J. Am. Chem. Soc., 99, 4836 (1977); E. J. Corey, P. Ulrich, and J. M. Fitzpatrick, ibid., 98, 222 (1976).
(19) The corresponding diethyl acetals are also readily prepared from 4 (p-TsOH, EtOH, 5 min, 0 °C).
(20) We are presently investigating the thermal stability of anion 1.
(21) This compound was previously prepared in 10% overall yield from geranyl bromide by application of the reagent 2,4,4,6-tetramethyl-5,6-dihydro-1,3-oxazine (see ref 3). The low yield was attributed to the vigorous acid hydrolysis step required by this procedure. See T. Kato, H. Maeda, M. Tsunakawa, and Y. Kitahara, Bull. Chem. Soc. Jpn., 44, 3437 (1971).
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(23) With lithio reagent 1, the halide was recovered unchanged (in THF containing 1 equiv of HMPA) at temperatures between −78 to 0 °C.

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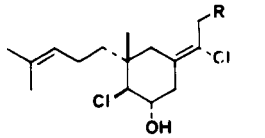
Carbonimidic Dichlorides from the Marine Sponge *Pseudaxinyssa pitys*

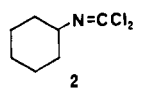
Sir:

Terpenoid isonitriles have been isolated from several sponges, mainly those of the order Halichondrida.[1] The isonitriles often coexist with the corresponding isothiocyanates, formamides, and primary amines.[2] We wish to report the isolation and structural elucidation of two carbonimidic dichlorides,[3] the first natural products found to contain this rare functionality.

The air-dried sponge *Pseudaxinyssa pitys* de Laubenfels (Axinellidae, Halichondrida)[4] was extracted with methanol. The chloroform-soluble material from the methanol extracts was chromatographed on Florisil to obtain the carbonimidic dichloride **1**, $C_{16}H_{23}NOCl_4$, $[\alpha]^{20}_D$ +36° (*c* 1.1, $CHCl_3$), as a clear oil (0.9% dry weight). The mass spectrum of **1** contained an $[M - Cl]^+$· cluster as the highest molecular weight peaks, as did the mass spectrum of cyclohexyl carbonimidic dichloride **2**, prepared by the method of Kühle et al.[3a] The ^{13}C NMR spectrum[5] of **1** contained 16 signals, including a low intensity signal at δ 127.1 ppm, assigned to the carbon atom in the carbonimidic dichloride functionality (cf. δ 122.0 for **2**). The infrared spectrum contained a strong N=CCl_2 band at 1647 cm^{-1} (lit.[3a] 1645-1660 cm^{-1}). Reduction of the carbonimidic dichloride **1** with lithium aluminum hydride in anhydrous tetrahydrofuran at −78 °C gave an isonitrile **3** (IR 2145 cm^{-1}) having the molecular formula $C_{16}H_{23}NOCl_2$.[6] The isonitrile **3** was converted into a formamide **4**[7] (IR 1680 cm^{-1}) by the action of 98% acetic acid.[1e] Treatment of the carbonimidic dichloride **1** with 0.1 N phosphoric acid in 95% methanol at 50 °C for ½ h resulted in the formation of a 2:1 mixture of the primary amine **5** (IR 3200 cm^{-1}) and the methylurethane **6**[8] (IR 3300, 1715 cm^{-1}). Each of these reactions was performed on cyclohexane carbonimidic dichloride **2** with similar results, confirming the presence of the carbonimidic dichloride functionality in **1.**



1 R = -N=CCl_2
3 R = -N⁺≡C⁻
4 R = -NHCHO
5 R = -NH_2
6 R = -NHCOOMe



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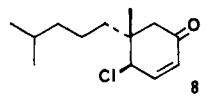

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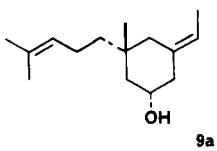
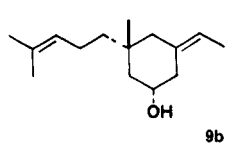
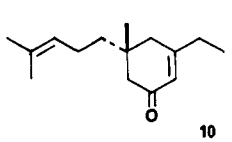


