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C_{15} Halogenated Compounds from the Hawaiian Marine Alga *Laurencia nidifica*. Maneonenes and Isomaneonenes

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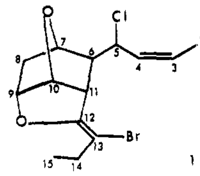
Six C_{15} nonterpenoid halo ethers from a green variety of the Hawaiian marine alga *Laurencia nidifica* have been isolated and characterized by chemical and spectroscopic methods. The maneonenes (1–4) have one carbocyclic ring and the isomaneonenes (5 and 6) possess two carbocyclic rings, an unusual feature for C_{15} nonterpenoid ethers of *Laurencia*. The structure of isomaneonene-B is confirmed by X-ray analysis.

Marine algae of the genus *Laurencia* have been extensively investigated in recent years and a variety of terpenoid and nonterpenoid metabolites have been isolated and characterized.[1] The Hawaiian alga *Laurencia nidifica* has been divided into two pink varieties, one elaborating laurinterol, aplysin, and pacifenol[2] and the second elaborating nidifidiene, nidificene,[2] nidifidienol,[3] and nidifocene,[4] and a green variety, containing sesquiterpenoid alcohols[5] and halogenated nonterpenoid C_{15} compounds, the maneonenes 1–4 and the isomaneonenes 5 and 6.[6–8] This paper describes the details of the structural work on the latter two groups of compounds together with X-ray confirmation of structure for isomaneonene-B.



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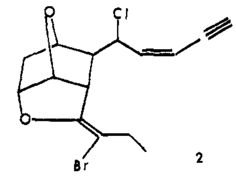

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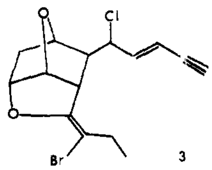

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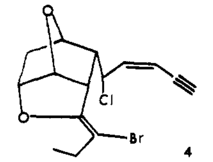

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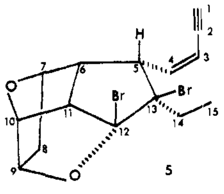

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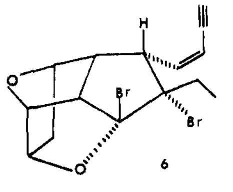

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Collections of the alga were made in January and June 1975 and January 1976 at Diamond Head and Black Point reefs on the island of Oahu, Hawaii. The alga is bright green in color and grows in patches on the reef where the wave action is substantial. Although its color and habitat are different from other varieties of *L. nidifica*, this alga has been classified as the same species.[9]

Ether extracts of the air-dried alga were chromatographed on silica gel columns. The benzene fraction afforded the *cis*-maneonenes **1**, **2**, and **4** and benzene–ether fractions gave *trans*-maneonene-B (**3**) together with the isomaneonenes **5** and **6**. *cis*-Maneonene-B (**2**) was consistently the major component, but amounts of the other compounds varied, apparently with the season; *trans*-maneonene-B (**3**) was found only in the January 1976 collection. Separation of the isomers was achieved by repeated thin layer chromatography on silica gel with multiple developments (Scheme I).

High resolution mass spectroscopy established the formula of $C_{15}H_{16}BrClO_2$ for the maneonenes **1–4**. All of the spectral and chemical data suggested that these four compounds were very closely related, consequently the component of greatest abundance, *cis*-maneonene-B (**2**), and its isomer, *cis*-maneonene-A (**1**), were investigated first. These two compounds differ only in the configuration of the C-12 double bond.

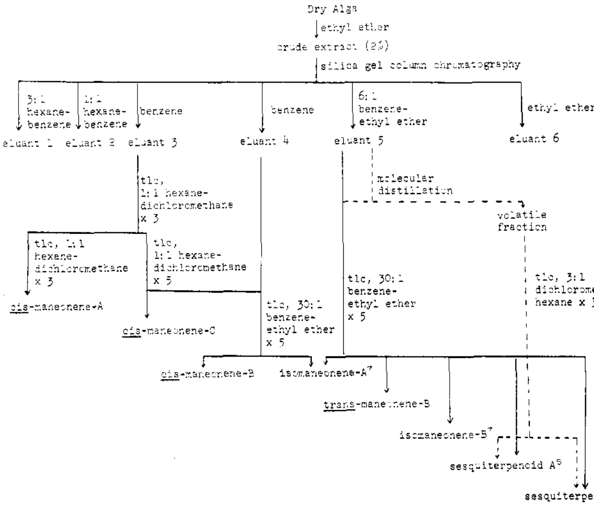
cis-Maneonene-A displays an acetylenic C–H stretch (3310 cm^{-1}) in the IR spectrum. The UV (225 nm) and ^{1}H and ^{13}C NMR spectra (Table I, C_1, C_3, and C_4) established the *cis*-enyne portion of the C-5 side chain. Downfield absorptions in the ^{13}C NMR (δ 58.3) and in the ^{1}H NMR spectra (δ 5.08) were ascribed to a halogen-bearing carbon with one proton attached. This proton is coupled by 10.5 Hz to the C-4 vinylic

Table I. ^{13}C ^{a} and ^{1}H ^{b} NMR Data for *cis*-Maneonene-A (1)

Carbon no.	^{13}C δ	^{1}H δ	Multiplicity, J (Hz)
1	84.8	2.67	d, $J_{1,3} = 2.3$
3	111.9	5.36	dd, $J_{1,3} = 2.3$, $J_{3,4} = 10.5$
4	142.0	6.05	t, $J_{3,4} = J_{4,5} = 10.5$
5	58.3	5.08	t, $J_{4,5} = J_{5,6} = 10.5$
6	58.3	1.89	dd, $J_{5,6} = 10.5$, $J_{6,11} = 1.5$
7	78.3	4.62	d, $J_{7,8\text{exo}} = 5$
8	38.6	1.34 (exo) 0.96 (endo)	td, $J_{8\text{exo},8\text{endo}} = 14$, $J_{7,8\text{exo}} = 5$, $J_{8\text{exo},9} = 8$ d, $J_{8\text{exo},8\text{endo}} = 14$
9	80.4	4.06	dd, $J_{8\text{exo},9} = 8$, $J_{9,10} = 5$
10	82.2	4.34	t, $J_{9,10} = J_{10,11} = 5$
11	46.1	2.75	dd, $J_{10,11} = 5$, $J_{6,11} = 1.5$
14	26.7	2.47 2.51	sextet, $J_{14,14} = 14$, $J_{14,15} = 7$ sextet, $J_{14,14} = 14$, $J_{14,15} = 7$
15	13.0	1.06	t, $J_{14,15} = 7$

^{a} Proton decoupled values (ppm downfield from Me$_4$Si) in C$_6$D$_6$. ^{b} 270 MHz values (ppm downfield from Me$_4$Si) in C$_6$D$_6$.

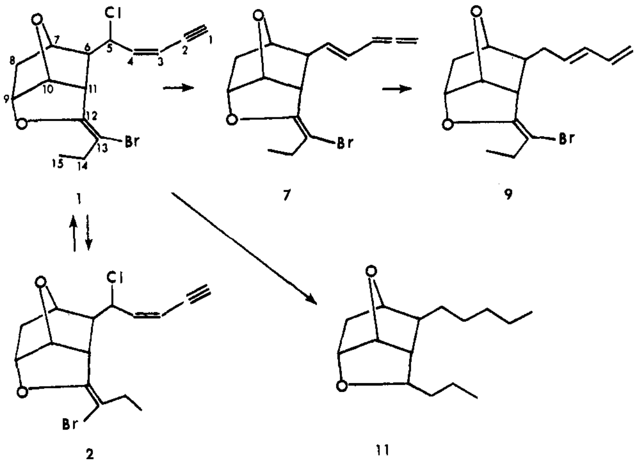
Scheme I



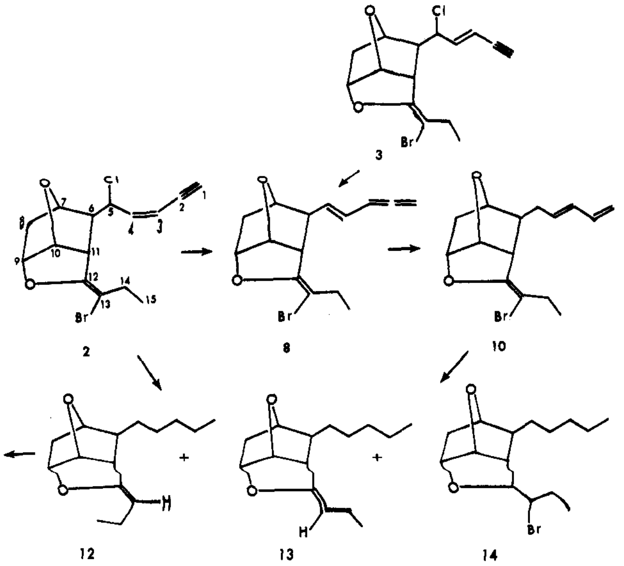
proton (and to a second neighboring proton by the same amount) indicating that this halogen-bearing carbon is C-5. The presence of halogen at this position is unusual in these systems, and additional evidence was sought to verify its placement. This was forthcoming when *cis*-maneonene-A was treated with bis(ethylenediamine)chromium(II)[10] in an attempt to remove halogen from the molecule. The product of this reaction (7) had retained bromine but not chlorine, and the enyne grouping was converted into a terminal allene conjugated with a double bond at C-4. The IR spectrum of this allenic material displays strong bands at 1940 (C=C=C) and 860 cm^{-1} (C=C=CH$_2$) and the UV spectrum (227 nm) demonstrates the conjugated nature of the allene grouping. ^{13}C NMR data were unavailable for 7 but were obtained for its C-12 double bond isomer, 8, derived from *cis*-maneonene-B (2) (Scheme III), and they fully confirmed the presence of a conjugated allene moiety with the terminal allenic carbon signal appearing at δ 76.6 and the C-3 allenic carbon signal at δ 93.4. The stereochemistry of the olefinic bond could not be ascertained with certainty, but a strong absorption in the 970-cm^{-1} region of the IR spectrum suggests that it is trans. The other functionalities in the parent molecule (vida infra) were unaffected by the chromous reagent.

Allenes 7 and 8 could be further reduced with chromous sulfate to conjugated dienes 9 and 10 (Schemes II and III), which could also be obtained by direct reduction of 1 and 2 with chromous sulfate. Whereas amine-complexed chromous ion does not reduce multiple bonds,[11] other chromous reagents do. Thus, triple bonds may be reduced to trans double bonds[11] and enynes[12] and enallenes[13] to conjugated dienes. The conversion of the 5-halo-3-en-1-yne system into a conjugated 4-en-1-allene by bis(ethylenediamine)chromium(II) would be expected to proceed analogously to the well-known allylic halide reductions with this reagent.[14] Although we are unaware of any reports in the literature on the conversion of such haloenynes into conjugated allenes by chromous reagents, lithium aluminum hydride has been used to effect such conversions.[15]

Scheme II



Scheme III



The remaining functionalities in *cis*-maneonene-A were assigned from IR and NMR analysis. A vinyl ether stretch (1685 cm^{-1}) and strong C–O bands (1100, 1040 cm^{-1}) are evident in the IR spectrum. Since there are no hydroxyl or carbonyl absorptions, the two oxygens of **1** were assumed to be involved as ether links. This was verified by the ^{13}C NMR spectrum which shows three oxygen-bearing carbons[16] and the ^1H NMR spectrum which shows three downfield methines (Table I). The assignment of these methine absorptions to the oxygen-bearing carbons was confirmed by specific hydrogen–carbon decoupling experiments. The fourth oxygen-bearing carbon would then be quaternary.

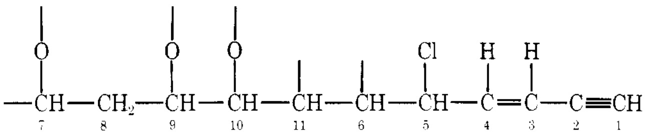
The ^{13}C NMR spectrum established the presence of 12 hydrogen-bearing carbons, only two of which were in the olefinic region. The three quaternary centers are accounted for by the internal acetylenic carbon and the vinyl carbons of the double bond bearing the ether function. The other substituents on this tetrasubstituted double bond can be shown to be an ethyl group and the bromine atom. Thus, the bromine must be at a quaternary center since there are no additional halomethine resonances in the ^1H NMR spectrum. Placement of the ethyl group also follows from the ^1H NMR spectrum. The ethyl resonances appear as a triplet at δ 1.06 (J = 7 Hz) and two doublets of quartets (J = 7, 14 Hz) at 2.47 and 2.51 indicating that the methylene hydrogens are nonequivalent and coupled only to each other and the methyl protons. This, plus their chemical shift values, establish the ethyl group as vinylic.

