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Enyne versus Diene RCM in the Synthesis of Cyclopentene Derivatives toward the A Ring of FR182877

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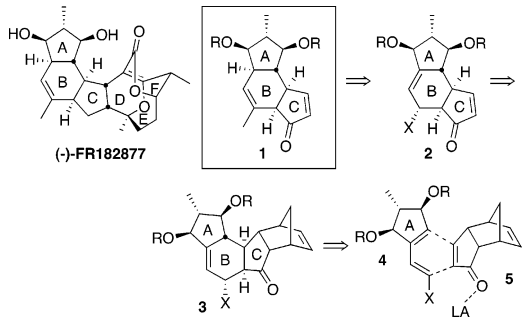
Abstract: The A ring of FR182877, exemplified by ***ent*-4-b,c**, has been synthesized, involving an enyne RCM as the key step. A systematic comparison of enyne vs diene RCM for the formation of cyclopentene derivatives showed that the latter metathesis proceeds much more easily even for this ring size.

In 1998, FR182877 (first named WS9885B) was isolated from *Streptomyces* sp. no. 9885 by Sato and coworkers.[1] Its absolute configuration was first reported as enantiomeric of the structure shown in Scheme 1[2] and later corrected by the same authors.[3] This compound promotes microtubule assembly and induces cell cycle arrest, and its performance similar to that of Taxol makes it a potential antitumor drug.[4] Because of its complex polycyclic structure, several groups have expressed interest in this molecule, and total syntheses of (+)-FR182877 and the natural (−)-enantiomer have been completed by Sorensen[5] and Evans,[6] respectively. Nakada[7] described a synthesis of the AB bicycle, a model of the DF ring system was published by Armstrong,[8] and Roush recently reported the synthesis of the ABC tricycle.[9]

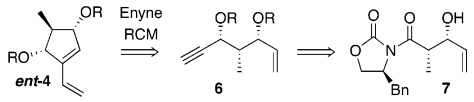
Synthesis of FR182877 is an ongoing project in our laboratory, and we decided to focus first on the construction of the ABC tricycle. The envisioned retrosynthesis is shown in Scheme 1. Compound **1** would arise from an olefin migration in **2**, which in turn would be obtained from diene **4** and dienophile **5** by a Diels−Alder/retro-Diels−Alder sequence via adduct **3**. The Lewis acid-catalyzed Diels−Alder reaction would proceed via an exo transition state.[10]

When we started this study, (+)-FR182877 was supposed to be the natural product, so we aimed for the enantiomers of the dienes **4** shown in Scheme 1. This paper describes the synthesis of dienes ***ent*-4** (where X = H) involving an enyne ring-closing metathesis (RCM)[11] of enynes **6** as the key step (Scheme 2). Comparison of enyne RCM with RCM of the dienes analogous to compounds **6** is also reported. Enyne RCM precursor **6** could be prepared from homochiral Evans aldol **7** (Scheme 2).

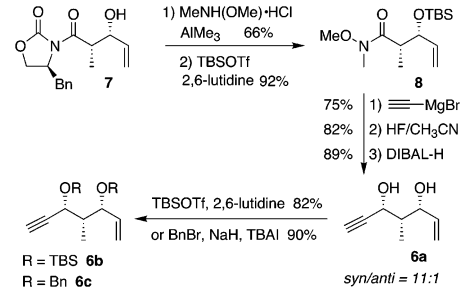
SCHEME 1



SCHEME 2



SCHEME 3



Compound **7**[12] was transformed into the corresponding Weinreb amide and the alcohol group protected as a TBS ether (Scheme 3) to afford amide **8** in reasonable yield. Addition of ethynylmagnesium bromide, followed by deprotection of the silyl ether and directed reduction of the resulting β-hydroxy ketone with DIBAL-H,[13] furnished diol **6a** as an 11:1 *syn*/*anti* mixture of diastereomers. This diol was protected as the bis-silyl derivative **6b** or the bis-benzyl ether **6c**.

