herein arise from interception of the kinetically formed Lewis acid acetal complex $(\pm)$-**1**·MX_n before equilibration with the diastereomeric intimate ion pair ii (Lewis acid flanking the C(6) methyl group) or the external ion pair iii can occur, Scheme II. Recent quantitative studies by Mayr on the relative nucleophilicity of allylmetals are in complete agreement with the notion that increased stereoselectivity parallels increased nucleophilicity.[6] Similar conclusions were reached in the studies by Yamamoto[7] on α-substituted chiral acetals and by Otera and Nozaki[8] with thioacetals.

In summary, we have demonstrated the extremely diastereoselective opening of chiral acetals using only one equivalent of allyltributylstannane. The high selectivities, minimal amounts of allylmetal and substrate generality combine to make this a preparatively significant reaction. Further studies with organotin-based nucleophiles are in progress.

Acknowledgment. We gratefully acknowledge financial support for this project from the National Science Foundation (NSF-CHE 881847). We are grateful to Professor Herbert Mayr (Lübeck) for a preprint of reference 6.

Registry No. **1a**, 136315-79-2; **1b**, 136315-80-5; **1c**, 97996-52-6; **1d**, 136315-81-6; **1e**, 130693-67-3; **1f**, 136237-96-2; **2a**, 136237-97-3; **2b** (isomer 1), 136315-82-7; **2b** (isomer 2), 136315-83-8; **2c** (isomer 1), 136315-84-9; **2c** (isomer 2), 136315-85-0; **2d** (isomer 1), 136237-98-4; **2d** (isomer 2), 136315-86-1; **2e** (isomer 1), 136237-99-5; **2e** (isomer 2), 136315-87-2; **2f** (isomer 1), 136262-84-5; **2f** (isomer 2), 136374-59-9; 4-pentenal, 2100-17-6; 2,4-pentanediol, 1825-14-5; cyclohexanecarboxaldehyde, 2043-61-0; phenylacetaldehyde, 122-78-1; 2-hexynal, 27593-24-4; allyltrimethylsilane, 762-72-1; allyltriphenylsilane, 18752-21-1; allyltrimethylgermane, 762-66-3; allyltributylstannane, 24850-33-7; allyltriphenylstannane, 76-63-1; titanium chloride, 7550-45-0; titanium isopropoxide, 546-68-9.

Supplementary Material Available: General procedures for the preparation of acetals and for their reaction with allyltributylstannane along with full characterization of **1b–d**, **1f**, and **2a–f** (10 pages). Ordering information is given on any current masthead page.

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Palladium-Catalyzed Polycyclization of Dienynes: Surprisingly Facile Formation of Tetracyclic Systems Containing a Three-Membered Ring

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Received May 29, 1991

Summary: Substituted dienynes **9** undergo a palladium-catalyzed 4-fold cyclization process to give tetracycles **12** as sole products.

The formation of carbon–carbon bonds by way of the Heck reaction has found widespread applications in organic synthesis.[1] In the past few years, the palladium-catalyzed construction of oligocyclic systems from open-chain precursors in one step has emerged as a new potent synthetic strategy.[2] So far, this methodology has mainly been used for biscyclization reactions and relatively little attention has yet been paid to the possible one-step construction of tri- and tetracyclic compounds.[3] We now wish to report an unprecedented palladium-catalyzed domino cyclization leading to a new type of tetracyclic skeleton.

In pursuing a concept for the novel construction of tricyclic systems like **7**, initiated by biscyclization under Heck coupling conditions[4] of a suitable dienyne followed by electrocyclization, we treated 2-bromo-4-oxa dienyne **1**[5,6] with 5 mol % $\mathrm{Pd(OAc)_2}$, 20 mol % $\mathrm{PPh_3}$, and 2 equiv of $\mathrm{K_2CO_3}$ in refluxing acetonitrile. Instead of the expected tricyclic diene **7**, the cross-conjugated triene **4** was isolated in 60% yield. Apparently, the reaction initially proceeded as expected by oxidative addition of the carbon–bromine bond to palladium (0), followed by a 6-*exo-dig*[7] and subsequently a 5-*exo-trig* ring closure to give the alkylpalladium species **2**. But under these conditions, the conjugated triene intermediate **5**, when formed from **2** by β-hydride elimination, completely isomerizes to **4**. With 1 equiv of silver nitrate added to the reaction mixture,[8] this isomerization is suppressed and **7**, formed by electrocyclic rearrangement of **5**, is isolated in 52% yield.

