amounts to n, to within the reliability of the calculation, as is seen also from the MO values in the last column, which are the averages of two MO sets given by Kerr *et al*.

The mean deviation of the VB and MO bond lengths is 0·005 Å, and those with the observed values are 0·007 Å (VB) and 0·006 Å (MO). The average standard error of the observed bond lengths is 0·004 Å.

Conclusion

The valence-bond method of calculating bond numbers and bond lengths is simple and straightforward. The calculated values of the bond lengths are found to agree with experimental values for several aromatic hydrocarbons to within about 0·010 Å and also to agree within the same amount with those calculated by the molecular-orbital method. This conclusion agrees with that reached by Cruickshank (1962).

References

CAMERMAN, A. & TROTTER, J. (1964). *Proc. R. Soc. London Ser. A*, **279**, 129–146.

CRUICKSHANK, D. W. J. (1956). *Acta Cryst.* **9**, 915–923.
CRUICKSHANK, D. W. J. (1957). *Acta Cryst.* **10**, 470.
CRUICKSHANK, D. W. J. (1962). *Tetrahedron*, **17**, 155–161.
FERGUSON, G. & PARVEZ, M. (1979). *Acta Cryst.* B35, 2419–2421.
HAZELL, A. C., LARSEN, F. K. & LEHMANN, M. D. (1972). *Acta Cryst.* B28, 2977–2984.
KAY, M. I., OKAYA, Y. & COX, D. E. (1971). *Acta Cryst.* B27, 26–33.
KERR, K. A., ASHMORE, J. P. & SPEAKMAN, J. C. (1975). *Proc. R. Soc. London Ser. A*, **344**, 199–215.
PAULING, L. (1933). *J. Chem. Phys.* **1**, 280–283.
PAULING, L. (1960). *The Nature of the Chemical Bond*, 3rd ed. Ithaca, New York: Cornell Univ. Press.
PAULING, L. & SHERMAN, J. (1933). *J. Chem. Phys.* **1**, 362–374.
PAWLEY, G. S. & YEATS, E. A. (1969). *Acta Cryst.* B25, 2009–2013.
STREITWIESER, A. JR & BRAUMAN, J. I. (1965). *Supplemental Tables of Molecular-Orbital Calculations and a Dictionary of π-Electron Calculations*, edited by C. A. COULSON & A. STREITWIESER JR. Oxford: Pergamon Press.
TROTTER, J. (1958). *Acta Cryst.* **11**, 423–428.
TROTTER, J. (1963). *Acta Cryst.* **16**, 605–608.

The Structure and Absolute Configuration at Low Temperature of the Acetate Derivative of Plexaurolone, a Marine Cembranoid

BY S. E. EALICK, D. VAN DER HELM, R. A. GROSS JR, A. J. WEINHEIMER AND L. S. CIERESZKO

Department of Chemistry, The University of Oklahoma, Norman, Oklahoma 73019, USA

AND R. E. MIDDLEBROOK

*Department of Chemistry, University of Puerto Rico, Mayaguez, Puerto Rico*

Abstract

The crystal structure and absolute configuration at low temperature of the acetate derivative of plexaurolone, a marine cembranoid isolated from a *Plexaura*-related species, have been determined and refined using three-dimensional X-ray diffraction data. The compound crystallizes in space group $P2_1$ with two molecules per asymmetric unit and with cell dimensions $a = 21·215$ (5), $b = 9·322$ (1), $c = 11·327$ (3) Å and $\beta = 99·30$ (1)° at 138 K. The absolute configuration was determined using the anomalous scattering of the O atoms. The final R value for all 4851 data is 5·3%. Comparison of geometrical parameters using half-normal probability plots indicates that the standard deviations are not underestimated. Because the olefinic unsaturation at position 7 is absent in plexaurolone, the configuration convention is not directly applicable. Evaluation of its oxygen substitution pattern in view of a proposed extension of the convention places plexaurolone in the α series. Plexaurolone thus appears to be the first α-cembranoid isolated from a Caribbean gorgonian.

Introduction

In a continuation of our study of the Caribbean gorgonians, we have isolated a new cembranoid diterpene, plexaurolone (1), from an as yet undescribed gorgonian which appears to be related to the genus *Plexaura*. Plexaurolone was first discovered in

the new gorgonian collected at Puerto Rico, and subsequently was found in the same species collected at Bonaire, Netherlands Antilles.
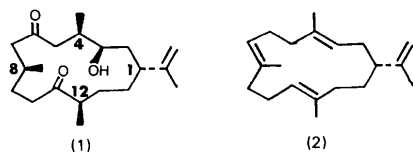
Cembranoids, or cembranes, are a class of diterpenes having the carbon skeleton first encountered in the crystalline unsaturated hydrocarbon cembrene (Drew, Templeton & Zalkin, 1969). The skeleton is characterized by a regular isoprene structure and a fourteen-membered ring system. Naturally occurring cembranoids vary widely in the extent of oxygenation of the ring system, and of its unsaturation. In many cases, a lactone function is observed and the compound is known as a cembranolide. A large number of cembranoid natural products have been encountered in the Caribbean gorgonians (alcyonarians) and the Western Pacific soft corals (alcyonaceans) (Ciereszko & Karns, 1973; Tursch, Braekman, Daloze & Kaisin, 1978; Fenical, 1978; Weinheimer, Chang & Matson, 1979).

