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(54) Title
CYTOTOXIC BICYCLO (7.3.1) TRIDEC-4-ENE-2,6-DIYNE COMPOUNDS AND PROCESS FOR THE PREPARATION THEREOF

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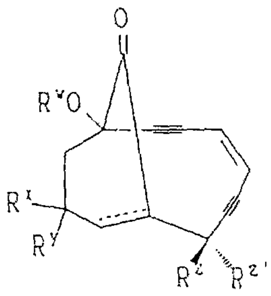
(57) Claim

1. A compound having the formula



VIIa

wherein

---- is a double bond, a single bond, or an epoxy;

one of R^x or R^y is hydrogen and the other is hydrogen or hydroxy;

R^w is hydrogen, $-C(O)R^s$, $-C(O)NR^tR^u$ or $-C(O)OR^v$;

.../2

R^z and $R^{z'}$ are each hydrogen, or one of R^z or $R^{z'}$ is hydrogen, and the other is hydroxy, $-OC(O)R^s$, $-OC(O)NR^tR^u$ or $-OC(O)OR^v$;

R^s is hydrogen, C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl or quinoxalyl;

R^t and R^u are independently hydrogen, C_{1-8}alkyl, amino-substituted C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl, pyridyl or quinoxalyl;

R^v is C_{1-8}alkyl, halo-substituted C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl or C_{7-14}aralkyl;

with the proviso that when R^w, R^x, R^y and $R^{z'}$ are each hydrogen, and $\underline{----}$ is a double bond, R^z is not hydroxy;

or a pharmaceutically acceptable salt thereof.

30. A method for treating malignant tumor sensitive to the compound of claim 1 in an animal which includes administering to said animal an antitumor effective amount of a compound of claim 1.

31. A pharmaceutical composition including a compound of claim 1 and a pharmaceutically acceptable carrier.

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COMPLETE SPECIFICATION
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Class Int. Class

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Name of Applicant:

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Invention Title:

CYTOTOXIC BICYCLO[7.3.1] TRIDEC-4-ENE-2,6-DIYNE COMPOUNDS AND PROCESS FOR THE PREPARATION THEREOF

Our Ref : 306498
POF Code: 129416/1490

The following statement is a full description of this invention, including the best method of performing it known to applicant(s):

CYTOTOXIC BICYCLO[7.3.1]TRIDEC-4-ENE-2,6-DIYNE COMPOUNDS AND PROCESS FOR THE PREPARATION THEREOF

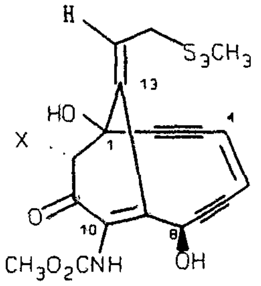
BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to cytotoxic compounds, their use as antitumor agents, a novel process for their preparation, and intermediates produced thereby.

2. Background Art

Esperamicins and calichemicins belong to a class of extremely potent antitumor antibiotics isolated from microbial sources. Structure elucidation studies of the esperamicins and calichemicins were reported in J. Am. Chem. Soc., 1987, 109:3461-3462, and J. Am. Chem. Soc., 1987, 109:3464-3466, respectively. These antibiotics share a common aglycone core which contains a bicyclo[7.3.1]tridecane ring system with an allylic trisulfide side chain.



calichemicin aglycone X = H
esperamicin aglycone X = OH

The proposed mechanism of action of these antibiotics involves, first, a bioreductive activation of the trisulfide to generate a thiol which adds intramolecularly to the α,β-unsaturated enone. The resulting change of hybridization of the bridgehead carbon atom brings the two ends of the diynene portion into closer proximity to coalesce and form a benzene 1,4-diradical which is capable of abstracting a hydrogen atom from the sugar phosphate backbone of DNA to effect single and double stranded breakage.

The unique structure and mechanism of action of these compounds have engendered much interest in the synthesis of the bicyclic diynene core fragment. A number of strategies have been devised to achieve ring closure of a cyclohexyl compound bearing the requisite diynene fragment to form the 10-membered ring.

Kende, et al., (Tet. Lett., 1988, 29:4217-4220) treated 3,3-(1,2-ethylenedioxy)-5-(3-hexene-1,5-diynyl)-1-cyclohexenecarboxaldehyde with lithium bis(trimethylsilyl)amide, followed by removal of the ethylenedioxy ketone protecting group to provide 8-hydroxy-bicyclo[7.3.1]tridec-4,9-diene-2,6-diyn-11-one.

Magnus, et al., (J. Am. Chem. Soc., 1988, 110:1626-1628) reported the preparation of 1-(TBSoxy)-bicyclo[7.3.1]tridec-4-ene-2,6-diyn-10-one, dicobalt hexacarbonyl complex [TBS = t-butyldimethylsilyl] from 1,4-bis(TBSoxy)-4-(7-methoxy-3-heptene-1,5-diynyl)cyclohexene dicobalt hexacarbonyl complex upon treatment with titanium tetrachloride/diazabicyclo[2.2.2]octane (DABCO) at -78°C. Decomplexation of the product, however, caused the molecule to collapse into the corresponding benzenoid compound.

Magnus, et al., (J. Am. Chem. Soc., 1988, 110:6921-6923) and Tomioka, et al., (Tet. Lett., 1989, 30:851-854) reported the preparation of 1-

(TBSoxy)bicyclo[7.3.1]tridec-4-ene-2,6-diyn-13-one (bicyclic ketone) from 1,6-bis-(TBSoxy)-6-(7-methoxy-3-heptene-1,5-diynyl)cyclohexene dicobalt hexacarbonyl complex upon treatment with titanium tetrachloride/DABCO, followed by decomplexation with iodine or trimethylamine oxide. Magnus, et al., further treated the bicyclic ketone product with potassium hexamethyldisilazane (KHMDS) and phenylselenium chloride to form the α-phenylselenide which, upon oxidation with hydrogen peroxide, provided 1-(TBSoxy)-bicyclo[7.3.1]tridec-4,9-diene-2,6-diyn-13-one (bicyclic enone). This latter product was also obtained as a minor product when the TBS enol ether of the bicyclic ketone was oxidized with selenium dioxide (Magnus, et al., Tet. Lett., 1989, 30:3637-3640).

Danishefsky, et al., (J. Am. Chem. Soc., 1988, 110:6890-6891) reported the preparation of 1-(TBSoxy)-8-hydroxy-11-methoxy-bicyclo[7.3.1]tridec-4,9,11-triene-2,6-diyne 13-spiroethylene epoxide from 3-methoxy-5-(TBSoxy)-5-(3-hexene-1,5-diynyl)-1,6-cyclohexadienecarboxaldehyde 6-spiro ethylene epoxide upon treatment with base. The product was further elaborated to provide inter alia 1,8-dihydroxy-bicyclo[7.3.1]tridec-4,9-diene-2,6-diyn-11,13-dione and the corresponding 11-ethylene ketal, and 1,8-dihydroxy-bicyclo[7.3.1]tridec-4-ene-2,6-diyn-11,13-dione. This latter compound was shown to cleave DNA in vitro (J. Org. Chem., 1989, 54:2781-2783 and J. Am. Chem. Soc., 1989, 111:7638-7641).

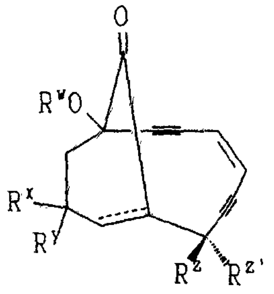
Magnus, et al., (J. Org. Chem., 1990, 55(6):1709-1711) reported the preparation of 8-hydroxy-1-TBSoxy-bicyclo[7.3.1]tridec-4-ene-2,6-diyn-13-one by treating 6-TBSoxy-6-(7-oxo-3-hexene-1,5-diynyl)cyclohexanone dicobalt complex with dibutylboron triflate/DABCO to effect ring closure, followed by N-methyl-morpholine oxide to remove the cobalt carbonyl group.

Danishefsky, et al., (J. Am. Chem. Soc., 1990, 112:3253-3255) reported the total synthesis of dl-calicheamicinone.

The known methods for ring closure either require the use of cumbersome precursors which are difficult to prepare, or they yield bicyclic diynenes lacking certain key functionalities. The process of the present invention circumvents these problems and provides a highly efficient route to bicyclic diynenes with multiple key functionalities. Furthermore, the present process results in the formation of a single pair of diastereomers and allows the introduction of the 8-hydroxy group having the same relative stereochemical configuration as the 8-hydroxy group of the esperamicin aglycone.

SUMMARY OF THE INVENTION

The present invention provides antitumor bicyclo[7.3.1]tridec-4-ene-2,6-diyne-13-one derivatives of formula VIIa.

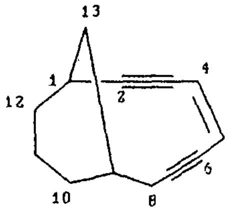


VIIa

wherein ---- is a double bond, single bond, or an epoxy; one of R^x or R^y is hydrogen and the other is hydrogen or hydroxy; or R^x and R^y together is an oxo group; R^w is hydrogen, $-C(O)R^s$, $-C(O)NR^tR^u$ or $-C(O)OR^v$; R^z and $R^{z'}$ are each hydrogen, or one of R^z or $R^{z'}$ is hydrogen, and the other is hydroxy, $-OC(O)R^s$, $-OC(O)NR^tR^u$ or $-OC(O)OR^v$; R^s is hydrogen, C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl, pyridyl or quinoxalyl; R^t and R^u are independently hydrogen, C_{1-8}alkyl, amino-substituted C_{1-8} alkyl, ~~C_{2-8}alkyl~~, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl, pyridyl or quinoxalyl; R^v is C_{1-8}alkyl, halo-substituted C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl or C_{7-14}aralkyl; with the proviso that when R^w, R^x, R^y and $R^{3'}$ are each hydrogen, and ---- is a double bond, R^z is not hydroxy; or a pharmaceutically acceptable salt thereof.

DETAILED DESCRIPTION OF THE INVENTION

The numbering of the bicyclo[7.3.1]tridec-4-ene-2,6-diyne ring system referred to in the specification is as follows:



"10-Membered ring" is the ring defined by carbon atoms 1-9 and 13 of the bicyclo[3.7.1]tridec-4-ene-2,6-diyne ring system.

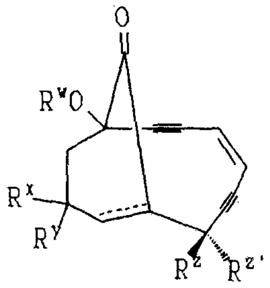
Dicobalt hexacarbonyl complexed carbon-carbon triple bond is represented by

$|||\ Co_2(CO)_6$.

This group is also referred to in the specification as "cobalt carbonyl complex" or "cobalt complex". The dicobalt hexacarbonyl group may be used as carbon-carbon triple bond protecting group. Cobalt complexed acetylene is the subject of the review by Nicholas, K. M., Accounts in Chemical Research, 1987, 20:207-214.

"TBS" is used throughout the specification as an abbreviation for t-butyldimethylsilyl [also referred to as (1,1-dimethylethyl)dimethylsilyl]. "Alkyl" includes straight and branched carbon chains. "Halo" or "halogen" includes fluorine, chlorine, bromine, and iodine. "Pharmaceutically acceptable salt" includes, where the compound contains one or more basic nitrogen atom, acid addition salts formed with inorganic acids such as hydrochloric acid, sulfuric acid, phosphoric acid, nitric acid, and the like, or with organic acids, such as acetic acid, citric acid, fumaric acid, lactic acid, tartaric acid, and the like.

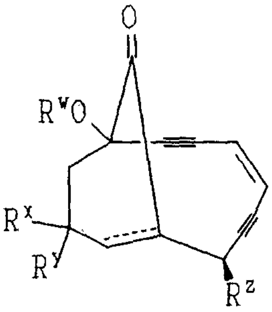
The present invention provides novel compounds having the formula VIIa



VIIa

wherein ---- is a double bond, a single bond, or an epoxy; one of R^x or R^y is hydrogen and the other is hydrogen or hydroxy; or R^x and R^y together is an oxo group; R^w is hydrogen, $-C(O)R^s$, $-C(O)NR^tR^u$ or $-C(O)OR^v$; R^z and $R^{z'}$ are each hydrogen, or one of R^z or $R^{z'}$ is hydrogen, and the other is hydroxy, $-OC(O)R^s$, $-OC(O)NR^tR^u$ or $-OC(O)OR^v$; R^s is hydrogen, C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl, pyridyl or quinoxalyl; R^t and R^u are independently hydrogen, C_{1-8}alkyl, amino-substituted C_{1-8} alkyl ~~C_{2-8}alkyl~~, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl, pyridyl or quinoxalyl; R^v is C_{1-8}alkyl, halo-substituted C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl or C_{7-14}aralkyl; with the proviso that when R^w, R^x, R^y and $R^{3'}$ are each hydrogen, and ---- is a double bond, R^z is not hydroxy; or a pharmaceutically acceptable salt thereof.

One preferred embodiment provides compounds of formula VIIb



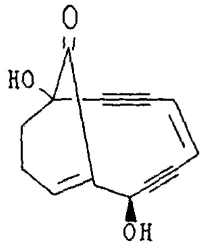
VIIb

wherein ---- is a double bond, a single bond, or an epoxy; one of R^x or R^y is hydrogen and the other is hydrogen or hydroxy; or R^x and R^y together is an oxo group; R^w is hydrogen, $-C(O)R^s$, $-C(O)NR^tR^u$ or $-C(O)OR^v$; R^z is hydrogen, hydroxy, $-OC(O)R^s$, $-OC(O)NR^tR^u$ or $-OC(O)OR^v$; R^s is hydrogen, C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl, pyridyl or quinoxalyl; R^t and R^u are independently hydrogen, C_{1-8}alkyl, amino-substituted C_{2-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl, pyridyl or quinoxalyl; R^v is C_{1-8}alkyl, halo-substituted C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl or C_{7-14}aralkyl; with the proviso that when R^w, R^x, R^y and $R^{3'}$ are each hydrogen, and ---- is a double bond, R^z is not hydroxy; or a pharmaceutically acceptable salt thereof. More preferably, R^w is hydrogen.

Another preferred embodiment provides compounds of formula VIIb wherein ---- is a double bond or an epoxy, R^w, R^x and R^y are each hydrogen; R^z is $-OC(O)R^s$, $-OC(O)NR^tR^u$ or $-OC(O)OR^v$; or R^z is hydroxy when ---- is an epoxy; R^s is hydrogen, C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl, pyridyl or quinoxalyl; R^t and R^u are independently hydrogen, C_{1-8}alkyl, amino-substituted C_{1-8} alkyl, ~~C_{2-8}alkyl,~~ C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl, pyridyl or quinoxalyl; R^v is C_{1-8}alkyl, halo-substituted C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl or C_{7-14}aralkyl. More preferably, R^s is C_{1-8}alkyl or quinoxalyl; R^t is hydrogen and R^u is C_{1-8}alkyl, amino-substituted C_{1-8}alkyl, pyridyl or quinoxalyl; or R^t and R^u are each C_{1-8}alkyl; R^v is C_{1-8}alkyl or halo-substituted C_{1-8}alkyl.

Another preferred embodiment provides compounds of formula VIIb wherein R^w and R^z are each hydrogen, ---- is a single bond or a double bond, one of R^x or R^y is hydrogen and the other is hydrogen or hydroxy, or R^x and R^y together is an oxo group. In a more preferred embodiment, R^w, R^x, R^y and R^z are each hydrogen, ---- is a single bond. In another preferred embodiment, R^w and R^z are each hydrogen, ---- is a double bond, one of R^x or R^y is hydrogen and the other is hydrogen or hydroxy, or R^x and R^y together is an oxo group.

Compounds of formula VIIb wherein R^w is hydrogen; R^2 is hydroxy; one of R^x or R^y is hydrogen and the other is hydrogen or hydroxy; or R^x and R^y together is an oxo group; and <u>----</u> is a double bond may be obtained from the compound of formula VIIc using conventional allylic oxidation reagent such as selenium dioxide.

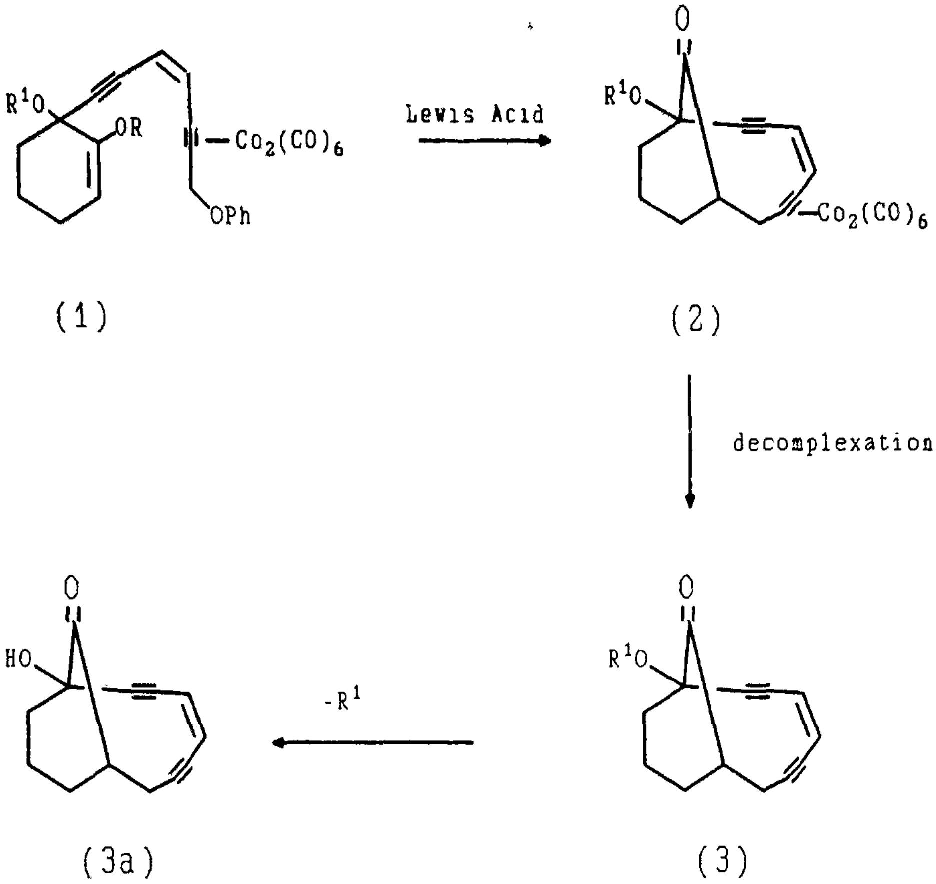


VIIc

In this process the hydroxy groups may be protected with a suitable blocking group such as t-butyldimethylsilyl, prior to oxidation. The oxidation typically yields a mixture of the allylic alcohol and the corresponding oxo products; this mixture may be separated by conventional chromatography techniques. The hydroxy protecting groups, if present, are removed after the oxidation and separation to provide the desired compounds. The deprotection method used depends on the nature of the protecting group and may be, for example, hydrolysis under acidic or basic conditions, alcoholysis. When R^1 is t-butyldimethylsilyl, this group may be removed with, for example, trifluoromethanesulfonic acid tetrabutylammonium fluoride, or aqueous hydrofluoric acid in acetonitrile. The compound of formula VIIc may be prepared by the methods described in Example 4, <u>infra</u>.