When *cis*-maneonene-A was catalytically hydrogenated, a saturated product, $C_{15}H_{26}O_2$ (**11**, Scheme II), was obtained confirming four sites of unsaturation and therefore three rings in the molecule. The specific ^{13}C and ^1H NMR absorptions of this saturated product show that the four oxygen methine groups are unchanged. The mass spectrum shows that both halogens were replaced by hydrogens. Facile loss of a pentyl and a propyl, but not an ethyl, group on electron impact supports the presence of C_5 and C_3 side chains. The C_5 side chain arises from the original chloroenyne group. The C_3 side chain must arise from the ethyl end of the molecule and can be accounted for only if the original bromine is attached to the vinyl carbon bearing the ethyl group as shown in **1**.

Further confirmation of this assignment comes from the sodium–ammonia reduction of *cis*-maneonene-B, the C-12 double bond isomer of *cis*-maneonene-A. The mixture of products obtained in this reaction was catalytically hydrogenated to give two isomeric vinyl ethers (**12** and **13**) and a saturated ether (**14**) which retained the bromine (Scheme III). The same product mixture was obtained when the diene from chromous sulfate treatment (**10**) was subjected to sodium–ammonia followed by catalytic hydrogenation (Scheme III(/ The bromo compound (**14**) displays a bromomethine at δ 3.52 in the ^1H NMR spectrum as a complex multiplet. Four oxygen methines are also evident with no hydroxyl absorption in the IR spectrum, again indicating that none of the ether bonds had broken. When passed through the gas chromatograph, this bromide eliminated HBr and gave one of the vinyl ethers (**12**) obtained directly in the reduction sequence. This vinyl ether was hydrogenated to the same saturated ether (**11**) obtained on hydrogenation of *cis*-maneonene-A (Scheme II). The trisubstituted vinyl ether functionality for **12** and **13** was assigned on the basis of IR (1700 cm^{-1} for **12** and 1695 cm^{-1} for **13**), ^1H NMR (δ 4.31 for **12** and 4.88 for **13**), and ^{13}C NMR (δ 95.6 for **13**) spectra. The fact that the vinyl hydrogen in these two vinyl ethers is vicinally coupled (t, J = 7 Hz) to the methylene protons of the ethyl group confirmed its placement and that of the original bromine at C-13.

The assignment of the Z configuration to vinyl ether **12** and the E configuration to vinyl ether **13** was made by comparing the influence of the oxygen atom on the chemical shifts of the vinyl hydrogen and the ethyl hydrogens. The vinyl hydrogen in **13** is cis to the oxygen function and occurs 0.57 ppm further downfield than the vinyl hydrogen in **12**. Similarly, the ethyl group in **12** is cis to the oxygen, and these protons are more deshielded than in **13**.

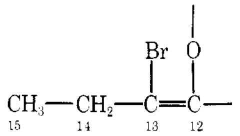
Thirteen of the fifteen carbon atoms and thirteen of the sixteen hydrogen atoms of *cis*-maneonene-A have now been defined; the remaining two carbons and three hydrogens were ascribed to a CH and a CH_2 group. A doublet (J = 14 Hz) centered at δ 0.96 in the ^1H NMR spectrum supports the presence of a geminally coupled pair of methylene hydrogens. Specific hydrogen–carbon decoupling experiments permitted the assignment of proton methine absorptions with oxygen-bearing carbons and with the chlorine-bearing carbon. Proton–proton decoupling experiments gave the following proton sequence:[17]



$$-\underset{7}{\overset{\overset{|}{O}}{\overset{|}{CH}}}-\underset{8}{CH_2}-\underset{9}{\overset{\overset{|}{O}}{\overset{|}{CH}}}-\underset{10}{\overset{\overset{|}{O}}{\overset{|}{CH}}}-\underset{11}{\overset{|}{CH}}-\underset{6}{\overset{|}{CH}}-\underset{5}{\overset{Cl}{\overset{|}{CH}}}-\underset{4}{\overset{H}{\overset{|}{C}}}=\underset{3}{\overset{H}{\overset{|}{C}}}-\underset{2}{C}\equiv\underset{1}{CH}$$

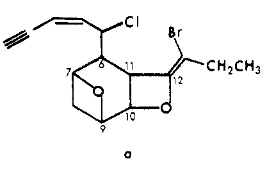
Thus, irradiation of the choromethine at δ 5.08 (C-5) affected not only the C-4 olefinic proton at 6.05 but also collapsed the doublet of doublets at 1.89 (C-6) to a broad singlet. Irradiation in the δ 2.7–2.8-region collapsed the olefinic doublet of doublets at 5.36 (C-3) and the doublet of doublets at 1.89 (C-6) each to doublets and effected a change in the absorption of the oxygen methine at 4.34 (C-10). Two protons are being irradiated in this region, the acetylenic proton at C-1, which is coupled to the olefinic proton at C-3, and the methine at C-11, which is coupled to the protons at C-6 and C-10. Irradiation of the oxygen methine at δ 4.06 (C-9) collapsed the oxygen methine at 4.34 (C-10) to a doublet and also changed the appearance of the multiplet at 1.34 (C-8_{exo}). Irradiation of this latter absorption likewise effected a change in the δ 4.06 (C-9) absorption and collapsed the oxygen methine doublet at 4.62 (C-7) and the doublet at 0.96 (C-8_{endo}) each to singlets. Finally irradiation of the oxygen methine at δ 4.62 (C-7) collapsed the multiplet at 1.34 (C-8_{exo}) to a doublet of doublets.

The butenyl unit

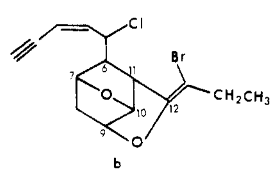


$$\underset{15}{CH_3}-\underset{14}{CH_2}-\underset{13}{\overset{Br}{\overset{|}{C}}}=\underset{12}{\overset{\overset{|}{O}}{\overset{|}{C}}}-$$

must be attached to the main chain and three rings must be formed to complete the structure of *cis*-maneonene-A. Two of these rings are oxide rings, and the third must be carbocyclic. Attachment of C-12 at C-7 would necessitate an additional bond between C-6 and C-11, and this is not tenable as there are only two double bonds in the molecule. Attachment at C-11 with bonding between C-6 and C-7 and ether closures gives three possible structures, two of which are shown below (a and b); the third possibility would contain an epoxide



a



b

moiety for which there is no evidence. Attachment of C-12 at C-6 with bonding between C-7 and C-11 and ether closures leads to three additional structures based on a branched C_{15} chain. These are considered highly unlikely on biogenetic grounds as C_{15} nonterpenoids of *Laurencia* are most probably fatty acid derived. Furthermore, an examination of the mo-

Table II. ^{13}C [a] and ^{1}H [b] NMR Data for *cis*-Maneonene-B (2)

Carbon no.	^{13}C δ	^{1}H δ	Multiplicity, J (Hz)
1	85.4	2.86	d, $J_{1,3} = 2.3$
3	111.9	5.35	dd, $J_{1,3} = 2.3$, $J_{3,4} = 10.5$
4	141.0	5.75	t, $J_{3,4} = J_{4,5} = 10.5$
5	58.3	4.96	t, $J_{4,5} = J_{5,6} = 10.5$
6	58.3	1.83	dd, $J_{5,6} = 10.5$, $J_{6,11} = 1.5$
7	78.1	4.60	br d, $J_{7,8\mathrm{exo}} = 5$
8	38.7	1.30	m
9	79.4	4.25	m
10	82.8	4.60	t, $J_{9,10} = J_{10,11} = 5$
11	43.7	2.68	br d, $J_{10,11} = 5$
14	29.2	2.32	q, $J_{14,15} = 7$
15	13.8	1.07	t, $J_{14,15} = 7$

[a] Proton decoupled values (ppm downfield from Me_4Si in C_6D_6. [b] 60 MHz values (ppm downfield from Me_4Si) in C_6D_6.

Table III. ^{13}C [a] and ^{1}H [b] NMR Data for *trans*-Maneonene-B (3)

Carbon no.	^{13}C δ	^{1}H δ	Multiplicity, J (Hz)
1	79.1	2.76	d, $J_{1,3} = 2$
3	113.3	5.43	dd, $J_{1,3} = 2$, $J_{3,4} = 15.5$
4	142.2	6.05	dd, $J_{3,4} = 15.5$, $J_{4,5} = 9$
5	63.8	3.90	dd, $J_{4,5} = 9$, $J_{5,6} = 11$
6	58.2	1.62	dd, $J_{5,6} = 11$, $J_{6,11} = 2$
7	78.0	3.87	d, $J_{7,8\mathrm{exo}} = 5$
8	39.0	~1.4	m
9	80.7	4.27	dd, $J_{8\mathrm{exo},9} = 6$, $J_{9,10} = 5$
10	82.6	4.57	t, $J_{9,10} = J_{10,11} = 5$
11	45.1	2.87	dd, $J_{10,11} = 5$, $J_{6,11} = 2$
14	29.3	2.7	m
15	14.2	1.23	t, $J_{14,15} = 7$

[a] Proton decoupled values (ppm downfield from Me_4Si) in C_6D_6. [b] 60 MHz values (ppm downfield from Me_4Si) in C_6D_6.

lecular models of all six of these structures clearly shows that only one is in agreement with the ^{1}H NMR spectra, that of b. This skeletal structure gives an excellent fit for all of the maneonenes. Thus, in *cis*-maneonene-A, represented by structure **1**, $J_{6\mathrm{endo},7} = J_{7,8\mathrm{endo}} = J_{8\mathrm{endo},9\mathrm{exo}} = 0$, in agreement with the literature for similar compounds[18] where these dihedral angles are 90°. The 30° angle between H-9 and H-10 and between H-10 and H-11 gives a satisfactory fit for the 5 Hz coupling constant observed as does the 0° angle between H-8_{exo} and H-9 where $J = 8$ Hz. The $J_{6\mathrm{endo},11\mathrm{exo}}$ is small (1.5 Hz) in agreement with their dihedral angle which is not far from 90°. This C-6, C-11 bond is unprecedented in these metabolites but is clearly necessary in order to accommodate the decoupling data. The H–H coupling constants around the carbocyclic ring for the other maneonenes (Tables II–IV) are also in excellent agreement with their predicted values.[18]

That the C-12 double bond is of the *E* configuration in *cis*-maneonene-A (**1**) is shown by comparison with its isomer, *cis*-maneonene-B (**2**). These two materials are interconvertible by treatment with catalytic amounts of acid. Starting with either isomer, a roughly equivalent mixture of both persists at equilibrium. As expected from the dipole alignments, **2** is the more polar material. The spectral characteristics of both compounds are essentially identical except in the region influenced by the substituents on the C-12 double bond. In the ^{1}H NMR spectrum, H-4 is 0.3 ppm further downfield in **1** than it is in **2**, a consequence of the deshielding effect of the bromine on this hydrogen in **1**. Similarly in **1**, the C-14 protons are 0.2 ppm further downfield than those in **2**, reflecting the influence of the cis oxygen atom in **1**.

trans-Maneonene-B (**3**) was shown to have a *trans*-enyne function by UV and ^{1}H NMR analysis. The two olefinic protons are coupled to each other by 15.5 Hz. The C-3 proton is also coupled to the acetylenic hydrogen (2 Hz), and the C-4 proton is further coupled to the C-5 halomethine (9 Hz) in analogy with *cis*-maneonene-A and *cis*-maneonene-B (Table III). In the IR spectrum a band at 955 cm^{-1} supports the trans-disubstituted double bond moiety. Treatment of *trans*-maneonene-B with bis(ethylenediamine)chromium(II) gave the same allene (**8**) as that derived from **2** (Scheme III) and established the structure of the molecule as **3**.

The spectral properties of *cis*-maneonene-C (**4**) and its conversion into a conjugated allene (**15**, Scheme IV) on treatment with bis(ethylenediamine)chromium(II) indicated that it has the same chloroenyne side chain as **1** and **2**. Catalytic reduction of *cis*-maneonene-C afforded compound **16** with the vinyl ether group intact as well as the other three ether bonds. Sodium–ammonia reduction of this vinyl bromo ether gave a new vinyl ether **17** in which the vinyl bromide had been replaced by a hydrogen which is vicinally coupled to the methylene protons of the ethyl group (Scheme IV). The chemical shift of this new vinyl hydrogen (δ 4.19) suggests that it is trans to the oxygen group (compare to δ 4.31 for **12** and δ 4.88 for **13**).

