Evaporation of the solvent afforded a 95:5 mixture (365 mg, 98% theoretical) of the two isomeric epoxides. A $CHCl_3$ solution (50 mL) of this mixture (365 mg) was treated with *p*-TsOH acid (3 mg) at room temperature for 18 h and worked up as described above. The reaction mixture (350 mg) was chromatographed on a silica gel H column eluted with EtOAc to yield compound **23** (294 mg, 82% theoretical): amorphous material ($CHCl_3$); mp 181–183 °C; IR ($CHCl_3$) 3580, 3390, 2920, 2870, 1460, 1375, 1365, 1160, 1080, 1045, 910 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.82 (3 H, s), 0.97 (3 H, s), 1.08 (3 H, s), 1.12 (6 H, s), 1.19 (3 H, s), 1.25 (3 H, s), 3.49 (1 H, dd, J = 10.9, 4.0 Hz), 3.79 (1 H, d, J = 6.5 Hz), 4.42 (1 H, br t), J = 4.6 Hz), 4.82 (1 H, br s), 5.19 (1 H, br s); mass spectrum (CI, isobutane), m/e (relative intensity) 475 ($MH^+ - H_2O$, 6), 457 (37), 439 (100), 421 (45); ^{13}C NMR (75.46 MHz, $CDCl_3$) δ 152.21 (s), 113.04 (t), 81.85 (s), 77.93 (s), 77.09 (d), 76.56 (d), 72.72 (s), 72.21 (d), 55.33 (d), 51.36 (d), 46.69 (d), 42.89 (s), 39.66 (t), 39.25 (t), 36.98 (s), 34.22 (t), 32.58 (d), 32.58 (t), 32.08 (t), 30.38 (q), 29.25 (q), 26.79 (t), 25.91 (t), 25.66 (q), 25.40 (t), 25.40 (t), 24.95 (q), 23.33 (q), 2149 (q), 13.17 (q).

DDQ Oxidation of Compound 23. A solution of compound **23** (170 mg) and DDQ (100 mg) in 1:1 $CHCl_3$/toluene solution (20 mL) was kept at room temperature, in the dark, for 5 days, until all the starting material disappeared. The solvent was evaporated in vacuo and the crude reaction mixture chromatographed on silica gel H with $CHCl_3$/EtOAc (1:1) as the eluant to yield a single product (**24**) (150 mg, 89% theoretical); amorphous ($CHCl_3$); mp 142–143.5 °C; IR ($CHCl_3$) 3400, 2920, 2870, 1720, 1670, 1600, 1375, 1250, 1210, 1165, 1085, 1045, 960, 910 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.97 (3 H, s), 0.98 (6 H, s), 1.13 (6 H, s), 1.26 (3 H, s), 1.33 (3 H, s), 3.50 (1 H, dd, J = 5.3, 11.7 Hz), 3.81 (1 H, d, J = 6.7 Hz), 5.23 (1 H, d, J = 2.0 Hz), 6.14 (1 H, d, J = 2.0 Hz); mass spectrum (CI, isobutane), m/e (relative intensity) 491 (MH^+, 1), 473 (35), 455 (100), 437 (93), 419 (19); ^{13}C NMR (75.46 MHz, $CDCl_3$) δ 202.59 (s), 147.59 (s), 125.84 (t), 82.19 (s), 78.03 (s), 76.80 (d), 76.44 (d), 72.10 (s), 56.88 (d), 55.11 (d) 51.16 (d), 48.76 (d), 42.65 (s), 42.14 (t), 39.09 (t), 36.99 (s), 36.84 (t), 34.11 (q), 33.75 (t), 32.15 (q), 29.95 (q), 28.99 (q), 28.42 (t), 26.56 (t), 26.26 (t), 25.54 (q), 25.21 (t), 24.73 (t), 21.35 (q), 12.90 (q).

Ozonolysis of Sipholenol-C (6). A cooled solution (−78 °C) of **6** (25 mg) in CH_2Cl_2 (2 mL) was titrated with a saturated blue solution of O_3 in CH_2Cl_2 (ca. 0.04 M, 5 mL). After 5 min at −78 °C, the mixture was allowed to warm up to room temperature and the solvent was removed under vacuo. The residual oil was taken in acetone (5 mL) and oxidized with a few drops of a Jones reagent. Following the usual workup, the residue (25 mg) was chromatographed on a silica gel column, eluted with increasing percent of EtOAc in $CHCl_3$ fractions of 10 mL each. Fraction 3 eluted with 20% EtOAc in $CHCl_3$ gave pure **27** (10 mg, 68% theoretically): an oil; IR ($CHCl_3$) 2920, 2850, 1770, 1710, 1460, 1380, 1285, 1170, 1125, 1095, 1068, 905 cm^{-1}; mass spectrum (EI, 12 eV), m/e (relative intensity) 280 (M^+, 3), 265 ($M^+ - CH_3$, 10), 252 ($M^+ - CO$, 14), 238 ($M^+ - CH_2CO$, 100), 222 (4), 197 (33), 195 (10), 194 ($M^+ - CO - C_3H_6O$, 23), 179 (194 − CH_3, 28), 166 (28), 151 (12), 138 (22), 129 (23), 121 (21). For ^1H NMR data, see Scheme IV. Fraction 6 eluted with the same solvent system gave **28**: an oil; mass spectrum, m/e 206 ($M^+ - H_2O$); IR ($CHCl_3$) 3450, 2970, 1705, 1240, 1175 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 2.14 (1 H, m), 1.47 (3 H, s), 1.28 (3 H, d, J = 7.5 Hz), 1.15 (3 H, s), 1.06 (3 H, s).

Jones Oxidation of Compound 26. Jones oxidation of sipholenol-E monoacetate (**26**, 3 mg) in the same manner described above for **2** gave the α,β-unsaturated ketone **25** (2 mg, 70% theoretical) identical in all respects with the authentic sample (see above); an oil; IR ($CHCl_3$) 3590, 3450, 2925, 2870, 1720, 1660, 1645, 1440, 1360, 1245, 1070, 1035, 960, 905 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.75 (3 H, s), 0.98 (3 H, s), 1.03 (3 H, s), 1.16 (3 H, s), 1.18 (3 H, s), 1.20 (3 H, s), 1.25 (3 H, s), 1.90 (3 H, s), 2.13 (3 H, s), 2.31 (1 H, dd, J = 12.5, 7.0 Hz), 2.37 (1 H, dd, J = 12.5, 3.8 Hz), 2.70 (1 H, br d, J = 5.0 Hz), 3.39 (1 H, dd, J = 11.5, 4.3 Hz), 4.98 (1 H, d, J = 6.6 Hz); ^{13}C NMR (75.46 MHz, $CDCl_3$) δ 199.75 (s), 170.22 (s), 161.98 (s), 132.74 (s), 79.15 (d), 77.26 (s), 76.61 (d), 72.17 (s), 71.33 (s), 56.08 (d), 45.72 (d), 45.48 (d), 43.08 (s), 40.41 (t), 39.51 (t), 38.17 (t), 36.46 (t), 35.92 (t), 35.59 (s), 34.24 (t), 30.67 (q), 30.52 (t), 29.02 (q), 28.52 (q), 26.54 (t), 24.23 (t), 23.09 (q), 22.67 (q), 21.48 (q), 21.21 (q), 13.09 (q), 11.71 (q). For mass spectral data, see Table III.

