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(54) **Title:**
FURO [3, 2 -B] PYRANE DERIVATIVES USEFUL IN THE SYNTHESIS OF HALICHONDRIN B ANALOGS

(57) **Abstract:**
In general, the invention features compounds useful for the synthesis of analogs of halichondrin B, such as eribulin or pharmaceutically acceptable salts thereof, e.g., eribulin mesylate. Exemplary compounds are of formula (I), (II), or (III).

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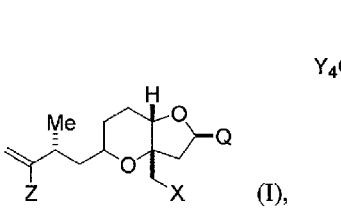
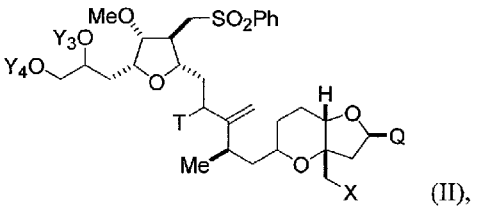
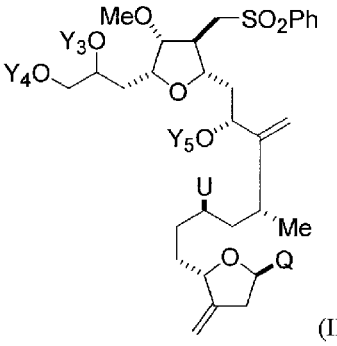
(54) Title: FURO [3, 2 -B] PYRANE DERIVATIVES USEFUL IN THE SYNTHESIS OF HALICHONDRIN B ANALOGS



(I),



(II),



(III).

(57) Abstract: In general, the invention features compounds useful for the synthesis of analogs of halichondrin B, such as eribulin or pharmaceutically acceptable salts thereof, e.g., eribulin mesylate. Exemplary compounds are of formula (I), (II), or (III).

WO 2011/094339 A1

FURO [3 , 2 -B] PYRANE DERIVATIVES USEFUL IN THE SYNTHESIS OF HALICHONDRIN B ANALOGS

BACKGROUND OF THE INVENTION

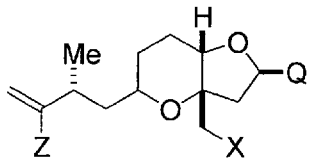
The invention relates to compounds useful in the synthesis of analogs of halichondrin B.

Eribulin mesylate, a nontaxane microtubule dynamics inhibitor, is a structurally simplified, synthetic analog of the marine natural product halichondrin B. Methods for the synthesis of eribulin and other halichondrin B analogs are described in International Publication No. WO 2005/118565 and U.S. Patent No. 6,214,865. New intermediates for the synthesis of halichondrin B analogs, in particular eribulin, are desirable.

SUMMARY OF THE INVENTION

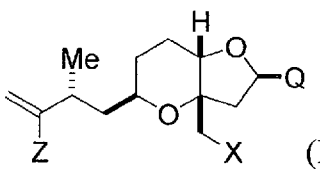
In general, the invention features compounds useful for the synthesis of analogs of halichondrin B, such as eribulin, including pharmaceutically acceptable salts thereof, e.g., eribulin mesylate.

In one aspect, the invention provides a compound having the formula (I):



(I),

wherein X is halogen or oxo; Z is a leaving group; Q is -C(O)H, -CH=CHC(O)OY_1, -C(R)H$(CH_2)_n OY_1$, or -C(R)HCH_2C(O)OY_1; R is H or -OY_2; Y_1 and Y_2 are each independently H or a hydroxyl protecting group; and n is 1 or 2. Exemplary compounds have the formula (Ia):

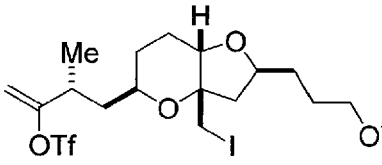


(Ia).

In particular embodiments, Q is $-(CH_2)_3OY_1$, for example wherein Y_1, together with the oxygen to which it is bound, is an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group. For example, Y_1 is pivaloyl, acetyl, benzoyl, p-bromobenzoyl, p-methoxybenzoyl, 1-naphthoyl, 2-naphthoyl, o-phthaloyl, benzyl, p-methoxybenzyl, triphenylmethyl, tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, or (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl.

In other embodiments, X is halogen, and/or Z is halogen or (C1-C6)alkylsulfonate (such as triflate, iodide, or bromide).

In other embodiments, the compounds are of the formula (Ib):

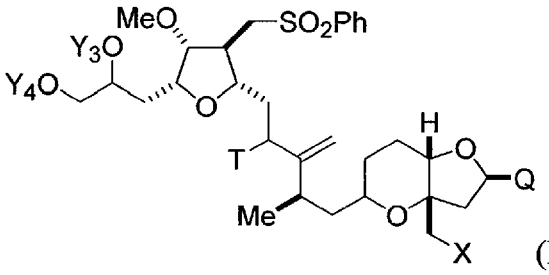


(Ib), wherein Y_1 is H, pivaloyl, benzoyl, p-bromobenzoyl, 1-naphthoyl, 2-naphthoyl, p-methoxybenzoyl, or o-phthaloyl or a salt thereof.

In certain embodiments, Q is -C(O)H, $-CH=CHC(O)OY_1$, or $-C(R)HCH_2C(O)OY_1$; X is bromo, chloro, fluoro, or oxo; or Z is halogen, C1-C12 alkoxy, C2-C12 alkylsulfonate, C2-C12 alkenylsulfonate, carbocyclic C6-C20 arylsulfonate, C4-C19 heteroarylsulfonate, monocyclic C1-C6 heteroarylsulfonate, (C6-C15)aryl(C1-C6)alkylsulfonate, (C4-C19)heteroaryl(C1-C6)alkylsulfonate, (C1-C6)heteroaryl(C1-C6)alkylsulfonate, or diazonium; or combinations thereof.

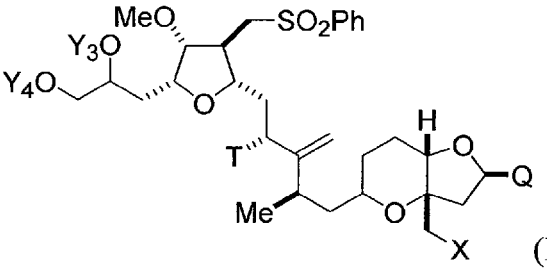
In other embodiments, when Q is $-(CH_2)_3OY_1$, Z is triflate, and X is iodide, Y_1 is not pivaloyl; when Q is $-(CH_2)_3OY_1$, Y_1 is pivaloyl, and Z is triflate, X is not iodide; or when Q is $-(CH_2)_3OY_1$, Y_1 is pivaloyl, and X is iodide, Z is not triflate. Alternatively, when Z is triflate, and X is iodide, Q is not $-(CH_2)_3OY_1$.

In another aspect, the invention features compounds having the formula (II):

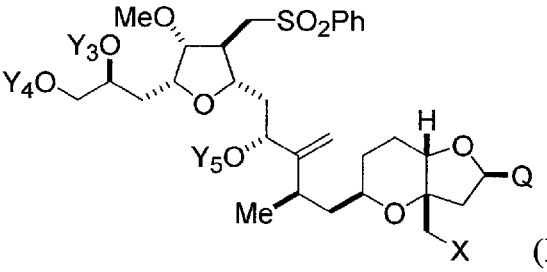


(II),

wherein X is halogen or oxo; Q is -C(O)H, -CH=CHC(O)OY_1, -C(R)H$(CH_2)_nOY_1$, or -C(R)HCH_2C(O)OY_1; R is H or -OY_2; n is 1 or 2; Y_1, Y_2, Y_3, and Y_4 are each independently H or a hydroxyl protecting group; T is oxo or -OY_5; and Y_5 is H or a hydroxyl protecting group, or Y_5, together with the oxygen atom to which it is bound, is a leaving group. Exemplary compounds have the formula:



(IIa) or

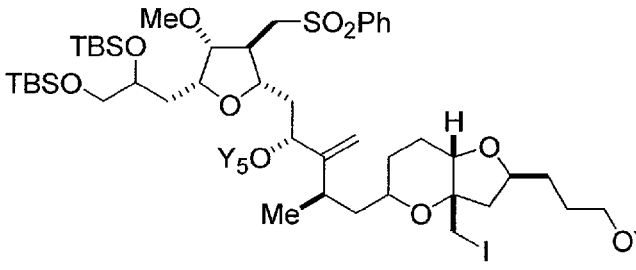


(IIb).

In particular embodiments, Q is $-(CH_2)_3OY_1$. In these embodiments, Y_1, together with the oxygen atom to which it is bound, can be an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group; Y_3 and Y_4 can each, independently and together with the oxygen atom to which it is bound, be an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group, or Y_3 and Y_4 together with the oxygen atoms to which they are bound can be a cyclic carbonate, cyclic boronate, acetal, ketal, or cyclic silylene hydroxyl protecting group or 1,1,3,3-tetraisopropylsiloxanediyl; T can be -OY_5; and/or Y_5, together

with the oxygen atom to which it is bound, can be an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group. In these embodiments, Y_1 is, for example, pivaloyl, acetyl, benzoyl, p-bromobenzoyl, p-methoxybenzoyl, 1-naphthoyl, 2-naphthoyl, o-phthaloyl, benzyl, p-methoxybenzyl, triphenylmethyl, tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, or (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl; Y_3 and Y_4 are, for example, each independently tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, or (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl, or Y_3 and Y_4 are together di(C1-C6alkyl)silylene; and/or Y_5 is, for example, acetyl, benzoyl, p-bromobenzoyl, p-methoxybenzoyl, 1-naphthoyl, 2-naphthoyl, or o-phthaloyl.

In other embodiments, X is halogen. These compounds can also have the formula (IIc):

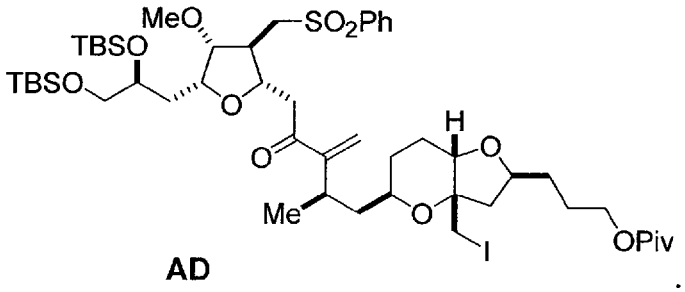


(IIc), wherein Y_1 and Y_5 are as follows:

Y_1	Y_5
H	H
benzoyl	benzoyl
p-bromobenzoyl	p-bromobenzoyl
pivaloyl	H
pivaloyl	acetyl
pivaloyl	benzoyl
2-naphthoyl	H
2-naphthoyl	2-naphthoyl
1-naphthoyl	H

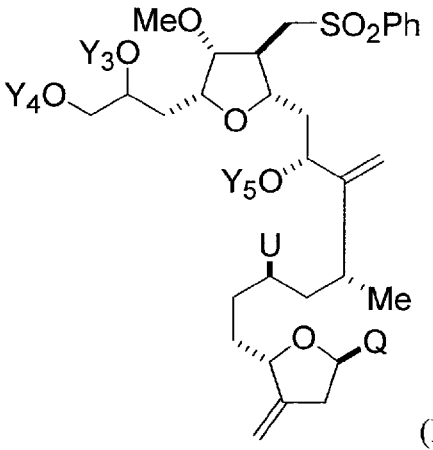
1-naphthoyl	1-naphthoyl
p-methoxybenzoyl	H
p-methoxybenzoyl	p-methoxybenzoyl
o-phthaloyl or salt thereof	H

A specific compound is



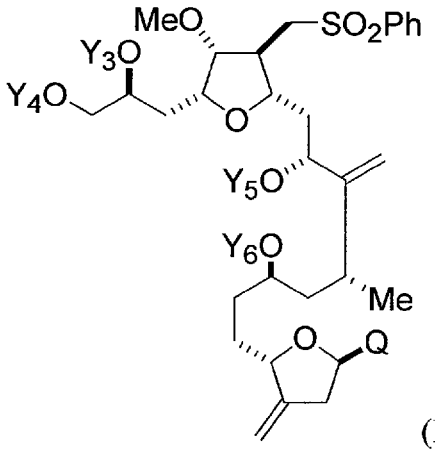
AD

In another embodiment, the invention features a compound having the formula (III):



(III),

wherein Q is -C(O)H, -CH=CHC(O)OY_1, -C(R)H$(CH_2)_nOY_1$, or -C(R)HCH_2C(O)OY_1; R is H or -OY_2; n is 1 or 2; Y_1, Y_2, Y_3, and Y_4 are each independently H or a hydroxyl protecting group; U is halogen or -OY_6; Y_5 is H or a hydroxyl protecting group or Y_5, together with the oxygen atom to which it is bound, is a leaving group; and Y_6 is H or a hydroxyl protecting group or Y_6, together with the oxygen atom to which it is bound, is a leaving group, provided that when Q is –$(CH_2)_3OY_1$, U is -OY_6, wherein -OY_6 is a leaving group, and Y_1, Y_3, and Y_4 are protecting groups, Y_5 is not H. Exemplary compounds have the formula (IIIa):



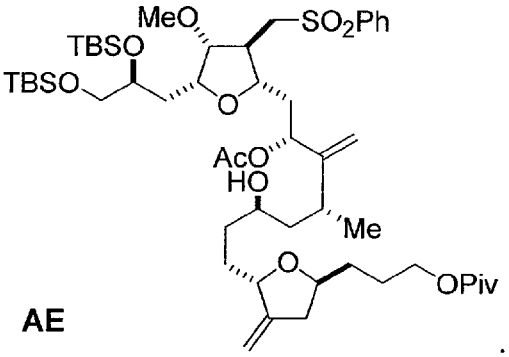
(IIIa).

In particular embodiments, Q is –$(CH_2)_3OY_1$. In these embodiments, Y_1, together with the oxygen atom to which it is bound, is, for example, an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group; each of Y_3 and Y_4 is, for example, independently and together with the oxygen atom to which it is bound, an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group, or Y_3 and Y_4 together with the oxygen atoms to which they are bound are, for example, a cyclic carbonate, cyclic boronate, acetal, ketal, or cyclic silylene hydroxyl protecting group or 1,1,3,3-tetraisopropylsiloxanediyl; and/or Y_5, together with the oxygen atom to which it is bound, is, for example, an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group. In specific examples, Y_1 is pivaloyl, acetyl, benzoyl, p-bromobenzoyl, p-methoxybenzoyl, 1-naphthoyl, 2-naphthoyl, o-phthaloyl, benzyl, p-methoxybenzyl, triphenylmethyl, tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, or

(C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl; Y_3 and Y_4 are each independently tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, or (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl, or Y_3 and Y_4 are together di(C1-C6)alkylsilylene; and/or Y_5 is acetyl, benzoyl, p-bromobenzoyl, p-methoxybenzoyl, 1-naphthoyl, 2-naphthoyl, or o-phthaloyl.

In other embodiments, Y_5 is H or a hydroxyl protecting group; Y_6 is H; or $-OY_6$ is a leaving group, such as (C1-C6)alkylsulfonate, (C6-C10 aryl or C1-C6 heteroaryl)sulfonate, (C6-C15)aryl(C1-C6)alkylsulfonate, or (C1-C6)heteroaryl(C1-C6)alkylsulfonate. Specific leaving groups include mesylate, toluenesulfonate, isopropylsulfonate, phenylsulfonate, or benzylsulfonate.

A specific example has the formula:



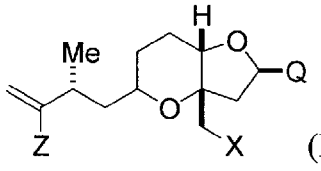
AE

Additional compounds of the invention are described herein.

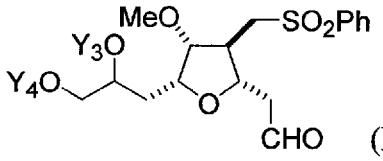
The invention further features use of the compounds of the invention, e.g., Compounds E-AM, in the manufacture of ER-804028 and analogs of halichondrin B, such as eribulin, or a pharmaceutically acceptable salt thereof, e.g., eribulin mesylate.

In one aspect, the invention features a method of synthesizing ER-804028 by

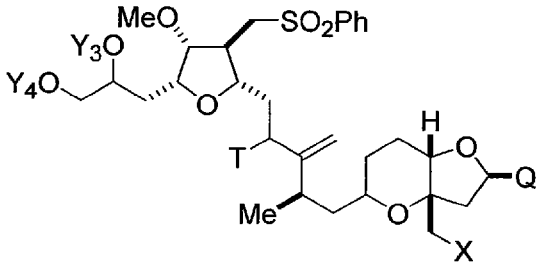
(i) reacting a compound having the formula (I):



(I) with a compound having the formula (IV):

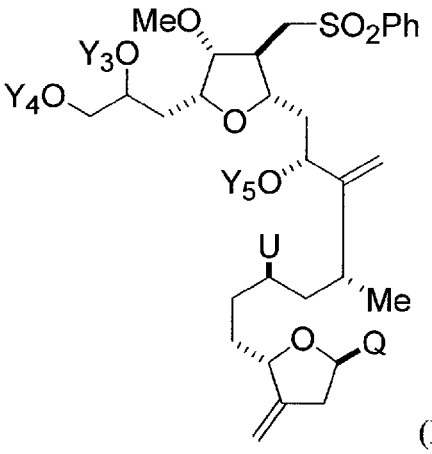


(IV), wherein Y_3, and Y_4, are each independently H or a hydroxyl protecting group, under Nozaki-Hiyama-Kishi (NHK) coupling conditions to produce a compound of formula (II):



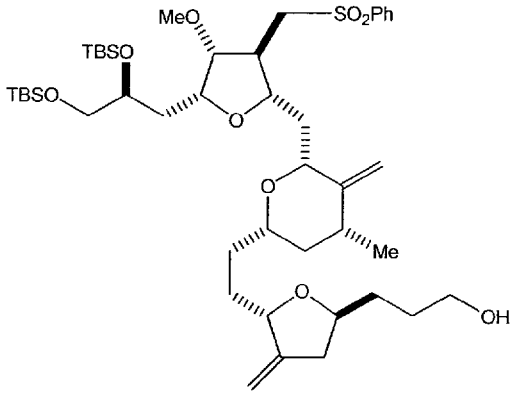
(II);

(ii) reacting the product of step (i) under Vasella fragmentation conditions to produce a compound of formula (III):



(III); and

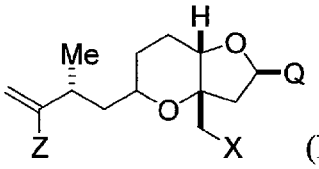
(iii) reacting the product of step (ii) under conditions for intramolecular Williamson etherification to produce ER-804028:



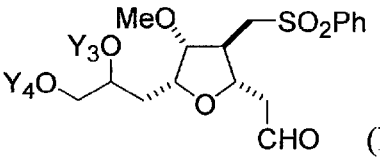
(ER-804028).