9a



9b



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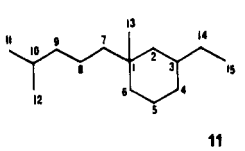


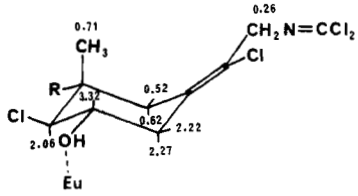
11

The ^1H NMR spectrum[9] of the carbonimidic dichloride **1** was almost identical with those of the isonitrile **3**,[6] formamide **4**,[7] and methyl urethane **6**,[8] except for variation of the chemical shift and multiplicity of a two-proton signal which appeared at δ 4.36 (s, 2 H) in **1.** Comparison of the chemical shift data for the two-proton signal in **1, 3, 4,** and **6** with suitable model compounds suggested that the carbonimidic dichloride was bonded to a methylene on an olefinic bond. The ^{13}C NMR spectrum[5] indicated the presence of trisubstituted and tetrasubstituted olefinic bonds, a carbon bearing hydroxyl (IR 3400 cm^{-1}) at δ 74.8 (d), a carbon bearing chlorine at 70.8 (d), a carbon bearing nitrogen at 57.4 (t), and one other tetrasubstituted carbon at 40.7 ppm. The carbon skeleton of **1** must therefore be monocyclic with the remaining chlorine atom on an olefinic bond.

The terminal trisubstituted olefinic bond gave rise to ^1H NMR signals at δ 1.62 (s, 3 H), 1.70 (s, 3 H), and 5.10 (br t, 1 H, *J* = 6 Hz). Hydrogenation of **1** over 10% palladium/charcoal gave a 9,10-dihydro derivative **7** having an isopropyl signal at δ 0.89 (d, 6 H, *J* = 6 Hz) in the ^1H NMR spectrum. Ozonolysis of **7** in methanol at −78 °C, followed by treatment with dimethyl sulfide, gave a γ-chloro-α,β-unsaturated ketone **8.** In the ^1H NMR spectrum[10] of **8,** all protons on the cyclohexenone ring were observed and their relationships determined by spin-decoupling experiments. Assuming that the hydroxy group had been eliminated from an intermediate β-hydroxy ketone formed by ozonolysis of the tetrasubstituted olefinic bond, we could place all the substituents on the six-membered ring of **1.** The ^1H NMR spectrum of **1** contained an α-chloro proton at δ 3.83 coupled to an α-hydroxy proton at δ 3.77 which was, in turn, coupled to two mutually coupled protons at 3.49 and 1.98 ppm. The lower field equatorial proton at C-4 exhibited a long-range coupling to an equatorial ring methylene proton at δ 2.52 which was, in turn, coupled to an axial methylene proton at 2.10 ppm. The tetrasubstituted carbon atom bearing a methyl group and the isoprenoid side chain must be located between the carbon bearing chlorine and the ring methylene. The coupling constants indicated that the chlorine and hydroxyl groups were both equatorial. The coupling constants were observed more clearly in the ^1H NMR spectrum[11] of the acetate of methylurethane **6.**

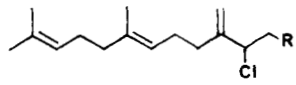
The relationship between the hydroxy group and the two-carbon side chain was confirmed by the following sequence. Reduction of **1** with lithium in liquid ammonia gave a 4:1 mixture of alcohols **9a** and **9b.** In the ^1H NMR spectrum of the mixture of alcohols, two quartets were observed at δ 5.35 (q, 0.8 H, *J* = 7 Hz) and 5.23 (q, 0.2 H, *J* = 7 Hz) and two doublets at 1.64 (d, 0.6 H, *J* = 7 Hz) and 1.57 (d, 2.4 H, *J* = 7 Hz), indicating that the alcohols were stereoisomeric at the newly formed trisubstituted olefinic bond. Oxidation of the alcohol mixture with Jones reagent, followed by isomerization of the olefinic bond into conjugation, using *p*-toluenesulfonic acid in benzene, gave the α,β-unsaturated ketone **10,**[12] which had an ethyl group at the β carbon.

