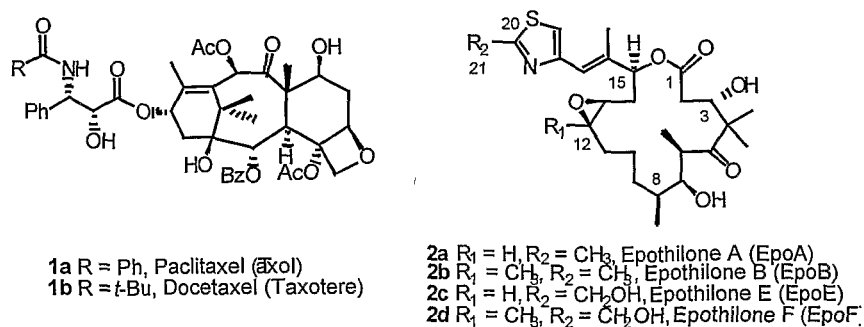


SYNTHESIS OF EPOTHILONES, INTERMEDIATES THERETO, ANALOGUES AND USES THEREOF

BACKGROUND OF THE INVENTION

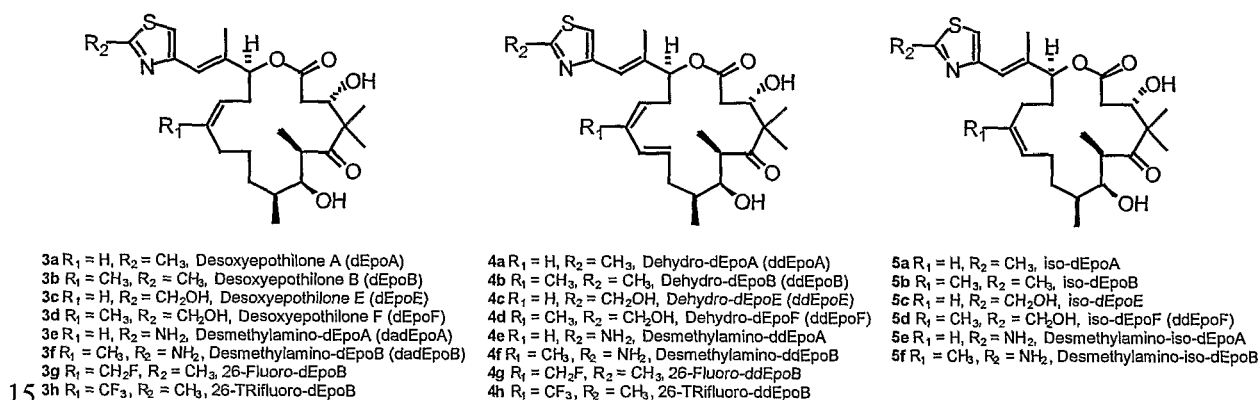
Epothilones A and B (**2a** and **2b**, Scheme 1) are naturally occurring cytotoxic macrolides that were isolated from a cellulose degrading mycobacterium, *Sorangium cellulosum* (Höfle *et al. Angew. Chem., Int. Ed. Engl.* **1996**, 35, 1567 and *J. Antibiot.* **1996**, 49, 560; each of which is incorporated herein by reference). Despite their vastly different structures, epothilones A and B share the same mechanism of action as paclitaxel (Taxol[®]) which involves growth inhibition of tumor cells by tubulin polymerization and stabilization of microtubule assemblies (Bollag *et al. Cancer Res.* **1995**, 55, 2325; incorporated by reference). In spite of its unquestioned clinical value as a front-line chemotherapeutic agent, Taxol[®] is far from an ideal drug. Its marginal water solubility necessitates recourse to formulation vehicles such as Cremophores that pose their own risks and management issues (Essayan *et al. J. Allergy Clin. Immunol.* **1996**, 97, 42; incorporated herein by reference). Moreover, Taxol[®] is vulnerable to deactivation through multiple drug resistance (MDR) (Giannakakou *et al. J. Biol. Chem.* **1997**, 272, 17118; incorporated herein by reference). However, it has also been demonstrated that epothilones A and B retain remarkable potency against MDR tumor cells (Kowalski *et al. Mol. Biol. Cell* **1995**, 6, 2137; incorporated herein by reference). Additionally, the increased water solubility in comparison to paclitaxel may be useful for the formulability of epothilones. While the naturally occurring compound, epothilone B (**2b**, EpoB, in Scheme 1), is a potent member of the epothilone family of natural products, it unfortunately possesses, at least in xenograft mice, a worryingly narrow therapeutic index (Su *et al. Angew. Chem. Int. Ed. Engl.* **1997**, 36, 1093; Harris *et al. J. Org. Chem.* **1999**, 64, 8434; each of which is incorporated herein by reference).



Scheme 1: Taxoids and Epothilones

Given the limited therapeutic index of EpoB, other epothilone analogues, in particular the 12,13-desoxyepothilones, were investigated for their ability to provide an improved therapeutic profile (see, U.S. Patent No.: 6,242,469, 6,284,781, 6,300,355, 6,369,234, 6,204,388, 6,316,630; each of which is incorporated herein by reference).

- 5 *In vivo* experiments conducted on various mouse models demonstrated that 12,13-desoxyepothilone B (**3b**, dEpoB in Scheme 2) possesses therapeutic potential against various sensitive and resistant human tumors in mice xenografts (Chou *et al. Proc. Natl. Acad. Sci. U.S.A.* **1998**, 95, 9642 and 15798; incorporated herein by reference). Recently, the therapeutic superiority of these desoxyepothilones over other anticancer agents has been conclusively demonstrated by thorough comparative studies (Chou *et al. Proc. Natl. Acad. Sci. U.S.A.* **2001**, 98, 8113; incorporated herein by reference). Due to its impressive *in vivo* profile, dEpoB has been advanced through toxicology evaluations in dogs, and is now in human trials as an anticancer drug.



Scheme 2. Various Desoxyepothilone Analogues

- In light of the promising therapeutic utility of the 12,13-desoxyepothilones, it would be desirable to investigate additional analogues as well as additional synthetic methodologies for the synthesis of existing epothilones, desoxyepothilones, and analogues thereof, as well as novel analogues thereof. In particular, given the interest in the therapeutic utility of this class of compounds, it would also be desirable to develop methodologies capable of providing significant quantities of any epothilones or desoxyepothilones previously described, or those described herein, for clinical trials and for large-scale preparation.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a table of IC₅₀ values of epothilones against CCRF-CEM, CCRF-CEM/VBL, and CCRF-CEM/Taxol cell growth. Cell growth inhibition was measured by XTT tetrazonium assay after 72-hour incubation for cell growth, as described previously (Scudiero *et al. Cancer Res.* 46:4827-4833, 1988; incorporated herein by reference). IC₅₀ values were determined from dose-effect relationship at six or seven concentrations of each drug, by using a computer program (Chou *et al. Adv. Enzyme Regul.* 22:27-55, 1984; Chou *et al. CalcuSyn* for Windows (Biosoft, Cambridge, UK), 1997; each of which is incorporated herein by reference) as described earlier (Chou *et al. Proc. Natl. Acad. Sci. USA* 95:15798-15802, 1998; incorporated herein by reference).

Figure 2 is a ¹H NMR spectrum of *trans*-9,10-dehydro-12,13-desoxyEpoB.

Figure 3 is a ¹³C NMR spectrum of *trans*-9,10-dehydro-12,13-desoxyEpoB.

Figure 4 shows a scheme for synthesis of 11-R and 14-R epothilones using LACDAC-ring closing olefin metathesis, and illustrates certain substitutions available with synthetic strategies that pass through a 9,10-dehydro epothilone.

Figure 5 presents relative cytotoxicity data against human leukemic cells *in vitro* for a variety of epothilone compounds and derivatives including certain 9,10-dehydro compounds (*e.g.*, compound 7 in Figure 5A and compound 88 and 89 in Figure 5B).

Figure 6 depicts alternative synthetic strategies for preparing 9,10-dehydro epothilone analogs. Figure 6A illustrates a Macro-Stille strategy, a sp³-sp³ coupling strategy, and β-Suzuki strategy. Figure 6B illustrates a Julia olefination strategy, a Wadsworth-Emmons strategy, and a Macro-Reformatsky strategy. Figure 6C illustrates a McMurry coupling strategy and a lactam analog synthesis.

Figure 7 shows various analogs of 9,10-dehydro-12,13-desoxy EpoB.

Figure 8 shows the therapeutic effect of 9,10-dehydro-dEpoB and dEpoB in nude mice bearing human mammary carcinoma MX-1 xenograft (iv infusion, Q2Dx3).

Figure 9 shows the stability of epothilone analogs in murine plasma. Epo 1 is 12,13-desoxyEpoB, Epo 2 is 26-F₃-12,13-desoxyEpoB, Epo 3 is (*E*)-9,10-dehydro-12,13-desoxyEpoB, and Epo 4 is 26-F₃-(*E*)-9,10-dehydro-12,13-desoxyEpoB.

Figure 10 depicts the therapeutic effect of epothilone analogs in nude mice bearing HCT-116 xenograft (iv infusion, Q2Dx7, n=3). Arrows indicate drug administration. Epo 3 is (*E*)-9,10-dehydro-12,13-desoxyEpoB.

Figure 11 shows the potencies of various epothilone analogues against tumor cell growth *in vitro* and therapeutic index, as compared to paclitaxel and vinblastine.

Figure 12 is a table summarizing the effect of dEpoB, Taxol, and 26-triF-9,10-deH-dEpoB against MX-1 xenograft in nude mice.

5 *Figure 13* shows the therapeutic effect of 26-trifluoro-9,10-dehydro-dEpoB and 9,10-dehydro-EpoB on tumor size in nude mice bearing MX-1 xenografts (6 hour iv infusion, Q2Dx6 & Q2Dx9, respectively).

10 *Figure 14* shows body weight changes of nude mice bearing human mammary carcinoma tumor MX-1 xenograft following treatment with 26-trifluoro-9,10-dehydro-dEpoB and 9,10-dehydro-EpoB (6 hour infusion, Q2Dx6 & Q2Dx9, respectively).

Figure 15 shows the therapeutic effect of 26-trifluoro-9,10-dehydro-dEpoB and 9,10-dehydroEpoB on tumor size in nude mice bearing MX-1 xenografts (6 hour iv infusion, Q2Dx6 & Q2Dx9, respectively).

15 *Figure 16* shows body weight changes of nude mice bearing human mammary carcinoma tumor MX-1 xenograft following treatment with 26-trifluoro-9,10-dehydro-dEpoB and 9,10-dehydro-EpoB (6 hour iv infusion, Q2Dx6 & Q2Dx9, respectively).

Figure 17 shows the therapeutic effect of 9,10-dehydro-dEpoB on tumor size in nude mice bearing HCT-116 xenografts (iv infusion, Q2Dx7).

20 *Figure 18* shows the effect of 9,10-dehydro-dEpoB on tumor size in nude mice bearing human colon carcinoma HCT-116 xenografts (iv infusion, Q3Dx5).

Figure 19 shows the effect of 9,10-dehydro-dEpoB on tumor size in nude mice bearing A549/Taxol xenografts (6 hour iv infusion, Q3Dx7).

25 *Figure 20* shows changes in body weight of nude mice bearing A549/Taxol xenograft treated with 26-trifluoro-9,10-dehydro-dEpoB and 9,10-dehydro-dEpoB (6 hour iv infusion, Q3Dx7).

Figure 21 shows the effect of 26-trifluoro-9,10-dehydro-dEpoB and 9,10-dehydro-dEpoB on tumor size in nude mice bearing A549/Taxol xenografts (6 hour iv infusion, Q2Dx7).

30 *Figure 22* shows changes in body weight of nude mice bearing A549/Taxol xenografts treated with 26-trifluoro-9,10-dehydro-dEpoB and 9,10-dehydro-dEpoB (6 hour iv infusion, Q2Dx7).

Figure 23 shows the effect of 9,10-dehydro-EpoB on tumor size in nude mice bearing human colon carcinoma HCT-116 tumor xenografts (6 hour iv infusion).

Figure 24 shows changes in body weight of nude mice bearing human colon carcinoma HCT-116 tumor xenograft following treatment with 9,10-dehydro-EpoB (6 hour iv infusion).

5 *Figure 25* shows microtubule formation from tubulin in the presence of various epothilone analogues at 37 °C

Figure 26 shows microtubule formation from tubulin in the presence of various epothilone analogues at 4 °C.

Figure 27 shows the effect of 9,10-dehydro-dEpoB and dEpoB on tumor size in nude mice bearing HCT-116 xenografts (iv infusion, Q2Dx6).

10 *Figure 28* shows changes in body weight of nude mice bearing HCT-116 xenografts after treatment with 9,10-dehydro-dEpoB and dEpoB (iv infusion, Q2Dx6).

Figure 29 shows the effect of 9,10-dehydro-dEpoB on tumor size in nude mice bearing human colon carcinoma HCT-116 xenografts (iv infusion, Q3Dx4).

15 *Figure 30* shows changes in body weight of nude mice bearing human colon carcinoma tumor HCT-116 xenografts following treatment with 9,10-dehydro-dEpoB (5 mg/kg, iv infusion, X3Dx4).

Figure 31 is a table with IC₅₀ values for epothilone analogues against CCRF-CEM cell growth.

Figure 32 shows the metabolic stability of epothilone analogues *in vitro*.

20 *Figure 33* is a table detailing the therapeutic effects of various epothilone analogues against human tumor xenografts in mice with 6 hour iv infusion.

Figure 34 shows the effect of 9,10-dehydro-EpoB on tumor size in nude mice bearing human colon carcinoma HCT-116 tumor xenograft (6 hour iv infusion, Q2Dx7).

25 *Figure 35* shows changes in body weight of nude mice bearing human colon carcinoma HCT-116 tumor xenografts following treatment with 9,10-dehydro-EpoB and oxazole-EpoD (6 hour infusion, Q2Dx7).

30 *Figure 36* shows the effect of 26-trifluoro-9,10-dehydro-dEpoB and 9,10-dehydro-dEpoB on tumor size in nude mice bearing A549/Taxol xenografts (6 hour iv infusion, Q2Dx4).

Figure 37 shows the effect of 9,10-dehydro-dEpoB on tumor size in nude mice bearing A549/Taxol xenografts (6 hour iv infusion, Q3Dx3).

Figure 38 shows the stability of epothilone analogues in 20% mouse plasma/PBS.

Figure 39 shows the stability of epothilone analogues in 10% Men Liver S9/PBS.

Figure 40 shows EpoD stability chromatogram in 10% Men Liver S9/PBS.

Figure 41 are tables describing the effect of various epothilone analogues on *in vitro* microtubule polymerization at 37 °C in the absence of GTP (A) and the cytotoxicity of various epothilone analogs in the human lung cell line A549 (B).

Figure 42 shows the stabilization of microtubule formation by epothilones at 35 °C and 4 °C.

Figure 43 shows the therapeutic effect of 9,10-dehydro-dEpoB in nude mice bearing T human mammary carcinoma (MX-1) xenograft (6 hour infusion, Q2Dx5).

Figure 44 shows the change in body weight of nude mice bearing human mammary carcinoma (MX-1) xenograft following treatment with 9,10-dehydro-dEpoB (6 hour infusion, Q2Dx8).

Figure 45 shows the change in body weight of nude mice bearing HCT-116 xenograft following treatment with 9,10-dehydro-dEpoB (iv infusion, Q2Dx7).

Figure 46 shows the therapeutic effect of 9,10-dehydro-dEpoF, dEpoB, and Taxol on tumor size in nude mice bearing human mammary carcinoma (MX-1) tumor xenograft (6 hour iv infusion, Q2Dx6).

Figure 47 shows the changes in body weight of nude mice bearing human mammary carcinoma (MX-1) tumor xenograft following treatment with 9,10-dehydro-dEpoF, dEpoB, and Taxol (6 hour infusion, Q2Dx6).

Figure 48 shows the therapeutic effect of 9,10-dehydro-dEpoF and dEpoB in nude mice bearing human colon carcinoma HCT-116 xenograft (6 hour infusion, Q2Dx8).

Figure 49 shows the changes in body weight of nude mice bearing HCT-116 xenograft following treatment with 9,10-dehydro-dEpoF and dEpoB (6 hour infusion, Q2Dx8).

Figure 50 shows the therapeutic effect of 9,10-dehydro-dEpoF and dEpoB in nude mice bearing Taxol-resistant human lung carcinoma (A549/Taxol) xenograft (6 hour infusion, Q2Dx5).

Figure 51 shows changes in body weight of nude mice bearing Taxol-resistant human lung carcinoma (A549/Taxol) xenograft following treatment with 9,10-dehydro-dEpoF and dEpoB (6 hour infusion, Q2Dx5).

Figure 52 is a table comparing the potency of various epothilone analogs with respect to inhibition of tumor growth *in vitro* and relative therapeutic index.

Figure 53 shows the therapeutic effect of 9,10-dehydro-dEpoB in nude mice bearing MX-1 xenograft (Q3Dx9, 6 hr.-iv infusion).

5 Figure 54 shows changes in body weight of nude mice bearing an MX-1 xenograft following treatment with 9,10-dehydro-dEpoB (Q3Dx9, 6 hr-iv infusion).

Figure 55 shows the therapeutic effect of 9,10-dehydro-epothilone B in nude mice bearing MX-1 xenograft (Q3Dx9, 6 hour infusion).

10 Figure 56 shows changes in body weight of nude mice bearing MX-1 xenograft following treatment with 9,10-dehydro-epothilone B (Q3Dx9, 6hr.-iv infusion).

Figure 57 shows the therapeutic effect at low doses of 26-trifluoro-9,10-dehydro-dEpoB in nude mice bearing MX-1 xenograft (6 hr.-i.v. infusion, Q2Dx12).

15 Figure 58 shows changes in body weight of nude mice bearing a MX-1 xenograft following treatment with low doses of 26-trifluoro-9,10-dehydro-dEpoB (6hr.-i.v. infusion, Q2Dx12).

Figure 59 shows the chemotherapeutic effect of epothilone analogs against human tumor xenografts in nude mice. Tumor tissue (40-50 mg) was implanted s.c. on Day 0. Treatment was started when tumor size reached about 100 mm³ or greater as indicated. All treatments as indicated by arrows were carried out with 6-hr-i.v. infusion
20 via tail vein using a mini-catheter and programmable pump as described earlier (Su, D.-S. et al, *Angew. Chem. Int. Ed.* **1997**, 36, 2093; Chou, T. C. et al. *Proc. Natl. Acad. Sci. USA.* **1998**, 95, 15798; each of which is incorporated herein by reference). Each dose group consisted of four or more mice. Body weight was referred to as the total body weight minus tumor weight assuming 1 mm³ of tumor equals 1 mg of tumor tissue. **A.**
25 Mammary carcinoma MX-1 xenograft treated with a low dose of 25-trifluoro-(*E*)-9,10-dehydro-12,13-desoxyEpoB (10 mg/kg) when compared with those in Table 1 (20 mg/kg and 30 mg/kg). **B.** MX-1 large xenografts (500 mm³) were treated with 25-trifluoro-(*E*)-9,10-dehydro-12,13-desoxyEpoB (25 mg/kg) and dEpoB (30 mg/kg). **C.** Slow growing A549 lung carcinoma xenograft treated with 25-trifluoro-(*E*)-9,10-
30 dehydro-12,13-desoxyEpoB (25 mg/kg) and dEpoB (30 mg/kg). **D.** A549/Taxol (44-fold resistance to paclitaxel *in vitro*) xenograft treated with 25-trifluoro-(*E*)-9,10-dehydro-12,13-desoxyEpoB (20 mg/kg) and (*E*)-9,10-dehydro-12,13-desoxyEpoB (4 mg/kg). The treatment for deH-dEpoB on day 28 was skipped due to marked and rapid body weight decreases.

Figure 60 depicts the synthesis of C-21 modified 9,10-(*E*)-dehydro-epothilones. *Figure 60A* shows the synthesis of 26-trifluoro-21-methylamino-9,10-(*E*)-dehydro-12,13-desoxyepothilone B. *Figure 60B* is a synthetic scheme for the preparation to 26-trifluoro-21-amino-9,10-(*E*)-dehydro-12,13-desoxyepothilone B as an intermediate in the synthesis of 26-trifluoro-21-dimethylamino-9,10-(*E*)-dehydro-12,13-desoxyepothilone B.

Figure 61 is table with IC₅₀ values for C-21 modified epothilones against tumor cell line CCRF-CEM and its drug-resistant sublines.

Figure 62 shows the therapeutic effect of 26-trifluoro-9,10-dehydro-dEpoB and Taxol in nude mice bearing human T-cell lymphoblastic leukemia CCRF-CEM xenograft (6 hour iv infusion, Q2Dx8).

Figure 63 shows the changes in body weight changes of nude mice bearing human T-cell lymphoblastic leukemia CCRF-CEM xenograft following treatment with 25-trifluoro-9,10-dehydro-dEpoB and Taxol (6 hour iv infusion, Q2Dx8).

Figure 64 shows the therapeutic effect of 26-trifluoro-9,10-dehydro-dEpoB and Taxol in nude mice bearing human T-cell lymphoblastic leukemia CCRF-CEM/Taxol xenograft (Taxol resistant) (6 hour iv infusion, Q2Dx7, x5).

Figure 65 shows the changes in body weight changes of nude mice bearing human T-cell lymphoblastic leukemia CCRF-CEM/Taxol xenograft (Taxol resistant) following treatment with 26-trifluoro-9,10-dehydro-dEpoB and Taxol (6 hour iv infusion, Q2Dx7, x5).

Figure 66 shows the therapeutic effect of 26-trifluoro-9,10-dehydro-dEpoB and Taxol in nude mice bearing human colon carcinoma HCT-116 xenograft (Q2Dx4, x2, 6 hour iv infusion).

Figure 67 shows the changes in body weight of nude mice bearing human colon carcinoma HCT-116 xenograft following treatment with 26-trifluoro-9,10-dehydro-dEpoB and Taxol (Q2Dx4, x2, 6 hour iv infusion).

Figure 68 shows the therapeutic effect of 9,10-dehydro-EpoB in nude mice bearing MX-1 xenograft (6 hour iv infusion).

Figure 69 shows the changes in body weight of nude mice bearing human mammary carcinoma MX-1 xenograft following treatment with 9,10-dehydro-EpoB (6 hour iv infusion).

Figure 70 shows the therapeutic effect of 9,10-dehydro-EpoB in nude mice bearing human T-cell lymphoblastic leukemia CCRF-CEM/Taxol xenograft (Taxol resistant) (6 hour iv infusion, Q3Dx5, x2).

5 *Figure 71* shows the changes in body weight of nude mice bearing human T-cell lymphoblastic leukemia CCRF-CEM/Taxol xenograft (Taxol resistant) following treatment with 9,10-dehydro-EpoB (6 hour iv infusion, Q3Dx5, x2).

Figure 72 shows the therapeutic effect of 26-trifluoro-dEpoB and 26-trifluoro-9,10-dehydro-dEpoF in nude mice bearing human mammary carcinoma MX-1 xenograft (Q2Dx11, iv injection).

10 *Figure 73* shows the changes in body weight of nude mice bearing human mammary carcinoma MX-1 xenograft following treatment with 26-trifluoro-dEpoB and 26-trifluoro-9,10-dehydro-dEpoF (Q2Dx11, iv injection).

Figure 74 shows the therapeutic effect of 9,10-dehydro-dEpoB in nude mice bearing human mammary carcinoma MX-1 xenograft (Q3Dx9, 6 hour iv infusion).

15 *Figure 75* shows the changes in body weight of nude mice bearing human mammary carcinoma MX-1 xenograft following treatment with 9,10-dehydro-dEpoB (Q3Dx9, 6 hour iv infusion).

Figure 76 shows the therapeutic effect of 26-trifluoro-9,10-dehydro-dEpoF in nude mice bearing human lung carcinoma (MX-1) xenograft (6 hour iv infusion and iv injection).

20 *Figure 77* shows the changes in body weight of nude mice bearing MX-1 xenograft following treatment with 26-trifluoro-9,10-dehydro-dEpoF (6 hour iv infusion and iv injection).

25

DEFINITIONS

Certain compounds of the present invention, and definitions of specific functional groups are also described in more detail below. For purposes of this invention, the chemical elements are identified in accordance with the Periodic Table of the Elements, CAS version, Handbook of Chemistry and Physics, 75th Ed., inside
30 cover, and specific functional groups are generally defined as described therein. Additionally, general principles of organic chemistry, as well as specific functional moieties and reactivity, are described in "Organic Chemistry", Thomas Sorrell, University Science Books, Sausalito: 1999, the entire contents of which are incorporated herein by reference. Furthermore, it will be appreciated by one of

ordinary skill in the art that the synthetic methods, as described herein, utilize a variety of protecting groups. By the term "protecting group", as used herein, it is meant that a particular functional moiety, e.g., O, S, or N, is temporarily blocked so that a reaction can be carried out selectively at another reactive site in a multifunctional compound. In preferred embodiments, a protecting group reacts selectively in good yield to give a protected substrate that is stable to the projected reactions; the protecting group must be selectively removed in good yield by readily available, preferably nontoxic reagents that do not attack the other functional groups; the protecting group forms an easily separable derivative (more preferably without the generation of new stereogenic centers); and the protecting group has a minimum of additional functionality to avoid further sites of reaction. As detailed herein, oxygen, sulfur, nitrogen and carbon protecting groups may be utilized. Exemplary protecting groups are detailed herein, however, it will be appreciated that the present invention is not intended to be limited to these protecting groups; rather, a variety of additional equivalent protecting groups can be readily identified using the above criteria and utilized in the method of the present invention. Additionally, a variety of protecting groups are described in "Protective Groups in Organic Synthesis" Third Ed. Greene, T.W. and Wuts, P.G., Eds., John Wiley & Sons, New York: 1999, the entire contents of which are hereby incorporated by reference.

It will be appreciated that the compounds, as described herein, may be substituted with any number of substituents or functional moieties. In general, the term "substituted" whether preceded by the term "optionally" or not, and substituents contained in formulas of this invention, refer to the replacement of hydrogen radicals in a given structure with the radical of a specified substituent. When more than one position in any given structure may be substituted with more than one substituent selected from a specified group, the substituent may be either the same or different at every position. As used herein, the term "substituted" is contemplated to include all permissible substituents of organic compounds. In a broad aspect, the permissible substituents include acyclic and cyclic, branched and unbranched, carbocyclic and heterocyclic, aromatic and nonaromatic substituents of organic compounds. For purposes of this invention, heteroatoms such as nitrogen may have hydrogen substituents and/or any permissible substituents of organic compounds described herein which satisfy the valencies of the heteroatoms. Furthermore, this invention is not intended to be limited in any manner by the permissible substituents of organic

compounds. Combinations of substituents and variables envisioned by this invention are preferably those that result in the formation of stable compounds useful in the treatment, for example of proliferative disorders, including, but not limited to cancer. The term "stable", as used herein, preferably refers to compounds which possess stability sufficient to allow manufacture and which maintain the integrity of the compound for a sufficient period of time to be detected and preferably for a sufficient period of time to be useful for the purposes detailed herein.

The term "aliphatic", as used herein, includes both saturated and unsaturated, straight chain (i.e., unbranched), branched, cyclic, or polycyclic aliphatic hydrocarbons, which are optionally substituted with one or more functional groups. As will be appreciated by one of ordinary skill in the art, "aliphatic" is intended herein to include, but is not limited to, alkyl, alkenyl, alkynyl, cycloalkyl, cycloalkenyl, and cycloalkynyl moieties. Thus, as used herein, the term "alkyl" includes straight, branched and cyclic alkyl groups. An analogous convention applies to other generic terms such as "alkenyl", "alkynyl" and the like. Furthermore, as used herein, the terms "alkyl", "alkenyl", "alkynyl" and the like encompass both substituted and unsubstituted groups. In certain embodiments, as used herein, "lower alkyl" is used to indicate those alkyl groups (cyclic, acyclic, substituted, unsubstituted, branched or unbranched) having 1-6 carbon atoms.

In certain embodiments, the alkyl, alkenyl and alkynyl groups employed in the invention contain 1-20 aliphatic carbon atoms. In certain other embodiments, the alkyl, alkenyl, and alkynyl groups employed in the invention contain 1-10 aliphatic carbon atoms. In yet other embodiments, the alkyl, alkenyl, and alkynyl groups employed in the invention contain 1-8 aliphatic carbon atoms. In still other embodiments, the alkyl, alkenyl, and alkynyl groups employed in the invention contain 1-6 aliphatic carbon atoms. In yet other embodiments, the alkyl, alkenyl, and alkynyl groups employed in the invention contain 1-4 carbon atoms. Illustrative aliphatic groups thus include, but are not limited to, for example, methyl, ethyl, n-propyl, isopropyl, cyclopropyl, -CH₂-cyclopropyl, allyl, n-butyl, sec-butyl, isobutyl, tert-butyl, cyclobutyl, -CH₂-cyclobutyl, n-pentyl, sec-pentyl, isopentyl, tert-pentyl, cyclopentyl, -CH₂-cyclopentyl, n-hexyl, sec-hexyl, cyclohexyl, -CH₂-cyclohexyl moieties and the like, which again, may bear one or more substituents. Alkenyl groups include, but are not limited to, for example, ethenyl, propenyl, butenyl, 1-methyl-2-buten-1-yl, and the like. Representative alkynyl

groups include, but are not limited to, ethynyl, 2-propynyl (propargyl), 1-propynyl and the like.

The term "alkoxy", or "thioalkyl" as used herein refers to an alkyl group, as previously defined, attached to the parent molecular moiety through an oxygen atom or through a sulfur atom. In certain embodiments, the alkyl group contains 1-20 aliphatic carbon atoms. In certain other embodiments, the alkyl group contains 1-10 aliphatic carbon atoms. In yet other embodiments, the alkyl, alkenyl, and alkynyl groups employed in the invention contain 1-8 aliphatic carbon atoms. In still other embodiments, the alkyl group contains 1-6 aliphatic carbon atoms. In yet other embodiments, the alkyl group contains 1-4 aliphatic carbon atoms. Examples of alkoxy, include but are not limited to, methoxy, ethoxy, propoxy, isopropoxy, n-butoxy, tert-butoxy, neopentoxy and n-hexoxy. Examples of thioalkyl include, but are not limited to, methylthio, ethylthio, propylthio, isopropylthio, n-butylthio, and the like.

The term "alkylamino" refers to a group having the structure -NHR' wherein R' is alkyl, as defined herein. In certain embodiments, the alkyl group contains 1-20 aliphatic carbon atoms. In certain other embodiments, the alkyl group contains 1-10 aliphatic carbon atoms. In yet other embodiments, the alkyl, alkenyl, and alkynyl groups employed in the invention contain 1-8 aliphatic carbon atoms. In still other embodiments, the alkyl group contains 1-6 aliphatic carbon atoms. In yet other embodiments, the alkyl group contains 1-4 aliphatic carbon atoms. Examples of alkylamino include, but are not limited to, methylamino, ethylamino, iso-propylamino and the like.

Some examples of substituents of the above-described aliphatic (and other) moieties of compounds of the invention include, but are not limited to aliphatic; heteroaliphatic; aryl; heteroaryl; arylalkyl; heteroarylalkyl; alkoxy; aryloxy; heteroalkoxy; heteroaryloxy; alkylthio; arylthio; heteroalkylthio; heteroarylthio; F; Cl; Br; I; -OH; -NO₂; -CN; -CF₃; -CH₂CF₃; -CHCl₂; -CH₂OH; -CH₂CH₂OH; -CH₂NH₂; -CH₂SO₂CH₃; -C(O)R_x; -CO₂(R_x); -CON(R_x)₂; -OC(O)R_x; -OCO₂R_x; -OCON(R_x)₂; -N(R_x)₂; -S(O)₂R_x; -NR_x(CO)R_x wherein each occurrence of R_x independently includes, but is not limited to, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl, wherein any of the aliphatic, heteroaliphatic, arylalkyl, or heteroarylalkyl substituents described above and herein may be substituted or unsubstituted, branched or unbranched, cyclic or acyclic, and wherein any of the aryl or heteroaryl substituents described above and herein may be substituted or unsubstituted.

Additional examples of generally applicable substituents are illustrated by the specific embodiments shown in the Examples that are described herein.

In general, the terms "aryl" and "heteroaryl", as used herein, refer to stable mono- or polycyclic, heterocyclic, polycyclic, and polyheterocyclic unsaturated moieties having preferably 3-14 carbon atoms, each of which may be substituted or unsubstituted. Substituents include, but are not limited to, any of the previously mentioned substituents, i.e., the substituents recited for aliphatic moieties, or for other moieties as disclosed herein, resulting in the formation of a stable compound. In certain embodiments of the present invention, "aryl" refers to a mono- or bicyclic carbocyclic ring system having one or two aromatic rings including, but not limited to, phenyl, naphthyl, tetrahydronaphthyl, indanyl, indenyl and the like. In certain embodiments of the present invention, the term "heteroaryl", as used herein, refers to a cyclic aromatic radical having from five to ten ring atoms of which one ring atom is selected from S, O and N; zero, one or two ring atoms are additional heteroatoms independently selected from S, O and N; and the remaining ring atoms are carbon, the radical being joined to the rest of the molecule via any of the ring atoms, such as, for example, pyridyl, pyrazinyl, pyrimidinyl, pyrrolyl, pyrazolyl, imidazolyl, thiazolyl, oxazolyl, isooxazolyl, thiadiazolyl, oxadiazolyl, thiophenyl, furanyl, quinolinyl, isoquinolinyl, and the like.

It will be appreciated that aryl and heteroaryl groups (including bicyclic aryl groups) can be unsubstituted or substituted, wherein substitution includes replacement of one, two or three of the hydrogen atoms thereon independently with any one or more of the following moieties including, but not limited to: aliphatic; heteroaliphatic; aryl; heteroaryl; arylalkyl; heteroarylalkyl; alkoxy; aryloxy; heteroalkoxy; heteroaryloxy; alkylthio; arylthio; heteroalkylthio; heteroarylthio; F; Cl; Br; I; -OH; -NO₂; -CN; -CF₃; -CH₂CF₃; -CHCl₂; -CH₂OH; -CH₂CH₂OH; -CH₂NH₂; -CH₂SO₂CH₃; -C(O)R_x; -CO₂(R_x); -CON(R_x)₂; -OC(O)R_x; -OCO₂R_x; -OCON(R_x)₂; -N(R_x)₂; -S(O)₂R_x; -NR_x(CO)R_x wherein each occurrence of R_x independently includes, but is not limited to, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl, wherein any of the aliphatic, heteroaliphatic, arylalkyl, or heteroarylalkyl substituents described above and herein may be substituted or unsubstituted, branched or unbranched, cyclic or acyclic, and wherein any of the aryl or heteroaryl substituents described above and herein may be substituted or unsubstituted. Additional examples of generally applicable

substituents are illustrated by the specific embodiments shown in the Examples that are described herein.

The term "cycloalkyl", as used herein, refers specifically to groups having three to seven, preferably three to ten carbon atoms. Suitable cycloalkyls include, but are not limited to cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cycloheptyl and the like, which, as in the case of other aliphatic, heteroaliphatic or heterocyclic moieties, may optionally be substituted with substituents including, but not limited to aliphatic; heteroaliphatic; aryl; heteroaryl; arylalkyl; heteroarylalkyl; alkoxy; aryloxy; heteroalkoxy; heteroaryloxy; alkylthio; arylthio; heteroalkylthio; heteroarylthio; F; Cl; Br; I; -OH; -NO₂; -CN; -CF₃; -CH₂CF₃; -CHCl₂; -CH₂OH; -CH₂CH₂OH; -CH₂NH₂; -CH₂SO₂CH₃; -C(O)R_x; -CO₂(R_x); -CON(R_x)₂; -OC(O)R_x; -OCO₂R_x; -OCON(R_x)₂; -N(R_x)₂; -S(O)₂R_x; -NR_x(CO)R_x wherein each occurrence of R_x independently includes, but is not limited to, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl, wherein any of the aliphatic, heteroaliphatic, arylalkyl, or heteroarylalkyl substituents described above and herein may be substituted or unsubstituted, branched or unbranched, cyclic or acyclic, and wherein any of the aryl or heteroaryl substituents described above and herein may be substituted or unsubstituted. Additional examples of generally applicable substituents are illustrated by the specific embodiments shown in the Examples that are described herein.

The term "heteroaliphatic", as used herein, refers to aliphatic moieties that contain one or more oxygen, sulfur, nitrogen, phosphorus or silicon atoms, e.g., in place of carbon atoms. Heteroaliphatic moieties may be branched, unbranched, cyclic or acyclic and include saturated and unsaturated heterocycles such as morpholino, pyrrolidinyl, etc. In certain embodiments, heteroaliphatic moieties are substituted by independent replacement of one or more of the hydrogen atoms thereon with one or more moieties including, but not limited to aliphatic; heteroaliphatic; aryl; heteroaryl; arylalkyl; heteroarylalkyl; alkoxy; aryloxy; heteroalkoxy; heteroaryloxy; alkylthio; arylthio; heteroalkylthio; heteroarylthio; F; Cl; Br; I; -OH; -NO₂; -CN; -CF₃; -CH₂CF₃; -CHCl₂; -CH₂OH; -CH₂CH₂OH; -CH₂NH₂; -CH₂SO₂CH₃; -C(O)R_x; -CO₂(R_x); -CON(R_x)₂; -OC(O)R_x; -OCO₂R_x; -OCON(R_x)₂; -N(R_x)₂; -S(O)₂R_x; -NR_x(CO)R_x wherein each occurrence of R_x independently includes, but is not limited to, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl, wherein any of the aliphatic, heteroaliphatic, arylalkyl, or heteroarylalkyl substituents described above and herein may be substituted or unsubstituted, branched or unbranched, cyclic or acyclic,

and wherein any of the aryl or heteroaryl substituents described above and herein may be substituted or unsubstituted. Additional examples of generally applicable substituents are illustrated by the specific embodiments shown in the Examples that are described herein.

5 The terms “halo” and “halogen” as used herein refer to an atom selected from fluorine, chlorine, bromine and iodine.

 The term “haloalkyl” denotes an alkyl group, as defined above, having one, two, or three halogen atoms attached thereto and is exemplified by such groups as chloromethyl, bromoethyl, trifluoromethyl, and the like.

10 The term “heterocycloalkyl” or “heterocycle”, as used herein, refers to a non-aromatic 5-, 6-, or 7- membered ring or a polycyclic group, including, but not limited to a bi- or tri-cyclic group comprising fused six-membered rings having between one and three heteroatoms independently selected from oxygen, sulfur and nitrogen, wherein (i)

15 each 5-membered ring has 0 to 1 double bonds and each 6-membered ring has 0 to 2 double bonds, (ii) the nitrogen and sulfur heteroatoms may be optionally be oxidized, (iii) the nitrogen heteroatom may optionally be quaternized, and (iv) any of the above heterocyclic rings may be fused to a benzene ring. Representative heterocycles include, but are not limited to, pyrrolidinyl, pyrazolinyl, pyrazolidinyl, imidazolinyl, imidazolidinyl, piperidinyl, piperazinyl, oxazolidinyl, isoxazolidinyl, morpholinyl,

20 thiazolidinyl, isothiazolidinyl, and tetrahydrofuryl. In certain embodiments, a “substituted heterocycloalkyl or heterocycle” group is utilized and as used herein, refers to a heterocycloalkyl or heterocycle group, as defined above, substituted by the independent replacement of one, two or three of the hydrogen atoms thereon with but are not limited to aliphatic; heteroaliphatic; aryl; heteroaryl; arylalkyl; heteroarylalkyl;

25 alkoxy; aryloxy; heteroalkoxy; heteroaryloxy; alkylthio; arylthio; heteroalkylthio; heteroarylthio; F; Cl; Br; I; -OH; -NO₂; -CN; -CF₃; -CH₂CF₃; -CHCl₂; -CH₂OH; -CH₂CH₂OH; -CH₂NH₂; -CH₂SO₂CH₃; -C(O)R_x; -CO₂(R_x); -CON(R_x)₂; -OC(O)R_x; -OCO₂R_x; -OCON(R_x)₂; -N(R_x)₂; -S(O)₂R_x; -NR_x(CO)R_x wherein each occurrence of R_x independently includes, but is not limited to, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl, wherein any of the aliphatic, heteroaliphatic, arylalkyl, or

30 heteroarylalkyl substituents described above and herein may be substituted or unsubstituted, branched or unbranched, cyclic or acyclic, and wherein any of the aryl or heteroaryl substituents described above and herein may be substituted or unsubstituted.

Additional examples of generally applicable substituents are illustrated by the specific embodiments shown in the Examples which are described herein.

“Labeled”: As used herein, the term “labeled” is intended to mean that a compound has at least one element, isotope or chemical compound attached to enable the detection of the compound. In general, labels fall into three classes: a) isotopic labels, which may be radioactive or heavy isotopes, including, but not limited to, ^2H , ^3H , ^{32}P , ^{35}S , ^{67}Ga , $^{99\text{m}}\text{Tc}$ (Tc-99m), ^{111}In , ^{123}I , ^{125}I , ^{169}Yb and ^{186}Re ; b) immune labels, which may be antibodies or antigens; and c) colored or fluorescent dyes. It will be appreciated that the labels may be incorporated into the compound at any position that does not interfere with the biological activity or characteristic of the compound that is being detected. In certain embodiments of the invention, photoaffinity labeling is utilized for the direct elucidation of intermolecular interactions in biological systems (e.g., to probe the epothilone binding site in a tubulin dimer). A variety of known photophores can be employed, most relying on photoconversion of diazo compounds, azides, or diazirines to nitrenes or carbenes (See, Bayley, H., *Photogenerated Reagents in Biochemistry and Molecular Biology* (1983), Elsevier, Amsterdam.), the entire contents of which are hereby incorporated by reference. In certain embodiments of the invention, the photoaffinity labels employed are o-, m- and p-azidobenzoyls, substituted with one or more halogen moieties, including, but not limited to 4-azido-2,3,5,6-tetrafluorobenzoic acid.

“Polymer”: The term “polymer”, as used herein, refers to a composition comprising chains that may be open, closed, linear, branched or cross-linked of repeating units (monomers) that may be the same or different. It will be appreciated that in certain embodiments the term polymer refers to biopolymers, which, as used herein, is intended to refer to polymeric materials found in nature or based upon those materials found in nature, including, but not limited to nucleic acids, peptides, and mimetics thereof. In certain other embodiments, the term polymer refers to synthetic polymers, such as biodegradable polymers or other polymeric materials. It will be appreciated that polymeric solid supports are also encompassed by the polymers of the present invention. Inventive compounds can be attached to polymeric supports and thus certain synthetic modifications can be conducted on the solid phase. As used herein, the term “solid support” is meant to include, but is not limited to, pellets, disks, capillaries, hollow fibers, needles, pins, solid fibers, cellulose beads, pore-glass beads, silica gels, polystyrene beads optionally cross-linked with divinylbenzene, grafted co-

poly beads, poly-acrylamide beads, latex beads, dimethylacrylamide beads optionally crosslinked with N-N'-bis-acryloylethylenediamine, and glass particles coated with a hydrophobic polymer. One of ordinary skill in the art will realize that the choice of particular solid support will be limited by the compatability of the support with the reaction chemistry being utilized. An exemplary solid support is a Tentagel amino resin, a composite of 1) a polystyrene bead crosslinked with divinylbenzene and 2) PEG (polyethylene glycol). Tentagel is a particularly useful solid support because it provides a versatile support for use in on-bead or off-bead assays, and it also undergoes excellent swelling in solvents ranging from toluene to water.

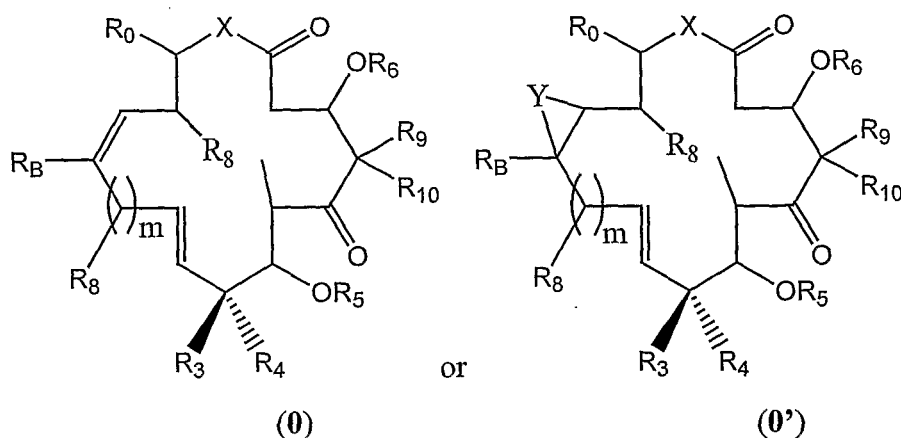
DESCRIPTION OF CERTAIN EMBODIMENTS OF THE INVENTION

In recognition of the need to develop novel and effective cancer therapies, the present invention provides novel synthetic methodologies enabling access to macrocycles having a broad range of biological and pharmacological activity, as well as novel compounds with such activity, novel therapeutic compositions, and methods of using these compounds and compositions.

In certain embodiments, the inventive compounds are useful in the treatment of cancer. Certain compounds of the invention exhibit cytotoxic or growth inhibitory effects on cancer cells lines, exhibit an ability to polymerize tubulin and stabilize microtubule assemblies, and/or lead to shrinkage or disappearance of tumors in cancer cell xenograft models. In certain embodiments, the compounds may have reduced or minimal side effects including toxicity to vital organs, nausea, vomiting, diarrhea, alopecia, weight loss, weight gain, liver toxicity, skin disorders, *etc.* The compounds may also be easier to formulate due to increased water solubility, decreased toxicity, increased therapeutic range, increased efficacy, *etc.*

General Description of Compounds of the Invention

Compounds of the invention include compounds of the general formula (0) and (0') as further defined below:



wherein R₀ is a substituted or unsubstituted aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety; in certain embodiments, R₀ is a arylalkyl, arylalkenyl, heteroarylalkyl, or heteroarylalkenyl moiety; in other embodiments, R₀ is a heteroarylalkenyl moiety; in certain embodiments, R₀ is a heteroarylalkyl moiety; in other embodiments, R₀ is a 5-7 membered aryl or heteroaryl moiety; in yet other embodiments, R₀ is an 8-12 membered bicyclic aryl or heteroaryl moiety; in still other embodiments, R₀ is a bicyclic moiety wherein a phenyl ring is fused to a heteroaryl or aryl moiety; in other embodiments, R₀ is a bicyclic moiety wherein a phenyl ring is fused to a thiazole, oxazole, or imidazole moiety; in yet other embodiments, R₀ is a substituted or unsubstituted phenyl moiety;

R₃ and R₄ are each independently hydrogen; or substituted or unsubstituted, linear or branched, cyclic or acyclic aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety, optionally substituted by one or more of hydroxy, protected hydroxy, alkoxy, carboxy, carboxaldehyde, linear or branched alkyl or cyclic acetal, fluorine, amino, protected amino, amino substituted with one or two alkyl or aryl moieties, N-hydroximino, or N-alkoxyimino; in certain embodiments, R₃ and R₄ are each independently hydrogen, fluorine, or lower alkyl; in other embodiments, R₃ and R₄ are each independently hydrogen or methyl; in still other embodiments, R₃ is methyl, and R₄ is hydrogen;

R₅ and R₆ are each independently hydrogen or a protecting group; in certain embodiments, R₅ and R₆ are both hydrogen;

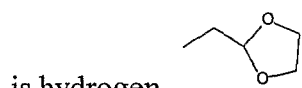
X is O, S, C(R₇)₂, or NR₇, wherein each occurrence of R₇ is independently hydrogen or lower alkyl; in certain embodiments, X is O; in other embodiments, X is NH;

Y is O, S, NH, C(R₇)₂, CH₂, N(R₇), or NH, wherein each occurrence of R₇ is independently hydrogen or lower alkyl; in certain embodiments, Y is O; in other embodiments, Y is NH; in yet other embodiments, Y is CH₂;

each R₈ is independently hydrogen; halogen, hydroxy, alkoxy, amino, dialkylamino, alkylamino, fluoro, cyano, or substituted or unsubstituted, linear or branched, cyclic or acyclic aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, or heteroarylalkyl, heteroarylalkenyl, heteroarylalkynyl moiety, optionally substituted by one or more of hydroxy, protected hydroxy, alkoxy, carboxy, carboxaldehyde, linear or branched alkyl or cyclic acetal, fluorine, amino, protected amino, amino substituted with one or two alkyl or aryl moieties, N-hydroximino, or N-alkoxyimino; in certain embodiments, R₈ is hydrogen; in other embodiments, R₈ is hydroxy; in yet other embodiments, R₈ is fluorine; in still other embodiments, R₈ is lower alkyl such as methyl; in other embodiments R₈ is -CF₃, -CF₂H, or -CFH₂; in other embodiments, R₈ is perfluorinated or fluorinated alkyl group; in yet other embodiments, R₈ is halogenated or perhalogenated alkyl group;

R₉ and R₁₀ are each independently hydrogen; or substituted or unsubstituted, linear or branched, cyclic or acyclic aliphatic, heteroaliphatic, aryl, heteroaryl, aryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety, optionally substituted by one or more of hydroxy, protected hydroxy, alkoxy, carboxy, carboxaldehyde, linear or branched alkyl or cyclic acetal, fluorine, amino, protected amino, amino substituted with one or two alkyl or aryl moieties, N-hydroximino, or N-alkoxyimino; in certain embodiments, one of R₉ and R₁₀ is methyl; in other embodiments, both R₉ and R₁₀ are methyl; in yet other embodiments, one of R₉ and R₁₀ is methyl, and the other is hydrogen; in other embodiments, both R₉ and R₁₀ are hydrogen;

R_B is, independently for each occurrence, hydrogen; halogen; -OR_B'; -SR_B'; -N(R_B')₂; -C(O)OR_B'; -C(O)R_B'; -CONHR_B'; -O(C=O)R_B'; -O(C=O)OR_B'; -NR_B'(C=O)R_B'; N₃; N₂R_B'; cyclic acetal; or cyclic or acyclic, linear or branched aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of hydrogen; halogen; -OR_B'; -SR_B'; -N(R_B')₂; -C(O)OR_B'; -C(O)R_B'; -CONHR_B'; -O(C=O)R_B'; -O(C=O)OR_B'; -NR_B'(C=O)R_B'; N₃; N₂R_B'; cyclic acetal; or cyclic or acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity label; or radiolabel; in certain embodiments, R_B

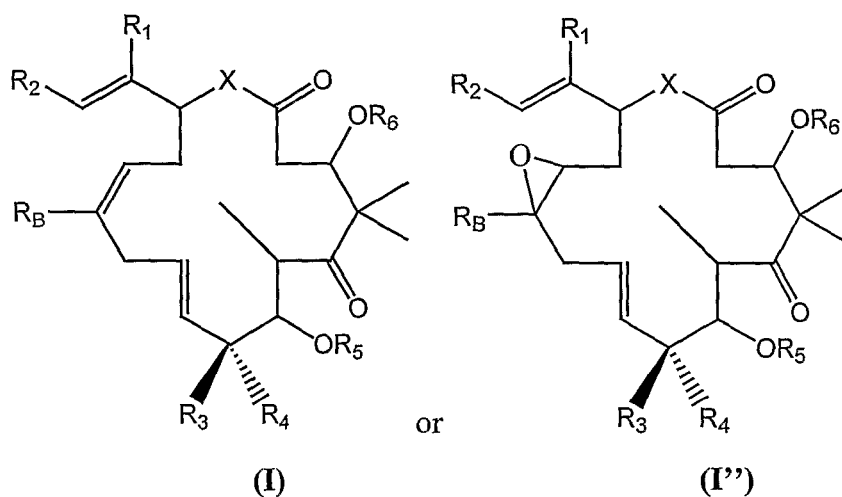


is hydrogen, , methyl, ethyl, propyl, butyl, pentyl, hexyl, cyclopropyl, cyclobutyl, cyclopentyl, or cyclohexyl, each unsubstituted or optionally substituted with one or more occurrences of halogen, $-\text{OH}$, $-\text{OR}_{\text{B}'}$, NH_2 , or $\text{N}(\text{R}_{\text{B}'})_2$, or any combination thereof, wherein each occurrence of $\text{R}_{\text{B}'}$ is independently hydrogen, alkyl, aryl, or a protecting group, in other embodiments, R_{B} is hydrogen, methyl, or ethyl, in still other embodiments, R_{B} is methyl, in other embodiments, $-\text{CY}_3$, $-\text{CHY}_2$, $-\text{CH}_2\text{Y}$, where Y is F, Br, Cl, I, $\text{OR}_{\text{B}'}$, $\text{NHR}_{\text{B}'}$, $\text{N}(\text{R}_{\text{B}'})_2$, or $\text{SR}_{\text{B}'}$; in yet other embodiments, R_{B} is $-\text{CF}_3$, $-\text{CH}_2\text{F}$, or CHF_2 ; in other embodiments, R_{B} is perfluorinated or fluorinated alkyl group; in yet other embodiments, R_{B} is halogenated or perhalogenated alkyl group;

each occurrence of $\text{R}_{\text{B}'}$ is independently hydrogen; a protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety;

m is 1, 2, 3, or 4, m is 1 or 2 in certain embodiments, m is 1 in other embodiments; and
pharmaceutically acceptable derivatives thereof.