In another aspect, the invention features a method of synthesizing eribulin, or a pharmaceutically acceptable salt thereof, by

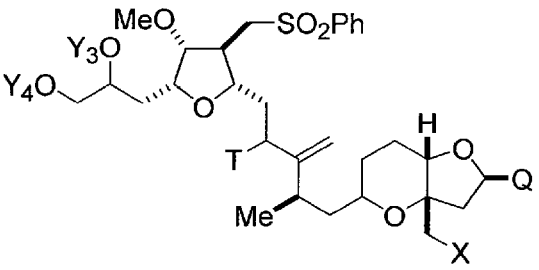
(i) reacting a compound having the formula (I):



(I) with a compound having the formula (IV):

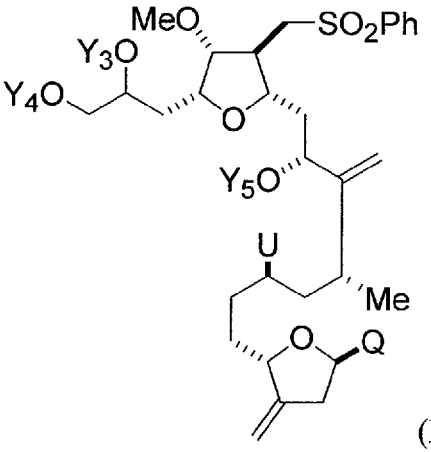


(IV), wherein Y_3, and Y_4, are each independently H or a hydroxyl protecting group, under NHK coupling conditions to produce a compound of formula (II)



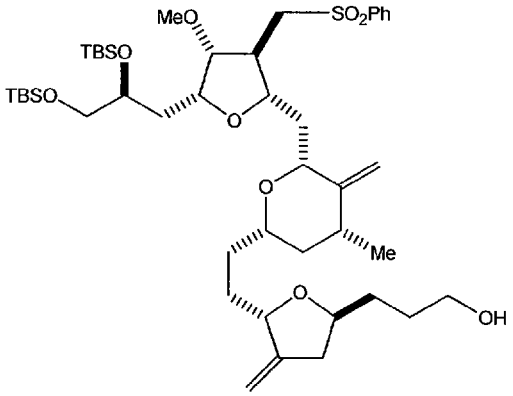
(II);

(ii) reacting the product of step (i) under Vasella fragmentation conditions to produce a compound of formula (III):



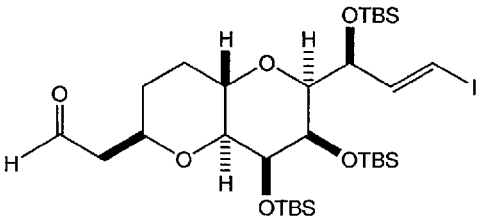
(III);

(iii) reacting the product of step (ii) under conditions for intramolecular Williamson etherification to produce ER-804028:



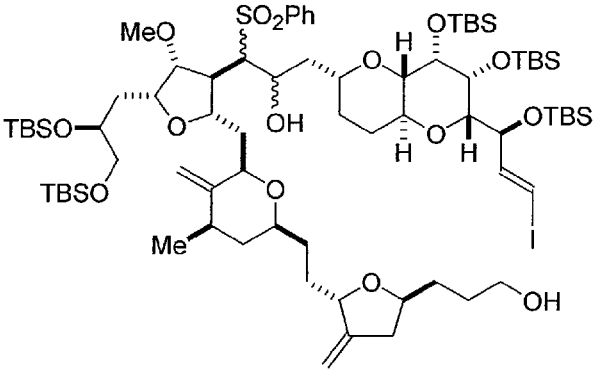
(ER-804028);

(iv) reacting ER-804028 with ER-803896:



(ER-803896)

under conditions to produce ER-804029:



(ER-804029); and

(v) reacting ER-804029 under conditions to produce eribulin, or the pharmaceutically acceptable salt thereof. The method may include salifying eribulin to produce the pharmaceutically acceptable salt thereof, e.g., eribulin mesylate. Additional intermediates and reaction conditions are described herein.

Asymmetric or chiral centers exist in the compounds of the invention. The present invention includes the various stereoisomers of the compounds and mixtures thereof, unless otherwise specified. Individual stereoisomers of the compounds of the present invention are prepared synthetically from commercially available starting materials that contain asymmetric or chiral centers or by preparation of mixtures of compounds followed by resolution as

is well known in the art. These methods of resolution are exemplified by direct separation of the mixture of diastereomers on chiral chromatographic columns or by chiral HPLC methods. Methods of chiral separation have been described previously (G.B. Cox (ed.) in *Preparative Enantioselective Chromatography*, 2005, Blackwell Publishing). Alternatively, chiral compounds can be prepared by an asymmetric synthesis that favors the preparation of one diastereomer over another. Geometric isomers may also exist in the compounds of the present invention. The present invention includes the various geometric isomers and mixtures thereof resulting from the arrangement of substituents around a carbon-carbon double bond, such as isomers of the Z or E configuration. It is also recognized that for structures in which tautomeric forms are possible, the description of one tautomeric form is equivalent to the description of both, unless otherwise specified. In certain embodiments, a diastereomer of a compound of the invention is present in a mixture at a ratio of 10:1, 20:1, 30:1, 50:1, or greater as compared to other diastereomers.

Compounds useful in the invention may be isotopically labeled compounds. Useful isotopes include hydrogen, carbon, nitrogen, and oxygen (e.g., ^{2}H, ^{3}H, ^{13}C, ^{14}C, ^{15}N, ^{18}O, and ^{17}O). Isotopically-labeled compounds can be prepared by synthesizing a compound using a readily available isotopically-labeled reagent in place of a non-isotopically-labeled reagent.

For any of the following chemical definitions, a number following an atomic symbol indicates that total number of atoms of that element that are present in a particular chemical moiety. As will be understood, other atoms, such as hydrogen atoms, or substituent groups, as described herein, may be present, as necessary, to satisfy the valences of the atoms. For example, an unsubstituted C2 alkyl group has the formula $-CH_2CH_3$. When used with the groups defined herein, a reference to the number of carbon atoms includes the divalent carbon in acetal and ketal groups but does not include the carbonyl carbon in acyl, ester, carbonate, or carbamate groups. A reference to the number of oxygen, nitrogen, or sulfur atoms in a heteroaryl group only includes those atoms that form a part of a heterocyclic ring.

By "acetal" is meant >CHR (or –CHR-), wherein R is H, alkyl, alkenyl, aryl, or arylalkyl.

By "acyl" is meant –C(O)R, wherein R is H, alkyl, alkenyl, aryl, or arylalkyl. In exemplary acyl groups, R is H, C1-C12 alkyl (e.g., C1-C8, C1-C6, C1-C4, C2-C7, C3-C12, and C3-C6 alkyl), C2-C12 alkenyl (e.g., C2-C8, C2-C6, C2-C4, C3-C12, and C3-C6 alkenyl), C6-C20 aryl (e.g., C6-C15, C6-C10, C8-C20, and C8-C15 aryl), monocyclic C1-C6 heteroaryl (e.g., monocyclic C1-C4 and C2-C6 heteroaryl), C4-C19 heteroaryl (e.g., C4-C10 heteroaryl), (C6-C15)aryl(C1-C6)alkyl, (C1-C6)heteroaryl(C1-C6)alkyl, or (C4-C19)heteroaryl(C1-C6)alkyl. As defined herein, any heteroaryl group present in an acyl group has from 1 to 4 heteroatoms selected independently from O, N, and S.

By "alkyl" is meant a straight or branched chain saturated cyclic (i.e., cycloalkyl) or acyclic hydrocarbon group of from 1 to 12 carbons, unless otherwise specified. Exemplary alkyl groups include C1-C8, C1-C6, C1-C4, C2-C7, C3-C12, and C3-C6 alkyl. Specific examples include methyl, ethyl, 1-propyl, 2-propyl, 2-methyl-1-propyl, 1-butyl, 2-butyl, and the like. Unless otherwise noted, alkyl groups, used in any context herein, are optionally substituted with halogen, alkoxy, aryloxy, arylalkyloxy, oxo, alkylthio, alkylenedithio, alkylamino, [alkenyl]alkylamino, [aryl]alkylamino, [arylalkyl]alkylamino, dialkylamino, silyl, sulfonyl, cyano, nitro, carboxyl, or azido.

By "alkylamino" is meant –NHR, wherein R is alkyl. By "[alkenyl]alkylamino" is meant –NRR', wherein R is alkyl, and R' is alkenyl. By "[aryl]alkylamino" is meant –NRR', wherein R is alkyl, and R' is aryl. By "[arylalkyl]alkylamino" is meant –NRR', wherein R is alkyl, and R' is arylalkyl. By "dialkylamino" is meant $–NR_2$, wherein each R is alkyl, selected indcpendently.

By "alkylene" is meant a divalent alkyl group. Alkylene groups, used in any context herein, are optionally substituted in the same manner as alkyl groups. For example, a C1 alkylene group is $–CH_2-$.

By "alkylenedithio" is meant –S-alkylene-S-.

By "alkylthio" is meant –SR, wherein R is alkyl.

By "alkenyl" is meant a straight or branched chain cyclic or acyclic hydrocarbon group of, unless otherwise specified, from 2 to 12 carbons and containing one or more carbon-carbon double bonds. Exemplary alkenyl groups include C2-C8, C2-C7, C2-C6, C2-C4, C3-C12, and C3-C6 alkenyl. Specific examples include ethenyl (i.e., vinyl), 1-propenyl, 2-propenyl (i.e., allyl), 2-methyl-1-propenyl, 1-butenyl, 2-butenyl (i.e., crotyl), and the like. Alkenyl groups, used in any context herein, are optionally substituted in the same manner as alkyl groups. Alkenyl groups, used in any context herein, may also be substituted with an aryl group.

By "alkoxy" is meant –OR, wherein R is alkyl.

By "aryl" is meant a monocyclic or multicyclic ring system having one or more aromatic rings, wherein the ring system is carbocyclic or heterocyclic. Heterocyclic aryl groups are also referred to as heteroaryl groups. A heteroaryl group includes 1 to 4 atoms selected independently from O, N, and S. Exemplary carbocyclic aryl groups include C6-C20, C6-C15, C6-C10, C8-C20, and C8-C15 aryl. A preferred aryl group is a C6-10 aryl group. Specific examples of carbocyclic aryl groups include phenyl, indanyl, indenyl, naphthyl, phenanthryl, anthracyl, and fluorenyl. Exemplary heteroaryl groups include monocylic rings having from 1 to 4 heteroatoms selected independently from O, N, and S and from 1 to 6 carbons (e.g., C1-C6, C1-C4, and C2-C6). Monocyclic heteroaryl groups preferably include from 5 to 9 ring members. Other heteroaryl groups preferably include from 4 to 19 carbon atoms (e.g., C4-C10). Specific examples of heteroaryl groups include pyridinyl, quinolinyl, dihydroquinolinyl, isoquinolinyl, quinazolinyl, dihydroquinazolyl, and tetrahydroquinazolyl. Unless otherwise specified, aryl groups, used in any context herein, are optionally substituted with alkyl, alkenyl, aryl, arylalkyl, halogen, alkoxy, aryloxy, arylalkyloxy, oxo, alkylthio, alkylenedithio, alkylamino, [alkenyl]alkylamino, [aryl]alkylamino, [arylalkyl]alkylamino, dialkylamino, silyl, sulfonyl, cyano, nitro, carboxyl, or azido.

By "arylalkyl" is meant –R'R", wherein R' is alkylene, and R" is aryl.

By "arylalkyloxy" is meant –OR, wherein R is arylalkyl.

By "aryloxy" is meant –OR, wherein R is aryl.

By "carbamate" is meant $-OC(O)NR_2$, wherein each R is independently H, alkyl, alkenyl, aryl, or arylalkyl.

By "carbonate" is meant –OC(O)OR, wherein R is alkyl, alkenyl, aryl, or arylalkyl.

By "carboxyl" is meant –C(O)OH, in free acid, ionized, or salt form.

By "cyclic boronate" is meant –OBRO-, wherein R is alkyl, alkenyl, aryl, arylalkyl, alkoxy, or 2,6-diacetamidophenyl.

By "cyclic carbonate" is meant –OC(O)O-.

By "cyclic silylene" is meant $-OSiR_2O-$, wherein each R is independently alkyl, alkenyl, aryl, arylalkyl, or alkoxy. By "dialkylsilylene" is meant a cyclic silylene, wherein each R is alkyl.

By "ester" is meant –OC(O)R, where –C(O)R is an acyl group, as defined herein, that is bound to the oxygen atom of a protected hydroxyl, as defined below.

By "ether" is meant –OR, wherein R is alkyl, alkenyl, arylalkyl, silyl, or 2-tetrahydropyranyl.

By "halogen" is meant fluoro, chloro, bromo, or iodo.

By "ketal" is meant $>CR_2$ (or - CR_2-), wherein each R is independently alkyl, alkenyl, aryl, or arylalkyl, or both R groups are together alkylene.

By "oxo" or (O) is meant =O.

By "silyl" is meant $-SiR_3$, wherein each R is independently alkyl, alkenyl, aryl, or arylalkyl. Examples of silyl groups include tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, and (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl. It will be understood that, when a silyl group includes two or more alkyl, alkenyl, aryl, heteroaryl, or arylalkyl groups, these groups are

independently selected. As defined herein, any heteroaryl group present in a silyl group has from 1 to 4 heteroatoms selected independently from O, N, and S.

By "sulfonate" is meant $-OS(O)_2R$, wherein R is alkyl, alkenyl, aryl, or arylalkyl. In exemplary sulfonates, R is C1-C12 alkyl (e.g., C1-C8, C1-C6, C1-C4, C2-C7, C3-C12, and C3-C6 alkyl), C2-C12 alkenyl (e.g., C2-C8, C2-C6, C2-C4, C3-C12, and C3-C6 alkenyl), carbocyclic C6-C20 aryl (e.g., C6-C15, C6-C10, C8-C20, and C8-C15 aryl), monocyclic C1-C6 heteroaryl (e.g., C1-C4 and C2-C6 heteroaryl), C4-C19 heteroaryl (e.g., C4-C10 heteroaryl), (C6-C15)aryl(C1-C6)alkyl, (C4-C19)heteroaryl(C1-C6)alkyl, or (C1-C6)heteroaryl(C1-C6)alkyl. As defined herein, any heteroaryl group present in a sulfonate group has from 1 to 4 heteroatoms selected independently from O, N, and S.

By "sulfonyl" is meant $-S(O)_2R$, wherein R is alkyl, alkenyl, aryl, arylalkyl, or silyl. Preferred R groups for sulfonyl are the same as those described above for sulfonates.

By "hydroxyl protecting group" is meant any group capable of protecting the oxygen atom to which it is attached from reacting or bonding. Hydroxyl protecting groups are known in the art, e.g., as described in Wuts, *Greene's Protective Groups in Organic Synthesis*, Wiley-Interscience, 4th Edition, 2006. Exemplary protecting groups (with the oxygen atom to which they are attached) are independently selected from esters, carbonates, carbamates, sulfonates, and ethers.

In exemplary ester hydroxyl protecting groups, R of the acyl group is C1-C12 alkyl (e.g., C1-C8, C1-C6, C1-C4, C2-C7, C3-C12, and C3-C6 alkyl), C2-C12 alkenyl (e.g., C2-C8, C2-C6, C2-C4, C3-C12, and C3-C6 alkenyl), carbocyclic C6-C20 aryl (e.g., C6-C15, C6-C10, C8-C20, and C8-C15 aryl), monocyclic C1-C6 heteroaryl (e.g., C1-C4 and C2-C6 heteroaryl), C4-C19 heteroaryl (e.g., C4-C10 heteroaryl), (C6-C15)aryl(C1-C6)alkyl, (C4-C19)heteroaryl(C1-C6)alkyl, or (C1-C6)heteroaryl(C1-C6)alkyl. Specific examples of acyl groups for use in esters include formyl, benzoylformyl, acetyl

(e.g., unsubstituted or chloroacetyl, trifluoroacetyl, methoxyacetyl, triphenylmethoxyacetyl, and p-chlorophenoxyacetyl), 3-phenylpropionyl, 4-oxopentanoyl, 4,4-(ethylenedithio)pentanoyl, pivaloyl (Piv), vinylpivaloyl, crotonoyl, 4-methoxy-crotonoyl, naphthoyl (e.g., 1- or 2-naphthoyl), and benzoyl (e.g., unsubstituted or substituted, e.g., p-methoxybenzoyl, phthaloyl (including salts, such a triethylamine and potassium), p-bromobenzoyl, and 2,4,6-trimethylbenzoyl). As defined herein, any heteroaryl group present in an ester group has from 1 to 4 heteroatoms selected independently from O, N, and S.

In exemplary carbonate hydroxyl protecting groups, R is C1-C12 alkyl (e.g., C1-C8, C1-C6, C1-C4, C2-C7, C3-C12, and C3-C6 alkyl), C2-C12 alkenyl (e.g., C2-C8, C2-C6, C2-C4, C3-C12, and C3-C6 alkenyl), carbocyclic C6-C20 aryl (e.g., C6-C15, C6-C10, C8-C20, and C8-C15 aryl), monocyclic C1-C6 heteroaryl (e.g., C1-C4 and C2-C6 heteroaryl), C4-C19 heteroaryl (e.g., C4-C10 heteroaryl), (C6-C15)aryl(C1-C6)alkyl, (C4-C19)heteroaryl(C1-C6)alkyl, or (C1-C6)heteroaryl(C1-C6)alkyl. Specific examples include methyl, 9-fluorenylmethyl, ethyl, 2,2,2-trichloroethyl, 2-(trimethylsilyl)ethyl, 2-(phenylsulfonyl)ethyl, vinyl, allyl, t-butyl, p-nitrobenzyl, and benzyl carbonates. As defined herein, any heteroaryl group present in a carbonate group has from 1 to 4 heteroatoms selected independently from O, N, and S.

In exemplary carbamate hydroxyl protecting groups, each R is independently H, C1-C12 alkyl (e.g., C1-C8, C1-C6, C1-C4, C2-C7, C3-C12, and C3-C6 alkyl), C2-C12 alkenyl (e.g., C2-C8, C2-C6, C2-C4, C3-C12, and C3-C6 alkenyl), carbocyclic C6-C20 aryl (e.g., C6-C15, C6-C10, C8-C20, and C8-C15 aryl), monocyclic C1-C6 heteroaryl (e.g., C1-C4 and C2-C6 heteroaryl), C4-C19 heteroaryl (e.g., C4-C10 heteroaryl), (C6-C15)aryl(C1-C6)alkyl, (C4-C19)heteroaryl(C1-C6)alkyl, or (C1-C6)heteroaryl(C1-C6)alkyl. Specific examples include N-phenyl and N-methyl-N-(o-nitrophenyl) carbamates. As defined herein, any heteroaryl group present in a carbamate group has from 1 to 4 heteroatoms selected independently from O, N, and S.

Exemplary ether hydroxyl protecting groups include C1-C12 alkylethers (e.g., C1-C8, C1-C6, C1-C4, C2-C7, C3-C12, and C3-C6 alkyl), C2-C12 alkenylethers (e.g., C2-C8, C2-C6, C2-C4, C3-C12, and C3-C6 alkenyl), (C6-C15)aryl(C1-C6)alkylethers, (C4-C19)heteroaryl(C1-C6)alkylethers, (C1-C6)heteroaryl(C1-C6)alkylethers, (C1-C6)alkoxy(C1-C6)alkylethers, (C1-C6)alkylthio(C1-C6)alkylethers, (C6-C10)aryl(C1-C6)alkoxy(C1-C6)alkylethers, and silylethers (e.g., tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, and (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl). Specific examples of alkylethers include methyl and t-butyl, and an example of an alkenyl ether is allyl. Examples of alkoxyalkylethers and alkylthioalkylethers include methoxymethyl, methylthiomethyl, (2-methoxyethoxy)methyl, and β-(trimethylsilyl)ethoxymethyl. Examples of arylalkylethers include benzyl, p-methoxybenzyl (MPM), 3,4-dimethoxybenzyl, triphenylmethyl (trityl), o-nitrobenzyl, p-nitrobenzyl, p-halobenzyl, 2,6-dichlorobenzyl, p-cyanobenzyl, naphthylmethyl, and 2- and 4-picolyl ethers. Specific examples of silylethers include trimethylsilyl (TMS), triethylsilyl (TES), t-butyldimethylsilyl (TBS), t-butyldiphenylsilyl (TBDPS), triisopropylsilyl (TIPS), and triphenylsilyl (TPS) ethers. An example of an arylalkyloxyalkylether is benzyloxymethyl ether. As defined herein, any heteroaryl group present in an ether group has from 1 to 4 heteroatoms selected independently from O, N, and S.

