New Germacrane Derivatives from *Nanothamnus sericeous*.† *X*-Ray Molecular Structure of (1*R*,4*R*,5*R*,6*R*,10*R*)-1,10;4,5-Diepoxy-11-hydroxygermacran-6-yl (*Z*)-2-Methylbut-2-enoate

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Four new closely related germacrane derivatives have been isolated from the acetone extract of *Nanothamnus sericeous*. Based on spectral data and some chemical evidence, the structures of these compounds have been established as (1*R*,4*R*,5*R*,6*R*,10*R*)-1,10;4,5-diepoxy-11-hydroxygermacran-6-yl (*Z*)-2-methylbut-2-enoate (**1a**), (4*R*,5*R*,6*R*)-4,5-epoxy-11-hydroxygermacr-1(10)-en-6-yl (*Z*)-2-methylbut-2-enoate (**6a**), (1*R*,4*R*,5*R*,6*R*,10*S*)-1,10;4,5-diepoxy-11-hydroxygermacrane-6,14-diyl bis-[(*Z*)-2-methylbut-2-enoate] (**7a**), and 4ξ,5ξ,11-trihydroxygermacran-6-yl (*Z*)-2-methylbut-2-enoate (**9a**). The structure and stereochemistry of compound (**1a**) have been confirmed by *X*-ray crystallography.

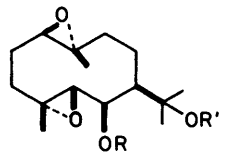
N. sericeous Thoms (family Compositae; tribe Inulae) is monotypic[1] and grows as a small prostrate plant at high altitudes. The acetone extract of the aerial parts of this plant on chemical examination afforded four germacrane derivatives. This paper deals with the structure elucidation of these compounds (**1a**), (**6a**), (**7a**), and (**9a**). Although *X*-ray crystallographic analysis of compound (**1a**) was carried out finally to confirm its structure, other spectral properties and some chemical reactions that led to its tentative structure will be briefly described below.

(1R,4R,5R,6R,10R)-1,10;4,5-*Diepoxy*-11-*hydroxygermacran*-6-*yl* (Z)-2-*Methylbut*-2-*enoate* (**1a**).—Compound (**1a**), m.p. 129—130 °C, had a molecular formula $C_{20}H_{32}O_5$ (M^+ 352.225), which suggested it was a germacrane derivative. It displayed in its ^{1}H n.m.r. spectrum four methyl singlets at δ 1.26, 1.29, 1.39, and 1.52, indicating that all of them are attached to carbon atoms bearing an oxygen function. The presence of a hydroxy group in (**1a**) was evident from its ^{1}H n.m.r. and i.r. spectra, and was confirmed by its conversion into the monoacetate (**1b**) and the anhydro compound (**2a**). The chemical shifts of two methyl groups in compounds (**1b**) and (**2a**) (Table 1) fixed the position of the hydroxy group at C-11. The other two methyl groups were thought to be present on oxirane rings, the presence of which was supported by the characteristic signals at δ 2.98 and 3.07. The mass spectrum of compound (**1a**) showed a prominent peak at *m/z* 83 for the presence of an angelate‡ ester, further supported by the characteristic signals in the ^{1}H n.m.r. spectrum of (**1a**).

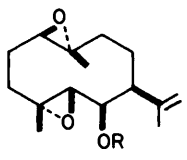
Alkaline hydrolysis of compound (**1a**) afforded the diol (**1d**) in which the 2-methylbutenoyl group was cleaved. Jones oxidation of diol (**1d**) gave ketone (**3**) in which the hydroxy(methyl)ethyl group was lost by retro-aldol cleavage, revealing that the 2-methylbutenoyl and the hydroxy(methyl)-ethyl groups are vicinal to each other. The CMe_2OH group can be placed at C-7 on biogenetic grounds. Furthermore, double-resonance experiments in the ^{1}H n.m.r. spectrum compound (**1a**) and its derivatives (**1b—d**), (**2a,b**), (**3**), and (**4a—c**) clearly established the position of two epoxides at C-1, C-10 and C-4, C-5 and the 2-methylbutenoyl group at C-6.

Chemical proof for the presence of two epoxides was also obtained by treating compound (**1a**) with formic acid to yield products (**4a**) and (**4c**).