The compounds of the invention include compounds of the general formula (I) or (I') as further defined below:



wherein R_1 is hydrogen or lower alkyl; in certain embodiments, R_1 is methyl; in certain embodiments, R_1 is $-\text{CF}_3$, $-\text{CF}_2\text{H}$, or CH_2F ; in other embodiments, R_1 is perfluorinated or fluorinated alkyl group; in yet other embodiments, R_1 is halogenated or perhalogenated alkyl group;

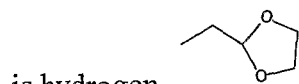
R_2 is a substituted or unsubstituted aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety; in certain embodiments, R_2 is substituted or unsubstituted oxazole; in other embodiments, R_2 is substituted or unsubstituted thiazole;

R_3 and R_4 are each independently hydrogen; or substituted or unsubstituted,
 5 linear or branched, cyclic or acyclic aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety, optionally substituted by one or more of hydroxy, protected hydroxy, alkoxy, carboxy, carboxaldehyde, linear or branched alkyl or cyclic acetal, fluorine, amino, protected amino, amino substituted with one or two alkyl or aryl moieties, N-hydroximino, or N-alkoxyimino; in certain embodiments, R_3 and R_4
 10 are each independently hydrogen, fluorine, or lower alkyl; in other embodiments, R_3 and R_4 are each independently hydrogen or methyl; in still other embodiments, R_3 is methyl, and R_4 is hydrogen;

R_5 and R_6 are each independently hydrogen or a protecting group; in certain embodiments, R_5 and R_6 are both hydrogen;

15 X is O, S, $C(R_7)_2$, or NR_7 , wherein each occurrence of R_7 is independently hydrogen or lower alkyl; in certain embodiments, X is O; in other embodiments, X is NH;

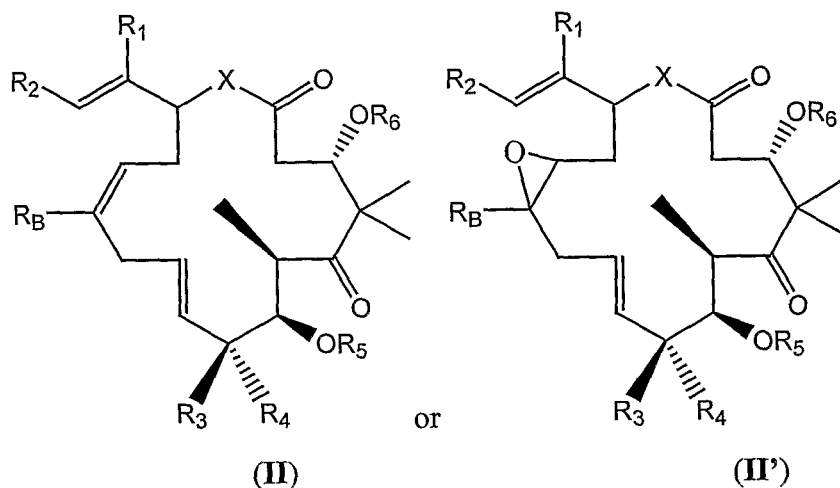
R_B is, independently for each occurrence, hydrogen; halogen; $-OR_B$; $-SR_B$; $-N(R_B)_2$; $-C(O)OR_B$; $-C(O)R_B$; $-CONHR_B$; $-O(C=O)R_B$; $-O(C=O)OR_B$; $-NR_B(C=O)R_B$; N_3 ; N_2R_B ; cyclic acetal; or cyclic or acyclic, linear or branched
 20 aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of hydrogen; halogen; $-OR_B$; $-SR_B$; $-N(R_B)_2$; $-C(O)OR_B$; $-C(O)R_B$; $-CONHR_B$; $-O(C=O)R_B$; $-O(C=O)OR_B$; $-NR_B(C=O)R_B$; N_3 ; N_2R_B ; cyclic acetal; or cyclic or acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl,
 25 or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity label; or radiolabel; in certain embodiments, R_B



cyclobutyl, cyclopentyl, or cyclohexyl, each unsubstituted or optionally substituted with one or more occurrences of halogen, $-OH$, $-OR_B$, NH_2 , or $N(R_B)_2$, or any
 30 combination thereof, wherein each occurrence of R_B is independently hydrogen, alkyl, aryl, or a protecting group, in other embodiments, R_B is hydrogen, methyl, or ethyl, in

still other embodiments, R_B is methyl, in yet other embodiments, R_B is $-\text{CF}_3$, $-\text{CH}_2\text{F}$, or CHF_2 ; and
pharmaceutically acceptable derivatives thereof.

- 5 In certain embodiments, the compounds of the invention include compounds of the general formula (II) or (II') with the stereochemistry defined as shown:



- 10 wherein X, R_1 , R_2 , R_3 , R_4 , R_5 , R_6 , R_B , and X are as defined above.

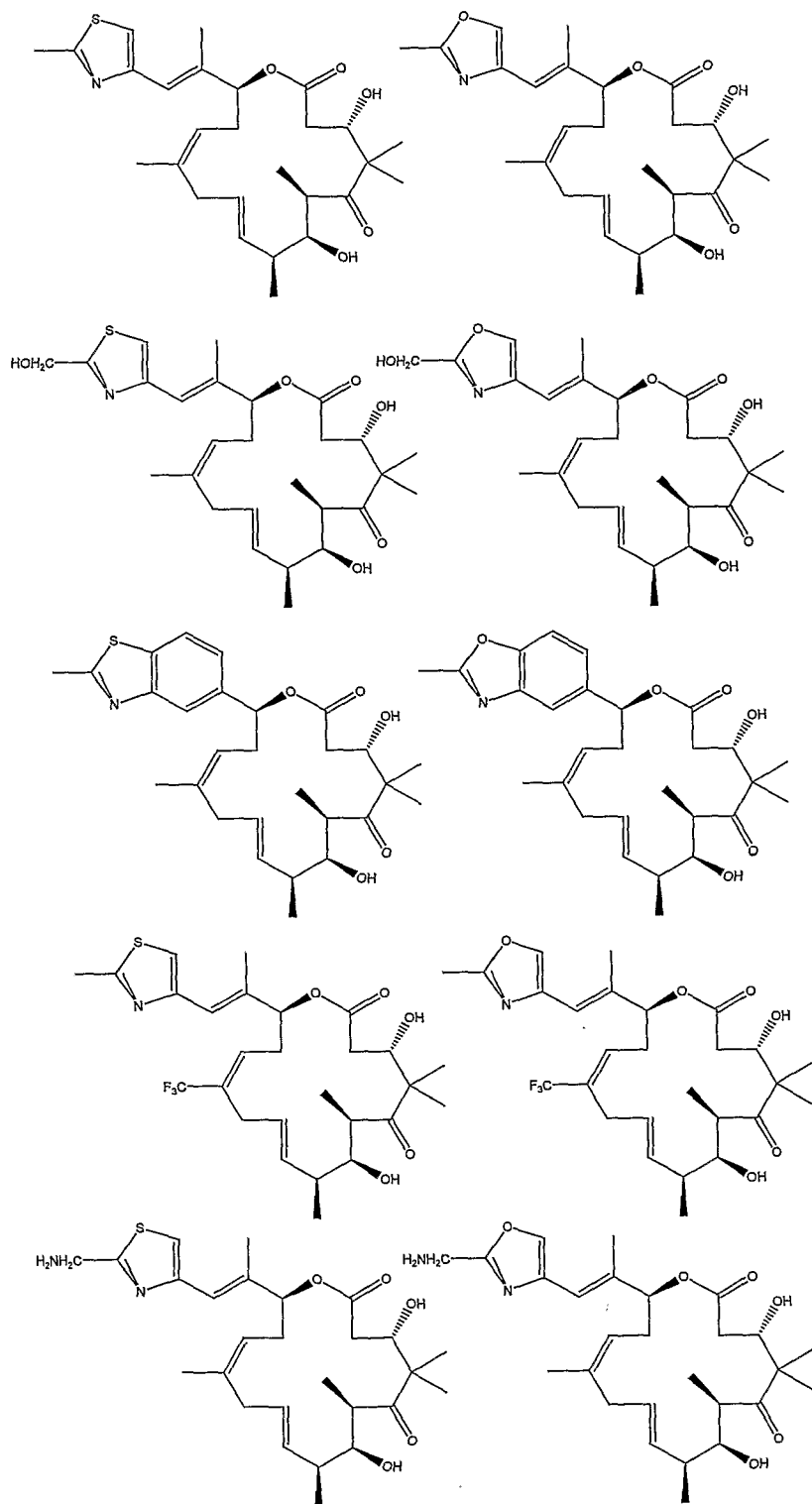
In certain embodiments, X is O. In other embodiments, X is NH. In other embodiments, X is CH_2 .

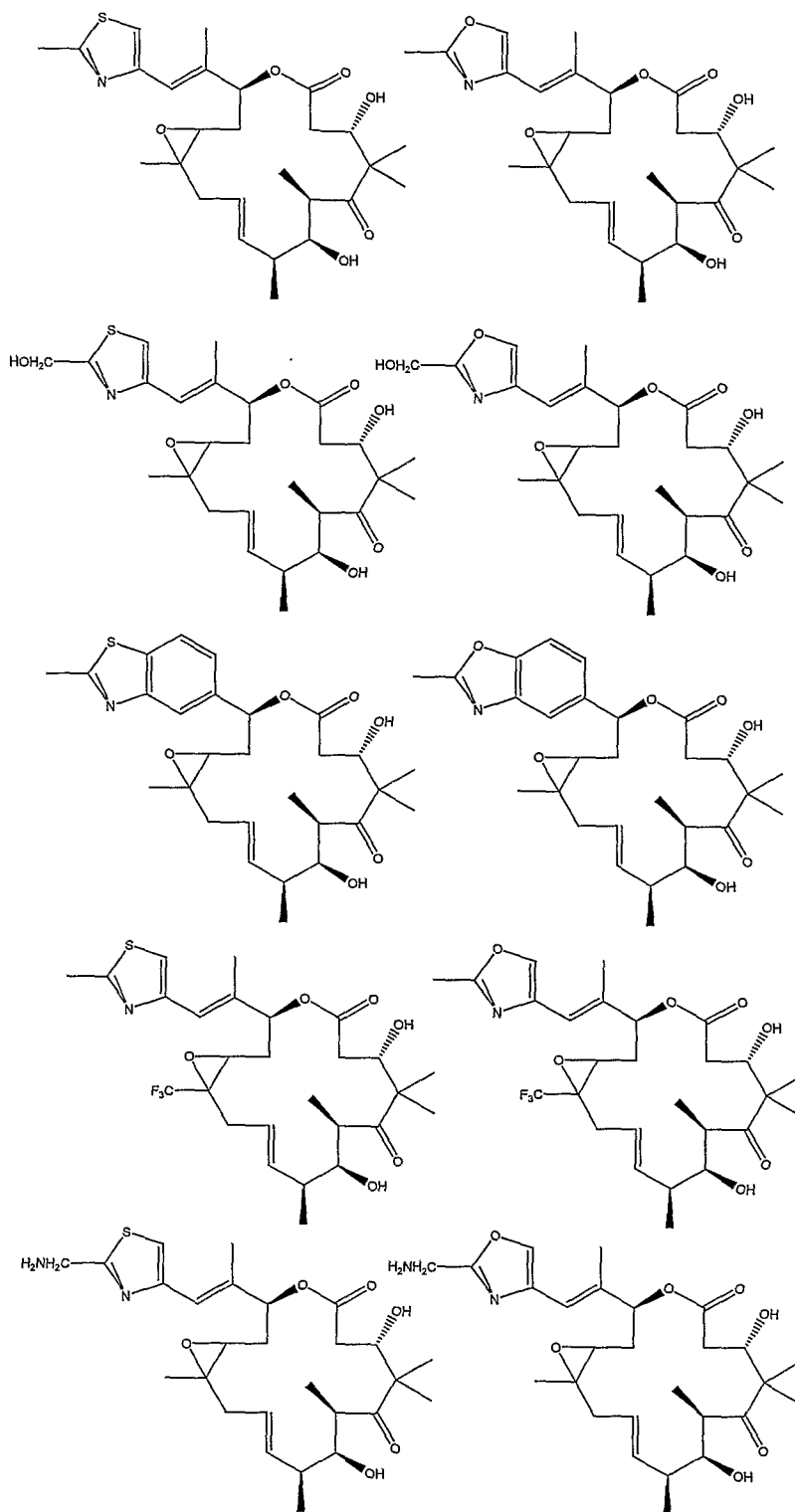
- 15 In some embodiments, R_2 is a substituted or unsubstituted thiazole. In certain embodiments, R_2 is 2-methyl-thiazo-4-yl. In other embodiments, R_2 is 2-hydroxymethyl-thiazo-4-yl. In yet other embodiments, R_2 is 2-aminomethyl-thiazo-4-yl. In other embodiments, R_2 is 2-thiolmethyl-thiazo-4-yl.

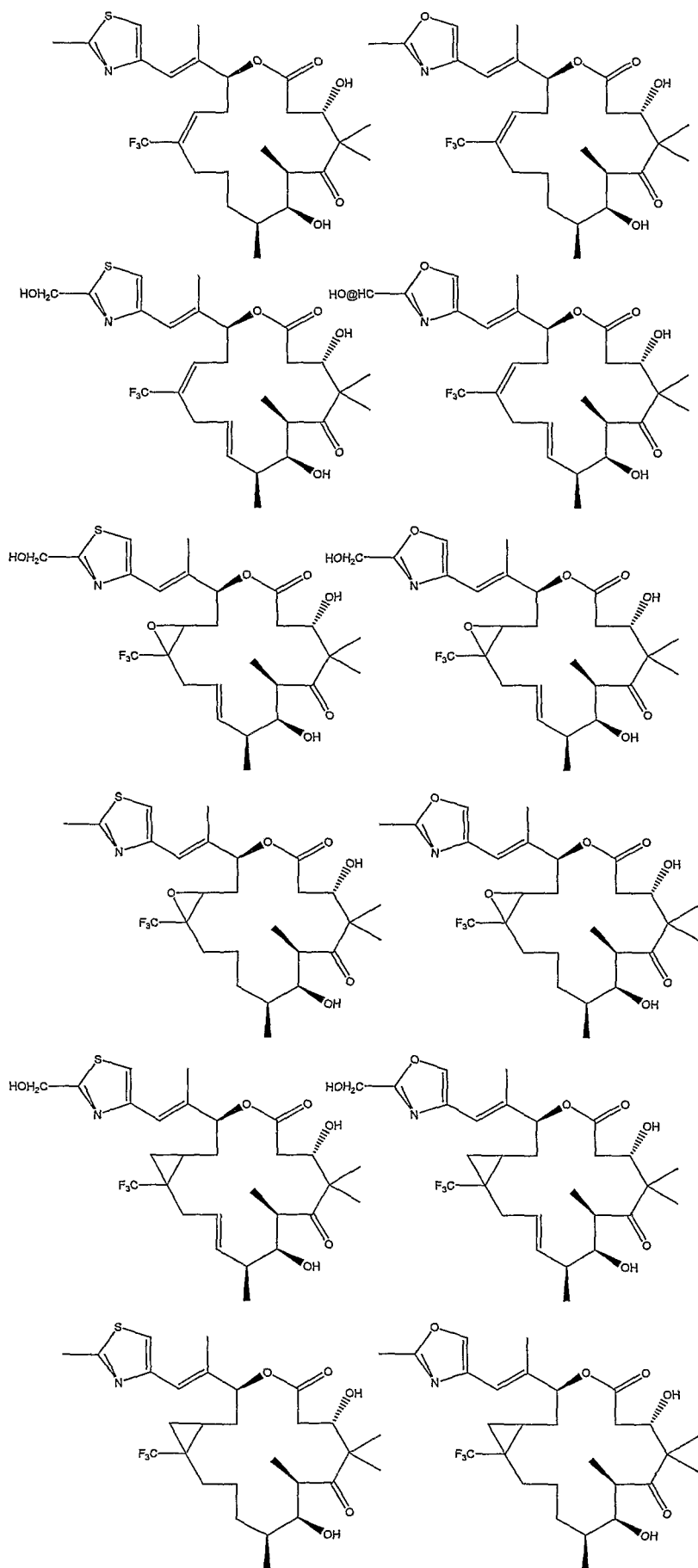
- 20 In certain embodiments R_2 is a substituted or unsubstituted oxazole. In certain embodiments, R_2 is 2-methyl-oxazo-4-yl. In other embodiments, R_2 is 2-hydroxymethyl-oxazo-4-yl. In yet other embodiments, R_2 is 2-aminomethyl-oxazo-4-yl. In other embodiments, R_2 is 2-thiolmethyl-oxazo-4-yl.

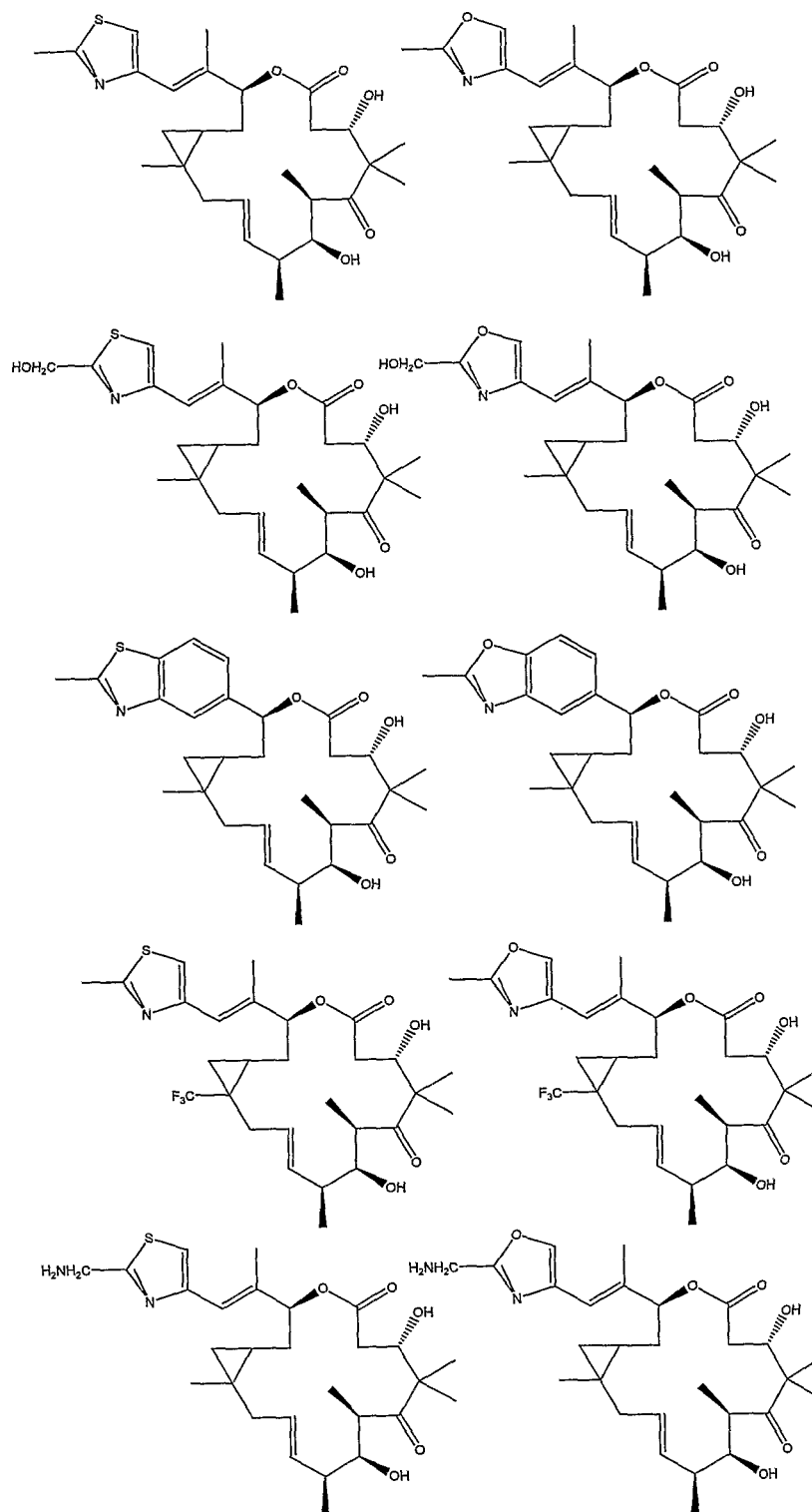
- 25 In certain embodiments, R_B is hydrogen, methyl, ethyl, $-\text{CF}_3$, $-\text{CH}_2\text{F}$, $-\text{CF}_2\text{H}$. In certain embodiments, R_B is methyl. In yet other embodiments, R_B is $-\text{CF}_3$. In certain embodiments, R_B is hydrogen. In other embodiments, R_B is ethyl.

Certain preferred compounds include, for example:









Compounds of this invention include those specifically set forth above and described herein, and are illustrated in part by the various classes, subgenera and species disclosed elsewhere herein.

5 It will be appreciated by one of ordinary skill in the art that asymmetric centers may exist in the compounds of the present invention. Thus, inventive compounds and pharmaceutical compositions thereof may be in the form of an individual enantiomer,

diastereomer or geometric isomer, or may be in the form of a mixture of stereoisomers. In certain embodiments, the compounds of the invention are enantiopure compounds. In certain other embodiments, a mixtures of stereoisomers or diastereomers are provided.

5 It will be appreciated that some of the foregoing classes and subclasses of compounds can exist in various isomeric forms. The invention encompasses the compounds as individual isomers substantially free of other isomers and alternatively, as mixtures of various isomers, *e.g.*, racemic mixtures of stereoisomers. Additionally, the invention encompasses both (Z) and (E) double bond isomers unless otherwise
10 specifically designated. Thus, compounds of the invention generally depicted in structure (0), (0'), (I), (I'), (II), and (II') encompass those structures in which double bonds are (Z) or (E). In certain preferred embodiments, the double bond at the C12-C13 position is in the cis or Z configuration. In some embodiments, the double bond at the C9-C10 position is in the trans or E configuration. In still other embodiments, the
15 double bond at the C12-C13 position is in the cis or Z configuration, and the double bond at the C9-C10 position is in the trans or E configuration. The invention also encompasses tautomers of specific compounds as described above.

 Additionally, the present invention provides pharmaceutically acceptable
20 derivatives of the inventive compounds, and methods of treating a subject using these compounds, pharmaceutical compositions thereof, or either of these in combination with one or more additional therapeutic agents. The phrase, "pharmaceutically acceptable derivative", as used herein, denotes any pharmaceutically acceptable salt, ester, or salt of such ester, of such compound, or any other adduct or derivative which,
25 upon administration to a patient, is capable of providing (directly or indirectly) a compound as otherwise described herein, or a metabolite or residue thereof. Pharmaceutically acceptable derivatives thus include among others pro-drugs. A pro-drug is a derivative of a compound, usually with significantly reduced pharmacological activity, which contains an additional moiety that is susceptible to removal *in vivo*
30 yielding the parent molecule as the pharmacologically active species. An example of a pro-drug is an ester that is cleaved *in vivo* to yield a compound of interest. Pro-drugs of a variety of compounds, and materials and methods for derivatizing the parent compounds to create the pro-drugs, are known and may be adapted to the present

invention. Certain exemplary pharmaceutical compositions and pharmaceutically acceptable derivatives will be discussed in more detail herein below.

Compounds of this invention which are of particular interest include those which:

- exhibit cytotoxic or growth inhibitory effect on cancer cell lines maintained *in vitro* or in animal studies using a scientifically acceptable cancer cell xenograft model;
- exhibit an ability to polymerize tubulin and stabilize microtubule assemblies;
- exhibit minimal levels of toxicity to vital organs;
- lead to tumor disappearance in scientifically acceptable cancer cell xenograft models;
- lead to tumor shrinkage in scientifically acceptable cancer cell xenograft models;
- lead to tumor disappearance in scientifically acceptable cancer cell xenograft models and delayed/or no recurrence of the tumor after stopping treatment;
- exhibit transient and reversible body weight decreases and show therapeutic effects in scientifically acceptable cancer cell xenograft models;
- exhibit enhanced water solubility over epothilones A, B, C or D, or paclitaxel, or additionally or alternatively exhibit sufficient solubility to be formulated in an aqueous medium using reduced proportion of chremophor; and/or
- exhibit a therapeutic profile (*e.g.*, optimum safety and curative effect) that is superior to that of epothilone B, epothilone D, or paclitaxel.

A variety of epothilone analogs as described *supra* have been prepared, characterized, and tested as exemplified herein. 9,10-dehydro-epothilone analogs have been found to be useful in the treatment of cancer, and in particular compounds have been prepared and found to possess one or more of the desired characteristics listed above.

Synthetic Methodology

The synthesis of certain epothilones, desoxyepothilones and analogues thereof have been previously described (see, U.S. Patents 6,242,469, 6,284,781, 6,300,355, 6,204,388, 6,316,630, and 6,369,234; U.S. Patent Applications 09/797,027, 09/796,959, and 10/236,135; and PCT Publication Nos. WO 99/01124, WO 99/43653, and WO

01/64650, the entire contents of which are hereby incorporated by reference). In recognition of the need for improved or additional synthetic methodologies to efficiently generate epothilones, desoxyepothilones and analogues thereof in large quantities, the present invention provides an efficient and modular route for the synthesis of epothilones, desoxyepothilones and analogues thereof. Although the synthesis of certain exemplary compounds is described in the Exemplification herein, it will be appreciated that this methodology is generally applicable to the generation of analogues and conjugates as discussed above for each of the classes and subclasses described herein.

In particular, the 9,10-dehydroepothilone compounds of the present invention may be prepared in a variety of ways using synthetic methodologies useful in the synthesis of epothilones. In certain embodiments, the compounds are prepared using a convergent synthetic route. For example, the epothilone may be synthesized by preparing two or three intermediates which are brought together to yield the desired compound. In one embodiment, one of the intermediates is an acyl portion containing carbons 1-9, and another intermediate contains carbons 10-15 and may also contain the thiazole side chain. These two roughly equal portions of the epothilone may be brought together first using an esterification reaction between C-1 and an oxygen off C-15. The macrocycle may then be closed using a carbon-carbon coupling reaction such as a Suzuki coupling or ring closing metathesis reaction. In one embodiment, the final ring closing step is accomplished using a ring closing metathesis reaction to form the 9,10-double bond and close the macrocycle. The ring closing metathesis reaction is accomplished using an organometallic catalyst such as the Grubbs catalyst as shown in Scheme 8 below. In certain embodiments, the 9,10-double bond is reduced or oxidized, or the 9,10-double bond may be further functionalized to prepare additional epothilone derivatives.

In other embodiments, the final ring closing step is accomplished using a ring closing metathesis reaction to form the 12,13-double bond and close the macrocycle. In certain embodiments, the 12,13-double bond is reduced or oxidized. In other embodiments, a macroaldolization or macrolactonization reaction is used to form the macrocycle.

Certain exemplary syntheses of the compounds of the invention are provided in the Figures and in the Examples. As would be appreciated by one of ordinary skill in the art, a variety of analogs and derivatives may be prepared using the synthetic

procedures described herein. For example, one could accomplish many of the synthetic steps with different protecting groups or different substituents on the 16-membered ring.

5 *Pharmaceutical Compositions*

This invention also provides a pharmaceutical preparation comprising at least one of the compounds as described above and herein, or a pharmaceutically acceptable derivative thereof, which compounds are capable of inhibiting the growth of or killing cancer cells, and, in certain embodiments of special interest are capable of inhibiting
10 the growth of or killing multidrug resistant cancer cells. In certain embodiments, the pharmaceutical preparation also comprises as solubilizing or emulsifying agent such as Cremophor (polyoxyl 35 castor oil) or Solutol (polyethylene glycol 660 12-hydroxystearate).

As discussed above, the present invention provides novel compounds having
15 antitumor and antiproliferative activity, and thus the inventive compounds are useful for the treatment of cancer. Accordingly, in another aspect of the present invention, pharmaceutical compositions are provided, wherein these compositions comprise any one of the compounds as described herein, and optionally comprise a pharmaceutically acceptable carrier. In certain embodiments, these compositions optionally further
20 comprise one or more additional therapeutic agents. In certain other embodiments, the additional therapeutic agent is an anticancer agent, as discussed in more detail herein.

It will also be appreciated that certain of the compounds of present invention can exist in free form for treatment, or where appropriate, as a pharmaceutically acceptable derivative thereof. According to the present invention, a pharmaceutically
25 acceptable derivative includes, but is not limited to, pharmaceutically acceptable salts, esters, salts of such esters, or any other adduct or derivative which upon administration to a patient in need is capable of providing, directly or indirectly, a compound as otherwise described herein, or a metabolite or residue thereof, e.g., a prodrug.

As used herein, the term "pharmaceutically acceptable salt" refers to those salts
30 which are, within the scope of sound medical judgement, suitable for use in contact with the tissues of humans and lower animals without undue toxicity, irritation, allergic response and the like, and are commensurate with a reasonable benefit/risk ratio. Pharmaceutically acceptable salts are well known in the art. For example, S. M. Berge, *et al.* describe pharmaceutically acceptable salts in detail in *J. Pharmaceutical*

Sciences, 66: 1-19 (1977), incorporated herein by reference. The salts can be prepared in situ during the final isolation and purification of the compounds of the invention, or separately by reacting the free base function with a suitable organic acid. Examples of pharmaceutically acceptable, nontoxic acid addition salts are salts of an amino group
5 formed with inorganic acids such as hydrochloric acid, hydrobromic acid, phosphoric acid, sulfuric acid and perchloric acid or with organic acids such as acetic acid, oxalic acid, maleic acid, tartaric acid, citric acid, succinic acid or malonic acid or by using other methods used in the art such as ion exchange. Other pharmaceutically acceptable salts include adipate, alginate, ascorbate, aspartate, benzenesulfonate, benzoate,
10 bisulfate, borate, butyrate, camphorate, camphorsulfonate, citrate, cyclopentanepropionate, digluconate, dodecylsulfate, ethanesulfonate, formate, fumarate, glucoheptonate, glycerophosphate, gluconate, harnisulfate, heptanoate, hexanoate, hydroiodide, 2-hydroxy-ethanesulfonate, lactobionate, lactate, laurate, lauryl sulfate, malate, maleate, malonate, methanesulfonate, 2-naphthalenesulfonate,
15 nicotinate, nitrate, oleate, oxalate, palmitate, pamoate, pectinate, persulfate, 3-phenylpropionate, phosphate, picrate, pivalate, propionate, stearate, succinate, sulfate, tartrate, thiocyanate, p-toluenesulfonate, undecanoate, valerate salts, and the like. Representative alkali or alkaline earth metal salts include sodium, lithium, potassium, calcium, magnesium, and the like. Further pharmaceutically acceptable salts include,
20 when appropriate, nontoxic ammonium, quaternary ammonium, and amine cations formed using counterions such as halide, hydroxide, carboxylate, sulfate, phosphate, nitrate, loweralkyl sulfonate and aryl sulfonate.

Additionally, as used herein, the term "pharmaceutically acceptable ester" refers to esters which hydrolyze in vivo and include those that break down readily in the
25 human body to leave the parent compound or a salt thereof. Suitable ester groups include, for example, those derived from pharmaceutically acceptable aliphatic carboxylic acids, particularly alkanoic, alkenoic, cycloalkanoic and alkanedioic acids, in which each alkyl or alkenyl moiety advantageously has not more than 6 carbon atoms. Examples of particular esters include formates, acetates, propionates, butyrates,
30 acrylates and ethylsuccinates.

Furthermore, the term "pharmaceutically acceptable prodrugs" as used herein refers to those prodrugs of the compounds of the present invention which are, within the scope of sound medical judgment, suitable for use in contact with the tissues of humans and lower animals with undue toxicity, irritation, allergic response, and the

like, commensurate with a reasonable benefit/risk ratio, and effective for their intended use, as well as the zwitterionic forms, where possible, of the compounds of the invention. The term "prodrug" refers to compounds that are rapidly transformed in vivo to yield the parent compound of the above formula, for example by hydrolysis in blood.

- 5 A thorough discussion is provided in T. Higuchi and V. Stella, Pro-drugs as Novel Delivery Systems, Vol. 14 of the A.C.S. Symposium Series, and in Edward B. Roche, ed., Bioreversible Carriers in Drug Design, American Pharmaceutical Association and Pergamon Press, 1987, both of which are incorporated herein by reference.

As described above, the pharmaceutical compositions of the present invention
10 additionally comprise a pharmaceutically acceptable carrier, which, as used herein, includes any and all solvents, diluents, or other liquid vehicle, dispersion or suspension aids, surface active agents, isotonic agents, thickening or emulsifying agents, preservatives, solid binders, lubricants and the like, as suited to the particular dosage form desired. Remington's Pharmaceutical Sciences, Fifteenth Edition, E. W. Martin
15 (Mack Publishing Co., Easton, Pa., 1975) discloses various carriers used in formulating pharmaceutical compositions and known techniques for the preparation thereof. Except insofar as any conventional carrier medium is incompatible with the anti-cancer compounds of the invention, such as by producing any undesirable biological effect or otherwise interacting in a deleterious manner with any other component(s) of the
20 pharmaceutical composition, its use is contemplated to be within the scope of this invention. Some examples of materials which can serve as pharmaceutically acceptable carriers include, but are not limited to, sugars such as lactose, glucose and sucrose; starches such as corn starch and potato starch; cellulose and its derivatives such as sodium carboxymethyl cellulose, ethyl cellulose and cellulose acetate; powdered
25 tragacanth; malt; gelatin; talc; Cremophor; Solutol; excipients such as cocoa butter and suppository waxes; oils such as peanut oil, cottonseed oil; safflower oil; sesame oil; olive oil; corn oil and soybean oil; glycols; such a propylene glycol; esters such as ethyl oleate and ethyl laurate; agar; buffering agents such as magnesium hydroxide and aluminum hydroxide; alginic acid; pyrogen-free water; isotonic saline; Ringer's
30 solution; ethyl alcohol, and phosphate buffer solutions, as well as other non-toxic compatible lubricants such as sodium lauryl sulfate and magnesium stearate, as well as coloring agents, releasing agents, coating agents, sweetening, flavoring and perfuming agents, preservatives and antioxidants can also be present in the composition, according to the judgment of the formulator.

Uses of Compounds and Pharmaceutical Compositions

The invention further provides a method for inhibiting tumor growth and/or tumor metastasis. In certain embodiments of special interest, the invention provides a method of treating cancers by inhibiting tumor growth and/or tumor metastasis for tumors multidrug resistant cancer cells. The method involves the administration of a therapeutically effective amount of the compound or a pharmaceutically acceptable derivative thereof to a subject (including, but not limited to a human or animal) in need of it. In certain embodiments, specifically for treating cancers comprising multidrug resistant cancer cells, the therapeutically effective amount is an amount sufficient to kill or inhibit the growth of multidrug resistant cancer cell lines. In certain embodiments, the inventive compounds are useful for the treatment of solid tumors.

The compounds and pharmaceutical compositions of the present invention may be used in treating or preventing any disease or conditions including proliferative diseases (*e.g.*, cancer), autoimmune diseases (*e.g.*, rheumatoid arthritis), and infections (*e.g.*, bacterial, fungal, *etc.*). The compounds and pharmaceutical compositions may be administered to animals, preferably mammals (*e.g.*, domesticated animals, cats, dogs, mice, rats), and more preferably humans. Any method of administration may be used to deliver the compound or pharmaceutical compositions to the animal. In certain embodiments, the compound or pharmaceutical composition is administered parenterally.

In yet another aspect, according to the methods of treatment of the present invention, tumor cells are killed, or their growth is inhibited by contacting the tumor cells with an inventive compound or composition, as described herein. Thus, in still another aspect of the invention, a method for the treatment of cancer is provided comprising administering a therapeutically effective amount of an inventive compound, or a pharmaceutical composition comprising an inventive compound to a subject in need thereof, in such amounts and for such time as is necessary to achieve the desired result. In certain embodiments of the present invention a "therapeutically effective amount" of the inventive compound or pharmaceutical composition is that amount effective for killing or inhibiting the growth of tumor cells. The compounds and compositions, according to the method of the present invention, may be administered using any amount and any route of administration effective for killing or inhibiting the

growth of tumor cells. Thus, the expression "amount effective to kill or inhibit the growth of tumor cells", as used herein, refers to a sufficient amount of agent to kill or inhibit the growth of tumor cells. The exact amount required will vary from subject to subject, depending on the species, age, and general condition of the subject, the severity of the infection, the particular anticancer agent, its mode of administration, and the like. The anticancer compounds of the invention are preferably formulated in dosage unit form for ease of administration and uniformity of dosage. The expression "dosage unit form" as used herein refers to a physically discrete unit of anticancer agent appropriate for the patient to be treated. It will be understood, however, that the total daily usage of the compounds and compositions of the present invention will be decided by the attending physician within the scope of sound medical judgment. The specific therapeutically effective dose level for any particular patient or organism will depend upon a variety of factors including the disorder being treated and the severity of the disorder; the activity of the specific compound employed; the specific composition employed; the age, body weight, general health, sex and diet of the patient; the time of administration, route of administration, and rate of excretion of the specific compound employed; the duration of the treatment; drugs used in combination or coincidental with the specific compound employed; and like factors well known in the medical arts.

Furthermore, after formulation with an appropriate pharmaceutically acceptable carrier in a desired dosage, the pharmaceutical compositions of this invention can be administered to humans and other animals orally, rectally, parenterally, intracisternally, intravaginally, intraperitoneally, topically (as by powders, ointments, or drops), buccally, as an oral or nasal spray, or the like, depending on the severity of the infection being treated. In certain embodiments of the invention, the inventive compounds as described herein are formulated by conjugating with water soluble chelators, or water soluble polymers such as polyethylene glycol as poly (1-glutamic acid), or poly (1-aspartic acid), as described in U.S. Patent 5,977,163, the entire contents of which are hereby incorporated by reference. In certain embodiments, the compounds of the invention may be administered orally or parenterally at dosage levels sufficient to deliver from about 0.001 mg/kg to about 100 mg/kg, from about 0.01 mg/kg to about 50 mg/kg, preferably from about 0.1 mg/kg to about 40 mg/kg, preferably from about 0.5 mg/kg to about 30 mg/kg, from about 0.01 mg/kg to about 10 mg/kg, from about 0.1 mg/kg to about 10 mg/kg, and more preferably from about 1 mg/kg to about 25 mg/kg, of subject body weight per day, one or more times a day, to obtain the desired

therapeutic effect. The desired dosage may delivered as delivered every other day, every third day, every week, every two weeks, every three weeks, or every four weeks. In certain embodiments, the desired dosage may be delivered using multiple administrations (*e.g.*, two, three, four, five, six, seven, eight, nine, or ten administrations).

Liquid dosage forms for oral administration include, but are not limited to, pharmaceutically acceptable emulsions, microemulsions, solutions, suspensions, syrups and elixirs. In addition to the active compounds, the liquid dosage forms may contain inert diluents commonly used in the art such as, for example, water or other solvents, solubilizing agents and emulsifiers such as ethyl alcohol, isopropyl alcohol, ethyl carbonate, ethyl acetate, benzyl alcohol, benzyl benzoate, propylene glycol, 1,3-butylene glycol, dimethylformamide, oils (in particular, cottonseed, groundnut, corn, germ, olive, castor, and sesame oils), glycerol, tetrahydrofurfuryl alcohol, polyethylene glycols and fatty acid esters of sorbitan, and mixtures thereof. Besides inert diluents, the oral compositions can also include adjuvants such as wetting agents, emulsifying and suspending agents, sweetening, flavoring, and perfuming agents.

Injectable preparations, for example, sterile injectable aqueous or oleaginous suspensions may be formulated according to the known art using suitable dispersing or wetting agents and suspending agents. The sterile injectable preparation may also be a sterile injectable solution, suspension or emulsion in a nontoxic parenterally acceptable diluent or solvent, for example, as a solution in 1,3-butanediol. Among the acceptable vehicles and solvents that may be employed are water, Ringer's solution, U.S.P. and isotonic sodium chloride solution. In addition, sterile, fixed oils are conventionally employed as a solvent or suspending medium. For this purpose any bland fixed oil can be employed including synthetic mono- or diglycerides. In addition, fatty acids such as oleic acid are used in the preparation of injectables.

The injectable formulations can be sterilized, for example, by filtration through a bacterial-retaining filter, or by incorporating sterilizing agents in the form of sterile solid compositions which can be dissolved or dispersed in sterile water or other sterile injectable medium prior to use.

In order to prolong the effect of a drug, it is often desirable to slow the absorption of the drug from subcutaneous or intramuscular injection. This may be accomplished by the use of a liquid suspension of crystalline or amorphous material with poor water solubility. The rate of absorption of the drug then depends upon its rate

of dissolution which, in turn, may depend upon crystal size and crystalline form. Alternatively, delayed absorption of a parenterally administered drug form is accomplished by dissolving or suspending the drug in an oil vehicle. Injectable depot forms are made by forming microencapsule matrices of the drug in biodegradable polymers such as polylactide-polyglycolide. Depending upon the ratio of drug to polymer and the nature of the particular polymer employed, the rate of drug release can be controlled. Examples of other biodegradable polymers include poly(orthoesters) and poly(anhydrides). Depot injectable formulations are also prepared by entrapping the drug in liposomes or microemulsions which are compatible with body tissues.

10 Compositions for rectal or vaginal administration are preferably suppositories which can be prepared by mixing the compounds of this invention with suitable non-irritating excipients or carriers such as cocoa butter, polyethylene glycol or a suppository wax which are solid at ambient temperature but liquid at body temperature and therefore melt in the rectum or vaginal cavity and release the active compound.

15 Solid dosage forms for oral administration include capsules, tablets, pills, powders, and granules. In such solid dosage forms, the active compound is mixed with at least one inert, pharmaceutically acceptable excipient or carrier such as sodium citrate or dicalcium phosphate and/or a) fillers or extenders such as starches, lactose, sucrose, glucose, mannitol, and silicic acid, b) binders such as, for example, 20 carboxymethylcellulose, alginates, gelatin, polyvinylpyrrolidinone, sucrose, and acacia, c) humectants such as glycerol, d) disintegrating agents such as agar--agar, calcium carbonate, potato or tapioca starch, alginic acid, certain silicates, and sodium carbonate, e) solution retarding agents such as paraffin, f) absorption accelerators such as quaternary ammonium compounds, g) wetting agents such as, for example, cetyl 25 alcohol and glycerol monostearate, h) absorbents such as kaolin and bentonite clay, and i) lubricants such as talc, calcium stearate, magnesium stearate, solid polyethylene glycols, sodium lauryl sulfate, and mixtures thereof. In the case of capsules, tablets and pills, the dosage form may also comprise buffering agents.

 Solid compositions of a similar type may also be employed as fillers in soft and 30 hard-filled gelatin capsules using such excipients as lactose or milk sugar as well as high molecular weight polyethylene glycols and the like. The solid dosage forms of tablets, dragees, capsules, pills, and granules can be prepared with coatings and shells such as enteric coatings and other coatings well known in the pharmaceutical formulating art. They may optionally contain opacifying agents and can also be of a

composition that they release the active ingredient(s) only, or preferentially, in a certain part of the intestinal tract, optionally, in a delayed manner. Examples of embedding compositions which can be used include polymeric substances and waxes. Solid compositions of a similar type may also be employed as fillers in soft and hard-filled
5 gelatin capsules using such excipients as lactose or milk sugar as well as high molecular weight polyethylene glycols and the like.

The active compounds can also be in micro-encapsulated form with one or more excipients as noted above. The solid dosage forms of tablets, dragees, capsules, pills, and granules can be prepared with coatings and shells such as enteric coatings, release
10 controlling coatings and other coatings well known in the pharmaceutical formulating art. In such solid dosage forms the active compound may be admixed with at least one inert diluent such as sucrose, lactose or starch. Such dosage forms may also comprise, as is normal practice, additional substances other than inert diluents, e.g., tableting lubricants and other tableting aids such as magnesium stearate and microcrystalline
15 cellulose. In the case of capsules, tablets and pills, the dosage forms may also comprise buffering agents. They may optionally contain opacifying agents and can also be of a composition that they release the active ingredient(s) only, or preferentially, in a certain part of the intestinal tract, optionally, in a delayed manner. Examples of embedding compositions which can be used include polymeric substances and waxes.

20 Dosage forms for topical or transdermal administration of a compound of this invention include ointments, pastes, creams, lotions, gels, powders, solutions, sprays, inhalants or patches. The active component is admixed under sterile conditions with a pharmaceutically acceptable carrier and any needed preservatives or buffers as may be required. Ophthalmic formulation, ear drops, and eye drops are also contemplated as
25 being within the scope of this invention. Additionally, the present invention contemplates the use of transdermal patches, which have the added advantage of providing controlled delivery of a compound to the body. Such dosage forms can be made by dissolving or dispensing the compound in the proper medium. Absorption enhancers can also be used to increase the flux of the compound across the skin. The
30 rate can be controlled by either providing a rate controlling membrane or by dispersing the compound in a polymer matrix or gel.

As discussed above, the compounds of the present invention are useful as anticancer agents, and thus may be useful in the treatment of cancer, by effecting tumor cell death or inhibiting the growth of tumor cells. In general, the inventive anticancer

agents are useful in the treatment of cancers and other proliferative disorders, including, but not limited to breast cancer, brain cancer, skin cancer, cervical cancer, colon and rectal cancer, leukemia, lung cancer, melanoma, multiple myeloma, non-Hodgkin's lymphoma, ovarian cancer, pancreatic cancer, prostate cancer, and gastric cancer, to
5 name a few. In certain embodiments, the inventive anticancer agents are active against leukemia cells and melanoma cells, and thus are useful for the treatment of leukemias (e.g., myeloid, lymphocytic, promyelocytic, myelocytic and lymphoblastic leukemias, whether acute or chronic forms) and malignant melanomas. In still other
10 embodiments, the inventive anticancer agents are active against solid tumors and also kill and/or inhibit the growth of multidrug resistant cells (MDR cells). In certain
embodiments, the inventive anticancer agents are active against cancers which are resistant to other known anti-neoplastic agents or which have been found not to respond clinically to other known anti-neoplastic agents. In other embodiments, the inventive
15 anticancer agents are active against cancer which are resistant to other anti-neoplastic microtubule-stabilizing agents (e.g., paclitaxel).

It will also be appreciated that the compounds and pharmaceutical compositions of the present invention can be employed in combination therapies, that is, the compounds and pharmaceutical compositions can be administered concurrently with,
prior to, or subsequent to, one or more other desired therapeutics or medical
20 procedures. The particular combination of therapies (therapeutics or procedures) to employ in a combination regimen will take into account compatibility of the desired therapeutics and/or procedures and the desired therapeutic effect to be achieved. It will
also be appreciated that the therapies employed may achieve a desired effect for the same disorder (for example, an inventive compound may be administered concurrently
25 with another anticancer agent), or they may achieve different effects (e.g., control of any adverse effects).

For example, other therapies or anticancer agents that may be used in combination with the inventive anticancer agents of the present invention include surgery, radiotherapy (in but a few examples, γ -radiation, neutron beam radiotherapy,
30 electron beam radiotherapy, proton therapy, brachytherapy, and systemic radioactive isotopes, to name a few), endocrine therapy, biologic response modifiers (interferons, interleukins, and tumor necrosis factor (TNF) to name a few), hyperthermia and cryotherapy, agents to attenuate any adverse effects (e.g., antiemetics), and other

approved chemotherapeutic drugs, including, but not limited to, alkylating drugs (mechlorethamine, chlorambucil, Cyclophosphamide, Melphalan, Ifosfamide), antimetabolites (Methotrexate), purine antagonists and pyrimidine antagonists (6-Mercaptopurine, 5-Fluorouracil, Cytarabine, Gemcitabine), spindle poisons (Vinblastine, Vincristine, Vinorelbine, Paclitaxel, Docetaxel), podophyllotoxins (Etoposide, Irinotecan, Topotecan), antibiotics (Doxorubicin, Bleomycin, Mitomycin), nitrosoureas (Carmustine, Lomustine), inorganic ions (Cisplatin, Carboplatin), enzymes (Asparaginase), and hormones (Tamoxifen, Leuprolide, Flutamide, and Megestrol), to name a few. For a more comprehensive discussion of updated cancer therapies see,
10 <http://www.nci.nih.gov/>, a list of the FDA approved oncology drugs at <http://www.fda.gov/cder/cancer/druglistframe.htm>, and The Merck Manual, Seventeenth Ed. 1999, the entire contents of which are hereby incorporated by reference.

In still another aspect, the present invention also provides a pharmaceutical pack
15 or kit comprising one or more containers filled with one or more of the ingredients of the pharmaceutical compositions of the invention, and in certain embodiments, includes an additional approved therapeutic agent for use as a combination therapy. Optionally associated with such container(s) can be a notice in the form prescribed by a governmental agency regulating the manufacture, use or sale of pharmaceutical
20 products, which notice reflects approval by the agency of manufacture, use or sale for human administration.

EQUIVALENTS

The representative examples which follow are intended to help illustrate the
25 invention, and are not intended to, nor should they be construed to, limit the scope of the invention. Indeed, various modifications of the invention and many further embodiments thereof, in addition to those shown and described herein, will become apparent to those skilled in the art from the full contents of this document, including the examples which follow and the references to the scientific and patent literature cited
30 herein. It should further be appreciated that the contents of those cited references are incorporated herein by reference to help illustrate the state of the art. The following examples contain important additional information, exemplification and guidance

which can be adapted to the practice of this invention in its various embodiments and equivalents thereof.

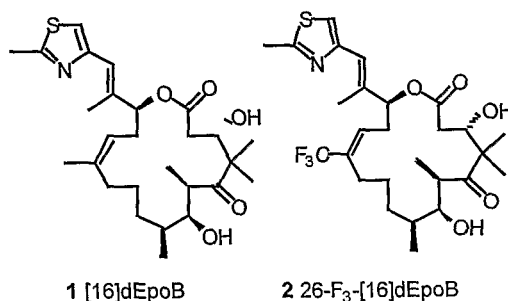
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EXEMPLIFICATION

Example 1: Synthesis of 9,10-dehydro-12,13-desoxy-epothilones

This Example describes the synthesis of *trans*-9,10-dehydro-12,13-desoxyepothilone B, 26-trifluoro-*trans*-9,10-dehydro-12,13-desoxyepothilone B, 26-trifluoro-12,13-desoxyepothilone B, and 12,13-desoxyepothilone B and biological testing of these compounds.

Fluorinated derivatives of epothilones were prepared and tested given the enhanced pharmacokinetics and chemotherapeutic indices of other medicinal agents with fluorine substitutions (Ojima, I.; Inoue, T.; Chakravarty, S.; *J. Fluorine Chem.* **1999**, 97; Newman, R. A.; Yang, J.; Finlay, M. R. V.; Cabral, F.; Vourloumis, D.; Stephens, L. C.; Troncoso, P.; Wu, X.; Logothetis, C. J.; Nicolaou, K. C.; Navone, N. M. *Cancer Chemother. Pharmacol.* **2001**, 48, 319-326; each of which is incorporated herein by reference).

