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FROM TETRACYCLES TO MACROCYCLES

CHEMICAL DIVERSITY IN THE DEFENSE SECRETIONS OF NASUTE TERMITES

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Abstract—Soldiers of the advanced genera of nasute termites (Isoptera: Termitidae: Nasutitermitinae) eject an irritating glue-like defensive secretion containing novel polycyclic cembrene-A derived diterpenes in a monoterpenoid solvent. These soldiers have lost their mandibles through evolutionary processes, but they have developed the ability to biosynthesize diterpenes which is unique in insects. Soldiers of some genera of the primitive mandibulate nasutes produce normal alkanes and simple mono- and sesquiterpenes, while others possess a homologous series of extraordinarily large-ring macrocyclic lactones containing 22 to 36 carbon atoms. Spectral details for the macrocyclic lactones and hydroxylactones are presented in this paper, and the biochemical, ecological and evolutionary significance of these chemicals will be discussed.

INTRODUCTION

The Nasutitermitinae is the most abundant and diverse subfamily of termites in the world; the soldiers of this subfamily have provided a chemically intriguing and diverse set of new diterpenoid,[1] and more recently, macrolide[2] defensive chemicals. First, recent results in the chemistry and biosynthesis of the diterpenoid secretions of the advanced glue-squirting genera of nasute termites will be discussed. Second, our recent discovery of macrolide defense chemicals in mandibulate nasutes of the genus *Armitermes* will be presented.

The soldiers of the advanced genera of this subfamily possess an elongate rostrum, called the nasus, which is used to eject a viscous and sticky terpenoid secretion. These secretions are sticky because they contain high concentrations of hydrogen-bonded, dome-shaped diterpenes in a monoterpene solvent.[3] The structures of the tricyclic trinervitanes (e.g. **1**)[4] and tetracyclic kempanes (e.g. **2**)[5] inspired further investigations into their biosynthetic origins and a search for biosynthetic key intermediates.[1] The recent discoveries of bicyclic secotrinervitanes (e.g. **3**) in *Nasutitermes*[6] and *Longipeditermes*[7] provide further evidence for a stepwise progression from the monocyclic 14-membered ring cembrene-A to bicyclic, tricyclic, and tetracyclic carbon skeletons. The correct cembrene-like arrangement of carbon atoms in space is preserved in the bicyclic compounds and in a new tricyclic tripropionate (**4**),[8] as well as in epoxy compounds (e.g. **5**).[9] Furthermore, alternative ring-forming pathways may occur in the tricyclic to tetracyclic conversion as shown by the existence of the 1,2-methyl shifted skeleton of the rippertanes (e.g. **6**).[10] Unique functionalization of the tetracyclic kempane skeleton (e.g. **7**)[11a] occurs in *Nasutitermes octopilis* from Guyana and this may be responsible for the unpalatability (to ants) of this litter-dwelling species relative to sympatric arboreal *Nasutitermes* species.[11b] These different diterpenes are shown in Fig. 1.

Intraspecific variation of defense chemicals in isolated populations of *Trinervitermes gratiosus*[12] and *T. bettonianus*[13] gives rise to genetically distinct chemical "races". In the latter species, the chemical composition of the soldier secretion was shown to be invariant under conditions in which field-collected alates were raised to incipient colony status in the laboratory and fed grass from the region of a different *T. bettonianus* chemotype. This was also taken as further evidence of the *de novo* biosynthetic origin of these secretions in the frontal glands.

Biosynthesis was unambiguously demonstrated by inject of ^{14}C-labelled acetate and mevalonate derivatives into the abdomens of *N. octopilis* soldiers using micropipettes.[14] Purified mono- and diterpenes showed 0.05–0.3% incorporation of label in 12–24 hr, indicating relatively rapid and efficient incorporation of the precursors. Biosynthetic relationships of the polycyclic diterpenes derived from mevalonate *via* cembrene-A are shown in Fig. 2.

The subfamily Nasutitermitinae is alleged to be a classical example of parallel diphyletic evolution[15] in which regression of the soldier mandibles and elongation of the rostrum to form the nasus occurred independently along two branches of this subfamily. Thus, the most primitive nasute *Syntermes* led to both a "*Procornitermes* branch", which includes *Rhynchotermes* and *Nasutitermes* as the hooked mandible and fully nasute types respectively, and to a "*Paracornitermes* branch", which includes *Armitermes* and *Subulitermes*. Chemical investigations of the frontal gland secretions of three *Subulitermes* spp. from Guyana revealed the presence of sesquiterpenes *neo*-intermediol and T-cadinol as well as tricyclic diterpenes identical to the trinervitanes found in several neotropical *Nasutitermes* species.[16] Thus, identical diterpenes occur in advanced nasutes at the ends of both alleged phyletic lines after over 70 million years of evolution from mandibulate ancestors. In view of the absence of diterpenes[5b,16] in the primitive mandibulate nasutes *Syntermes*, *Cornitermes*, *Armitermes* and *Rhynchotermes*, we had suggested that the diphyletic hypothesis for the origins of the Nasutitermitinae was improbable. Invoking the principle of Occam's razor, an

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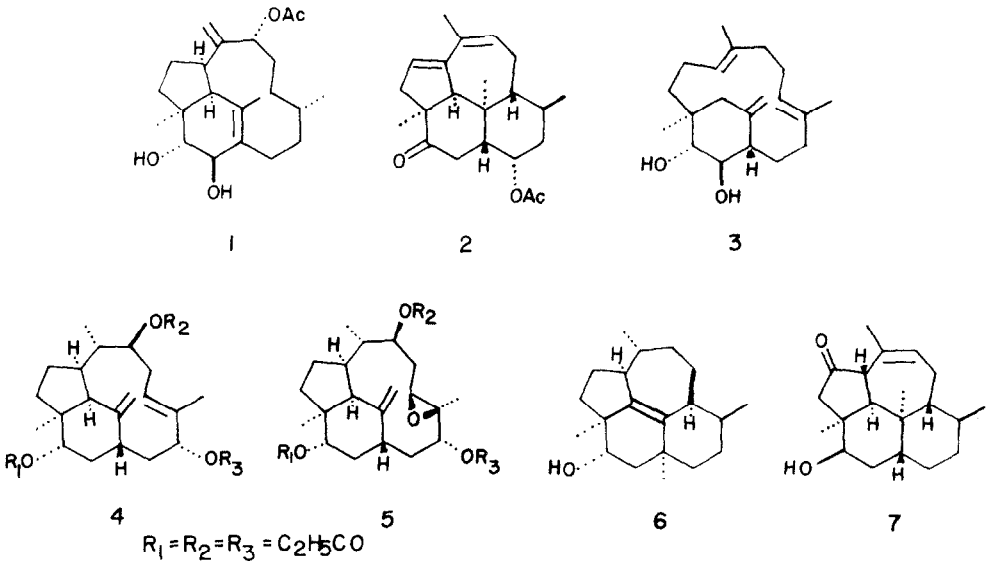


Fig. 1. Diterpene structural variants occurring in advanced nasute soldier secretions.