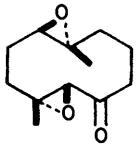
A critical comparison of the chemical shifts and the coupling constants of the signals for 1-H, 5-H, and 6-H and the methyl



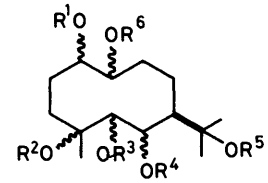
(**1a**) R = Ang, R' = H
(**1b**) R = Ang, R' = Ac
(**1c**) R = COCH(Me)Et, R' = H
(**1d**) R = R' = H
(**1e**) R = Ac, R' = H
(**1f**) R = R' = Ac



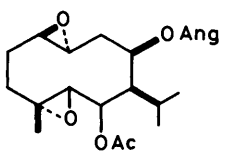
(**2a**) R = Ang
(**2b**) R = H



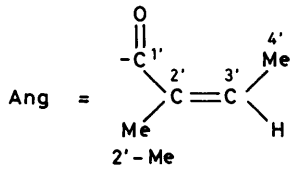
(**3**)



(**4a**) $R^1 = R^2 = R^3 = R^5 = R^6 = H$, R^4 = Ang
(**4b**) $R^1 = R^3$ = Ac, $R^2 = R^5 = R^6 = H$, R^4 = Ang
(**4c**) $R^1 = R^2 = R^3 = R^5 = H$, R^4 = Ang, R^6 = CHO



(**5**)



† NCL Communication No. 3897.
‡ (*Z*)-2-Methylbut-2-enoate.

Table 1. ^{1}H N.m.r. spectral data for compounds (**1a—f**), (**2a,b**), (**3**), (**6a**), (**7a**), and (**9a**). Chemical shifts in p.p.m. Values in parentheses are coupling constants in Hz

Proton	(1a)	(6a)	(7a)	(9a)	(1b)	(1c)	(1d)	(1e)	(1f)	(2a)	(2b)	(3)
1-H	2.98br d (10)	5.33d (8)	3.0br d (10)		2.97br d (10)	2.98br d (10)	3.00br d (10)	2.98br d (10)	2.96br d (10)	2.96br d (10)	2.99br d (10)	2.97dd (10, 0.5)
5-H	3.07d (6.5)	2.68d (6.5)	3.20d (6.5)	3.69d (6)	3.0d (6.5)	3.04d (6.5)	3.09d (6.5)	3.06d (6.5)	3.03d (6.5)	3.06d (6.5)	3.04d (6.5)	3.60s
6-H	5.23dd (6.5, 1)	5.29dd (6.5, 1)	5.33dd (6.5, 1)	5.15dd (8, 6)	5.19dd (6.5, 1)	5.18dd (6.5, 1)	4.03dd (6.5, 2)	5.17dd (6.5, 1)	5.10dd (6.5, 1)	4.98dd (6.5, 1)	3.57dd (6.5, 1)	
12-H	1.26s	1.20s	1.22s	1.19s	1.58s	1.24s	1.29s	1.23s	1.50s	1.78br s	1.92br s	
13-H	1.29s	1.26s	1.28s	1.25s	1.33s	1.28s	1.29s	1.27s	1.25s	4.82br s 4.91br s	4.91br s 5.0br s	
14-H	1.39s	1.69br s	3.83br d (12) 4.79d (12)	1.03d (7)	1.44s	1.36s	1.38s	1.36s	1.40s	1.40s	1.36s	1.24s
15-H	1.52s	1.33s	1.56s	1.29s	1.56s	1.51s	1.44s	1.50s	1.50s	1.45s	1.49s	1.37s
OAng 3′-H	6.16qq (7, 1.5)	6.13qq (7, 1.5)	6.16qq (7, 1.5)	6.11qq (7, 1.5)	6.11qq (7, 1.5)	0.94t (7)				6.10qq (7, 1.5)		
OAng 4′-H_3	1.91dq (7, 1.5)	1.91dq (7, 1.5)	2.14dq (7, 1.5)	1.98dq (7, 1.5)	1.95dq (7, 1.5)	1.16d (7)				1.90dq (7, 1.5)		
OAng 2′-Me	2.04dq											
OAc					1.98s			2.10s	1.97s 2.01s			

* For $COCH(Me)CH_2Me$.

