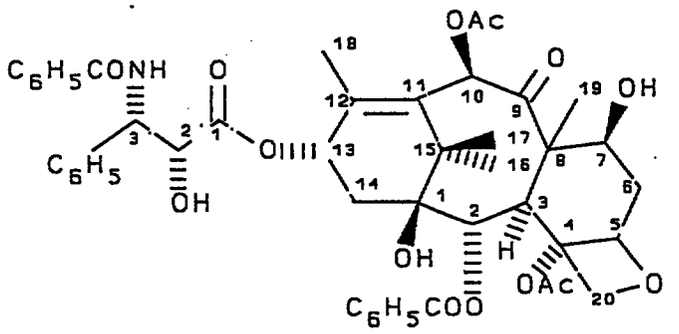
TAXANES PREPARED BY BETA-LACTAMS AND AMMONIUM ALKOXIDES

BACKGROUND OF THE INVENTION

Three esters of N-acyl phenyl isoserine, taxol, taxotere and cephalomannine have been found to possess significant properties as antitumor agents. This application describes a process for the preparation of N-acyl, N-sulfonyl and N-phosphoryl substituted isoserine esters, in general, and to a semi-synthesis for the preparation of taxane derivatives such as taxol, taxotere and other biologically active derivatives involving the use of ammonium alkoxides and ß-lactams, in particular.

The taxane family of terpenes, of which taxol is a member, has attracted considerable interest in both the biological and chemical arts. Taxol is a promising cancer chemotherapeutic agent with a broad spectrum of antileukemic and tumor-inhibiting activity. Taxol has the following structure:



wherein Ac is acetyl. Because of this promising activity, taxol is currently undergoing clinical trials in both France and the United States.

The supply of taxol for these clinical trials is presently being provided by the bark from Taxus brevifollia (Western Yew). However, taxol is found only in minute quantities in the bark of these slow growing evergreens, causing considerable concern that the limited

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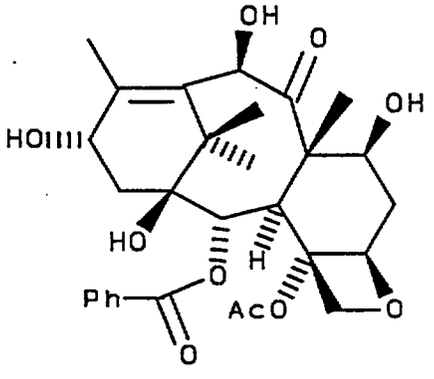
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supply of taxol will not meet the demand. Consequently, chemists in recent years have expended their energies in trying to find a viable synthetic route for the preparation of taxol. So far, the results have not been entirely satisfactory.

One synthetic route that has been proposed is directed to the synthesis of the tetracyclic taxane nucleus from commodity chemicals. A synthesis of the taxol congener taxusin has been reported by Holton, et al. in JACS 110, 6558 (1988). Despite the progress made in this approach, the final total synthesis of taxol is, nevertheless, likely to be a multi-step, tedious, and costly process.

A semi-synthetic approach to the preparation of taxol has been described by Greene, et al. in JACS 110, 5917 (1988), and involves the use of a congener of taxol, 10-deacetyl baccatin III which has the structure of formula II shown below:



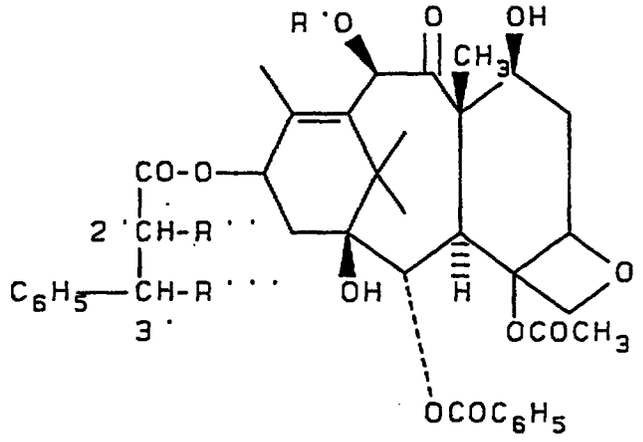
10-deacetyl baccatin III is more readily available than taxol since it can be obtained from the needles of Taxus baccata. According to the method of Greene et al., 10-deacetyl baccatin III is converted to taxol by attachment of the C-10 acetyl group and by attachment of the C-13 ß-amido ester side chain through the esterification of the C-13 alcohol with a ß-amido carboxylic acid unit. Although this approach requires

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relatively few steps, the synthesis of the ß-amido carboxylic acid unit is a multi-step process which proceeds in low yield, and the coupling reaction is tedious and also proceeds in low yield. However, this coupling reaction is a key step which is required in every contemplated synthesis of taxol or biologically active derivative of taxol, since it has been shown by Wani, et al. in JACS 93, 2325 (1971) that the presence of the ß-amido ester side chain at C13 is required for anti-tumor activity.

More recently, it has been reported in Colin et al. U.S. Patent No. 4,814,470 that taxanes corresponding to the following formula **III**, have an activity significantly greater than that of taxol **(I)**.



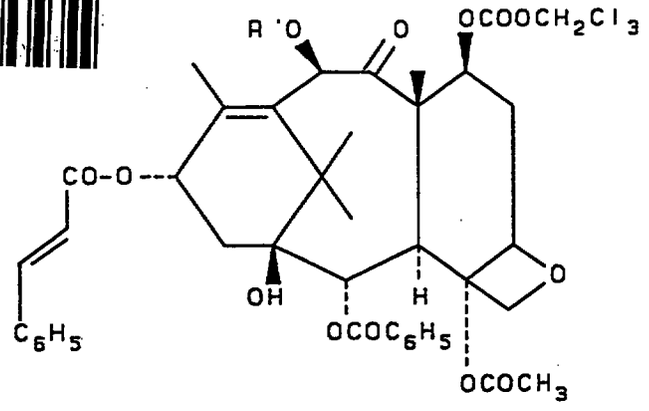
(III)

R' represents hydrogen or acetyl and one of R" and R"' represents hydroxy and the other represents tert-butoxy-carbonylamino and their stereoisomeric forms, and mixtures thereof.

According to Colin et al., U.S. Patent 4,418,470, the products of general formula **(III)** are obtained by the action of the sodium salt of tert-butyl N-chlorocarbamate on a product of general formula:

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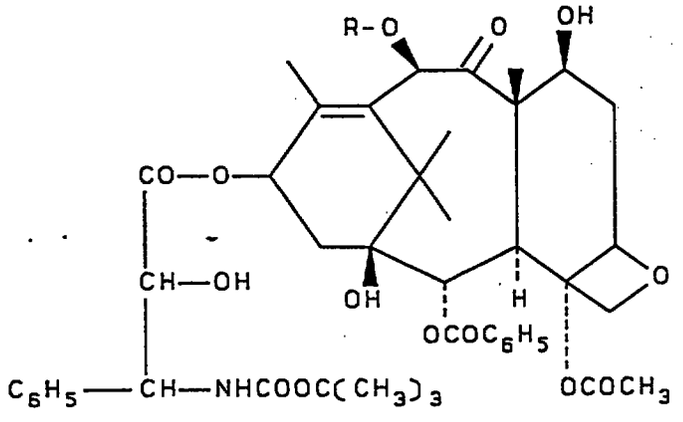


(IV)

(IV)

in which R' denotes an acetyl or 2,2,2-trichloroethoxycarbonyl radical, followed by the replacement of the 2,2,2-trichloroethoxycarbonyl group or groups by hydrogen. It is reported by Denis et al. in U.S. Patent No. 4,924,011, however, that this process leads to a mixture of isomers which has to be separated and, as a result, not all the baccatin III or 10-deactylbaccatin III employed for the preparation of the product of general formula **(IV)** can be converted to a product of general formula **(III)**.

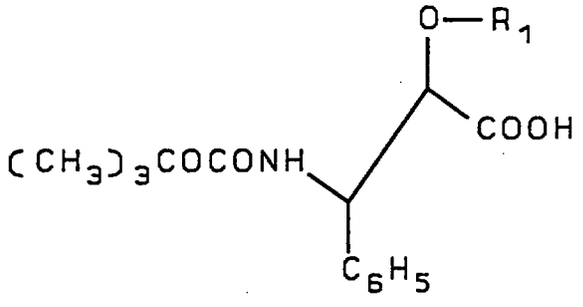
In an effort to improve upon the Colin et al. process, Denis et al. disclose a different process for preparing derivatives of baccatin III or of 10-deactylbaccatin III of general formula



(V)

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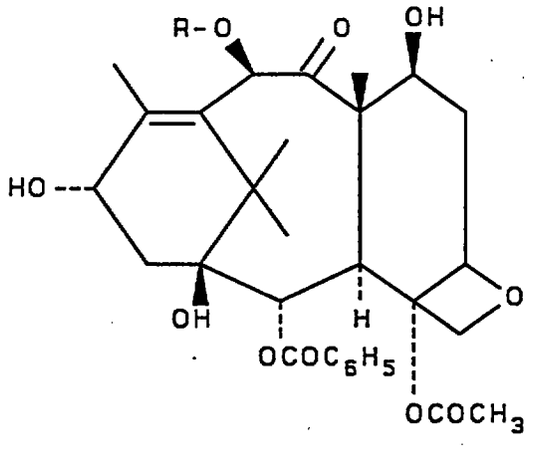
in which R' denotes hydrogen or acetyl wherein an acid of general formula:



(VI)

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in which R_1 is a hydroxy-protecting group, is condensed with a taxane derivative of general formula:



(VII)

in which R_2 is an acetyl hydroxy-protecting group and R_3 is a hydroxy-protecting group, and the protecting groups R_1, R_3 and, where appropriate, R_2 are then replaced by hydrogen. However, this method employs relatively harsh conditions, proceeds with poor conversion, and provides less than optimal yields.

A major difficulty remaining in the synthesis of taxol and other potential anti-tumor agents is the lack of a readily available method for easy attachment, to the C-13 oxygen, of the chemical unit which provides the ß-amido ester side chain. Development of such a process for its attachment in high yield would facilitate the synthesis of taxol as well as related anti-tumor agents having a modified set of nuclear substituents or a

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modified C-13 side chain. This need has been fulfilled by the discovery of a new, efficient process for attachment, to the C-13 oxygen, of the chemical unit which provides the ß-amido ester side chain.

Another major difficulty encountered in the synthesis of taxol is that known processes for the attachment of the ß-amido ester side chain at C-13 are generally not sufficiently diastereoselective. Therefore, the side chain precursor must be prepared in optically active form to obtain the desired diastereomer during attachment. The process of this invention, however, is highly diastereoselective, thus permitting the use of a racemic mixture of side chain precursor, eliminating the need for the expensive, time-consuming process of separating the precursor into its respective enantiomeric forms. The reaction additionally proceeds at a faster rate than previous processes, thus permitting the use of less side-chain precursor than has been required by such previous processes.

SUMMARY OF THE INVENTION

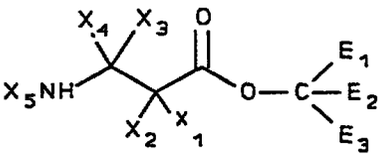
Among the objects of the present invention, therefore, is the provision of a process for the preparation of N-acyl, N-sulfonyl and N-phosphoryl esters of isoserine; the provision of a side chain precursor for the synthesis of taxane derivatives; the provision of a process for the attachment of the side chain precursor in relatively high yield to provide an intermediate which is readily converted to the desired taxane derivative; and the provision of such a process which is highly diastereoselective.

In accordance with the present invention, a process is provided for the preparation of isoserine esters having the formula

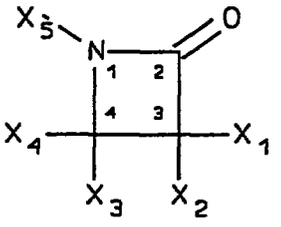
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comprising reacting a ß-lactam with an alkoxide, the ß-lactam having the formula:



and the alkoxide having the formula

$$MOCE_1E_2E_3$$

wherein

X_1 is $-OX_6$, $-SX_7$, or $-NX_8X_9$;

X_2 is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl;

X_3 and X_4 are independently hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, acyl or hetero-substituted alkyl, alkenyl, alkynyl, aryl or heteroaryl, provided, however, that X_3 and X_4 are not both acyl;

X_5 is $-COX_{10}$, $-COOX_{10}$, $-COSX_{10}$, $-CONX_8X_{10}$, or $-SO_2X_{11}$;

X_6 is hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, hydroxy protecting group, or a functional group which increases the water solubility of the taxane derivative;

X_7 is alkyl, alkenyl, alkynyl, aryl, heteroaryl, or sulfhydryl protecting group;

X_8 is hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, or heterosubstituted alkyl, alkenyl, alkynyl, aryl or heteroaryl;

X_9 is an amino protecting group;

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X_{10} is alkyl, alkenyl, alkynyl, aryl, heteroaryl, or heterosubstituted alkyl, alkenyl alkynyl, aryl or heteroaryl;

X_{11} is alkyl, alkenyl, alkynyl, aryl, heteroaryl, $-OX_{10}$, or $-NX_8X_{14}$;

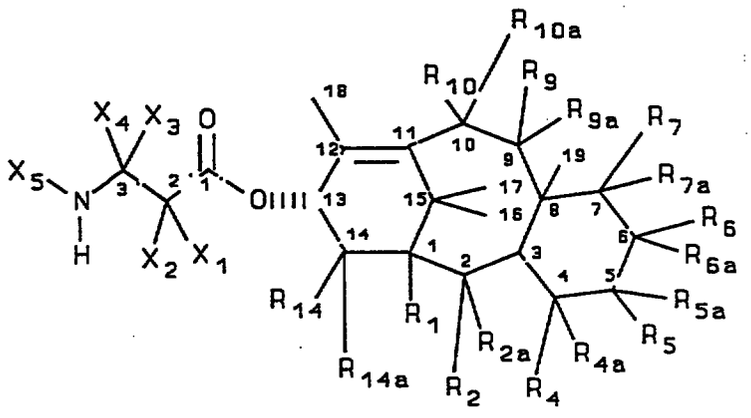
X_{14} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl;

E_1, E_2 and E_3 are independently hydrogen, hydrocarbon or cyclic, provided, at least one of E_1, E_2 and E_3 is other than hydrogen; and

M comprises ammonium.

In accordance with another aspect of the present invention, the alkoxide and ß-lactam are selected so as to provide a process for preparing taxol, taxotere and other biologically active taxane derivatives having the following structural formula:

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(3)

wherein

X_1 - X_{14} are as previously defined;

R_1 is hydrogen, hydroxy, protected hydroxy or together with R_{14} forms a carbonate;

R_2 is hydrogen, hydroxy, $-OCOR_{31}$, or together with R_{2a} forms an oxo;

R_{2a} is hydrogen or together with R_2 forms an oxo;

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R_4 is hydrogen, together with R_{4a} forms an oxo, oxirane or methylene, or together with R_{5a} and the carbon atoms to which they are attached form an oxetane ring;

R_{4a} is hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, cyano, hydroxy, $-OCOR_{30}$, or together with R_4 forms an oxo, oxirane or methylene;

R_5 is hydrogen or together with R_{5a} forms an oxo,

R_{5a} is hydrogen, hydroxy, protected hydroxy, acyloxy, together with R_5 forms an oxo, or together with R_4 and the carbon atoms to which they are attached form an oxetane ring;

R_6 is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl, hydroxy, protected hydroxy or together with R_{6a} forms an oxo;

R_{6a} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl, hydroxy, protected hydroxy or together with R_6 forms an oxo;

R_7 is hydrogen, halogen, protected hydroxy, $-OR_{28}$, or together with R_{7a} forms an oxo;

R_{7a} is hydrogen or together with R_{20} forms an oxo;

R_9 is hydrogen or together with R_{9a} forms an oxo;

R_{9a} is hydrogen, hydroxy, protected hydroxy, acyloxy, or together with R_9 forms an oxo;

R_{10} is hydrogen or together with R_{10a} forms an oxo;

R_{10a} is hydrogen, hydroxy, protected hydroxy, $-OCOR_{29}$ or together with R_{10} forms an oxo;

R_{14} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl, hydroxy, protected hydroxy or together with R_1 forms a carbonate;

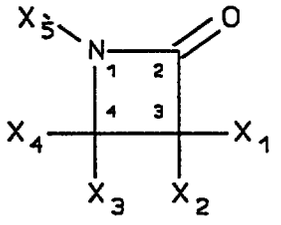
R_{14a} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl;

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R_{28} is hydrogen, acyl, hydroxy protecting group or a functional group which increases the solubility of the taxane derivative; and

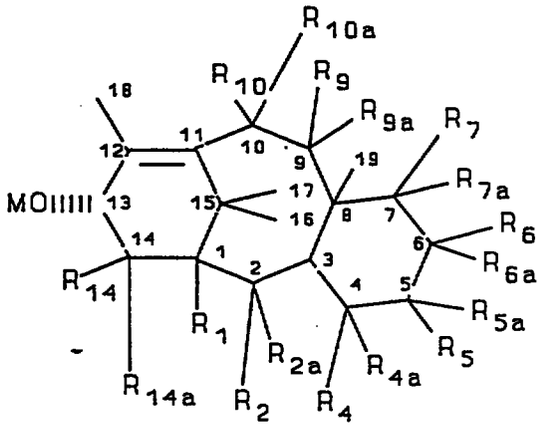
R_{29}, R_{30} and R_{31} are independently hydrogen, alkyl, alkenyl, alkynyl, monocyclic aryl or monocyclic heteroaryl.

