue was purified by CC (silica gel; AcOEt/petroleum ether 2:8) to give **2** and **3** except for **4–6** (AcOEt/petroleum ether 1:9). The diastereoisomers **2** and **3** were separated by CC.

1-(6a,7,13,13b-Tetrahydro-7,7-dimethyl-6H-[1]benzopyrano[4',3':4,5]pyrano[3,2-b]indol-13-yl)ethan-1-one (**2a** and **3a**) [7]. Time 3 d; 62% yield (*cis/trans* 76:24). *cis*-Isomer **2a**: m.p. 165–166° (AcOEt/hexane). *trans*-Isomer **3a**: m.p. 195–197° (AcOEt/hexane).

1-(6a,7,13,13b-Tetrahydro-10-methoxy-7,7-dimethyl-6H-[1]benzopyrano[4',3':4,5]pyrano[3,2-b]indol-13-yl)ethan-1-one (**2b** and **3b**). Time 4 d; 36% yield (*cis/trans* 69:31).

*cis*-Isomer **2b**: oil. IR (film): 3059, 2926, 1691, 1615, 1489, 1135, 1033, 757. <sup>1</sup>H-NMR (250 MHz, CDCl<sub>3</sub>): 7.77 (*d*, *J* = 9.1, 1 arom. H); 7.17 (*d*, *J* = 7.7, 1 arom. H); 7.09 (*t*, *J* = 7.7, 1 arom. H); 7.03 (*d*, *J* = 2.6, 1 arom. H); 6.95 (*dd*, *J* = 2.6, 9.1, 1 arom. H); 6.83 (*td*, *J* = 1.1, 7.7, 1 arom. H); 6.73 (*dd*, *J* = 1.1, 7.7, 1 arom. H); 5.03 (*d*, *J* = 5.4, H–C(13b)); 4.58 (*dd*, *J* = 5.0, 12.1, 1 H, CH<sub>2</sub>); 4.42 (*dd*, *J* = 3.1, 12.1, 1 H, CH<sub>2</sub>); 3.89 (*s*, Me); 2.78 (*s*, Me); 2.46–2.44 (*m*, H–C(6a)); 1.61 (*s*, Me); 1.12 (*s*, Me). <sup>13</sup>C-NMR (62.90 MHz, CDCl<sub>3</sub>): 169.3 (CO); 156.1 (C); 154.0 (C); 138.6 (C); 129.1 (CH); 129.0 (CH); 127.8 (CH); 124.9 (C); 123.0 (C); 120.9 (CH); 117.8 (C); 116.1 (CH); 115.9 (CH); 113.7 (CH); 100.3 (C); 78.7 (C); 66.1 (CH<sub>2</sub>); 55.7 (Me); 40.6 (C(13b)); 33.4 (C(6a)); 28.2 (Me); 27.2 (Me); 23.0 (Me). MS: 378 ([*M* + 1]<sup>+</sup>). Anal. calc. for C<sub>23</sub>H<sub>23</sub>NO<sub>4</sub>: C 73.19, H 6.14, N 3.71; found: C 72.81, H 5.98, N 3.91.

*trans*-Isomer **3b**: oil. IR (film): 3059, 2926, 1691, 1615, 1489, 1135, 1033, 757. <sup>1</sup>H-NMR (250 MHz, CDCl<sub>3</sub>): 8.08 (*d*, *J* = 9.0, 1 arom. H); 7.18–7.16 (*m*, 2 arom. H); 7.05 (*d*, *J* = 2.6, 1 arom. H); 7.00 (*dd*, *J* = 2.6, 9.0, 1 arom. H); 6.92 (*dd*, *J* = 1.1, 7.7, 1 arom. H); 6.87 (*t*, *J* = 7.7, 1 arom. H); 4.44 (*dd*, *J* = 6.3, 9.7, 1 H, CH<sub>2</sub>); 4.42 (*d*, *J* = 10.7, H–C(13b)); 4.18 (*dd*, *J* = 9.7, 12.3, 1 H, CH<sub>2</sub>); 3.90 (*s*, Me); 2.61 (*s*, Me); 2.27–2.21 (*m*, H–C(6a)); 1.52 (*s*, Me); 1.39 (*s*, Me). <sup>13</sup>C-NMR (62.90 MHz, CDCl<sub>3</sub>): 169.5 (CO); 156.3 (C); 153.8 (C); 140.4 (C); 129.7 (C); 128.8 (CH); 128.0 (CH); 124.7 (CH); 124.5 (C); 121.1 (CH); 117.1 (CH); 116.7 (CH); 115.3 (C); 114.2 (CH); 100.1 (C); 77.1 (C); 69.0 (CH<sub>2</sub>); 55.8 (Me); 47.5 (C(13b)); 35.5 (C(6a)); 27.3 (Me); 26.4 (Me); 18.4 (Me). MS: 378 ([*M* + 1]<sup>+</sup>). Anal. calc. for C<sub>23</sub>H<sub>23</sub>NO<sub>4</sub>: C 73.19, H 6.14, N 3.71; found: C 72.94, H 6.31, N 3.76.

Ethyl 13-Acetyl-6a,7,13,13b-tetrahydro-6H-[1]benzopyrano[4',3':4,5]pyrano[3,2-b]indole-7-carboxylate (**2c** and **3c**). Time 24 h; 57% yield (*cis/trans* 60:40).

