Cyclizations Initiated by a Pd^{2+}–Ag^{+} Mixed-Metal System

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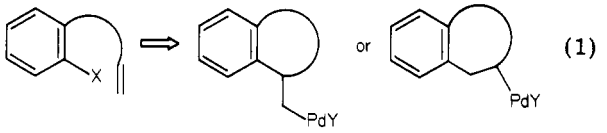
The mixed-metal system palladium chloride and silver fluoroborate initiated cyclization of an indole ring onto an olefin to form six- and seven-membered rings. The geometric dependence of the reaction was probed. Mechanistic considerations invoking either nucleophilic addition to a double bond or a Heck-type process were presented. The implications of this approach for the synthesis of Iboga alkaloids were considered. In ancillary work, the presence of a trimethylsilyl group on the nitrogen of indole effectively directed acylation to C(3).

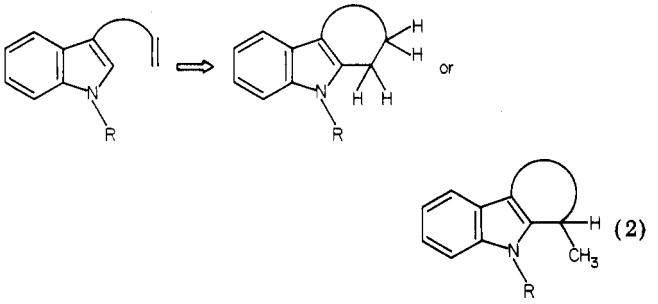
Introduction

The Heck arylation constitutes a powerful method for introduction of aryl groups via addition to olefins—a truly unique behavior.[1] While extensive examples of intermolecular cases abound, intramolecular versions (eq 1) were



(1)

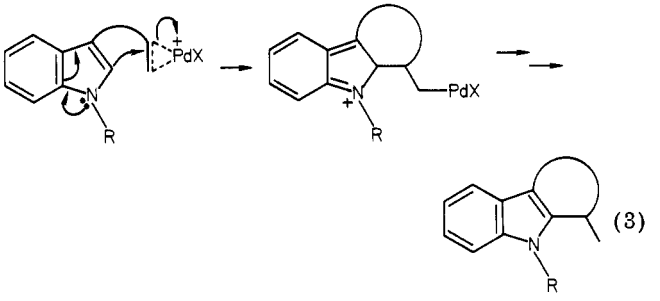
nonexistent until recently.[2,3] One difficulty is associated with regiochemical control in the palladation step which has been obviated by substituting the ortho position of the aromatic ring with halogen[2] or a metal.[3] As part of our program in the total synthesis of alkaloids,[4] we were most interested in a version of the arylation which did not rely on such a regiochemical control element.[5] We focused our attention on the problem outlined in eq 2. Regioselectivity



(2)

in the direct palladation of heteroaromatics should be higher.[6] Since the palladation reaction resembles electrophilic aromatic substitution[7] and 3-substituted indoles generally undergo such substitution in the 2-position,[8] a direct cyclization as illustrated in eq 2 appears reasonable.

Alternatively, a pathway for this reaction invoking nucleophilic attack of the electron-rich heteroaromatic ring on a palladium-complexed olefin as represented in eq 3 may be envisioned.



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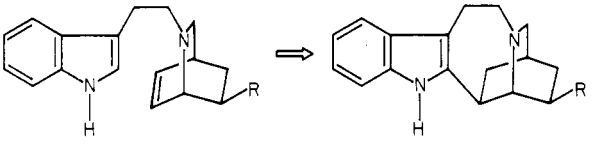
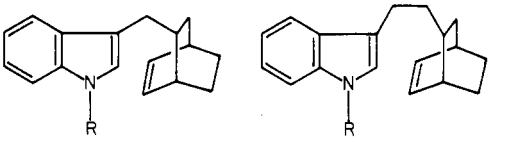
Initial studies were performed on isoquinuclidine (**1**) as a critical step in total syntheses of deethylibogamine,[4a] ibogamine,[4b] and catharanthine.[4c] Since the yields varied



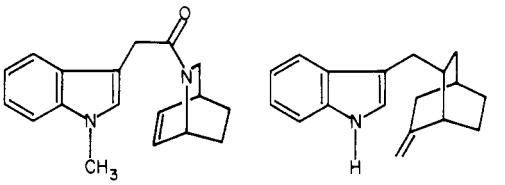
1

a, R = H; b, R = C_2H_5; c, R = $O_2CC(CH_3)_3$

from 20% to 45% and the isoquinuclidine nitrogen appeared to be a complicating factor, we chose substrates **2**–**5** to probe the steric and electronic factors of this cyclization.



2 **3**



4 **5**

a, R = H; b, R = CH_3

Synthesis of Substrates

The basic strategy for the synthesis of the requisite substrates uses the known Diels–Alder adduct **6**[9] (eq 4).

(1) For reviews, see: Tsuji, J. "Organic Synthesis with Palladium Compounds"; Springer Verlag: Berlin, 1980. Heck, R. F. *Acc. Chem. Res.* **1979**, *12*, 146. Trost, B. M. *Tetrahedron* **1977**, *33*, 2615. Heck, R. F. *Org. React.*, in press.

(2) Melpolder, J. B.; Heck, R. F. *J. Org. Chem.* **1976**, *41*, 265. Ban, Y.; Wakamatsu, T.; Mori, M. *Heterocycles* **1977**, *7*, 1711. Terpko, M. P.; Heck, R. F. *J. Am. Chem. Soc.* **1979**, *101*, 5281. Mori, M.; Ban, Y. *Tetrahedron Lett.* **1979**, 1133. Odle, R.; Blevins, B.; Ratcliff, M.; Hegedus, L. S. *J. Org. Chem.* **1980**, *45*, 2709.

(3) Trost, B. M.; Tanigawa, Y. *J. Am. Chem. Soc.* **1979**, *101*, 4748.

(4) (a) Trost, B. M.; Genet, J. P. *J. Am. Chem. Soc.* **1976**, *98*, 8516. (b) Trost, B. M.; Godleski, S. G.; Genet, J. P. *Ibid.* **1978**, *100*, 3930. (c) Trost, B. M.; Godleski, S. G.; Belletire, J. L. *J. Org. Chem.* **1979**, *44*, 2052.

(5) Fujiwara, Y.; Moritani, I.; Danno, S.; Asano, R.; Teranishi, S. *J. Am. Chem. Soc.* **1969**, *91*, 7166. Asano, R.; Moritani, I.; Sonoda, A.; Fujiwara, Y.; Teranishi, S. *J. Chem. Soc. C* **1971**, 3691. Moritani, I.; Fujiwara, Y. *Synthesis* **1973**, 524.

(6) Fugiwara, Y.; Mariyama, O.; Yoshidomi, M.; Taniguchi, H. *J. Org. Chem.* **1981**, *46*, 851.

(7) Danno, S.; Moritani, I.; Fujiwara, Y. *Tetrahedron* **1969**, *25*, 4815. Fujiwara, Y.; Asano, R.; Moritani, I.; Teranishi, S. *J. Org. Chem.* **1976**, *41*, 1681.

(8) Remers, W. A. *Chem. Heterocycl. Compd.* **1972**, *25*, 70.

(9) Skeda, R.; Tramposeh, O. *Chem. Ber.* **1942**, *75*, 1379. Running the Diels–Alder reaction in the presence of BCl_3 enhances the stereochemistry.

