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Angucyclinone Antibiotics: Total Syntheses of YM-181741, (+)-Ochromycinone, (+)-Rubiginone B_2, (−)-Tetrangomycin, and MM-47755

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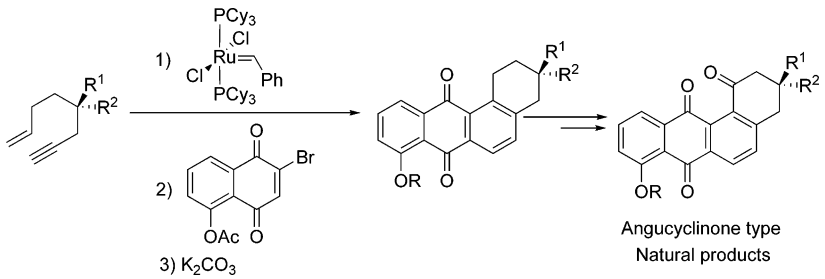

A concise and highly enantioselective route has been developed for the synthesis of angucyclinone-type natural products. Utilizing this strategy, total syntheses of five natural products YM-181741, (+)-ochromycinone, (+)-rubiginone B_2, (−)-tetrangomycin, and MM-47755 have been accomplished in 22%, 23%, 19%, 18%, and 12% overall yields, respectively. Our approach for the synthesis of these natural products having the benz[*a*]anthraquinone skeleton is based on a sequential intramolecular enyne metathesis, intermolecular Diels−Alder reaction (DAR), and aromatization. The intramolecular enyne metathesis reaction was employed for the synthesis of enantiopure 1,3-dienes in excellent yields. Furthermore, the synthesis of YM-181741 as well as structurally similar angucyclinones such as (+)-ochromycinone and (+)-rubiginone B_2 was achieved via asymmetric enolate alkylation of an oxazolidinone in excellent *de*. The related angucyclinones (−)-tetrangomycin and MM-47755, bearing a labile tertiary alcohol, were synthesized via Sharpless asymmetric epoxidation of a known allylic alcohol followed by opening the epoxide with Red-Al. The introduction of oxygen functionality at C-1 in all these natural products was accomplished by photooxygenation under a positive pressure of oxygen.

Introduction

The angucycline family[1] represents a large number of novel antibiotic natural products, isolated from the culture broths of different microorganisms. They exhibit a broad spectrum of biological activities including antitumor, enzyme inhibitory, antiviral, and antifungal effects.[2] Furthermore, a few members of this group of antibiotics are known to be selective against certain microorganisms.[1a] This group of antibiotics includes naturally occurring quinones[3] having an angular tetracyclic framework which are believed to be biosynthesized from a decaketide derivative.[4] In general, the angucyclines possess a benz[*a*]anthraquinone as a common structural framework that bears oxygen functionalities at both C-1 and C-8 along with a single alkyl group or a combination of alkyl group and oxygen functionality at C-3. Angucyclines can be further classified into two subgroups depending on the presence or absence of C-glycoside moiety. The latter group of angucyclines, which do not possess a hydrolyzable sugar moiety, are called angucyclinones.

(+)-Ochromycinone (**1**) and (+)-rubiginone B_2 (**2**) are a set of structurally similar and simple angucyclinones which differ only at the C-8 functionality. The (+)-rubiginone B_2, which bears a phenolic methyl ether functionality at C-8 in contrast

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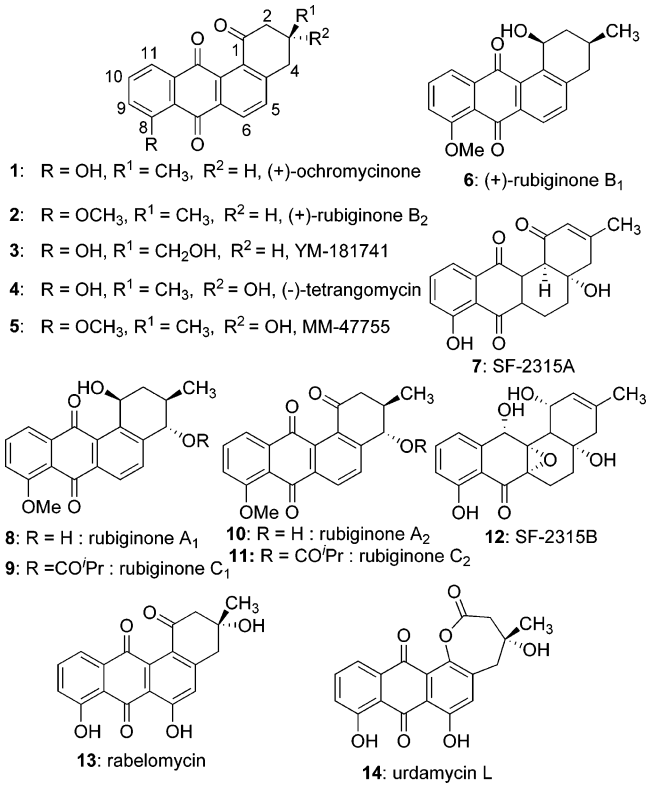

FIGURE 1. Examples of angucyclinone natural products.

to the phenolic OH of (+)-ochromycinone, was isolated by Oka and co-workers[5] from the culture broth of *Streptomyces griseorubiginosus* and found to enhance the cytotoxicity of vincristine against vincristine-resistant P388 leukemia and Moser cells. On the other hand, (+)-ochromycinone was isolated from several strains of *streptomyces* by Bowie[6] in 1967. Recently, Taniguchi *et al*. found that (+)-ochromycinone could be effective in the treatment of peptic ulcer.[7] In the same paper, they also reported the isolation of a novel angucylinone YM-181741 (**3**) from the culture broth of *Streptomyces* sp. Q57219, which bears a hydroxy methyl functionality at C-3 in place of the methyl group in (+)-ochromycinone, and further revealed that both (+)-ochromycinone and YM-181741 (**3**) are selective against *H. pylori*, the major cause of peptic ulcer with MIC values of 0.1 and 0.2 μg/mL, respectively. The existing treatment for the peptic ulcer involves the use of broad-spectrum antibiotics like amoxicillin and clarithromycin to kill this bacterium with reasonable success.[8] Nevertheless, the unselective nature of these broad-spectrum antibiotics causes several side effects[9] like diarrhea, build up of drug resistance, etc., which necessitated the need for the development of new drugs for the selective peptic ulcer treatment.[10] In this context, the selectivity of (+)-ochromycinone and YM-181741 against *H. Pylori* significantly kindles the interest toward the synthesis of these angucyclinones and their simpler analogues.

Another set of structurally very similar angucyclinones, which again differ only at C-8 functionality, includes (−)-tetrangomycin (**4**) and MM-47755 (**5**). These two angucyclinones possess a labile tertiary alcohol at C-3 along with the methyl group present in (+)-ochromycinone. Tetrangomycin, one of the first members of angucyclinones, was isolated from the culture broth of *Streptomyces rimosus* and found to display a broad spectrum of biological activities.[11] MM-47755 [or (−)-8-*O*-methyltetrangomycin (**5**)] was isolated from certain strains of *Streptomyces* bacteria and shows activity against Gram-positive organisms such as *Bacillus subtilis* (MIC = 32 μg/mL).[12] As a consequence of their remarkable biological activity profile and their low availability from microorganisms, many synthetic groups are actively involved in the synthesis of these natural products. Various strategies such as Diels−Alder,[13,18−22] Friedel−Crafts reactions,[14] anionic[15] and free radical benzannulations,[16a−d,f,g] rearrangements of cyclobutenones,[16e] and cobalt-mediated [2+2+2] cycloadditions[17] have

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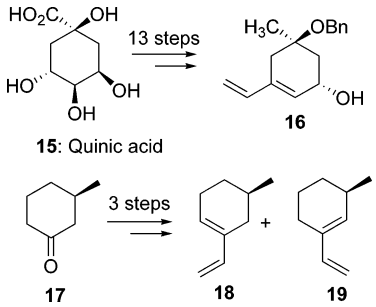
SCHEME 1



been employed for the construction of the tetracyclic skeleton of angucyclines. A comprehensive account of all these efforts is available in three excellent reviews.[1] In spite of the notable accomplishments made so far, there is always room for the development of simple and efficient strategies for the synthesis of these natural products and also for some of the simpler analogues of these molecules, which could be designed to modulate their biological activity.

Among the above-mentioned strategies, the Diels−Alder reaction between a quinone and a 1,3-diene has been widely used for the construction of the angular benz[*a*]anthraquinone skeleton. One of the important advantages of the DAR is the ease of predicting the regioselective outcome of the product by changing substituents at the quinone part. Apart from its operational simplicity, the other benefit of Diels−Alder reaction is its convergent approach that allows for introduction of diversity into the molecules while we plan for the synthesis of simpler analogues of angucyclinones. As far as the synthesis of enantiopure angucyclinones is concerned, the chirality in angucyclinones has been derived by one of the following means: (i) chiral 1,3-dienes,[18−20] (ii) chiral dienophiles,[21] and (iii) chiral Lewis acid.[22]

Among the three sources of chirality, the chiral 1,3-dienes have been used for the synthesis of enantiopure angucyclinones with limited success because of the difficulties associated with the synthesis of optically pure 1,3-dienes. However, a few elegant methods demonstrated the utility of chiral 1,3-dienes for the synthesis of angucyclinones (Scheme 1). Sulikowski has synthesized enantiopure 1,3-diene **16** starting from quinic acid **15** in 13 steps that was subsequently utilized for the synthesis of various angucyclines such as (+)-urdamycinone B, shunt metabolite 104-2, and (+)-SF-2315A (**7**).[18] Krohn[19] and Motoyoshiya[20] independently synthesized chiral 1,3-diene **18** as a mixture of regioisomers along with **19** in 3 steps starting from commercially available (*R*)-3-methylcyclohexanone (99% *ee*) **17** and further elaborated the mixture to (+)-ochromycinone and (+)-rubiginone B_2. It is clear from the above syntheses that most of the existing strategies start from cyclic precursors and hence either require more steps or result in a mixture of regioisomeric 1,3-dienes. With the advent of enyne metathesis, we envisioned the possibility of obtaining these optically pure 1,3-dienes directly from an acyclic precursor in a highly regioselective manner and thus an efficient general strategy could be developed for the synthesis of anguyclinones. With this plan, we set out to design a new versatile strategy for the synthesis of angucyclinones based on sequential enyne metathesis and Diels−Alder reaction/aromatization.