*cis*-Isomer **2c**: M.p. 197–198° (AcOEt/hexane). IR (KBr): 2973, 2925, 1746, 1635, 1489, 1461, 1373, 1030, 755. <sup>1</sup>H-NMR (250 MHz, CDCl<sub>3</sub>): 7.81 (*d*, *J* = 8.3, 1 arom. H); 7.59 (*d*, *J* = 7.6, 1 arom. H); 7.40–7.25 (*m*, 2 arom. H); 7.14–7.08 (*m*, 2 arom. H); 6.86–6.79 (*m*, 2 arom. H); 5.24 (*d*, *J* = 4.7, H–C(13b)); 4.71 (*d*, *J* = 11.3, H–C(7)); 4.45–4.41 (*m*, CH<sub>2</sub>); 4.39 (*q*, *J* = 7.1, CH<sub>2</sub>); 2.88 (*s*, Me); 2.75–2.68 (*m*, H–C(6a)); 1.40 (*t*, *J* = 7.1, Me). <sup>13</sup>C-NMR (62.90 MHz, CDCl<sub>3</sub>): 169.6 (CO); 169.5 (CO); 152.2 (C); 138.5 (C); 134.0 (C); 130.3 (CH); 128.3 (CH); 125.4 (CH); 123.4 (CH); 123.0 (C); 122.9 (C); 121.3 (CH); 118.9 (C); 118.4 (CH); 117.0 (CH); 115.0 (CH); 74.1 (C(7)); 65.9 (CH<sub>2</sub>); 62.0 (CH<sub>2</sub>); 34.0 (C(13b)); 33.8 (C(6a)); 27.8 (Me); 14.3 (Me). MS: 392 ([*M* + 1]<sup>+</sup>). Anal. calc. for C<sub>23</sub>H<sub>21</sub>NO<sub>5</sub>: C 70.58, H 5.41, N 3.58; found: C 70.87, H 5.61, N 3.56.

*trans*-Isomer **3c**: M.p. 217–218° (AcOEt/hexane). IR (KBr): 2973, 2925, 1746, 1635, 1489, 1461, 1373, 1030, 755. <sup>1</sup>H-NMR (250 MHz, CDCl<sub>3</sub>): 8.13 (*d*, *J* = 8.3, 1 arom. H); 7.67 (*d*, *J* = 7.8, 1 arom. H); 7.41 (*t*, *J* = 7.8, 1 arom. H); 7.31 (*t*, *J* = 7.6, 1 arom. H); 7.16 (*t*, *J* = 7.6, 1 arom. H); 7.09 (*d*, *J* = 7.6, 1 arom. H); 6.93–6.84 (*m*, 2 arom. H); 4.58 (*d*, *J* = 9.8, H–C(13b)); 4.49 (*d*, *J* = 10.3, H–C(7)); 4.40–4.35 (*m*, 2 CH<sub>2</sub>); 2.66 (*s*, Me); 2.55–2.48 (*m*, H–C(6a)); 1.37 (*t*, *J* = 7.1, Me). <sup>13</sup>C-NMR (62.90 MHz, CDCl<sub>3</sub>): 169.9 (CO); 168.2 (CO); 154.3 (C); 141.7 (C); 134.8 (C); 128.5 (CH); 128.2 (C); 126.1 (CH); 124.1 (CH); 123.6 (CH); 122.5 (C); 121.5 (CH); 118.1 (CH); 117.4 (CH); 115.9 (C); 115.5 (CH); 76.6 (C(7)); 68.0 (CH<sub>2</sub>); 62.2 (CH<sub>2</sub>); 41.9 (C(6a)); 38.2 (C(13b)); 26.8 (Me); 14.3 (Me). MS: 392 ([*M* + 1]<sup>+</sup>). Anal. calc. for C<sub>23</sub>H<sub>21</sub>NO<sub>5</sub>: C 70.58, H 5.41, N 3.58; found: C 70.25, H 5.45, N 3.43.

1-(13-Acetyl-5,6,6a,7,13,13b-hexahydro-7,7-dimethylindolo[2',3':5,6]pyrano[3,4-c]quinolin-5-yl)-2,2-dimethylpropan-1-one (**4**). According to the procedure for the synthesis of **2** and **3**, compound **4** was prepared from **13**. Time 24 h; 86% yield; *cis*-isomer exclusively; m.p. 225–226° (CH<sub>2</sub>Cl<sub>2</sub>/hexane).