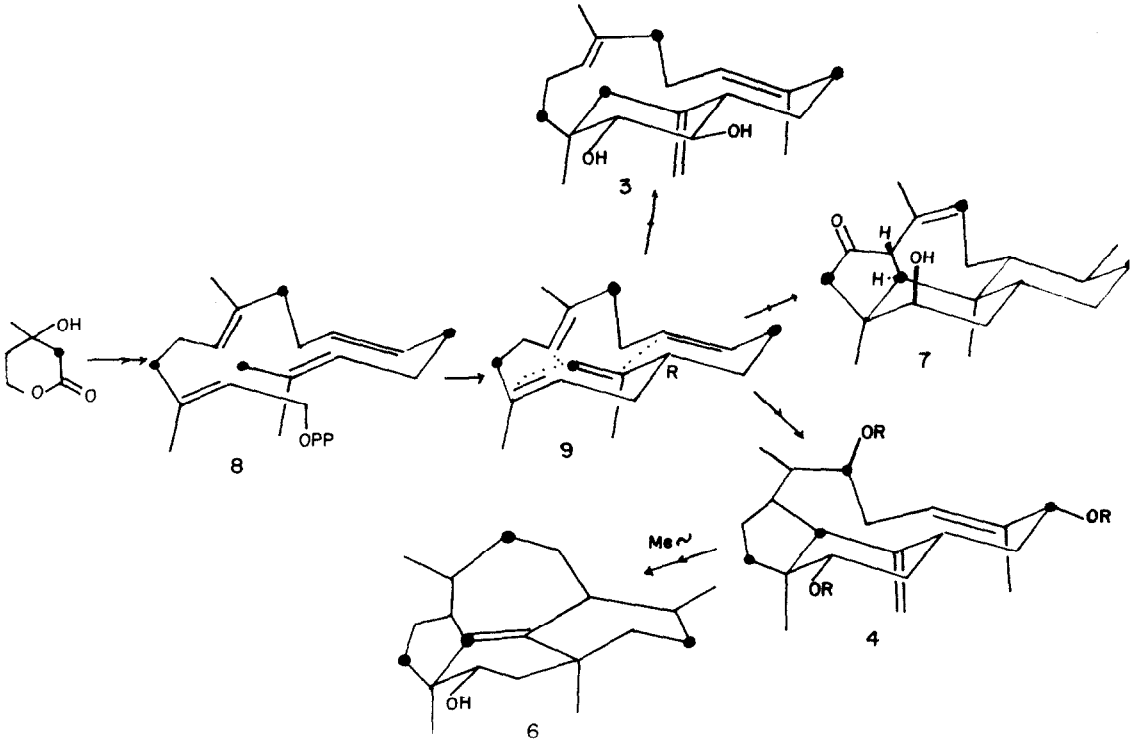


Fig. 2. Proposed biogenetic derivation of bicyclic, tricyclic, and tetracyclic diterpenes from cembrene-A, derived in turn from 2-^{14}C-mevalonate.

alternate monophyletic route (Fig. 3) was proposed[16] in which all glue-squirting, non-mandibulate nasutes diverged from a common diterpene-producing ancestor which evolved prior to the separation of West Gondwana into proto-Africa and proto-South America in the Cretaceous.

Very recently, the compositions of the soldier defense glands of the heavy-mandibled nasute *Syntermes* spp.[17] and the hooked-mandibled nasutes *Curvitermes stric-tinasus*[18] and *Armitermes* spp.[2] were reported. Four Brazilian species of *Syntermes* were shown to possess mono- and sesquiterpenes *cis*-β-ocimene, germacrene-A, β-elemene, aristolochene, and *epi*-α-selinene; the largest species, *Syntermes grandis*, lacked terpenoid compounds. Baker and his collaborators[17] also found an inverse correlation between mandible development and glandular size. In *Curvitermes*, the Southampton group identified

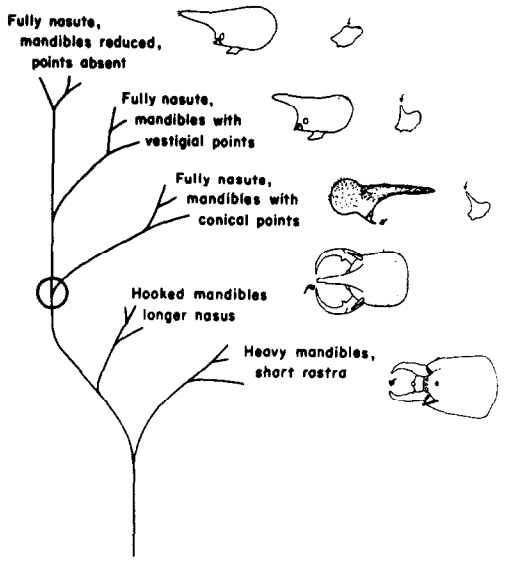


Fig. 3. Development of the soldier nasus and regression of the mandibles during the evolution of the nasute termites. The evolutionary scheme shown is monophyletic,[16] in contrast to the earlier diphyletic scheme.[15] The left mandibles of fully nasute soldiers are small and are shown as insets with arrows indicating the points. From bottom to top, representative species pictured are: *Syntermes* (dorsal view), *Armitermes* (dorsal), *Angularitermes* (lateral), *Grallatotermes* (lateral), and *Trinervitermes* (lateral).

limone, terpinolene, *p*-cymen-8-ol, tridecan-2-one, and (*Z*), (*E*)- and (*E*), (*E*)-farnesal as soldier-specific chemicals.[18]

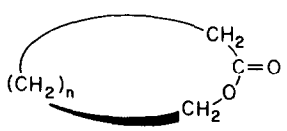
We had also been intrigued by the lack of diterpenoid materials in *Cornitermes pugnax*, *Labiotermes labralis*, *Rhynchotermes perarmatus*, and *Armitermes* spp. collected from Guyana and Costa Rica,[16] and had been examining the secretions of freshly collected *Armitermes* soldiers.[2] We report below the details of our elucidation of the structures of C_{22} to C_{36} macrocyclic lactones and the C_{24} and C_{26} α- and β-hydroxy macrolides from three primitive nasute species in the genus *Armitermes*.

RESULTS AND DISCUSSION

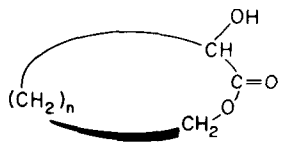
Armitermes holmgreni, *A. neotenicus* and *A. teevani* colonies were collected at Kartabo Point, Guyana over a period of three years. Soldiers were removed from the nest material, decapitated, and the heads were crushed in hexane. We also performed microcapillary collections ("milkings") of the defense secretion directly from the nasus, and found the tlc and glc profiles for these two collection methods were indistinguishable. For preparative purposes, the crushed head extracts were used. The three species showed distinctly different chromatograms.[2] *A. teevani* showed a mixture of homologous compounds from C_{22} to C_{36}, as indicated by M^+, $M^+ - 18$, and $M^+ - 60$ ions in the high mass region of the GC-MS analysis, and similar low mass regions with prominent *m/z* 55, 69, 83, 97 and 111 ions. The C_{34} compound was the only identifiable component of the *A. holmgreni* secretion, while *A. neotenicus* produced a mixture of C_{22}, C_{24}, and C_{26} compounds dominated by C_{24}. *A. holmgreni* was also found to produce substantial amounts of *n*-tridecane and *n*-pentadecane, which were the only detectable major compounds of the Brazilian termite *A. euamignathus*.