Acknowledgment. We express our appreciation to Professor Y. Loya for collection of the sponge, Professor J. Vacelet for its identification, and the United States–Israel Binational Science Foundation for support (Grant 2201/80).

Registry No. 1, 78518-73-7; 2, 78518-74-8; 3, 86748-27-8; 3a, 86748-28-9; 4, 86766-01-0; 5, 86783-84-8; 6, 86748-29-0; 7, 86748-30-3; 8, 86748-31-4; 9, 86783-85-9; 10, 86783-86-0; 11, 86748-32-5; 12, 86748-33-6; 13, 86783-87-1; 14, 86748-34-7; 15, 86748-35-8; 16, 78518-75-9; 17, 86783-88-2; 18, 86748-36-9; 19, 86783-89-3; 20, 86748-37-0; 21, 86748-38-1; 22, 86748-39-2; 23, 86748-40-5; 24, 86748-41-6; 25, 86748-42-7; 26, 86748-43-8; 27, 86748-44-9; 28, 86748-45-0.

Ant-Repellent Triterpenoids from *Cordia alliodora*

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Received January 29, 1982

Six triterpenoids have been isolated from leaves of the tropical tree *Cordia alliodora* (Boraginaceae) and assigned structures on the basis of spectral and crystallographic data and chemical interconversions. All six compounds, 3α-hydroxyolean-12-en-27-oic acid and five oxidized derivatives, were found to be significantly ant repellent in a bioassay that measures the feeding preferences of the leafcutter ant *Atta cephalotes*.

The leafcutter ants (Hymenoptera, Formicidae, Attini) are classed as agricultural pests throughout the tropical Americas, both because of the massive amount of leaf material they harvest and their special fondness for agriculturally important plant species. Colonies whose foraging is restricted to areas of native forest encounter a great variety of potential host plants, but while the leafcutter ants are considered polyphagous, they are nonetheless quite specific in their preference for some plant species and dislike of others.[1] From native plant species that escape leafcutter attack, we have reported the isolation of the ant-repellent sesquiterpenoids lasidiol angelate[2,3] and caryophyllene epoxide.[3] In continuation of our

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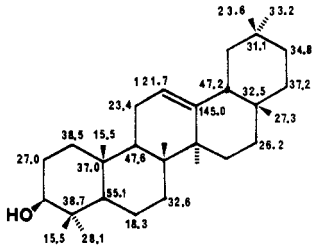
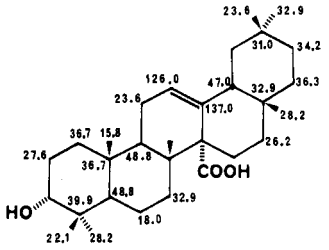
0022-3263/83/1948-3525$01.50/0



β-amyrin



A

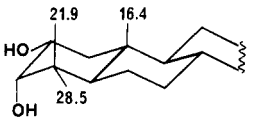
Figure 1. Comparison of the ^{13}C NMR spectral data of compound A with those of β-amyrin.

study of plant chemical defenses against insect herbivory, we now report the isolation of six new ant-repellent triterpenoids from *Cordia alliodora* (Boraginaceae), a plant species common in areas inhabited by *Atta cephalotes* yet seldom attacked by this leafcutter ant.

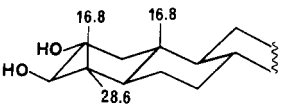
Our isolation sequence was guided by a novel bioassay that quantifies the ant-repellent activity of plant extracts or chromatographic fractions.[1] The predominant activity was located in the chloroform extract of *C. alliodora* leaves and associated with the hexane layer of a hexane/50% aqueous methanol partition. After further purification by column chromatography, the activity was found to be concentrated in a group of moderately polar fractions. The most repellent of these fractions yielded two active compounds, designated A and B, after final purification by column chromatography. Four related compounds, designated C–F, were isolated from more polar but somewhat less active column fractions.

The most abundant of the active agents, compound A, gave an electron-impact mass spectrum (EI MS) with peaks up to m/z 412. However, the chemical ionization mass spectrum (CI MS, CH_4) revealed an $M^+ + 1$ peak at m/z 457 (100%), suggesting that the molecule had undergone a facile loss of CO_2 under EI MS conditions. The presence of a carboxyl group was confirmed by reaction with diazomethane to afford a methyl ester with the expected molecular weight of 470 (CI MS, CH_4, m/z 471 (100%)).

The broad-band decoupled ^{13}C NMR spectrum of compound A contained a total of 30 resonances (Table I), including a carboxyl carbon, a carbinol carbon, and the two carbons of a trisubstituted double bond. Off-resonance decoupling experiments gave rise to complicated overlapping signals for the 26 aliphatic carbons, but the delayed-decoupling spectra[4] allowed ready interpretation of the carbon multiplicities. To account for these multiplicities, the functional groups listed above and the molecular weight established by mass spectrometry, a molecular formula of $C_{30}H_{48}O_3$ and a pentacyclic skeleton is required for compound A.



methyl 3-epimaslinate

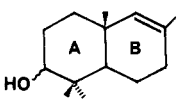


methyl maslinate

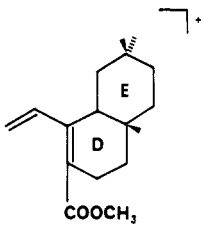
Figure 2. Effect of C-3 stereochemistry on the ^{13}C NMR resonance of C-4 methyl groups.[10]

The ^1H NMR spectrum of compound A shows an olefinic one-proton triplet at δ 5.6 and a broad singlet at δ 3.3 ($W_{1/2}$ = 7 Hz) attributed to the CHOH group. Following acetylation with acetic anhydride–pyridine this resonance shifted from δ 3.3 to 4.6 ($W_{1/2}$ = 7 Hz). Treatment of compound A with pyridinium dichromate (PDC) in DMF[5] oxidized the secondary hydroxyl group to a carbonyl group, as indicated by the disappearance of the δ 3.3 resonance in the ^1H NMR spectrum and the shift of a carbon resonance from 76.4 to 217.8 ppm. Finally, a keto methyl ester, with the expected molecular ion at m/z 468, was obtained upon treatment of this keto acid with diazomethane.