Chart I. Eu(fod)$_3$-Induced Shifts ($\Delta\delta$) of Selected Protons in the ^{1}H NMR Spectrum of **1**



The remaining stereochemical assignments were made by analysis of Eu(fod)$_3$-induced shifts (Chart I) in the ^{1}H NMR spectrum of **1.** Using established procedures,[13] the induced shifts of the ring protons were used to calculate an average location for the europium atom. Europium–proton distances calculated from induced shifts for the C-13 methyl group and the C-15 methylene group indicated an axial methyl group and a 3(14)-Z tetrasubstituted olefin. The carbon skeleton **11** is a new sesquiterpene skeleton for which we suggest the name axinyssane.[14]

A second carbonimidic dichloride **12,** $C_{16}H_{24}NCl_3$,[15] was isolated as a minor product (0.2% dry weight). The infrared

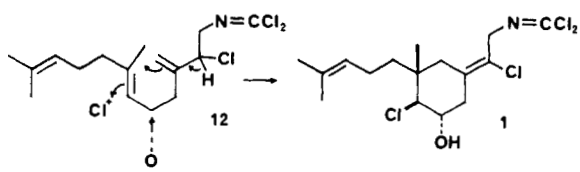


12 R = -N=CCl$_2$
13 R = -N$^+$≡C$^-$
14 R = -NHCHO

(1645 cm^{-1}) spectrum indicated the presence of a carbonimidic dichloride functionality. The ^{1}H NMR spectrum of **12** contained three methyl signals at δ 1.61, 1.62, and 1.68, exocyclic methylene proton signals at 5.08 and 5.22, two overlapping olefinic signals at 5.12 and 5.16, and two mutually coupled signals at 3.40 (d, 2 H, J = 7 Hz) and 4.64 (t, 1 H, J = 7 Hz). Using reaction conditions outlined above, the carbonimidic dichloride **12** could be reduced to an unstable isonitrile **13,**[16] which was hydrolyzed to a formamide **14.** In the ^{1}H NMR spectrum[17] of the formamide **14,** coupling between the -NH proton at δ 5.88 and the methylene protons at 3.46 and 3.91 allowed assignment of the formamide at C-1 and chlorine at C-2. The ^{13}C NMR spectrum of **12**[15] contained signals at chemical shifts predicted for a trans linear isoprenoid chain. The ^{1}H NMR and mass spectra support this assignment.

Since *P. pitys* is capable of chlorination reactions, we propose that the carbonimidic dichlorides may result from enzymatic chlorination of the corresponding isonitriles, which have not been detected. The axinyssane skeleton can result from a "chloronium ion" initiated cyclization of the minor carbonimidic dichloride or an equivalent molecule (Scheme I). Although we have not yet found a biological function for the carbonimidic dichlorides **1** and **12,** the corresponding isonitriles **3** and **13** inhibit the growth of *Staphylococcus aureus.*

Scheme I. Possible Biosynthesis of Axinyssane Skeleton



Acknowledgments. We wish to thank Dr. Bill Stewart for the collection of *P. pitys,* which was identified by Ms. Linda Jones. Antimicrobial screening was performed by Mrs. Marilynne Tseng. NMR spectra were obtained at the UCSD NMR Facility, supported by the National Institutes of Health (RR-708). This research was supported by grants from the National Institutes of Health (AI-11969) and the National Science Foundation (PCM-02539).