Results and Discussion

In recent times, olefin metathesis[23] has become a more attractive and frequently used synthetic tool in organic synthesis due to the ready availability of many air-stable metathetic catalysts [Grubbs' I-generation catalyst,[24] Grubbs' II-generation catalyst,[25] and phosphine-free Hoveyda's catalyst[26]] that can tolerate numerous functional groups. Among the metathetic reactions, the intramolecular enyne metathesis[27] reaction has received significant attention because of its atom economical nature and its ability to form a conjugated diene. Furthermore, the intramolecular enyne metathesis reaction efficiently transforms an enyne into a 1,3-diene, which not only could act as a diene in the Diels−Alder reaction but also could be easily functionalized further to yield complex natural and unnatural products.[28] However, to the best of our knowledge, until our recent preliminary communication,[29d] no metathetic approach had been utilized for the synthesis of angucyclinones. As a part of our ongoing efforts in exploiting the synthetic utility of sequential enyne metathesis and DAR,[29] we initiated an attempt

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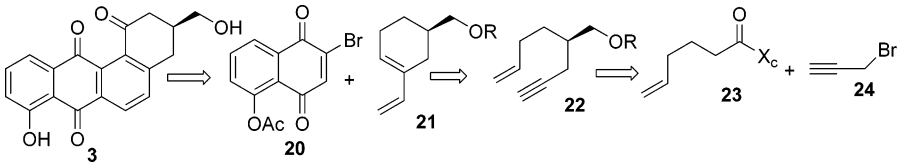
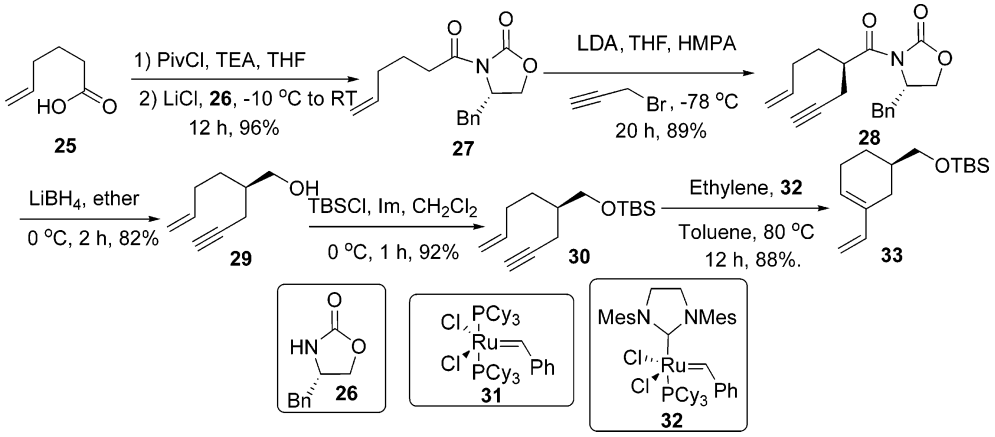
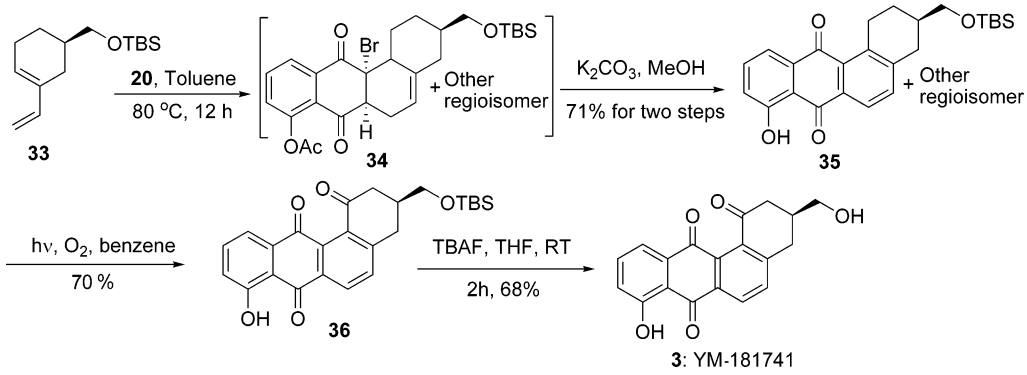
SCHEME 2



SCHEME 3



SCHEME 4



to develop a general strategy for the synthesis of angucyclinone natural products. As an outcome of our endeavor, we recently published the first total synthesis of YM-181741 (**3**).[29d] Herein, we discuss in detail all our efforts which culminated in the syntheses of (+)-ochromycinone (**1**), (+)-rubiginone B_2 (**2**), (−)-tetrangomycin (**4**), and MM-47755 (**5**) in addition to YM-181741 (**3**).

Total Synthesis of YM-181741. Our retrosynthetic analysis of YM-181741 (**3**) is depicted in Scheme 2 and not surprisingly, our thought was to utilize a Diels−Alder reaction between the diene **21** and bromoquinone **20**. We envisaged that the requisite diene **21** could be formed by an intramolecular enyne metathesis of **22**. Enyne **22** could then be traced back to *N*-acyloxazolidinone **23** and propargyl bromide **24**, which could be coupled via an asymmetric enolate alkylation.

The synthesis of diene **21** (Scheme 3) began with the preparation of known **27**[30] from hexenoic acid **25**, using a modified protocol.[31] The key asymmetric enolate alkylation was successfully accomplished by treatment with LDA in the presence of HMPA[32] followed by quenching with propargyl bromide to afford the enyne **28** in greater than 95% *de*, which was confirmed by HPLC.[33] After chromatographic purification, it was possible to obtain **28** as a single diastereomer. The chiral auxiliary was then reductively removed by $LiBH_4$ to afford the primary alcohol **29**, which was subsequently protected as its TBS ether **30**. When this enyne **30** was subjected to the metathesis reaction conditions under an argon atmosphere with Grubbs' catalyst **31**, the reaction was found to be sluggish. However, when the reaction was carried out under an ethylene[34] atmosphere, the required diene **33** was obtained in 73% yield. Subsequently, the yield of the reaction was improved to 88% by performing the reaction with Grubbs' second-generation catalyst **32** under an ethylene atmosphere.

With diene **33** in hand, its Diels−Alder reaction with the appropriate quinone was then investigated (Scheme 4). Treatment of diene **33** with 5-acetoxy-2-bromo-1,4-naphthoquinone **20**[35] at 80 °C in toluene afforded the cycloadduct **34**, which

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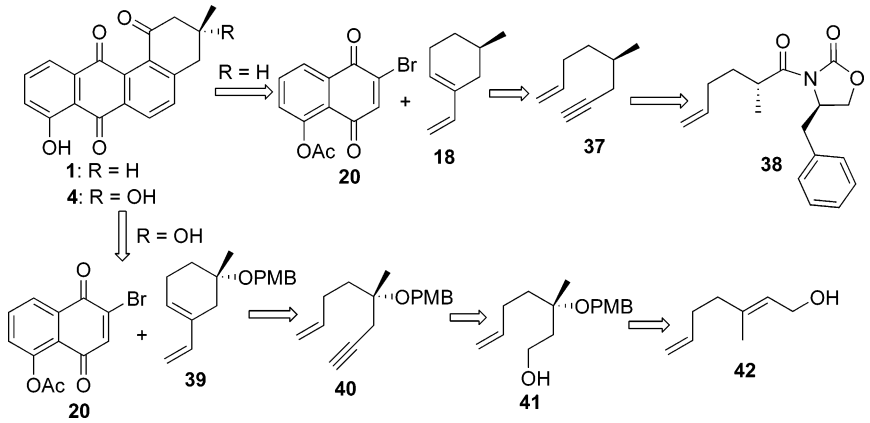
SCHEME 5



was immediately subjected to the aromatization reaction with K_2CO_3 in MeOH to provide an inseparable mixture of **35** and its regioisomer in 9:1 ratio as confirmed by ^{1}H NMR spectroscopy. Subsequent photooxygenation[36] (Hg Lamp, 125 W, Philips India) of **35** provided the ketone **36** in 70% yield and the other regioisomer, which was separated by column chromatography, was found to be unreactive under this condition. Finally, removal of the TBS group with TBAF afforded the natural product YM-181741 (**3**) in 68% yield. The spectral data of the synthesized product in all aspects matched that reported, thus confirming the first total synthesis of YM-181741.[7,29d]

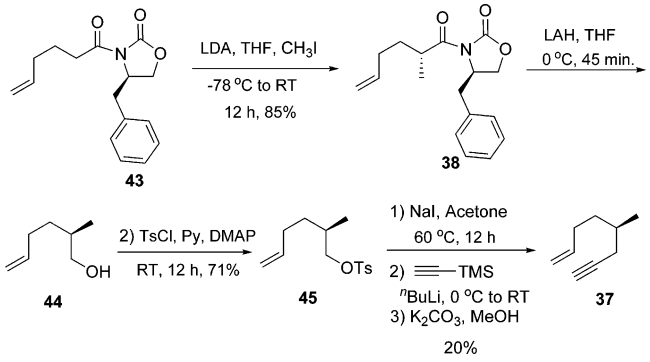
Total Syntheses of (+)-Ochromycinone and (+)-Rubiginone B_2. After the successful synthesis of YM-181741, we shifted our focus to the synthesis of other important angucyclinones and devised a general strategy for these natural products as depicted in Scheme 5.

Synthesis of (+)-ochromycinone (**1**) and (+)-rubiginone B_2 (**2**) was based on the Diels−Alder reaction between 1,3-diene **18** and 5-acetoxy-2-bromo-1,4-naphthoquinone **20**. From the retro-synthetic perspective, we envisaged that the requisite diene **18** could be generated by an enyne metathesis reaction of the corresponding enyne **37**, which in turn could be obtained from the known oxazolidinone **38** by functional group transformations.[30]

As planned, we embarked upon the synthetic journey (Scheme 6) toward (+)-ochromycinone and (+)-rubiginone B_2, with methylation of known oxazolidinone **43**, by following the previously established protocol.[30] The reductive removal of chiral auxiliary followed by treatment of alcohol **44** with *p*-TsCl in pyridine yielded the tosylate **45** in 71% yield over two steps. Subsequently, our attempts to convert the tosylate **45** to the enyne **37** in three steps via conventional route did not provide the product in respectable yield. The poor yield was presumably due to the volatility of the enyne **37**, which also hampered the handling of this compound in small scale as well as the preparation of an analytically pure sample.

To circumvent this difficulty, we decided to introduce a bulky functionality in the enyne **37** that would be removed after enyne

SCHEME 6



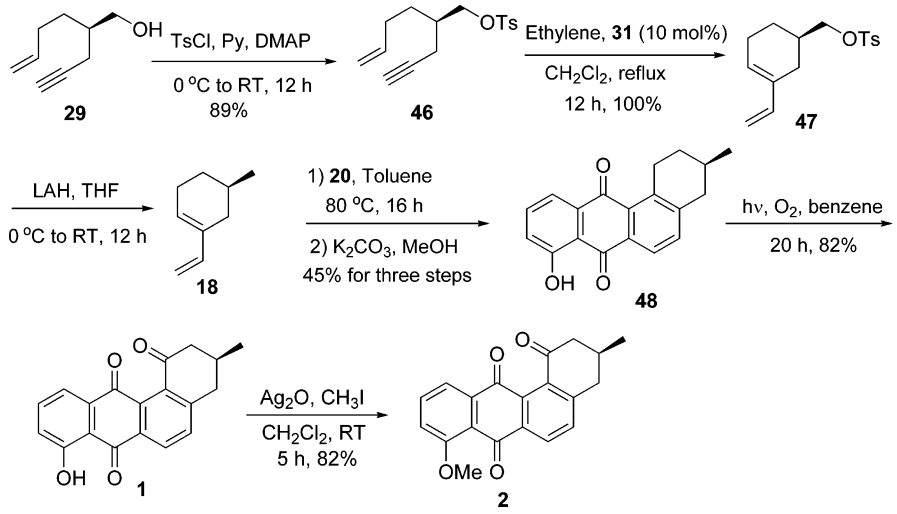
metathesis reaction and prior to Diels−Alder reaction. Toward this end, we set off for the synthesis of diene **18** from the tosylate **46** by an intramolecular enyne metathesis reaction followed by reductive removal of the tosyl group. We envisaged that the enyne tosylate **46** could be traced back to the corresponding alcohol **29**, which was used in the synthesis of YM-181741.