Adjacent hydroxyl groups may be protected with a diol protecting group, such as acetal (e.g., C1-C6 alkyl), ketal (e.g., C2-C6 alkyl or C3-C6 cycloalkyl), cyclic silylene, cyclic carbonate, and cyclic boronate. Examples of acetal and ketal groups include methylene, ethylidene, benzylidene, isopropylidene, cyclohexylidene, and cyclopentylidene. An example of a cyclic silylene is di-t-butylsilylene. Another diol protecting group is 1,1,3,3-tetraisopropylsiloxanediyl. Examples of cyclic boronates include methyl, ethyl, phenyl, and 2,6-diacetamidophenyl boronates.

Protecting groups may be substituted as is known in the art; for example, aryl and arylalkyl groups, such as phenyl, benzyl, naphthyl, or pyridinyl, can be

substituted with C1-C6 alkyl, C1-C6 alkoxy, nitro, cyano, carboxyl, or halogen. Alkyl groups, such as methyl, ethyl, isopropyl, n-propyl, t-butyl, n-butyl, and sec-butyl, and alkenyl groups, such as vinyl and allyl, can also be substituted with oxo, arylsulfonyl, halogen, and trialkylsilyl groups. Preferred protecting groups are TBS and Piv. Protecting groups that are orthogonal are removed under different conditions, as in known in the art.

By "leaving group" is meant a group that is displaced during a chemical reaction. Suitable leaving groups are well known in the art, e.g., see, *Advanced Organic Chemistry*, March, 4th Ed., pp. 351-357, John Wiley and Sons, N.Y. (1992). Such leaving groups include halogen, C1-C12 alkoxy (e.g., C1-C8, C1-C6, C1-C4, C2-C7, and C3-C6 alkoxy), C1-C12 alkylsulfonate (e.g., C1-C8, C1-C6, C1-C4, C2-C7, C3-C12, and C3-C6 alkylsulfonate), C2-C12 alkenylsulfonate (e.g., C2-C8, C2-C6, C2-C4, C3-C12, and C3-C6 alkenylsulfonate), carbocyclic C6-C20 arylsulfonate (e.g., C6-C15, C6-C10, C8-C20, and C8-C15 arylsulfonate), C4-C19 heteroarylsulfonate (e.g., C4-C10 heteroarylsulfonate), monocyclic C1-C6 heteroarylsulfonate (e.g., C1-C4 and C2-C6 heteroarylsulfonate), (C6-C15)aryl(C1-C6)alkylsulfonate, (C4-C19)heteroaryl(C1-C6)alkylsulfonate, (C1-C6)heteroaryl(C1-C6)alkylsulfonate, and diazonium. Alkylsulfonates, alkenylsulfonates, arylsulfonates, heteroarylsulfonates, arylalkylsulfonates, and heteroarylalkylsulfonates can be optionally substituted with halogen (e.g., chloro, iodo, bromo, or fluoro), alkoxy (e.g., C1-C6 alkoxy), aryloxy (e.g., C6-C15 aryloxy, C4-C19 heteroaryloxy, and C1-C6 heteroaryloxy), oxo, alkylthio (e.g., C1-C6 alkylthio) , alkylenedithio (e.g., C1-C6 alkylenedithio), alkylamino (e.g., C1-C6 alkylamino), [alkenyl]alkylamino (e.g., [(C2-C6)alkenyl](C1-C6)alkylamino), [aryl]alkylamino (e.g., [(C6-C10)aryl](C1-C6)alkylamino, [(C1-C6)heteroaryl](C1-C6)alkylamino, and [(C4-C19)heteroaryl](C1-C6)alkylamino), [arylalkyl]alkylamino (e.g., [(C6-C10)aryl(C1-C6)alkyl](C1-C6)alkylamino, [(C1-C6)heteroaryl(C1-C6)alkyl](C1-C6)alkylamino, and [(C4-C19)heteroaryl(C1-C6)alkyl](C1-C6)alkylamino), dialkylamino (e.g., di(C1-C6 alkyl)amino), silyl (e.g., tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-

C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, and (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl), cyano, nitro, or azido. Alkenylsulfonates can be optionally substituted with carbocyclic aryl (e.g., C6-C15 aryl), monocyclic C1-C6 heteroaryl, or C4-C19 heteroaryl (e.g., C4-C10 heteroaryl). Arylsulfonates can be optionally substituted with alkyl (e.g., C1-C6 alkyl) or alkenyl (e.g. C2-C6 alkenyl). As defined herein, any heteroaryl group present in a leaving group has from 1 to 4 heteroatoms selected independently from O, N, and S.

Specific examples of suitable leaving groups include chloro, iodo, bromo, fluoro, methanesulfonate (mesylate), 4-toluenesulfonate (tosylate), trifluoromethanesulfonate (triflate, OTf), nitro-phenylsulfonate (nosylate), and bromo-phenylsulfonate (brosylate). Leaving groups may also be further substituted as is known in the art.

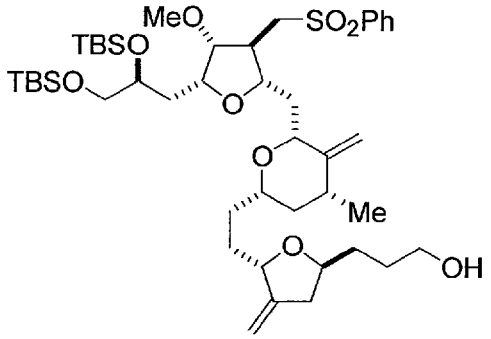
By "pharmaceutically acceptable salt" is meant a salt within the scope of sound medical judgment, suitable for use in contact with the tissues of humans and animals without undue toxicity, irritation, allergic response and the like and commensurate with a reasonable benefit/risk ratio. Pharmaceutically acceptable salts are well known in the art. For example, pharmaceutically acceptable salts are described in: Berge et al., *J. Pharmaceutical Sciences* 66:1-19, 1977 and in *Pharmaceutical Salts: Properties, Selection, and Use*, (Eds. P.H. Stahl and C.G. Wermuth), Wiley-VCH, 2008. Representative acid addition salts include acetate, adipate, alginate, ascorbate, aspartate, benzenesulfonate, benzoate, bisulfate, borate, butyrate, camphorate, camphorsulfonate, citrate, cyclopentanepropionate, digluconate, dodecylsulfate, ethanesulfonate, fumarate, glucoheptonate, glycerophosphate, hemisulfate, heptonate, hexanoate, hydrobromide, hydrochloride, hydroiodide, 2-hydroxy-ethanesulfonate, lactobionate, lactate, laurate, lauryl sulfate, malate, maleate, malonate, methanesulfonate, 2-naphthalenesulfonate, nicotinate, nitrate, oleate, oxalate, palmitate, pamoate, pectinate, persulfate, 3-phenylpropionate, phosphate, picrate, pivalate, propionate, stearate, succinate, sulfate, tartrate,

thiocyanate, toluenesulfonate, undecanoate, valerate salts and the like. A preferred salt is the mesylate salt.

Other features and advantages of the invention will be apparent from the following description and the claims.

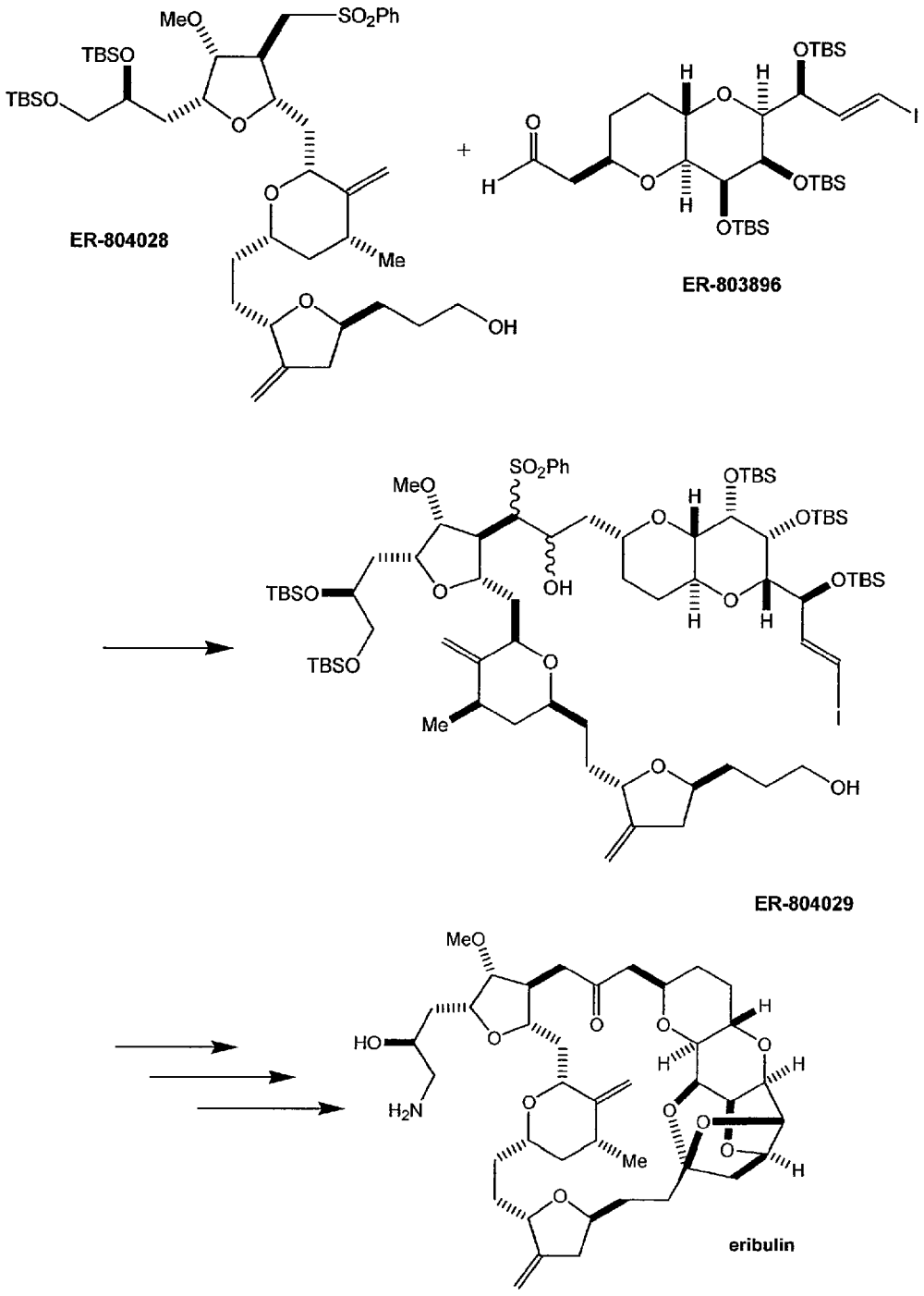
DETAILED DESCRIPTION OF THE INVENTION

The present invention provides compounds and methods of their use in the synthesis of halichondrin B analogs. In particular, the compounds are useful for the synthesis of the C14-C35 portion of halichondrin B analogs. ER-804028 is a C14-C35 fragment that has been employed in the synthesis of eribulin:



ER-804028.

Halichondrin B analogs, e.g., eribulin or pharmaceutically acceptable salts thereof, can be synthesized from the C14-C35 fragment as described in U.S. Patent No. 6,214,865 and International Publication No. WO 2005/118565. In one example described in these references, the C14-C35 portion, e.g., ER-804028, of the molecule is coupled to the C1-C13 portion, e.g., ER-803896, to produce ER-804029, and additional reactions are carried out to produce eribulin (Scheme 1):

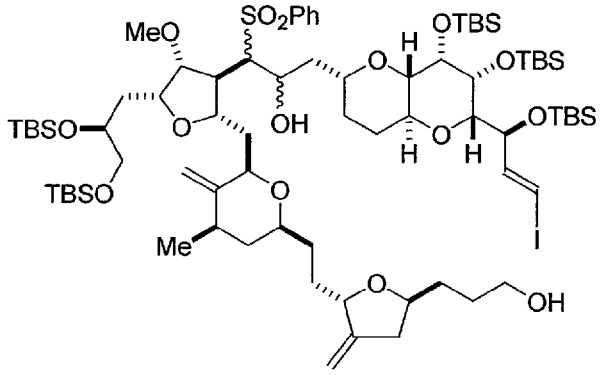


Scheme 1

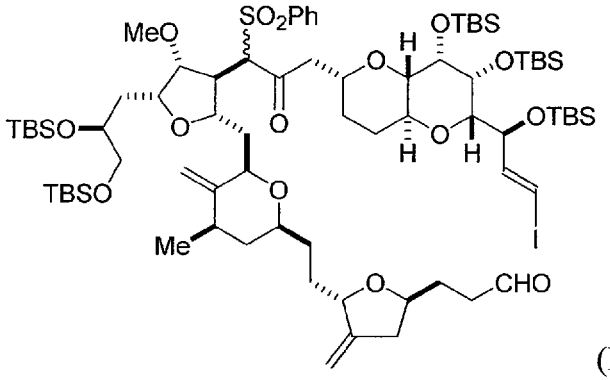
Lithiation of the C14-C35 sulfone fragment followed by coupling to the C1-C13 aldehyde fragment furnishes a mixture of diastereomeric alcohols (ER-804029). Additional protecting group manipulation and oxidation followed by removal of the sulfonyl group and an intramolecular Nozaki-Hiyama-Kishi (NHK) reaction affords an intermediate, which, when oxidized and treated with

tetrabutylammonium fluoride, undergoes intramolecular oxy-Michael ring closure. Pyridinium *p*-toluenesulfonate mediated ketal formation and conversion of the terminal alcohol to an amine furnishes eribulin.

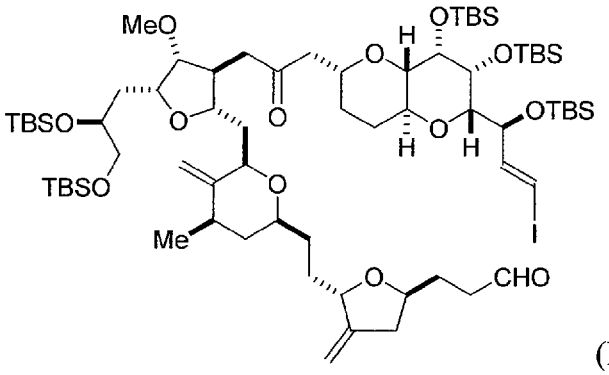
For example, as described in WO 2005/118565 (Example 6), ER-804029:



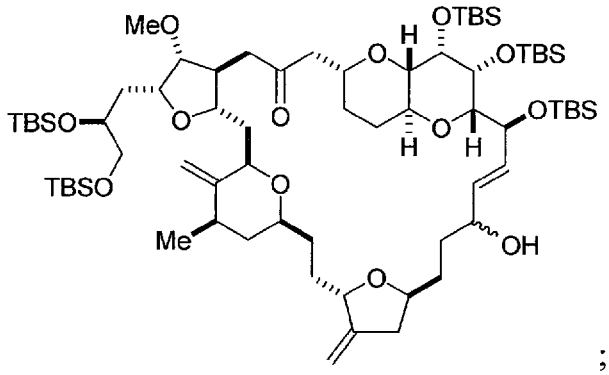
(ER 804029) is reacted, e.g., oxidized, to produce ER-804030:



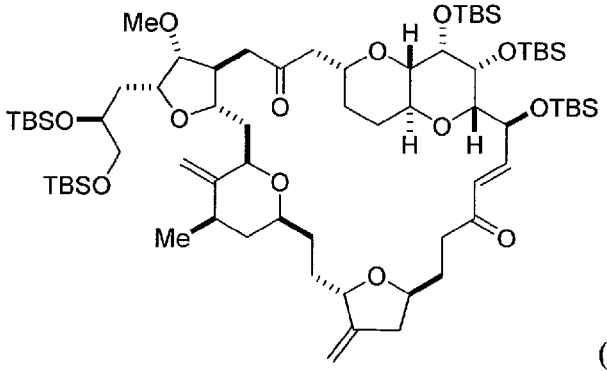
(ER-804030); ER-804030 is reacted, e.g., desulfonylated, to produce ER-118049:



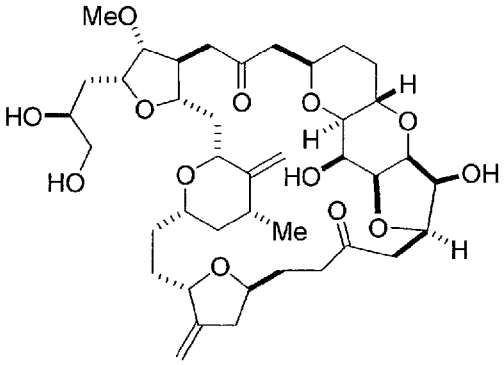
(ER-118049); ER-118049 is reacted, e.g., under coupling conditions, to produce mixture ER-118047/118048:



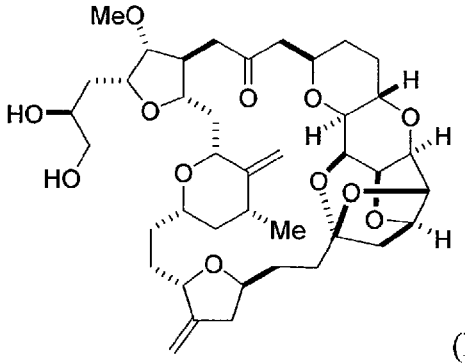
; the mixture ER-118047/118048 is reacted, e.g., oxidized, to produce ER-118046:



(ER-118046); ER-118046 is reacted to produce ER-811475:

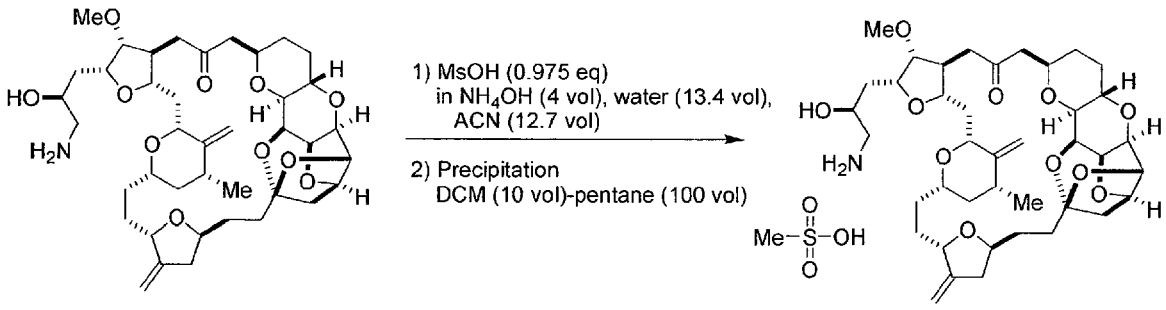


(ER-811475); ER-811475 is reacted to produce ER-076349:



(ER-076349); and ER-076349 is reacted, e.g., by converting the primary hydroxyl group to an amine, to produce eribulin.