The compound of formula VIIb wherein R^w, R^x, R^y and R^z are each hydrogen and $\underline{----}$ is a single bond may be prepared by the procedure depicted in Scheme I.

Scheme I

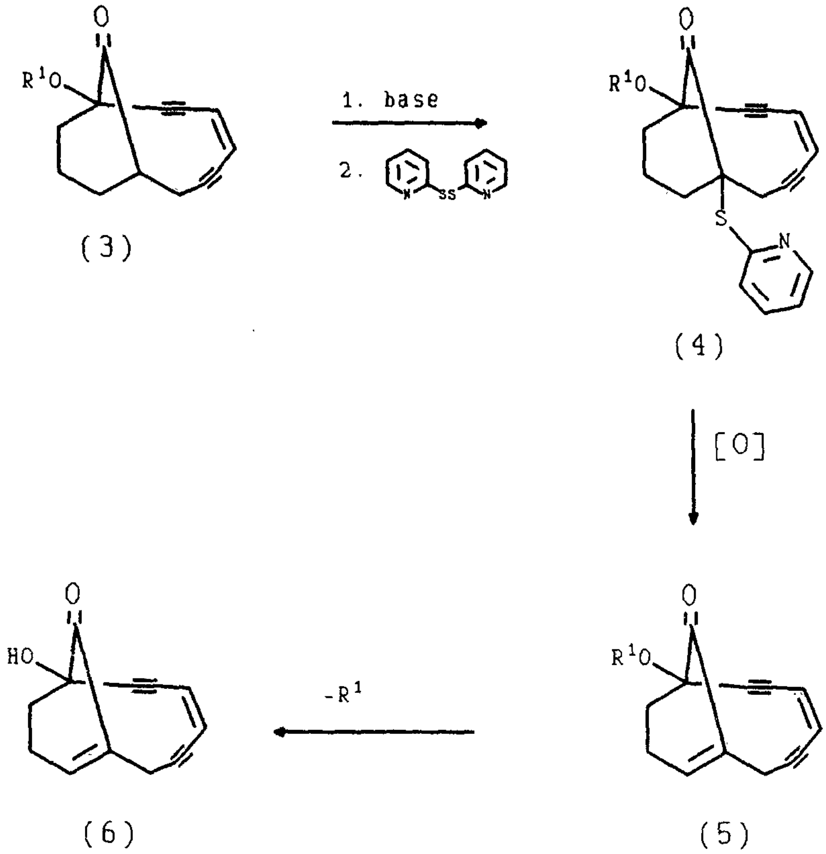


In Scheme I, R^1 and R are independently a hydroxy protecting group; R^1 is preferably t-butyldimethylsilyl, R is preferably trimethylsilyl. Compound (1) is depicted with the preferred leaving group, phenoxy; however, other leaving groups, for example, trifluoromethanesulfonyloxy, methoxy or acetoxy, may also be used. Cyclization of compound (1) to compound (2) is effected by treating compound (1) with a Lewis acid; suitable Lewis acids are for example titanium (IV) chloride, boron triflouride etherate, ethyl aluminum dichloride, titanium (IV) isopropoxide, and the like, or a mixture thereof; preferred Lewis acid include ethyl aluminum dichloride, and a mixture of titanium (IV) chloride and titanium (IV) isopropoxide. The Lewis acid is used in at least equimolar amount relative to compound (1). The reaction is carried out in a suitable inert organic solvent such as a chlorinated hydrocarbon, e.g. methylene chloride, and typically at reduced temperature, for example, between -78°C and 0°C, for a period of time sufficient to effect cyclization of the starting material, generally the reaction is complete in one hour or less.

The dicobalt hexacarbonyl group of compound (2) may be removed using a decomplexation reagent such as iodine, iron (III) nitrate (ferric nitrate), a tertiary amine N-oxide, e.g., N-methylmorpholine-N-oxide or trimethylamine-N-oxide, meta-chloroperbenzoic acid (mCPBA), or cerium ammonium nitrate (CAN). Preferably, the decomplexation agent is ferric nitrate, and the reaction is carried out in an alcohol solvent such as methanol or ethanol at room temperature to provide compound (3). The hydroxy protecting group of compound (3) is then removed using a conventional deprotecting method as previously discussed to provide compound (3a).

Compound (3) can be converted to a compound of formula VIIb wherein R^w, R^x, R^y and R^z are each hydrogen and $\underline{---}$ is a double bond by the following procedure depicted in Scheme II.

Scheme II

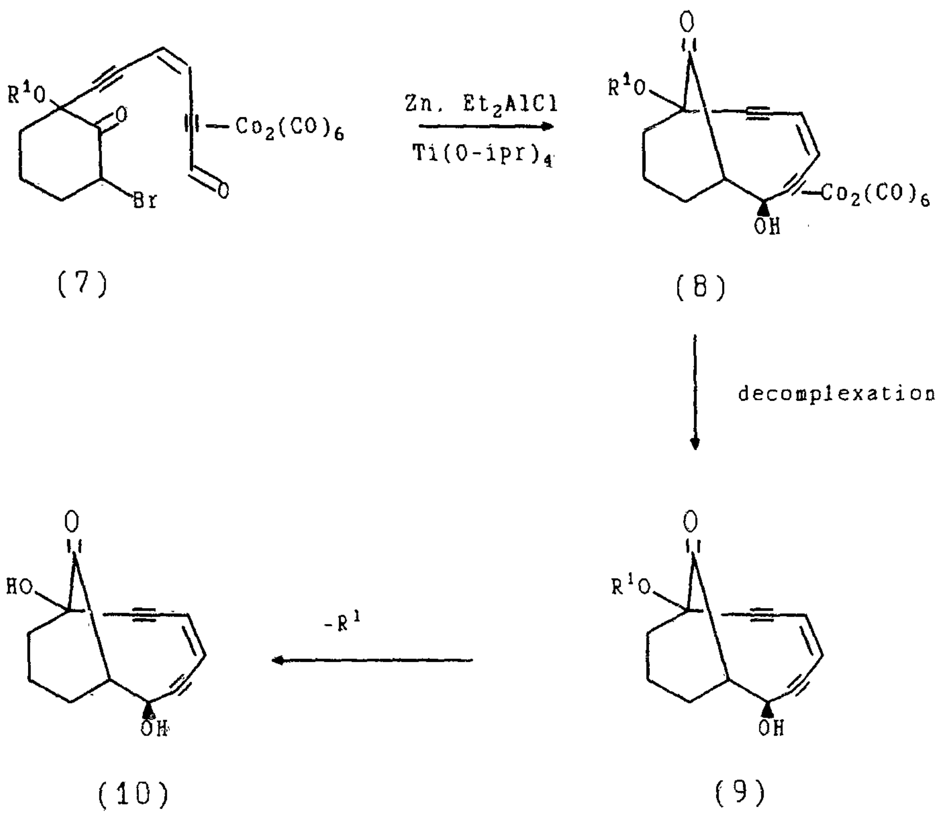


In Scheme II, R^1 is a hydroxy protecting group, preferably t-butyldimethylsilyl. Compound (3) is treated with a base to generate the enolate, which is reacted with 2,2'-dipyridyl disulfide to give the 9-pyridylthio-substituted intermediate, compound (4). In this step the base may be any capable of deprotonation, examples of which include potassium or lithium bis(trimethylsilyl)amide, lithium diisopropylamide, and the like; the preferred base is potassium bis(trimethylsilyl)amide. The reaction is carried out in an inert solvent such as tetrahydrofuran and at temperature below 0°C, e.g. at about -78°C. Compound (4) is oxidized to the corresponding sulfoxide using an oxidant such as mCPBA. The reaction is carried out in an inert organic solvent such as methylene chloride at a temperature, and for a period of sufficient time to cause the elimination of the sulfoxide to form compound (5); typically, at ambient temperature the elimination is substantially complete in about half an hour. Removal of the hydroxy protecting group on compound (5) provides compound (6). Although 2,2'-dipyridyl disulfide is illustrated as the preferred reagent, other substrates may be used to introduce a group functionally equivalent to the phenylthio group; such other suitable substrates are for example phenylselenyl chloride, aryldisulfides, and alkyl- or arysulfinyl chlorides.

Compound (5) may be converted to a compound of formula VIIb wherein R^w and R^z are each hydrogen, one of R^x or R^y is hydroxy, or R^x and R^y together is an oxo group. Thus, compound (5) is treated with selenium dioxide or another agent suitable for allylic oxidation in a suitable inert organic solvent such as dioxane and at elevated temperature in the range of about 50 to 110°C. The product obtained typically containing a mixture of the starting material, the desired allylic alcohol as the major product (where R^x or R^y is hydroxy), and the desired dione (where R^x and R^y together form an oxo group); the desired components are separated by conventional chromatographic technique. The dione may also be prepared from the allylic alcohol using an ordinary oxidant such as manganese dioxide. The R^1 hydroxy protecting group is then removed to give the desired compounds.

The compound of formula VIIb wherein R^w, R^x and R^y are each hydrogen, R^z is hydroxy, and $\underline{----}$ is a single bond may be prepared by the procedure shown in Scheme IV.

Scheme IV



In Scheme IV, R^1 is a hydroxy protecting group, preferably t-butyldimethylsilyl. Compound (7) is treated with zinc, diethylaluminum chloride and titanium (IV) isopropoxide in tetrahydrofuran to effect ring closure to give compound (8). The cobalt carbonyl is removed using a decomplexation reagent as previously described, preferably the decomplexation agent is ferric nitrate, to give compound (9).

Removal of the hydroxy protecting group yields the desired compound (10).

A compound of formula VIIa in which R^z is hydrogen and $R^{z'}$ is hydroxy may be converted from its 8-epimer through the use of either of two common epimerization strategies known by practicing organic chemists. The preferred method, commonly known as the Mitsunobu inversion (reviewed in O. Mitsunobu, Synthesis, 1981, p. 1), entails reacting the hydroxy group with an aryl carboxylic acid such as benzoic acid or a substituted benzoic acid, e.g. p-nitrobenzoic acid, in the presence of triphenyl phosphine and a dialkylazodicarboxylate, e.g. diethyl or diisopropyl azodicarboxylate. The resulting aryl ester is subjected to ester hydrolysis or alcoholysis under acidic or mild basic condition to produce the desired epimerized alcohol.

In an alternate procedure, the hydroxy group is oxidized to a ketone using a reagent known to be useful in such transformations; for example, reagents based on activated DMSO (reviewed in Swern and Omura, Tetrahedron, 1978, 34:1651), the periodinanone reported in Dess and Martin, J. Org. Chem., 1983, 48:4155, other common oxidants such as barium manganate, pyridinium chlorochromate, pyridinium dichromate, manganese dioxide, or tetra-n-propyl ammonium perruthenate. The ketone thus formed may be selectively reduced with common reducing agents such as diisobutylaluminum hydride, sodium borohydride, other aluminum hydrides, or substituted borane reagents to provide the desired epimerized alchol. In this procedure, other functional groups that may also be oxidized or reduced by the reagents used are preferably first protected.

Compounds of formula VIIa wherein R^w is an acyl group, or R^z is an acyloxy group, or R^w is acyl and R^z is acyloxy, are prepared from the corresponding hydroxy compound by known acylation processes. The term or prefix "acyl" as used herein means generically or individually the groups $-C(O)R^s$, $-C(O)NR^tR^u$, and $-C(O)OR^v$. In general, where both $-OR^w$ and R^z are hydroxy, the secondary hydroxy group, i.e. R^z, is preferably acylated over the tertiary hydroxy group, i.e. $-OR^w$. Thus, where acylation of only the tertiary hydroxy is desired, the secondary hydroxy is first protected with a conventional hydroxy protecting group, preferably, an organic silyl group such as the t-butyldimethylsilyl group which can be removed with e.g. aqueous hydrofluoric acid after the acylation of the tertiary hydroxy group. Where bisacylated products are desired, at least two equivalents of the the acylating agent is used relative to the bicyclic diynene.

A $R^sC(O)-$ group may be introduced by employing the carboxylic acid R^sCO_2H or an acylating equivalent derived therefrom, examples of which include symmetrical or mixed acid anhydride, active esters, active amide, and acid halide. When the carboxylic acid is used, the reaction is preferably conducted in the presence of a condensing agent such as dicyclohexylcarbodiimide. Acid halide, for example acid chloride, is the preferred acylating agent and the acylation reaction is carried out generally at room temperature in an organic solvent, e.g. pyridine, methylene chloride, tetrahydrofuran, etc., and in the presence of an acid scavenger, e.g. a tertiary amine such as triethylamine, dimethylaminopyridine, etc.

A $R^tR^uNC(O)$- group may be introduced by converting the hydroxy group into a chloroformate using phosgene or trichloromethyl chloroformate; this intermediate is then reacted with an appropriate amine HNR^tR^u either in the presence of a base, or an excess of the amine component may be used to neutralized the acid generated by the condensation. Where R^t is hydrogen, the hydroxy group may be condensed with an isocyanate R^uN-C=O to give the carbamate. The reaction is carried out generally at a temperature of about 20 to about 100°C in an organic solvent, e.g. pyridine, methylene chloride, tetrahydrofuran, benzene, toluene, etc, and optionally in the presence of a catalytic amount of dimethylaminopyridine.

A $R^vOC(O)$- group may be introduced by reacting the hydroxy group with a chloroformate $R^vOC(O)Cl$ in an organic solvent, e.g. pyridine, methylene chloride, tetrahydrofuran, etc., at ambient temperature and in the presence of an acid scanvenger such as a tertiary amine base, e.g. pyridine, triethylamine, dimethylaminopyridine, and the like.

Compound of VIIa wherein ---- is an epoxy may be prepared from the corresponding compound wherein ---- is a double bond by oxidation with hydrogen peroxide or a peracid. Prior to oxidation, it is desirable to protect any free hydroxy groups. The oxidation is preferably effected with hydrogen peroxide in the presence of sodium hydroxide. The reaction is carried out in an alcohol solvent such as methanol at ambient temperature. Any hydroxy protecting groups are then removed to give the desired epoxy product.

It will be appreciated that the various compounds produced by the novel process of the present invention can exist as optical isomers; the individual isomers, as well as racemic mixtures and diastereomeric mixtures, are all contemplated as being within the scope of the invention. Similarly, the novel process of the invention is applicable to the individual stereoisomers, as well as racemic and diastereomeric mixtures thereof. The stereochemical notations used in the structural formulas depicted in the specification and claims are meant to represent the relative orientations of the various substituents on the bicyclo[7.3.1]tridec-4-ene-2,6-diyne ring system and are not meant to restrict the compounds represented by these formulas to specific absolute configurations.

Compounds of formula VIIa are cytotoxic compounds and are, therefore, useful in inhibiting unwanted rapid proliferation of cells, such as that in the neoplastic process. As therapeutic agents for treating mammalian tumors sensitive to a compound of formula VIIa, these compounds may be administered in the same manners as those suitable for esperamicin and calichemicin. Thus, they may be administered by systemic or topical routes; parenteral administration is the preferred route. The dosage may be similar to that used for esperamicin; but in general, because compounds of the present invention are less cytotoxic than esperamicin, dosage ten to one thousand times that for esperamicin may be tolerated and may be more suitable. The route of administration and the optimal dosage may be readily ascertained by those skilled in the art and will, of course, vary depending on factors such as the type and site of tumor to be treated, and individual patient charateristics, such as extent of the disease, age, weight, and the like.

The invention includes within its scope pharmaceutical compositions containing an effective tumor-inhibiting amount of a compound of formula VIIa in combination with an inert pharmaceutically acceptable carrier of diluent. Such compositions may be made up in any pharmaceutical form appropriate for the desired route of administration. Examples of such compositions include solid compositions for oral administration such as tablets, capsules, pills, powders and granules; liquid compositions for oral administration such as solutions, suspensions, syrups or elixirs; and preparations for parenteral administration such as sterile solutions, suspensions or emulsions. The pharmaceutical compositions may also be manufactured in the form of sterile solid compositions which can be dissolved in sterile water, physiological saline or some other sterile injectable medium immediately before use.

Furthermore, compounds of formula VIIa are effective in causing damages to DNA and in double stranded DNA cleavage. They are, therefore, valuable as laboratory reagents for such purposes.

Biological Activity

Compound of Example 4 was evaluated *in vitro* against three human colon tumor cell lines: HCT-116, HCT/VM46, and HCT/VP35; the latter two are resistant to teniposide and etoposide, respectively. The *in* vitro cytotoxicity assay involved growing tumor cells on microtitre plates employing established tissue culture methods. The concentration of the test compound required to inhibit cell growth by 50% (IC_{50}) was then determined by four-fold serial dilution technique. In the experiment, etoposide and teniposide were included as positive controls. The results obtained are shown in Table I:

Table I. Results of In Vitro Cytotoxicity Assay

Compound	IC_{50} (μg/ml) HCT-116	HCT/VM46	HCT/VP35
Example 4	0.037	<0.031	0.042
	0.043	<0.031	0.046
	<0.031	0.047	0.072
Etoposide	0.101	4.24	5.14
	0.128	3.57	6.29
	0.140	2.08	6.75
Teniposide	0.077	0.313	0.084
	0.088	0.237	0.091
	0.083	0.236	0.111

The compound of Example 4 was also evaluated against transplantable murine P388 leukemia. CDF_1 mice were implanted intraperitoneally with a tumor inoculum of 10^6 cells of P388 leukemia and treated with various doses of the test compound. Six mice were used for each dose level and 10 mice were treated with saline to serve as control. The test compound was administered intraperitoneally on 5 consecutive days starting on day 1 after tumor implantation. Antitumor activity is expressed as % T/C which is the ratio of mean survival time (MST) for the drug-treated group to the MST of saline-treated control group.

A compound showing a % T/C of 125 or greater is considered to have significant antitumor activity. The results of P388 test on day 39 of the experiment for compound of Example 4 are provided in Table II. The data indicates this compound as having high activity against P388 leukemia.

Table II. In Vivo Activity Against P388 Leukemia

Dose (mg/kg/dose)	Med. Survival Time (d)	% T/C	Survival d.5 (39)*
32	7	64	6/6
16	9.5	86	6/6
8	>39	>355	6/6 (4)
4	20.0	182	6/6
2	16.5	150	6/6
1	13	118	6/6
Control	11	100	10/10

* The number in parenthesis represents the number of surviving mice on day 39.

Compounds of Examples 6, 8, 15, 19 and 20 were evaluated against P388 leukemia using the same protocol given above, with the exception that compounds of Examples 19 and 20 were administered intraperitoneally only on day 1 after tumor transplantation. Compound of Example 6 showed a maximum %T/C of 235 at a dose of 20 mg/kg/dose (with one mouse surviving on day 31); compound of Example 8 showed a max. %T/C of 145 at a dose of 15 mg/kg/dose; compound of Example 15 showed a max. %T/C of 230 at a dose of 40 mg/kg/dose; compound of Example 19 showed a max. %T/C of 180 at a dose of 32 mg/kg/dose (with one mouse surviving on day 20); and compound of

Example 20 showed a max. %T/C of 160 at a dose of 16 mg/kg/dose (with two mice surviving on day 20).