As planned, our modified approach commenced with the tosylation of alcohol **29** by treatment with tosyl chloride in pyridine to afford the enyne **46** in 89% yield (Scheme 7). The synthesis of enyne **46** set the stage for the key intramolecular enyne metathesis reaction. The enyne **46** on treatment with Grubbs' first-generation catalyst **31** in refluxing CH_2Cl_2 under ethylene atmosphere afforded the diene **47** in quantitative yield. The diene tosylate **47** upon treatment with $LiAlH_4$ in THF yielded the diene **18**, and due to its volatile nature it was treated as such with the jugulone derivative **20** in toluene at 80 °C for 16 h. The resultant adduct after the dehydrobromination/aromatization reaction with K_2CO_3 in MeOH yielded the tetracycle **48** in respectable yield (45% over three steps starting from **47**). Having the tetracycle **48** in hand, our next task was to introduce the oxygen functionality at C-1 by the well-established photooxygenation procedure.[36] Although this reaction has been exploited in many angucyclinone syntheses, we were skeptical about this reaction on the tetracycle **48**. Motoyoshiya *et al*. have reported[22] that the photooxygenation on the tetracycle **48** was sluggish and resulted in a low yield along with byproducts. When we irradiated **48** (Hg lamp, 125 W, Philips India) under a positive pressure of oxygen for 20 h, we were delighted to see that the reaction went smoothly and yielded (+)-ochromycinone (**1**) in excellent yield (82%). The (+)-ochromycinone (**1**) upon methylation under a mild condition[37] yielded the (+)-rubiginone B_2 (**2**) and thus completed

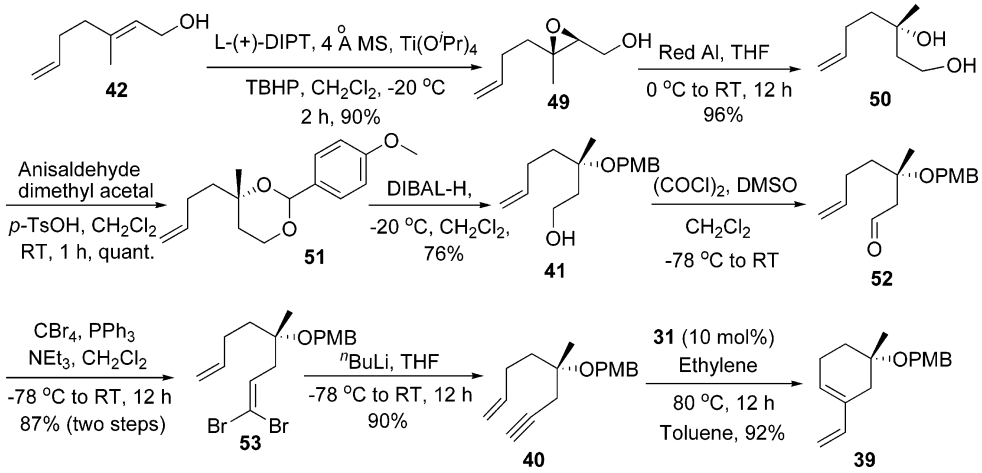
(35) (a) Heinzman, S. W.; Grunwell, J. R. *Tetrahedron Lett.* **1980**, *21*, 4305−4308. (b) Jung, M. E.; Hagenah, J. A. *J. Org. Chem.* **1983**, *48*, 5359−5361.

(36) (a) Huffman, K. R.; Loy, M.; Ullman, E. F. *J. Am. Chem. Soc.* **1965**, *87*, 5417−5423. (b) Blankespoor, R. B.; De Jong, R. L.; Dystra, R.; Hamstra, D. A.; Rozema, D. B.; VanMeurs, D. P.; Vink, P. *J. Am. Chem. Soc.* **1991**, *113*, 3507−3513. (c) Garcia-Garibay, M. A.; Gamarnik, A.; Pang, L.; Jenks, W. S. *J. Am. Chem. Soc.* **1994**, *116*, 12095−12096. (d) Krohn, K.; Khanbabaee, K.; Micheel, J. *Liebigs Ann. Chem.* **1995**, 1529−1537.

SCHEME 7



SCHEME 8



the total syntheses of (+)-ochromycinone and (+)-rubiginone B_2. The chemical and physical data of these two natural products were in agreement in all aspects with the reported values.[4c,5,6,17b,22]

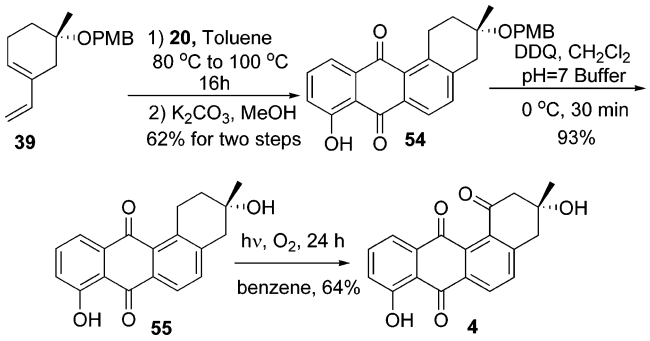
Total Syntheses of (−)-Tetrangomycin and MM-47755. After the successful syntheses of YM-181741, (+)-ochromycinone (**1**), and (+)-rubiginone B_2 (**2**), we targeted (−)-tetrangomycin (**4**) and MM-47755 (**5**) for total synthesis. Our synthetic approach for (−)-tetrangomycin (**4**) made use of 1,3-diene **39** as the starting material for the pivotal DAR (Scheme 5). The requisite 1,3-diene **39** in turn could be derived from the corresponding enyne **40** by an intramolecular enyne metathesis reaction. We envisaged that the enyne **40** could be derived from the alcohol **41** through routine functional group transformations and the alcohol **41** could be traced back to the known allylic alcohol **42**.[38]

Our synthesis as delineated in Scheme 8 began with the Sharpless asymmetric epoxidation of alcohol **42** to afford the epoxide **49** in excellent yield, which was subsequently opened with Red Al to furnish the 1,3-diol **50** in 96% yield.[17c] The diol **50** was protected as its PMB-acetal **51** by using anisaldehydedimethyl acetal in quantitative yield and the resulting acetal **51** was regioselectively opened with DIBAL-H to afford the primary alcohol **41** in 76% yield. The alcohol **41** upon oxidation under Swern condition yielded the aldehyde **52**. Unfortunately, our attempts to convert the aldehyde **52** to enyne **40** in a single step employing the Ohira−Bestmann protocol were not successful.[39] However, as anticipated, the conventional Corey−Fuchs' protocol worked very well for this purpose.[40] Accordingly, we converted the aldehyde **52** to the corresponding dibromo compound **53**, followed by treatment with ^{n}BuLi to afford the enyne **40** in excellent yield. Having made the precursor **40**, our next task was to carry out the key intramolecular enyne metathesis reaction, which was achieved with Grubbs' first-generation catalyst **31** in toluene at 80 °C under an ethylene atmosphere.

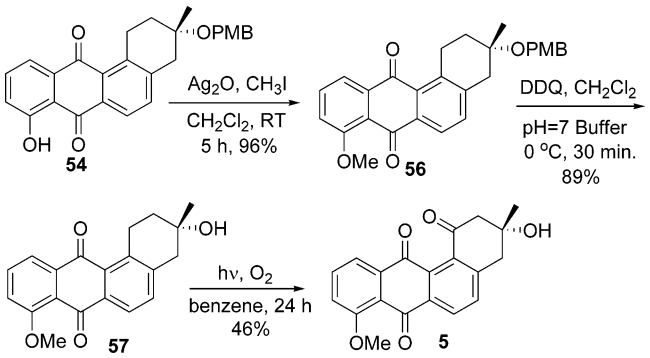
The enantiopure 1,3-diene **39** was then treated with the bromojugulone **20** in toluene to yield a tetracycle, which on further treatment with K_2CO_3 in MeOH yielded the aromatized product **54** in 62% yield over two steps (Scheme 9). Oxidative removal of PMB group in 93% yield followed by photooxygenation furnished the natural product (−)-tetrangomycin (**4**) in 64% yield.

(37) Krohn, K.; Khanbabaee, K. *Liebigs Ann. Chem.* **1994**, 1109−1112.
(38) Foote, K. M.; Hayes, C. J.; John, M. P.; Pattenden, G. *Org. Biomol. Chem.* **2003**, *1*, 3917−3948.
(39) (a) Ohira, S. *Synth. Commun.* **1989**, *19*, 561−564. (b) Muller, S.; Liepold, B.; Roth, G. J.; Bestmann, H. J. *Synlett* **1996**, 521−522.
(40) Corey, E. J.; Fuchs, P. L. *Tetrahedron Lett.* **1972**, *36*, 3769−3772.
(41) For a general section on the experimental procedure, please see the Supporting Information of ref 29c.

SCHEME 9



SCHEME 10



After the synthesis of (−)-tetrangomycin, our initial attempt to selectively methylate the phenolic OH using diazomethane was not fruitful. This forced us to go one step backward to methylate the tetracyclic alcohol **54** with MeI in the presence of Ag_2O to yield the methyl ether **56** in 96% yield (Scheme 10). Removal of the PMB group followed by photooxygenation of the resultant tertiary alcohol **57** yielded the natural product MM-47755 (**5**). The chemical and physical data of these two natural products were in agreement in all aspects with the reported values.[15,16,17c,37]

Conclusion

In conclusion, we have disclosed a straightforward and effective enantioselective strategy involving sequential intramolecular enyne metathesis and Diels−Alder reaction as key steps for the synthesis of angucyclinone natural products such as YM-181741 (**3**), (+)-ochromycinone (**1**), (+)-rubiginone B_2 (**2**), (−)-tetrangomycin (**4**), and MM-47755 (**5**). YM-181741, (+)-ochromycinone, and (+)-rubiginone B_2 were synthesized in 9, 8, and 9 steps with 22%, 23%, and 19% overall yields, respectively. The related angucyclinones (−)-tetrangomycin and MM-47755 were obtained in 12 and 13 steps in 18% and 12% overall yields, respectively. This strategy could be easily extended for the synthesis of other angucyclinones as well as analogues of these natural products.