Briefly, therefore, the taxane derivatives are prepared by reacting a ß-lactam (2) with an alkoxide having the bi-, tri- or tetracyclic taxane nucleus to form a ß-amido ester intermediate. The intermediate is then converted to the taxane derivative. ß-lactam (2) has the general formula:



(2)

wherein X_1 - X_5 are as previously above. The alkoxide preferably has the tricyclic taxane nucleus corresponding to the general formula:



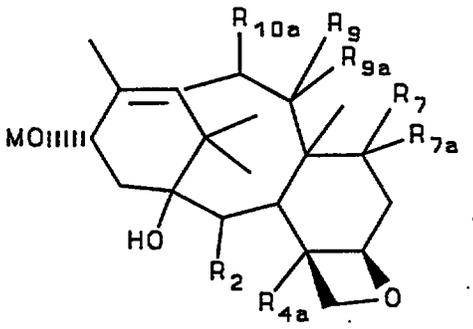
(3)

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wherein R_1 - R_{14a} are as previously defined and M comprises ammonium. More preferably, the alkoxide has the tetracyclic taxane nucleus corresponding to alkoxide

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(3) wherein R_4 and R_{5a} together form an oxetane ring. Most preferably, the alkoxide has the tetracyclic taxane nucleus and corresponds to the structural formula:



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wherein M, R_2, R_{4a}, R_7, R_{7a}, R_9, R_{9a}, R_{10}, and R_{10a} are as previously defined.

Other objects and features of this invention will be in part apparent and in part pointed out hereinafter.

DETAILED DESCRIPTION

As used herein "Ar" means aryl; "Ph" means phenyl; "Ac" means acetyl; "Et" means ethyl; "R" means alkyl unless otherwise defined; "Bu" means butyl; "Pr" means propyl; "TES" means triethylsilyl; "TMS" means trimethylsilyl; "TPAP" means tetrapropylammonium perruthenate; "DMAP" means p-dimethyl-amino pyridine; "DMF" means dimethylformamide; "LDA" means lithium diisopropylamide; "LAH" means lithium aluminum hydride; "Red-Al" means sodium bis(2-methoxyethoxy) aluminum hydride; "AIBN" means azo-(bis)-isobutyronitrile; "FAR" means 2-chloro-1,1,2-trifluorotriethylamine; "10-DAB" means 10-desacetylbaccatin III; protected hydroxy means -OR wherein R is a hydroxy protecting group; sulfhydryl protecting group" includes, but is not limited to, hemithioacetals such as 1-ethoxyethyl and methoxymethyl, thioesters, or thiocarbonates; "amine protecting group"

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includes, but is not limited to, carbamates, for example, 2,2,2-trichloroethylcarbamate or tertbutylcarbamate; and "hydroxy protecting group" includes, but is not limited to, ethers such as methyl, t-butyl, benzyl, p-methoxybenzyl, p-nitrobenzyl, allyl, trityl, methoxymethyl, methoxyethoxymethyl, ethoxyethyl, tetrahydropyranyl, tetrahydrothiopyranyl, and trialkylsilyl ethers such as trimethylsilyl ether, triethylsilyl ether, dimethylarylsilyl ether, triisopropylsilyl ether and t-butyldimethylsilyl ether; esters such as benzoyl, acetyl, phenylacetyl, formyl, mono-, di-, and trihaloacetyl such as chloroacetyl, dichloroacetyl, trichloroacetyl, trifluoroacetyl; and carbonates including but not limited to alkyl carbonates having from one to six carbon atoms such as methyl, ethyl, n-propyl, isopropyl, n-butyl, t-butyl; isobutyl, and n-pentyl; alkyl carbonates having from one to six carbon atoms and substituted with one or more halogen atoms such as 2,2,2-trichloroethoxymethyl and 2,2,2-trichloroethyl; alkenyl carbonates having from two to six carbon atoms such as vinyl and allyl; cycloalkyl carbonates have from three to six carbon atoms such as cyclopropyl, cyclobutyl, cyclopentyl and cyclohexyl; and phenyl or benzyl carbonates optionally substituted on the ring with one or more C_{1-6} alkoxy, or nitro. Other hydroxyl, sulfhydryl and amine protecting groups may be found in "Protective Groups in Organic Synthesis" by T. W. Greene, John Wiley and Sons, 1981.

The alkyl groups described herein, either alone or with the various substituents defined hereinabove are preferably lower alkyl containing from one to six carbon atoms in the principal chain and up to 15 carbon atoms. They may be straight or branched chain and include methyl, ethyl, propyl, isopropyl, butyl, hexyl and the like.

The alkenyl groups described herein, either alone or with the various substituents defined herein-

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above are preferably lower alkenyl containing from two to six carbon atoms in the principal chain and up to 15 carbon atoms. They may be straight or branched chain and include ethenyl, propenyl, isopropenyl, butenyl, isobutenyl, hexenyl, and the like.

The alkynyl groups described herein, either alone or with the various substituents defined herein-above are preferably lower alkynyl containing from two to six carbon atoms in the principal chain and up to 15 carbon atoms. They may be straight or branched chain and include ethynyl, propynyl, butynyl, isobutynyl, hexynyl, and the like.

The aryl moieties described herein, either alone or with various substituents, contain from 6 to 15 carbon atoms and include phenyl. Substituents include alkanoxy, protected hydroxy, halogen, alkyl, aryl, alkenyl, acyl, acyloxy, nitro, amino, amido, etc. Phenyl is the more preferred aryl.

The heteroaryl moieties described herein, either alone or with various substituents, contain from 5 to 15 atoms and include, furyl, thienyl, pyridyl and the like. Substituents include alkanoxy, protected hydroxy, halogen, alkyl, aryl, alkenyl, acyl, acyloxy, nitro, amino, and amido.

The acyloxy groups described herein contain alkyl, alkenyl, alkynyl, aryl or heteroaryl groups.

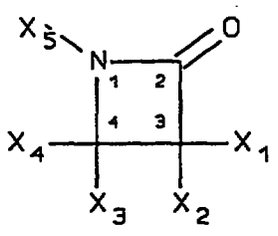
The heterosubstituents of the heterosubstituted alkyl, alkenyl, alkynyl, aryl, and heteroaryl moieties described herein, contain nitrogen, oxygen, sulfur, halogens and/or one to six carbons, and include lower alkoxy such as methoxy, ethoxy, butoxy, halogen such as chloro or fluoro, and nitro.

The present invention is directed to a process for preparing substituted isoserine esters, in general, and taxol, taxotere and other taxane derivatives which

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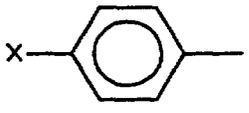
are biologically active using ß-lactam **(2)**, the structure of which is depicted hereinbelow:



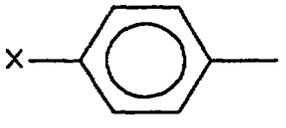
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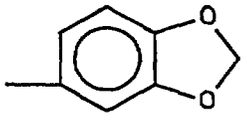
wherein X_1 - X_5 are as previously above.

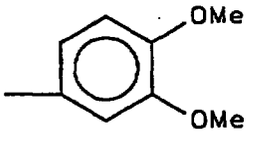
In accordance with the present invention, X_5 of ß-lactam **(2)** is preferably $-COX_{10}$ or $-COOX_{10}$ with X_{10} being lower alkyl, aryl, heteroaryl (such as furyl or thienyl), or substituted phenyl, and most preferably phenyl, methyl, ethyl, tert-butyl, or

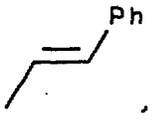


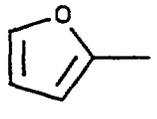
wherein X is Cl, Br, F, CH_3O-, or NO_2-. Preferably X_2 and X_4 are hydrogen or lower alkyl. X_3 is preferably aryl, most preferably, naphthyl, phenyl,



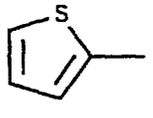








or



wherein X is as previously defined, Me is methyl and Ph is phenyl. Preferably, X_1 is selected from $-OX_6$, $-SX_7$ or

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$-NX_8X_9$ wherein X_6, X_7 and X_9, are hydroxy, sulfhydryl, and amine protecting groups, respectively, and X_8 is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl. Most preferably, X_1 is $-OX_6$ wherein X_6 is triethylsilyl ("TES"), 1-ethoxyethyl ("EE") or 2,2,2-trichloroethoxymethyl.

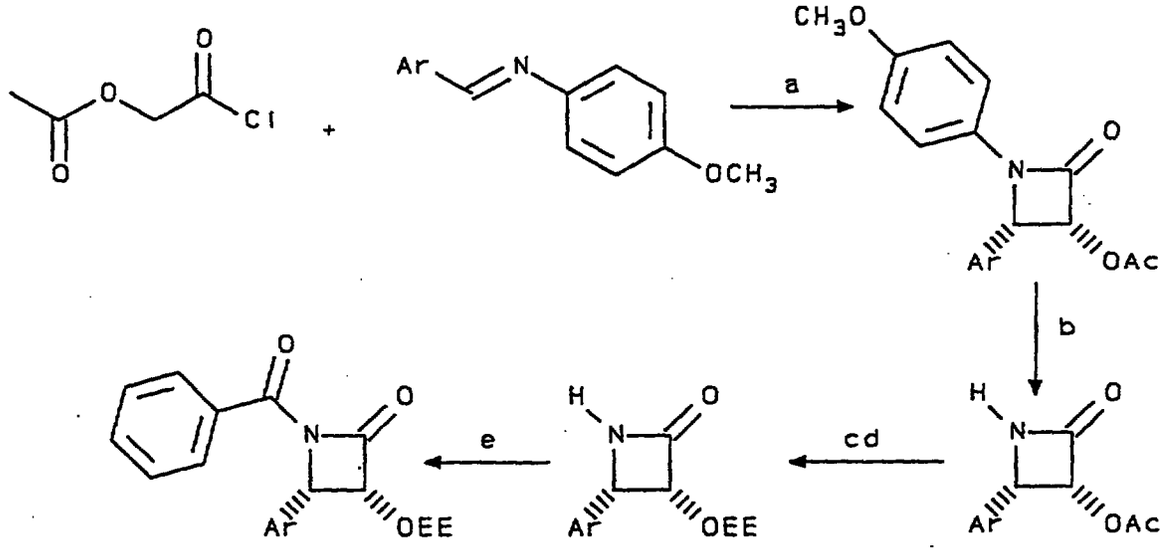
As noted above, X_1 of ß-lactam **(2)** may be $-OX_6$ with X_6 being alkyl, acyl, ethoxyethyl ("EE"), triethylsilyl ("TES"), 2,2,2-trichloroethoxymethyl, or other hydroxyl protecting group such as acetals and ethers, i.e., methoxymethyl ("MOM"), benzyloxymethyl; esters, such as acetates; carbonates, such as methyl carbonates; and alkyl and aryl silyl such as triethylsilyl, trimethylsilyl, dimethyl-t-butylsilyl, dimethylarylsilyl, dimethylheteroarylsilyl, and triisopropylsilyl, and the like. A variety of protecting groups for the hydroxyl group and the synthesis thereof may be found in "Protective Groups in Organic Synthesis" by T. W. Greene, John Wiley and Sons, 1981. The hydroxyl protecting group selected should be easily removed under conditions that are sufficiently mild, e.g., in 48% HF, acetonitrile, pyridine, or 0.5% HCl/water/ethanol, and/or zinc, acetic acid so as not to disturb the ester linkage or other substituents of the taxol intermediate. However, X_6 is preferably triethylsilyl, 1-ethoxyethyl or 2,2,2-trichloroethoxymethyl, and most preferably triethylsilyl.

Since ß-lactam **(2)** has several asymmetric carbons, it is known to those skilled in the art that the compounds of the present invention having asymmetric carbon atoms may exist in diastereomeric, racemic, or optically active forms. All of these forms are contemplated within the scope of this invention. More specifically, the present invention includes enantiomers, diastereomers, racemic mixtures, and other mixtures thereof.

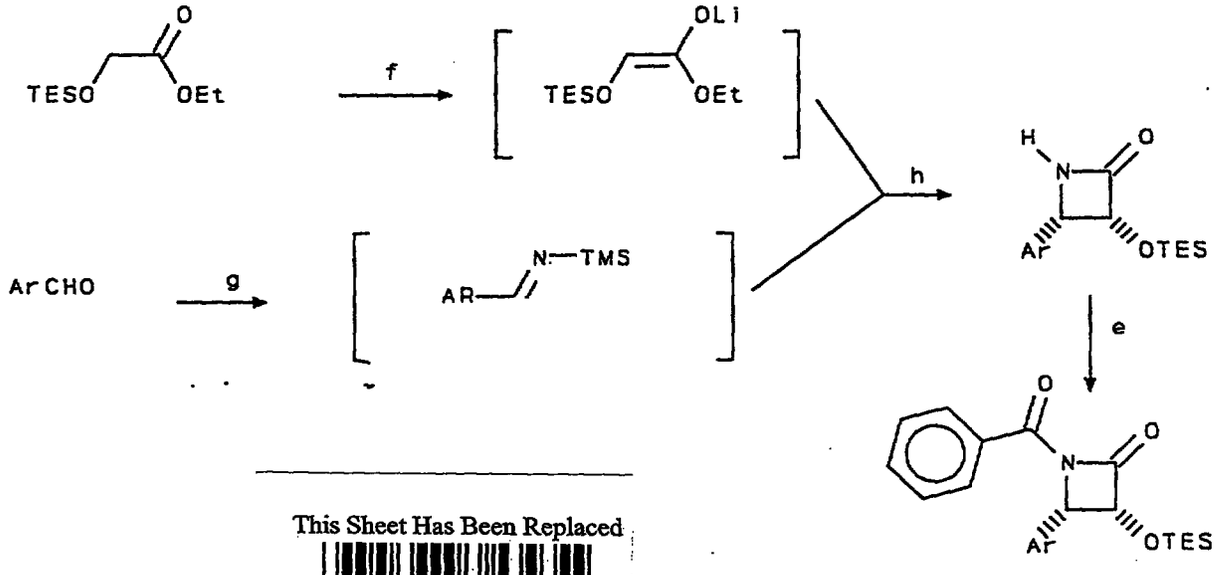
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ß-lactam (2) can be prepared from readily available materials, as is illustrated in schemes A and B below:

Scheme A



Scheme B



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reagents: (a) triethylamine, CH_2Cl_2, 25°C, 18h; (b) 4 equiv ceric ammonium nitrate, CH_3CN, -10°C, 10 min; (c) KOH, THF, H_2O, 0°C, 30 min; (d) ethyl vinyl ether, THF, toluene sulfonic acid (cat.), 0°C, 1.5h; (e) n-butyl-lithium, ether, -78°C, 10 min; benzoyl chloride, -78°C, 1h; (f) lithium diisopropyl amide, THF -78°C to -50°C; (g) lithium hexamethyldisilazide, THF -78°C to 0°C; (h) THF, -78°C to 25°C, 12h.

The starting materials are readily available. In scheme A, α-acetoxy acetyl chloride is prepared from glycolic acid, and, in the presence of a tertiary amine, it cyclocondenses with imines prepared from aldehydes and p-methoxyaniline to give 1-p-methoxyphenyl-3-acyloxy-4-arylazetidin-2-ones. The p-methoxyphenyl group can be readily removed through oxidation with ceric ammonium nitrate, and the acyloxy group can be hydrolyzed under standard conditions familiar to those experienced in the art to provide 3-hydroxy-4-arylazetidin-2-ones. The 3-hydroxyl group is protected with 1-ethoxyethyl, but may be protected with variety of standard protecting groups such as the triethylsilyl group or other trialkyl (or aryl) silyl groups. In Scheme B, ethyl-α-triethyl-silyloxyacetate is readily prepared from glycolic acid.