We pooled three collections of *Armitermes neotenicus* secretions and chromatographed this material on a Pasteur pipette packed with Silica Gel by successive elution with hexane, 10% ethyl acetate-hexane and 20% ethyl acetate–hexane. Three tlc-homogeneous fractions were obtained, and each fraction contained only one major compound and a two-carbon higher homolog as determined by glc. Without further purifications, proton and carbon NMR spectra were obtained (Fig. 5).

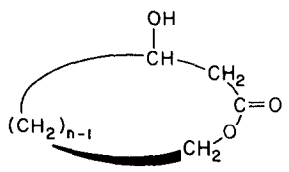
The absence of absorptions for terminal Me groups on either the acyl or alkyl portions of these fatty acid esters, and the absence of alkene carbons indicated the presence



10 a, n=19
b, n=21
⋮ ⋮ ⋮
i, n=35

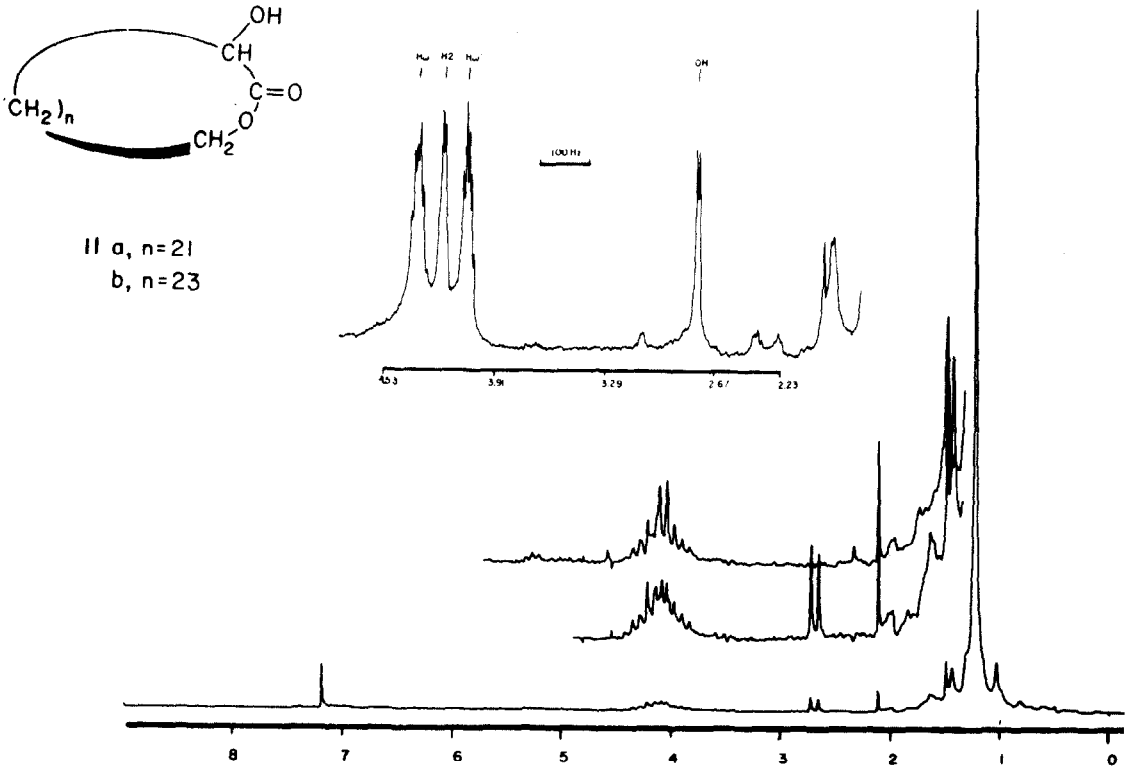


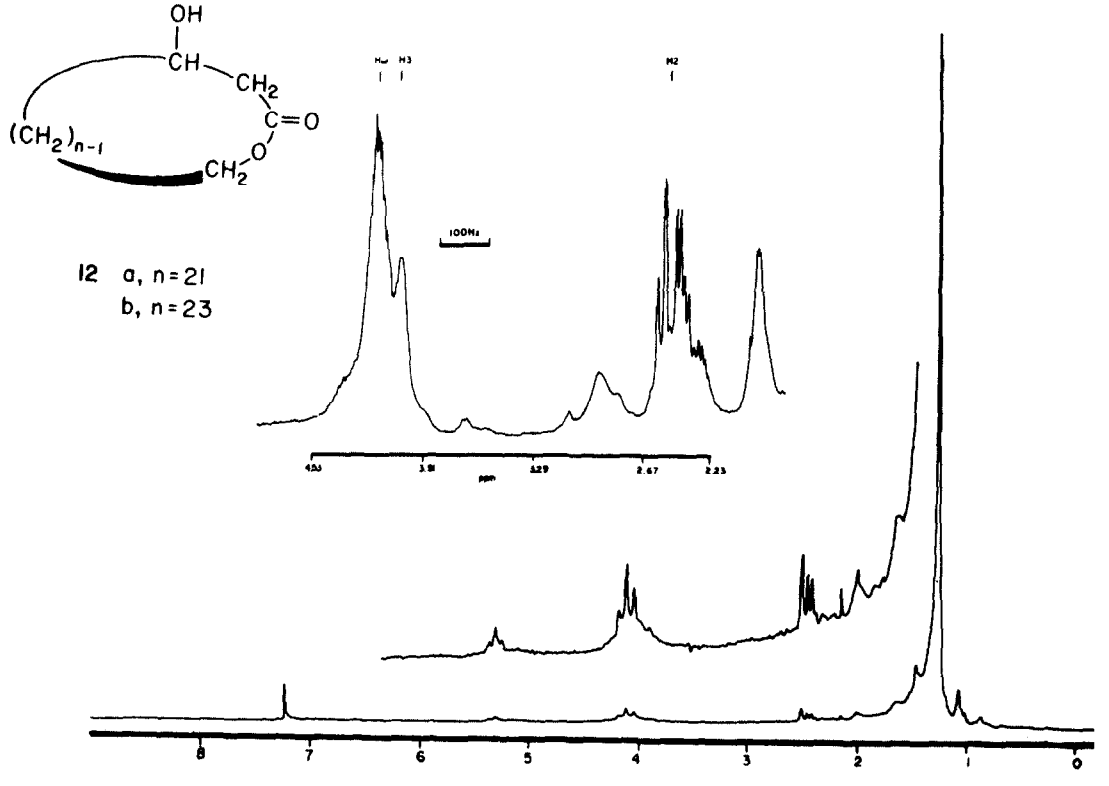
11 a, n=21
b, n=23



12 a, n=21
b, n=23

Fig. 4. Macrocyclic lactones from *Armitermes* soldiers.