Experimental Section[41]

General Procedure for Intramolecular Enyne Metathesis Reaction. A solution of enyne (1.0 mmol) in toluene or CH_2Cl_2 (310 mL) was purged with ethylene gas for 10 min before being treated with a solution of **31** or **32** (10 mol %) in toluene or CH_2Cl_2 (10 mL) and then refluxed for 12 h. The reaction mixture was cooled to room temperature and stirred with DMSO (50 equiv with respect to the catalyst, 5.0 mmol) for 6 h to remove the Ru impurities. Evaporation of the solvent and purification by silica gel column chromatography (5−10% ethyl acetate in hexanes) provided the 1,3-dienes.

General Procedure for DAR Followed by Aromatization. A solution of 5-acetoxy-2-bromo-1,4-naphthaquinone (**20**) (1.1 mmol) in toluene (15 mL) was treated with a solution of 1,3-diene (1.0 mmol) in toluene (3 mL) at room temperature and then the mixture was heated at 80 °C for 12 h followed by 100 °C for 2 h. After removing the solvent in vacuo, the crude Diels−Alder adduct was dissolved in MeOH (10 mL), treated with solid K_2CO_3 (3 mmol), and stirred in the dark for 12 h. The solvent was removed in vacuo, treated with water, and extracted with $CHCl_3$. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography to afford the tetracycle.

General Procedure for Photooxygenation. A solution of tetracyclic quinone (1 mmol) in benzene (315 mL) was irradiated with a mercury lamp (125 W, Philips India) under a positive pressure of oxygen for 20 to 24 h. Solvent was removed in *vacuo* and then purified by silica gel column chromatography.

General Procedure for the Removal of PMB Protection. A solution of PMB−ether (1 mmol) in a mixture of CH_2Cl_2 (16 mL) and pH 7 buffer (1.6 mL) at 0 °C was treated with DDQ (1.5 mmol) portion-wise and stirred at the same temperature for 30 min. The reaction mixture was treated with a saturated solution of $NaHCO_3$ and extracted with CH_2Cl_2. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography.

(*S*)-4-Benzyl-3-((*R*)-2-(prop-2-ynyl)hex-5-enoyl)oxazolidin-2-one (28).[29d] To a solution of hexenoic acid (1.2 g, 10.52 mmol) and NEt_3 (3.81 mL, 27.35 mmol) in THF (55 mL) was added pivolyl chloride (1.32 mL, 10.52 mmol) at −10 °C and the stirring was continued at the same temperature for 1 h. LiCl (0.49 g, 11.57 mmol) and (*S*)-4-benzyloxazolidin-2-one (**26**) (1.77 g, 10.0 mmol) were added to the reaction mixture and then warmed to room temperature. After being stirred for 12 h at room temperature, the suspension was treated with $NaHCO_3$ and the organic layer was separated. The aqueous layer was extracted with ethyl acetate. The combined organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography (10% ethyl acetate in hexanes) to afford the oxazolidinone **27** (2.6 g) as a colorless syrup in 96% yield. R_f 0.33 (1:9 ethyl acetate/hexanes).[30]

A solution of *N*,*N*-diisopropylamine (1.41 mL, 9.99 mmol) in THF (8 mL) at 0 °C was treated with ^{n}BuLi (5.65 mL, 1.6 M solution in hexanes, 9.04 mmol) and stirred for 30 min at the same temperature. Then, the reaction mixture was cooled to −78 °C, HMPA (1.14 mL) and a solution of (4*S*)-4-benzyl-3-hexeinoyloxazolidin-2-one (**27**) (1.72 g, 6.32 mmol) in THF (2.5 mL) were added. The resulting mixture was stirred for 30 min at the same temperature and then propargyl bromide (2.25 mL, 25.3 mmol) was added dropwise. After being stirred for 24 h at − 78 °C, a saturated aqueous solution of ammonium chloride was added. The mixture was extracted with ether. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography (10% ethyl acetate in hexanes) to afford the enyne **28** (1.74 g) as a brown syrup in 89% yield. R_f 0.3 (1:9 ethyl acetate/hexanes); $[\alpha]^{20}_D$ +113.7 (*c* 1.56, $CHCl_3$); IR (neat) cm^{-1} 3462, 2927, 2376, 2108, 1948, 1779, 1694, 1390; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.36−7.20 (m, 5H), 5.83−5.74 (m, 1 H), 5.06−4.96 (m, 2 H), 4.74−4.68 (m, 1 H), 4.22−4.14 (m, 2 H), 4.04−3.97 (m, 1 H), 3.31 (dd, 1 H, J = 13.2, 3.2 Hz), 2.78 (dd, 1 H, J = 13.2, 9.2 Hz), 2.64−2.52 (m, 2 H), 2.14−2.06 (m, 2 H), 2.03 (t, 1 H, J = 5.2 Hz), 2.01−1.89 (m, 1 H), 1.8−1.59 (m, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 174.5, 153, 137.7, 135.3, 129.6, 129.0, 127.4, 115.4, 81.1, 70.5, 66.1, 55.4, 41.5, 38.0, 31.2, 30.2, 21.2. HRMS (EI) calcd for $C_{19}H_{21}NO_3Na$ *m*/*z* 334.1419, found *m*/*z* 334.1406.

(*R*)-2-(Prop-2-ynyl)hex-5-en-1-ol (29).[29d] To a solution of **28** (1.7 g, 5.48 mmol) in ether (16 mL) at 0 °C was added MeOH (0.4 mL, 7.18 mmol). After the solution was stirred at 0 °C for 5 min,

$LiBH_4$ (4.64 mL, 9.28 mmol, 2 M solution in THF) was added and the stirring was continued for 2 h at 0 °C. The reaction mixture was treated with a saturated aqueous solution of sodium potassium L-(+)-tartrate at 0 °C. After being warmed to room temperature, the reaction mixture was stirred for 5 h and then the mixture was extracted with ether (3 × 20 mL). The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography (25% ether in pentane) to afford the enyne **29** (0.618 g) as a colorless oil in 82% yield. R_f 0.4 (1:4 ether/pentane); $[\alpha]^{20}_D$ −20.39 (*c* 1.03, $CHCl_3$); IR (neat) cm^{-1} 3425, 2926, 2378, 1653, 1091; ^1H NMR ($CDCl_3$, 400 MHz) δ 5.86−5.76 (m, 1 H), 5.07−4.96 (m, 2 H), 3.72−3.61 (m, 2 H), 2.39−2.21 (m, 2 H), 2.16−2.0 (m, 2 H), 1.99 (t, 1 H, J = 2.4 Hz), 1.82−1.55 (m, 1 H), 1.54−1.47 (m, 2 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 138.3, 114.8, 82.4, 69.7, 64.6, 38.8, 30.9, 29.1, 19.9. HRMS (EI) calcd for $C_9H_{14}OK$ *m*/*z* 177.0682, found *m*/*z* 177.0674.

(*R*)-*tert*-Butyldimethyl(2-(prop-2-ynyl)hex-5-enyloxy)silane (30).[29d] A solution of alcohol **29** (0.25 g, 1.81 mmol), imidazole (0.246 g, 3.62 mmol), and a catalytic amount of DMAP in CH_2Cl_2 (15 mL) was treated with TBSCl (0.41 g, 2.71 mmol) at 0 °C. After being stirred at the same temperature for 1 h, the reaction mixture was treated with water and extracted with CH_2Cl_2. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography (2% ethyl acetate in hexanes) to afford the silyl ether **30** (0.419 g) as a colorless oil in 82%. R_f 0.9 (3:7 ethyl acetate/hexanes); $[\alpha]^{20}_D$ +267.9 (*c* 1.09, $CHCl_3$); IR (neat) cm^{-1} 3307, 2936, 2859, 1641, 1465, 1257, 1216; ^1H NMR ($CDCl_3$, 400 MHz) δ 5.87−5.74 (m, 1 H), 5.06−4.94 (m, 2 H), 3.63−3.51 (m, 2 H), 2.27 (dd, 2 H, J = 8.0, 2.7 Hz), 2.24−2.05 (m, 2 H), 1.92 (t, 1 H, J = 2.7 Hz), 1.73−1.64 (m, 1 H), 1.52−1.43 (m, 2 H), 0.89 (s, 9 H), 0.05 (s, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 138.6, 114.5, 82.8, 69.1, 64.2, 39.1, 31.1, 29.1, 25.9, 19.8, 18.3, −5.4, −5.5. HRMS (EI) calcd for $C_{15}H_{29}OSi$ *m*/*z* 253.1988, found *m*/*z* 253.1987.

(*R*)-*tert*-Butyldimethyl((3-vinylcyclohex-3-enyl)methoxy)silane (33).[29d] Following the general procedure for intramolecular enyne metathesis reaction, a solution of enyne **30** (0.25 g, 0.99 mmol) and **32** (0.14 g, 10 mol %) in toluene was heated at 80 °C for 12 h. After the solution was treated with DMSO, solvent was removed in vacuo and purification by silica gel column chromatography (1% ethyl acetate in hexanes) provided the diene **33** (0.22 g) as a colorless oil in 88% yield. R_f 0.9 (3:7 ethyl acetate/hexanes); $[\alpha]^{20}_D$ +99.1 (*c* 1.35, $CHCl_3$); IR (neat) cm^{-1} 3454, 2930, 1655, 1465, 1257, 1104; ^1H NMR ($CDCl_3$, 300 MHz) δ 6.37 (dd, 2 H, J = 17.6, 10.8 Hz), 5.75 (br s, 1 H), 5.07 (d, 1 H, J = 17.7 Hz), 4.9 (d, 1 H, J = 10.8 Hz), 3.59−3.49 (m, 2 H), 2.3−2.18 (m, 2 H), 2.3−2.18 (m, 1 H), 1.8−1.76 (m, 2 H), 1.29−1.20 (m, 1H), 0.89 (s, 9 H), 0.06 (s, 6 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 140.0, 135.3, 129.6, 109.8, 67.9, 36.3, 26.9, 26.0, 25.3, 18.4, −5.4, −5.3. HRMS (EI) calcd for $C_{15}H_{29}OSi$ *m*/*z* 253.1988, found *m*/*z* 253.1984.

(*R*)-3-((*tert*-Butyldimethylsilyloxy)methyl)-8-hydroxy-1,2,3,4-tetrahydrotetraphene-7,12-dione (35).[29d] Following the general procedure for Diels−Alder reaction followed by aromatization, a solution of 5-acetoxy-2-bromo-1,4-naphthaquinone **20** (0.27 g, 0.92 mmol) and diene **33** (0.21 g, 0.83 mmol) in toluene was heated at 80 °C for 12 h and then at 100 °C for 2 h. After the solvent was removed in vacuo, the crude Diels−Alder adduct was dissolved in MeOH (10 mL), treated with solid K_2CO_3 (0.35 g, 2.49 mmol), and stirred in the dark for 12 h. The solvent was removed in vacuo, treated with water, and extracted with $CHCl_3$. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by a silica gel column chromatography (2% ethyl acetate in hexanes) to afford the tetracycle **35** (0.25 g) as a yellow solid in 71% yield for three steps. R_f 0.4 (1:19 ethyl acetate/hexanes); mp 86−88 °C; $[\alpha]^{20}_D$ +130.0 (*c* 0.9, $CHCl_3$); IR (KBr) cm^{-1} 3444, 2896, 2930, 1667, 1634, 1454, 1284, 1256, 1107; ^1H NMR ($CDCl_3$, 300 MHz) δ 12.55 (s, 1H), 8.14 (d, 1 H, J = 8.4 Hz), 7.72 (dd, 1 H, J = 7.6, 1.2 Hz), 7.64 (t, 1 H, J = 7.8 Hz), 7.50 (d, 1 H, J = 7.6 Hz), 7.24 (dd, 1 H, J = 8.4, 1.2 Hz), 3.68−3.29 (m, 2 H), 3.28−3.20 (m, 1 H), 3.0 (dd,1 H, J = 17.2, 2.8 Hz), 2.67 (dd, 1 H, J = 17.2, 10.8 Hz), 2.09−2.0 (m, 2 H), 1.47−1.25 (m, 1H), 3.05−2.81 (m, 2 H), 0.92 (s, 9 H), 0.07 (s, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 188.8, 161.9, 146.2, 141.7, 136.6, 136.5, 135.1, 135.0, 132.8, 131.2, 124.8, 123.1, 119.4, 115.7, 67.5, 35.7, 34.5, 28.9, 26.1, 18.5, −5.1, −5.2; HRMS (EI) calcd for $C_{25}H_{31}O_4Si$ *m*/*z* 423.1992, found *m*/*z* 423.1981.