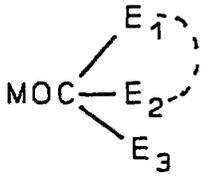
The racemic ß-lactams may be resolved into the pure enantiomers prior to protection by recrystallization of the corresponding 2-methoxy-2-(trifluoromethyl) phenylacetic esters. However, the reaction described hereinbelow in which the ß-amido ester side chain is attached has the advantage of being highly diastereo-selective, thus permitting the use of a racemic mixture of side chain precursor.

The 3-(1-ethoxyethoxy)-4-phenylazetidin-2-one of scheme A and the 3-(1-triethylsilyloxy)-4-phenyl-azetidin-2-one of scheme B can be converted to ß-lactam (2), by treatment with a base, preferably n-butyllithium, and an acyl chloride, alkylchloroformate, sulfonyl

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chloride, phosphinyl chloride or phosphoryl chloride at -78 °C or below.

The process of the present invention is particularly useful for the esterification of mono- or polycyclic alkoxides represented by the formula



in which E_1, E_2 and the carbon to which they are attached define a carbocyclic and/or heterocyclic skeleton which may be mono- or polycyclic and E_3 is hydrogen or hydrocarbon, preferably lower alkyl. Most preferably, the carbocyclic and/or heterocyclic skeleton comprises about 6 to 20 atoms and the hetero atoms are oxygen. The cyclic skeleton may be hydrocarbon and/or hetero-substituted with heterosubstituents including, for example, esters, ethers, amines, alcohols, protected alcohols, carbonyl groups, halogens, oxygen, substituted oxygen or substituted nitrogen.

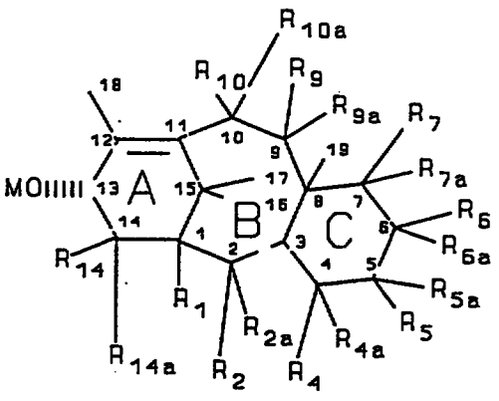
When the alkoxides have the bi-, tri- or tetracyclic taxane nucleus, the process of the present invention may advantageously be used to prepare taxane derivatives, many of which have been found to have significant biological activity. As used herein, an alkoxide having the bicyclic taxane nucleus has the carbocyclic skeleton corresponding to rings A and B of alkoxide (3):

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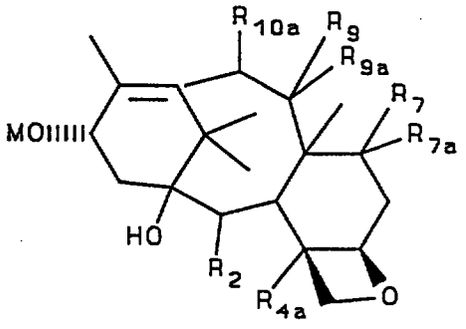


(3)

wherein R_1 - R_{14a} and M are as previously defined. An alkoxide having the tricyclic taxane nucleus has the carbocyclic skeleton corresponding to rings A, B and C of alkoxide (3). An alkoxide having the tetracyclic taxane nucleus has carbocyclic rings A, B and C of alkoxide (3) and the oxetane ring defined by R_4, R_{5a}, and the carbons to which they are attached.

Substituent, M, of alkoxide 3 comprises ammonium, preferably tetraalkylammonium, and the alkyl component of the tetraalkylammonium substituent is preferably C_1 - C_{10} alkyl such as methyl or butyl.

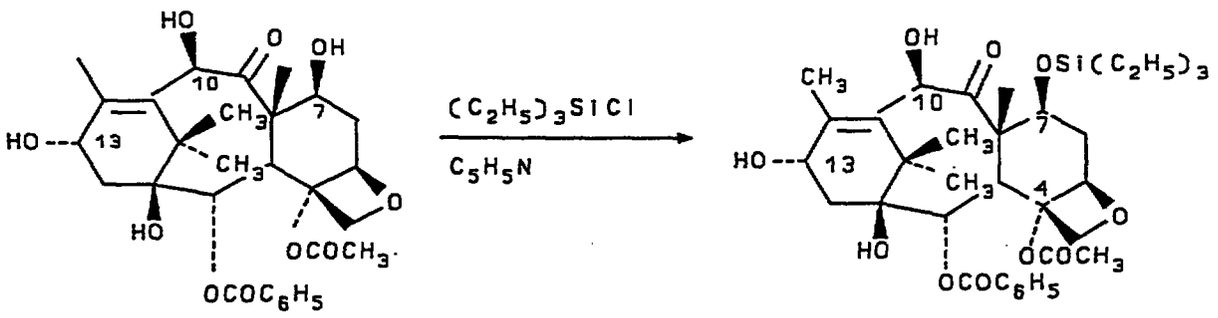
Alkoxides (3) are prepared by reacting an alcohol having two to four rings of the taxane nucleus and a C-13 hydroxyl group with a tetraalkylammonium halide such as tetrabutylammonium chloride in a suitable solvent. Preferably, the alcohol is a derivative of baccatin III or 10-deacetyl baccatin III having the formula:



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wherein M, R_2, R_{4a}, R_7, R_{7a}, R_9, R_{9a}, R_{10}, and R_{10a} are as previously defined. More preferably, R_{10a} is protected hydroxy or $-OCOR_{29}$, R_{7a} is hydrogen, R_7 is hydrogen, halogen or protected hydroxy, R_{4a} is acetoxy, and R_2 is benzoyloxy. Most preferably, the alcohol is a protected baccatin III, in particular, 7-O-triethylsilyl baccatin III (which can be obtained as described by Greene, et al. in JACS 110, 5917 (1988) or by other routes) or 7,10-bis-O-triethylsilyl baccatin III.

As reported in Greene et al., 10-deacetyl baccatin III is converted to 7-O-triethylsilyl-10-deacetyl baccatin III according to the following reaction scheme:



(5) (6a)

Under what is reported to be carefully optimized conditions, 10-deacetyl baccatin III is reacted with 20 equivalents of $(C_2H_5)_3SiCl$ at 23°C under an argon atmosphere for 20 hours in the presence of 50 ml of pyridine/mmol of 10-deacetyl baccatin III to provide 7-triethylsilyl-10-deacetyl baccatin III (**6a**) as a reaction product in 84-86% yield after purification. The reaction product is then acetylated with 5 equivalents of CH_3COCl and 25 mL of pyridine/mmol of (**6a**) at 0 °C under an argon atmosphere for 48 hours to provide 86% yield of 7-O-triethylsilyl baccatin III (**6b**). Greene, et al. in JACS 110, 5917 at 5918 (1988).

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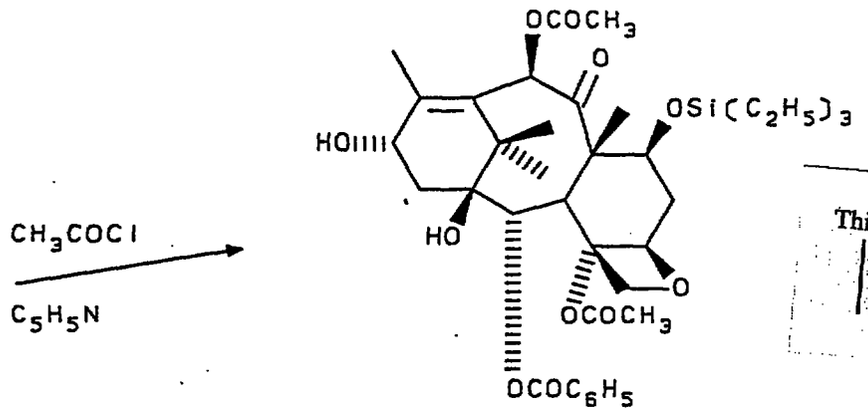
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Alternatively, 7-triethylsilyl-10-deacetyl baccatin III **(6a)** can be protected at C-10 oxygen with an acid labile hydroxyl protecting group. For example, treatment of **(6a)** with n-butyllithium in THF followed by triethylsilyl chloride (1.1 mol equiv.) at 0°C gives 7,10-bis-O-triethylsilyl baccatin III **(6c)** in 95% yield. Also, **(6a)** can be converted to 7-O-triethylsilyl-10-(1-ethoxyethyl) baccatin III **(6d)** in 90% yield by treatment with excess ethyl vinyl ether and a catalytic amount of methane sulfonic acid. These preparations are illustrated in the reaction scheme below.

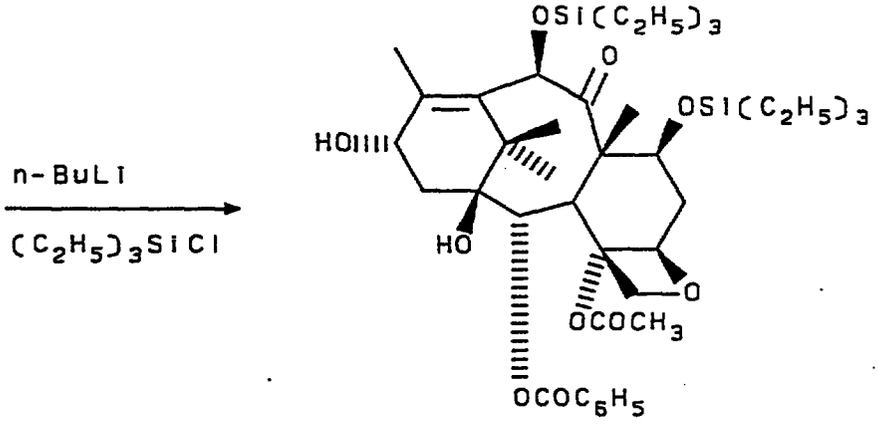
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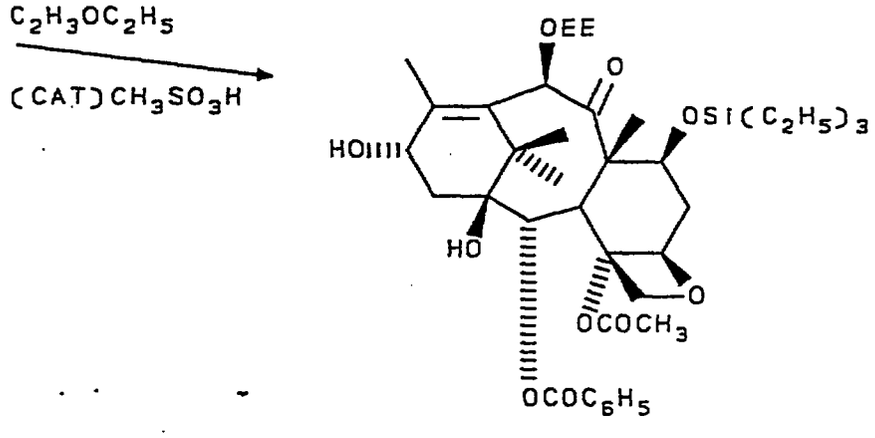
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(6a) (6b)



(6c)



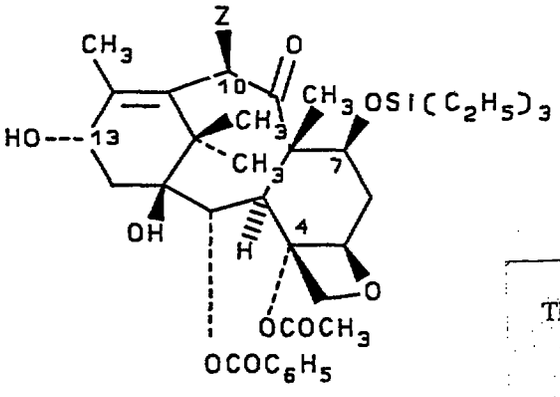
(6d)

7-O-triethylsilyl baccatin III (**6b**), 7,10-bis-O-triethylsilyl baccatin III (**6c**), or 7-O-triethylsilyl-10-(1-ethoxyethyl) baccatin III (**6d**) is reacted with base such as an organometallic compound (for example,

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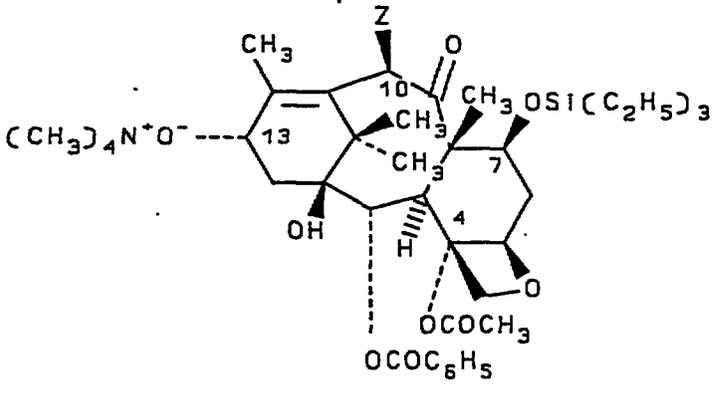
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butyllithium), an amide (for example, potassium hexamethyldisilazide ("KHMDS"), a hydride (for example, potassium hydride) and the like and an ammonium compound such as anhydrous tetramethylammonium chloride in a solvent such as tetrahydrofuran (THF), to form 13-O-tetramethylammonium-7-O-triethylsilyl baccatin III **(7b)** 13-O-tetramethylammonium-7,10-bis-O-triethylsilyl baccatin III **(7c)**, or 13-O-tetramethylammonium-7-O-triethylsilyl-10-(1-ethoxyethyl) baccatin III **(7d)** as shown in the following reaction scheme:



a) KHMDS

b) $(CH_3)_4NCl$



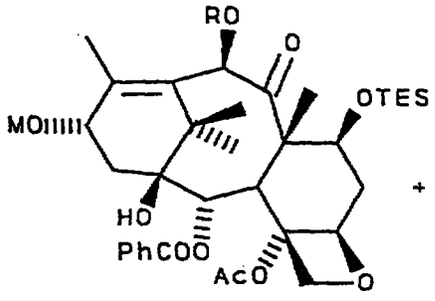
(7b) Z = $-OCOCH_3$
(7c) Z = $-OSi(C_2H_5)_3$
(7d) Z = -OEE

As illustrated in the following reaction scheme, a suitable ammonium alkoxide of the present invention such as 13-O-tetramethylammonium-7-O-

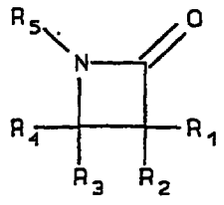
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triethylsilyl baccatin III derivative (**7b**, **7c**, or **7d**) reacts with a ß-lactam of the present invention to provide an intermediate (**8b**, **8c**, or **8d**) in which the C-7 hydroxyl group is protected with a triethylsilyl or 1-ethoxyethyl group.



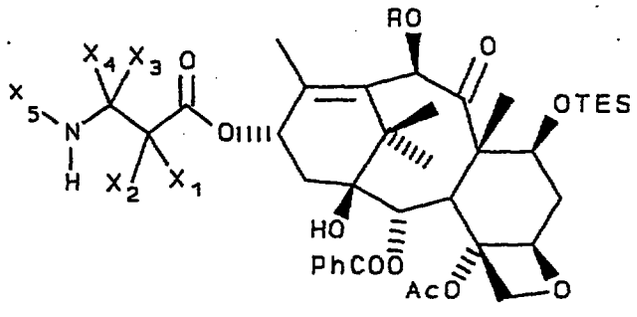
7 b-d



(2)

(1) THF

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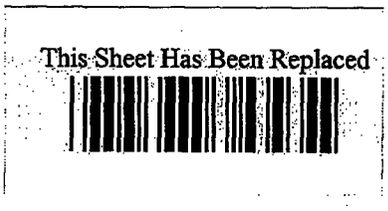
8 b-d
b, R = -COCH$_3$
c, R = -Si(C$_2$H$_5$)$_3$
d, R = -EE

Intermediate compound (**8b**) readily converts to taxol when X_1 is $-OX_6$, X_2 and X_3 are hydrogen, X_4 is phenyl, X_5 is benzoyl and X_6 is a hydroxy protecting group such as triethylsilyl. Intermediate compound (**8c**) readily converts to taxotere when X_1 is $-OX_6$, X_2 and X_3 are hydrogen, X_4 is phenyl, X_5 is tertbutoxycarbonyl and X_6 is

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a hydroxy protecting group such as triethylsilyl. Intermediate compound **(8d)** readily converts to 10-deacetyl taxol when X_1 is $-OX_6$, X_2 and X_3 are hydrogen, X_4 is phenyl, X_5 is benzoyl, and X_6 is a hydroxy protecting group such as triethylsilyl. Intermediate compounds **(8b, 8c** and **8d)** may be converted to the indicated compounds by hydrolyzing the triethylsilyl and 1-ethoxyethyl groups under mild conditions so as not to disturb the ester linkage or the taxane derivative substituents.