Table 2. ^{1}H N.m.r. spectral data for compounds (**4a—c**), (**6b,c**), (**7b—d**), (**8**), (**9b**), (**10**), and (**11**). Chemical shifts in p.p.m. Values in parentheses are coupling constants in Hz

Proton	(4a)	(4b)	(4c)	(6b)	(6c)	(7b)	(7c)	(7d)	(8)	(9b)	(10)	(11)
1-H	3.47dd (11, 5)	4.69dd (9, 5)	3.78dd (9.5)	5.42d (8)	5.28d (8)	3.00d (10)	2.98d (10)	2.89br d (10)	3.02br d (10)	unresolved	unresolved	unresolved
5-H	3.84br d (9)	5.56br d (9)	3.85br d (9)	2.63d (6.5a)	2.66d (6.5)	3.16d (6.5)	3.20d (6.5)	3.08d (6.5)	3.24dd (6.5)	5.45d (5)	3.84d (8)	—
6-H	5.16dd (9.5)	5.35dd (9.5)	5.04dd (9, 6)	5.29dd (7.5, 0.5)	3.96dd (7.5, 1)	5.27dd (6.5, 0.5)	4.27dd (6.5, 1)	5.18dd (6.5, 0.5)	5.08dd (6.5, 0.5)	5.45dd (5, 9)	5.13dd (8, 6)	5.84d (6.5)
12-H	1.33s	1.36s	1.33s	1.50s	1.22s	1.53s	1.33s	1.13s	1.79br s	1.24s	1.72br s	1.24s
13-H	1.34s	1.40s	1.40s	1.34s	1.27s	1.43s	1.43s	1.18s	4.81br s 4.90br s	1.31s	4.93s 2H 1.01d	1.42s
14-H	0.97s	1.07s	1.29s	1.69br s	1.69br s	3.82br d (12) 4.63d (12)	3.55br d (12) 3.90br s	3.82br d (12) 4.63d (12)	3.84br d (12) 4.78d (12)	1.08d (7)	(7)	1.11d (7)
15-H	1.12s	1.13s	0.99s	1.50s	1.36s	1.59s	1.48s	1.42s	1.50s	1.31s	1.22s 6.09qq	1.46s
OAng	6.16qq (7, 1.5)	6.09qq (7, 1.5)	6.22qq (7, 1.5)	6.16qq (7, 1.5)		6.11qq (7, 1.5)			6.11qq (7, 1.5)	6.11qq (7, 1.5)	(7, 1.5)	6.12qq (7, 1.5)
OAng	1.96dq (7, 1.5)	1.92dq	1.98dq (7, 1.5)	1.95 (7, 1.5)		1.96dq (7, 1.5)			1.94dq (7, 1.5)	1.95dq (7, 1.5)	1.96dq (7, 1.5)	2.00dq (7, 1.5)
OAc		2.03s 2.13s	(OC*H*O) 7.91s	1.95s				2.01s 2.07s		2.02s		

groups at C-4 and C-10 of (**1a**) with those of a known germacrane derivative (**5**) isolated from *Klenia articulata*[2] showed striking similarity. Dreiding models of both compounds (**1a**) and (**5**) showed that the epoxides have preferred conformations where the angles H(1)–C–C–H(2_a) and H(6)–C–C–H(7) are *ca.* 90° and hence give rise to small coupling constants.

The ^{13}C n.m.r. spectrum of (**1a**) (Table 3) was in full agreement with the structure assigned.

Crystal Structure.—In order to confirm the assigned structure and relative stereochemistry of compound (**1a**) an *X*-ray structure analysis was undertaken. The molecules are held together in the crystal mainly by van der Waals interactions. The endocyclic angles in the ten-membered ring are in the range 110—129° [mean 117.0(9)°] indicating a considerable amount of angular strain.[3] The largest such deviations occur at C(1)–C(10) and C(4)–C(5) where the two epoxide groups are fused. The C(1)–C(5) distance is 3.12(1) Å which is favourable for a transannular interaction. The conformation of the ten-membered ring is 'chair-boat' as is the case in most *trans-trans* germacranolides. Torsion angles in the ring (Table 6) agree closely with the type-II conformation for the (*E,E*)-cyclodeca-1(10), 4-diene.[4]

The atomic parameters for non-H atoms are given in Table 4, bond lengths and angles in Table 5, and torsion angles in Table 6. The Figure gives a perspective view of the molecule along with the crystallographic numbering scheme. Hydrogen atoms positional co-ordinates and anisotropic thermal parameters of non-hydrogen atoms have been deposited at the Cambridge crystallographic data centre.*

* See section 5.6.3 in Instructions for Authors, *J. Chem. Soc., Perkin Trans. 1*, 1988, issue 1.