Pharmaceutically acceptable salts of eribulin, e.g., eribulin mesylate, can be formed by methods known in the art, e.g., in situ during the final isolation and purification of the compound or separately by reacting the free base group with a suitable organic acid. In one example, eribulin is treated with a solution of MsOH and NH_4OH in water and acetonitrile. The mixture is concentrated. The residue is dissolved in DCM-pentane, and the solution is added to anhydrous pentane. The resulting precipitate is filtered and dried under high vacuum to provide eribulin mesylate, as shown in Scheme 2.

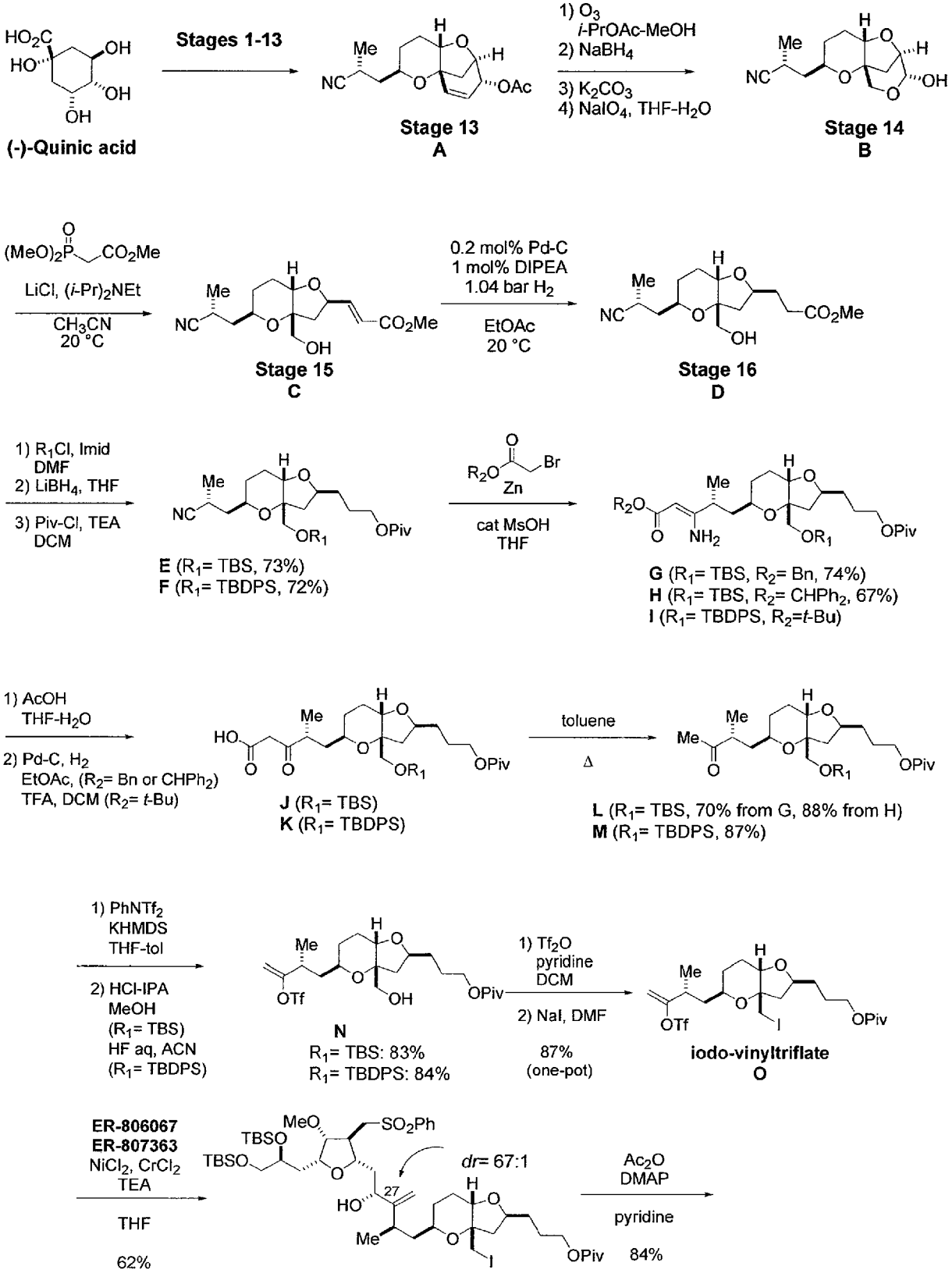


eribulin

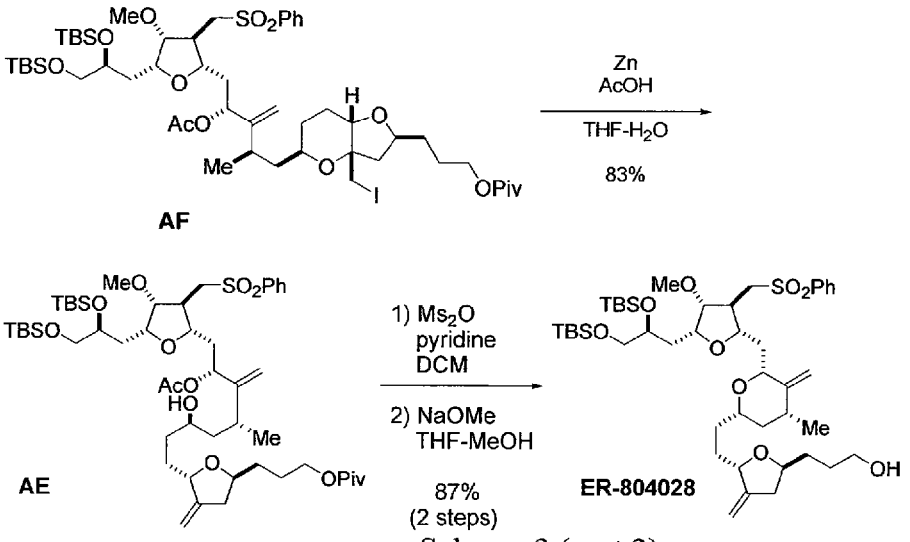
eribulin mesylate

Scheme 2

A scheme for producing one example of a C14-C35 fragment (ER-804028) is as follows (Scheme 3).



Scheme 3 (part 1)



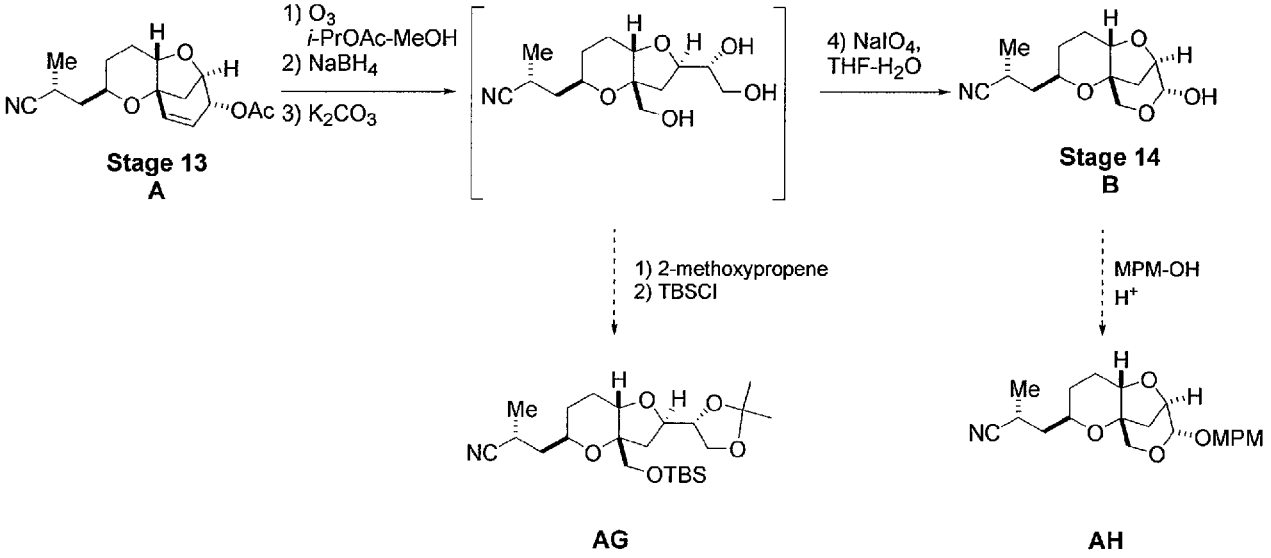
Scheme 3 (part 2)

Generally, (-)-quinic acid is converted to Compound A through stages 1-13 as described in International Publication Nos. WO 2009/046308 and WO 2005/118565. As outlined in Scheme 3, oxidation followed by Horner-Wadsworth-Emmons (HWE) reaction of the resulting lactol, hydrogenation, and protecting group modification furnishes Compounds E and F. Blaise reaction followed by methyl ketone formation, dehydration, enolization, triflation, desilylation, and iodination produces iodo-vinyl triflate, Compound O. NHK coupling of Compound O with ER-806067 furnishes Compound P. Acetylation followed by Vasella fragmentation, intramolecular Williamson etherification, and protecting group modification affords C14-C35 fragment ER-804028. This scheme is advantageous as it results in improved stereoselectivity at C27, i.e., 67:1 *dr* compared to 13:1 *dr* in previous processes. The scheme is also advantageous as the C14-C26 starting material and C14-C35 product of the NHK coupling of this scheme exhibit greater stability than the starting material and product of previous methods. The C14-C26 starting material and C14-C35 product of the NHK coupling are stable indefinitely at room temperature, allowing for a flexible manufacturing schedule.

One skilled in the art would also understand that variations on the above scheme are possible. For example, the hydroxyl protecting groups employed in particular reactions may be varied. In other variations, the leaving groups

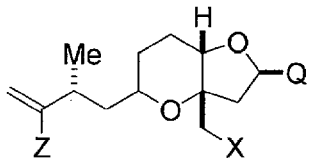
employed may be altered; for example, triflate groups can be replaced with halogens such as iodine or bromine.

In addition, although the scheme depicts Compound C et seq. with carbons C14-C16, the reactions leading to the addition of carbons C14 and C15 can occur at any point prior to the synthesis of ER-804028. Synthetic steps for adding carbons C14 and C15 are disclosed in WO 2009/046308. In specific examples, Compound A or Compound B can be altered as shown in Scheme 4, and the products AG and AH substituted for Compound E or F in Scheme 3.



Scheme 4

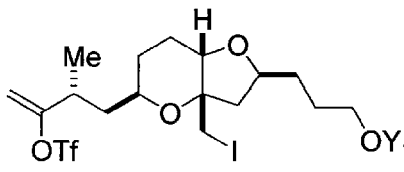
In accordance with the synthetic scheme, the invention provides compounds having the formula:



(I), e.g., Compound O, Compound AI, and Compound AJ,

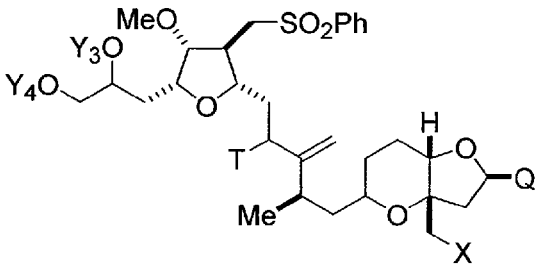
wherein X is halogen or oxo; Z is a leaving group; Q is -C(O)H, -CH=CHC(O)OY_1, -C(R)H$(CH_2)_nOY_1$, or -C(R)HCH_2C(O)OY_1; R is H or -OY_2; Y_1 and Y_2 are each independently H or a hydroxyl protecting group; and n is 1 or 2. When both Y_1 and Y_2 are present, they may be the same or different. In addition, when Y_1 and Y_2 are on adjacent carbons, e.g., when n=1, they may

together form a divalent hydroxyl protecting group. Compounds of this formula include those having the formula:

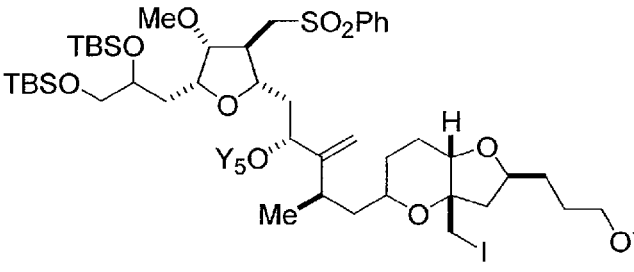


(Ib), wherein Y_1 is H, pivaloyl, benzoyl, p-bromobenzoyl, 1-naphthoyl, 2-naphthoyl, p-methoxybenzoyl, or o-phthaloyl (including salts such as triethylamine and potassium).

The invention also provides compounds having the formula:



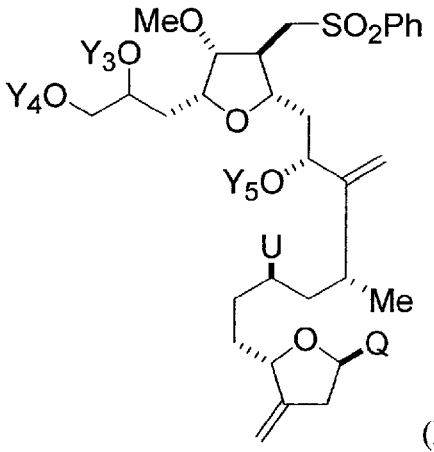
(II), e.g., Compound P, Compound AD, Compound AF, Compound AK, Compound AL, and Compound AM, wherein X is halogen or oxo; Q is -C(O)H, -CH=CHC(O)OY_1, -C(R)H$(CH_2)_nOY_1$, or -C(R)HCH_2C(O)OY_1; R is H or -OY_2; n is 1 or 2; Y_1, Y_2, Y_3, and Y_4 are each independently H or a hydroxyl protecting group; T is oxo or -OY_5; and Y_5 is H or a hydroxyl protecting group, or Y_5, together with the oxygen atom to which it is bound, is a leaving group. In certain embodiments, Y_3 and Y_4 are together a divalent hydroxyl protecting group. In other embodiments, Y_1, Y_3, and Y_4 are protecting groups, and Y_1 is orthogonal to Y_3 and Y_4. In further embodiments, Y_1, Y_3, Y_4, and Y_5 are protecting groups; Y_3 and Y_4 are orthogonal to Y_1 and Y_5; and Y_1 is orthogonal to Y_5. Compounds of this formula include those having the formula:



(IIb), wherein Y_1 and Y_5 are as follows:

Y_1	Y_5
H	H
benzoyl	benzoyl
p-bromobenzoyl	p-bromobenzoyl
pivaloyl	H
pivaloyl	acetyl
pivaloyl	benzoyl
2-naphthoyl	H
2-naphthoyl	2-naphthoyl
1-naphthoyl	H
1-naphthoyl	1-naphthoyl
p-methoxybenzoyl	H
p-methoxybenzoyl	p-methoxybenzoyl
o-phthaloyl	H
o-phthaloyl, triethylamine salt	H

The invention also features compounds having the formula:



(III), e.g., Compound AE,

wherein Q is -C(O)H, -CH=CHC(O)OY_1, -C(R)H$(CH_2)_nOY_1$, or -C(R)HCH_2C(O)OY_1; R is H or -OY_2; n is 1 or 2; Y_1, Y_2, Y_3, and Y_4 are each independently H or a hydroxyl protecting group; U is halogen or -OY_6; Y_5 is H or a hydroxyl protecting group or Y_5, together with the oxygen atom to which it

is bound, is a leaving group; and Y_6 is H or a hydroxyl protecting group or Y_6, together with the oxygen atom to which it is bound, is a leaving group, provided that when Q is $-C(R)H(CH_2)_nOY_1$ (e.g., $-(CH_2)_3OY_1$), U is $-OY_6$, $-OY_6$ is a leaving group, and Y_1, Y_3, and Y_4 are protecting groups, Y_5 is not H. In certain embodiments, Y_3 and Y_4 are together a divalent hydroxyl protecting group. In other embodiments, Y_1, Y_3, and Y_4 are protecting groups, and Y_1 is orthogonal to Y_3 and Y_4. In further embodiments, Y_1, Y_3, Y_4, and Y_5 are protecting groups; Y_3 and Y_4 are orthogonal to Y_1 and Y_5; and Y_1 is orthogonal to Y_5.

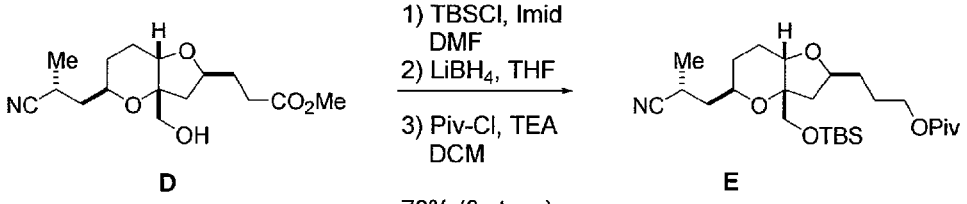
As described herein, the compounds of the invention can be used in the synthesis of ER-804028 and in turn eribulin, or a pharmaceutically acceptable salt thereof, e.g., eribulin mesylate.

Experimental Procedures

Compound D

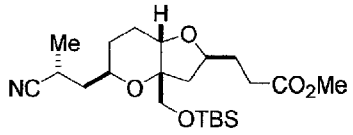
The synthesis of Compound D from (-)-quinic acid is described in WO 2009/046308, which is hereby incorporated by reference.

Compound E



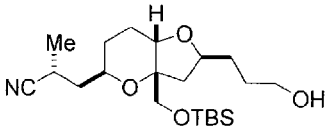
Compound D (3.05 g, 9.80 mmol, 1 eq) was dissolved in DMF (6.1 ml) at 22 °C, and imidazole (1.00 g, 14.7 mmol, 1.5 eq) was added. Upon complete dissolution of imidazole, the mixture was cooled to 0 °C, and TBSCl (1.55 g, 10.3 mmol, 1.05 eq) was added. The mixture was stirred at 0 °C for 1 h, allowed to warm to room temperature and stirred for an additional 1 h. The reaction mixture was diluted with MTBE (37 ml) and washed with water (30

ml). The organic layer was separated, further washed with water (9.2 ml), and concentrated to give Compound S:



S as colorless oil (4.43 g with residual solvents, theoretical 100% yield assumed). The crude product was used for the next reaction without purification. ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.20 (1H, m), 3.91 (1H, m), 3.85 (1H, m), 3.64 (3H, s), 3.50 (1H, d, J= 10.8 Hz) 3.45 (1H, d, J= 10.8 Hz), 2.90 (1H, m), 2.39 (1H, m), 2.31 (1H, m), 2.22 (1H, dd, J= 14.0 Hz, 8.8 Hz), 1.77-1.90 (2H, m), 1.60-1.74 (4H, m), 1.51 (1H, m), 1.27 (3H, d, J= 6.8 Hz), 1.26 (1H, m), 0.86 (9H, s), 0.02 (6H, s); and ^{13}C NMR (100 MHz, $CDCl_3$): δ 174.08, 122.93, 84.86, 75.78, 73.45, 66.82, 66.31, 51.77, 41.04, 38.16, 31.44, 31.04, 26.20, 26.06 (3C), 22.51, 22.20, 18.51, 18.48, -5.12, -5.17.