OH
CH
C=O
O
$CH_2)_n$
CH_2
11 a, n=21
b, n=23
OH
8
7
6
5
4
3
2
1
0


OH
CH
CH_2
C=O
O
$(CH_2)_{n-1}$
CH_2
12 a, n=21
b, n=23
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8
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Fig. 5(a).

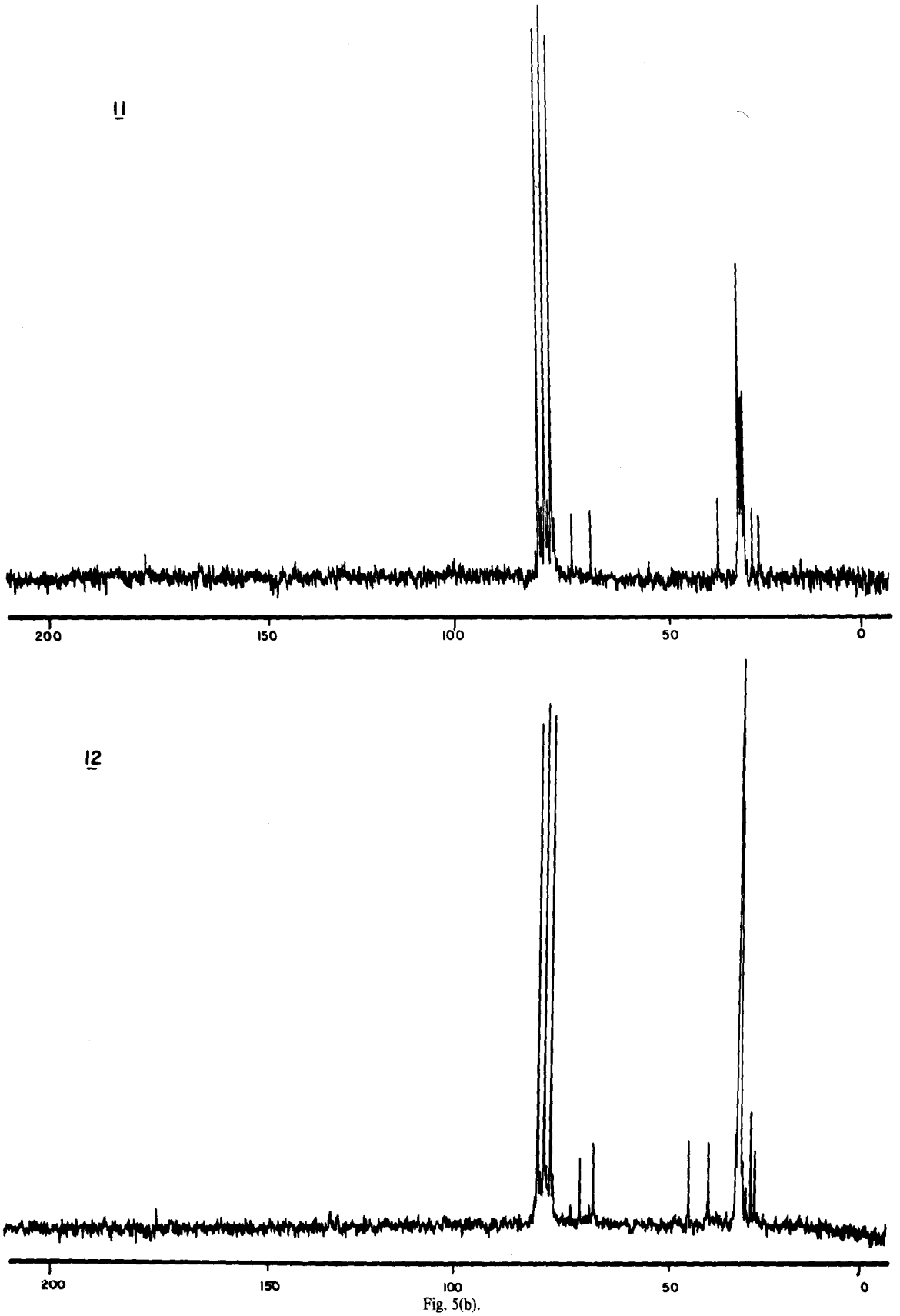

Fig. 5(b).

Fig. 5. 80 MHz proton (a) and 20 MHz carbon (b) NMR spectra of hydroxymacrolides in $CDCl_3$ solution. The 2.2 to 4.5 ppm regions of the 360 MHz spectra are shown as insets on the proton spectra. The effect of a D_2O wash is shown in the top curve of each proton spectrum.

of a macrocyclic ring. The major *A. neotenicus* compound was tetracosanolide **10b**, the major *A. holmgreni* compound was tetratriacontanolide **10g**, and the *A. teevani* secretion contained even-carbon macrocycles from docosanolide (**10a**) to hexatricontanolide (**10h**).

Lactones possessing 16, 18 and 20 carbons were found in the Dufour's gland of the solitary bees *Colletes cunicularius* and *Halictus calceatus*, and their mass spectra were examined in detail.[19] Subsequently, C_{18}–C_{22} macrocyclic lactones were found in Dufour's gland and as the corresponding linear polyesters in the brood cells of *Colletes* bees.[20] An unsaturated C_{18} macrolide of unknown double bond location was also present. Other halictid bees had "extra-large ring size" lactones from C_{18} to C_{24} which are hypothesized to serve as both marking pheromones and brood cell polyester precursors.[21] Following the initial submission of this manuscript, two further reports[22] of macrolides in *Lasioglossum* and in eighteen Nearctic halictids including *Augochlora* species.[22a] Saturated C_{26} and unsaturated C_{20}, C_{22} and C_{24} lactones (unspecific double bond positions) were reported as new natural products from the Dufour's glands and cell linings of these bees, and an approach to apoid chemical systematics was discussed.[22a] Long-chain ω-hydroxy fatty acids, the ring-opened hydrolysis products of the corresponding lactones, have been previously identified from the hydrolysis of lanolin (C_{22}–C_{36}).[23]

Confirmatory evidence for the structures of the *Armitermes* macrolides was obtained by acid-catalyzed methanolysis followed by trimethylsilylation, thereby providing the methyl ω-trimethysiloxy alkanoates. The mass spectra of the methyl esters of the trimethylsilyl ethers of unbranched ω-hydroxy fatty acids give highly characteristic mass spectra.[24] In particular, the *A. teevani* secretion provided a homologous series of compounds **13** showing very intense peaks at $M^+ - 15$ and $M^+ - 47$, in addition to rearrangement fragments at *m/z* 146 and 159 indicative of aliphatic compounds with both carboxyl and trimethylsiloxy moieties. The major fragments[24] are shown in Fig. 6.