Specific-hydrogen decoupling in the ^{13} NMR spectrum and proton–proton decoupling experiments confirmed that *cis*-maneonene-C has the same proton and heteroatom sequence and therefore the same carbon skeleton as **1–3**. The most obvious difference in the spectral properties between *cis*-ma-

Table IV. ^{13}C [a] and ^{1}H [b] NMR Data for *cis*-Maneonene-C (4)

Carbon no.	^{13}C δ	^{1}H δ	Multiplicity, J (Hz)
1	85.3	2.83	d, $J_{1,3} = 2.3$
3	109.9	5.15	dd, $J_{1,3} = 2.3$, $J_{3,4} = 10.5$
4	141.9	5.56	t, $J_{3,4} = J_{4,5} = 10.5$
5	54.5	5.01	t, $J_{4,5} = J_{5,6} = 10.5$
6	54.0	2.61	m, $J_{5,6} = 10.5$, $J_{6,7} = 4.5$, $J_{6,11} = 9.5$
7	77.9	3.98	t, $J_{6,7} = J_{7,8\mathrm{exo}} = 4.5$
8	36.4	1.42 (exo) 1.90 (endo)	td, $J_{8\mathrm{exo},8\mathrm{endo}} = 14$, $J_{7,8\mathrm{exo}} = 4.5$, $J_{8\mathrm{exo},9} = 7$ d, $J_{8\mathrm{exo},8\mathrm{endo}} = 14$
9	81.2	4.31	dd, $J_{8\mathrm{exo},9} = 7$, $J_{9,10} = 5$
10	83.5	4.65	t, $J_{9,10} = J_{10,11} = 5$
11	45.0	3.52	dd, $J_{10,11} = 5$, $J_{6,11} = 9.5$
14	27.9	2.61 2.97	m, $J_{14,14} = 14$, $J_{14,15} = 7$ sextet, $J_{14,14} = J_{14,15} = 7$
15	13.6	1.35	t, $J_{14,15} = 7$

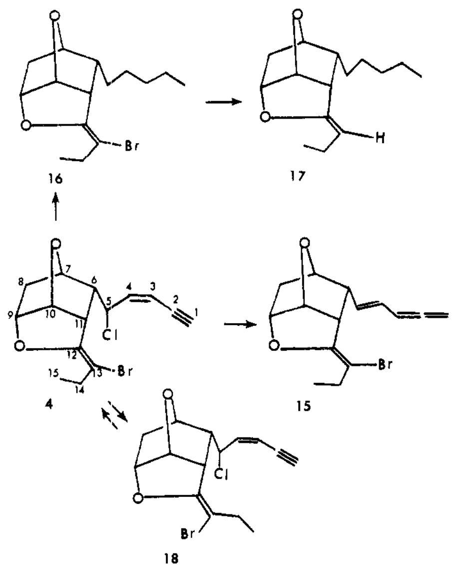
[a] Proton decoupled values (ppm downfield from Me_4Si) in C_6D_6. [b] 270 MHz values (ppm downfield from Me_4Si) in C_6D_6.

Table V. ^{13}C [a] and ^{1}H [b] NMR Data for Isomaneonene-A (5)

Carbon no.	^{13}C δ	^{1}H δ	Multiplicity, J (Hz)
1	84.7	2.72	d, $J_{1,3} = 2$
2	79.5[c]		
3	109.2	4.98	dd, $J_{1,3} = 2$, $J_{3,4} = 10.5$
4	144.5	5.66	dd, $J_{3,4} = 10.5$, $J_{4,5} = 8$
5	49.7	4.33	dd, $J_{4,5} = 8$, $J_{5,6} = 10$
6	50.5	3.38	sextet, $J_{5,6} = J_{6,11} = 10$, $J_{6,7} = 5$
7	77.6	4.19	t, $J_{6,7} = J_{7,8exo} = 5$
8	41.4	1.15 (exo) 1.59 (endo)	dt, $J_{7,8exo} = J_{8exo,9} = 5$, $J_{8exo,8endo} = 13$ d, $J_{8exo,8endo} = 13$
9	83.3	4.31	t, $J_{8exo,9} = J_{9,10} = 5$
10	82.9	5.02	t, $J_{9,10} = J_{10,11} = 5$
11	63.1	3.88	dd, $J_{10,11} = 5$, $J_{6,11} = 10$
12	110.6[c]		
13	89.7[c]		
14	26.8	2.08 2.33	sextet, $J_{14,14} = 14$, $J_{14,15} = 7$ sextet, $J_{14,14} = 14$, $J_{14,15} = 7$
15	10.0	1.06	t, $J_{14,15} = 7$

[a] Proton decoupled values (ppm downfield from Me_4Si) in $CDCl_3$. [b] 270 MHz values (ppm downfield from Me_4Si) in C_6D_6. [c] Quaternary carbon.

Scheme IV



neonene-C and its isomers is the coupling of H-6 with its neighbors on the carbocyclic ring. Thus, whereas $J_{6,7} = 0$ in **1–3**, in *cis*-maneonene-C $J_{6,7} = 4.5$ Hz. Similarly, $J_{6,11} = 1.5$ Hz in **1** and **2** and 2 Hz in **3**, while in *cis*-maneonene-C $J_{6,11} = 9.5$ Hz. These J values for *cis*-maneonene-C are in excellent agreement with the literature for couplings of an exo H-6 to a bridgehead H-7, and an exo H-6 to an exo H-11,[18] and again confirm the C-6, C-11 bond. *cis*-Maneonene-C is then the C-6 epimer of **1** or **2**.

Catalytic amounts of acid equilibrated *cis*-maneonene-C with its C-12 double bond isomer (**18**, Scheme IV). Since the H-4 and the H-14 protons of *cis*-maneonene-C absorb further downfield than the same protons in its isomer, *cis*-maneonene-C was assigned the *E* configuration at the C-12 double bond and its isomer the *Z* configuration. *cis*-Maneonene-C is then represented by structure **4**.

The maneonenes are unique in structure for C_{15} nonterpenoids from *Laurencia* and *Aplysia* species. Although a number of these materials have been described, only one recently reported example, panacene, contains a carbocyclic ring (C-8, C-13 juncture).[19] The maneonenes contain one carbocyclic ring by virtue of the C-6, C-11 bond. Also occurring with them are the isomaneonenes which contain this same carbocyclic ring and an additional one as well.

Isomaneonene-A (**5**) and isomaneonene-B (**6**) were obtained from the benzene and benzene–ether eluants of the chromatography of the crude algal extract (Scheme I). Both compounds analyzed for $C_{15}H_{16}Br_2O_2$ by high resolution and field desorption mass spectroscopy. Their UV (229, 228 nm), IR (3300, 2970 cm^{-1}), and ^{13}C and ^{1}H NMR spectra (Tables V and VI) indicated the presence of a conjugated *cis*-enyne group.

The IR spectrum of isomaneonene-A shows no hydroxyl, carbonyl, or vinyl ether absorption. Strong bands in the 1000–1100-cm^{-1} region indicate the presence of ether functions. The ^{13}C NMR spectrum shows three oxygen-bearing carbons which could be correlated with three oxygen methine absorptions in the ^{1}H NMR spectrum (Table V) by specific hydrogen–carbon decoupling experiments. The fourth oxygen-bearing carbon, having no associated proton absorption, must be quaternary.

The ^{13}C NMR spectrum established that 3 of the 15 carbon atoms of isomaneonene-A are quaternary. One of these quaternary centers is the internal acetylenic carbon and the other two bear the second oxygen atom, both bromines, and an ethyl group. The placement of the ethyl group follows from the ^{1}H NMR spectrum. A three-proton triplet ($J = 7$ Hz) at δ 1.06 and two doublets of quartets ($J = 7, 14$ Hz) at 2.08 and 2.33 show that the methylene protons of the ethyl group are magnetically nonequivalent and are coupled only to each other and the adjacent methyl protons. The attachment of the two bromine atoms and the fourth oxygen link to the remaining quaternary centers is indicated by the deshielded chemical shift values for these carbons (δ 110.6 and 89.7). Catalytic hydrogenation of either isomaneonene-A or isomaneonene-B afforded a saturated ether with all oxygen bonds intact but with both bromines replaced by hydrogens (**19**, Scheme V). This ether has four oxygen methines rather than three as found in the original compound. A new oxygen methine can arise from reductive debromination of a quaternary carbon bearing an oxygen and a bromine but not from one bearing two bromines.

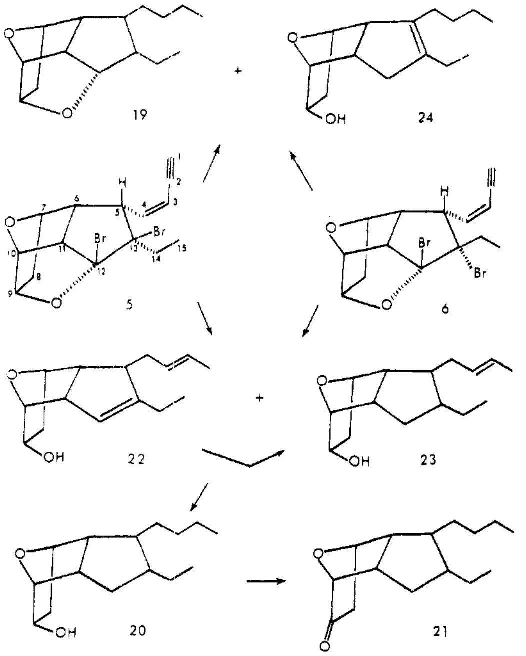
The quaternary ether linkage of isomaneonene-A was cleaved under dissolving metal reduction conditions. Treatment with sodium in ammonia followed by catalytic hydrogenation gave a saturated ether alcohol (**20**, Scheme V) again with both bromines replaced by hydrogens. The mass spectrum of this alcohol shows the loss of butyl (from the original enyne side chain) and ethyl fragments. The loss of an ethyl rather than a propyl group fixes this substituent at the qua-

Table VI. ^{13}C [a] and ^{1}H [b] NMR Data for Isomaneonene-B (6)

Carbon no.	^{13}C δ	^{1}H δ	Multiplicity, J (Hz)
1	83.5	2.72	d, $J_{1,3} = 2$
2	79.9 [c]		
3	108.7	5.08	dd, $J_{1,3} = 2$, $J_{3,4} = 10.5$
4	146.9	6.34	dd, $J_{3,4} = 10.5$, $J_{4,5} = 9$
5	43.2	3.53	t, $J_{4,5} = J_{5,6} = 9$
6	50.0	2.75	sextet, $J_{5,6} = 9$, $J_{6,7} = 5$, $J_{6,11} = 10$
7	77.6	4.08	t, $J_{6,7} = J_{7,8\mathrm{exo}} = 5$
8	41.1	1.15 (exo) 1.67 (endo)	dt, $J_{7,8\mathrm{exo}} = J_{8\mathrm{exo},9} = 5$, $J_{8\mathrm{exo},8\mathrm{endo}} = 13$ d, $J_{8\mathrm{exo},8\mathrm{endo}} = 13$
9	81.4	4.25	t, $J_{8\mathrm{exo},9} = J_{9,10} = 5$
10	84.6	5.03	t, $J_{9,10} = J_{10,11} = 5$
11	58.7	2.96	dd, $J_{10,11} = 5$, $J_{6,11} = 10$
12	109.5 [c]		
13	85.2 [c]		
14	38.0	1.30 2.36	sextet, $J_{14,14} = 14$, $J_{14,15} = 7$ sextet, $J_{14,14} = 14$, $J_{14,15} = 7$
15	10.6	0.95	t, $J_{14,15} = 7$

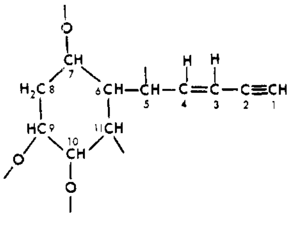
[a] Proton decoupled values (ppm downfield from Me_4Si) in $CDCl_3$. [b] 270 MHz values (ppm downfield from Me_4Si) in C_6D_6. [c] Quaternary carbon.

Scheme V



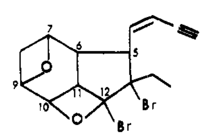
ternary carbon bearing the single bromine and completes the assignment of C-12 through C-15 as shown in **5**.