Among these compounds is the non-crystalline hydrocarbon (−)-cembrene-A (2) (Patil, Nayak & Dev, 1973; Herin & Tursch, 1976) which possesses three nuclear unsaturations ($\varDelta^{3,7,11}$) and one in the isopropenyl side chain. The substitution pattern of the oxygen functions in the various marine cembranoids strongly suggests that cembrene-A is their common biogenetic precursor. Most of these functions can be formally regarded as the result of oxidation either directly at, or allylic to, one of the four unsaturated sites of this hydrocarbon. In all compounds reported thus far, the 7-unsaturation, or a vestigial indication of its original location, is clearly discernible, and has been employed (Weinheimer, Matson, Hossain & van der Helm, 1977) as the unsymmetrical marker in the symmetrical cembrane skeleton for the purpose of configurational assignments and correlations. Plexaurolone is of particular interest because this marker is not unambiguously evident.

Experimental

The new gorgonian was collected at both Puerto Rico and Bonaire, Netherlands Antilles. It was regarded by F. M. Bayer to be an as yet unclassified species having taxonomic characteristics of the genera *Plexaura* and *Pseudoplexaura*.

The hexane extract of the air-dried, ground gorgonian (426 g) was evaporated, then reconstituted with 100 ml of hexane and allowed to stand overnight. Chromatography of the deposit of crystalline solid on silica gel using benzene containing increasing proportions of ethyl acetate as eluant afforded nearly pure plexaurolone. After several recrystallizations from benzene–hexane, 1·38 g of pure plexaurolone was obtained, m.p. 384·7 − 385·2 K; $[\alpha]_D^{24°C}$ −7·8° ($c = 0.9$ g dm^{-3}, $CHCl_3$); M_r = 322·24770, 74·66%C, 10·39%H ($C_{20}H_{34}O_3$ requires M_r = 322·25079, 74·48%C, 10·63%H); UV: no significant absorption; IR: 3500 (hydroxyl), 1700 (carbonyl) and 1640 cm^{-1} (olefin); 100 MHz ^{1}H NMR ($CDCl_3$): δ (p.p.m.) 0·97, 1·00, 1·04 (each 3H, $d, J = 6.5$ Hz), 1·69 (3H, $d, J = 1$ Hz), 3·36 (1H, $dt, J = 8.5, 2.5$ Hz, HCOH), 4·71 (2H, m, C=CH$_2$); 25·2 MHz ^{13}C NMR, PND ($CDCl_3$): δ (p.p.m.) 216·1 and 213·3 (C=O), 148·2 (C=CH$_2$), 109·6 (C=CH$_2$), 70·1 (HCOH), 48·0, 47·6, 46·5, 42·6, 38·9, 37·1, 36·1, 30·9, 29·0, 28·7, 27·1, 20·5, 20·3, 15·6 and 13·0.

Treatment of plexaurolone with acetic anhydride–pyridine afforded the acetate, m.p. 368 K (benzene–hexane), in which the carbinyl proton (HCO) appeared at δ 4·7 p.p.m. $C_{22}H_{36}O_4$ requires 72·49%C, 9·96%H; found: 72·85%C, 10·04%H.

Long needle-shaped crystals of the acetate were obtained by evaporating a hexane solution at 275 K. The crystal used for the data collection was cut to a more suitable size (0·11 × 0·16 × 0·55 mm) from one of the larger crystals. Crystallographic data (Table 1) and integrated X-ray intensity data were collected at 138 K on a Nonius CAD-4 automatic diffractometer. For intensity data Ni-filtered Cu $K\bar{\alpha}$ radiation (λ = 1·54178 Å) was used and for unit-cell parameters Cu $K\alpha_1$ radiation (λ = 1·54051 Å). Preliminary data indicated that the crystals were monoclinic and systematic absences ($0k0$, $k = 2n + 1$) limited the space group to $P2_1$ or $P2_1/m$. Since the compound is a derivative of an optically active natural product, the space group was chosen as $P2_1$ with two molecules per asymmetric unit, which was verified by the structure solution and refinement. A total of 4851 independent reflections with $2\theta \leq 150°$ were measured using θ–2θ scan techniques. The scan width ($\varDelta\theta$) was corrected for dispersion and calculated as $\varDelta\theta = (1.00 + 0.10 \tan \theta)°$ for each intensity. A receiving aperture with variable width, $(4.00 + 0.86 \tan \theta)$ mm, and constant height of 4·0 mm was located 173 mm from the crystal. A maximum of 60 s was used for each measurement with $\frac{2}{3}$ of the time used for scanning the peak and $\frac{1}{6}$ of the time used for scanning each left and right background. A monitor reflection was measured after every 25 observations and did not show a systematic change during the data collection. Three additional reflections were recentered after every 100 observations. If any angle for any of these reflections changed by more than 0·1°, a new orientation matrix was automatically determined using a predetermined list of reflections. A total of 597 intensities were considered indistinguishable from the background on the basis that the