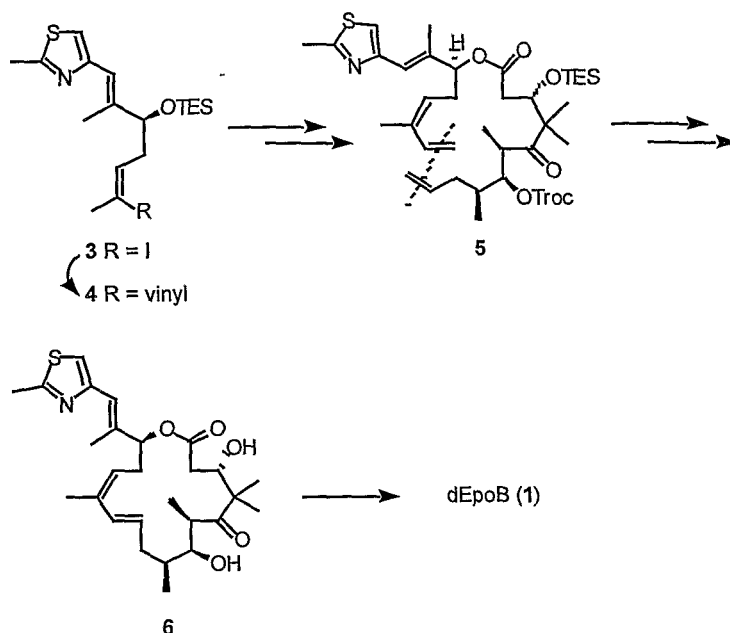


To reach compound **2**, we sought to take advantage of a highly convergent route recently reported from our laboratory for the synthesis of epothilone 490 (**6**, dehydrodeoxy Epo B) en route to dEpoB (**1**, Scheme 3) (Biswas, K.; Lin, H.; Njardarson, J. T.; Chappell, M.D.; Chou, T.C.; Guan, Y.; Tong, W. P.; He, L.; Horwitz, S.B.; Danishefsky, S.J. *J. Am. Chem. Soc.* **2002**, 124 (33); 9825-9832; Rivkin, A.; Njardarson, J. T.; Biswas, K.; Chou, T.C.; Danishefsky, S. J. *J. Org. Chem.* **2002**, 67, 7737-7740; each of which is incorporated herein by reference). In that synthesis, we introduced a flanking vinyl group to compound **4** via a stereospecific Stille coupling of a vinyl iodide precursor **3** with tri-*n*-butylvinylstannane. Ring closing metathesis

followed by deprotection led to **6**, which was then transformed to dEpoB (**1**) via a regioselective diimide reduction.

Scheme 3. Synthesis of Epothilone 490

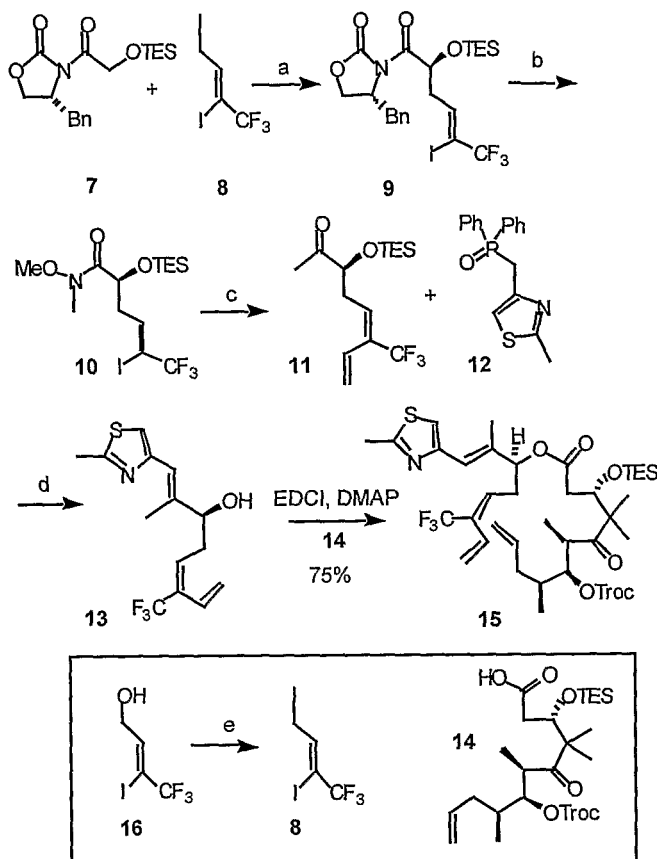
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Attention was first directed to the synthesis of **15** (Scheme 4). Alkylation of the previously reported lithium enolate of **7** (Chappell, M. D.; Stachel, S. J.; Lee, C. B.; Danishefsky, S. J. *Org. Lett.* **2000**, 2(11), 1633-1636; incorporated herein by reference) with iodide **8** (synthesized from the known alcohol **16** using TMSI in methylene chloride) afforded **9** in 78% yield and high diastereoselectivity (>25:1 de). Compound **9** was advanced in three steps to **10** as shown. Attempts to accomplish addition of methylmagnesium bromide to the Weinreb amide linkage of **10** failed. The breakdown of this reaction was attributed to the presence of the iodoalkene linkage. However we could accomplish our goal by changing the order of these two C-C bond forming steps. Thus, reaction of **10** with vinyltributyltin under Stille conditions could then be followed by addition of methyl Grignard reagent to give the desired ketone **11**. Condensation of ketone **11** with phosphine oxide **12**, followed by deprotection of the triethylsilyl ether, afforded fragment **13** in good yield. Esterification of the resulting **13** with C1-C10 acid fragment **14** (Biswas, K.; Lin, H.; Njardarson, J. T.; Chappell, M.D., Chou, T.C., Guan, Y.; Tong, W. P., He, L.; Horwitz, S.B., Danishefsky, S.J. *J. Am. Chem. Soc.* **2002**, 124 (33); 9825-9832; Rivkin, A.; Njardarson, J. T.; Biswas, K.; Chou, T.C.; Danishefsky, S.

J. *J. Org. Chem.* **2002**, 67, 7737-7740; incorporated herein by reference), provided the desired **15**, in 75% yield (Scheme 4).

Scheme 4. Synthesis of the RCM precursor **15**

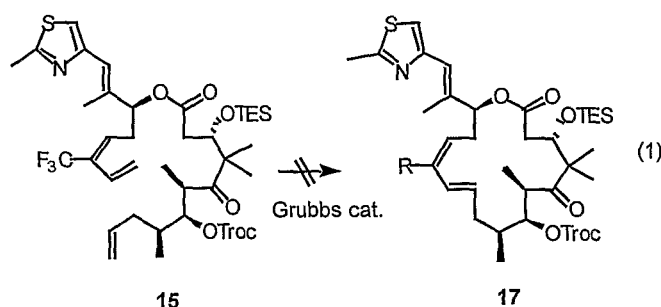


(a) LHMDS, -78°C , 78%; (b) i) HOAc:THF:H₂O (3:1:1); ii) CH₃ONHCH₃, AlMe₃; iii) TESCl, imidazole, DMF, 79% overall; (c) i) Vinyltributyltin, Pd(dba)₃, DMF, 80°C , 3h 43%; ii) MeMgBr, 0°C , 94%; (d) i) *n*-BuLi, THF, -78°C , 30 min., ii) **12**, -78°C to rt, 81%; iii) HOAc:THF:H₂O (3:1:1), 94%; (e) TMSI, CH₂Cl₂, 0°C , 92%

5

Unfortunately, attempts to carry out the ring-closing metathesis reaction of **15** using the second generation Grubbs catalyst (Reviews: Grubbs, R. H.; Miller, S. J.; Fu, G. C. *Acc. Chem. Res.* **1995**, 28, 446; Trnka, T. M.; Grubbs, R. H. *Acc. Chem. Res.* **2001**, 34, 18; *Alkene Metathesis in Organic Chemistry* Ed.: Fürstner, A.; Springer, Berlin, **1998**; Fürstner, A. *Angew. Chem. Int. Ed. Engl.* **2000**, 39, 3012; Schrock, R. R. *Top. Organomet. Chem.* **1998**, 1, 1; each of which is incorporated herein by reference) in methylene chloride led primarily to apparent dimerization of the starting material (Equation 1). Given the fact that the RCM works quite well in the related setting of **5** →

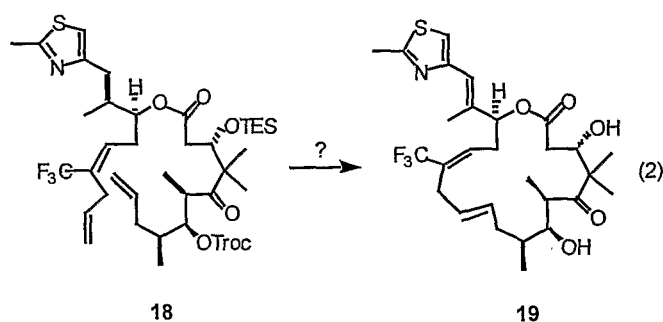
6, we naturally attributed the failure in the case of **15** to the presence of the trifluoromethyl group at C₁₂.



5

It was conjectured that the detrimental impact of the resident 26-trifluoro substituent on the desired reaction, might be alleviated by adding a carbon spacer between the RCM reaction center and the trifluoromethyl group. Accordingly, we undertook a synthesis of **19** (Equation 2) via the ring-closing metathesis of **18**, which would present the trifluoromethyl group in the context of a 17-membered ring containing a shipped (1,4)-diene.

10

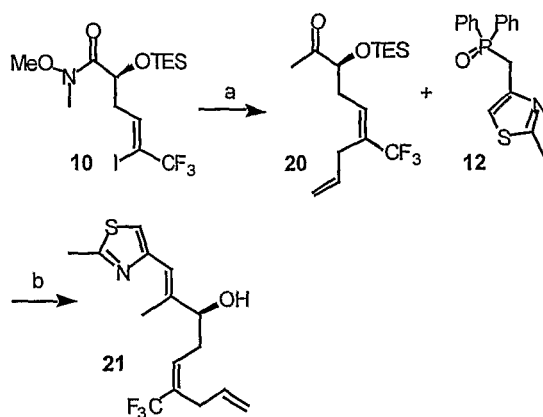


15

The synthesis program directed to **19** commenced with the preparation of compound **21**, which corresponds to the O-alkyl sector of our proposed RCM substrate (Scheme 5). We began with allylation of **10**, this time under radical reaction conditions as shown (Keck, G. E.; Yates, J. B. *J. Am. Chem. Soc.* **1982**, *104*, 5829; review: Curran, D. P. *Synthesis* **1988**, Part 1, pp 417-439; Part 2, pp. 489; each of which is incorporated herein by reference). This conversion was followed by reaction of the alkylated product with methyl magnesium bromide, thus affording the required ketone **20**. Condensation of this compound with phosphine oxide **12**, followed by deprotection of the triethylsilyl ether function provided **21** in good yield.

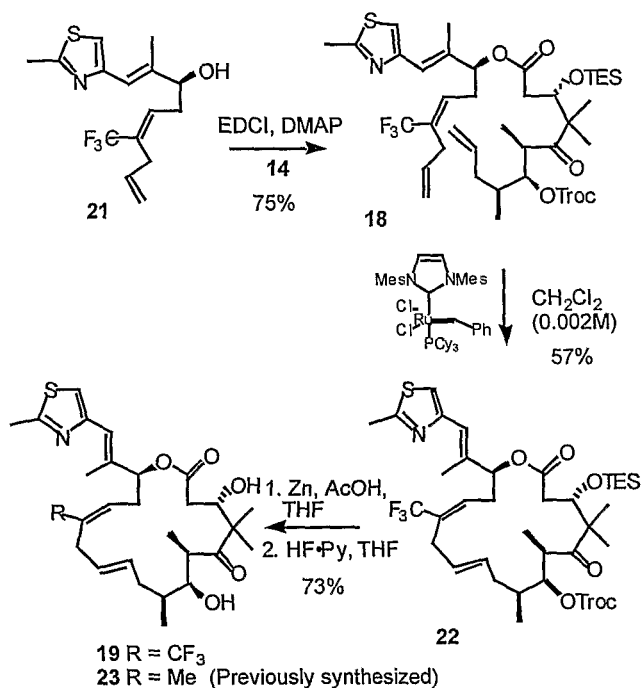
25

Scheme 5. Synthesis of the alcohol fragment 21



(a) i) Allyltributyltin, AIBN, Benzene, 80 °C, 3h 74%; ii) MeMgBr, 0 °C, 93%; (b) i) **12**, *n*-BuLi, THF, -78 °C, 30 min., ii) **20**, -78 °C to rt, 85%; iii) HOAc:THF:H₂O (3:1:1), 98%; (c) TMSI, CH₂Cl₂, 0 °C, 92%

Esterification of **21** with the C1-C10 acid fragment **14**, provided the proposed
 5 RCM precursor **18** in 75% yield (Scheme 6). Happily in this case, the ring-closing
 metathesis reaction of **18** could be accomplished using the second generation Grubbs
 catalyst in methylene chloride. As in the case of the conversion of **5**→**6**, the reaction
 provided exclusively the *trans* isomer **22** in 57% yield.⁶ Finally, reductive cleavage of
 the trichloro ethoxycarbonyl protecting group with zinc and acetic acid, followed by
 10 deprotection of the TES ether with HF-pyridine, provided the desired **19** containing a
 trifluoromethyl function at C₁₂, albeit in the context of the 17-membered ring series.

Scheme 6. Synthesis 27-F₃-ddEpoB (19)

Synthetic **19** was evaluated as to its cytotoxic activity. As shown in Table 1-1 below, direct comparison of the previously reported [17]ddEpoB (**23**) with 27-F₃-[17]ddEpoB (**19**) indicated that the new perfluorinated compound possessed a comparably high cytotoxic potency.

Table 1-1. *In vitro* Cytotoxicities (IC₅₀) with tumor cell lines^a

Compound	CCRF-CEM (IC ₅₀ (μM) ^a)	CCRF-CEM/ VBL (IC ₅₀ (μM) ^a)
27-F ₃ -[17]ddEpoB (19)	0.068	0.191
[17]ddEpoB (23)	0.040	0.126
[16]ddEpoB (6)	0.020	0.068

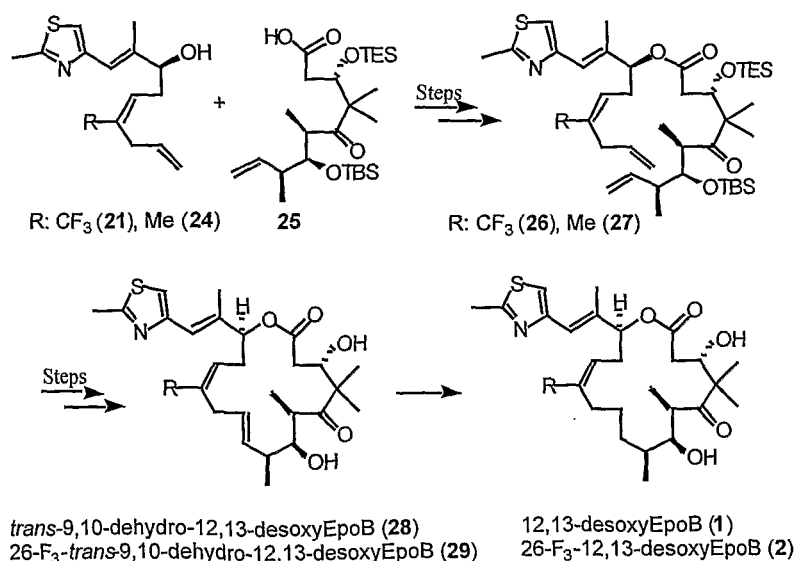
^aXTT assay following 72 h inhibition. CCRF-CEM is a human T-cell acute lymphoblastic leukemia cell line. The CCRF-CEM/VBL₁₀₀, CCRF-CEM/VM₁ and CCRF-CEM/Taxol cell lines all overexpress P-glycoprotein and display a multidrug resistance phenotype to MDR associated oncolytics (Ojima, I.; Inoue, T.; Chakravarty, S.; *J. Fluorine Chem.* **1999**, 97; Newman, R. A.; Yang, J.; Finlay, M. R. V.; Cabral, F., Vourloumis, D.; Stephens, L. C.; Troncoso, P.; Wu, X.; Logothetis, C. J.; Nicolaou, K.

C.; Navone, N. M. *Cancer Chemother. Pharmacol.* **2001**, *48*, 319-326; each of which is incorporated herein by reference).

Though the trifluoromethyl isosteric substitution had little effect on the gross cytotoxic activity, preliminary data from metabolic degradation studies in mouse plasma showed **19** to be notably more stable than is the parent **23**. Exposure of epothilones **19** and **23** to nude mouse and human plasma led to degradation of **23** within 30 minutes, while epothilone **19** remained mostly intact. Since pharmacokinetic issues are likely to be critical in the actual use of any epothilone agent as a drug, we take this finding to be quite encouraging.

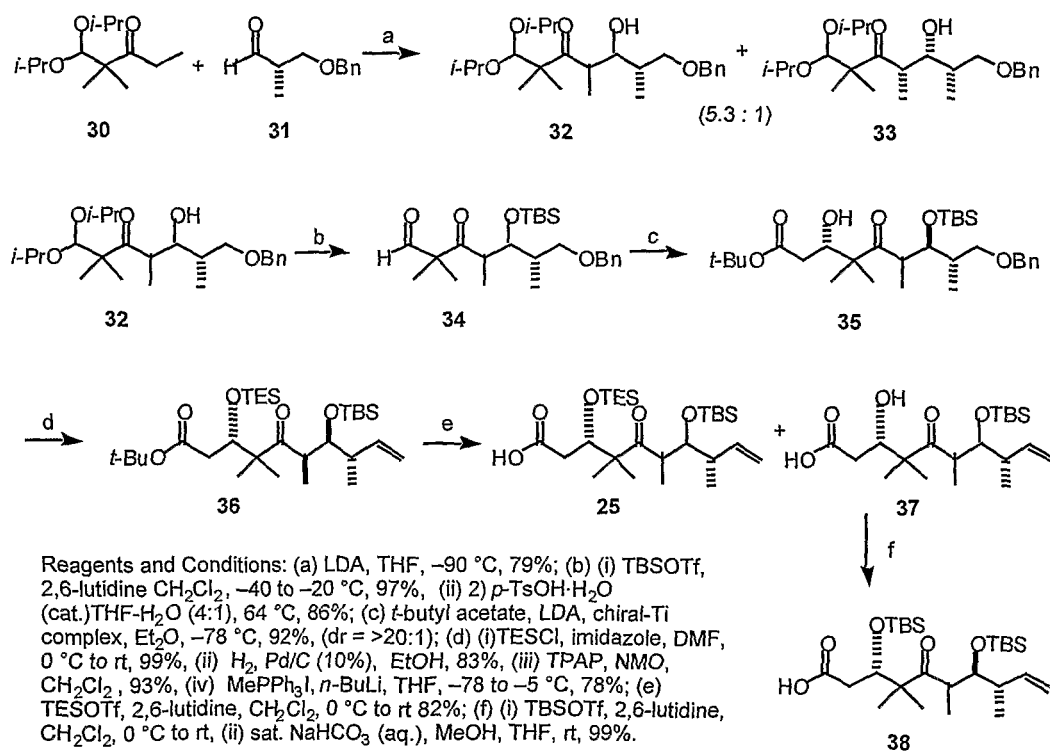
The synthesis of 26-F₃-dEpoB (**2**) could be accomplished via a highly convergent strategy, related to that employed in the synthesis of 27-F₃-[17]ddEpoB (**19**). Accordingly, fragments of similar complexity would serve as key building blocks (Scheme 7). We envisioned that the acyl sector **25**, could serve as the polypropionate domain and the alkyl sector **21** or **24** would be prepared as previously described in the introduction. The union of the two fragments **21**(**24**) and **25** would be initiated through an esterification and consummated via a subsequent ring-closing metathesis. Finally, cleavage of the protecting groups would provide the desired analogs **28** and **29**. Chemoselective reduction of the 9,10-olefin of **28** and **29** would furnish dEpoB (**1**) and the desired 26-F₃-12,13-desoxyEpoB (**2**).

Scheme 7



The synthesis of **1** and **2** commenced with the preparation of acyl sector **25**. Ketone **30**, previously reported, was subjected to an aldol reaction with the readily available aldehyde **31**. Upon deprotonation and reaction of “lithio” **30** with **31**, smooth condensation gave rise to a 5.3:1 mixture of aldol products **32** and **33**. The major diastereoisomer **32** was easily separated by flash chromatography and protected as a TBS silyl ether. Hydrolysis of the diisopropyl acetal group under acid catalysis gave keto aldehyde **34**, setting the stage for the second aldol reaction. Following the previously practiced “titano” tert-butyl ester method, with the new aldehyde **34** as the coupling partner, the desired aldol product **35** was obtained in high diastereoselectivity (dr > 20:1) and yield (86%). Protection of the C3 alcohol of **35** with a TES silyl group was followed by deprotection of the benzyl ether. Oxidation of the resultant primary hydroxy provided the corresponding aldehyde, which was then converted to a terminal olefin via a Wittig reaction to provide **36** in high yield. Finally, hydrolysis of the t-butyl ester of **36** with TESOTf provided the acyl sector **25** (82%) along with side-product **37** (14%), which was converted to acyl sector **38** in high yield. Spectral and chromatographic properties of **38** were identical to previously obtained material from other programs in Dr. Sinha’s laboratories (Scripps).

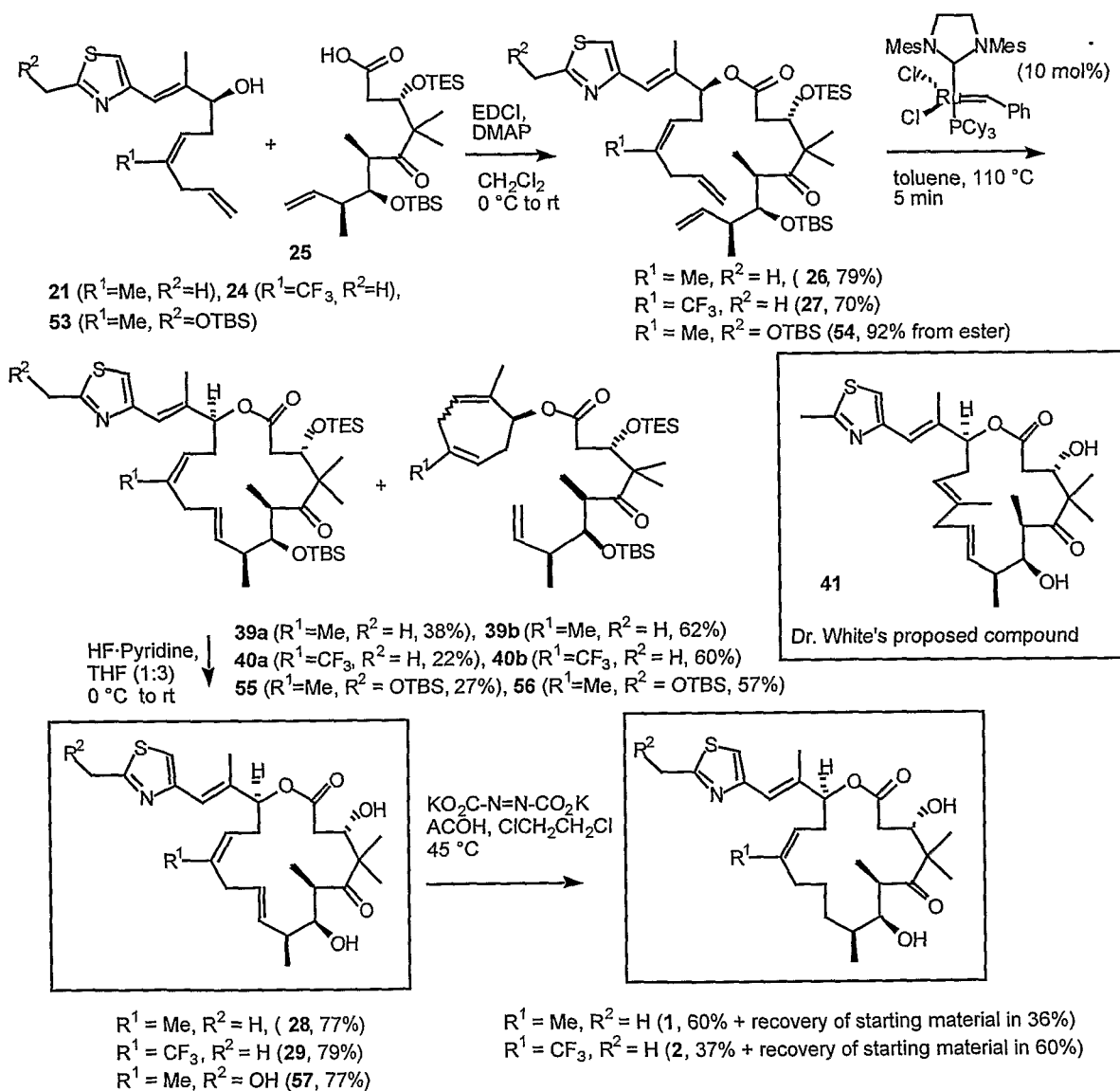
Scheme 8.



Esterification of the allylic alcohols **21** and **24** with C₁-C₉ acid fragment **25** provided the corresponding RCM cyclization precursors **26** and **27**, respectively (Scheme 9).

5

Scheme 9.



The ring-closing metathesis reactions **26**, **27** and **54** were then carried out using the second generation Grubbs catalyst in toluene, which provided, as in our earlier study, exclusively the *trans* isomer **39a**, **40a**, and **55** along with the corresponding side products **39b**, **40b**, and **56**. Finally, deprotection of silyl ethers with HF-pyridine led to the desired compounds **28**, **29**, and **57**. Spectral and chromatographic properties of **28** were not identical to previously obtained material from the epothilone program in Dr.

James D. White's laboratories (Oregon State University). Dr. James D. White thought he had synthesized **28**, however inadvertently he made the 12,13E isomer **41** instead, which would explain the poor biological activity he observed. Consequently, we are the first ones to have synthesized **28** and tested this compound for its antitumor activity.

The fully synthetic **28**, **29**, and **2** have been evaluated against a variety of cell types to determine their antitumor potential. As shown in Table 1-2, all three compounds exhibited high cytotoxic activity against a variety of sensitive and resistant tumor cell lines. Direct comparison of **28** with the previously reported dEpoB (**1**) indicates that the new compound possesses nearly three times more potency.

Table 1-2. *In vitro* Cytotoxicities (IC₅₀) with tumor cell lines^a.

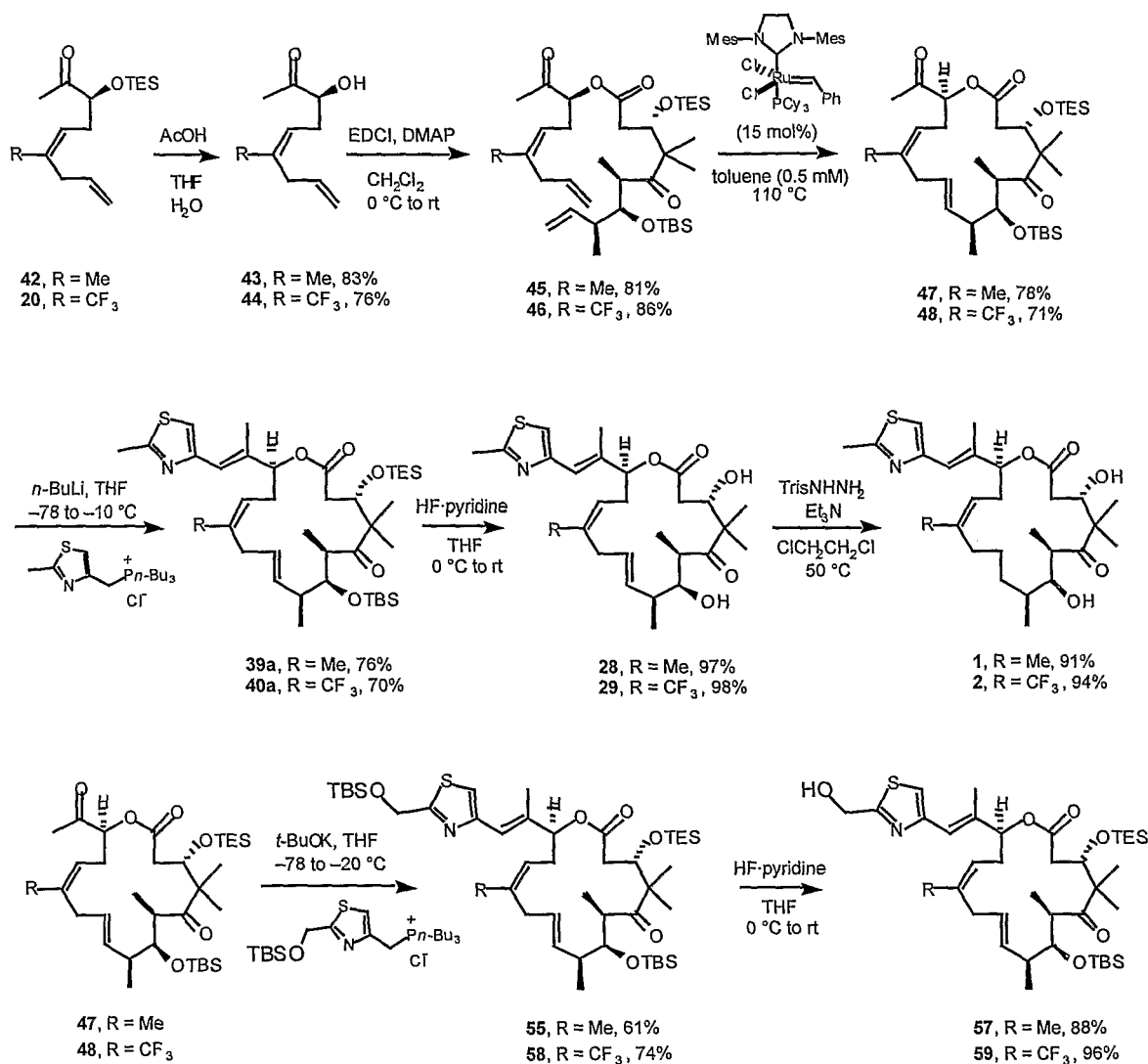
Tumor Cell Lines	IC ₅₀ (μM) ^a			
	28	29	dEpoB (1)	57
CCRF-CEM	0.0014	0.0035	0.0036	0.00051
CCRF-CEM/VBL ₁₀₀	0.0065	0.0210	0.014	0.0106
CCRF-CEM/Taxol	0.0017	0.0057	0.0057	0.00073

^aXTT assay following 72 h inhibition. CCRF-CEM is a human T-cell acute lymphoblastic leukemia cell line. The CCRF-CEM/VBL₁₀₀, CCRF-CEM/V_{M1} and CCRF-CEM/Taxol cell lines all overexpress P-glycoprotein and display a multidrug resistance phenotype to MDR associated oncolytics (Prié, G.; Thibonnet, J.; Abarbri, M.; Duchêne, A.; Parrain, J. *Synlett* **1998**, 839; incorporated herein by reference).

To improve the overall yield of our synthesis of **28**, **29**, and **2**, we decided to carry out the RCM reaction in the absence of the thiazole substituted olefin and in so doing avoid the formation of the undesired side product **39b** and **40b**. Deprotection of the silyl ether of the previously reported **42** and **20** provided hydroxyketones **43** and **44**. Esterification of the resultant hydroxyketones **43** and **44** with C₁-C₉ acid fragment **25** provided the corresponding RCM cyclization precursors **45** and **46**, respectively (Scheme 10). The ring-closing metathesis reaction of **45** and **46** was then carried out using the second generation Grubbs catalyst in toluene, which provided, as in our earlier study, exclusively the *trans* isomer **47** and **48** in high yields. Installation of the thiazole moiety gave **39a**, **40a**, and **55** in high yield. Deprotection of the two silyl ethers with HF-pyridine led to **28** and **29**. Finally, selective reduction of the C9-C10

olefin afforded the corresponding epothilones **1** and **2**. The structure of **28** was rigorously corroborated by its high yielding conversion to **1**. The total synthesis of **1** has been very substantially simplified relative to previously practiced routes. Thus the use of the readily available **31**, obtained from the chiral pool, is certainly a large improvement relative to reliance on (*S*)-2-methyl-4-pentenal whose synthesis requires intervening chiral auxiliaries.

Scheme 10



With compound **28** of rigorously proven structure in hand, we were surprised to find that its spectral properties were not congruent with those previously reported for a compound presumed to be the same entity. However it is clear in retrospect that **28** had not been previously prepared and, in fact the whole family of (*E*)-9,10-dehydroepothilones reported here is a new class of compounds.

Examination of synthetic analogs (**2**, **28**, and **29**), in cell culture settings, revealed stronger inhibitory effects on various sensitive and MDR tumor cell lines than are exhibited by our clinical entry dEpoB (**1**) (Table 1-3). We note that **Epo 3 (28)** is the first 12,13-desoxyepothilone compound that possessrd substantially improved cytotoxicity relative to that of dEpoB (**1**).

Table 1-3. *In vitro* Cytotoxicities (IC₅₀) with Tumor Cell Lines^a

Compound	CCRF-CEM(C) (μM)	C/VBL ₁₀₀ (μM)	C/Taxol (μM)
Epo 1 (1, dEpoB)	0.0036	0.016	0.0046
Epo 2 (2)	0.0041	0.080	0.018
Epo 3 (28)	0.0009	0.0042	0.0012
Epo 4 (29)	0.0035	0.0210	0.0057

^aXTT assay following 72 h inhibition. CCRF-CEM is a human T-cell acute lymphoblastic leukemia cell line. The CCRF-CEM/VBL₁₀₀ cell line is resistant to vinblastine and CCRF-CEM/Taxol to taxol.

The impressive cell growth inhibition exhibited by epothilones **2**, **28** and **29 (Epo 2-4)** across a range of various drug-resistant tumors prompted determination of the blood plasma stability of these new (*E*)-9,10 congeners. For instance the recently described (*E*)-10,11-dehydro-dEpoB (of case 1 with a CH₃ group at C-12) exhibits very poor plasma stability with respect to lactone opening. It is this plasma instability which has stifled advancement of (*E*)-10,11-dehydro-dEpoB. By contrast, on exposure of **2**, **28** and **29 (Epo 2-4)** to murine plasma, we observed a much slower drug degradation as compared to dEpoB (**1**) by a factor of seven. This stability constitutes a substantial advance from a drug availability perspective relative to dEpoB (see Figure 9).

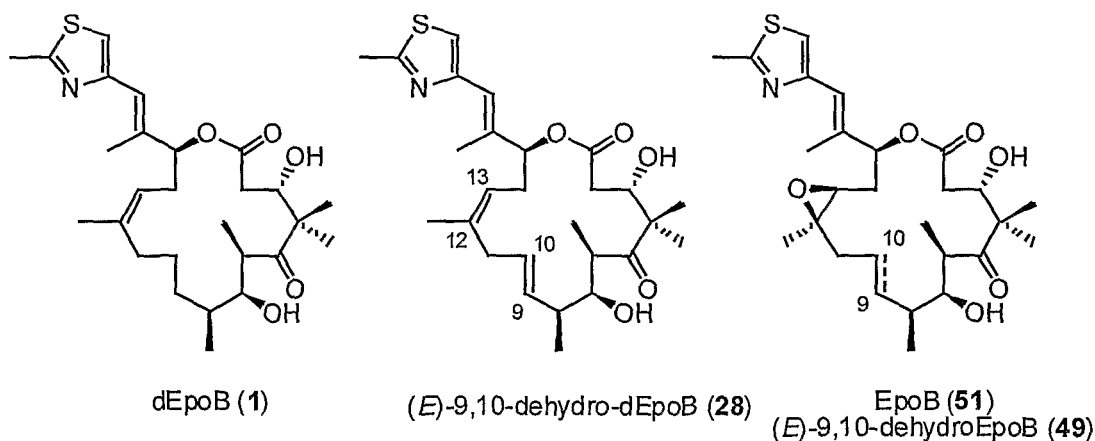
The combination of the cytotoxicity and plasma stability data encouraged us to synthesize substantial amounts of **28 (Epo 3)** in order to determine its *in vivo* efficacy, in nude mice bearing human tumor xenografts. Epothilone **28 (Epo 3)** demonstrated a markedly improved potency in inhibiting on the growth of implanted tumors, relative to dEpoB (see Figure 10). The improved potency and plasma stability allows very

substantial reduction of drug dosing (an order of magnitude) in the context of xenografts of **28** (**Epo 3**).

In our early studies we had found that epothilone B, by way of the 12,13 epoxide, is significantly more cytotoxic than is its 12,13-desoxy analog (dEpoB).

5 However, from the perspective of therapeutic index, the desoxy compound seemed to us to be more much promising. More recently, we reported the total synthesis of (*E*)-9,10-dehydro-12,13-desoxyepothilone B (**28**) using a stereoselective ring closing metathesis. We showed that the incorporation of *E*-9,10 unsaturation in the context of the usual *Z*-12,13 olefin (see compound **1**) results in a great increase in in vitro potency. More to
10 the point, this is translatable to an in vivo setting in xenografts mice. Moreover, compound **28** enjoys major pharmaceutical advantages relative to dEpoB (**1**). This allowed for the reduction of the dosing levels for **28** relative to **1** in xenograft experiments to be reduced by an order of magnitude.

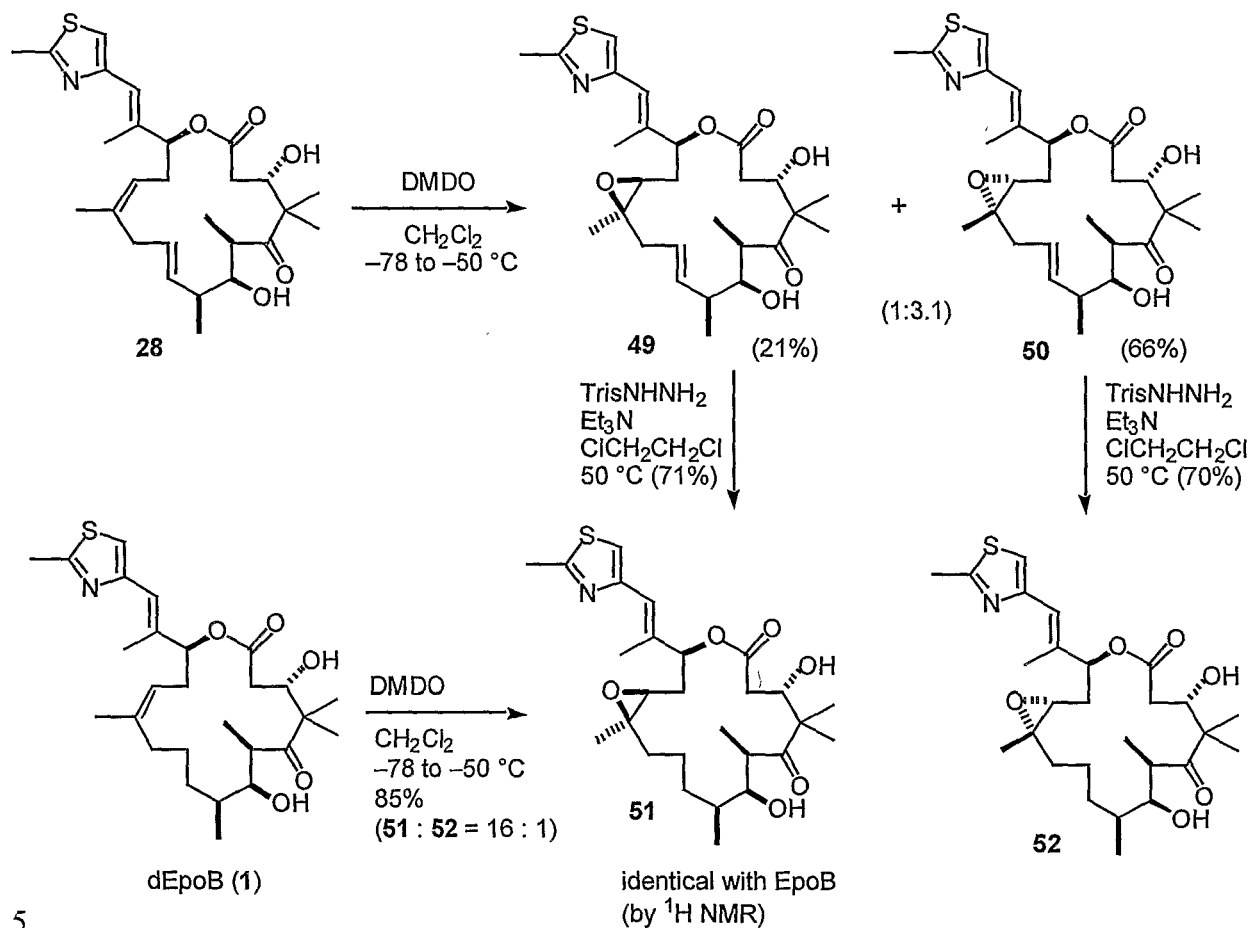
Accordingly, we wondered if the incorporation of C9-C10 olefin in epothilone
15 B (**51**, EpoB) would alter its biological profile in the same direction.



Epoxidation of **28** with 2,2'-dimethyldioxirane (DMDO) proceeded with high
20 chemoselectivity at the more substituted C12-C13 olefin to give an 87% yield of a 1:2.6 ratio of the (*E*)-9,10-dehydroepothilone B (**49**) and its diastereomer (**50**). The stereochemistry of the epoxides was determined by selective diimide reduction of the C9-C10 double bonds. Examination of the spectral properties of these products revealed the minor product (**49**) to be dEpoB. The preference for α -epoxidation in the
25 case of **28** stands in striking contrast to the highly stereoselective epoxidation of dEpoB, which occurs from the β face leading to EpoB (Meng, D.; Bertinato, P.; Balog,

A.; Su, D.-S.; Kamenecka, T.; Sorensen, E. J.; Danishefsky, S. J. *J. Am. Chem. Soc.* **1997**, *119*, 10073; incorporated herein by reference).

Scheme 11



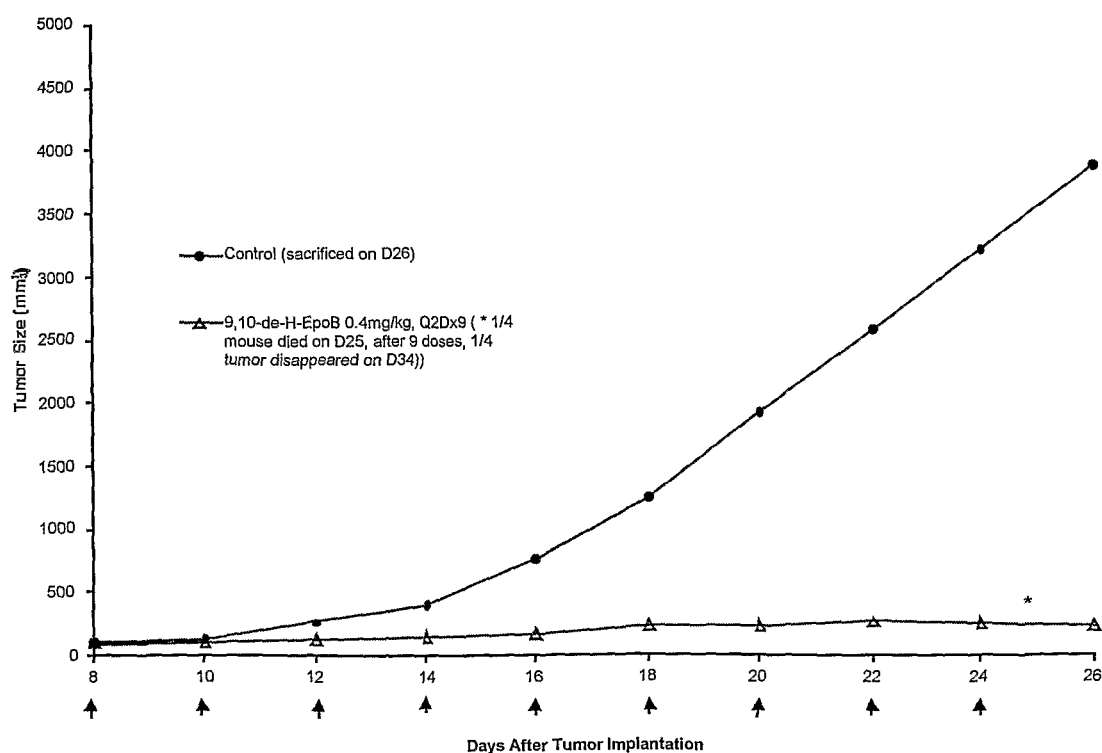
(*E*)-9,10-dehydroepothilone B (**51**) was evaluated against a variety of cell types to determine their antitumor potential. As shown in Table 1-4, (*E*)-9,10-dehydroepothiloneB (**49**) exhibits high cytotoxic activity against a variety of sensitive and resistant tumor cell lines. Direct comparison of **49** and EpoB (**51**) indicates this new analog possesses nearly 3-fold more potency than EpoB (**51**) making it one of the most potent epothilone analogs reported to date. Interestingly, α -epoxide series (**50**, **52**) displayed a much lower activity than EpoB (**51**). The graph below shows the findings for *in vivo* studies of compound **49**.

Table 1-4. In vitro cytotoxicities (IC₅₀) with tumor cell lines^a

	compound	CCRF-CEM	CCRF-CEM/VBL	CCRF-CEM/Taxol
5	1 (dEpoB)	0.0036	0.016	0.0046
	28	0.0009	0.0042	0.0012
	51 (EpoB)	0.00062	0.0037	0.0011
	49	0.00023	0.00032	0.00042
	50	0.0134	0.0959	0.0802
10	52	0.083	0.4519	0.1507

^aXTT assay following 72 h inhibition. CCRF-CEM is a human T-cell acute lymphoblastic leukemia cell line. The CCRF-CEM/VBL and CCRF-CEM/Taxol cell lines all overexpress P-glycoprotein and display a multidrug resistance phenotype to MDR-associated oncolytics.

Therapeutic effect of 9,10-de-H-EpoB in nude mice bearing MX-1 xenograft (6hr-iv infusion, n=4)



In summary, delineated above is a powerful stereoselective total synthesis of **28** (**Epo 3**) and, following site-selective diimide reduction, dEpoB (**1**) itself. The described herein strategy was then straightforwardly applied to the preparation of the corresponding trifluoro analogs **2** and **29** (**Epo 4**). Furthermore, epoxidation of **28** provided **49** and **50**, which upon site-selective diimide reduction gave Epothilone B (**51**) and **52**. The data reported above point to the emergence of a most promising new family of anticancer drugs appropriate for further evaluation en route to then possible advancement to a human clinical setting. Furthermore the new synthesis strategy comprises a significant practical improvement in the total synthesis of dEpoB and Epothilone B.

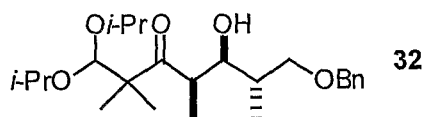
Experimentals

General Methods: Reagents obtained from commercial suppliers were used without further purification unless otherwise noted. The following solvents were obtained from a dry solvent system (passed through a prepacked column of alumina) and used without further drying: tetrahydrofuran, methylene chloride, diethyl ether, benzene, and toluene. All air and water sensitive reactions were performed in flame-dried glassware under a positive pressure of prepurified argon gas. NMR (^1H and ^{13}C) spectra were recorded on Bruker AMX-400 MHz or Bruker Advance DRX-500 MHz as noted individually, referenced to CDCl_3 (7.27 ppm for ^1H and 77.0 ppm for ^{13}C). Infrared spectra (IR) were obtained on a Perkin-Elmer FT-IR model 1600 spectrometer. Optical rotations were obtained on a JASCO model DIP-370 digital polarimeter at 22 ± 2 °C. Analytical thin-layer chromatography was performed on E. Merck silica gel 60 F254 plates. Compounds which were not UV active were visualized by dipping the plates in a ceric ammonium molybdate or *para*-anisaldehyde solution and heating. Silica gel chromatography was performed using the indicated solvent on Davisil[®] (grade 1740, type 60A, 170-400 mesh) silica gel.

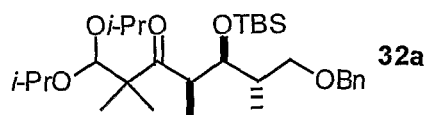
Acronyms and Abbreviations

TES, triethylsilyl; TBS, Dimethyltertbutylsilyl; EDCI, 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide; HF-PY, hydrogen fluoride in pyridine; DMAP, 4-

N,N-dimethylaminopyridine; DCM, dichloromethane; DMF, *N,N*-dimethylformamide; THF, tetrahydrofuran.

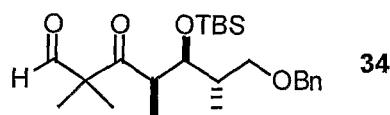


- 5 **Compound 32:** To a solution of freshly prepared LDA (11.6 mmol) in THF (25 mmol) was added dropwise a solution of ketone **30** (2.40 g, 10.4 mmol) in THF (6.8 mL) at –78 °C. After stirring at –40 °C for 0.5 h, the mixture was cooled to –90 °C. A solution of aldehyde **31** (1.38 g, 7.72 mmol) in THF (6.8 mL) was added dropwise. After stirring at –90 °C for 35 min, the reaction was quenched with sat. aq. NH₄Cl (15 mL)
- 10 and extracted with EtOAc (50 mL x 3). The combined organic extracts were dried over Na₂SO₄ and concentrated. Purification by flash column chromatography (SiO₂, hexane/EtOAc = 15:1 to 12:1) gave **32** (2.09 g, 66%) and isomer **33** (0.39 g, 12%) both as yellow oils. **32**: [α]_D²⁵ 13.1 (c 1.22, CHCl₃); IR (film) ν 3494, 2972, 2932, 1708, 1454, 1380, 1329, 1120, 1038, 998, 734 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 0.98 (3H, d, *J* = 6.9 Hz), 1.06 (3H, d, *J* = 6.9 Hz), 1.10 (3H, d, *J* = 6.1 Hz), 1.14 (3H, d, *J* = 6.9 Hz), 1.15 (3H, s), 1.17 (3H, d, *J* = 6.2 Hz), 1.18 (3H, s), 1.20 (3H, d, *J* = 6.2 Hz), 1.81-1.92 (1H, m), 3.33 (1H, qd, *J* = 7.0, 2.2 Hz), 3.51 (1H, dd, *J* = 8.9, 6.3 Hz), 3.64 (1H, d, *J* = 1.8 Hz), 3.66-3.71 (2H, m), 3.78-3.86 (2H, m), 4.51 (1H, d, *J* = 12.0 Hz), 4.54 (1H, d, *J* = 12.0 Hz), 4.58 (1H, s), 7.25-7.35 (5H, m); ¹³C NMR (100 MHz, CDCl₃) δ
- 15 10.0, 14.3, 20.5, 21.3, 21.9, 22.5, 23.5, 23.6, 36.4, 42.1, 54.1, 69.8, 71.2, 72.8, 73.3, 73.4, 103.8, 127.6, 127.7 (2C), 128.5 (2C), 138.9, 221.6; LRMS (ESI) calcd for C₂₄H₄₀O₅Na [M+Na⁺] 431.3, found 431.4.
- 20

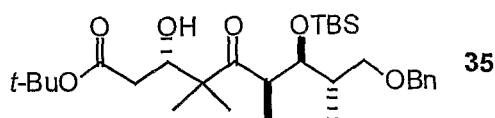


- 25 **Compound 32a (not shown):** To a cooled (–40 °C) solution of alcohol **32** (1.01 g, 2.47 mmol) and 2,6-lutidine (691 μ L, 5.93 mmol) was added TBSOTf (681 μ L, 3.00 mmol), and the mixture was warmed to –20 °C over 3.5 h. The reaction was quenched with sat. aq. NaHCO₃ (10 mL). After extraction with hexane (50 mL x 3), the combined organic extracts were dried over Na₂SO₄ and concentrated. Purification by flash column

chromatography (SiO₂, hexane/EtOAc = 50:1) gave **32a** (1.25 g, 2.39 mmol, 97%) as a colorless oil; $[\alpha]_D^{25}$ -19.7 (c 0.58, CHCl₃); IR (film) ν 2966, 2931, 1696, 1455, 1378, 1320, 1255, 1091, 1044, 991, 873, 838, 773 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 0.08 (6H, s), 0.89 (9H, s), 0.99 (3H, d, J = 7.0 Hz), 1.04 (3H, d, J = 7.0 Hz), 1.07 (3H, d, J = 7.0 Hz), 1.07 (3H, s), 1.14 (3H, d, J = 6.1 Hz), 1.17 (3H, s), 1.17 (3H, d, J = 6.0 Hz), 1.20 (3H, d, J = 6.2 Hz), 1.76-1.85 (1H, m), 3.21 (1H, dd, J = 9.2, 7.3 Hz), 3.32 (1H, quint, J = 7.4 Hz), 3.62 (1H, dd, J = 9.2, 5.7 Hz), 3.78-3.85 (2H, m), 3.87 (1H, dd, J = 7.7, 2.0 Hz), 4.46 (1H, d, J = 12.1 Hz), 4.50 (1H, d, J = 12.1 Hz), 4.73 (1H, s), 7.24-7.37 (5H, m); ¹³C NMR (100 MHz, CDCl₃) δ -3.6, -3.3, 15.6, 16.8, 18.7, 18.8, 21.8, 22.1, 22.5, 23.5, 23.7, 26.4 (3C), 39.0, 46.2, 54.0, 69.7, 70.9, 72.1, 73.4, 76.7, 103.1, 127.6, 127.8 (2C), 128.5 (2C), 139.0, 218.9; LRMS (ESI) calcd for C₃₀H₅₄O₅SiNa [M+Na⁺] 545.4, found 545.4.