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(4) P. R. Berquist, *Pac. Sci.* **19,** 175 (1965); M. W. de Laubenfels, *Mono. Ser.—Stud. Zool., Oreg. State Coll.,* **7,** 178 (1954).
(5) ^{13}C NMR δ ($CDCl_3$) 132.9 (s), 132.0 (s), 127.1 (s), 124.3 (s), 123.6 (d), 74.8 (d), 70.8 (d), 57.4 (t), 40.9 (t), 40.7 (s), 40.0 (t), 38.4 (t), 25.7 (q), 21.7 (t), 19.4 (q), 17.7 (q).
(6) ^{1}H NMR δ ($CDCl_3$) 0.92 (s, 3 H), 1.63 (s, 3 H), 1.70 (s, 3 H), 1.97 (dd, 1 H, J = 13, 11 Hz), 2.15 (d, 1 H, J = 14 Hz), 2.41 (dd, 1 H, J = 14, 3 Hz), 2.59 (s, 1 H, –OH), 3.44 (m, 1 H, J = 13, 5, 3 Hz), 3.78 (m, 1 H, J = 11, 10, 5 Hz), 3.82 (d, 1 H, J = 10 Hz), 4.25 (d, 1 H, J = 15 Hz), 4.31 (d, 1 H, J = 15 Hz), 5.09 (t, 1 H, J = 6 Hz).
(7) ^{1}H NMR δ ($CDCl_3$) 0.88 (s, 3 H), 1.62 (s, 3 H), 1.69 (s, 3 H), 1.91 (dd, 1 H, J = 13, 11 Hz), 2.09 d, 1 H, J = 14 Hz), 2.57 (s, 1 H, –OH), 2.70 (dd, 1 H, J = 14, 3 Hz), 3.41 (m, 1 H, J = 13, 5, 3 Hz), 3.73 (m, 1 H, J = 11, 10, 5 Hz), 3.82 (d, 1 H, J = 10 Hz), 4.21 (d, 2 H, J = 6 Hz), 5.09 (t, 1 H, J = 6 Hz), 8.18 (s, 1 H).
(8) ^{1}H NMR δ ($CDCl_3$) 0.87 (s, 3 H), 1.62 (s, 3 H), 1.69 (s, 3 H), 1.91 (dd, 1 H, J = 12, 11 Hz), 2.11 (d, 1 H, J = 14 Hz), 2.70 (dd, 1 H, J = 14, 3 Hz), 3.40 (m, 1 H, J = 12, 5, 3 Hz), 3.68 (s, 3 H), 3.76 (m, 1 H, J = 11, 10, 5 Hz), 3.81 (d, 1 H, J = 10 Hz), 3.97 (dd, 1 H, J = 15, 6 Hz), 4.14 (dd, 1 H, J = 15, 6 Hz), 5.08 (t, 1 H, J = 6 Hz).
(9) ^{1}H NMR δ ($CDCl_3$) 0.89 (s, 3 H), 1.62 (s, 3 H), 1.70 (s, 3 H), 1.98 (t, 1 H, J = 11 Hz), 2.10 (d, 1 H, J = 14 Hz), 2.52 (dd, 1 H, J = 14, 3 Hz), 2.65 (s, 1 H, –OH), 3.49 (m, 1 H, J = 11, 5, 3 Hz), 3.77 (m, 1 H, J = 11, 10, 5 Hz), 3.83 (d, 1 H, J = 10 Hz), 4.36 (s, 2 H), 5.10 (br t, 1 H, J = 6 Hz).
(10) IR ($CHCl_3$) 1665 cm^{-1}; ^{1}H NMR δ ($CDCl_3$) 0.87 (d, 6 H, J = 6 Hz), 1.11 (s, 3 H), 2.36 (d, 1 H, J = 16 Hz), 2.53 (d, 1 H, J = 16 Hz), 4.65 (dd, 1 H, J = 3.5, 1.5 Hz), 5.99 (dd, 1 H, J = 10, 1.5 Hz), 6.82 (dd, 1 H, J = 10, 3.5 Hz).