Table 1. *Crystallographic data*

$C_{22}H_{36}O_4$, $M_r = 364\cdot51$, space group $P2_1$, $T = 138$ K

$a = 21\cdot215\,(5)$ Å	$Z = 4$
$b = 9\cdot322\,(1)$	$V = 2210\cdot6$ Å^3
$c = 11\cdot327\,(3)$	$\rho_{calc} = 1\cdot095$ Mg m^{-3}
$\beta = 99\cdot30\,(1)°$	

(determined by least-squares fit to the $+2\theta$ and -2θ values of 57 reflections distributed throughout reciprocal space)

unscaled intensity $[I = P - 2(\mathrm{LB} + \mathrm{RB})]$ was less than $2\sigma(I)$ where P = peak count, LB = left background and RB = right background. For the purpose of further data analysis these reflections were assigned an intensity of $1\cdot0T^{1/2}$ where $T = P + 4(\mathrm{LB} + \mathrm{RB})$. Lorentz and polarization corrections were applied and structure factor magnitudes were derived but no absorption corrections were made ($\mu = 0\cdot591$ mm^{-1}). Each amplitude was assigned an experimental weight, w_F, based on counting statistics (Ealick, van der Helm & Weinheimer, 1975).

Structure determination and refinement

The intensities were placed on an absolute scale with the results of a Wilson (1942) plot and normalized structure factor magnitudes, $|E|$, were derived. The phases for 400 $|E|$'s with $|E| > 1\cdot49$ were derived using the program *MULTAN* (Germain, Main & Woolfson, 1971). A total of 128 starting sets were used with the correct phase set having an absolute figure of merit of $1\cdot11$ (range $0\cdot79$–$1\cdot25$), a ψ_0 of 317 (range 310–762) and a residual of $35\cdot6\%$ (range $35\cdot1$–$44\cdot1\%$). The combined figure of merit for the correct phase set was the largest value. An E map calculated using these phases revealed the positions of 48 of 52 non-hydrogen atoms. An initial structure factor calculation gave an R value ($R = \sum ||kF_o| - |F_c||/\sum |kF_o|$) of $30\cdot7\%$. After a few cycles of block-diagonal least-squares refinement a difference Fourier map was calculated from which the remaining non-hydrogen atom positions were determined. The least-squares refinement including all 52 non-hydrogen atoms with anisotropic thermal parameters converged with an R value of $10\cdot7\%$ for all data. The 72 H atoms were located from three different difference Fourier maps which were calculated as the refinement proceeded. Least-squares refinement using anisotropic thermal parameters for C and O atoms and isotropic thermal parameters for H atoms was terminated when all shifts were less than $0\cdot5$ of the corresponding estimated standard deviation. The R value based on the final parameters (Table 2) is $5\cdot3\%$ for all 4851 data.

Table 2. *Positional parameters* ($x \times 10^5$; y, $z \times 10^4$) *for C and O atoms*

Estimated standard deviations are in parentheses.