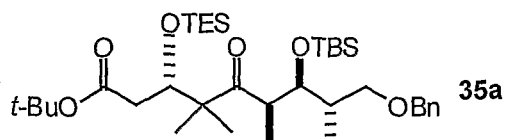


Compound 34: The mixture of **32a** (3.03 g, 5.79 mmol) and *p*-TsOH·H₂O (286 mg) in aqueous THF (64 mL, THF/H₂O = 4:1) was heated under reflux for 6.5 h. The reaction mixture was cooled to rt and poured into sat. aq. NaHCO₃ (25 mL). After extraction with EtOAc (100 mL + 50 mL x 2), the combined organic layers were washed with brine, dried over Na₂SO₄ and concentrated. Purification by flash column chromatography (SiO₂, hexane/EtOAc = 50:1 to 30:1) gave **34** (2.37 g, 5.64 mmol, 98%) as a colorless oil; $[\alpha]_D^{25}$ -25.8 (c 0.515, CHCl₃); IR (film) ν 2955, 2931, 1731, 1696, 1455, 1360, 1255, 1091, 1026, 873, 826, 767 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 0.06 (3H, s), 0.07 (3H, s), 0.90 (9H, s), 0.95 (3H, d, J = 7.1 Hz), 1.03 (3H, d, J = 7.0 Hz), 1.28 (3H, s), 1.33 (3H, s), 1.73-1.82 (1H, m), 3.16 (1H, dd, J = 9.2, 6.1 Hz), 3.28 (1H, quint, J = 7.3 Hz), 3.55 (1H, dd, J = 9.2, 6.7 Hz), 3.91 (1H, dd, J = 7.8, 2.1 Hz), 4.46 (2H, s), 7.27-7.36 (5H, m), 9.58 (1H, s); ¹³C NMR (100 MHz, CDCl₃) δ -3.6, -3.5, 15.7, 16.3, 18.6, 19.8, 20.1, 26.3 (3C), 39.1, 47.0, 61.1, 71.9, 73.4, 75.8, 127.7, 128.0 (2C), 128.5 (2C), 138.6, 201.3, 213.3; LRMS (ESI) calcd for C₂₄H₄₀O₄SiNa [M+Na⁺] 443.3, found 443.2.



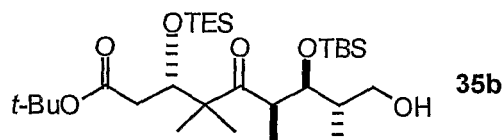
Compound 35: To a solution of freshly prepared LDA (18 mL of a 0.5 M solution in Et₂O, 9.0 mmol) in Et₂O (20 mL) was added *t*-butyl acetate (1.16 mL, 8.61 mmol) at –78 °C. After stirring for 50 min, CpTiCl(OR)₂ (100 mL of a 0.1 M solution in Et₂O, 10.0 mmol) was added dropwise over 65 min via syringe pump. After stirring for 20 min, the reaction mixture was warmed to –30 °C, stirred for 50 min, and re-cooled to –78 °C. A solution of **34** (2.42 g, 5.75 mmol) in Et₂O (9 mL) was added dropwise over 10 min, and the resulting mixture was stirred at –78 °C. After stirring for 2 h, the reaction was quenched with aqueous THF (5 M H₂O, 37 mL) and stirred at rt for 2 h.

After addition of water (40 mL), the mixture was stirred for further 1 h. The precipitate formed was filtered off by Celite (Et₂O rinse), and the filtrate was washed with water (40 mL). The aqueous layer was extracted with Et₂O (100 mL x 2) and the combined organic layers were washed with brine (40 mL), dried over Na₂SO₄ and concentrated. Purification by flash column chromatography (SiO₂, hexane/EtOAc = 10:1) gave **35** (2.65 g, 4.94 mmol, 86%) as a pale yellow oil; [α]_D²⁵ –20.3 (c 1.0, CHCl₃); IR (film) ν 3523, 2957, 2930, 2856, 1732, 1700, 1472, 1368, 1252, 1152, 1091, 1042, 986, 834, 774 cm^{–1}; ¹H NMR (400 MHz, CDCl₃) δ 0.07 (3H, s), 0.07 (3H, s), 0.90 (9H, s), 0.99 (3H, d, *J* = 7.0 Hz), 1.07 (3H, d, *J* = 7.0 Hz), 1.10 (3H, s), 1.14 (3H, s), 1.47 (9H, s), 1.77–1.83 (1H, m), 2.26 (1H, dd, *J* = 16.0, 10.0 Hz), 2.34 (1H, dd, *J* = 15.9, 2.7 Hz), 3.23 (1H, dd, *J* = 9.2, 7.1 Hz), 3.35 (1H, d, *J* = 2.7 Hz, –OH), 3.36 (1H, quint, *J* = 7.0 Hz), 3.61 (1H, dd, *J* = 9.2, 5.9 Hz), 3.88 (1H, dd, *J* = 7.6, 2.0 Hz), 4.17 (1H, dt, *J* = 10.0, 2.7 Hz), 4.48 (2H, s), 7.27–7.36 (5H, m); ¹³C NMR (100 MHz, CDCl₃) δ –3.5, –3.4, 16.3, 16.7, 18.7, 20.1, 21.6, 26.4 (3C), 28.3 (3C), 38.0, 39.1, 45.8, 51.8, 72.2, 72.9, 73.5, 76.7, 81.4, 127.7, 128.0 (2C), 128.5 (2C), 138.8, 172.7, 219.6; LRMS (ESI) calcd for C₃₀H₅₂O₆SiNa [M+Na⁺] 559.3, found 559.4.



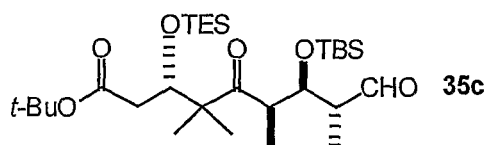
Compound 35a (Not Shown): To a mixture of alcohol **35** (10.2 g, 18.9 mmol) and imidazole (2.70 g, 39.7 mmol) in DMF (25 mL) was added TESCl (3.3 mL, 19.8 mmol) at 0 °C, and the mixture was stirred at rt for 2 h. The reaction was quenched

with sat. aq. NaHCO₃ (50 mL). After extraction with hexane (500 mL + 120 mL x 2), the combined organic extracts were washed successively water (30 mL x 2) and brine (30 mL), dried over Na₂SO₄ and concentrated. Purification by flash column chromatography (SiO₂, hexane/EtOAc = 40:1) gave **35a** (12.1 g, 18.5 mmol, 98%) as a colorless oil; $[\alpha]_D^{25}$ -38.0 (c 0.46, CHCl₃); IR (film) ν 2955, 2877, 1733, 1697, 1456, 1367, 1298, 1251, 1155, 1099, 988, 835, 742 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 0.05 (6H, s), 0.57-0.68 (6H, m), 0.89 (9H, s), 0.95 (9H, t, *J* = 7.9 Hz), 0.99 (3H, d, *J* = 7.0 Hz), 1.02 (3H, d, *J* = 6.8 Hz), 1.04 (3H, s), 1.18 (3H, s), 1.45 (9H, s), 1.70-1.79 (1H, m), 2.16 (1H, dd, *J* = 17.0, 7.0 Hz), 2.40 (1H, dd, *J* = 17.0, 3.1 Hz), 3.22 (1H, dd, *J* = 9.1, 7.5 Hz), 3.31 (1H, quint, *J* = 6.9 Hz), 3.61 (1H, dd, *J* = 9.1, 5.4 Hz), 3.83 (1H, dd, *J* = 7.3, 2.3 Hz), 4.30 (1H, dd, *J* = 6.9, 3.1 Hz), 4.48 (2H, s), 7.27-7.36 (5H, m); ¹³C NMR (100 MHz, CDCl₃) δ -3.5, -3.4, 5.3 (3C), 7.3 (3C), 15.3, 16.9, 18.7, 20.1, 23.4, 26.4 (3C), 28.3 (3C), 39.1, 41.1, 46.2, 53.4, 72.2, 73.4, 74.3, 76.7, 80.6, 127.6, 127.9 (2C), 128.5 (2C), 138.9, 171.5, 218.4; LRMS (ESI) calcd for C₃₆H₆₆O₆Si₂Na [M+Na⁺] 673.4, found 673.5.

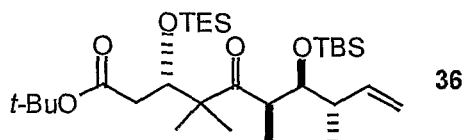


Compound 35b (Not Shown): To a stirred solution of **35a** (4.37 g, 6.72 mmol) in THF (67 mL) was added Pd/C (purchased from Acros, 10%wt, 437 mg) and the mixture was stirred under an atmosphere of H₂. After stirring for 2.2 h, the mixture was filtered through a pad of Celite, which was rinsed with THF (120 mL). The filtrate was concentrated and purified by flash column chromatography (SiO₂, hexane/EtOAc = 30:1 to 10:1) to give **35b** (3.53 g, 6.28 mmol, 94%) as a colorless oil; $[\alpha]_D^{25}$ -16.1 (c 0.62, CHCl₃); IR (film) ν 3543, 2956, 1732, 1696, 1472, 1368, 1299, 1252, 1155, 1100, 988, 837, 775, 742 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 0.10 (3H, s), 0.12 (3H, s), 0.60-0.68 (6H, m), 0.93 (9H, s), 0.96 (9H, t, *J* = 8.0 Hz), 0.99 (3H, d, *J* = 7.1 Hz), 1.10 (3H, d, *J* = 6.9 Hz), 1.14 (3H, s), 1.20 (3H, s), 1.45 (9H, s), 1.46-1.55 (1H, m), 2.21 (1H, dd, *J* = 17.2, 7.1 Hz), 2.39 (1H, dd, *J* = 17.2, 2.8 Hz), 2.54 (1H, t, *J* = 5.8 Hz, -OH), 3.30 (1H, quint, *J* = 6.9 Hz), 3.58 (1H, dt, *J* = 11.5, 5.5 Hz), 3.66 (1H, dt, *J* = 11.3, 5.4 Hz), 3.92 (1H, dd, *J* = 8.0, 2.1 Hz), 4.32 (1H, dd, *J* = 7.1, 2.9 Hz); ¹³C NMR (100 MHz, CDCl₃) δ -3.6, -3.5, 5.3 (3C), 7.2 (3C), 16.0, 16.1, 18.6, 20.0, 23.4, 26.4 (3C), 28.3

(3C), 40.0, 40.9, 46.9, 53.7, 64.8, 73.3, 78.1, 80.9, 171.7, 218.5; LRMS (ESI) calcd for $C_{29}H_{60}O_6Si_2Na$ $[M+Na^+]$ 583.4, found 583.5.

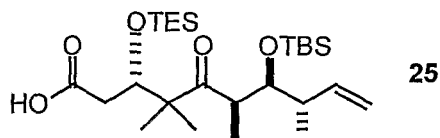


- 5 **Compound 35c (Not shown):** To a stirred mixture of alcohol **35b** (3.53 g, 6.28 mmol) and powdered MS4A (freshly activated, 2.50 g) in CH_2Cl_2 (32 mL) were added NMO (1.17 g, 10.0 mmol) followed by TPAP (132 mg, 0.377 mmol). After stirring at rt for 35 min, the mixture was filtered through a silica gel column (hexane/ Et_2O = 8:1) to give **35c** (3.34 g, 5.98 mmol, 95%) as a colorless oil; $[\alpha]_D^{25}$ -69.6 (c 0.25, $CHCl_3$); IR (film) ν 2955, 2878, 1732, 1696, 1472, 1368, 1253, 1155, 1097, 989, 837 cm^{-1} ; 1H NMR (400 MHz, $CDCl_3$) δ 0.09 (3H, s), 0.10 (3H, s), 0.59-0.68 (6H, m), 0.89 (9H, s), 0.95 (9H, t, J = 8.0 Hz), 1.08 (3H, s), 1.11 (3H, d, J = 6.9 Hz), 1.14 (3H, d, J = 7.1 Hz), 1.24 (3H, s), 1.45 (9H, s), 2.19 (1H, dd, J = 17.0, 6.7 Hz), 2.33 (1H, qt, J = 7.1, 2.2 Hz), 2.41 (1H, dd, J = 17.0, 3.3 Hz), 3.28 (1H, quint, J = 7.5 Hz), 4.07 (1H, dd, J = 7.9, 2.2 Hz), 4.32 (1H, dd, J = 6.7, 3.2 Hz), 9.74 (1H, d, J = 2.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ -3.8 , -3.5 , 5.3 (3C), 7.2 (3C), 12.6, 15.6, 18.5, 20.5, 23.3, 26.2 (3C), 28.3 (3C), 41.1, 46.9, 51.1, 53.5, 74.0, 76.5, 80.7, 171.1, 204.3, 218.0; LRMS (ESI) calcd for $C_{29}H_{58}O_6Si_2Na$ $[M+Na^+]$ 581.3, found 581.3.



- 20 **Compound 36:** $MePPh_3I$ (2.56 g, 7.18 mmol) in THF (40.0 mL) was treated with *t*-BuOK (6.57 mL of a 1.0 M solution in THF, 6.57 mmol) at 0 °C. After stirring at 0 °C for 20 min, the resulting suspension was cooled to -78 °C and a solution of aldehyde **35c** (3.34 g, 5.98 mmol) in THF (14 mL) was added. After stirring at -78 °C for 15 min, the mixture was stirred at 0 °C for 15 min and at rt for 15 min. The reaction was quenched with sat. aq. NH_4Cl (20 mL) and extracted with Et_2O (120 mL + 50 mL x 2). The combined organic extracts were washed with brine (20 mL), dried over Na_2SO_4 , and concentrated. The residue was purified by flash column chromatography (SiO_2 ~80 g, hexane/ Et_2O = 40:1) to give **36** (125.3 mg, 0.225 mmol, 78%) as a colorless oil;

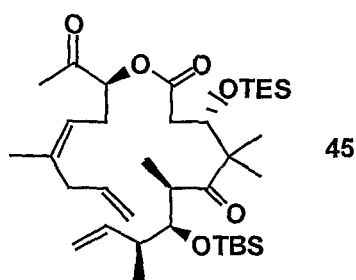
$[\alpha]_D^{25} -33.6$ (c 0.250, CHCl_3); IR (film) ν 2956, 2878, 1733, 1696, 1472, 1367, 1299, 1253, 1156, 1100, 988, 837, 774 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.08 (3H, s), 0.08 (3H, s), 0.60-0.68 (6H, m), 0.93 (9H, s), 0.96 (9H, t, $J = 8.0$ Hz), 1.04 (6H, d, $J = 7.0$ Hz), 1.09 (3H, s), 1.20 (3H, s), 1.45 (9H, s), 2.08-2.15 (1H, m), 2.29 (1H, dd, $J = 17.0$, 7.0 Hz), 2.41 (1H, dd, $J = 17.0$, 3.1 Hz), 3.08 (1H, quint, $J = 7.0$ Hz), 3.84 (1H, dd, $J = 7.0$, 2.1 Hz), 4.32 (1H, dd, $J = 7.0$, 3.1 Hz), 5.02 (1H, dd, $J = 17.9$, 1.0 Hz), 5.06 (1H, dd, $J = 10.5$, 1.0 Hz), 5.93 (1H, ddd, $J = 17.9$, 10.5, 7.7 Hz); ^{13}C NMR (100 MHz, CDCl_3) δ -3.6, -3.3, 5.4 (3C), 7.2 (3C), 15.2, 18.7, 19.0, 20.2, 23.6, 26.4 (3C), 28.3 (3C), 41.1, 43.8, 46.4, 53.5, 73.9, 76.6, 80.6, 115.5, 140.2, 171.5, 218.5; LRMS (ESI) calcd for $\text{C}_{30}\text{H}_{60}\text{O}_5\text{Si}_2\text{Na}$ $[\text{M}+\text{Na}^+]$ 579.4, found 579.4.



Compound 25: To a solution of *t*-butyl ester **36** (4.87 g, 8.74 mmol) and 2,6-lutidine (freshly distilled, 4.1 mL, 35.0 mmol) in CH_2Cl_2 (58 mL) was added TESOTf (4.0 mL, 17.5 mmol) at 0 °C. After stirring at 0 °C for 25 min, the mixture was stirred at rt for 3.2 h. The mixture was diluted with Et_2O (600 mL), washed with successively 5% aqueous KHSO_4 (60 mL x 2) and brine (60 mL), dried over Na_2SO_4 , and concentrated. The residue was dried under high vacuum for 1.5 h to give crude acid **25** (6.30 g, contaminated with TESOH). The crude product (6.30 g) was dissolved in aqueous THF (87.5 mL, THF/ H_2O = 6:1) and treated with sat. aq. NaHCO_3 (12.5 mL). After stirring at rt for 20 min, the resulting suspension was diluted with Et_2O (500 mL) and acidified with aqueous 5% KHSO_4 (55 mL). After the layers were separated, the aqueous layer was extracted with Et_2O (100 mL x 2) and the combined organic layers were washed with brine (50 mL x 2), dried over Na_2SO_4 and concentrated. The residue was dried under high vacuum overnight to give crude acid (5.60 g, contaminated with TESOH) as a colorless oil, which was used for next reaction without further purification. Purified for characterization by flash column chromatography over silica gel eluting with hexane/ EtOAc = 4/1.

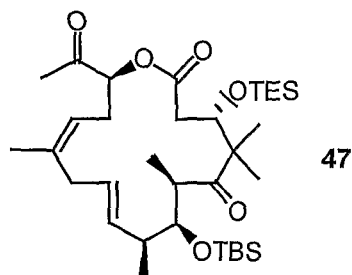
$[\alpha]_D^{25} -30.7$ (c 0.985, CHCl_3); IR (film) ν 2956, 2936, 2879, 1712, 1472, 1417, 1303, 1253, 1107, 1046, 1003, 988, 872, 837, 775, 741 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.08 (3H, s), 0.09 (3H, s), 0.59-0.67 (6H, m), 0.93 (9H, s), 0.96 (9H, t, $J = 8.1$ Hz), 1.05

- (3H, d, $J = 7.0$ Hz), 1.05 (3H, d, $J = 7.0$ Hz), 1.20 (3H, s), 1.21 (3H, s), 2.06-2.13 (1H, m), 2.34 (1H, dd, $J = 16.4, 7.4$ Hz), 2.50 (1H, dd, $J = 16.4, 3.0$ Hz), 3.06 (1H, quint, $J = 7.3$ Hz), 3.87 (1H, dd, $J = 7.5, 1.8$ Hz), 4.40 (1H, dd, $J = 7.3, 2.9$ Hz), 5.01 (1H, dd, $J = 18.0, 0.9$ Hz), 5.07 (1H, dd, $J = 10.4, 1.2$ Hz), 5.93 (1H, ddd, $J = 18.0, 10.4, 7.8$ Hz);
- 5 ^{13}C NMR (100 MHz, CDCl_3) δ -3.6, -3.3, 5.3 (3C), 7.1 (3C), 15.6, 18.7, 19.1, 19.2, 24.1, 26.4 (3C), 39.8, 43.6, 46.4, 53.5, 73.7, 76.6, 115.6, 140.0, 177.9, 218.7; LRMS (ESI) calcd for $\text{C}_{26}\text{H}_{52}\text{O}_5\text{Si}_2\text{Na}$ $[\text{M}+\text{Na}^+]$ 523.3, found 522.9.

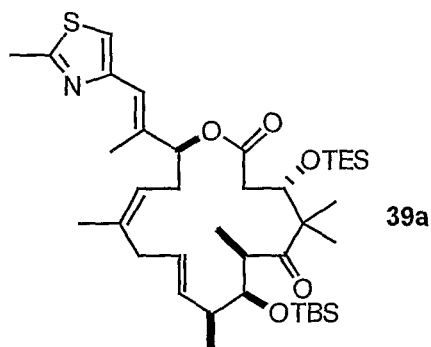


- 10 **Compound 45:** The 3-O-TES-6-O-TBS protected acid **25** was dried through azeotropic distillation from benzene. Freshly dried alcohol **43** (200 mg, 1.19 mmol) is dissolved in DCM (10 mL) and cooled to 0 °C, at which point solid DMAP (167 mg, 1.37 mmol) and solid EDCI (261 mg, 1.37 mmol) are added. After stirring the reaction mixture at 0 °C for 15 min, a solution of acid **25** (425 mg, 0.85 mmol) in DCM (2 mL) is added
- 15 dropwise. The cooling bath is removed and stirring continued for another 2 hours. The crude reaction mixture is diluted with DCM (10 mL) and purified by silica gel chromatography employing 10% EtOAc/Hexanes as the eluent to give ester **45** (380 mg, 81% yield, two steps, starting from **36**) as a clear oil: $[\alpha]_D -15.1$ (c 1.2, CDCl_3); IR (neat) 2955, 2932, 2877, 1743, 1732, 1694, 1474, 1461, 1417, 1380, 1360, 1295, 1252,
- 20 1169, 1094, 1043, 988.3, 912.9, 871.4, 836.5, 774.8, 741.6 cm^{-1} ; ^1H NMR (500 MHz, CDCl_3) 0.08 (3H, s), 0.08 (3H, s), 0.60-0.68 (6H, m), 0.93 (9H, s), 0.95 (9H, t, $J = 8.0$ Hz), 1.04 (3H, d, $J = 6.9$ Hz), 1.05 (3H, d, $J = 6.9$ Hz), 1.10 (3H, s), 1.25 (3H, s), 1.69 (3H, s), 2.08-2.15 (2H, m), 2.16 (3H, s), 2.38 (1H, dd, $J = 17.0, 7.0$ Hz), 2.48 (2H, t, $J = 6.5$ Hz), 2.57 (1H, dd, $J = 17.0, 2.7$ Hz), 2.71-2.76 (2H, m), 3.07 (1H, quint, $J = 7.0$
- 25 Hz), 3.83 (1H, d, $J = 7.2$ Hz), 4.36 (1H, dd, $J = 7.0, 2.7$ Hz), 4.97-5.07 (4H, m), 5.19 (1H, t, $J = 7.0$), 5.73 (1H, td, $J = 15.4, 5.9$ Hz), 5.92 (1H, dd, $J = 15.7, 8.0$ Hz); ^{13}C NMR (500 MHz, CDCl_3) δ 218.4, 205.4, 172.1, 140.1, 137.4, 135.4, 119.1, 115.8, 115.6, 78.7, 76.5, 73.9, 53.3, 46.3, 43.7, 39.6, 36.6, 29.2, 26.7, 26.4, 23.8, 23.7, 19.9,

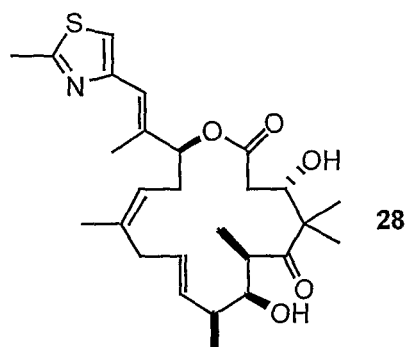
18.9, 18.7, 15.4, 7.06, 5.30, -3.29, -3.62; LRMS (ESI) calcd for $C_{36}H_{66}O_6Si_2Na$ $[M+Na^+]$ 673.4, found 673.5 .



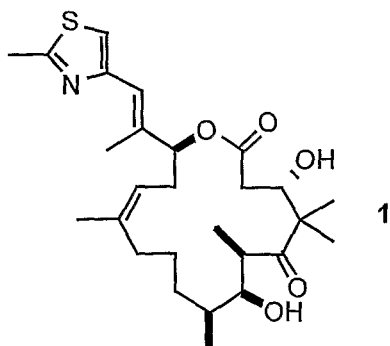
- 5 **Compound 47:** To a solution of compound **45** (20 mg, 0.031 mmol) in dry toluene (60 mL) at reflux was added in one portion a solution of tricyclohexylphosphine[1,3-bis(2,4,6-trimethylphenyl)-4,5-dihydroimidazol-2-ylidene][benzylidene]ruthenium (IV) dichloride (5.2 mg, 0.0061 mmol) in dry toluene (2 mL) and the mixture was heated for 10 minutes. The reaction mixture was cooled immediately in an ice bath and stripped
- 10 onto silica and purified using silica gel chromatography employing 4-10% EtOAc/pentane gradient as the eluent to furnish compound **47** (15 mg, 78% yield) as an oil: $[\alpha] -28.6$ (c 1.2, $CHCl_3$); IR (neat) 2955, 2933, 2878, 1745, 1731, 1695, 1471, 1462, 1380, 1361, 1251, 1159, 1104, 1080, 1019, 985.0, 876.1, 835.5, 774.7, 743.1, 670.1 cm^{-1} ; 1H NMR (500 MHz, $CDCl_3$) 0.07 (3H, s), 0.10 (3H, s), 0.59-0.68 (6H, m), 0.91 (9H, t, $J = 8.0$ Hz), 0.93 (9H, s), 1.04 (3H, d, $J = 7.0$ Hz), 1.10 (3H, s), 1.11 (3H, d, $J = 7.0$ Hz), 1.17 (3H, s), 1.71 (3H, s), 2.21 (3H, s), 2.27-2.32 (1H), 2.38 (1H, dd, $J = 14.6, 6.8$ Hz), 2.51-2.61 (2H, m), 2.57 (1H, dd, $J = 15.5, 3.3$ Hz), 2.93-3.1 (3H, m), 3.94 (1H, d, $J = 8.5$ Hz), 4.28 (1H, dd, $J = 8.6, 3.0$ Hz), 5.04 (1H, dd, $J = 8.7, 2.4$), 5.16 (1H, t, $J = 7.5$), 5.73 (1H, tdd , $J = 12.8, 9.94, 6.9$ Hz), 5.92 (1H, ddd, $J = 18.0, 10.3, 7.8$ Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 215.9, 204.8, 171.3, 140.0, 132.7, 129.2, 118.6, 79.1, 78.2, 75.4, 54.0, 48.2, 41.7, 40.3, 35.0, 29.2, 26.6, 26.5, 23.5, 22.8, 20.6, 18.8, 17.5, 14.3, 7.19, 5.53, -3.36; LRMS (ESI) calcd. for $C_{34}H_{62}O_6Si_2$ 645.4, found 645.4 ($M+Na^+$).
- 15
- 20



Compound 39a: To a solution of Wittig reagent (19.1 mg, 54.7 μmol) in THF (0.4 mL) was added KHMDS (109 μL of a 0.5 M solution in toluene, 54.7 μmol) at 0 $^{\circ}\text{C}$. The mixture was stirred at 0 $^{\circ}\text{C}$ for 0.5 h and then cooled to -78°C . To the mixture was added dropwise a solution of ketone **47** (5.7 mg, 9.12 μmol) in THF (0.3 mL), and the resulting mixture was allowed to warm to -20°C over 1.5 h. The reaction was quenched with sat. aq. NH_4Cl (2 mL) and extracted with EtOAc (7 mL x 3). The combined organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash column chromatography (SiO_2 , hexane/ Et_2O = 10:1) to give 5.6 mg of an inseparable mixture of *E/Z* olefins (*E/Z* = 9:1). The mixture was purified by preparative TLC (hexane/ Et_2O = 4:1) to give pure **39a** (5.0 mg, 6.96 μmol , 76%) as a colorless oil; $[\alpha]_D^{25} -41.5$ (c 0.715, CHCl_3); IR (film) ν 2955, 2884, 1737, 1690, 1467, 1378, 1249, 1179, 1102, 1014, 979, 879, 826, 773 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.08 (3H, s), 0.12 (3H, s), 0.57 (6H, q, J = 7.8 Hz), 0.89 (9H, t, J = 8.0 Hz), 0.93 (9H, s), 1.04 (3H, s), 1.06 (3H, d, J = 7.1 Hz), 1.12 (3H, s), 1.17 (3H, d, J = 7.1 Hz), 1.68 (3H, s), 2.15 (3H, d, J = 0.8 Hz), 2.14-2.27 (2H, m), 2.45 (1H, dd, J = 14.0, 4.8 Hz), 2.50 (1H, dd, J = 14.9, 3.2 Hz), 2.64-2.74 (2H, m), 2.72 (3H, s), 3.02 (1H, quint, J = 7.0 Hz), 3.10 (1H, dd, J = 14.4, 7.3 Hz), 3.96 (1H, d, J = 8.7 Hz), 4.43 (1H, dd, J = 8.3, 2.9 Hz), 5.22 (1H, dd, J = 9.8, 5.7 Hz), 5.33-5.42 (2H, m), 5.69 (1H, dd, J = 15.8, 8.2 Hz), 6.57 (1H, s), 6.96 (1H, s); ^{13}C NMR (100 MHz, CDCl_3) δ -3.3, -3.2, 5.6 (3C), 7.1 (3C), 15.0, 17.2, 18.8, 19.4, 21.4, 21.7, 23.8, 24.3, 26.5 (3C), 33.2, 35.6, 41.3, 41.8, 48.2, 54.0, 74.4, 77.4, 79.3, 116.4, 120.5, 121.0, 129.3, 132.1, 137.8, 138.0, 152.7, 164.8, 170.7, 216.8; LRMS (ESI) calcd for $\text{C}_{39}\text{H}_{68}\text{NO}_5\text{SSi}_2$ $[\text{M}+\text{H}^+]$ 718.4, found 718.3.



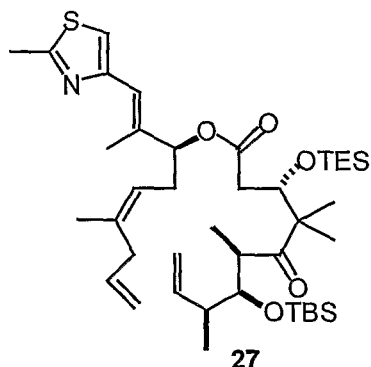
Compound 28 (Epo 3): To a solution of **39a** (298.8 mg, 0.416 mmol) in THF (6.5 mL) was added HF·pyridine (3.2 mL) at 0 °C, and the mixture was stirred at rt for 3 h. The reaction was quenched by dropwise addition of TMSOMe (30 mL) at 0 °C. After
 5 concentrating and drying under high vacuum, the residue was purified by flash column chromatography (SiO₂, hexane/EtOAc = 1:1) to give **28** (196.6 mg, 0.402 mmol, 97%) as a white solid; $[\alpha]_D^{25}$ -96.6 (c 0.235, CHCl₃); IR (film) ν 3502, 2970, 2927, 1733, 1685, 1506, 1456, 1375, 1251, 1152, 1040, 977 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 1.06 (3H, s), 1.11 (3H, d, J = 7.0 Hz), 1.22 (3H, d, J = 6.8 Hz), 1.28 (3H, s), 1.72 (3H, s), 2.10 (3H, s), 2.31-2.40 (2H, m), 2.43 (1H, dd, J = 16.0, 3.7 Hz), 2.49 (1H, dd, J = 16.0, 9.2 Hz), 2.55-2.68 (2H, m), 2.71 (3H, s), 2.98 (1H, dd, J = 14.4, 6.4 Hz), 3.16 (1H, quint, J = 6.2 Hz), 3.76 (1H, dd, J = 5.9, 3.2 Hz), 4.30 (1H, dd, J = 9.2, 3.7 Hz), 5.18 (1H, brt, J = 7.3 Hz), 5.32 (1H, dd, J = 8.4, 2.5 Hz), 5.63 (1H, dd, J = 15.7, 6.4 Hz), 5.60 (1H, ddd, J = 15.7, 6.9, 5.1 Hz), 6.60 (1H, s), 6.98 (1H, s); ¹³C NMR (100
 10 MHz, CDCl₃) δ 15.1, 16.0, 17.7, 19.2, 19.5, 22.5, 23.6, 32.0, 35.0, 39.6, 40.3, 44.8, 53.3, 71.8, 75.6, 78.3, 116.1, 119.6, 120.5, 129.9, 131.3, 137.5, 138.2, 152.2, 165.0, 170.7, 218.8; LRMS (ESI) calcd for C₂₇H₄₀NO₅S [M+H]⁺ 490.3, found 490.2.



dEpoB (1, Epo 1): To a solution of **28** (1.2 mg, 2.5 μ mol) and TrisNHNH₂ (29.3 mg, 98 μ mol) in ClCH₂CH₂Cl (0.7 mL) at 50 °C was added Et₃N (13.7 μ L, 98 μ mol). The reaction was monitored by HPTLC (hexane/EtOAc/CH₂Cl₂ = 1/1/2). After stirring for 7

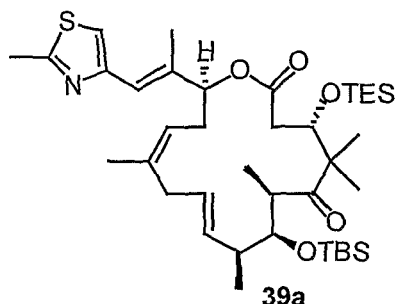
h, the mixture was cooled to rt, diluted with EtOAc and filtered through a pad of silica gel, which was rinsed with EtOAc. After concentrating, the residue was purified by preparative TLC (hexane/EtOAc/CH₂Cl₂ = 1/1/2) to give **1** (1.1 mg, 2.2 μmol, 91%) as a white solid.

- 5 The spectral data of **1** was identical to those reported of dEpoB.

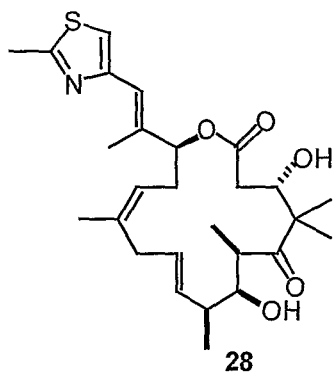


- Compound 27:** Acid **25** and alcohol **24** were azeotroped with dry benzene (5 mL x 2) and dried under high vacuum before reaction. To a solution of alcohol **24** (639 mg, 2.63 mmol) in CH₂Cl₂ (13 mL) were added EDCI (576 mg, 3.09 mmol) and DMAP (366 mg, 3.09 mmol) at 0 °C. To the mixture was added a solution of acid **25** (1.11 g, as 1.88 mmol) in CH₂Cl₂ (5 mL + 2 mL rinse) dropwise over 16 min at 0 °C. After stirring at 0 °C for 1.5 h, the mixture was stirred at rt for 3.5 h. After concentrating, the residue was purified by flash column chromatography (SiO₂, hexane/EtOAc = 30:1 to 20:1) to give
- 10 **27** (1.20 g, 1.61 mmol, 86% from *t*-butyl ester) as a colorless oil;
- [α]_D²⁴ -25.1 (c 1.30, CHCl₃); IR (film) ν 2955, 2925, 2872, 1732, 1696, 1461, 1378, 1290, 1243, 1173, 1091, 985, 873, 773 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 0.06 (3H, s), 0.06 (3H, s), 0.58-0.66 (6H, m), 0.92 (9H, s), 0.95 (9H, t, *J* = 8.0 Hz), 1.02 (3H, d, *J* = 6.5 Hz), 1.03 (3H, d, *J* = 6.5 Hz), 1.07 (3H, s), 1.21 (3H, s), 1.67 (3H, s), 2.07 (3H, s), 2.05-2.12 (1H, m), 2.30 (1H, dd, *J* = 16.9, 7.5 Hz), 2.39 (1H, dt, *J* = 14.8, 6.7 Hz), 2.49 (1H, dd, *J* = 17.0, 3.0 Hz), 2.50 (1H, dt, *J* = 14.8, 6.7 Hz), 2.70 (3H, s), 2.74-2.30 (2H, m), 3.07 (1H, dd, *J* = 7.0 Hz), 3.83 (1H, dd, *J* = 7.1, 2.0 Hz), 4.35 (1H, dd, *J* = 7.4, 2.8 Hz), 4.98-5.07 (4H, m), 5.16 (1H, brt, *J* = 7.0 Hz), 5.23 (1H, t, *J* = 6.9 Hz), 5.74 (1H, ddt, *J* = 16.7, 10.2, 6.5 Hz), 5.91 (1H, ddd, *J* = 17.8, 10.5, 7.8 Hz), 6.50 (1H, s),
- 20 6.95 (1H, s); ¹³C NMR (100 MHz, CDCl₃) δ -3.7, -3.3, 5.3 (3C), 7.2 (3C), 14.8, 15.2, 18.7, 18.9, 19.4, 20.3, 23.6, 23.7, 26.4 (3C), 31.7, 36.7, 40.1, 43.8, 46.4, 53.3, 74.2,
- 25

76.5, 79.6, 115.5, 115.6, 116.5, 120.5, 121.3, 135.8, 136.1, 137.4, 140.2, 152.9, 164.7, 171.5, 218.4; LRMS (ESI) calcd for $C_{41}H_{71}NO_5SSi_2$ $[M+Na^+]$ 768.5, found 768.5.

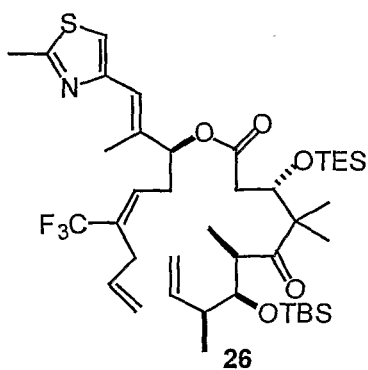


- 5 **Compound 39a:** A solution of **27** (26.9 mg, 36.1 μ mol) in toluene (70 mL) was heated to reflux and treated with a solution of Grubbs' catalyst (3.1 mg, 3.61 μ mol) in toluene (2 mL). The mixture was stirred for 25 min, cooled to 0 °C and filtered through a pad of silica gel, which was rinsed with hexane/EtOAc = 2/1. The combined filtrates were concentrated and purified by flash column chromatography (SiO₂, hexane/Et₂O = 40:1
- 10 to 5:1) to give **39a** (9.9 mg, 13.8 μ mol, 38%) as a colorless oil;
 $[\alpha]_D^{25}$ -41.5 (c 0.715, CHCl₃); IR (film) ν 2955, 2884, 1737, 1690, 1467, 1378, 1249, 1179, 1102, 1014, 979, 879, 826, 773 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 0.08 (3H, s), 0.12 (3H, s), 0.57 (6H, q, J = 7.8 Hz), 0.89 (9H, t, J = 8.0 Hz), 0.93 (9H, s), 1.04 (3H, s), 1.06 (3H, d, J = 7.1 Hz), 1.12 (3H, s), 1.17 (3H, d, J = 7.1 Hz), 1.68 (3H, s), 2.15
- 15 (3H, d, J = 0.8 Hz), 2.14-2.27 (2H, m), 2.45 (1H, dd, J = 14.0, 4.8 Hz), 2.50 (1H, dd, J = 14.9, 3.2 Hz), 2.64-2.74 (2H, m), 2.72 (3H, s), 3.02 (1H, quint, J = 7.0 Hz), 3.10 (1H, dd, J = 14.4, 7.3 Hz), 3.96 (1H, d, J = 8.7 Hz), 4.43 (1H, dd, J = 8.3, 2.9 Hz), 5.22 (1H, dd, J = 9.8, 5.7 Hz), 5.33-5.42 (2H, m), 5.69 (1H, dd, J = 15.8, 8.2 Hz), 6.57 (1H, s), 6.96 (1H, s); ¹³C NMR (100 MHz, CDCl₃) δ -3.3, -3.2, 5.6 (3C), 7.1 (3C), 15.0, 17.2,
- 20 18.8, 19.4, 21.4, 21.7, 23.8, 24.3, 26.5 (3C), 33.2, 35.6, 41.3, 41.8, 48.2, 54.0, 74.4, 77.4, 79.3, 116.4, 120.5, 121.0, 129.3, 132.1, 137.8, 138.0, 152.7, 164.8, 170.7, 216.8; LRMS (ESI) calcd for $C_{39}H_{68}NO_5SSi_2$ $[M+H^+]$ 718.4, found 718.3.

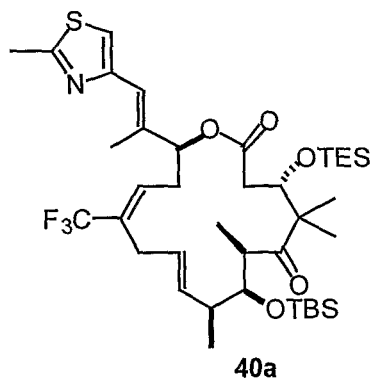


Compound 28: To a solution of **39a** (298.8 mg, 0.416 mmol) in THF (6.5 mL) was added HF·pyridine (3.2 mL) at 0 °C, and the mixture was stirred at rt for 3 h. The reaction was quenched with dropwise addition of TMSOMe (30 mL) at 0 °C and the mixture was stirred at rt for 3 h. After concentrating and drying under high vacuum, the residue was purified by flash column chromatography (SiO₂, hexane/EtOAc = 1:1) to give **28** (196.6 mg, 0.402 mmol, 97%) as a white solid;

$[\alpha]_D^{25}$ -96.6 (c 0.235, CHCl₃); IR (film) ν 3502, 2970, 2927, 1733, 1685, 1506, 1456, 1375, 1251, 1152, 1040, 977 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 1.06 (3H, s), 1.11 (3H, d, J = 7.0 Hz), 1.22 (3H, d, J = 6.8 Hz), 1.28 (3H, s), 1.72 (3H, s), 2.10 (3H, s), 2.31-2.40 (2H, m), 2.43 (1H, dd, J = 16.0, 3.7 Hz), 2.49 (1H, dd, J = 16.0, 9.2 Hz), 2.55-2.68 (2H, m), 2.71 (3H, s), 2.98 (1H, dd, J = 14.4, 6.4 Hz), 3.16 (1H, quint, J = 6.2 Hz), 3.76 (1H, dd, J = 5.9, 3.2 Hz), 4.30 (1H, dd, J = 9.2, 3.7 Hz), 5.18 (1H, brt, J = 7.3 Hz), 5.32 (1H, dd, J = 8.4, 2.5 Hz), 5.63 (1H, dd, J = 15.7, 6.4 Hz), 5.60 (1H, ddd, J = 15.7, 6.9, 5.1 Hz), 6.60 (1H, s), 6.98 (1H, s); ¹³C NMR (100 MHz, CDCl₃) δ 15.1, 16.0, 17.7, 19.2, 19.5, 22.5, 23.6, 32.0, 35.0, 39.6, 40.3, 44.8, 53.3, 71.8, 75.6, 78.3, 116.1, 119.6, 120.5, 129.9, 131.3, 137.5, 138.2, 152.2, 165.0, 170.7, 218.8; LRMS (ESI) calcd for C₂₇H₄₀NO₅S [M+H⁺] 490.3, found 490.2.



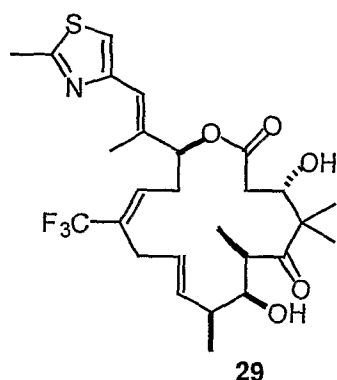
Compound 26: Acid **25** and alcohol **21** were azeotropered with dry benzene (5 mL x 2) and dried under high vacuum before reaction. To a solution of alcohol **21** (240 mg, 0.756 mmol) in CH₂Cl₂ (5 mL) were added EDCI (192.7 mg, 1.01 mmol) and DMAP (122.8 mg, 1.01 mmol) at 0 °C. To the mixture was added a solution of acid **25** (314.6 mg, 0.628 mmol) in CH₂Cl₂ (2 mL + 1 mL rinse) dropwise over 15 min at 0 °C. After stirring at 0 °C for 2 h, the mixture was stirred at rt for 2 h. After concentrating, the residue was purified by flash column chromatography (SiO₂, hexane/EtOAc = 20:1 to 15:1) to give **26** (340.1 mg, 0.425 mmol, 68% based on acid) as a colorless oil; $[\alpha]_D^{24}$ -27.5 (c 0.28, CHCl₃); IR (film) ν 2956, 2878, 1740, 1692, 1472, 1378, 1317, 1253, 1174, 1118, 988, 915, 872, 837, 775 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 0.06 (6H, s), 0.57-0.65 (6H, m), 0.92 (9H, s), 0.94 (9H, t, *J* = 7.9 Hz), 1.02 (3H, d, *J* = 6.9 Hz), 1.03 (3H, d, *J* = 6.8 Hz), 1.07 (3H, s), 1.22 (3H, s), 2.07-2.10 (1H, m), 2.09 (3H, s), 2.31 (1H, dd, *J* = 16.9, 7.3 Hz), 2.51 (1H, dd, *J* = 16.8, 3.0 Hz), 2.49-2.65 (2H, m), 2.71 (3H, s), 2.96-2.99 (2H, m), 3.06 (1H, quint, *J* = 7.1 Hz), 3.83 (1H, dd, *J* = 7.3, 2.1 Hz), 4.35 (1H, dd, *J* = 7.2, 3.0 Hz), 4.98-5.12 (4H, m), 5.30 (1H, t, *J* = 6.7 Hz), 5.76 (1H, ddt, *J* = 16.7, 10.2, 6.2 Hz), 5.92 (1H, ddd, *J* = 17.8, 9.9, 7.8 Hz), 6.19 (1H, t, *J* = 7.0 Hz), 6.51 (1H, s), 6.97 (1H, s); LRMS (ESI) calcd for C₄₁H₆₈F₃NO₅SSi₂Na [M+Na⁺] 822.4, found 822.4.



Compound 40a (via RCM of 26): A solution of **26** (57.6 mg, 72.0 μ mol) in toluene (142 mL) was heated to reflux and treated with a solution of Grubbs' catalyst (6.1 mg, 7.20 μ mol) in toluene (2 mL). The mixture was stirred for 28 min, cooled to 0 °C and filtered through a pad of silica gel, which was rinsed with hexane/EtOAc = 2/1 (300 mL). The combined filtrates were concentrated and purified by flash column chromatography (SiO₂, hexane/Et₂O = 40:1 to 15:2) to give **40a** (12.0 mg, 15.5 μ mol, 22%) as a colorless oil;

IR (film) ν 2955, 2884, 1743, 1690, 1472, 1320, 1173, 1114, 1038, 1008, 873, 832, 773 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.09 (3H, s), 0.12 (3H, s), 0.55 (6H, q, $J = 7.7$ Hz), 0.88 (9H, t, $J = 8.0$ Hz), 0.96 (9H, s), 1.01 (3H, s), 1.06 (3H, d, $J = 7.1$ Hz), 1.12 (3H, s), 1.20 (3H, d, $J = 7.1$ Hz), 2.07-2.17 (1H, m), 2.19 (3H, s), 2.38 (1H, dd, $J = 14.3, 3.5$ Hz), 2.39-2.49 (1H, m), 2.50 (1H, dd, $J = 14.3, 7.3$ Hz), 2.73 (3H, s), 2.77-2.91 (2H, m), 2.96-3.09 (2H, m), 3.98 (1H, dd, $J = 8.9$ Hz), 4.54 (1H, dd, $J = 7.3, 3.4$ Hz), 5.28-5.38 (1H, m), 5.63 (1H, dd, $J = 9.6, 2.3$ Hz), 5.77 (1H, dd, $J = 15.9, 8.5$ Hz), 6.21-6.28 (1H, m), 6.60 (1H, s), 6.99 (1H, s); LRMS (ESI) calcd for $\text{C}_{39}\text{H}_{65}\text{F}_3\text{NO}_5\text{SSi}_2$ $[\text{M}+\text{H}^+]$ 772.4, found 772.4.

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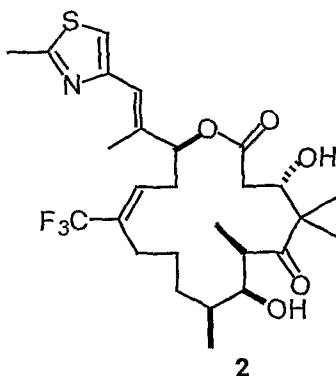


Compound 29: To a solution of **40a** (1.78 g, 2.31 mmol) in THF (25 mL) was added slowly $\text{HF}\cdot\text{pyridine}$ (12.5 mL) at 0 °C, and the mixture was stirred at rt for 4 h. The reaction was quenched with dropwise addition of TMSOMe (80 mL) over 10 min at 0 °C. The mixture was vigorously stirred at rt for 2.5 h. After concentrating and drying under high vacuum for 2 h, the residue was purified by flash column chromatography (SiO_2 ~50 g, hexane/EtOAc = 1:1) to give **29** (1.20 g, 2.21 mmol, 96%) as a colorless powder;

$[\alpha]_D^{25} -54.6$ (c 0.28, CHCl_3); IR (film) ν 3478, 2974, 2929, 1736, 1689, 1449, 1381, 1318, 1247, 1169, 1113, 1039, 983, 867, 736 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 1.05 (3H, s), 1.12 (3H, d, $J = 7.0$ Hz), 1.23 (3H, d, $J = 6.8$ Hz), 1.37 (3H, s), 2.04 (1H, brd, $J = 3.8$ Hz, -OH), 2.12 (3H, s), 2.25-2.33 (1H, m), 2.38 (1H, dd, $J = 15.3, 3.0$ Hz), 2.48 (1H, dd, $J = 15.4, 9.8$ Hz), 2.54-2.61 (1H, m), 2.66-2.76 (1H, m), 2.71 (3H, s), 2.96 (1H, dd, $J = 16.5, 4.5$ Hz), 3.02 (1H, dd, $J = 16.3, 6.5$ Hz), 3.11 (1H, quint, $J = 6.7$ Hz), 3.19 (1H, brs, =OH), 3.74 (1H, brs), 4.35 (1H, brd, $J = 9.5$ Hz), 5.42 (1H, dd, $J = 6.2, 4.1$ Hz), 5.60 (1H, ddd, $J = 15.8, 5.6, 4.5$ Hz), 5.66 (1H, dd, $J = 15.8, 5.8$ Hz), 6.24 (1H, t, $J = 7.2$ Hz), 6.64 (1H, s), 7.00 (1H, s); ^{13}C NMR (100 MHz, CDCl_3) δ 15.1, 16.1,

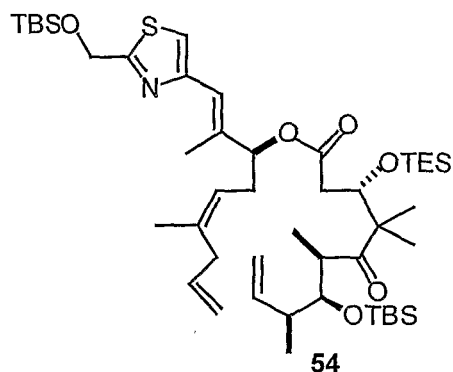
17.7, 18.5, 19.3, 22.5, 28.8, 31.1, 39.6, 39.7, 45.0, 53.7, 71.4, 75.3, 76.8, 116.7, 120.2, 124.3 [q, $^1J(\text{C},\text{F}) = 273.4$ Hz], 127.9, 130.2 [q, $^3J(\text{C},\text{F}) = 6.0$ Hz], 130.6 [q, $^2J(\text{C},\text{F}) = 28.4$ Hz], 132.5, 136.7, 152.0, 165.4, 170.2, 218.4; LRMS (ESI) calcd for $\text{C}_{27}\text{H}_{37}\text{F}_3\text{NO}_5\text{S}$ $[\text{M}+\text{H}^+]$ 544.2, found 544.1.