1-(5,6,6a,7,13,13b-Hexahydro-7,7-dimethylbenzo[5,6][2]benzopyrano[4,3-b]indol-13-yl)ethan-1-one (**5**). According to the procedure for the synthesis of **2** and **3**, compound **5** was prepared from **14** in 24 h; yield 71%; *cis*-isomer exclusively. M.p. 173–175° (AcOEt/petroleum ether). IR (KBr): 3027, 2902, 1686, 1623, 1485, 1455, 1126, 753. <sup>1</sup>H-NMR (250 MHz, CDCl<sub>3</sub>): 8.13 (*d*, *J* = 8.2, 1 arom. H); 7.60 (*br. d*, *J* = 7.5, 1 arom. H); 7.39–7.24 (*m*, 2 arom. H); 7.16–7.00 (*m*, 4 arom. H); 4.39 (*d*, *J* = 7.0, H–C(13b)); 2.75–2.64 (*m*, CH<sub>2</sub>, H–C(6a)); 2.55 (*s*, Me); 2.40–2.29 (*m*, 1 H, CH<sub>2</sub>); 1.37 (*s*, Me); 1.23–1.07 (*m*, 1 H, CH<sub>2</sub>); 0.66 (*s*, Me). <sup>13</sup>C-NMR (62.90 MHz, CDCl<sub>3</sub>): 169.3 (CO); 139.3 (C); 139.2 (C); 138.7 (C); 134.7 (C); 126.5 (CH); 126.4 (CH); 126.3 (2 CH); 125.2 (CH); 124.0 (C); 123.1 (CH); 117.7 (CH); 115.9 (CH); 115.8 (C); 80.0 (C); 41.4 (C(13b)); 36.6 (C(6a)); 28.4 (CH<sub>2</sub>); 28.1 (Me); 26.6 (Me); 25.3 (CH<sub>2</sub>); 19.8 (Me). MS: 346 ([*M* + 1]<sup>+</sup>). Anal. calc. for C<sub>23</sub>H<sub>23</sub>NO<sub>2</sub>: C 79.97, H 6.71, N 4.05; found: C 79.75, H 6.89, N 3.91.

1-(6a,7,13,13b-tetrahydro-7,7-dimethyl-6H-[1]benzothiopyrano[4',3':4,5]pyrano[3,2-b]indol-13-yl)ethan-1-one (**6**). According to the procedure for the synthesis of **2** and **3**, compound **6** was prepared from **15** ((*E*)/(*Z*)).

mixture). Time 24 h; 57% yield; *cis*-isomer exclusively. Brown solid. M.p. 212°. IR (KBr): 3054, 2982, 2932, 1704, 1633, 1480, 1459, 1445, 1416, 1370. <sup>1</sup>H-NMR (250 MHz, CDCl<sub>3</sub>): 8.19 (*d*, *J* = 8.1, 1 arom. H); 7.61 (*d*, *J* = 7.1, 1 arom. H); 7.44 (*d*, *J* = 7.7, 1 arom. H); 7.37 (*t*, *J* = 8.1, 1 arom. H); 7.29 (*t*, *J* = 7.7, 1 arom. H); 7.21–7.05 (*m*, 3 arom. H); 4.50 (*d*, *J* = 6.3, H–C(13b)); 3.20–3.05 (*m*, CH<sub>2</sub>); 2.41 (*s*, MeCO); 2.39–2.31 (*m*, H–C(6a)); 1.39 (*s*, Me); 0.81 (*s*, Me). <sup>13</sup>C-NMR (62.90 MHz, CDCl<sub>3</sub>): 169.1 (CO); 140.4 (C); 139.4 (C); 136.5 (C); 134.8 (C); 129.5 (CH); 127.6 (CH); 127.0 (CH); 126.5 (CH); 125.4 (CH); 123.4 (C); 123.1 (CH); 117.5 (CH); 116.0 (CH); 114.5 (C); 79.3 (C); 47.5 (CH); 39.1 (CH); 31.8 (CH<sub>2</sub>); 28.3 (Me); 26.2 (Me); 19.9 (Me). MS: 364 ([*M* + 1]<sup>+</sup>). Anal. calc. for C<sub>22</sub>H<sub>21</sub>NO<sub>2</sub>S: C 72.70, H 5.82, N 3.85; found: C 73.07, H 5.99, N 3.97.

2. General Procedure for the Aldolization Reaction. A soln. of **1** (1.0 mmol), **7** (1.5 mmol), and piperidine (0.25 ml) in toluene (25 ml) was stirred at 110° for a given time. After cooling and evaporation of toluene, the crude residue was purified by CC (silica gel; AcOEt/petroleum ether 1:9 for **8a** and **8b** and 2:8 for **8c**) to give **8**.

1-Acetyl-2,3-dihydro-2-(1-[2-(3-methylbut-2-enyl)oxy]phenyl)methylidene)-1H-indol-3-one (**8a**). Time 1 h; yield 83% ((*Z*)/(*E*) 83:17). Oil.

(*Z*)-Isomer: IR (film): 3070, 2926, 1713, 1602, 1487, 1486, 1456, 1004, 755. <sup>1</sup>H-NMR (250 MHz, CDCl<sub>3</sub>): 8.32 (*d*, *J* = 8.4, 1 arom. H); 7.84 (*d*, *J* = 7.3, 1 arom. H); 7.63 (*d*, *J* = 7.3, 1 arom. H); 7.52 (*s*, H<sub>a</sub>); 7.46 (*d*, *J* = 7.3, 1 arom. H); 7.38–7.24 (*m*, 2 arom. H); 7.01–6.93 (*m*, 2 arom. H); 5.45 (*br. t*, *J* = 6.5, H<sub>b</sub>); 4.58 (*d*, *J* = 6.2, CH<sub>2</sub>); 1.89 (*s*, Me); 1.74 (*s*, Me); 1.70 (*s*, Me). <sup>13</sup>C-NMR (62.90 MHz, CDCl<sub>3</sub>): 185.9 (CO); 170.4 (CO); 157.6 (C); 150.1 (C); 138.1 (C); 136.2 (CH); 134.9 (C); 131.5 (CH); 131.0 (NC=CHC<sub>6</sub>H<sub>4</sub>); 124.7 (CH); 124.2 (CH); 123.9 (C); 123.5 (C); 120.9 (CH); 119.4 (Me<sub>2</sub>C=C); 118.7 (CH); 117.7 (CH); 112.5 (CH); 65.5 (CH<sub>2</sub>); 25.8 (Me), 25.0 (Me), 18.4 (Me). MS: 348 ([*M* + 1]<sup>+</sup>). Anal. calc. for C<sub>22</sub>H<sub>21</sub>NO<sub>3</sub>: C 76.06, H 6.09, N 4.03; found: C 75.82, H 5.91, N 3.85.