	Molecule (I)				Molecule (II)			
	x	y	z	B_{eq} (Å^2)*	x	y	z	B_{eq} (Å^2)*
C(1)	100813 (11)	1855 (3)	1923 (2)	2·3	33698 (11)	6263 (4)	354 (2)	2·4
C(2)	107397 (12)	2392 (4)	1690 (2)	2·7	32834 (12)	5714 (4)	1596 (2)	2·6
C(3)	113005 (11)	2067 (4)	2699 (2)	2·5	38563 (12)	6005 (4)	2589 (2)	2·5
C(4)	115535 (12)	3367 (3)	3449 (2)	2·4	42231 (13)	4648 (4)	3059 (2)	2·8
C(5)	120441 (13)	2918 (4)	4550 (3)	2·6	48452 (14)	5051 (5)	3913 (2)	3·2
C(6)	117593 (12)	1965 (3)	5396 (2)	2·6	52782 (12)	6012 (4)	3331 (2)	2·9
C(7)	113460 (14)	2673 (3)	6192 (2)	2·7	56460 (13)	5324 (4)	2445 (2)	2·9
C(8)	110023 (13)	1667 (3)	6932 (2)	2·7	60379 (12)	6363 (4)	1815 (2)	2·8
C(9)	104387 (14)	2371 (4)	7392 (2)	2·9	62563 (12)	5704 (4)	710 (2)	2·9
C(10)	99184 (14)	3012 (3)	6448 (3)	2·7	57300 (13)	5075 (3)	−231 (2)	2·8
C(11)	95654 (12)	1975 (3)	5559 (2)	2·2	52446 (12)	6120 (3)	−838 (2)	2·3
C(12)	90991 (12)	2605 (3)	4531 (2)	2·2	46730 (13)	5500 (4)	−1664 (2)	2·7
C(13)	92467 (12)	2069 (3)	3327 (2)	2·3	40483 (12)	6054 (4)	−1320 (2)	2·7
C(14)	99009 (11)	2517 (3)	3065 (2)	2·3	39448 (12)	5564 (4)	−87 (2)	2·6
C(15)	95766 (12)	2171 (4)	834 (2)	2·6	27548 (11)	6053 (4)	−528 (2)	2·6
C(16)	91539 (15)	1138 (4)	381 (3)	3·6	24879 (14)	7138 (5)	−1185 (3)	4·0
C(17)	95531 (15)	3607 (4)	297 (3)	3·7	24697 (15)	4593 (4)	−631 (3)	3·8
C(18)	118493 (15)	4500 (4)	2738 (3)	3·6	38337 (15)	3608 (5)	3690 (3)	3·9
C(19)	114750 (15)	1041 (4)	7967 (3)	3·8	66218 (16)	6883 (5)	2690 (3)	4·2
C(20)	84168 (13)	2222 (4)	4700 (3)	3·0	47285 (15)	5888 (5)	−2956 (3)	3·5
C(21)	118614 (17)	126 (4)	1961 (3)	3·7	35842 (14)	8108 (5)	3602 (3)	3·7
C(22)	123842 (22)	−195 (6)	1245 (4)	5·2	33159 (19)	8652 (6)	4667 (3)	5·0
O(23)	118352 (9)	1548 (3)	2151 (2)	3·1	36280 (9)	6661 (3)	3613 (2)	3·3
O(24)	115156 (15)	−734 (3)	2301 (3)	5·3	37277 (12)	8863 (3)	2835 (2)	4·9
O(25)	118437 (10)	672 (3)	5403 (2)	3·5	53076 (10)	7293 (3)	3545 (2)	4·4
O(26)	96306 (9)	675 (2)	5663 (2)	2·8	53058 (9)	7413 (3)	−715 (2)	3·2

* Calculated from $B_{eq} = (B_1B_2B_3)^{1/3}$, in which B_1, B_2 and B_3 are the values along the principal axes of the ellipsoid.

The standard error in an observation of unit weight, $[\sum w|kF_o - F_c|^2/(m - n)]^{1/2}$, is 2·23 e where w is the experimental weight, m is the number of observations and n is the number of parameters.

All structure factor refinement was done using the block-diagonal least-squares program of Ahmed (1966a) in which the quantity $\sum w(|kF_o| - |F_c|)^2$ was minimized. All Fourier maps were calculated using the program of Ahmed (1966b). Atomic scattering factors for C and O atoms were taken from *International Tables for X-ray Crystallography* (1962) and those for H atoms from Stewart, Davidson & Simpson (1965). A final difference Fourier map showed no peak greater than 0·2 e Å^{-3}. For the structure factor analysis the average value of $w_F \Delta F^2$ did not vary with either sin θ/λ or $|F_o|$, thus validating the weighting scheme used.*

Determination of absolute configuration

We chose the 20 reflections in which the calculated difference $|F_+|^2 - |F_-|^2$ divided by the standard deviation estimated from counting statistics, $\sigma(F^2)$, were largest (F_+ and F_- are the calculated structure factors for the hkl and $\bar{h}\bar{k}\bar{l}$ reflections, respectively). We refer to this quantity as the enantiomer sensitivity

---

* Lists of structure factors, hydrogen atom parameters and thermal parameters have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 35257 (27 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

Table 3. *Comparison of observed and calculated Bijvoet differences*

The values are ESF $= (F_+^2 - F_-^2)/\sigma(F_o^2)$, $\Delta I_1 = (I_{hkl} - I_{\bar{h}k\bar{l}})/\sigma(I)$, $\Delta I_2 = (I_{hk\bar{l}} - I_{\bar{h}k\bar{l}})/\sigma(I)$, $\bar{\Delta I} = (\Delta I_1 + \Delta I_2)/2$.