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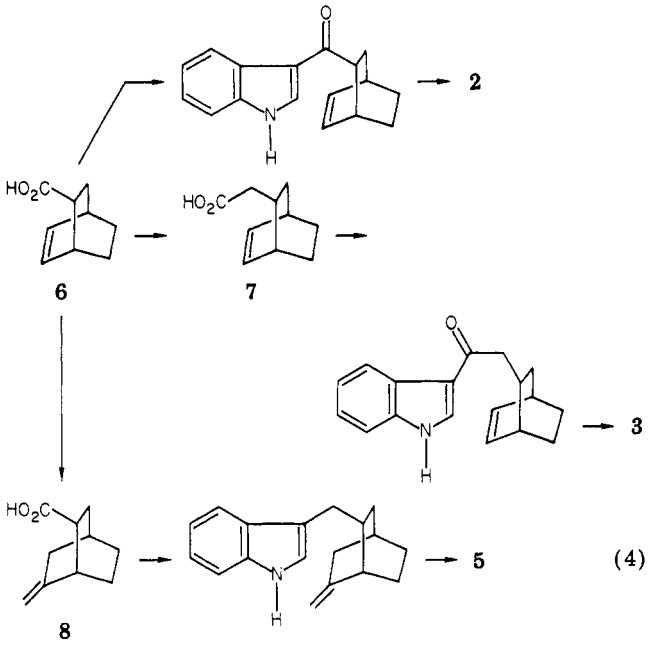
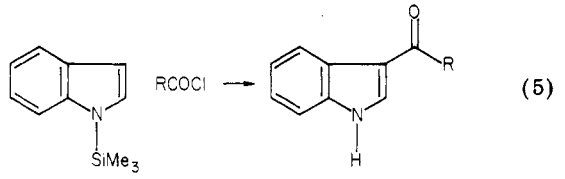


(4)

While details will be reported elsewhere, the general scheme involves acylation of *N*-(trimethylsilyl)indole with the acid chloride corresponding to **6**, **7**, or **8** (except in the last case where *N*-indolylmagnesium bromide was employed) followed by $LiAlH_4$ reduction. It is interesting to take note of high regioselectivity of acylation of *N*-(trimethylsilyl)indole for C(3)—an observation that should be generally useful (eq 5). The final substrate **4** was



(5)

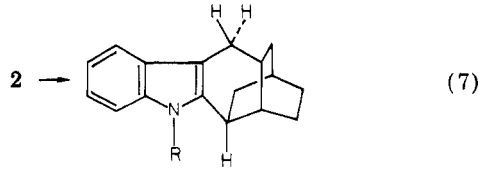
available by acylation of the known isoquinuclidine (**9**)[10] (eq 6). In the case of **5**, separation from a small amount

(6)

of the endocyclic olefin isomer was not possible, and the mixture was used.

Cyclization

Treatment of **2a** with 1.0 equiv of $PdCl_2$, 2.0 equiv of $AgBF_4$, and 1.0 equiv of triethylamine in refluxing acetonitrile followed by reductive workup gave **9a** in only 12–15% yields (eq 7). The identification of **9a** rests upon



(7)

9a, R = H
b, R = CH_3

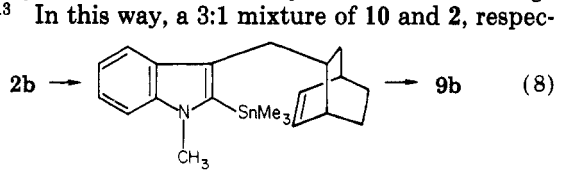
analytical and spectroscopic data. Combustion analysis and mass spectrometry establish the isomeric nature of **9a** compared to **2a**. That the 2-position of the indole and the olefin of **2a** have been modified is indicated by the disappearance of the ^1H absorptions at δ 6.8 (C(2), d, $J \sim 2$ Hz) and 6.14 and 6.24 (vinyl H). Further, the absorption at δ 2.39 (d, $J = 7$ Hz) for the 3-CH_2 group in **2a** has been replaced by the AB portion (δ 2.53 and 2.76, $J_{AB} = 15.6$, $J_{AX} = 4.8$, $J_{BX} = 1.6$ Hz) of an ABX pattern.

Attempted ring closure by catalysis with Lewis acids (boron trifluoride etherate, aluminum chloride, mercuric acetate, stannous or stannic chloride, zinc chloride, magnesium bromide, titanium tetrachloride, lead tetraacetate) gave only a regioisomeric mixture of aromatic ring acetoxylated products (from mercuric acetate or lead tetraacetate) or a complex mixture in which **9a** could not be detected in more than trace amounts. Other mixed-metal systems containing palladium (with stannic chloride, boron trifluoride, titanium trichloride, stannous chloride, aluminum chloride) were similarly undisposed toward catalysis of the desired cyclization.

Visual following of the cyclization reaction revealed that the original yellow, heterogeneous reaction mixture that formed upon mixing the substrate with the palladium and silver salts blackened and deposited palladium metal upon addition of triethylamine. It was also felt that excess silver salts might increase the electrophilicity of the mixed-metal system so as to destroy its selectivity. Indeed, premixing 1.1 equiv of palladium(II) chloride and 1.1 equiv of silver fluoroborate in acetonitrile for 2 h, adding the substrate **2a**, and stirring at ambient temperature for 40 h gave, after reductive workup, a crude solid in 75% yield consisting of an approximately 5:1 mixture of the pentacyclic product **9a** and the dihydro starting material. Recrystallization from hexane gave pure **9a**, mp 204–206 °C, in 61% yield. To verify that the liberated HCl does not affect the reaction, repetition of the reaction in the presence of propylene oxide gave the pentacyclic product **9a** in 57% yield, insignificantly different from the yield in the absence of the epoxide.

The role of the mixed-metal catalyst remains undefined. A reasonable rationale involves enhancement of the electrophilicity of the palladium chloride in the presence of silver ion. Use of a more electrophilic palladium salt might preclude the need for the silver salt. While palladium trifluoroacetate did effect cyclization of **2** to **9**, the yield was a disappointing 10%. Palladium acetate failed to effect cyclization at all.

The *N*-methyl analogue **2b** behaved similarly—producing its corresponding cyclization product **9b** in 60% yield under similar conditions. Thus, initial N-palladation followed by rearrangement to C(2) can be ruled out.[11] For examination of the addition step independent of the palladation step, the trimethylstannyl derivative **10** was formed by lithiation[12] followed by metal-metal exchange (eq 8).[13] In this way, a 3:1 mixture of **10** and **2**, respec-



(8)

10

tively, was obtained and used as such. Simple addition of 1.1 equiv of palladium chloride to **10** at room temperature and normal reductive workup led to the cyclized product **9b** in 67% yield (corrected for the 3:1 ratio of **10**

(10) Cava, M. P.; Wilkins, C. K., Jr.; Dalton, D. R.; Bessho, K. *J. Org. Chem.* **1965**, *30*, 3772.

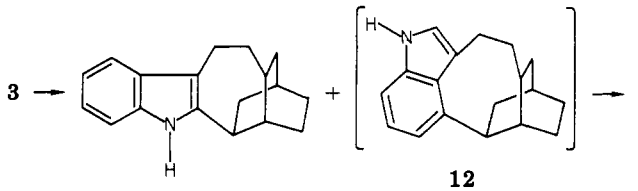
(11) Cf. ref 4a.

(12) For lithiation of *N*-methylindole, see: Shirley, D. A.; Roussel, P. A., *J. Am. Chem. Soc.* **1953**, *75*, 375. Sundberg, R. J.; Parton, R. L. *J. Org. Chem.* **1976**, *41*, 163. In our experiments TMEDA was employed as solvent and activator.

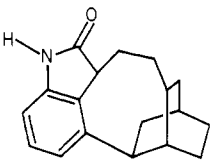
(13) Cf. ref 3. Also see: Hcek, R. F. *J. Am. Chem. Soc.* **1968**, *90*, 5542.

to **2b** of the starting material). The **2b** that was present was unreactive toward the palladium salt as shown by the fact that it was recovered as its dihydro derivative in 22% yield (88% recovery)—a consequence of its reduction during workup. Independent treatment of **2b** with palladium chloride as its bis(acetonitrile) complex verified the failure of **2b** to participate directly in cyclizations under the conditions in which the tin derivative reacts completely.