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8b $\xrightarrow{HF,\ C_5H_5N,\ CH_3CN}$ TAXOL

8c $\xrightarrow{HF,\ C_5H_5N,\ CH_3CN}$ TAXOTERE

8d $\xrightarrow{0.1\%\ HCl,\ EtOH}$ 10-DEACETYL TAXOL

Both the conversion of the alcohol to the ammonium alkoxide and the ultimate synthesis of the taxol can take place in the same reaction vessel. Preferably, the ß-lactam is added to the reaction vessel after formation therein of the ammonium alkoxide.

Although THF is the preferred solvent for the reaction mixture, other ethereal solvents, such as dimethoxyethane, or aromatic solvents may also be suitable. Certain solvents, including some halogenated solvents and some straight-chain hydrocarbons in which the reactants are too poorly soluble, are not suitable. Other solvents are not appropriate for other reasons. For example, esters are not appropriate for use with certain organometallic compounds such as n-butyllithium due to incompatibility therewith.

Although the reaction scheme disclosed herein is directed to the synthesis of certain taxol derivatives, it can be used with modifications in either

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the ß-lactam or the tetracyclic ammonium alkoxide. Therefore, alkoxides other than 13-O-tetramethylammonium--7-O-tri-ethylsilyl baccatin III may be used to form a taxol or other taxanes according to the method of this invention. The ß-lactam and the tetracyclic alkoxide can be derived from natural or unnatural sources, to prepare other taxol derivatives, 10-deacetyltaxanes, and synthetic taxanes, and the enantiomers and diastereomers thereof contemplated within the present invention.

The process of the invention also has the important advantage of being highly diastereoselective. Therefore racemic mixtures of the side chain precursors may be used. Substantial cost savings may be realized because there is no need to resolve racemic ß-lactams into their pure enantiomers. Additional cost savings may be realized because less side chain precursor, e.g., 60-70% less, is required relative to prior processes.

The water solubility of compounds of formula (3) may be improved by modification of the C2' and/or C7 substituents. For instance, water solubility may be increased if R_1 is $-OX_6$ and R_7 is $-OR_{28}$, and X_6 and R_{28} are independently hydrogen or $-COGCOR^1$ wherein:

G is ethylene, propylene, -CH=CH-, 1,2-cyclohexylene, or 1,2-phenylene;

R^1 = OH base, NR^2R^3, OR^3, SR^3, $OCH_2CONR^4R^5$, or OH;

R^2 = hydrogen or methyl;

R^3 = $(CH_2)_nNR^6R^7$ or $(CH_2)_nN^{\oplus}R^6R^7R^8X^{\ominus}$;

n = 1 to 3;

R^4 = hydrogen or lower alkyl containing 1 to 4 carbons;

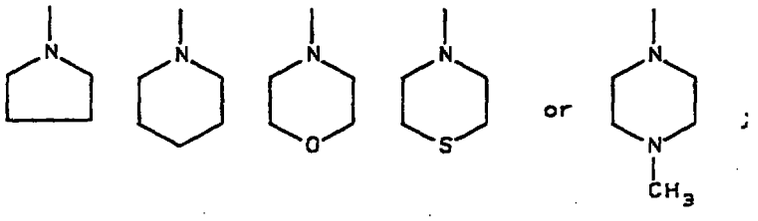
R^5 = hydrogen, lower alkyl containing 1 to 4 carbons, benzyl, hydroxyethyl, CH_2CO_2H, or dimethylaminoethyl;

R^6 and R^7 = idependently selected from lower alkyl containing 1 or 2 carbons or benzyl, or R^6 and R^7 together with

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the nitrogen atom of NR^6R^7 forms one of the following rings



R^8 = lower alkyl containing 1 or 2 carbons, benzyl;

$X^\ominus$ = halide; and

base = NH_3, $(HOC_2H_4)_3N$, $N(CH_3)_3$, $CH_3N(C_2H_4OH)_2$, $NH_2(CH_2)_6NH_2$, N-methylglucamine, NaOH, or KOH.

The preparation of compounds in which X_1 or X_2 is $-COGCOR^1$ is set forth in Haugwitz U.S. Patent 4,942,184 which is incorporated herein by reference.

Alternatively, water solubility may be increased when X_1 is $-OX_6$ and X_6 is a radical having the formula $-COCX{=}CHX$ or $-COX-CHX-CHX-SO_2O-M$ wherein X is hydrogen, alkyl or aryl and M is hydrogen, alkaline metal or an ammonio group as described in Kingston et al., U.S. Patent No. 5,059,699 (incorporated herein by reference).

Taxanes having alternative C9 substituents may be prepared by selectively reducing the C9 keto substituent to yield the corresponding C9 β-hydroxy derivative. The reducing agent is preferably a borohydride and, most preferably, tetrabutylammonium-borohydride (Bu_4NBH_4) or triacetoxy-borohydride.

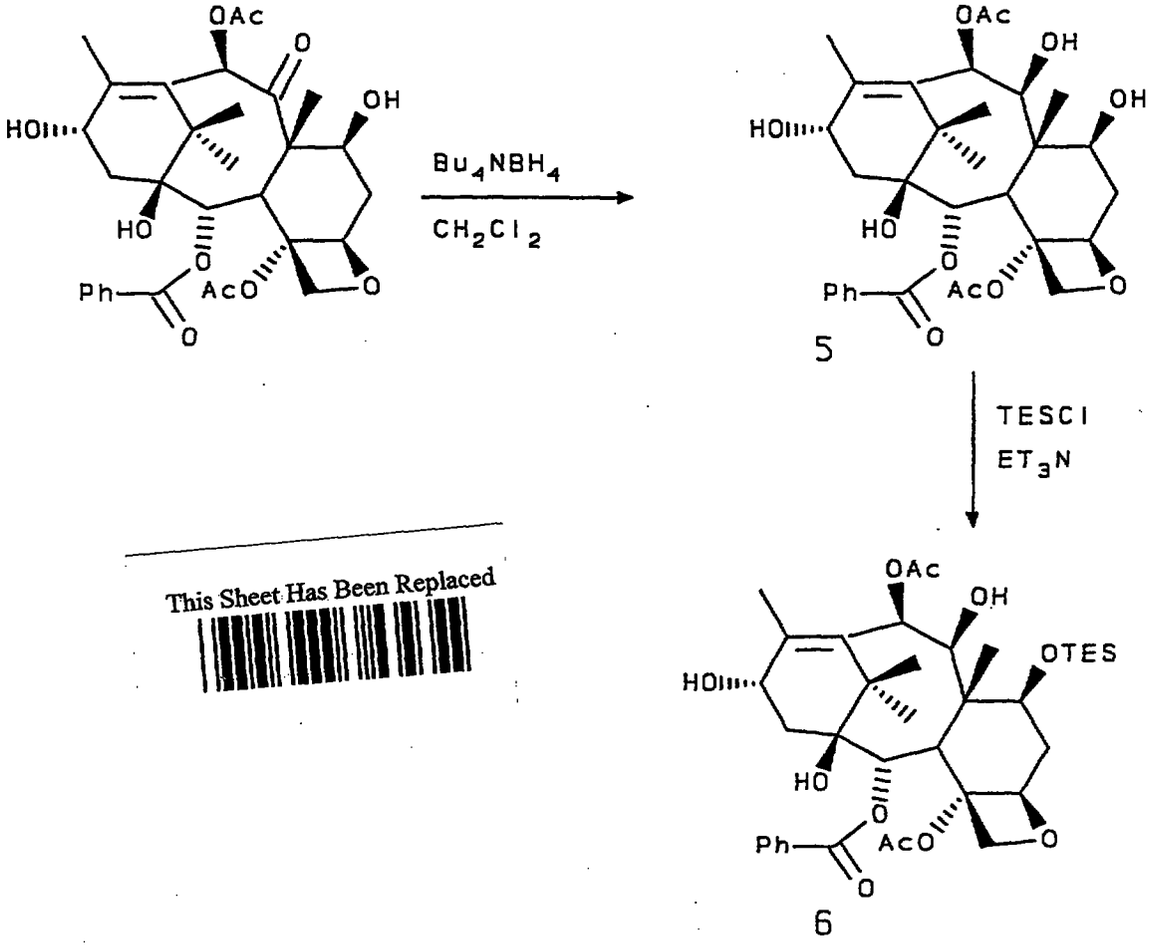
As illustrated in Reaction Scheme 1, the reaction of baccatin III with Bu_4NBH_4 in methylene chloride yields 9-desoxo-9β-hydroxybaccatin III 5. After the C7 hydroxy group is protected with the triethylsilyl protecting group, for example, a suitable side chain may be attached to 7-protected-9ß-hydroxy derivative 6 as

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elsewhere described herein. Removal of the remaining protecting groups thus yields 9ß-hydroxy-desoxo taxol or other 9β-hydroxytetracylic taxane having a C13 side chain.

REACTION SCHEME 1



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Alternatively, the C13 hydroxy group of 7-protected-9β-hydroxy derivative **6** may be protected with trimethylsilyl or other protecting group which can be selectively removed relative to the C7 hydroxy protecting group as illustrated in Reaction Scheme 2, to enable further selective manipulation of the 1 various substituents of the taxane. For example, reaction of 7,13-protected-9β-hydroxy derivative **7** with KH causes the

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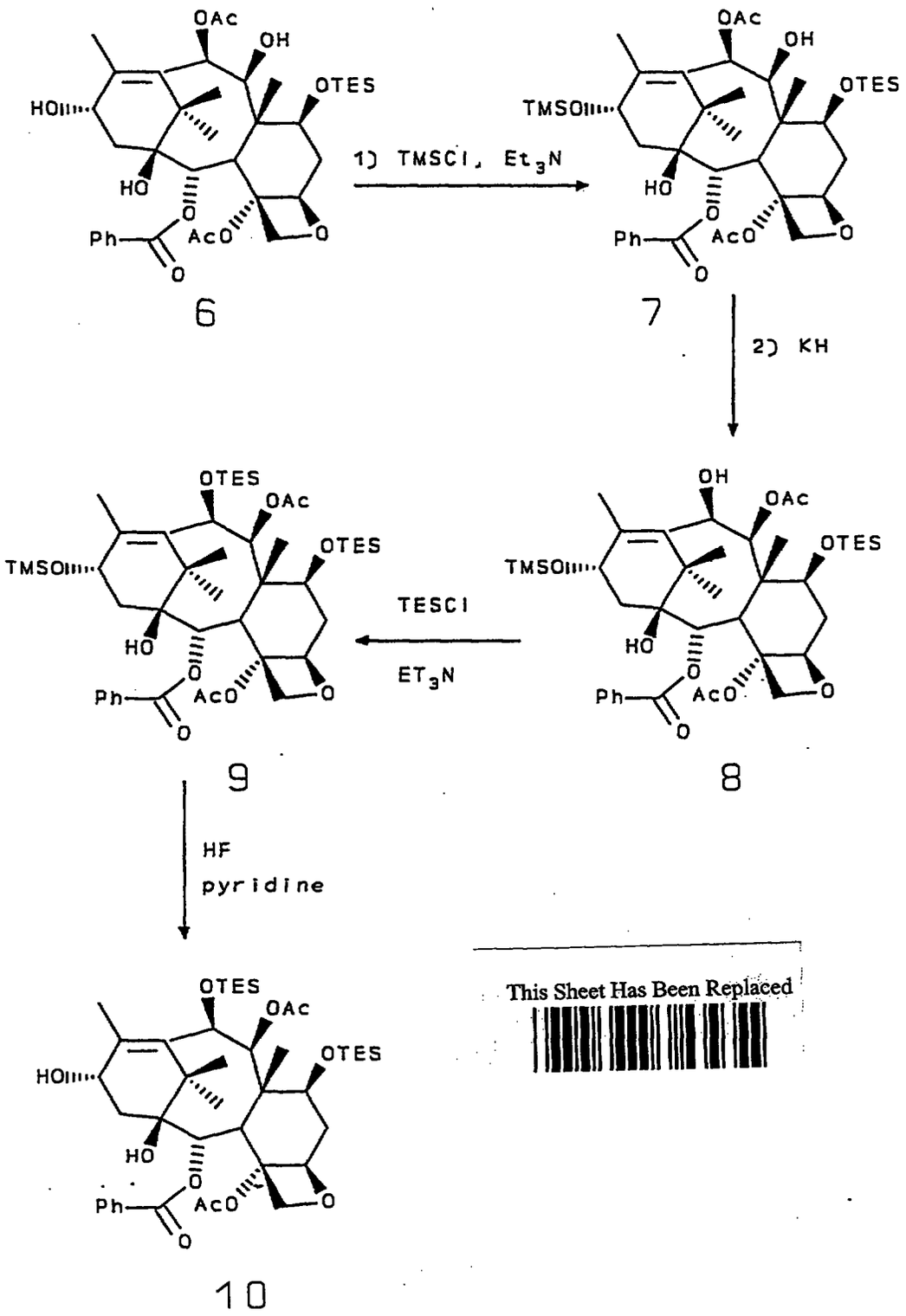
acetate group to migrate from C10 to C9 and the hydroxy group to migrate from C9 to C10, thereby yielding 10-desacetyl derivative **8**. Protection of the C10 hydroxy group of 10-desacetyl derivative **8** with triethylsilyl yields derivative **9**. Selective removal of the C13 hydroxy protecting group from derivative **9** yields derivative **10** to which a suitable side chain may be attached as described above.

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REACTION SCHEME 2



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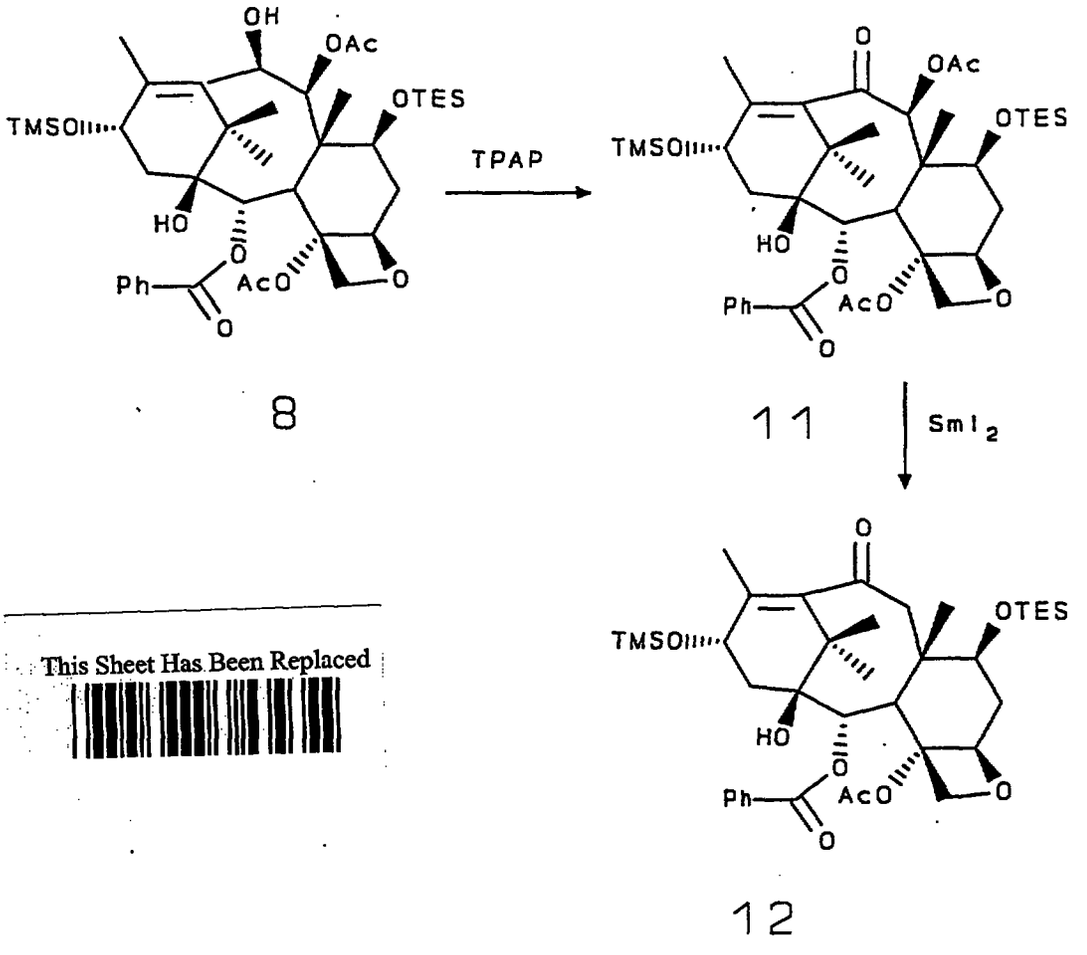
As shown in Reaction Scheme 3, 10-oxo derivative **11** can be provided by oxidation of 10-desacetyl derivative **8**. Thereafter, the C13 hydroxy protecting group can be selectively removed followed by attachment of a side chain as described above to yield 9-acetoxy-10-oxo-taxol or other 9-acetoxy-10-oxotetracylic taxanes having a C13 side chain. Alternatively, the C9 acetate group can be selectively removed by reduction of 10-oxo derivative **11** with a reducing agent such as samarium diiodide to yield 9-desoxo-10-oxo derivative **12** from which the C13 hydroxy protecting group can be selectively removed followed by attachment of a side chain as described above to yield 9-desoxo-10-oxo-taxol or other 9-desoxo-10-oxotetracylic taxanes having a C13 side chain.