1-Acetyl-2,3-dihydro-5-methoxy-2-(1-[2-(3-methylbut-2-enyl)oxy]phenyl)methylidene)-1H-indol-3-one (**8b**). Time 4.5 h; yield 86% ((*Z*)/(*E*) 81:19). Oil.

(*Z*)-Isomer: IR (film): 3078, 2931, 1687, 1629, 1486, 1132, 1027, 753. <sup>1</sup>H-NMR (250 MHz, CDCl<sub>3</sub>): 8.25 (*d*, *J* = 9.0, 1 arom. H); 7.52 (*s*, H<sub>a</sub>); 7.47–7.17 (*m*, 5 arom. H); 7.04–6.89 (*m*, 1 arom. H); 5.45 (*t*, *J* = 6.4, H<sub>b</sub>); 4.58 (*d*, *J* = 6.3, CH<sub>2</sub>); 3.85 (*s*, Me); 1.87 (*s*, Me); 1.75 (*s*, Me); 1.71 (*s*, Me). <sup>13</sup>C-NMR (62.90 MHz, CDCl<sub>3</sub>): 186.0 (CO); 170.2 (CO); 157.7 (C); 157.1 (C); 144.8 (C); 138.1 (C); 135.5 (C); 131.6 (CH); 131.0 (NC=CHC<sub>6</sub>H<sub>4</sub>); 124.9 (C); 124.5 (CH); 123.6 (CH); 120.9 (CH); 119.4 (C); 119.2 (CH); 119.0 (Me<sub>2</sub>C=C); 112.5 (CH); 105.8 (CH); 65.6 (CH<sub>2</sub>); 56.0 (Me), 25.9 (Me); 24.9 (Me); 18.4 (Me). MS: 378 ([*M* + 1]<sup>+</sup>). Anal. calc. for C<sub>23</sub>H<sub>23</sub>NO<sub>4</sub>: C 73.19, H 6.14, N 3.71; found: C 72.87, H 6.30, N 3.56.

Ethyl (E)-4-[2-(1-Acetyl-2,3-dihydro-3-oxo-1H-indol-2-ylidene)methyl]phenoxy]but-2-enoate (**8c**). Time 8 h; yield 37% ((*Z*)/(*E*) 60:40). Oil.

(*Z*)-Isomer: IR (film): 3078, 2931, 1704, 1487, 1462, 1031, 756. <sup>1</sup>H-NMR (250 MHz, CDCl<sub>3</sub>): 8.26 (*d*, *J* = 8.4, 1 arom. H); 7.83 (*d*, *J* = 7.5, 1 arom. H); 7.62 (*d*, *J* = 7.5, 1 arom. H); 7.51 (*s*, H<sub>a</sub>); 7.47 (*d*, *J* = 8.5, 1 arom. H); 7.39–7.22 (*m*, 2 arom. H); 7.08–6.98 (*m*, 2 arom. H); 6.87–6.83 (*m*, H<sub>b</sub>); 6.06 (*d*, *J* = 15.6, EtOCOC(H)); 4.75 (*m*, CH<sub>2</sub>); 4.15 (*q*, *J* = 7.1, CH<sub>2</sub>); 1.88 (*s*, Me); 1.25 (*t*, *J* = 7.1, Me). <sup>13</sup>C-NMR (62.90 MHz, CDCl<sub>3</sub>): 182.8 (CO); 170.2 (CO); 165.9 (CO); 156.4 (C); 150.0 (C); 141.4 (CH); 137.9 (C); 136.4 (CH); 135.1 (C); 131.8 (CH); 131.1 (CH); 129.1 (CH); 124.8 (CH); 124.3 (CH); 122.7 (NC=CHC<sub>6</sub>H<sub>4</sub>); 122.5 (C); 121.7 (CH); 117.6 (CH); 112.2 (CH=CHCH<sub>2</sub>); 67.0 (CH<sub>2</sub>), 60.7 (CH<sub>2</sub>), 24.9 (Me), 14.3 (Me). MS: 392 ([*M* + 1]<sup>+</sup>). Anal. calc. for C<sub>23</sub>H<sub>21</sub>NO<sub>5</sub>: C 70.58, H 5.41, N 3.58; found: C 70.77, H 5.57, N 3.45.