Variation of ring size has a dramatic effect on the cyclization. Treatment of **3** with 1.0 equiv each of palladium chloride and silver fluoroborate in identical fashion to **2** led to a 20% yield of the pentacyclic product **11** in addition to 12% of the oxindole **13** (eq 9). The latter presumably



11 **12**



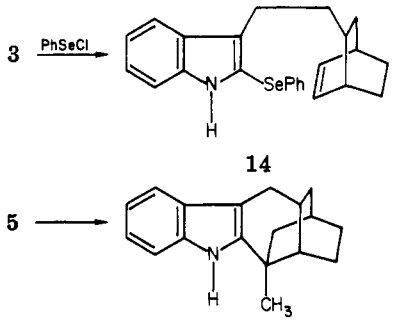
13 (9)

arises from the air oxidation of the initially formed product **12**. The ratio of **11** to **13** varied with reaction temperature (0 °C, 3.5; 25 °C, 1.7; 35 °C, 0.63) while the combined yield remained relatively constant (30–36%).

Spectroscopic data confirm the structural assignments. Mass spectroscopy established that **11** was isomeric with **3**. The absorptions for the proton at C(2) (δ 6.82) and the olefinic protons (δ 6.07 and 6.19) in **3** have disappeared, and the benzylic-type methylene absorption at 2.71 changes from a triplet (J = 7.8 Hz) to a complex AB portion of an ABXY pattern at δ 2.82–2.89. For the byproduct, mass spectroscopy establishes a formula of $C_{18}H_{21}NO$. The oxindole structure was suggested by a carbonyl stretch in the IR spectrum at 1730 cm^{-1} [14] and NH absorption at 3170 cm^{-1}. The N–H absorption in the NMR spectrum appeared at δ 9.70 (exchangeable with D_2O), considerably downfield from the simple indole systems (δ 7.5–8.0). The aromatic region of the proton NMR spectrum showed only three contiguous aromatic protons (δ 7.15, dd, J = 8.1, 8.0 Hz; 7.40, d, J = 8.1 Hz; 8.04, d, J = 8.1 Hz).

Because of the difficulties encountered in obtaining high yields of stannylated indoles, alternative group transfer metals were considered in this case. Palladium-catalyzed arylations with diphenyl selenide[15] initiated examination of the 2-benzeneselenenyl derivative **14** which forms in high yield upon treatment of **3** with benzeneselenenyl chloride in benzene containing triethylamine. Unfortunately, transmetalation to palladium and consequently cyclization failed.

In examination of the geometrical dependence of the cyclization, substrate **5** was subjected to the cyclization conditions (eq 10). Most rewardingly, this palladium-initiated cyclization to **15** was the most efficient of all—84%.



14

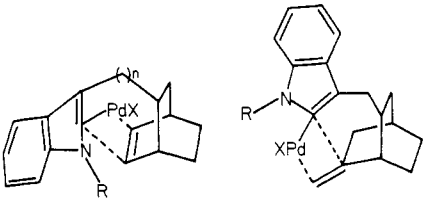
15 (10)

It was repeated in the presence of propylene oxide to give **15** in 79% yield to verify that the liberated HCl did not affect the reaction. Considering that this case most closely resembles the type of cyclization desired in our projected synthesis of catharanthine, this result was most gratifying.

We extended our studies to the amide **4** in order to determine if a less basic nitrogen would substitute for the basic nitrogen of **1a**. Unfortunately, no cyclization products were obtained from any cyclization conditions.

Discussion

The palladium(2+) cyclization clearly shows a preference for six-membered ring formation over seven. Assuming a Heck type of mechanism, it implies that a bicyclo[4.2.0] type transition state (i.e., **16**, n = 1) is preferred over a



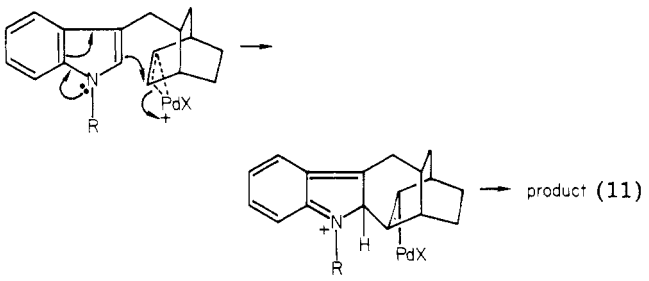
16 **17**

bicyclo[5.2.0] type (i.e., **16**, n = 2). On the other hand, models indicate the exo-type array as shown in **17** is geometrically less strained than the endo-type array as in **16**. Indeed, the cyclization of **5** was the most favorable.

The palladation step appears to be the source of most complications, as suggested by the following observations. First, the generation of the organopalladium species from the tin derivative leads to particularly facile cyclization. Second, in the case of **3**, the product mixture can be interpreted as arising from indiscriminate palladation, with **11** arising from palladation at C(2) and **13** from palladation at C(4). The temperature dependence of the ratio of these two products supports this view. Further, 50% of the product appears to be oligomeric. If palladation occurs at C(5) or C(6) or C(7), only oligomeric products can arise. The ratio of products arising from attack at C(5) vs. C(4) is consistent with the normal reactivity patterns for 3-substituted indoles.[16] On the other hand, the greater competition for palladation in the benzene ring of the indole for **3** compared to **2** or **5** is difficult to comprehend at the present time. Further, the fact that mercuration of 3-methylindole is specific for C(2) contributes to the confusion.[17] One possible rationale would be a divergence in mechanism between **2** and **5** on the one hand and **3** on the other. Formation of an (olefin)palladium(2+) complex would likely be kinetically faster than aromatic palladation.

(14) Kellie, A. E.; O'Sullivan, D. G.; Sadler, P. W. *J. Chem. Soc.* **1956**, 3809.
(15) Kawamura, T.; Kikukawa, K.; Takagi, K.; Matsuda, M. *Bull. Chem. Soc. Jpn.* **1977**, *50*, 2021.
(16) Noland, W. E.; Smith, L. R.; Johnson, D. C. *J. Org. Chem.* **1963**, *28*, 2262. Brown, K.; Katritzky, A. R. *Tetrahedron Lett.* **1964**, 803. Noland, W. E.; Smith, L. R.; Rush, K. R. *J. Org. Chem.* **1965**, *30*, 3463. Berti, G.; DaSettimo, A.; Nannipeiri, E. *J. Chem. Soc. C* **1968**, 2145.
(17) Mingoia, Q. *Gazz. Chim. Ital.* **1930**, *60*, 509. Ramachandran, L. K.; Witkop, B. *Biochem. J.* **1964**, *3*, 1603.

It might then be argued that the favorability of six-membered ring formation in the cases of **2** and **5** leads to trapping of this kinetically formed complex by the nucleophilic indole ring (eq 11) faster than rearrangement



to the arylpalladium species. Such palladium-assisted nucleophilic attack by carbon nucleophiles is precedented.[18] Attempts to explore this suggestion by determining the stereochemistry of the C–Pd bond by quenching with $NaBD_4$ were thwarted by the complexity of the NMR spectra of the products. In the case of **3** where such trapping forms a seven-membered ring, the (olefin)palladium complex is not rapidly trapped but leads to cyclization only after ring palladation. The nature of the product mixture and the earlier work in the isoquinuclidine series support the view that seven-membered ring formation does indeed arise from a Heck-type process. It does indicate that, at least in this case, palladation is not regioselective. The resolution of this fascinating dichotomy must await further exploration. It is noteworthy that these cyclizations proceed in substantially higher yields than the intermolecular versions.[6]

The failure of **4** to cyclize by either mechanism is expected on geometric grounds. The planarity of the isoquinuclidine nitrogen forces the indole nucleus far away from the olefin, thereby precluding cyclization.