The methyl ester derived from compound A shows a strong peak in its mass spectrum at m/z 262 (46%), as do the methyl esters of the simple derivatives of compound A (ketone, 80%; acetate, 44%). This is consistent with a fragment having structure 1,[6] as well as other isomers that



2



1

would place the carboxyl group in the C, D, or E rings. The mass spectrum of compound A itself does not contain this ion, but this could be due to its ready decarboxylation. If the structure suggested for this ion is valid, it implies a complementary fragment such as **2**, a C-12 double bond, and an oleane skeleton for the triterpenoid.[6,7]

The ^{13}C NMR spectra of compound A strongly support this hypothesis. The observed pattern of carbon multiplicities rules out most of the known triterpene skeletons but does fit that expected for an oleane derivative. Comparison of compound A's ^{13}C NMR spectrum with that of β-amyrin[8] is especially helpful (Figure 1). Close agreement is found for the carbon resonances of the D and E rings, confirming our earlier assumption that these rings are devoid of functionality. Because the resonances assigned to carbons 2, 4, 6, 7, 10, 24, and 25 of β-amyrin also have close correspondence with resonances in the spectrum of compound A, assignment of the hydroxyl group to the C-3 position is indicated. Once this assignment is made, the stereochemistry of the C-3 position is clear from the ^1H NMR data; with a $W_{1/2}$ of 7 Hz for the hydrogen geminal to the hydroxyl group, an equatorial hydrogen and axial hydroxyl group is required.[9]

Further chemical and spectral evidence for this assignment was readily obtained. Crews and Kho-Wiseman[10] have shown that the ^{13}C resonances of methyl groups at

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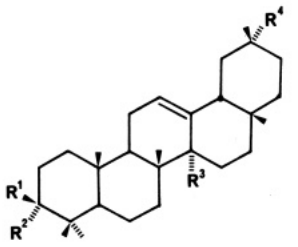
Table I. ^{13}C NMR Resonances of Isolated Triterpenoids and Their Synthetic Derivatives

	chemical shift, ppm													
C	3a (A)	3b	3c	3d	4a (B)	4b	5	β-amyrin	6a (C)	6b	9 (D)	10 (E)[c]	11a (F)	11b
1	36.7 t[a]	36.7 t[a]	36.9 t[a]	36.7 t[a]	39.0 t	39.4 t	36.9 t	38.5 t	38.8 t	39.4 t	36.7 t	35.7 t	36.2 t	36.7 t
2	27.6 t	27.6 t	27.5 t	27.6 t	34.3 t	34.2 t	27.8 t	27.0 t	35.6 t	35.3 t	27.5 t	27.6 t	27.3 t	27.6 t
3	76.4 d	75.8 d	78.1 d	78.1 d	217.8 s	217.8 s	78.8 d	78.9 d	217.9 s	217.5 s	76.0 d	73.6 d	75.8 d	75.8 d
4	39.9 s	40.0 s	40.3 s	39.7 s	47.1 s	47.0 s	40.2 s	38.7 s	47.2 s	47.9 s	39.6 s	39.3 s	39.9 s	40.0 s
5	48.8 d	49.0 d	49.9 d	50.0 d	54.5 d	54.8 d	55.5 d	55.1 d	54.2 d	54.8 d	48.5 d	48.0 d	48.5 d	48.0 d
6	18.0 t	18.1 t	18.2 t	18.0 t	19.5 t	19.4 t	18.3 t	18.3 t	19.3 t	18.5 t	18.0 t	18.0 t	18.0 t	18.1 t
7	32.9 t	33.2 t	33.3 t	33.0 t	34.0 t	33.8 t	33.5 t	32.6 t	33.8 t	33.8 t	32.9 t	32.9 t	32.7 t	33.2 t
8	36.7 s	37.3 s	36.5 s	36.4 s	39.8 s	39.4 s	37.3 s	39.7 s	39.5 s	39.4 s	36.7 s	36.7 s	37.0 s	37.3 s
9	48.8 d	49.0 d	49.3 d	48.9 d	49.2 d	48.9 d	49.2 d	47.6 d	46.9 d	47.1 d	46.8 d	48.0 d	47.9 d	49.0 d
10	36.7 s	37.1 s	36.4 s	36.4 s	36.1 s	36.3 s	38.8 s	37.0 s	36.5 s	36.6 s	37.0 s	36.8 s	37.0 s	37.1 s
11	23.6 t[b]	22.7 t[b]	23.6 t[b]	22.5 t	22.9 t[a]	22.8 t[a]	23.0 t[a]	23.4 t	21.9 t[a]	23.0 t[a]	22.6 t[a]	23.6 t[a]	22.5 t[a]	22.7 t[a]
12	126.0 d	125.5 d	126.4 d	125.3 d	125.8 d	125.0 d	125.5 d	121.7 d	125.8 d	126.0 d	126.8 d	124.8 d	126.8 d	125.5 d
13	137.6 s	137.5 s	137.6 s	137.4 s	137.6 s	137.4 s	137.5 s	145.0 s	137.6 s	137.8 s	136.1 s	137.5 s	135.8 s	137.5 s
14	56.0 s	56.1 s	55.9 s	56.1 s	55.7 s	55.8 s	56.1 s	41.7 s	55.5 s	55.9 s	55.6 s	55.3 s	55.5 s	56.1 s
15	22.7 t[b]	22.3 t[b]	22.5 t[b]	22.5 t	22.2 t[a]	22.2 t[a]	22.3 t[a]	28.3 t	22.8 t[a]	21.2 t[a]	21.8 t[a]	22.7 t[a]	21.7 t[a]	22.3 t[a]
16	26.2 t	25.3 t	23.6 t	23.6 t	29.7 t	28.0 t	27.3 t	26.2 t	27.3 t	27.5 t	25.3 t	26.2 t	25.2 t	25.3 t
17	32.9 s	32.9 s	32.9 s	32.8 s	32.9 s	32.7 s	32.9 s	32.5 s	32.8 s	32.9 s	32.7 s	32.9 s	32.7 s	32.9 s
18	47.0 d	47.4 d	47.0 d	47.4 d	46.2 d	46.3 d	47.5 d	47.2 d	46.4 d	46.5 d	47.1 d	46.3 d	46.4 d	46.5 d
19	44.2 t	44.0 t	44.2 t	43.8 t	44.0 t	43.7 t	44.0 t	46.8 t	34.4 t	39.6 t	35.1 t	40.5 t	38.1 t	39.6 t
20	31.0 s	30.9 s	31.0 s	30.7 s	31.0 s	31.3 s	30.9 s	31.1 s	46.0 s	42.5 s	46.6 s	35.7 s	42.0 s	42.5 s
21	34.2 t	34.3 t	34.3 t	34.2 t	35.8 t	35.8 t	34.3 t	34.8 t	25.6 t	29.6 t	24.6 t	29.0 t	27.2 t	29.6 t
22	36.2 t[a]	36.5 t[a]	36.5 t[a]	36.4 t[a]	36.5 t	36.3 t	36.8 t	37.2 t	36.5 t	36.0 t	34.6 t	38.7 t	35.1 t	36.0 t
23	28.2 q	28.2 q	27.8 q	27.6 q	26.9 q	26.9 q	28.3 q	28.1 q	26.2 q	26.8 q	28.0 q	28.0 q	28.2 q	26.8 q
24	22.1 q	22.8 q	22.6 q	22.5 q	21.4 q	21.1 q	15.7 q	15.5 q	21.1 q	23.0 q	21.9 q	22.2 q	22.3 q	22.8 q
25	15.8 q	16.3 q	16.2 q	16.0 q	16.2 q	16.0 q	16.4 q	15.5 q	15.9 q	16.1 q	15.8 q	15.9 q	16.1 q	16.3 q
26	18.0 q	18.1 q	18.2 q	18.0 q	17.9 q	18.0 q	18.1 q	16.8 q	17.8 q	17.9 q	17.7 q	17.7 q	17.9 q	18.1 q
27	179.0 s	176.0 s	181.7 s	176.0 s	181.4 s	175.9 s	176.1 s	26.0 q	180.4 s	175.8 s	178.5 s	176.9 s	185.5 s	175.8 s
28	28.2 q	28.2 q	28.2 q	28.1 q	28.2 q	27.4 q	28.2 q	27.3 q	27.9 q	28.0 q	28.0 q	28.5 q	27.8 q	28.2 q
29	32.9 q	33.2 q	33.8 q	34.0 q	33.5 q	33.4 q	33.2 q	33.2 q	205.8 d	172.4 s	206.0 s	73.1 t	183.0 s	172.4 s
30	23.6 q	23.5 q	23.6 q	23.4 q	23.5 q	23.4 q	23.5 q	23.6 q	15.9 q	19.4 q	15.8 q	19.0 q	19.3 q	19.4 q
$CH_3C=O$			170.6 s	170.3 s										
$CH_3C=O$			21.7 q	21.7 q										
$CH_3OC=O$		51.3 q		51.3 q										51.6 q (×2)

