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Structure of Chelonaplysin C: a Spongian Diterpenoid from Nudibranch *Chromodoris luteorosea*

By Raffaella Puliti, Magherita Gavagnin and Guido Cimino

Istituto per la Chimica di Molecole di Interesse Biologico CNR, Via Toiano 6, 80072 *Arco Felice, Napoli, Italy*

and Carlo Andrea Mattia and Lelio Mazzarella

Dipartimento di Chimica, Università Federico II, *Via Mezzocannone* 4, 80134 *Napoli, Italy*

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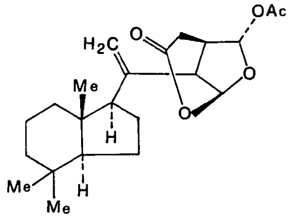
Abstract. 8-[1-(Octahydro-4,4,7a-trimethyl-1*H*-inden-1-yl)ethenyl]-3-oxo-2,7-dioxabicyclo[3.2.1]octan-6-yl acetate, $C_{22}H_{32}O_5$, $M_r = 376.5$, orthorhombic, $P2_12_12_1$, $a = 8.3737\,(8)$, $b = 10.6469\,(8)$, $c = 22.429\,(2)$ Å, $V = 1999.7\,(3)$ Å^3, $Z = 4$, $D_x = 1.251$ Mg m^{-3}, $\lambda(\mathrm{Cu}\ K\alpha) = 1.54178$ Å, $\mu = 0.67$ mm^{-1}, $F(000) = 816$, room temperature, final $R = 0.046$ for 2181 reflections with $I \geq 2.5\sigma(I)$ and 245 variables. The X-ray analysis confirms the novel rearranged diterpenoid skeleton proposed by Bobzin & Faulkner [*J. Nat. Prod.* (1991), **54**, 225–232] on the basis of spectral data and chemical correlations.

Introduction. Several diterpenes with ichthyotoxic and pharmacological activity, recently isolated from marine organisms, present rearranged 'spongian' skeletons (Kazlauskas, Murphy, Wells, Noack, Oberhänsli & Schönholzer, 1979) consisting of a hydrocarbon ring system and an oxygenated moiety which includes a lactone ring (Cimino, Crispino, Gavagnin & Sodano, 1990; Bobzin & Faulkner, 1989). These unusual structures are often complex and open to ambiguous interpretation and the definite proof of their stereochemistry has been, in some cases, based on the results of X-ray studies of correlated molecules (Buckleton, Cambie & Clark, 1991; Dumdei, de Silva, Andersen, Choudhary & Clardy, 1989; Molinski, Faulkner, Cun-Heng, Van Duyne & Clardy, 1986; Buckleton, Bergquist, Cambie, Clark, Karuso & Rickard, 1986).

The title compound (1) has been isolated (Gavagnin, Vardaro, Avila, Ortea & Cimino, 1992) as the main diterpene from Cantabrian sea nudibranch *Chromodoris luteorosea*. On the basis of spectral data, it is identical to chelonaplysin C (Bobzin & Faulkner, 1991) from the encrusting Pacific sponge *Chelonaplysilla* sp., whose structure and relative stereochemistry was assigned by spectral data and chemical correlations with norrisolide (Hochlowski, Faulkner, Matsumoto & Clardy, 1983). Owing to the uniqueness of the C-atom skeleton of (1), together with apparent disagreement in some reported data ($[\alpha]_D$ and m.p.), a single-crystal X-ray study was carried out on the product from *C. luteorosea* nudibranch, in order to confirm the given structure.



(I)