Experimental Section

General. All reactions were run under a positive pressure of dry nitrogen unless otherwise noted. Anhydrous reactions were performed in flame-dried glassware cooled under a stream of nitrogen. Anhydrous solvents were transferred via oven-dried syringe or cannula. Solvents were distilled before use: dimethylformamide (DMF), acetonitrile, dichloromethane, chloroform, pyridine, hexane, toluene, and triethylamine from calcium hydride; diethyl ether, tetrahydrofuran (THF), and benzene from benzophenone ketyl. Thionyl chloride was distilled from triphenyl phosphite; oxalyl chloride from potassium carbonate; chlorotrimethylsilane from tri-*n*-butylamine. Other reagents were used as obtained commercially. The term "in vacuo" refers to removal of solvent on a Büchi–Brinkman Rotoevaporator at water aspirator pressure. The term "drying of solvents" refers to stirring over anhydrous magnesium sulfate (or, if specifically noted, another anhydrous desiccant) for removal of water as the hydrate salt. Silica gel (Merck 60-PF 254) was used for analytical and all preparative (1.5 mm thick) thin-layer chromatography (TLC) and was activated by heating at 120 °C for 2 h before use. Typical loadings on preparative plates were less than 50 mg on 20 × 10 cm, 50–200 mg on 20 × 20 cm, and 200–500 mg on 20 × 40 cm. Column chromatography was carried out with Grace (grade 62, 60–200 mesh) silica gel and Fisher (60–200 mesh) Florisil adsorbent. Removal of material from silica gel (TLC) was accomplished by successive washings with chloroform or ethyl acetate. Medium-pressure liquid chromatography (MPLC) was carried out on a Lobar prepacked size B (310-25) LI Chroprep S:60 column (40–63 μm) from EM Reagents; a model RRP lab pump (FMI Corp.) to provide pressures of 35–50 psi was used. Melting points were obtained on a Thomas-Hoover apparatus in open capillary tubes and are uncorrected. Boiling points are uncorrected.

Proton (^1H) NMR spectra were determined in the indicated solvent on a Bruker WH-270 (270 MHz) spectrometer. Chemical shifts are reported in δ units, parts per million (ppm) downfield from tetramethylsilane (Me_4Si). Splitting patterns are designated as s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; with the prefix br indicating a broadened signal. Coupling constants are reported in hertz (Hz). Infrared spectra (IR) were determined on a Beckman AccuLab 7 or a Perkin-Elmer 267 instrument and are reported in cm^{-1}. Mass spectra (MS) were obtained on an AEI-902 instrument at an ionizing current of 98 mA and an ionizing voltage of 70 eV unless otherwise indicated. Data are reported as *m/e* (%). Microanalyses were performed by Spang Microanalytical Laboratories, Eagle Harbor, MI.

2-*syn*-(3-Indolemethyl)bicyclo[2.2.2]oct-5-ene (2a). Treatment of 1.52 g (10 mmol) of acid **6**[9] with 1.78 g of thionyl chloride (15 mmol, 1.17 mL) neat, at ambient temperature with stirring, resulted in dissolution of the solid acid over a few minutes and a steady evolution of gas from the reaction vessel. After 1 h the excess thionyl chloride was removed in vacuo (18 torr followed by 0.05 torr) to yield the acid chloride as a light yellow oil. Kugelrohr distillation (70 °C, 0.5 torr) gave a colorless oil (1.71 g, 100%).

The acid chloride was dissolved in 125 mL of dry methylene chloride and cooled with stirring, to 0 °C. Magnesium bromide solution (5.38 mL of 1.86 M solution in ether/benzene, 10 mmol) was added in a single portion via syringe, followed quickly by the addition of 2.46 g (13 mmol, 1.3 equiv) of *N*-(trimethylsilyl)indole in 5 mL of methylene chloride. The reaction was allowed to warm to room temperature, and after an additional 0.75 h of stirring, the mixture was cautiously worked up by the dropwise addition of 50 mL of saturated ammonium chloride solution. The organic material was diluted with 200 mL of ethyl acetate and washed with two 100-mL ammonium chloride and one 100-mL brine solutions. Drying ($MgSO_4$) followed by solvent removal in vacuo yielded the crude oxoindole as a highly crystalline, white solid (2.41 g, 96%) after trituration with 50% hexane/ether (2 × 40 mL) with mp 220–228 °C dec.

The oxoindole was stirred with 60 mL of dry ether and cooled to 0 °C. To this mixture was added 950 mg (25 mmol, 10 hydride equiv) of lithium tetrahydroidoaluminate in small portions over 10–15 min. After 0.5 h the reaction was warmed to room temperature and stirred for 6 h. Workup was achieved by cautious destruction of remaining active hydride in the normal manner (see general procedure) and washing of the aluminum salts with 4 × 75 mL of ethyl acetate. Drying of the organic layers ($MgSO_4$) followed by in vacuo solvent removal yielded 1.8 g (79%) of a heavy oil which was chromatographed on a medium-pressure liquid chromatograph (40–45 psi, R_f 0.25, 20% ether/hexane) to give 1.66 g (70%) of a white solid, mp 82–84 °C. Small scale reactions (less than 1 g) gave yields in the range 55–62% when purified by preparative TLC.

NMR (270 MHz, $CDCl_3$): 0.86 (m, 1 H), 1.13 (dm, 2 H, J = 8.1 Hz and smaller), 1.35 (dm, 2 H, J = 7.2 Hz and smaller), 1.65 (ddd, 1 H, J = 2.9, 9.4, 9.4 Hz), 2.00 (br m), 2.34 (m, 2 H), 2.38–2.41 (series of m, 2 H), 6.14 (dd, 1 H, J = 7.9, 7.9 Hz), 6.24 (ddd, 1 H, J = 1.3, 7.9, 7.9 Hz), 6.79 (d, 1 H, J = 2.9 Hz), 6.99–7.12 (series of m, 2 H), 7.21 (d, 1 H, J = 7.8 Hz), 7.53 (d, 1 H, J = 7.8 Hz), 7.66 (br s, 1 H, N–*H*). IR ($CDCl_3$): 3480, 3420, 3060, 2940, 2864, 1723, 1705, 1624, 1460, 1425, 1383, 1362, 1345, 1270, 1205, 1235, 1179, 1096, 1022, 940, 873, 810, 780. MS: Calcd for $C_{17}H_{19}N$: 237.1516. Found: 237.1506, 238 (4.9), 237 (33.4), 157 (6.6), 156 (4.0), 147 (3.5), 131 (10.1), 130 (100), 129 (2.3), 128 (1.3), 117 (3.8), 103 (2.9), 89 (2.9), 79 (7.9), 77 (7.4), 57 (3.9), 56 (4.7), 41 (5.3), 40 (3.8). Anal. Calcd for $C_{17}H_{19}N$: C, 86.08; H, 8.02; N, 5.90. Found: C, 86.12; H, 7.94; N, 6.02.

2-*syn*-(*N*-Methyl-3-indolemethyl)bicyclo[2.2.2]oct-5-ene (2b). The 3-alkylindole from above (237 mg, 1.0 mmol) was dissolved in 15 mL of dry DMF. To this was added 80 mg (2.0 mmol) of a 60% dispersion in oil of sodium hydride. After being stirred at room temperature for 0.5 h the solution was cooled to 0 °C, and 426 mg (3.0 mmol, 0.187 mL) of distilled methyl iodide was added. Stirring was continued at ambient temperature for

(18) Hegedus, L. S.; Williams, R. E.; McGuire, M. A.; Hayashi, T. *J. Am. Chem. Soc.* **1980**, *102*, 4973. Hirai, K.; Ishii, N.; Suzuki, H. *Chem. Lett.* **1979**, 1113. Holton, R. A.; Kjonaas, R. A. *J. Am. Chem. Soc.* **1977**, *99*, 4177. Stille, J. K.; Fox, D. B. *Ibid.* **1970**, *92*, 1274. Johnson, B. F. G.; Lewis, J.; White, D. A. *Ibid.* **1969**, *91*, 5186. Takahashi, H.; Tsuji, J. *Ibid.* **1968**, *90*, 2387.