(*S*)-3-((*tert*-Butyldimethylsilyloxy)methyl)-8-hydroxy-3,4-dihydrotetraphene-1,7,12(2H)-trione(36).[29d] Following the general procedure for photooxygenation, a solution of quinone **35** (0.17 g, 0.4 mmol) in benzene (45 mL) on irradiation for 20 h afforded compound **36** (0.122 g) in 70% yield as an orange solid along with 0.036 g of unreacted regioisomer. R_f 0.33 (1:9 ethyl acetate/hexanes); mp 91−93 °C; $[\alpha]^{20}_D$ +56.5 (*c* 0.52, $CHCl_3$); IR (KBr) cm^{-1} 3425, 2927, 1706, 1672, 1592, 1457, 1363, 1284, 1099; ^1H NMR ($CDCl_3$, 300 MHz) δ 12.30 (s, 1H), 8.30 (d, 1 H, J = 7.8 Hz), 7.69 (dd, 1 H, J = 5.4, 1.8 Hz), 7.65 (d, 1 H, J = 7.8 Hz), 7.58 (d, 1 H, J = 8.1 Hz), 7.28 (dd, 1 H, J = 8.1, 2.1 Hz), 3.71 (dd, 1 H, J = 9.9, 5.1 Hz), 3.62 (dd, 1 H, J = 10.2, 6.3 Hz), 3.05−2.81 (m, 2 H), 2.73 (dd, 2 H, J = 16.2, 10.8 Hz), 2.56−2.49 (m, 1 H), 0.91 (s, 9 H) , 0.07 (s, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 199.3, 187.6, 183.0, 162.2, 150.4, 137.2, 136.9, 135.8, 135.1, 133.5, 133.4, 129.1, 123.8, 119.8, 115.5, 66.2, 42.3, 38.0, 33.0, 26.0, 18.4, −5.3; HRMS (EI) calcd for $C_{25}H_{29}O_5Si$ *m*/*z* 437.1784, found *m*/*z* 437.1779. Anal. Calcd for $C_{25}H_{28}O_5Si$: C, 68.78; H, 6.46. Found: C, 69.1675; H, 6.8989.

YM-181741 (3).[29d] A solution of TBS−ether **36** (0.1 g, 0.23 mmol) in THF (4 mL) at 0 °C was treated with a solution of TBAF (0.045 g, 0.34 mmol) in THF (2 mL) at 0 °C and then allowed to warm to room temperature and stirred for 2 h. The reaction mixture was treated with water and then extracted with $CHCl_3$. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography to afford YM 181741 (**3**) (0.05 g) in 68% yield. R_f 0.3 (3:2 ethyl acetate/hexanes); mp 192 °C; $[\alpha]^{25}_D$ +27.2 (*c* 0.367, $CHCl_3$); IR (KBr) cm^{-1} 3433, 2927, 1702, 1671, 1588, 1453, 1362, 1276, 1588, 1453, 1362, 1276, 1215; UV(MeOH) λ_{max} nm (ϵ) 276, 402; ^1H NMR ($CDCl_3$, 400 MHz) δ 12.30 (s, 1H), 8.30 (d, 1 H, J = 7.6 Hz), 7.68 (dd, 1 H, J = 7.6, 2.4 Hz), 7.65 (d, 1 H, J = 7.2 Hz), 7.58 (d, 1 H, J = 8.0 Hz), 7.28 (dd, 1 H, J = 8.0, 2.4 Hz), 3.77 (dd, 1 H, J = 10.4, 4.8 Hz), 3.70 (dd, 1 H, J = 10.4, 7.2 Hz), 3.10 (dd, 1 H, J = 16.8, 4.8 Hz), 3.03 (dd, 1 H, J = 16.0, 6.4 Hz), 2.85 (dd, 1 H, J = 16.4, 10.4 Hz), 2.69 (dd, 1 H, J = 16.0, 10.4 Hz), 2.61−2.54 (m, 1 H), 1.86 (br s, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 198.8, 187.4, 182.9, 162.0, 149.8, 137.0, 136.7, 135.6, 134.9, 133.5, 133.2, 129.1, 123.8, 119.6, 115.4, 65.8, 42.0, 37.6, 32.7; HRMS (EI) calcd for $C_{19}H_{15}O_5$ *m*/*z* 323.0919, found *m*/*z* 323.0910. Anal. Calcd for $C_{19}H_{16}O_6$: C, 67.05; H, 4.74. Found: C, 66.7777; H, 4.9084.

(*R*)-2-Methylhex-5-enyl 4-Methylbenzenesulfonate (45). A suspension of LAH (2.3 g, 60.62 mmol) in ether at 0 °C was treated with a solution of oxazolidinone **38** (5.8 g, 20.20 mmol)[30] in ether and stirred at the same temperature for 45 min. The reaction mixture was slowly treated with a saturated solution of Na_2SO_4 at 0 °C. The resulting granules were filtered and washed well with ether. The filtrate was concentrated in vacuo and proceeded further without any purification.

To a stirred solution of the resulting alcohol in pyridine (30 mL) at 0 °C was added *p*-TsCl (9.6 g, 50.5 mmol) followed by a catalytic amount of DMAP. The reaction mixture was warmed to room temperature and after being stirred for 5 h it was treated with cold water. The mixture was extracted with $CHCl_3$ (3 × 100 mL). The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography (10% ethyl acetate in hexanes) to afford the compound **45** (3.85 g) as a colorless oil in 71% yield over two steps. R_f 0.59 (1:4 ethyl acetate/hexanes); $[\alpha]^{20}_D$ −5.098 (*c* 1.04, $CHCl_3$); IR (neat) cm^{-1} 2974, 2925, 2638, 1597, 1458, 1368, 1176; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.79 (d, 2 H, J = 10.8 Hz), 7.35 (d, 2 H, J = 10.8 Hz), 5.78−5.65 (m, 1 H),

4.99−4.90 (m, 2 H), 3.89 (dd, 1 H, J = 12.0, 8.0 Hz), 3.82 (dd, 1 H, J = 12.4, 8.0 Hz), 2.45 (s, 3 H), 2.02−1.91 (m, 2 H), 1.84−1.75 (m, 1 H), 1.50−1.39 (m, 1 H), 1.26−1.16 (m, 1 H), 0.9 (d, 3 H, J = 8.8 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 144.9, 138.3, 133.2, 130.0, 128.1, 115.0, 75.1, 32.4, 31.9, 30.9, 21.8, 16.4; HRMS (EI) calcd for $C_{14}H_{20}O_3NaS$ m/z 291.1031, found m/z 291.1031.

(*R*)-2-(Prop-2-ynyl)hex-5-enyl 4-Methylbenzenesulfonate (46). To a stirred solution of alcohol **29** (0.4 g, 2.9 mmol) in pyridine (5 mL) at 0 °C was added *p*-TsCl (1.4 g, 7.33 mmol) followed by a catalytic amount of DMAP. The reaction mixture was warmed to room temperature and after being stirred for 5 h it was treated with cold water. The mixture was extracted with $CHCl_3$ (3 × 20 mL). The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography (15% ethyl acetate in hexanes) to afford the enyne **46** (0.752 g) as a colorless oil in 89% yield. R_f 0.44 (3:7 ethyl acetate/hexanes); $[\alpha]^{20}_D$ +11.617 (*c* 0.835, $CHCl_3$); IR (neat) cm^{-1} 3294, 2923, 1640, 1363, 1177; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.8 (d, 2 H, J = 8.0 Hz), 7.35 (d, 2 H, J = 8.0 Hz), 5.76−5.67 (m, 1 H), 5.66−4.94 (m, 2 H), 4.05 (dd, 1 H, J = 9.6, 4.8 Hz), 4.0 (dd, 1 H, J = 9.6, 6.4 Hz), 2.45 (s, 3 H), 2.31−2.27 (m, 2 H), 2.21−2.02 (m, 2 H), 1.99−1.88 (m, 1 H), 1.86 (t, 1 H, J = 2.4 Hz), 1.51−1.42 (m, 2 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 144.8, 137.6, 132.8, 129.9, 128.0, 115.3, 80.7, 71.3, 70.3, 36.2, 30.6, 28.7, 21.7, 19.8. HRMS (EI) calcd for $C_{16}H_{20}O_3NaS$ m/z 315.1031, found m/z 315.1129.

(*R*)-(3-Vinylcyclohex-3-enyl)methyl 4-Methylbenzenesulfonate (47). Following the general procedure for intramolecular enyne metathesis reaction, a solution of enyne **46** (0.5 g, 1.71 mmol) and **31** (0.14 g, 10 mol %) in CH_2Cl_2 was refluxed for 12 h. After the solution was treated with DMSO, solvent was removed in vacuo and purification by silica gel column chromatography (15% ethyl acetate in hexanes) furnished the diene **47** (0.5 g) as a colorless oil in quantitative yield. R_f 0.44 (3:7 ethyl acetate/hexanes); $[\alpha]^{20}_D$ +50.963 (*c* 0.675, $CHCl_3$); IR (neat) cm^{-1} 2924, 1600, 1361, 1190, 1177, 1098; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.81 (d, 2 H, J = 8.0 Hz), 7.36 (d, 2 H, J = 8.0 Hz), 6.31 (dd, 1 H, J = 17.2, 10.8 Hz), 5.72 (br s, 1 H), 4.99 (d, 1 H, J = 17.2 Hz), 4.89 (d, 1 H, J = 10.8 Hz), 3.96 (d, 2 H, J = 6.8 Hz), 2.46 (s, 3 H), 2.27−2.18 (m, 1 H), 2.05−1.96 (m, 1 H), 1.77−1.70 (m, 2 H), 1.29−1.22 (m, 1 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 144.8, 139.4, 134.2, 133.0, 129.9, 129.1, 127.9, 110.3, 74.4, 33.2, 26.4, 24.7, 24.6, 21.7. HRMS (EI) calcd for $C_{16}H_{20}O_3NaS$ m/z 315.1031, found m/z 315.1034.