N-(2-Formylphenyl)-2,2-dimethyl-N-(3-methylbut-2-enyl)propanamide (**11a**). To a soln. of N-(2-formylphenyl)-2,2-dimethylpropanamide (2.6 g, 12.5 mmol) in dry DMF (25 ml) was added portionwise NaH (607 mg, 15.4 mmol, 60% in dispersion) at 0°. Then, 2-methyl-4-bromobut-2-ene (2.8 g, 18.8 mmol) dissolved in DMF (25 ml) was added dropwise at 0°. The final mixture was stirred for 5 h at r.t. The mixture was poured into H<sub>2</sub>O (100 ml) and then extracted with AcOEt (2 × 40 ml). The org. layer was washed with brine, then dried (MgSO<sub>4</sub>), and evaporated *in vacuo*. The crude residue was purified by CC (silica gel; petroleum ether/AcOEt 95:5) to afford **11a** (2.2 g, 65%). Oil. IR (film): 3088, 2994, 2870, 1688, 1638, 1597, 1394, 1356, 1172, 751. <sup>1</sup>H-NMR (250 MHz, CDCl<sub>3</sub>): 10.09 (*s*, CHO); 7.96 (*dd*, *J* = 1.6, 7.7, 1 arom. H); 7.63 (*dt*, *J* = 1.6, 7.7, 1 arom. H); 7.48 (*t*, *J* = 7.7, 1 arom. H); 7.24 (*d*, *J* = 7.7, 1 arom. H); 5.27 (*t*, *J* = 7.0, =CH); 4.33 (*dd*, *J* = 7.1, 13.9, 1 H, CH<sub>2</sub>); 4.15 (*dd*, *J* = 8.1, 13.9, 1 H, CH<sub>2</sub>); 1.61 (*s*, Me); 1.15 (*s*, Me); 1.03 (*s*, 3 Me). <sup>13</sup>C-NMR (62.90 MHz, CDCl<sub>3</sub>): 189.3 (CO); 177.2 (CO); 145.2 (C); 138.2 (C); 134.5 (CH); 133.6 (C); 131.1 (CH); 128.5 (CH); 128.4 (CH); 117.9 (CH); 50.8 (CH<sub>2</sub>); 41.1 (C); 29.2 (3 Me); 25.4 (Me); 17.1 (Me). MS: 274 ([*M* + 1]<sup>+</sup>). Anal. calc. for C<sub>17</sub>H<sub>23</sub>NO<sub>2</sub>: C 74.69, H 8.48, N 5.12; found: C 74.35, H 8.38, N 4.95.

N-[2-(1-Acetyl-2,3-dihydro-3-oxo-1H-indol-2-ylidene)methyl]penyl]-2,2-dimethyl-N-(3-methylbut-2-enyl)propanamide (**13**). According to the procedure for the synthesis of **8**, **13** was prepared from **1a** and **11a**. Time 3 h; 78% yield ((*Z*)/(*E*) 51:49). Oil. IR (film): 3062, 2967, 1690, 1639, 1480, 1381, 1361, 1276, 757. <sup>1</sup>H-NMR

(250 MHz,  $\text{CDCl}_3$ ): (*E*)-Isomer: 8.21 (br. *d*,  $J = 8.3$ , 1 arom. H); 8.10–8.05 (*m*, 1 arom. H); 7.87 (*dd*,  $J = 1.0$ , 7.5, 1 arom. H); 7.72–7.68 (*m*, 1 arom. H,  $\text{H}_a$ ); 7.43–7.40 (*m*, 2 arom. H); 7.35–7.24 (*m*, 1 arom. H); 7.23–7.19 (*m*, 1 arom. H); 5.36–5.23 (*m*,  $\text{H}_b$ ); 4.66 (*dd*,  $J = 6.1$ , 14.3, 1 H,  $\text{CH}_2$ ); 3.90–3.68 (*m*, 1 H,  $\text{CH}_2$ ); 2.63 (*s*, Me); 1.66 (*s*, Me); 1.38 (*s*, Me); 1.13 (*s*, 3 Me).  $^1\text{H-NMR}$  (250 MHz,  $\text{CDCl}_3$ ): (*Z*)-Isomer: 8.21 (br. *d*,  $J = 8.3$ , 1 arom. H); 8.07–8.05 (*m*, 1 arom. H); 7.76 (*dd*,  $J = 1.0$ , 7.5, 1 arom. H); 7.67–7.63 (*m*, 1 arom. H,  $\text{H}_a$ ); 7.39–7.37 (*m*, 2 arom. H); 7.35–7.24 (*m*, 1 arom. H); 7.16–7.13 (*m*, 1 arom. H); 5.36–5.23 (*m*,  $\text{H}_b$ ); 4.39 (*dd*,  $J = 6.1$ , 14.3, 1 H,  $\text{CH}_2$ ); 3.90–3.68 (*m*, 1 H,  $\text{CH}_2$ ); 2.12 (*s*, Me); 1.56 (*s*, Me); 1.23 (*s*, Me); 1.05 (*s*, 3 Me).  $^{13}\text{C-NMR}$  (62.90 MHz,  $\text{CDCl}_3$ ): (*E*)/(*Z*)-mixture: 185.5 (CO); 182.6 (CO); 178.0 (CO); 177.8 (CO); 169.9 (CO); 168.9 (CO); 150.1 (C); 148.3 (2 C); 144.3 (C); 142.7 (C); 136.4 (C); 136.3 (CH); 135.5 (C); 135.2 (C); 132.9 (C); 132.2 (CH); 130.9 (2 CH); 130.3 (CH); 130.2 (CH); 130.1 (CH); 128.0 (CH); 127.2 (CH); 126.0 (CH); 125.1 (CH); 124.7 (CH); 124.3 (2 CH); 124.0 (2 C); 119.0 (CH); 118.9 (CH); 117.7 (CH); 117.5 (CH); 117.3 (2 CH); 50.5 ( $\text{CH}_2$ ); 41.2 (C); 41.0 (C); 29.2 (3 Me); 26.6 (Me); 25.8 (Me); 25.7 (Me); 25.2 (Me); 17.7 (Me). MS: 431 ( $[M + 1]^+$ ). Anal. calc. for  $\text{C}_{27}\text{H}_{30}\text{N}_2\text{O}_3$ : C 75.32, H 7.02, N 6.51; found: C 75.15, H 7.20, N 6.50.