Table 3. ^{13}C N.m.r. spectral data of compounds (**1a**), (**6a**), (**7a**)[a]

Carbon	(**1a**)	(**6a**)	(**7a**)	(**7a**) + $Eu(fod)_3$ 3:1
C-1	61.40 (d)	123.73 (d)	61.68 (d)	
C-2	36.97 (t)**	39.44 (t)	37.07 (t)**	
C-3	23.64 (t)†	23.51 (t)†	23.40 (t)†	
C-4	58.74 (s)*	59.84 (s)	59.92 (s)*	
C-5	66.54 (d)	66.41 (d)	66.87 (d)	
C-6	73.10 (d)	73.23 (d)	72.14 (d)	
C-7	46.91 (d)	49.31 (d)	48.35 (d)	
C-8	22.54 (t)†	22.80 (t)†	23.20 (t)†	
C-9	36.54 (t)**	36.90 (t)	31.26 (t)**	
C-10	61.40 (s)*	137.18 (s)	61.81 (s)*	
C-11	73.10 (s)	73.43 (s)	73.44 (s)	
C-12	27.80 (q)	27.41 (q)	27.82 (q)	
C-13	28.45 (q)	28.71 (q)	28.99 (q)	
C-14	16.56q	16.50q**	62.33 (t)	
C-15	22.80q	18.12q**	23.07q	
OAng				
C-1′	167.08 (s)	167.61 (s)	167.15 (s)	166.99 (s)
C-2′			167.87 (s)	168.03 (s)
	127.50 (s)	128.61 (s)	127.64(2) (2 C)	127.71 (s) 127.90 (s)
C-3′				139.86 (s)
C-4′	139.26 (d)	138.61 (d)	139.53 (d) 139.99 (d)	140.90 (s)
2′-Me	20.20 (q)	20.33 (q)	20.60 (q)	20.83 (q)
			(2 C)	20.93 (q)
	15.64 (q)	15.71 (q)	16.05 (q) (2 C)	16.25 (q) 16.60 (q)

[a] Signal multiplicities in the single-frequency off-resonance decoupled (SFOD) spectrum.*,**,† Chemical shifts with similar marks in each column interchangeable.

Table 4. Atomic co-ordinates for non-hydrogen atoms, with e.s.d.s in parentheses (crystallographic numbering) for compound (**1a**)

	x	*y*	*z*
C(1)	0.430 4(13)	0.510 5(9)	0.318 1(5)
C(2)	0.314 3(13)	0.521 1(12)	0.318 2(5)
C(3)	0.260 7(10)	0.420 1(10)	0.302 3(5)
C(4)	0.293 7(9)	0.330 4(9)	0.337 5(3)
C(5)	0.384 6(7)	0.270 6(8)	0.322 3(4)
C(6)	0.453 9(7)	0.211 5(8)	0.361 5(4)
C(7)	0.524 5(7)	0.288 2(7)	0.392 4(4)
C(8)	0.601 5(8)	0.348 8(9)	0.357 1(4)
C(9)	0.607 7(11)	0.462 5(9)	0.364 7(4)
C(10)	0.506 6(13)	0.522 0(10)	0.364 1(4)
C(11)	0.577 2(8)	0.233 8(8)	0.442 2(4)
C(12)	0.495 8(10)	0.191 9(10)	0.478 7(4)
C(13)	0.657 1(9)	0.151 6(9)	0.428 9(4)
C(14)	0.465 3(16)	0.556 9(14)	0.417 7(8)
C(15)	0.250 6(12)	0.332 1(13)	0.394 0(5)
C(16)	0.506 5(15)	0.040 0(13)	0.337 8(7)
C(17)	0.591 0(17)	−0.030 0(19)	0.312 0(8)
C(18)	0.592 3(16)	−0.145 0(20)	0.333 2(12)
C(19)	0.646 0(26)	0.004 8(28)	0.275 2(15)
C(20)	0.670 6(28)	0.091 0(30)	0.256 4(18)
O(1)	0.496 6(12)	0.602 3(9)	0.324 8(5)
O(2)	0.281 6(7)	0.225 7(8)	0.312 5(4)
O(3)	0.519 5(7)	0.141 0(8)	0.330 7(3)
O(4)	0.444 5(10)	−0.000 1(9)	0.367 0(5)
O(5)	0.629 2(7)	0.320 3(7)	0.467 9(4)