For compound **11**, lactone opening in methanol–hex-

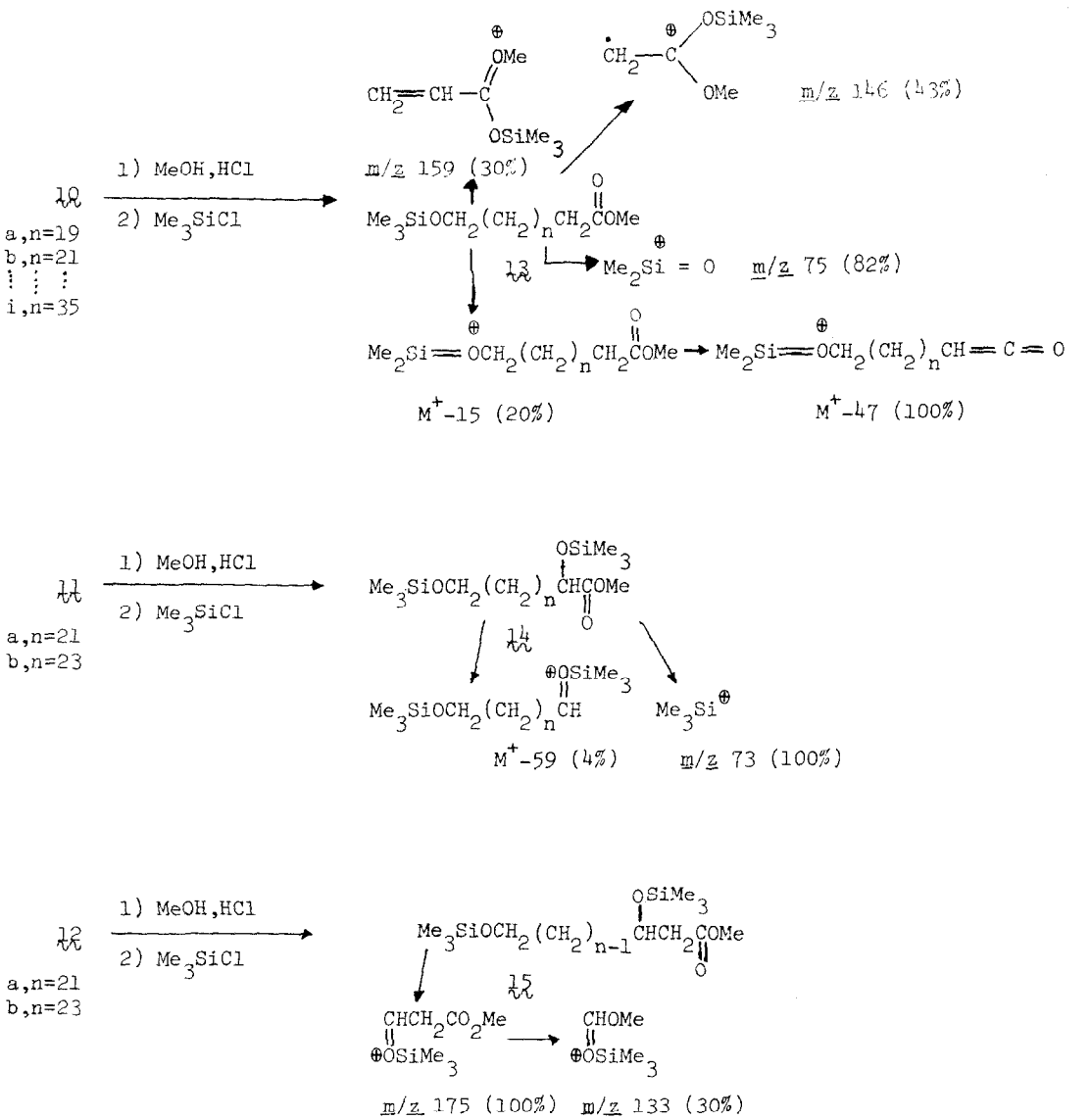

Fig. 6. Formation and mass spectral fragmentation of trimethylsiloxy alkanoates derived from *Armitermes* macrolides.[24]

ane–HCl (g) followed by silylation gave C_{24} and C_{26} bis(trimethylsiloxy)alkanoates (**14**) which showed only weak M^+-15, M^+-31, and M^+-47 fragments, small M^+-32 (2%) and M^+-59 (4%) fragments, and large peaks at *m/z* 73, 75, 129, 147, 163, 411 and 453. The presence of the M^+-59 fragment is considered to be diagnostic for α-trimethylsiloxyl methyl esters.[24] It is noteworthy that the TMS ether of the parent α-hydroxymacrolide also shows an M^+-59 (12%) ion with *m/z* 129 as the base peak. The position of the OH group is further confirmed by the new downfield signal at δ 70.50 in the ^{13}C-NMR and the loss of the H-2 methylene triplet of **1**. In the 360 MHz ^{1}H-NMR spectrum of **11** (Fig. 5, top, insert) the complex carbinyl signals between 4.0 and 4.4 ppm are clearly resolved. The OH group doublet at 2.70 ppm is coupled to the center carbinyl signal at δ 4.17; irradiation of the OH proton collapses this broadened doublet to a double doublet (J = 4.7 Hz, 5.2 Hz). We reasoned that the rigidity imparted by the 5-membered ring H-bonded character of the α-hydroxylactone rendered the carbinyl protons at the ω position nonequivalent, yielding separate multiplets (ddd) at δ 4.06 and 4.31 ppm.

Compounds **12** (C_{24}, C_{26}) did not give parent ions in the mass spectrum, showing only a weak M^+-18; the TMS ethers of **3** clearly show M^+-15 and M^+-33 fragments. Methanolysis and silylation as before gave C_{24} and C_{26} bis(trimethylsiloxy) methyl esters **15** isomeric to **14**. The mass spectrum of **15a** showed small M^+-15 and M^+-47 ions, the base peak at *m/z* 175, and large *m/z* 73 and 75 ions. The major fragment at *m/z* 175 in conjunction with substantial *m/z* 89, 133, 131, and 159 peaks provide diagnostic evidence[24] for the β-trimethysiloxy methyl ester **15**.

NMR evidence for **12** provided confirmation of its β-hydroxy macrolide nature. The ^{13}C spectrum showed two carbinyl carbons at δ 68.26 (C-3) and 64.93 (C-ω) and the appearance of two downfield alkyl carbons at 41.37 (C-2), and 36.48 (C-4). The 80 MHz proton spectrum showed a triplet for H-ω, a broad multiplet at δ 4.1–4.2 for H-3 and an ABX system for the diastereotopic H-2 protons. The 360 MHz ^{1}H-NMR of **12** (Fig. 5, bottom, inset) showed H-3 as a broad singlet and the H-ω triplet at δ 4.21 had become more complex as the nonequivalence of the two ω protons was rendered detectable at higher field. The small shift difference for these carbinyl protons resembles the apparent equivalence of the H-ω signals in the nonhydroxylated macrolides **10**, and reflects increased flexibility of the 6-membered-ring H-bonded character of the β-hydroxylactone.