(11) ^{1}H NMR δ ($CDCl_3$), 0.93 (s, 3 H), 1.63 (s, 3 H), 1.70 (s, 3 H), 2.10 (s, 3 H), 2.72 (dd, 1 H, J = 14, 2 Hz), 3.38 (m, 1 H, J = 13, 5, 2 Hz), 3.69 (s, 3 H), 3.89 (d, 1 H, J = 10 Hz), 3.97 (dd, 1 H, J = 15, 6 Hz), 4.14 (dd, 1 H, J = 15, 6 Hz), 5.01 (m, 1 H, J = 11, 10, 5 Hz), 5.09 (t, 1 H, J = 6 Hz).
(12) IR ($CHCl_3$) 1690 cm^{-1}; ^{1}H NMR δ ($CDCl_3$) 1.00 (s, 3 H), 1.10 (t, 3 H, J = 7 Hz), 1.59 (s, 3 H), 1.67 (s, 3 H), 1.9–2.3 (m, 8 H), 5.06 (t, 1 H, J = 6 Hz), 5.88 (s, 1 H).
(13) In this example, the simplified formula $\Delta\delta = -k/r^3$ was employed (A. F. Cockerill, G. L. O. Davies, R. C. Harden, and D. M. Rackham, *Chem. Rev.,* **73,** 553 (1973)): C-13 methyl group, r_{calcd} = 7.4, r_{ax} = 7.3, r_{eq} = 8.6; C-15 methylene group, r_{calcd} = 9.9, r_Z = 9.7, r_E = 7.4 Å. (Subscripts refer to the alternative geometrical arrangements.)
(14) The full name of **1** becomes (1*R**,5*S**,6*S**)-6,14-dichloro-5-hydroxy-9,3(14)-(*Z*)-axinyssadien-15-yl carbonimidic dichloride.
(15) IR (film) 1645 cm^{-1}; ^{1}H NMR δ ($CDCl_3$) 1.61 (s, 3 H), 1.62 (s, 3 H), 1.68 (s, 3 H), 1.9 –2 2 (m, 8 H), 3.40 (d, 2 H, J = 7 Hz), 4.64 (t, 1 H, J = 7 Hz), 5.08 (br s, 1 H), 5.12 (br t, 1 H), 5.16 (br t, 1 H), 5.22 (br s, 1 H); ^{13}C NMR δ ($CDCl_3$) 145.9 (s), 136.0 (s), 131.3 (s), 124.3 (d), 123.3 (d), 114.4 (t), 62.4 (d), 59.5 (t), 39.6 (t), 31.7 (t), 26.7 (t), 26.2 (t), 25.7 (q), 17.7 (q), 16.1 (q) (N=CCl_2 signal not observed).
(16) IR ($CHCl_3$) 2130 cm^{-1}; ^{1}H NMR δ ($CDCl_3$) 1.61 (s, 3 H), 1.62 (s, 3 H), 1.68 (s, 3 H), 3.76 (d, 2 H, J = 7 Hz), 4.53 (t, 1 H, J = 7 Hz), 5 08 (m, 2 H), 5.16 (br s, 1 H), 5.27 (br s, 1 H).
(17) IR ($CHCl_3$) 3140, 1680 cm^{-1}; ^{1}H NMR δ ($CDCl_3$) 1.60 (s, 3 H), 1.62 (s, 3 H), 1.68 (s, 3 H), 2.0–2.2 (m, 8 H), 3.46 (m, 1 H, J = 14, 9, 5 Hz), 3.91 (m, 1 H, J = 14, 7, 5 Hz), 4.49 (dd, 1 H, J = 9, 5 Hz), 5.08 (br s, 1 H), 5.12 (m, 2 H), 5.22 (br s, 1 H), 5.88 (br, 1 H, –NH), 8.21 (br s, 1 H).

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Mixed Ammine–Olefin Complexes of Ruthenium(II)

Sir:

The known olefin complexes of ruthenium are largely confined to examples where the formal oxidation state at ruthenium is relatively low and strong π-acid ligands such as CO