Compound S (4.2 g, 9.8 mmol, 1 eq) was dissolved in THF (21 ml) and cooled to 0 °C. $LiBH_4$ (2.0 M solution in THF, 12.2 ml, 24.5 mmol, 2.5 eq) was added, and the mixture was allowed to warm to 20 °C. Stirring was continued at 20-23 °C overnight (16 h). Another reactor was charged with 20 wt% citric acid (aqueous solution, 25 g, 26 mmol, 2.6 eq) and MTBE (40 ml), and the mixture was cooled to 0 °C. The reaction mixture was carefully/slowly poured into the pre-chilled citric acid-MTBE while maintaining T-internal <10 °C. Upon complete addition, the mixture was stirred at 0-5 °C for 30 min. The organic layer was separated, sequentially washed with: 1) saturated $NaHCO_3$ (12 g) and 2) 20 wt% NaCl (12 g), and concentrated to give crude Compound T:

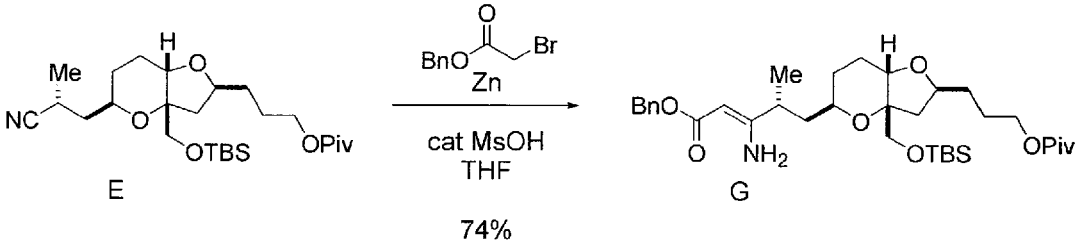


T as colorless oil (3.32 g, 8.3 mmol, 85% yield in 2 steps). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.20 (1H, m), 3.93 (1H, dd, J= 6.4 Hz, 4.8 Hz), 3.80 (1H, m), 3.57 (2H, m), 3.47 (1H, d, J= 10.4 Hz), 3.42 (1H, d, J=

10.4 Hz), 2.88 (1H, m), 2.57 (1H, br), 2.18 (1H, dd, *J*=7.2 Hz, 14.4 Hz), 1.68-1.81 (2H, m), 1.45-1.68 (6H, m), 1.24 (3H, d, *J*= 7.2 Hz), 1.22 (1H, m), 0.83 (9H, s), 0.02 (6H, s); and ^{13}C NMR (100 MHz, $CDCl_3$): δ 122.90, 84.72, 76.75, 73.56, 67.14, 66.53, 62.87, 40.94, 38.18, 33.58, 29.91, 26.36, 26.04, 22.60, 22.48 (3C), 18.478, 18.43, -5.11, -5.16.

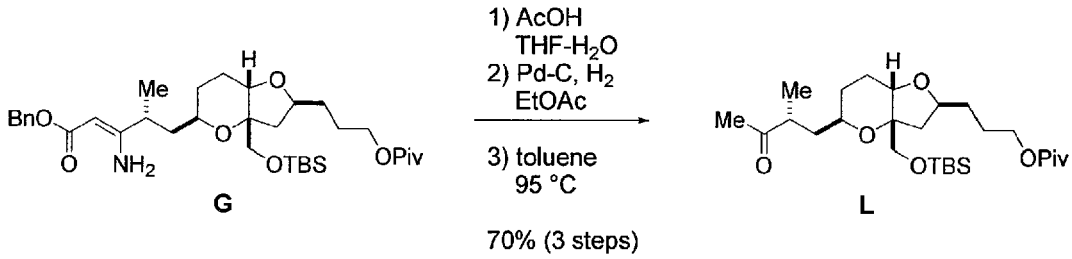
Compound T (2.30 g, 5.78 mmol, 1 eq) was dissolved in CH_2Cl_2 (12 ml). TEA (1.6 ml, 12 mmol, 2.0 eq) was added followed by DMAP (71 mg, 0.58 mmol, 0.10 eq). The mixture was cooled to 0 °C, and pivaloyl chloride (0.747 ml, 6.07 mmol, 1.05 eq) was added. The mixture was allowed to warm to 0 °C, and stirring was continued at 20-22 °C for an additional 2 h. The reaction mixture was diluted with MTBE (23 ml), sequentially washed with: 1) 20 wt% citric acid (aqueous solution, 12 g, 12 mmol, 2.1 eq) and 2) saturated $NaHCO_3$ (aqueous solution, 4.6 g, 5.5 mmol, 0.95 eq), and concentrated to give crude product as pale yellow oil. The crude was purified by Biotage (Uppsala, Sweden) 40M (heptane-MTBE 7:3 v/v) to give Compound E as pale yellow oil (2.79 g, 5.04 mmol, 87% yield). ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.22 (1H, m), 4.04 (1H, d, *J*= 6.4 Hz), 4.03 (1H, d, *J*= 6.4 Hz), 4.93 (1H, dd, *J*= 3.2 Hz, 6.4 Hz), 3.85 (1H, m), 3.50 (1H, d, *J*= 10.4 Hz), 3.45 (1H, d, *J*= 10.4 Hz), 2.92 (1H, m), 2.21 (1H, dd, *J*= 8.4 Hz, 13.6 Hz), 1.48-1.85 (7H, m), 1.43 (1H, m), 1.29 (3H, d, *J*= 7.6 Hz), 1.25 (1H, m), 1.17 (9H, s), 0.87 (9H, s), 0.02 (6H, s); and ^{13}C NMR (100 MHz, $CDCl_3$): δ 178.78, 122.96, 84.83, 76.25, 73.45, 67.11, 66.53, 64.43, 41.00, 38.94, 37.89, 32.98, 27.42 (3C), 26.47, 26.06 (3C), 25.60, 22.60, 22.52, 18.51, 18.48, -5.09, -5.15.

Compound G

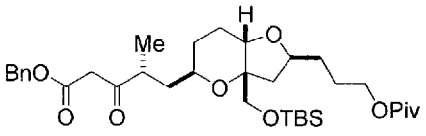


Zinc dust (876 mg, 13.4 mmol, 10.0 eq) was suspended in THF (3.9 ml). MsOH (0.0087 ml, 0.13 mmol, 0.10 eq) was added, and the mixture was heated at reflux for 20 min. A mixture of Compound E (0.645 g, 1.34 mmol, 1 eq) and benzyl bromoacetate (0.315 ml, 2.01 mmol, 1.50 eq) in THF (2.6 ml + 1.3 ml) was added under reflux. After 2 h, benzyl bromoacetate (0.10 ml, 0.67 mmol, 0.50 eq) was added, and heating was continued for an additional 3 h (total 5 h). After cooling down, the reaction mixture was diluted with MTBE (10 ml) and cooled to 5 °C. 20 wt% citric acid (aqueous solution, 3.2 g, 3.4 mmol, 2.5 eq) was added, and vigorous stirring was continued at 5-10 °C for 10 min. The whole mixture was filtered through a pad of Celite (1.3 g). The organic layer was separated and set aside. The aqueous layer was extracted with MTBE (10 ml). All organic layers were combined, sequentially washed with: 1) saturated $NaHCO_3$ (aqueous solution, 3.2 g) and 2) 20 wt% NaCl (aqueous solution, 3.2 g), and concentrated to give crude product as yellow oil. The crude was purified by Biotage (Uppsala, Sweden) 25M (heptane-MTBE 3:1 & 3:2 v/v) to give Compound G as pale yellow oil (0.627 g, 0.992 mmol, 74% yield). ^1H NMR (400 MHz, $CDCl_3$): δ 7.95 (1H, br), 7.24-7.37 (5II, m), 5.11 (1H, d, J= 12.8 Hz), 5.07 (1H, d, J= 12.8 Hz), 4.58 (1H, s), 4.10 (1H, m), 4.02 (2H, m), 3.78 (1H, dd, J= 5.6 Hz, 7.2 Hz), 3.56 (1H, m), 3.54 (1H, d, J= 10.4 Hz), 3.46 (1H, d, J= 10.4 Hz), 2.46 (1H, m), 2.15 (1H, dd, J= 8.8 Hz, 14.0 Hz), 1.35-1.82 (10H, m), 1.18 (1H, m), 1.17 (9H, s), 1.10 (3H, d, J= 6.8 Hz), 0.88 (9II, s), 0.04 (6H, s); and ^{13}C NMR (100 MHz, $CDCl_3$): δ178.77, 170.63, 168.91, 137.49, 128.66 (2C), 127.99 (2C), 127.19, 84.27, 81.26, 75.91, 73.63, 67.52, 67.17, 64.71, 64.44, 42.75, 38.94, 37.03, 35.46, 33.22, 27.43 (3C), 26.08, 26.01 (3C), 25.56, 23.50, 20.06, 18.51, -5.09 (2C).

Compound L



Compound G (0.596 g, 0.943 mmol, 1 eq) was dissolved in THF (3.0 ml)-water (1.0 ml) and cooled to 10 °C. AcOH (2.0 ml, 35 mmol, 37 eq) was added, and the mixture was allowed to warm to room temperature. After 10 h, the reaction mixture was poured into a pre-chilled (0 °C) mixture of $NaHCO_3$ (4.8 g, 57 mmol, 60 eq), water (6 ml), and MTBE (20 ml). The organic layer was separated, washed with water (6 ml), and concentrated to give crude product. The crude was azeotroped with toluene (20 ml) and purified by Biotage (Uppsala, Sweden) 25 M (heptane-EtOAc 9:1 v/v) to give Compound U:



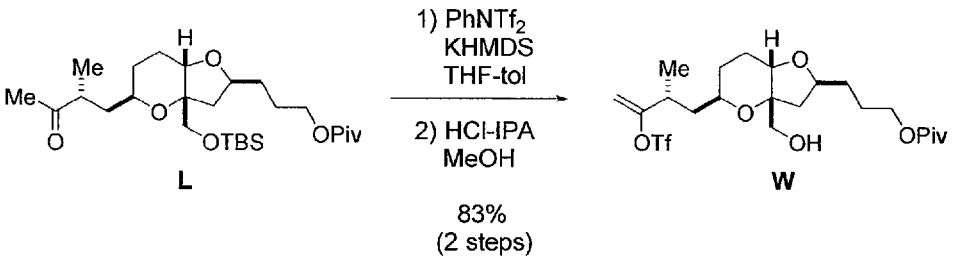
U

(0.493 g, 0.779 mmol, 82% yield) as colorless oil.

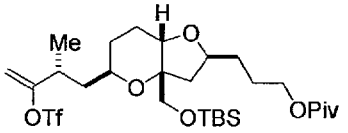
An inert flask was charged with 10 wt% Pd-C (wet-type, 15 mg, 0.014 mmol, 0.050 eq). A solution of Compound U (0.182 g, 0.288 mmol, 1 eq) in EtOAc (3.6 ml) was added under N_2. The internal atmosphere was replaced with H_2, and stirring was continued at room temperature for 2 h. The mixture was filtered through a pad of Celite (1.0 g). The reactor and the filter cake were rinsed with EtOAc (3.6 ml). The filtrate was concentrated to give crude keto-acid Compound J as colorless film. A portion (10%) of crude Compound J was retained for analytical and stability testing. The remaining portion (90%) of Compound J was dissolved in toluene (3.0 ml). The mixture was heated at 95 °C for 15 min and then concentrated to give crude product as pale yellow oil.

The crude was purified by Biotage (Uppsala, Sweden) 12M (heptane-EtOAc 95:5 v/v) to give Compound L (110 mg, 0.220 mmol, 85% adjusted yield) as colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.08 (1H, m), 4.00 (1H, d, J= 6.8 Hz), 3.98 (1H, d, J= 6.8 Hz), 3.81 (1H, t, J= 5.6 Hz), 3.49 (1H, m), 3.44 (1H, d, J= 10.4 Hz), 3.39 (1H, d, J= 10.4 Hz), 2.73 (1H, m), 2.09 (3H, s), 1.99 (1H, dd, J= 8.8 Hz, 14.0 Hz), 1.32-1.75 (10H, m), 1.16 (1H, m), 1.13 (9H, s), 1.03 (3H, d, J= 7.2 Hz), 0.84 (9H, s), 0.07 (6H, s); and ^{13}C NMR (100 MHz, $CDCl_3$): δ 212.79, 178.68, 84.49, 76.05, 73.52, 67.30, 66.67, 64.38, 43.45, 39.79, 39, 37.22, 32.98, 28.75, 27.37 (3C), 26.91, 26.04 (3C), 25.53, 22.85, 18.47, 17.26, -5.15, -5.20.

Compound W



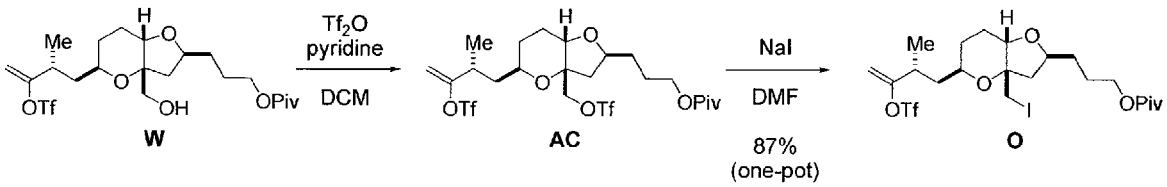
Compound L (109 mg, 0.218 mmol, 1 eq) was dissolved in THF (1.1 ml), and $PhNTf_2$ (117 mg, 0.328 mmol, 1.50 eq) was added. Upon complete dissolution of $PhNTf_2$, the mixture was cooled to -30 °C. 0.5 M KHMDS (solution in toluene, 0.590 ml, 0.295 mmol, 1.35 eq) was added, while maintaining T-internal <-25 °C. Upon complete addition, stirring was continued at -25 °C for 1 h. 20 wt% NH_4Cl (aqueous solution, 0.33 g, 1 2 mmol, 5.6 eq) was added while maintaining T-internal <-20 °C, and the resultant mixture was allowed to warm to 0 °C. The mixture was diluted with water (0.33 g) and MTBE (2.2 ml) and then further stirred for 5 min. The organic layer was separated, washed with saturated $NaHCO_3$ (aqueous solution, 0.54 g), and concentrated to give crude Compound V:



V

Compound V was dissolved in MeOH (1.0 ml) and treated with 6 M HCl (solution in 2-propanol, 0.25 ml, 2 mmol, 7 eq) at 20 °C. After 1 h, the reaction mixture was cooled to 0 °C, neutralized with saturated $NaHCO_3$ (1.6 g) and extracted with MTBE (6 ml). The organic layer was separated, washed with 20 wt% NaCl (0.54 g), and concentrated to give crude product as pale yellow oil. The crude was purified by Biotage (Uppsala, Sweden) 12M (heptane-MTBE 1:1 & 3:7 v/v) to give Compound W (94.1 mg, 0.182 mmol, 83% yield) as colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 5.09 (1H, d, J= 3.6 Hz), 4.87 (1H, d, J= 3.6 Hz), 4.12 (1H, m), 4.03 (1H, m), 3.84 (1H, dd, J= 6.4 Hz, 8.8 Hz), 3.59 (1H, m), 3.49 (1H, d, J= 11.2 Hz), 3.45 (1H, d, J= 11.2 Hz), 2.68 (1H, m), 2.19 (1H, dd, J= 8.8 Hz, 14.0 Hz), 2.13 (1H, br), 1.87 (1H, m), 1.40-1.75 (8H, m), 1.35 (1H, dd, J= 5.6 Hz, 14.0 Hz), 1.20 (1H, m), 1.16 (9H, s), 1.13 (3H, d, J= 6.8 Hz); and ^{13}C NMR (100 MHz, $CDCl_3$): δ 178.75, 160.06, 120.20, 103.03, 83.76, 75.16, 73.41, 68.59, 67.83, 64.25, 40.08, 38.94, 35.47, 35.21, 33.36, 28.05, 27.39 (3C), 25.51, 24.55, 18.90.

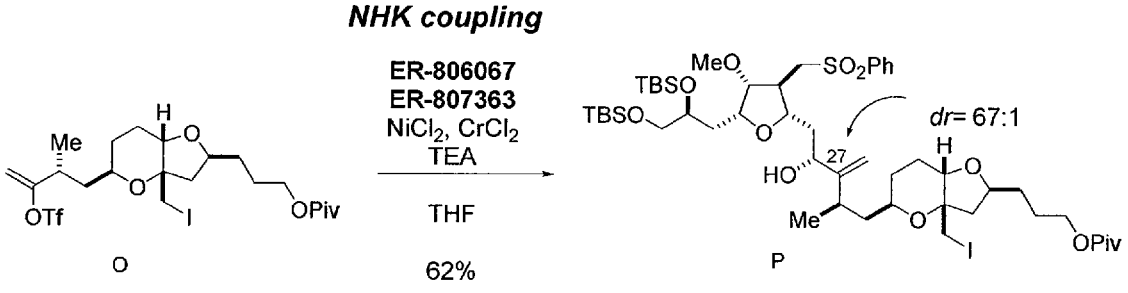
Compound O



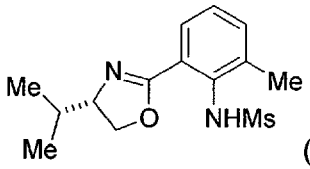
Compound W (90.0 mg, 0.174 mmol, 1 eq) was dissolved in CH_2Cl_2 and cooled to -10 °C. Pyridine (0.042 ml, 0.52 mmol, 3.0 eq) was added, followed by Tf_2O (0.044 ml, 0.26 mmol, 1.5 eq) (T-internal <-3 °C). After stirring at -5 to 0 °C for 1 h, DMF (0.45 ml) was added, followed by NaI (78 mg, 0.52 mmol, 3.0 eq). Stirring was continued at 20-22 °C for 3 h, and then the reaction mixture was poured into a pre-chilled (0 °C) mixture of MTBE (2.0 ml) and

water (2.0 ml). The organic layer was separated and set aside. The aqueous layer was extracted with MTBE (2.0 ml). All organic layers were combined, washed with a mixture of water (0.4 ml) and 10 wt% Na_2SO_3 (0.9 g), and concentrate to give crude product as yellow oil. The crude was purified by Biotage (Uppsala, Sweden) 12M (heptane-MTBE 85:15 v/v) to give Compound O (95.6 mg, 0.153 mmol, 87% yield from Compound W) as colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.08 (1H, d, J= 3.6 Hz), 5.01 (1H, d, J= 3.6 Hz), 4.18 (1H, m), 4.05 (2H, m), 3.74 (1H, dd, J= 6.4 Hz, 9.2 Hz), 3.53 (1H, m), 3.44 (1H, dd, J= 1.2 Hz, 10.0 Hz), 3.37 (1H, d, J= 10.0 Hz), 2.84 (1H, m), 2.32 (1H, dd, J= 8.8 Hz, 14.0 IIz), 1.85 (1H, m), 1.44-1.76 (9H, m), 1.22 (1H, m), 1.17 (9H, s), 1.13 (3H, d, J= 6.8 Hz); and ^{13}C NMR (100 MHz, $CDCl_3$): δ 178.75, 159.70, 120.20, 103.21, 81.42, 76.18, 75.51, 68.06, 64.18, 39.71, 38.96, 37.69, 35.43, 33.40, 27.94, 27.42 (3C), 25.51, 25.10, 20.10, 18.72.