Experimental. Single crystals of chelonaplysin C (Gavagnin *et al.*, 1992) were grown as rectangular colourless prisms by slow evaporation from *n*-hexane–ethyl ether mixture. A sample of size 0.30 × 0.28 × 0.08 mm was used for data collection on an Enraf–Nonius CAD-4F diffractometer with graphite-monochromated Cu $K\alpha$ radiation at room temperature. Cell parameters were determined from 24 reflections with $23 < \theta < 27°$, and ω–2θ scans as suggested by peak-shape analysis. Three standard reflections were monitored every 4 h and showed no significant decay (4% variation). 2326 reflections with $\theta \leq 74°$ were measured, for $0 \leq h \leq 10$, $0 \leq k \leq 13$, $0 \leq l \leq 27$. 2181 reflections had $I \geq 2.5\sigma(I)$. Lp corrections were applied, but absorption was ignored. The structure was solved using *MULTAN*11/82 (Main, Fiske, Hull, Lessinger, Germain, Declercq & Woolfson, 1982). Anisotropic full-matrix refinement was based on F. H atoms, from geometrical considerations and ΔF suggestions (methyl groups), were not refined; B was set equal to the B_{eq} value of the parent atom. Final $R = 0.046$, $wR = 0.052$. The function minimized was $\sum w(\Delta F)^2$, where $w^{-1} = [\sigma^2(F_o) + (0.02F_o)^2 + 1]$ (Killean &

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Table 1. *Positional coordinates and equivalent isotropic thermal parameters* (Å^2) *with e.s.d.'s in parentheses*

$$B_{eq} = (4/3)\sum_i\sum_j\beta_{ij}\mathbf{a}_i.\mathbf{a}_j.$$

	x	y	z	B_{eq}
O1	0.2647 (3)	0.0018 (2)	0.59523 (9)	3.66 (4)
O2	0.3999 (4)	−0.1667 (2)	0.5700 (1)	5.41 (6)
O3	0.2820 (3)	0.1966 (2)	0.54833 (9)	3.82 (4)
O4	0.4664 (3)	0.3602 (2)	0.54327 (9)	3.85 (4)
O5	0.4066 (3)	0.3811 (2)	0.4460 (1)	4.62 (5)
C1	0.1654 (5)	0.2553 (3)	0.7645 (2)	4.28 (7)
C2	0.0671 (5)	0.3092 (3)	0.8162 (2)	5.24 (8)
C3	−0.0535 (5)	0.2139 (4)	0.8405 (2)	4.95 (8)
C4	0.0239 (4)	0.0896 (3)	0.8617 (1)	3.89 (6)
C5	0.1299 (4)	0.0440 (3)	0.8106 (1)	3.14 (5)
C6	0.2228 (5)	−0.0793 (3)	0.8167 (2)	4.25 (7)
C7	0.3407 (5)	−0.0765 (3)	0.7637 (2)	4.35 (7)
C8	0.4549 (4)	0.0987 (3)	0.6956 (1)	3.06 (5)
C9	0.3155 (4)	0.0522 (3)	0.7326 (1)	3.09 (5)
C10	0.2531 (4)	0.1359 (2)	0.7845 (1)	2.89 (5)
C11	0.4025 (4)	−0.0541 (3)	0.5786 (1)	3.56 (6)
C12	0.5527 (4)	0.0220 (3)	0.5715 (1)	3.66 (6)
C13	0.5354 (4)	0.1620 (3)	0.5871 (1)	3.14 (5)
C14	0.4168 (3)	0.1732 (3)	0.6390 (1)	2.93 (5)
C15	0.2693 (4)	0.1373 (3)	0.6045 (1)	3.24 (5)
C16	0.4457 (4)	0.2258 (3)	0.5378 (1)	3.46 (6)
C17	0.6057 (4)	0.0806 (3)	0.7104 (2)	4.22 (7)
C18	0.1081 (5)	0.1086 (4)	0.9215 (1)	5.15 (8)
C19	−0.1110 (5)	−0.0068 (4)	0.8718 (2)	5.47 (8)
C20	0.3917 (4)	0.1702 (3)	0.8261 (1)	4.17 (7)
C21	0.4432 (4)	0.4269 (3)	0.4926 (1)	3.53 (6)
C22	0.4698 (5)	0.5646 (3)	0.5032 (2)	4.84 (8)

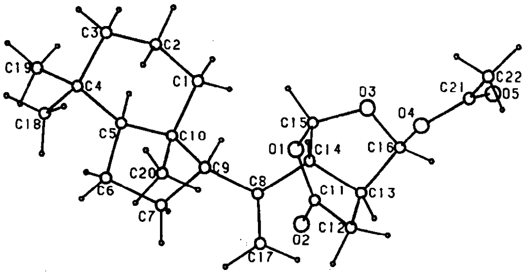

Fig. 1. Drawing of the molecule of chelonaplysin C. Labels for H atoms have been omitted for clarity.