h k l	ESF	ΔI_1	ΔI_2	$\bar{\Delta I}$
−4 4 5	1·59	0·87	1·40	1·13
−5 1 4	−1·36	−1·17	1·43*	0·13*
−4 5 2	−1·35	−1·51	0·72*	−0·40
13 1 0	1·27	1·44	0·91	1·18
−6 4 2	−1·26	−0·38	−0·37	−0·38
3 4 3	−1·19	−0·68	−0·70	−0·69
−9 4 2	−1·10	−0·54	1·37*	0·42*
8 5 1	−1·09	−0·36	−1·66	−1·01
4 4 4	1·01	1·83	0·83	1·33
−11 1 2	−1·01	−0·53	−1·30	−0·91
10 1 0	0·95	1·09	1·13	1·11
4 5 5	0·91	1·13	2·35	1·74
−6 1 2	0·91	2·45	1·76	2·10
9 4 4	−0·90	−2·40	−0·36	−1·38
4 2 3	0·87	0·82	1·84	1·33
5 4 2	−0·78	−3·30	−4·45	−3·88
−4 2 7	0·75	0·24	0·50	0·37
−3 5 3	0·68	0·20	−3·00*	−1·40*
−2 5 5	0·66	1·32*	1·04*	1·18*
4 3 5	0·65	1·20	0·69	0·94

factor (ESF) (Ealick, van der Helm & Weinheimer, 1975) and have tabulated the 20 largest values in Table 3. For each of these reflections the hkl, $\bar{h}kl$, $hk\bar{l}$ and $\bar{h}k\bar{l}$ intensities were measured ten times each at 138 K and an average value and a standard deviation calculated. The values of the differences $|I(hkl) - I(\bar{h}k\bar{l})|/\sigma(I)$ and $|I(\bar{h}kl) - I(hk\bar{l})|/\sigma(I)$ were calculated and compared with the calculated ESF. Of the 20 pairs of observations (40 total trials), 34 indicated that the absolute configuration used to calculate the ESF values was the correct one. Of the six trials indicating the opposite absolute configuration, two were the ΔI_1 and ΔI_2 for the same reflection ($\bar{2}55$) while the remaining four were the ΔI_2 values of different reflections. It should also be pointed out that the $\bar{2}55$ reflections had the 19th highest ESF out of the 20 reflections measured. Although the measured differences are small the fact that 34 out of 40 observations indicate one absolute configuration allows one to accept that absolute configuration with reasonable confidence. The anomalous-scattering factors used for the calculation of F_+^2 and F_-^2 were those of Cromer & Liberman (1970).

Interpretation of spectra

The NMR and IR spectral features establish that plexaurolone contains one secondary hydroxyl group and two non-conjugated ketone functions, thereby characterizing its three O atoms. Double irradiation showed that the terminal methylene and vinyl methyl groups were mutually coupled, establishing an isopropenyl moiety. The total of three unsaturations (two ketones, one olefin), together with the molecular formula, required plexaurolone to be monocyclic. The isopropenyl and three methyl groups which were evident in plexaurolone are the characteristic substituents of the cembrane nucleus, and permitted a ring size no larger than 14-membered. The infrared carbonyl frequency (1700 cm^{-1}) of the isolated ketone functions was also compatible with the possibility that plexaurolone was a cembrane derivative. However, it remained for the X-ray study to prove this postulate and, further, to establish the substitution pattern and absolute configuration.

Description and discussion of the structure

The asymmetric unit contains two very similar molecules, referred to as (I) and (II) and shown as stereodiagrams in Figs. 1 and 2 respectively. The bond distances and numbering scheme for both molecules are shown in Fig. 3 and bond angles in Fig. 4. The molecule contains both the fourteen-membered ring and the substitution pattern of an isopropenyl group at C(1) and three methyl groups at C(4), C(8) and C(12),
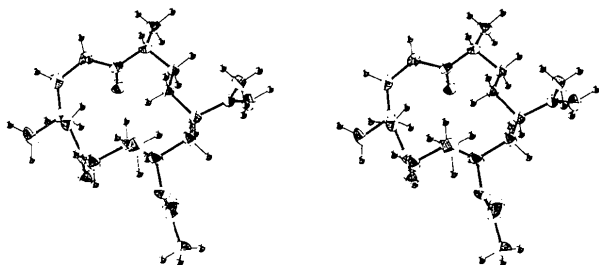
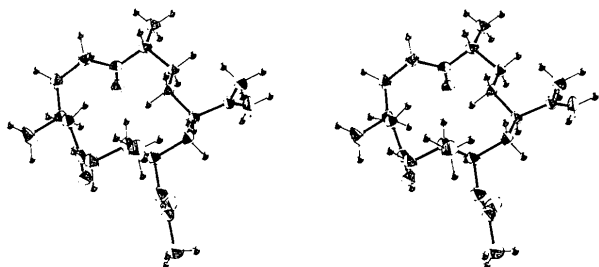Fig. 1. Stereoview of molecule (I) (Johnson, 1965).