Enyne metathesis was first tested on diol **6a** (R = H). First-generation Grubbs catalyst **9**[14] (**[Ru]**) (Figure 1) did not lead to any of the desired product: the starting material was recovered if the reaction was performed at 20 °C and degraded in CH_2Cl_2 at reflux (Scheme 4). Only Grubbs' complex **10**[15] (**[RuIMesH$_2$]**) (Figure 1) met with some success. Diene ***ent*-4a** was obtained in 15% yield if the reaction was conducted with 15 mol % of catalyst **10** under an ethylene atmosphere, under Mori's conditions.[16] Without ethylene, even at higher concentration, only degradation of diol **6a** was observed. No product was

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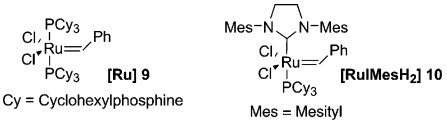
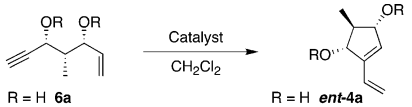


FIGURE 1. Metathesis catalysts.

SCHEME 4



R	Catalyst	Conc. (M)	Temp. (°C)	Yield (%)
H	10 mol% **9**	0.05	20	No reaction
		0.05	42	Degradation
	8 mol% **10**	0.17	20	Degradation
	15 mol% **10**[a]	0.05	20	15
TBS	15 mol% **10**[a]	0.03	20	73
	45 mol% **9**[a]	0.03	20	80
Bn	15 mol% **10**[a]	0.03	20	68

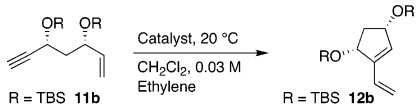
[a]Reaction performed under an ethylene atmosphere

observed with either **[RuIMes]**[17] or with the second-generation Hoveyda–Grubbs complex.[18] Use of $Pd(OAc)_2$ or $PtCl_2$ in toluene at 80 °C did not effect cyclization.[19]

Protected diols **6b** and **6c** gave much better results (Scheme 4). This feature is in agreement with Poulsen's and Madsen's results for the RCM of carbohydrate-derived enynes.[20] In their case, the free hydroxyl groups had to be protected in order to obtain metathesis products. Under the conditions optimized for diol **6a** (15 mol % **10**, 0.03 M, CH_2Cl_2, ethylene, 20 °C, 16 h), cyclopentene derivatives ***ent*-4b** (R = TBS) and ***ent*-4c** (R = Bn) were obtained in 73% and 68% yield, respectively. No six-membered ring was detected, nor any dimer resulting from diene cross-metathesis. These side products were obtained in some cases by Lièvre and co-workers when performing enyne RCM of carbohydrate derivatives.[21] Grubbs' first-generation catalyst **9** could also be used in conjunction with ethylene, but it was less efficient and slower; a half-equivalent was needed to drive the reaction to completion after 48 to 72 h. However, the reaction was cleaner and compound ***ent*-4b** was obtained in slightly better yield (80 vs 73%).

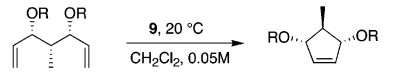
To study the influence of substrate substitution on the cyclization, we prepared substrates **11b**,**c** lacking the methyl group between the two hydroxyl functions.[22] The results with catalyst **10** are similar to those obtained with compounds **6** (Scheme 5); the diol needs to be protected and the reaction carried out under an ethylene atmosphere to obtain decent metathesis yields. Here also,

SCHEME 5

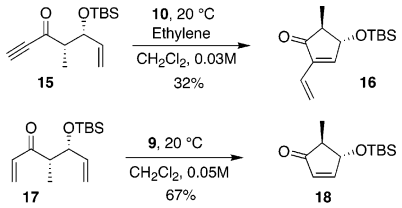


R	Catalyst	Yield (%)
TBS	15 mol% **10**	72
	25 mol% **9**	94
Bn	15 mol% **10**	70

SCHEME 6



SCHEME 7



RCM could be performed with **9** if a large amount (25 mol %) of catalyst was used, and **12b** was produced in an excellent 94% yield.

For the purpose of comparing diene RCM with enyne RCM, dienes **13a–c**[23] were treated with **[Ru] 9**. Good yields (unoptimized) were obtained in all cases with this first-generation catalyst,[24] especially when the diol is unprotected (Scheme 6).[25] These reactions underscore the ease of diene vs enyne RCM on similar substrates, even for the formation of five-membered rings.

RCM of electron-deficient ynone **15** proceeded in 32% yield (Scheme 7). Once again, reaction of the analogous diene **17** was easier and furnished known enone **18**[26] in 67% unoptimized yield. In this case, however, the poor yield of enyne RCM could be due to the sensitivity of the ynone precursor to both basic and acidic conditions. To the best of our knowledge, this is the first case of enyne RCM involving an ynone moiety.