The full characterization of the unique nonterpenoid *Armitermes* defense compounds suggest that this primitive nasute secretion functions as an oily antihealant,† as documented for the C_{21} to C_{33} normal alkanes and C_{27}, C_{29} (*Z*)-9-alkenes of *Macrotermes subhyalinus* and *M. michaelseni*.[25] Thus, ants and other small arthropods wounded by the mandibles receive a coating of defense secretion at the site of the wound. This results in uncontrolled loss of hemolymph and eventual death of the attacker by dehydration. Since they are very similar to cuticular lipids, the large nonpolar hydrocarbons appear to mask the wound in such a manner that hemolymph coagulation is inhibited. This mode of chemical defense is also postulated to function in *Cubitermes* species, which possess several novel diterpene hydrocarbons.[1,26] The apparent ecological kinship of the humivorous mound-building *Armitermes* species (Nasutitermitinae) studied here with the mound-building African termites *Macrotermes* (Macrotermitinae) and *Cubitermes* (Termitinae) indicates that this "biting-antihealant" form of chemical defense evolved independently in three subfamilies of the higher termite family Termitidae. The frequent occurrence of this defensive strategy in termites suggests that it is effective in the field, but little direct behavioral evidence is available yet. Preliminary work by Emerson[15] in comparing mandibular and chemical defense of primitive nasutes has already demonstrated the efficacy of the defense secretions of *Armitermes* and *Rhynchotermes* in deterring ant predation. The chemistry and ecology of these genera are now under closer scrutiny to determine the role of these novel macrolides in colony defense.

†This has been verified using *Armitermes chagresi* secretion by J. Traniello and B. L. Thorne (private communication).

EXPERIMENTAL

Termites were collected from soil and carton nests in rotten tree trunks or at the bases of trees in rain forest at Kartabo Point, Guyana, with Dr. Margaret S. Collins. *Armitermes* nests were not particularly abundant relative to those of *Coptotermes*, *Heterotermes* and *Nasutitermes* species. Three species were collected: *Armitermes neotenicus* (Holmgren), originally identified as *A. percutiens* by Emerson[27]; *A. holmgreni* (Snyder), originally identified[27] as *A. albidus*; and *A. teevani* (Emerson). Synonomies are summarized by Araujo.[28] *A. euamignathus* was collected from soil mounds in the Goias state (Brazil) by Mr. Kent Redford (Harvard University).

During the first field season (July 1978), extractions were performed on site. Thus, soldiers were collected individually, decapitated, the heads were crushed in hexane, and the extracts were hand-carried to Stony Brook for analysis. During the last two years, we have imported intact colonies to Stony Brook, where collection and analysis could proceed without fear of decomposition in transit, and where individual secretion "milkings" could be carried out just prior to analysis. These precautions were unnecessary for many species of the advanced nasutes, but were crucial to our success in studying the chemically labile β-ketoaldehydes of the rhinotermitines.[29] The milkings were performed by inserting the nasus into a 1.7 mm capillary and irritating the soldier with forceps. The secretion was discharged into the inner walls of the capillary and was free from enteric and salivary contaminants. The material was rinsed into Microflex vials with hexane and analyzed by glc as described below. Since gas chromatograms of "milked" secretion and the hexane-head extract were indistinguishable, the latter method was preferred for collection. The three species gave the following extractable materials: *A. holmgreni*, 10 μg/soldier; *A. neotenicus*, 80 μg/soldier; *A. teevani* 230 μg/soldier.

Gas chromatography was performed on a Varian 3700 instrument equipped with 2 m × 2 mm I.D. glass column packed with 1% SP-2100 on Supelcoport, temperature programmed from T_i = 200° (2 min delay), T_p = 4°/min, T_f = 300° (hold 20 min). No lower molecular weight volatiles were observed when the secretion was examined from 50° to 200° on this column. Low-resolution electron-impact mass spectra were obtained using a Hewlett Packard Model 5980A mass spectrometer interfaced to an HP5710A GC equipped with a 1% SP-2100-packed glass column. High resolution mass spectra were obtained on an MS-30 instrument interfaced to an HP7210A GC and a DS-50 data system. NMR spectra were obtained on Varian Associates CFT-20 instruments operating at 20 MHz for ^{13}C and 80 MHz for ^{1}H. High resolution ^{1}H-NMR spectra were obtained on a Bruker 360 spectrometer. Shifts are reported for $CDCl_3$ solns as ppm downfield from $(CH_3)_4Si$, using the $CHCl_3$ resonance as the internal standard for ^{1}H and the $CDCl_3$ resonance for ^{13}C. Microcell ^{13}C-NMRs required Wilmad 8-mm, 120 μl spherical cavities and data acquistion was performed in the double precision mode.

The crude *A. neotenicus* secretion, consisting of 45 mg from 600 soldier heads, was chromatographed on a Pasteur pipette packed with 230–400 mesh silica gel 60 (4 mm × 10 cm). Gradient elution with 5%, 10% and 20% ethyl acetate in hexane gave **10** (14.3 mg, R_f 0.47 in 15% ethyl acetate-hexane), **11** (5.3 mg, R_f 0.17) and **12** (7.0 mg, R_f 0.06) which were used directly for NMR, GC-MS, and derivatization procedures. Methanolysis was performed by stirring a 1:1 hexane-methanol solution of the macrolide (*ca.* 100 μg) at 20° while bubbling dry HCl gas into the soln for 10 min. The mixture was heated to reflux, stirred 2 hr as it cooled, diluted with water, and extracted with 1:1 ether–hexane. Extracts were filtered through $MgSO_4$ and solvent was removed under N_2. Silylation was accomplished by the addition of 200 μl of TriSil to the hydroxy esters or to the parent macrolides.

Macrolides **10a–c**. The least polar fraction from the *A. neotenicus* secretion contained **10a**, **10b** and **10c** in a ratio of 6:86:7. ^{13}C-NMR, δ 174.04 (C-1), 64.39 (C-ω), 34.66 (C-2), 29.15, 28.75, 28.46, 28.38, 28.30 (internal methylenes), 26.11, 25.17 (penultimate methylenes); ^{1}H-NMR, δ 4.10 (t, J = 6 Hz, H-ω), 2.32 (t, J = 7 Hz, H-2), 1.3 (br s, $-CH_2-$).

High resolution mass spectra gave the following data: docosanolide (**10a**) *m/z* 338.3183 ($C_{22}H_{42}O_2$ requires 338.3185); tetracosanolide (**10b**), 366.3502 ($C_{24}H_{46}O_2$ requires 366.3498); hexacosanolide (**10c**), 394.3801 ($C_{26}H_{50}O_2$ requires 394.3811). The low resolution spectra gave the following values for *m/z* (relative intensity): **10a**, 338 (4), 320 (4), 278 (3), 125 (20), 111 (43), 98 (48), 97 (94), 96 (53), 84 (52), 83 (100), 82 (54), 70 (40), 69 (87), 55 (74); **10b**, 366 (9), 348 (8), 306 (4), 139 (12), 125 (27), 111 (51), 97 (100), 83 (82), 69 (56), 55 (44); **10c**, 394 (4), 376 (2), 334 (1), 139 (9), 125 (22), 111 (50), 97 (95), 83 (100), 69 (96), 55 (58).