(4R,5R,6R)-4,5-*Epoxy*-11-*hydroxygermacr*-1(10)-*en*-6-*yl* (Z)-2-*Methylbut*-2-*enoate* (**6a**).—The ^1H n.m.r. spectrum of (**6a**) (Table 1) (molecular formula $C_{20}H_{32}O_4$, M^+ 336) revealed that it was closely related to compound (**1a**). The only difference was the presence of a broad doublet at δ 5.33 assignable to an olefinic proton in place of the C-1 epoxy proton at δ 2.98 present as a broad doublet in the spectrum of (**6a**). This was further supported by the molecular formula of compound (**6a**) which had one fewer oxygen than that of (**1a**). That the epoxide in (**6a**) is present at C-4,C-5 was shown as follows. Alkaline hydrolysis of compound (**6a**) yielded the diol (**6c**) whose ^1H n.m.r. spectrum (Table 2) showed the absence of the angelate ester side-

Table 5. Bond lengths (in Å) and angles (in degrees) with e.s.d.s in parentheses for compound (**1a**)

(*a*) Bond lengths

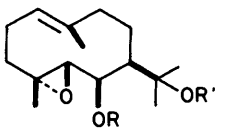
C(1)–O(1)	1.45(2)	C(9)–C(10)	1.50(2)
C(1)–C(2)	1.49(2)	C(10)–C(1)	1.52(2)
C(2)–C(3)	1.51(2)	C(10)–C(14)	1.51(2)
C(3)–C(4)	1.51(2)	C(10)–O(1)	1.43(2)
C(4)–C(5)	1.44(1)	C(11)–O(5)	1.44(1)
C(4)–C(15)	1.52(1)	C(11)–C(12)	1.48(2)
C(4)–O(2)	1.49(1)	C(11)–C(13)	1.50(2)
C(5)–C(6)	1.52(1)	C(16)–O(3)	1.31(2)
C(5)–O(2)	1.46(1)	C(16)–O(4)	1.19(2)
C(6)–C(7)	1.54(1)	C(16)–C(17)	1.54(3)
C(6)–O(3)	1.45(1)	C(17)–C(18)	1.56(4)
C(7)–C(8)	1.53(1)	C(17)–C(19)	1.24(4)
C(7)–C(11)	1.58(1)	C(19)–C(20)	1.24(5)
C(8)–C(9)	1.47(2)		

(*b*) Bond angles

C(2)–C(1)–O(1)	120(1)	C(9)–C(10)–C(1)	121(1)
C(2)–C(1)–C(10)	129(1)	C(1)–C(10)–C(14)	119(1)
O(1)–C(1)–C(10)	57(1)	C(1)–C(10)–O(1)	59(1)
C(1)–C(2)–C(3)	112(1)	C(9)–C(10)–C(14)	116(1)
C(2)–C(3)–C(4)	112(1)	C(9)–C(10)–O(1)	117(1)
C(3)–C(4)–C(5)	118(1)	C(14)–C(10)–O(1)	112(1)
C(3)–C(4)–O(2)	114(1)	C(7)–C(11)–C(12)	110(1)
C(5)–C(4)–O(2)	60(1)	C(7)–C(11)–C(13)	115(1)
C(3)–C(4)–C(15)	116(1)	C(7)–C(11)–O(5)	102(1)
C(5)–C(4)–C(15)	123(1)	C(12)–C(11)–C(13)	111(1)
C(15)–C(4)–O(2)	112(1)	C(12)–C(11)–O(5)	109(1)
C(4)–C(5)–C(6)	124(1)	C(13)–C(11)–O(5)	109(1)
C(4)–C(5)–O(2)	62(1)	C(17)–C(16)–O(3)	115(2)
C(6)–C(5)–O(2)	116(1)	C(17)–C(16)–O(4)	118(2)
C(5)–C(6)–C(7)	110(1)	O(3)–C(16)–O(4)	126(2)
C(5)–C(6)–O(3)	107(1)	C(16)–C(17)–C(18)	114(2)
O(3)–C(6)–C(7)	109(1)	C(16)–C(17)–C(19)	120(2)
C(6)–C(7)–C(8)	114(1)	C(18)–C(17)–C(19)	126(2)
C(6)–C(7)–C(11)	112(1)	C(17)–C(19)–C(20)	138(4)
C(8)–C(7)–C(11)	114(1)	C(1)–O(1)–C(10)	63(1)
C(7)–C(8)–C(9)	117(1)	C(4)–O(2)–C(5)	59(1)
C(8)–C(9)–C(10)	117(1)	C(6)–O(3)–C(16)	118(1)