(*R*)-8-Hydroxy-3-methyl-1,2,3,4-tetrahydrotetraphene-7,12-dione (48). A suspension of LAH (0.122 g, 3.22 mmol) in THF (5 mL) at 0 °C was treated with a solution of diene **47** (0.47 g, 1.61 mmol) in THF (1 mL), and after being warmed to room temperature, the reaction mixture was stirred for 12 h. Then, the reaction mixture was treated with a saturated solution of Na_2SO_4 at 0 °C. The resultant granules were filtered and washed well with ether. The filtrate was concentrated under atmospheric pressure at 40 °C to afford diene **18**, which was used for the next step without making any attempt to remove the THF from the crude mixture.

Following the general procedure for Diels−Alder reaction followed by aromatization, a solution of 5-acetoxy-2-bromo-1,4-naphthaquinone **20** (0.52 g, 1.77 mmol) and diene **18** in toluene was heated at 80 °C for 12 h. After the solvent was removed in vacuo, the crude Diels−Alder adduct was dissolved in MeOH (16 mL), treated with solid K_2CO_3 (0.67 g, 4.83 mmol), and stirred in the dark for 12 h. The solvent was removed in *vacuo*, treated with water, and extracted with $CHCl_3$. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography (20% ethyl acetate in hexanes) to afford the tetracycle **48** (0.21 g) as a yellow solid in 45% yield for three steps. R_f 0.8 (1:4 ethyl acetate/hexanes); mp 160−161 °C; $[\alpha]^{20}_D$ +106.634 (*c* 0.615, $CHCl_3$); IR (KBr) cm^{-1} 3431, 2952, 2922, 1664, 1631, 1580, 1451, 1371, 1272; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 12.54 (s, 1H), 8.11 (d, 1 H, J = 7.6 Hz), 7.70 (dd, 1 H, J = 7.2, 0.8 Hz), 7.62 (t, 1 H, J = 8.0 Hz), 7.44 (d, 1 H, J = 8.0 Hz), 7.22 (dd, 1 H, J = 8.4, 1.2 Hz), 3.55 (dq, 1 H, J = 19.2, 3.2 Hz), 3.25−3.18 (m, 1 H), 2.94 (dq, 1 H, J = 17.2, 1.6 Hz), 2.53 (dd, 1 H, J = 17.2, 10.4 Hz), 2.05−2.0 (m, 2 H), 1.99−1.83 (m, 1H), 1.41−1.31 (m, 1H), 1.09 (d, 3 H, J = 6.8 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 188.9, 184.9, 161.8, 146.5, 141.6, 136.6, 135.2, 134.8, 132.8, 131.3, 124.8, 123.0, 119.3, 115.6, 39.9, 31.4, 29.2, 27.8, 21.7; HRMS (EI) calcd for $C_{19}H_{17}O_3$ m/z 293.1178, found m/z 293.1175. Anal. Calcd for $C_{19}H_{16}O_3$: C, 78.06; H, 5.52. Found: C, 78.4790; H, 5.7794.

(+)-Ochromycinone (1). Following the general procedure for photooxygenation, a solution of quinone **48** (0.07 g, 0.24 mmol) in benzene (90 mL) on irradiation for 20 h afforded (+)-ochromycinone (**1**) (0.06 g, 82%) as a yellow solid. R_f 0.24 (2:3 ethyl acetate/hexanes); mp 159−160 °C; $[\alpha]^{20}_D$ +103.246 (*c* 0.345, $CHCl_3$); IR (KBr) cm^{-1} 2956, 2923, 1703, 1667, 1635, 1589, 1453; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 12.21 (s, 1 H), 8.29 (d, 1 H, J = 8.0 Hz), 7.70−7.58 (m, 2 H), 7.55 (d, 1 H, J = 8.0 Hz), 7.29−7.24 (m, 1 H), 3.06−2.98 (m, 2 H), 2.69 (dd, 1 H, J = 16.0, 10.4 Hz), 2.58 (dd, 1 H, J = 16.0, 10.4 Hz), 2.5−2.42 (m, 1 H), 1.21 (d, 3 H, J = 6.4 Hz); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 199.1, 187.5, 182.9, 161.9, 150.3, 136.9, 136.5, 135.8, 135.0, 133.4, 132.9, 128.9, 123.6, 119.5, 115.3, 47.4, 38.3, 30.7, 21.4; HRMS (EI) calcd for $C_{19}H_{15}O_4$ m/z 307.0970, found m/z 307.0976. Anal. Calcd for $C_{20}H_{16}O_4$: C, 74.50; H, 4.61. Found: C, 75.5750; H, 4.3945.

(+)-Rubiginone B_2 (2). A solution of alcohol **1** (0.04 g, 0.13 mmol) and MeI (0.32 mL, 5.17 mmol) in CH_2Cl_2 (4 mL) was treated with freshly prepared Ag_2O (0.5 g, 2.1 mmol) at room temperature and the solution was stirred for 5 h. The mixture was filtered, the filtrate was concentrated, and the resultant residue was purified by silica gel column chromatography (40% ethyl acetate in hexanes) to afford (+)-rubiginone B_2 (**2**) (0.034 g, 82%) as a yellow solid. R_f 0.16 (2:3 ethyl acetate/hexanes); mp 237−239 °C; $[\alpha]^{20}_D$ +77.545 (*c* 0.44, $CHCl_3$); IR (KBr) cm^{-1} 1706, 1697, 1674, 1592, 1585; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.26 (d, 1 H, J = 8.4 Hz), 7.77 (dd, 1 H, J = 7.6, 0.8 Hz), 7.70 (t, 1 H, J = 8.0 Hz), 7.51 (d, 1 H, J = 8.0 Hz), 7.30 (d, 1 H, J = 8.4 Hz), 4.04 (s, 3 H), 3.02−2.97 (m, 2 H), 2.68 (dd, 1 H, J = 16.4, 10.4 Hz), 2.56 (dd, 1 H, J = 15.6, 10.8 Hz), 2.5−2.42 (m, 1 H), 1.19 (d, 3 H, J = 6.4 Hz); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 198.9, 184.5, 181.6, 159.8, 149.2, 137.6, 135.4, 135.1, 135.0, 133.1, 129.6, 120.6, 119.6, 117.2, 56.5, 47.6, 38.3, 30.9, 21.5; HRMS (EI) calcd for $C_{20}H_{17}O_4$ m/z 321.1127, found m/z 321.1128. Anal. Calcd for $C_{20}H_{16}O_4$: C, 74.99; H, 5.03. Found: C, 74.8822; H, 4.8840.

((2*S*, 3*S*)-3-(But-3-enyl)-3-methyloxiran-2-yl)methanol (49). A suspension of 4 Å MS (0.69 g) in CH_2Cl_2 at room temperature was treated with L-(+)-diisopropyl tartrate (0.82 mL, 3.85 mmol)-and $Ti(O^iPr)_4$ (0.76 mL, 2.5 mmol) and the mixture was cooled to −20 °C. Dry *tert*-butyl hydroperoxide (4 mL, 3.3 M solution in toluene, 37.5 mmol) was added to this mixture, which was stirred at the same temperature for 40 min. A solution of alcohol **42** (3.2 g, 25 mmol) in CH_2Cl_2 (25 mL) was added dropwise and the stirring was continued for an additional 2 h. The reaction mixture was warmed to 0 °C and treated with water (15 mL). Finally, the mixture was warmed to room temperature and treated with a 30% solution of NaOH in saturated NaCl solution (3.5 mL). The mixture was stirred at room temperature for about 1 h until the two layers separated and then extracted with CH_2Cl_2. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography (35% ethyl acetate in hexanes) to afford the epoxy alcohol **49** (3.1 g) as a colorless oil in 90% yield. R_f 0.5 (1:1 ethyl acetate/hexanes); $[\alpha]^{20}_D$ −4.277 (*c* 1.59, $CHCl_3$); IR (neat) cm^{-1} 3424, 3077, 2933, 1643, 1450, 1389, 1251, 1034; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.86−5.76 (m, 1 H), 5.07−4.97 (m, 2 H), 3.83 (d, 1 H, J = 12.4 Hz), 3.68 (dd, 1 H, J = 12.0, 6.8 Hz), 2.99 (dd, 1 H, J = 6.8, 4.0 Hz), 2.23−2.10 (m, 2 H), 1.87 (br s, 1 H), 1.79−1.72 (m, 1 H), 1.60−1.52 (m, 1 H), 1.31 (s, 3 H); ^{13}C NMR ($CDCl_3$, 75 MHz) 137.7, 115.1, 63.3, 61.3, 61.1, 37.7, 29.3, 16.8; HRMS (EI) calcd for $C_8H_{14}O_2Na$ m/z 165.0891, found m/z 165.0891.

(*S*)-3-Methylhept-6-ene-1,3-diol (50). A solution of epoxy alcohol **49** (3.2 g, 22.5 mmol) in THF (108 mL) at 0 °C was treated with a solution of Red Al (14 mL, 3.5 M solution in toluene, 49.5 mmol) in THF (32 mL). After being stirred at the same temperature for 10 min, the reaction mixture was warmed to room temperature and stirred for 12 h. A saturated solution of potassium sodium L-tartrate tetra hydrate was added at 0 °C to the reaction mixture, which was then warmed to room temperature. The stirring was continued for 1 h until the two layers separated and then extracted with ethyl acetate. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography (40% ethyl acetate in hexanes) to afford the 1,3-diol **50** (3.25 g) as a colorless oil in quantitative yield. R_f 0.2 (1:1 ethyl acetate/hexanes); $[\alpha]^{20}_D$ +23.186 (*c* 1.13, $CHCl_3$); IR (neat) cm^{-1} 3364, 2972, 2935, 1643, 1452, 1378, 1126, 1060; ^1H NMR ($CDCl_3$, 300 MHz) δ 5.91−5.78 (m, 1 H), 5.07−4.93 (m, 2 H), 3.92−3.80 (m, 2 H), 3.64 (s, OH), 2.18−2.03 (m, 2 H), 1.83−1.44 (m, 4 H), 1.23 (s, 3 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 138.8, 114.5, 73.6, 61.5, 59.5, 41.4, 28.4, 26.5; HRMS (EI) calcd for $C_8H_{16}O_2Na$ *m*/*z* 167.1048, found *m*/*z* 167.1048.

(4*S*)-4-(But-3-enyl)-2-(4-methoxyphenyl)-4-methyl-1,3-dioxane (51). To a solution of 1,3-diol **50** (2 g, 13.88 mmol) and anisaldehydedimethyl acetal (3.54 mL, 20.82 mmol) in CH_2Cl_2 (150 mL) at room temperature was added a catalytic amount of TsOH and the solution was stirred for 1 h at room temperature. The reaction mixture was treated with 10 drops of NEt_3, and after concentrating the reaction mixture, the residue was purified by silica gel column chromatography (7% ethyl acetate in hexanes) to afford the acetal **51** (3.9 g) as a colorless oil in quantitative yield. R_f 0.6 (1:9 ethyl acetate/hexanes); $[\alpha]^{20}_D$ +17.293 (*c* 1.33, $CHCl_3$); IR (neat) cm^{-1} 2939, 1611, 1516, 1458, 1382, 1251, 1095; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.41 (d, 2 H, J = 8.7 Hz), 6.88 (d, 2 H, J = 8.7 Hz), 5.94−5.79 (m, 1 H), 5.69 (s, 1 H), 5.10−4.93 (m, 2 H), 4.17−4.05 (m, 2 H), 3.79 (s, 3 H), 2.30−1.61 (m, 4 H), 1.59−1.30 (m, 2 H), 1.41 (s, 3 H); HRMS (EI) calcd for $C_{16}H_{23}O_3$ *m*/*z* 263.16547, found *m*/*z* 263.1655.

