

## Natural Chlorine Updates – No. 3

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## I. Introduction

This literature review is the third in a series of periodic updates to the natural halogen literature, with a particular focus on organochlorine compounds.

The coverage is approximately from mid-November 1995 to mid-April 1996, with inclusions of earlier material as appropriate.

Several reviews of natural organochlorines are in press and will soon appear in the context of larger discussions of the chlorine issue (1-3). In addition, this topic will be presented at the MIT Chlorine Conference (4), the 14th Annual Meeting of the Society of Environmental Toxicology and Chemistry (5), and a special Colloquium on Biohalogenation (6). Bayer has published a timely, exhaustive, and elegant brochure entitled "Chemistry with Chlorine", which examines the benefits and risks of chlorine in our society (7).

A review of the production of organohalogen compounds by basidiomycetes fungi has appeared (8). Some 53 such compounds (halomethanes, halogenated aromatics, haloaliphatic compounds) have been isolated from 34 genera of basidiomycetes. These natural organochlorines have physiological roles in biosynthesis and are often biologically active compounds (e.g., antibiotic or antifungal).

An excellent review of the chloroindole auxins of various plants and their possible function has been published (9). A thorough review on the sources, strengths, and chemical processes for chlorine and nine reactive chlorine species has appeared (10). The authors emphasize that "by far the most vigorous chlorine cycling appears to occur among seasalt aerosol, HCl, and Cl<sub>2</sub>\* (thought to be HOCl and/or Cl<sub>2</sub>). The principal sources of reactive chlorine are volatilization from seasalt (enhanced by anthropogenically generated reactants), marine algae, volcanoes, and coal combustion (natural sources being thus quite important to the budget)" (10).

Fleming has published a review on "Organochlorines in Perspective", which provides extensive coverage of natural organochlorines and the occurrence of these compounds in foods (11).

## II. New Natural Organohalogens

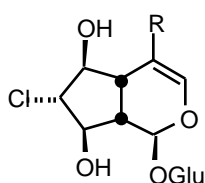
The discovery of new natural organochlorine, organobromine, and organoiodine compounds

continues at an amazing rate. 154 new natural organohalogens are reported herein, bringing the total to 2685. It seems likely that 3000 natural organohalogens will have been described by the turn of the century. As in previous *Updates*, only new natural organohalogens are assigned a compound number.

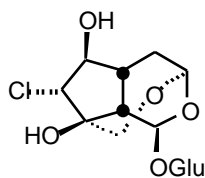
The remarkably active Ecuadorian frog metabolite epibatidine, which was discussed in *Updates No. 2*, is now commercially available (12).

A surprising development is the report of the production of both trichloroethylene (1) and perchloroethylene (2) by 27 species of marine macroalgae and a microalga (13). The highest production rates were exhibited by *Asparagopsis taxiformis* and *Falkenbergia hillebrandii*, and the authors conclude that "the measured rates suggest that emission of trichloroethylene and perchloroethylene from the oceans to the atmosphere may be of such a magnitude that it cannot be neglected in the global atmospheric chlorine budget" (13). These workers have also reported the natural formation of chloroform (14). McCulloch and Midgley have concluded that "the calculated atmospheric concentration of trichloroethylene is very much less than that observed, suggesting a significant additional global source of this compound" (15).

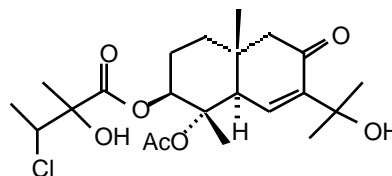
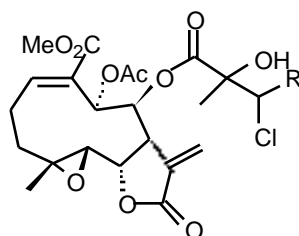
The iridoid 7-chlorodeutzol (3) from *Mentzelia* sp. has apparently only been reported in a Ph.D. thesis and in a review of iridoids (16). This compound along with mentzefoliol (4) and glucosylmentzefoliol (5) have been isolated from *Mentzelia cordifolia*, a South American shrub (17). The absolute configuration of the previously known iridoid glutinoside (*Rehmannia glutinosa*) has been determined as shown (18). The antibacterial sesquiterpene 6 has been found in *Pluchea arguta* (19), and *Centaurea conifera* has yielded the C-17 epimer of chlorohyssopifolin A (= centaurepensin), which was first described in *Updates No. 1*, along with the well known chlorojanerin and chlorohyssopifolin A (20). The eastern India medicinal plant *Enhydra fluctuans* has furnished two new chlorinated melampolides, 7 and 8 (21).



- 3** R=Me (7-chlorodeutzol)  
**4** R=CH<sub>2</sub>OH (mentzefoliol)  
**5** R=CH<sub>2</sub>OGlu (glucosylmentzefoliol)

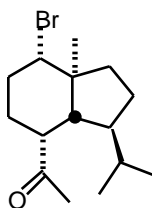
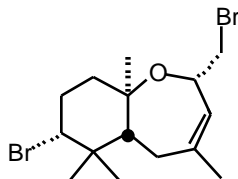


glutinoside

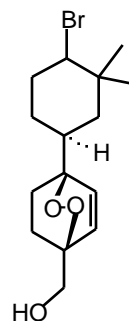
**6**

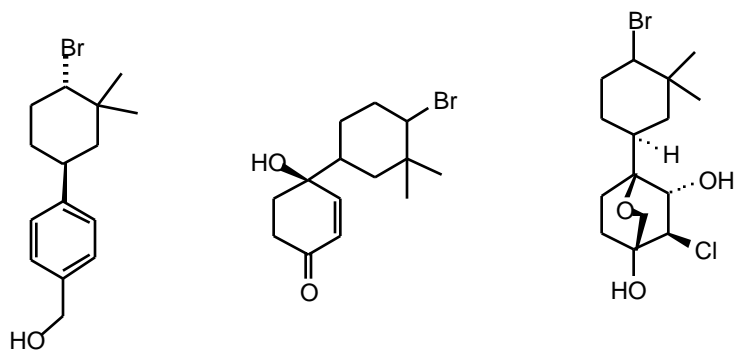
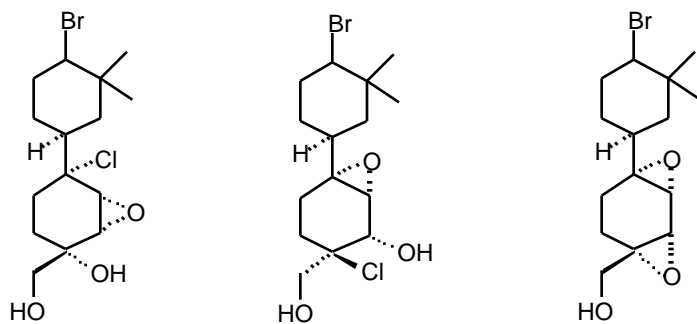
- 7** R=H  
**8** R=Me

The red alga *Laurencia marianensis*, which is a new species from the Great Barrier Reef, has yielded the new sesquiterpene **9**, along with the known pacifenol and deoxyrepacifenol, which are now fully characterized by NMR for the first time (22). Likewise, the absolute configuration of palisadin B from *Laurencia Karlae* has been determined by X-ray crystallography (23). This sesquiterpene had been previously isolated in 1980 (24). The Philippine *Laurencia majuscula* has furnished thirteen novel halogenated sesquiterpenes (**10-22**) (25). The major compounds are the majapolenes A (**10, 11**) (two diastereomers), which are also found in *Laurencia caraibica*. Most occur as inseparable diastereomers (hence, two compound numbers are listed).