[a, b] Assignments bearing the same superscript may be interchanged. [c] In Me_2SO-d_6.

the C-4 position are strongly influenced by the stereochemistry of the hydroxyl group at C-3 (Figure 2). Conversion of the hydroxyl group from axial to equatorial stereochemistry results in an upfield shift of about 5 ppm for an axial C-4 methyl group, while the equatorial C-4 methyl group is essentially unaffected by this transformation. With the triterpenoid A, oxidation of its methyl ester (**3b**) affords the expected keto ester (**4b**) in good yield,



3a (A), $R^1 = H; R^2 = OH; R^3 = COOH; R^4 = CH_3$
b, $R^1 = H; R^2 = OH; R^3 = COOCH_3; R^4 = CH_3$
c, $R^1 = H; R^2 = OCOCH_3; R^3 = COOCH_3; R^4 = CH_3$
d, $R^1 = H; R^2 = OCOCH_3; R^3 = COOCH_3; R^4 = CH_3$
4a (B), $R^1 = R^2 = O; R^3 = COOH; R^4 = CH_3$
b, $R^1 = R^2 = O; R^3 = COOCH_3; R^4 = CH_3$
5, $R^1 = OH; R^2 = H; R^3 = COOCH_3; R^4 = CH_3$
6a (C), $R^1 = R^2 = O; R^3 = COOH; R^4 = CHO$
b, $R^1 = R^2 = O; R^3 = COOCH_3; R^4 = COOCH_3$
9 (D), $R^1 = H; R^2 = OH; R^3 = COOH; R^4 = CHO$
10 (E), $R^1 = H; R^2 = OH; R^3 = COOH; R^4 = CH_2OH$
11a (F), $R^1 = H; R^2 = OH; R^3 = COOH; R^4 = COOH$
b, $R^1 = H; R^2 = OH; R^3 = COOCH_3; R^4 = COOCH_3$

and reduction of this keto ester with excess sodium borohydride affords specifically[11] the β-hydroxy ester (3α-H, $W_{1/2}$ = 13 Hz; C-3, 78.8 ppm). As shown in Table I, one result of this transformation is a shift in one methyl resonance of 6–7 ppm upfield, as would be expected for the neighboring axial methyl group.[12]

Assuming an oleane skeleton for compound A, the only point remaining to be established is the position of the carboxyl group. The most significant differences between the ^{13}C NMR spectrum of compound A and that of β-amyrin involve the resonances of the olefinic carbons. This was interpreted as an indication that the carboxyl group is at C-27. Thus the complete structure of compound A would be 3α-hydroxyolean-12-en-27-oic acid, **3a**.

Once an assignment is made for compound A, determination of the structure of compound B is relatively straightforward. Compound B did not give a molecular ion in its EI mass spectrum. Instead an ion at m/z 410, resulting from decarboxylation of the molecular ion was observed. This was readily established because its CI mass spectrum contained an $M^+ + 1$ peak at m/z 455, and the EI mass spectrum of B's methyl ester gave the expected ion at m/z 468. The delayed-decoupling ^{13}C NMR spectra of B gave unambiguous evidence that B is the keto acid analogue of compound A, and comparison of the methyl ester of B with the keto ester derived from A showed that they were, in fact, identical. Thus compound B was assigned structure **4a**.

The ^1H, ^{13}C and mass spectra of compounds C–F, indicate that they are closely related, but more highly oxidized, triterpenoids. The series E, D, and F is that of an alcohol, aldehyde, and acid that can be interconverted by

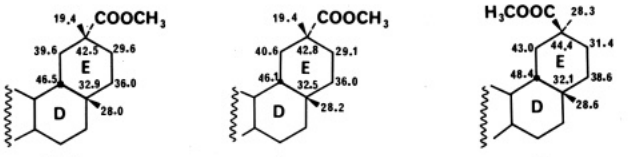


Figure 3. Comparison of the E ring ^{13}C resonances of **11b** with methyl 3β-acetoxyolean-12-en-29-oate (**7**) and methyl 3β-acetoxyolean-12-en-30-oate (**8**).

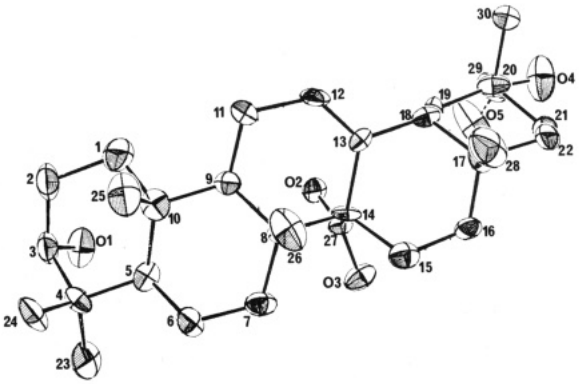


Figure 4. Crystal structure of 3α,29-dihydroxyolean-12-en-27-oic acid. The disordered position of the primary hydroxyl group is indicated by O5 (dotted line). Hydrogen atoms have been omitted for clarity.

oxidation or reduction after appropriate protection of the other functionality of these compounds. Furthermore, Wolff–Kishner reduction[13] of the aldehyde D affords the triterpenoid A, confirming the skeletal relationship of these compounds. Finally, compound C is also an aldehyde, or more specifically, a keto acid aldehyde analogous to compound B.

To establish the position of additional oxidation in these last four compounds, we examined carefully the series of ^{13}C NMR spectra and found the key in the spectrum of the methyl ester of compound F. The resonances assigned to the E-ring carbons of this compound are shifted somewhat relative to those of compounds A and B, but the A–C-ring resonances are in close agreement. A C-20 location for the additional carboxyl group appeared most consistent with this data. Furthermore the ^{13}C resonances of the E-ring carbons of this ester (cf. **11b**, Figure 3) nicely fit the pattern previously observed[14] in methyl 3β-acetoxyolean-12-en-29-oate (**7**) but were not consistent with the pattern reported for the isomeric 3β-acetoxyolean-12-en-30-oate (**8**). Therefore the series of compounds E, D, and F was assigned structures **10**, **9**, and **11a**, respectively, while compound C was assigned structure **6a**.