Twelve of the fifteen carbon atoms and twelve of the sixteen hydrogen atoms of isomaneone-A have now been defined. The remaining groups must be a methylene and two methines as the one methyl carbon and the three quaternary carbons have already been assigned. A geminally coupled pair of hydrogens is evident from the ^{1}H NMR spectrum where a doublet (J = 13 Hz) appears at δ 1.59. The two methine protons and the second hydrogen of the methylene group are also shown in the ^{1}H NMR spectrum (Table V, C-6, C-11, and C-8_{exo}). Proton–proton decoupling experiments established the proton sequence as:[17]

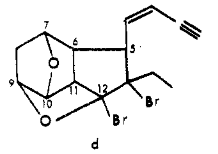


Irradiation at δ 4.98 (C-3) collapsed the doublet at 2.72 (C-1) to a singlet and the doublet of doublets at 5.66 (C-4) to a doublet. Irradiation at δ 3.38 (C-6) effected changes in the signals at 4.33 (C-5), 4.19 (C-7), and 3.88 (C-11). The sextet at δ 3.38 (C-6) collapsed to a triplet upon irradiation of the 4.19 signal (C-7) and the doublet of triplets at 1.15 (C-8_{exo}) collapsed to a doublet of doublets. Irradiation of the latter (C-8_{exo}) converted the triplets at 4.19 (C-7) and 4.31 (C-9) each to doublets and the doublet at 1.59 (C-8_{endo}) to a singlet. Irradiation at δ 5.02 (C-10) collapsed the triplet at 4.31 (C-9) and the doublet of doublets at 3.88 (C-11) each to doublets.

The quaternary carbons bearing the ethyl, bromines, and one oxygen must be attached to the main chain through carbons 5 and 11. If the bromine, ethyl-bearing carbon is attached at C-5 and the bromine, oxygen-bearing carbon at C-11 followed by ether ring closures, two viable structures (c and d) are generated which are based on an unbranched C_{15} chain:



c



d

Since no epoxide moiety is evident in isomaneonene-A, the structure resulting from oxide ring closure between C-9 and C-10 is not considered possible. If the bromine, ethyl-bearing carbon is attached at C-11 and the bromine, oxygen-bearing carbon at C-5, three additional structures arise, these based on a branched C_{15} chain. As with the maneonenes, a branched carbon skeleton for these compounds is considered highly unlikely on biogenetic grounds. Moreover, molecular models of all isomers of these six structures show that only structure d will fit the spectroscopic data. Structure d is confirmed also on the basis of the following information. The secondary alcohol (**20**) obtained from the sodium and ammonia hydrogenation sequence (Scheme V), when treated with Jones reagent, afforded a ketone (**21**). Proton–proton decoupling experiments with this ketone showed that the oxygen-bearing methine at δ 4.39 (C-7) is coupled to two protons, one at 2.62 (C–6) and the other at 2.20 (C-8_{exo}); the other oxygen-bearing methine (δ 4.06, C-10) is coupled to a proton at 2.49 (C-11). The proton at δ 2.49 (C-11) and the proton at 2.62 (C-6) *are also coupled with each other as well as to additional protons other than the oxygen methines.* This data can only be accommodated by ketone **21** arising from **5** (Scheme V).

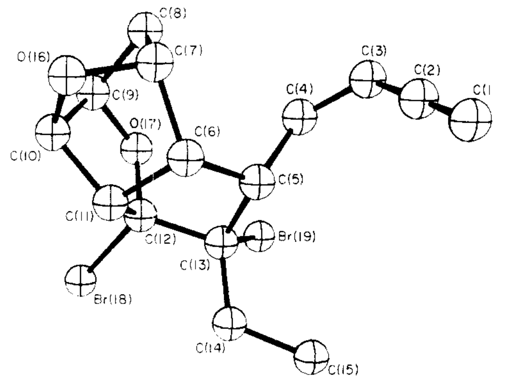


Figure 1. A computer generated perspective drawing from the crystal structure of isomaneonene-B (**6**).

An analysis of the H–H couplings in the ^1H NMR spectrum of isomaneonene-A shows an excellent agreement with the structure assigned. The coupling constants $J_{5,6}$ (10 Hz) and $J_{6,11}$ (10 Hz) indicate that H-6 is cis to H-5 and H-11. The dihedral angle between H-6 and H-7, H-9 and H-10, and H-10 and H-11 is approximately 30°, which gives a satisfactory fit for the observed coupling constant of 5 Hz.[18]

The different chemical environments of H-8_{exo} and H-8_{endo} give two absorptions, coupled to each other by 13 Hz. The dihedral angle between H-7 and H-8_{exo} and H-8_{exo} and H-9 is also approximately 30° to give rise to a 5 Hz coupling. $J_{7,8endo}$ and $J_{8endo,9} = 0$ in agreement with their 90° dihedral angles (Table V).

Isomaneonene-B (**6**) is the C-13 isomer of isomaneonene-A. The distinction between them is made on the basis of their ^1H NMR spectra. In **5** the bromine atom on C-13 is cis to H-5 and trans to the enyne function and H-4, while the opposite situation obtains in **6.** The deshielding effect of this bromine is reflected in the chemical shift of H-5 where it occurs 0.80 ppm further downfield in **5** than in **6,** while H-4 is 0.68 ppm further downfield in **6** than in **5.** H-6 and H-11 also occur substantially further downfield when the C-13 bromine is cis to them (Table V).

Several olefinic intermediates were isolated in the reductions shown in Scheme V. In the sodium–ammonia reaction olefins **22** and **23** were the immediate products. No stereochemistry at the side chain junctures is implied by the formulas shown. Diene **22** analyzed for $C_{15}H_{22}O_2$ by mass spectroscopy. The presence of two nonconjugated double bonds was indicated by three olefinic protons and three olefinic carbons[16] in the ^1H and ^{13}C NMR spectra. Three oxygen methines and an OH stretch (IR 3540 cm^{-1}) indicated that one oxygen link remained intact, while the quaternary C–O linkage was reductively cleaved. Further treatment with sodium–ammonia converted diene **22** to the monoene **23.** Both compounds show strong absorption in the IR spectrum for a disubstituted trans double bond (960 cm^{-1}). The presence of only one ethyl group suggests the placement of this double bond as shown (Scheme V); this would be expected for a 1,4 reduction of the conjugated system. The trisubstituted double bond in **22** cannot be exo to the oxirane ring as the oxygen methine couplings, $J_{6,7}$ and $J_{10,11}$, are unchanged from the isomaneonenes themselves. It also cannot be exo to the five-membered carbocyclic ring as its IR signal (1630 cm^{-1}) occurs at too low a frequency. Both diene **22** and monoene **23** were catalytically reduced to the fully saturated alcohol ether **20.**

Direct hydrogenation of isomaneonene-A or isomaneonene-B afforded an olefinic product (**24**) as well as the fully saturated material (**19,** Scheme V). The olefin analyzes for $C_{15}H_{24}O_2$ by mass spectroscopy and its IR spectrum shows hydroxyl absorption (3570, 3430 cm^{-1}). Three oxygen methines are indicated by the ^1H NMR spectrum, again consistent with reductive cleavage of the quaternary ether link. The tetrasubstituted nature of the double bond is evident from the lack of vinylic proton absorption in the ^1H NMR spectrum. Proton–proton decoupling studies indicated that the H-6 and H-11 protons are still present, therefore this double bond must be between C-5 and C-13.

The complexity of the isomaneonene structures and their abundance of chiral centers (eight) made an X-ray study of these materials desirable. Accordingly a single-crystal X-ray diffraction experiment on isomaneonene-B was carried out. The computer-generated perspective drawing of the final model is shown in Figure 1. The indications of absolute stereochemistry given by the anomalous scattering of bromine were not decisive and the enantiomer shown was only marginally favored. The relative stereochemistry of isomaneonene-B is that predicted on chemical and spectral grounds. All bond distances and angles generally agree with accepted values.

Experimental Section

Melting points were determined on a Hoover Unimelt apparatus and are uncorrected. IR spectra were recorded on Perkin-Elmer 700 and 337 spectrophotometers in CCl_4. The ^1H NMR spectra were recorded with JEOL C-60H, Perkin-Elmer R-12, Perkin-Elmer R-20, Varian HA 100, JEOL-PFT-100, or Brucker 270 HX spectrometers, and the ^{13}C NMR spectra were determined on JEOL-PFT-100 or Varian CFT-20 spectrometers with C_6D_6 or $CDCl_3$ as solvents. Chemical shift values are reported as ppm downfield from Me_4Si at 60 MHz for protons and at 25 MHz for ^{13}C unless otherwise specified. Low resolution mass spectra were obtained on a Finnigan 1015 D GC–mass spectrometer and high resolution mass spectra on a CEC-21-110B spectrometer. Field desorption mass spectra were taken on a Varian CH 5/DF spectrometer. UV spectra were recorded with a Perkin-Elmer 202 spectrophotometer in 95% ethanol unless otherwise indicated. Optical rotations were measured in $CHCl_3$ on a Zeiss Type VDr Na polarimeter. Vapor phase chromatography was done with a Varian-Aerograph 90-P3 instrument. Brinkmann silica gel 60 (30–70 mesh) was used for column chromatography and Brinkmann silica gel HF-254 + 366, Type 60 (500 μm, activated 0.5 h at 100 °C), for TLC.

All solvents and chemicals were reagent grade.

Separation of the Maneonenes. The air-dried alga, 160 g, was ground to a fine powder with a Waring blender, covered with 400 mL of anhydrous ether, and allowed to stand with occasional shaking for 1 week. The ether was decanted and the extraction was repeated with 250 mL of fresh ether for an additional 7 days. The ether extracts were combined, concentrated, and centrifuged and the ether was removed to give 3.3 g (2%) of a green brown oil. This oil was dissolved in 5 mL of 3:1 hexane–benzene and applied to a 4-step glass column (2.50–0.75 cm) packed with 45 g of silica gel. Elution was begun with 3:1 hexane–benzene, and the following eluants were obtained: eluant 1, 3:1 hexane–benzene, 231 mg (7%); eluant 2, 1:1 hexane–benzene, 309 mg (9%); eluant 3, benzene, 329 mg (10%); eluant 4, benzene, 465 mg (14%); eluant 5, 6:1 benzene–ether, 426 mg (13%); eluant 6, ether, 561 mg (17%). The total recovery was 2.37 g (70%).

Isolation of *cis*-Maneonene-A (1), *cis*-Maneonene-B (2), and *cis*-Maneonene-C (4). Eluant 3 (150 mg) was dissolved in ether and spotted onto TLC plates so that each spot contained about 3 mg of material. The plates were developed twice in benzene, drying between developments, and the spots were scraped off and extracted with ether. After filtering and evaporating the ether, the following fractions were obtained: 1, R_f 0.63, 32 mg (21%); 2, R_f 0.50, 47 mg (31%); 3, R_f 0.09, 11 mg (8%).

Thirty milligrams of fraction 1 was spotted onto a TLC plate with ether so that each spot contained about 1.5 mg of material. The plate was developed three times in 1:1 dichloromethane–hexane, drying between developments. The spots were scraped off and extracted with ether. *cis*-Maneonene-A (**1**) was obtained as a colorless oil, R_f 0.47, 16 mg (0.02% of dry alga): $[\alpha]^{21}_D$ +39° (*c* 0.97); UV λ_{max}^{hexane} 225 nm (ε 14 900); IR ν_{max} 3310, 2960, 2940, 1685, 1455, 1430, 1185, 1160, 1100, 1040, 975, 905, and 865 cm^{-1}; NMR Table I; mass spectrum *m/e* 346 (3), 344 (9), 342 (8), 310 (8), 309 (36), 308 (8), 307 (36), 265 (6), 263 (11), 249 (5), 247 (5), 237 (5), 235 (5), 229 (5), 228 (17), 227 (14), 219 (3), 213 (5), 210 (5), 209 (8), 201 (9), 200 (9), 199 (28), 185 (28), 184 (42), 171 (28), 169 (22), 159 (23), 157 (30), 155 (23), 153 (20), 145 (20), 143 (28), 141 (34), 129 (55), 128 (45), 115 (52), 108 (50), 91 (55), 79 (50), 77 (81), 69 (100), 65 (48), 55 (41), 53 (41), 51 (42), 41 (84), 39 (66). High resolution mass spectrum. Calcd for $C_{15}H_{16}Br^{79}Cl^{35}O_2$ (M^+): 342.0021. Found: 342.0026.

Forty-five milligrams of fraction 2 was dissolved in ether and spotted onto TLC plates so that each spot contained approximately 1 mg of material. The plates were developed five times in 1:1 dichloromethane–hexane, drying between developments, and the spots were scraped off and extracted with ether to give *cis*-maneonene-B (**2**), R_f 0.45 (19 mg), and *cis*-maneonene-C (**4**), R_f 0.57 (17 mg), as colorless oils. Additional amounts of both compounds were obtained from rechromatography of eluant 4 or the original column chromatography. Based on dry weight of alga, the total yield of **2** was 0.15% and that of **4** was 0.08%.