α-Hydroxymacrolides **11a, b**. The R_f 0.17 fraction of the *A. neotenicus* secretion contained **11a** and **11b** in a ratio of 80:20. ^{13}C-NMR, δ 175.73 (C-1), 70.50 (C-2), 65.89 (C-ω), 34.45 (C-3), 29.30, 29.13, 28.89, 28.71, 28.63, 28.46, 28.18, 27.91 (internal methylenes), 26.14, 24.47 (penultimate methylenes); ^{1}H-NMR (360 MHz), δ 4.31 (ddd, each 5 ~ 6 Hz, H-ω), 4.17 (ddd, 4.7, 5.2, 6, H-2), 4.06 (ddd, each 5 ~ 6 Hz, H-ω^1), 2.70 (d, 6 Hz, OH).

High resolution mass spectra of 2-hydroxytetracosanolide (**11a**) showed *m/z* 382.3429 ($C_{24}H_{46}O_3$ requires 382.3447); the less volatile **11b** would not pass the membrane separator. Low resolution MS of **11a**: *m/z* (rel. int.) 382 (1), 364 (1), 336 (2), 318 (1), 137 (13), 123 (23), 109 (41), 97 (79), 96 (83), 95 (68), 83 (83), 82 (100), 81 (60), 69 (60), 57 (33), 55 (36).

The trimethylsilylethers of **11a** and **11b** gave the following diagnostic mass spectral information: **11a**, *m/z* 454 (1), 439 (5), 411 (6), 395 (12), 185 (14), 171 (7), 129 (100), 75 (43), 73 (57); **11b** *m/z* 482 (2), 439 (8), 423 (11), 207 (7), 185 (11), 171 (7), 129 (100), 75 (63), 73 (72).

β-Hydroxymacrolides **12a, b**. The R_f 0.06 fraction of the *A. neotenicus* secretion contained 36% of **12a** and 53% **12b** in addition to 7% of **11a** and 3% of **11b**. ^{13}C-NMR, δ 173.10 (C-1), 68.26 (C-3), 64.93 (C-ω), 41.37 (C-2), 36.48 (C-4), 29.78, 29.19, 29.06, 28.85, 28.68, 28.16, 27.32, (internal CH_2), 26.12, 25.11 (penultimate CH_2); ^{1}H-NMR (360 MHz), δ 4.21 (m, H-ω; appears as t, J = 6 Hz at 80 MHz), 4.17 (br s, H-3), 2.50 (ABX, J_{AB} = 15 Hz, J_{AX} = 2.8 Hz, J_{BX} = 8.0 Hz).

Molecular ions were not observed in these compounds due to the facile dehydration of β-hydroxyesters. The M^+-H_2O peak for compound **12a** had *m/z* 364.3330 ($C_{24}H_{44}O_2$ requires 364.3341); the C_{26} β-hydroxymacrolide could not pass the membrane separator. Low resolution spectra: **12a**, *m/z* 364 (3), 346 (2), 304 (2), 97 (100), 96 (81), 95 (66), 83 (97), 82 (82), 81 (59), 69 (66), 55 (36); **12b**, *m/z* 392 (2), 374 (1), 97 (100), 96 (75), 95 (63), 83 (78), 82 (67), 81 (53), 69 (44), 55 (23).

The β-OTMS compounds gave the following diagnostic mass spectral fragments: **12a**, *m/z* 454 (1), 439 (36), 421 (43), 411 (5), 397 (8), 395 (9), 185 (11), 171 (8), 161 (23), 145 (93), 143 (41), 133 (35), 129 (79), 117 (44), 75 (90), 73 (100); **12b**, *m/z* 482 (1), 467 (51), 449 (54), 425 (10), 161 (25), 145 (100), 143 (34), 133 (41), 129 (26), 117 (53), 75 (72), 73 (71).

Macrolides **10a–i** *from* A. teevani. The secretion of *Armitermes teevani* provided a mixture of homologous macrolides in the following relative proportions: **10a**, 1.2%; **10b**, 11.9%, **10c**, 16.9%; **10d**, 13.4%; **10e**, 12.9%; **10f**, 13.9%; **10g**, 16.9%; **10h**, 10.1%; **10i**, 1.0%. High resolution mass spectra for **10d**: *m/z* 422.4108 ($C_{28}H_{54}O_2$ requires 422.4124). Low resolution MS for **10d**, *m/z* (relative intensity) 422 (5), 404 (4), 362 (1.5), 139 (10), 125 (25), 111 (52), 97 (100), 83 (84), 71 (34), 69 (71), 57 (30), 55 (40); **10e**, 450 (3.8), 432 (2.5), 390 (1.4), 125 (26), 111 (51), 97 (100), 83 (93), 71 (36), 69 (76), 57 (32), 55 (42); **10f**; 478 (3.5), 460 (2.8), 418 (0.9), 125 (23), 111 (48), 97 (100), 83 (83), 71 (39), 69 (69), 57 (30), 55 (32); **10g**, 506 (2.4), 488 (1.9), 446 (0.6), 125 (23), 111 (50), 97 (100), 83 (93), 71 (36), 69 (79), 57 (32), 55 (34); **10h**, 534 (1.1), 516 (0.6), 474 (0.5), 125 (20), 111 (45), 97 (94), 83 (91), 71 (50), 69 (100), 57 (55), 55 (56). The compound assigned structure **10i** could not be detected by MS and its identity is inferred from the GC retention index only.[21]

Methyl ω-trimethylsiloxyalkanoates **13a–i**. Treatment of **10a–i** from *A. teevani* with HCl in methanol-hexane, followed by aqueous workup and silylation of the hydroxyesters (which would not elute from the glc prior to silylation), gave the homologous even-carbon ω-trimethylsiloxy methyl esters from methyl 24-trimethylsiloxytetradecanoate (**13b**) to methyl 34-trimethylsiloxytetratriacontanoate (**13g**). Low resolution mass spectra were as follows: **13b**, 470 (0), 455 (19), 423 (100), 159 (30), 146 (43), 103 (48), 75 (82), 73 (47); **13c**, 498 (0.1), 483 (24), 451 (100), 159 (21), 146 (28), 103 (25), 75 (46), 73 (26); **13d**, 526 (0), 511 (22), 479 (100), 451 (8), 159 (40), 146 (57), 103 (54), 75 (91), 73 (52); **13e**, 554 (0), 539 (10), 507 (43), 479 (5), 159 (36), 146 (49), 103 (45), 75 (100), 73 (53); **13f**, 582 (0), 567 (6), 535 (23), 507 (13), 159 (37), 146 (56), 103 (49), 75 (100), 73 (62); **13g**, 610 (0), 595 (1.5), 563 (4), 535 (5), 159 (32), 146 (41), 103 (44), 75 (100), 73 (78). Minor components **13a, h, i** were not detected by mass spectrometry.