These structure assignments, made on the basis of spectral data and chemical interconversions, are self-consistent, but a number of assumptions were made to assign the carbon skeleton. To remove any doubt about the structures, and to provide detailed structural data for anticipated studies of their biological properties, a crystallographic analysis was undertaken. The limited quantities of material and the limited solubilities of the compounds made it difficult to obtain appropriate crystals, but eventually compound E (**10**) crystallized in a marginally acceptable form, i.e., very small crystals that decomposed with time under X-ray bombardment. The crystallographic data did allow determination of the structure and stereochemistry of this compound but did not refine as well

(11) Allen, W. S.; Bernstein, S.; Littell, R. *J. Am. Chem. Soc.* **1954**, *76*, 6116.
(12) The C-24 and C-25 resonances of the β-hydroxy ester **5** may be interchanged. However, this would not affect the assignment of the C-4 stereochemistry since a large, upfield shift is still observed for one of the methyl resonances.
(13) Cram, D. J.; Shahyun, M. R. V. *J. Am. Chem. Soc.* **1962**, *84*, 1734.
(14) Ricca, G. S.; Daniele, B.; Palmisano, G.; Duddeck, H.; Elgamal, M. H. A. *Org. Magn. Reson.* **1978**, *11*, 163.

as one might hope. As shown in Figure 4, this compound was found to be 3α,29-dihydroxyolean-12-en-27-oic acid. The bond distances and angles observed in the crystal structure support the proposed structure of the molecule. In particular, the location of the double bond between C-12 and C-13 is supported by the bond distance (1.29 Å) and the planarity of C-11, C-12, C-13, C-14, and C-18 (sum of bond angles about C-13 = 359.8°; deviation of atoms from the best plane = 0.023, 0.021, 0.014, 0.013, and 0.013). Together with the chemical interconversions described above, this establishes conclusively the structure of these six compounds.

The six triterpenoids we isolated from this plant are significantly active as repellents of the leafcutter ants used in our bioassay.[15] While these compounds do not have the highest molar activity of the compounds we have isolated by this approach, they are relatively abundant in this plant and could well be important components of its chemical defense against leafcutter ant attack. Further work to establish the mechanism(s) of this biological activity will be reported in due course.

Experimental Section

Melting points were recorded on a Thomas-Hoover melting point apparatus and are uncorrected. The ^{1}H NMR spectra were obtained on a JEOL FX-90Q or a Brucker WM 360 spectrometer using deuteriochloroform as the solvent. Chemical shifts are reported in parts per million downfield from $(CH_3)_4Si$. The broad-band decoupled ^{13}C NMR spectra were obtained on a JEOL FX-90Q spectrometer, while the delayed-decoupling ^{13}C NMR spectra were obtained on a Bruker HX-90E instrument. The following parameters represent a typical set of experimental conditions: spectral width, 6000 Hz; acquisition time, 0.7 s; pulse width, 4.7 μs; data points 8192. Chemical shifts are reported in parts per million downfield from $(CH_3)_4Si$ with deuteriochloroform as both the solvent and the internal standard (77.0). Low-resolution mass spectra were recorded with a Hewlett-Packard 5985B instrument; only selected ions are reported here. High-resolution mass spectra were obtained on an AEI MS-902 instrument at Cornell University, Mass Spectrometry Laboratories. Microanalyses were performed by Galbraith Laboratories, Knoxville, TN, or by the Microanalytical Service, University of Iowa.

Isolation. The isolation sequence was guided by a bioassay[1a] that measures repellency by monitoring ant choices among an array of treated and control food flakes. Because large numbers of individual choices are involved, standard statistical analyses indicate whether or not the ants have demonstrated a significant preference for control flakes and avoided those treated with an extract or chromatographic fraction.

Approximately 1.8 kg of *Cordia alliodora* leaves (collected at Santa Rosa, Costa Rica, July 1980, and kept frozen) were extracted successively with 2 L of chloroform and then with 2 L of ethanol in a Soxhlet extractor for 24 h. Both extracts were then concentrated and bioassayed. Ant-repellent activity was found to reside with the chloroform extract ($p \leq 0.005$). The bulk of the chloroform extract (32.5 g) was divided into nonpolar and polar fractions by partitioning with hexane/methanol/water (2:1:1). Upon evaporation of the solvents, 27 g (from hexane) and 5.5 g (from methanol–water) of gummy materials were obtained. Each extract was again bioassayed; only the hexane layer showed activity ($p \leq 0.001$).

After column chromatography of the hexane residue on silica gel (270 g, hexane/ethyl acetate gradient) one band of activity was located at fractions that eluted with 40% ethyl acetate (0.6 g). Further chromatography on silica gel (89% chloroform, 1% MeOH, and 10% acetone) yielded two active compounds, designated A (200 mg) and B (35 mg). Both were shown to be pure by GC and TLC analyses.

Compound A (3α-hydroxyolean-12-en-27-oic acid, 3a): mp 211–212 °C; ^{1}H NMR δ 5.6 (1, br), 3.27 (1, br, $W_{1/2}$ = 7 Hz), 1.8–1.2 (24, m), 1.02 (3, s), 0.95 (3, s), 0.92 (3, s), 0.849 (3, s), 0.845 (3, s), 0.841 (3, s), 0.822 (3, s); ^{13}C NMR (see Table I); EI GC/MS (70 eV), m/z (relative intensity) 412 (M^+ – 44, 55), 397 (83), 379 (21), 243 (54), 241 (70), 231 (24), 205 (12), 204 (39), 191 (53), 190 (53), 135 (100). Anal. Calcd for $C_{30}H_{48}O_3$: C, 78.94; H, 10.53. Found: C, 78.70; H, 10.60.

Compound B (3-oxoolean-12-en-27-oic acid, 4a): mp 209 °C; ^{1}H NMR δ 5.7 (1, br), 2.0–1.2 (23, m), 1.07 (3, s), 1.06 (3, s), 1.05 (3, s), 1.03 (3, s), 0.87 (3, s), 0.85 (3, s), 0.82 (3, s); ^{13}C NMR (see Table I); EI GC/MS (70 eV), m/z (relative intensity) 410 (M^+ – 44, 62), 395 (100), 243 (43), 231 (14), 205 (14), 204 (15), 191 (86), 190 (36), 189 (16); high-resolution mass spectrum, found m/z 454.3454, calcd for $C_{30}H_{46}O_3$ m/z 454.3447.

Compounds C and D were located in fractions that eluted at 90% ethyl acetate. Further chromatography on silica gel (first with methylene chloride, which eluted all the colored components, followed by 7% ethyl acetate–methylene chloride) gave 45 mg of pure compound C (3,29-dioxoolean-12-en-27-oic acid, **6a**) and 120 mg of compound D (3α-hydroxy-29-oxoolean-12-en-27-oic acid, **9**).