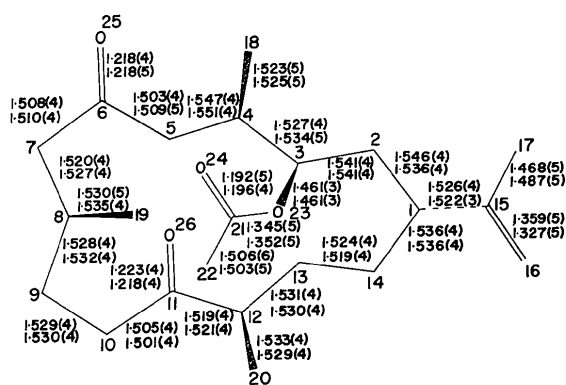Fig. 2. Stereoview of molecule (II) (Johnson, 1965).

Fig. 3. Bond distances (Å). The upper values are for molecule (I) and the lower for molecule (II).
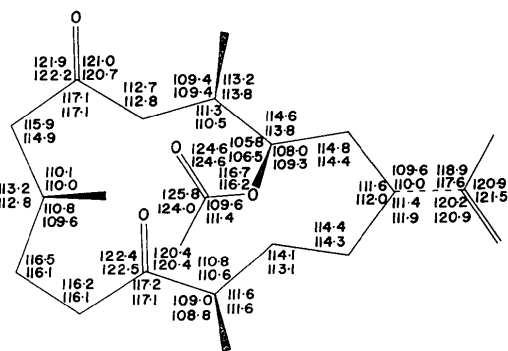

Fig. 4. Bond angles (°). The upper values are for molecule (I) and the lower for molecule (II). Standard deviations are between 0·22 and 0·37°.

which together characterize the regular isoprenoid cembrane skeleton. The acetoxy group (hydroxyl in plexaurolone) at C(3) and the carbonyl groups at C(6) and C(10) are a result of oxygenation of the cembrene skeleton. The ketone function at C(6) is unprecedented in marine cembranoids. The five asymmetric C atoms in the structure can be designated as 1R, 3R, 4R, 8S, 12R. The structure reported here is the only cembranoid which has no olefinic unsaturation in the fourteen-membered ring and thus has a conformation determined only by the presence of exocyclic substituents and crystal packing forces.

Because the 7-unsaturation is absent in plexaurolone, the configuration convention (Weinheimer *et al.*, 1977) is not directly applicable. The absence of the often-present 3- and 11-unsaturations further compounds the problem of configuration correlation, and whether plexaurolone should be viewed as (1) [related to (−)-cembrene-A, (2)] or (3) [related to (+)-cembrene-A, (4)] can be decided only by inference.

(3)   (4)
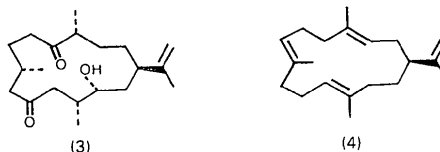
In the absence of the 7-unsaturation, it appears useful to extend the convention to the 3-unsaturation for reference to cembrene-A. Exception must be made for cembranoids containing a 2,3 double bond (Kashman, Zadock & Neeman, 1974). Otherwise, in all known marine cembranoids, the precursor 3-unsaturation either is present as such, or is in a form in which both C(3) and C(4) are directly oxygenated, as an epoxide, or as functions resulting from interaction of the epoxide with an O nucleophile. Using this secondary criterion, it can be inferred that the 3-hydroxyl of plexaurolone shown in (1) originated by reduction of the 3,4-epoxide of (−)-cembrene-A, and that the 11-ketone originated from a similar process followed by oxidation, or simply by isomerization of the 11,12-epoxide. The origin of the 6-ketone can reasonably be attributed to allylic oxidation followed by reduction of the 7-unsaturation. In contrast, neither C(3) nor C(4) is oxidized in (3). All of its O functions would require allylic oxidations at appropriate centers in (+)-cembrene-A.

On the basis of these observations, we prefer to view plexaurolone as (1), thereby classifying it as a member of the α series. It is interesting to point out that all of the Caribbean cembranes for which absolute configurations have been reported belong to the β series while all Pacific cembranes of known absolute configuration belong to the α series (Weinheimer *et al.*, 1977, and references therein). Thus, plexaurolone may represent the first example of a Caribbean cembranoid belonging to the α series.