SPECIFIC EMBODIMENTS

Preparation of Starting Materials

The structures of the compounds described in this section are provided on separate pages following the Examples section.

Preparation I. (Z)-7,7-diethoxy-1-trimethylsilyl-3-hepten-1,5-diyne [compound A]

(a) (Z)-5-chloro-1,1-diethoxy-4-pentene-2-yne [compound B]

Neat cis-1,2-dichloroethylene (4.5 ml, 60 mmol) followed by butylamine (8.0 ml, 81 mmol) was added to a solution of copper iodide (0.90 g, 4.73 mmol) and palladium tetrakis(triphenylphosphine) (1 g, 0.86 mmol) in 40 mL of dry benzene stirring at 25°C under argon. Immediately thereafter, a solution of 3,3-diethoxypropyne (5 g, 39 mmol) in 10 mL of benzene was added via cannula. The reaction vessel was wrapped in foil to shield it from light, and the reaction mixture was stirred for 4.2 h at 25°C. The dark brown reaction mixture was filtered by suction through a coarse frit and diluted to approximately 180 ml with diethylether. The solution was washed with 75 mL of water and 120 mL saturated brine, and the organic layer was dried over anhydrous Na_2SO_4 and then concentrated in vacuo. The residue was flash chromatographed on SiO_2 using 5%, then 10%, and then 15% diethylether/pentane as eluent to provide the desired product as a clear liquid (3.9 g, 55%).

^{1}H NMR ($CDCl_3$) δ: 6.46 (d, J = 7.5 Hz, 1H), 5.92 (dd, J = 1.5, 7.6 Hz, 1H), 5.45 (d, J = 1.4 Hz, 1H), 3.80 (m, 2H), 3.64 (m, 2H), 1.26 (t, J = 7.0 Hz, 3H).

(b) (Z)-7,7-diethoxy-1-trimethylsilyl-3-heptene-1,5-diyne

A solution of 5-chloro-1,1-diethoxy-4-pentene-2-yne (compound B, 3.8 g, 20 mmol) in 10 mL of benzene was added via cannula to a solution of palladium tetrakis(triphenyl-phosphine) (1.1 g, 0.95 mmol) and copper iodide (0.47 g, 2.46 mmol) in 20 mL benzene stirring at 25°C under argon. Immediately thereafter, butylamine (4 mL, 40 mmol), followed by trimethylsilylacetylene (5 mL, 40 mmol) was added via syringe. The reaction vessel was wrapped in foil, and the reaction mixture was stirred at 25°C for 4.25 h. The reaction mixture was poured into 100 mL water and 100 mL diethyl ether and extracted. The aqueous layer was reextracted with 2 x 40 mL of diethyl ether. The combined organic extracts were washed with 50 mL saturated aqueous NaCl, dried over Na_2SO_4, and concentrated in vacuo. Flash chromatography over SiO_2 using 2%, then 4%, and then 5% diethylether/pentane as eluent provided the title compound (2.7 g, 54%) as a light brown oil.

^{1}H NMR ($CDCl_3$) δ: 5.89 (s, 2H), 5.46 (s, 1H), 3.83-3.75 (m, 2H), 3.69-3.61 (m, 2H), 1.25 (t, J = 7.1 Hz, 6H), 1.40E-4 (s, 9H).

^{13}C NMR ($CDCl_3$) δ: 130.6, 111.6, 92.8, 92.0, 79.4, 61.3, 15.2.

Preparation II. (Z)-6-[[(1,1-dimethylethyl)dimethylsilyl]oxy]-6-(7,7-diethoxy-3-heptene-1,5-diynyl)-2-cyclohexenone [compound C]

(a) (Z)-6-[[(1,1-dimethylethyl)dimethylsilyl]oxy]-6-(7,7-diethoxy-3-heptene-1,5-diynyl)cyclohexanone [compound D]

Solid lithium hydroxide monohydrate (3 g, 71.5 mmol) was added to a solution of (Z)-7,7-diethoxy-1-trimethylsilyl-3-heptene-1,5-diyne (compound A, 3.20 g, 12.6 mmol) in 30 mL of tetrahydrofuran and 5 mL water. The reaction mixture was stirred for 4 h and poured into 100 mL of pentane and 50 mL of H_2O. The organic layer was washed with 50 mL saturated aqueous NaCl, dried over Na_2SO_4, and then concentrated in vacuo by rotary evaporation. Methylene chloride (50 mL) was added, and the solution was again concentrated by rotary evaporation and then placed under high vaccuum for 25 min to provide approximately 3.3 g of a light brown oil which was immediately dissolved in 160 mL of dry tetrahydrofuran. The solution was cooled to -78°C, and then lithium hexamethyl-disilazane (1.0 M, in tetrahydrofuran, 15.5 mL, 15.5 mmol) was added via syringe in one portion. The reaction mixture was stirred for 20 min, and then a solution of 2-tertbutyldimethylsilyloxy-2-cyclohexenone (3.65 g, 6.12 mmol) in 10 mL of dry tetrahydrofuran, which had been precooled to approximately -50°C, was added in one portion via syringe. The reaction mixture was stirred for 1 min, and then all of the cooling baths were removed. The reaction mixture was allowed to stir for 2.5 h and attain ambient temperature (25°C) to generate in situ the lithium enolate. The enolate was quenched with water to provide the corresponding ketone as follows. The reaction mixture was poured into 400 mL of 9:1 ethyl acetate/diethyl-ether and 100 mL of water. The mixture was extracted, and then the aqueous layer was reextracted with 100 ml of 1:1 ethyl acetate/diethyl ether. The combined organic extracts were washed with 50 mL saturated aqueous NaCl, dried over anhydrous Na_2SO_4, and concentrated in vacuo. Flash chromatography using 3%, then 4%, and then 5% ethyl acetate/hexane provided 3.50g (72%) of the desired title cyclohexanone as a very faint green oil.

^{1}H NMR ($CDCl_3$) δ: 5.92 (s, 2H), 5.41 (s, 1H), 3.80-3.70 (m, 2H), 3.65-3.55 (m, 2H), 2.88 (dt, J = 13.3, 5.7 Hz, 1H), 2.46 (td, J = 7.7, 12.2 Hz, 1H), 2.27-2.23 (m, 1H), 2.00-1.58 (m, 5H), 1.24 (t, J = 7.08 Hz, 6H), 0.91 (s, 9H), 0.046 (s, 3H), 0.018 (s, 3H).

(b) (Z)-1,6-bis[[[(1,1-dimethylethyl)dimethyl]-silyl]oxy]-6-(7,7-diethoxy-3-heptene-1,5-diynyl]cyclohexene [compound E]

Neat tert-butyldimethylysilyl trifluoromethanesulfonate (0.62 mL) was added via syringe to a solution of triethyl-amine (0.69 mL, 2.72 mmol) and compound D prepared above (0.54 g, 1.33 mmol) in 20 ml of methylene chloride stirring at 25°C under a nitrogen atmosphere. The reaction mixture was stirred for 22.5 h and then poured into 100 mL of methylene chloride and 50 mL of water. The organic layer was dried over anhydrous Na_2SO_4 and concentrated in vacuo, and the residue was flash chromatographed on SiO_2 using 3% ethyl acetate/hexane to provide the title bis-silyloxy cyclohexene (683 mg, 98%) as a clear liquid.

IR (NaCl, Film): 3046, 2954, 2932, 2890, 2858, 2212, 1660, 1468, 1252 cm^{-1}.

^{1}H NMR ($CDCl_3$) δ: 5.88 (d, J = 11.0 Hz, 1H), 5.81 (dd, J = 11.0, 1.3 Hz, 1H), 4.82 (t, J = 3.9 Hz, 1H), 3.79-3.74 (m, 2H), 3.64-3.58 (m, 2H), 2.05-1.99 (m, 4H), 1.81-1.56 (m, 2H), 1.24 (t, J = 7.1 Hz, 6H), 0.94 (s, 9H), 0.87 (s, 9H), 0.21 (s, 3H), 0.18 (s, 3H), 0.17 (s, 3H), 0.16 (s, 3H).

^{13}C NMR ($CDCl_3$) δ: 151.1, 121.4, 118.1, 105.0, 102.1, 92.2, 91.5, 82.9, 81.5, 70.2, 61.2, 41.1, 26.1, 24.4, 18.8, 18.5, 18.4, 15.3, -2.8, -3.0, -4.3, -4.4.

(c) (Z)-6-[[(1,1-dimethylethyl)dimethylsilyl]oxy]-6-(7,7-diethoxy-3-heptene-1,5-diynyl]-2-cyclohexenone [compound C]

Selenium dioxide (600 mg, 5.41 mmol) was added to a solution of compound E (1.0 g, 1.98 mmol) in 60 mL of dioxane. The reaction mixture was refluxed for 1.5 h, an additional 300 mg (2.71 mmol) of selenium dioxide was added, and reflux continued for an additional 3 h. The reaction mixture was then poured into 150 mL of ethyl acetate and 100 mL of saturated aqueous $NaHCO_3$. The aqueous layer was reextracted with 50 mL of ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4, concen-trated in vacuo, and purified by flash chromatography on SiO_2 using 3% and then 5% ethyl acetate/hexane to provide the title cyclohexenone (620 mg, 77%) as a clear oil.

Anal. calcd. for $C_{23}H_{34}O_4Si$: C, 68.62; H, 8.51.
Found: C, 68.26; H, 8.42.

^1H NMR ($CDCl_3$) δ: 6.93-6.88 (m, 1H), 5.98 (doublet of multiplets, J = 9.49 Hz, 1H), 5.89 (s, 2H), 5.41 (s, 1H), 3.80-3.70 (m, 2H), 3.66-3.55 (m, 2H), 2.82-2.66 (m, 1H), 2.53-2.40 (m, 1H), 2.35-2.16 (m, 2H), 1.24 (t, J = 7.04 Hz, 6H), 0.89 (s, 9H), 0.22 (s, 3H), 0.20 (s, 3H).

^{13}C NMR ($CDCl_3$) δ: 194.4, 150.7, 127.4, 120.5, 120.0, 95.4, 92.4, 92.2, 84.6, 82.5, 73.6, 61.3, 39.0, 26.0, 25.4, 18.5, 15.3, -3.0, -3.1.

Preparation III. Cobalt, hexacarbonyl [μ-[6-[(5,6-η:5,6-η)-7,7-diethoxy-3-heptene-1,5-diynyl]-6-[[(1,1-dimethylethyl)-dimethylsilyl]oxy]-2-cyclohexenone]], di(Co-Co), (Z) [compound F]

Solid dicobalt octacarbonyl (0.542 g, 1.58 mmol) was added to a solution of compound C (0.64 g, 1.584 mmol) stirring at 25°C under a nitrogen atmosphere in 28 mL of anhydrous heptane. The reaction mixture was stirred for 2 h and concentrated in vacuo. Flash chromatography using 2%, then 3%, and then 5% ethyl acetate/hexane on SiO_2 provided 728 mg (66%) of the desired title cobalt complex as a dark purple oil.

Anal. calcd. for $C_{29}H_{34}O_{10}SiCo_2$: C, 50.59; H, 4.98; N, 0.0.
Found: C, 50.56; H, 4.99; N, 0.0.

IR (NaCl, Film): 2978, 2956, 2932, 2896, 2858, 2094, 2056, 2028, 1700, 1624, 840 cm^{-1}.

^{1}H NMR (CDC13) δ: 6.89 and 6.86 (t, 3.91 Hz, 0.5H), 6.78 (d, J = 11.1 Hz, 1H), 5.99 and 5.96 (t, J = 2.0 Hz, 0.5H), 5.87 (d, J = 11.1 Hz, 1H), 5.58 (s, 1H), 3.83-3.75 (m, 2H), 3.68-3.59 (m, 2H), 2.50-2.43 (m, 2H), 2.26 (t, 5.6 Hz, 2H), 1.21 (t, J = 6.9 Hz, 6H), 0.84 (s, 9H), 0.17 (s, 3H), 0.07 (s, 3H).

^{13}C NMR (CDCl$_3$) δ: 199.1 (b), 192.6, 149.9, 137.1, 126.9, 110.5, 101.6, 98.9, 96.0, 85.3, 82.0, 73.6, 63.2, 38.2, 25.7, 24.2, 18.3, 15.0, -3.3, -3.5.

Preparation IV. Cobalt, hexacarbonyl [μ-[6-[(5,6-η:5,6-η)-7-oxo-3-heptene-1,5-diynyl]-6-[[1,1-dimethylethyl)dimethylsiyl]oxy]-2-cyclohexenone]] di-(Co-Co), (Z) [compound G]

Titanium tetrachloride (0.195 mL, 1.79 mmol) was added via syringe to a solution of the cobalt complexed cyclohexenone compound F (0.41 g, 0.60 mmol) and 1,4-diazabicyclo[2.2.2]octane (67 mg, 0.60 mmol) in 40 mL of methylene chloride stirring at -65°C under a nitrogen atmosphere. The reaction mixture was stirred for 5 min and then poured into 60 mL of methylene chloride and 25 mL of water. The mixture was extracted, and then the aqueous layer was reextracted with 10 mL methylene chloride. The combined organic layers were dried over Na$_2$SO$_4$, filtered, concentrated by rotary evaporation, and chromatographed to provide the title cobalt complexed aldehyde (301 mg, 82%) as a thick viscous reddish purple semi solid.

Anal. calcd. for C$_{25}$H$_{24}$O$_9$SiCo$_2$: C, 48.87; H, 3.94; N, 0.00. Found: C, 48.42; H, 3.82; N, 0.04.

^1H NMR ($CDCl_3$) δ: 10.39 (s, 1H), 6.93 (dt, J = 10.1, 4.0 Hz, 1H), 6.82 (d, J = 10.6 Hz, 1H), 6.03 (dt, 10.1, 1.9 Hz, 1H), 5.93 (d, J = 10.8 Hz, 1H), 2.56-2.18 (m, 4H), 0.87 (s, 9H), 0.19 (s, 3H), 0.11 (s, 3H).

^{13}C NMR ($CDCl_3$) δ: 198.5-198.1 (b, -CO's), 193.3, 190.8, 150.9, 136.6, 127.4, 111.5, 100.4, 85.2, 73.9, 38.1, 25.9, 24.4, 18.5, -3.15, -3.35.

Preparation V. Alternative method for the preparation of compound E

Following the procedure described in Preparation II (a), a solution of the lithium enolate was prepared from 5 mmol of 7,7-diethoxy-1-trimethylsilyl-3-heptene-1,5-diyne. To this solution stirring at -78°C in 85 mL of solvent was added 1.15 mL (5.0 mmol) of tertbutyldimethyl silyl trifluoromethanesulfonate. The reaction mixture was stirred for 15 min at -78°C and then removed from the cooling bath and allowed to stir for an additional 25 min before being poured into a mixture of 100 mL water, 70 mL ethyl acetate, 25 mL diethyl ether, and 25 mL pentane. The mixture was extracted, and the aqueous layer was reextracted with 100 mL of 50:50 pentane/ethyl acetate. The combined organic extracts were washed with 75 mL saturated aqueous NaCl, dried over Na_2SO_4, concentrated in vacuo, and purified by flash chromatography on SiO_2 using 2% and then 3% ethyl acetate/hexane as eluent to provide 1.47 g (51%) of the desired silylenol ether identical with material prepared in Preparation II (b).

Preparation VI. Alternative methods for the preparation of compound C

(a) Alternative method A

Following the procedure of Preparation II (a), a solution of the lithium enolate in 85 mL of solvent was prepared from 5 mmol of 7,7-diethoxy-1-trimethylsilyl-3-heptene-1,5-diyne. To this solution at -78°C was added via syringe over a 2 min period a solution of phenylselenium chloride (0.99 g, 5 mmol) in 6 mL of dry tetrahydrofuran which had been precooled to -78°C. The reaction mixture was stirred for 20 min at -78°C, then the cooling bath was removed, and stirring continued for an additional 20 min. The reaction mixture was poured into 100 mL diethylether/100 mL ethyl acetate/100 mL water and extracted. The aqueous layer was reextracted with 50 mL 1:1 ethylether/ethyl acetate, and the combined organic extracts were washed with 75 mL saturated aqueous NaCl, dried over Na_2SO_4, and concentrated in vacuo. Flash chromatography on SiO_2 using 4% and then 5% ethyl acetate/hexane provided 1.68 g (57%) of a light brown liquid which was a mixture of phenyselenide, 2-[[(1,1-dimethylethyl)dimethyl]silyl]oxy-2-(7,7-diethoxy-3-heptene-1,5-diynyl)-6-phenylseleno-cyclohexanone [compound H].

The crude mixture of selenides as dissolved in 10 mL of methylene chloride and 0.485 mL (6.0 mmol) of pyridine was added. The solution was cooled in an ice-water bath, and a solution of 0.82 mL (8 mmol) 30% hydrogen peroxide in 1 mL of water was added via syringe in one portion. The reaction mixture was stirred for 5 min, and the ice bath was removed. The reaction mixture was stirred for 25 min, and 0.25 mL of the same hydrogen peroxide (1 mmol) solution was added. The reaction mixture was stirred for 15 min, and 1.57 mL (7 mmol) of H_2O_2 solution was added. The reaction mixture was poured into 160 mL methylene chloride, 50 mL saturated aqueous $NaHCO_3$, and 50 mL water. The shaken mixture was filtered by suction to separate the emulsion, and the layers separated. The organic extracts were washed with 50 mL saturated aqueous NaCl, dried over Na_2SO_4, and filtered in vacuo. Flash chromatography using 4% EtOAc/Hexane provided the desired enone whose physical properties were consistent with the material obtained in Preparation II (c).

(b) Alternative method B

A 1.0M solution of lithium bis(trimethyl)silylamide in THF (28.7 mL, 28.77 mmol) was added to 30 mL of dry THF stirring under N_2, and the solution was cooled to -10°C. A solution of 1.54 g (13.7 mmol) 1,2-cyclohexanedione in 7 mL of THF was added in a slow stream via syringe. The reaction mixture turned dark-reddish brown. The reaction mixture was stirred for 15 min at -10°C and then cooled to -50°C. A solution of 4-methylphenyl 4-methyl-benzenethiosulfonate (3.5 g, 14.2 mmol) in 10 mL of THF at -50°C was added in one portion via syringe. The reaction mixture was stirred for 2 h at -50°C and allowed to warm at ambient temperature until approximately 0°C, and then 100 mL of 0.1N HCl was added. The mixture was extracted with 300 mL and then 100 mL of diethyl ether, and the combined organic extracts were dried over anhydrous sodium sulfate. Concentration in vacuo provided a yellow solid which was purified by flash chromatography over silica gel using CH_2Cl_2, 10% EtOAc/Hexane, and then 3% $MeOH/CH_2Cl_2$ as eluent. The desired product, 2-hydroxy-3-[(4-methylphenyl)thio]-2-

cyclohexenone [compound Iy], was isolated as a white solid (1.939 g, 60%).