5



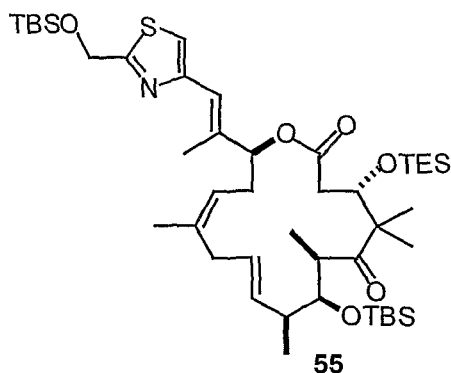
Compound 2: To a solution of **29** (1.22 mg, 2.24 μmol) and TrisNHNH_2 (26.7 mg, 89.6 μmol) in $\text{ClCH}_2\text{CH}_2\text{Cl}$ (1 mL) at 50 °C was added Et_3N (12.5 μL , 89.6 μmol). The reaction was monitored by HPTLC (hexane/ $\text{EtOAc}/\text{CH}_2\text{Cl}_2 = 1/1/2$). After stirring for 6.5 h, further TrisNHNH_2 (26.7 mg, 89.6 μmol) and Et_3N (12.5 μL , 89.6 μmol) were added to the mixture. After stirring for 14 h, the mixture was cooled to rt, diluted with EtOAc and filtered through a pad of silica gel, which was rinsed with EtOAc . After concentrating, the residue was purified by preparative TLC (hexane/ $\text{EtOAc}/\text{CH}_2\text{Cl}_2 = 1/1/2$) to give **2** (1.16 mg, 2.13 μmol , 94%) as a white solid;

^1H NMR (400 MHz, CDCl_3) δ 1.03 (3H, d, $J = 7.0$ Hz), 1.08 (3H, s), 1.19 (3H, d, $J = 6.8$ Hz), 1.25-1.35 (2H, m), 1.37 (3H, s), 1.42-1.55 (2H, m), 1.65-1.82 (2H, m), 2.10 (3H, d, $J = 0.8$ Hz), 2.21-2.47 (2H, m), 2.27 (1H, dd, $J = 14.2, 2.6$ Hz), 2.48 (1H, dd, $J = 14.3, 10.8$ Hz), 2.70 (3H, s), 2.70-2.28 (1H, m), 3.02 (1H, d, $J = 2.0$ Hz, -OH), 3.19 (1H, qd, $J = 6.9, 2.2$ Hz), 3.65 (1H, d, $J = 6.2$ Hz, -OH), 3.69-3.72 (1H, m), 4.34 (1H, ddd, $J = 10.8, 6.2, 2.6$ Hz), 5.28 (1H, dd, $J = 10.2, 2.2$ Hz), 6.12 (1H, dd, $J = 10.2, 5.2$ Hz), 6.61 (1H, s), 6.98 (1H, s); LRMS (ESI) calcd for $\text{C}_{27}\text{H}_{39}\text{F}_3\text{NO}_5\text{S}$ $[\text{M}+\text{H}^+]$ 546.3, found 546.2.

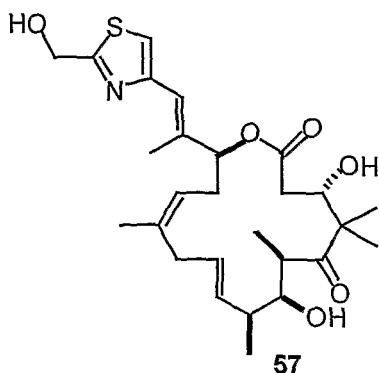


Compound 54: Acid **25** and alcohol **53** were azeotroped with dry benzene (3 mL x 2) and dried under high vacuum before reaction. To a solution of alcohol **53** (68.0 mg, 0.173 mmol) in CH₂Cl₂ (1.3 mL) were added EDCI (37.8 mg, 0.197 mmol) and DMAP (24.1 mg, 0.197 mmol) at 0 °C. To the mixture was added a solution of acid **25** (72.6 mg, as 0.123 mmol) in CH₂Cl₂ (0.7 mL) dropwise over 5 min at 0 °C. After stirring at 0 °C for 1 h, the mixture was stirred at rt for 2.5 h. After concentrating, the residue was purified by flash column chromatography (SiO₂, hexane/EtOAc = 30:1) to give **54** (99.5 mg, 0.114 mmol, 92% from *t*-butyl ester) as a colorless oil;

[α]_D²⁵ -23.4 (c 0.56, CHCl₃); IR (film) ν 2955, 2931, 2880, 1735, 1696, 1506, 1472, 1386, 1362, 1294, 1254, 1174, 1104, 988, 878, 776, 742 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 0.06 (3H, s), 0.06 (3H, s), 0.14 (6H, s), 0.63 (6H, q, *J* = 8.0 Hz), 0.92 (9H, s), 0.94 (9H, t, *J* = 8.0 Hz), 0.97 (9H, s), 1.02 (3H, d, *J* = 6.6 Hz), 1.05 (3H, d, *J* = 6.5 Hz), 1.07 (3H, s), 1.21 (3H, s), 1.67 (3H, s), 2.06 (3H, d, *J* = 0.8 Hz), 2.05-2.14 (1H, m), 2.30 (1H, dd, *J* = 16.9, 7.5 Hz), 2.33-2.53 (2H, m), 2.50 (1H, dd, *J* = 16.9, 2.7 Hz), 2.76-2.80 (2H, m), 3.07 (1H, quint, *J* = 7.0 Hz), 3.83 (1H, dd, *J* = 7.0, 2.2 Hz), 4.35 (1H, dd, *J* = 7.4, 2.8 Hz), 4.97 (2H, s), 4.97-5.07 (4H, m), 5.16 (1H, t, *J* = 7.2 Hz), 5.24 (1H, t, *J* = 6.9 Hz), 5.74 (1H, ddt, *J* = 16.6, 10.0, 6.5 Hz), 5.91 (1H, ddd, *J* = 17.6, 9.9, 7.7 Hz), 6.50 (1H, s), 7.06 (1H, s); ¹³C NMR (100 MHz, CDCl₃) δ -5.2 (2C), -3.7, -3.3, 5.3 (3C), 7.2 (3C), 14.7, 15.2, 18.5, 18.7, 18.9, 20.3, 23.6, 23.7, 26.0 (3C), 26.4 (3C), 31.7, 36.7, 40.1, 43.8, 46.4, 53.3, 63.4, 74.2, 76.5, 79.6, 115.5, 115.6, 116.6, 120.5, 121.3, 135.8, 136.1, 137.4, 140.1, 153.0, 171.5, 172.2, 218.4; LRMS (ESI) calcd for C₄₇H₈₆NO₆SSi₃ [M+H⁺] 876.6, found 876.5.



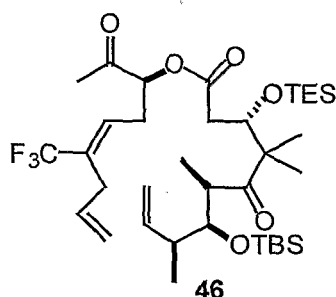
Compound 55: A solution of **54** (69.7 mg, 79.5 μmol) in toluene (158 mL) was heated to reflux and treated with a solution of Grubbs' catalyst (6.7 mg, 7.95 μmol) in toluene (2 mL). The mixture was stirred for 11 min, cooled to 0 °C and filtered through a pad of silica gel, which was rinsed with hexane/EtOAc = 3/1 (280 mL). The combined filtrates were concentrated and purified by flash column chromatography (SiO₂, hexane/Et₂O = 20:1 to 15:1) to give **55** (18.4 mg, 21.7 μmol , 27%) as a colorless oil; $[\alpha]_D^{24}$ -40.4 (c 0.26, CHCl₃); IR (film) ν 2955, 2930, 2879, 1740, 1694, 1472, 1387, 1362, 1253, 1200, 1107, 1007, 838, 776, 742 cm^{-1} ; ¹H NMR (400 MHz, CDCl₃) δ 0.08 (3H, s), 0.12 (3H, s), 0.15 (6H, s), 0.57 (6H, q, J = 7.9 Hz), 0.88 (9H, t, J = 8.0 Hz), 0.95 (9H, s), 0.97 (9H, s), 1.04 (3H, s), 1.06 (3H, d, J = 7.1 Hz), 1.12 (3H, s), 1.17 (3H, d, J = 7.0 Hz), 1.69 (3H, s), 2.06-2.30 (2H, m), 2.14 (3H, s), 2.45 (1H, dd, J = 15.6, 3.6 Hz), 2.50 (1H, dd, J = 14.9, 3.1 Hz), 2.63-2.75 (2H, m), 2.97-3.06 (1H, m), 3.10 (1H, dd, J = 14.6, 7.7 Hz), 3.97 (1H, d, J = 8.5 Hz), 4.44 (1H, dd, J = 8.4, 2.9 Hz), 4.97 (2H, s), 5.22 (1H, dd, J = 8.7, 5.2 Hz), 5.33-5.44 (2H, m), 5.70 (1H, dd, J = 15.6, 8.1 Hz), 6.57 (1H, s), 7.07 (1H, s); LRMS (ESI) calcd for C₄₅H₈₂NO₆SSi₃ [M+H⁺] 848.5, found 848.5.



Compound 57: To a solution of **55** (61.8 mg, 72.8 μmol) in THF (2 mL) was added HF·pyridine (1 mL) at 0 °C, and the mixture was stirred at rt for 3.2 h. The reaction was

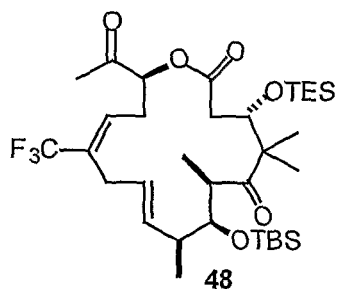
quenched with dropwise addition of TMSOMe (15 mL) at 0 °C. The mixture was stirred at rt for 2 h. After concentrating and drying under high vacuum, the residue was purified by flash column chromatography (SiO₂, hexane/EtOAc = 1:3) to give **57** (32.4 mg, 64.1 μmol, 88%) as a white solid;

- 5 $[\alpha]_D^{25} -108.4$ (c 0.285, CHCl₃); IR (film) ν 3422, 2968, 2919, 2729, 1689, 1449, 1377, 1252, 1152, 1064, 978 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 1.05 (3H, s), 1.12 (3H, d, J = 6.9 Hz), 1.22 (3H, d, J = 6.8 Hz), 1.32 (3H, s), 1.72 (3H, s), 2.08 (3H, s), 2.31-2.40 (3H, m), 2.43 (1H, dd, J = 15.5, 3.5 Hz), 2.49 (1H, dd, J = 15.5, 9.5 Hz), 2.55-2.67 (2H, m), 2.95 (1H, dd, J = 14.6, 6.3 Hz), 3.13 (1H, quint, J = 6.6 Hz), 3.34 (1H, brs, -OH),
 10 3.75 (1H, dd, J = 6.6, 2.4 Hz), 4.06 (1H, brs, -OH), 4.33 (1H, dd, J = 9.4, 3.0 Hz), 4.92 (2H, s), 5.18 (1H, t, J = 6.9 Hz), 5.33 (1H, dd, J = 8.0, 2.5 Hz), 5.52 (1H, dd, J = 15.8, 6.4 Hz), 5.59 (1H, ddd, J = 15.8, 6.6, 5.0 Hz), 6.63 (1H, s), 7.13 (1H, s); ¹³C NMR (100 MHz, CDCl₃) δ 15.3, 16.3, 17.8, 19.2, 22.8, 23.7, 31.9, 35.1, 39.7, 40.2, 45.0, 53.4, 61.8, 71.7, 75.8, 78.1, 116.7, 119.0, 120.5, 130.0, 131.2, 137.6, 138.9, 152.5, 170.0,
 15 170.7, 218.7; LRMS (ESI) calcd for C₂₇H₃₉NO₆SNa [M+Na⁺] 528.2, found 528.0.



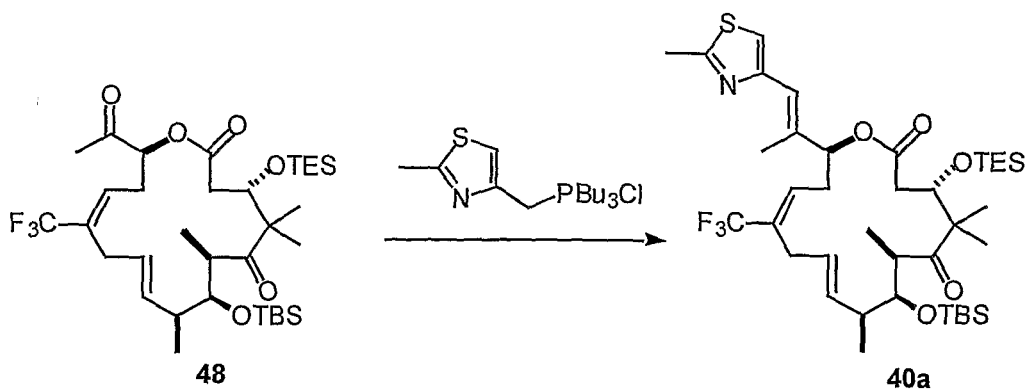
- Compound 46:** Crude acid **25** (4.65 g, as 7.27 mmol) and alcohol **44** (2.18 g, 9.84 mmol) were azeotroped with dry benzene and dried under high vacuum before reaction.
 20 To a solution of alcohol **44** (2.18 g, 9.84 mmol) in CH₂Cl₂ (65 mL) were added EDCI (2.09 g, 10.9 mmol) and DMAP (1.33 g, 10.9 mmol) at 0 °C. To the mixture was added a solution of crude acid **25** (4.65 g, as 7.27 mmol) in CH₂Cl₂ (20 mL + 5 mL rinse) dropwise over 20 min at 0 °C. After stirring at 0 °C for 40 min, the mixture was stirred at rt for 4 h. After concentrating, the residue was purified by flash column
 25 chromatography (SiO₂~160 g, hexane/EtOAc = 20:1) to give **46** (4.85 g, 6.87 mmol, 94% from *t*-butyl ester) as a colorless oil;
¹H NMR (400 MHz, CDCl₃) δ 0.08 (3H, s), 0.08 (3H, s), 0.60 (6H, q, J = 7.8 Hz), 0.93 (9H, s), 0.94 (9H, t, J = 8.0 Hz), 1.04 (3H, d, J = 7.0 Hz), 1.04 (3H, d, J = 7.0 Hz), 1.11 (3H, s), 1.23 (3H, s), 2.05-2.14 (1H, m), 2.17 (3H, s), 2.40 (1H, dd, J = 16.9, 7.0 Hz),

2.59 (1H, dd, $J = 17.0, 3.6$ Hz), 2.56-2.64 (2H, m), 2.90-3.01 (2H, m), 3.06 (1H, quint, $J = 7.0$ Hz), 3.85 (1H, dd, $J = 7.3, 2.0$ Hz), 4.38 (1H, d, $J = 7.0, 3.4$ Hz), 4.97-5.14 (5H, m), 5.75 (1H, ddt, $J = 16.0, 9.9, 6.2$ Hz), 5.92 (1H, ddd, $J = 17.8, 10.5, 7.8$ Hz), 6.21 (1H, td, $J = 7.2, 1.5$ Hz); LRMS (ESI) calcd for $C_{36}H_{63}F_3O_6Si_2Na$ [$M+Na^+$] 727.4, found 727.3.



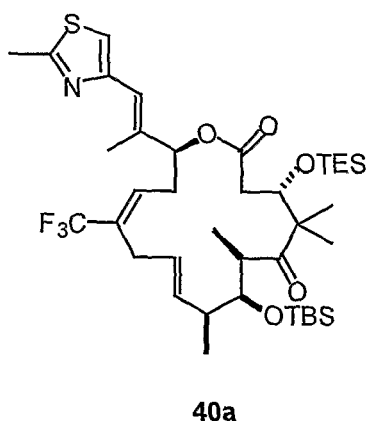
Compound 48: A solution of **46** (510.0 mg, 0.723 mmol) in toluene (500 mL) was heated to reflux and treated with a solution of Grubbs' catalyst (92.1 mg, 0.109 mmol) in toluene (10 mL). The mixture was stirred for 17 min under reflux and immediately cooled to 0 °C and kept at 0 °C before filtration through a pad of silica gel. A second batch of diene (510.0 mg, 0.723 mmol) was processed identically and simultaneously. The combined reaction mixtures were filtered through a pad of silica gel (100 g), which was rinsed with hexane/EtOAc = 3/1 (1.4 L). The combined filtrates were concentrated and purified by flash column chromatography ($SiO_2 \sim 65$ g, hexane/ Et_2O = 10:1 to 5:1) to give **48** (742.4 mg, 1.10 mmol, 76%) as a colorless oil;

1H NMR (400 MHz, $CDCl_3$) δ 0.08 (3H), 0.10 (3H, s), 0.60 (6H, q, $J = 7.8$ Hz), 0.93 (9H, s), 0.94 (9H, t, $J = 7.8$ Hz), 1.03 (3H, d, $J = 7.1$ Hz), 1.08 (3H, s), 1.13 (3H, d, $J = 7.0$ Hz), 1.17 (3H, s), 2.26 (3H, s), 2.25-2.34 (1H, m), 2.64 (1H, dd, $J = 15.5, 5.0$ Hz), 2.68-2.75 (2H, m), 2.76 (1H, dd, $J = 15.6, 6.4$ Hz), 2.85 (1H, dd, $J = 15.6, 5.7$ Hz), 2.97 (1H, dq, $J = 8.3, 6.9$ Hz), 3.04 (1H, dd, $J = 15.6, 6.3$ Hz), 3.92 (1H, dd, $J = 8.3, 1.2$ Hz), 4.36 (1H, t, $J = 5.3$ Hz), 5.30-5.39 (2H, m), 5.58 (1H, dd, $J = 15.5, 8.0$ Hz), 6.13 (1H, brt, $J = 7.2$ Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ -3.6, -3.6, 5.4 (3C), 7.0 (3C), 17.5, 18.5, 19.0, 21.6, 23.5, 26.3 (3C), 26.5, 28.6, 29.1, 41.0, 42.3, 47.3, 54.1, 74.2, 76.8, 77.7, 124.0 [$^1J(C,F) = 273.7$ Hz], 126.0, 128.7 [$^3J(C,F) = 5.9$ Hz], 132.2 [$^2J(C,F) = 28.1$ Hz], 133.8, 170.5, 204.1, 216.1; LRMS (ESI) calcd for $C_{34}H_{59}F_3O_6Si_2Na$ [$M+Na^+$] 699.4, found 699.4.



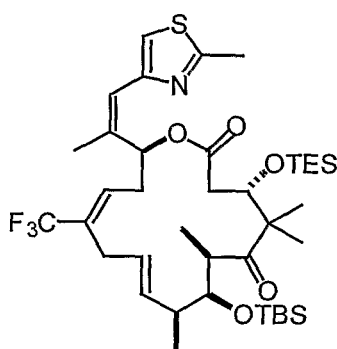
Compound 40a (via Wittig reaction of ketone 48):

Ketone **48** was azeotroped with benzene (5 mL x 2) and then dried under high vacuum for 0.5 h. To a solution of Wittig salt (907 mg, 2.59 mmol) in THF (19 mL) was added *t*-BuOK (2.4 mL of a 1.0 M solution in THF, 2.43 mmol) dropwise over 5 min at 0 °C. The mixture was stirred at 0 °C for 0.5 h and then cooled to -78 °C. To the mixture was added dropwise a solution of ketone **48** (1.10 g, 1.62 mmol) in THF (13 mL) over 10 min, and the resulting mixture was allowed to warm to -20 °C over 2 h. The reaction was quenched with sat. aqueous NH₄Cl (15 mL) and extracted with EtOAc (50 mL x 3). The combined organic layers were washed with brine (20 mL), dried over Na₂SO₄ and concentrated. The residue was purified by flash chromatography (SiO₂, hexane/Et₂O = 20:1 to 10:1) to give the desired 16(*E*)-isomer **40a** (940 mg, 1.22 mmol, 75%) along with the undesired 16(*Z*)-isomer **40b** (140.9 mg, 0.182 mmol, 11%), both as colorless oils;



$[\alpha]_D^{26} -17.1$ (c 0.14, CHCl₃); ¹H NMR (400 MHz, CDCl₃) δ 0.09 (3H, s), 0.12 (3H, s), 0.55 (6H, q, *J* = 7.7 Hz), 0.88 (9H, t, *J* = 8.0 Hz), 0.96 (9H, s), 1.01 (3H, s), 1.06 (3H, d, *J* = 7.1 Hz), 1.12 (3H, s), 1.20 (3H, d, *J* = 7.1 Hz), 2.07-2.17 (1H, m), 2.19 (3H, s), 2.38 (1H, dd, *J* = 14.3, 3.5 Hz), 2.39-2.49 (1H, m), 2.50 (1H, dd, *J* = 14.3, 7.3 Hz), 2.73

(3H, s), 2.77-2.91 (2H, m), 2.96-3.09 (2H, m), 3.98 (1H, dd, $J = 8.9$ Hz), 4.54 (1H, dd, $J = 7.3, 3.4$ Hz), 5.28-5.38 (1H, m), 5.63 (1H, dd, $J = 9.6, 2.3$ Hz), 5.77 (1H, dd, $J = 15.9, 8.5$ Hz), 6.21-6.28 (1H, m), 6.60 (1H, s), 6.99 (1H, s); ^{13}C NMR (100 MHz, CDCl_3) δ -3.4, -3.3, 5.5 (3C), 7.0 (3C), 14.6, 17.1, 18.7, 19.4, 19.9, 21.3, 24.8, 26.4 (3C), 29.6, 32.8, 42.0, 42.1, 48.2, 54.1, 73.4, 76.9, 77.8, 117.0, 121.6, 124.3 [$^1J(\text{C},\text{F}) = 273.5$ Hz], 127.2, 130.6 [$^2J(\text{C},\text{F}) = 28.2$ Hz], 130.8 [$^3J(\text{C},\text{F}) = 6.1$ Hz], 133.2, 136.5, 152.3, 165.0, 170.1, 217.1; HRMS (ESI) calcd. for $\text{C}_{39}\text{H}_{65}\text{F}_3\text{NO}_5\text{SSi}_2$ [$\text{M}+\text{H}^+$] 772.4074, found 772.4102.

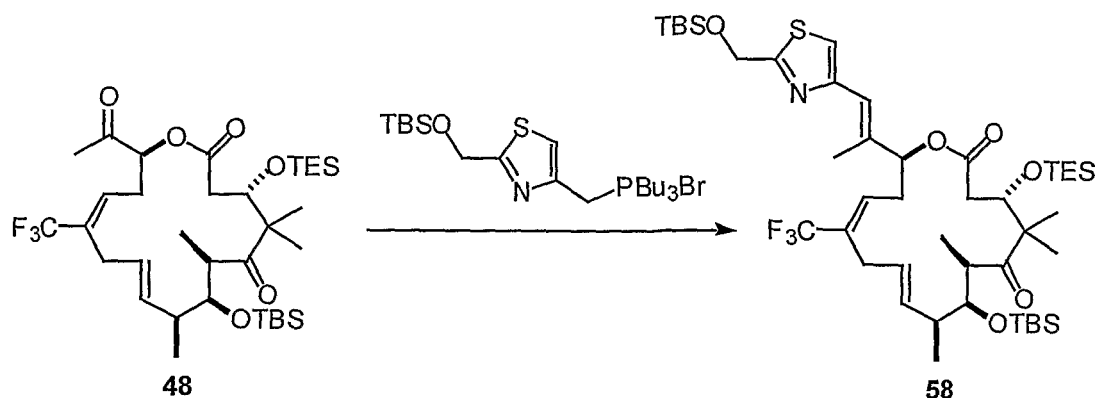


10

40b

$[\alpha]_{\text{D}}^{25}$ 62.7 (c 0.33, CHCl_3); ^1H NMR (400 MHz, CDCl_3) δ 0.09 (3H, s), 0.13 (3H, s), 0.49 (6H, q, $J = 7.8$ Hz), 0.85 (9H, t, $J = 7.8$ Hz), 0.97 (9H, s), 0.99 (3H, s), 1.06 (3H, d, $J = 7.1$ Hz), 1.11 (3H, s), 1.20 (3H, d, $J = 7.1$ Hz), 2.00 (3H, s), 2.03-2.13 (1H, m), 2.35 (1H, dd, $J = 14.3, 3.0$ Hz), 2.46 (1H, dd, $J = 14.3, 7.8$ Hz), 2.41-2.50 (1H, m), 2.73 (3H, s), 2.71-2.90 (2H, m) 2.98-3.12 (2H, m), 3.99 (1H, d, $J = 9.2$ Hz), 4.56 (1H, dd, $J = 7.7, 2.8$ Hz), 5.33 (1H, ddd, $J = 15.6, 8.9, 4.1$ Hz), 5.82 (1H, dd, $J = 15.6, 8.4$ Hz), 6.29 (1H, s), 6.33-6.40 (1H, m), 6.94 (1H, m), 7.09 (1H, brd, $J = 8.4$ Hz); ^{13}C NMR (100 MHz, CDCl_3) δ -3.2, -3.2, 5.5 (3C), 7.0 (3C), 17.2, 18.7, 19.3, 19.6, 20.0, 22.3, 24.9, 26.4 (3C), 29.7, 32.9, 41.9, 42.0, 48.6, 54.0, 72.2, 73.3, 77.0, 116.7, 120.7, 124.5 [$^1J(\text{C},\text{F}) = 273.3$ Hz], 127.9, 129.7 [$^2J(\text{C},\text{F}) = 28.0$ Hz], 131.9 [$^3J(\text{C},\text{F}) = 6.1$ Hz], 132.9, 136.6, 152.1, 165.4, 170.2, 217.4; LRMS (ESI) calcd for $\text{C}_{39}\text{H}_{65}\text{F}_3\text{NO}_5\text{SSi}_2$ [$\text{M}+\text{H}^+$] 772.4, found 772.4

20



Compound 58 (via Wittig reaction of ketone 48):

Ketone **48** was azeotroped with benzene (5 mL x 2) and then dried under high vacuum

for 0.5 h. To a solution of Wittig salt (1.19 g, 2.27 mmol) in THF (18 mL) was added *t*-

5 BuOK (2.2 mL of a 1.0 M solution in THF, 2.20 mmol) dropwise over 5 min at 0 °C.

The mixture was stirred at 0 °C for 20 min and then cooled to -78 °C. To the mixture

was added dropwise a solution of ketone (1.06 g, 1.51 mmol) in THF (10 mL + 2 mL rinse) over 10 min, and the resulting mixture was allowed to warm to $-20\text{ }^{\circ}\text{C}$ over 2 h.

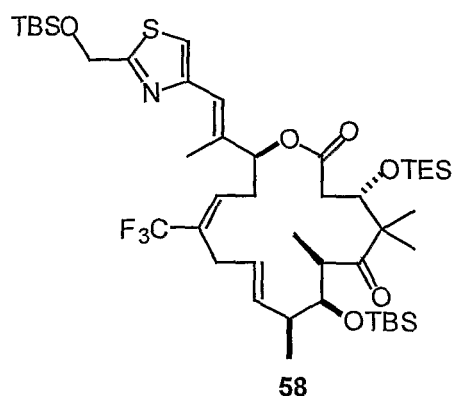
The reaction was quenched with sat. aqueous NH_4Cl (15 mL) and extracted with

10 EtOAc (50 mL x 3). The combined organic layers were washed with brine (20 mL),

dried over Na_2SO_4 and concentrated. The residue was purified by flash column

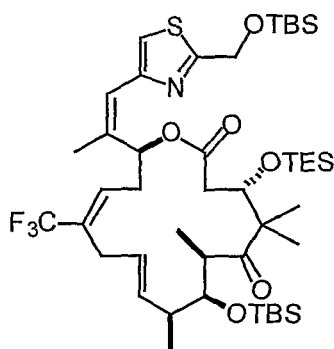
chromatography (SiO₂~ 65 g, hexane/Et₂O = 30:1 to 20:1) to give the desired 16(*E*)-

isomer **58** (1.01 g, 1.11 mmol, 74%) along with the undesired 16(*Z*)-isomer **58a** (154.5 mg, 0.182 mmol, 11%) both as colorless oils:



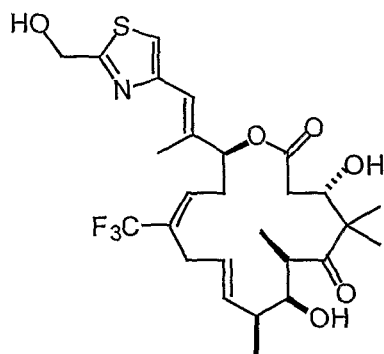
¹H NMR (400 MHz, CDCl₃) δ 0.09 (3H, s), 0.12 (3H, s), 0.15 (6H, s), 0.55 (6H, q, *J* = 7.8 Hz), 0.87 (9H, t, *J* = 8.0 Hz), 0.96 (9H, s), 0.97 (9H, s), 1.01 (3H, s), 1.06 (3H, d, *J*

- = 7.1 Hz), 1.12 (3H, s), 1.20 (3H, d, $J = 7.1$ Hz), 2.07-2.16 (1H, m), 2.18 (3H, d, $J = 1.0$ Hz), 2.38 (1H, dd, $J = 14.4, 3.3$ Hz), 2.34-2.46 (1H, m), 2.49 (1H, dd, $J = 14.4, 7.4$ Hz), 2.78-2.90 (2H, m), 2.97-3.09 (2H, m), 3.98 (1H, d, $J = 8.9$ Hz), 4.54 (1H, dd, $J = 7.3, 3.3$ Hz), 4.97 (2H, s), 5.33 (1H, ddd, $J = 15.8, 8.6, 4.9$ Hz), 5.63 (1H, dd, $J = 9.6, 2.4$ Hz), 5.78 (1H, dd, $J = 15.8, 8.2$ Hz), 6.22-6.27 (1H, m), 6.60 (1H, s), 7.09 (1H, s); ^{13}C NMR (100 MHz, CDCl_3) δ -5.3 (2C), -3.4, -3.3, 5.5 (3C), 7.0 (3C), 14.6, 17.1, 18.4, 18.7, 19.8, 21.3, 24.8, 25.9 (3C), 26.4 (3C), 29.6, 32.9, 42.0, 42.1, 48.2, 54.1, 63.4, 73.4, 76.9, 77.8, 117.2, 121.7, 124.3 [$^1J(\text{C},\text{F}) = 273.6$ Hz], 127.2, 130.7 [$^2J(\text{C},\text{F}) = 27.5$ Hz], 130.8 [$^3J(\text{C},\text{F}) = 6.2$ Hz], 133.2, 136.4, 152.6, 170.1, 172.4, 217.1;
- 10 LRMS (ESI) calcd. for $\text{C}_{45}\text{H}_{78}\text{F}_3\text{NO}_6\text{SSi}_3\text{Na}$ [$\text{M}+\text{Na}^+$] 924.5, found 924.5.



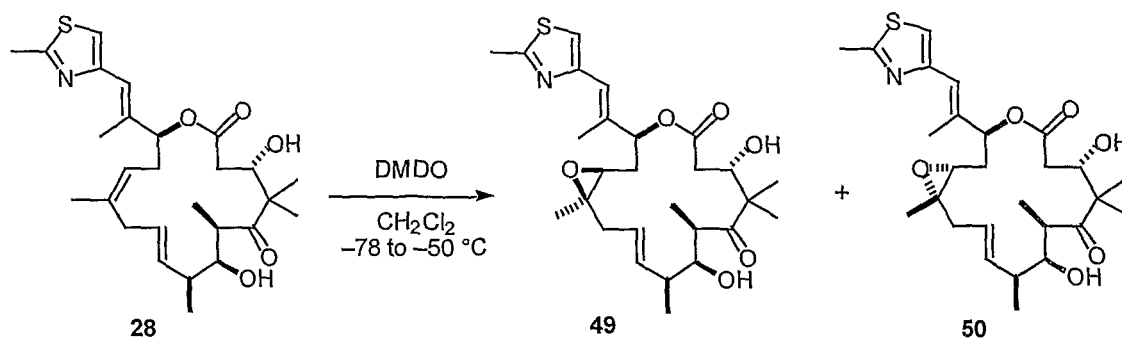
58a

- ^1H NMR (400 MHz, CDCl_3) δ 0.07 (3H, s), 0.13 (3H, s), 0.16 (6H, s), 0.48 (6H, q, $J = 7.8$ Hz), 0.84 (9H, t, $J = 7.9$ Hz), 0.97 (18H, s), 0.98 (3H, s), 1.06 (3H, d, $J = 7.1$ Hz), 1.11 (3H, s), 1.20 (3H, d, $J = 7.2$ Hz), 2.00 (3H, s), 2.03-2.11 (1H, m), 2.33 (1H, dd, $J = 14.1, 2.8$ Hz), 2.43 (1H, dd, $J = 14.0, 7.8$ Hz), 2.40-2.48 (1H, m), 2.76-2.89 (2H, m), 2.97-3.10 (2H, m), 3.99 (1H, d, $J = 9.3$ Hz), 4.57 (1H, dd, $J = 7.8, 2.6$ Hz), 4.95 (1H, d, $J = 14.6$ Hz), 5.00 (1H, d, $J = 14.6$ Hz), 5.33 (1H, ddd, $J = 15.6, 9.1, 3.8$ Hz), 5.82 (1H, dd, $J = 15.6, 8.3$ Hz), 6.30 (1H, s), 6.32-6.38 (1H, m), 7.04 (1H, s), 7.11 (1H, dd, $J = 11.0, 2.3$ Hz); LRMS (ESI) calcd for $\text{C}_{45}\text{H}_{78}\text{F}_3\text{NO}_6\text{SNa}$ [$\text{M}+\text{Na}^+$] 924.5, found 924.5.
- 15
- 20

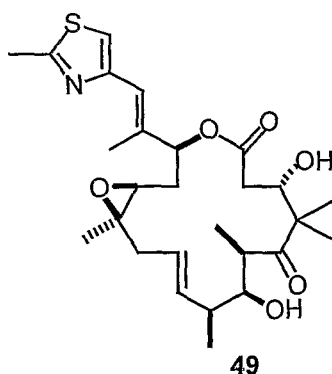
**59****Compound 59:**

To a solution of **58** (1.04 g, 2.25 mmol) in THF (22 mL) was added slowly HF·pyridine (11 mL) at 0 °C, and the mixture was stirred at rt for 4.3 h. The reaction was quenched with dropwise addition of TMSOMe (75 mL) over 10 min at 0 °C. The mixture was vigorously stirred at rt for 4.2 h. After concentrating and drying under high vacuum for 1 h, the residue was purified by flash column chromatography (SiO₂~25 g, hexane/EtOAc = 3:4 to 1:2) to give **59** (615.7 mg, 1.00 mmol, 96%) as a colorless powder;

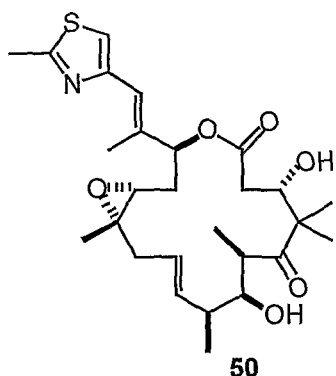
- 10 $[\alpha]_D^{25} -57.7$ (c 1.20, CHCl₃); ¹H NMR (400 MHz, CDCl₃) δ 1.04 (3H, s), 1.12 (3H, d, *J* = 6.9 Hz), 1.25 (3H, d, *J* = 6.8 Hz), 1.36 (3H, s), 1.90 (1H, d, *J* = 6.6 Hz, OH), 2.08 (3H, s), 2.23-2.32 (1H, m), 2.34 (1H, dd, *J* = 15.7, 2.4 Hz), 2.49 (1H, dd, *J* = 15.7, 10.1 Hz), 2.59-2.69 (2H, m), 2.95-3.01 (2H, m), 3.04 (1H, quintet, *J* = 6.8 Hz), 3.72 (1H, td, *J* = 7.0, 3.0 Hz), 3.78 (1H, d, *J* = 5.7 Hz, OH), 4.38 (1H, ddd, *J* = 10.1, 5.7, 2.4 Hz),
- 15 4.90 (2H, d, *J* = 6.1 Hz), 5.10 (1H, t, *J* = 6.1 Hz, OH), 5.44 (1H, t, *J* = 4.7 Hz), 5.60 (1H, dd, *J* = 15.9, 4.4 Hz), 5.66 (1H, dd, *J* = 15.9, 5.0 Hz), 6.28 (1H, t, *J* = 6.7 Hz), 6.73 (1H, s), 7.16 (1H, s); LRMS (ESI) calcd for C₂₇H₃₇F₃NO₆SNa [M+H⁺] 560.2, found 560.1.



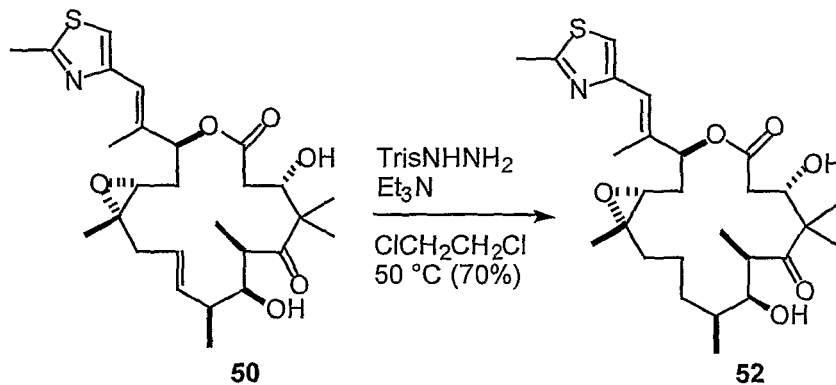
Compounds 49 and 50: A solution of **28** (12.2 mg, 24.9 μmol) in CH_2Cl_2 (1.25 mL) was cooled to -78°C and treated with a cooled solution of DMSO (-78°C , 0.06 M in acetone, 914 μL , 54.8 μmol). The mixture was allowed to warm to -50°C and stirred at -50°C for 2.7 h. The excess DMSO was quenched at -50°C by the addition of dimethylsulfide (117 μL) and the mixture was stirred at this temperature for 0.5 h. The solvent was removed in vacuo. Purification by preparative thin layer chromatography (hexane/EtOAc = 1/2) gave β -epoxide **49** (3.0 mg, 5.93 μmol , 24%) and α -epoxide **50** (7.9 mg, 15.6 μmol , 63%) both as colorless solids.



Compound 49: ^1H NMR (400 MHz, CDCl_3) δ 1.03 (3H, s), 1.11 (3H, d, $J = 7.0$ Hz), 1.14 (3H, d, $J = 6.9$ Hz), 1.34 (3H, s), 1.36 (3H, s), 2.00 (1H, ddd, $J = 15.1, 7.3, 4.0$ Hz), 2.14 (1H, dt, $J = 15.1, 5.2$ Hz), 2.14 (3H, s), 2.21 (1H, dd, $J = 14.6, 8.0$ Hz), 2.33 (1H, dd, $J = 14.7, 4.8$ Hz), 2.47 (1H, dd, $J = 13.8, 3.3$ Hz), 2.59 (1H, dd, $J = 13.8, 9.4$ Hz), 2.73 (3H, s), 2.77 (1H, brs, OH), 2.93 (1H, dd, $J = 7.3, 4.8$ Hz), 3.34 (1H, qd, $J = 6.9, 3.7$ Hz), 3.75-3.82 (1H, m), 4.12-4.24 (2H, m, including OH), 5.54 (1H, ddd, $J = 15.7, 7.4, 5.0$ Hz), 5.54-5.60 (1H, m), 5.64 (1H, dd, $J = 15.7, 5.6$ Hz), 6.94 (1H, s), 7.01 (1H, s); LRMS (ESI) calcd for $\text{C}_{27}\text{H}_{40}\text{NO}_6\text{S}$ [$\text{M} + \text{H}^+$] 506.3, found 506.3.



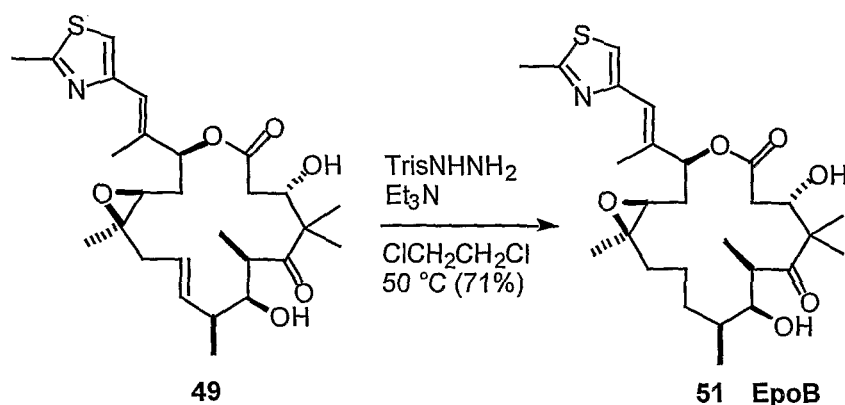
Compound 50: ^1H NMR (400 MHz, CDCl_3) δ 1.00 (3H, s), 1.04 (3H, d, $J = 6.9$ Hz), 1.12 (3H, d, $J = 7.0$ Hz), 1.35 (3H, s), 1.35 (3H, s), 1.87 (1H, dt, $J = 15.0, 9.2$ Hz), 2.03 (1H, dd, $J = 13.9, 9.2$ Hz), 2.13 (3H, s), 2.13-2.19 (1H, m), 2.36 (1H, dd, $J = 13.9, 3.4$ Hz), 2.39 (1H, dd, $J = 12.2, 2.1$ Hz), 2.42-2.51 (1H, m), 2.49 (1H, dd, $J = 12.4, 10.9$ Hz), 2.69 (1H, d, $J = 2.7$ Hz), 2.72 (3H, s), 3.06 (1H, dd, $J = 9.7, 3.1$ Hz), 3.54 (1H, qd, $J = 7.0, 2.0$ Hz), 3.76-3.80 (1H, m), 4.07-4.14 (1H, m), 4.31 (1H, d, $J = 4.1$ Hz), 5.52 (1H, dd, $J = 15.5, 8.7$ Hz), 5.60 (1H, ddd, $J = 15.1, 9.4, 3.4$ Hz), 5.71 (1H, d, $J = 8.4$ Hz), 6.63 (1H, s), 6.99 (1H, s); LRMS (ESI) calcd for $\text{C}_{27}\text{H}_{39}\text{NO}_6\text{SNa}$ $[\text{M} + \text{Na}^+]$ 528.2, found 528.2.



Compound 52: To a solution of **50** (1.7 mg, 3.4 μmol) and TrisNHNH_2 (40.1 mg, 0.134 mmol) in $\text{ClCH}_2\text{CH}_2\text{Cl}$ (0.8 mL) at 50 $^\circ\text{C}$ was added Et_3N (18.7 μL , 0.134 mmol). The reaction was monitored by HPTLC (hexane/ $\text{EtOAc} = 1/2$). After stirring for 4 h, the mixture was cooled to rt, diluted with EtOAc and filtered through a pad of silica gel, which was rinsed with EtOAc . After concentrating, the residue was purified by preparative TLC (hexane/ $\text{EtOAc} = 1/2$) to give **52** (1.2 mg, 2.4 μmol , 70%) as a white solid.

^1H NMR (400 MHz, CDCl_3) δ 0.95 (3H, d, $J = 7.1$ Hz), 1.04 (3H, s), 1.11 (3H, d, $J = 7.0$ Hz), 1.28 (3H, s), 1.37 (3H, s), 1.35-1.44 (1H, m), 1.45-1.59 (4H, m), 1.71-1.82

(2H, m), 1.86 (1H, dt, $J = 15.3, 9.5$ Hz), 2.10 (1H, dd, $J = 15.3, 3.6$ Hz), 2.13 (3H, s), 2.40 (1H, dd, $J = 12.5, 2.5$ Hz), 2.49 (1H, dd, $J = 12.5, 11.0$ Hz), 2.74 (3H, s), 2.80 (1H, brs, OH), 3.07 (1H, dd, $J = 10.3, 3.3$ Hz), 3.34 (1H, qd, $J = 7.0, 1.0$ Hz), 3.89 (1H, brs, OH), 4.03-4.09 (1H, m), 4.12-4.17 (1H, m), 5.69 (1H, d, $J = 9.1$ Hz), 6.63 (1H, s), 7.00 (1H, s); LRMS (ESI) calcd for $C_{27}H_{41}NO_6SNa$ $[M+Na]^+$ 530.3, found 530.2.



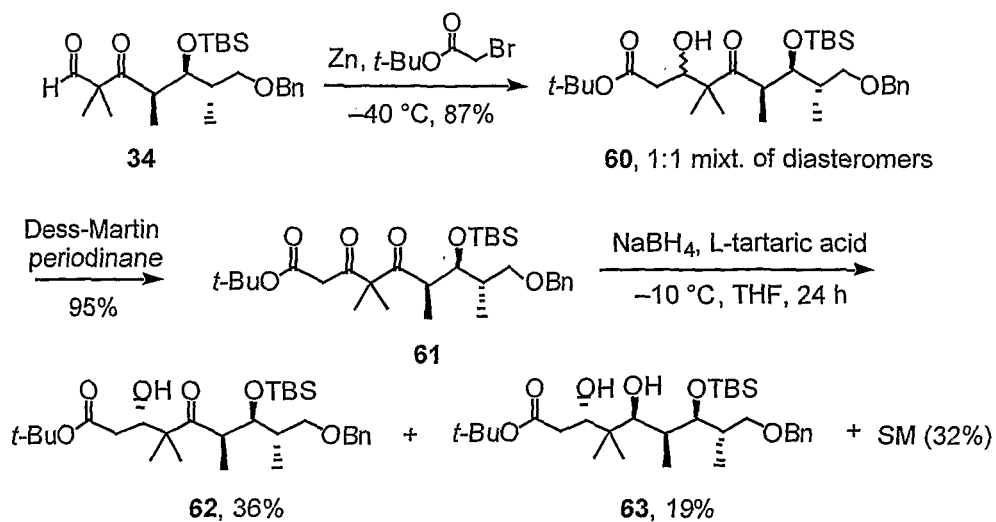
Compound 51: To a solution of **49** (0.7 mg, 1.38 μmol) and $\text{TrisNH}_2\text{NH}_2$ (20.6 mg, 69 μmol) in $\text{ClCH}_2\text{CH}_2\text{Cl}$ (0.4 mL) at 50 $^\circ\text{C}$ was added Et_3N (9.6 μL , 69 μmol). The reaction was monitored by HPTLC (hexane/ EtOAc = 1/2). After stirring for 6 h, the mixture was cooled to rt, diluted with EtOAc and filtered through a pad of silica gel, which was rinsed with EtOAc . After concentrating, the residue was purified by preparative TLC (hexane/ EtOAc = 1/2) gave **51** (0.5 mg, 0.985 μmol , 71%) as a white solid. The spectral data of **51** was identical to those reported of EpoB.

Example 2: Alternative synthetic strategies for synthesizing intermediates of epothilones

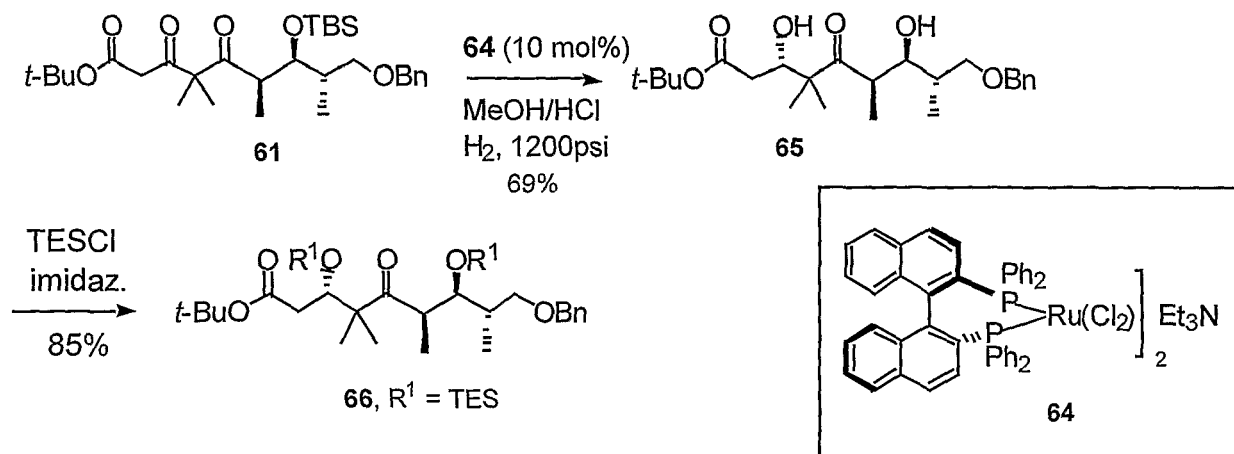
The following examples offer methods of preparing the various intermediates in
20 the synthesis of epothilone analogs.