In summary, we have synthesized the enantiomer of the FR182877 A-ring using an enyne RCM as the key step. A study of enyne RCM leading to cyclopentene derivatives has also been effected. Grubbs' catalysts **[Ru] 9** and **[RuIMesH$_2$] 10** both effect enyne cyclization in the presence of ethylene. The second-generation catalyst **10** is faster and more efficient in terms of catalyst loading, but reactions with complex **9** are cleaner and yields up to 94% are obtained. A systematic comparison with the corresponding diene RCM showed the ease of diene vs enyne RCM, even for the formation of five-membered rings. Studies on Diels–Alder reactions of dienes ***ent*-4a–c** and **16** with enone **5** will be reported in due course.

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Experimental Section

Ynone 15. To a solution of Weinreb amide **8** (540 mg, 1.90 mmol) in 10 mL of ether at −78 °C was added dropwise 18.8 mL of a 0.5 M solution of ethynylmagnesium bromide in THF. The mixture was stirred at −78 °C for 30 min and allowed to warm to 20 °C overnight. A saturated aqueous NH_4Cl solution was then added. The layers were separated, and the aqueous phase was extracted three times with ether. The combined organic extracts were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Flash chromatography on silica gel (petroleum ether/ether 60:1) afforded the corresponding ynone **15** (356 mg, 75%) as a colorless oil: $[\alpha]_D$ +44.8 (*c* 1.90, $CHCl_3$); IR (thin film) 3300, 3256, 2956, 2857, 2093, 1685, 1253 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 5.82 (ddd, J = 17.0, 10.3, 6.2 Hz, 1H), 5.25 (dt, J = 17.0, 1.1 Hz, 1H), 5.15 (dt, J = 10.3, 1.1 Hz, 1H), 4.71−4.69 (m, 1H), 3.28 (s, 1H), 2.66 (qd, J = 7.2, 4.2 Hz, 1H), 1.17 (d, J = 7.2 Hz, 3H), 0.87 (s, 9H), 0.05 (s, 3H), 0.01 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 189.1, 139.0, 115.9, 81.2, 79.3, 73.8, 54.9, 25.7, 18.1, 9.4, −4.2, −5.1; MS (CI, NH_3) *m*/*z* 270 (M + NH_4^+), 253 (M + H^+), 195, 122 (M − OTBS + H^+); HRMS calcd for $C_{14}H_{25}O_2Si + H^+$ 253.1624, found 253.1618.

Enyne 6a. A solution of ynone **15** (400 mg, 1.60 mmol) in 8 mL of a 5:95 mixture of HF/CH_3CN was stirred at 20 °C for 16 h. A saturated aqueous $NaHCO_3$ solution was then added followed by ether. The aqueous layer was extracted three times with ether. The combined organic extracts were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Flash chromatography on silica gel (petroleum ether/ether 2:1) afforded the expected hydroxy ketone (218 mg, 82%) as an orange oil: $[\alpha]_D$ +22.7 (*c* 1.61, CH_2Cl_2); IR (thin film) 3444, 3264 (br), 2985, 2092, 1674, 1454 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 5.85 (ddd, J = 17.2, 10.5, 5.4 Hz, 1H), 5.34 (dt, J = 17.2, 1.5 Hz, 1H), 5.23 (dt, J = 10.5, 1.5 Hz, 1H), 4.72−4.67 (m, 1H), 3.34 (s, 1H), 2.75 (qd, J = 7.2, 3.8 Hz, 1H), 1.24 (d, J = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 206.2, 137.4, 116.4, 80.2, 71.9, 53.1, 9.5; MS (CI, NH_3) *m*/*z* 156 (M + NH_4^+), 139 (M + H^+), 121 (M − H_2O + H^+); HRMS calcd for $C_8H_{10}O_2 + H^+$ 139.0759, found 139.0754.