6 h and the solution was diluted with 125 mL of ether and washed with 5 × 100 mL of water. Drying was followed by in vacuo solvent removal and chromatography of the residual oil on silica gel (20 × 40 cm preparative plate, 20% ether/hexane, R_f 0.43 after two elutions) to give 203 mg (81%) of the product as a colorless, heavy oil.

NMR (270 MHz, $CDCl_3$): 0.90 (dm, 1 H, J = 12.1 Hz and smaller), 1.22 (m, 2 H), 1.43 (m, 2 H), 1.74 (ddd, 1 H, J = 2.6, 9.4, 9.4 Hz), 2.07 (m, 1 H), 2.40–2.56 (m, 4 H), 3.70 (s, 3 H), 6.22 (t, 1 H, J = 7.8 Hz), 6.31 (1 H, J = 1.1, 7.8 Hz), 6.75 (s, 1 H), 7.07 (ddd, 1 H, J = 1.5, 6.6, 8.2 Hz), 7.18 (dt, 1 H, J = 1.1, 8.2 Hz), 7.24 (dm, 1 H, J = 7.8 Hz and smaller), 7.58 (d, 1 H, J = 7.8 Hz). IR ($CDCl_3$): 3050, 2941, 2870, 1620, 1487, 1473, 1428, 1379, 1328, 1250, 1156, 1128, 1095, 1068, 1017, 918, 708, 652. MS: Calcd for $C_{18}H_{21}N$: 251.1673. Found: 251.1672, 252 (2.9), 251 (20.7), 170 (3.5), 145 (11.8), 144 (100), 143 (2.7), 129 (1.3), 91 (2.8), 85 (3.7), 79 (2.0), 77 (5.8), 57 (7.0), 55 (4.4), 44 (7.0), 43 (3.0), 41 (12.6), 40 (47.5), 39 (3.4).

2-*syn*-(β-3-Indoleethyl)bicyclo[2.2.2]oct-5-ene (3). The crystalline acid **7**[19] (3.32 g, 20 mmol) is dissolved in 200 mL of dry benzene. A slight excess of 60% sodium hydride dispersion (840 mg, 21 mmol) was added to the solution in small portions over 0.75 h. After being stirred for an additional 2 h, the heterogeneous sodium carboxylate was treated with 1.68 g (40 mmol) of anhydrous sodium fluoride, and 2.79 g (1.92 mL, 1.1 equiv) of oxalyl chloride (freshly distilled from sodium carbonate) was added in a single portion via syringe. After the vigorous evolution of gas ceased (ca. 0.5 h), the crude solution was filtered through a fritted glass funnel and 5.30 g (28 mmol, 1.4 equiv) of *N*-(trimethylsilyl)indole was added to the solution. After cooling to 10 °C and addition of 1.68 g (20 mmol) of sodium fluoride, 30 mmol (16.1 mL of a 1.86 M solution) of magnesium bromide in ether/benzene was added over ca. 5 min via syringe. The solution was stirred at 10 °C for 0.5 h and at ambient temperature for 3 h. Quenching was accomplished by cautious addition of 50 mL of aqueous ammonium chloride. Dilution with 20 mL of ethyl acetate was followed by washing with 3 × 100 mL of water and 200 mL of saturated sodium chloride. Drying was followed by in vacuo removal of solvent and trituration with 3 × 40 mL of 50% ether/hexane of the crude gum to give a white powder in ca. 50% yield (2.7 g); mp 168–174 °C dec. Spectral evidence (no C(3) proton of the indole at δ 6.4 as was very characteristic, a peak match in the mass spectrum for $C_{18}N_{19}NO$, and an IR carbonyl absorption at 1719) indicated that the slightly unstable powder is the 3-oxoindole.

Suspension of the white solid in 100 mL of dry ether at 0 °C was followed by addition of 1.14 g (30 mmol, 6 hydride equiv) of solid lithium tetrahydridoaluminate in small portions over 0.5 h. Stirring for 6 h at room temperature after the exotherm was complete was followed by cautious decomposition of excess hydride (general procedure). Washing of the aluminum salts with 4 × 75 mL of ether was followed by drying of the organic materials. Solvent removal in vacuo yielded a thick, brown oil which was distilled in a Kugelrohr apparatus (60 °C, 0.005 torr) to remove unreacted indole, and then chromatographed on a medium-pressure liquid chromatograph (see general procedure) with 30% ether/hexane (R_f 0.20 at 35 psi) to give 1.99 g (40%) of a white solid, mp 75–76 °C after recrystallization from hexane.

NMR (270 MHz, $CDCl_3$): 0.90 (dm, 1 H, J = 8.0 Hz and smaller), 1.23–1.82 (series of m, 8 H), 2.48 (br s, 2 H), 2.71 (t, 2 H, J = 7.8 Hz), 6.15 (t, 1 H, J = 7.2 Hz), 6.25 (t, 1 H, J = 7.2 Hz), 6.91 (s, 1 H), 7.13 (m, 2 H), 7.31 (d, 1 H, J = 7.7 Hz), 7.58 (d, 1 H, J = 7.7 Hz), 7.82 (br s, 1 H, N-*H*). IR ($CDCl_3$): 3479, 3045, 2940, 2863, 1705, 1457, 1422, 1378, 1355, 1338, 1292, 1250, 1227, 1093, 880 (broad), 862. MS: Calcd for $C_{18}H_{21}N$: 251.1673. Found: 251.1674, 252 (1.1), 251 (13.2), 144 (1.6), 143 (13.4), 131 (34.0), 130 (100), 129 (3.0), 118 (1.2), 117 (4.9), 115 (1.2), 110 (6.3), 103 (7.7), 91 (3.3), 88 (4.7), 86 (53.5), 85 (5.0), 84 (85.4), 80 (4.7), 79 (13.3), 77 (22.8), 51 (14.4), 49 (28.8), 47 (29.9), 44 (12.0), 41 (18.0), 40 (82.2), 35 (23.5). Anal. Calcd for $C_{18}H_{21}N$: C, 86.06; H, 8.37; N, 5.58. Found: C, 85.92; H, 8.44, N, 5.68.

2-*syn*-(3-Indolemethyl)-5-*exo*-methylenebicyclo[2.2.2]octane (5). Acid **8** (2.17 g, 13.1 mmol) was dissolved in 50 mL of dry benzene and stirred at room temperature. To this was added in small portions, over 0.5 h, 600 mg (15.0 mmol) of 60% sodium hydride dispersion in oil. After stirring for 2 h, 150 additional mL of benzene was added to the heavy suspension, and 1.78 g (1.22 mL, 14 mmol) of oxalyl chloride, freshly distilled from sodium carbonate, was added in a single portion via syringe to the rapidly stirred mixture. After being stirred in this manner for 0.5 h, a two-phase ethereal solution (75 mL) of 15 mmol of indolemagnesium bromide (freshly prepared from 1.76 g of indole and 8.1 mL of a 1.85 M solution of isopropylmagnesium bromide in ether) was added dropwise over ca. 5 min via syringe to the solution of the acid chloride. After the solution was stirred for 2.5 h at ambient temperature, the magnesium salts were cautiously decomposed via dropwise additon of 45 mL of saturated aqueous ammonium chloride. Dilution with 100 mL of ethyl acetate was followed by washing with 50 mL of 5% aqueous HCl and 2 × 100 mL of saturated ammonium chloride. Drying over $MgSO_4$ was followed by in vacuo removal of solvent to yield 4.04 g of a crude red oil. Trituration with ether (40 mL) yielded a white powder upon filtration, which was suspended in 100 mL of dry ether and stirred with cooling to 0 °C. Lithium tetrahydridoaluminate (760 mg, 20 mmol) was added in small portions to the solution and stirring was continued, with warming to room temperature, over 4.5 h. Cautious decomposition of excess hydride (see general procedure) and washing of the aluminum salts (3 × 50 mL of ethyl acetate) were followed by drying of the organic layers. Removal of solvent in vacuo followed by preparative TLC (20 × 40 cm plate, silica gel, two elutions with 2% triethylamine/30% ether/hexane) yielded a mixture (3:1) of the desired product and the endocyclic olefin isomer as a semisolid mass (104 mg, 3.2%) which could not be separated by chromatography or recrystallization.