(*S*)-3-(4-Methoxybenzyloxy)-3-methylhept-6-en-1-ol (41). A solution of acetal **51** (3 g, 11.5 mmol) in CH_2Cl_2 (150 mL) was treated with DIBAL-H (46 mL, 1 M solution in toluene) at −20 °C over a period of 15 min and the solution was stirred at the same temperature for 2 h. The reaction mixture was treated with ethylacetate and warmed to room temperature. A saturated solution of potassium sodium L-tartrate tetrahydrate was added to the reaction mixture, and after being stirred for 30 min, the reaction mixture was extracted with ethyl acetate. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography (50% ethyl acetate in hexanes) to afford the primary alcohol **41** (2.3 g) as a colorless oil in 76% yield. R_f 0.3 (2:3 ethyl acetate/hexanes); $[\alpha]^{20}_D$ +36.22 (*c* 1.27, $CHCl_3$); IR (neat) cm^{-1} 3423, 2934, 1611, 1515, 1463, 1249; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.23 (dt, 2 H, J = 9.6, 2.7 Hz), 6.86 (dt, 2 H, J = 9.6, 3.0 Hz), 5.91−5.77 (m,1 H), 5.08−4.95 (m, 2 H), 4.34 (s, 2 H), 3.90−3.55 (m, 2 H), 3.79 (s, 3 H), 2.42 (br s, 1 H), 2.17−2.08 (m, 2 H), 2.04−1.93 (m, 1 H), 1.82−1.76 (m, 1 H), 1.75−1.64 (m, 2 H), 1.33 (s, 3 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 159.0, 138.5, 130.9, 129.0, 114.5, 113.8, 78.2, 63.2, 59.3, 55.2, 39.8, 37.3, 28.0, 23.0; HRMS (EI) calcd for $C_{16}H_{24}O_3Na$ *m*/*z* 287.1623, found *m*/*z* 287.1628.

(*S*)-3-(4-Methoxybenzyloxy)-3-methylhept-6-enal (52). To a solution of oxalyl chloride (0.72 mL, 8.18 mmol) in CH_2Cl_2 (24 mL) was added DMSO (1.11 mL, 15.68 mmol) at −78 °C, and after the solution was stirred at the same temperature for 10 min a solution of alcohol **41** (1.8 g, 6.8 mmol) in CH_2Cl_2 (12 mL) was added. The stirring was continued for an additional 1 h and triethylamine (5.03 mL, 36.1 mmol) was added to the reaction mixture at −78 °C. After being stirred at the same temperature for 20 min, the mixture was gradually warmed to room temperature and treated with water. The mixture was extracted with CH_2Cl_2, the organic layer was washed with brine, dried (Na_2SO_4), and concentrated, and the crude product **52** was used for further reaction without any purification. R_f 0.5 (3:7 ethyl acetate/hexanes); IR (neat) cm^{-1} 2929, 1720, 1639, 1515, 1248.

(*S*)-1-((1,1-Dibromo-4-methylocta-1,7-dien-4-yloxy)methyl)-4-methoxybenzene (53). To a stirred solution of triphenylphosphine (7.15 g, 27.2 mmol) in CH_2Cl_2 (42 mL) was added carbon tetrabromide (4.52 g, 13.63 mmol) at room temperature. After the solution was stirred for 30 min at room temperature, NEt_3 (7.6 mL, 54.5 mmol) was added and the mixture was cooled to −78 °C. To this cold mixture was added a solution of aldehyde **52** (1.8 g, 6.8 mmol) in CH_2Cl_2 (5 mL) and then mixture was stirred at −78 °C for 1 h and then at room temperature for 12 h. The reaction mixture was concentrated and purified by silica gel column chromatography (3% ethyl acetate in hexanes) to afford the product **53** (2.47 g) as a colorless oil in 87% yield for two steps from alcohol. R_f 0.8 (1:4 ethyl acetate/hexanes); $[\alpha]^{20}_D$ +6.452 (*c* 1.55, $CHCl_3$); IR (neat) cm^{-1} 2934, 1614, 1514, 1460, 1379, 1248; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.25 (dt, 2 H, J = 9.6, 2.7 Hz), 6.88 (dt, 2 H, J = 9.6, 2.7 Hz), 6.54 (t, 1 H, J = 7.5 Hz), 5.91−5.78 (m, 1 H), 5.08−4.94 (m, 2 H), 4.32 (s, 2 H), 3.80 (s, 3 H), 2.46−2.31 (m, 2 H), 2.16−2.10 (m, 2 H), 1.76−1.57 (m, 2 H), 1.25 (s, 3 H); ^{13}C NMR ($CDCl_3$, 75 MHz) 159.1, 138.6, 135.0, 131.1, 128.9, 114.6, 113.9, 89.8, 76.4, 63.4, 55.4, 42.1, 37.5, 28.0, 23.4; HRMS (EI) calcd for $C_{17}H_{22}O_2NaBr_2$ *m*/*z* 438.9884, found *m*/*z* 438.9897.

(*S*)-1-Methoxy-4-((4-methyloct-7-en-1-yn-4-yloxy)methyl)benzene (40). A solution of dibromo compound **53** (2.45 g, 5.86 mmol) in THF (60 mL) at −78 °C was treated with ^{n}BuLi (8.42 mL, 1.6 M solution in hexane) and the solution was stirred at the same temperature for 10 min. The reaction mixture was slowly warmed to room temperature over a period of 2 h, quenched with saturated aqueous NH_4Cl solution, and extracted with ethyl acetate. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by silica gel column chromatography (4% ethyl acetate in hexanes) to afford the enyne **40** (1.35 g) as a colorless oil in 90% yield. R_f 0.4 (1:19 ethyl acetate/hexanes); $[\alpha]^{20}_D$ −2.025 (*c* 1.20, $CHCl_3$); IR (neat) cm^{-1} 3302, 2975, 2111, 1734, 1611, 1513, 1460, 1249; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.27 (dt, 2 H, J = 9.6, 3 Hz), 6.86 (dt, 2 H, J = 9.6, 3.0 Hz), 5.92−5.79 (m, 1 H), 5.09−4.94 (m, 2 H), 4.37 (s, 2 H), 3.79 (s, 3 H), 2.47(d, 2 H, J = 2.7 Hz), 2.20−2.12 (m, 2 H), 2.03 (t, 1 H, J = 2.4 Hz), 1.88−1.68 (m, 2 H), 1.35 (s, 3 H); ^{13}C NMR ($CDCl_3$, 75 MHz) 159.1, 138.6, 135.0, 131.1, 114.6, 113.9, 89.8, 76.4, 63.4, 55.4, 42.1, 37.5, 28.0, 23.4; HRMS (EI) calcd for $C_{17}H_{22}O_2Na$ *m*/*z* 281.1517, found *m*/*z* 281.1510.

(*S*)-1-Methoxy-4-((1-methyl-3-vinylcyclohex-3-enyloxy)methyl)benzene (39). Following the general procedure for intramolecular enyne metathesis reaction, a solution of enyne **40** (0.27 g, 1.05 mmol) and **31** (0.086 g, 10 mol %) in toluene (335 mL) was heated at 80 °C for 12 h. After the mixture was treated with DMSO (0.37 mL, 5.3 mmol), the solvent was removed in vacuo and purification by silica gel column chromatography (6% ethyl acetate in hexanes) furnished the 1,3-diene **39** (0.26 g) as a colorless oil in 92% yield. R_f 0.4 (1:19 ethyl acetate/hexanes); $[\alpha]^{20}_D$ +65.0 (*c* 1.56, $CHCl_3$); IR (neat) cm^{-1} 3442, 2926, 2385, 1964, 1611, 1511, 1251; ^1H NMR ($CDCl_3$, 400 MHz) δ 7.25 (d, 2 H, J = 8.0 Hz), 6.85 (dt, 2 H, J = 9.6, 2.8 Hz), 6.39 (dd, 1 H, J = 17.6, 10.8 Hz), 5.75 (br s, 1 H), 5.07 (d, 1 H, J = 17.2 Hz), 4.9 (d, 1 H, J = 10.4 Hz), 4.42 (dd, 2 H, J = 16.0, 11.2 Hz), 3.78 (s, 3 H), 2.46−2.22 (m, 2 H), 2.18−2.15 (m, 2 H), 1.85 (dt, 1 H, J = 13.2, 6.8 Hz), 1.69 (dt, 1 H, J = 13.2, 6.8 Hz), 1.31 (s, 3 H); ^{13}C NMR ($CDCl_3$, 100 MHz) 158.9, 139.7, 134.0, 131.9, 128.8, 128.5, 113.8, 109.9, 73.4, 63.2, 55.3, 35.6, 32.6, 23.9, 23.8; HRMS (EI) calcd for $C_{17}H_{22}O_2Na$ *m*/*z* 281.1517, found *m*/*z* 281.1513.

(*S*)-3-(4-Methoxybenzyloxy)-11-hydroxy-3-methyl-1,2,3,4-tetrahydrotetraphene-7,12-dione (54). Following the general procedure for Diels−Alder reaction followed by aromatization, a solution of 5-acetoxy-2-bromo-1,4-naphthaquinone **20** (0.3 g, 1.02 mmol) and diene **39** (0.24 g, 0.93 mmol) in toluene (15 mL) was heated at 80 °C for 12 h followed by 100 °C for 2 h. After the

solvent was removed in vacuo, the crude Diels−Alder adduct was dissolved in MeOH (10 mL), treated with solid K_2CO_3 (0.39 g, 2.79 mmol), and stirred in the dark for 12 h. The solvent was removed in vacuo, treated with water, extracted with $CHCl_3$. The organic layer was washed with brine, dried (Na_2SO_4), concentrated, and purified by a silica gel column chromatography (20% ethyl acetate in hexanes) to afford the tetracycle **54** (0.245 g) as a yellow solid in 62% yield for two steps. R_f 0.33 (1:9 ethyl acetate/hexanes); mp 129−131 °C; $[\alpha]^{20}_D$ −119.464 (*c* 1.12, $CHCl_3$); IR (KBr) cm^{-1} 3443, 2925, 1664, 1632, 1613, 1581, 1514, 1451, 1369, 1271, 1251; ^1H NMR ($CDCl_3$, 400 MHz) δ 12.56 (s, 1 H), 8.16 (d, 1 H, J = 8.0 Hz), 7.75 (dd, 1 H, J = 8.4, 0.8 Hz), 7.65 (t, 1 H, J = 8.0 Hz), 7.45 (d, 1 H, J = 8.0 Hz), 7.25 (dd, 1 H, J = 8.4, 1.2 Hz), 7.14 (d, 2 H, J = 8.8 Hz), 6.78 (dt, 2 H, J = 9.6, 2.8 Hz), 4.46 (dd, 2 H, J = 16.8, 10.4 Hz), 3.74 (s, 3 H), 3.51 (t, 2 H, J = 6.4 Hz), 3.17 (d, 1 H, J = 17.6 Hz), 2.97 (d, 1 H, J = 17.6 Hz), 2.27−2.20 (m, 1 H), 1.89−1.82 (m, 1 H), 1.42 (s, 3 H); ^{13}C NMR ($CDCl_3$, 100 MHz) 188.6, 184.6, 161.6, 158.8, 144.5, 140.7, 136.4, 134.9, 132.7, 131.1, 130.6, 128.7, 124.8, 122.9, 119.2, 115.4, 113.6, 71.8, 63.3, 55.2, 55.1, 42.7, 32.4, 26.4, 23.8; HRMS (EI) calcd for $C_{27}H_{24}O_5$-Na *m*/*z* 451.1521, found *m*/*z* 451.1509. Anal. Calcd for $C_{27}H_{26}O_6$: C, 72.63; H, 5.87. Found: C, 72.47; H, 5.87.