To a solution of the preceding hydroxy ketone (180 mg, 1.30 mmol) in 20 mL of THF at −78 °C was added dropwise 3.30 mL of a 1.0 M solution of Dibal-H in hexanes. The resulting mixture was stirred at this temperature for 5 h. Ethyl acetate was then added followed by a 1.0 M aqueous HCl solution. Vigorous stirring was maintained over 1 h. The resulting clean layers were then separated. The aqueous layer was extracted five times with ethyl acetate. The combined organic extracts were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Flash chromatography on silica gel (petroleum ether/ethyl acetate 1:1) afforded the expected diol **6a** (163 mg, 89%), a colorless oil that solidified upon standing in the fridge, as an inseparable *syn*/*anti* mixture of diastereoisomers in a 11:1 ratio: $[\alpha]_D$ +36.7 (*c* 1.43, MeOH); IR (thin film) 3282, 2978, 2914, 2115, 1643, 1453 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 5.92 (ddd, J = 17.0, 10.4, 5.4 Hz, 1H), 5.31 (dt, J = 17.0, 1.4 Hz, 1H), 5.21 (dt, J = 10.4, 1.4 Hz, 1H), 4.66−4.63 (m, 1H), 4.49−4.47 (m, 1H), 2.59 (d, 1H), 2.53 (d, J = 2.4 Hz, 1H), 1.90 (qd, J = 7.2, 3.6 Hz, 1H), 1.10 (d, J = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) 139.0, 115.4, 83.6, 75.1, 73.9, 65.9, 43.3, 7.3; MS (CI, NH_3) *m*/*z* 142 (M + H^+), 124 (M − H_2O + H^+), 106 (M − $2H_2O$ + H^+); HRMS calcd for $C_8H_{12}O_2$ + NH_4^+ 158.1181, found 158.1184.

Enyne 6b. To a solution of diol **6a** (50 mg, 0.36 mmol) and 2,6-lutidine (145 μL, 1.25 mmol, 3.50 equiv) in CH_2Cl_2 (1.5 mL) at −78 °C was added dropwise TBSOTf (246 μL, 1.10 mmol, 3.0 equiv). The mixture was stirred at this temperature for 30 min and then allowed to warm to 20 °C for 1.5 h. MeOH was added followed by a 1.0 M aqueous solution of HCl. The aqueous layer was extracted three times with CH_2Cl_2. The combined organic extracts were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Filtration through a plug of silica gel (petroleum ether/ether 100:1) afforded protected diol **6b** (108 mg, 82%) as a colorless oil: $[\alpha]_D$ +31.1 (*c* 1.12, $CHCl_3$); IR (thin film) 3312, 2955, 2930, 2886, 2858, 1472, 1463, 1254, 1074, 1032 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 5.82 (ddd, J = 17.3, 10.4, 6.4 Hz, 1H), 5.16 (dt, J = 17.3, 1.4 Hz, 1H), 5.09 (dt, J = 10.4, 1.4 Hz, 1H), 4.39−4.37 (m, 1H), 4.31 (dd, J = 7.2, 2.2 Hz, 1H), 2.43 (d, J = 2.0 Hz, 1H), 1.71 (qdd, J = 6.8, 4.2, 2.2 Hz, 1H), 0.99 (d, J = 6.8 Hz, 3H), 0.92 (s, 9H), 0.91 (s, 9H), 0.16 (s, 3H), 0.10 (s, 3H), 0.07 (s, 3H), 0.02 (s, 3H; ^{13}C NMR ($CDCl_3$, 100 MHz) 140.7, 114.8, 83.8, 74.1, 73.1, 64.5, 47.0, 25.9, 25.8, 18.3, 18.2, 9.4, −4.0, −4.4, −4.9, −5.1; MS (CI, NH_3) *m*/*z* 386 (M + NH_4^+), 369 (M + H^+), 199 (M − OTBS + NH_4^+), 170 (M − OTBS + H^+), 104 (M − 2OTBS + H^+); HRMS calcd for $C_{20}H_{40}O_2Si_2 + H^+$ 369.2645, found 369.2640.