Lawrence, 1969) with σ from counting statistics. A correction for secondary extinction (Stout & Jensen, 1968) was refined [g coefficient = 3.14 (2) × 10^{-6}]; $S = 0.78$; final $(\Delta/\sigma)_{max} = 0.01$; $-0.22 \le \Delta\rho \le 0.25$ e Å^{-3}. Scattering factors were taken from *International Tables for X-ray Crystallography* (1974, Vol. IV), and calculations performed using Enraf–Nonius *SDP* software (B. A. Frenz & Associates, Inc., 1985) on a MicroVAX 3100 computer. Final atomic parameters for the non-H atoms are listed in Table 1,* the atomic numbering scheme is given in Fig. 1.

Table 2. *Selected bond lengths* (Å), *bond angles* (°) *and torsion angles* (°) *with e.s.d.'s in parentheses*

O1—C11	1.352 (4)	C6—C7	1.546 (5)
O1—C15	1.457 (4)	C7—C9	1.552 (4)
O2—C11	1.214 (4)	C8—C9	1.516 (4)
O3—C15	1.413 (3)	C8—C14	1.530 (4)
O3—C16	1.425 (4)	C8—C17	1.320 (5)
C1—C2	1.533 (5)	C9—C10	1.556 (4)
C1—C10	1.535 (4)	C11—C12	1.505 (5)
C2—C3	1.533 (5)	C12—C13	1.538 (4)
C3—C4	1.549 (5)	C13—C14	1.535 (4)
C4—C5	1.529 (4)	C13—C16	1.498 (4)
C5—C6	1.532 (4)	C14—C15	1.507 (4)
C5—C10	1.538 (4)		

C11—O1—C15	116.9 (2)	C8—C9—C10	118.8 (2)
C15—O3—C16	108.5 (2)	C5—C10—C9	98.4 (2)
C16—O4—C21	115.5 (2)	C5—C10—C20	115.3 (2)
C5—C4—C18	115.6 (3)	O1—C11—C12	120.3 (3)
C4—C5—C10	118.3 (2)	C11—C12—C13	114.8 (3)
C6—C5—C10	103.8 (2)	C12—C13—C14	108.0 (2)
C5—C6—C7	103.8 (2)	C14—C13—C16	101.5 (2)
C6—C7—C9	106.0 (2)	C8—C14—C13	117.0 (2)
C9—C8—C14	117.6 (2)	C13—C14—C15	96.9 (2)
C9—C8—C17	123.5 (3)	O1—C15—C14	110.3 (2)
C14—C8—C17	118.9 (3)	O3—C15—C14	106.4 (2)
C7—C9—C10	102.4 (2)	O3—C16—C13	105.2 (2)

C15—O1—C11—O2	−179.1 (2)	C14—C8—C9—C10	−92.2 (3)
C11—O1—C15—C14	−43.9 (3)	C17—C8—C9—C10	86.2 (4)
C21—O4—C16—C13	157.4 (2)	C9—C8—C14—C13	−149.2 (2)
C16—O4—C21—O5	0.7 (4)	C17—C8—C14—C13	32.3 (4)
C18—C4—C5—C10	−70.6 (3)	C11—C12—C13—C14	34.9 (3)
C19—C4—C5—C10	168.6 (3)	C12—C13—C14—C15	−70.0 (3)
C4—C5—C10—C9	−175.2 (2)	C16—C13—C14—C15	44.1 (2)
C4—C5—C10—C20	68.3 (3)	C13—C14—C15—O1	77.0 (2)

Discussion. A perspective view of the molecule is shown in Fig. 1: both chemical structure and relative stereochemistry are in total agreement with those proposed by Bobzin & Faulkner (1991) for chelonaplysin C. The molecule presents a *trans* 6/5 bicyclic hydrocarbon moiety linked, by means of a C9 equatorial C=CH$_2$ group, to an acetylated oxabicyclic system containing a δ-lactone ring. The conformation of the C8 methylene group is defined by the torsion angles 86.2 (4) and 32.3 (4)° with respect to C10 and C13 atoms.