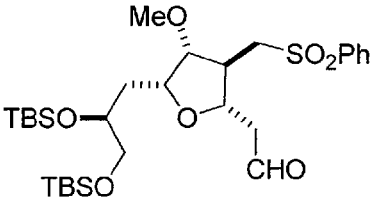
Compound P



A solution of ER-807363:



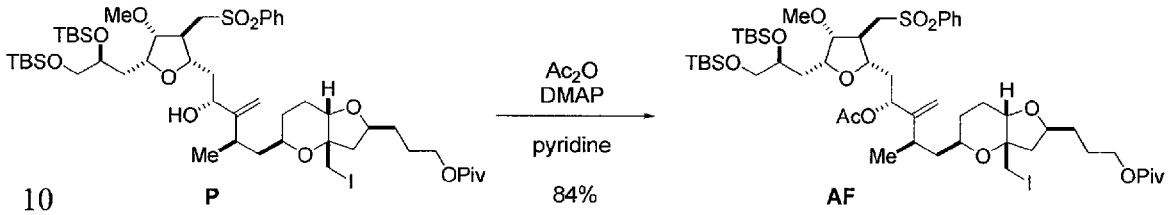
(ER-807363) (4.10 g, 13.8 mmol, 3.55 eq; WO 2005/118565) in THF (34.2 ml) was purged with N_2 for 1 h, and $CrCl_2$ (1.70 g, 13.8 mmol, 3.55 eq) was added under N_2. The mixture was heated to 35 °C, and TEA (1.93 ml, 13.8 mmol, 3.55 eq) was added while maintaining T-internal <38 °C. The mixture was heated at 30-35 °C for 1 h and cooled to 0 °C. $NiCl_2$ (75.7 mg, 0.15 eq) was added, and the mixture was purged with N_2 for 3 min. A previously degassed mixture of Compound O (2.44 g, 3.89 mmol, 1 eq), and ER-806067:



(ER-806067) (2.57 g, 4.28 mmol, 1.10 eq; WO 2005/118565) in THF (17 ml) was added. The reaction was allowed to warm to 22 °C over 30 min, and stirring was continued at 22-24 °C for 20 h. The reaction mixture was cooled to 0 °C and diluted with heptane (70 ml). A solution of ethylenediamine (2.1 ml, 31 mmol, 8.0 eq) in water (12 ml) was added while maintaining T-internal <5 °C. The resultant mixture was vigorously stirred at 0 °C for 1 h and filtered through a pad of Celite (2.4 g, rinsed with 12 ml heptane). The organic layer was separated, washed with water (12 ml), and concentrated to give a green solid-oil, which was suspended in heptane (20 ml), filtered for removal of ER-807363, and re-concentrated to give crude product. The crude was purified by Biotage (Uppsala, Sweden) 25M (heptane-MTBE 2:1 & 1:1) to give Compound P (2.64 g, 2.44 mmol, 62% yield; C27-*dr* 67:1) as pale yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.88 (2H, m), 7.64 (1H, m), 7.57 (2H, m), 5.17 (1H, s), 4.84 (1H, s), 4.12 (2H, m), 4.00 (2H, m), 3.91 (1H, m), 3.72 (4H, m), 3.53 (1H, dd, J= 5.6 Hz, 10.0 Hz), 3.30-3.50 (4H, m), 3.35 (3H, s), 3.06 (2H, m), 2.55 (1H, m), 2.34 (1H, dd, J= 8.8 Hz, 13.6 Hz), 2.28 (1H, m), 1.97 (1H, m), 1.88 (1H, m), 1.40-1.83 (13H, m),

1.14 (9H, s), 1.03 (3H, d, J= 6.8 Hz), 0.85 (18H, s), 0.05 (6H, s), 0.01 (6H, s); and ^{13}C NMR (100 MIIz, $CDCl_3$): δ 178.71, 156.78, 139.72, 134.26, 129.74 (2C), 128.06 (2C), 107.98, 85.78, 83.71, 81.19, 79.09, 76.36, 75.43, 73.77, 71.33, 68.86, 67.95, 64.22, 58.35, 57.65, 44.46, 44.31, 41.51, 38.92, 37.39, 33.60, 33.40, 32.31, 28.30, 27.43, 27.19, 26.20 (6C), 26.15 (3C), 25.50, 25.20, 22.65, 20.84, 18.58, 18.37, -3.89, -4.49, -5.10 (2C).

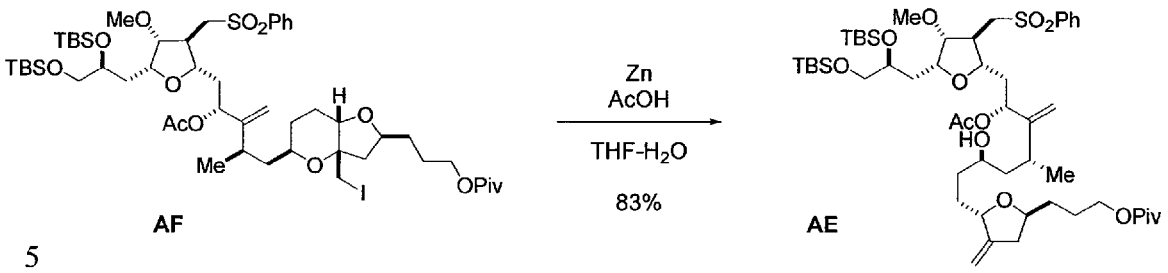
Compound AF



Compound P (620 mg, 0.574 mmol, 1 eq) was dissolved in pyridine (1.2 ml, 15 mmol, 27 eq). Ac_2O (0.31 ml, 3.3 mmol, 5.7 eq) was added, followed by DMAP (7.0 mg, 0.057 mmol, 0.10 eq). After stirring at 20-23 °C for 3 h, the reaction mixture was diluted with toluene (12 ml) and concentrated. The same operation was repeated with toluene (12 ml × 2) to give crude product. The crude was purified by Biotage (Uppsala, Sweden) 25M (heptane-MTBE 7:3 v/v) to give Compound AF (541 mg, 0.482 mmol, 84% yield) as colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.93 (2H, m), 7.66 (1H, m), 7.58 (2H, m), 5.22 (1H, dd, J= 3.2 Hz, 8.0 Hz), 4.98 (1H, s), 4.90 (1H, s), 4.15 (1H, m), 4.12 (2H, m), 3.82 (2H, m), 3.73 (2H, m), 3.44-3.57 (4H, m), 3.44 (1H, d, J= 10.4 Hz), 3.38 (1H, d, J= 10.4 Hz), 3.37 (3H, s), 3.12 (1H, dd, J= 4.0 Hz, 14.0 Hz), 2.96 (1H, dd, J= 10.4 Hz, 14.0 Hz), 2.63 (1H, m), 2.46 (1H, dd, J= 8.8 Hz, 13.6 Hz), 2.37 (1H, dd, J= 6.8 Hz, 13.6 Hz), 2.11 (1H, m), 2.04 (3H, s), 1.92 (2H, m), 1.45-1.85 (12H, m), 1.16 (9H, s), 1.01 (3H, d, J= 6.8 Hz), 0.85 (18H, s), 0.06 (6II, s), 0.02 (6H, s); ^{13}C NMR (100 MHz, $CDCl_3$): δ 178.74, 170.37, 152.99, 139.98, 134.14, 129.69 (2C), 128.08 (2C), 110.14, 85.58, 81.24, 81.07, 78.42, 76.39, 75.54, 73.52, 71.47, 68.96, 68.01, 64.27, 57.97, 57.56, 43.88, 43.82, 39.94, 38.94, 37.83, 33.54, 33.40, 32.72, 28.13, 27.43 (3C), 26.21 (3C),

26.17 (3C), 25.51, 25.03, 22.21, 21.56, 20.29, 18.59, 18.38, -3.87, -4.48, -5.09 (2C).

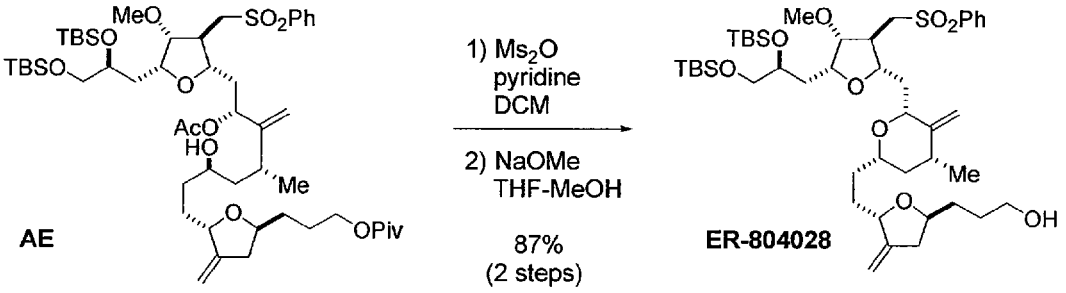
Compound AE



Zinc powder (1.54 g, 23.6 mmol, 50 eq) was suspended in water (1.1 ml) and cooled to 0 °C. AcOH (0.40 ml, 7.1 mmol, 15 eq) was added at 0 °C. A solution of Compound AF (530 mg, 0.473 mmol, 1 eq) in THF (2.7 ml) was added at 0 °C, and the mixture was allowed to warm to 20 °C. After 3 h, the reaction mixture was filtered for removal of zinc powder. The reactor was rinsed with a mixture of THF (1.1 ml) and water (1.1 ml). The filtrate was diluted with MTBE (10.6 ml), sequentially washed with: 1) 20 wt% Rochelle salt (aqueous solution, 2.7 g, 4.0 eq), 2) saturated $NaHCO_3$ (6.0 g), and 3) 20 wt% NaCl (aqueous solution, 2.6 g), and concentrated to give crude product as colorless oil. The crude was purified by Biotage (Uppsala, Sweden) 25M (heptane-MTBE 1:1 v/v) to give Compound AE (393 mg, 0.394 mmol, 83% yield) as colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 7.93 (2H, m), 7.66 (1H, m), 7.58 (2H, m), 5.23 (1H, t, J= 6.4 Hz), 5.05 (1H, s), 4.95 (1H, d, J= 1.6 Hz), 4.88 (1H, s), 4.83 (1H, d, J= 1.6 Hz), 4.33 (1H, br), 4.02 (3H, m), 3.83 (2H, m), 3.76 (1H, m), 3.60 (1H, m), 3.54 (1H, dd, J= 5.6 Hz, 10.4 Hz), 3.47 (2H, m), 3.37 (3H, s), 3.15 (1H, dd, J= 4.0 Hz, 14.0 Hz), 2.95 (1H, dd, J= 10.0 Hz, 14.0 Hz), 2.83 (1H, d, J= 5.2 Hz), 2.65 (2H, m), 2.40 (1H, m), 2.23 (1H, m), 2.03 (3H, s), 1.96-2.03 (2H, m), 1.81 (1H, m), 1.67-1.80 (3H, m), 1.40-1.67 (7H, m), 1.17 (9H, s), 1.01 (3H, d, J= 6.8 Hz), 0.86 (18H, s), 0.06 (6H, s), 0.03 (6H, s); ^{13}C NMR (100 MHz, $CDCl_3$): δ 178.80, 170.77, 153.18, 151.49, 139.77, 134.16, 129.67 (2C), 128.16 (2C), 109.77, 105.27, 85.84, 80.92, 80.15, 78.57,

76.97, 74.59, 71.51, 68.80, 68.05, 64.43, 58.01, 57.56, 45.21, 43.49, 39.78, 38.94, 34.58, 33.55, 32.28, 31.77, 31.74, 27.42 (3C), 26.21 (3C), 26.17 (3C), 25.49, 22.78, 21.51, 18.60, 18.39, -3.87, -4.51, -5.11 (2C).

ER-804028

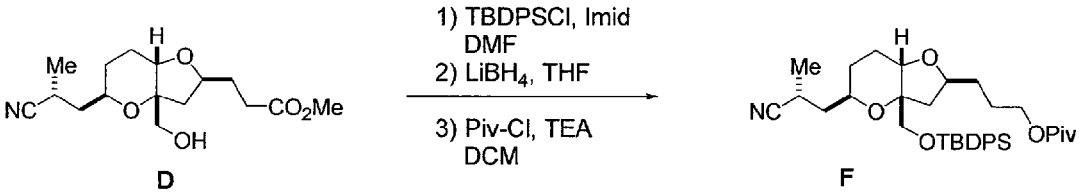


Compound AE (280 mg, 0.281 mmol, 1 eq) was dissolved in CH_2Cl_2 and cooled to 0 °C. Pyridine (0.045 ml, 0.56 mmol, 2.0 eq) was added followed by Ms_2O (58.8 mg, 0.338 mmol, 1.20 eq). The reaction was allowed to warm to room temperature, and stirring was continued for an additional 1 h. The reaction mixture was cooled to 0 °C, diluted with MTBE (5.6 ml), washed with saturated $NaHCO_3$ (0.84 g), and concentrated to give crude product as colorless film. The crude was azeotropically dried with heptane (3 ml × 2) and re-dissolved in THF (7.0 ml). The mixture was cooled to 0 °C and treated with 25 wt% NaOMe (0.13 ml). After 10 min, the reaction was allowed to warm to room temperature, and stirring was continued for an additional 30 min. The mixture was treated with additional 25 wt% NaOMe (0.045 ml), and stirring was continued for an additional 20 min. The reaction mixture was diluted with heptane (7.0 ml) and washed with water (1.4 ml). The organic layer was separated, sequentially washed with: 1) 20 wt% NH_4Cl (0.84 g) and 2) 20 wt% NaCl (3 g), and concentrated to give crude product as brownish oil. The crude was purified by Biotage (Uppsala, Sweden) 12M (heptane-MTBE 2:3 v/v) to give ER-804028 (209 mg, 0.245 mmol, 87%) as pale yellow oil. ^1H NMR (400 MHz, $CDCl_3$): δ 7.89 (2H, m), 7.64 (1H, m), 7.56 (2H, m), 4.85 (1H, d, J= 1.6 Hz), 4.80 (1H, s), 4.72 (1H, s), 4.61 (1H, d, J= 1.6 Hz), 4.23 (1H, br), 3.91 (1H, m), 3.79 (1H, m), 3.76 (2H, m), 3.63 (1H, m), 3.50-3.60 (4H, m), 3.43 (1H, dd, J= 5.6 Hz, 10.0 Hz), 3.38 (3H, s), 3.32 (1H, m), 2.98 (2H, m), 2.61 (1H, br),

2.56 (1H, m), 2.50 (1H, m), 2.08-2.22 (3H, m), 1.96 (1H, m), 1.84 (1H, m), 1.78 (1H, m), 1.70 (1H, m), 1.42-1.63 (6H, m), 1.28-1.42 (2H, m), 1.01 (3H, d, J= 6.8 Hz), 0.84 (18H, s), 0.05 (3H, s), 0.04 (3H, s), 0.00 (3H, s), -0.01 (3H, s); and ^{13}C NMR (100 MHz, $CDCl_3$): δ 150.34, 150.75, 139.91, 134.18, 129.73 (2C), 128.14 (2C), 105.10, 85.97, 80.92, 79.72, 78.50, 77.45, 77.09, 75.53, 71.59, 68.04, 62.88, 58.27, 57.73, 43.51, 42.82, 39.16, 37.68, 35.69, 33.31, 32.41, 31.89, 31.48, 29.79, 26.21 (3C), 26.17 (3C), 18.58, 18.38, 18.13, -3.85, -4.71, -5.12 (2C).

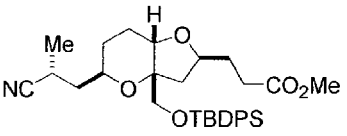
Alternate Route to Compound W

Compound F



72% (3 steps)

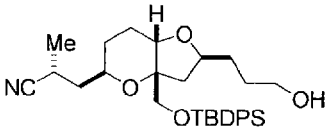
Compound D (0.657 g, 2.11 mmol, 1 eq) was dissolved in DMF (1.3 ml) and cooled to 0 °C. Imidazole (0.287 g, 4.22 mmol, 2.00 eq) was added, followed by TBDPSCl (0.576 ml, 2.22 mmol, 1.05 eq). The mixture was stirred at 0-5 °C for 1 h and allowed to warm to room temperature. After stirring overnight (16 h), the reaction mixture was diluted with water (5.2 ml) and extracted with MTBE (5.2 ml). The organic layer was separated and set aside. The aqueous layer was extracted with MTBE (5.2 ml). All organic layers were combined, washed with water (2.6 ml), and concentrated to give crude Compound X:



X

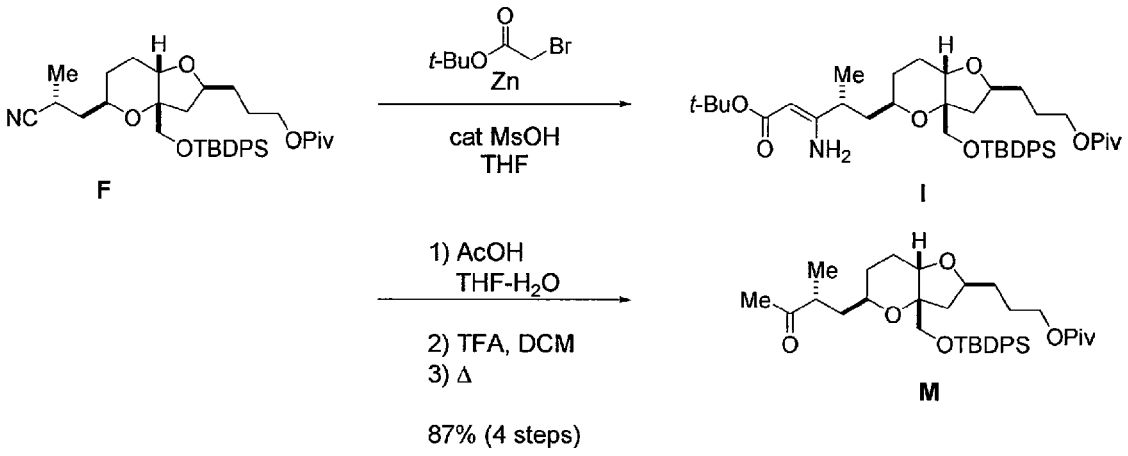
as pale yellow oil. Compound X (2.11 mmol assumed, 1 eq) was dissolved in toluene (4.6 ml) and cooled to -5 °C. 2.0 M $LiBH_4$ (solution in THF, 2.43 ml, 4.85 mmol, 2.30 eq) was added while maintaining T-internal <0 °C. A mixture of MeOH (0.196 ml, 4.85 mmol, 2.30

eq) and toluene (0.80 ml) was added at <0 °C, and then reaction was allowed to warm to 20-22 °C. After 22 h, the reaction mixture was carefully/slowly poured into a pre-chilled (0 °C) mixture of 20 wt% citric acid (aqueous solution, 6.0 g, 6.2 mmol, 3.0 eq) and MTBE (20 ml) while maintaining T-internal <10 °C. The organic layer was separated, sequentially washed with: 1) saturated $NaHCO_3$ (3.0 g) and 2) water (3.0 g), and concentrated to give crude Compound Y:

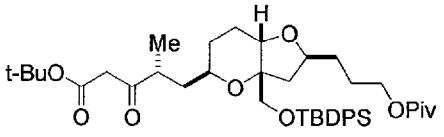


Y . Compound Y (2.11 mmol assumed, 1 eq) was dissolved in CH_2Cl_2 (2.5 ml) at room temperature. TEA (0.441 ml, 3.16 mmol, 1.50 eq) was added followed by DMAP (26 mg, 0.21 mmol, 0.10 eq). The mixture was cooled to 0 °C and treated with pivaloyl chloride (0.272 ml, 2.22 mmol, 1.05 eq). The reaction was allowed to warm to room temperature and stirring was continued overnight (16 h). The reaction mixture was diluted with MTBE (10 ml), sequentially washed with: 1) 20 wt% citric acid (aqueous solution, 3.0 g, 1.5 eq) and 2) saturated $NaHCO_3$ (aqueous solution, 3.0 g), and concentrated to give crude product as orange-colored oil. The crude was purified by Biotage (Uppsala, Sweden) 25M (heptane-MTBE 7:3 v/v) to give Compound F (0.920 g, 1.52 mmol, 72% overall yield) as colorless oil.