Enyne 6c. To an ice-cold solution of diol **6a** (33 mg, 0.22 mmol) and TBAI (16 mg, 0.05 mmol, 0.20 equiv) in dry DMF (1.5 mL) was added NaH (45% in mineral oil, 35 mg, 0.65 mmol, 3.0 equiv). The resulting mixture was stirred for 30 min, and BnBr (80 μL, 0.65 mmol, 3.0 equiv) was then added. The mixture was allowed to warm to 20 °C over 5 h. Water was added followed by ether. The aqueous layer was extracted three times with ether. The combined organic extracts were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Flash chromatography on silica gel (petroleum ether/ether 50:1) afforded the expected protected diol **6c** (69 mg, 90%) as a colorless oil: $[\alpha]_D$ +30.9 (*c* 0.54, $CHCl_3$); IR (thin film) 3297, 3065, 3030, 2865, 1497, 1454, 1068, 1028 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 7.43−7.31 (m, 10H), 5.82 (ddd, J = 17.2, 10.8, 7.6 Hz, 1H), 5.28 (ddd, J = 10.4, 1.6, 0.8 Hz, 1H), 5.23 (ddd, J = 17.2, 2.0, 0.8 Hz, 1H), 4.84 (d, J = 11.5 Hz, 1H), 4.61 (d, J = 11.6 Hz, 1H), 4.46 (d, J = 11.6 Hz, 1H), 4.36 (d, J = 11.5 Hz, 1H), 4.25 (ddm, J = 5.6, 2.0 Hz, 1H), 4.03−3.99 (m, 1H), 2.47 (d, J = 2.0 Hz, 1H), 1.94 (qm, J = 6.8 Hz, 1H), 1.23 (d, J = 6.8 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) 138.7, 137.8, 137.1, 128.2, 128.0, 127.6, 127.3, 118.2, 82.1, 81.6, 74.6, 70.6, 70.5, 70.2, 43.5, 10.5; MS (CI, NH_3) *m*/*z* 338 (M + NH_4^+), 321 (M + H^+), 213 (M − OBn + NH_4^+), 109 (M − 2OBn + H^+); HRMS calcd for $C_{22}H_{24}O_2 + Na^+$ 343.1674, found 343.1679.

General Procedure for Enyne Metathesis. The enyne was dissolved in dry CH_2Cl_2 so that the concentration reached approximately 0.035 M. This solution was then degassed under Ar using the freeze−thaw−pump technique. Ethylene was bubbled through the solution for 5 min. Ruthenium catalyst **9** or **10** was added, and ethylene was again passed through the solution for an additional 5 min. The solution was then stirred under an ethylene atmosphere (fitted balloon) at 20 °C until TLC revealed completion of the reaction. Silica gel was added and the mixture concentrated to dryness. Purification was achieved by flash chromatography on silica gel.

General Procedure for Alkene Metathesis. The enyne was dissolved in dry CH_2Cl_2 so that the concentration reached approximately 0.035 M. Catalyst **9** was then added. The progress of the reaction was monitored by TLC analysis. More catalyst was added if necessary. After the mentioned reaction time, silica gel was added and the mixture concentrated to dryness. Purification was achieved by flash chromatography on silica gel.

Every analytical sample of metathesis product was obtained after treatment of the product with $Pb(OAc)_4$ (a CH_2Cl_2 solution of the sample was stirred for 16 h with 1.5 equiv relative to the ruthenium catalyst of $Pb(OAc)_4$).[27]

Diene *ent*-4b. This compound was prepared according to the general procedure for enyne metathesis from 60 mg (0.16 mmol) of **6b** in 6 mL of CH_2Cl_2 using 21 mg (15 mol %) of catalyst **10**. After the mixture was stirred at 20 °C for 16 h, flash chromatography on silica gel (petroleum ether/ether 150:1) afforded 44 mg (73%) of the expected diene ***ent*-4b**. This compound was also prepared according to the general procedure for enyne metathesis from 50 mg (0.14 mmol) of **6b** in 4 mL of CH_2Cl_2 using 17 mg (15 mol %) of catalyst **9**. After the mixture was stirred at 20 °C for 16 h, an additional 10 mol % of catalyst (11 mg) was added sequentially every 15 h. After a total amount of 45 mol % of catalyst added and 3 d stirring under an ethylene atmosphere, purification according to the general procedure (petroleum ether/ether 150:1) afforded 40 mg (80%) of the expected diene ***ent*-4b**: $[\alpha]_D$ −37.2 (*c* 1.02, $CHCl_3$); IR (thin film) 2929, 2858, 1472, 1464, 1362, 1256, 1070 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 6.31 (dd, J = 17.6, 10.8 Hz, 1H), 5.81 (br s, 1H), 5.49 (dd, J = 17.6, 1.6 Hz, 1H), 5.17 (dd, J = 10.8, 1.6 Hz, 1H), 4.27 (d, J = 5.2 Hz, 1H), 4.15 (dm, J = 3.2 Hz, 1H), 1.99 (qd, J = 7.4, 5.2 Hz, 1H),

(27) Paquette, L. A.; Schloss, J. D.; Efremov, I.; Fabris, F.; Gallou, F.; Méndez-Andino, J.; Yang, J. I. *Org Lett.* **2000**, *2*, 1259.