NMR: 0.91–1.09 (2 × m, 1 H), 1.22 (m, 1 H), 1.39–1.85 (series of m with sharp d at 1.84, 5 H), 2.03–2.66 (series of m, 6 H), 4.76 (dd, 1 H, J = 2.2, 4.4 Hz), 4.80 (dd, 1 H, J = 2.2, 4.4 Hz), 5.92 (br d, 1 H, J = 6.6 Hz), 6.90 (m, 1 H), 7.12 (m, 2 H), 7.31 (dm, 1 H, J = 7.8 Hz and smaller), 7.61 (dm, 1 H, J = 7.8 Hz and smaller), 7.87 (br s, 1 H). IR ($CDCl_3$): 3477, 3058, 2925, 2853, 1650, 1452, 1417, 1350, 1335, 1223, 1084, 1009, 871, 839, 802, 700 (br). MS: Calcd for $C_{18}H_{21}N$: 251.1674. Found: 251.1674, 253 (0.5), 252 (11.0), 251 (72.6), 250 (1.8), 157 (6.2), 156 (16.7), 148 (1.6), 144 (1.2), 143 (1.8), 133 (2.7), 132 (1.2), 131 (15.2), 130 (100), 129 (2.9), 128 (1.3), 119 (3.0), 118 (35.6), 117 (2.3), 103 (2.3), 93 (3.4), 91 (2.1), 86 (5.2), 84 (10.3), 77 (6.1), 47 (1.3), 44 (1.4), 41 (1.7), 40 (2.1), 39 (1.3).

4,5-(2,3-Indolo)tricyclo[5.3.1.0^{3,8}]undecane (9a). Dry, crystalline silver tetrafluoroborate (214 mg, 1.1 mmol) and 195 mg of palladium chloride (1.1 mmol) were stirred together in 2 mL of dry acetonitrile for 1 h. At the end of this time 237 mg (1.0 mmol) of unsaturated indole **2a** in 3 mL of acetonitrile was added via syringe to the yellow-grey suspension of metal salts. Stirring was continued for 40 h at room temperature. At the end of this time, the solution was cooled to 0 °C and 3 mL of absolute ethanol was added. Sodium borohydride (38 mg, 1.0 mmol) was then added in very small portions over 0.75 h to the chilled suspension. After addition was complete, the mixture was stirred for 1 h at 0 °C, diluted with 25 mL of ether, and stirred for 2 h at ambient temperature. Filtration through filter cel to remove the precipitate was followed by dilution to 100 mL with ether, washing with 75 mL of 2% aqueous HCl solution, and drying. Removal of solvent in vacuo yielded 175 mg (74%) of a white solid which was mostly the desired pentacyclic product. Recrystallization from hexane yielded the pure product as a white solid, mp 204–206 °C, 144 mg (61%).

NMR (270 MHz, $CDCl_3$): 1.20 (dd, 1 H, J = 12.8, 6.6 Hz), 1.43–1.58 (m, 4 H), 1.66–1.86 (m, 5 H), 2.20 (m, 1 H), 2.53 (dd, 1 H, J = 15.6, 1.6 Hz), 2.76 (dd, 1 H, J = 15.6, 4.8 Hz), 2.84 (br d, 1 H, J = 10.6 Hz), 7.03–7.13 (m, 2 H), 7.27 (d, 1 H, J = 7.7 Hz), 7.45 (d, 1 H, J = 7.7 Hz), 7.64 (br s, 1 H). IR ($CDCl_3$): 3465, 3255, 2928, 2864, 1790, 1465, 1383, 1332, 1306, 1350, 1239, 1098, 900 (br), 790–600 (br). MS: Calcd for $C_{17}H_{19}N$: 237.1519. Found: 237.1511, 240 (1.0), 239 (14.3), 238 (0.4), 237 (9.4), 180 (3.1), 167 (2.2), 156 (2.5), 131 (3.9), 130 (66.8), 57 (2.4), 55 (2.0), 44 (100), 43 (5.7), 41 (6.6), 40 (46.0), 39 (1.2). Anal. Calcd for $C_{17}H_{19}N$: C, 86.08; H, 8.02; N, 5.91. Found: C, 86.24; H, 7.88; N, 5.77.

4,5-(*N*-Methyl-2,3-indolo)tricyclo[5.3.1.0^{3,8}]undecane (9b). Palladium chloride (98 mg, 0.55 mmol) and 172 mg (0.88 mmol)

(19) Whitlock, H. W., Jr. *J. Am. Chem. Soc.* **1962**, *84*, 3412.

of silver fluoroborate were added separately to 3 mL of freshly distilled acetonitrile and stirred for 2 h. Starting material **2b** (125.5 mg, 0.50 mmol) in 2 mL of acetonitrile was added in a single portion, via syringe, to the stirred heterogeneous mixture. Stirring was continued for 80 h at ambient temperature. After cooling to 0 °C and addition of 3 mL of absolute ethanol the reaction was quenched with 38 mg (1.0 mmol) of sodium borohydride and added in very small portions over 1.5 h. Stirring for an additional 2 h at room temperature was followed by filtration through filter cel and washing of the salts with 25 mL of ether. In vacuo removal of solvent was followed by chromatography of the residual material on silica gel (TLC, 15% Et_2O/hexane, two elutions, R_f 0.75) to yield the pentacyclic product as a heavy oil (76.1 mg, 61%).

NMR: 1.17 (dd, 1 H, J = 13.4, 6.8 Hz), 1.35 (br d, 1 H, J = 12.5 Hz and smaller), 1.50 (m, 1 H), 1.54 (m, 2 H), 1.64–1.88 (series of m, 5 H), 2.19 (m, 1 H), 2.54 (dd, 1 H, J = 1.8, 15.5 Hz), 2.76 (dd, 1 H, J = 4.6, 15.5 Hz), 2.90 (dd, 1 H, J = 3.3, 10.1 Hz), 3.59 (s, 3 H), 7.05 (ddd, 1 H, J = 1.1, 8.1, 6.6 Hz), 7.13 (dt, 1 H, 1.1, 8.1 Hz), 7.24 (d, 1 H, J = 8.1 Hz), 7.46 (d, 1 H, J = 7.7 Hz). IR ($CDCl_3$): 3052, 2920, 2855, 1734, 1616, 1580, 1469, 1418, 1377, 1357, 1322, 1290, 1244, 1181, 1010. MS: Calcd for $C_{18}H_{21}N$: 251.1673. Found: 251.1672, 253 (3.3), 252 (40.1), 251 (100), 250 (21.9), 195 (15.3), 194 (73.0), 182 (17.6), 181 (14.8), 180 (15.9), 171 (14.5), 170 (62.1), 167 (19.2), 158 (10.7), 145 (12.1), 144 (77.3), 85 (19.0), 83 (28.1), 47 (6.5), 42 (5.7), 41 (7.8), 40 (9.0). Anal. Calcd for $C_{18}H_{21}N$: C, 86.06; H, 8.37; N, 5.58. Found: C, 86.15; H, 8.32; N, 5.68.