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REACTION SCHEME 3



8

11

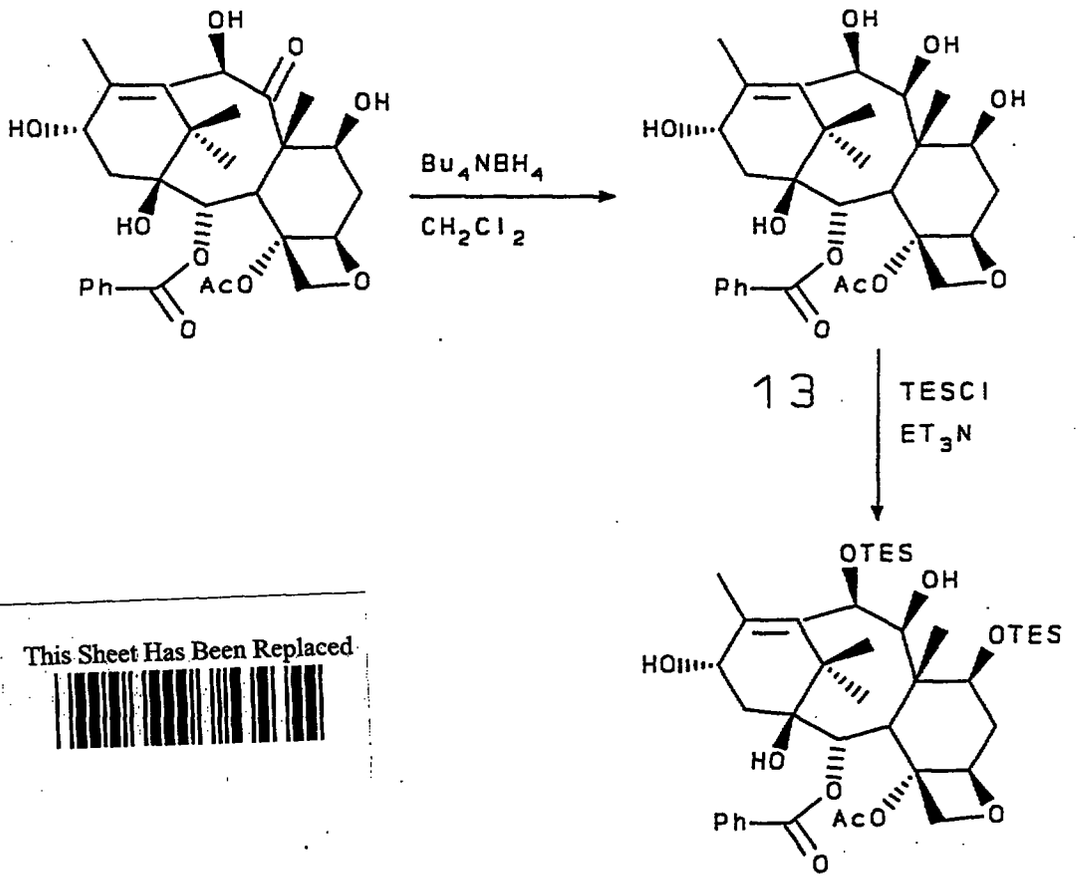
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Reaction Scheme 4 illustrates a series of reactions in which 10-DAB is used as the starting material. Reduction of 10-DAB yields pentaol **13**, the C7 and C10 hydroxyl groups of which can be selectively protected with the triethylsilyl or another protecting group to produce triol **14**. A C13 side chain can be attached to triol **14** as described above or, alternatively, after further modification of the tetracylic substituents.

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REACTION SCHEME 4

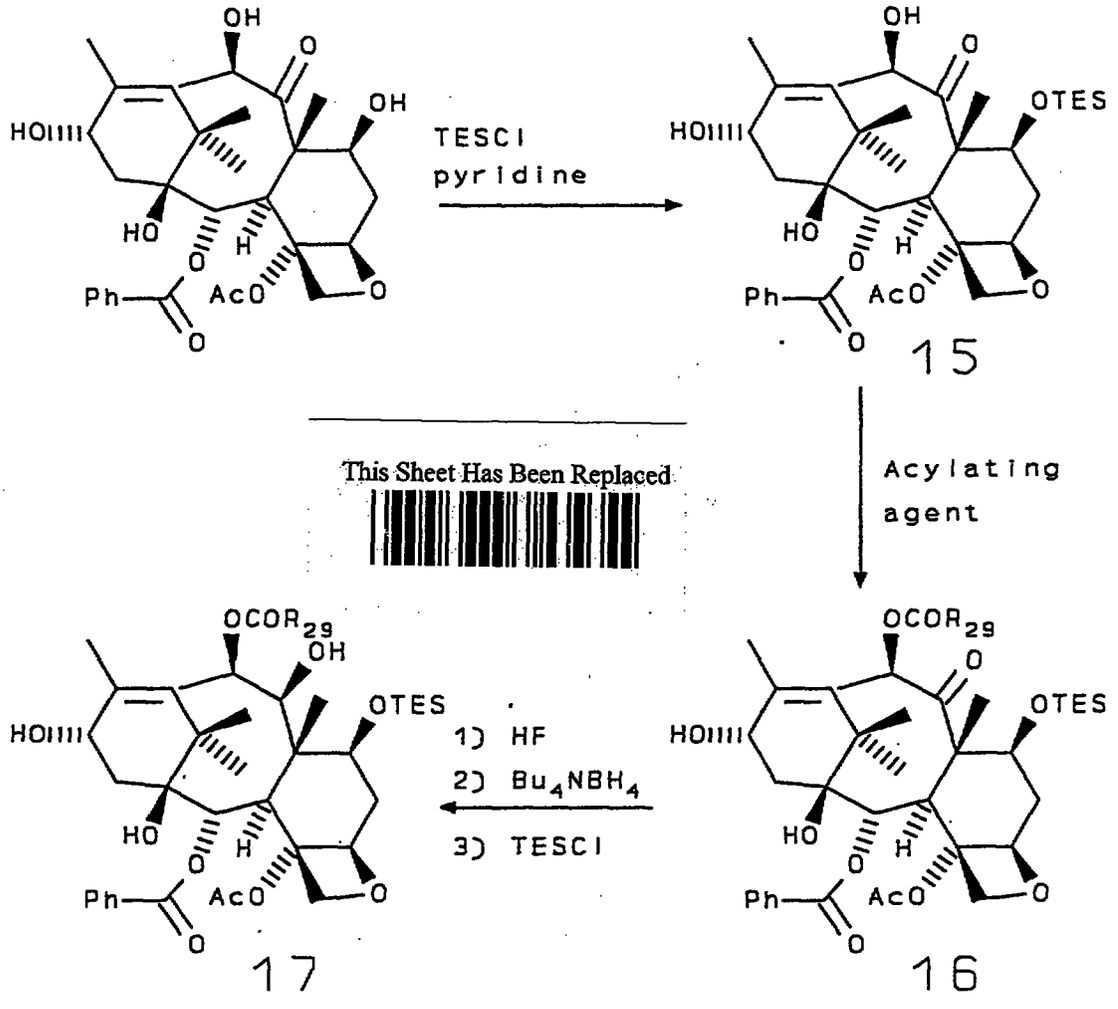


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Taxanes having C9 and/or C10 acyloxy substituents other than acetate can be prepared using 10-DAB as a starting material as illustrated in Reaction Scheme 5. Reaction of 10-DAB with triethylsilyl chloride in pyridine yields 7-protected 10-DAB **15**. The C10 hydroxy substituent of 7-protected 10-DAB **15** may then be readily acylated with any standard acylating agent to yield derivative **16** having a new C10 acyloxy substituent. Selective reduction of the C9 keto substituent of derivative **16** yields 9ß-hydroxy derivative **17** to which a C13 side chain may be attached. Alternatively, the C10 and C9 groups can be caused to migrate as set forth in Reaction Scheme **2**, above.

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REACTION SCHEME 5



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Taxanes having alternative C2 and/or C4 esters can be prepared using baccatin III and 10-DAB as starting materials. The C2 and/or C4 esters of baccatin III and 10-DAB can be selectively reduced to the corresponding alcohol(s) using reducing agents such as LAH or Red-Al, and new esters can thereafter be substituted using standard acylating agents such as anhydrides and acid chlorides in combination with an amine such as pyridine, triethylamine, DMAP, or diisopropyl ethyl amine. Alternatively, the C2 and/or C4 alcohols may be converted to new C2 and/or C4 esters through formation of the corresponding alkoxide by treatment of the alcohol with a

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suitable base such as LDA followed by an acylating agent such as an acid chloride.

Baccatin III and 10-DAB analogs having different substituents at C2 and/or C4 can be prepared as set forth in Reaction Schemes 6-10. To simplify the description, 10-DAB is used as the starting material. It should be understood, however, that baccatin III derivatives or analogs may be produced using the same series of reactions (except for the protection of the C10 hydroxy group) by simply replacing 10-DAB with baccatin III as the starting material. Derivatives of the baccatin III and 10-DAB analogs having different substituents at C2 and/or C4 can then be prepared by carrying out the other reactions described herein.

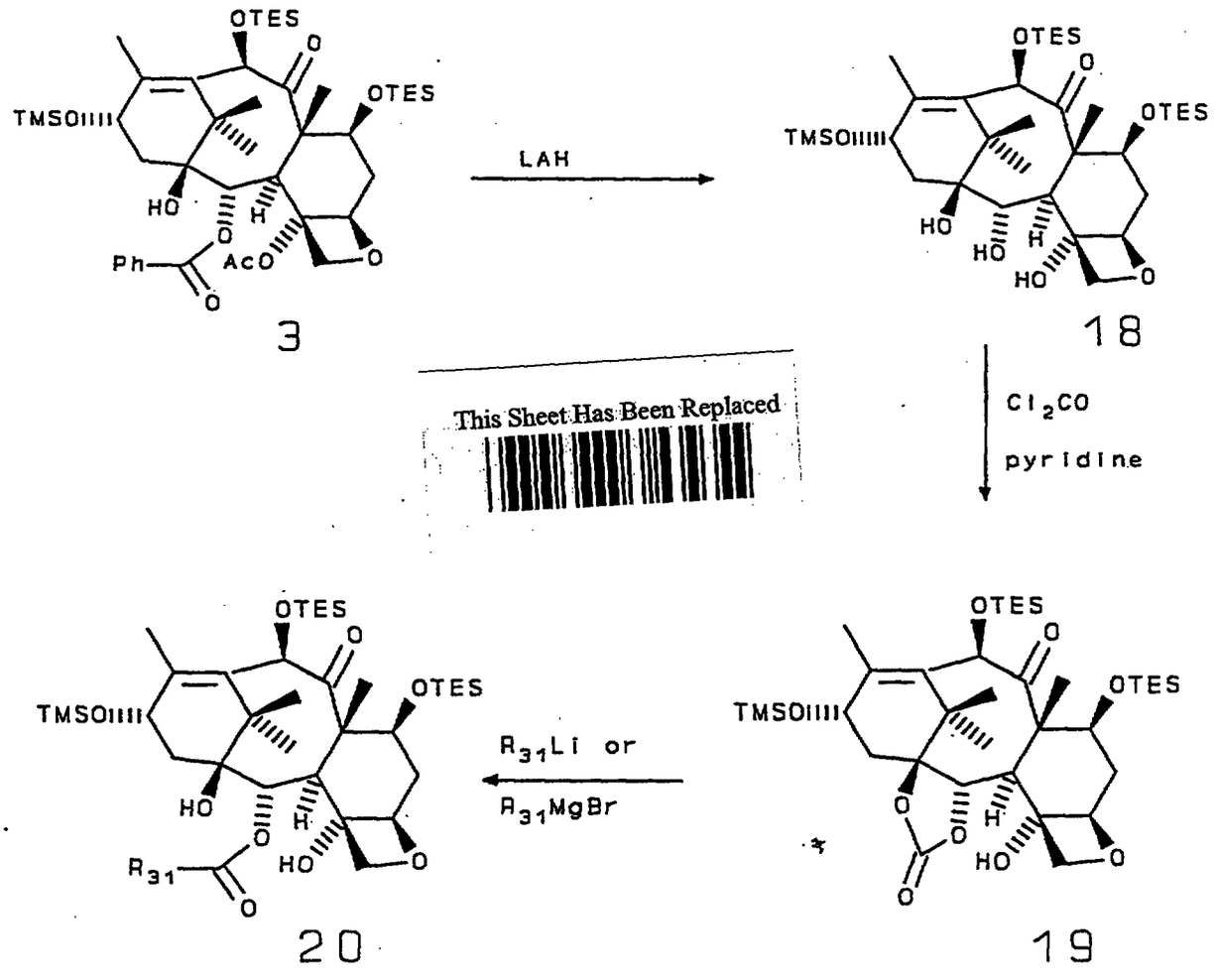
In Reaction Scheme 6, protected 10-DAB **3** is converted to the triol **18** with lithium aluminum hydride. Triol **18** is then converted to the corresponding C4 ester using Cl_2CO in pyridine followed by a nucleophilic agent (e.g., Grignard reagents or alkyllithium reagents).

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Scheme 6



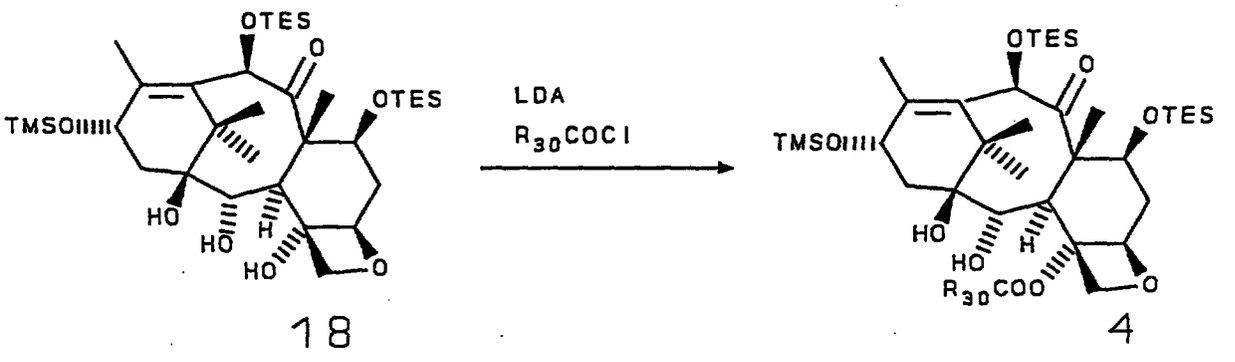
Deprotonation of triol **18** with LDA followed by introduction of an acid chloride selectively gives the C4 ester. For example, when acetyl chloride was used, triol **18** was converted to 1,2 diol **4** as set forth in Reaction Scheme 7.

Triol **18** can also readily be converted to the 1,2 carbonate **19**. Acetylation of carbonate **19** under vigorous standard conditions provides carbonate **21** as described in Reaction Scheme 8; addition of alkyllithiums or Grignard reagents to carbonate **19** provides the C2

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ester having a free hydroxyl group at C4 as set forth in Reaction Scheme 6.