*1-Acetyl-2,3-dihydro-2-[[2-(4-methylpent-3-enyl)phenyl]methylidene]-1H-indol-3-one* (**14**). According to the procedure for the synthesis of **8**, **14** was prepared from **1a** and **11b** [11]. Time 9 h; yield 80% ((*Z*)/(*E*) 93 : 7). Oil.

(*Z*)-Isomer: IR (film): 3061, 2927, 1697, 1459, 1008, 758.  $^1\text{H-NMR}$  (250 MHz,  $\text{CDCl}_3$ ): 8.31 (*d*,  $J = 8.2$ , 1 arom. H); 7.83 (*d*,  $J = 7.6$ , 1 arom. H); 7.63 (*t*,  $J = 8.2$ , 1 arom. H); 7.50 (*s*,  $\text{H}_a$ ); 7.44 (*d*,  $J = 7.3$ , 1 arom. H); 7.31–7.18 (*m*, 4 arom. H); 5.19 (br. *t*,  $J = 6.1$ ,  $\text{H}_b$ ); 2.79 (*t*,  $J = 7.4$ ,  $\text{CH}_2$ ); 2.33 (*q*,  $J = 7.4$ ,  $\text{CH}_2$ ); 1.80 (*s*, MeCO); 1.69 (*s*, Me); 1.59 (*s*, Me).  $^{13}\text{C-NMR}$  (62.90 MHz,  $\text{CDCl}_3$ ): 185.5 (CO); 170.1 (CO); 150.1 (C); 142.5 (C); 136.3 (CH); 135.4 (C); 132.9 (C); 132.8 (C); 130.3 (CH); 129.8 (CH); 128.9 (CH); 126.6 (CH); 124.8 (CH); 124.1 (CH); 123.7 (C); 123.0 (CH); 120.4 (CH); 117.7 (CH); 33.8 ( $\text{CH}_2$ ); 29.2 ( $\text{CH}_2$ ); 25.7 (Me); 25.0 (Me); 17.7 (Me). MS: 346 ( $[M + 1]^+$ ). Anal. calc. for  $\text{C}_{25}\text{H}_{23}\text{NO}_2$ : C 79.97, H 6.71, N 4.05; found: C 80.18, H 6.67, N 4.19.

*1-Acetyl-2,3-dihydro-2-[[2-[(3-methylbut-2-enyl)sulfanyl]benzylidene]-1H-indol-3-one* (**15**). According to the procedure for the synthesis of **8**, **15** was prepared from **1a** and **11c** [12][14] in 4 h; yield 78% ((*Z*)/(*E*) 79 : 21). Yellow oil. IR (film): 3056, 2974, 2930, 1694, 1634, 1459, 1365, 1311, 1277, 1188.  $^1\text{H-NMR}$  (250 MHz,  $\text{CDCl}_3$ ): (*E*)-Isomer: 8.23 (*d*,  $J = 8.3$ , 1 arom. H); 7.84 (*d*,  $J = 7.6$ , 1 arom. H); 7.77 (*s*,  $\text{H}_a$ ); 7.73 (*d*,  $J = 7.6$ , 1 arom. H); 7.63 (*t*,  $J = 7.1$ , 1 arom. H); 7.46–7.21 (*m*, 4 arom. H); 5.25 (br. *t*,  $J = 7.8$ ,  $\text{H}_b$ ); 3.50 (*d*,  $J = 7.8$ ,  $\text{CH}_2$ ); 2.68 (*s*, MeCO); 1.66 (*s*, Me); 1.54 (*s*, Me).  $^1\text{H-NMR}$  (250 MHz,  $\text{CDCl}_3$ ): (*Z*)-Isomer: 8.30 (*d*,  $J = 8.3$ , 1 arom. H); 7.86 (*d*,  $J = 7.6$ , 1 arom. H); 7.65 (*t*,  $J = 7.9$ , 1 arom. H); 7.61 (*s*,  $\text{H}_a$ ); 7.44–7.18 (*m*, 5 arom. H); 5.33 (br. *t*,  $J = 7.6$ ,  $\text{H}_b$ ); 3.63 (*d*,  $J = 7.6$ ,  $\text{CH}_2$ ); 1.80 (*s*, MeCO); 1.74 (*s*, Me); 1.69 (*s*, Me).  $^{13}\text{C-NMR}$  (62.90 MHz,  $\text{CDCl}_3$ ): (*Z*)-Isomer: 185.4 (CO); 170.2 (CO); 150.0 (C); 139.1 (C); 137.5 (C); 136.3 (CH); 135.8 (C); 134.1 (C); 129.7 (CH); 129.1 (CH); 129.0 (CH); 126.0 (CH); 124.8 (CH); 124.1 (CH); 123.7 (C); 119.9 (CH); 118.2 (CH); 117.7 (CH); 31.8 ( $\text{CH}_2$ ); 25.6 (Me); 24.8 (Me); 17.8 (Me). MS: 386.5 ( $[M + \text{Na}]^+$ ). Anal. calc. for  $\text{C}_{22}\text{H}_{21}\text{NO}_2\text{S}$ : C 72.70, H 5.82, N 3.85; found: C 72.42, H 5.67, N 3.74.