2-*syn*-(*N*-Methyl-2-(trimethylstannyl)-3-indolemethyl)-bicyclo[2.2.2]oct-5-ene (10). Starting indole **2b** (100 mg, 0.40 mmol) was stirred in 5 mL of dry TMEDA. Addition of 0.80 mmol (0.485 mL of 1.65 M solution) of *n*-butyllithium in hexane dropwise over a 5-min period was followed by stirring for 1.5 h at ambient temperature. After cooling to 0 °C, 394 mg (1.2 mmol, 0.163 mL, 3.0 equiv) of iodotrimethylstannane was added via syringe. Stirring for 0.5 h was followed by dilution with 75 mL of ether, washing with 2 × 75 mL of saturated sodium bicarbonate solution, and drying of the organic layers. Removal of solvent in vacuo (aspirator pressure followed by oil pump at 0.005 torr) yielded a mixture of ca. 3:1 product stannylated at C(2) of the indole ring and starting material. A large singlet was seen at δ ~0.35 for the trimethylstannyl protons and the diminishment of the singlet at 6.8 due to the C-2 proton on the indole ring was noted. The product was unstable upon chromatography and was somewhat sensitive to light and air. The crude material was therefore carried directly to the cyclization reaction.

4,5-(2,3-Indolo)tricyclo[5.3.1.$0^{3,8}$]undecane from 10. To the crude stannylated material **10** at ambient temperature in 3 mL of distilled acetonitrile was added, in a single portion, 71 mg (0.40 mmol) of palladium chloride. As stirring was continued, the reddish color of insoluble palladium chloride faded over 0.5 h and was replaced by a murky black deposit of metal salts. After being stirred for 12 h, the solution was cooled to 0 °C, 2 mL of absolute ethanol was added, and workup was effected by addition of 38 mg (1.0 mmol) of sodium borohydride in very small portions over 1.5 h. Stirring for 2 h at room temperature was followed by dilution with 100 mL of ether, filtration through filter cel, and washing of saturated ammonium chloride solution. Drying followed by in vacuo solvent removal and charomatography (TLC on silica gel, 2% triethylamino/30% ether/hexane) yielded the cyclized product, R_f 7.2 after two elutions (48 mg, 67% from **2b** and corrected for degree of stannylation), and the dihydro derivative of **2b**, R_f 0.66 (24 mg, 25%).

4,5-(2,3-Indolo)tricyclo[6.3.1.$0^{3,9}$]dodecane (11) and 4,6-(5,3-2-Oxindolo)tricyclo[7.3.1.$0^{3,10}$]tridecane (13). Palladium chloride (71 mg, 0.40 mmol) and silver fluoroborate (78 mg, 0.40 mmol) were stirred together as a heterogeneous mixture in 2 mL of acetonitrile. After 2 h, starting indole **3** (100 mg, 0.40 mmol) in 2 mL of acetonitrile was added to the cooled (0 °C) solution over 15 min. The mixture was stirred for 10 h at 0 °C and then 30 h at 25 °C. After cooling to 0 °C, 2 mL of absolute ethanol was added and 19 mg (0.50 mmol) of sodium borohydride was added in very small portions over 1.5 h. Stirring for 1 h at room temperature was followed by dilution with 75 mL of ether and washing with 50 mL saturated ammonium chloride and 50 mL saturated sodium chloride solutions. Drying of solvent was followed by in vacuo concentration and chromatography (TLC on silica gel, 30% ether/hexane, 3% triethylamine) to give 9 mg of a fraction with R_f 0.8 and 28 mg of a product with R_f 0.55. Another band of 44 mg (R_f 0.40) was also isolated. The least polar band consisted of oxindole **13** (8%), while band 2 was pentacycle **11** (28%). Band 3 was tentatively identified (from mass spectral evidence) as a mixture of dimers. Running the reaction in an exactly identical manner save for the temperature gave varying amounts of the different products.

At 25 °C: Relative amounts of **11** and **13** were 20 mg (20%) and 13 mg (12%), respectively. Band 3 was obtained in the amount of 49 mg. **At 35 °C**: Relative amounts of **11** and **13** after chromatography were 12 (12%) and 21 mg (19%). Band 3 was obtained in the amount of 53 mg.

Compound 11: NMR (270 MHz, $CDCl_3$): 1.26 (m, 1 H), 1.58–1.76 (m, 8 H), 1.89 (m, 2 H), 2.03 (m, 1 H), 2.17 (m, 1 H), 2.82–2.89 (m, 3 H), 7.07 (m, 2 H), 7.24 (m, 1 H), 7.48 (m, 1 H), 7.65 (m, 1 H). IR ($CDCl_3$): 3475, 2933, 2870, 1467, 1338, 1243, 1183, 1166, 890 (br). MS: Calcd for $C_{18}H_{21}N$: 251.1673. Found: 251.1677, 251 (0.2), 214 (4.0), 202 (9.1), 167 (11.8), 143 (19.4), 142 (11.4), 141 (22), 137 (4.0), 111 (10), 107 (8.3), 89 (14.9), 88 (11.2), 87 (24.9), 79 (40.3), 78 (20), 77 (22.2), 55 (44.3), 51 (10.5), 43 (100), 42 (48.4), 41 (20.0), 40 (11.7), 39 (22.4), 36 (77.3).

Compound 13: NMR (270 MHz, $CDCl_3$): 1.23–1.8 (m, 6 H), 1.92 (m, 1 H), 2.11 (m, 2 H), 2.30 (m, 1 H), 2.62–2.75 (m, 3 H), 3.00–3.17 (m, 3 H), 3.95 (m, 1 H), 7.15 (t, 1 H, J = 8.1 Hz), 7.50 (dd, 1 H, J = 8.1, 0.8 Hz), 8.04 (dd, 1 H, J = 8.1, 0.8 Hz), 9.70 (s, 1 H). IR ($CDCl_3$): 3165, 2968, 2935, 2870, 1735, 1565, 1463, 1387, 1268, 1223, 1105, 1120, 980 (br), 810 (br), 702 (br), 650 (br). MS: Calcd for $C_{18}H_{21}NO$: 267.1622. Found: 267.1622, 267 (0.1), 242 (2.2), 212 (1.0), 189 (11.3), 141 (22), 134 (22), 133 (8.4), 131 (8.9), 101 (9.8), 89 (22.8), 87 (14.3), 79 (10.8), 77 (29.3), 68 (11.0), 43 (100), 42 (92.4), 41 (55.8), 40 (20), 39 (11.7), 36 (43.5).

2-*syn*-(β-(2-(Phenylselenyl)indole)ethyl)bicyclo[2.2.2]-oct-5-ene (14). Benzeneselenenyl chloride (95.7 mg, 0.50 mmol) was added to 3 mL of dry benzene. Starting material **3a** (125.5 mg, 0.50 mmol) in 2 mL of benzene was added in a single portion via syringe. After stirring for ~5 min, 60.7 mg (0.60 mmol, 1.2 equiv) of triethylamine was added dropwise via syringe. Immediate deposition of a white precipitate was seen, and the characteristic dark orange color due to benzeneselenenyl chloride was discharged to yield a pale yellow liquid solution. Workup after 5 min by pouring into 50 mL ether and washing with 2 × 75 mL of saturated sodium bicarbonate was followed by drying over sodium sulfate. In vacuo removal of solvent and chromatography (TLC on silica gel, 30% chloroform/hexane, two elutions) gave the product R_f 0.40 in nearly quantitative yield (279 mg) as a heavy gum.