1.18 (d, J = 7.4 Hz, 3H), 0.91 (s, 9H), 0.90 (s, 9H), 0.12 (s, 3H), 0.17 (s, 3H), 0.09 (2s, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz) 144.9, 132.8, 131.2, 116.8, 81.4, 80.8, 52.7, 26.6, 25.9, 18.3, 18.2, 16.5, −3.6, −4.3, −4.4, −4.5; MS (CI, NH_3) m/z 386 (M + NH_4^+), 369 (M + H^+), 311, 254 (M − OTBS + NH_4^+), 237 (M − OTBS + H^+), 132 (M − 2OTBS + H^+); HRMS calcd for $C_{20}H_{40}O_2Si_2$ + H^+ 369.2645, found 369.2647.

Diene *ent*-4c. This compound was prepared according to the general procedure for enyne metathesis from 38 mg (0.16 mmol) of **6c** in 5 mL of CH_2Cl_2 using 15 mg (15 mol %) of catalyst **10**. After the mixture was stirred at 20 °C for 16 h, flash chromatography on silica gel (petroleum ether/ether 30:1) afforded 26 mg (68%) of the expected diene ***ent*-4c**: $[\alpha]_D$ −112.0 (*c* 0.9, $CHCl_3$); IR (thin film) 3090, 3066, 3032, 2960, 1496, 1454, 1350, 1263, 1062 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.39−7.28 (m, 10H), 6.48 (dd, J = 17.6, 11.0 Hz, 1H), 5.99 (d, J = 1.7 Hz, 1H), 5.62 (d, J = 17.6 Hz, 1H), 5.26 (dd, J = 11.0, 1.7 Hz, 1H), 4.61 (s, 2H), 4.53 (s, 2H), 4.26 (dm, 1H, J = 3.6 Hz, 1H), 4.05−4.04 (m, 1H), 2.41 (qd, J = 7.2, 3.2 Hz, 1H), 1.23 (d, J = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) 144.8, 138.5, 132.6, 131.8, 128.3, 128.2, 127.8, 127.6, 127.5, 127.4, 118.0, 87.6, 87.5, 70.6, 68.2, 44.0, 18.9; MS (CI, NH_3) m/z 338 (M + NH_4^+), 321 (M + H^+), 230 (M − OBn + NH_4^+), 213 (M − OBn + H^+), 196, 108 (M − 2OBn + H^+); HRMS calcd for $C_{22}H_{24}O_2$ + Na^+ 343.1674, found 343.1683.

Diene 12b. This compound was prepared according to the general procedure for enyne metathesis from 65 mg (0.18 mmol) of **11b** in 6 mL of CH_2Cl_2 using 25 mg (15 mol %) of catalyst **10**. After the mixture was stirred at 20 °C for 16 h, flash chromatography on silica gel (petroleum ether/ether 100:1) afforded 47 mg (72%) of the expected diene **12b**. This compound was also prepared according to the general procedure for enyne metathesis from 50 mg (0.14 mmol) of **11b** in 4 mL of CH_2Cl_2 using 17 mg (15 mol %) of catalyst **9**. After the mixture was stirred at 20 °C for 16 h, 10 mol % of catalyst (11 mg) was added and the resulting mixture stirred for another 24 h. Flash chromatography on silica gel (petroleum ether/ether 100:1) afforded 47 mg (94%) of the expected diene **12b**: IR (thin film) 2930, 2857, 1472, 1463, 1363, 1255, 1070, 1034 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 6.35 (dd, J = 17.8, 11.2 Hz, 1H), 5.77 (br s, 1H), 5.56 (dd, J = 17.8, 2.0 Hz, 1H), 5.18 (dd, J = 11.2, 2.0 Hz, 1H), 4.74 (t, J = 6.9 Hz, 1H), 4.63 (t, J = 5.8 Hz, 1H), 2.70 (dt, J = 13.0, 6.9 Hz, 1H), 1.66 (dt, J = 13.0, 5.8 Hz, 1H), 0.903 (s, 9H), 0.901 (s, 9H), 0.12 (s, 3H), 0.10 (s, 3H), 0.09 (s, 3H), 0.08 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) 145.2, 133.0, 131.0, 116.9, 74.2, 73.4, 45.7, 25.9, 25.8, 18.2, 18.0, −3.9, −4.6, −4.8, −5.0; MS (CI, NH_3) m/z 372 (M + NH_4^+), 356 (M + H^+), 299, 240 (M − OTBS + NH_4^+), 224 (M − OTBS + H + H^+), 170 (M − OTBS + H^+), 133. Anal. Calcd for $C_{19}H_{38}O_2Si_2$: C, 64.34; H, 10.80. Found: C, 64.48; H, 10.87.