Anal. calcd. for $C_{13}H_{14}O_2S$: C, 66.64; H, 6.02; N, 0.00. Found: C, 66.63; H, 6.10; N, 0.00.

IR (KBr): 3372, 3054, 2954, 2920, 2870, 2834, 1642, 1600, 820, 656, 628 cm^{-1}.

^{1}H NMR ($CDCl_3$) δ: 7.38 (d, J = 8.1 Hz, 2H), 7.16 (d, J = 8.2 Hz, 2H), 6.47 (s, 1H, -OH), 2.44 (t, J = 6.2 Hz, 2H), 2.35 (s, 3H), 2.17 (t, J = 5.9 Hz, 2H), 1.87 (m, 2H).

^{13}C NMR ($CDCl_3$) δ: 191.1, 143.0, 140.3, 136.0, 133.5, 130.6, 126.3, 35.4, 28.3, 22.8, 21.5.

Tert butyldimethylsilyltrifluoromethanesulfonate (TBSOTf) (20.75 mL, 90.03 mmol) was added via syringe to a solution of compound Iy (17.64 g, 75.28 mmol) and Et_3N (15.7 mL, 112.92 mmol) stirring in 250 mL of methylene chloride under a nitrogen atmosphere at 2°C. After 5 min, the cooling bath was removed, and the reaction mixture was allowed to stir for 22 h. An additional 0.78 mL (5.59 mmol) of Et_3N followed by 0.865 mL (3.76 mmol) TBSOTf was added, and the reaction mixture was stirred for 2 h more. The reaction mixture was poured into 200 mL of water and 50 mL CH_2Cl_2 and extracted. The organic layer was washed with saturated aqueous brine, dried over Na_2SO_4, and concentrated in vacuo. Purification by flash chromatography over SiO_2 using a 0-10% EtOAc/hexane gradient as eluent provided 21.22 g (81%) as an off-white solid of 2-TBSoxy-3-[(4-methyl-phenyl)thio]-2-cyclohexenone [compound J].

^{1}H NMR ($CDCl_3$) δ: 7.38 (d, J = 8.06 Hz), 2H), 7.15 (d, J = 7.9 Hz, 2H), 2.35 (s, 3H), 2.38-2.34 (m, 2H), 2.12 (t, J = 6.05 Hz, 2H), 1.82 (m, 2H), 1.00 (s, 9H), 0.21 (s, 6H).

A solution of 8.64 g (40 mmol) 80-85% pure MCPBA in 125 mL of dichloromethane at 25°C was added via pipette to a solution of 12.7 g (36.4 mmol) compound J in 600 mL of dichloromethane at -78°C. The reaction mixture stirred for 1.75 h at -78°C and poured into 1,100 mL of diethyl ether and 500 mL sat aq. Na_2SO_3. After extraction, the organic layer was washed successively with 300 mL and 200 mL portions of saturated aqueous $NaHCO_3$ and then dried over sodium sulfate. After removal of the solvent in vacuo, the crude product was purified by flash chromatography on SiO_2 using 10% and then 20% EtOAc/Hexane as eluent to provide 12.2017 g (92%) of the corresponding sulfoxide [compound K] as viscous, light-yellow oil.

Anal. calcd. for $C_{19}H_{28}O_3SSi$: C, 62.59; H, 7.49; N, 0.00. Found: C, 62.24; H, 7.49; N, 0.06.

IR (NaCl, Film): 2954, 2930, 2886, 2858, 1694, 1610, 1080 cm^{-1}.

^{1}H NMR ($CDCl_3$) δ: 7.48 (d, J = 8.3 Hz, 2H), 7.28 (d, J = 8.2 Hz, 2H), 2.82-2.74 (m, 1H), 2.55-2.46 (m, 1H), 2.38 (s, 3H), 2.38-2.29 (m, 1H), 2.05-1.86 (m, 3H), 0.98 (s, 9H), 0.32 (s, 3H), 0.20 (s, 3H).

^{13}C NMR ($CDCl_3$) δ: 195.5, 142.6, 141.6, 140.5, 130.6, 124.3, 38.3, 26.1, 22.4, 21.5, 19.2, 18.5, -3.4, -4.0.

Lithium bis(trimethylsilyl)amide (40 ml of 1.0 M solution in THF) was added via syringe to a solution of 7.13 g (40.0 mmol) of 7,7-diethoxy-3-heptene-1,5-diyne stirring in 250 mL dry THF at -78°C under a nitrogen atmosphere. The dark solution was stirred for 30 min, and then a solution of 12.15 g (33.3 mmol) of compound K which had been precooled to -78°C was added via cannula over 5 min. The reaction mixture was removed from the cooling bath and allowed to stir at ambient temperature for 1.6 h. The reaction mixture was poured into 500 mL 1N HCl and 1 L 1:1 ether:ethyl acetate and extracted. The aqueous layer was reextracted with two 150 mL portions of the same solvent, and the combined organic extracts were washed with 200 mL saturated aqueous NaCl and then dried over anhydrous Na_2SO_4. Purification by flash chromatography over SiO_2 using a gradient of 10-25% EtOAc/Hexane as eluent provided 15.5 g (86%) of a viscous brown liquid which was the desired product as a mixture of diastereomers [compound L].

IR (NaCl, Film): 2930, 2858, 2214, 2256, 1736, 1652, 1798, 1086, 1052 cm^{-1}.

A solution of 12.02 g (22.1 mmol) of compound L and 7.4 g (44.3 mmol) of 2-mercaptobenzothiazole in 100 g of heptyne was heated at reflux for 50 min, allowed to cool, and then poured into 400 mL diethyl ether and 400 mL water. The layers were separated and the organic layer dried over anhydrous sodium sulfate. Removal of most of the ether by rotary evaporation caused deposition of a brown precipitate which was removed by suction filtration and discarded. Purification of the filtrate by flash chromatography over silica gel in the usual manner provided 4.47 g (50%) of the desired enone which had the physical characteristics described previously.

(c) Alternative method C

Compound D (16.96 g, 41.91 mmol) was dissolved in 400 mL of dry THF and cooled to -78°. A 1.0 M solution of lithium bistrimethylsilylamide in THF (48 mL, 48 mmol) was added via syringe over about 2 minutes. The reaction mixture was stirred for four minutes and then the cooling bath was replaced with an ice water bath. The reaction mixture was stirred for 1.5h, and then allyl chloroformate (6.5 mL, 58.7 mmol) was added neat, quickly via syringe. The reaction mixture was stirred for 1.5h, poured into water, and extracted with three portions of ethyl acetate. The combined organic extracts were washed with saturated brine and then dried over anhydrous Na_2SO_4. Concentration and purification by flash chromatography over silica gel using 4% then 5% ethyl acetate/hexane as eluent provided the enol allylcarbonate (compound S, 16.97 g 84%) of a slightly yellow, clear oil.

^1H NMR ($CDCl_3$) δ 5.97-5.80 (m, 3H), 5.53 (t, 4.0Hz, 1H), 5.40-5.22 (m,3H), 4.61 (m,2H), 3.75-3.68 (m, 2H), 3.63-3.55 (m, 2H), 2.27-1.99 (m, 4H), 1.79 (m, 2H), 1.21 (t, J=7.1Hz, 6H), 0.82 (s, 9H), 0.179 (s,3H), 0.173 (s, 3H).

^{13}C NMR ($CDCl_3$) δ 153.37, 147.20, 131.38, 120.24, 118.72, 118.52, 117.30, 98.68, 91.61, 91.48, 86.49, 82.07, 68.51, 68.11, 60.77, 40.47, 25.46, 23.84, 18.82, 17.87, 14.95, -3.13, -3.56.

Anal. calcd. for $C_{26}H_{40}O_6Si$: C, 66.36; H, 8.25; N, 0.00. Found: C, 66.28; H, 8.31; N, 0.00.

IR (film on NaCl) 2932, 1766, 1682, 1650 cm^{-1}.

Acetonitrile (115 mL) was added to a flask containing Pd(OAc)$_2$ (0.1 g, 0.445 mmol) and compound S (16.47 g, 33.7 mmol) under an argon atmosphere and a reflux condenser. The reaction mixture was heated at reflux for 3h and then concentrated in vacuo. Purification by flash chromatography over silica gel using 4% then 5% ethyl acetate/hexane as eluent provided some non polar products and then 11.12g (82%) of a colorless oil which was the desired compound C. The spectral data of this reaction product is the same as that reported in preparation C.

Preparation VII. Alternative method for the preparation of compound G

(a) (Z) 5-chloro-1-(2-tetrahydropyranyloxy)-4-pentene-2-yne (compound M)

Tetrahydrofuran (degassed, 600mL) was added via cannula to a flask containing 7.55g (39.6 mmol) CuI and 5.93g (5.13mmol) tetrakis(triphenylphosphine)palladium(0) stirring under an argon atmosphere. Neat cis 1,2-dichloroethylene (50g, 516mmol) was added via syringe followed by 68mL (688mmol) of butylamine. 2-(3-propynyloxy)tetrahydropyran (48g, 344mmol) was added dropwise over 10 min. After the addition was complete the reaction mixture was stirred for 10 min and then cooled in an external ice water bath for 40 min. The cooling bath was removed and the rection mixture allowed to stir for 4h at ambient temperature (25°C). Air was bubbled through the reaction mixture for 15min and then the reaction mixture was filtered by suction through a glass frit using pentane then ether washes for transfer. The reaction was taken up in ethyl acetate and washed twice with water. The aqueous layers were reextracted with ethyl acetate and the combined organic layers dried over sodium sulfate, filtered and concentrated in vacuo. Flash chromatography over silica gel using 2.5% then 4% ethyl acetate/hexane as eluent provided 48.74g (71%) of clear, slightly reddish liquid:

^{1}H NMR ($CDCl_3$) δ 6.33 (d,J=7.5Hz,1H), 5.84 (m,1H), 4.80 (m,1H), 4.36(m,2H), 3.78 (m,1H), 3.48 (m,1H), 1.80-1.40 (m,6H).

^{13}C NMR ($CDCl_3$) δ 128.7, 111.6, 96.7, 93.5, 79.6, 62.0, 54.5, 30.2, 25.3, 19.0.

IR (NaCl film) 3084, 3026, 2944, 2870, 2854, 1592 cm^{-1}.

Anal.calcd. for $C_{10}H_{13}ClO_2$: C, 59.86; H, 6.53.
Found: C, 59.74; H, 6.44; N, 0.03.

(b) (Z) 7-(2-tetrahydropyranyloxy)-1-(trimethylsilyl)-3-heptene-1,5-diyne (compound N)

Degassed anhydrous tetrahydrofuran (500mL) was added to 5.86g (4.32mmol) solid tetrakis(triphenylphosphine) palladium(0) and copper (I) iodide (5.17g, 27.1mmol) stirring under argon. A solution of the vinyl chloride (compound M of step (a) 45.38g, 226.1mmol) in 100mL of dry tetrahydrofuran was added via cannula followed immediately by the addition of 45mL (455mmol) neat butylamine. The flask was wrapped in aluminum foil to exclude light and then 41.6 mL (294mmol) of trimethylsilyl acetylene was added via syringe over 4min. After about 10 min the reaction became very warm and was cooled in an ice water bath for 3 min. The cooling bath was then removed and the reaction allowed to stir for 4h at ambient temperature. Air was bubbled through the reaction for 15 min and then the reaction was filtered by suction through a glass frit using pentane then ether washes for transfer. The reaction was diluted with ether and washed with five 500ml portions of water. The aqueous washes were reextracted with a small amount of diethyl ether and the combined organic extracts were dried over anhydrous Na_2SO4, filtered, and concentrated on a rotary evaporator. Flash chromatography over SiO_2 using 2.5% to 4% ethyl acetate/hexane as eluent provided 52.86g (89%) of liquid as the desired product:

^{1}HNMR ($CDCl_3$) δ 5.83 (m,2H), 4.86 (bs, 1H), 4.44 (ABq, Jab=14Hz,2H), 3.82 (m,1H), 3.52 (m,1H), 1.89-1.49 (m,6H), o.33(s,9H).

^{13}C NMR ($CDCl_3$) δ 120.1, 119.7, 103.0, 101.7, 96.5, 93.4, 83.0, 61.8, 54.6, 30.2, 25.3, 18.9, -0.21.

IR (NaCl film) 2956, 2144, 844 cm^{-1}.

Anal.calcd for $C_{15}H_{22}O_2Si$: C, 68.65; H, 8.45; N, 0.00. Found: C, 68.79; H, 8.35. N, 0.06.

(c) (Z) 7-(2-tetrahydropyranyloxy)-3-heptene-1,5-diyne (compound-O)

Lithium hydroxide monohydrate (22.55g, 0.54mol) was added in one portion to a solution of 21.62g (82.38 mmol) silyl diynene (compound N of step (b)) in 240 mL tetrahydrofuran and 40mL water stirring at 25°C. The reaction was stirred for 1.58h and then diluted with 1:1 ether:hexane and water. The aqueous layer was reextracted with three portions of ether and then the combined organic extracts were dried over anhydrous sodium sulfate. Flash chromatography over silica gel using a gradient of 2.5 to 10% ethyl acetate/hexane as eluent provided 15.69g (98%) of brown liquid:

^{1}HNMR (CDCl$_3$) δ 5.92 (d,J=11.0Hz,1H), 5.78 (dd,J=11.1, 2.2Hz,1H), 4.87 (m,1H), 4.45 (tallmultiplet, 2H), 3.83 (m,1H), 3.52 (m,1H), 3.30 (d,J=2.1Hz,1H), 1.79-1.48 (m,6H).

^{13}CNMR (CDCl$_3$) δ 121.2, 118.7, 96.6, 93.5, 84.7, 82.7, 80.5, 62.0, 54.6, 30.2, 25.4, 19.0.

IR (NaCl film) 3288, 2944, 2870, 2854, 2096 cm-1.

Anal calcd for $C_{12}H_{14}$O2= C, 75.76; H, 7.42.
Found= C, 75.22; H, 7.30.

(d) (Z) 6-{[(1,1-dimethylethyl)dimethylsilyloxy]-6-[7-(2-tetrahydropyranyloxy)-3-heptene-1,5-diynyl]-2-cyclohexenone (compound P)

A 1.0M solution of lithium bis(trimethylsilylamide) in tetrahydrofuran (89mL, 89mmol) was added via syringe to a solution of 15.4g (80.9mmol) diynene (compound O of step (c)) in 500mL of tetrahydrofuran stirring at -78°C under an atmosphere of nitrogen. The reaction was stirred for 35min and then a solution of 24.6g (67.46mmol) sulfoxide ketone (compound K) in 100mL of tetrahydrofuran at -70°C was added via cannula. The cooling bath was removed and the reaction was allowed to stir at ambient temperature for 2h (gradually reaching 25°C). The reaction was quenched with saturated aqueous ammonium chloride and extracted with two portions of 1:1 ethyl acetate:ethyl ether. The combined organic extracts were washed with saturated aqueous sodium bicarbonate then saturated sodium chloride, dried over sodium sulfate, and concentrated in vacuo. Purification by flash chromatography over silica gel using a gradient of 2.5 to 20% ethyl acetate/hexane as eluent provided 27.3g (73%) of viscous oil which was the desired keto sulfoxides as a mixture of diastereomers.

A solution of 27.3g (49.2mmol) of the sulfoxide from above in 540mL of pyridine was heated at 105°C for 1.75h and then diluted with toluene (several portions were added to help remove the pyridine azeotropically) and concentrated on a rotary evaporator. The crude product was purified by flash chromatography using 5 then 10% ethyl acetate/hexane as eluent to provide 18.0g (88%) of a light yellow oil which was the desired product contaminated with trace amounts of sulfur byproducts. This material was used directly in the next alcohol deprotection reaction:

^{1}HNMR ($CDCl_3$) δ 6.89-6.82 (m,1H), 5.96 (dd,J=10.9,1.2Hz,1H), 5.87-5.77 (m,2H), 4.78 (m,1H), 4.46-4.31 (m,2H), 3.81(m,1H), 3.51 (m,1H), 2.70-2.64 (m,1H), 2.47-2.39 (m,1H), 2.29-2.14 (m,2H), 1.81-1.49 (m.6H), 0.68 (s,9H), 0.20 (s,3H), 0.18 (s,3H).

(e) (Z) 6-[[(1,1-dimethylethy)dimethylsilyl]-6-[(7-hydroxy)-3-heptene-1,5-diynyl]-2-cyclohexenone (compound Q)

Para-toluenesulfonic acid (1.21g, 6.36mmol) was added to a solution of the tetrahdropyranyl ether (compound P of step (d) 18.0g, 43.3mmol) in 200mL of methanol stirring at 25°C. The reaction was stirred for 30 min and then concentrated on a rotary evaporator. The crude oil was taken up in ethyl acetate and washed with saurated aqueous $NaHCO_3$ and then saturated aqueous NaCl. The organic extracts were dried over anhydrous sodium sulfate and then concentrated in vacuo. Purification by flash chromatography over silica gel using a gradient of 5%-20% ethyl acetate/hexane as eluent provided 10.75g (75%) of the desired product as a light yellow oil:

^{1}HNMR ($CDCl_3$) δ 6.91 (m,1H), 5.98 (dt,J=10.3,1.9Hz,1H), 5.88 (dt,J=10.8,0.6Hz,1H), 5.80 (d,J=10.7Hz,1H), 4.40 (d,J=6.2Hz,2H), 2.51-2.20 (m,4H), 1.59 (s.1H), 0.85 (s,9H), 0.20 (s,3H), 0.18 (s,3H).

^{13}C NMR ($CDCl_3$) 194.3, 150.7, 127.0, 121.0, 119.0, 95.9, 94.3, 84.8, 82.6, 72.9, 51.3, 38.3, 25.5, 24.5, 18.0, -3.5, -3.6.

(f) Cobalt, hexacarbonyl [μ-[6-[($5,6^{n}:5,6^{n}$)-(Z) 6-[[(1,1-dimethylethy)dimethylsilyl]-6-[(7-hydroxy)-3-heptene-1,5-diynyl]-2-cyclohexenone, di(Co-Co) (compound R)

Octacarbonyldicobalt (Alfa, 4.41g, 12.9mmol) was added in one portion to a solution of 4.27g (12.9 mmol) enone alcohol (compound Q of step (e)) stirring in 170 mL of dichloromethane at 25°C under an atmosphere of nitrogen. The reaction was stirred for 2h and then concentrated on a rotary evaporator. Purification by flash chromatography over silica gel using a gradient of 5 to 20% ethyl acetate/hexane provided 6.18g (78%) of the desired product as a purple oil:

^{1}H NMR ($CDCl_3$) δ 6.91 (m,1H), 6.72 (d,J=10.7Hz,1H), 6.01 (broad doublet,J=10.1Hz,1H), 5.77 (d,J=10.6Hz,1H), 4.85 (d,J=6.5Hz,2H), 2.56-2.30 (m,2H), 2.27

(t,J=5.6Hz,2H), 1.50 (bs,1H), 0.85 (s,9H), 0.19 (s,3H), 0.074 (s,3H).

A slower eluting minor isomer (1.29g, 16%) was also isolated and is the cobalt complex of the other acetylene of the diynene.