*1-(7,13-Dihydro-7,7-dimethylindolo[2',3':5,6]pyrano[3,4-*c*]quinolin-13-yl)ethan-1-one* (**16**). To a soln. of **4** (133 mg, 0.31 mmol) in  $\text{CCl}_4$  (10 ml) at reflux was added *N*-bromosuccinimide (NBS; 55 mg, 0.31 mmol). The final mixture was stirred for 45 min at reflux. After cooling, the solvent was removed *in vacuo*, and  $\text{CH}_2\text{Cl}_2$  was added (10 ml). Then,  $\text{Et}_3\text{N}$  (0.5 ml, 3.6 mmol) was added, and the soln. was stirred for 2 h at reflux. The latter was poured into  $\text{H}_2\text{O}$  (10 ml). The medium was acidified with 37% HCl (1 ml) and extracted twice with  $\text{CH}_2\text{Cl}_2$  (2  $\times$  10 ml). The org. layer was washed with brine, then dried ( $\text{MgSO}_4$ ), and evaporated *in vacuo*. The crude residue was purified by CC (silica gel; petroleum ether/AcOEt 8 : 2) to afford **16** (79 mg, 75%) as an oil [7].

*1-(7,13-Dihydro-7,7-dimethylbenzo[5,6][2]benzopyrano[4,3-*b*]indol-13-yl)ethan-1-one* (**17**). According to the procedure for the synthesis of **16**, **17** was prepared from **5** in 50% yield. Oil. IR (film): 3057, 2929, 1701, 1453, 1277, 1107, 751.  $^1\text{H-NMR}$  (250 MHz,  $\text{CDCl}_3$ ): 8.45–8.39 (*m*, 2 arom. H); 7.80 (br. *d*,  $J = 7.8$ , 1 arom. H); 7.73 (*d*,  $J = 8.5$ , 1 arom. H); 7.65 (br. *d*,  $J = 7.0$ , 1 arom. H); 7.56–7.41 (*m*, 4 arom. H); 7.35 (*t*,  $J = 7.5$ , 1 arom. H); 2.16 (*s*, Me); 2.03 (*s*, Me); 1.66 (*s*, Me).  $^{13}\text{C-NMR}$  (62.9 MHz,  $\text{CDCl}_3$ ): 172.7 (CO); 144.1 (C); 138.0 (C); 133.6 (C); 133.5 (C); 128.6 (CH); 127.4 (CH); 127.0 (CH); 126.9 (CH, C); 126.2 (CH); 125.1 (CH); 123.9 (CH); 122.5 (C); 122.4 (C); 121.8 (CH); 120.3 (C); 118.0 (CH); 116.3 (CH); 81.9 (C); 27.4 (Me); 27.3 (Me); 24.6 (Me). MS: 342 ( $[M + 1]^+$ ). Anal. calc. for  $\text{C}_{25}\text{H}_{19}\text{NO}_2$ : C 80.92, H 5.61, N 4.10; found: C 81.27, H 5.43, N 3.95.

Crystallographic data for the structures **2a**, **3a**, and **4** (Table) have been deposited with the Cambridge Crystallographic Data Centre as deposition No CCDC-203686, CCDC-203687, and CCDC-203688. Copies of the data can be obtained, free of charge, on application to the CCDC, 12 Union Road, Cambridge CB2 1EZ (fax: +44(1223) 336 033; e-mail: ccdc.cam.ac.uk).

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Table 1. Crystallographic Data of Compounds **2a**, **3a**, and **4**