Optimization of The Syntheses of 9,10-dehydroEpothilones

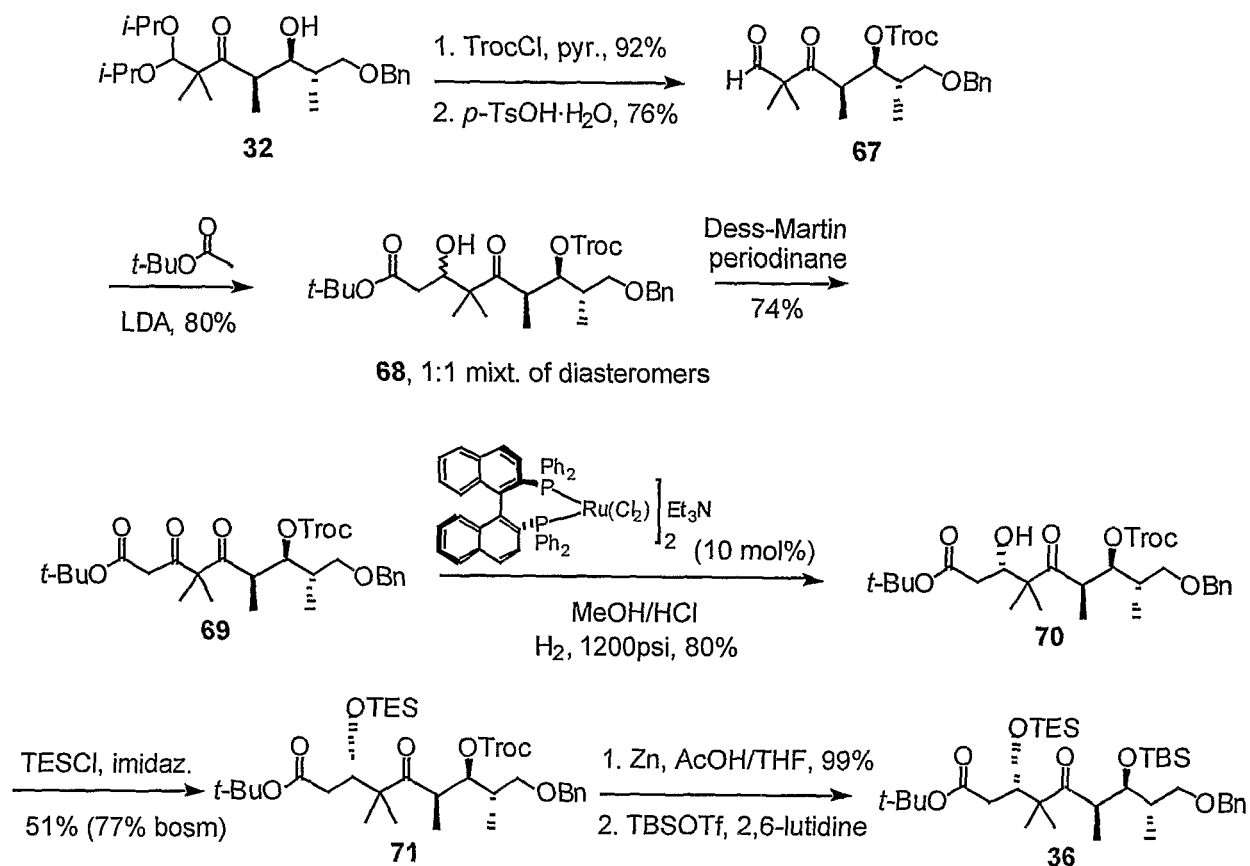
Example 1:



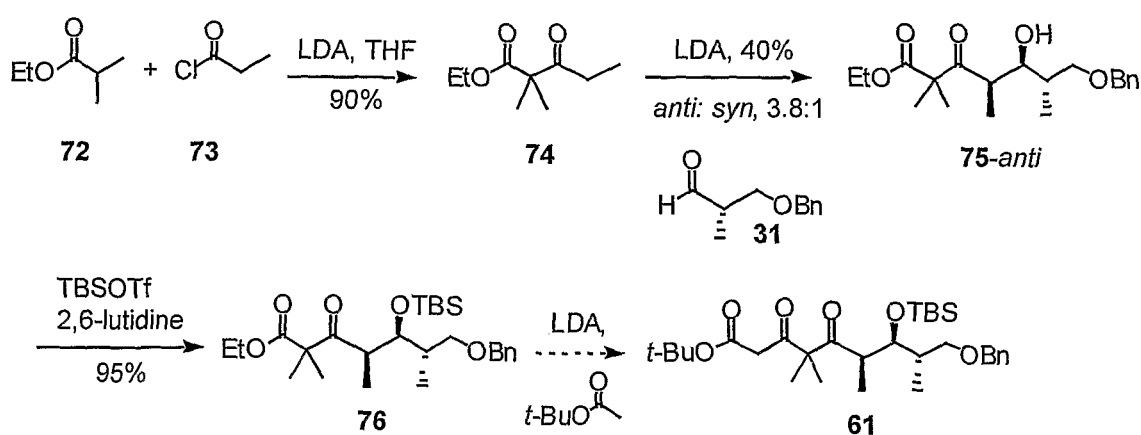
Example 2. Noyori Reductions

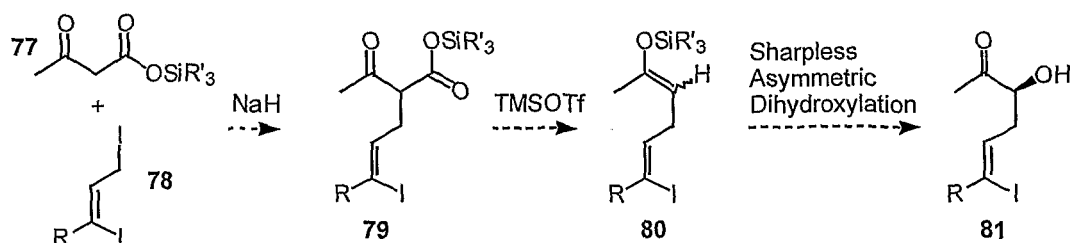
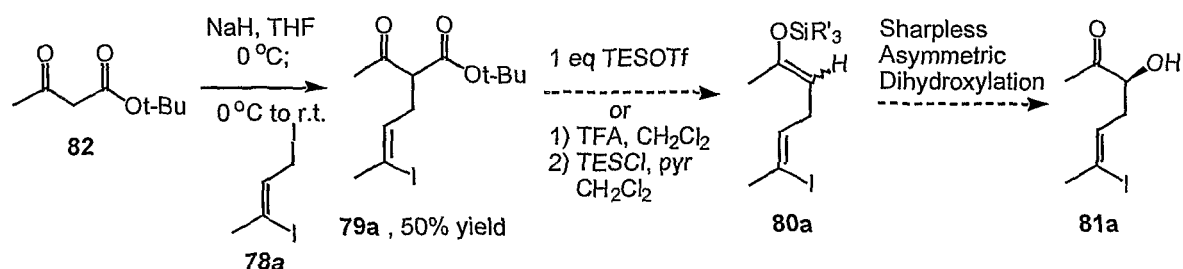
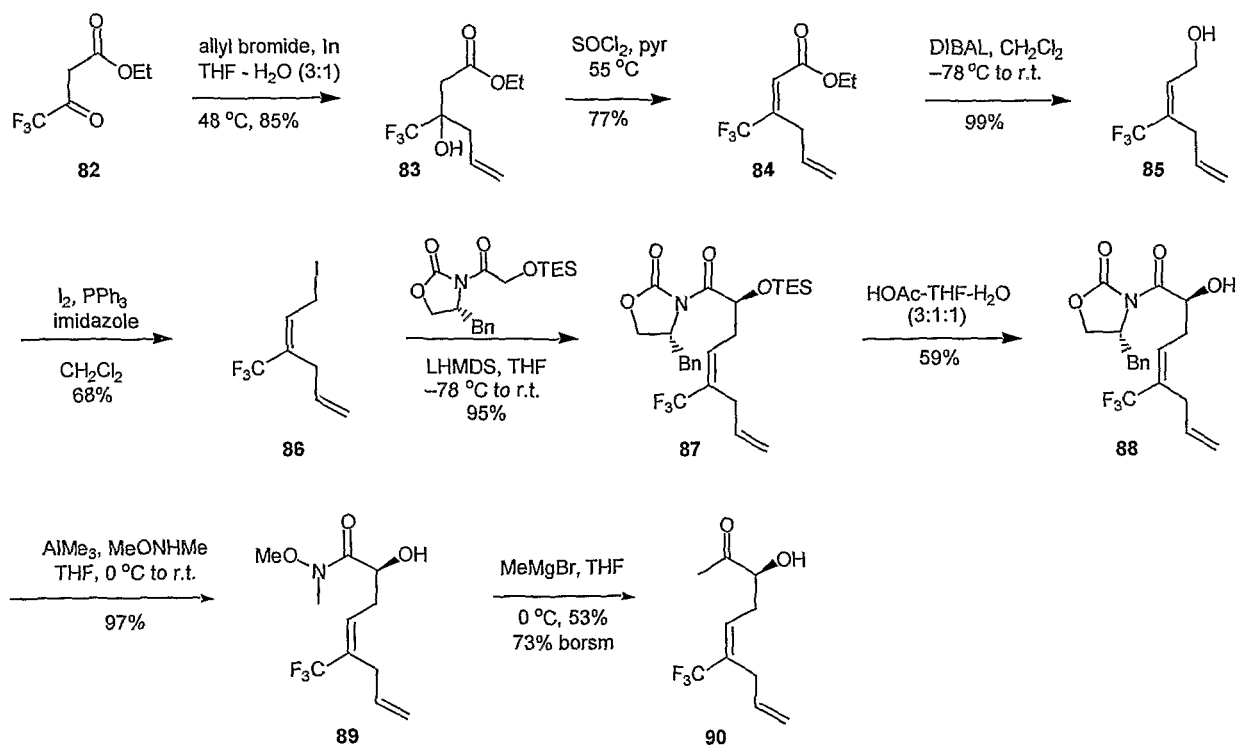


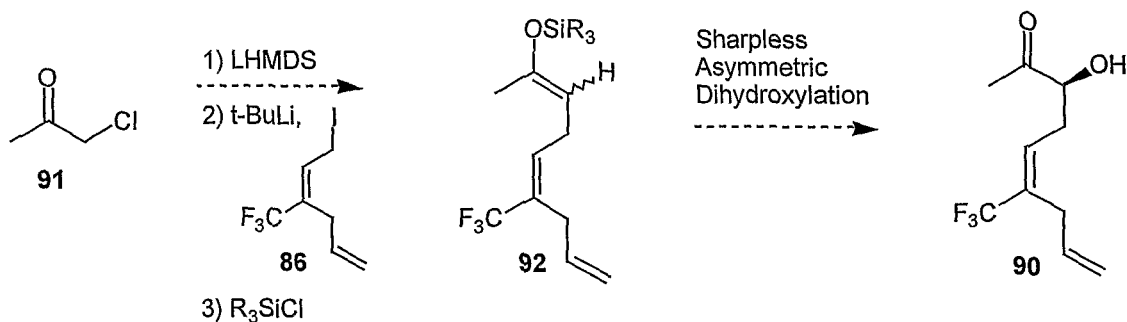
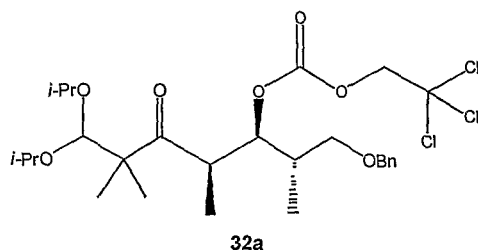
Example 3. Noyori Reductions



Example 4. Alternative Synthesis of the Key Diketone

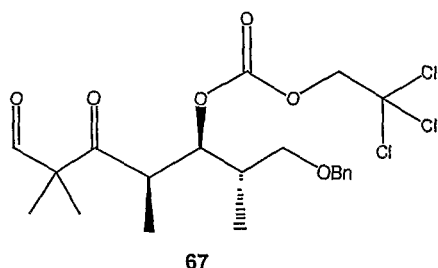


Example 5.**Approach 1. Silyl Group Migration - Decarboxylation****Approach 2. Decarboxylation - Silyl Group Incorporation****Example 6. Evans Auxiliary Approach to the Synthesis of 2-Hydroxyketone**

Example 7. Kowalsky - Sharpless Approach to the Synthesis of 2-Hydroxyketone**Experimentals**

5 Carbonic acid 1-(2-benzyloxy-1-methylethyl)-5,5-diisopropoxy-2,4,4-trimethyl-3-oxopentyl ester 2,2,2-trichloroethyl ester (32a)

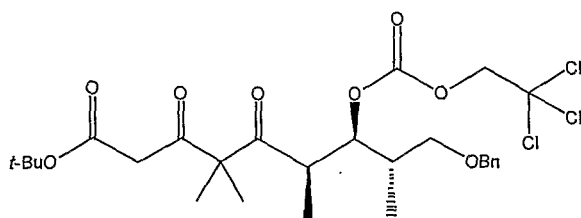
To a solution of 7-Benzyloxy-5-hydroxy-1,1-diisopropoxy-2,2,4,6-tetramethyl-heptan-3-one **32** (1.0 g, 2.4 mmol) and pyridine (0.8 mL, 7.3 mmol) in CH_2Cl_2 (10.0 mL) at 0 °C was added 2,2,2-trichloroethyl chloroformate (668.0 μ L, 4.9 mmol) and the mixture was then allowed to warm to rt. After 1 h, the reaction mixture was quenched with brine and then extracted with CH_2Cl_2 . The combined organic layers were dried over $MgSO_4$ and concentrated under reduced pressure. The crude product was purified by flash chromatography (gradient hexane to hexane/EtOAc 93:7) to give **32a** (1.285 g, 92%) as a clear oil: 1H NMR (400 MHz, $CDCl_3$) δ 1.03-1.09 (m, 12H), 1.15 (d, J = 1.8 Hz, 3H), 1.17 (d, J = 1.9 Hz, 3H), 1.19-1.21 (m, 6H), 1.97-2.11 (m, 1H), 3.2 (dd, J = 6.2 and 9.0 Hz, 1H), 3.54 (dd, J = 4.8 and 9.1 Hz, 1H), 3.57-3.60 (m, 1H), 3.82 (qd, J = 3.6 and 5.9 Hz, 2H), 4.47 (s, 2H), 4.57 (s, 1H), 4.72 (d, J = 11.9 Hz, 1H), 4.81 (d, J = 11.9 Hz, 1H), 5.08 (t, J = 6.0 Hz, 1H), 7.29-7.35 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 11.9, 15.0, 18.8, 21.4, 21.7, 22.3, 23.2, 23.4, 35.7, 42.5, 53.4, 53.9, 69.4, 70.9, 71.4, 73.3, 81.3, 94.7, 103.4, 127.5, 127.6, 128.2, 138.2, 154.0, 215.6; IR (film, NaCl, cm^{-1}) 2966, 1760, 1698, 1247; LRMS (ESI) calcd for $C_{27}H_{41}O_7Cl_3Na$ $[M+Na]^+$ 605.2, found 605.2; $[\alpha]_D^{23} = -20.4$ (c = 1.0, $CHCl_3$).



67

Carbonic acid 1-(2-benzyloxy-1-methylethyl)-2,4,4-trimethyl-3,5-dioxopentyl ester 2,2,2-trichloroethyl ester (67)

- 5 To solution of **32a** (1.28 g, 2.25 mmol) in 4:1 THF/H₂O (25 mL) was added *p*-TsOH (111.0 mg, 0.6 mmol). After heating at 70 °C. 5 h, the reaction mixture was poured into a cold (0 °C) sat. NaHCO₃ aq solution (12 mL) and then extracted with EtOAc. The combined organic layers were washed with brine, dried over MgSO₄ and concentrated under reduced pressure. The crude product was purified by flash chromatography
- 10 (gradient hexane to hexane/EtOAc 84:16) to give **67** (793.2 mg, 76%) as a clear oil: ¹H NMR (400 MHz, CDCl₃) δ 0.90 (d, *J* = 5.8 Hz, 3H), 1.0 (d, *J* = 6.9 Hz, 3H), 1.24 (s, 6H), 1.97-2.04 (m, 1H), 3.24 (dd, *J* = 4.8 and 9.2 Hz, 1H), 3.34 (m, 1H), 3.42 (dd, *J* = 5.8 and 9.2 Hz, 1H), 4.35 (d, *J* = 11.9 Hz, 1H), 4.39 (d, *J* = 11.9 Hz, 1H), 4.64 (d, *J* = 11.9 Hz, 1H), 4.69 (d, *J* = 11.9 Hz, 1H), 4.96 (t, *J* = 6.0 Hz, 1H), 7.19-7.28 (m, 5H),
- 15 9.49 (s, 1H); ¹³C NMR (100 MHz, CDCl₃) – 12.0, 14.8, 19.5, 19.6, 35.4, 43.3, 60.9, 71.1, 73.3, 80.37, 94.5, 127.7, 127.8, 128.3, 137.9, 154.1, 201.0, 210.1; IR (film, NaCl, cm⁻¹) 2973, 2880, 1758, 1701, 1453, 1380, 1248; LRMS (ESI) calcd for C₂₁H₂₇O₆Cl₃Na [M+Na⁺] 503.0, found 503.0; [α]_D²³ = –18.5 (c = 0.8, CHCl₃).



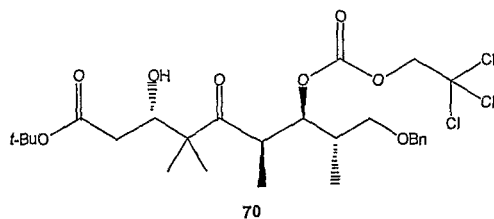
69

9-Benzyloxy-4,4,6,8-tetramethyl-3,5-dioxo-7-(2,2,2-trichloroethoxycarbonyloxy)-nonanoic acid *tert*-butyl ester (69)

- To a solution of LDA (1.17 mmol, 0.3 M in Et₂O) at –78 °C was added *t*-butyl acetate
- 25 (1.0 mmol, 135.0 μ L). After 30 min, a solution of **67** (464.0 mg, 1 mmol) in Et₂O (2

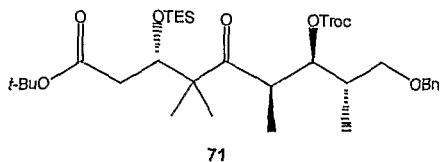
mL) was slowly added over 15 min. After stirring for 1 h, the reaction was quenched with a sat. NH_4Cl aq solution and then extracted with EtOAc. The combined organic layers were washed with brine, dried over MgSO_4 and concentrated under reduced pressure. The crude product was purified by flash chromatography (gradient hexane to hexane/EtOAc 86:14) to give **68** (1:1 epimeric mixture, 461.4 mg, 80%) as a clear oil: ^1H NMR (400 MHz, CDCl_3) δ 0.87 (d, $J = 5.3$ Hz, 3H), 0.89 (d, $J = 5.5$ Hz, 3H), 1.02-1.10 (m, 18H), 1.38 (s, 18H), 1.97-2.2 (m, 2H), 2.27-2.31 (m, 2H), 3.22-3.27 (m, 3H), 3.39-3.48 (m, 5H), 4.03-4.06 (m, 1H), 4.11-4.14 (m, 1H), 4.38-4.45 (m, 4H), 4.58-4.73 (m, 4H), 4.97 (t, $J = 5.8$ Hz, 1H), 5.02 (t, $J = 5.8$ Hz, 1H), 7.18-7.27 (m, 10H); ^{13}C NMR (100 MHz, CDCl_3) δ 11.9, 12.7, 14.9, 15.2, 18.7, 19.3, 21.4, 21.6, 28.0, 35.6, 37.4, 41.7, 42.0, 51.8, 51.9, 71.3, 71.3, 72.5, 73.0, 73.3, 73.3, 80.6, 81.2, 81.3, 94.6, 127.5, 127.7, 127.8, 128.3, 138.0, 138.1, 154.0, 154.1, 172.3, 172.4, 216.0, 216.3; IR (film, NaCl, cm^{-1}) 3509, 2975, 1759, 1707, 1368, 1248, 1152; LRMS (ESI) calcd for $\text{C}_{27}\text{H}_{39}\text{O}_8\text{Cl}_3\text{Na}$ [$\text{M} + \text{Na}^+$] 619.1, found 619.2.

To a 0°C solution of **68** (350.0 mg, 0.6 mmol) in CH_2Cl_2 (10 mL) was added Dess-Martin periodinane (398.0 mg, 0.9 mmol). The mixture was stirred at rt for 1 h and then poured into a well-stirred mixture of 1:1 sat. $\text{Na}_2\text{S}_2\text{O}_3$ /sat. NaHCO_3 . The layers were separated after 30 min. The aqueous layer was extracted three times with Et_2O . The combined organic extracts were washed with sat. NaHCO_3 , brine, dried over MgSO_4 and concentrated under vacuum. The crude product was purified by flash chromatography (gradient hexane to hexane/EtOAc 91:9) to give **69** (258.4 mg, 74%) as a clear oil: ^1H NMR (400 MHz, CDCl_3) δ 0.80 (d, $J = 6.9$ Hz, 3H), 0.87 (d, $J = 6.9$ Hz, 3H), 1.13 (s, 3H), 1.19 (s, 3H), 1.23 (s, 9H), 2.04-2.12 (m, 1H), 3.09-3.28 (m, 5H), 4.23 (s, 2H), 4.48 (d, $J = 11.9$ Hz, 1H), 4.55 (d, $J = 11.9$ Hz, 1H), 4.79 (dd, $J = 4.6$ and 7.3 Hz, 1H), 7.04-7.13 (m, 5H); ^{13}C NMR (100 MHz, CDCl_3) δ 11.7, 14.6, 20.7, 21.5, 27.9, 35.5, 42.2, 43.4, 63.3, 71.3, 73.3, 79.9, 81.5, 90.5, 94.5, 127.6, 127.7, 128.2, 138.0, 154.0, 166.2, 202.9, 210.0; IR (film, NaCl, cm^{-1}) 2977, 1758, 1697, 1368, 1248, 1154; LRMS (ESI) calcd for $\text{C}_{27}\text{H}_{37}\text{O}_8\text{Cl}_3\text{Na}$ [$\text{M} + \text{Na}^+$] 617.1, found 617.1; $[\alpha]_D^{23} = -49.1$ ($c = 0.9$, CHCl_3).



9-Benzyloxy-3-hydroxy-4,4,6,8-tetramethyl-5-oxo-7-(2,2,2-trichloroethoxycarbonyloxy)-nonanoic acid *tert*-butyl ester (70)

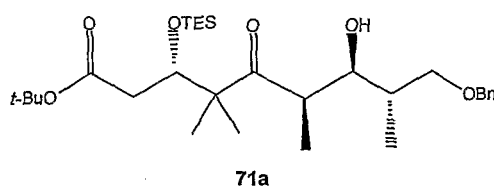
- 5 A bomb liner was charged with (*R*)-RuBINAP catalyst (16.8 mg, 10.0 μ mol). HCl (555 μ L, 0.2N in MeOH) was added and the mixture was then sonicated for 15 sec. Then a solution of **69** (59.4 mg, 0.1 mmol) in MeOH (555 μ L) was added and the mixture transferred to a Parr apparatus. The vessel was purged with H₂ for 5 min and then pressurized to 1200 psi. After 17 h, the reaction was returned to atmospheric pressure
- 10 and poured into a sat NaHCO₃ aq solution. The aqueous layer was extracted three times with EtOAc. The combined organic extracts were dried over MgSO₄ and concentrated under reduced pressure. The crude product was purified by flash chromatography (gradient hexane to hexane/EtOAc 88:12) to give **70** (dr >20:1 as judged by ¹H NMR analysis) (47.6 mg, 80%) as a clear oil: ¹H NMR (400 MHz, CDCl₃) δ 1.06 (d, *J* = 6.9 Hz, 3H), 1.11 (d, *J* = 6.8 Hz, 3H), 1.14 (s, 3H), 1.18 (s, 3H), 1.47 (s, 9H), 2.05-2.12 (m, 1H), 2.35-2.40 (m, 1H), 3.31-3.37 (m, 2H), 3.51-3.54 (m, 2H), 4.11-4.14 (m, 1H), 4.46 (s, 2H), 4.72 (d, *J* = 11.9 Hz, 1H), 4.80 (d, *J* = 11.9 Hz, 1H), 5.05 (dd, *J* = 5.0 and 6.7 Hz, 1H), 7.27-7.35 (m, 5H); ¹³C NMR (100 MHz, CDCl₃) δ 12.0, 15.0, 19.3, 21.7, 28.0, 35.6, 37.5, 41.7, 51.8, 71.3, 73.0, 73.3, 80.6, 81.3, 94.7, 127.5, 127.7, 128.3,
- 15 138.2, 154.1, 172.4, 216; IR (film, NaCl, cm⁻¹) 3849, 2974, 2879, 1758, 1701, 1454, 1368, 1248, 1152, 926, 734; LRMS (ESI) calcd for C₂₇H₃₉O₈Cl₃Na [M+Na⁺] 619.1, found 619.2; [α]_D²³ = -13.0 (c = 0.4, CHCl₃).
- 20



- 25 **9-Benzyloxy-4,4,6,8-tetramethyl-5-oxo-7-(2,2,2-trichloroethoxycarbonyloxy)-3-(triethylsilanyloxy)-nonanoic acid *tert*-butyl ester (71)**

To a solution of **70** (37.6 mg, 6.3 μ mol) and imidazole (9.4 mg, 13.8 μ mol) in DMF (0.4 mL) at 0 °C was added TESCl (11.6 μ L, 69.3 μ mol). After 3 h, the mixture was

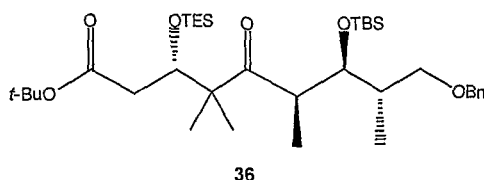
diluted with sat aq NaHCO₃. The aqueous layer was extracted three times with hexanes. The combined organic extracts were washed with brine, dried over MgSO₄ and concentrated under reduced pressure. The crude product was purified by flash chromatography (gradient hexane to hexane/EtOAc 93:7) to yield, in order of elution, 71 (22.9 mg, 51%), and recovered 70 (12.9 mg, 34%) as clear oils. 7: ¹H NMR (400 MHz, CDCl₃) δ 0.66 (q, *J* = 7.9 Hz, 6H), 0.96 (t, *J* = 7.9 Hz, 9H), 1.01 (s, 3H), 1.05 (d, *J* = 5.2 Hz, 3H), 1.07 (d, *J* = 5.3 Hz, 3H), 1.35 (s, 3H), 1.44 (s, 9H), 2.05-2.11 (m, 2H), 2.50 (dd, *J* = 3.5 and 17.2 Hz, 1H), 3.35 (dd, *J* = 5.9 and 9.0 Hz, 1H), 3.49 (dd, *J* = 4.0 and 9.0 Hz, 1H), 3.53 (dd, *J* = 3.8 and 6.7 Hz, 1H), 4.18 (dd, *J* = 3.5 and 6.5 Hz, 1H), 4.45 (s, 2H), 4.65 (d, *J* = 11.9 Hz, 1H), 4.79 (d, *J* = 11.9 Hz, 1H), 4.97 (dd, *J* = 3.7 and 8.1 Hz, 1H), 7.29-7.52 (m, 5H); ¹³C NMR (125 MHz, CDCl₃) δ 5.3, 7.3, 10.9, 14.9, 21.3, 22.6, 28.4, 35.9, 41.1, 42.7, 53.7, 71.9, 73.7, 75.7, 80.1, 80.9, 95.1, 127.9, 128.0, 128.7, 138.6, 154.3, 171.7, 215.7; IR (film, NaCl, cm⁻¹) 2956, 2876, 1732, 1694, 1456, 1366, 1257, 1154, 1098, 988, 835, 774, 741; LRMS (ESI) calcd for C₃₃H₅₃O₈SiCl₃Na [M+Na⁺] 733.2, found 733.3. [α]_D²³ = -16.1 (c = 0.1, CHCl₃).



9-Benzyloxy-3-(diethylmethylsilanyloxy)-7-hydroxy-4,4,6,8-tetramethyl-5-oxononanoic acid *tert*-butyl ester (71a)

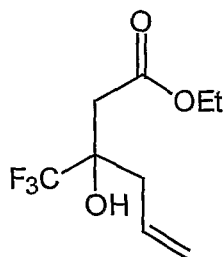
To a solution of 71 (22.9 mg, 3.2 μmol) in 1:1 THF/AcOH (1.4 mL) was added Zn (5.0 mg, 7.8 μmol, nanosize). The mixture was sonicated for 15 min. More Zn (5.0 mg, 7.8 μmol, nanosize) was added, followed by sonication for a further 15 min. The suspension was filtered through a celite pad, washing with EtOAc several times. The filtrates were washed with sat. NaHCO₃, brine, dried over MgSO₄ and concentrated under vacuum. The crude residue was passed through a short plug of silica gel eluting with hexane/EtOAc 4:1 to give 17.1 mg (99% yield) of 71a as colorless oil: ¹H NMR (400 MHz, CDCl₃) δ (m, 6H), 0.96 (t, *J* = 7.9 Hz, 9H), 0.97 (d, *J* = 6.8 Hz, 3H), 1.05 (d, *J* = 6.8 Hz, 3H), 1.11 (s, 3H), 1.26 (s, 3H), 1.44 (s, 9H), 1.84-1.90 (m, 1H), 2.21 (dd, *J* = 6.7 and 17.0 Hz, 1H), 2.36 (dd, *J* = 6.7 and 17.0 Hz, 1H), 3.24-3.29 (m, 1H), 3.44-3.52 (m, 2H), 3.67 (dd, *J* = 3.9 and 8.9 Hz, 1H), 4.36 (dd, *J* = 3.5 and 6.5 Hz, 1H),

- 4.50 (d, $J = 12.0$ Hz, 1H), 4.54 (d, $J = 12.0$ Hz, 1H), 7.32-7.36 (m, 5H); ^{13}C NMR (100 MHz, CDCl_3) δ 5.0, 6.9, 9.7, 13.9, 20.2, 21.8, 28.0, 36.3, 40.8, 41.5, 53.7, 72.5, 72.9, 73.2, 73.6, 80.7, 127.4, 127.5, 128.2, 138.6, 171.0, 221.4; IR (film, NaCl, cm^{-1}) 3502, 2959, 2875, 1731, 1683, 1456, 1366, 1154, 1098, 996, 739; LRMS (ESI) calcd for
- 5 $\text{C}_{30}\text{H}_{52}\text{O}_6\text{SiCl}_3\text{Na}$ $[\text{M}+\text{Na}^+]$ 559.3, found 559.3; $[\alpha]_D^{23} = -41.0$ ($c = 0.4$, CHCl_3).



9-Benzyloxy-7-(*tert*-butyldimethylsilanyloxy)-3-(diethylmethylsilanyloxy)-4,4,6,8-tetramethyl-5-oxo-nonanoic acid *tert*-butyl ester (36)

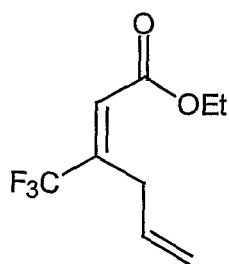
- 10 To a solution of **71a** (4.1 mg, 7.6 μmol) and 2,6-lutidine (10.0 μL , 43.5 mmol) in CH_2Cl_2 (0.2 mL) at -78°C was added TBSOTf (10.0 μL , 85.8 mmol). After 2 h, more ,6-lutidine (10.0 μL , 43.5 mmol) and TBSOTf (10.0 μL , 85.8 mmol) were added. After 6 h, the mixture was diluted with sat aq NaHCO_3 . The aqueous layer was extracted three times with EtOAc. The combined organic extracts were washed with brine, dried
- 15 over MgSO_4 and concentrated under reduced pressure. The crude product was purified by flash chromatography (gradient hexane to hexane/EtOAc 91:9) to give **36** (5.4 mg, 82%) as a clear oil. Spectroscopic data agreed well with the reported values.



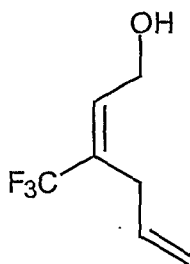
83

- 20 **Alcohol 83.** To a solution of ethyl 4,4,4-trifluoroacetoacetate (24.0 mL, 0.164 mol) in THF-water (3:1 = V:V, 320 mL) at room temperature were added allyl bromide (20.0 mL, 1.4 equiv) and indium (powder, -100 mesh, 25 g, 1.3 equiv) and the resulting mixture was stirred at 48°C for 15 h. The reaction mixture was cooled to room temperature, quenched with 2 N aq. HCl (400 mL) and extracted with CH_2Cl_2 (400 mL,
- 25 2 x 200 mL). Combined organics were dried (MgSO_4), filtered, and concentrated *in*

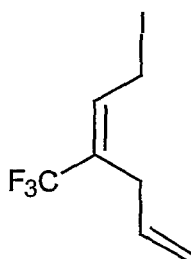
vacuo. Flash chromatography (hexanes → hexanes-ether 10:1 → 8:1 → 6:1 → 4:1) gave alcohol **83** as a clear oil (31.64 g, 85% yield): IR (film) 3426 (br m), 2986 (m), 1713 (s), 1377 (m), 1345 (m), 1301 (m), 1232 (m), 1173 (s), 1095 (m), 1023 (m), 927 (m) cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 5.82 (m, 1 H), 5.15 (m, 3 H), 4.17 (m, 2 H), 2.59 (m, 1 H), 2.58 (d, $J = 3.4$ Hz, 2 H), 2.29 (dd, $J = 14.2, 8.6$ Hz, 1 H), 1.24 (t, $J = 7.2$ Hz, 3 H); ^{13}C NMR (100 MHz, CDCl_3) δ 172.08, 130.89, 125.65 (q, $J = 280$ Hz), 120.27, 73.79 (q, $J = 28$ Hz), 61.55, 38.97, 35.65, 13.82; high resolution mass spectrum m/z 227.0895 $[(\text{M}+\text{H})^+]$; calcd for $\text{C}_9\text{H}_{14}\text{O}_3\text{F}_3$: 227.0895].



84
Ester 84. A mixture of alcohol **83** (16.71 g, 0.07386 mol) and pyridine (15.0 mL, 2.5 equiv) was cooled to -10 $^\circ\text{C}$ and treated with thionyl chloride (11.3 mL, 2.1 equiv) slowly over 11 min. The resulting mixture was warmed to 55 $^\circ\text{C}$ and stirred for 12 h. The reaction mixture was cooled to -5 $^\circ\text{C}$, quenched with water (200 mL) and extracted with CH_2Cl_2 (2 x 200 mL, 2 x 150 mL). Combined organics were washed with saturated NaHCO_3 (2 x 200 mL), and brine (200 mL), dried (MgSO_4), and concentrated *in vacuo*. Flash chromatography (pentane:ether 15:1) afforded ester **84** (11.90 g, 77% yield) as yellow oil: IR (film) 2986 (w), 1731 (s), 1308 (s), 1265 (w), 1227 (m), 1197 (s), 1133 (s), 1025 (m), 920 (w), 896 (w) cm^{-1} ; ^1H NMR (400MHz, CDCl_3) δ 6.36 (s, 1 H), 5.79 (ddt, $J = 16.9, 10.2, 6.6$ Hz, 1 H), 5.15 (dd, $J = 17.1, 1.5$ Hz, 1 H), 5.08 (dd, $J = 10.0, 1.4$ Hz, 1 H), 4.22 (q, $J = 7.1$ Hz, 2 H), 3.44 (d, $J = 6.5$ Hz, 2 H), 1.29 (t, $J = 7.1$ Hz, 3 H); ^{13}C NMR (100 MHz, CDCl_3) δ 164.22, 143.37 (q, $J = 29$ Hz), 132.71, 123.21 (q, $J = 274$ Hz), 122.60 (q, $J = 6$ Hz), 117.32, 60.85, 30.54, 13.85; high resolution mass spectrum m/z 209.0788 $[(\text{M}+\text{H})^+]$; calcd for $\text{C}_9\text{H}_{12}\text{O}_2\text{F}_3$: 209.0789].

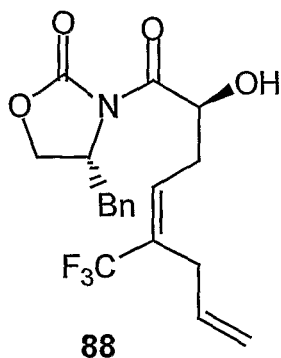
**85**

Alcohol 85. To a cooled (-75°C) solution of ester **84** (7.12 g, 0.0342 mol) in CH_2Cl_2 (120 mL) was added a solution of DIBAL-H (75 mL, 2.2 equiv) in CH_2Cl_2 (1.0 M) and the resulting mixture was warmed to room temperature over 3 h. The reaction mixture
 5 was cooled to 0°C , quenched with saturated NH_4Cl (12 mL) and stirred at room temperature for 20 min. The reaction mixture was diluted with ether (200 mL), dried (MgSO_4), and concentrated *in vacuo*. Flash chromatography (pentane:ether 3:1 $\rightarrow$ 1:1) provided alcohol **85** (5.68 g, 99%) as clear oil: IR (film) 3331 (br s), 2929 (m), 1642 (m), 1445 (m), 1417 (w), 1348 (s), 1316 (s), 1217 (s), 1175 (s), 1119 (s), 1045 (m), 985
 10 (s), 921 (m), 831 (w) cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 6.33 (td, $J = 6.1, 1.6$ Hz, 1 H), 5.75 (ddt, $J = 17.2, 10.0, 6.2$ Hz, 1 H), 5.07 (m, 2 H), 4.29 (ddd, $J = 6.3, 4.3, 2.1$ Hz, 2 H), 2.95 (d, $J = 6.2$ Hz, 2 H); ^{13}C NMR (100 MHz, CDCl_3) δ 134.45 (q, $J = 6$ Hz), 133.38, 127.97 (q, $J = 29$ Hz), 123.76 (q, $J = 271$ Hz), 116.25, 57.87, 29.79

**86**

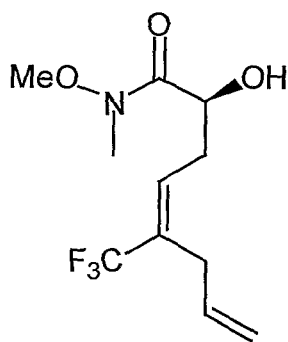
Iodide 86. A cooled (0°C) solution of alcohol **85** (5.97 g, 0.0358 mol) in CH_2Cl_2 (50 mL) was treated with PPh_3 (11.17 g, 1.2 equiv), imidazole (3.55 g, 1.5 equiv) and I_2 (9.10 g, 1.1 equiv) and the resulting mixture was stirred at 0°C for 10 min. The reaction mixture was quenched with saturated $\text{Na}_2\text{S}_2\text{O}_3$ -saturated NaHCO_3 (1:1 = V:V, 200 mL) and extracted with pentane (3 x 200 mL). Combined organics were washed
 20 with saturated $\text{Na}_2\text{S}_2\text{O}_3$ -saturated NaHCO_3 (1:1 = V:V, 200 mL), and brine (100 mL), dried (MgSO_4), and concentrated *in vacuo*. Flash chromatography (pentane) gave iodide **86** (6.69 g, 68%) as pale red oil: IR (film) 3083 (w), 2982 (w), 1636 (w), 1558 (w), 1456 (w), 1367 (w), 1317 (s), 1216 (m), 1181 (s), 1151 (s), 1120 (s), 989 (m), 921

(m), 896 (m) cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 6.45 (td, $J = 8.9, 1.5$ Hz, 1 H), 5.79 (ddt, $J = 16.8, 10.3, 6.2$ Hz, 1 H), 5.12 (m, 2 H), 3.85 (ddd, $J = 8.9, 2.9, 1.4$ Hz, 2 H), 3.00 (dt, $J = 6.1, 1.4$ Hz, 2 H); ^{13}C NMR (100 MHz, CDCl_3) δ 132.42, 131.64 (q, $J = 6$ Hz), 129.63 (q, $J = 29$ Hz), 123.64 (q, $J = 272$ Hz), 117.00, 29.32, -4.27 ; low resolution mass spectrum m/z 298.7 $[(\text{M}+\text{Na})^+]$; calcd for $\text{C}_7\text{H}_8\text{F}_3\text{INa}$: 299.0].

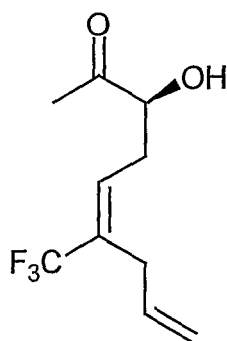


α -Hydroxyoxazolidinone 88. To a cooled (-78°C) of TES protected 4-Benzyl-3-hydroxy acetyl-oxazolidin-2-one **7** (16.28 g, 1.92 equiv) in THF (160 mL) was added a solution of LHMDS (42.0 mL, 1.73 equiv) in THF (1.0 M) dropwise over 51 min and the resulting mixture was stirred at -78°C for 35 min. The reaction mixture was treated with a solution of iodide **86** (6.69 g, 24.2 mmol) in THF (10 mL) and the resulting mixture was allowed to warm to room temperature slowly overnight. The reaction mixture was quenched with saturated NaHCO_3 (200 mL) and extracted with EtOAc (3 x 200 mL). Combined organics were washed with saturated NH_4Cl (150 mL), brine (150 mL), dried (MgSO_4), and concentrated *in vacuo*. Flash chromatography (hexanes:EtOAc 6:1 $\rightarrow$ 3:1) provided a mixture of alkylation products (13.6 g) which were used for the next reaction without further purification. A solution of the alkylation products in HOAc-water-THF (3:1:1 = V:V:V, 200 mL) was stirred at room temperature for 4 h. The reaction mixture was concentrated *in vacuo* to remove HOAc, quenched with saturated NaHCO_3 (400 mL), and extracted with EtOAc (3 x 200 mL). Combined organics were dried (MgSO_4), and concentrated *in vacuo*. Flash chromatography (hexanes:EtOAc 3:1 $\rightarrow$ 2:1) provided α -hydroxyoxazolidinone **88** (7.55 g, 81% yield for two steps) as clear oil: $[\alpha]_D^{25} -48.2$ (c 1.08, CHCl_3); IR (film) 3486 (br s), 3030 (m), 2983 (s), 2925 (m), 1790 (s), 1682 (s), 1481 (m), 1393 (m), 1360 (m), 1217 (m), 1171 (m), 1113 (m), 992 (m), 919 (m), 847 (w) cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 7.32 (m, 3 H), 7.17 (m, 2 H), 6.33 (td, $J = 7.2, 1.5$ Hz, 1 H), 5.77 (ddt, $J = 16.6, 10.1, 6.2$ Hz, 1 H), 5.08 (m, 3 H), 4.74 (ddt, $J = 4.8, 3.7, 4.4$ Hz, 1 H), 4.33 (dd, $J = 8.6, 8.6$

Hz, 1 H), 4.26 (dd, $J = 9.2, 3.4$ Hz, 1 H), 3.42 (br d, $J = 6.4$ Hz, 1 H), 3.24 (dd, $J = 13.5, 3.4$ Hz, 1 H), 2.99 (m, 2 H), 2.79 (dd, $J = 13.5, 9.4$ Hz, 1 H), 2.70 (m, 1 H), 2.50 (m, 1 H); ^{13}C NMR (125 MHz, CDCl_3) δ 173.93, 153.05, 134.43, 133.64, 129.98 (q, $J = 6$ Hz), 129.82 (q, $J = 28$ Hz), 129.29, 120.01, 127.58, 124.00 (q, $J = 272$ Hz), 116.34, 69.60, 67.31, 54.95, 37.78, 32.29, 29.84; high resolution mass spectrum m/z 384.1421 $[(\text{M}+\text{H})^+]$; calcd for $\text{C}_{19}\text{H}_{21}\text{NO}_4\text{F}_3$: 384.1423].

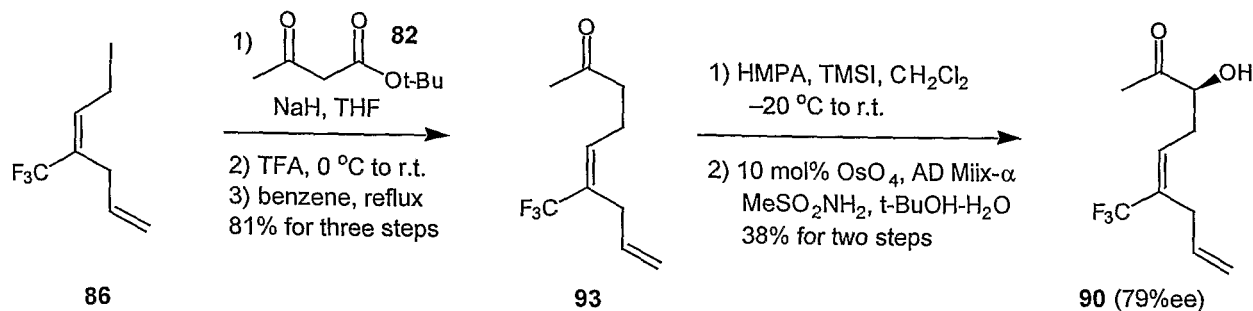
**89**

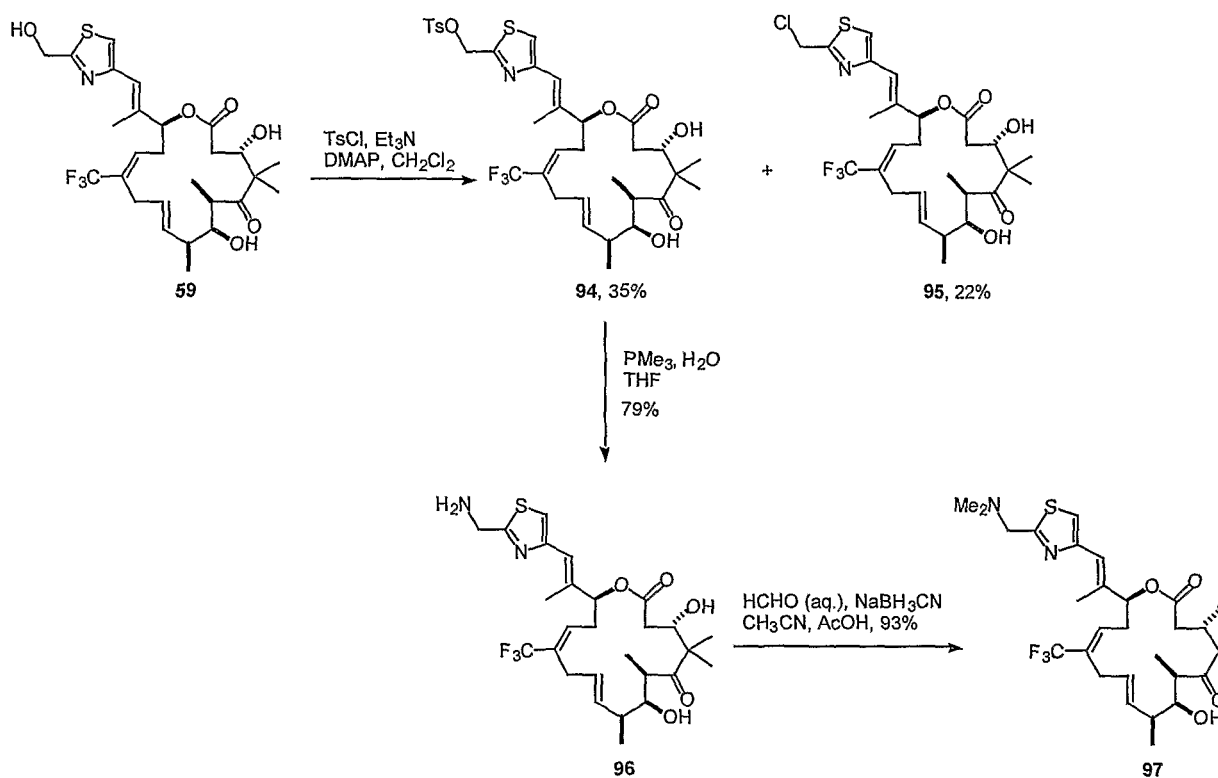
α -Hydroxyamide 89. A suspension of $(\text{MeO})\text{NHMe}\cdot\text{HCl}$ (10.1 g, 5.25 equiv) in THF (100 mL) at 0°C was treated with a solution of AlMe_3 (50 mL, 5.1 equiv) in toluene (2.0 M) dropwise and the resulting clear solution was stirred at room temperature for 34 min, then added to a cooled (0°C) solution of α -hydroxyoxazolidinone **88** (7.55 g, 19.7 mmol) in THF (70 mL). The resulting mixture was warmed to room temperature and stirred for 12 h. The reaction mixture was cooled to 0°C , quenched by slow addition of 1N aq. Tartaric acid (100 mL), stirred at room temperature for 25 min, and extracted with EtOAc (3 x 200 mL). Combined organics were dried (MgSO_4), and concentrated *in vacuo*. Flash chromatography (hexanes:EtOAc 2:1 $\rightarrow$ 1:1) gave α -hydroxyamide **89** (5.12 g, 97% yield) as clear oil: $[\alpha]_{\text{D}}^{25} -57.2$ (c 1.03, CHCl_3); IR (film) 3432 (br s), 3084 (w), 2980 (m), 2943 (m), 1652 (s), 1464 (m), 1373 (m), 1318 (m), 1214 (m), 1171 (m), 1112 (m), 991 (m), 919 (m), 818 (w) cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 6.32 (td, $J = 7.3, 1.5$ Hz, 1 H), 5.74 (ddt, $J = 16.9, 10.3, 6.1$ Hz, 1 H), 5.05 (m, 2 H), 4.43 (dd, $J = 7.6, 3.5$ Hz, 1 H), 3.70 (s, 3 H), 3.35 (br s, 1 H), 3.24 (s, 3 H), 2.94 (d, $J = 6.1$ Hz, 2 H), 2.59 (m, 1 H), 2.36 (m, 1 H); ^{13}C NMR (100 MHz, CDCl_3) δ 173.43, 133.68, 130.59 (q, $J = 6$ Hz), 129.25 (q, $J = 28$ Hz), 124.05 (q, $J = 271$ Hz), 116.17, 67.57, 61.44, 32.56, 32.38, 29.75; high resolution mass spectrum m/z 268.1161 $[(\text{M}+\text{H})^+]$; calcd for $\text{C}_{11}\text{H}_{17}\text{NO}_3\text{F}_3$: 268.1161].

**90**

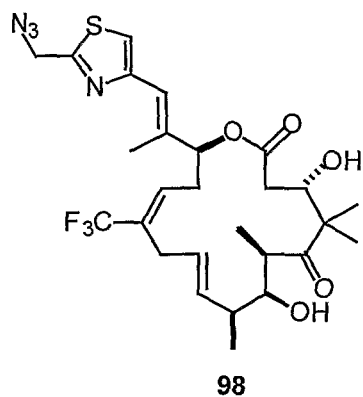
α -Hydroxyketone 90. To a cooled (0 °C) solution of α -hydroxyamide **89** (4.87 g, 18.2 mmol) in THF (150 mL) was added a solution of MeMgBr (75 mL, 12 equiv) in ether (3.0 M). After 5 min, the reaction mixture was quenched with saturated NH₄Cl (250 mL), and extracted with EtOAc (5 x 200 mL). Combined organics were dried (MgSO₄), and concentrated *in vacuo*. Flash chromatography (hexanes:EtOAc 4:1 → 2:1 → 1:2) provided α -hydroxyketone **90** (2.16 g, 53% yield, 73% yield based on the recovered starting material) as clear oil and the starting material α -hydroxyamide **89** (1.30 g, 27% yield): $[\alpha]_D^{25} +58.5$ (c 1.30, CHCl₃); IR (film) 3460 (br s), 3085 (w), 2984 (m), 2926 (m), 1716 (s), 1679 (m), 1641 (m), 1417 (m), 1361 (m), 1319 (s), 1247 (m), 1216 (s), 1172 (s), 1113 (s), 1020 (m), 994 (m), 968 (w), 919 (m) cm⁻¹; ¹H NMR (500 MHz, CDCl₃) δ 6.21 (t, J = 7.0 Hz, 1 H), 5.75 (ddt, J = 16.7, 10.4, 6.2 Hz, 1 H), 5.07 (m, 2 H), 4.26 (dt, J = 7.1, 4.5 Hz, 1 H), 3.51 (d, J = 4.7 Hz, 1 H), 2.96 (d, J = 6.1 Hz, 2 H), 2.66 (m, 1 H), 2.42 (m, 1 H), 2.19 (s, 3 H); ¹³C NMR (100 MHz, CDCl₃) δ 208.53, 133.43, 129.80 (q, J = 28 Hz), 129.76 (q, J = 6 Hz), 123.85 (q, J = 271 Hz), 116.32, 75.36, 31.22, 29.81, 25.11; high resolution mass spectrum m/z 223.0945 [(M+H)⁺; calcd for C₁₀H₁₄NO₂F₃: 223.0946].

Example 8: Catalytic Asymmetric Oxidation Approach



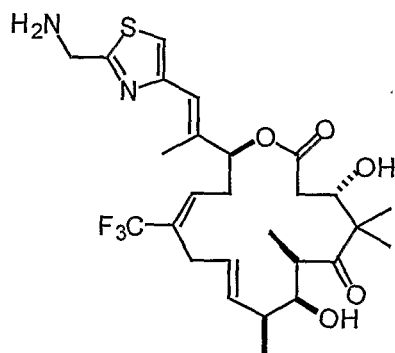
Example 9: Synthesis of 21-amino-26-trifluoro-(*E*)-9,10-dehydro-dEpoB

5

**Compound 98:**

To a solution of **59** (50.4 mg, 90.1 μ mol) in THF (1 mL) was added (PhO)₂PON₃ (27.2 μ L, 126 μ mol) at 0 °C. After stirring at 0 °C for 5 min, DBU (16.2 μ L, 108 μ mol) was added. After stirring at 0 °C for 2 h, the mixture was stirred at rt for 20.5 h. The reaction mixture was diluted with EtOAc and quenched by addition of water (2 mL). After the layers were separated, the aqueous layer was extracted with EtOAc (three times), and the combined organic layers were dried over Na₂SO₄. After concentrating,

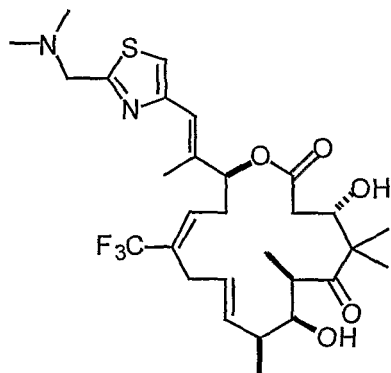
the residue was dried under high vacuum for 10 min to remove DBU. Purification by flash column chromatography (SiO₂, hexane/EtOAc = 3:2) gave azide **98** (45.6 mg, 78.0 μmol, 87%) as a colorless solid; ¹H NMR (400 MHz, CDCl₃) δ 1.05 (3H, s), 1.12 (3H, d, *J* = 7.0 Hz), 1.23 (3H, d, *J* = 6.8 Hz), 1.33 (3H, s), 2.01 (1H, d, *J* = 5.5 Hz, OH), 2.17 (3H, s), 2.25-2.35 (1H, m), 2.41 (1H, dd, *J* = 15.5, 3.2 Hz), 2.49 (1H, dd, *J* = 15.5, 9.5 Hz), 2.54-2.60 (1H, m), 2.66 (1H, d, *J* = 6.0 Hz), 2.65-2.76 (1H, m), 2.96 (1H, dd, *J* = 16.0, 4.2 Hz), 3.03 (1H, dd, *J* = 16.1, 6.7 Hz), 3.11 (1H, quintet, *J* = 6.8 Hz), 3.71-3.76 (1H, m), 4.31 (1H, ddd, *J* = 9.2, 5.9, 3.2 Hz), 4.65 (2H, s), 5.43 (1H, dd, *J* = 6.0, 4.3 Hz), 5.58 (1H, ddd, *J* = 15.8, 6.4, 4.6 Hz), 5.66 (1H, dd, *J* = 15.8, 6.1 Hz), 6.23 (1H, t, *J* = 7.3 Hz), 6.63 (1H, s), 7.18 (1H, s); LRMS (ESI) calcd for C₂₇H₃₅F₃N₄O₅SNa [M+Na⁺] 607.2, found 607.2.