(g) <u>Compound G</u>

A 2.0 M solution of ethylmagnesium bromide in tetrahydrofuran (6.50mL, 13mmol) was added dropwise to a solution of t-butanal (1.29mL, 13.5mmol) in 30 mL of dry tetrahydrofuran at 0°C. The reaction was stirred for 15min and then the cooling bath was removed. After 5 min a solution of the cobalt complexed alcohol (compound R of step (f) 6.18g, 10.03 mmol) was added via cannula. A solution of 3.39g (13.4mmol) 1,1'-(azodicarbonyl)-dipiperidine in 30 mL dry tetrahydrofuran was added dropwise via cannula. After the addition was complete the reaction was poured into a saturated aqueous brine solution and extracted. The organic layer was washed with saturated aqueous sodium bicarbonate and then saturated aqueous brine. The combined aqueous washes were extracted once with 1:1 ethyl acetate: ethyl ether and then the combined organic extracts were dried over anhdrous sodium sulfate and concentrated in vacuo. Flash chromatography using 10% ethyl acetate/hexane provided 5.57g (89%) of reddish purple viscous oil.

<u>Preparation VIII. Preparation of dimethylphenylthiol aluminum</u>

A solution of 1.0 mL of 2.0 M trimethylaluminum in hexanes was added dropwise over 0.5 min to a solution of

0.2054 mL (2.0 mmol) thiophenol stirring in 2 mL dry hexane under a nitrogen atmosphere in an ice water cooling bath.

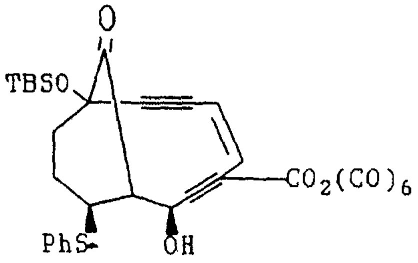
The reaction mixture was stirred for 30 min, and then 6 mL of dry tetrahydrofuran was added via syringe.

Preparation X. Preparation of 2-quinoxalyl isocyanate

Diphenylphosphoryl azide (1.23mL) was added to a solution of triethylamine (800ul) and 2-quinoxaline carboxylic acid 1g (5.74mmol) stirring in 10mL of dry dimethylformamide in an icewater cooling bath (2°). The reaction was stirred for 2.33h during which time the reaction was allowed to warm to 25°. The reaction was poured into ice water and extracted three times with diethyl ether. The combined organic extracts were dried over anhydrous sodium sulfate, filtered, and then concentrated in vacuo. The crude azide was dissolved in 15mL of benzene and heated at reflux for 1.5h. The solvent was removed in vacuo to provide the desired solid isocyanate. FT IR indicated a strong isocyanate absorption.

The following examples are provided to more fully illustrate the invention and are not to be construed as limiting the scope of the invention in any manner.

Example 1. Cobalt, hexacarbonyl[μ-[(6,7-η)-1-[[(1,1-dimethylethyl) dimethylsilyl]oxy]-8-hydroxy-10-phenylthio-bicyclo[7.3.1]tridec-4-ene-2,6-diyn-13-one]] di (Co-Co)



A previously prepared stock solution of dimethyl(phenylthio)aluminum (6.85 ml, 1.49 mmol) was added in one portion via syringe to a solution of enone cobalt complex aldehyde (compound G, 297 mg, 0.483 mmol) in 11 mL of dry tetrahydrofuran stirring under a nitrogen atmosphere at -50°C. The reaction mixture was stirred for 15 min and then cooled to -78°C. The reaction mixture was then allowed to warm to -50°C over 90 min, and neat titanium isopropoxide (1.0 mL, 3.34 mmol) was added thereto in one portion via syringe. The reaction mixture was stirred for 15 min at a temperature between -50°C and -45°C, and then an additional 2.0 mL (6.68 mmol) of neat titanium isopropoxide was added. The reaction mixture was stirred for 15 min between -50° and -45°C and then 20 min between -45° and -40°, and then an additional 2.0 mL (6.68 mmol) of titanium isopropoxide was added. The reaction mixture was stirred for 15 min between -40°C and -30°C and then recooled to -65°. The reaction mixture was allowed to warm to -55° over 30 min, and then the cooling bath was removed. The reaction mixture was stirred for 20 min at ambient temperature and then poured into 300 ml of ethyl acetate and 100 mL of water and extracted. The aqueous layer was reextracted with 100 ml of ethyl acetate, and the combined organic layers were washed with 100 ml saturated aqueous NaCl solution and then dried over anhydrous Na_2SO_4. After filtration and concentration in vacuo, the crude product was purified by flash chromatography on SiO_2 to provide four fractions of material described in their order of elution from the column:

Fraction 1 contained 56 mg (16%) of purple viscous oil which was an aldehyde resulting from simple conjugate addition of phenylmercaptan; fraction 2 contained 68.2 mg (23%) of pure recovered starting material; and fraction 3 contained a 6:4 mixture of the desired product and starting material (59 mg, 11% desired, 6% starting material).

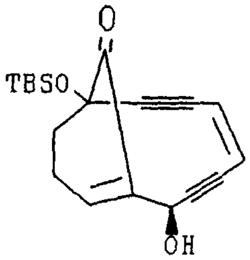
Fraction 4 provided 142 mg (41%) of the desired title compound as a reddish-purple foam.

IR (KBr): 3442, 3060, 2954, 2930, 2894, 2858, 2096, 2060, 2029, 1730, 1080, 838, 780, 744 cm^{-1}.

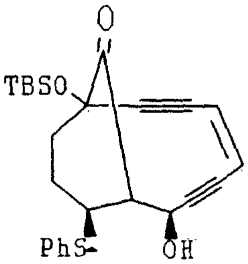
^1H NMR ($CDCl_3$) δ: 7.50-7.47 (m, 2H), 7.36-7.24 (m, 3H), 7.03 (d, J = 9.9 Hz, 1H), 5.79 (d, J = 9.9 Hz, 1H), 5.29 (bt, J = 7.5 Hz, 1H), 4.32 (bs, 1H), 2.77 (d, J = 9.2 Hz, 1H), 2.51-2.38 (m, 2H), 2.28-2.27 (m, 1H), 1.98-1.93 (m, 1H), 1.38 (d, J = 7.5 Hz, 1H, -OH), 0.83 (s, 9H), 0.19 (s, 3H), 0.13 (s, 3H).

^{13}C NMR ($CDCl_3$) δ: 199.1 (b), 198.3, 142.4, 133.7, 129.7, 128.4, 110.5, 99.2, 97.4, 92.1, 82.6, 69.4, 62.6, 48.5, 37.1, 25.9, 23.4, 18.5, -2.6, -2.9.

Example 2. 8-Hydroxy-1-TBSoxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyn-13-one



(a) Preparation of 1-[[(1,1-dimethylethyl))dimethylsilyl]oxy]-8-hydroxy-10-phenylthio-bicyclo[7.3.1]tridec-4-ene-2,6-diyn-13-one



Iodine crystals (12 mg, 0.095 mmol) were added to a solution of cobalt complex reaction product of Example 1 (19 mg, 0.026 mmol) in 5 mL of dry benzene stirring under a nitrogen atmosphere at 25°C. The reaction mixture was stirred for 2 h, concentrated slightly in vacuo, and then flash chromatographed on SiO_2 using 4% ethyl acetate/hexane as eluent to provide 6 mg (53%) of the desired decomplexed substrate as a clear oil.

FAB MS (NOBA): M^+ 438.

IR Neat (NaCl, Film): 3484, 3060, 2954, 2958, 2208(w), 1714, 1584 cm^{-1}.

^1H NMR ($CDCl_3$) δ: 7.48-7.38 (m, 2H), 7.36-7.31 (m, 3H), 5.92 (s, 2H), 5.25 (dd, J = 11.0, 4.5 Hz, 1H), 4.43 (d, J = 11.0 Hz, 1H, -OH), 4.05 (dt, J = 5.5, 9.8 Hz, 1H), 2.81 (dd, J = 10.1, 4.6 Hz, 1H), 2.43 (m, 1H), 2.29 (m, 1H), 2.10 (m, 1H), 1.91 (m, 1H), 0.88 (s, 9H), 0.19 (s, 3H), 0.17 (s, 3H).

^{13}C NMR ($CDCl_3$) δ: 207.1, 134.7, 132.6, 129.8, 129.0, 125.1, 123.6, 99.6, 98.0, 92.9, 85.0, 74.4, 65.7, 59.1, 43.1, 34.7, 26.9, 25.9, 18.4, -2.9, -3.0.

(b) Preparation of 1-[[(1,1-dimethylethyl)dimethylsilyl]-oxy]-8-hydroxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyn-13-one

Solid sodium periodate (120 mg, 0.56 mmol) was added to a solution of the product of step (a) above (5 mg, 0.011 mmol) in 5 mL methanol and 2 mL water at 25°C. The reaction mixture was stirred for 10 min, and 1 mL of water was added to dissolve the precipitate, and the stirring continued for 90 min. An additional 149 mg (0.70 mmol) of sodium periodate was added, and the reaction mixture stirred for 45 min and extracted with 50 mL of methylene chloride and 5 mL of water. The aqueous layer was reextracted with 10 mL of methylene chloride. The combined organic layers were dried over anhydrous Na_2SO_4, concentrated in vacuo, and flash chromatographed on SiO_2 using 10% ethyl acetate/hexane as eluent to provide two fractions:

Fraction 1 provided less than 1 mg of a minor, faster eluting side product. Fraction 2 provided 2 mg (56%) of the desired title compound as a white solid.

FAB MS (NOBA): (M+H) 329.

IR Neat (NaCl) 3356, 2952, 2928, 2856, 1712, 1690, 1414, 782 cm^{-1}.

^1H NMR ($CDCl_3$) δ: 6.37 (bs, 1H), 5.84 (s, 2H), 5.22 (d, J = 10.8 Hz, 1H), 4.82 (d, J = 10.8 Hz, 1H, -OH), 2.51-2.47 (m, 2H), 2.28-2.25 (m, 1H), 2.16-2.10 (m, 1H), 0.91 (s, 9H), 0.22 (s, 3H), 0.19 (s, 3H).

^{13}C NMR ($CDCl_3$) δ: 196.8, 139.4, 137.2, 124.8, 123.1, 101.4, 96.3, 93.0, 87.7, 74.6, 69.2, 34.6, 26.0, 24.8, 18.5, -2.8, -3.1.

Example 3. Alternative preparations of compound of Example 2

(a) Alternative method A

Solid 3-chloroperbenzoic acid, (mCPBA, 10.3 mg, .059 mmol) was added to a solution of the product of Example 1 (23.4 mg, .032 mmol) in 10 ml of methylene chloride at 25°C. The reaction mixture was stirred for 15 min, and an additional 14.9 mg (.086 mmol) was added. The reaction mixture was stirred for another hour during which 6.2 mg (.035 mmol) more of mCPBA was added. The reaction mixture was poured into approximately 20 ml of methylene chloride and 10 ml of saturated solution of $NaHCO_3$. The aqueous layer was extracted with methylene chloride and the organic layer washed with saturated solution of NaCl, and the combined organic layer was dried over anhydrous Na_2SO_4 and concentrated in vacuo. Flash chromatography on SiO_2 using 5% ethylacetate/hexane as eluent provided 4.6 mg (43%) of the desired product as an off-white solid.

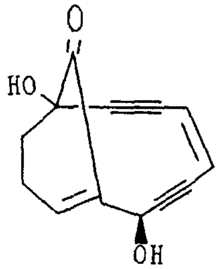
(b) Alternative method B

A solution of 0.595 g (3.45 mmol) of 85% pure MCPBA in 15 mL of CH_2Cl_2 was added dropwise via pipet to a solution of 2.0 g (2.76 mmol) of the product of Example 1 in 100 mL of CH_2Cl_2 stirring at -78° under a nitrogen atmosphere. The reaction mixture was stirred for 30 min at -78° and then removed from the cooling bath. Immediately, 50 mL of 1-hexyne was added and then the reaction mixture was allowed to stir for 1.33 h at ambient temperature. The reaction mixture was then poured into a mixture of 400 mL CH_2Cl_2, 200 mL water, and 100 mL sat. aq. $NaHCO_3$. After extraction the aqueous layer was reextracted with two 150 mL portions of CH_2Cl_2. The combined organic extracts were washed with 200 mL of saturated brine, dried over sodium sulfate, and concentrated in vacuo. The resulting red oil was dissolved in 60 mL of acetone which contained 0.15 mL (1.08 mmol) of triethylamine. A single portion of cerric ammonium nitrate (CAN, 4.5 g, 8.21 mmol) was added and the reaction was sttirred for 35 min. An additional 1.00 g (1.82 mmol) of CAN was added and the reaction mixture was stirred for 15 min longer. The reaction mixture was poured into 500 mL of ethyl acetate and 200 mL of water and extracted. The aqueous layer was reextracted with three 100 mL portions of ethyl acetate and then the combined organic extracts were washed with 100 mL sat. aq. brine. The solution was dried over sodium sulfate, filtered, concentrated in vacuo and placed on top of a 8 inch x 1.7 inch flash column of silica gel. Elution with

3-10% ethyl acetate/hexane provided, after concentration in vacuo, 504 mg (56%) of the desired enone as a white solid.

Example 4. 1,8-Dihydroxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyn-13-one

(a) Alternative method A



Trifluromethanesulfonic acid (2 drops from a 22 gauge needle, 0.010 mL, 0.11 mmol) was added to a solution of 8-hydroxy-1-TBSoxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyn-13-one (product of Example 2, 12.2 mg, 0.040 mmol) in 7 mL of dichloromethane containing 800 mg of 4A molecular sieves stirring at 25°C. The reaction mixture was stirred for 10 minutes, diluted with 50 mL dichloromethane, and washed with 50 mL of saturated aqueous sodium bicarbonate. The organic layer was concentrated in vacuo. The crude product thus obtained was combined with the crude product from a similar experiment in which 2.5 mg of the enone alcohol was utilized. Flash chromatography of the combined crude product over silica gel using 10% and then 20% ethyl acetate/hexane as eluent provided 8.6 mg (83%) of the desired product as a white stable solid.

MS: m/e 214.

^1H NMR ($CDCl_3$) δ: 6.51 (m, 1H), 5.84 (s, 2H), 5.23 (d, J = 11.2 Hz, 1H), 4.38 (d, J = 11.2 Hz, 1H, -OH), 3.93 (s, 1H, -OH), 2.58-2.51 (m, 2H), 2.46-2.39 (m, 1H), 2.13-2.01 (m, 1H).

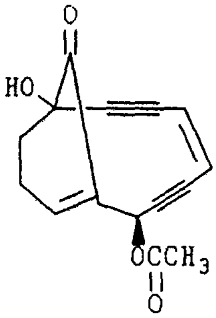
^{13}C NMR ($CDCl_3$) δ: 195.8, 141.1, 135.8, 124.3, 122.9, 100.2, 95.7, 91.5, 87.6, 72.0, 68.4, 31.4, 24.1.

Anal. calcd. for $C_{13}H_{10}O_3$: C, 72.89,; H, 4.71
Found: C, 73.06; H, 4.95.

(b) Alternative method B

A 48% aqueous solution of HF (0.5 mL) was added to a stirred solution of 15 mg (0.046 mmol) of silyl enone in 1.5 mL of CH_3CN at 25° under a nitrogen atmosphere. The reaction mixture was stirred for 5 min at 25°. TLC (20% EtOAc/hexane on SiO_2) showed only starting material. The reaction mixture was heated to reflux and then refluxed for 5 min. The heat source was then removed and the reaction mixture was allowed to stir for 15 min at ambient temperature. The reaction mixture was poured into 40 mL of CH_2Cl_2 and 40 mL water. The mixture was extracted and the aqueous layer was reextracted with an additional 20 mL portion of CH_2Cl_2. The combined organic extracts were washed with 20 mL of saturated aqueous brine, dried over sodium sulfate, and concentrated in vacuo. Flash chromatography on SiO_2 using 30% then 50% diethyl ether/pentane as eluent provided 8.7 mg (89%) of a white solid which was the desired desilylated diol.

Example 5. 8-Acetoxy-1-hydroxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyn-13-one



To a solution of 1,8-dihydroxy-bicyclo[7.3.1]-trideca-4,9-diene-2,6-diyn-13-one (product of Example 4, 32 mg, 0.149 mmol) in 1 ml of pyridine was added dimethylaminopyridine and 1 eq of acetic anhydride (14 ul, 0.149 mmol). The reaction mixture was stirred at ambient temperature for 30 minutes and then pyridine was stripped off on rotovap and on high vacuum. This residue was purified on a silica gel column using 10% and 20% ethyl acetate/hexane mixture as the solvent system. The title compound was obtained as light yellow foam in 85% yield (32.4 mg).

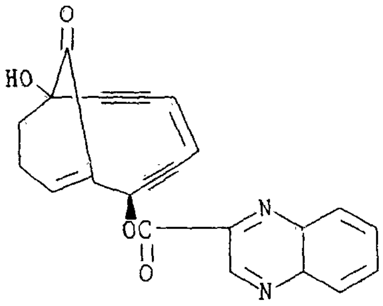
IR (KBr): 3450, 3058, 2926, 2856, 2196, 1742, 1710, 1634, 1418, 1342

^{1}H NMR($CDCl_3$): δ 2.07 (1H, m), 2.18 (3H, s), 2.43 (1H, m), 2.56 (2H, m), 4.12 (1H, s), 5.86 (2H, q), 6.11 (1H, s), 6.69 (1H, t)

^{13}C NMR($CDCl_3$): δ 21.069, 24.410, 32.090, 68.547, 72.456, 90.591, 90.822, 96.120, 97.016, 123.980, 124.846, 134.952, 143.671, 171.210, 192.392

MS: 257 (M+), 239, 215, 169

Example 6. 1-Hydroxy-8-[[(2-quinoxoly)carbonyl]oxy]-bicyclo[7.3.1]trideca-4,7-diene-2,6-diyn-13-one



Solid 2-quinoxaloyl chloride (25 mg, 0.13 mmol) was added to a solution of 4-(N,N-dimethylamino)pyridine (32 mg, 0.26 mmol) and the product of Example 4 (19 mg, 0.089 mmol) in 2 mL pyridine stirring at 25° under an atmosphere of N_2. The reaction mixture was stirred for 30 min and then an additional 25 mg (0.13 mmol) of the acid chloride was added. The reaction mixture was stirred for another hour and then poured into 100 mL of ethyl acetate and 50 mL of water. The mixture was extracted and the aqueous layer was rextracted with two 25 mL portions of ethyl acetate. The combined organic extracts were washed with 50 mL sat. aqueous brine and dried over sodium sulfate. Concentration in vacuo followed by flash chromatography over silica gel using a 20-50% ethyl acetate/hexane gradient provided the title compound (29 mg 88%) as a white solid:

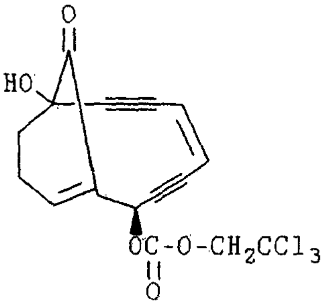
DCI MS: $MH^+ = 371$

IR (KBr) 3470(b), 2194, 1726, 1696, 1228 cm^{-1}.