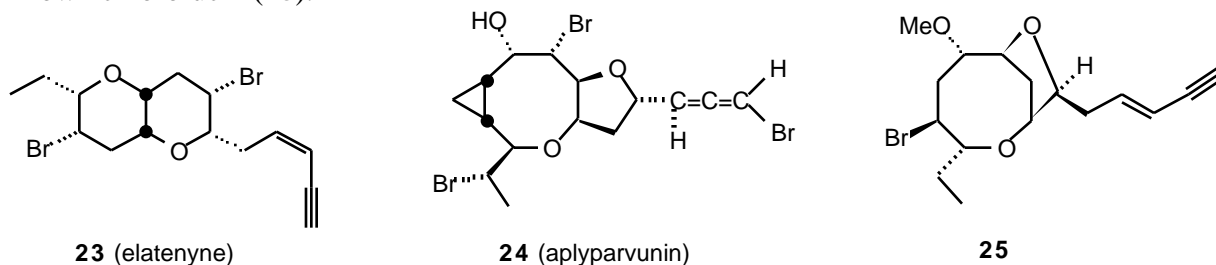
**9**

palisadin B

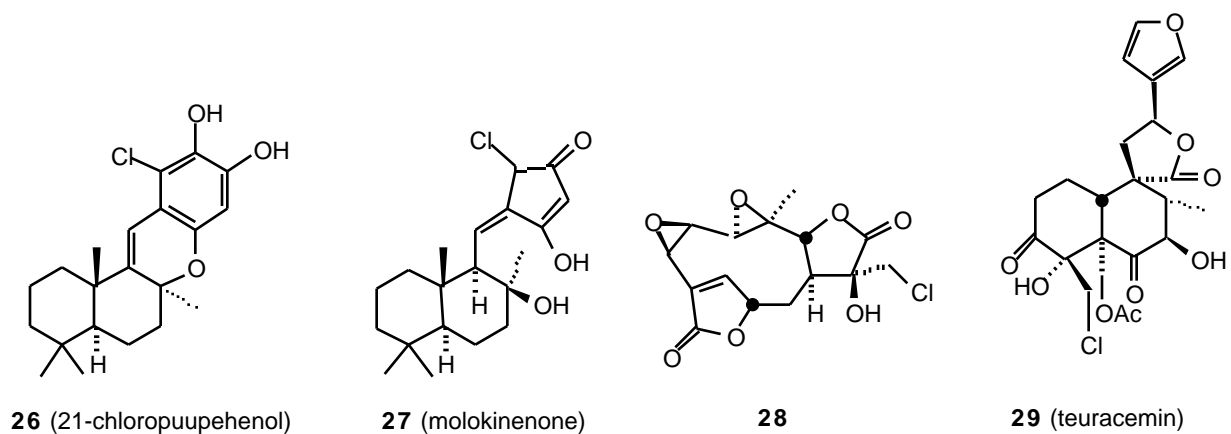
**10, 11** (majapolene A)

**12** (majapolene B)**13, 14** (majapolene)**15, 16** (majapol A)**17, 18** (majapol B)**19, 20** (majapol C)**21, 22** (majapol D)

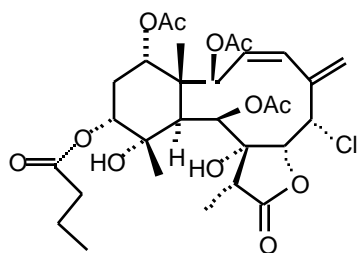
The Australian red alga *Laurencia elata* produces the brominated acetogenin elatenyne (**23**) (**26**), and the sea hare *Aplysia parvula*, known to feed on red algae, contains aplyparvunin (**24**) (**27**). The red alga *Dasyphila plumariodes* from the Coral Sea produces the novel **25** along with the known chlorofucin (**28**).

**23** (elatenyne)**24** (aplyparvunin)**25**

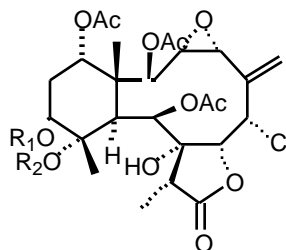
Quite a few new diterpenes have been described since the last *Updates*. Two Hawaiian *Hyrtios* spp. sponges from Oahu and the Molokini Crater on Maui have yielded 21-chloropuupehenol (**26**) and molokinenone (**27**), respectively, in addition to the known 21-chloro- and 21-bromopuupehenone (**29**). The novel germacranolide **28** has been isolated from the Philippine plant *Mikania cordata* (**30**). The new *neo*-clerodane teuracemin (**29**) is found in *Teucrium racemosum* (**31**). An examination of fresh plant material showed the presence of **29** by TLC.



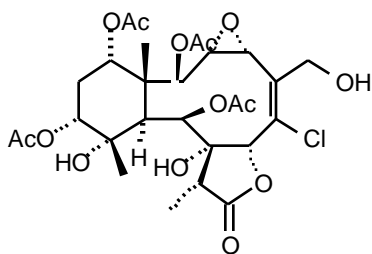
Six new chlorinated briareins have been identified in the Puerto Rican gorgonian *Briareum asbestinum* (**30-35**) (32).



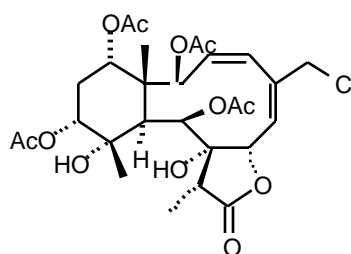
**30** (briarein C)