6a: mp 223 °C; ^{1}H NMR δ 9.31 (1, s), 5.6 (1, br s), 1.96–1.2 (24, m), 1.10 (3, s), 1.08 (3, s), 1.07 (3, s), 0.96 (3, s), 0.84 (3, s), 0.80 (3, s); ^{13}C NMR (see Table I); EI GC/MS (70 eV), m/z (relative intensity) 439 (M^+ – 29, 2), 424 (84), 409 (68), 391 (24), 381 (16), 257 (44), 245 (17), 229 (42), 219 (11), 218 (20), 217 (18), 213 (15), 204 (30), 203 (30), 191 (36), 190 (23), 189 (23); CI MS (CH_4), m/z (relative intensity) 469 (M^+ + 1, 100); high-resolution mass spectrum, found m/z 468.3253, calcd for $C_{30}H_{44}O_4$ m/z 468.3239.

9: mp 205–207 °C; ^{1}H NMR δ 9.31 (1, s), 5.6 (1, br s), 3.27 (1, m, $W_{1/2}$ = 7 Hz), 2.1–1.2 (23, m), 1.08 (3, s), 1.03 (3, s), 0.96 (3, s), 0.92 (3, s), 0.89 (3, s), 0.83 (3, s); ^{13}C NMR (see Table I); EI GC/MS (70 eV), m/z (relative intensity) 426 (M^+ – 44, 15), 411 (14), 393 (16), 375 (10), 257 (10), 255 (25), 243 (13), 241 (13), 239 (17), 229 (26), 218 (12), 203 (24), 191 (23), 190 (46), 189 (27), 187 (21), 185 (12), 135 (100); high-resolution mass spectrum, found m/z 470.3385, calcd for $C_{30}H_{46}O_4$ m/z 470.3396.

A fifth active compound was located at fractions that eluted at 60% methanol–ethyl acetate. Recrystallization from chloroform–diethyl ether yielded 58 mg of pure compound E (3α,29-dihydroxyolean-12-en-27-oic acid, **10**): mp 219 °C; ^{1}H NMR δ 5.6 (1, br s), 3.38 (1, br s), 3.23 (s, 2), 2.2–1.2 (24, m), 1.04 (3, s), 0.97 (3, s), 0.92 (3, s), 0.88 (3, s), 0.87 (3, s), 0.83 (3, s); ^{13}C NMR (see Table I); EI GC/MS (70 eV), m/z (relative intensity) 472 (M^+, 1.5), 428 (M^+ – 44, 13), 413 (20), 395 (9), 221 (14), 220 (18), 190 (23), 189 (29), 40 (100); high-resolution mass spectrum, found m/z 472.3567, calcd for $C_{30}H_{48}O_4$ m/z 472.3552.

Compound F was located at fractions that eluted at 80% methanol–ethyl acetate. Further chromatography on silica gel (88% chloroform, 4% methanol, 8% acetone as eluent) gave 35 mg of pure active compound F (3α-hydroxyolean-12-ene-27,29-dioic acid, **11a**): ^{1}H NMR δ 5.6 (1, br s), 3.3 (1, m, $W_{1/2}$ = 7 Hz), 2.0–1.2 (24, m), 1.1 (3, s), 1.0 (3, s), 0.95 (6, s), 0.8 (6, s); ^{13}C NMR (see Table I); EI GC/MS (70 eV), m/z (relative intensity) 396 (M^+ – 44–45, 19), 381 (9), 243 (12), 189 (14), 188 (17), 43 (100); EI GC/MS (25 eV), m/z (relative intensity) 468 (M^+ – 18, 23), 453 (17), 442 (54), 427 (54), 409 (56), 396 (51); high-resolution mass spectrum of its dimethyl ester, found m/z 514.3661, calcd for $C_{32}H_{50}O_5$ m/z 514.3658.

Methylation of 3α-Hydroxyolean-12-en-27-oic Acid. Excess diazomethane was added to an ether solution of 3α-hydroxyolean-12-en-27-oic acid (10 mg, 2.2×10^{-2} mmol), and the resulting solution was allowed to stand overnight. Evaporation of the volatile materials gave 10.1 mg (98%) of methyl 3α-hydroxyolean-12-en-27-oate (**3b**): ^{1}H NMR δ 5.6 (1, br t), 3.67 (3, s), 3.38 (1, m, $W_{1/2}$ = 7 Hz), 1.9–1.2 (24, m), 1.01–0.82 (21, br); EI GC/MS (70 eV), m/z (relative intensity) 470 (M^+, 5), 452 (7), 438 (9), 411 (3), 393 (6), 264 (7), 263 (27), 262 (46), 261 (16), 247 (13), 231 (8), 205 (5), 190 (100); CI MS (CH_4), m/z (relative intensity) 471 (M^+ + 1, 100), 453 (65).

Preparation of 3α-Acetoxyolean-12-en-27-oic Acid. Anhydrous pyridine (3 drops) was added to a solution of 3α-hydroxyolean-12-en-27-oic acid (10 mg, 2.2×10^{-2} mmol) in redistilled acetic anhydride (5 mL), and the resulting solution was stirred at room temperature overnight. Evaporation of the volatile materials in vacuo yielded 8.6 mg (79%) of 3α-acetoxyolean-12-en-27-oic acid (**3c**): ^{1}H NMR δ 5.69 (1, br t), 4.62 (1, m, $W_{1/2}$ =

(15) Hubbell, S. P., personal communication.

7 Hz), 2.04 (3, s), 1.8–1.13 (23, m), 1.04–0.87 (21, m); EI GC/MS (70 eV), m/z (relative intensity) 454 ($M^+ - 44$, 21), 439 (30), 379 (20), 257 (8), 241 (51), 231 (17), 217 (16), 205 (22), 191 (24), 190 (32), 189 (18).

Preparation of Methyl 3α-Acetoxyolean-12-en-27-oate. Excess diazomethane was added to an ether solution of 3α-acetoxyolean-12-en-27-oic acid (8.6 mg, 1.7×10^{-2} mmol), and the resulting solution was allowed to stand overnight. A workup in the usual manner yielded 8.2 mg (93%) of methyl 3α-acetoxyolean-12-en-27-oate (**3d**): ^{1}H NMR δ 5.6 (1, br t), 4.61 (1, m, $W_{1/2}$ = 7 Hz), 3.68 (3, s), 2.01 (3, s), 1.9–0.8 (44, m); EI GC/MS (70 eV), m/z (relative intensity) 512 (M^+, 4), 480 (7), 453 (9), 452 (7), 263 (18), 262 (44), 261 (13), 250 (15), 247 (9), 203 (21), 190 (29), 189 (14), 45 (100).

Oxidation of 3α-Hydroxyolean-12-en-27-oic Acid. Pyridinium dichromate (98 mg, 0.26 mmol) was added to a stirred solution of 3α-hydroxyolean-12-en-27-oic acid (17 mg, 3.7×10^{-2} mmol) in 1 mL of anhydrous DMF, and the resultant solution was stirred overnight at room temperature. The reaction mixture was then poured into 10 mL of water, stirred for 0.5 h, extracted with diethyl ether (3 × 30 mL), and dried (Na_2SO_4). Evaporation of the ether gave 12.8 mg (75%) of 3-oxoolean-12-en-27-oic acid (**4a**), which was identical with the isolated natural product B in all respects (TLC, GC, GC/MS, and ^{1}H and ^{13}C NMR).