Compound M



Zinc dust (982 mg, 15.0 mmol, 10.0 eq) was suspended in THF (1.8 ml), and MsOH (0.0097 ml, 0.15 mmol, 0.10 eq) was added. The resultant mixture was heated at reflux for 30 min and then cooled to 20 °C. A solution of Compound F (910 mg, 1.50 mmol, 1 eq) and *t*-butyl bromoacetate (0.222 ml, 15.0 mmol, 1.00 eq) in THF (4.6 ml) was added, and the mixture was heated at reflux. After 2 h, *t*-butyl bromoacetate (0.222 ml, 1.50 mmol, 1.00 eq) was added, and heating was continued for 4 h. *t*-Butyl bromoacetate (0.111 ml, 1.50 mmol, 0.50 eq) was added, and heating was continued for an additional 6 h. After cooling down, the reaction mixture was diluted with MTBE (14 ml) and cooled to 0 °C. 20 wt% citric acid (aqueous solution, 7.2 g, 7.5 mmol, 5.0 eq) was added at <10 °C, and vigorous stirring was continued for 10 min. The whole biphasic mixture was filtered for removal of Zn. The reactor and Zn were rinsed with MTBE (9 ml). The organic layer was separated, sequentially washed with: 1) saturated $NaHCO_3$ (aqueous solution, 3.8 g) and 2) 20 wt% NaCl (2.7 g), and concentrated to give crude Compound I as pale yellow oil. Compound I (1.50 mmol assumed, 1 eq) was suspended in THF (2.5 ml)-water (1.5 ml) and treated with AcOH (4.5 ml, 7.9 mmol) at room temperature for 2 h. The reaction mixture was diluted with toluene (20 ml) and concentrated. The same operation was repeated with toluene (20 ml × 2) to give crude Compound Z:

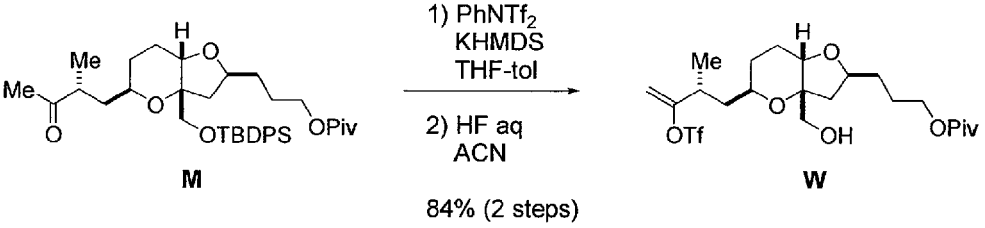


Z

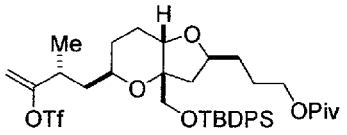
. The crude was purified by Biotage (Uppsala, Sweden) 25M (heptane-MTBE 4:1 v/v) to give Compound Z (1.062 g, 1.47 mmol, 97% yield) as colorless oil.

Compound Z (1.00 g, 1.38 mmol, 1 eq) was dissolved in CH_2Cl_2 (9.0 ml) and treated with TFA (1.00 ml, 13.0 mmol) at room temperature. After 4 h, the reaction mixture was diluted with toluene (15 ml) and concentrated. The same operation was repeated with toluene (15 ml × 2) to give crude Compound K. Compound K was dissolved in toluene (10 ml), heated at 100 °C for 30 min, and concentrated to give crude Compound M. The crude was purified by Biotage (Uppsala, Sweden) 25M (heptane-MTBE 7:3 v/v) to give Compound M (775 mg, 1.24 mmol, 90% yield) as colorless oil.

Compound W



Compound M (745 mg, 1.20 mmol, 1 eq) was dissolved in THF (4.5 ml) and $PhNTf_2$ (641 mg, 1.79 mmol, 1.50 eq) was added at 20 °C. Upon complete dissolution of $PhNTf_2$, the mixture was cooled to -23 °C. 0.5 M KHMDS (solution in toluene, 2.63 ml, 1.32 mmol, 1.10 eq) was added while maintaining T-internal <-18 °C, and the mixture was stirred at -18 to -20 °C for 1 h. Under vigorous stirring, 20 wt% NH_4Cl (aqueous solution, 0.32 g) was added while maintaining T-internal <-10 °C, and then the mixture was allowed to warm to 0 °C. The mixture was diluted with MTBE (7.5 ml) and water (0.74 ml), and vigorous stirring was continued for 5 min. The organic layer was separated, washed with water (1.5 ml), and concentrated to give crude Compound AA:

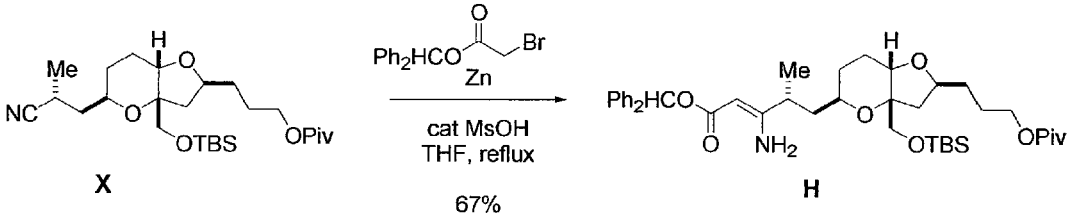


AA

as yellow solid-oil. Compound AA was dissolved in CH_3CN (9.0 ml) and treated with 49 wt% HF (aqueous solution, 3.0 g) at room temperature for 20 h. The reaction mixture was carefully/slowly poured into a pre-chilled (0 °C) mixture of MTBE (40 ml), water (7.5 ml), and $NaHCO_3$ (8.5 g) while maintaining T-internal <10 °C. The organic layer was separated and set aside. The aqueous layer was extracted with MTBE (7.5 ml). All organic layers were combined, washed with 20 wt% NaCl (aqueous solution, 3.7 g), and concentrated to give crude Compound W as yellow solid-oil. The crude was purified by Biotage (Uppsala, Sweden) 25M (heptane-MTBE 1:1 & 2:3 v/v) to give Compound W (522 mg, 1.01 mmol, 84% yield) as pale yellow oil.

Alternate Route to Compound L

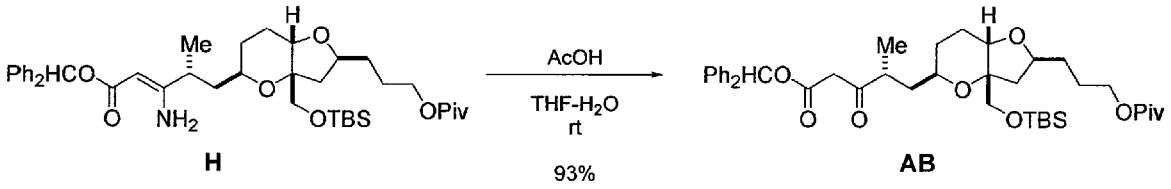
Compound H



Zinc (1.06 g, 16.2 mmol, 10 eq) was suspended in THF (2.3 ml). MsOH (0.010ml, 0.02 mmol, 0.1 eq) was added at room temperature, and the resultant slurry was heated at reflux for 30 min. After cooling down, a mixture of Compound X (780 mg, 1.62 mmol, 1 eq) and benzhydryl bromoacetate (0.74 g, 2.4 mmol, 1.5 eq; Kume *et al.*, *Tetrahedron*, 1997, *53*, 1635) in THF (3.9 ml) was added, and the reaction was heated to reflux. After heating for 3h, benzhydryl bromoacetate (0.74 g, 2.4 mmol, 1.5 eq) was added, and heating was continued for an additional 7 h. After cooling down, the mixture was diluted with MTBE (16 ml) and filtered through a pad of Celite (1.6 g). The filtrate was sequentially washed with: 1) 20 wt% citric acid (aqueous solution, 3.9 g), 2) 10 wt% $NaHCO_3$ (aqueous solution, 3.9 g), and 3) 20 wt% NaCl

(aqueous solution, 2.3 g), and concentrated to give crude product as yellow oil. The crude was purified by Biotage (Uppsala, Sweden) 40M (heptane-MTBE 1:1 v/v) to give Compound H as pale yellow oil (770 mg, 1.08 mmol, 67% yield).

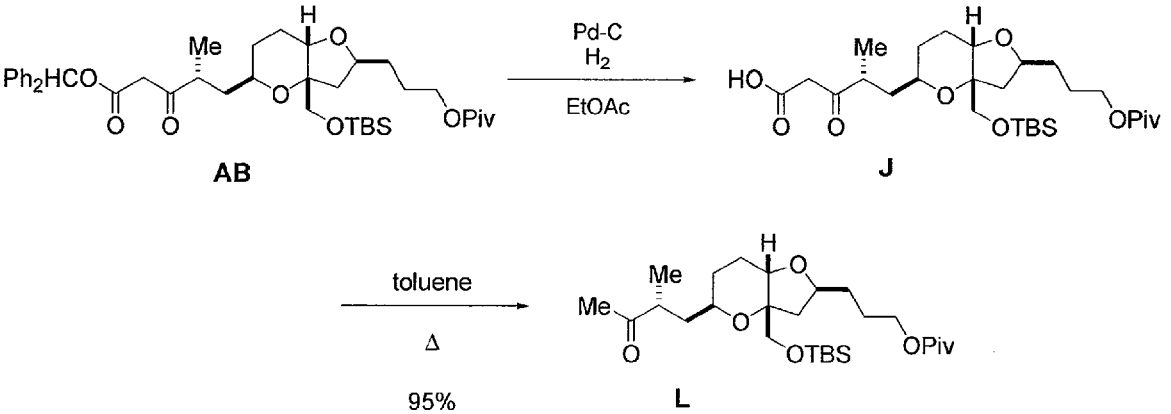
Compound AB



H AB

Compound H (770 mg, 1.08 mmol, 1 eq) was dissolved in THF (0.77 ml) and cooled to 0 °C. Water (0.38 ml) was added followed by AcOH (1.54 ml). The mixture was allowed to warm to room temperature, and stirring was continued for 8 h. The reaction mixture was diluted with toluene (15 ml) and concentrated. The residue was further azeotroped with toluene (15 ml × 2) and purified by Biotage (Uppsala, Sweden) 25M (heptane-MTBE 2:1 v/v) to give Compound AB (716 mg, 1.01 mmol, 93% yield) as pale yellow oil.

Compound L

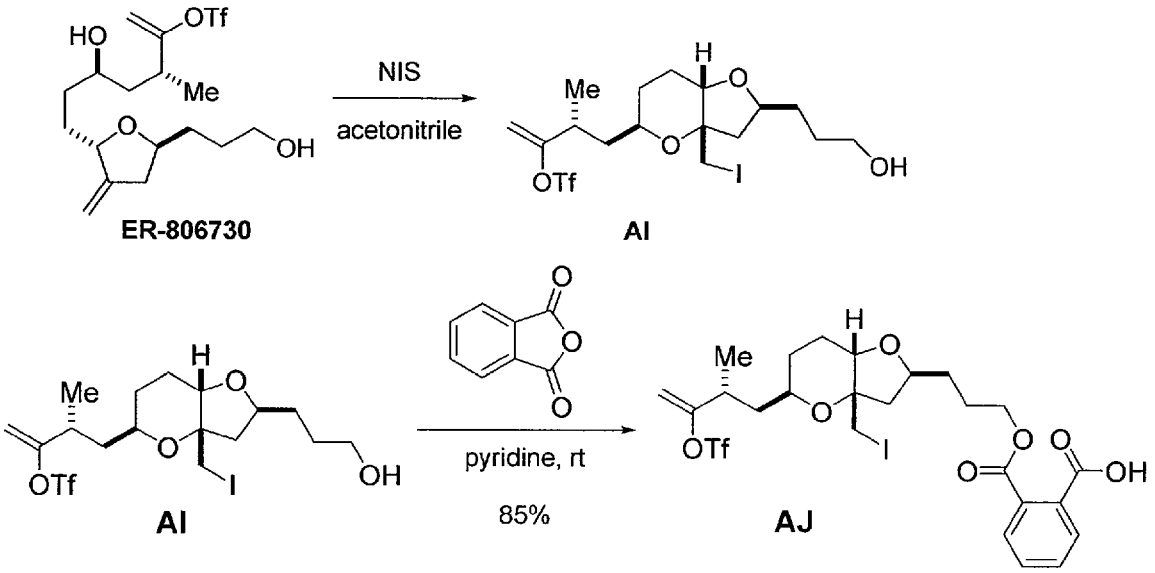


AB J

Compound AB (716 mg, 1.01 mmol, 1 eq) was hydrogenated with 10 wt% Pd-C (wet-type, 0.11 g, 0.050 mmol, 0.05 eq), H_2 (balloon), and EtOAc (7.2 ml) for 2 h. The reaction mixture was filtered, concentrated, and re-

dissolved in toluene (7.2 ml). The mixture was heated at 100 °C for 15 min. After cooling down, the mixture was concentrated and purified by Biotage (Uppsala, Sweden) 25M (heptane-MTBE 2:1 v/v) to give Compound L (476 mg, 0.954 mmol, 95% yield) as colorless oil.

Compound AJ

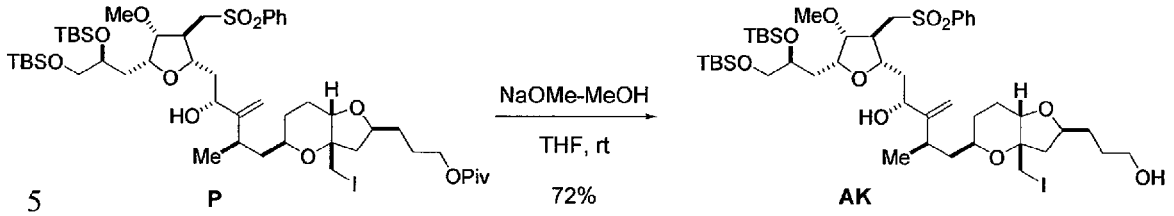


Compound AI was synthesized from ER-806730 (WO 2005/118565, Example 2) by iodo-etherification with N-iodosuccinimide in acetonitrile.

Compound AI (2.95 g, 5.44 mmol, 1 eq) was dissolved in pyridine (3.0 ml, 36 mmol, 6.7 eq) and treated with phthalic anhydride (0.846 g, 5.71 mol, 1.05 eq) at room temperature for 18 h. The reaction mixture was diluted with MTBE (200 ml), sequentially washed with: 1) 20 wt% citric acid (35 g); 2) 20 wt% citric acid (35 g); 3) water (9 g); and 4) water (9 g), and concentrated to give crude product as pale yellow oil. The crude was purified by Biotage (Uppsala, Sweden) 25M (heptane-MTBE 1:1 & MTBE 100%) to give Compound AJ as colorless oil (3.20g, 4.63 mmol, 85% yield). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.83 (1H, m), 7.71 (1H, m), 7.53-7.59 (2H, m), 5.08 (1H, d, *J*= 3.6 Hz), 5.01 (1H, d, *J*= 3.6 Hz), 4.51 (1H, m), 4.27 (1H, m), 4.20 (1H, m), 3.87 (1H, dd, *J*= 6.0 Hz, 9.2 Hz), 3.54 (1H, m), 3.50 (1H, d, *J*= 10.8 Hz), 3.48

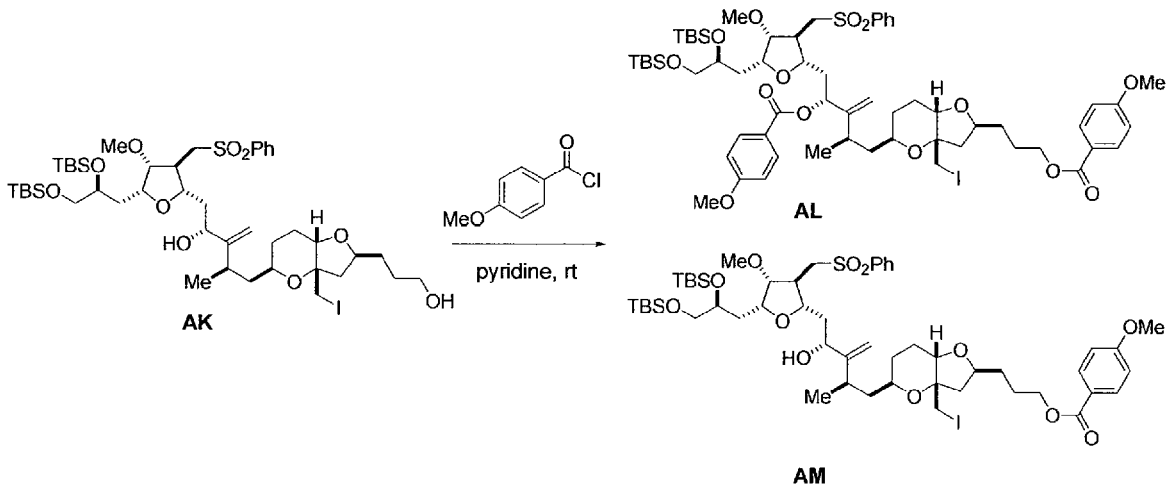
(1H, d, *J*= 10.8 Hz), 2.84 (1H, m), 2.33 (1H, dd, *J*= 8.8 Hz, 13.6 Hz), 1.83-1.94 (2H, m), 1.46-1.80 (8H, m), 1.22 (1H, m), 1.13 (3H, d, *J*= 6.8 Hz).

Compound AK



Compound P (0.050 g, 0.046 mmol, 1 eq) was dissolved in THF (0.30 mL) and treated with NaOMe (25 wt% solution in MeOH, 0.10 ml, 0.44 mmol, 9.4 eq) at room temperature for 1 h. The reaction mixture was diluted with MTBE (3.0 ml), sequentially washed with: 1) water (0.30 g); 2) water (0.30 g); and 3) 20 wt% NaCl (0.30 g), and concentrated to give crude product as colorless oil. The crude product was purified by preparative TLC (MTBE 100%) to give Compound AK as colorless film (33mg, 0.033 mmol, 72% yield).