**31**  $R_1=R_2=Ac$  (briarein D)  
**32**  $R_1=Ac, R_2=H$  (briarein E)  
**33**  $R_1=COPr, R_2=Ac$  (briarein G)

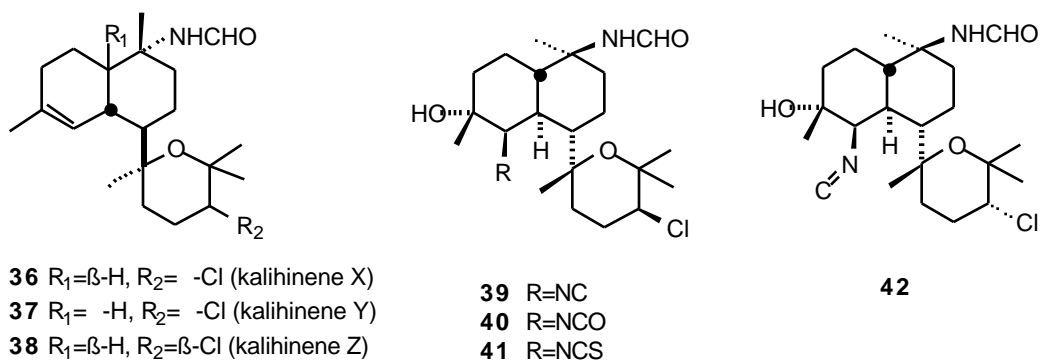


**34** (briarein F)

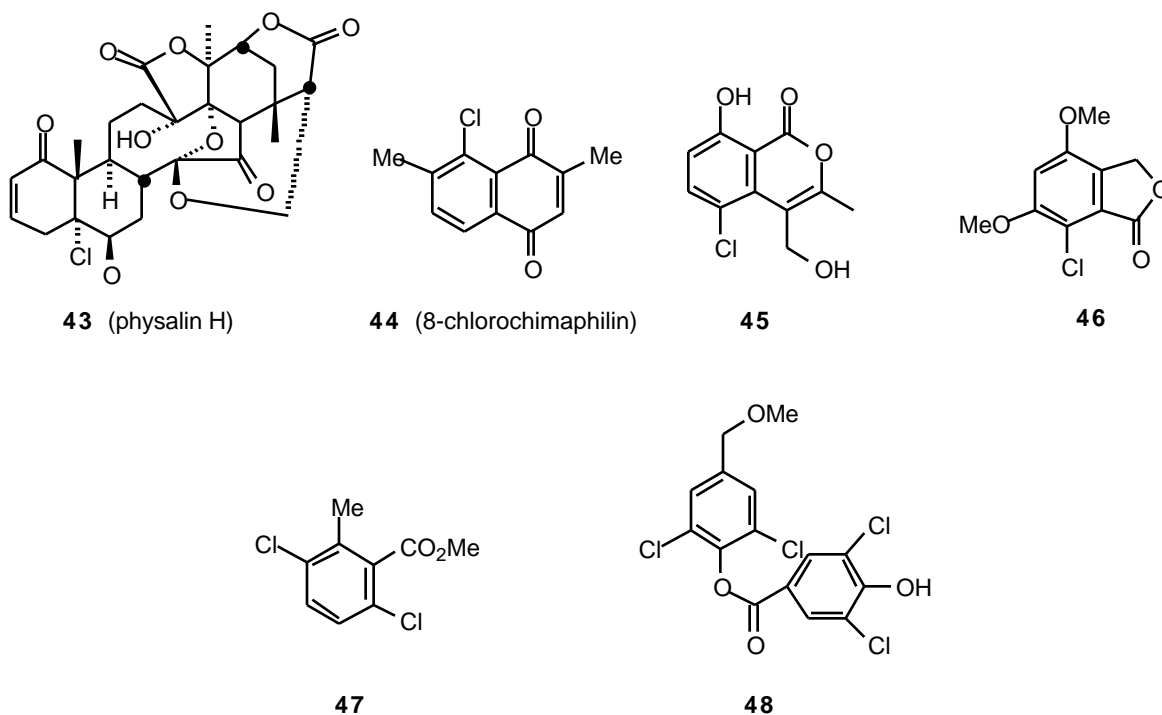


**35** (briarein J)

The marine sponge *Acanthella cavernosa*, which has been a rich source of novel metabolites, has yielded several new antifouling kalihinenes (**36-38**) (33). These compounds show activity against the barnacle larvae of *Balanus amphitrite*. Another study of this sponge yielded the new diterpenes **39-42** (34).

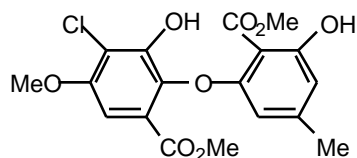


The steroid physalin H, which was previously thought not to contain chlorine, has been assigned structure **43** (35). This metabolite is found in *Physalis alkekengi* L. var. *francheti*. Several new simple plant and fungal metabolites have been identified in recent years. These include 8-chlorochimaphilin (**44**) (*Moneses uniflora*) (36), **45** (*Heterbasidion annosum*) (37), **46** (*Luecoagaricus carneifolia*) (38), **47** (*Kuehneromyces mutabilis*) (39), and **48** (*Hypholoma fasciculare*) (40).

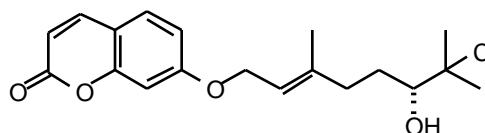


The fungus *Pestalotiopsis* sp. produces the endothelin antagonist RES-1214-2 (**49**) (41), and the Indonesian medicinal plant *Aegle marmelos* has yielded chloromarmin (**50**) (42). The lichen *Catarrhaphia dictyoplaca* contains the depsidone cyclographin (**51**) (43), and *Lachnum papyraceum* has been found to synthesize the chlorinated coumarins **52-54** (44). In the presence of added bromide, brominated coumarins are also formed, but these are not considered to be

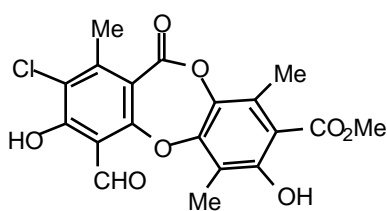
natural. However, bromo compounds also continue to be found in nature. The lignan **55** is found in *Gmelina arborea* (45) and a detailed structural study of the brominated lactones of *Delisea pulchra* has established their absolute configuration (46).



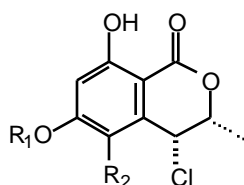
**49** (RES-1214-2)



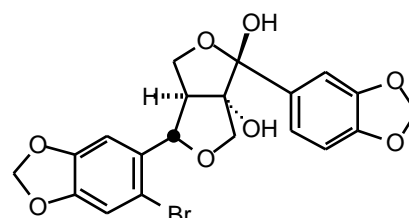
**50** (chloromarmin)



**51** (cyclographin)

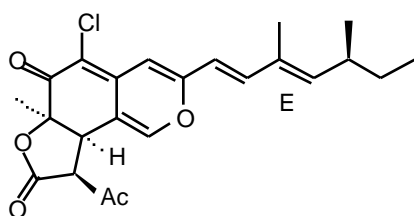


**52**  $R_1=H, R_2=H$   
**53**  $R_1=H, R_2=OH$   
**54**  $R_1=Me, R_2=H$

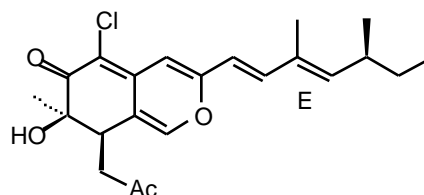


**55**

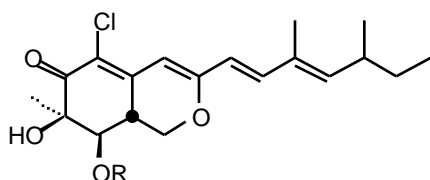
The fungus *Penicillium multicolor* has furnished a series of isochromophilones (**56-63**), which are potent ACAT inhibitors (47, 48). The former study also established the structure of the venerable sclerotiorin. The fungus *Talaromyces helicus* has yielded the new azaphilones helicisins A-D (**64-67**) (49).



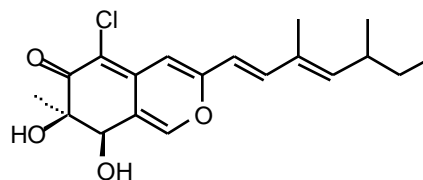
**56** (isochromophilone I)  
**57** (Z-isochromophilone I)



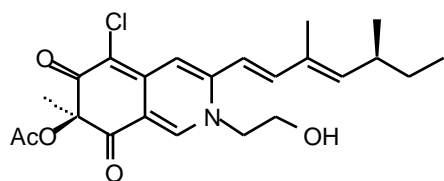
**58** (isochromophilone II)  
**59** (Z-isochromophilone II)



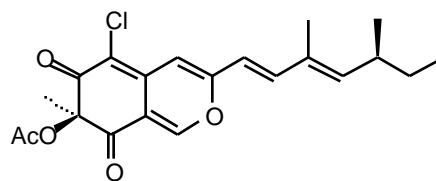
**60**  $R=H$  (isochromophilone III)  
**61**  $R=Ac$  (isochromophilone IV)



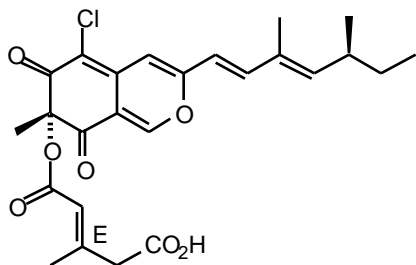
**62** (isochromophilone V)