^1H NMR ($CDCl_3$) δ: 9.68 (bs, 1H), 8.34 (d, J = 7.9 Hz, 1H), 8.20 (d, J = 8.0 Hz, 2H), 7.89 (m, 2H), 6.84 (bs, 1H), 6.53 (s, 1H), 5.94 (ABq, J_{AB} = 9.61 Hz, 2H), 4.13 (bs, 1H), 2.66-2.61 (m, 2H), 2.51 (m, 1H), 2.16-2.05 (m, 1H).

^{13}C NMR ($CDCl_3$) δ: 192.16, 189.74, 145.98, 144.09, 134.60, 133.14, 131.60, 130.08, 125.30, 123.95, 97.12, 95.49, 91.76, 90.65, 72.49, 69.99, 32.14, 24.52.

Example 7. 1-Hydroxy-8-[[(2,2,2-trichloroethoxy)-carbonyl]oxy]-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyne-13-one

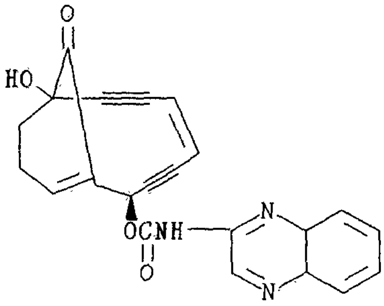


To a solution of the product of Example 4 (7.3 mg, 0.034 mmol) in 500 ul of pyridine was added trichloroethyl chloroformate (5 ul, 0.03 mmol). Additional trichloroethyl chloroformate and pyridine (500 ul) were added. The reaction mixture was stirred at ambient temperature for 1 hour and 10 minutes, washed with saturated solution of sodium chloride, and the aqueous layer extracted 3 times with methylene chloride. The combined organic layer was dried over sodium sulfate and concentrated in vacuo. The residue was purified on a silica gel column using ethyl acetate/hexane as the solvent system to yield the title compound (3.3 mg, 25% yield).

^{1}H NMR ($CDCl_3$): 2.08 (1H, m), 2.40 (1H,m), 2.60 (2H, m), 4.11 (1H, s), 4.78 (2H, d), 5.91 (2H, dd), 6.06 (1H, s), 6.69 (1H, t)

MS: 197, 169

Example 8. 1-Hydroxy-8-[[(2-quinoxolyamino)carbonyl]-oxy]-bicyclo[7.3.1]trideca-4,7-diene-2,6-diyn-13-one



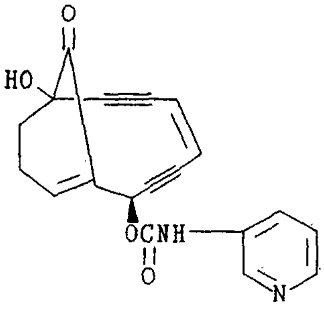
To a solution of 8-hydroxy-1-TBSoxy-bicyclo[7.3.1]-trideca-4,9-diene-2,6-diyn-13-one (product of Example 2, 137 mg, 0.419 mmol) in 10 ml of pyridine was added in portions 2.8 eq of quinoxaline-2-isocyanate (prepared by the method described in), first 140 mg, then 60 mg in an additional 2 ml of pyridine. To this was added dimethylamino pyridine (25 mg, 0.2 mmol). The reaction mixture was stirred at ambient temperature under nitrogen for 4 hours, washed with water, and the aqueous layer extracted twice with diethyl ether. The combined organic layer was dried over sodium sulfate and concentrated in vacuo. This residue was purified on a silica gel column using a gradient of 5% to 20% ethyl acetate/hexane mixture as the solvent system. The 1-TBS protected title compound was obtained as a yellow powder in 74% yield (44.1 mg, based on recovered starting material).

A solution of the 1-TBS protected title compound (40 mg, 0.08 mmol) in 16 ml of anhydrous methylene chloride and 1.8 g 4Å molecular sieves was stirred at ambient temperature under nitrogen for 10-15 minutes. To this mixture was added 2.8 eq of trifluoromethanesulfonic acid (first 15 ul, then 5 ul, 0.226 mmol). The reaction is complete upon addition of the trifluoromethanesulfonic acid. Saturated solution of sodium bicarbonate was added to the reaction mixture and the aqueous layer was extracted three times with methylene chloride. The combined organic layer was washed with saturated solution of sodium chloride, dried over sodium sulfate and concentrated in vacuo.

The solid residue was then triturated with 5% ethyl acetate/hexane mixture. The title compound was obtained as light yellow crystals and film in 97% yield (30.4 mg).

^{1}H NMR ($CDCl_3$): 2.07 (1H, m), 2.47 (1H, m), 2.61 (2H, m), 4.23 (1H, s), 5.89 (2H, q), 6.26 (1H, s), 6.76 (1H, t), 7.65 (2H, m), 7.84 (1H,d), 8.04 (1H, d), 9.62 (1H, s)

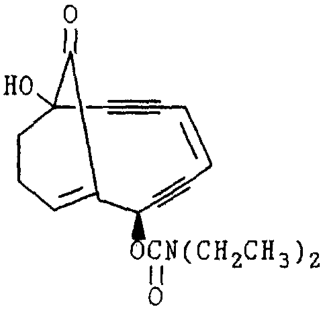
Example 9. 1-Hydroxy-8-[[(3-pyridylamino)carbonyl]oxy]-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyne-13-one



Pyridine 3-isocyanate (disclosed in US Patent 3,342,545, 56 mg, 0.464mmol) was added to a solution of the product of Example 4 (28.9 mg, 0.135 mmol) in 4 mL of dry benzene. The reaction vessel was placed in an oil bath and the bath temperature was raised from 25° to 90° over 15 min. The reaction mixture was stirred for 1.1 h and then an additional 15 mg (0.125 mmol) of pyridine 3-isocyanate was added. The reaction mixture was stirred for 0.9 h more and then concentrated *in vacuo*. Purification over silica gel using a diethyl ether/hexane gradient as eluent provided the title compound (17.9 mg) as an offwhite solid.

^{1}H NMR (drop DMSO-d_6 in $CDCl_3$) δ 9.59 (bs, 1H), 8.56 (bs, 1H), 8.08 (bs, 1H), 7.75 (d, J=6Hz, 1H), 7.03 (m, 1H), 6.56 (m, 1H), 6.05 (s, 1H), 5.75 (d, J=10.4Hz, 1H), 5.66 (dd, J=1.1, 10.4Hz, 1H), 4.76 (bs, 1H), 2.21 (m,2H), 2.24 (m, 1H), 1.89 (m, 1H).

Example 10. 1-Hydroxy-8-[[(N,N-diethlyamino)carbonyl]-oxy]-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyne-13-one

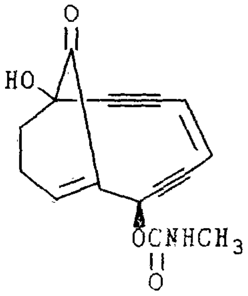


A solution of 1.90 M phosgene in toluene (0.1 mL) was added to a stirtred solution of the product of Example 2 (12.5 mg, 0.038 mmol) and 26.5 ul (0.19 mmol) triethylamine in 1.5 mL CH_2Cl_2 at 25°. The reaction mixture was stirred for 1.5h and then 25 ul (0.238 mmol) of diethylamine was added. After 10 min, the reaction mixture was poured into CH_2Cl_2 and water and extracted three times with methylene chloride. The combined organic extracts were washed with aqueous brine, dried over Na_2SO_4, and concentrated in vacuo to provide a tan solid.

The tan solid was dissolved in 6 mL of dry tetrahydrofuran and (25 ul, 0.025 mmol) of a 1.0 M solution of tetra n-butylammonium fluoride in tetrahydrofuran was added. The reaction began to darken immediately but was allowed to stir for 1h. The reaction mixture was poured into CH_2Cl_2 and water and extracted. The aqueous layer was reextracted once with dichloromethane and once with ether and then the combined organic extracts were dried over sodium sulfate. The reaction was concentrated in vacuo and purified by flash chromatography over silica gel to provide 2 mg of carbamate which was still silylated and a second fraction which contained mainly the title compound. This material was filtered through a small pad of silica gel to provide after concentration *in vacuo* 2.3 mg of white solid.

^{1}H NMR ($CDCl_3$) δ 6.65 (m, 1H), 6.15 (s,1H), 5.85 (ABq, JAB=8.2Hz, 2H), 4.12 (s, 1H), 3.39-3.29 (m, 4H), 2.55 (m,1H), 2.50-2.39 (m,1H), 2.10-2.00 (m,2H), 1.19 (t, J=7.69Hz, 3H), 1.11 (t, J=7.03Hz, 3H)

<u>Example 11. 1-Hydroxy-8-[[(methlyamino)carbonyl]oxy]-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyne-13-one</u>



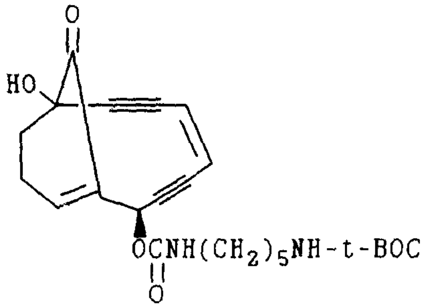
To a solution of the product of Example 2 (10.4 mg, 0.032 mmol) in 800 ul of pyridine was added methyl isocyanate (11 ul, 0.19 mmol) and dimethylaminopyridine . The reaction mixture was stirred at ambient temperature for about 3 hours at which time additional methyl isocyante (15 ul, 026 mmol) as added. The reaction mixture was stirred overnight (23 hours) at ambient temperature, washed with water, and the aqueous layer extracted twice with methylene chloride and once with ether. The organic layer was dried over sodium sulfate and then concentrated in vacuo. The residue was then purified on a silica gel pipet column and eluted with 5%, 10%, 20%, 35% ethyl acetate/hexane to provide the 1-TBS protected title compound (3.8 mg, 31% yield).

To a solution of the 1-TBS protected title compound (3.8 mg, 0.009 mmol) in 4 ml of methylene chloride was added 600 mg of 4A molecular sieves, and the mixture was stirred for 10 minutes at ambient temperature. To this was added trifluoromethanesulfonic acid (2 ul, 0.022 mmol) and the reaction was stopped immediately with a saturated solution of sodium bicarbonate. The aqueous layer was extracted twice with methylene chloride and the organic layer was then washed with saturated solution of sodium chloride, dried over sodium sulfate and concentrated in vacuo. The residue was purified on a silica gel column and eluted with 5%, 10%, 20%, 35% ethyl acetate/hexane to provide the title compound in nearly quantitative yield (3.2 mg).

^{1}H NMR ($CDCl_3$): 2.05 (1 H,m), 2.45 (1H, m), 2.57 (2H, m), 2.80 (3H, d), 4.12 (1H, s), 4.93 (1H, bs), 5.86 (2H, dd), 6.16 (1H, s), 6.69 (1H, t)

MS: 272 (MH+), 254, 228, 215, 197, 187, 169, 154, 141

Example 12. 1-Hydroxy-8-[[[(t-butoxycarbonyl)amino]-pentyl aminocarbonyl]oxy]-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyne-13-one



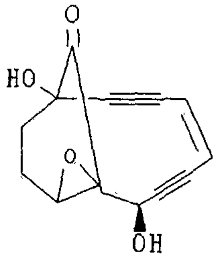
To a solution the product of Example 2 (20.3 mg, 0.06 mmol) in 1 ml of pyridine was added a solution of 5-(t-BOC amino)-pentylisocyanate in 500 ul of pyridine and dimethylamino pyridine. The reaction mixture was stirred at ambient temperature for 3 hours, washed with water, and the aqueous layer extracted 4 times with methylene chloride. The organic layer was dried over sodium sulfate and concentrated in vacuo. The residue was purified by flash column chromatography on a silica gel column and eluted with 5%, 10%, 20% ethyl acetate/hexane. The 1-TBS protected title compound was obtained as a yellow oil in 90% yield (31 mg).

The 1-TBS protected title compound (10.3 mg, .018 mmol) was dissolved in 1.2 ml of tetrahydrofuran. To this solution was added 6 ul of acetic acid and of tetrabutylammonium fluoride (10 ul, 0.01 mmol). Additional tetrabutylammonium fluoride (190 ul, 0.19 mmol) was added over a 45 minutes period. The reaction mixture was washed with water and the aqueous layer extracted 3 times with ether. The organic layer was dried over sodium sulfate and concentrated in vacuo. The residue was purified on a silica gel column and eluted with ethyl acetate/hexane to provide the title compound (1 mg).

^{1}H NMR ($CDCl_3$): 1.31 - 1.60 (6H, m), 1.4 (9H, s), 2.06 (1H, s), 2.43 (1H, m), 2.57 (2H, m), 3.13 (4H, m), 4.14 (1H, bs), 4.58 (1H, bs), 5.03 (1H, bs), 5.87 (2H, dd), 6.11 (1H, s), 6.68 (1H, t)

The t-BOC amino protecting group may be removed using a known deblocking reagent such as hydrochloric acid, trifluoroacetic acid, trimethylsilyl iodide, trimethysilyl chloride, trimethylsilyl triflate, and aluminum chloride, to give 1-hydroxy-8-[[(aminopentyl aminocarbonyl]oxy]-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyne-13-one.

Example 13. 1,8-Dihydroxy-bicyclo[7.3.1]trideca-2,6-diyne-9,10-epoxy-4-ene-13-one



To a solution of the product of Example 2 (113.2 mg, 0.344 mmol) in 13 ml of methylene chloride was added 1.5 eq of triethylamine (75 ul, .516 mmol) and 1.2 eq of tert-butyl dimethylsilyl trifluoromethanesulfonate (95 ul, .413 nmmol). The reaction mixture was stirred at ambient temperature for 18 minutes, washed with water, and the aqueous layer extracted 2 times with methylene chloride. The organic layer was dried over sodium sulfate and concentrated in vacuo. The residue was purified by flash column chromatography on a silica gel column eluting with ethyl acetate/hexane to give the 1,8-bis(TBS)-protected starting material as a yellow solid in 94% yield (143.3 mg).

To a solution of this bis silyl compound (123.4 mg, .28 mmol) in 13 ml of methanol was added 600ul of 30% hydrogen peroxide and 300 ul of 6N sodium hydroxide. The reaction mixture was stirred at ambient temperature, and an additional 1ml of 30% hydrogen peroxide and 375 ul of 6N sodium hydroxide was added portionwise over a 12 minute period. The reaction was quenched with saturated solution of ammonium chloride. The aqueous layer was extracted 3 times with methylene chloride and once with ether. The organic layer was washed with water, dried over sodium sulfate, and concentrated in vacuo to provide the 1,8-bis(TBS)-protected title compound (121.8 mg) in crude form.

Without further purification, the bis silyl epoxide was dissolved in 37 ml of methylene chloride. To this solution was added 2.5 g of 4A molecualr sieves, and this mixture was stirred at ambient temperature for 10 minutes. Trifluoromethanesulfonic acid (40 ul, 20ul, 6 ul, - .76 mmol) was added portionwise in 5 minute intervals. The reaction mixture was taken up in methylene chloride and washed with saturated solution of sodium bicarbonate. The aqueous layer was extracted 3 times with methylene chloride and once with ether. The organic layer was dried over sodium sulfate and concentrated in vacuo.

The residue from this reaction was combined with 10 mg. of the same from an earlier experiment and purified by flash column chromatography on a silica gel column using ether/pentane as eluant to give the title compound (59.4 mg, 79% overall yield).

IR (KBr): 3434, 2922, 2852, 2196, 1736, 1632, 1246, 1218, 1138, 914, 846

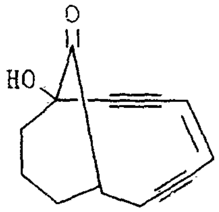
^{1}H NMR ($CDCl_3$): 1.89 (1H, m), 1.98 (1H, m), 2.32 (2H, m), 3.40 (1H, s), 3.74 (1H, s), 3.91 (1H, d), 4.31 (1H, d), 5.96 (2H, s)

^{13}C NMR ($CDCl_3$): δ 21.056, 25.844, 58.572, 68.515, 73.281, 76.736, 87.940, 93.218, 95.216, 97.393, 123.990, 124.726, 200.073

MS: 231 (M+), 213, 197, 185, 169, 157, 141, 129, 115

EXACT MASS: Calculated for $C_{13}H_{10}O_4$ 231.0657
Experimental Value 231.0653

Example 14. 1-Hydroxy-bicyclo[7.3.1]trideca-2,6-diyne-4-ene-13-one



(a) (Z)-5-chloro-1-phenoxy-4-pentene-2-yne

To a 1 L flask under Argon was added CuI (7.86 g, 41.2 mmol) and $Pd(PPh_3)_4$ (5 g, 4.3 mmol). The catalyst was covered with 600 mL of degassed THF, cis-1,2-dichloroethylene (50 g, 516 mmol), and butylamine (68 mL, 688 mmol). Phenoxy-2-propyne (45g, 340 mmol) was added neat over 10 min and the reaction mixture stirred for 5.5 h. Air was bubbled through the reaction mixture for 15 min and the reaction filtered through a pad of celite and washed with pentane. The filtrate was washed with water and brine and the aqueous fractions extracted with ether. The organic fractions were combined, dried ($MgSO_4$), filtered through celite and concentrated. The residue was chromatographed over silica gel (hexane) to give 44.3 g of a yellow oil (67%).

IR (film) 1598, 1494, 1236, 1214, 1032, 754, 690 cm^{-1};

^1H NMR ($CDCl_3$, 300 MHz) δ 7.47 (m, 2H), 6.99 (m, 3H), 6.42 (d, J= 7.5 Hz, 1H), 5.90 (dt, J= 7.5, 2.0 Hz, 1H), 4.88 (d, J= 1.9 Hz, 2H).

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 157.5, 129.5, 129.4, 121.4, 114.9, 111.3, 92.1, 80.9, 56.3;

(b) (Z)-7-phenoxy-1-trimethylsilyl-3-heptene-1,5-diyne

To a 1 L flask under Argon was added CuI (5.24 g, 27 mmol) and $Pd(PPh_3)_4$ (4.9 g, 4 mmol) and the catalyst covered with 500 mL of degassed THF. To this solution was added the product of step (a) (42.7 g, 220 mmol) and degassed butylamine (44 mL, 440 mmol). To this solution was added trimethylsilyl acetylene (29 g, 290 mmol) and the reaction mixture was stirred for 7 h. Air was bubbled through the solution for 15 min and the reaction mixture filtered through celite and washed with pentane. The filtrate was washed several times with water and the aqueous fractions extracted with ether. The organic fractions were combined, dried ($MgSO_4$) and concentrated.

The residue was chromatographed over silica gel (hexane) to give 35.1 g of a tan oil (62%).