**96****Compound 96:**

To a solution of azide **98** (21.0 mg, 35.9 μmol) in THF (0.6 mL) was added PMe₃ (1.0 M in THF, 43.1 μL, 43.1 μmol). After stirring at rt for 2 min, water (0.1 mL) was added and the mixture was stirred at rt for 3 h. PMe₃ (1.0 M in THF, 7.2 μL, 7.2 μmol) was added and the mixture was stirred at rt for 1.5 h. To the mixture was added 28% NH₄OH (aq.) (54.5 μL). After stirring for 1 h, the mixture was directly purified by preparative TLC (CH₂Cl₂/MeOH = 100:7.5) to give amine **96** (15.9 mg, 28.5 μmol, 79%) as a colorless solid;

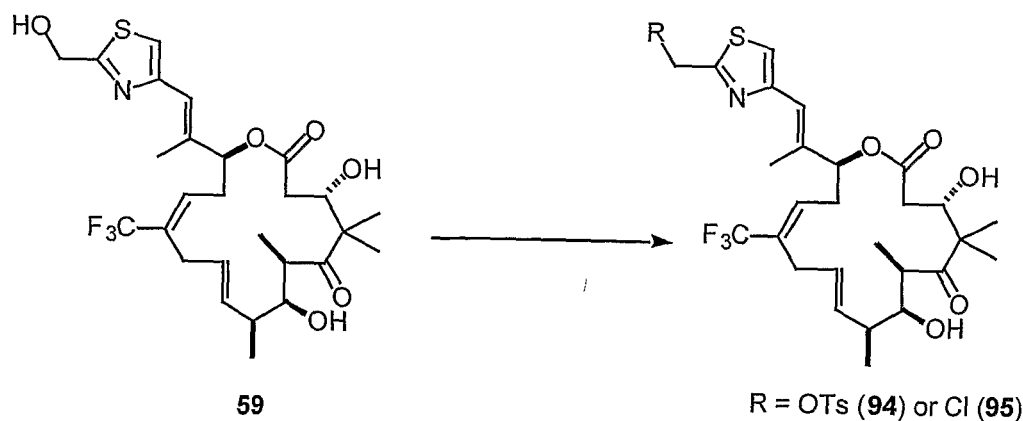
¹H NMR (400 MHz, CDCl₃) δ 1.05 (3H, s), 1.12 (3H, d, *J* = 7.0 Hz), 1.23 (3H, d, *J* = 6.8 Hz), 1.34 (3H, s), 2.12 (3H, d, *J* = 0.7 Hz), 2.24-2.35 (1H, m), 2.39 (1H, dd, *J* = 15.4, 3.0 Hz), 2.49 (1H, dd, *J* = 15.4, 9.8 Hz), 2.54-2.63 (1H, m), 2.66-2.76 (1H, m), 2.97 (1H, dd, *J* = 16.2, 4.2 Hz), 3.03 (1H, dd, *J* = 16.3, 6.5 Hz), 3.10 (1H, quintet, *J* = 6.8 Hz), 3.74 (1H, dd, *J* = 6.7, 3.5 Hz), 4.18 (2H, s), 4.34 (1H, dd, *J* = 9.8, 2.9 Hz), 5.43

(1H, dd, $J = 6.0, 4.3$ Hz), 5.55-5.64 (1H, m), 5.67 (1H, dd, $J = 15.9, 5.8$ Hz), 6.24 (1H, brt, $J = 7.3$ Hz), 6.66 (1H, s), 7.10 (1H, s); LRMS (ESI) calcd for $C_{27}H_{38}F_3N_2O_5S$ $[M+H^+]$ 559.2, found 559.2.

**97****Compound 97:**

To a solution of amine **96** (15.9 mg, 28.5 μ mol) in CH_3CN (0.78 mL) was added 37% HCHO (aq.) (31.4 μ L, 0.143 mmol) followed by $NaBH_3CN$ (1.0 M in THF, 85.5 μ L, 85.5 μ mol), and the mixture was stirred at rt for 20 min. AcOH (1 drop) was added, and the mixture was stirred at rt for 40 min. The mixture was purified directly by preparative TLC ($CH_2Cl_2/MeOH = 100:8$) to give the product **97** (15.6 mg, 26.6 μ mol, 93%) as a colorless solid;

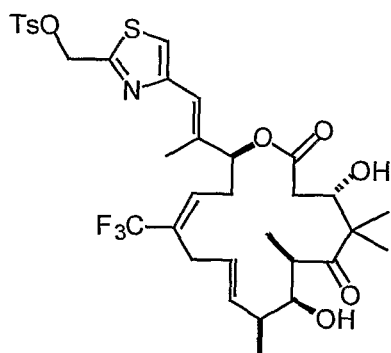
1H NMR (400 MHz, $CDCl_3$) δ 1.05 (3H, s), 1.12 (3H, d, $J = 6.9$ Hz), 1.23 (3H, d, $J = 6.8$ Hz), 1.33 (3H, s), 2.17 (3H, s), 2.24-2.35 (1H, m), 2.43 (1H, dd, $J = 15.7, 3.6$ Hz), 2.49 (1H, dd, $J = 15.6, 9.1$ Hz), 2.55-2.64 (2H, m, including OH), 2.68-2.77 (1H, m), 2.80 (3H, s), 2.81 (3H, s), 2.92-3.06 (2H, m), 3.10 (1H, quintet, $J = 6.8$ Hz), 3.69-3.76 (1H, m), 4.25-4.34 (1H, m), 4.33 (2H, s), 5.42 (1H, t, $J = 5.5$ Hz), 5.57 (1H, dt, $J = 15.8, 6.3$ Hz), 5.66 (1H, dd, $J = 15.7, 6.4$ Hz), 6.22 (1H, brt, $J = 7.2$ Hz), 6.64 (1H, s), 7.30 (1H, s); LRMS (ESI) calcd for $C_{29}H_{42}F_3N_2O_5S$ $[M+H^+]$ 580.2, found 580.2.



Compounds **94** and **95**:

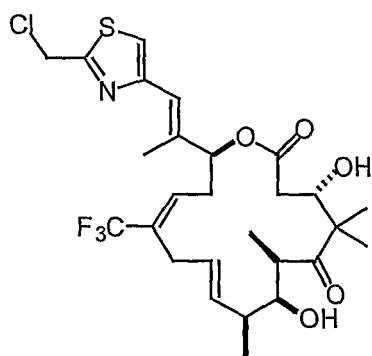
To a mixture of **59** (18.9 mg, 33.8 μ mol) and Et₃N (18.8 μ L, 0.135 mmol) in CH₂Cl₂ (1 mL) was added TsCl (12.9 mg, 67.5 μ mol) and DMAP (2.1 mg, 16.9 μ mol) at 0 °C.

- 5 After stirring at rt for 1.5 h, the mixture was diluted with EtOAc and filtered through a pad of silica gel (EtOAc rinse). After concentrating, the residue was purified by preparative TLC (hexane/EtOAc = 1:1) to give tosylate **94** (8.5 mg, 11.9 μ mol, 35%) and chloride **95** (4.3 mg, 7.44 μ mol, 22%); both as colorless solids;

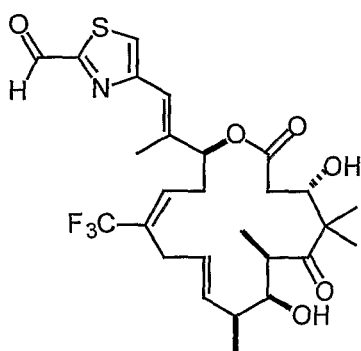


10

- ¹H NMR (400 MHz, CDCl₃) δ 1.06 (3H, s), 1.12 (3H, d, J = 7.0 Hz), 1.23 (3H, d, J = 6.7 Hz), 1.33 (3H, s), 1.99 (1H, d, J = 5.5 Hz), 2.10 (3H, s), 2.25-2.34 (1H, m) 2.41 (1H, dd, J = 15.5, 3.3 Hz), 2.47 (3H, s), 2.48 (1H, dd, J = 15.7, 9.4 Hz), 2.51-2.63 (1H, m), 2.63 (1H, d, J = 6.1 Hz, OH), 2.64-2.75 (1H, m), 2.91-3.05 (2H, m), 3.10 (1H, quintet, J = 6.8 Hz), 3.70-3.75 (1H, m), 4.30 (1H, ddd, J = 9.3, 6.1, 3.2 Hz), 5.32 (2H, s), 5.41 (1H, dd, J = 5.8, 4.5 Hz), 5.57 (1H, ddd, J = 15.8, 6.4, 4.6 Hz), 5.65 (1H, dd, J = 15.8, 6.0 Hz), 6.21 (1H, t, J = 7.1 Hz), 6.59 (1H, s), 7.18 (1H, s), 7.37 (2H, d, J = 8.1 Hz), 7.84 (2H, d, J = 8.3 Hz); LRMS (ESI) calcd for C₃₄H₄₂F₃NO₈S₂Na [M+Na⁺] 736.2, found 736.3.
- 15

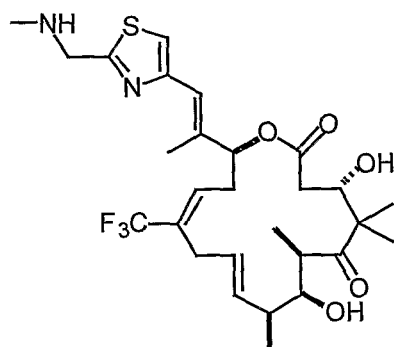
**95**

¹H NMR (400 MHz, CDCl₃) δ 1.06 (3H, s), 1.12 (3H, d, *J* = 6.9 Hz), 1.23 (3H, d, *J* = 6.7 Hz), 1.34 (3H, s), 2.00 (1H, d, *J* = 5.6 Hz, OH), 2.15 (3H, s), 2.25-2.35 (1H, m),
 5 2.41 (1H, dd, *J* = 15.5, 3.2 Hz), 2.49 (1H, dd, *J* = 15.5, 9.4 Hz), 2.53-2.62 (1H, m), 2.69 (1H, d, *J* = 6.1 Hz, OH), 2.66-2.76 (1H, m), 2.92-3.05 (2H, m), 3.11 (1H, quintet, *J* = 6.4 Hz), 3.70-3.76 (1H, m), 4.32 (1H, ddd, *J* = 9.2, 5.9, 3.1 Hz), 4.85 (2H, s), 5.43 (1H, dd, *J* = 6.0, 4.4 Hz), 5.59 (1H, ddd, *J* = 15.9, 6.4, 4.5 Hz), 5.66 (1H, dd, *J* = 15.9, 6.1 Hz), 6.23 (1H, t, *J* = 6.8 Hz), 6.63 (1H, s), 7.20 (1H, s); LRMS (ESI) calcd for
 10 C₂₇H₃₅ClF₃NO₅SNa [M+Na⁺] 600.2, found 600.2.

**99****Compound 99:**

To a solution of **59** (6.9 mg, 12.3 μmol) in CH₂Cl₂ (0.4 mL) was added activated MnO₂
 15 (purchased from Acros, 26.8 mg, 0.308 mmol). After vigorously stirring at rt for 4 h, the mixture was filtered through a pad of Celite, which was rinsed with EtOAc. After concentrating, the residue was purified by preparative TLC (hexane/EtOAc = 1:1) to give aldehyde **99** (2.7 mg, 4.84 μmol, 39%) as a colorless solid;

^1H NMR (400 MHz, CDCl_3) δ 1.06 (3H, s), 1.13 (3H, d, $J = 7.2$ Hz), 1.24 (3H, d, $J = 6.9$ Hz), 1.35 (3H, s), 1.96 (1H, d, $J = 5.6$ Hz, OH), 2.22 (3H, d, $J = 0.7$ Hz), 2.25-2.35 (1H, m), 2.44 (1H, dd, $J = 15.4, 3.5$ Hz), 2.46 (1H, d, $J = 5.9$ Hz, OH), 2.51 (1H, dd, $J = 15.7, 9.3$ Hz), 2.57-2.8 (1H, m), 2.68-2.79 (1H, m), 2.96-3.03 (2H, m), 3.10 (1H, quintet, $J = 6.8$ Hz), 3.71-3.76 (1H, m), 4.31 (1H, ddd, $J = 9.4, 6.3, 3.5$ Hz), 5.45 (1H, t, $J = 5.0$ Hz), 5.53-5.63 (1H, m), 5.67 (1H, dd, $J = 15.7, 6.2$ Hz), 6.24 (1H, t, $J = 6.6$ Hz), 6.72 (1H, s), 7.57 (1H, d, $J = 0.9$ Hz), 10.01 (1H, d, $J = 1.2$ Hz).

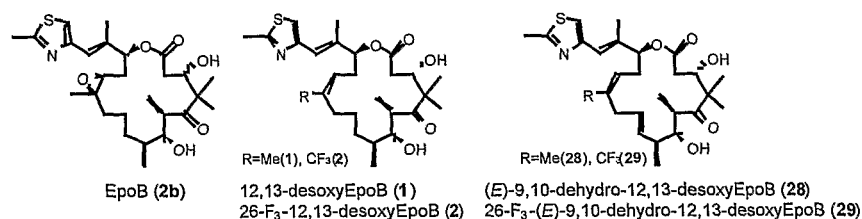
**100****10 Compound 100:**

To a solution of aldehyde **99** (4.6 mg, 8.25 μmol) in CH_3CN (0.5 mL) at 0 $^\circ\text{C}$ was added MeNH_2 (2.0 M in THF, 41.3 μL , 41.3 μmol). After stirring at 0 $^\circ\text{C}$ for 15 min, NaBH_3CN (1.0 M in THF, 25 μL , 25 μmol) was added. After stirring at 0 $^\circ\text{C}$ for 0.5 h, AcOH (3 drops) was added. After stirring at 0 $^\circ\text{C}$ for 2 h, 28% NH_4OH (aq.) (40 μL) was added, and the mixture was stirred at rt for 10 min. The mixture was directly purified twice by preparative TLC ($\text{CH}_2\text{Cl}_2/\text{MeOH} = 100:9$) to give **100** (2.4 mg, 4.19 μmol , 51%) as a colorless solid;

^1H NMR (400 MHz, CDCl_3) δ 1.05 (3H, s), 1.12 (3H, d, $J = 7.0$ Hz), 1.23 (3H, d, $J = 6.8$ Hz), 1.34 (3H, s), 2.13 (3H, s), 2.25-2.34 (1H, m), 2.39 (1H, dd, $J = 15.3, 3.0$ Hz), 2.49 (1H, dd, $J = 15.3, 9.7$ Hz), 2.56 (3H, s), 2.54-2.64 (1H, m), 2.66-2.75 (1H, m), 2.89 (1H, d, $J = 5.1$ Hz), 2.94-3.05 (2H, m), 3.11 (1H, quintet, $J = 6.8$ Hz), 3.74 (1H, dd, $J = 6.6, 3.5$ Hz), 4.08 (2H, s), 4.34 (1H, dd, $J = 9.6, 2.9$ Hz), 5.43 (1H, dd, $J = 6.2, 4.1$ Hz), 5.56-5.63 (1H, m), 5.66 (1H, dd, $J = 15.9, 5.7$ Hz), 6.24 (1H, t, $J = 7.3$ Hz), 6.66 (1H, s), 7.11 (1H, s); LRMS (ESI) calcd for $\text{C}_{28}\text{H}_{40}\text{F}_3\text{N}_2\text{O}_5\text{S}$ [$\text{M}+\text{H}^+$] 573.3, found 573.3.

Example 10: Epothilone Analogs that ablate Xenograft Tumors to a Non-Relapsable State

By a combination of chemical synthesis, molecular modeling, and spectroscopic analysis, we discovered that introduction of an *E*-9,10-double bond (see compound **28** below) accomplishes ca. 10 fold enhancement of drug potency in xenograft experiments with drug resistive MX-1 tumors (A. Rivkin *et al. J. Am. Chem. Soc.* **2003**, *125*, 2899; incorporated herein by reference). Following correlation of in vitro and in vivo experiments directed to MX-1 tumor types, it was apparent that **28** is inherently more cytotoxic than **2b**. However, another contributing factor is that the lactone moiety in the 9,10-dehydro series is significantly more stable in mouse and human plasma than is the case for 9,10-dehydro congeners. The sum of these two complementary effects was to render **28** capable of accomplishing complete suppression of tumor in a variety of xenografts at 3 mg/kg as opposed to 30 mg/kg regimen for **1**.



Upon suspension of treatment, palpable tumors re-appear in some fraction of the animals. Accordingly, at least at present, fully synthetic **28** has not fully met the stringent standards of highly favorable effective therapeutic index and elimination of tumors to a non-relapsing state.

These findings directed our attention to the consequences of substituting the three hydrogens of the 26-methyl group of **28** with three fluorine atoms. Incorporation of the fluorine atoms at this site led to improved stability of the 12,13-double bond toward oxidation (Smart, B. E. *J. Fluorine Chem.* **2001**, *109*, 3; incorporated herein by reference). Previous experience had pointed toward some attenuation of cytotoxicity, by placement of polar groups in the area of the C12-C13 double bond (A. Rivkin *et al. J. Am. Chem. Soc.* **2003**, *125*, 2899; incorporated herei by reference). In this disclosure, we report the discovery, through total chemical synthesis, of the 9,10-dehydro-26-trifluoroepothilones, focusing particularly on the unique biological performance of parent structure **29**.

The therapeutic efficacy of dEpoB (30 mg/kg), paclitaxel (20 mg/kg) and F₃-deH-dEpoB (**29**, 20 and 30 mg/kg) against human mammary carcinoma MX-1 xenografts in terms of tumor disappearance and relapse were closely studied, and the results are shown in Table 10-1. Each dose group consisted of four or more nude mice.

- 5 Body weight refers to total body weight minus tumor weight. All three compounds achieved tumor disappearance. On day 10 after suspension of treatment, 5/10 (dEpoB), 2/7 (Paclitaxel), and 0/4 (compound **29**) mice relapsed. Extended observation following suspension of treatment with 20 mg/kg dosages of **29** showed a long term absence of tumors until day 27 at which point 2 out of 4 mice's tumors relapsed.
- 10 Remarkably, treatment with 30 mg/kg dosages of **29**, resulted in complete tumor disappearance and the absence of any relapse for over two months after suspension of treatment.

Table 10-1. Therapeutic effect of dEpoB, Paclitaxel and F₃-deH-dEpoB against MX-1 xenograft in nude mice^[a]

Drug	Dosage (mg/kg)	Changes of body weight (%)		Tumor free after Q2Dx6 6hr-iv. Infusion	Tumor reappeared on day 10 after administration
		On day 4 after stopping administration	On day 8 after stopping administration		
dEpoB (1)	30	- 25.3 ± 2.1	- 9.1 ± 4.1	10/10	5/10
Paclitaxel	20	- 23.9 ± 3.7	- 8.7 ± 0.7	7/7	2/7
F ₃ -deH-dEpoB (29)	20	- 22.4 ± 0.6	- 7.3 ± 0.7	4/4	0/4 ^[b]
	30	- 27.1 ± 2.7	- 17.4 ± 5.5	4/4	0/4 ^[b]

- ^[a] Human mammary carcinoma MX-1 xenograft tissue 50 mg was implanted S.C. on Day 0. The treatment, Q2Dx 6 6hr-iv infusion was started on Day 8 and stopped on Day 18.

^[b] Detectable tumor reappearance in 2/4 on 27th day after stopping treatment. No further tumor reappearance during the 28th - 64th days after stopping treatment.

^[c] No tumor reappearance during 64 days after stopping treatment when experiment terminated.

Lowering the dose of agent **29** to 10 mg/kg (Q2D) also led to MX-1 tumor disappearance, but nine doses were required to achieve this result (Figures 57, 58 and 59A). As an added challenge, chemotherapeutic treatment was delayed until the tumor

size reached 0.5 g (~2.3% of body weight). Treatment with 25 mg/kg (Q2Dx7) dosages of **29**, caused 4/4 of the mouse tumors to disappear. By contrast for dEpoB, 30 mg/kg dosages (Q2Dx8) were required to induce the disappearance of tumors in 3 of 4 mice. However, unlike the case with **29**, the apparent disappearances that occurred following treatment with dEpoB were subject to relapses with time. (Figure 59B).

The fact that agent **29** completely suppressed the growth of the human mammary carcinoma MX-1 xenografts, shrank the tumors and made them disappear for as long as 64 days is impressive. Moreover, following the cures accomplished by **29**, (20 mg/kg or 30 mg/kg Q2Dx6, i.v.-6hr infusion, Table 1, above) the body weight of the xenografts returned to pretreatment control level within 12-18 days after suspension of treatment. This finding suggests the lack of vital organ damage. At a curative low dosage of 10 mg/kg, Q2DX12 (Figure 59B), the maximal body weight decrease was only 12%, with a body weight gain of 6% during the last three doses. The body weight recovered to the pretreatment control level only three days after cessation of treatment. Table 1 above shows that the animals could survive body weight losses of as much as 27%. The therapeutic safety margin realized herein is remarkably broad for a curative cancer therapeutic agent.

The therapeutic efficacy of **29** against human lung carcinoma xenograft (A549) and the paclitaxel resistant human lung carcinoma A549/Taxol xenografts were also evaluated (Figure 59C and 59D). The slow growing lung carcinoma xenografts A549 were treated with **29** (25 mg/kg, Q2DX6, twice, eight days apart), which resulted in 99.5% tumor suppression with the eventual complete eradication of 4 of the 4 tumors after two more doses (Figure 59C). Interestingly, the body weight of the mice decreased as much as 35% without any lethality and suspension of the treatment led to rapid body weight recovery to near the pretreatment control level (Figure 59C). In contrast, a parallel study with dEpoB (30 mg/kg, Q2Dx6) resulted in 97.6% tumor suppression but led to no tumor eradication. In an additional study of **29** (20 mg/kg dosage) against A549/Taxol resistant xenograft (Figure 59D), tumor growth was totally suppressed and the tumor eventually reduced by 24.4% of the pretreatment control. During this study, the maximal body weight decreased by 24%, however upon suspension of drug treatment the body weight recovered to 90% of the pretreatment control. In a comparison study of (*E*)-9,10-dehydro-dEpoB (**28**, 4 mg/kg group), tumor growth was suppressed by 41.6%.

The pertinent data for analyzing what factors endow compound **29** with its remarkable therapeutic index in conjunction with comparable data pertinent to closely related congeners are provided in Table 10-2. One notes that in terms of inherent cytotoxicity in moving from EpoB(**2b**) to dEpoB (**1**) a whole order of magnitude is lost. About 60% of this loss is restored in the case of 9,10-dehydro-dEpoB (**28**). Some of this inherent cytotoxicity is forfeited in going to **29**, which at least in the cell is ~ 1.8 fold as cytotoxic as the benchmark compound dEpoB.

We note that among the 12,13-dehydroepothilones, **29** exhibits by far the best stability in mouse plasma and is also the most stable in human liver S9 plasma. We also note that, in the 2-sets of 12,13-dehydro isomers, the 26-trifluoro pattern carries with it decreased lypophilicity and somewhat increased water solubility (Table 10-2, below). For the moment it would appear that the great advantage of **29** arises from improvements in serum stability and bioavailability.

Table 10-2: Profile of dEpoB derivatives.

Compounds	Cytotoxic Efficacy IC ₅₀ (nM) ^[a]	Maximal b.w. % drop without death	Stability half-life		Solubility in water (µg/mL)	Lipophilicity octanol/water partition (POW)	Therapeutic dose regimen for Q2D 6hr – iv infusion (mg/kg)	Relative therapeutic index at MTD ^[b]
			Mouse plasma (min)	Human Liver S9 Fraction (hr)				
EpoB (2b)	0.53± 0.2	15	57	15.8	ND	ND	0.6-0.8	+++
dEpoB (1)	5.6± 2.8	32	46 ± 7	1.0±0.1	9.4	4.4	25-30	++++
deH-dEpoB (28)	0.90± 0.40	29	84 ± 6	4.9±0.7	27	3.3	3-4	++++
F ₃ -dEpoB (2)	9.3± 5.2	22	66 ± 7	1.6±0.4	8	4.1	15-20	++
F ₃ -deH-dEpoB (29)	3.2± 0.3	33	212± 88	10.5±2.3	20	3.3	10-30	+++++

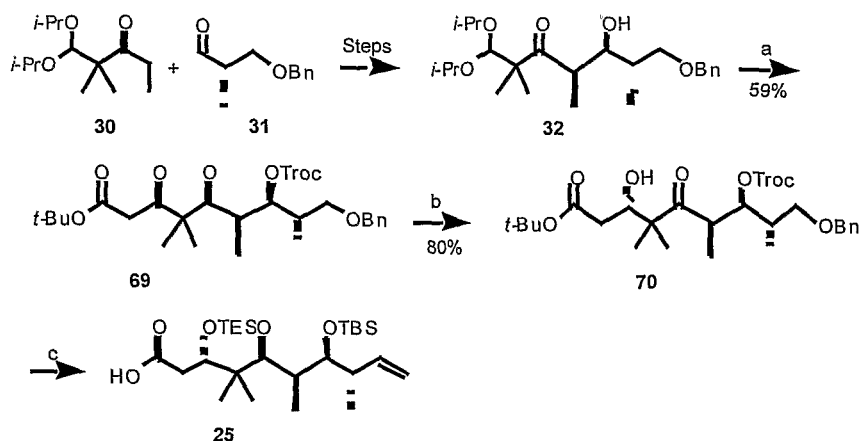
^[a] IC₅₀ values are for CCRF-CEM leukemic cells. Values are the range of two experiments; all values are obtained from seven concentration points; ND = Not Determined.

^[b] Graded relative therapeutic index (TI) at MTD (maximal tolerated dose):

- + Tumor growth suppressed 25-50%.
 - ++ Tumor growth suppressed 50-100%.
 - +++ Tumor shrinkage but no tumor disappearance.
 - ++++ Tumor disappearance in some or all nude mice with slow body weight recovery and/or with relapse in some mice within one week after stopping treatment.
 - +++++ Tumor disappeared in all nude mice, body weight rapidly recovered and/or without relapse.
- The therapeutic experiment for epothilones against human xenografts in nude mice, such as MX-1, were studied in Chou, T. C. et al. *Proc. Natl. Acad. Sci. USA*. **1998**, *95*, 15798 and in **2001**, *98*, 8113.

All of the agents, **1-2** and **28-29**, were initially discovered through total synthesis. A practical synthesis of **1** has been previously described (Rivkin *et al. J. Am. Chem. Soc.* **2003**, *125*, 2899; White *et al. J. Am. Chem. Soc.* **2001**, *123*, 5407; Yoshimura *et al. Angew. Chem.* **2003**, *42*, 2518; Rivkin *et al. J. Org. Chem.* **2002**, *124*, 7737; each of which is incorporated herein by reference). First generation discovery level routes to **28** and **29** have also been described. Selective reduction of the 9,10-double bond of **29** afforded **2**. The remarkable results obtained from xenograft studies described above, for what is currently the most promising compound **29**, clearly called for its advancement for detailed toxicology and pharmacokinetic studies in higher animals and, from there if appropriate, advancement to human clinical trials. Such prospects totally altered the nature of the synthesis challenge from the preparation of probe samples, to that of producing multigram quantities of these new epothilone agents. A major revamping of our previous routes, initially conceived and demonstrated in a discovery setting, has been accomplished. In particular our new protocols accomplished major simplifications in the stereospecific elaborations of carbons 3 and 26. Alcohol **32** is prepared as described earlier (Rivkin *et al. J. Am. Chem. Soc.* **2003**, *125*, 2899; incorporated herein by reference). It will be noted that in the new synthesis, stereocenters 6, 7, and 8 are derived from the trivially available ketone **30** and aldehyde **31**. Upon alcohol protection and acetal hydrolysis, the corresponding aldehyde was condensed with t-butyl acetate to afford an aldol like product. Since this condensation is not diastereomerically-controlled, a remedial measure was necessary and achieved. Oxidation of this 1:1 mixture of C3 epimers, afforded ketone **69**. Following a highly successful Noyori reduction (Noyori *et al. J. Am. Chem. Soc.* **1987**, *109*, 5856; incorporated herein by reference) under the conditions shown, alcohol **70** was in hand. Preparation of acid **25** was then accomplished in a few additional simple steps as shown.

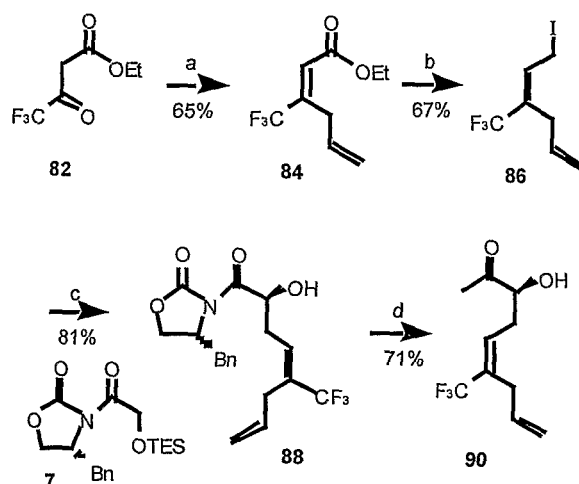
Scheme 12. Synthesis of the acyl sector **25**.



Reagents and conditions: (a) (i) TrocCl, pyr., 92%; (ii) p-TsOH·H₂O, 76%; (iii) LDA, *t*-butyl acetate, THF, 80%; (iv) Dess-Martin periodinane, 74%; (b) Noyori catalyst (10 mol%), MeOH/HCl, H₂, 1200psi, 80%. (c) (i) TESCl, imidazole, 77%; (ii) Zn, AcOH, THF, 99%; (iii) TBSOTf, 2,6-lutidine, 82%; for remaining steps see Rivkin *et al.* *J. Am. Chem. Soc.* **2003**, 125, 2899.

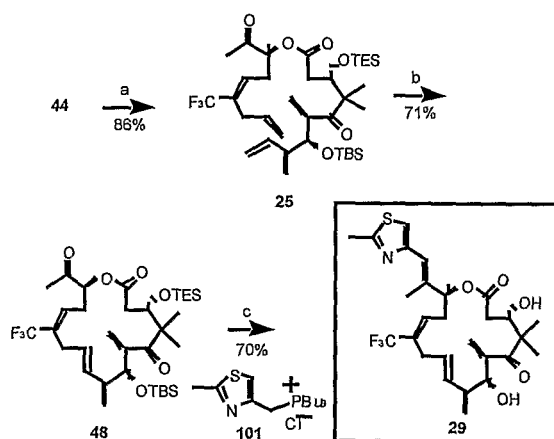
A new, straightforward and readily scalable synthesis has also been developed for **90** (Scheme 13). The synthesis starts with reaction of commercially available trifluoro ketoester **82** with allyl indium bromide. The key step in the synthesis is the positionally specific and stereospecific dehydration of the resulting tertiary alcohol to produce **84** (in 65% overall yield for two steps). The stereocontrol of this reaction arises from a “dipolar effect” wherein the strongly electron-withdrawing CF₃ and CO₂Et groups are best presented *trans* with respect to the emerging double bond. The required iodide **86** was obtained in two steps from **84**. Alkylation of the previously reported lithium enolate of **7** with iodide **86** in THF afforded **88** in 81% yield and high diastereoselectivity (>25:1 de). Following deprotection of the secondary alcohol, compound **88** was advanced in three steps to **90** as shown.

Scheme 13. Synthesis of the alkyl sector 17.



Reagents and conditions: (a) (i) Allyl bromide, In, THF-water (3:1) 48 °C, 85%; SOCl₂, pyr 55 °C, 77%; (b) (i) DIBAL-H, CH₂Cl₂, -78 °C to r.t. 99%; (ii) I₂, PPh₃, imidazole, CH₂Cl₂, 74%; (c) (i) LHMDS, THF, -78 °C to r.t.; (ii) HOAc-THF-H₂O (3:1:1), 81% for two steps; (d) (i) AlMe₃, MeONHMe, THF, 0 °C to r.t., 97%; (ii) MeMgBr, THF, 0 °C, 53% (73% overall)

With **25** and **90** in hand by easily processable chemistry, the route to **29** was clear following protocols first developed in our discovery phase (A. Rivkin et al. *J. Am. Chem. Soc.* **2003**, *125*, 2899; incorporated herein by reference). The key ring-closing metathesis reaction of **25** was carried out in toluene using the second generation Grubbs catalyst (Grubbs, R. H.; Miller, S. J.; Fu, G. C. *Acc. Chem. Res.* **1995**, *28*, 446; Trnka, T. M.; Grubbs, R. H. *Acc. Chem. Res.* **2001**, *34*, 18; *Alkene Metathesis in Organic Chemistry* Ed.: Fürstner, A.; Springer, Berlin, (1998); Fürstner, A. *Angew. Chem. Int. Ed. Engl.* **2000**, *39*, 3012; Schrock, R. R. *Top. Organomet. Chem.* **1998**, *1*, 1; each of which is incorporated herein by reference). The reaction afforded, exclusively the *trans* isomer **48** in 71% yield. Installation of the thiazole moiety via the protocol shown in Scheme 14 was followed by removal of the two silyl protecting groups with HF-pyridine thereby leading to **29**, which was then converted via reduction of the 9,10-olefin to **2** in high yield. Gram quantities of structurally novel epothilones have been prepared by total syntheses in the setting of an academic scale laboratory.

Scheme 14. Final steps of the synthesis of 26-CF₃-(*E*)-9,10-dehydro-dEpoB (**29**).

Reagents and conditions: (a) EDCI, DMAP, CH₂Cl₂, **25**, 0 °C to rt, 86% from *t*-butyl ester; (b) Grubb's catalyst, toluene, 110 °C, 20 min, 71%; (c) (i) KHMDS, **101**, THF, –
 5 78 °C to –20 °C, 70%; (ii) HF-pyridine, THF, 98%.

Experimentals.

General Methods: Reagents obtained from commercial suppliers were used without
 10 further purification unless otherwise noted. Methylene chloride was obtained from a
 dry solvent system (passed through a prepacked column of alumina) and used without
 further drying. All air and water sensitive reactions were performed in flame-dried
 glassware under a positive pressure of prepurified argon gas. NMR (¹H and ¹³C) spectra
 were recorded on Bruker AMX-400 MHz or Bruker Advance DRX-500 MHz as noted
 15 individually, referenced to CDCl₃ (7.27 ppm for ¹H and 77.0 ppm for ¹³C) or CD₂Cl₂
 (5.32 ppm for ¹H and 53.5 ppm for ¹³C). Infrared spectra (IR) were obtained on a
 Perkin-Elmer FT-IR model 1600 spectrometer. Optical rotations were obtained on a
 JASCO model DIP-370 digital polarimeter. Analytical thin-layer chromatography was
 performed on E. Merck silica gel 60 F254 plates. Compounds which were not UV
 20 active were visualized by dipping the plates in *para*-anisaldehyde solution and heating.
 Preparative thin layer chromatography was performed using the indicated solvent on
 Whatman® (LK6F Silica gel 60A) TLC plate.

Chemicals. All epothilones were synthesized in-house (C. R. Harris, S. J. Danishefsky,
 25 *J. Org. Chem.* **1999**, 64, 8434; D.-S. Su et al. *Angew. Chem. Int. Ed. Engl.* **1997**, 36,
 2093; Smart, B. E. *J. Fluorine Chem.* **2001**, 109, 3; F. Yoshimura, et al. *Angew. Chem.*

2003, 42, 2518; Rivkin et al. *J. Org. Chem.* **2002**, 124, 7737; each of which is incorporated herein by reference). Paclitaxel (Taxol[®]) and vinblastine sulfate (VBL) were purchased from Sigma. All these compounds were dissolved in dimethylsulfoxide for the *in vitro* assays, (except VBL in saline). For *in vivo* studies, all epothilones and paclitaxel were dissolved in Cremophor/ethanol (1:1) vehicle and then diluted with saline for iv infusion for 6 hrs via tail vein using a custom-designed mini-catheter (T.-C. Chou et al. *Proc. Natl. Acad. Sci. USA.* **2001**, 98, 8113-8118; T.-C. Chou et al. *Proc. Natl. Acad. Sci. U. S. A.* **1998**, 95, 15798-15802; each of which is incorporated herein by reference).

Tumor and Cell Lines. The CCRF-CEM human lymphoblastic leukemia cells were obtained from Dr. William Beck of the University of Illinois, Chicago. Human mammary carcinoma (MX-1) and human lung carcinoma cells (A549) were obtained from American Type Culture Collection (ATCC, Rockville, MD). The paclitaxel-resistant A549/taxol cells (44-fold resistance) were developed with the method as described above (T.-C. Chou et al. *Proc. Natl. Acad. Sci. USA.* **2001**, 98, 8113-8118; incorporated herein by reference).

Animals. Athymic nude mice bearing the nu/nu gene were obtained from NCI, Frederick, MD and used for all human tumor xenografts. Male nude mice 6 weeks or older weighing 20-22 g or more were used. Drugs were administered via the tail vein for 6 hours by i.v. infusion using a home-made infusion mini-catheter and containment tube (T.-C. Chou et al. *Proc. Natl. Acad. Sci. USA.* **2001**, 98, 8113-8118; incorporated herein by reference). A programmable Harvard PHD2000 syringe pump with multitrack was used for i.v. infusion. A typical 6 hrs infusion volume for each drug in Cremophor/ethanol (1:1) was 100 µl in 2.0 ml of saline. Tumor volume was assessed by measuring length x width x height (or width) by using a caliper. For tumor-bearing nude mice during the course of experiment, the body weight refers to total weight minus the weight of the tumor. All animal studies conducted in accordance with the guidelines for the National Institute of Health Guide for the Care and Use of Animals and the protocol approved by the Memorial Sloan-Kettering Cancer Center's Institutional Animal Care and Use Committee.

Cytotoxicity Assays. In preparation for *in vitro* cytotoxicity assays, cells were cultured at an initial density $2-5 \times 10^4$ cells per milliliter. They were maintained in a 5% CO₂-humidified atmosphere at 37°C in RPMI medium 1640 (GIBCO/BRL) containing penicillin (100 units/mL), streptomycin (100 µg/mL, GIBCO/BRL), and 5% heat-inactivated FBS. For solid tumor cells growing in a monolayer (such as A549), cytotoxicity of the drug was determined in 96-well microtiter plates by using the sulforhodamine B method (P. Skehan et al. *J. Natl. Cancer. Inst.* **1990**, 82, 1107-1112; incorporated herein by reference). For cells grown in suspension (such as CCRF-CEM and its sublines), cytotoxicity was measured, in duplicate, by using the 2,3-bis-(2-methoxy-4-nitro-5-sulfophenyl)-5-carboxanilide)-2H-terazodium hydroxide (XTT) microculture method (D. A. Scudiero et al. *Cancer Res.* **1988**, 48, 4827-4833; incorporated herein by reference) in 96-well microtiter plates. For both methods, the absorbance of each well was measured with a microplate reader (Power Wave XS, Bio-Tek, Winooski, VT). Dose-effect relationship data from 6 to 7 concentrations of each drug, in duplicate, were analyzed with the median-effect plot by using a computer program (T.-C. Chou, M. Hayball. *CalcuSyn for Windows*, Multiple-drug dose effect analyzer and manual. Biosoft, Cambridge Place, Cambridge, UK (1997); incorporated herein by reference).

Stability of epothilones in mouse and in human liver S9 fraction. The stability study was carried out with a fully automated HPLC system which consisted of a Prospekt-2 (Spark Holland, Netherlands) sample preparation system and an Agilent 1100 HPLC system. Briefly, the Prospekt 2 picked up a C8 extraction cartridge and washed it with acetonitrile and water. The Agilent autosampler, set at 37°C, picked up 20 µl of the sample, loaded it onto the cartridge, washed it with water, then the Prospekt-2 diverted the mobile phase stream through the extraction cartridge onto the analytical column, Reliance Stable Bond C8 4x80 mm with guard column (MacMod, Chadds Ford, PA) and the eluent was monitored at 250 nm. The mobile phase consisted of 53 or 65% acetonitrile/0.1% formic acid at 0.4 ml/min, so that the retention time of the compound of interest was about 6 minutes. Sample preparation involved the addition of equal volumes of plasma to PBS for a total volume of 300-400 µl, filtered, and the addition of 0.5-2 µl of the substrate (20 mM) to achieve about 30-50 mAU at 250 nm in the HPLC analysis. For pooled human liver microsome S9 fraction (Xeno Tech, Lenex, KS), 20 µl (400 µg) or S9 fraction was mixed with 280 µl of PBS then proceeded as above.

The sampling period was controlled by the autosampler and peak area data were collected to compare the rate of disappearance of the parent compound.

Determination of partition of octanol-water (POW) number. An HPLC method is used to estimate octanol-water partition. An Agilent 1100 HPLC system is used with an eclipse XDB C18 column 4.6x250 mm with a mobile phase of 60% acetonitrile/40% 25mM potassium phosphate buffer at pH 7.4 with a flow rate of 0.8 ml per min. and the eluent is monitored at 250 nm. The standards used are benzyl alcohol, acetophenone, benzophenone, naphthalene, diphenyl ether and dibenzyl with known POW of 1.1, 1.7, 3.2, 4.2, and 4.8 respectively. Sodium dichromate is used to evaluate time zero which is 2.5 min and the retention times for the standards are 3.9, 5.4, 10.6, 14. 18.7 and 19.8 min, respectively. The k value is calculated by the formula of $k=(t_{rt}-t_0)/t_0$. Linear regression of log k vs. log POW gives a straight line with $r^2=0.966$. This graph is used to evaluate the POW value of the epothilone analogs.

15

Spectroscopic data for 29 (26-trifluoro-(E)-9,10-dehydro-dEpoB):

$[\alpha]_D^{25}$ -54.6 (c 0.28, CHCl_3); IR (film) ν 3478, 2974, 2929, 1736, 1689, 1449, 1381, 1318, 1247, 1169, 1113, 1039, 983, 867, 736 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 1.05 (3H, s), 1.12 (3H, d, $J = 7.0$ Hz), 1.23 (3H, d, $J = 6.8$ Hz), 1.37 (3H, s), 2.04 (1H, brd, $J = 3.8$ Hz, -OH), 2.12 (3H, s), 2.25-2.33 (1H, m), 2.38 (1H, dd, $J = 15.3$ and 3.0 Hz), 2.48 (1H, dd, $J = 15.4$ and 9.8 Hz), 2.54-2.61 (1H, m), 2.66-2.76 (1H, m), 2.71 (3H, s), 2.96 (1H, dd, $J = 16.5$ and 4.5 Hz), 3.02 (1H, dd, $J = 16.3$ and 6.5 Hz), 3.11 (1H, quintet, $J = 6.7$ Hz), 3.19 (1H, brs, =OH), 3.74 (1H, brs), 4.35 (1H, brd, $J = 9.5$ Hz), 5.42 (1H, dd, $J = 6.2$ and 4.1 Hz), 5.60 (1H, ddd, $J = 15.8$, 5.6, and 4.5 Hz), 5.66 (1H, dd, $J = 15.8$ and 5.8 Hz), 6.24 (1H, t, $J = 7.2$ Hz), 6.64 (1H, s), 7.00 (1H, s); ^{13}C NMR (100 MHz, CDCl_3) δ 15.1, 16.1, 17.7, 18.5, 19.3, 22.5, 28.8, 31.1, 39.6, 39.7, 45.0, 53.7, 71.4, 75.3, 76.8, 116.7, 120.2, 124.3 [q, $^1J(\text{C},\text{F}) = 273.4$ Hz], 127.9, 130.2 [q, $^3J(\text{C},\text{F}) = 6.0$ Hz], 130.6 [q, $^2J(\text{C},\text{F}) = 28.4$ Hz], 132.5, 136.7, 152.0, 165.4, 170.2, 218.4; LRMS (ESI) calcd for $\text{C}_{27}\text{H}_{37}\text{F}_3\text{NO}_5\text{S}$ $[\text{M}+\text{H}^+]$ 544.2, found 544.1.

30

Example 11: In vitro studies

A typical experiment involves culturing cells (*e.g.*, CCRF-CEM) at an initial density of 2.5×10^4 cells per ml. They are maintained in a 5% CO₂-humidified atmosphere at 37°C in RPMI medium 1640 (GIBCO/BRL) containing penicillin (100 units/ml), streptomycin (100 µg/ml) (GIBCO/BRL), and 5% heat-inactivated fetal bovine serum. For cells that were grown in suspension (such as CCRF-CEM and its sublines), cytotoxicity is measured by using the 2,3-bis (2-methoxy-4-nitro-5-sulfophenyl)-5 carboxanilide)-2H tetrazolium hydroxide (XTT)-microculture tetrazolium method in duplicate in 96-well microtiter plates. For both methods, the absorbance of each well is measured with a microplate reader (EL-340, Bio-Tek, Burlington, VT). Each run entails six or seven concentrations of the tested drugs. Dose-effect relationship data are analyzed with the median-effect plot.

The CCRF-CEM human T cells, acute lymphoblastic leukemic cells, its teniposide-resistant subline (CCRF-CEM/VM₁) and vinblastine-resistant subline (CCRF-CEM/VBL₁₀₀) are obtained from W.T. Beck (University of Illinois, Chicago, Ill).

In a typical experiment, as outlined generally above, certain of the inventive compounds (*e.g.*, 9,10-dehydro-EpoD) demonstrated activity in CCRF-CEM cell lines and CCRF-CEM cell lines resistant to Taxol. Certain of these compounds exhibit IC₅₀s in the range of 0.0015 to about 0.120 for CCRF-CEM cell lines. Certain other compounds exhibit IC₅₀s in the range of 0.0015 to about 10.5. Certain of these compounds also exhibit IC₅₀s in the range of 0.011 to about 0.80 for CCRF-CEM/Taxol resistant cell lines and certain other compounds exhibit IC₅₀s in the range of about 0.011 to about 13.0 µM. In certain embodiments, 26F-EpoD exhibits activities in the range of 0.0015 µM for CCRF-CEM cell lines and in the range of 0.011 µM for CCRF-CEM/Taxol resistant cell lines (Figure 11).

Example 12: *In vivo* studies

Athymic nude mice bearing the nu/nu gene are typically used for tumor xenografts. Outbred, Swiss-background mice were obtained from Charles River Laboratories. Male mice 8 weeks or older weighing 22 g and up were used for most experiments. The drug was administered via the tail vein for 6 hr.-i.v. infusion. Each individual mouse was confined in a perforated Falcon polypropylene tube restrainer for

drug administration. Tumor volume was assessed by measuring length x width x height (or width) using a caliper. The programmable Harvard PHD2000 syringe pump (Harvard Apparatus) with multi-track was used for i.v. infusion. All animal studies were conducted in accordance with the guidelines of the National Institutes of Health
5 "Guide for the Care and Use of Animals" and the protocol approved by the Memorial Sloan-Kettering Cancer Center's Institutional Animal Care and Use Committee. In keeping with the policy of this committee for the humane treatment of tumor-bearing animals, mice were euthanized when tumors reached $\geq 10\%$ of their total body weight.

As depicted in Figure 8, 9,10-dehydro-EpoB was tested in nude mice bearing
10 human mammary carcinoma MX-1. In general, 9,10-dehydro-EpoB was formulated as follows: 9,10-dehydro-EpoB was dissolved in ethanol and Cremophor was added (1:1) at a concentration of 20 mg/ml. This solution was diluted with saline for i.v. infusion. The diluted solution was used for i.v. infusion within one hour. Tumor size and body weight were then measured using dosages of 10 mg/kg, 20 mg/kg, and 30 mg/kg over
15 15 days. Tumor size and body weight were also measured using a dosage regimen of 0.4 mg/kg Q3Dx2, 0.5 mg/kg Q3Dx2, and 0.6 mg/kg Q3Dx5 (see Figures 33, 34, 55 and 56). The every third day dosing regimen was used to reduce toxicity. Other therapeutic studies on 9,10-dehydro-Epo B are shown in Figures 70 and 71 (CCRF-CEM/Taxol Q3Dx5) and in Figures 23 and 24 (HCT-116, Q2Dx7).

20 The compound, 9,10-dehydro-12,13-desoxyepothilone B (iso-490 epothilone), is three times more efficacious than dEpoB. 9,10-dehydro-12,13-desoxyepothilone D has been shown to arrest tumor growth after two to three infusions of 10 mg/kg or 20 mg/kg, each of which was administered every other day. Better results in mice were obtained using a dose of 30 mg/kg of 9,10-dehydro-12,13-desoxyepothilone B using
25 two 6 hour infusion iv every other day. 9,10-dehydro-dEpoB at 5 mg/kg, Q3Dx9, 6 hr.-iv infusion, was also shown to achieve tumor disappearance in nude mice bearing MX-1 xenograft without mouse death and with only a moderate loss of body weight (Figures 74 and 75). This seems to have been accomplished by administering the epothilone analogs every third day to reduce toxicity (see Figures 53 and 54). In
30 summary, 9,10-dehydro-12,13-desoxyepothilone B shows decreased toxicity as compared to other epothilones, greater potency in arresting tumor growth, and greater serum stability. Other therapeutic studies are shown in Figures 17 and 18 (HCT-116, Q2Dx5 and Q3Dx5); in Figures 19 and 20 (A549/Taxol, Q3Dx7); and in Figures 21 and 22 (A549/Taxol, Q2Dx7).

9,10-dehydro-Epo B when administered every three days 9-11 times, 6 hour iv infusion, at 0.4-0.6 mg/kg, led to shrinkage and disappearance of the tumor in nude mice with implanted human mammary carcinoma MX-1 xenografts (Figures 68 and 69). Administration every other day for 8 doses led to tumor growth suppression but no shrinkage of the tumor. When 9,10-dehydro-Epo B was administered every other day for 9 doses, the implanted tumor continued to shrink moderately from the second to the eighth day, but body weight recovered very slowly from 76% to 82% of the control during the same period. On the tenth day, one-fourth of tumor was gone. When a dosage of 0.6 mg/kg of 9,10-dehydro-EpoB was administered Q2Wx6, 6 hour infusion, to nude mice with HCT-116 xenografts, four out of four mice died of toxicity within three days after the sixth dosage. 9,10-dehydro-EpoB abolished tumor growth against CCRF-CEM/Taxol using 0.6 mg/kg, Q3Dx5,x2 schedule (Figures 70 and 71).

26-trifluoro-9,10-dehydro-12,13-desoxy-epothilone B (F₃-deH-dEpoB) as shown in the Figures is curative at 20 mg/kg and 30 mg/kg, Q2Dx6, 6 hour infusions, in a nude mouse model implanted with human mammary carcinoma MX-1 xenografts. The data also suggests that 30 mg/kg Q2Dx6 is approximately the maximal tolerated dose. At 20 mg/kg, Q2Dx6, 6 hour infusion, 26-trifluoro-9,10-dehydro-12,13-desoxy-epothilone B led to tumor shrinkage and disappearance in four out of four nude mice with human mammary carcinoma MX-1 xenografts. There was no reappearance of the tumor on the 20th day after stopping treatment. On the 27th day after stopping treatment 2/4 reappeared. No further tumor reappearance during 28th-64th days after stopping treatment. By comparison, dEpoB at 30 mg/kg achieved tumor disappearance in the same mouse model in seven out of seven mice; however, the tumor reappeared in 2 out of five mice on the 8th day after stopping treatment. Administration of 26-trifluoro-9,10-dehydro-12,13-desoxy-epothilone B at 20 mg/kg, Q2Dx6, 6 hr. iv infusion led to a transient drop in body weight of the mice up to 26%. This drop in body weight did not lead to death suggesting no severe toxicity toward vital organs. Two days after the last treatment, body weight began to recover. On the 16th day after treatment, body weight returned to 109% of the pretreatment control suggesting that toxicity, if any, is completely reversible. In comparison, dEpoB administered at 30 mg/kg led to a 31% decrease in body weight without lethality.