**63** (isochromophilone VI)

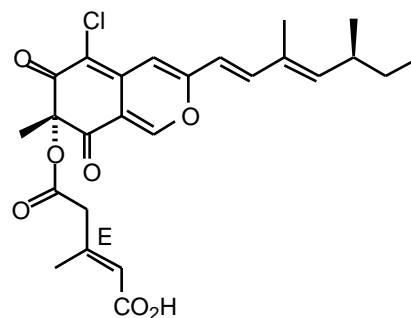


sclerotiorin



**64** (helicisin A)

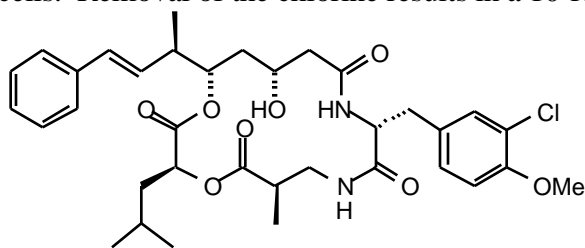
**65** (Z)(helicisin B)



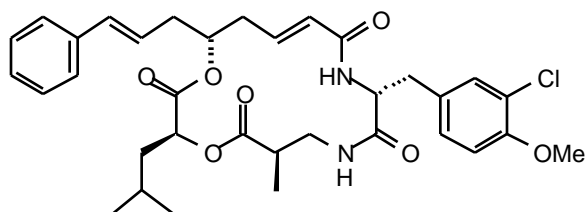
**66** (helicisin C)

**67** (Z)(helicisin D)

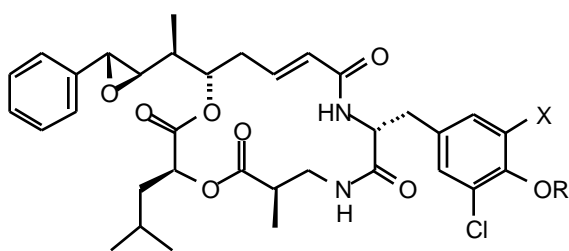
In a powerful display of tenacity and skill, Moore and his colleagues have isolated an additional 16 new chlorine-containing cryptophycins (**68-83**) from the blue-green alga *Nostoc* sp. (50). A few of the 16 are shown below and several have enormous biological activity even against solid tumors. It is important to note that the chlorine is essential for optimal activity against cancer cells. Removal of the chlorine results in a 10-fold reduction in cytotoxicity.



**68** (cryptophycin-30)



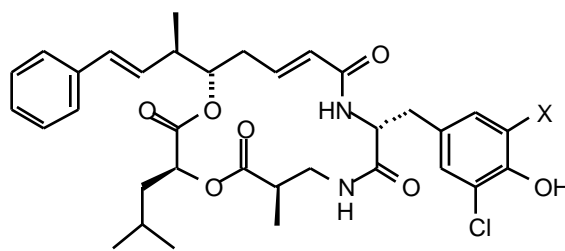
**69** (cryptophycin-40)



**70** R=H, X=H (cryptophycin-16)

**71** R=H, X=Cl (cryptophycin-23)

**72** R=Me, X=Cl (cryptophycin-31)



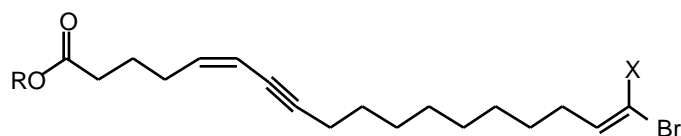
**73** X=H (cryptophycin-17)

**74** X=Cl (cryptophycin-45)

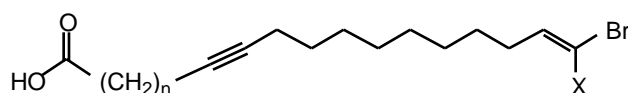
[not shown: cryptophycin-26 (**75**), -28 (**76**), -18 (**77**), -29 (**78**), -50 (**80**), -54 (**81**), -49 (**82**), -19 (**83**)]

The Okinawan sponge *Xestospongia* sp. contains 14 new brominated fatty acids, in addition to 3 others reported earlier as phospholipids (51). These compounds are shown below (84-97).

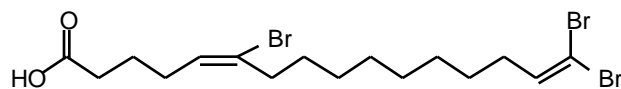
An anemone (*Condylactis gigantea*) and a zoanthid (*Palythoa caribaeorum*) contain fatty acid 98 (52).



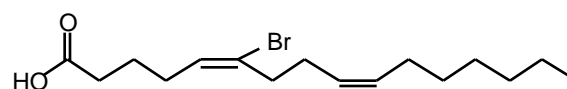
- 84 R=H, X=Br  
 85 R=X=H  
 86 R=Me, X=H  
 87 R=Me, X=Br



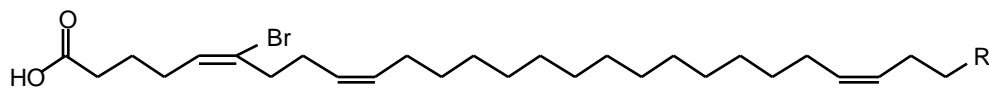
- 88 n=3 X=Br  
 89 n=3 X=H  
 90 n=5 X=Br  
 91 n=5 X=H



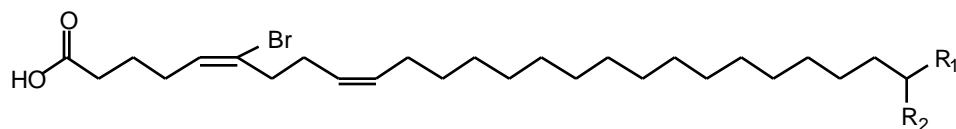
92



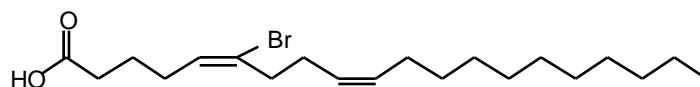
93



- 94 R=H  
 95 R=Me

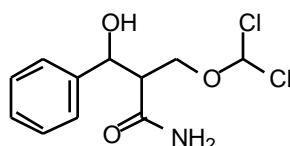
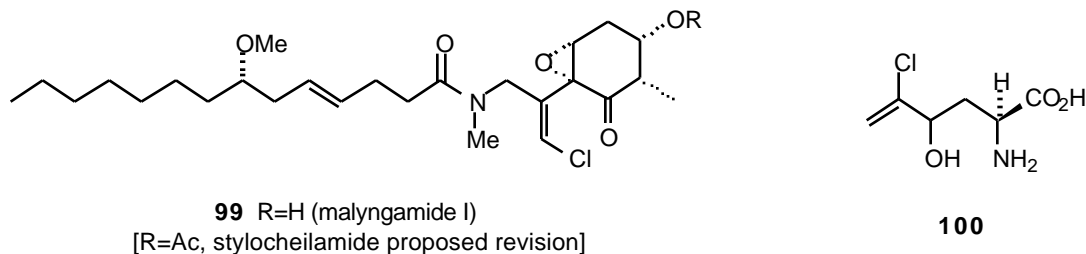


- 96 R<sub>1</sub>=R<sub>2</sub>=Me  
 97 R<sub>1</sub>=H, R<sub>2</sub>=*i*-Pr

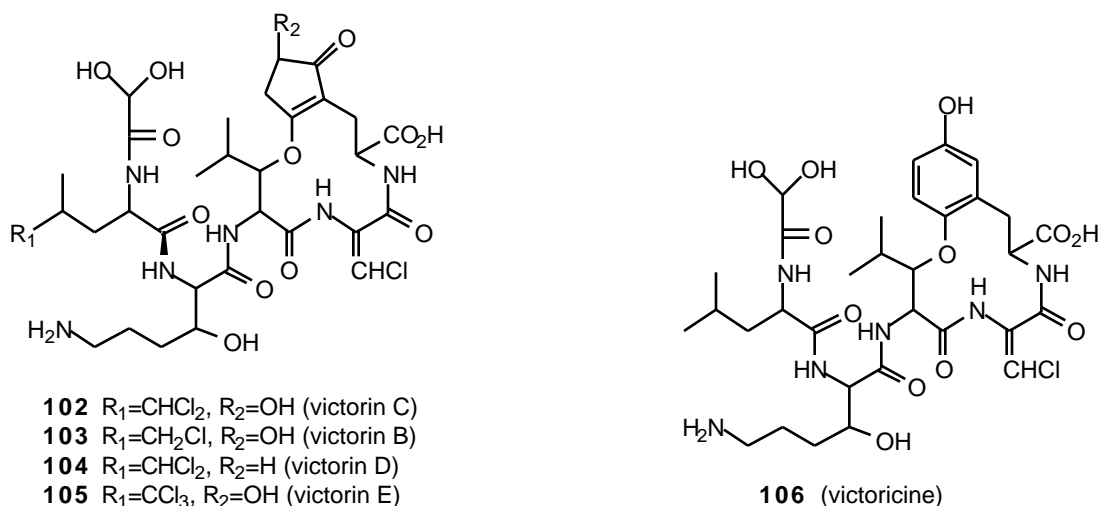


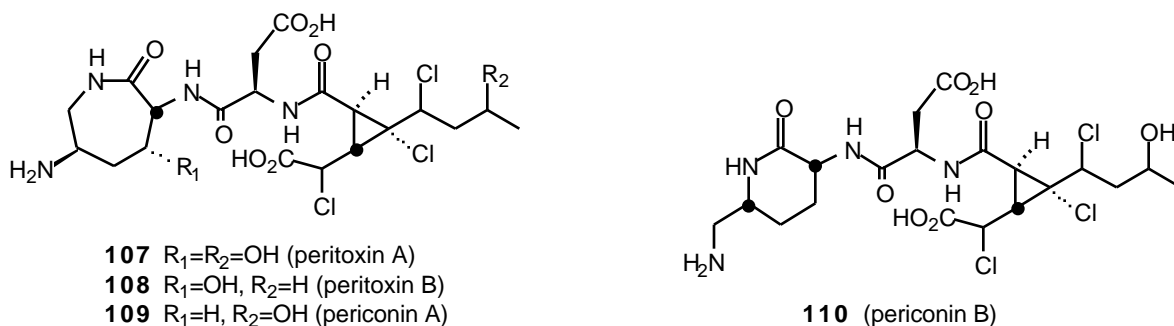
98

The novel malyngamide I (**99**) was isolated from the tropical marine blue-green bacterium *Lyngbya majuscula* (53), and this study also suggested a structural revision of the known stylocheilamide. The biosynthesis of the known chlorine-containing amino acid armentomycin has been reported (54), and a new amino acid **100** has been extracted from the mushroom *Amanita gymopus* (55). The antifungal compound acrodontiolamide (**101**), which is structurally related to chloramphenicol, is produced by *Acrodontium salmonium* (56).

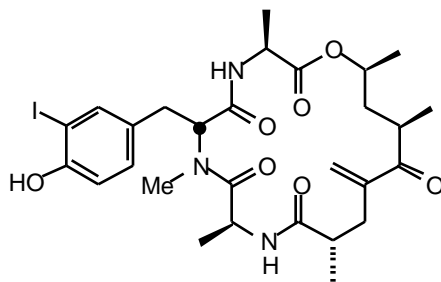


A number of chlorinated toxins from *Cochliobolus victoriae*, the causal agent of victoria blight of oats, have been identified as victorin C (**102**), B (**103**), D (**104**), E (**105**), and victoricine (**106**) (57, 58). The fungal pathogen *Periconia circinata*, which causes milo disease of grain, has yielded peritoxins A (**107**) and B (**108**), and periconins A (**109**) and B (**110**) (59).





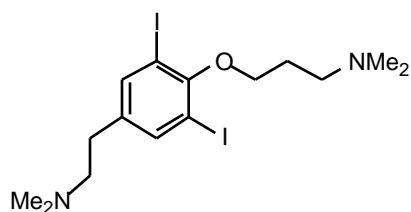
Several new halogen-containing cyclic peptides have been discovered since the last *Updates*. Due to their complexity, these compounds are not each shown here. The sponge *Halichondria cylindrata* contains halicylindramides D (**111**) and E (**112**), both which contain a 4-bromophenylalanine unit (60), and a *Theonella* sp. sponge produces theonellamides A-E (**113-117**) all of which contain bromine (61). The sponge *Cymbastela* sp. produces several known halogenated cyclic peptides (geodianolides A-F, hemiasterlin) in addition to the new geodiamolide G (**118**) (62).



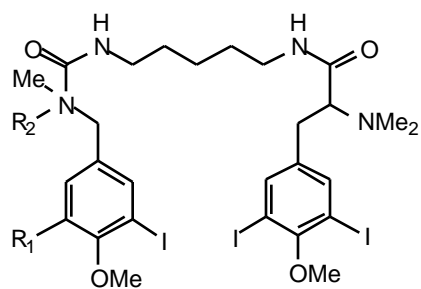
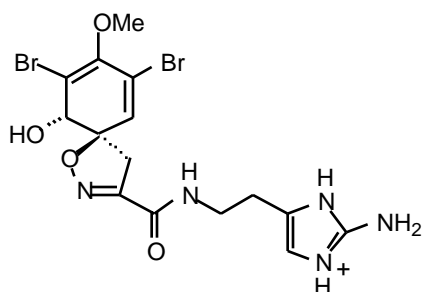
**118** (geodiamolide G)

Synthetic analogs of the cyclic peptides syringomycin and syringotoxin demonstrate that the C-terminal tripeptide, which contains a 4-chlorothreonine unit, is important for antibiotic activity (63). A full paper describing the structures of the previously known cyclic peptides astins A, B, and C has appeared (64). These *Aster tataricus* compounds each contain a chloro-proline residue.

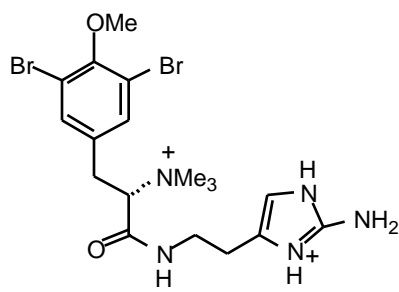
Several new halogenated tyrosine metabolites have been found in marine organisms. The Senegalese sponge *Ptilocaulis spiculifer* contains dakaramine (**119**) (65), and the colonial ascidian *Aplidium* sp. secretes the novel iodine-containing, cytotoxic metabolites **120-122** (66). The sponge *Pseudoceratina verrucosa* has yielded the novel pseudoceratinines A-C (**123-125**), in addition to the known aplysamine-1, -2, purealin, and purealidins A and B (67).



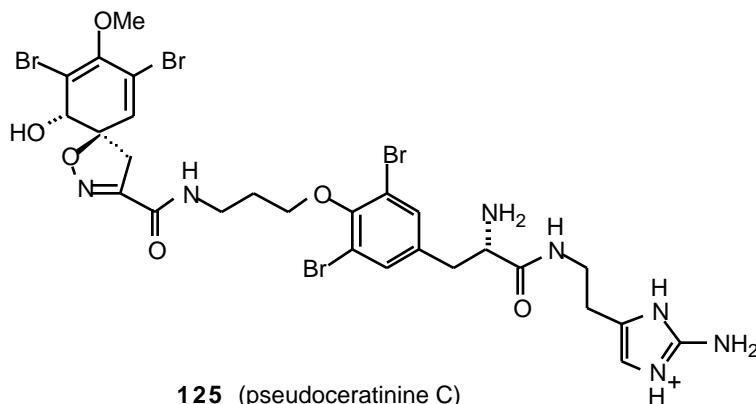
119 (dakaramine)

120 R<sub>1</sub>=H, R<sub>2</sub>=Me121 R<sub>1</sub>=I, R<sub>2</sub>=Me122 R<sub>1</sub>=R<sub>2</sub>=H

123 (pseudoceratinine A)

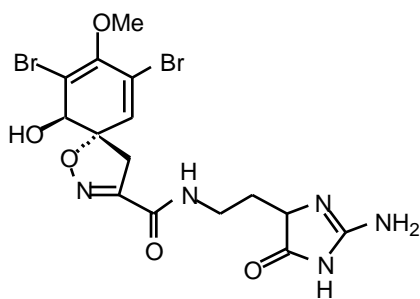


124 (pseudoceratinine B)

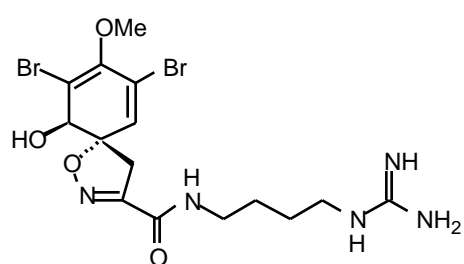


125 (pseudoceratinine C)

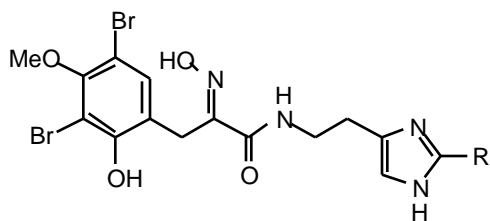
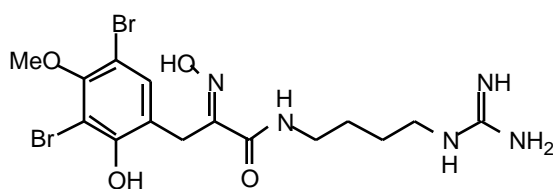
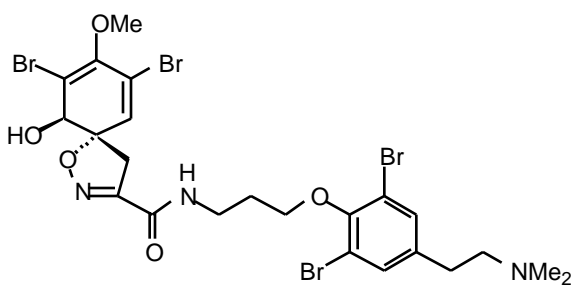
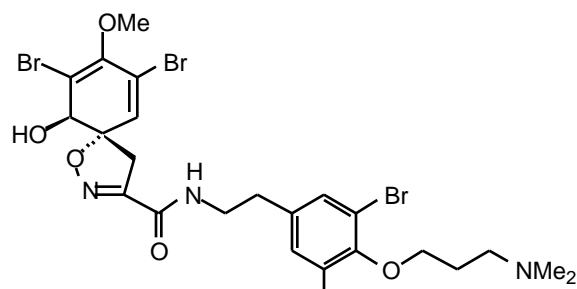
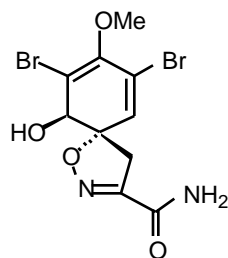
The incredibly prolific sponge *Psammaphysilla pura* from Okinawa has afforded another nine new bromine-containing tyrosines, the purealidins K-R (**126-133**) (68). Purealidin J seems to be the same (or the enantiomer) as the free base of pseudoceratinine A.



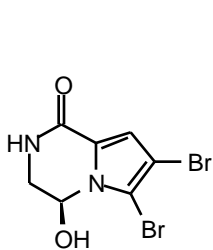
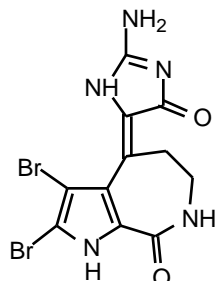
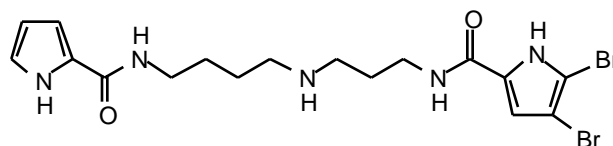
126 (purealidin K)



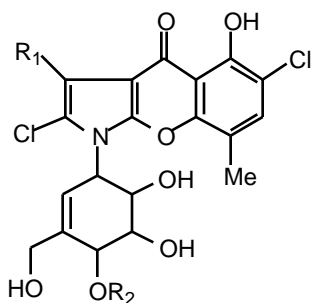
127 (purealidin L)

**128** R=NH<sub>2</sub> (purealidin M)**129** R=H (purealidin N)**130** (purealidin O)**131** (purealidin P)**132** (purealidin Q)**133** (purealidin R)

Pyrroles and indoles continue to be highlighted in the field of naturally occurring organohalogen compounds. The novel fused pyrrole longamide (**134**) is found in the sponge *Agelas longissima* (69), and the sponge *Axinella carteri* produces 3-bromohymenialdisine (**135**) (70). The novel antifouling spermidine metabolite pseudoceratidine (**136**) has been extracted from the sponge *Pseudoceratina purpurea* (71).

**134** (longamide)**135** (3-bromohymenialdisine)**136** (pseudoceratidine)

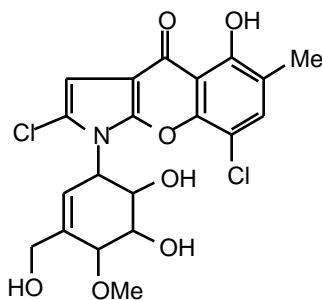
The microbe *Actinomadura spiralis* has yielded seven novel chlorinated pyralomicins (**137-143**) (72).



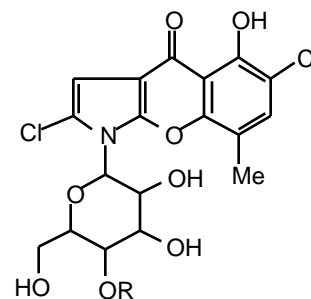
**137** R<sub>1</sub>=H, R<sub>2</sub>=Me (pyralomicin 1a)

**138** R<sub>1</sub>=R<sub>2</sub>=H (pyralomicin 1c)

**139** R<sub>1</sub>=Cl, R<sub>2</sub>=H (pyralomicin 1d)

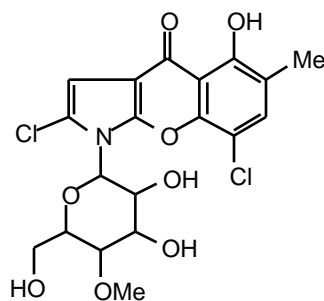


**140** (pyralomicin 1b)



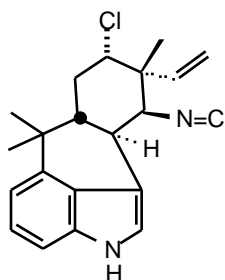
**141** R=Me (pyralomicin 2a)

**142** R=H (pyralomicin 2c)

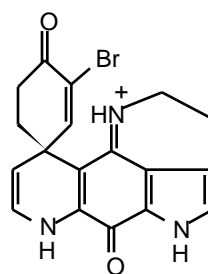


**143** (pyralomicin 2b)

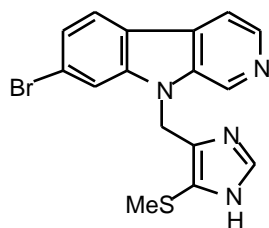
The blue-green alga *Hapalosiphon laingii*, which has been a rich source of chlorine-containing indoles, has afforded the new metabolite 12-epi-hapalindole G (**144**) (73). The antarctic sponge *Latrunculia apicalis* contains the new discorhabdin G (**145**) (74), and the marine ascidian *Didemnum* sp. has yielded the novel carbolines didemnolines A (**146**) and C (**147**) (75). The sea hare *Dolabella auricularia* contains dolabellin (**148**), a novel bis-thiazole (76).



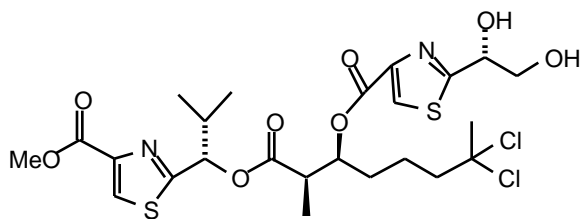
**144**



**145** (discorhabdin G)

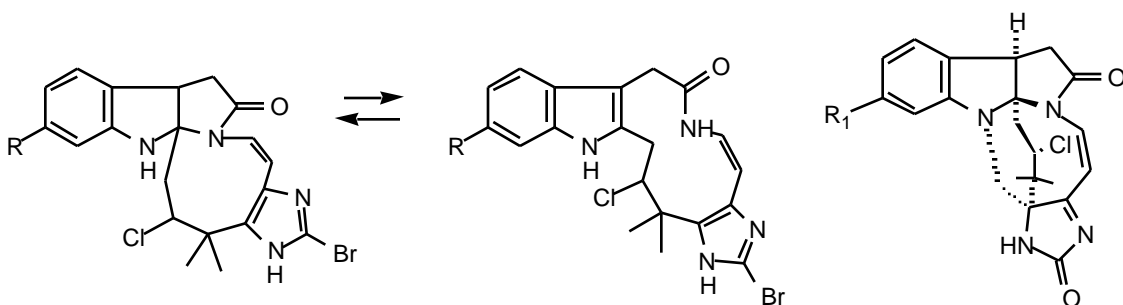


**146** R=MeS (didemnoline A)  
**147** R=MeSO (didemnoline C)



**148** (dolabellin)

The bryozoan *Securiflustra securifrons* produces the securamines A-D (**149-152**), the former two of which are in equilibrium with securines A and B (77).

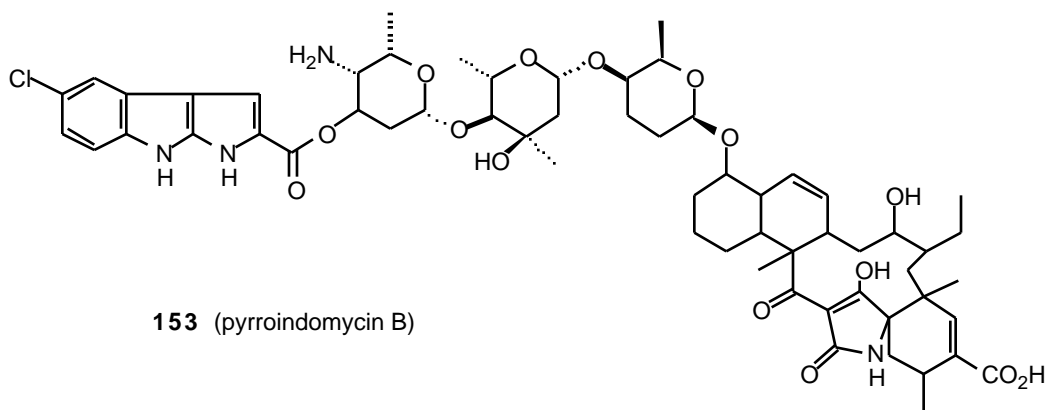


**149** R=H (securamine A)  
**150** R=Br (securamine B)

securine A (R=H)  
 securine B (R=Br)

**151** R=Br (securamine C)  
**152** R=H (securamine D)

The microorganism *Streptomyces rugosporus* produces the novel antibiotic pyrroindomycin B (**153**), which is active against both methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant Enterococci (78).

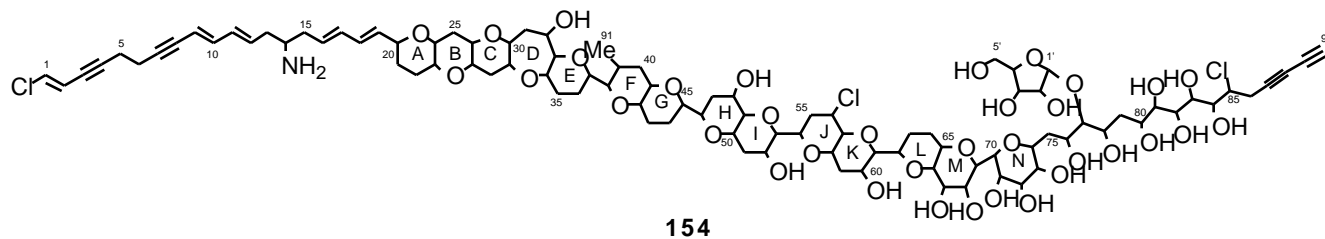


**153** (pyrroindomycin B)

In an extraordinary finding, de Blas has shown that benzodiazepines, including several chlorine-containing examples, are found in human and animal brains. These compounds were previously found in several plants (79, 80). There is strong evidence of the *in vivo* formation of chlorinated benzodiazepines in the mammalian brain (80). For comparison, the biosynthesis of the

*Penicillium cyclopium* benzodiazepine alkaloids cyclopeptine, dehydrocyclopeptine, cyclopenin, and cyclophenol is well established (81, 82). However, until this finding is confirmed, such natural chlorine-containing mammalian benzodiazepines will not be counted here.

It is fitting to end this section on new natural organohalogen compounds with the presentation of prymnesin-2 (**154**), a potent chlorine-containing polyether from the red tide alga *Prymnesium parvum* (83).



### III. Biohalogenation

The interest in biohalogenation remains as keen as ever and a special Colloquium on this subject will be held in Amsterdam in September, 1996 (6).

Numerous investigations have focused on the isolation, purification, and characterization of haloperoxidase enzymes. A few recent examples include chloroperoxidase from *Streptomyces lividans* (84), *Curvularia inaequalis* (85), and *Serratia marcescens* (86). In some cases the gene responsible for encoding the chloroperoxidase was cloned. Chloroperoxidase (CPO) from *Caldaromyces fumago* has been used in asymmetric oxidations (87), and a study of the reaction between CPO, chloride, and humic acid material has demonstrated the formation of chloroform, chloroacetic acids, chloroacetones, chloropyruvic acids, chloromaleic acids, chlorofumaric acids, chloroacetonitriles, and chloroacetamides (88). The authors conclude that "chloroperoxidase-mediated chlorination is an environmentally significant process" (88).