Compounds AL and AM

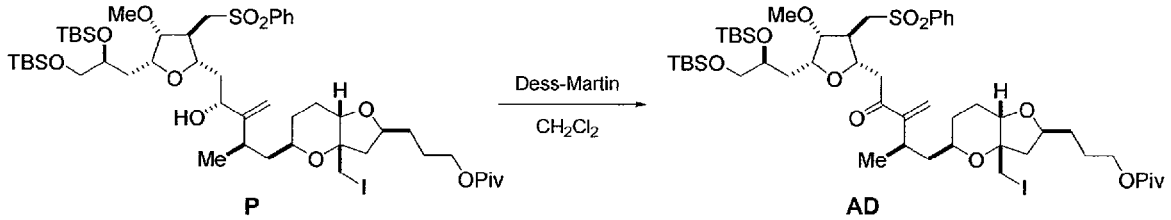


Compound AK (0.175 g, 0.176 mmol, 1 eq) was dissolved in pyridine (0.56 ml, 6.9 mmol, 39 eq). 4-methoxybenzoly chloride (0.066 g, 0.39 mmol, 2.2 eq) was added at room temperature, and the mixture was stirred for 15 h. The reaction mixture was diluted with MTBE (7 ml) and washed with 20 wt% citric acid (7 g). The organic layer was separated and set aside. The aqueous

layer was extracted with MTBE (7 ml). All organic layers were combined, sequentially washed with 20 wt% citric acid (3 g) and water (3 g), and concentrated to give crude product as pale yellow oil. The crude product was purified by Biotage (Uppsala, Sweden) 12M KP-Sil (heptane-MTBE 7:3 & 1:1) to give Compound AL (0.02 g, 0.02 mmol, 9% yield, colorless film) and Compound AM (0.14 g, 0.12 mmol, 70% yield, colorless oil). Compound AM: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (2H, d, *J*= 8.8 Hz), 7.89 (2H, d, *J*= 7.2 Hz), 7.65 (1H, m), 7.57 (2H, m), 6.87 (2H, d, *J*= 8.8 Hz), 5.18 (1H, s), 4.85 (1H, s), 4.26 (2H, m), 4.20 (1H, m), 4.12 (1H, m), 3.92 (1H, m), 3.83 (3H, s), 3.70-3.80 (3H, m), 3.53 (1H, m), 3.40-3.50 (4H, m), 3.36 (3H, s), 3.08 (2H, m), 2.57 (1H, m), 2.38 (1H, dd, *J*= 9.2 Hz, 14 Hz), 2.29 (1H, m), 1.98 (1H, m), 1.71-1.92 (7H, m), 1.52-1.68 (7H, m), 1.48 (1H, m), 1.18 (1H, m), 1.04 (3H, d, *J*= 7.2 Hz), 0.86 (9H, s), 0.84 (9H, s), 0.05 (6H, s), 0.02 (3H, s), 0.01 (3H, s).

Synthesis of Compound AD and Synthesis of Compound P from Compound AD

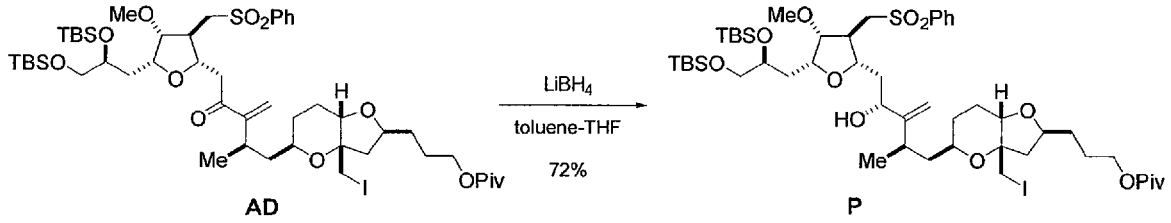
Compound AD



Compound AD was prepared in the process of producing a mixture of Compound P with its C27 diastereomer. Compound P (50.2 mg, 0.0465 mmol, 1 eq) was dissolved in CH_2Cl_2 (0.50 ml). Dess-Martin periodinane (23.6 mg, 0.0556 mol, 1.2 eq) was added at room temperature. After 10 min, $NaHCO_3$ (40 mg, 0.5 mmol) was added followed by isopropyl alcohol (0.014 ml, 0.19 mol, 4 eq), and stirring was continued for an additional 1h. The mixture was diluted with MTBE (2 ml), washed with water (0.5 ml), and concentrated to give crude product as a colorless oil. The crude was purified by Biotage

(Uppsala, Sweden) 12M (heptane-MTBE 7:3 & 1:1) to give Compound AD (42 mg, 0.039 mmol, 84% yield) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.92 (2H, m), 7.63 (1H, m), 7.56 (2H, m), 5.96 (1H, s), 5.74 (1H, s), 4.15 (1H, m), 4.04 (2H, m), 3.94 (1H, d, *J*= 3.2 Hz), 3.89 (2H, m), 3.75 (2H, m), 3.54 (2H, m), 3.39 (3H, s), 3.44 (1H, m), 3.43 (1H, d, *J*= 10.4 Hz), 3.34 (1H, d, *J*= 10.4 Hz), 3.19 (1H, m), 3.02 (1H, dd, *J*= 10.8 Hz, 14 Hz), 2.98 (1H, dd, *J*= 8.0 Hz, 17.2 Hz), 2.81 (1H, m), 2.42 (1H, m), 2.31 (1H, dd, *J*= 8.8 Hz, 14 Hz), 1.98 (1H, m), 1.45-1.85 (12H, m), 1.17 (9H, s), 1.02 (3H, d, *J*= 7.2 Hz), 0.87 (9H, s), 0.86 (9H, s), 0.07 (3H, s), 0.06 (3H, s), 0.03 (3H, s), 0.02 (3H, s).

Compound P



Compound P can also be obtained from reduction of Compound AD, made by any means. Compound AD (33 mg, 0.031 mmol) was dissolved in toluene (0.50 ml) and cooled to 0 °C. 2.0 M $LiBH_4$ (solution in THF, 8 µl) was added at 0 °C, and stirring was continued at 0 °C for 10 min. 2.0 M $LiBH_4$ (solution in THF, 8 µl) was added, and stirring was continued for an additional 10 min. The reaction mixture was diluted with MTBE (1.0 ml), sequentially washed with 20 wt% citric acid (aqueous solution, 0.20 g) and saturated $NaHCO_3$ (aqueous solution, 0.20 g), and concentrated to give crude product. The crude was purified by preparative TLC (heptane-MTBE 2:3) to give Compound P (24mg, 72% yield, C27-*dr* 5:1).

Other Embodiments

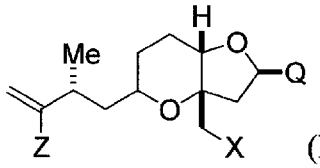
All publications, patents, and patent application publications mentioned herein are hereby incorporated by reference. Various modifications and variations of the described compounds of the invention will be apparent to

those skilled in the art without departing from the scope and spirit of the invention. Although the invention has been described in connection with certain embodiments, it should be understood that the invention as claimed should not be unduly limited to such embodiments. Indeed, various modifications of the described modes for carrying out the invention that are obvious to those skilled in the relevant art are intended to be within the scope of the invention.

What is claimed is:

CLAIMS

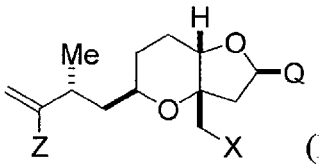
1. A compound having the formula (I):



(I),

wherein X is halogen or oxo; Z is a leaving group; Q is -C(O)H, -CH=CHC(O)OY_1, -C(R)H$(CH_2)_n OY_1$, or -C(R)HCH_2C(O)OY_1; R is H or -OY_2; Y_1 and Y_2 are each independently H or a hydroxyl protecting group; and n is 1 or 2.

2. The compound of claim 1 having the formula (Ia):



(Ia).

3. The compound of claim 1, wherein Q is –$(CH_2)_3OY_1$.

4. The compound of claim 3, wherein Y_1, together with the oxygen to which it is bound, is an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group.

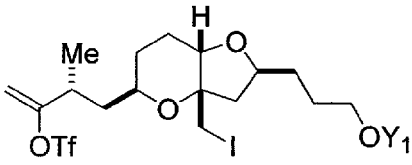
5. The compound of claim 4, wherein Y_1 is pivaloyl, acetyl, benzoyl, p-bromobenzoyl, p-methoxybenzoyl, 1-naphthoyl, 2-naphthoyl, o-phthaloyl, benzyl, p-methoxybenzyl, triphenylmethyl, tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, or (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl.

6. The compound of claim 1, wherein X is halogen.

7. The compound of claim 1, wherein Z is halogen or (C1-C6)alkylsulfonate.

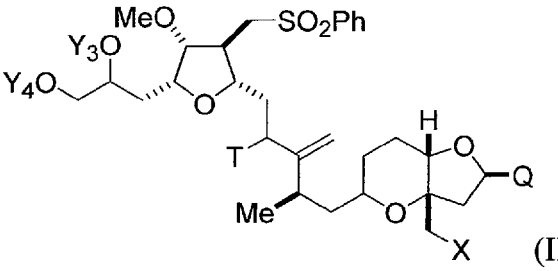
8. The compound of claim 7, wherein Z is triflate, iodide, or bromide.

9. The compound of claim 1 having the formula (Ib):



(Ib), wherein Y_1 is H, pivaloyl, benzoyl, p-bromobenzoyl, 1-naphthoyl, 2-naphthoyl, p-methoxybenzoyl, or o-phthaloyl or a salt thereof.

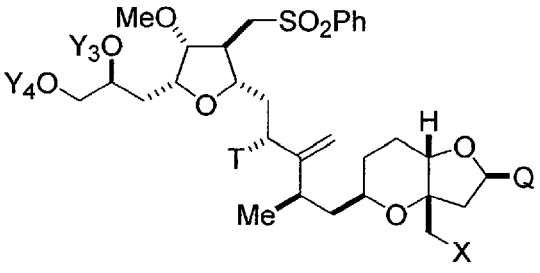
10. A compound having the formula:



(II),

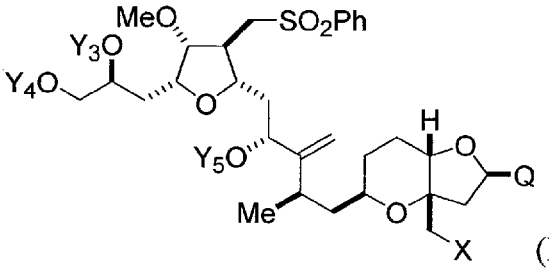
wherein X is halogen or oxo; Q is -C(O)H, -CH=CHC(O)OY_1, -C(R)H$(CH_2)_n OY_1$, or -C(R)HCH_2C(O)OY_1; R is H or -OY_2; n is 1 or 2; Y_1, Y_2, Y_3, and Y_4 are each independently H or a hydroxyl protecting group; T is oxo or -OY_5; and Y_5 is H or a hydroxyl protecting group, or Y_5, together with the oxygen atom to which it is bound, is a leaving group.

11. The compound of claim 10 having the formula:



(IIa).

12. The compound of claim 10 having the formula:



(IIb).

13. The compound of claim 10, wherein Q is $-(CH_2)_3OY_1$.

14. The compound of claim 13, wherein Y_1, together with the oxygen atom to which it is bound, is an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group;

each of Y_3 and Y_4 is, independently and together with the oxygen atom to which it is bound, an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group, or Y_3 and Y_4 together with the oxygen atoms to which they are bound are a cyclic carbonate, cyclic boronate, acetal, ketal, or cyclic silylene hydroxyl protecting group or 1,1,3,3-tetraisopropylsiloxanediyl;

T is $-OY_5$; and

Y_5, together with the oxygen atom to which it is bound, is an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group.

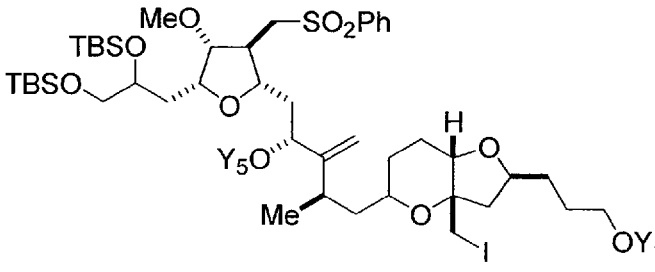
15. The compound of claim 14, wherein Y_1 is pivaloyl, acetyl, benzoyl, p-bromobenzoyl, p-methoxybenzoyl, 1-naphthoyl, 2-naphthoyl, o-phthaloyl, benzyl, p-methoxybenzyl, triphenylmethyl, tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, or (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl.

16. The compound of claim 14, wherein Y_3 and Y_4 are each independently tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, or (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl, or Y_3 and Y_4 are together di(C1-C6alkyl)silylene.

17. The compound of claim 14, wherein Y_5 is acetyl, benzoyl, p-bromobenzoyl, p-methoxybenzoyl, 1-naphthoyl, 2-naphthoyl, or o-phthaloyl.

18. The compound of claim 10, wherein X is halogen.

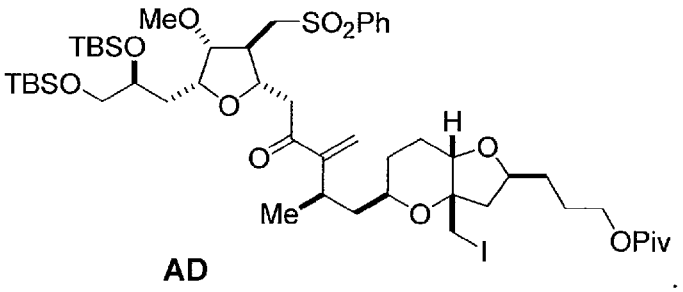
19. The compound of claim 10 having the formula:



(IIc), wherein Y_1 and Y_5 are as follows:

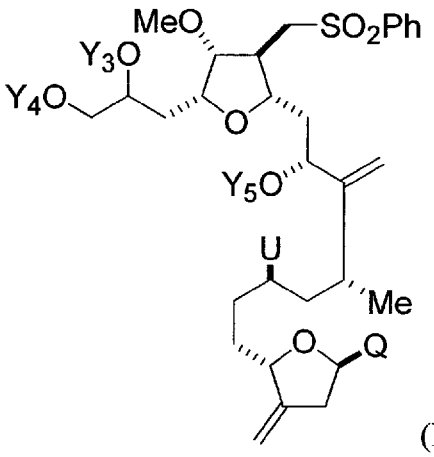
Y_1	Y_5
H	H
benzoyl	benzoyl
p-bromobenzoyl	p-bromobenzoyl
pivaloyl	H
pivaloyl	acetyl
pivaloyl	benzoyl
2-naphthoyl	H
2-naphthoyl	2-naphthoyl
1-naphthoyl	H
1-naphthoyl	1-naphthoyl
p-methoxybenzoyl	H
p-methoxybenzoyl	p-methoxybenzoyl
o-phthaloyl or salt thereof	H.

20. The compound of claim 10 having the formula:



AD

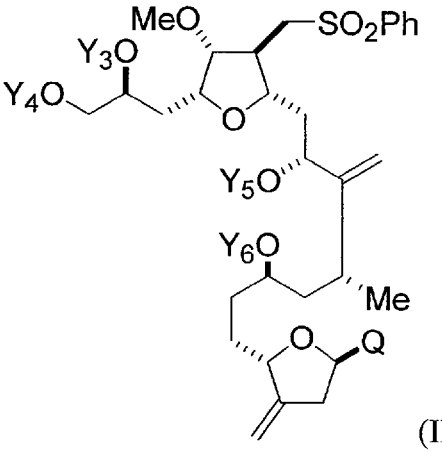
21. A compound having the formula:



(III),

wherein Q is -C(O)H, -CH=CHC(O)OY_1, -C(R)H$(CH_2)_nOY_1$, or -C(R)HCH_2C(O)OY_1; R is H or -OY_2; n is 1 or 2; Y_1, Y_2, Y_3, and Y_4 are each independently H or a hydroxyl protecting group; U is halogen or -OY_6; Y_5 is H or a hydroxyl protecting group or Y_5, together with the oxygen atom to which it is bound, is a leaving group; and Y_6 is H or a hydroxyl protecting group or Y_6, together with the oxygen atom to which it is bound, is a leaving group, provided that when Q is –$(CH_2)_3OY_1$, U is -OY_6, -OY_6 is a leaving group, and Y_1, Y_3, and Y_4 are protecting groups, Y_5 is not H.

22. The compound of claim 21 having the formula (IIIa):



(IIIa).

23. The compound of claim 21, wherein Q is –$(CH_2)_3OY_1$.

24. The compound of claim 23, wherein Y_1, together with the oxygen atom to which it is bound, is an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group;
Y_3 and Y_4 are each, independently and together with the oxygen atom to which it is bound, an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group, or Y_3 and Y_4 together with the oxygen atoms to which they are bound are a cyclic carbonate, cyclic boronate, acetal, ketal, or cyclic silylene hydroxyl protecting group or 1,1,3,3-tetraisopropylsiloxanediyl; and
Y_5, together with the oxygen atom to which it is bound, is an ester, carbonate, carbamate, sulfonate, or ether hydroxyl protecting group.

25. The compound of claim 24, wherein Y_1 is pivaloyl, acetyl, benzoyl, p-bromobenzoyl, p-methoxybenzoyl, 1-naphthoyl, 2-naphthoyl, o-phthaloyl, benzyl, p-methoxybenzyl, triphenylmethyl, tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, or (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl.

26. The compound of claim 24, wherein Y_3 and Y_4 are each independently tri(C1-C6 alkyl)silyl, tri(C6-C10 aryl or C1-C6 heteroaryl)silyl, di(C6-C10 aryl or C1-C6 heteroaryl)(C1-C6 alkyl)silyl, or (C6-C10 aryl or C1-C6 heteroaryl)di(C1-C6 alkyl)silyl, or Y_3 and Y_4 are together di(C1-C6)alkylsilylene.

27. The compound of claim 24, wherein Y_5 is acetyl, benzoyl, p-bromobenzoyl, p-methoxybenzoyl, 1-naphthoyl, 2-naphthoyl, or o-phthaloyl.

28. The compound of claim 21, wherein Y_5 is H or a hydroxyl protecting group.

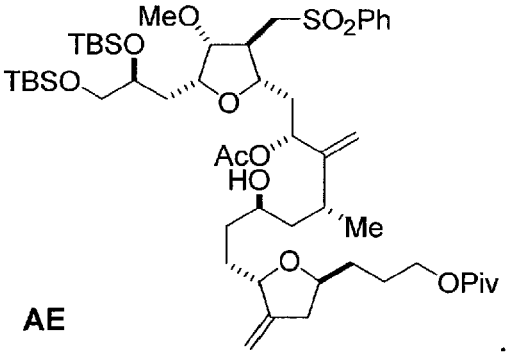
29. The compound of claim 21, wherein Y_6 is H.

30. The compound of claim 21, wherein $-OY_6$ is a leaving group.

31. The compound of claim 30, wherein $-OY_6$ is (C1-C6)alkylsulfonate, (C6-C10 aryl or C1-C6 heteroaryl)sulfonate, (C6-C15)aryl(C1-C6)alkylsulfonate, or (C1-C6)heteroaryl(C1-C6)alkylsulfonate.

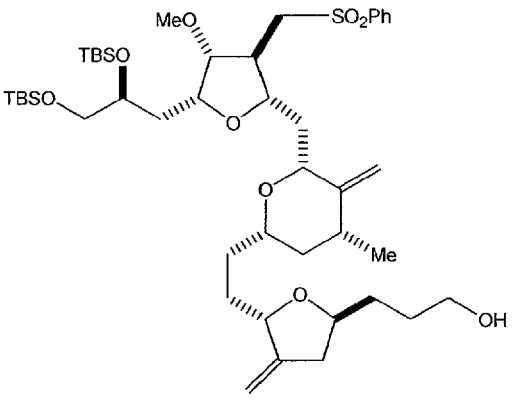
32. The compound of claim 31, wherein $-OY_6$ is mesylate, toluenesulfonate, isopropylsulfonate, phenylsulfonate, or benzylsulfonate.

33. The compound of claim 21 having the formula:



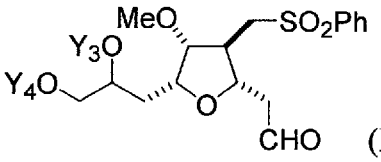
AE

34. A method of synthesizing ER-804028:



(ER-804028), said method comprising the steps of:

(i) reacting the compound of claim 1 with a compound having the formula (IV):



(IV), wherein Y_3, and Y_4, are each independently H or a hydroxyl protecting group, under NHK coupling conditions to produce the compound of claim 10;

(ii) reacting the product of step (i) under Vasella fragmentation conditions to produce the compound of claim 21; and

(iii) reacting the product of step (ii) under conditions for intramolecular Williamson etherification to produce ER-804028.