IR (film) 2144, 1600, 1494, 1250, 1214, 844, 754;

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.30 (m, 2H), 7.00 (m, 3H), 5.87 (s, 2H), 4.89 (s, 2H), 0.21 (s, 9H);

^{13}C NMR ($CDCL_3$, 75.5 MHz) δ 157.7, 129.3, 121.3, 120.4, 119.6, 114.8, 103.4, 101.5, 91.8, 84.1, 56.4, -0.31;

(c) (Z)-6-[[(1,1-dimethylethyl)dimethyl]silyloxy]-6-(7-phenoxy-3-heptene-1,5-diynyl)-1-trimethylsilyloxy-cyclohexene

To a solution of the product of step (b) (5.0 g, 19.7 mmol) in 20 mL THF was added 5 mL of water and $LiOH-H_2O$ (5.6 g, 133 mmol). The solution was stirred for 4 h, diluted with ether and washed with water. The aqueous layer extracted with ether and then ethyl acetate. The organic fractions were combined, dried ($MgSO_4$) and concentrated. The residue was chromatographed over silica (30:1 hexane/ethyl acetate) to give 3.37 g of (94%) of 7-phenoxy-3-heptene-1,5-diyne.

This diynene (3.37 g, 18.5 mmol) was dissolved in 60 mL of THF and cooled to -78 °C. To the cold solution was added LiHMDS (20 mL, 1.0M in THF, 20 mmol) and stirred 20 min. To this solution was added 2-TBSoxy-2-cyclohexeneone (3.8 g, 16.8 mmol) in 20 mL of THF. The reaction was immediately brought to 0 °C and stirred for 30 min. Trimethylsilyl chloride was added at 0 °C (3.1 mL, 24.4 mmol) and stirred for 30 min. The solution was diluted with pentane and washed with water, dried

($MgSO_4$), and concentrated. The residue was chromatographed over silica (200:1 hexane/ethyl acetate) to give 5.22 g of the desired product (65%) and 627 mg of recovered diynene.

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.30 (m, 2H), 6.98 (m, 3H), 5.84 (m, 2H), 4.85 (d, J= 1.8 Hz, 2H), 4.81 (t, J= 4.0 Hz, 1H), 2.02 (m, 4H), 1.68 (m, 2H), 0.89 (s, 9H), 0.22 (s, 12H), 0.19 (s, 3H);

(d) (Z)-6-[[(1,1-dimethylethyl)dimethyl]silyloxy]-6-(7-phenoxy-3-heptene-1,5-diynyl)-1-trimethylsilyloxy-cyclohexene hexacarbonyl cobalt complex

To a solution of octacarbonyl dicobalt (4.0 g, 11.7 mmol) in 70 mL of heptane was added the product of step (c) (5.2g, 10.8 mmol) in 30 mL of heptane. The solution was stirred for 2.5 h, concentrated and the residue chromatographed over silica gel (98:2 hexane/chloroform) to give 5.88 g of the desired cobalt complex as the major product (71%) and 1.06 g of the minor cobalt complexed isomer (13%).

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.28 (m, 2H), 6.98 (m, 3H), 6.67(d, J= 10.6 Hz, 1H), 5.83 (d, J= 10.6 Hz, 1H), 5.34 (s, 2H), 4.82 (t, J= 4.0 Hz, 1H), 2.01 (m, 4H), 1.75 (m, 1H), 1.56 (m, 1H), 0.87 (s, 9H), 0.17 (s, 12H), 0.14 (s, 3H);

(e) 1-[[(1,1-dimethylethyl)dimethyl]silyloxy]-bicyclo-[7.3.1]trideca-2,6-diyne-4-ene-13-one, hexacarbonyl cobalt complex

To the major cobalt complexed product of step (d) (5.02 g, 6.54 mmol) in 265 mL of dichloromethane at -15 °C was added ethyl aluminum dichloride (3.8 mL, 1.8 M in toluene, 6.84 mmol). The reaction mixture was stirred for 30 min and poured into water. The organic fraction was separated and the aqueous fraction washed with hexane. The organic fractions were combined, dried ($MgSO_4$), and concentrated. The residue was chromatographed over silica gel (30:1 hexane/ethyl acetate) to give 2.64 gm of a burgundy solid (67%).

^{1}H NMR ($CDCl_3$, 300 MHz) δ 6.97 (d, J= 9.8 Hz, 1H), 5.73 (d, J= 9.8 Hz, 1H), 4.22 (t, J= 15.1 Hz, 1H), 3.18 (m, 2H), 2.39 (br d, J= 13.0 Hz, 1H), 2.04 (m, 1H), 1.90 - 1.68 (m, 4H), 0.84 (s, 9H), 0.12 (s, 3H), 0.04 (s, 3H);

(f) 1-[[(1.1-dimethylethyl)dimethyl]silyloxy]-bicyclo-[7.3.1]trideca-2,6-diyne-4-ene-13-one

To the cyclized cobalt complex of step (e) (1.21 g, 2.0 mmol) was added 41 mL of 95% ethanol and ferric nitrate nonahydrate (4.05 g, 10.0 mmol) and the solution stirred for 3 h. Another equivalent of ferric nitrate was added (807 mg, 2.0 mmol) and the reaction stirred for an additional 2 h. The solution was diluted with ether and washed with water and brine. The organic fraction was dried ($MgSO_4$) and concentrated. The residue was chromatographed over silica gel (40:1 hexane/ethyl acetate) to give 541 mg of a white crystaline solid (86%).

^{1}H NMR ($CDCl_3$, 300 MHz) δ 5.85 (s, 2H), 3.20 (dd, J= 17.5, 3.0 Hz, 1H), 2.71 (m, 2H), 2.40 (dd, J= 17.5, 3.0 Hz, 1H), 2.36 (m, 1H), 2.00 (m, 2H), 1.73 (m, 2H), 0.90 (s, 9H), 0.19 (s, 3H), 0.17 (s, 3H);

(g) 1-Hydroxy-bicyclo[7.3.1]trideca-2,6-diyne-4-ene-13-one

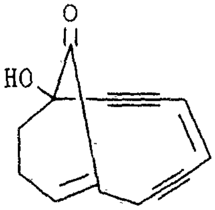
A solution of 1.0M tetra-nbutyl ammonium fluoride in THF (0.3375mL & mmol) was added to a solution of 96.5mg (0.3375mmol) of the product of step (f) stirring in 5mL of THF at 25° under an N_2 atmosphere. After 30min 50mL of water was added and the mixture was extracted with three 25 mL portions of diethyl ether. The combined organic extracts were washed with saturated aqueous brine and dried over sodium sulfate. Flash chromatography (twice) over silica gel using 20% EtOAc/hexane provided 44mg (72%) of the title compound as a white solid:

IR (NaCl) 3466, 2200, 1718, 1456, 1424 cm^{-1}.

^1H NMR ($CDCl_3$) δ 5.82 (s,2H), 4.04 (bs, -OH), 3.19 (dd, J=17.6,2.44Hz,1H), 2.85-2.70 (m,2H), 2.51-2.41 (m,2H), 2.05-1.85 (m,2H), 1.78-1.65 (m,2H).

^{13}C NMR ($CDCl_3$) δ 207.17, 125.33, 122.19, 99.98, 97.42, 90.32, 84.14, 72.11, 47.75, 33.73, 24.11, 24.02, 18.40.

Example 15. 1-Hydroxy-bicylco[7.3.1]trideca-4,9-diene-2,6-diyne-13-one



(a) 1-[[(1,1-dimethyethyl)dimethyl]silyloxy]-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyne-13-one

To the product of Example 14 (593 mg, 1.88 mmol) in 40 mL of THF at -78 °C was added KHMDS (4.7 mL, 0.5M in toluene, 2.35 mmol) and stirred 20 min. 2,2'-Dipyridyl disulfide (515 mg, 2.34 mmol) in 2 mL of THF was added to the deeply colored enolate. The reaction was held at -78 °C for 30 min and then poured into water and diluted with ether. The organic fraction was dried ($MgSO_4$), concentrated and chromatographed over silica (20:1 hexane/ethyl acetate) to give 583 mg of 9-(2-pyridylthio)-substituted starting material (73%) which was immediately oxidized.

This sulfide (585 mg, 1.376 mmol) was dissolved in 27 mL dichloromethane and cooled to 0 °C. To the cold solution was added *m*CPBA (453 mg, 55%, 1.44 mmol) and the solution was stirred for 30 min. The cold bath was removed and the solution stirred at room temperature for 4 h. The solution was diluted with chloroform and washed with sat. bicarbonate, dried ($MgSO_4$), and concentrated. The residue was chromatographed over silica gel (30:1 hexane/ethyl acetate) to give 412 mg of the desired product as a white solid (70%).

^1H NMR ($CDCl_3$, 300 MHz) δ 6.34 (br t, J= 3.0 Hz, 1H), 5.81 (s, 2H), 3.66 (d, J = 16.7 Hz, 1H), 2.99 (d, J= 16.7 Hz, 1H), 2.48 (m, 2H), 2.29 (m, 1H), 2.14 (m, 1H), 0.92 (s, 9H), 0.21 (s, 3H), 0.17 (s, 3H);

(b) 1-Hydroxy-bicylco[7.3.1]trideca-4,9-diene-2,6-diyne-13-one

To the product of step (a) (73 mg, 0.234 mmol) was added 10.5 mL of acetonitrile and 1.8 mL of 48% HF and the solution was stirred in a plastic reactor for 18 h. The solution was diluted with chloroform and washed with water. The aqueous fraction was extracted with chloroform and the organic fractions combined, dried (K_2CO_3), and concentrated. The residue was chromatographed over silica gel (5:1 hexane/ ethyl acetate) to give 44 mg of the title compound as a white solid (96%).

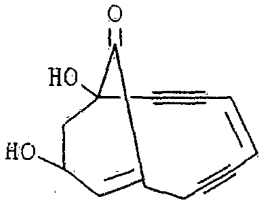
IR(KBr) 3468, 2186 (w), 1692, 1640, 1364, 1340, 1128, 1108, 1046, 964 cm^{-1};

^1H NMR ($CDCl_3$,300 MHz) δ 6.48 (m, 1H), 5.79 (s, 2H), 4.08 (s, 1H), 3.77 (d, J= 16.7 Hz, 1H), 3.04 (d, J= 16.7 Hz, 1H), 2.51 (m, 2H), 2.45 (m, 1H), 2.06 (m, 1H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 192.8, 141.2, 135.4, 124.4, 121.2, 99.9, 95.5, 90.6, 87.4, 72.0, 32.0, 24.8, 23.9;

MS (DCI) *m/z* 199 MH^+, 181 MH^+-OH), 153 (MH^+-CO);

Example 16. 1,11-Dihydroxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyne-13-one



(a) 1-[[(1,1-dimethylethyl)dimethyl]silyloxy]-11-hydroxy-bicyclo-[7.3.1]trideca-4,9-diene-2,6-diyne-13-one and 1-[[(1,1-dimethylethyl)dimethyl]silyloxy]-bicyclo-[7.3.1]-trideca-4,9-diene-2,6-diyne-11,13-dione

To the product of Example 15, step (a) (142 mg, 0.45 mmol) in 25 mL dioxane was added selenium dioxide (164 mg, 1.47 mmol) and the solution heated to 90 °C for 5 h. The solution was diluted with chloroform and washed with bicarbonate. The aqueous fraction was extracted with chloroform and the organic fractions combined and dried ($MgSO_4$). The solution was concentrated and the residue chromatographed over silica gel (3:1 hexane / ethyl acetate) to give 82 mg of allylic alcohol (55%), 6 mg of dione (4%) and 20 mg of recovered starting enone (14%).

enone:

IR (film) 3424, 2956, 2930, 2856, 2194 (w), 1716, 1256, 1162, 1040, 1014, 976, 834, 782 cm^{-1};

^1H NMR ($CDCl_3$, 300 MHz) δ 6.38 (t, J= 2.5 Hz, 1H), 5.82 (ABq, 2H), 4.55 (m, 1H), 3.73 (d, J= 16.6 Hz, 1H), 3.04 (d, J= 16.6 Hz, 1H), 2.80 (ddd, J= 12.9, 6.1, 20 Hz, 1H), 2.08 (dd, J= 12.9, 9.6 Hz, 1H), 0.92 (s, 9H), 0.21 (s, 3H), 0.18 (s, 3H);

MS (DCI) *m/z* 329 (MH^+), 311(MH^+-OH), 271(MH^+-tBu), 197(MH^+-$OSiMe_2$tBu)

dione:

^1H NMR ($CDCl_3$, 300 MHz) δ 6.39 (s, 1H), 5.86 (s, 2H), 3.84 (d, J= 16.1 Hz, 1H), 3.25 (dd, J= 17.4, 1.7 Hz, 1H), 3.21 (d, J= 16.1 Hz, 1H), 2.95 (d, J= 17.4 Hz, 1H), 0.91 (s, 9H), 0.20 (s, 3H), 0.17 (s, 3H);

(b) 1,11-Dihydroxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyne-13-one

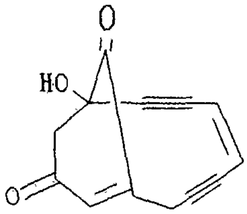
To the protected allylic alcohol of step (a) (88 mg, 0.268 mmol) was added 8.5 mL of acetonitrile and 2.5 mL of 48% HF and the reaction stirred 30 h. The solution was diluted with chloroform and washed with water. The aqueous fraction was extracted with chloroform and the organic fractions combined and dried over K_2CO_3. The solution was concentrated and chromatographed over silica (1:1 hexane/ ethyl acetate) to give 58 mg of the title compound as a white solid (quantitative).

IR (KBr) 3388, 2188 (w), 1706, 1156, 1038 cm^{-1};

^1H NMR ($CDCl_3$, 300 MHz) δ 6.50 (t, J= 2.5 Hz, 1H), 5.80 (ABq, 2H), 4.60 (m, 1H), 4.04 (br s, 1H), 3.70 (d, J= 16.6 Hz, 1H), 3.08 (d, J= 16.6 Hz, 1H), 2.91 (d ABq, 1H), 2.02 (ABq, 1H);

^{13}C NMR (DMSO, 75.5 MHz) δ 194.1, 144.4, 136.5, 125.6, 122.6, 101.3, 97.6, 91.2, 88.9, 74.0, 67.2, 44.0, 24.9;

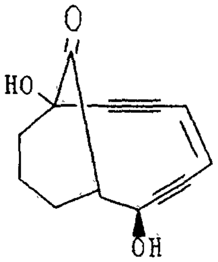
Example 17. 1-Hydroxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyne- 11,13-dione.



The silyl protected dione obtained in Example 16, step (a) was dissolved in 4.25 mL of acetonitrile and stirred with 0.75 mL of 48% HF for 24 h. The solution was diluted with chloroform and washed with water. The organic fraction was dried over K_2CO_3, concentrated and the residue chromatographed over silica gel (3:1 hexane/ethyl acetate) to yield 4.5 mg of the deprotected dione (88%).

^{1}H NMR ($CDCl_3$, 300 MHz) δ 6.48 (s, 1H), 5.87 (s, 2H), 3.92 (s, 1H), 3.88 (d, J= 16.3 Hz, 1H), 3.42 (d, J= 17.6 Hz, 1H), 3.26 (d J= 16.3 Hz, 1H), 2.94 (d, J= 17.6 Hz, 1H);

Example 18. 1,8-Dihydroxy-bicyclo[7.3.1]trideca-4-ene-2,6-diyne-13-one



Bromine (0.341 mL) was added dropwise to a solution of 1.5g (6.62mmol) of 2-(t-butyldimethylsilyloxy)-2-cyclohexenone stirring in 100mL of CH_2Cl_2 at 25° under an atmosphere of nitrogen. The color of the the bromine was nearly completely discharged after addition was complete. After 5 min 2.2 mL of triethylamine was added and the reaction was stirred for 2.5h. The reaction was poured into 50mL of water and extracted. The aqueous layer was reextracted with 10 mL of CH_2Cl_2 and the combined organic extracts were dried over anhydrous sodium sulfate. Concentration in vacuo provided a tan solid which was purified by flash chromatography over silica gel using 3-5% ethyl acetate in hexane as eluent. Concentration of the product fractions in vacuo provided 1.85g (91%) of white crystalline solid which was the desired 3-bromo-2-TBSoxy-2-cyclohexenone. Spectroscopy showed this material to be about 95% pure and to contain about 5% of the starting enone.

A 1.0M solution of lithium bistrimethylsilylamide in tetrahydrofuran (5.7mL) was added to a solution of 0.97g (5.44mmol) of (Z)-1-lithio-7,7-diethoxy-3-heptene-1,5-diyne in 54 mL of THF stirring at -78°. A solution of the bromide prepared as above (1.58g, 5.18mmol) in 10mL of THF at -78° was added via cannula over 1min. The cooling baths were removed and the reaction allowed to stir at ambient temperature (25°) for 1.25h. The reaction was poured into 200mL of water and extracted with 300mL of 3:1 diethyl ether/ ethyl acetate. The aqueous layer was reextracted with 100mL of diethyl ether and then the combined organic extracts were washed with 100 mL of saturated brine. The extracts were dried over sodium sulfate, filtered, and concentrated in vacuo to provide 2.22g of brown syrup which by ^{1}H NMR was amixture of a major and minor bromoketone (Z)-2-bromo-6-TBSoxy-6-(7,7-diethoxy-3-heptene-1,5-diynyl)cyclohexanone. This crude material was used directly in the cobalt complexation step.

Octacarbonyl dicobalt (0.17g) was added to a solution of 0.241g of the bromoketones in 15mL of CH_2Cl_2 stirring at 25° under an N_2 atmosphere. The reaction was stirred for 1h, concentrated in vacuo, and purified by flash chromatography. Isolation of only the major product provided 166 mg of a dark reddish purple oil which was a single compound and the desired cobalt complex of (Z)-2-bromo-6-TBSoxy-6-(7,7-diethoxy-3-heptene-1,5-diynyl)cyclohexanone.

Titanium tetrachloride (71ul) was added in one portion to a solution of the above cobalt complexed (Z)-2-bromo-6-TBSoxy-6-(7,7-diethoxy-3-heptene-1,5-diynyl)cyclohexanone (166mg) and DABCO (25mg) in 15mL CH_2Cl_2 stirring at -78° under an atmosphere of nitrogen. The reaction was stirred for 5 minutes and then poured into water. The reaction was extracted and dried over sodium sulfate. Filtration, concentration, and purification by flash chromatography over silica gel using 5% ethyl acetate in hexane provided 121 mg of the desired cobalt complexed (Z)-2-bromo-6-TBSoxy-6-(7-oxo-3-heptene-1,5-diynyl)cyclohexanone as a purple oil.