Bond distances for the two independent molecules compare very well, with the largest differences being found in the isopropenyl group [$\Delta = 0.022$ Å for C(15)—C(16) and $\Delta = 0.019$ Å for C(15)—C(17)] which are just at the limit of statistical significance ($\simeq 4\sigma$). One possible explanation is disorder in the isopropenyl group. If, however, such disorder exists it is not very significant as the H thermal parameters are not unusually large and the major axes of the thermal ellipsoids for C(16) and C(17) do not point along the bonds to C(15) (Fig. 1). The only other notable influence is a number of short intermolecular contacts involving the isopropenyl group of molecule (II) which will be mentioned later. The 26 pairs of bond distances are compared in Fig. 5 using a half-normal probability plot (Abrahams & Keve, 1971). The most notable feature is that the plot gives a straight line with a slope approximately equal to 1·0, thus indicating that the observed differences and the standard deviations estimated from the inverse matrix in the least-squares refinement are consistent with the values expected for a normal distribution. If the standard deviations had been underestimated the slope would be greater than 1·0. We believe that the use of low-temperature techniques and consequent lowering of the thermal motion plays a

role in obtaining reasonable standard deviations. The two points farthest from the line correspond to the distances in the isopropenyl groups and are discussed above.

The bond angles about C(15) sum to 360·0°, as expected for an sp^2-hybridized atom. The endocyclic bond angles are all greater than 109·5°, a fact which is generally observed in all cembranoids. A comparison of 35 pairs of bond angles using a half-normal probability plot (Abrahams & Keve, 1971) is shown in Fig. 6. The fact that the slope is greater than 1·0 indicates that either the standard deviations are underestimated or the observed differences are influenced by factors other than random error. Since the former assumption would be inconsistent with the results of the half-normal probability plot for bond distances (Fig. 5), we accept the latter. Furthermore, we identify the systematic influence as the packing environment and conclude that bond angles are much more easily affected than bond distances, which is consistent with a previous observation (van der Helm, Wu, Ansell, Ruehle & Eisenbraun, 1977).

The least-squares planes through molecules (I) and (II) and the ring torsion angles are given in Fig. 7. Each fourteen-membered ring possesses a pseudo mirror plane passing through atoms C(7) and C(14) and perpendicular to the least-squares plane. The conformation can also be described as two extended five-carbon-atom chains joined to each other by two dimethylene bridges, as is found in the fourteen-membered ring of sinulariolide (Karlsson, 1977), although the pseudo mirror plane is not obvious in sinulariolide. The fourteen-membered rings are very flat with the maximum deviations from the least-squares planes being −0·815 and 0·718 Å for molecule (I) and −0·818 and 0·727 Å for molecule (II). The methyl groups and isopropenyl group are generally in the plane while the O atoms are all on the same side of the plane of the ring. It is noteworthy that the conformations adopted by the molecules approach the degree of planarity of the cembranolides crassin acetate (Hossain
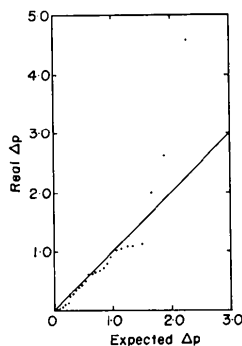

Fig. 5. Half-normal probability plot for 26 pairs of bond distances. The expected values are from *International Tables for X-ray Crystallography* (1974).
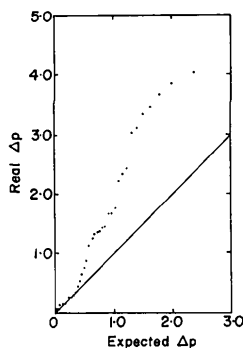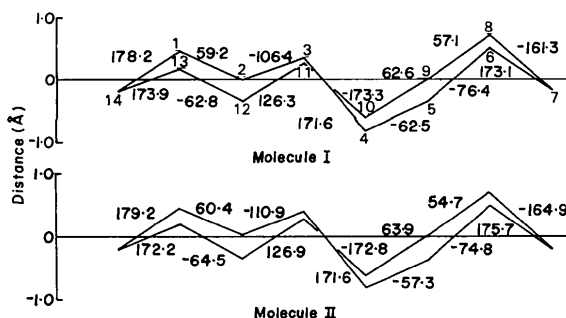

Fig. 6. Half-normal probability plot for 35 pairs of bond angles. The expected values are from *International Tables for X-ray Crystallography* (1974).

Fig. 7. Least-squares planes and torsion angles (°). The equations of the least-squares planes are $0.985x - 9.312y + 0.011z + 1.178 = 0$ and $0.244x + 9.299y + 0.750z - 5.473 = 0$ for molecules (I) and (II), respectively. The standard deviations for the torsion angles are between 0·3 and 0·5°.

& van der Helm, 1969), eunicin (Hossain, Nicholas & van der Helm, 1968), jeunicin (van der Helm, Enwall, Weinheimer, Karns & Ciereszko, 1976) and eupalmerin acetate (Ealick *et al.*, 1975), despite the absence of *trans* double bonds in the carbocyclic ring, and the fusion of lactone rings. The near planarity of the other cembranoids might be attributed in part to the conformational requirements of several such locally rigid components. Plexaurolone adopts comparable planarity in the absence of these constraints.