(*S*)-3,11-Dihydroxy-3-methyl-1,2,3,4-tetrahydrotetraphene-7,-12-dione (55). Following the general procedure for removal of the PMB group, a solution of PMB−ether **54** (0.16 g, 0.37 mmol) in a mixture of CH_2Cl_2 (6 mL) and pH 7 buffer (0.6 mL) upon treatment with DDQ (0.13 g, 0.56 mmol) afforded the diol **55** (0.107 g) as a yellow solid in 93% yield. R_f 0.2 (3:7 ethyl acetate/hexanes); mp 165−170 °C dec; $[\alpha]^{20}_D$ −58.566 (*c* 1.06, $CHCl_3$); IR (KBr) cm^{-1} 3423, 2961, 2930, 1664, 1632, 1582, 1478, 1454, 1274, 1249; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.18 (d, 1 H, J = 8.0 Hz), 7.74 (dd, 1 H, J = 7.6, 1.2 Hz), 7.64 (t, 1 H, J = 8.4 Hz), 7.48 (d, 1 H, J = 8.4 Hz), 7.25 (dd, 1 H, J = 8.4, 1.2 Hz), 3.53 (t, 2 H, J = 6.8 Hz), 2.99 (s, 2 H), 2.01−1.97 (m, 1 H), 1.89−1.82 (m, 1 H), 1.54 (br s, 1 H), 1.41 (s, 3 H); ^{13}C NMR ($CDCl_3$, 100 MHz) 188.9, 185.0, 162.0, 144.7, 140.3, 136.8, 135.2, 135.0, 133.3, 131.3, 125.3, 123.3, 119.6, 115.7, 68.1, 45.1, 35.9, 28.9, 26.7; HRMS (EI) calcd for $C_{19}H_{17}O_4$ *m*/*z* 309.1127, found *m*/*z* 309.1113. Anal. Calcd for $C_{19}H_{16}O_4$: C, 74.01; H, 5.23. Found: C, 74.3297; H, 5.0838.

(−)-Tetrangomycin (4). Following the general procedure for the photooxygenation, a solution of quinone **55** (0.06 g, 0.19 mmol) in benzene (60 mL) on irradiation for 24 h provided (−)-tetrangomycin (**4**) (0.04 g, 64%) as a yellow solid. R_f 0.29 (3:2 ethyl acetate/hexanes); mp 173−175 °C; $[\alpha]^{20}_D$ −85.612 (*c* 0.49, $CHCl_3$); IR (KBr) cm^{-1} 3426, 2965, 2924, 1700, 1667, 1633, 1589, 1455, 1366, 1282; ^1H NMR ($CDCl_3$, 400 MHz) δ 12.26 (s, 1 H), 8.32 (d, 1 H, J = 8.0 Hz), 7.68−7.64 (m, 2 H), 7.56 (d, 1 H, J = 8.0 Hz), 7.28 (dd, 1 H, J = 7.6, 2.4 Hz), 3.18 (s, 2 H), 3.13 (d, 1 H, J = 14.8 Hz), 3.02 (d, 1 H, J = 14.8 Hz), 1.87 (br s, 1 H), 1.52 (s, 3 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 197.3, 187.4, 183.2, 162.0, 147.8, 137.1, 136.1, 135.7, 135.5, 135.2, 133.9, 129.4, 123.7, 119.6, 115.4, 72.6, 53.8, 44.1, 30.2; HRMS (EI) calcd for $C_{19}H_{14}O_5Na$ *m*/*z* 345.0739, found *m*/*z* 345.0739. Anal. Calcd for $C_{38}H_{30}O_{11}$: C, 68.88; H, 4.56. Found: C, 69.3096; H, 4.2692

(*S*)-8-Methoxy-3-(4-methoxybenzyloxy)-3-methyl-1,2,3,4-tetrahydrotetraphene-7,12-dione (56). A solution of alcohol **54** (0.14 g, 0.33 mmol) and MeI (0.82 mL, 13.12 mmol) in CH_2Cl_2 (10 mL) was treated with freshly prepared Ag_2O (1.23 g, 5.23 mmol) at room temperature and stirred for 5 h. The mixture was filtered, the filtrate was concentrated, and the resultant residue was purified by silica gel column chromatography (40% ethyl acetate in hexanes) to afford the methyl ether **56** (0.14 g, 96%) as a yellow solid. R_f 0.3 (2:3 ethyl acetate/hexanes); mp 130−131 °C; $[\alpha]^{20}_D$ −60.754 (*c* 1.22, $CHCl_3$); IR (KBr) cm^{-1} 3435, 2924, 1666, 1612, 1586, 1513, 1463, 1274, 1249, 1098; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.20 (d, 1 H, J = 7.6 Hz), 7.87 (dd, 1 H, J = 7.6, 1.2 Hz), 7.69 (t, 1 H, J = 8.0 Hz), 7.42 (d, 1 H, J = 8.0 Hz), 7.27 (dd, 1 H, J = 8.0, 0.4 Hz), 7.15 (dt, 2 H, J = 9.6, 2.4 Hz), 6.78 (dt, 2 H, J = 11.6, 2.4 Hz), 4.49 (d, 1 H, J = 10.4 Hz), 4.42 (d, 1 H, J = 11.2 Hz), 4.04 (s, 3 H), 3.74 (s, 3 H), 3.49 (t, 2 H, J = 6.4 Hz), 3.14 (d, 1 H, J = 16.8 Hz), 2.92 (d, 1 H, J = 17.2 Hz), 2.23−2.17 (m, 1 H), 1.90−1.83 (m, 1 H), 1.41 (s, 3 H); ^{13}C NMR ($CDCl_3$, 75 MHz) 185.7, 183.1, 159.6, 158.8, 142.5, 139.3, 137.5, 135.0, 134.7, 131.3, 129.9, 128.7, 125.2, 120.9, 119.6, 116.7, 113.6, 72.0, 63.3, 56.4, 55.2, 55.1, 42.6, 32.7, 26.3, 23.7; HRMS (EI) calcd for $C_{28}H_{27}O_5$ *m*/*z* 443.1858, found *m*/*z* 443.1878. Anal. Calcd for $C_{28}H_{26}O_5$: C, 76.00; H, 5.92. Found: C, 76.2522; H, 5.9684.

(*S*)-3-Hydroxy-8-methoxy-3-methyl-1,2,3,4-tetrahydrotetraphene-7,12-dione (57). Following the general procedure for the removal of the PMB group, a solution of PMB−ether **56** (0.12 g, 0.27 mmol) in a mixture of CH_2Cl_2 (5 mL) and pH 7 buffer (0.5 mL) upon treatment with DDQ (0.11 g, 0.46 mmol) afforded the diol **57** (0.077 g) as a yellow solid in 89% yield. R_f 0.2 (2:3 ethyl acetate/hexanes); mp 191−193 °C; $[\alpha]^{20}_D$ −0.661 (*c* 0.515, $CHCl_3$); IR (KBr) cm^{-1} 3520, 2921, 1664, 1647, 1586, 1567, 1464, 1269; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.11 (d, 1 H, J = 8.0 Hz), 7.86 (dd, 1 H, J = 7.6, 0.8 Hz), 7.69 (t, 1 H, J = 8.0 Hz), 7.44 (d, 1 H, J = 8.0 Hz), 7.28 (dd, 1 H, J = 9.6, 8.4 Hz), 4.04 (s, 3 H), 3.50 (t, 2 H, J = 8.0 Hz), 2.97 (s, 2 H), 2.01−1.95 (m, 1 H), 1.89−1.81 (m, 1 H), 1.59 (br s, 1 H), 1.39 (s, 3 H); ^{13}C NMR ($CDCl_3$, 75 MHz) 185.6, 182.9, 142.2, 138.5, 137.4, 135.2, 135.1, 134.8, 130.1, 125.3, 120.7, 119.6, 116.8, 67.9, 56.4, 44.1, 35.7, 28.6, 26.3; HRMS (EI) calcd for $C_{20}H_{19}O_4$ *m*/*z* 323.1283, found *m*/*z* 323.1273. Anal. Calcd for $C_{20}H_{18}O_4$: C, 74.52; H, 5.63. Found: C, 75.0741; H, 5.5600.

MM-47755 (5). Following the general procedure for photooxygenation, a solution of quinone **57** (0.06 g, 0.186 mmol) in benzene (90 mL) on irradiation for 24 h provided MM-47755 (**5**) (0.029 g, 46%) as a yellow solid. R_f 0.2 (7:3 ethyl acetate/hexanes); mp 160−170 °C dec; $[\alpha]^{20}_D$ −89.079 (*c* 0.315, MeOH); IR (KBr) cm^{-1} 3415, 2925, 2856, 1695, 1668, 1591, 1466, 1301, 1268, 1232; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.29 (d, 1 H, J = 8.0 Hz), 7.76 (dd, 1 H, J = 7.6, 1.2 Hz), 7.70 (t, 1 H, J = 8.0 Hz), 7.52 (d, 1 H, J = 8.0 Hz), 7.30 (dd, 1 H, J = 9.6, 1.2 Hz), 4.04 (s, 3 H), 3.17 (s, 2 H), 3.10 (d, 1 H, J = 14.4 Hz), 3.0 (d, 1 H, J = 14.8 Hz), 1.88 (br s, 1 H), 1.51 (s, 3 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 197.1, 184.7, 181.5, 159.9, 146.5, 137.7, 135.5, 135.2, 135.1, 134.2, 133.8, 130.1, 120.6, 119.7, 117.3, 72.6, 56.6, 53.8, 44.0, 30.0; HRMS (EI) calcd for $C_{20}H_{17}O_5$ *m*/*z* 337.1076, found *m*/*z* 337.1093. Anal. Calcd for $C_{40}H_{34}O_{11}$: C, 69.56; H, 4.96. Found: C, 69.2920; H, 5.0658.

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Supporting Information Available: Characterization data for all new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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