NMR (270 MHz, $CDCl_3$): 0.83 (br d, 1 H, J = 10.7 Hz and smaller), 1.18–1.72 (series of m, 11 H), 2.43 (m, 2 H), 2.82 (t, 2 H, J = 7.9 Hz), 6.07 (t, 1 H, J = 7.7 Hz), 6.20 (ddd, 1 H, J = 1.1, 6.6, 7.7 Hz), 7.10–7.22 (br m, 5 H), 7.59 (d, 1 H, J = 7.7 Hz), 7.93 (br s, 1 H). IR ($CDCl_3$): 3420, 3045, 2920, 2850, 1635, 1451, 1408, 1398, 1292, 1278, 1250, 1227, 1090, 880, 851. MS: Calcd for $C_{24}H_{25}NSe$: 407.1166. Found: 407.1157, 409 (0.0), 407 (0.0), 286 (0.4), 250 (0.4), 206 (0.5), 130 (2.0), 88 (9.4), 86 (74.7), 84 (100), 82 (2.0), 69 (2.1), 51 (5.8), 49 (28.4), 47 (38.8), 44 (16.2), 43 (3.5), 40 (9.9), 37 (8.4), 36 (17.3), 35 (26.4).

3-*endo*-Methyl-4,5-(2,3-indolo)tricyclo[5.3.1.$0^{3,8}$]undecane (15). Palladium chloride (22 mg, 0.12 mmol) and silver fluoroborate (24 mg, 0.12 mmol) were added to 1.5 mL of dry acetonitrile. After 1.5 h of stirring, 30 mg of bicyclic indole **5** in 0.5 mL of acetonitrile was added in a single portion via syringe. Stirring for 40 h at ambient temperature was followed by cooling to 0 °C, addition of 1 mL of absolute ethanol, and quenching of the palladium intermediate with 19 mg (0.50 mmol) of sodium borohydride added in small portions over 0.5 h. Stirring for 3 h at room temperature was followed by dilution with 75 mL of ether, filtration to remove palladium black, and washing with 75 mL of 5% aqueous HCl solution. Drying followed by in vacuo solvent removal and chromatography on silica gel (TLC, 2% Et_3N/30% Et_2O/hexane, two elutions, 20 × 20 cm plate) yielded the pentacyclic product as a yellow crystalline solid, mp 154–156 °C, in 84% yield (25.2 mg). Recrystallization from hexane at low temperature (−20 °C) gave the crystalline product, mp 154–156 °C.

NMR (270 MHz, $CDCl_3$): 1.16 (ddm, 1 H, J = 12.8, 6.4 and smaller Hz), 1.37 (s, 3 H), 1.35–1.60 (series of m, 7 H), 1.79 (m,

1 H), 1.94 (m, 1 H), 2.23 (m, 1 H), 2.50 (dd, 1 H, J = 1.9, 15.3 Hz), 2.78 (dd, 1 H, J = 4.7, 15.3 Hz), 7.09 (AB m, 2 H), 7.30 (dd, 1 H, J = 6.7, 1.5 Hz), 7.45 (dd, 1 H, J = 6.7, 1.5 Hz), 7.75 (br s, 1 H, N-*H*). IR ($CDCl_3$): 3469, 2920, 2860, 1464, 1380, 1349, 1329, 1310, 1297, 1238, 1177, 1156, 938, 876, 774, 665. MS: Calcd for $C_{18}H_{21}N$: 251.1674. Found: 251.1674, 253 (0.8), 252 (13.6), 251 (100), 250 (5.3), 236 (3.9), 195 (12.5), 194 (78.6), 182 (4.8), 181 (5.5), 180 (9.0), 167 (5.3), 44 (4.2), 40 (4.2).

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Registry No. 2a, 78672-93-2; **2b**, 78672-94-3; **3a**, 78672-95-4; **5a**, 78672-96-5; **6**, 41977-03-1; **6** acid chloride, 51372-02-2; **6** oxoindole, 78672-97-6; **7**, 42916-91-6; **7** 3-oxoindole, 78672-98-7; **8**, 78672-99-8; **9a**, 78685-49-1; **9b**, 78673-00-4; **10**, 78673-01-5; **11**, 78673-02-6; **13**, 78673-03-7; **14**, 78673-04-8; **15**, 78673-05-9; *N*-(trimethylsilyl)indole, 17983-42-5; silver tetrafluoroborate, 14104-20-2; palladium chloride, 7647-10-1.

Structures of Dineopentylbis(triethylphosphine)platinum(II) and Bis(triethylphosphine)-3,3-dimethylplatinacyclobutane: Reactant and Product in a Thermal Cyclometalation Reaction

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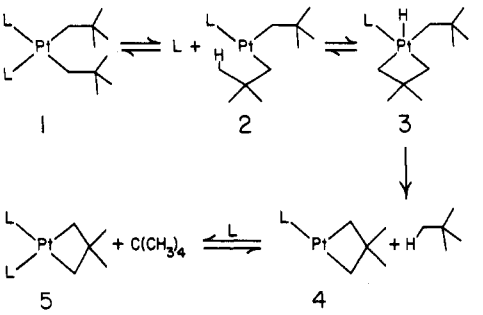
Thermal decomposition of dineopentylbis(triethylphosphine)platinum(II), **1**, $Pt(CH_2C(CH_3)_3)_2(P(C_2H_5)_3)_2$, yields neopentane and bis(triethylphosphine)-3,3-dimethylplatinacyclobutane, **5**, $Pt(CH_2C(CH_3)_2CH_2)(P(C_2H_5)_3)_2$. Compound **1** crystallizes with four molecules in space group C_{2h}^6—$C2/c$ of the monoclinic system in a cell at −158 °C of dimensions a = 8.776 (2) Å, b = 17.761 (3) Å, c = 17.669 (3) Å, and β = 109.62 (1)°. The structure has been refined to an R index on F^2 of 0.035 for 6877 observations and 115 variables. Compound **1** has crystallographically imposed C_2 symmetry. Compound **5** crystallizes with four molecules in space group C_{2v}^9—$Pn2_1a$ of the orthorhombic system in a cell at −158 °C of dimensions a = 15.947 (3) Å, b = 14.301 (2) Å, and c = 9.383 (2) Å. The structure has been refined to a R index on F^2 of 0.032 for 3255 observations and 181 variables. Some average metrical parameters for **1** and **5** respectively are as follows: Pt–P, 2.322 (1), 2.285 (2) Å; Pt–C, 2.118 (2), 2.083 (3) Å; P–C, 1.839 (2), 1.827 (2) Å; C–C (ethyl), 1.525 (3), 1.521 (4) Å; P–Pt–P, 94.09 (3), 103.01 (9)°; C–Pt–C, 85.5 (1), 67.3 (3)°. In **1** the neopentyl group is of normal geometry with a C–C(terminal) distance of 1.529 (3) Å; in **5** the C–C distances of the metallacycle average 1.535 (6) Å and the β-C atom is 0.38 Å out of the plane through PPPtCC. A comparison of structures of **1** and **5** indicates that **1** is significantly sterically congested and suggests that relief of this congestion may be an important component of the thermodynamic driving force for the conversion of **1** to **5**.

Introduction

The cleavage of carbon–hydrogen bonds of saturated hydrocarbons occurs readily over supported or bulk transition metals.[2-5] Only a few examples of analogous reactions involving soluble transition metals have been reported,[6-10] and rigorous proof that metal colloids are not involved in these reactions has been difficult to construct. By contrast, homogeneous *intramolecular* reactions which cleave unactivated carbon–hydrogen bonds ("unactivated" in the sense of having neither adjacent unsaturation nor heteroatoms) are well-known.[6,11-17]

Scheme I. Conversion of Dineopentylbis(triethylphosphine)platinum(II) to Bis(triethylphosphine)-3,3-dimethylplatinacyclobutane (L = PEt_3)



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