The most significant difference between molecules (I) and (II) is in the conformation of the isopropenyl group with respect to the cembrane ring. The torsion angle $C(2)C(1)C(15)C(17)$ is $-47 \cdot 6$ (5)° in molecule (I) and $-53 \cdot 2$ (5)° in molecule (II). This difference may be caused by a number of close intermolecular contacts of the isopropenyl group in molecule (II). The most significant of these are $H(16)A$ (II) to $H(13)A$ (I) of $2 \cdot 32$ Å and $H(16)B$ (II) to $H(20)A$ (I) of $2 \cdot 12$ Å $[H(13)A$ (I) and $H(20)A$ (I) are transformed by $1 - x$, $\frac{1}{2} + y$, $-z]$. One short contact involving $O(24)$ (II) with $H(22)A$ (I) $(x, 1 + y, z)$ of $2 \cdot 46$ Å was also observed.

References

ABRAHAMS, S. C. & KEVE, E. T. (1971). *Acta Cryst.* A27, 157–165.
AHMED, F. R. (1966a). SFLS Program *NRC*-10. National Research Council, Ottawa.
AHMED, F. R. (1966b). Fourier Program *NRC*-8. National Research Council, Ottawa.
CIERESZKO, L. S. & KARNS, T. K. B. (1973). *Biology and Geology of Coral Reefs*. Vol. II. *Biology*, Part 1, edited by O. A. JONES & N. R. ENDEAN, pp. 183–203. New York: Academic Press.
CROMER, D. T. & LIBERMAN, D. (1970). *J. Chem. Phys.* 53, 1891–1898.
DREW, M. G. B., TEMPLETON, D. H. & ZALKIN, A. (1969). *Acta Cryst.* B25, 261–267.
EALICK, S. E., VAN DER HELM, D. & WEINHEIMER, A. J. (1975). *Acta Cryst.* B31, 1618–1626.
FENICAL, W. (1978). *Marine Natural Products*, Vol. II, edited by P. J. SCHEUER, pp. 173–245. New York: Academic Press.
GERMAIN, G., MAIN, P. & WOOLFSON, M. M. (1971). *Acta Cryst.* A27, 368–376.
HERIN, M. & TURSCH, B. (1976). *Bull. Soc. Chim. Belg.* 85, 707–719.
HOSSAIN, M. B. & VAN DER HELM, D. (1969). *Recl Trav. Chim. Pays-Bas*, 88, 1413–1423.
HOSSAIN, M. B., NICHOLAS, A. F. & VAN DER HELM, D. (1968). *Chem. Commun.* pp. 385–386.
International Tables for X-ray Crystallography (1962). Vol. III. Birmingham: Kynoch Press.
International Tables for X-ray Crystallography (1974). Vol. IV. Birmingham: Kynoch Press.
JOHNSON, C. K. (1965). *ORTEP*. Report ORNL-3794. Oak Ridge National Laboratory, Tennessee.
KARLSSON, R. (1977). *Acta Cryst.* B33, 2027–2031.
KASHMAN, Y., ZADOCK, E. & NEEMAN, I. (1974). *Tetrahedron*, 30, 3615–3620.
PATIL, V. D., NAYAK, U. R. & DEV, S. (1973). *Tetrahedron*, 29, 341–348.
STEWART, R. F., DAVIDSON, E. R. & SIMPSON, W. T. (1965). *J. Chem. Phys.* 42, 3175–3187.
TURSCH, B., BRAEKMAN, J. C., DALOZE, D. & KAISIN, M. (1978). *Marine Natural Products*, Vol. II, edited by P. J. SCHEUER, pp. 247–296. New York: Academic Press.
VAN DER HELM, D., ENWALL, E. L., WEINHEIMER, A. J., KARNS, T. K. B. & CIERESZKO, L. S. (1976). *Acta Cryst.* B32, 1558–1560.
VAN DER HELM, D., WU, K. K., ANSELL, L. L., RUEHLE, P. H. & EISENBRAUN, E. J. (1977). *Acta Cryst.* B33, 2041–2047.
WEINHEIMER, A. J., CHANG, C. W. J. & MATSON, J. A. (1979). *Progress in the Chemistry of Organic Natural Products. Naturally Occurring Cembranes*, edited by W. HERZ, H. GRISEBACH & G. W. KIRBY, pp. 285–387. Berlin: Springer.
WEINHEIMER, A. J., MATSON, J. A., HOSSAIN, M. B. & VAN DER HELM, D. (1977). *Tetrahedron Lett.* pp. 2923–2926.
WILSON, A. J. C. (1942). *Nature (London)*, 150, 151–152.