***cis*-Maneonene-B (2):** $[\alpha]^{21}{}_D$ −49° (*c* 3.60); UV λ_{max} 227 nm (ϵ 12 200); IR ν_{max} 3310, 2980, 2950, 2880, 1685, 1455, 1430, 1345, 1315, 1305, 1290, 1220, 1190, 1160, 1135, 1110, 1085, 1025, 975, 950, 895, 875, and 845 cm^{-1}; NMR Table II; mass spectrum identical to *cis*-maneonene-A (**1**). High resolution mass spectrum. Calcd for $C_{15}H_{16}Br^{79}Cl^{35}O_2$ (M^+): 342.0021. Found: 341.9990.

***cis*-Maneonene-C (4):** $[\alpha]^{21}{}_D$ +336° (*c* 1.46); UV λ_{max} 222 (ϵ 21 700); IR ν_{max} 3310, 2985, 2945, 2880, 1680, 1455, 1440, 1180, 1165, 1100, 1040, 985, 965, 955, 890, 870, and 850 cm^{-1}; NMR Table IV; mass spectrum *m/e* 346 (3), 344 (9), 342 (6), 310 (6), 309 (37), 308 (6), 307 (37), 266 (3), 265 (19), 264 (3), 263 (19), 228 (4), 227 (9), 221 (4), 219 (4), 203 (5), 202 (4), 201 (14), 200 (6), 199 (21), 189 (6), 187 (9), 185 (9), 183 (8), 181 (6), 171 (11), 169 (11), 159 (41), 143 (21), 141 (31), 129 (38), 128 (41), 123 (29), 122 (46), 121 (38), 115 (52), 108 (44), 107 (39), 91 (67), 81 (52), 79 (68), 77 (100), 69 (71), 65 (57), 53 (46), 51 (47), 41 (76), 39 (72). High resolution mass spectrum. Calcd for $C_{15}H_{16}Br^{79}Cl^{35}O_2$: 342.0021. Found: 342.0019.

Isolation of *trans*-Maneonene-B (3). Approximately 700 mg of eluant 5 from the original column chromatography was dissolved in ether and spotted onto TLC plates so that each plate contained 70 mg of material. The plates were developed five times in 30:1 benzene–ether, drying between developments, and the spots were scraped off and extracted with ether. After filtering and evaporation of the ether, the following compounds were obtained: isomaneonene-A (**5**) (R_f 0.86), *trans*-maneonene-B (**3**) (R_f 0.77), isomaneonene-B (**6**) (R_f 0.63), sesquiterpenoid A (R_f 0.57),[5] and sesquiterpenoid B (R_f 0.50).[5] *trans*-Maneonene-B (**3**) was repurified by the same TLC procedure to give a colorless oil (30 mg, 0.01% of dry alga): $[\alpha]^{21}{}_D$ −25° (*c* 0.397); UV λ_{max} 232 nm (ϵ 15 000); IR ν_{max} 3330, 3000, 2960, 2900, 1685, 1630, 1455, 1435, 1350, 1320, 1295, 1265, 1220, 1190, 1140, 1120, 1030, 955, 890, and 880 cm^{-1}; NMR Table III; mass spectrum *m/e* 346 (3), 344 (11), 342 (8), 309 (3), 307 (3), 265 (2), 263 (3), 249 (2), 247 (2), 237 (2), 235 (2), 228 (6), 227 (6), 201 (8), 199 (14), 189 (8), 187 (14), 185 (13), 184 (14), 181 (6), 171 (11), 169 (11), 165 (9), 159 (10), 157 (11), 155 (11), 153 (10), 149 (14), 141 (25), 129 (28), 128 (22), 121 (22), 115 (28), 109 (19), 108 (33), 107 (22), 99 (22), 97 (28), 95 (33), 91 (36), 85 (24), 83 (33), 81 (39), 79 (36), 77 (47), 71 (42), 69 (100), 57 (47), 55 (72), 53 (39), 51 (39), 41 (50), 39 (47). High resolution mass spectrum. Calcd for $C_{15}H_{16}Br^{79}Cl^{35}O_2$: 342.0021. Found: 341.9989.

Reaction of *cis*-Maneonene-A (1) with Bis(ethylenediamine)chromium(II) to Produce 7. Chromous sulfate solution was prepared by stirring an aqueous solution of 1.14 g of $Cr_2(SO_4)\cdot nH_2O$ with 0.65 g of activated powdered zinc in a nitrogen atmosphere overnight. The resultant blue solution was filtered under nitrogen and a 2.50-mL aliquot (0.5 mmol Cr^{2+}) was added to 1.25 mL of an aqueous solution of $enSO_4$ (1.0 mmol). This mixture was added to a degassed solution of 22 mg (0.048 mmol) of *cis*-maneonene-A (**1**) in 4 mL of DMF. Nitrogen was bubbled through the solution for 4 h; a precipitate formed during this time. Ten milliliters of water was added and the resulting suspension was extracted with three 10-mL portions of CCl_4. The extracts were dried over Na_2CO_3 and filtered and the CCl_4 was evaporated to give a yellow oil. This oil was dissolved in ether, spotted onto TLC plates, and developed twice in 1:1 dichloromethane–hexane, drying between runs. The spots were scraped off, extracted with ether, and filtered and the ether was evaporated to give 11 mg (50%) of **7** as a colorless oil, R_f 0.50: UV λ_{max} 220 nm (ϵ 24 200); IR ν_{max} 3000, 2955, 1940, 1685, 1460, 1440, 1350, 1320, 1290, 1260, 1195, 1170, 1125, 1100, 1055, 1035, 990, 975, 880, 860 cm^{-1}; ^{1}H NMR (C_6D_6) δ 1.0–1.3 (2 H, m), 1.12 (3 H, t, *J* = 7 Hz), 2.34 (2 H, m), 2.58 (2 H, q, *J* = 7 Hz), 2.98 (1 H, br d, *J* = 5 Hz), 3.94 (1 H, d, *J* = 4.5 Hz), 4.22 (1 H, br dd), 4.50 (1 H, t, *J* = 5 Hz), 4.70 (1 H, br s), 4.80 (1 H, br s), and 5.35–6.25 (3 H, several m); mass spectrum *m/e* 310 (15), 308 (15), 267 (1), 265 (1), 253 (1), 251 (1), 239 (1), 237 (1), 231 (6), 229 (13), 202 (28), 200 (28), 189 (14), 187 (23), 185 (14), 121 (52), 108 (77), 91 (48), 79 (83), 77 (100), 65 (34), 53 (43), 51 (32), 41 (55), 39 (63).

Reaction of 7 with $CrSO_4$ to Produce 9. A solution of 62 mg (0.20 mmol) of **7** in 15 mL of degassed DMF and 10 mL of an aqueous solution containing 2.0 mmol of $CrSO_4$ was stirred at 25 °C for 3 days under a nitrogen atmosphere. The solution was diluted with 50 mL of water and the resulting suspension was extracted with three 20-mL portions of CCl_4. The combined extracts were washed with water, dried over Na_2CO_3, filtered, and evaporated to give 51 mg (82%) of **9** as a yellow oil: IR ν_{max} 3080, 2990, 2950, 1690, 1640, 1460, 1435, 1380, 1350, 1320, 1295, 1260, 1195, 1165, 1100, 1040, 985, 950, 915, 875 cm^{-1}; ^{1}H NMR (C_6D_6) δ 1.09 (3 H, t, *J* = 7.5 Hz), 1.5–2.9 (5 H, several m), 2.58 (2 H, q, *J* = 7.5 Hz), 3.00 (1 H, br d, *J* = 5 Hz), 4.00 (1 H, d, *J* = 5 Hz), 4.28 (1 H, br dd, *J* = 7, 5 Hz), 4.58 (1 H, t, *J* = 5 Hz), and 4.9–5.8 (5 H, several m); mass spectrum *m/e* 312 (11), 310 (11), 244 (8), 242 (8), 231 (26), 229 (11), 215 (5), 213 (5), 203 (28), 202 (55), 201 (33), 200 (55), 189 (23), 187 (37), 185 (15), 121 (69), 110 (36), 108 (78), 95 (56), 91 (58), 81 (100), 79 (87), 77 (63), 69 (38), 68 (33), 67 (38), 65 (38), 57 (18), 55 (52), 53 (54), 51 (21), 43 (33), 41 (62), 39 (52).

Hydrogenation of *cis*-Maneonene-A (1) to Produce 11. A suspension of 76 mg (0.22 mmol) of *cis*-maneonene-A (**1**) and 16 mg of PtO_2 (previously reduced) in 15 mL of anhydrous ethanol was stirred for 2.25 h under an atmosphere of hydrogen. The catalyst was centrifuged and the ethanol was evaporated to give 60 mg of a tan oil. This oil was spotted onto TLC plates with ether, the plates were developed twice in 5:1 dichloromethane–ether, drying between runs, and the spots were scraped off and extracted with ether to give 9 mg (17%) of a colorless oil, R_f 0.64: IR ν_{max} 2950, 2860, 1465, 1430, 1380, 1280, 1245, 1200, 1155, 1130, 1055, 1025, 960, 890, and 835 cm^{-1}; ^{1}H NMR (C_6D_6) δ 0.93 (3 H, br t), 1.0–2.1 (br envelope), 3.78 (1 H, br m), 4.16 (1 H, br t, *J* = 4 Hz), 4.35 (1 H, br m), and 4.85 (1 H, br t, *J* = 5 Hz); ^{13}C NMR (C_6D_6) δ 14.4 (2), 20.3, 23.0, 27.5, 32.4, 34.8, 36.1, 42.3, 43.1, 51.0, 77.3, 78.5, 79.5, and 83.7; mass spectrum *m/e* 238 (10), 221 (2), 209 (1), 195 (100), 167 (10), 165 (22), 152 (18), 151 (27), 138 (18), 123 (24), 109 (17), 95 (28), 81 (31), 71 (24), 69 (20), 67 (28), 57 (20), 55 (37), 43 (36), 41 (34). High resolution mass spectrum. Calcd for $C_{15}H_{26}O_2$: 238.1933. Found: 238.1952.

Interconversion of *cis*-Maneonene-A (1) with *cis*-Maneonene-B (2). A solution of 20 mg of *cis*-maneonene-A (**1**) and one crystal of *p*-toluenesulfonic acid monohydrate in 1.0 mL of anhydrous benzene was heated at reflux for 4 h. The benzene was evaporated and the residue was dissolved in ether and spotted onto a TLC plate. The plate was developed in benzene, the spots were scraped off and extracted with ether, and the two major spots were identified as unreacted **1** and *cis*-maneonene-B (**2**) by comparison of their IR spectra with authentic compounds. The ratio of **1**:**2** was approximately 1:1. The same results were obtained by starting with *cis*-maneonene-B (**2**).

Reaction of *cis*-Maneonene-B (2) with $Cr(en)_2SO_4$ to Produce 8. This reaction was carried out in a manner identical to that with *cis*-maneonene-A (**1**) to give 10 mg (50%) of **8** as a colorless oil, R_f 0.56 (1:1 dichloromethane–hexane, three developments): IR ν_{max} 3010, 2970, 1940, 1690, 1460, 1440, 1355, 1325, 1290, 1270, 1200, 1175, 1150, 1120, 1100, 1070, 1060, 1035, 995, 980, 910, 895, and 860 cm^{-1}; ^{1}H NMR (C_6D_6) δ 1.07 (3 H, t, *J* = 7 Hz), 1.3 (2 H, m), 2.2 (1 H, m) 2.28 (2 H, q, *J* = 7 Hz), 2.54 (1 H, br d, *J* = 5 Hz), 3.93 (1 H, br d, *J* = 4 Hz), 4.26 (1 H, br dd), 4.60 (1 H, t, *J* = 5 Hz), 4.82 (2 H, m), and 5.84 (3 H, m); ^{13}C NMR (C_6D_6) δ 14.3, 29.7, 39.2, 48.1, 56.3, 76.6, 79.8, 80.8, 82.6, 93.4, 125.4, 133.2; mass spectrum *m/e* 310 (9), 308 (9), 231 (5), 229 (11), 203 (9), 202 (30), 201 (16), 200 (30), 189 (16), 187 (29), 185 (16), 121 (50), 108 (85), 107 (39), 91 (45), 79 (85), 77 (100), 69 (34), 67 (24), 65 (34), 57 (28), 55 (37), 53 (37), 51 (28), 43 (35), 41 (62), 39 (62).