| Parameters                               | <b>2a</b>                                                                                                                             | <b>3a</b>                                                                                                                               | <b>4</b>                                                                                                                                             |
|------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Empirical formula                        | C <sub>22</sub> H <sub>21</sub> N <sub>2</sub> O <sub>3</sub>                                                                         | C <sub>22</sub> H <sub>21</sub> N <sub>2</sub> O <sub>3</sub>                                                                           | C <sub>27</sub> H <sub>30</sub> N <sub>2</sub> O <sub>3</sub>                                                                                        |
| Formula weight [g · mol <sup>-1</sup> ]  | 347.40                                                                                                                                | 347.40                                                                                                                                  | 450.53                                                                                                                                               |
| Temp. [K]                                | 296(2)                                                                                                                                | 296(2)                                                                                                                                  | 296(2)                                                                                                                                               |
| Crystal size [mm]                        | 0.50 × 0.37 × 0.25                                                                                                                    | 0.37 × 0.10 × 0.05                                                                                                                      | 0.30 × 0.15 × 0.10                                                                                                                                   |
| Wavelength [Å]                           | 1.54178                                                                                                                               | 1.54178                                                                                                                                 | 1.54180                                                                                                                                              |
| Crystal system                           | monoclinic                                                                                                                            | monoclinic                                                                                                                              | triclinic                                                                                                                                            |
| Space group                              | <i>P</i> 2 <sub>1</sub> / <i>c</i>                                                                                                    | <i>P</i> 2 <sub>1</sub> / <i>n</i>                                                                                                      | <i>P</i> $\bar{1}$                                                                                                                                   |
| Goodness-of-fit on <i>F</i> <sup>2</sup> | 1.049                                                                                                                                 | 1.049                                                                                                                                   | 1.035                                                                                                                                                |
| Unit-cell parameters                     | <i>a</i> = 8.793(2) Å<br><i>b</i> = 15.462(4) Å<br><i>c</i> = 12.743(8) Å<br><i>α</i> = 90°<br><i>β</i> = 91.39(3)°<br><i>γ</i> = 90° | <i>a</i> = 10.523(3) Å<br><i>b</i> = 17.839(2) Å<br><i>c</i> = 10.586(3) Å<br><i>α</i> = 90°<br><i>β</i> = 116.06(2)°<br><i>γ</i> = 90° | <i>a</i> = 11.063(1) Å<br><i>b</i> = 11.138(2) Å<br><i>c</i> = 11.222(1) Å<br><i>α</i> = 103.88(1)°<br><i>β</i> = 90.98(1)°<br><i>γ</i> = 119.26(1)° |
| Volume [Å <sup>3</sup> ]                 | 1732.0(12)                                                                                                                            | 1785.2(7)                                                                                                                               | 1156.3(3)                                                                                                                                            |
| Z, calc. density                         | 4, 1.332 mg/m <sup>3</sup>                                                                                                            | 4, 1293 mg/m <sup>3</sup>                                                                                                               | 2, 1237 mg/m <sup>3</sup>                                                                                                                            |
| Absorption coefficient                   | 0.711 mm <sup>-1</sup>                                                                                                                | 0.689 mm <sup>-1</sup>                                                                                                                  | 0.641 mm <sup>-1</sup>                                                                                                                               |
| <i>F</i> (000)                           | 736                                                                                                                                   | 736                                                                                                                                     | 460                                                                                                                                                  |
| <i>θ</i> Range for data collection       | 4.50 to 64.92°                                                                                                                        | 4.94 to 54.94°                                                                                                                          | 4.11 to 54.95°                                                                                                                                       |
| Index ranges                             | – 10 ≤ <i>h</i> ≤ 10<br>0 ≤ <i>k</i> ≤ 18<br>0 ≤ <i>l</i> ≤ 14                                                                        | – 11 ≤ <i>h</i> ≤ 10<br>0 ≤ <i>k</i> ≤ 18<br>0 ≤ <i>l</i> ≤ 11                                                                          | – 11 ≤ <i>h</i> ≤ 11<br>– 11 ≤ <i>k</i> ≤ 11<br>0 ≤ <i>l</i> ≤ 11                                                                                    |
| Reflections coll.                        | 2898                                                                                                                                  | 2230                                                                                                                                    | 2890                                                                                                                                                 |
| Max. and min. transmission               | 0.8424 and 0.7177                                                                                                                     | 0.9663 and 0.7845                                                                                                                       | 0.9387 and 0.8310                                                                                                                                    |
| Refinement method                        | full-matrix<br>least-squares on <i>F</i> <sup>2</sup>                                                                                 | full-matrix<br>least-squares on <i>F</i> <sup>2</sup>                                                                                   | full-matrix<br>least-squares on <i>F</i> <sup>2</sup>                                                                                                |
| Data, restraints, parameters             | 2898, 0, 248                                                                                                                          | 2230, 3, 246                                                                                                                            | 2890, 0, 302                                                                                                                                         |
| Final <i>R</i> indices                   | <i>R</i> <sub>1</sub> = 0.0570,<br><i>wR</i> <sub>2</sub> = 0.1420                                                                    | <i>R</i> <sub>1</sub> = 0.0535,<br><i>wR</i> <sub>2</sub> = 0.1085                                                                      | <i>R</i> <sub>1</sub> = 0.0433,<br><i>wR</i> <sub>2</sub> = 0.1000                                                                                   |
| <i>R</i> Indices (all data)              | <i>R</i> <sub>1</sub> = 0.0906,<br><i>wR</i> <sub>2</sub> = 0.1691                                                                    | <i>R</i> <sub>1</sub> = 0.1046,<br><i>wR</i> <sub>2</sub> = 0.1349                                                                      | <i>R</i> <sub>1</sub> = 0.0776,<br><i>wR</i> <sub>2</sub> = 0.1196                                                                                   |
| Extinction coefficient                   | 0.0095(10)                                                                                                                            | 0.0039(4)                                                                                                                               | 0.0108(7)                                                                                                                                            |
| Largest diff. peak and hole              | 0.235 and – 0.239 e · Å <sup>-3</sup>                                                                                                 | 0.158 and – 0.179 e · Å <sup>-3</sup>                                                                                                   | 0.217 and – 0.149 e · Å <sup>-3</sup>                                                                                                                |

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