Scheme 7

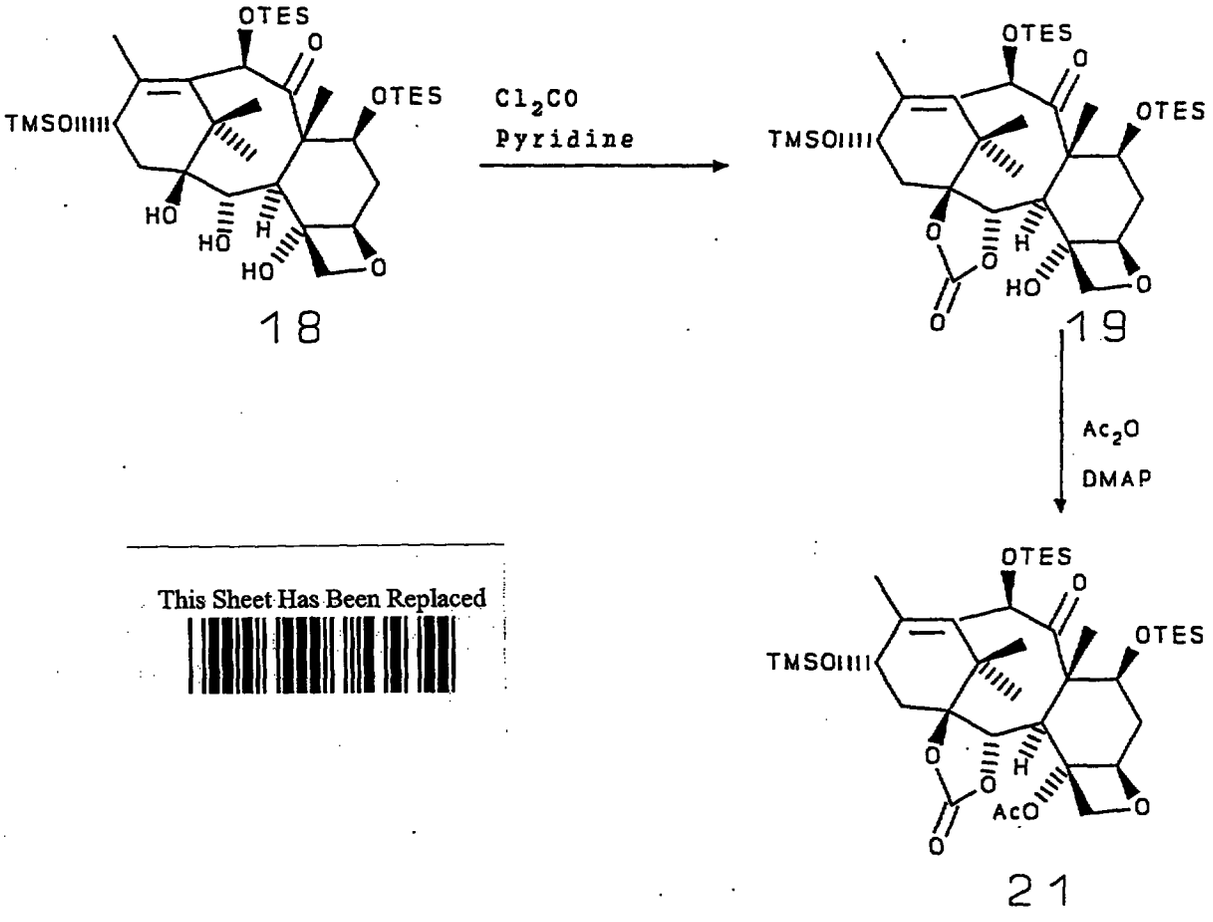


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Scheme 8



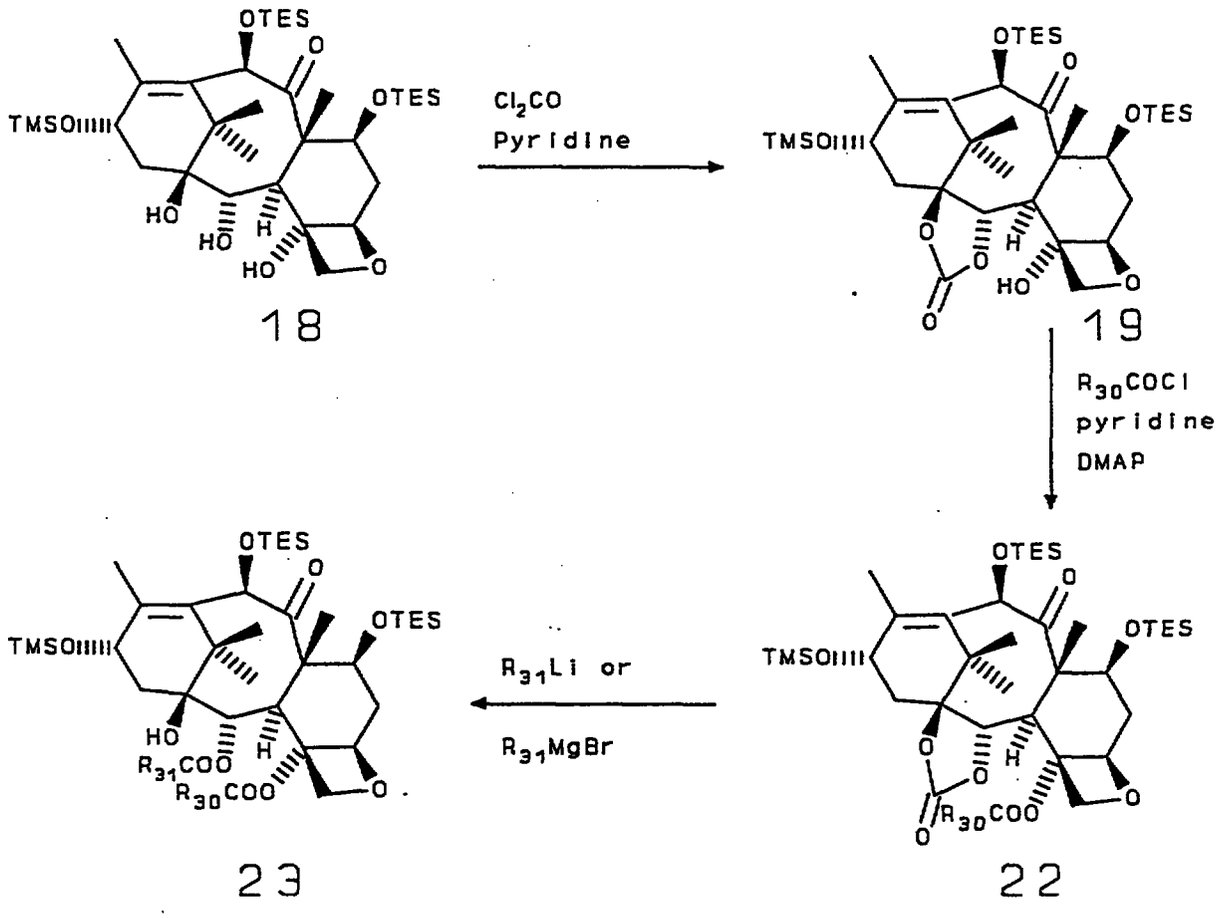
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As set forth in Reaction Scheme 9, other C4 substituents can be provided by reacting carbonate **19** with an acid chloride and a tertiary amine to yield carbonate **22** which is then reacted with alkyllithiums or Grignard reagents to provide 10-DAB derivatives having new substituents at C2.

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Scheme 9



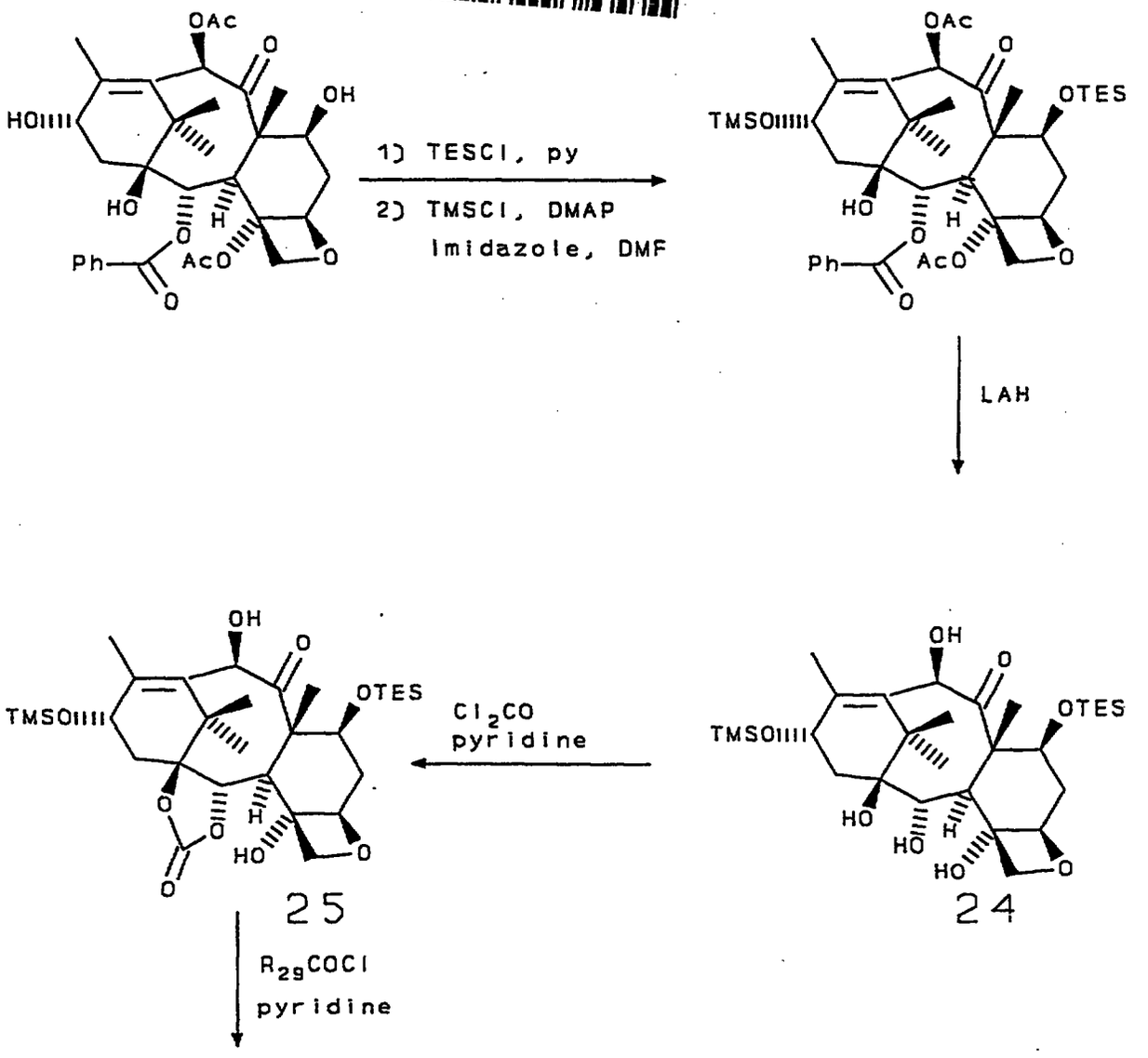
Alternatively, baccatin III may be used as a starting material and reacted as shown in Reaction Scheme 10. After being protected at C7 and C13, baccatin III is reduced with LAH to produce 1,2,4,10 tetraol **24**. Tetraol **24** is converted to carbonate **25** using Cl_2CO and pyridine, and carbonate **25** is acylated at C10 with an acid chloride and pyridine to produce carbonate **26** (as shown) or with acetic anhydride and pyridine (not shown). Acetylation of carbonate **26** under vigorous standard conditions provides carbonate **27** which is then reacted with alkyl

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lithiums to provide the baccatin III derivatives having new substituents at C2 and C10.