Under both types of conditions, the interesting tetracyclic byproduct **8** is formed in 5 and 10% yield, respectively. This can be rationalized in terms of a relatively slow β-hydride elimination in **2**, so that this alkylpalladium species can undergo another 5-*exo-trig* ring closure to the

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(1) (a) Heck, R. F. *Org. React.* **1982**, *27*, 345. (b) Heck, R. F. *Pure Appl. Chem.* **1978**, 50. (c) Heck, R. F. *Acc. Chem. Res.* **1979**, *12*, 41.
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(5) All compounds reported herein were fully characterized by IR and ^{1}H and ^{13}C NMR spectroscopy. Satisfactory molecular mass and/or combustion analysis were obtained for new compounds. Stereochemical assignments are based on 2D-NOESY and COLOC studies.
(6) Dienyne **1** was readily assembled by alkylation of non-8-en-3-yn-1-ol with 2,3-dibromopropene under phase-transfer conditions in 79% yield.
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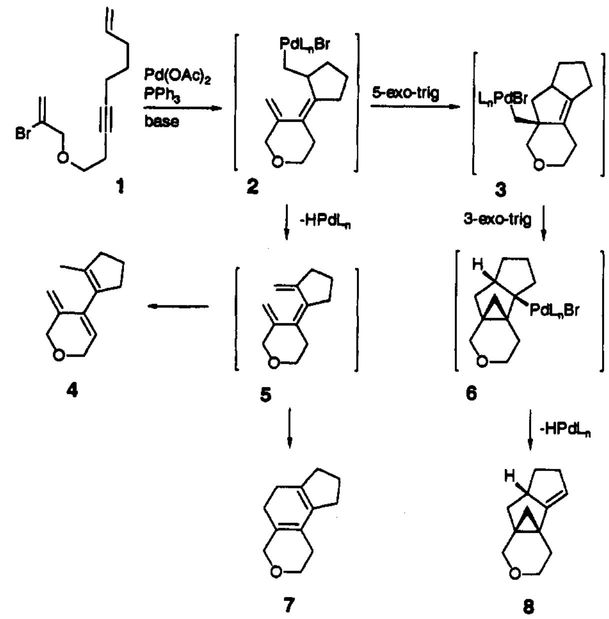
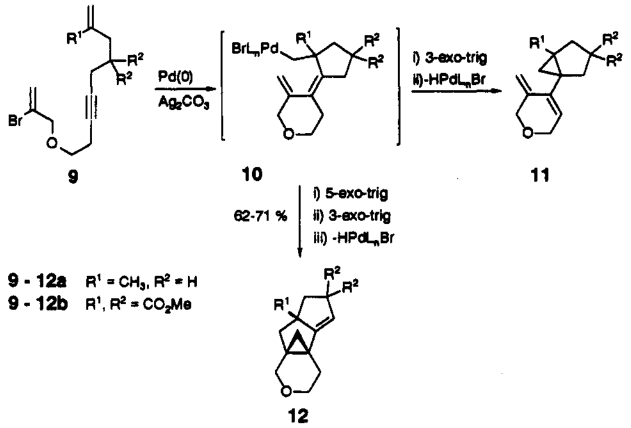
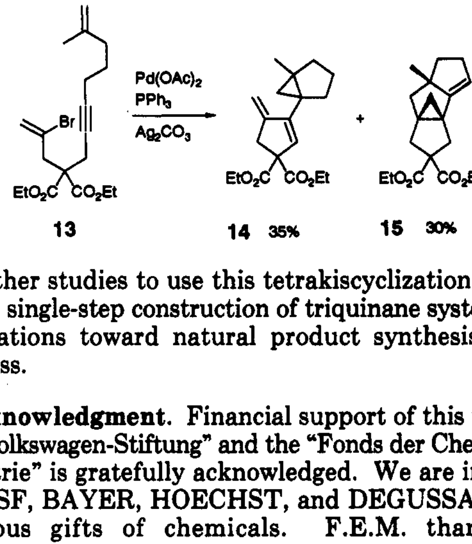


tricyclic intermediate **3**, which has no other choice but to cyclize again with formation of a three-membered ring. The secondary alkylpalladium bromide **6** thus formed can eventually eliminate β-hydride and give the byproduct **8**. The β-hydride elimination in **2** can be prevented with a suitable substituent in the 12-position of the starting dienyne **1**. Thus, dienyne **9a**,[9] when treated with 3–5 mol % $Pd(PPh_3)_4$ and 2 equiv of silver carbonate in refluxing acetonitrile for 3 days, formed the tetracyclic compound **12a** as the sole product, isolated in 62% yield. Moreover, when dienyne **9b** was subjected to similar cyclization conditions (3–5 mol % $Pd(OAc)_2$, 12–20 mol % PPh_3, and 2 equiv of silver carbonate, acetonitrile, 3 h, 130 °C), tetracycle **12b** was obtained in 71% isolated yield.[10]



Under these circumstances, the alkylpalladium species **10** apparently prefers to undergo a 5-*exo-trig* ring closure to an intermediate of type **3** over a 3-*exo-trig* process eventually leading to **11**.[2a] With potassium carbonate instead of silver carbonate, however, small amounts (4%) of the isomeric product **11** could be detected by ^1H NMR spectroscopy.