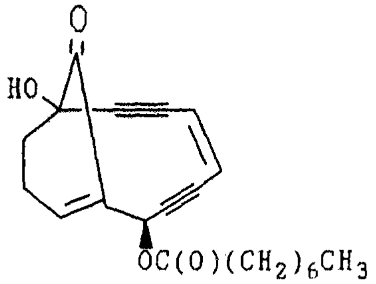
Activated granular zinc (19mg) was added to a solution of 0.21mL 1.0M Et_2AlCl in hexanes, 2.0 mL $Ti(OiPr)_4$, 2mg CuBr, and 0.121g of cobalt complexed (Z)-2-bromo-6-TBSoxy-6-(7-oxo-3-heptene-1,5-diynyl)cyclohexanone stirring at 2° in 4.5mL of dry THF. The reaction was allowed to warm to 10° over 20min and then was allowed to stir for 60min during which time the temperature was maintained between 10 and 20°. The reaction was poured into 40mL of 1N HCl and 50mL diethyl ether and extracted. The aqueous layer was reextracted with an additional 10mL of diethyl ether and the combined organic extracts were dried over sodium sulfate. Filtration, concentration in vacuo, and purification by flash chromatography on silica gel using 5% then 10% ethyl acetate in hexane as eluent provided 35mg of reddish purple oil which was the desired cobalt complexed 8-hydroxy-1-TBSoxy-bicyclo[7.3.1]trideca-4-ene-2,6-diyne-13-one.

Solid $Fe(NO_3)_3 \cdot 9H_2O$ (0.48g) was added in one portion to a solution of 0.24g cobalt complexed 8-hydroxy-1-TBSoxy-bicyclo[7.3.1]trideca-4-ene-2,6-diyne-13-onestirring in 45mL of CH_2Cl_2 at 25°. The reaction was stirred for 3h and then an additional 155mL of CH_2Cl_2 and 0.66g ferric nitrate was added. The reaction was stirred for 40 min and then an additional 0.71g of ferric nitrate was added. The reaction was stirred for 1h and then 200mL of water was added. The reaction was extracted and the aqueous layer was rextracted with 200mL of diethyl ether. The combined organic extracts were washed with saturated brine and then dried over sodium sulfate. Flash chromatography over silica gel using 3% then 5% ethyl acetate in hexane as eluent provided 72mg of the desired 8-hydroxy-1-TBSoxy-bicyclo[7.3.1]trideca-4-ene-2,6-diyne-13-one as an offwhite solid.

Trifluoromethane sulfonic acid (16ul) was added in one portion to a solution of 65mg 8-hydroxy-1-TBSoxy-bicyclo[7.3.1]trideca-4-ene-2,6-diyne-13-one in 20 mL of CH_2Cl_2 stirring over 1g of 2A molecular sieves at 25°. The reaction was stirred for 10min and then poured into 10%aq $NaHCO_3$ and CH_2Cl_2. The mixture was extracted and the organic extracts were dried over sodium sulfate. Filtration, concentration, and purification by flash chromotography over silica gel using 1:1 diethyl ether/hexane as eluent provided 26mg of the desired 1,8-dihydroxy-bicyclo[7.3.1]trideca-4-ene-2,6-diyne-13-one:

^1H NMR ($CDCl_3$) 5.90 (s, 2H), 4.57 (m,1H), 3.95 (m, 1H) 3.83 (s,1H), 2.98 (m, 1H), 2.45 (m, 2H), 2.20-1.60 (m, 4H).

Example 19. 1-Hydroxy-8-n-octanoyloxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyn-13-one



Octanoyl chloride (0.040 mL, 0.23 mmoL) was added in a single portion via syringe to a solution of 1,8-dihydroxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyn-13-one (product of Example 4, 42 mg, 0.196 mmol) in pyridine (1 mL) stirring at 25° under an atmosphere of nitrogen. Immediately thereafter 4-(N,N-dimethylamino)pyridine (5 mg) was added thereto. After 35 min. additional octanoyl chloride (0.005 mL, 0.03 mmol) was added. Stirring was continued for an additional 50 min. and then another portion of octanoyl chloride (0.005 mL) was added. The reaction mixture was stirred for 25 min. and then concentrated in vacuo. Flash chromatography over silica gel (twice) using a gradient of 5 to 20% diethyl ether/hexane as eluent provided the title compound (66 mg, 100%) as a faintly yellow crystalline solid:

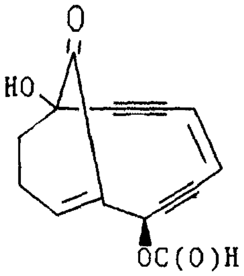
^{1}H NMR ($CDCl_3$) δ 6.70 (m, 1H), 6.14 (s, 1H), 5.89 (ABq, J_{AB}=10.1 Hz, 2H), 4.14 (bs, 1H), 2.60 (m, 2H), 2.45 (m, 2H), 2.36 (t, J=7.5 Hz, 1H), 2.20 (m, 1H), 1.68 (m, 2H), 1.30 (m, 2H), 0.87 (t, J= 8.1 Hz, 3H).

^{13}C NMR ($CDCl_3$) δ 191.5, 173.3, 142.9, 134.4, 124.2, 123.4, 96.5, 95.8, 90.3, 90.1, 72.1, 68.0, 34.1, 31.6, 24.6, 24.2, 22.6, 14.0, 31.8, 29.0, 28.8.

IR (KBr) 3380, 2930, 2886, 1714 (b), 1028 cm^{-1}.

FAB HRMS MH^+calcd. for $C_{21}H_{25}O_4$: 341.1753. Found: 341.1742.

Example 20. 1-Hydroxy-8-formyloxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyn-13-one

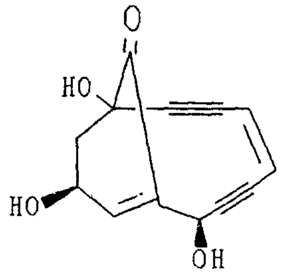


A solution of 1,8-dihydroxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyn-13-one (product of Example 4, 53 mg, 0.25 mmol) in dry pyridine (2 mL) under argon was cooled to -15 °C and acetic-formic anhydride (21 µL) was added. After 2 hr, a few small crystals of 4-(N,N-dimethylamino)pyridine were added together with more acetic-formic anhydride (21 µL). The solvent was removed under high vacuum after 1 hr and the residue was chromatographed twice on silica gel, first eluting with a mixture of ethyl acetate:hexane = 1:9 to 1:1, and then with a mixture of diethyl ether:hexane = 1:9 to 1:1 to afford the title compound as a white solid (37 mg, 62%):

^1H NMR ($CDCl_3$) δ 8.17 (d, J=1.2 Hz, 1H), 6.74-6.71 (m, 1H), 6.24 (s, 1H), 5.93 (d, J=9.5 Hz, 1H), 5.85 (dd, J=1.4, 9.5 Hz), 4.11 (s, 1H), 2.63-2.43 (m, 3H), 2.18-2.02 (m, 1H).

IR (KBr) 3480, 2190, 1720, 1690, 1160, 1120 cm^{-1}.

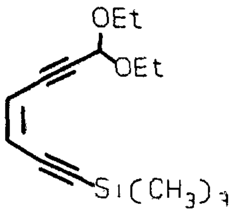
Example 21. 1,8,11-Trihydroxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyn-13-one



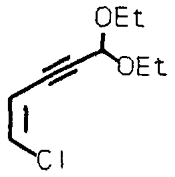
To a solution of 1,8-dihydroxy-bicyclo[7.3.1]trideca-4,9-diene-2,6-diyn-13-one (product of Example 4, 73 mg, 0.34 mmol) in dioxane (10 mL) was added selenium dioxide (117 mg, 1.05 mmol) and the solution heated to 85 oC for 6 h. The solution was diluted with chloroform and washed with bicarbonate. The aqueous fraction was extracted 3 times with ethyl acetate and the organic fractions combined and dried ($MgSO_4$). The solution was concentrated and the residue chromatographed over silica gel (2:1 hexane/ethyl acetate then 1:1 hexane/ethyl acetate) to give the title compound (10 mg, 12%) and the starting material (22 mg, 30%).

^{1}H NMR ($CDCl_3$, 300 MHz) δ 6.56 (t, J = 2.4 Hz, 1H), 5.88 (s, 2H), 5.30 (br d, J = 9.8 Hz, 1H), 4.60 (m, 1H), 4.36 (br d, J = 10.4 Hz, 1H), 3.90 (br s, 1H), 2.90 (ddd, J= 12.9, 5.9, 1.9 Hz, 1H), 2.07 (dd, J= 12.9, 9.7 Hz, 2H).

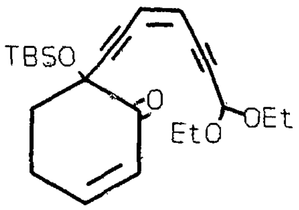
Compound A



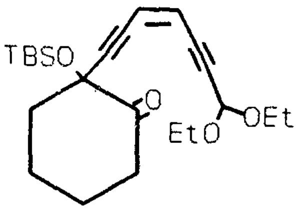
Compound B



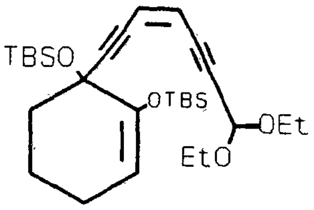
Compound C



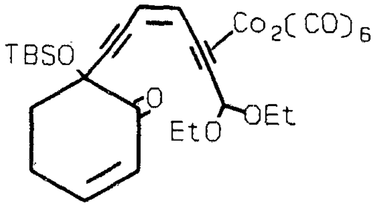
Compound D



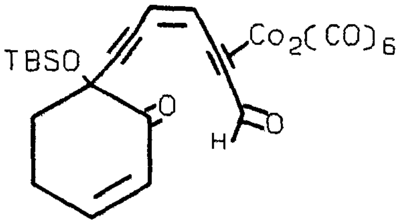
Compound E



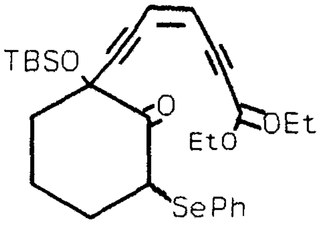
Compound F



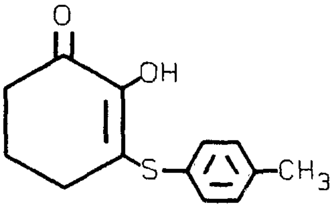
Compound G



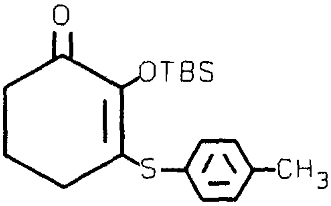
Compound H



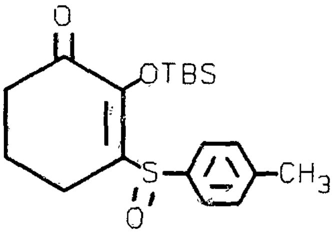
Compound I



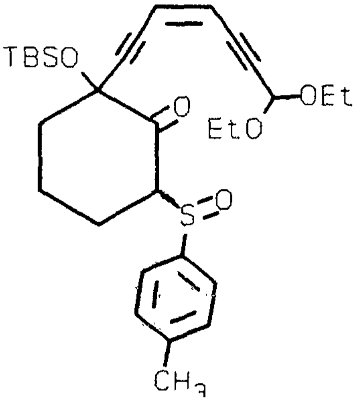
Compound J



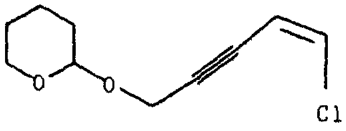
Compound K



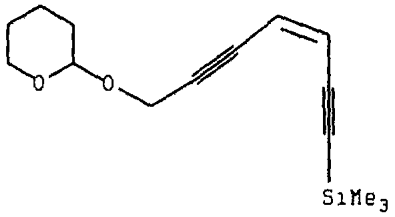
Compound L



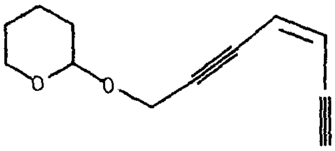
Compound M



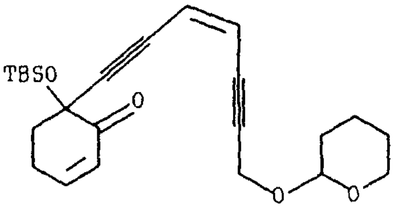
Compound N



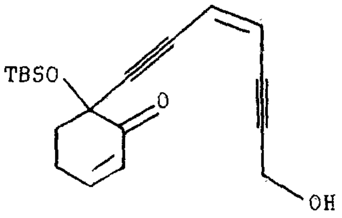
Compound O



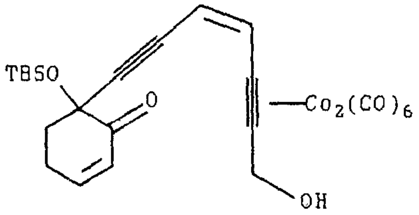
Compound P



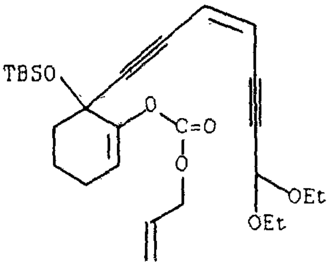
Compound Q



Compound R

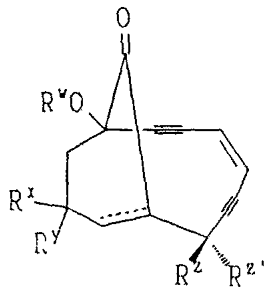


Compound S



The claims defining the invention are as follows:

1. A compound having the formula



VIIa

wherein

$\underline{----}$ is a double bond, a single bond, or an epoxy;

one of R^x or R^y is hydrogen and the other is hydrogen or hydroxy;

R^w is hydrogen, $-C(O)R^s$, $-C(O)NR^tR^u$ or $-C(O)OR^v$;

R^z and $R^{z'}$ are each hydrogen, or one of R^z or $R^{z'}$ is hydrogen, and the other is hydroxy, $-OC(O)R^s$, $-OC(O)NR^tR^u$ or $-OC(O)OR^v$;

R^s is hydrogen, C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl or quinoxalyl;

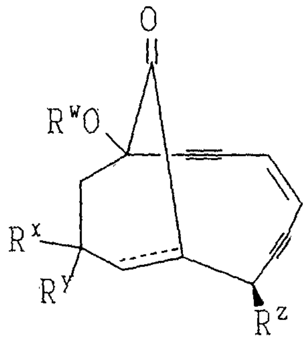
R^t and R^u are independently hydrogen, C_{1-8}alkyl, amino-substituted C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl, pyridyl or quinoxalyl;

R^v is C_{1-8}alkyl, halo-substituted C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl or C_{7-14}aralkyl;

with the proviso that when R^w, R^x, R^y and $R^{z'}$ are each hydrogen, and $\underline{----}$ is a double bond, R^z is not hydroxy;

or a pharmaceutically acceptable salt thereof.

2. A compound of claim 1 having the formula



VIIb

wherein

$\underline{----}$ is a double bond, a single bond, or an epoxy;

one of R^x or R^y is hydrogen and the other is hydrogen or hydroxy;

R^w is hydrogen, $-C(O)R^s$, $-C(O)NR^tR^u$ or $-C(O)OR^v$;

R^z is hydrogen, hydroxy, $-OC(O)R^s$, $-OC(O)NR^tR^u$ or $-OC(O)OR^v$;

R^s is hydrogen, C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl or quinoxalyl;

R^t and R^u are independently hydrogen, C_{1-8}alkyl, amino-substituted C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl, C_{7-14}aralkyl, pyridyl or quinoxalyl;

R^v is C_{1-8}alkyl, halo-substituted C_{1-8}alkyl, C_{3-6}cycloalkyl, C_{6-10}aryl or C_{7-14}aralkyl;

with the proviso that when R^w, R^x, R^y and $R^{z'}$ are each hydrogen, and <u>----</u> is a double bond, R^z is not hydroxy;

or a pharmaceutically acceptable salt thereof.

3. A compound of claim 2 wherein R^w is hydrogen.

4. A compound of claim 3 wherein R^z is hydroxy, $-OC(O)R^s$, $OC(O)NR^tR^u$ or $-OC(O)OR^v$; R^s, R^t, R^u and R^v are as defined in claim 1; with the proviso that when R^x and R^y are each hydrogen and <u>----</u> is a double bond, R^z is not hydroxy.

5. A compound of claim 4 wherein R^x and R^y are each hydrogen with the proviso that when <u>----</u> is a double bond, R^z is not hydrozy.

6. A compound of claim 5 wherein <u>----</u> is a double bond or an epoxy.

7. A compound of claim 6 wherein <u>----</u> is a double bond.

8. A compound of claim 7 wherein R^z is $-OC(O)R^s$; R^s is hydrogen, C_{1-8}alkyl or quinoxalyl.

9. A compound of claim 7 wherein R^z is $-OC(O)NR^tR^u$; R^t is hydrogen, and R^u is C_{1-8}alkyl, amino-substituted C_{1-8}alkyl, pyridyl or quinoxalyl; or R^t and R^u are each C_{1-8}alkyl.

10. A compound of claim 7 wherein R^z is $-OC(O)OR^v$; R^v is halo-substituted C_{1-8}alkyl.

11. A compound of Claim 8 wherein R^s is methyl.

12. A compound of claim 8 wherein R^s is quinoxalyl.

13. A compound of claim 8 wherein R^s is hydrogen.

14. A compound of claim 8 wherein R^z ~~R^s~~ is n-heptanoyl.

15. A compound of claim 9 wherein R^t is hydrogen and R^u is methyl.

16. A compound of claim 9 wherein R^t is hydrogen and R^u is quinoxalyl.

17. A compound of claim 9 wherein R^t and R^u are each ethyl.

18. A compound of claim 9 wherein R^t is hydrogen and R^u is 5-aminopentyl.

19. A compound of claim 9 wherein R^t is hydrogen and R^u is 2-pyridyl.

20. A compound of claim 10 wherein R^v is 2,2,2-trichloroethyl.

21. A compound of claim 6 wherein $\underline{----}$ is an epoxy.

22. A compound of claim 21 wherein R^Z is hydroxy.

23. A compound of claim 3 wherein R^Z is hydrogen.

24. A compound of claim 23 wherein ---- is a single bond.

25. A compound of claim 24 wherein R^X and R^Y are each hydrogen.

26. A compound of claim 23 wherein ---- is a double bond.

27. A compound of claim 26 wherein R^X and R^Y are each hydrogen.

28. A compound of claim 26 wherein one of R^X and R^Y is hydroxy.

29. A compound of claim 3 wherein R^z is hydroxy, one of R^x or R^y is hydroxy and the other is hydrogen, and ---- is a double.

30. A method for treating malignant tumor sensitive to the compound of claim 1 in an animal which includes administering to said animal an antitumor effective amount of a compound of claim 1.

31. A pharmaceutical composition including a compound of claim 1 and a pharmaceutically acceptable carrier.

32. A compound according to claim 1 substantially as described herein with reference to any one of the examples.

33. A method of preparation of a compound according to claim 1 substantially as described herein with reference to any one of the examples.

Dated: 6 January, 1995
PHILLIPS ORMONDE & FITZPATRICK
Attorneys for:
BRISTOL-MYERS SQUIBB COMPANY

David B Fitzpatrick

ABSTRACT

The present invention relates to a novel and efficient process for the preparation of 8-hydroxybicyclo[7.3.1]tridec-4-ene-2,6-diyne ring system which is part of the aglycone of esperemicin and to novel cytotoxic antitumor agents having said bicyclic ring system. The present invention also provides a method for treating mammalian malignant tumors by administering to an animal in need of such treatment an antitumor effective amount of a compound of the present invention.