Reaction of *cis*-Maneonene-B (2) with $CrSO_4$ to Produce 10. A solution of 80 mg (0.232 mmol) of *cis*-maneonene-B (**2**) in 20 mL of degassed DMF and 10 mL of an aqueous solution containing 2.0 mmol $CrSO_4$ was allowed to stand for 4 days at 25 °C under an atmosphere of nitrogen. The solution was diluted with 50 mL of water and the resulting suspension was extracted with three 20-mL portions of CCl_4. The combined extracts were washed with 25 mL of water, dried over Na_2CO_3, filtered, and evaporated to give 69 mg (96%) of **10** as a yellow oil: IR ν_{max} 3080, 2995, 2945, 1685, 1640, 1455, 1430, 1370, 1340, 1315, 1270, 1190, 1160, 1135, 1100, 1030, 980, 970, 910, 875, and 845 cm^{-1}; mass spectrum identical to that of **9**.

This same compound is produced when **8** is treated with $CrSO_4$.

Reaction of 10 with Na/NH_3 and H_2/Pt to Produce 14. To a solution of 70 mg (3 mg atom) of sodium in 20 mL of anhydrous ammonia at −78 °C was slowly added a solution of 69 mg (0.221 mmol) of **10** in 5 mL of anhydrous ether. The solution was stirred for 1 h under a nitrogen atmosphere. The reaction was quenched by slow addition of solid NH_4Cl until the blue color disappeared. Twenty milliliters of ether and 20 mL of water were added, and the layers were separated. The aqueous layer was extracted with an additional two 20-mL portions of ether. The combined ether extracts were washed with 25 mL of water, dried over Na_2CO_3, filtered, and evaporated to give 40 mg of a colorless oil, which was dissolved in ether and spotted onto a TLC plate. The plate was developed four times in 1:1 hexane–ether, drying between developments, and the spots were scraped off and extracted with ether to give 14 mg (20%) of a colorless oil, R_f 0.50. ^{1}H NMR and GC–mass spectra showed this oil to be a mixture of at least two partially reduced unstable compounds. The mixture was therefore hydrogenated with 2 mg of PtO_2 (previously reduced) in 10 mL of anhydrous ethanol for 30 min. The catalyst was removed by centrifugation and the ethanol was evaporated to give a colorless oil which was dissolved in ether and spotted onto a TLC plate. The plate was developed four times in 9:1 hexane–ether, drying between runs, and the spots were scraped off and extracted with ether to give 5 mg (40%) of **14** as a colorless oil, R_f 0.41: IR $\nu_{\max}$ 2960, 2885, 1475, 1385, 1330, 1295, 1265, 1220, 1165, 1125, 1075, 1025, 975, 910, and 855 cm^{-1}; ^{1}H NMR (C_6D_6) δ 0.95 (6 H, br t), 1.1–2.3 (br envelope), 3.50 (1 H, dd, J = 11, 6 Hz), 3.52 (1 H, m), 4.13 (1 H, br d, J = 4 Hz), 4.30 (1 H, br t, J = 6 Hz), and 5.38 (1 H, t, J = 5 Hz); mass spectrum *m/e* 236 (9) ($M^+ - HBr$), 221 (29), 177 (4), 165 (11), 137 (7), 123 (10), 109 (17), 107 (17), 97 (15), 95 (28), 93 (17), 91 (11), 85 (14), 83 (17), 81 (34), 79 (18), 77 (9), 71 (34), 69 (42), 67 (31), 57 (38), 55 (100), 53 (10), 43 (56), 41 (58), 39 (14).

This same product is obtained by allowing *cis*-maneonene-B (**2**) to react under the same conditions.

Reaction of *cis*-Maneonene-B (2) with Na/NH$_3$ and H$_2$/Pt to Produce 12 and 13. One-hundred milligrams (0.29 mmol) of *cis*-maneonene-B (**2**) was allowed to react with sodium in liquid ammonia under the same conditions as that for **10**. Fifty milligrams (56%) of the crude mixture of olefins was obtained. This was suspended in 15 mL of ethanol with 7 mg of PtO_2 (previously reduced) and stirred for 30 min under a hydrogen atmosphere. The catalyst was centrifuged and the ethanol was evaporated to give a colorless oil, which was spotted onto a TLC plate with ether. The plate was developed three times in 9:0.5:0.5 hexane–dichloromethane–ether, drying between runs, and the spots were scraped off and extracted with ether to give 10 mg (20%) of **12** as a colorless oil, R_f 0.40, and 10 mg (20%) of **13** also as a colorless oil, R_f 0.30.

12: IR $\nu_{\max}$ 2950, 2875, 1700, 1460, 1360, 1320, 1295, 1275, 1165, 1060, 1040, 975, 945, 910, and 855 cm^{-1}; ^{1}H NMR (C_6D_6, 270 MHz) δ 0.88 (3 H, t, J = 7 Hz), 1.06 (3 H, t, J = 7 Hz), 1.1–1.3 (9 H, br envelope), 1.26 (1 H, d, J = 14 Hz), 1.51 (1 H, td, J = 5, 8, 14 Hz), 2.21 (1 H, d, J = 5 Hz), 2.31 (1 H, septet, J = 7, 14 Hz), 2.34 (1 H, sextet, J = 7, 14 Hz), 3.89 (1 H, d, J = 5 Hz), 4.30 (1 H, dd, J = 5, 8 Hz), 4.31 (1 H, t, J = 7 Hz), 4.62 (1 H, t, J = 5 Hz); mass spectrum *m/e* 236 (21), 221 (60), 207 (3), 203 (2), 193 (5), 177 (6), 165 (19), 153 (9), 151 (7), 149 (6), 147 (5), 137 (10), 135 (6), 133 (5), 123 (14), 111 (12), 109 (22), 107 (20), 97 (19), 95 (33), 93 (20), 91 (12), 85 (16), 83 (22), 81 (38), 79 (18), 71 (42), 69 (45), 67 (32), 54 (39), 45 (100), 43 (52), 41 (54).

13: IR $\nu_{\max}$ 2950, 2875, 1695, 1460, 1375, 1360, 1315, 1290, 1265, 1165, 1125, 1100, 1030, 970, 940, 910, and 880 cm^{-1}; ^{1}H NMR (C_6D_6, 270 MHz) δ 0.88 (3 H, t, J = 7 Hz), 0.98 (3 H, t, J = 7 Hz), 1.1–1.3 (9 H, br envelope), 1.26 (1 H, d, J = 14 Hz), 1.51 (1 H, td, J = 5, 8, 14 Hz), 1.99 (2 H, quintet, J = 7 Hz), 2.40 (1 H, d, J = 5 Hz), 3.91 (1 H, d, J = 5 Hz), 4.27 (1 H, dd, J = 5, 8 Hz), 4.61 (1 H, t, J = 5 Hz), and 4.88 (1 H, t, J = 7 Hz); ^{13}C NMR (C_6D_6) δ 10.7, 12.5, 17.8, 19.5, 23.9, 28.6, 30.7, 36.2, 41.6, 49.6, 75.1, 76.3, 78.6, and 95.6; mass spectrum identical to that of **12**.

The same two products, **12** and **13**, are obtained from the reaction of **10** under the same conditions.

Dehydrobromination of 14 to Produce 12. A solution of **14** was injected onto a 0.25 in. × 10 ft GC column (20% SE-30 on 60/80 Chromosorb W, AW DMCS) at 200 °C and the single peak with a retention time of 7 min was collected. The IR and ^{1}H NMR spectra showed this compound to be identical to **12**.

Hydrogenation of 12 to Produce 11. A suspension of 5 mg of **12** and 1 mg of PtO_2 (previously reduced) in 10 mL of anhydrous ethanol was stirred for 1 h under a hydrogen atmosphere. The catalyst was removed by centrifugation and the ethanol was evaporated to give 5 mg of a colorless oil. The IR spectrum of this oil was identical to **11** obtained from the hydrogenation of *cis*-maneonene-A (**1**).

Reaction of *trans*-Maneonene-B (3) with Cr(en)$_2$SO$_4$ to Produce 8. The Cr(en)$_2$SO$_4$ solution was prepared by mixing 1.25 mL of a solution containing 0.25 mmol of $CrSO_4$ with 0.6 mL of a solution of enSO_4 (0.48 mmol) in water. This solution was added to a degassed solution of 8 mg (0.023 mmol) of *trans*-maneonene-B (**3**) in 2 mL of DMF. The reaction and the workup procedure were the same as that described for *cis*-maneonene-A (**1**). TLC purification of the crude product (1:1 dichloromethane–hexane, three developments) gave 4.5 mg (56%) of **8** as a colorless oil. This product was identical to that derived from *cis*-maneonene-B (**2**) as determined by a comparison of the IR, ^{1}H NMR, and mass spectra.

Reaction of *cis*-Maneonene-C (4) with Cr(en)$_2$SO$_4$ to Produce 15. A procedure identical to that used for *cis*-maneonene-A (**1**) gave 11 mg (42%) of **15** as a colorless oil, R_f 0.65 (1:1 dichloromethane–hexane, three developments): IR $\nu_{\max}$ 3000, 2970, 2920, 1940, 1690, 1460, 1440, 1350, 1330, 1310, 1250, 1220, 1190, 1170, 1105, 1050, 990, 970, 930, 900, 885, and 855 cm^{-1}; ^{1}H NMR (C_6D_6) δ 1.10 (3 H, t, J =8 Hz), 1.43 (2 H, m), 2.58 (2 H, q, J = 8 Hz), 2.5–2.9 (1 H, m), 3.25 (1 H, dd, J = 5, 10 Hz), 4.02 (1 H, m), 4.26 (1 H, m), 4.58 (1 H, t, J = 5 Hz). 4.75 (2 H, m), and 5.83 (3 H, m); mass spectrum *m/e* 310 (8), 308 (10), 231 (6), 229 (14), 203 (10), 202 (35), 201 (17), 200 (35), 189 (18), 187 (31), 185 (18), 121 (52), 108 (81), 107 (42), 91 (54), 81 (35), 80 (35), 79 (77), 77 (100), 69 (29), 67 (25), 65 (38), 57 (23), 55 (28), 53 (44), 51 (32), 43 (30), 41 (58), 39 (62).

Hydrogenation of *cis*-Maneonene-C (4) to Produce 16. A suspension of 15 mg of *cis*-maneonene-C (**4**) and 2 mg of PtO_2 (previously reduced) in 10 mL of absolute ethanol was stirred for 20 min at 25 °C under an atmosphere of hydrogen. The catalyst was filtered and the ethanol was evaporated to give 9 mg of a yellow oil. The oil was spotted onto a TLC plate with ether and the plate was developed three times in 2:1 dichloromethane–hexane, drying between developments. The spots were scraped off and extracted with ether to give 3 mg (20%) of **16** as a colorless oil, R_f 0.55: IR $\nu_{\max}$ 2985, 2950, 2885, 1690, 1460, 1435, 1380, 1345, 1330, 1250, 1185, 1165, 1105, 1045, 990, 925, 895, 880, and 860 cm^{-1}; ^{1}H NMR (C_6D_6) δ 1.02 (3 H, t, J = 7 Hz), 1.15 (3 H, t, J = 7 Hz), 1.0–2.0 (several m), 2.4–2.8 (m), 2.67 (2 H, q, J = 7 Hz), 3.27 (1 H, dd, J = 5, 10 Hz), 4.32 (1 H, m), 4.74 (1 H, t, J = 5 Hz), and 5.50 (1 H, br t, J = 5 Hz); ^{13}C NMR (C_6D_6) δ 13.6 (2), 26.8 (2), 28.2, 32.0, 35.2, 36.2, 45.2, 45.9, 79.0, 81.9, and 83.4; mass spectrum *m/e* 316 (20), 314 (20), 301 (2), 299 (2), 273 (1), 271 (1), 257 (1), 255 (1), 245 (1), 243 (1), 236 (5), 235 (25), 233 (3), 231 (3), 229 (3), 217 (7), 215 (3), 203 (3), 202 (4), 201 (3), 200 (4), 193 (47), 151 (62), 123 (87), 109 (51), 95 (43), 91 (37), 81 (71), 69 (67), 67 (55) 55 (63), 43 (69), 41 (100).