When 26-trifluoro-9,10-dehydro-12,13-desoxy-epothilone B was administered at 30 mg/kg, Q2Dx6, 6 hour iv infusion, tumor disappearance was 2-3 days earlier than the 20 mg/kg dosage. Body weight dropped 27% at this higher dose and persisted 4

days without leading to lethality confirming no severe toxicity to vital organs. Four days after the last treatment at 30 mg/kg, body weight began to recover. On the 16th day after treatment, body weight returned to 98% of the pretreatment control again confirming the reversibility of toxicity. Treatment with 26-trifluoro-9,10-dehydro-dEpoB at 20 mg/kg and 30 mg/kg led to total tumor disappearance, and no relapse after 62 days was seen at the 30 mg/kg dose. Tumor disappearance was also achieved at 10mg/kg by administering 9 doses with three additional doses given (Figure 57). Only minor loss of body weight was observed at 10 mg/kg 26-trifluoro-9,10-dehydro-dEpoB (Figure 58). No further loss of body weight was seen with continued treatment.

Figure 59 summarizes the effect of 26-F₃-9,10-deH-dEpo B (and other epothilones) against MX-1 xenograft, A. at low dose; B. against large tumor; against A549 lung carcinoma xenograft, C; and against Taxol resistant lung carcinoma A549/Taxol xenograft, D.

Figure 61 lists in vitro potency of C-21 modified epothilones against CCRF-CEM, CCRF-CEM/VBL and CCRF-CEM/Taxol.

Figure 62 shows therapeutic effect of 26-F₃-9,10-deH-dEpoB (15mg/kg and 30mg/kg) and Taxol (20mg/kg) Q2Dx8, 6 hour i.v. infusion against human T-cell lymphoblastic leukemia CCRF-CEM xenograft. Similar body weight decreases were observed in all three groups of treatment (Figure 63).

Treatment of CCRF-CEM/Taxol xenograft (Taxol resistant) with 26-F₃-9,10-deH-dEpo B, 15mg/kg achieved 1/3 tumor disappearance, and 30mg/kg achieved ¾ tumor disappearance. The same treatment with Taxol, 20mg/kg yielded only partial suppression of tumor growth and failed to achieve tumor shrinkage (Figure 64). The body weight changes during this experiment were shown in Figure 65.

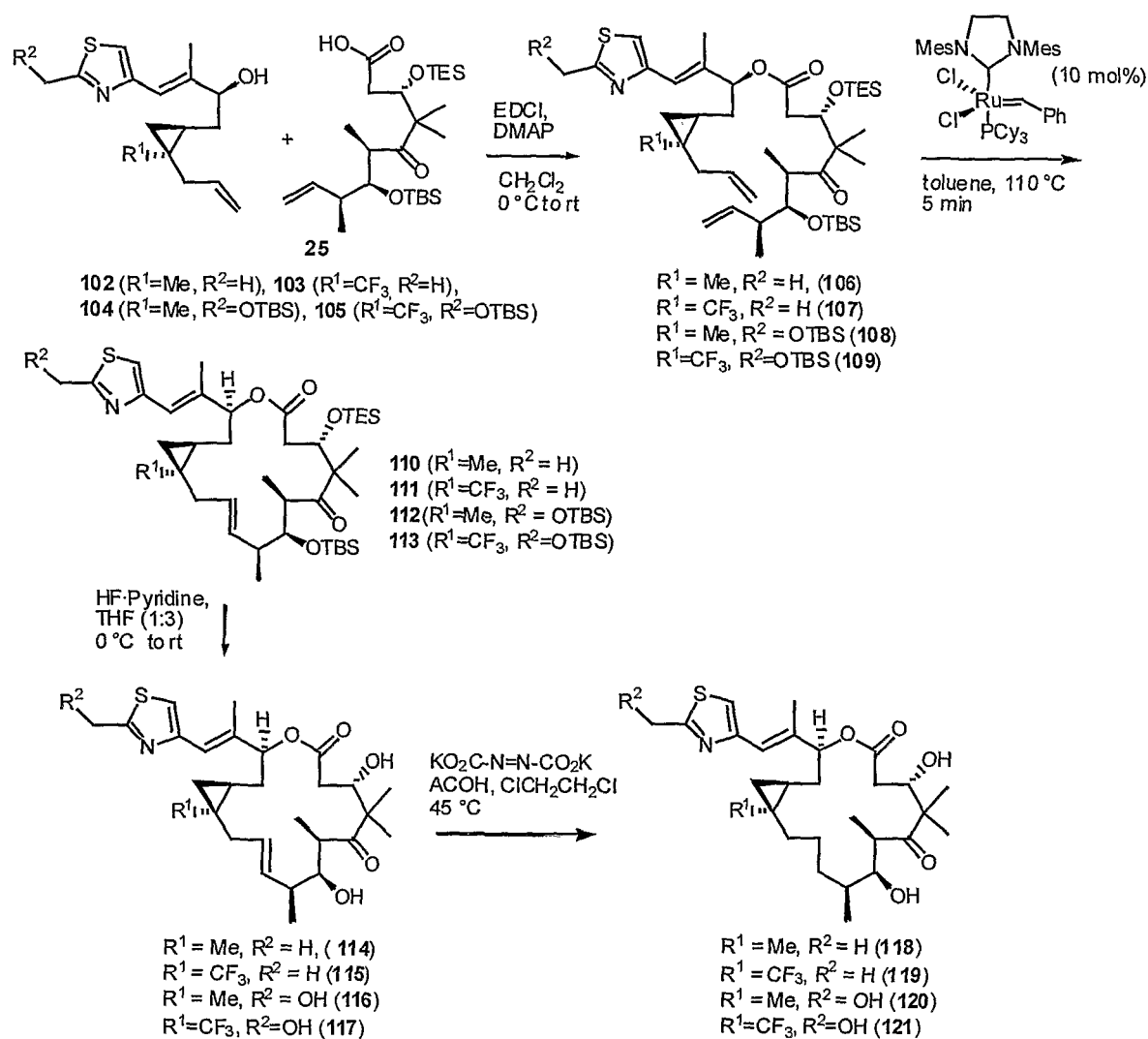
Treatment of human colon carcinoma HCT-116 xenograft with 26-F₃-9,10-deH-dEpo B (20mg/kg) achieved similar efficacy as Taxol (20mg/kg). However, F₃-deH-dEpo B at 30mg/kg yield better therapeutic effect with 2/4 tumor disappearance following 5 doses (Figure 66). The body weight changes during this experiment were shown in Figure 67.

The therapeutic effects of F₃-9,10-dehydro-dEpoF against MX-1 xenografts at different doses (5-30mg/kg) with 6 hour i.v. infusion and i.v. injection are shown in Figures 76 and 77.

Conclusion. The 9,10-dehydro, 26-trifluoro, or both modifications to dEpoB result in a 1.5- to 5-fold increase in cytotoxicity *in vitro* and a 2- to 5-fold increase in

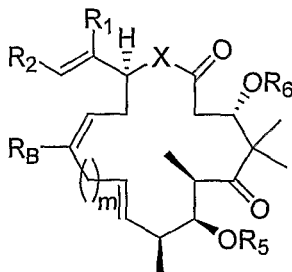
half-life in mouse plasma *in vitro*. By using human solid tumor xenograft models in nude mice and using the Q2Dx5~9, 6 hr-i.v. infusion technique via tail vein at maximal tolerated doses, the antitumor efficacy and toxicity of 9,10-dehydro-epothilones were evaluated. The ability to achieve complete tumor growth suppression, tumor shrinkage, and disappearance allowed for further investigation to determine the relapse rate and cure rate after stopping treatment. 9,10-dehydro-EpoB, the most potent epothilone known *in vitro*, although highly efficacious, showed a narrow therapeutic safety margin *in vivo*. 9,10-dehydro-dEpoB at 4 mg/kg, 9,10-dehydro-EpoB at 0.4 mg/kg, and 21-hydroxy-9,10-dehydro-dEpoB at 3 mg/kg all strongly suppressed tumor growth for a sustained period of time and achieved some tumor shrinkage, and some achieved tumor disappearance. dEpoB at 30 mg/kg, 26-trifluoro-9,10-dehydro-dEpoB at 20 mg/kg, and paclitaxel at 20 mg/kg all showed strong suppression of tumor growth and achieved tumor shrinkage and disappearance of human mammary carcinoma MX-1 xenografts in all mice tested. 26-trifluoro-9,10-dehydro-dEpoB, when compared with dEpoB or paclitaxel, achieved a long term cure without a tumor relapse and showed an equally rapid recovery of body weight to the pretreatment control level.

Example 13. Synthesis of Cyclopropyl-Epothilone Analogs



CLAIMS

1. A compound of the formula:



wherein R_1 is hydrogen or lower alkyl;

R_2 is a substituted or unsubstituted aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety;

R_5 and R_6 are each independently hydrogen or a protecting group;

X is O, S, $C(R_7)_2$, or NR_7 , wherein each occurrence of R_7 is independently hydrogen or lower alkyl;

R_B is, independently for each occurrence, hydrogen; halogen; $-OR_B$; $-SR_B$;

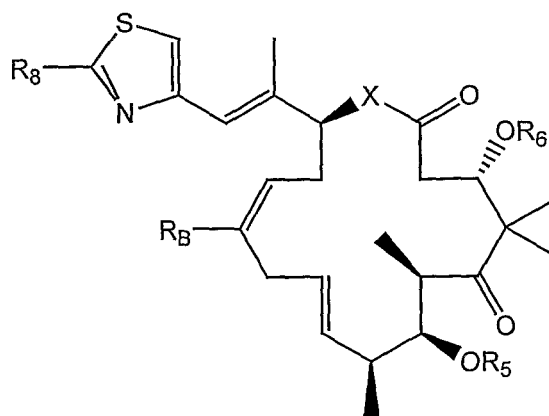
$-N(R_B)_2$; $-CY_3$, $-CHY_2$, $-CH_2Y$, where Y is F, Br, Cl, I, OR_B , NHR_B , $N(R_B)_2$, or SR_B ; $-C(O)OR_B$; $-C(O)R_B$; $-CONHR_B$; $-O(C=O)R_B$; $-O(C=O)OR_B$; $-$

$NR_B(C=O)R_B$; N_3 ; N_2R_B ; cyclic acetal; or cyclic or acyclic, linear or branched aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of hydrogen; halogen; $-OR_B$; $-SR_B$; $-N(R_B)_2$; $-C(O)OR_B$; $-C(O)R_B$; $-CONHR_B$; $-$

$O(C=O)R_B$; $-O(C=O)OR_B$; $-NR_B(C=O)R_B$; N_3 ; N_2R_B ; cyclic acetal; or cyclic or acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity label; or radiolabel; wherein each occurrence of R_B is independently hydrogen; a protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety; and

m is 1, 2, 3, or 4.

2. A compound of the formula:



wherein

X is O, S, C(R₇)₂, or NR₇, wherein each occurrence of R₇ is independently
 5 hydrogen or lower alkyl;

R₅ and R₆ are each independently hydrogen or a protecting group;

R_B is hydrogen; halogen; -OR_{B'}; -SR_{B'}; -N(R_{B'})₂; -CY₃, -CHY₂, -CH₂Y, where
 Y is F, Br, Cl, I, OR_{B'}, NHR_{B'}, N(R_{B'})₂, or SR_{B'}; -C(O)OR_{B'}; -C(O)R_{B'}; -CONHR_{B'}; -
 10 O(C=O)R_{B'}; -O(C=O)OR_{B'}; -NR_{B'}(C=O)R_{B'}; N₃; N₂R_{B'}; cyclic acetal; or cyclic or
 acyclic, linear or branched aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally
 substituted with one or more of hydrogen; halogen; -OR_{B'}; -SR_{B'}; -N(R_{B'})₂; -
 C(O)OR_{B'}; -C(O)R_{B'}; -CONHR_{B'}; -O(C=O)R_{B'}; -O(C=O)OR_{B'}; -NR_{B'}(C=O)R_{B'}; N₃;
 N₂R_{B'}; cyclic acetal; or cyclic or acyclic, linear or branched substituted or
 unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone,
 15 desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity
 label; or radiolabel; wherein each occurrence of R_{B'} is independently hydrogen; a
 protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic,
 aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl,
 heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety;

R₈ is independently hydrogen, halogen, -OR₉, -SR₉, -N(R₉)₂, -CY₃, -CHY₂, -
 CH₂Y, where Y is F, Br, Cl, I, OR_{B'}, NHR_{B'}, N(R_{B'})₂, or SR_{B'}; -(CV₂)_nOR₉, -
 (CV₂)_nN(R₉)₂, -(CV₂)_nSR₉, -(C=O)R₉, -O(C=O)R₉, -(C=O)OR₉, -O(C=O)OR₉;
 NH(C=O)R₉, -NH(C=O)OR₉, -(C=O)NHR₉, or a cyclic or acyclic, linear or branched
 aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety
 25 optionally substituted with one or more occurrences of halogen, -OR₉, -SR₉, -N(R₉)₂, -
 (CV₂)_nOR₉, -(CV₂)_nN(R₉)₂, -(CV₂)_nSR₉, -(C=O)R₉, -O(C=O)R₉, -(C=O)OR₉, -
 O(C=O)OR₉; -NH(C=O)R₉, -NH(C=O)OR₉, -(C=O)NHR₉, or a cyclic or acyclic, linear

or branched, substituted or unsubstituted aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety,

wherein each occurrence of R_9 is independently hydrogen; a protecting group; a cyclic or acyclic, linear or branched, substituted or unsubstituted aliphatic,

- 5 heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone or analogues thereof; a polymer; carbohydrate; photoaffinity label; or radiolabel;

wherein each occurrence of V is independently hydrogen, halogen, hydroxyl, thio, amino, alkylamino, or protected hydroxyl, thio or amino; each occurrence of t is independently 0, 1 or 2; and each occurrence of n is independently 0-10; and

- 10 pharmaceutically acceptable derivatives thereof.

3. The compound of claim 2 wherein R_B is methyl.

4. The compound of claim 2 wherein R_B is $-\text{CF}_3$.

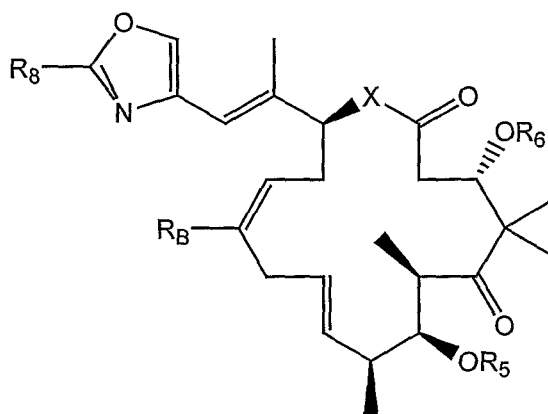
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5. The compound of claim 2, 3, or 4, wherein R_8 is methyl.

8. The compound of claim 2, 3, or 4, wherein R_8 is $-\text{CH}_2\text{OH}$.

- 20 9. The compound of claim 2, 3, or 4, wherein R_8 is $-\text{CH}_2\text{NH}_2$.

10. A compound of the formula:



25

wherein

X is O, S, C(R₇)₂, or NR₇, wherein each occurrence of R₇ is independently hydrogen or lower alkyl;

R₅ and R₆ are each independently hydrogen or a protecting group;

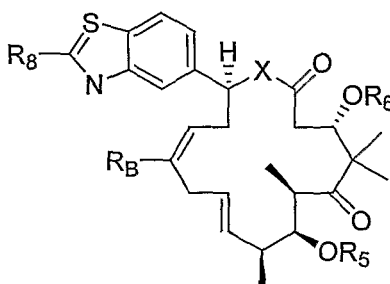
R_B is hydrogen; halogen; -OR_B'; -SR_B'; -N(R_B')₂; -CY₃, -CHY₂, -CH₂Y, where
 5 Y is F, Br, Cl, I, OR_B', NHR_B', N(R_B')₂, or SR_B'; -C(O)OR_B'; -C(O)R_B'; -CONHR_B'; -
 O(C=O)R_B'; -O(C=O)OR_B'; -NR_B'(C=O)R_B'; N₃; N₂R_B'; cyclic acetal; or cyclic or
 acyclic, linear or branched aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally
 substituted with one or more of hydrogen; halogen; -OR_B'; -SR_B'; -N(R_B')₂; -
 C(O)OR_B'; -C(O)R_B'; -CONHR_B'; -O(C=O)R_B'; -O(C=O)OR_B'; -NR_B'(C=O)R_B'; N₃;
 10 N₂R_B'; cyclic acetal; or cyclic or acyclic, linear or branched substituted or
 unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone,
 desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity
 label; or radiolabel; wherein each occurrence of R_B' is independently hydrogen; a
 protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic,
 15 aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl,
 heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety;

R₈ is independently hydrogen, halogen, -OR₉, -SR₉, -N(R₉)₂; -CY₃, -CHY₂, -
 CH₂Y, where Y is F, Br, Cl, I, OR_B', NHR_B', N(R_B')₂, or SR_B'; -(CV₂)_nOR₉, -
 (CV₂)_nN(R₉)₂, -(CV₂)_nSR₉, -(C=O)R₉, -O(C=O)R₉, -(C=O)OR₉, -O(C=O)OR₉;-
 20 NH(C=O)R₉, -NH(C=O)OR₉, -(C=O)NHR₉, or a cyclic or acyclic, linear or branched
 aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety
 optionally substituted with one or more occurrences of halogen, -OR₉, -SR₉, -N(R₉)₂, -
 (CV₂)_nOR₉, -(CV₂)_nN(R₉)₂, -(CV₂)_nSR₉, -(C=O)R₉, -O(C=O)R₉, -(C=O)OR₉, -
 O(C=O)OR₉;-NH(C=O)R₉, -NH(C=O)OR₉, -(C=O)NHR₉, or a cyclic or acyclic, linear
 25 or branched, substituted or unsubstituted aliphatic, heteroaliphatic, aryl, heteroaryl,
 arylalkyl, or heteroarylalkyl moiety,

wherein each occurrence of R₉ is independently hydrogen; a protecting group; a
 cyclic or acyclic, linear or branched, substituted or unsubstituted aliphatic,
 heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone or
 30 analogues thereof; a polymer; carbohydrate; photoaffinity label; or radiolabel;

wherein each occurrence of V is independently hydrogen, halogen, hydroxyl,
 thio, amino, alkylamino, or protected hydroxyl, thio or amino; each occurrence of t is
 independently 0, 1 or 2; and each occurrence of n is independently 0-10; and
 pharmaceutically acceptable derivatives thereof.

11. The compound of claim 10, wherein R_B is methyl.
12. The compound of claim 10, wherein R_B is $-\text{CF}_3$.
- 5 13. The compound of claim 10, 11, or 12, wherein R_8 is methyl.
14. The compound of claim 10, 11, or 12, wherein R_8 is $-\text{CH}_2\text{OH}$.
- 10 15. The compound of claim 10, 11, or 12, wherein R_8 is $-\text{CH}_2\text{NH}_2$.
16. A compound of the formula:



- 15 wherein R_5 and R_6 are each independently hydrogen or a protecting group;
- R_8 is independently hydrogen, halogen, $-\text{OR}_9$, $-\text{SR}_9$, $-\text{N}(\text{R}_9)_2$, $-\text{CY}_3$, $-\text{CHY}_2$, $-\text{CH}_2\text{Y}$, where Y is F, Br, Cl, I, $\text{OR}_{B'}$, $\text{NHR}_{B'}$, $\text{N}(\text{R}_{B'})_2$, or $\text{SR}_{B'}$; $-(\text{CV}_2)_n\text{OR}_9$, $-(\text{CV}_2)_n\text{N}(\text{R}_9)_2$, $-(\text{CV}_2)_n\text{SR}_9$, $-(\text{C}=\text{O})\text{R}_9$, $-\text{O}(\text{C}=\text{O})\text{R}_9$, $-(\text{C}=\text{O})\text{OR}_9$, $-\text{O}(\text{C}=\text{O})\text{OR}_9$;
- 20 $\text{NH}(\text{C}=\text{O})\text{R}_9$, $-\text{NH}(\text{C}=\text{O})\text{OR}_9$, $-(\text{C}=\text{O})\text{NHR}_9$, or a cyclic or acyclic, linear or branched aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety optionally substituted with one or more occurrences of halogen, $-\text{OR}_9$, $-\text{SR}_9$, $-\text{N}(\text{R}_9)_2$, $-(\text{CV}_2)_n\text{OR}_9$, $-(\text{CV}_2)_n\text{N}(\text{R}_9)_2$, $-(\text{CV}_2)_n\text{SR}_9$, $-(\text{C}=\text{O})\text{R}_9$, $-\text{O}(\text{C}=\text{O})\text{R}_9$, $-(\text{C}=\text{O})\text{OR}_9$, $-\text{O}(\text{C}=\text{O})\text{OR}_9$;
- 25 $\text{NH}(\text{C}=\text{O})\text{R}_9$, $-\text{NH}(\text{C}=\text{O})\text{OR}_9$, $-(\text{C}=\text{O})\text{NHR}_9$, or a cyclic or acyclic, linear or branched, substituted or unsubstituted aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety,
- wherein each occurrence of R_9 is independently hydrogen; a protecting group; a cyclic or acyclic, linear or branched, substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone or
- 30 analogues thereof; a polymer; carbohydrate; photoaffinity label; or radiolabel;

wherein each occurrence of V is independently hydrogen, halogen, hydroxyl, thio, amino, alkylamino, or protected hydroxyl, thio or amino;

X is O, S, C(R₇)₂, or NR₇, wherein each occurrence of R₇ is independently hydrogen or lower alkyl;

- 5 R_B is, independently for each occurrence, hydrogen; halogen; -OR_B'; -SR_B'; -N(R_B')₂; -CY₃, -CHY₂, -CH₂Y, where Y is F, Br, Cl, I, OR_B', NHR_B', N(R_B')₂, or SR_B'; -C(O)OR_B'; -C(O)R_B'; -CONHR_B'; -O(C=O)R_B'; -O(C=O)OR_B'; -NR_B'(C=O)R_B'; N₃; N₂R_B'; cyclic acetal; or cyclic or acyclic, linear or branched aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of hydrogen; halogen; -
- 10 OR_B'; -SR_B'; -N(R_B')₂; -C(O)OR_B'; -C(O)R_B'; -CONHR_B'; -O(C=O)R_B'; -O(C=O)OR_B'; -NR_B'(C=O)R_B'; N₃; N₂R_B'; cyclic acetal; or cyclic or acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity label; or radiolabel; wherein each occurrence of R_B' is
- 15 independently hydrogen; a protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety; and
- pharmaceutically acceptable derivatives thereof.

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17. The compound of claim 16, wherein R_B is methyl.

18. The compound of claim 16, wherein R_B is -CF₃.

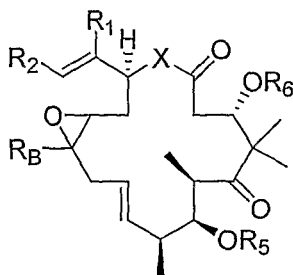
25 19. The compound of claim 16, 17, or 18, wherein R₈ is methyl.

20. The compound of claim 16, 17, or 18, wherein R₈ is -CH₂OH.

21. The compound of claim 16, 17, or 18, wherein R₈ is -CH₂NH₂.

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22. A compound of the formula:



wherein R_1 is hydrogen or lower alkyl;

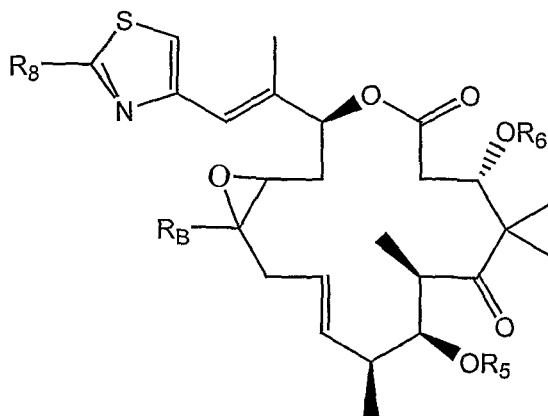
R_2 is a substituted or unsubstituted aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety;

R_5 and R_6 are each independently hydrogen or a protecting group;

X is O, S, $C(R_7)_2$, or NR_7 , wherein each occurrence of R_7 is independently hydrogen or lower alkyl;

R_B is, independently for each occurrence, hydrogen; halogen; $-OR_{B'}$; $-SR_{B'}$; $-N(R_{B'})_2$; $-CY_3$, $-CHY_2$, $-CH_2Y$, where Y is F, Br, Cl, I, $OR_{B'}$, $NHR_{B'}$, $N(R_{B'})_2$, or $SR_{B'}$; $-C(O)OR_{B'}$; $-C(O)R_{B'}$; $-CONHR_{B'}$; $-O(C=O)R_{B'}$; $-O(C=O)OR_{B'}$; $-NR_{B'}(C=O)R_{B'}$; N_3 ; $N_2R_{B'}$; cyclic acetal; or cyclic or acyclic, linear or branched aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of hydrogen; halogen; $-OR_{B'}$; $-SR_{B'}$; $-N(R_{B'})_2$; $-C(O)OR_{B'}$; $-C(O)R_{B'}$; $-CONHR_{B'}$; $-O(C=O)R_{B'}$; $-O(C=O)OR_{B'}$; $-NR_{B'}(C=O)R_{B'}$; N_3 ; $N_2R_{B'}$; cyclic acetal; or cyclic or acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity label; or radiolabel; wherein each occurrence of $R_{B'}$ is independently hydrogen; a protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety.

23. A compound of the formula:



wherein

- R_B is hydrogen; halogen; $-OR_{B'}$; $-SR_{B'}$; $-N(R_{B'})_2$; $-CY_3$; $-CHY_2$; $-CH_2Y$, where
- 5 Y is F, Br, Cl, I, $OR_{B'}$, $NHR_{B'}$, $N(R_{B'})_2$, or $SR_{B'}$; $-C(O)OR_{B'}$; $-C(O)R_{B'}$; $-CONHR_{B'}$; $-O(C=O)R_{B'}$; $-O(C=O)OR_{B'}$; $-NR_{B'}(C=O)R_{B'}$; N_3 ; $N_2R_{B'}$; cyclic acetal; or cyclic or acyclic, linear or branched aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of hydrogen; halogen; $-OR_{B'}$; $-SR_{B'}$; $-N(R_{B'})_2$; $-C(O)OR_{B'}$; $-C(O)R_{B'}$; $-CONHR_{B'}$; $-O(C=O)R_{B'}$; $-O(C=O)OR_{B'}$; $-NR_{B'}(C=O)R_{B'}$; N_3 ;
- 10 $N_2R_{B'}$; cyclic acetal; or cyclic or acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity label; or radiolabel; wherein each occurrence of $R_{B'}$ is independently hydrogen, alkyl, aryl, or a protecting group; wherein each occurrence of $R_{B'}$ is independently hydrogen;
- 15 a protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety;

R_5 and R_6 are each independently hydrogen or a protecting group;

- R_8 is independently hydrogen, halogen, $-OR_9$, $-SR_9$, $-N(R_9)_2$, $-CY_3$, $-CHY_2$, $-CH_2Y$, where Y is F, Br, Cl, I, $OR_{B'}$, $NHR_{B'}$, $N(R_{B'})_2$, or $SR_{B'}$; $-(CV_2)_nOR_9$, $-(CV_2)_nN(R_9)_2$, $-(CV_2)_nSR_9$, $-(C=O)R_9$, $-O(C=O)R_9$, $-(C=O)OR_9$, $-O(C=O)OR_9$; $-NH(C=O)R_9$, $-NH(C=O)OR_9$, $-(C=O)NHR_9$, or a cyclic or acyclic, linear or branched aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety optionally substituted with one or more occurrences of halogen, $-OR_9$, $-SR_9$, $-N(R_9)_2$, $-(CV_2)_nOR_9$, $-(CV_2)_nN(R_9)_2$, $-(CV_2)_nSR_9$, $-(C=O)R_9$, $-O(C=O)R_9$, $-(C=O)OR_9$, $-O(C=O)OR_9$; $-NH(C=O)R_9$, $-NH(C=O)OR_9$, $-(C=O)NHR_9$, or a cyclic or acyclic, linear
- 20
- 25

or branched, substituted or unsubstituted aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety,

wherein each occurrence of R_9 is independently hydrogen; a protecting group; a cyclic or acyclic, linear or branched, substituted or unsubstituted aliphatic,

5 heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone or analogues thereof; a polymer; carbohydrate; photoaffinity label; or radiolabel;

wherein each occurrence of V is independently hydrogen, halogen, hydroxyl, thio, amino, alkylamino, or protected hydroxyl, thio or amino; each occurrence of t is independently 0, 1 or 2; and each occurrence of n is independently 0-10; and

10 pharmaceutically acceptable derivatives thereof.

24. The compound of claim 23 wherein R_B is methyl.

25. The compound of claim 23 wherein R_B is $-\text{CF}_3$.

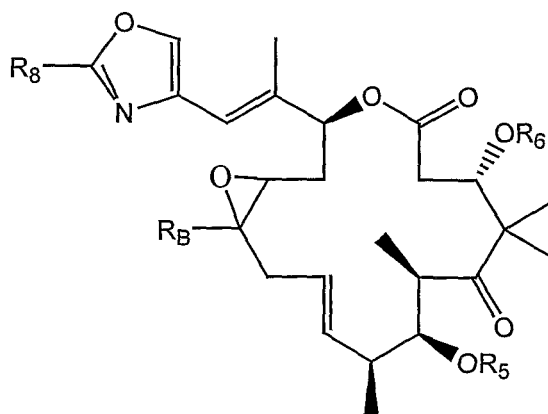
15

26. The compound of claim 23, 24, or 25, wherein R_8 is methyl.

27. The compound of claim 23, 24, or 25, wherein R_8 is $-\text{CH}_2\text{OH}$.

20 28. The compound of claim 23, 24, or 25, wherein R_8 is $-\text{CH}_2\text{NH}_2$.

29. A compound of the formula:



25

wherein

R_B is hydrogen; halogen; $-OR_B$; $-SR_B$; $-N(R_B)_2$; $-CY_3$, $-CHY_2$, $-CH_2Y$, where Y is F, Br, Cl, I, OR_B , NHR_B , $N(R_B)_2$, or SR_B ; $-C(O)OR_B$; $-C(O)R_B$; $-CONHR_B$; $-O(C=O)R_B$; $-O(C=O)OR_B$; $-NR_B(C=O)R_B$; N_3 ; N_2R_B ; cyclic acetal; or cyclic or acyclic, linear or branched aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of hydrogen; halogen; $-OR_B$; $-SR_B$; $-N(R_B)_2$; $-C(O)OR_B$; $-C(O)R_B$; $-CONHR_B$; $-O(C=O)R_B$; $-O(C=O)OR_B$; $-NR_B(C=O)R_B$; N_3 ; N_2R_B ; cyclic acetal; or cyclic or acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity label; or radiolabel; wherein each occurrence of R_B is independently hydrogen; a protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety;

R_5 and R_6 are each independently hydrogen or a protecting group;

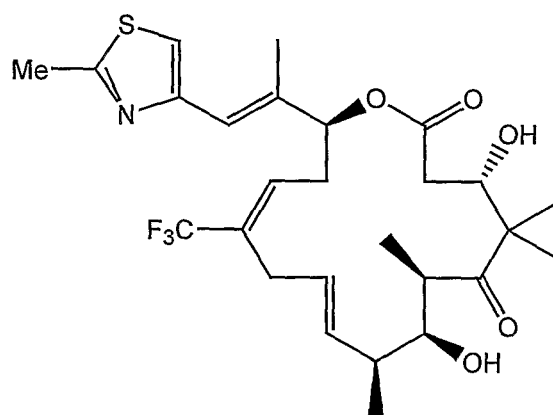
R_8 is independently hydrogen, halogen, $-OR_9$, $-SR_9$, $-N(R_9)_2$, $-CY_3$, $-CHY_2$, $-CH_2Y$, where Y is F, Br, Cl, I, OR_B , NHR_B , $N(R_B)_2$, or SR_B ; $-(CV_2)_nOR_9$, $-(CV_2)_nN(R_9)_2$, $-(CV_2)_nSR_9$, $-(C=O)R_9$, $-O(C=O)R_9$, $-(C=O)OR_9$, $-O(C=O)OR_9$; $-NH(C=O)R_9$, $-NH(C=O)OR_9$, $-(C=O)NHR_9$, or a cyclic or acyclic, linear or branched aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety optionally substituted with one or more occurrences of halogen, $-OR_9$, $-SR_9$, $-N(R_9)_2$, $-(CV_2)_nOR_9$, $-(CV_2)_nN(R_9)_2$, $-(CV_2)_nSR_9$, $-(C=O)R_9$, $-O(C=O)R_9$, $-(C=O)OR_9$, $-O(C=O)OR_9$; $-NH(C=O)R_9$, $-NH(C=O)OR_9$, $-(C=O)NHR_9$, or a cyclic or acyclic, linear or branched, substituted or unsubstituted aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety, wherein each occurrence of R_9 is independently hydrogen; a protecting group; a cyclic or acyclic, linear or branched, substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone or analogues thereof; a polymer; carbohydrate; photoaffinity label; or radiolabel;

wherein each occurrence of V is independently hydrogen, halogen, hydroxyl, thio, amino, alkylamino, or protected hydroxyl, thio or amino; each occurrence of t is independently 0, 1 or 2; and each occurrence of n is independently 0-10; and pharmaceutically acceptable derivatives thereof.

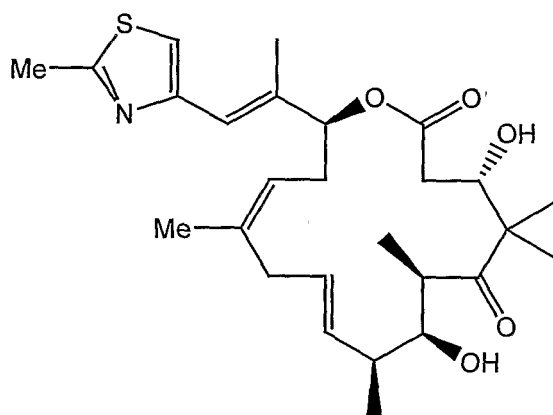
30. The compound of claim 29 wherein R_B is methyl.

31. The compound of claim 29 wherein R_B is $-\text{CF}_3$.
32. The compound of claim 29, 30, or 31, wherein R_8 is methyl.
33. The compound of claim 29, 30, or 31, wherein R_8 is $-\text{CH}_2\text{OH}$.
34. The compound of claim 29, 30, or 31, wherein R_8 is $-\text{CH}_2\text{NH}_2$.

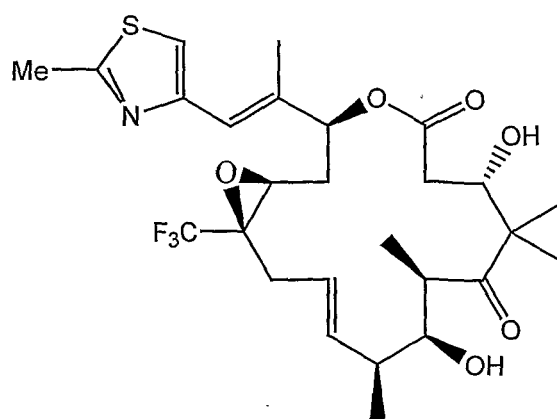
35. A compound of the formula:



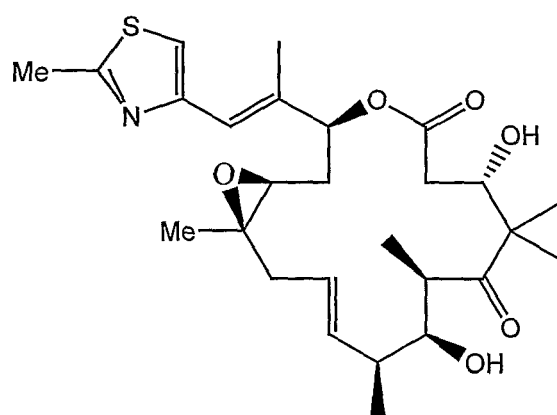
36. A compound of the formula:



37. A compound of the formula:

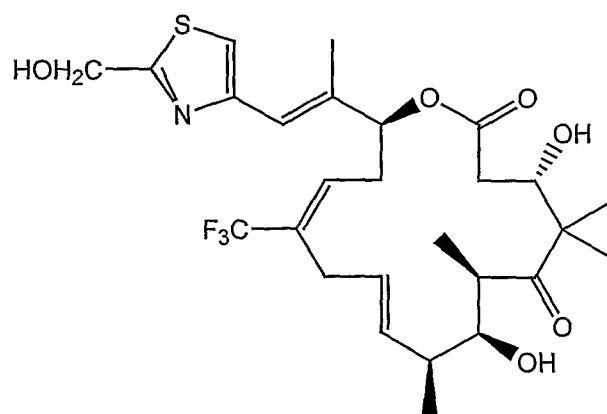


38. A compound of the formula:

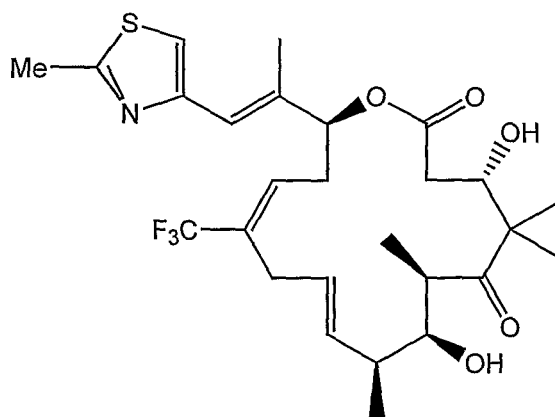


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38a. A compound of the formula:

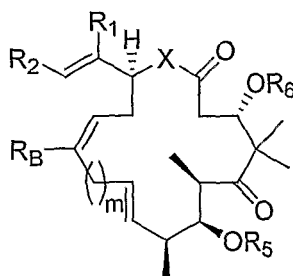


38b. A compound of the formula:



39. A *trans*-9,10-dehydro-*cis*-12,13-dehydroepothilone analog.
- 5 40. The *trans*-9,10-dehydro-*cis*-12,13-dehydroepothilone analog, wherein the analog is characterized by an IC_{50} of less than 0.01 in a CCRF-CEM cell line.
41. The *trans*-9,10-dehydro-*cis*-12,13-dehydroepothilone analog, wherein the analog is characterized by an IC_{50} of less than 0.05 in a CCRF-CEM cell line.
- 10 42. The *trans*-9,10-dehydro-*cis*-12,13-dehydroepothilone analog, wherein the analog is characterized by an IC_{50} of less than 0.01 in a CCRF-CEM cell line resistant to Taxol.
- 15 43. The *trans*-9,10-dehydro-*cis*-12,13-dehydroepothilone analog, wherein the analog is characterized by an IC_{50} of less than 0.05 in a CCRF-CEM cell line resistant to Taxol.
- 20 44. A pharmaceutical composition comprising a *trans*-9,10-dehydro-*cis*-12,13-dehydroepothilone analog and a pharmaceutically acceptable excipient.
45. A pharmaceutical composition for the treatment of cancer comprising a compound of any one of claims 1-32 and a pharmaceutically acceptable excipient.
- 25 46. The pharmaceutical composition of claim 44 or 45 further comprising Cremophor.

47. The pharmaceutical composition of claim 44 or 45 further comprising Cremophor and ethanol.
48. The pharmaceutical composition of claim 44 or 45, wherein the compound is
5 suspended in 1:1 Cremophor/EtOH.
49. The pharmaceutical composition of claim 44 or 45 further comprising an additional cytotoxic agent.
- 10 50. A pharmaceutical composition for the treatment of cancer comprising:
a therapeutically effective amount of a compound of any one of claims 1-43, or
pharmaceutically acceptable salts thereof; and
a pharmaceutically acceptable carrier or diluent,
wherein the therapeutically effective amount of the compound is an amount
15 sufficient to deliver about 0.001 to about 40 mg compound per kg body weight of a subject.
51. A method of treating cancer comprising:
administering a therapeutically effective amount of a compound of any one of
20 claims 1-32 to a subject in need thereof.
52. The method of claim 51, wherein the therapeutically effective amount of the compound is an amount sufficient to deliver about 0.001 mg to about 40 mg compound
per kg body weight.
25
53. The method of claim 51, wherein the therapeutically effective amount of the compound is an amount sufficient to deliver about 0.1 mg to about 25 mg compound
per kg body weight.
- 30 54. A method of preparing a compound of formula:



wherein R_1 is hydrogen or lower alkyl;

R_2 is a substituted or unsubstituted aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety;

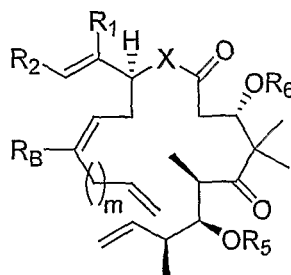
5 R_5 and R_6 are each independently hydrogen or a protecting group;

X is O, S, $C(R_7)_2$, or NR_7 , wherein each occurrence of R_7 is independently hydrogen or lower alkyl;

R_B is, independently for each occurrence, hydrogen; halogen; $-OR_B$; $-SR_B$; $-N(R_B)_2$; $-CY_3$, $-CHY_2$, $-CH_2Y$, where Y is F, Br, Cl, I, OR_B , NHR_B , $N(R_B)_2$, or SR_B ; $-C(O)OR_B$; $-C(O)R_B$; $-CONHR_B$; $-O(C=O)R_B$; $-O(C=O)OR_B$; $-NR_B(C=O)R_B$; N_3 ; N_2R_B ; cyclic acetal; or cyclic or acyclic, linear or branched aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of hydrogen; halogen; $-OR_B$; $-SR_B$; $-N(R_B)_2$; $-C(O)OR_B$; $-C(O)R_B$; $-CONHR_B$; $-O(C=O)R_B$; $-O(C=O)OR_B$; $-NR_B(C=O)R_B$; N_3 ; N_2R_B ; cyclic acetal; or cyclic or acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity label; or radiolabel; wherein each occurrence of R_B is independently hydrogen; a protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety; and

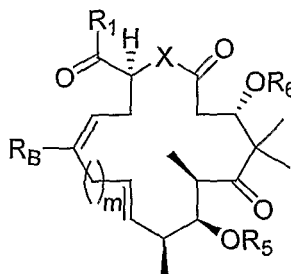
m is 1, 2, 3, or 4, the method comprising steps of:

subjecting a compound of the formula:



25 to conditions of a ring closing metathesis reaction.

55. A method of preparing a compound of formula:



wherein R₁ is hydrogen or lower alkyl;

5 R₂ is a substituted or unsubstituted aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety;

R₅ and R₆ are each independently hydrogen or a protecting group;

X is O, S, C(R₇)₂, or NR₇, wherein each occurrence of R₇ is independently hydrogen or lower alkyl;

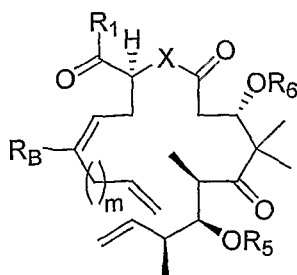
10 R_B is, independently for each occurrence, hydrogen; halogen; -OR_{B'}; -SR_{B'}; -N(R_{B'})₂; -CY₃, -CHY₂, -CH₂Y, where Y is F, Br, Cl, I, OR_{B'}, NHR_{B'}, N(R_{B'})₂, or SR_{B'}; -C(O)OR_{B'}; -C(O)R_{B'}; -CONHR_{B'}; -O(C=O)R_{B'}; -O(C=O)OR_{B'}; -NR_{B'}(C=O)R_{B'}; N₃; N₂R_{B'}; cyclic acetal; or cyclic or acyclic, linear or branched aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of

15 hydrogen; halogen; -OR_{B'}; -SR_{B'}; -N(R_{B'})₂; -C(O)OR_{B'}; -C(O)R_{B'}; -CONHR_{B'}; -O(C=O)R_{B'}; -O(C=O)OR_{B'}; -NR_{B'}(C=O)R_{B'}; N₃; N₂R_{B'}; cyclic acetal; or cyclic or acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity label; or radiolabel; wherein each occurrence of

20 R_{B'} is independently hydrogen; a protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety; and

m is 1, 2, 3, or 4, the method comprising steps of:

25 subjecting a compound of the formula:



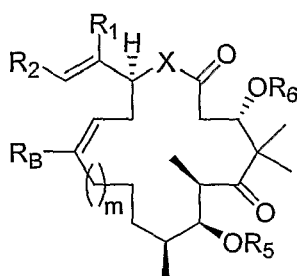
to conditions of a ring closing metathesis reaction.

56. The method of claim 54, wherein the conditions of a ring closing metathesis
5 reaction include a Grubbs catalyst.

57. The method of claim 565, wherein the Grubbs catalyst is
tricyclohexylphosphine[1,3-bis(2,4,6-trimethylphenyl)-4,5-dihydroimidazol-2-
ylidene][benzylidene]ruthenium (IV) chloride.

10

58. A method of preparing a compound of formula:



wherein R₁ is hydrogen or lower alkyl;

R₂ is a substituted or unsubstituted aryl, heteroaryl, arylalkyl, or heteroarylalkyl
15 moiety;

R₅ and R₆ are each independently hydrogen or a protecting group;

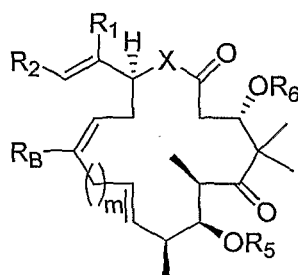
X is O, S, C(R₇)₂, or NR₇, wherein each occurrence of R₇ is independently
hydrogen or lower alkyl;

R_B is, independently for each occurrence, hydrogen; halogen; -OR_B'; -SR_B';
20 -N(R_B')₂; -CY₃, -CHY₂, -CH₂Y, where Y is F, Br, Cl, I, OR_B', NHR_B', N(R_B')₂, or
SR_B'; -C(O)OR_B'; -C(O)R_B'; -CONHR_B'; -O(C=O)R_B'; -O(C=O)OR_B'; -
NR_B'(C=O)R_B'; N₃; N₂R_B'; cyclic acetal; or cyclic or acyclic, linear or branched
aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of
hydrogen; halogen; -OR_B'; -SR_B'; -N(R_B')₂; -C(O)OR_B'; -C(O)R_B'; -CONHR_B'; -
25 O(C=O)R_B'; -O(C=O)OR_B'; -NR_B'(C=O)R_B'; N₃; N₂R_B'; cyclic acetal; or cyclic or

acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity label; or radiolabel; wherein each occurrence of $R_{B'}$ is independently hydrogen; a protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety; and

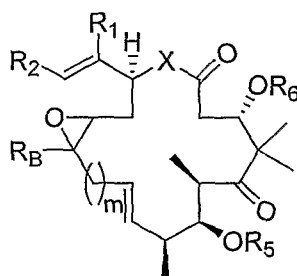
m is 1, 2, 3, or 4, the method comprising steps of:

reducing a compound of the formula:



10

59. A method of preparing a compound of formula:



wherein R_1 is hydrogen or lower alkyl;

R_2 is a substituted or unsubstituted aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety;

R_5 and R_6 are each independently hydrogen or a protecting group;

X is O, S, $C(R_7)_2$, or NR_7 , wherein each occurrence of R_7 is independently hydrogen or lower alkyl;

R_B is, independently for each occurrence, hydrogen; halogen; $-OR_{B'}$; $-SR_{B'}$;

$-N(R_{B'})_2$; $-CY_3$; $-CHY_2$; $-CH_2Y$, where Y is F, Br, Cl, I, $OR_{B'}$, $NHR_{B'}$, $N(R_{B'})_2$, or $SR_{B'}$; $-C(O)OR_{B'}$; $-C(O)R_{B'}$; $-CONHR_{B'}$; $-O(C=O)R_{B'}$; $-O(C=O)OR_{B'}$; $-$

$NR_{B'}(C=O)R_{B'}$; N_3 ; $N_2R_{B'}$; cyclic acetal; or cyclic or acyclic, linear or branched

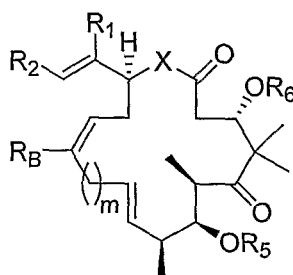
aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of hydrogen; halogen; $-OR_{B'}$; $-SR_{B'}$; $-N(R_{B'})_2$; $-C(O)OR_{B'}$; $-C(O)R_{B'}$; $-CONHR_{B'}$; $-$

O(C=O)R_{B'}; -O(C=O)OR_{B'}; -NR_{B'}(C=O)R_{B'}; N₃; N₂R_{B'}; cyclic acetal; or cyclic or acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is a polymer; carbohydrate; photoaffinity label; or radiolabel; wherein each occurrence of

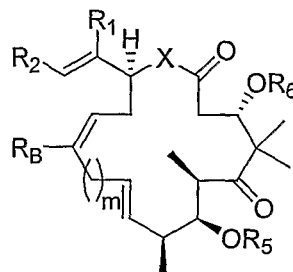
5 R_{B'} is independently hydrogen; a protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety; and

m is 1, 2, 3, or 4, the method comprising steps of:

10 oxidizing a compound of the formula:



60. A method of preparing a compound of formula:



15 wherein R₁ is hydrogen or lower alkyl;

R₂ is a substituted or unsubstituted aryl, heteroaryl, arylalkyl, or heteroarylalkyl moiety;

R₅ and R₆ are each independently hydrogen or a protecting group;

X is O, S, C(R₇)₂, or NR₇, wherein each occurrence of R₇ is independently

20 hydrogen or lower alkyl;

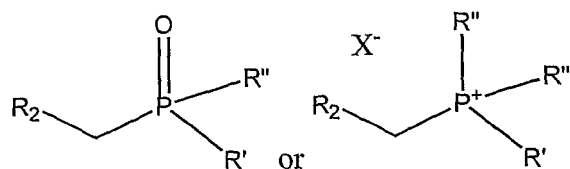
R_B is, independently for each occurrence, hydrogen; halogen; -OR_{B'}; -SR_{B'}; -N(R_{B'})₂; -CY₃; -CHY₂; -CH₂Y, where Y is F, Br, Cl, I, OR_{B'}, NHR_{B'}, N(R_{B'})₂, or SR_{B'}; -C(O)OR_{B'}; -C(O)R_{B'}; -CONHR_{B'}; -O(C=O)R_{B'}; -O(C=O)OR_{B'}; -

NR_{B'}(C=O)R_{B'}; N₃; N₂R_{B'}; cyclic acetal; or cyclic or acyclic, linear or branched

25 aliphatic, heteroaliphatic, aryl, or heteroaryl, optionally substituted with one or more of

hydrogen; halogen; $-\text{OR}_{\text{B}'}$; $-\text{SR}_{\text{B}'}$; $-\text{N}(\text{R}_{\text{B}'})_2$; $-\text{C}(\text{O})\text{OR}_{\text{B}'}$; $-\text{C}(\text{O})\text{R}_{\text{B}'}$; $-\text{CONHR}_{\text{B}'}$; $-\text{O}(\text{C}=\text{O})\text{R}_{\text{B}'}$; $-\text{O}(\text{C}=\text{O})\text{OR}_{\text{B}'}$; $-\text{NR}_{\text{B}'}(\text{C}=\text{O})\text{R}_{\text{B}'}$; N_3 ; $\text{N}_2\text{R}_{\text{B}'}$; cyclic acetal; or cyclic or acyclic, linear or branched substituted or unsubstituted aliphatic, heteroaliphatic, aryl, or heteroaryl moiety; or is an epothilone, desoxyepothilone, or analogues thereof; or is
 5 a polymer; carbohydrate; photoaffinity label; or radiolabel; wherein each occurrence of $\text{R}_{\text{B}'}$ is independently hydrogen; a protecting group; a linear or branched, substituted or unsubstituted, cyclic or acyclic, aliphatic, heteroaliphatic, aryl, heteroaryl, arylalkyl, arylalkenyl, arylalkynyl, heteroarylalkyl, heteroarylalkenyl, or heteroarylalkynyl moiety; and

10 m is 1, 2, 3, or 4, the method comprising steps of:
 condensing a phosphine oxide or Wittig reagent having the structure:



wherein R' and R'' are independently C_{1-8} linear or branched chain alkyl, or a substituted or unsubstituted phenyl, aryl, alkoxy or aryloxy; and

15 X is a counteranion such as chloride or bromide;
 with a ketone having the structure:

:

