

tion. Formation of a ketene from **3** is presumed to be minor since aromaticity must be destroyed. Significant amounts of products resulting from migration of oxygen were not detected.

In summary, only **2** produces a keto tautomer without a detectable amount of the corresponding phenol at 77°K. This ketone gains the least amount of resonance stabilization on enolization. Despite the large amount of ketone from **2**, this is the only oxide for which a ketene could not be detected as aromaticity in two rings must be destroyed. In contrast **1** produced the largest amount of ketene even though the concentration of the keto tautomer was below detection at 77°K. Migration of oxygen was readily detected for **1** and **2**. In principle these isomerizations might be explicable in terms of the generation of an oxene or oxygen atom from the parent oxide followed by readdition at a different pair of ring carbons to form an isomerized arene oxide. The extrusion of oxygen, though previously observed²⁴ for **1** and detected here for **2**, is an unlikely explanation for these isomerizations, since attempts to trap the oxygen liberated from arene oxides by reactive aromatic acceptors, such as anisole, have been unsuccessful.³³

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(33) Unpublished observations by D. R. Boyd, previously at NIH.

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Rhodophytin, a Halogenated Vinyl Peroxide of Marine Origin

Sir:

Marine algae have recently received considerable attention due to their synthesis of unusual secondary metabolites. In particular, members of the genus *Laurencia*¹⁻⁵ (Rhodomelaceae, Rhodophyta) are noted

(1) J. J. Sims, W. Fenical, P. Radlick, and R. M. Wing, *J. Amer. Chem. Soc.*, **93**, 3774 (1971).

(2) S. S. Hall, D. J. Faulkner, J. Fayos, and J. Clardy, *J. Amer. Chem. Soc.*, **95**, 7187 (1973).

(3) A. G. González, J. Darias, J. D. Martin, and C. Pérez, *Tetrahedron Lett.*, 1249 (1974).

(4) T. Irie, M. Suzuki, and T. Masamune, *Tetrahedron*, **24**, 4193 (1968).

(5) J. J. Sims, G. H. Y. Lin, R. M. Wing, and W. Fenical, *J. Chem. Soc., Chem. Commun.*, 470 (1973).

for their unique synthesis of bromine- and chlorine-containing compounds. Recently, we reported⁶ the X-ray structure of chondriol (**1**), an antiviral acetylene-containing metabolite identified first as a constituent of *Chondria oppositoclada* Dawson. Subsequent chemotaxonomic studies of this morphologically complex group of seaweeds have revealed the origin of chondriol as a distinct *Laurencia* species⁷ indigenous to the Gulf of California. In this communication I wish to report the structure of rhodophytin (**2**), a most unusual natural product obtained from the same *Laurencia* source. Rhodophytin contains the first example of a vinyl peroxide moiety.

Rhodophytin, $[\alpha]_D^{25} -141.5^\circ$ (*c* 6.85, hexane), is a light mobile oil obtained in high yield (0.05% dry weight) by column chromatography of a chloroform extract of the alga. The high resolution mass spectrum of rhodophytin showed an intense *M* - 16 fragment at 328/330/332, which established its halogen content ($C_{15}H_{18}OBrCl$). The facile loss of an oxygen atom under mass spectral conditions was the first indication of the peroxide functionality of this metabolite.

The infrared absorption of **2** showed the terminal acetylene (3300 cm^{-1}), the multiple double bonds (3030 and 1648 cm^{-1}), and the carbon-oxygen single bond stretch (1109 cm^{-1}), in close analogy to the spectral characteristics of chondriol. Bands were not observed for either the hydroxyl or carbonyl functional groups.

Hydrogenation of rhodophytin with platinum in ether gave 7-chloro-6-hydroxypentadeca-12-one. The nmr and mass spectra of this keto-alcohol, *m/e* 276 ($C_{15}H_{29}O_2Cl$), established that rhodophytin was based on an *n*-pentadecane skeleton and confirmed the presence of two oxygen atoms. An intense fragment at *m/e* 86 in the mass spectrum was strong evidence⁸ for positioning the carbonyl at C-12. Jones oxidation⁹ converted the keto-alcohol to 7-chloropentadeca-6,12-dione in high yield. A comparison of the 220-MHz nmr spectra of these products, aided by double resonance experiments, proved the vicinal arrangement of oxygen and chlorine atoms on C-6 and C-7 in these derivatives.

A comparison of the ¹³C nmr spectra of rhodophytin and chondriol (Table I) showed six identical olefin carbon atoms in each structure. It follows from the molecular weight and the total of 18 hydrogen atoms that rhodophytin must contain seven double-bond equivalents: one assigned to two halogen substituents, five for unsaturation, and one for the ring system. Since rhodophytin is based on an *n*-pentadecane skeleton, and, since neither oxygen atom component is part of a hydroxyl or carbonyl function, ring formation must involve peroxide bond formation. In confirmation, rhodophytin gives a strong iodine coloration upon treatment with acidified potassium iodide in aqueous methanol.¹⁰

(6) W. Fenical, K. B. Gifkins, and J. Clardy, *Tetrahedron Lett.*, 1507 (1974).

(7) W. Fenical and J. N. Norris, *J. Phycology*, in press.

(8) An *m/e* fragment = 86 is strongly suggestive of a ketone β scission reaction to yield $CH_2CH_2CH_2C(=OH^+)CH_2$. See F. W. McLafferty, "Interpretation of Mass Spectra," W. A. Benjamin, New York, N. Y., 1967.

(9) K. Bowden, I. M. Heilbron, E. R. H. Jones, and B. C. L. Weedon, *J. Chem. Soc.*, 39 (1946).

(10) A. G. Davies, "Organic Peroxides," Butterworths, London, 1961.

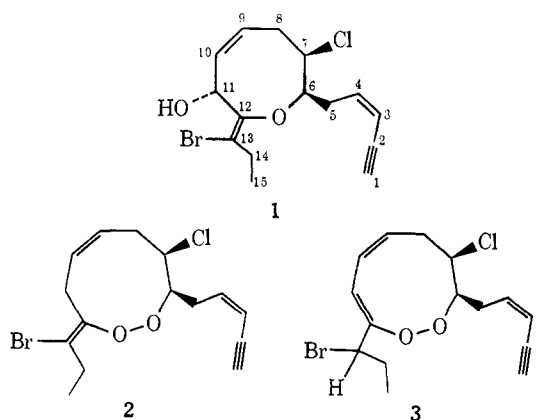
Table I. ^1H and ^{13}C Nmr Spectra of Chondriol^a and Rhodophytin

$^{13}\text{C}^b$		Proton (s) C no.	$^1\text{H}^c$	
Chondriol	Rhodophytin		Chondriol acetate	Rhodophytin
12.38 (15)	12.42 (15)	1	3.04 (2)	3.05 (2)
27.71 (5,8,14)	27.08 (5,8,11,14)	2		
32.76 (5,8,14)	29.41 (5,8,11,14)	3	5.68 (4)	5.53 (4)
33.97 (5,8,14)	32.52 (5,8,11,14)	4	6.09 (8)	6.00 (8)
62.99 (1,6,7)	33.78 (5,8,11,14)	5	2.82, 2.82 (m)	2.83, 2.83 (m)
68.14 (1,6,7)	63.58 (1,6,7)	6	4.83 (8)	4.38 (8)
73.53 (1,6,7)	76.11 (1,6,7)	7	3.91 (8)	3.89 (8)
80.03 (2)	79.60 (2)	8	3.13, 2.54 (8,m)	3.09, 2.40 (8,8)
82.46 (11)	82.61 (1,6,7)	9	5.81 (m)	5.53 (m)
110.47 (3,4,9,10)	110.86 (3,4,9,10)	10	5.88 (16)	5.73 (16)
113.28 (12,13)	112.71 (12,13)	11	6.60 (2)	3.76, 2.83 (8,4)
124.54 (3,4,9,10)	124.46 (3,4,9,10)	12		
134.49 (3,4,9,10)	130.67 (3,4,9,10)	13		
140.56 (3,4,9,10)	140.09 (3,4,9,10)	14	2.82 (m)	2.60 (m)
149.83 (12,13)	148.43 (12,13)	15	1.12 (3)	1.03 (3)

^a ^1H nmr values are for chondriol acetate. ^b Proton decoupled values in ppm downfield relative to internal TMS. Values in parentheses refer to potential carbon assignments. ^c ^1H values were recorded at 220 MHz and are expressed as ppm downfield from internal TMS (δ). Values in parentheses refer to band multiplicity.

The complete structure assignment of this unusual peroxide was facilitated by a comparison of the ^{13}C and proton nmr characteristics of this compound with those of chondriol. The 220-MHz proton nmr of rhodophytin was closely comparable to chondriol acetate for all protons except those associated with the alcohol portion of chondriol at C-11 (Table I). Comparisons of chemical shift, multiplicity, and coupling constants, together with double resonance experiments, showed **1** and **2** to be nearly identical in structure, stereochemistry, and ring confirmation. Protons on carbons 1–10 and 12–15 appear as nearly identical bands for the acetate of **1** and for **2**. The extra methylene protons in rhodophytin (C-11) appear as an AB system at δ 3.76 and 2.83, respectively, the lower field band indicating deshielding from the proximal bromine on C-13.

When rhodophytin was allowed to stand in unpurified CCl_4 , it was slowly but quantitatively converted to the conjugated diene peroxide (**3**), λ_{max} 220 (ϵ 10,400),



228 (ϵ 9350), and 275 nm (ϵ 7630), via an allylic rearrangement. This somewhat less stable and equally unusual peroxide¹¹ showed strong infrared bands at 1610 and 1640 cm^{-1} , indicative of the conjugated diene system, and also gave a strong iodide–iodine peroxide test.

Two other peroxides, ascaridole¹² and ergosterol

(11) This peroxide is very sensitive to traces of acid and cannot be stored. It is effectively reduced with sodium sulfite in aqueous methanol.

(12) H. Szmant and A. Halpern, *J. Amer. Chem. Soc.*, **71**, 1133 (1949).

peroxide,^{13,14} have been reported from natural sources. Each of these structures may be formally considered the cycloaddition product of an oxygen molecule with a conjugated diene precursor. Rhodophytin differs significantly from these earlier examples in that the ring system of **2** is probably generated from a hydroperoxide intermediate. Peroxidation of a logical precursor such as laurediol,¹⁵ followed by bromonium ion induced ring closure, would generate the cyclic peroxide structure of **2**.

Rhodophytin exhibits unusual thermal and base stability. These factors provided for its isolation and structure elucidation.

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A Nucleophilic Ethynyl Group Equivalent and Its Use in Conjugate Addition to α,β -Enones

Sir:

As a result of previous studies,¹ an excellent method is now available for the introduction of angular vinyl groups² in fused cyclic structures starting from a cyclic α,β -enone and the vinyl (\hat{V}) Gilman³ reagent $\hat{V}_2\text{CuLi}$. An analogous process for the establishment of angular

(1) E. J. Corey and R. L. Carney, *J. Amer. Chem. Soc.*, **93**, 7318 (1971).

(2) Substituents derivable from vinyl which can be generated¹ at angular positions by a further step include C_2H_5 , CH_2CHO , CHO , and COOH .

(3) H. Gilman, R. G. Jones, and L. A. Woods, *J. Org. Chem.*, **17**, 1630 (1952); H. Gilman and J. M. Straley, *Recl. Trav. Chim. Pays-Bas*, **55**, 821 (1936).