Methyl 2, *ω-bis(trimethylsiloxy)alkanoates* **14a, b**. Treatment of **11a, b** from *A. neotenicus* with HCl in methanol-hexane, followed by aqueous workup and silylation of the dihydroxy esters (non-GC-eluting), gave methyl 2,24-bis(trimethylsiloxy) tetracosanoate **14a** and the C_{26} homolog **14b**. Low resolution mass spectral data are: **14a**, *m/z* (rel. inten.) 558 (0.7), 543 (1.3), 526 (2), 499 (4), 453 (19), 411 (28), 163 (55), 159 (21), 147 (25), 129 (44), 103 (44), 97 (40), 95 (42), 75 (65), 73 (100); **14b** (very weak), 586 (0), 439 (4), 411 (1.4), 163 (24), 159 (15), 147 (17), 129 (33), 103 (4), 97 (28), 95 (29), 89 (45), 75 (62), 73 (100).

Methyl 3, *ω-bis(trimethylsiloxy)alkanoates* **15a, b**. Acid methanolysis and silylation of **12a, b** gave a mixture of methyl 3,24-bis(trimethylsiloxy) tetracosanoate **15a** and its C_{26} homolog **15b**. Low resolution mass spectral data are: **15a**, *m/z* (rel. int.) 558 (0), 543 (3.0), 511 (2.1), 453 (10), 421 (4.8), 175 (100), 163 (23), 159 (41), 147 (28), 133 (30), 129 (23), 103 (37), 89 (58), 75 (62), 73 (91); **15b**, 586 (0), 571 (2.5), 539 (1.3), 481 (5), 449 (3.6), 425 (2.6), 175 (100), 163 (15), 159 (39), 147 (19), 133 (30), 129 (15), 103 (27), 89 (47), 75 (51), 73 (79).

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REFERENCES

[1a]G. D. Prestwich, *J. Chem. Ecol.* **5**, 459 (1979); [b]G. D. Prestwich, *Sociobiol.* **4**, 127 (1979).

[2]G. D. Prestwich and M. S. Collins, *Tetrahedron Letters* **22**, 4587 (1981).

[3]G. D. Prestwich, *Biochem. System. Ecol.* **7**, 211 (1979).

[4a]G. D. Prestwich, S. P. Tanis, F. Pilkiewicz, I. Miura and K. Nakanishi, *J. Am. Chem. Soc.* **98**, 6062 (1976); [b]J. Vrkoč, M. Budéšinsky and P. Sedmera, *Coll. Czech. Chem. Commun.* **43**, 2478 (1978).

[5a]G. D. Prestwich, B. A. Solheim, J. Clardy, F. Pilkiewicz, I. Miura, S. P. Tanis and K. Nakanishi, *J. Am. Chem. Soc.* **99**, 8082 (1977); [b]G. D. Prestwich, S. H. Goh and Y. P. Tho, *Experientia*, **37**, 11 (1981).
[6]J. C. Braekman, D. Daloze, A. Dupont, J. Pasteels, B. Tursch, J. P. DeClerq, G. Germain and M. van Meerssche, *Tetrahedron Letters* 2761 (1980).
[7]G. D. Prestwich, S. H. Goh and Y. P. Tho, unpublished results quoted in *Chem. Eng. News* Sept. 8, 37 (1980).
[8]G. D. Prestwich, S. G. Spanton, S. H. Goh and Y. P. Tho, *Tetrahedron Letters* 1563 (1981).
[9]A. Dupont, J. C. Braekman, D. Daloze, J. M. Pasteels and B. Tursch, *Bull. Chim. Soc. Belges* **90**, 485 (1981).
[10]G. D. Prestwich, S. G. Spanton, J. W. Lauher and J. Vrkoč, *J. Am. Chem. Soc.* **102**, 6825 (1980).
[11a]G. D. Prestwich, J. W. Lauher and M. S. Collins, *Tetrahedron Letters* 3827 (1979); M. S. Collins and G. D. Prestwich, *Insectes Soc.*, in press (1982).
[12]G. D. Prestwich, *Experientia* **34**, 682 (1978).
[13]G. D. Prestwich and D. Chen, *J. Chem. Ecol.* **7**, 147 (1981).
[14]G. D. Prestwich, R. W. Jones and M. S. Collins, *Insect. Biochem.* **11**, 331 (1981).
[15]A. E. Emerson, *Evolution* **15**, 115 (1961).
[16]G. D. Prestwich and M. S. Collins, *Biochem. System. Ecol.* **9**, 83 (1981).
[17]R. Baker, H. R. Coles, M. Edwards, D. A. Evans, P. E. Howse and S. Walmsley, *J. Chem. Ecol.* **7**, 135 (1981).
[18]R. Baker, M. Edwards, D. A. Evans and S. Walmsley, *J. Chem. Ecol.* **7**, 127 (1981).
[19]G. Bergström, *Chem. Scripta* **5**, 39 (1973).
[20]A. Hefetz, H. M. Fales and S. W. T. Batra, *Science* **204**, 415 (1979).
[21]G. Bergström and J. Tengö, *Acta Chem. Scand. Ser. B*, **29**, 390 (1979).
[22a]R. M. Duffield, A. Fernandes, C. Lamb, J. W. Wheeler and G. Eickwort, *J. Chem. Ecol.* **7**, 319 (1981); [b]J. H. Cane, *Ibid.* **7**, 404 (1981).
[23]F. Fawaz, C. Miet, F. Puiseux, *Ann. Pharm. Fr.* **32**, 59 (1974).
[24]G. Eglinton, D. H. Hunnerman and A. McCormick, *Org. Mass. Spec.* **1**, 593 (1968).
[25]G. D. Prestwich, B. A. Bierl, E. D. DeVilbiss and M. F. B. Chaudhury, *J. Chem. Ecol.* **3**, 579 (1977).
[26a]G. D. Prestwich, D. F. Wiemer, J. Meinwald and J. Clardy, *J. Am. Chem. Soc.* **100**, 2560 (1978); [b]D. F. Wiemer, J. Meinwald, G. D. Prestwich and I. Miura, *J. Org. Chem.* **44**, 3950 (1979); [c]D. F. Wiemer, J. Meinwald, G. D. Prestwich, B. A. Solheim and J. Clardy, *Ibid.* **45**, 191 (1980).
[27]A. E. Emerson, *Zoologica* **6**, 291 (1925).
[28]R. L. Araujo, *Catalogo dos Isoptera do Novo Mundo.* Acad. Brasil Ciencas, Rio de Janeiro (1977).
[29a]G. D. Prestwich and M. S. Collins, *Tetrahedron Letters* 5001 (1980); [b]G. D. Prestwich and M. S. Collins, *J. Org. Chem.* **46**, 2383 (1981).