Diene 12c. This compound was prepared according to the general procedure for enyne metathesis from 80 mg (0.26 mmol) of **11c** in 7 mL of CH_2Cl_2 using 33 mg (15 mol %) of catalyst **10**. After the mixture was stirred at 20 °C for 16 h, flash chromatography on silica gel (petroleum ether/ether 50:1) afforded 56 mg (70%) of the expected diene **12c**: IR (thin film) 3295, 3065, 3031, 2868, 1497, 1455, 1070, 1028 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.42−7.31 (m, 10H), 6.51 (dd, J = 17.6, 11.1 Hz, 1H), 6.04 (d, J = 1.6 Hz, 1H), 5.65 (dd, J = 17.6, 1.6 Hz, 1H), 5.29 (dd, J = 11.1, 1.6 Hz, 1H), 4.81 (dd, J = 7.4, 3.9 Hz, 1H), 4.61 (d, J = 2.0 Hz, 2H), 4.54 (dm, J = 1.2 Hz, 3H), 2.68 (dt, J = 14.2, 7.4 Hz, 1H), 2.02 (dt, J = 14.2, 3.9 Hz, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) 144.7, 138.5, 138.4, 132.5, 128.3, 128.2, 127.9, 127.7, 127.6, 127.5, 127.4, 118.0, 80.0, 79. 9, 70.4, 68.6, 36.6; MS (CI, NH_3) m/z 324 (M + NH_4^+), 213 (M − OBn + NH_4^+), 200 (M − OBn + H^+). Anal. Calcd for $C_{21}H_{22}O_2$: C, 82.32; H, 7.24. Found: C, 82.18; H, 7.43.

Cyclopentene 14a. This compound was prepared according to the general procedure for alkene metathesis from 40 mg (0.28 mmol) of diol **13a** in 5 mL of CH_2Cl_2 using 14 mg (5 mol %) of catalyst **9**. After 2 h, flash chromatography on silica gel (petroleum ether/ethyl acetate 1:1) afforded 28 mg (87%) of the expected compound **14a**: IR (thin film) 3365 (br), 2980, 2910, 1366, 1257, 1077 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.94 (br s, 2H), 4.19 (d, J = 4.8 Hz, 2H), 2.23 (br s, 1H), 1.79 (qd, J = 7.2, 4.8 Hz, 1H), 1.75 (br s, 1H), 1.24 (d, J = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) 135.9, 81.7, 53.2, 15.8; MS (CI, NH_3) m/z 132 (M + NH_4^+), 115 (M + H^+), 98 (M − H_2O + H^+); HRMS calcd for $C_6H_{10}O_2$ + Na^+ 137.0578, found 137.0577.

Cyclopentene 14b. This compound was prepared according to the general procedure for alkene metathesis from 65 mg (0.18 mmol) of **13b** in 5 mL of CH_2Cl_2 using 7 mg (5 mol %) of catalyst **9**. After 2 h, flash chromatography on silica gel (petroleum ether/ether 125:1) afforded 46 mg (76%) of the expected compound **14b**: IR (thin film) 2956, 2929, 2857, 1257, 1076 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.75 (s, 2H), 4.15 (d, J = 6.5 Hz, 2H), 1.87 (qd, J = 7.2, 6.8 Hz, 1H), 1.19 (d, J = 7.2 Hz, 3H), 0.90 (s, 18H), 0.08 (br s, 12H); ^{13}C NMR ($CDCl_3$, 100 MHz) 135.4, 81.2, 53.5, 25.8, 18.1, 15.1, −4.5, −4.6; MS (CI, NH_3) m/z 360 (M + NH_4^+), 343 (M + H^+), 211 (M − OTBS + NH_4^+), 104 (M − 2OTBS + H^+); HRMS calcd for $C_{18}H_{38}O_2Si_2$ + NH_4^+ 360.2760, found 360.2751.