The bromoperoxidase from *Streptomyces aureofaciens* has been successfully characterized by X-ray crystallography (89). The biosynthesis of halomethanes by a methyltransferase enzyme from *Brassica oleracea* has been determined (90). Moreover, this enzyme, or an equivalent one, which is capable of producing CH<sub>3</sub>Cl, CH<sub>3</sub>Br, and CH<sub>3</sub>I, was found in 87 of 118 higher plant species. This study illustrates the potential of higher plants to contribute to the atmospheric budget of halomethanes. More recently, this methyltransferase enzyme has been purified and characterized (91). A study of the production of chloroform and other haloalkanes by 11 species of macroalgae

indicates that this may represent a significant source of  $\text{CHCl}_3$  to the atmosphere (92). The other haloalkanes produced by these macroalgae are  $\text{CH}_3\text{I}$ ,  $\text{CH}_2\text{Br}_2$ ,  $\text{CHBr}_3$ ,  $\text{CHBr}_2\text{Cl}$ , and  $\text{CHBrCl}_2$ , and the release of these compounds was observed within a rock pool for the first time. Production of  $\text{CCl}_4$ ,  $\text{CHClCCl}_2$ ,  $\text{CCl}_2\text{CCl}_2$ , or  $\text{CH}_3\text{CCl}_3$  was not observed. Harper has published an excellent, concise review of the natural production of chloromethane and some other haloalkanes (93), and a study of the oceanic production of chloromethane in the northwest Atlantic ocean has been reported (94). Although the oceans remain an important natural source of  $\text{CH}_3\text{Cl}$ , the flux from ocean to atmosphere may be smaller than previously thought.

#### IV. Other Sources of Organohalogens

Biomass burning is a significant source of organohalogens.

A detailed examination of Canadian forest fires has been reported, but the organochlorine compounds identified in the smoke ( $\text{CH}_3\text{Cl}$ ,  $\text{CH}_3\text{CCl}_3$ ,  $\text{Cl}_2\text{C}=\text{CCl}_2$ ,  $\text{CCl}_4$ , CFC's) were assumed to be largely from anthropogenic sources, with the exception of  $\text{CH}_3\text{Cl}$  (95). It is interesting to note that 10,000 Canadian forest fires are reported annually, with lightning being responsible for 35% of these fires but consuming 85% of the total burn area. Two recent studies reiterate the large contribution of biomass burning to the production of atmospheric chloromethane (96, 97). However, biomass burning is not a significant source for other organochlorines ( $\text{CH}_2\text{Cl}_2$ ,  $\text{CHCl}_3$ ,  $\text{CCl}_4$ ,  $\text{CH}_3\text{CCl}_3$ ,  $\text{Cl}_2\text{C}=\text{CHCl}$ ,  $\text{Cl}_2\text{C}=\text{CCl}_2$ ), which have lower emission ratios (96).

A revised estimate of the atmospheric budget of  $\text{CH}_3\text{Br}$  puts the total emissions at 75-105 x  $10^6$  tons/year (91 x  $10^6$  tons/year is best estimate) with 26-67% of this from natural sources (46% best estimate) (98). A review on biomass burning has recently appeared (99).

Several studies have described the occurrence of halogenated organic compounds in water and sediments. For example, a study of the Skagerrak region of the North Sea revealed higher amounts of the biogenic haloalkanes (1-iodopropane, 2-iodopropane, 1-iodobutane, 2-iodobutane,  $\text{CH}_2\text{ClI}$ ,  $\text{CH}_2\text{I}_2$ ,  $\text{CH}_2\text{Br}_2$ ,  $\text{CHBr}_3$ ) than anthropogenic compounds ( $\text{CCl}_4$ ,  $\text{ClCH}=\text{CCl}_2$ ,  $\text{Cl}_2\text{C}=\text{CCl}_2$ ) (100). Another study indicates that organically bound halogens are produced in the forest soil, and that these compounds are part of the dynamic processes occurring during the decay of organic material in the soil of forests (101). A study of halogenated organic compounds in Denmark groundwaters

has revealed that chloroform is produced in soil and that halogenated organics are present in dissolved organic carbon originating from terrestrial and marine source rocks, from both coastal and non-coastal areas, and from both very old and recent rocks (102). An excellent summary of the evidence of both naturally produced and anthropogenic organohalogens in water and sediments is available (103). The major conclusion of this study in the context of the present survey is that the natural halogenation of humic substances is an important explanation for the widespread occurrence of organohalogens in unpolluted waters.

An examination of ancient sediments has shown unequivocally the presence of natural adsorbable organic halogens, in peat, lignite, bituminous coal, and anthracite, which reflect different stages of coalification.

Following two early reports on the presence of chloroaromatics and chloroalkanes in carbonaceous chondrites (meteorites) (105, 106), a more recent examination of four meteorites has shown the presence of adsorbable organic halogens (124-209 ppm) (107). For example, 2-chloro, 2,4- and 2,6-dichlorobenzoic acids could be detected in the Cold Bokkeveld meteorite.

The question of natural sources of dioxins and polychlorinated dibenzofurans is a hotly debated topic (108). But, there seems to be no doubt that some of the background levels of these organochlorines are from the combustion of organic matter (e.g., forest fires). A recent study of sediments revealed that both dioxins and chlorinated dibenzofurans were detected "in small but significant levels during the period 1882-1962," including sediments from 1882, 1906, 1922, 1938, 1954, and 1962. Increased levels of these compounds were found in sediments from the period 1970-1985 (109).

## V. Biodegradation

During the period surveyed by this *Updates*, a number of reports on the biodegradation of organic halogen compounds, as well as reviews on microbial reductive dehalogenation (110) and biodegradation of aromatic compounds by anaerobic and aerobic bacteria (111) have appeared.

A study has demonstrated that  $\text{CH}_3\text{Br}$  is rapidly and irreversibly removed by soil bacteria, representing a sink for  $\text{CH}_3\text{Br}$  of  $42 \pm 32 \times 10^6$  g/year (112). As a result, the authors of this study conclude that the  $\text{CH}_3\text{Br}$  ozone depletion potential is 30% smaller than previously estimated. The

reductive dehalogenation of trichloroethylene,  $\text{CHCl}_3$ ,  $\text{CH}_2\text{Cl}_2$ ,  $\text{CCl}_4$ , and  $\text{CH}_3\text{CCl}_3$  by the white rot fungus *Phanerochaete chrysosporium* has been observed (113). Long-chain haloalkanes are incorporated into fatty acids by *Rhodococcus rhodochrous* (114), which suggests a mechanism whereby such bacterial degradation products could enter the food chain.

Field studies have demonstrated the feasibility of treating polychlorophenol-contaminated soil with the lignin-degrading fungus *Phanerochaete sordida* leading to a 64% decrease in polychlorophenol after 5 months (115). Similarly, the biodegradation of chlorobenzene in contaminated soils by indigenous *Pseudomonas* sp. has been described (116), and the reductive dechlorination of dioxins and chlorinated dibenzofurans by anaerobic microorganisms has also been reported (117). The effect of various factors on the dehalogenation of chlorinated phenols during oxidative coupling has been examined (118). A novel catalytic system consisting of a phthalocyanine-iron complex and hydrogen peroxide converts chlorophenols to aliphatic diacids (119).

The crystal structure of the PCB-cleaving extradiol dioxygenase enzyme from *Pseudomonas cepacia* has been determined (120), and a study of the mechanisms whereby different white-rot fungi degrade lignin has been reported (121).

## VI. Function

A review of the utility of chlorine-containing aryl alcohols in the physiology of white-rot fungi has appeared (122). The function of these compounds was discussed in *Updates #1*.

The interaction between the iodine-containing calicheamicin and DNA has been probed in depth (123), and the potential anticancer utility of the chlorine-containing sponigistatin-1 has been emphasized in a news brief (124).

Finally, a review has noted the improvements made by the pulp and paper industry to reduce emissions of organochlorines and other chemicals to the environment (125).

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