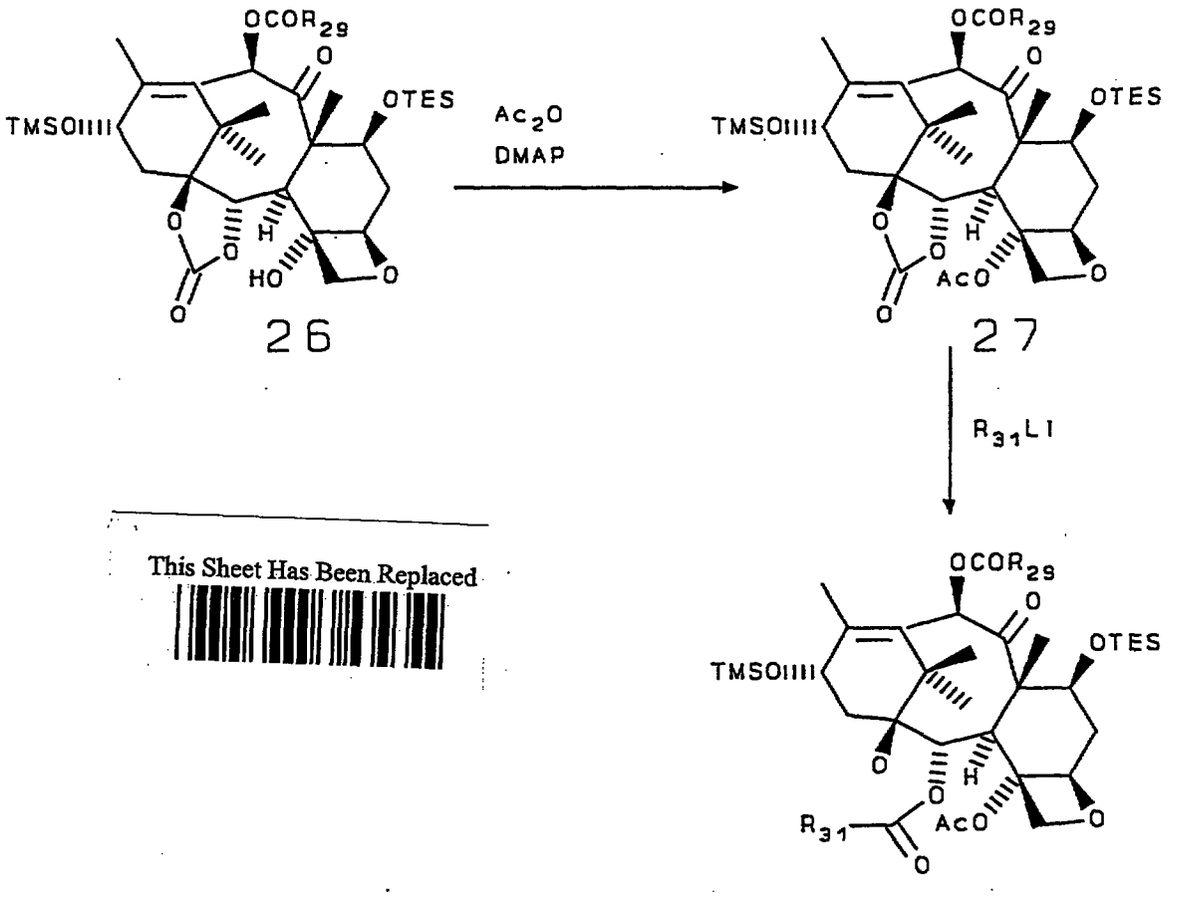
Scheme 10

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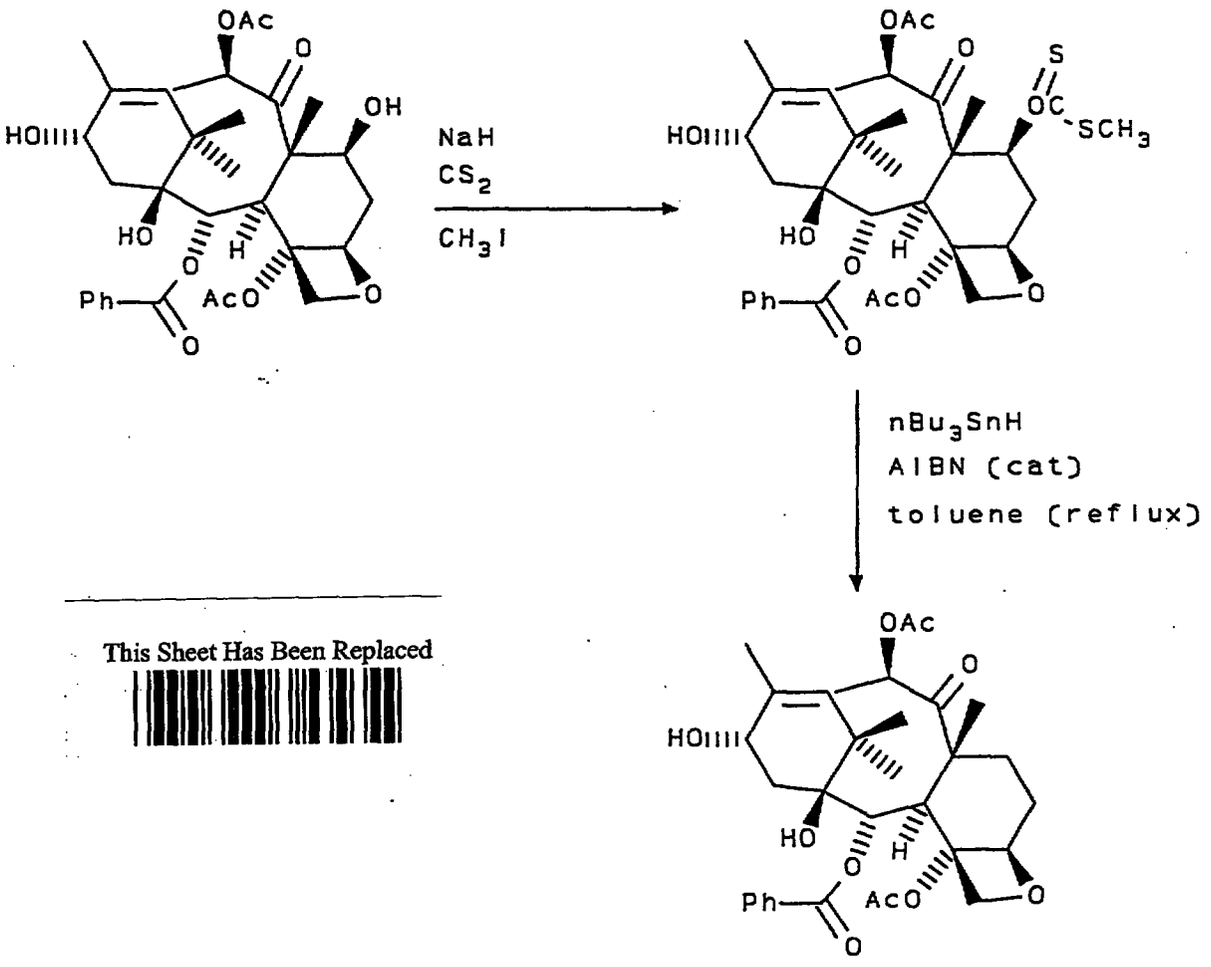
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10-desacetoxy derivatives of baccatin III and 10-desoxy derivatives of 10-DAB may be prepared by reacting baccatin III or 10-DAB (or their derivatives) with samarium diiodide. Reaction between the tetracyclic taxane having a C10 leaving group and samarium diiodide may be carried out at 0°C in a solvent such as tetrahydrofuran. Advantageously, the samarium diiodide selectively abstracts the C10 leaving group; C13 side chains and other substituents on the tetracyclic nucleus remain undisturbed. Thereafter, the C9 keto substituent may be reduced to provide the corresponding 9-desoxo-9β-hydroxy-10-desacetyoxy or 10-desoxy derivatives as otherwise described herein.

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C7 dihydro and other C7 substituted taxanes can be prepared as set forth in Reaction Schemes 11, 12 and 12a.

REACTION SCHEME 11

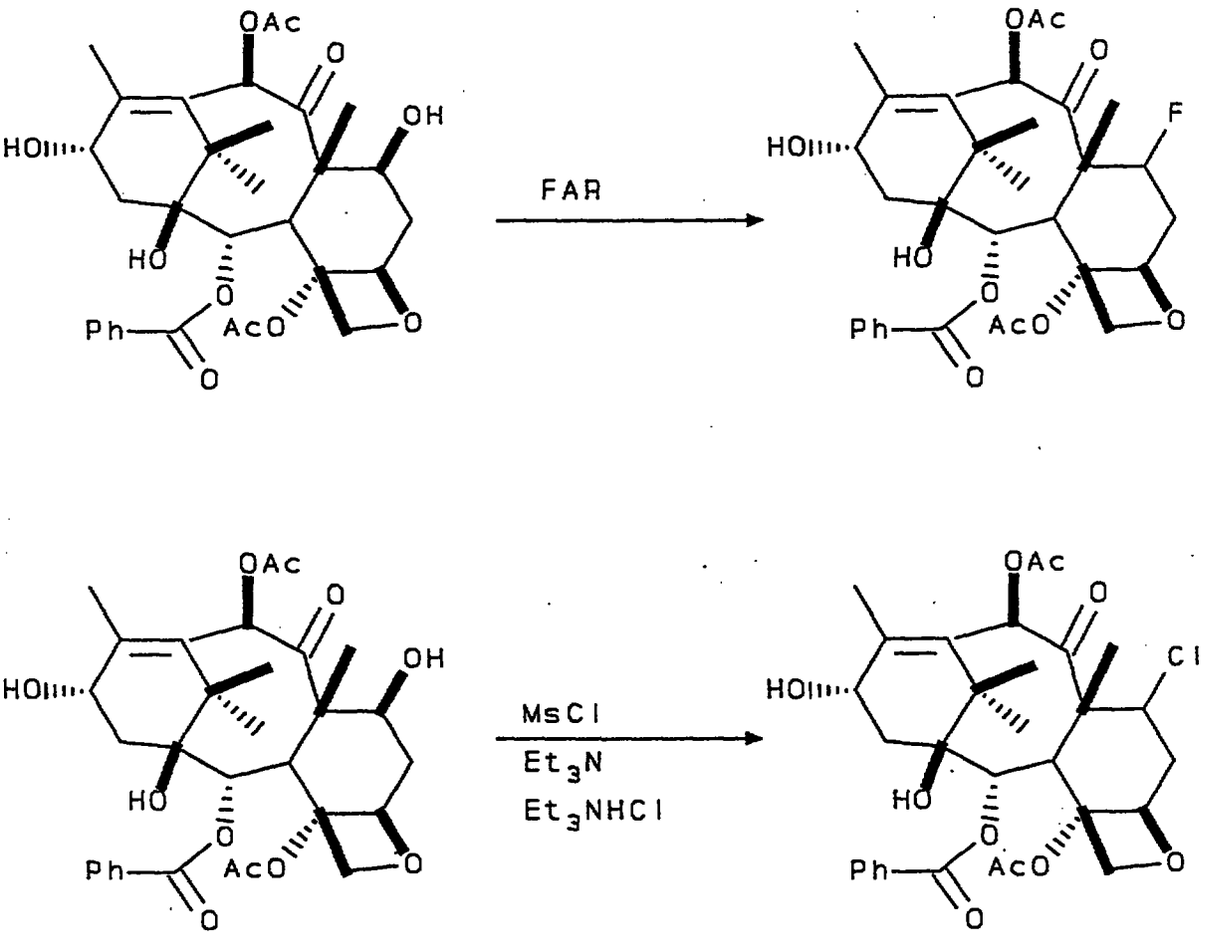


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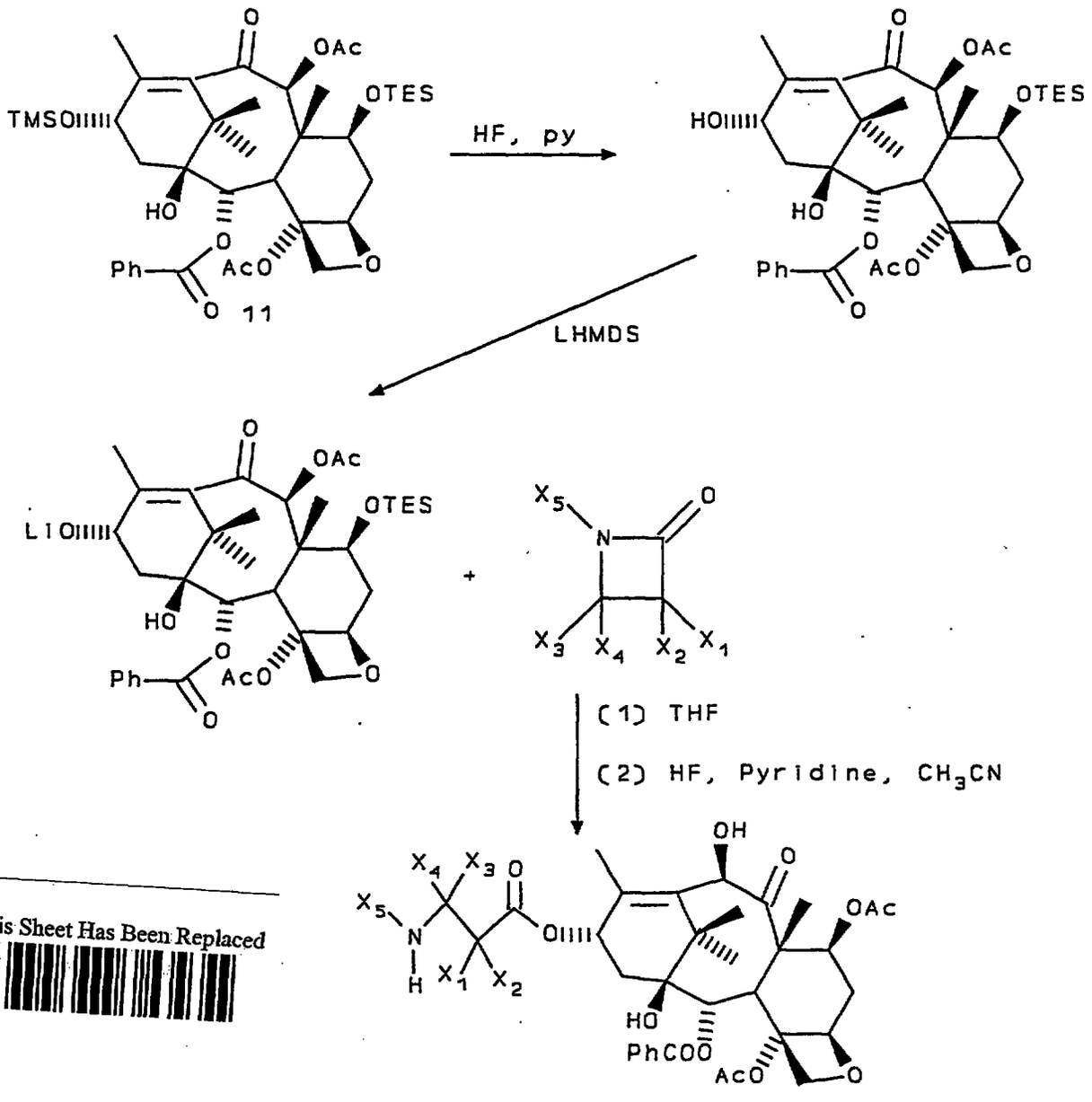
REACTION SCHEME 12



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REACTION SCHEME 12a



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As shown in Reaction Scheme 12, Baccatin III may be converted into 7-fluoro baccatin III by treatment with FAR at room temperature in THF solution. Other baccatin derivatives with a free C7 hydroxyl group behave similarly. Alternatively, 7-chloro baccatin III can be

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prepared by treatment of baccatin III with methane sulfonyl chloride and triethylamine in methylene chloride solution containing an excess of triethylamine hydrochloride.

Taxanes having C7 acyloxy substituents can be prepared as set forth in Reaction Scheme 12a, 7,13-protected 10-oxo-derivative 11 is converted to its corresponding C13 alkoxide by selectively removing the C13 protecting group and replacing it with ammonium. The alkoxide is then reacted with a β-lactam or other side chain precursor. Subsequent hydrolysis of the C7 protecting groups causes a migration of the C7 hydroxy substituent to C10, migration of the C10 oxo substituent to C9, and migration of the C9 acyloxy substituent to C7.

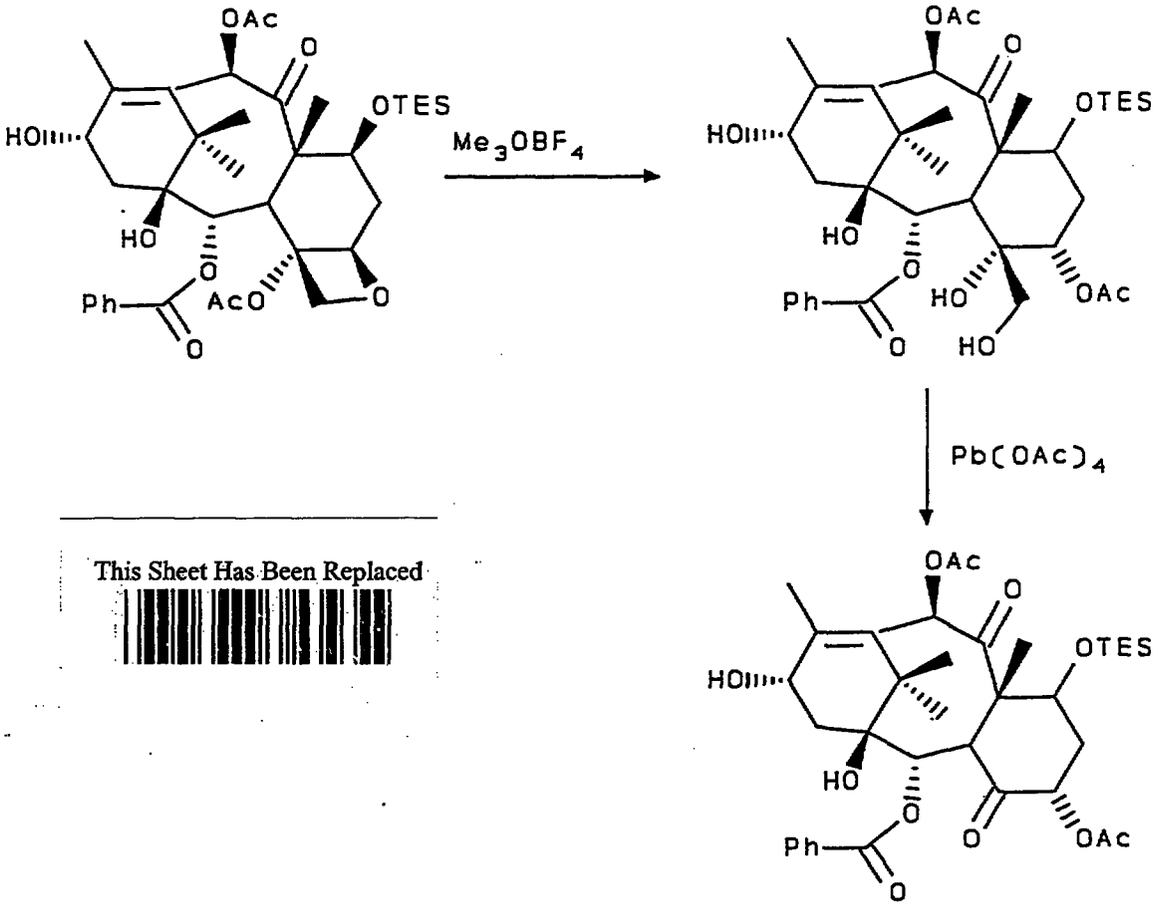
A wide variety of tricyclic taxanes are naturally occurring, and through manipulations analogous to those described herein, an appropriate side chain can be attached to the C13 oxygen of these substances. Alternatively, as shown in Reaction Scheme 13, 7-O-triethylsilyl baccatin III can be converted to a tricyclic taxane through the action of trimethyloxonium tetrafluoroborate in methylene chloride solution. The product diol then reacts with lead tetraacetate to provide the corresponding C4 ketone. This ketone can be reduced to the alcohol with a hydride reducing agent such as sodium borohydride and subsequent acetylation produces the C4, C5 diacetate.

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REACTION SCHEME 13



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Recently a hydroxylated taxane (14-hydroxy-10-deacetylbaccatin III) has been discovered in an extract of yew needles (C&EN, p 36-37, April 12, 1993). Derivatives of this hydroxylated taxane having the various C2, C4, etc. functional groups described above may also be prepared by using this hydroxylated taxane. In addition, the C14 hydroxy group together with the C1 hydroxy group of 10-DAB can be converted to a 1,2-carbonate as described in C&EN or it may be converted to a variety of esters or other functional groups as otherwise described herein in connection with the C2, C4, C9 and C10 substituents.

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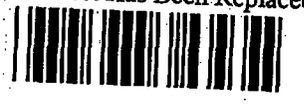
The following example is provided to more fully illustrate the invention.