Cyclopentene 14c. This compound was prepared according to the general procedure for alkene metathesis from 50 mg (0.16 mmol) of **13c** in 5 mL of CH_2Cl_2 using 6.5 mg (5 mol %) of catalyst **9**. After 2 h, flash chromatography on silica gel (petroleum ether/ether 30:1) afforded 34 mg (74%) of the expected compound **14c**: IR (thin film) 3062, 3031, 1497, 1456, 1361, 1070 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.40−7.28 (m, 10H), 6.05 (s, 2H), 4.06 (br s, 4H), 4.06 (d, J = 4.5 Hz, 2H), 4.15 (d, J = 6.5 Hz, 2H), 1.87 (dq, J = 7.4, 4.5 Hz, 1H), 1.26 (d, J = 7.4 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) 138.7, 133.8, 128.3, 127.6, 127.4, 88.5, 70.6, 46.3, 17.7; MS (CI, NH_3) m/z 312 (M + NH_4^+), 295 (M + H^+), 188 (M − OBn + NH_4^+), 110 (M − 2OBn + H^+); HRMS calcd for $C_{20}H_{22}O_2$ + NH_4^+ 312.1964, found 312.1960.

Dienone 16. This compound was prepared according to the general procedure for enyne metathesis from 50 mg (0.20 mmol) of **15** in 6 mL of CH_2Cl_2 using 25 mg (15 mol %) catalyst **10**. After the mixture was stirred at 20 °C for 16 h, flash chromatography on silica gel (petroleum ether/ether 75:1) afforded 16 mg (32%) of the expected diene **16**: $[\alpha]_D$ −33.0 (*c* 1.14, $CHCl_3$); IR (thin film) 2956, 2929, 2857, 1718, 1471, 1462, 1349, 1257, 1087 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.14 (d, J = 2.0 Hz, 1H), 6.38 (dd, J = 17.8, 11.4 Hz, 1H), 6.17 (dd, J = 17.8, 2.0 Hz, 1H), 5.42 (dd, J = 11.2, 2.0 Hz, 1H), 4.47−4.46 (m, 1H), 2.40 (qd, J = 7.4, 2.8 Hz, 1H), 1.24 (d, J = 7.4 Hz, 3H), 0.93 (s, 9H), 0.16 (s, 3H), 0.15 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) 206.2, 155.3, 140.2, 126.3, 121.1, 76.8, 52.2, 25.7, 18.1, 12.7, −4.6; MS (CI, NH_3) m/z 270 (M + NH_4^+), 253 (M + H^+), 214, 198, 122 (M − OTBS + H^+); HRMS calcd for $C_{28}H_{48}O_4Si_2$ + Na^+ 527.2989, found 527.2997.

Enone 18. This compound was prepared according to the general procedure for alkene metathesis from 50 mg (0.19 mmol) of **17** in 5 mL of CH_2Cl_2 using 8 mg (5 mol %) of catalyst **9**. After the mixture was stirred at 20 °C for 16 h, 5 mol % (8 mg) of catalyst was added and the mixture stirred for another 24 h. Flash chromatography on silica gel (petroleum ether/ether 25:1) afforded 30 mg (67%) of the expected enone **18**: IR (thin film) 2930, 2958, 1719, 1472, 1463, 1361, 1258, 1110, 1051 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.37 (dd, J = 5.8, 2.0 Hz, 1H), 6.16 (d, J = 5.8 Hz, 1H), 4.51 (br s, 1H), 2.26 (qd, J = 7.6, 2.5 Hz, 1H), 1.22 (d, J = 7.6 Hz, 3H), 0.92 (s, 9H), 0.15 (s, 3H), 0.14 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) 208.1, 162.0, 133.3, 78.8, 50.7, 25.7, 18.0, 12.5, −4.7; MS (CI, NH_3) m/z 244 (M + NH_4^+), 227 (M + H^+), 213 (M − Me + H^+), 170, 133 (M − OTBS + H^+); HRMS calcd for $C_{12}H_{22}O_2Si$ + H^+ 227.1467, found 227.1471. Anal. Calcd for $C_{12}H_{22}O_2Si$: C, 63.66; H, 9.80. Found: C, 63.16; H, 9.67.

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Supporting Information Available: Experimental procedures and characterization for compounds **8**, **11a**−**c**, and **13a**−**c**. This material is available free of charge via the Internet at http://pubs.acs.org.

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