On average, the intramolecular geometrical parameters agree with the generally accepted values (Puliti, De Rosa, Mattia & Mazzarella, 1990). A selection of bond distances and angles are given in Table 2 together with some notable torsion angles. There are four 1–5 intramolecular short contacts: C18···C20, C20···C17, C17···C12 and C8···C11, respectively 3.262 (5), 3.296 (4), 3.208 (4) and 3.119 (4) Å, and this crowding can be considered responsible for some variations with respect to the normal geometrical parameters, in particular the opening of the angles C4—C5—C10 [118.3 (4)°], C10—C9—C8 [118.8 (4)°] and C9—C8—C17 [123.5 (4)°], as well as the lengthening of the bond C8—C14 [1.530 (4) Å]. In the oxabicyclic system, the geometrical distortions around C14, as observed in similar systems (Buckleton *et al.*, 1986), are indicative of the steric strain imposed by the —C16—O3— bridge between the positions β and δ of the lactone ring.

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* Lists of structure factors, anisotropic thermal parameters, H-atom parameters and complete molecular geometry have been deposited with the British Library Document Supply Centre as Supplementary Publication No. SUP 55297 (16 pp.). Copies may be obtained through The Technical Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England. [CIF reference: GE0309]

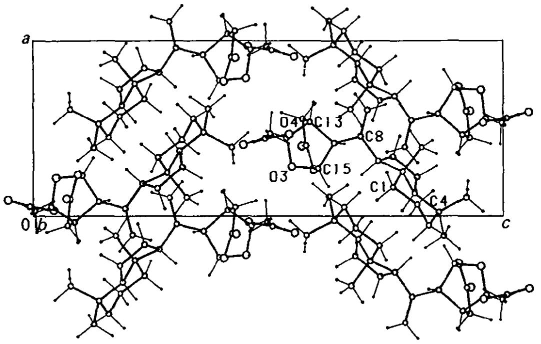

Fig. 2. Crystal packing projected on the *ac* plane.

The cyclohexane is in a nearly ideal chair conformation with C1 and C4 displaced 0.681 (3) and 0.651 (3) Å in opposite directions from the best plane through the remaining endocyclic C atoms. The puckering parameters (Cremer & Pople, 1975) are: $Q = 0.560$ (6) Å, $\theta = 3.7$ (7)°. The *trans*-fused pentacyclic ring adopts an envelope C_s conformation with apex at C10, which is 0.750 (4) Å out of the mean plane passing through the other four atoms. In the oxabicyclic system, the furanoid ring is in a distorted twist form with C13 and C14 out of the plane defined by the remaining ring atoms, at distances of 0.219 (4) and 0.521 (3) Å, respectively. The δ-lactone can be described as a half-boat form with C14 0.915 (3) Å out of the best plane of the remaining atoms. The axial acetoxy group is strictly planar with O5 *cis* to C16.

Fig. 2 shows the molecular packing which is governed by normal van der Waals interactions.

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Pyramidalization in a Tetracyclic Perpendicular Diene Derivative

By Barry A. Lloyd*

Department of Chemistry, Weber State University, Ogden, Utah 84408, *USA*

and Atta M. Arif and Evan L. Allred†

Department of Chemistry, University of Utah, Salt Lake City, Utah 84112, *USA*

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Abstract. *endo,exo*-11,11-Dimethoxy-12-methylenetetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (1), $C_{15}H_{20}O_2$, $M_r = 232.32$, monoclinic, $P2/n$, $a = 19.362$ (1), $b = 6.703$ (1), $c = 20.011$ (1) Å, $\beta = 109.656$ (4)°, $V = 2445.59$ Å^3, $Z = 8$, $D_x = 1.262$ g cm^{-3}, λ(Cu $K\alpha$) = 1.54056 Å, $\mu = 6.088$ cm^{-1}, $F(000) = 1008$, $T = 148$ K, $R = 0.0483$ and $wR = 0.0494$ for 4648 unique reflections. The molecule contains a methylenenorbornyl unit fused to a substituted norbornene. The

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* Author to whom correspondence should be addressed.

† Deceased 8 July 1991.

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