Methylation of 3-Oxoolean-12-en-27-oic Acid. Excess diazomethane was added to an ether solution of 3-oxoolean-12-en-27-oic acid (12.8 mg, 2.8×10^{-2} mmol), and the resulting solution was allowed to stand overnight. A workup in the usual manner gave 13.1 mg (99%) of methyl 3-oxoolean-12-en-27-oate (**4b**): ^{1}H NMR δ 5.6 (1, br t), 3.67 (3, s), 2.0–0.8 (44, m); EI GC/MS (70 eV), m/z (relative intensity) 468 (M^+, 12), 436 (31), 409 (31), 262 (80), 250 (34), 247 (21), 243 (12), 231 (18), 205 (17), 191 (19), 190 (9), 189 (17), 135 (100); CI MS (CH_4), m/z (relative intensity) 469 ($M^+ + 1$, 100).

Preparation of Methyl 3β-Hydroxyolean-12-en-27-oate. Sodium borohydride (12 mg, 3.1×10^{-1} mmol) was added to a solution of methyl 3-oxoolean-12-en-27-oate (10 mg, 2.1×10^{-2} mmol) in 5 mL of THF and 2 drops of 5% NaOH solution. The resultant solution was heated overnight at reflux, and then water (1 mL) was added to the cooled reaction mixture. After the mixture was heated for 15 min, the THF was removed with a rotary evaporator and the residue was extracted with diethyl ether (4 × 15 mL). This solution was dried ($MgSO_4$) and then evaporated to give 9.2 mg (92%) of methyl 3β-hydroxyolean-12-en-27-oate (**5**): ^{1}H NMR δ 5.6 (1, br t), 3.7 (3, s), 3.3 (1, m, $W_{1/2}$ = 13 Hz), 1.9–1.2 (24, m), 1.0–0.8 (21, m); EI GC/MS (70 eV), m/z (relative intensity) 470 (M^+, 15), 452 (3), 438 (9), 411 (16), 393 (5), 263 (41), 262 (100), 261 (23), 247 (17), 231 (7), 205 (5), 190 (37).

Preparation of Dimethyl 3-Oxoolean-12-ene-27,29-dioate. A solution of methyl 3,29-dioxoolean-12-en-27-oate (17.9 mg, 3.7×10^{-2} mmol) and PDC (98 mg, 0.26 mmol) in anhydrous DMF was stirred at room temperature overnight. The reaction mixture was then poured into water (10 mL), stirred for 0.5 h, extracted with diethyl ether (3 × 30 mL), and dried (Na_2SO_4). After treatment with excess diazomethane, evaporation of the ether yielded 12.5 mg of dimethyl 3-oxoolean-12-ene-27,29-dioate (**6b**): ^{1}H NMR δ 5.7 (1, br t), 3.67 (6, s), 2.0–0.8 (40, m); EI GC/MS (70 eV), m/z (relative intensity) 452 ($M^+ - 60$, 52), 436 (41), 420 (100), 393 (39), 262 (71), 247 (24), 203 (30), 190 (10); CI MS (CH_4), m/z (relative intensity) 513 ($M^+ + 1$, 100).

Preparation of 3α,29-Dihydroxyolean-12-en-27-oic Acid. A solution of sodium borohydride (2 mg) in 0.2 N NaOH (1 mL) was added dropwise to a cooled solution of 3α-hydroxy-29-oxoolean-12-en-27-oic acid (20 mg, 4.3×10^{-2} mmol). The reaction mixture was allowed to warm to room temperature and then stirred for an additional 20 min. After TLC analysis showed that reduction was complete, the solvent was evaporated in vacuo and 10 mL of water was added to the residue. The resultant mixture was extracted with diethyl ether (3 × 20 mL) and dried ($MgSO_4$). Evaporation of the combined ether extracts yielded 17.6 mg (87%) of the product, identical with the 3α,29-dihydroxyolean-12-en-27-oic acid isolated earlier.

Preparation of Dimethyl 3α-Hydroxyolean-12-ene-27,29-dioate. A solution of 8 mg (0.017 mmol) of 3α-hydroxyolean-12-ene-27,29-dioic acid was treated with excess of diazomethane solution in ether. Workup in the usual manner yielded 8.1 mg (97%) of dimethyl 3α-hydroxyolean-12-ene-27,29-dioate: ^{1}H NMR δ 5.6 (1, br s), 3.69 (3, s), 3.61 (3, s), 3.3 (1, m, $W_{1/2}$ = 7 Hz), 1.9–1.2 (23, m), 1.15 (3, s), 1.00 (3, s), 0.96 (3, s), 0.86 (6, s), 0.81 (3, s); EI GC/MS (70 eV), m/z (relative intensity) 514 (M^+, 12), 496 (5), 482 (11), 455 (13), 454(27), 437 (19), 262 (37), 43 (100); high-resolution mass spectrum, found m/z 514.3661, calcd for $C_{32}H_{50}O_5$ m/z 514.3658.

Oxidation of Dimethyl 3α-Hydroxyolean-12-ene-27,29-dioate. PDC (26 mg, 7.5×10^{-2} mmol) was added to a stirred solution of dimethyl 3α-hydroxyolean-12-ene-27,29-dioate (5 mg, 9.0×10^{-3} mmol) in 1 mL of anhydrous DMF. After stirring overnight at room temperature, the reaction mixture was poured into water (10 mL) and stirred at room temperature for 0.5 h. The resulting mixture was then extracted with diethyl ether (3 × 10 mL) and dried ($MgSO_4$). Evaporation of the combined ether extracts gave 2.9 mg (59%) of dimethyl 3-oxoolean-12-ene-27,29-dioate, identical with that previously obtained via oxidation of 3,29-dioxoolean-12-en-27-oic acid and treatment of the resulting diacid with excess diazomethane.

Preparation of Dimethyl 3α-Acetoxyolean-12-ene-27,29-dioate. Anhydrous pyridine (3 drops) was added to a solution of dimethyl 3α-hydroxyolean-12-ene-27,29-dioate in 5 mL of redistilled acetic anhydride. After stirring at room temperature overnight, the solvent was evaporated in vacuo to give 1.9 mg (71%) of dimethyl 3α-acetoxyolean-12-ene-27,29-dioate: ^{1}H NMR δ 5.6 (1, br s), 4.6 (1, m, $W_{1/2}$ = 7 Hz), 3.69 (3, s), 3.61 (3, s), 2.0 (3, s), 1.9–1.2 (23, m), 1.15 (3, s), 1.01 (3, s), 0.96 (3, s), 0.86 (6, s), 0.81 (3, s); EI GC/MS (70 eV), m/z (relative intensity) 556 (M^+, 8), 524 (3), 497 (27), 481 (11), 464 (7), 437 (16), 306 (20), 274 (22), 190 (100), 175 (49).