These observations tempted us to try the assembly of a linear triquinane skeleton containing no heteroatoms. For example, dienyne **13** was cyclized by using 3 mol % $Pd(OAc)_2$, 12 mol % PPh_3, and 2 equiv of silver carbonate in DME/acetonitrile (1:1) at 60 °C for 2 days. After workup, compounds **14**, **15**, and an as yet unidentified product were isolated in 35, 30, and 10% yield, respectively.



Further studies to use this tetrakiscyclization process for the single-step construction of triquinane systems and applications toward natural product synthesis are in progress.

Acknowledgment. Financial support of this work by the "Volkswagen-Stiftung" and the "Fonds der Chemischen Industrie" is gratefully acknowledged. We are indebted to BASF, BAYER, HOECHST, and DEGUSSA AG for generous gifts of chemicals. F.E.M. thanks the "Studienstiftung des Deutschen Volkes" for a scholarship.

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(9) Dienyne **9a** can be prepared from 8-methylnon-8-en-3-yn-1-ol and 2,3-dibromopropene under phase-transfer conditions in 60% yield.

(10) Typical experimental procedure for the preparation of trimethyl 10-oxatetracyclo[6.4.1.$0^{1,8}$.$0^{2,6}$]tridec-2-ene-4,4,6-tricarboxylate (**12b**): A mixture of 0.5 g (1.16 mmol) of **9b**, $Pd(OAc)_2$ (0.015 g; 0.058 mmol), PPh_3 (0.065 g, 0.232 mmol), and Ag_2CO_3 (0.638 g; 2.318 mmol) in 10 mL of MeCN was heated in a sealed tube at 130 °C for 3 h. Extractive workup and flash column chromatography (silica gel; 1:12 ether–petroleum ether) provided 0.288 g (71%) of **12b**. IR (neat): 3090, 3020, 1960, 1860, 1725, 1670, 1440, 1390, 1250, 1095, 1055, 975, 920, 840 cm^{-1}. ^1H NMR (250 MHz, $CDCl_3$): δ 5.70 (1 H, s, H-12), 4.03 (1 H, d, J = 11.2 Hz, H-6), 3.76 (3 H, s, CO_2Me-11), 3.74 (3 H, s, CO_2Me-11), 3.64 (3 H, s, CO_2Me-9), 3.60 (2 H, m, H-4,6), 3.08 (1 H, m, H-4), 3.00 (1 H, d, J = 13.5 Hz, H-10), 2.69 (1 H, d, J = 12.73 Hz, H-8), 2.46 (1 H, d, J = 13.5 Hz, H-10), 2.02 (2 H, m, H-3), 1.58 (1 H, d, J = 12.76 Hz, H-8), 1.03 (1 H, d, J = 6.01 Hz, H-13), 0.90 (1 H, d, J = 6.00 Hz, H-13). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 175.3, 171.1, 170.3, 158.4, 118.4, 70.2, 70.0, 63.6, 60.6, 52.8, 52.6, 52.1, 47.0, 39.5, 31.2, 25.8, 25.1, 21.3. Anal. Calcd for $C_{18}H_{21}O_7$: C, 61.71; H, 6.33. Found: C, 61.78; H, 6.53.

Palladium-Catalyzed Coupling of 2-Bromonaphthoquinones with Stannanes: A Concise Synthesis of Antibiotics WS 5995 A and C and Related Compounds[†]

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Received August 1, 1991

Summary: The syntheses of antibiotics WS 5995 A and C and a hypothetical intermediate in the biosynthesis of the kinamycin antibiotics have been completed by using as the key step the palladium-catalyzed coupling of 2-bromo-1,4-naphthoquinones with stannanes.

The kinamycin antibiotics (e.g. **1**, Kinamycin D), isolated from *Streptomyces murayamaensis*, are biosynthesized from benz[*a*]anthraquinones, such as dehydrorabelomycin

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[†] Dedicated to Professor Francisco Fariña on the occasion of his 65th birthday.

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