Reaction of 16 with Na/NH$_3$ to Produce 17. To a solution of 60 mg (2.6 mg-atom) of sodium in 20 mL of anhydrous ammonia at −78 °C was slowly added a solution of 53 mg (0.17 mmol) of **16** in 5 mL of anhydrous ether. The solution was stirred for 1 h under a nitrogen atmosphere. The workup procedure was the same as that for **12** and **13**. Thirty milligrams of a colorless oil was obtained which was chromatographed on TLC developing four times with 9:1 hexane–ether. The spots were scraped off and extracted with ether to give 6 mg (15%) of **17** as a colorless oil, R_f 0.58: IR $\nu_{\max}$ 2975, 2890, 1700, 1465, 1370, 1335, 1280, 1255, 1210, 1190, 1170, 1055, 1000, 980, 960, 915, 900, 880, and 855 cm^{-1}; ^{1}H NMR (C_6D_6, 270 MHz) δ 0.87 (3 H, t, J = 7 Hz), 1.04 (3 H, t, J = 7 Hz), 1.1–1.6 (9 H, several m), 1.90 (2 H, br m), 2.29 (2 H br m), 2.50 (1 H, dd, J = 5, 9.5 Hz), 4.08 (1 H, t, J = 5 Hz), 4.19 (1 H, t, J = 7 Hz), 4.28 (1 H, br dd, J = 7.5 Hz), and 4.72 (1 H, br t, J = 5 Hz); ^{13}C NMR (C_6D_6) δ 15.2 (2), 18.7, 22.9, 27.1, 28.5, 32.3, 34.3, 45.0, 46.0, 78.9, 80.0, 83.4, and 101.6; mass spectrum *m/e* 236 (4), 221 (2), 193 (9), 153 (57), 124 (31), 123 (80), 111 (32), 109 (29), 95 (65), 81 (93), 71 (53), 69 (58), 67 (43), 57 (54), 55 (100), 43 (80), 41 (93).

Isomerization of *cis*-Maneonene-C (4) to Produce 18. A solution of 10 mg of *cis*-maneonene-C (**4**) and one crystal of *p*-toluenesulfonic acid monohydrate in 1.5 mL of benzene was heated at reflux for 4 h. The benzene was evaporated and the residue was dissolved in ether and spotted onto a TLC plate. The plate was developed twice in 1:1 dichloromethane–hexane and the spots were scraped off and extracted with ether to give 3 mg (30%) of unreacted *cis*-maneonene-C (**4**) and 3 mg (30%) of **18**, R_f 0.30: $[\alpha]^{21}{}_D$ +137° (c 0.60); IR $\nu_{\max}$ 3300, 2970, 2920, 1680, 1450, 1345, 1320, 1260, 1245, 1215, 1200, 1180, 1160, 1125, 1040, 985, 965, 950, 880, and 825 cm^{-1}; ^{1}H NMR (C_6D_6, 270 MHz) δ 1.33 (3 H, t, J = 7 Hz), 1.42 (1 H, td, J = 5, 8, 14 Hz), 1.91 (1 H, d, J = 14 Hz), 2.43 (1 H, td, J = 5, 10, 10 Hz), 2.59 (1 H, sextet, J = 7, 14 Hz), 2.65 (1 H, sextet, J = 7, 14 Hz), 2.85 (1 H, d, J = 2 Hz), 2.92 (1 H, dd, J = 5, 10 Hz), 3.96 (1 H, t, J = 5 Hz), 4.30 (1 H, dd, J = 5, 8 Hz), 4.61 (1 H, t, J = 5 Hz), 5.00 (1 H, t, J = 10 Hz), 5.17 (1 H, dd, J = 2, 10 Hz), and 5.56 (1 H, t, J = 10 Hz); mass spectrum *m/e* 346 (1), 344 (3), 342 (2), 308 (8), 306 (8), 265 (7), 263 (7), 227 (4), 204 (4), 202 (7), 200 (11), 159 (17), 149 (13), 123 (21), 122 (21), 121 (21), 115 (17), 111 (21), 109 (28), 108 (19), 107 (19), 97 (40), 95 (43), 91 (30), 85 (30), 83 (43), 81 (62), 79 (34), 77 (45), 71 (55), 69 (83), 57 (100), 55 (77), 43 (74), 41 (87), 39 (47).

Isolation and Purification of Isomaneonene-A (5) and Isomaneonene-B (6). Approximately 730 mg of eluate 4 from column chromatography of the algal extract was dissolved in a small volume of anhydrous ether and spotted on TLC plates so that each plate contained 70 mg of material. The plates were developed five times in 30:1 benzene–ether, drying between developments, and the spots were scraped off and extracted with ether. After filtering and evaporation of the ether, *cis*-maneonene-B and isomaneonene-A were obtained. These two compounds were repurified by TLC developing in 30:1 benzene–ether and approximately 86 mg of *cis*-maneonene-B, R_f 0.90, and 100 mg of isomaneonene-A, R_f 0.86 (0.04% of dry alga), were obtained.

Approximately 700 mg of eluate 5 from the column chromatography was dissolved in a small amount of anhydrous ether and spotted onto TLC plates so that each plate contained 70 mg of material. The plates were developed five times in 30:1 benzene–ether, drying between developments, and the spots were scraped off and extracted with ether. After filtering and evaporation of the ether, the following compounds were obtained: isomaneonene-A, isomaneonene-B, *trans*-maneonene-B, sesquiterpenoid A,[5] and sesquiterpenoid B.[5] All the compounds were repurified by TLC developing in 30:1 benzene–ether five times, and approximately 40 mg of isomaneonene-A, R_f 0.86 (0.015% of dry alga), 30 mg of *trans*-maneonene-B, R_f 0.77, 105 mg of isomaneonene-B, R_f 0.63 (0.04% of dry alga), 90 mg of sesquiterpenoid A,[5] R_f 0.57 (0.03% of dry alga), and 50 mg of sesquiterpenoid B,[5] R_f 0.50 (0.02% of dry alga), were obtained.

Isomaneonene-A (5): yellow crystals, mp 114.5–115.5 °C; $[\alpha]^{21}{}_{\mathrm{D}}$ +106° (*c* 1.72); UV $\lambda_{\max}$ 229 nm (ϵ 14 500); IR $\nu_{\max}$ 3300, 2970, 2940, 2870, 1680, 1460, 1440, 1380, 1320, 1290, 1150, 1130, 1110, 1090, 1070, 1050, 1030, 1010, 960, 890, 855, and 835 cm^{-1}; NMR Table V; mass spectrum *m/e* 390 (0.2), 388 (0.4), 386 (0.2), 309 (4), 307 (4), 265 (3), 263 (3), 228 (6), 227 (14), 202 (4), 201 (5), 200 (6), 199 (9), 189 (5), 187 (5), 185 (5), 184 (4), 183 (5), 181 (6), 171 (8), 169 (8), 159 (10), 157 (10), 155 (10), 149 (11), 141 (23), 131 (22), 129 (25), 123 (18), 121 (18), 115 (19), 111 (24), 109 (24), 97 (46), 95 (50), 91 (29), 85 (33), 83 (50), 81 (57), 79 (36), 77 (32), 71 (64), 69 (75), 67 (46), 57 (100), 55 (89), 43 (79), 41 (75). FD mass spectrum *m/e* 390 (32), 389 (10), 388 (100), 386 (53), and 58 (26). High resolution mass spectrum. Calcd for $C_{15}H_{16}O_2Br_2{}^{79}$ (M$^+$): 385.9517. Found: 385.9495.

Isomaneonene-B (6): white crystals; mp 136.5–137.0 °C; $[\alpha]^{21}{}_{\mathrm{D}}$ +87° (*c* 0.83); UV $\lambda_{\max}$ 228 nm (ϵ 13 500); IR $\nu_{\max}$ 3330, 2970, 2940, 2850, 1680, 1460, 1440, 1380, 1320, 1280, 1220, 1160, 1120, 1100, 1060, 1030, 1020, 1015, 960, 940, and 890 cm^{-1}; NMR Table VI; mass spectrum *m/e* 390 (2), 388 (4), 386 (2), 309 (36), 307 (36), 265 (14), 263 (11), 228 (21), 227 (34), 203 (15), 202 (21), 201 (18), 200 (34), 199 (29), 189 (10), 187 (13), 185 (13), 184 (8), 183 (10), 181 (7), 171 (13), 169 (11), 159 (18), 157 (16), 155 (16), 153 (11), 143 (18), 141 (32), 131 (27), 129 (39), 128 (40), 121 (24), 115 (51), 108 (28), 107 (47), 105 (25), 103 (24), 95 (21), 91 (60), 81 (43), 79 (84), 78 (52), 77 (100), 69 (35), 67 (35), 65 (60), 63 (30), 55 (38), 53 (48), 51 (51), 41 (78), 39 (85). High resolution mass spectrum. Calcd for $C_{15}H_{16}O_2Br_2{}^{79}$ (M$^+$): 385.9517. Found: 385.9532.

Catalytic Hydrogenation of Isomaneonene-A (5) to Produce 19 and 24. A suspension of 100 mg (0.258 mmol) of isomaneonene-A (**5**) and 40 mg of 5% Pd/C in approximately 10 mL of anhydrous ethanol was stirred for 5 h under an atmosphere of hydrogen. The catalyst was centrifuged and the supernatant was evaporated to give an oil. This oil was dissolved in a small volume of ether and spotted onto a TLC plate. The plate was developed twice in 5:1 dichloromethane–ether, drying between developments, and the spots were scraped off and extracted with ether to give 15 mg (25%) of **19,** R_f 0.60, and 11 mg (18%) of **24,** R_f 0.30.

19: colorless oil; IR $\nu_{\max}$ 2950, 2870, 1460, 1435, 1375, 1350, 1290, 1160, 1120, 1080, 1050, 1035, 1015, 975, 925, and 850 cm^{-1}; ^{1}H NMR (270 MHz, C_6D_6) δ 0.91 (3 H, t, J = 7 Hz), 1.10 (3 H, t, J = 7 Hz), 1.14–1.40 (m), 1.64 (m), 2.03 (m), 2.61 (m), 4.23 (1 H, m), 4.30 (2 H, m) and 4.77 (1 H, t, J = 5 Hz); ^{13}C NMR (C_6D_6) δ 13.7, 14.4, 21.2, 23.4, 27.8, 32.7, 38.7, 40.5, 51.6, 52.3, 54.9, 76.6, 78.2, 83.6, and 85.4; mass spectrum *m/e* 236 (12), 221 (1), 218 (2), 208 (6), 207 (35), 193 (6), 192 (5), 189 (17), 179 (11), 163 (18), 151 (14), 149 (22), 139 (11), 137 (11), 135 (18), 133 (12), 125 (12), 124 (14), 123 (18), 121 (20), 111 (45), 109 (24), 108 (29), 107 (41), 95 (61), 83 (55), 81 (100), 79 (43), 69 (68), 67 (63), 57 (55), 55 (78), 43 (59), 41 (94).

24: colorless oil; IR $\nu_{\max}$ 3570, 3430, 2950, 2930, 2850, 1460, 1440, 1370, 1210, 1120, 1090, 1075, 1010, 965, and 900 cm^{-1}; ^{1}H NMR (270 MHz, C_6D_6) δ 0.90 (3 H, t, J = 7 Hz), 1.00 (3 H, t, J = 7 Hz), 1.17–1.40 (m), 1.28 (1 H, dd, J = 12, 4 Hz), 1.58 (m), 1.89–2.20 (m), 2.87 (1 H, m), 3.05 (1 H, dd, J = 16, 2 Hz), 3.45 (1 H, m), 4.08 (1 H, t, J = 5 Hz), 4.23 (1 H, m), and 4.46 (1 H, t, J = 5 Hz); mass spectrum *m/e* 236 (13), 218 (3), 207 (5), 193 (7), 192 (7), 189 (13), 179 (10), 164 (10), 163 (40), 151 (8), 150 (8), 149 (10), 135 (13), 133 (11), 121 (30), 119 (13), 108 (28), 107 (70), 105 (25), 95 (25), 93 (32), 91 (40), 81 (25), 79 (50), 77 (25), 69 (25), 67 (25), 57 (100), 55 (48), 43 (40), and 41 (70).

The same products were obtained on catalytic hydrogenation of isomaneonene-B (**6**).

Sodiun Reduction of Isomaneonene-A (5) to Produce 22 and 23. To a solution of 70 mg (3 mg-atoms) of sodium in approximately 20 mL of anhydrous ammonia at −78 °C was slowly added a solution of 95 mg (0.245 mmol) of isomaneonene-A (**5**) in approximately 5 mL of anhydrous ether. The solution was stirred for 2 h under a nitrogen atmosphere. The reaction was quenched by slow addition of solid ammonium chloride until the blue color disappeared. Approximately 20 mL of ether and 20 mL of distilled water was added and the layers were allowed to separate. The aqueous layer was extracted with an additional two 20-mL portions of ether. The combined ether extracts were washed with 25 mL of distilled water, dried over anhydrous sodium carbonate, filtered, and evaporated to give 52 mg of a colorless oil which was dissolved in a small volume of ether and spotted onto a TLC plate. The plate was developed in 5:1 dichloromethane–ether to give 10 mg (17%) of **22,** R_f 0.35, and 15 mg (26%) of **23,** R_f 0.20, as colorless oils.