EXAMPLE

Taxol Using Tetrabutylammonium Alkoxide

To a solution of 7-triethylsilyl baccatin III (100 mg, 0.143 mmol)) in 1 mL of THF at -45 °C was added dropwise 0.286 mL of a 0.5 M solution of potassium hexamethyldi-silazide in toluene. After 15 min, a solution of 16 mg (0.143 mmol) of anhydrous tetramethyl-ammonium chloride in 0.5 mL of THF was added. After an additional 1 h at -45 °C, the mixture was warmed to 0 °C and a solution of (+)-cis-1-benzoyl-3-triethylsilyloxy-4-phenylazetidin-2-one (82 mg, 0.215 mmol) in 1 mL of THF was added dropwise to the mixture. The solution was stirred at 0 °C for 3 h before 1 mL of a 10% solution of AcOH in THF was added. The mixture was partitioned between saturated aqueous $NaHCO_3$ and 60/40 ethyl acetate/hexane. Evaporation of the organic layer gave a residue which was purified by flash chromatography followed by recrystallization to give 134 mg (87%) of (2'R,3'S)-2',7-(bis)triethylsilyl taxol.

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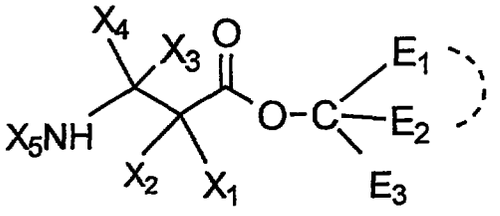


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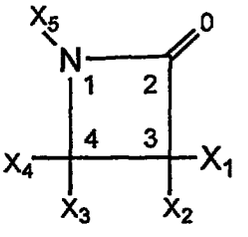
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CLAIMS

1. A process for the preparation of a substituted isoserine ester having the formula



comprising reacting a β-lactam with an alkoxide, the β-lactam having the formula:



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and the alkoxide having the formula

$MOCE_1E_2E_3$

wherein

X_1 is $-OX_6$, $-SX_7$, or $-NX_8X_9$;

X_2 is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl;

X_3 and X_4 are independently hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, acyl or hetero-substituted alkyl, alkenyl, alkynyl, aryl or heteroaryl, provided, however, that X_3 and X_4 are not both acyl;

X_5 is $-COX_{10}$, $-COOX_{10}$, $-COSX_{10}$, $-CONX_8X_{10}$, or $-SO_2X_{11}$;

X_6 is hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, hydroxy protecting group, or a functional group

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which increases the water solubility of the taxane derivative;

X_7 is alkyl, alkenyl, alkynyl, aryl, heteroaryl, or sulfhydryl protecting group;

X_8 is hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, or heterosubstituted alkyl, alkenyl, alkynyl, aryl or heteroaryl;

X_9 is an aminoprotecting group;

X_{10} is alkyl, alkenyl, alkynyl, aryl, heteroaryl, or heterosubstituted alkyl, alkenyl, alkynyl, aryl or heteroaryl;

X_{11} is alkyl, alkenyl, alkynyl, aryl, heteroaryl, $-OX_{10}$, or $-NX_8X_{14}$;

X_{14} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl;

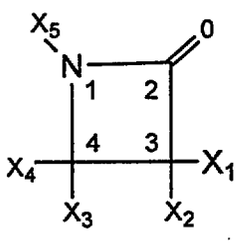
E_1, E_2 and E_3 are independently hydrogen, hydrocarbon or cyclic, provided at least one of E_1, E_2 and E_3 is other than hydrogen; and

M is an ammonium-containing substituent.

2. A process according to claim 1, wherein two of E_1, E_2 and E_3 together with the carbon to which they are attached comprise a polycyclic skeleton.

3. A process for the preparation of a taxane derivative comprising:

reacting an ammonium alkoxide having the formula $MOCE_1E_2E_3$ with a β-lactam, the β-lactam having the formula:



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wherein

M is an ammonium-containing substituent;

one of E_1, E_2 and E_3 is hydrogen or a hydrocarbon and the other two of E_1, E_2 and E_3 together with the carbon to which they are attached comprise a polycyclic skeleton;

X_1 is $-OX_6$, $-SX_7$, or $-NX_8X_9$;

X_2 is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl;

X_3 and X_4 are independently hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, acyl or heterosubstituted alkyl, alkenyl, alkynyl, aryl or heteroaryl, provided, however, that X_3 and X_4 are not both acyl;

X_5 is $-COX_{10}$, $-COOX_{10}$, $-COSX_{10}$, $-CONX_8X_{10}$, or $-SO_2X_{11}$;

X_6 is hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, hydroxy protecting group, or a functional group which increases the water solubility of the taxane derivative;

X_7 is alkyl, alkenyl, alkynyl, aryl, heteroaryl, or sulfhydryl protecting group;

X_8 is hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, or heterosubstituted alkyl, alkenyl, alkynyl, aryl or heteroaryl;

X_9 is an amino protecting group;

X_{10} is alkyl, alkenyl, alkynyl, aryl, heteroaryl, or heterosubstituted alkyl, alkenyl, alkynyl, aryl or heteroaryl;

X_{11} is alkyl, alkenyl, alkynyl, aryl, heteroaryl, $-OX_{10}$,

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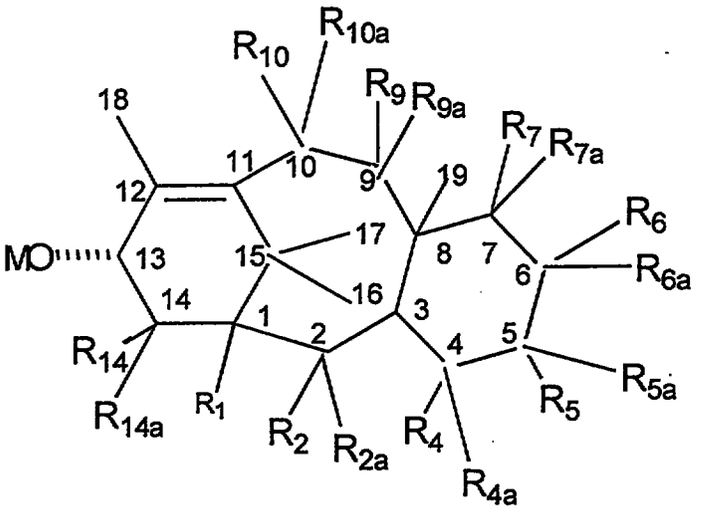
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or $-NX_8X_{14}$; and

X_{14} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl.

4. A process according to any one of claims 1 to 3, wherein the alkoxide has the formula:



(3)

wherein

R_1 is hydrogen, hydroxy, protected hydroxy or together with R_{14} forms a carbonate;

R_2 is hydrogen, hydroxy, $-OCOR_{31}$, or together with R_{2a} forms an oxo;

R_{2a} is hydrogen or together with R_2 forms an oxo;

R_4 is hydrogen, together with R_{4a} forms an oxo, oxirane or methylene, or together with R_{5a} and the carbon atoms to which they are attached form an oxetane ring;

R_{4a} is hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, cyano, hydroxy, $-OCOR_{30}$, or together with R_4 forms an oxo, oxirane or methylene;

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R_5 is hydrogen or together with R_{5a} forms an oxo,

R_{5a} is hydrogen, hydroxy, protected hydroxy, acyloxy, together with R_5 forms an oxo, or together with R_4 and the carbon atoms to which they are attached form an oxetane ring;

R_6 is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl, hydroxy, protected hydroxy or together with R_{6a} forms an oxo;

R_{6a} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl, hydroxy, protected hydroxy or together with R_6 forms an oxo;

R_7 is hydrogen, halogen, protected hydroxy, $-OR_{28}$, or together with R_{7a} forms an oxo;

R_{7a} is hydrogen or together with R_7 forms an oxo;

R_9 is hydrogen or together with R_{9a} forms an oxo;

R_{9a} is hydrogen, hydroxy, protected hydroxy, acyloxy, or together with R_9 forms an oxo;

R_{10} is hydrogen or together with R_{10a} forms an oxo;

R_{10a} is hydrogen, hydroxy, protected hydroxy, $-OCOR_{29}$ or together with R_{10} forms an oxo;

R_{14} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl, hydroxy, protected hydroxy or together with R_1 forms a carbonate;

R_{14a} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl;

R_{28} is hydrogen, acyl, hydroxy protecting group or a functional group which increases the solubility of the taxane derivative; and

R_{29}, R_{30} and R_{31} are independently hydrogen, alkyl, alkenyl, alkynyl, monocyclic aryl or monocyclic heteroaryl.

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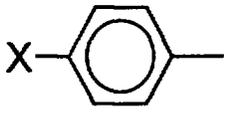
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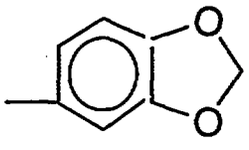
5. A process according to any one of claims 1 to 4, wherein X_2 and X_4 are hydrogen or lower alkyl, X_3 is aryl, X_1 is $-OX_6$, and X_6 is a hydroxy protecting group.

6. A process according to any one of claims 1 to 5, wherein X_3 is phenyl and X_1 is $-OX_6$ wherein X_6 is triethylsilyl, ethoxyethyl, or 2,2,2-trichloroethoxymethyl.

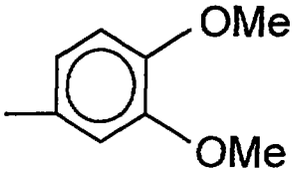
7. A process according to any one of claims 1 to 4, wherein X_3 is



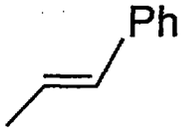
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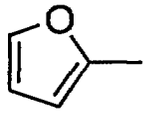
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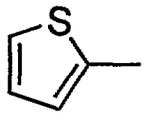
,



,



, or



wherein Ph is phenyl, Me is methyl, and X is Cl, Br, F, CH_3O- or NO_2-.

8. A process according to any one of claims 1 to 4, wherein X_1 is $-OX_6$; X_3 and X_4 are independently hydrogen, alkyl, alkenyl, alkynyl, aryl or heteroaryl; X_5 is $-COX_{10}$ or

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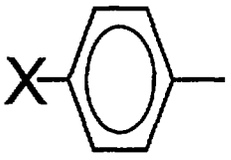
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-$COOX_{10}$; X_6 is hydroxy protecting group; and X_{10} is alkyl, alkenyl, alkynyl, aryl or heteroaryl.

9. A process according to any one of claims 1 to 8, wherein M is tetraalkylammonium, X_1 is -OX_6; X_5 is -COX_{10}, -$COOX_{10}$, or -$CONX_8X_{10}$, and X_{10} is alkyl, phenyl, furyl or thienyl.

10. A process according to any one of claims 1 to 9, wherein X_5 is -COX_{10}, and X_{10} is phenyl, methoxy, ethoxy, tert-butoxy or



and X is Cl, Br, F, CH_3O- or NO_2-.

11. A process as set forth in any one of claims 1 to 10, wherein E_1 and E_2 and the carbon to which they are attached comprise a carbocyclic or a heterocyclic skeleton having about 6 - 20 ring atoms, the hetero atoms of the heterocyclic skeleton being oxygen; and E_3 is hydrogen or a hydrocarbon.

12. A process according to any one of claims 1 to 9, wherein

R_{7a} is hydrogen;

R_7 is halogen, protected hydroxy, or -OR_{28};

R_5 is hydrogen;

R_{5a} is acyloxy or together with R_4 and the carbon atoms

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to which they are attached form an oxetane ring;

R_4 together with R_{4a} forms an oxo, or together with R_{5a} and the carbon atoms to which they are attached form an oxetane ring;

R_{4a} is hydroxy or $-OCOR_{30}$;

R_2 is hydroxy, or $-OCOR_{31}$;

R_{2a} is hydrogen;

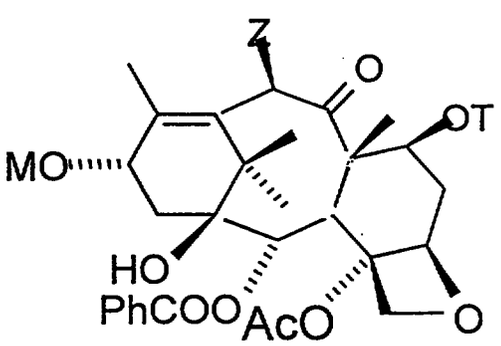
R_1 is hydroxy or protected hydroxy;

R_{28} is hydrogen, acyl, or hydroxy protecting group; and

R_{29}, R_{30} and R_{31} are independently hydrogen, alkyl, alkenyl, alkynyl, monocyclic aryl or monocyclic heteroaryl.

13. A process according to any one of claims 1 to 12, wherein M is tetraalkylammonium.

14. A process according to any one of claims 1 to 13, wherein the alkoxide has the formula



wherein

Z is $-OCOCH_3$ or $-OT_2$,

T_1 is a hydroxy protecting group,

T_2 is a hydroxy protecting group,

Ph is phenyl,

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Ac is acetyl, and

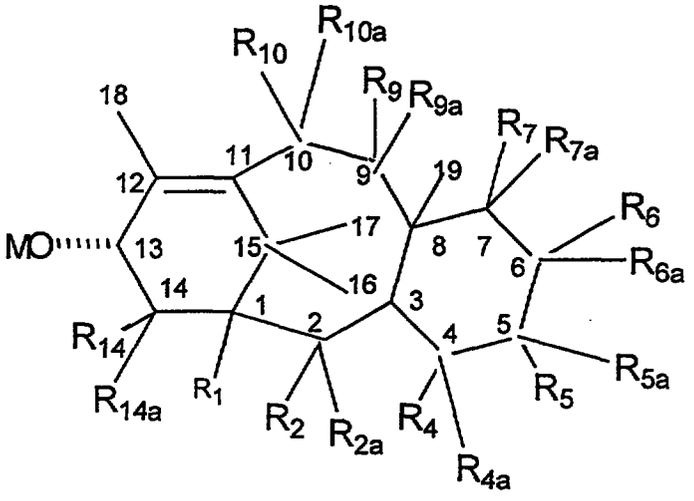
M is an ammonium containing substitutent.

15. A process according to claim 14 wherein X_1 is $-OX_6$, X_2 is hydrogen, X_3 is phenyl, X_4 is hydrogen, X_5 is $-COX_{10}$, X_6 is a hydroxy protecting group, and X_{10} is phenyl.

16. A process according to any one of claims 1 to 13, wherein the alkoxide comprises the tricyclic taxane nucleus.

17. A process according to any one of claims 1 to 13, wherein the alkoxide comprises the tetracyclic taxane nucleus.

18. An alkoxide having the formula:



(3)

wherein

R_1 is hydrogen, hydroxy, protected hydroxy or together

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with R_{14} forms a carbonate;

R_2 is hydrogen, hydroxy, $-OCOR_{31}$, or together with R_{2a} forms an oxo;

R_{2a} is hydrogen or together with R_2 forms an oxo;

R_4 is hydrogen, together with R_{4a} forms an oxo, oxirane or methylene, or together with R_{5a} and the carbon atoms to which they are attached form an oxetane ring;

R_{4a} is hydrogen, alkyl, alkenyl, alkynyl, aryl, heteroaryl, cyano, hydroxy, $-OCOR_{30}$, or together with R_4 forms an oxo, oxirane or methylene;

R_5 is hydrogen or together with R_{5a} forms an oxo,

R_{5a} is hydrogen, hydroxy, protected hydroxy, acyloxy, together with R_5 forms an oxo, or together with R_4 and the carbon atoms to which they are attached form an oxetane ring;

R_6 is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl, hydroxy, protected hydroxy or together with R_{6a} forms an oxo;

R_{6a} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl, hydroxy, protected hydroxy or together with R_6 forms an oxo;

R_7 is hydrogen, halogen, protected hydroxy, $-OR_{28}$, or together with R_{7a} forms an oxo;

R_{7a} is hydrogen or together with R_7 forms an oxo;

R_9 is hydrogen or together with R_{9a} forms an oxo;

R_{9a} is hydrogen, hydroxy, protected hydroxy, acyloxy, or together with R_9 forms an oxo;

R_{10} is hydrogen or together with R_{10a} forms an oxo;

R_{10a} is hydrogen, hydroxy, protected hydroxy, $-OCOR_{29}$ or together with R_{10} forms an oxo;

R_{14} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or

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heteroaryl, hydroxy, protected hydroxy or together with R_1 forms a carbonate

R_{14a} is hydrogen, alkyl, alkenyl, alkynyl, aryl, or heteroaryl;

R_{28} is hydrogen, acyl, hydroxy protecting group or a functional group which increases the solubility of the taxane derivative;

R_{29}, R_{30} and R_{31} are independently hydrogen, alkyl, alkenyl, alkynyl, monocyclic aryl or monocyclic heteroaryl; and

M is an ammonium-containing substituent.

19. An alkoxide according to claim 18, wherein M is tetraalkylammonium.

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