Oxidation of 3α-Hydroxy-29-oxoolean-12-en-27-oic Acid. Pyridinium chlorochromate[16] (24 mg, 0.11 mmol) was added to a solution of 3α-hydroxy-29-oxoolean-12-en-27-oic acid (35 mg, 7.5×10^{-2} mmol) in 2 mL of anhydrous methylene chloride. After stirring 3 h at room temperature, the reaction mixture was poured in diethyl ether (20 mL). The supernatant was separated and the fine insoluble residue was washed with ether (3 × 10 mL). The combined ether solutions were filtered through a short pad of silica gel. Evaporation of the solvent yielded 20 mg (56%) of 3,29-dioxoolean-12-en-27-oic acid, identical with that isolated earlier.

Wolff–Kishner Reduction of 3α-Hydroxy-29-oxoolean-12-en-27-oic Acid. A solution of the aldehyde **9** (10 mg, 2.1×10^{-2} mmol) and hydrazine hydrate (10 mg, 0.2 mmol) in 5 mL of anhydrous methanol was heated at reflux for 4 h. After evaporation of the reaction mixture to dryness in vacuo, the residue was added to anhydrous dimethyl sulfoxide (1 mL). This solution was then added to a mixture of potassium *tert*-butoxide (40 mg) in Me_2SO, and the resulting mixture was stirred at room temperature for 4 h. The mixture was then shaken with 4 mL of water and extracted with methylene chloride (4 × 5 mL). Evaporation of the combined methylene chloride extracts gave 3.2 mg (33%) of 3α-hydroxyolean-12-en-27-oic acid, identical with that isolated earlier.

Crystallographic Analysis. Slow diffusion of pentane and dimethyl sulfide into a chloroform solution of compound E produced colorless crystals suitable for X-ray diffractional analysis. The crystal data are as follows: system monoclinic; space group $P2_1$; crystal dimensions (mm) 0.1 × 0.2 × 1.5; a = 16.626 (14) Å; b = 8.486 (3) Å; c = 13.014 (12) Å; β = 105.09 (7)°; V = 1772.8 Å^3; Z = 2; d_{calcd} = 1.00 g/cm^3; μ'(Mo Kα) = 1.6 cm^{-1}; R_1 = 0.1032; R_2 = 0.1522. Intensity data in the range of $3° < \theta < 40°$ were collected with a Picker FACS-1 diffractometer as previously described.[16] Of the 2480 unique reflections, the 1430 reflections with $I > 3\sigma(I)$ were used for subsequent calculations.

The positions of 16 non-hydrogen atoms were located by direct methods with use of the program MULTAN.[17] The remaining non-hydrogen atoms were located in the electron density difference map following least-squares refinement of the input atomic co-

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ordinates. In the final refinements anisotropic temperature factors were used for the carbon and oxygen atoms and isotropic temperature factors were used for the hydrogen and solvent atoms. The hydrogen atoms were included in the structure factor calculations at their calculated positions, and were not refined. Computer drawings were done by using ORTEP[18] (see Figure 4). The primary hydroxyl group in the E ring was found to be disordered, occupying two positions with an approximate relative weight of 0.6–0.4.

Acknowledgment. We are grateful to Dr. S. P. Hubbell (Department of Zoology, University of Iowa) for collection of the plant material. We thank the National Science Foundation for financial support (Grant No. DEB 8010638) and instrumentation awards for the purchase of mass (Grant No. CHE 8007937) and NMR (Grant No. CHE 8201836) spectrometers.

Registry No. **3a**, 64652-15-9; **3b**, 86782-62-9; **3c**, 86727-48-2; **3d**, 86783-77-9; **4a**, 86747-46-8; **4b**, 25671-04-9; **5**, 25671-07-2; **6a**, 86727-49-3; **6b**, 86727-50-6; **9**, 86727-51-7; **10**, 86727-52-8; **11a**, 86727-53-9; **11b**, 86727-54-0.

Supplementary Material Available: Table II listing the positional and thermal parameters in 3 (2 pages). Ordering information is given on any current masthead page.

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Studies on the Preparation and Reactions of Tritylsulfenimines[1]

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Received October 20, 1982

Carbonyl compounds react with stable, crystalline triphenylmethanesulfenamide ($TrSNH_2$, **4**) under mild conditions to form tritylsulfenimines **5** and **6**. Lithiation of acetone tritylsulfenimine (**5c**) at 0 °C led to a novel rearrangement–decomposition producing tritylacetone (**8**). Lithiated tritylsulfenimines were found to undergo temperature-dependent ambident alkylation reactions leading to carbon-alkylated products **9** at −78 °C and nitrogen-alkylated products **10** at −20 °C. Lithiated tritylsulfenimines **5** reacted with carbonyl compounds at −78 °C to form adducts **11** from which the sulfenimine could be hydrolytically cleaved under mild conditions ($AgNO_3/H_2O$–THF), thus effecting "directed aldol" condensation. Tritylsulfenimines **5** and **6** were reduced with $NaBH_3CN$ under mildly acidic conditions to form stable triphenylmethanesulfenamides **13** and **14**.

The sulfenamide functional group[3] has until recently not been exploited for synthetic purposes. Davis has developed a preparation of phenylsulfenimines, useful as secondary imine equivalents, which does not rely on the isolation of the intermediate primary sulfenamide **1**.[4,5] The scope of Davis' reaction is somewhat limited; for example, the phenylsulfenimine of crotonaldehyde cannot be prepared due to the polymerization of crotonaldehyde under the reaction conditions.[4a] Nevertheless, Davis' work demonstrated that the sulfenimine functional group could be useful for the construction of nitrogen-containing molecules and that the potential utility of the sulfenimine group could not be fully realized with phenylsulfenimines.

It seemed that utilization of a stable, isolable primary sulfenamide could greatly extend the scope of sulfenamide-based synthetic methodology. Many primary sulfenamides are known[3] although not all qualify as stable, isolable substances. Many preparations which should in principle lead to the formation of the primary sulfenamide often lead instead to the formation of the apparently more stable corresponding sulfenimide **2** (eq 1).

$$\underset{X=Cl,Br,SR\ldots etc.}{RSX} \xrightarrow{NH_3} \underset{\underline{1}}{RSNH_2} \longrightarrow \underset{\underline{2}}{\tfrac{1}{2}(RS)_2NH} + \tfrac{1}{2}NH_3 \qquad (1)$$

We describe in this and the accompanying paper various studies on the preparation and reactions of triphenylmethanesulfenamides and tritylsulfenimines and applications (1) of tritylsulfenimines for carbon–carbon bond-forming alkylation, (2) of tritylsulfenimines for "directed aldol" condensation, (3) of tritylsulfenimines and triphenylmethanesulfenamides for reductive amination of carbonyl compounds, and (4) of triphenylmethanesulfenamides for the protection of nitrogen.

Results and Discussion

Our attention was focused upon triphenylmethanesulfenamide ($TrSNH_2$, **4**) as a stable primary sulfenamide. Crystalline **4** can be easily prepared (eq 2) by a modification of the original preparation[6] from crystalline, commercially available trityl mercaptan (TrSH) via crystalline

$$Ph_3CSH = TrSH \xrightarrow{SO_2Cl_2} \underset{\underline{3}}{TrSCl} \xrightarrow{NH_4OH} \underset{\underline{4}}{TrSNH_2} \qquad (2)$$

(1) Taken from the Ph.D. thesis of B.P.B., Harvard University, 1981.

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