22: IR $\nu_{\max}$ 3540, 2970, 2850, 1630, 1445, 1400, 1375, 1255, 1155, 1110, 1090, 1060, 1010, 960, 905, and 845 cm^{-1}; ^{1}H NMR (270 MHz, C_6D_6) δ 0.88 (3 H, t, J = 7 Hz), 1.31 (1 H, dd, J = 12, 4 Hz), 1.28–1.38 (m), 1.57 (m), 1.73 (m), 1.89 (m), 2.15 (m), 2.48 (1 H, m), 2.97 (1 H, sextet, J = 9, 9, 5 Hz), 3.19 (1 H, m), 4.31 (1 H, t, J = 5 Hz), 4.38 (1 H, m), 4.50 (1 H, t, J = 5 Hz), 5.31 (2 H, m), and 5.44 (1 H, m); ^{13}C NMR (C_6D_6)[16] δ 12.4, 18.0, 22.7, 31.8, 35.8, 45.8, 51.1, 52.2, 76.5, 80.2, 80.7, 123.3, 125.9, and 130.8; mass spectrum *m/e* 234 (2), 216 (1), 205 (3), 187 (3), 179 (8), 175 (8), 161 (26), 159 (8), 147 (4), 145 (16), 133 (34), 131 (15), 119 (79), 107 (62), 105 (47), 95 (26), 93 (26), 91 (56), 83 (19), 81 (27), 79 (41), 77 (27), 71 (22), 69 (29), 67 (25), 65 (14), 57 (38), 55 (100), 43 (38) 41 (55), 39 (38).

23: IR $\nu_{\max}$ 3600, 3430, 2970, 2930, 2860, 1450, 1380, 1120, 1080, 965, 920, and 900 cm^{-1}; ^{1}H NMR (270 MHz, C_6D_6) δ 0.99 (3 H, t, J = 7 Hz), 0.90–1.14 (m), 1.40–1.72 (m), 1.90 (1 H, m), 2.04 (1 H, ddd, J = 13, 10, 6 Hz), 2.24 (1 H, m), 2.55 (1 H, dd, J = 13, 7 Hz), 2.72 (1 H, sextet, J = 10, 10, 5 Hz), 2.85 (1 H, sextet, J = 10, 10, 6 Hz), 4.05 (1 H, t, J = 5 Hz). 4.13 (1 H, dd, J = 10, 5 Hz), 4.46 (1 H, t, J = 6 Hz), and 5.41 (2 H, m); ^{13}C NMR (C_6D_6) δ 12.7, 24.6, 28.1, 31.3, 33.1, 35.3, 45.3, 46.8, 47.2, 52.9, 75.3, 79.6, 81.1, 125.1, and 131.5; mass spectrum *m/e* 236 (1), 218 (1) 207 (2), 205 (8), 203 (12), 193 (5), 189 (6), 181 (4), 177 (4), 163 (18), 145 (15), 137 (19), 135 (18), 133 (1), 121 (21), 119 (27), 109 (48), 107 (35), 97 (24), 95 (66), 93 (39), 91 (29), 83 (32), 81 (50), 79 (48), 77 (21), 71 (26), 69 (40), 67 (61), 57 (68), 55 (100), 43 (53), 41 (68).

Sodium Reduction of 22 to Produce 23. Approximately 17 mg (0.073 mmol) of **22** was allowed to react with sodium in liquid ammonia under conditions identical to those used for isomaneonene-A to give 15 mg (87%) of a colorless oil. Its IR, ^{1}H NMR, and mass spectra were identical to those of **23.**

Catalytic Hydrogenation of 23 to Produce 20. A suspension of 30 mg (0.127 mmol) of **23** and 40 mg of PtO_2 (previously reduced) in approximately 10 mL of anhydrous ethanol was stirred for 6 h under an atmosphere of hydrogen. The catalyst was centrifuged and the supernatant was evaporated to give 25 mg of an oil. This oil was dissolved in a small volume of ether and spotted onto a TLC plate. The plate was developed in 3:1 chloroform–ethyl acetate. The spots were scraped off and extracted with ether to give 16 mg (53%) of **20** as a colorless oil, R_f 0.37: IR $\nu_{\max}$ 3610, 3430, 2960, 2930, 2850, 1455, 1375, 1210, 1100, 1075, 965, 915, and 895 cm^{-1}; ^{1}H NMR (270 MHz, C_6D_6) δ 0.89 (3 H, t, J = 7 Hz), 0.99 (3 H, t, J = 7 Hz), 1.19–1.39 (m), 1.48 (1 H, m), 1.58 (1 H, dd, J = 13, 4 Hz), 1.69 (1 H, m), 2.00 (1 H, ddd, J = 13, 10, 6 Hz), 2.16 (1 H, m), 2.53 (1 H, dd, J = 13, 7 Hz), 2.73 (1 H, sextet, J = 10, 10, 5 Hz), 2.82 (1 H, sextet, J = 10, 10, 6 Hz), 4.05 (1 H, t, J = 5 Hz), 4.10 (1 H, br m), and 4.39 (1 H, t, J = 6 Hz); ^{13}C NMR (C_6D_6) δ 13.0, 14.4, 23.3, 28.1, 29.2, 31.1, 31.9, 35.2, 45.3, 46.9, 47.0, 52.7, 73.5, 77.7, and 79.1; mass spectrum *m/e* 238 (1), 220 (3), 209 (1), 195 (4), 194 (3), 191 (5), 181 (3), 179 (4), 177 (6), 165 (8), 164 (7), 163 (10), 152 (9), 151 (10), 149 (12), 139 (9), 137 (13), 135 (12), 125 (12), 123 (16), 121 (13), 111 (19), 109 (31), 107 (17), 97 (37), 95 (57), 86 (26), 83 (52), 81 (55), 71 (47), 69 (77), 67 (51), 57 (100), 55 (94), 43 (77), 41 (81). High resolution mass spectrum. Calcd for $C_{15}H_{26}O_2$ (M$^+$): 238.1933. Found: 238.1950.

Reaction of Isomaneonene-B (6) with Na/NH$_3$ and H$_2$/Pt to Produce 20. Approximately 55 mg (0.142 mmol) of isomaneonene-B (**6**) was allowed to react with sodium in liquid ammonia under conditions identical to those used for isomaneonene-A (**5**) to give 34 mg of a mixture of **22** and **23.** A suspension of this mixture and 20 mg of PtO_2 (previously reduced) in approximately 15 mL of anhydrous ethanol was stirred for 3 h under an atmosphere of hydrogen. The catalyst was centrifuged and the supernatant was evaporated to give a colorless oil. The oil was dissolved in a small volume of ether and spotted onto a TLC plate. The plate was developed in 5:1 dichloromethane–ether, and the spots were scraped off and extracted with anhydrous ether to give 6.5 mg (19%) of a colorless oil. Its IR and ^{1}H NMR spectra were identical to those of **20.**

Oxidation of 20 to Produce 21. To a solution of 16 mg (0.067 mmol) of **20** in 5 mL of acetone was added drop by drop a solution of 11 mg (0.110 mmol) of chromium trioxide in 0.05 mL of concentrated sulfuric acid and 0.5 mL of water. The suspension was stirred for 50 min at 25 °C and the acetone was decanted and evaporated to give an aqueous suspension which was mixed with 5 mL of ether, dried over anhydrous sodium sulfate, and filtered, and the ether was evaporated to give 14 mg of a brown oil. This was dissolved in a small volume of anhydrous ether and spotted onto a TLC plate so that each spot contained approximately 2 mg of material. The plate was developed twice in 1:2 hexane–dichloromethane, drying between developments, and the spots were scraped off and extracted with ether to give 10 mg (63%) of **21** as a colorless oil, R_f 0.45: IR ν_{max} 2960, 2940, 2870, 1760, 1460, 1410, 1380, 1300, 1140, 1070, 1000, and 910 cm^{-1}; ^{1}H NMR (270 MHz, C_6D_6) δ 0.81 (3 H, t, J = 7 Hz), 0.89 (3 H, br t, J = 7 Hz), 1.03–1.27 (m), 1.43 (1 H, br m), 1.73 (1 H, dd, J = 12, 6 Hz), 2.05 (1 H, d, J = 17 Hz), 2.20 (1 H, dd, J = 17, 5 Hz), 2.49 (1 H, sextet, J = 10, 10, 6 Hz), 2.62 (1 H, sextet, J = 10, 10, 5 Hz), 4.06 (1 H, d, J = 6 Hz), and 4.39 (1 H, t, J = 5 Hz); mass spectrum m/e 236 (2), 208 (7), 207 (1), 193 (7), 179 (17), 165 (7), 163 (7), 161 (8), 152 (10), 151 (27), 149 (11), 137 (14), 135 (17), 125 (13), 123 (43), 111 (17), 109 (47), 107 (17), 97 (40), 95 (80), 83 (77), 81 (62), 71 (43), 69 (73), 67 (57), 57 (73), 55 (100), 43 (67), 41 (87).

X-ray Crystallographic Analysis of Isomaneonene-B (6). A clear, pale yellow crystal of isomaneonene-B, approximately 0.3 × 0.2 × 0.1 mm, proved to be monoclinic with a = 6.122 (3) Å, b = 15.457 (6) Å, c = 8.425 (3) Å, β = 111.30°, and ρ_{calcd} = 1.74 g/cm^3 for two molecules in the unit cell. Systematic absences of $0k0$, $k = 2n + 1$, reflections identified the space group as $P2_1$. Unique reflections with $2\theta \leq 114.1°$ were measured on a Syntex $P2_1$ four-circle diffractometer using graphite monchromated Cu Kα radiation (λ 1.5418 Å) and 1° ω scans with a scan rate dependent on the intensity of the reflection. Three check reflections measured after every 50 reflections showed no decrease in intensity during data collection. Data were corrected for Lorentz, polarization, and background effects and 1028 out of 1050 reflections, about 98% of the data, had $F_o^2 \geq 3\sigma(F_o^2)$.

Both bromines were located by means of a Patterson synthesis and a bromine phased F_o synthesis served to reveal the remaining atoms.[20] Theoretical positions for the hydrogens were computed and included for full-matrix least-squares refinement of the structure. All nonhydrogen atoms were assigned anisotropic thermal parameters and hydrogens were assigned isotropic parameters.

Anomalous dispersion corrections for the bromines brought the standard crystallographic residual to 0.061 for both enantiomers and the weighted residual to 0.062 and 0.064 for the structure shown and its enantiomer, respectively.[21] The intensities of 11 pairs of the most enantiomorph sensitive reflections were carefully measured and five were consistent with the enantiomer chosen while for the remaining six the intensities of the hkl and $\overline{hkl}$ reflections did not differ by more than one standard deviation.

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Registry No.—**1**, 61661-24-3; **2**, 61661-25-4; **3**, 61688-65-1; **4**, 62624-86-6; **5**, 62583-57-7; **6**, 62623-94-3; **7**, 61666-69-1; **8**, 61688-72-0; **9**, 66290-73-1; **10**, 66322-54-1; **11**, 61666-70-4; **12**, 61666-72-6; **13**, 61688-73-1; **14**, 61666-71-5; **15**, 66322-55-2; **16**, 66290-74-2; **17**, 66322-56-3; **18**, 62624-86-6; **19**, 62583-59-9; **20**, 62583-58-8; **21**, 62583,60-2; **22**, 66290-75-3; **23**, 66290-76-4; **24**, 66290-77-5.

Supplementary Material Available: Fractional coordinates (Table VIII), bond distances (Table IX), and bond angles (Table X) (4 pages). Ordering information is given on any current masthead page.

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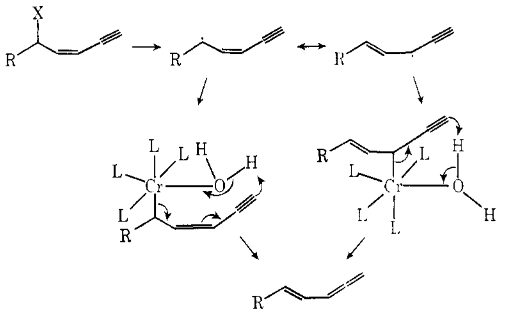

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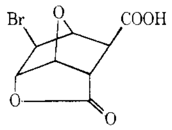

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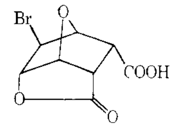

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