Table 6. Some important torsional angles (in degrees) for compound (**1a**)

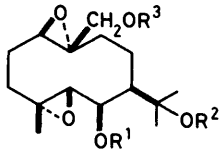
C(1)–C(2)–C(3)–C(4)	56
C(2)–C(3)–C(4)–C(5)	−89
C(3)–C(4)–C(5)–C(6)	153
C(4)–C(5)–C(6)–C(7)	−75
C(5)–C(6)–C(7)–C(8)	−63
C(6)–C(7)–C(8)–C(9)	132
C(7)–C(8)–C(9)–C(10)	−51
C(8)–C(9)–C(10)–C(1)	−53
C(9)–C(10)–C(1)–C(2)	151
C(10)–C(1)–C(2)–C(3)	−118
C(9)–C(10)–O(1)–C(1)	112
C(14)–C(10)–O(1)–C(1)	−111
C(10)–O(1)–C(1)–C(2)	119
C(15)–C(4)–O(2)–C(5)	−117
C(4)–O(2)–C(5)–C(6)	116
C(3)–C(4)–C(5)–O(2)	−103



(**6a**) R = Ang, R' = H

(**6b**) R = Ang, R' = Ac

(**6c**) R = R' = H

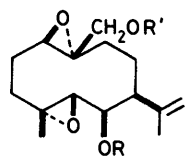


(**7a**) $R^1 = R^3$ = Ang, R^2 = H

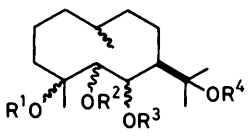
(**7b**) $R^1 = R^3$ = Ang, R^2 = Ac

(**7c**) $R^1 = R^2 = R^3$ = H

(**7c**) $R^1 = R^3$ = Ac, R^2 = H

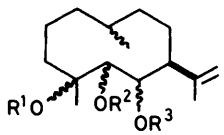


(**8**) R = R' = Ang

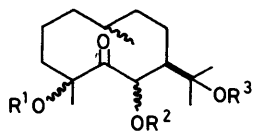


(**9a**) $R^1 = R^2 = R^4$ = H, R^3 = Ang

(**9b**) $R^1 = R^4$ = H, R^2 = Ac, R^3 = Ang



(**10**) $R^1 = R^2$ = H, R^3 = Ang



(**11**) $R^1 = R^3$ = H, R^2 = Ang

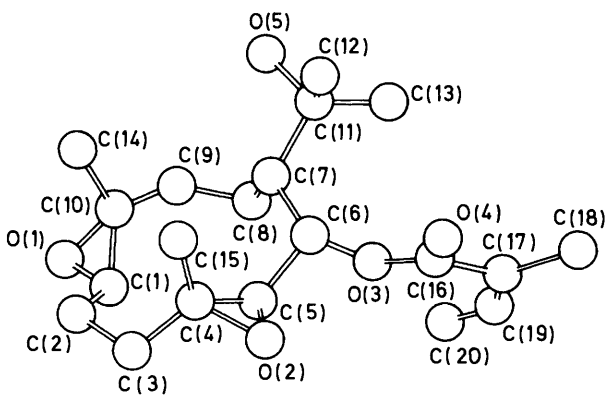


Figure.

chain, and the double doublet at δ 5.29 assignable to 6-H had shifted to δ 3.96 as in the case of compound (**1a**). Irradiation at the doublet (δ 2.66) due to the epoxide proton caused the collapse of the double doublet at δ 5.29 into a broad singlet and *vice versa*. These observations along with the nature of the epoxy proton resonance as a sharp doublet established the location of the epoxide at C-4,C-5 and the 2-methylbutenoyl group at C-6 in compound (**6a**). The small coupling constant $J_{6,7}$ (1 Hz) as in (**1a**) indicated that 6-H and 7-H are both α-oriented. Biogenetically the double bond is placed at C-1,C-10. The ^{13}C n.m.r. spectrum of (**6a**) (Table 3) fully supported the structure assigned.

Correlation between compounds (**6a**) and (**1a**) was achieved as follows. The diol (**6c**) was treated with *m*-chloroperbenzoic acid (MCPBA) to yield an inseparable mixture of two epimeric epoxides in the ratio 80:20. A critical examination of the ^1H n.m.r. spectrum of this mixture showed that the signals due to the minor compound were identical with those of (**1d**), the hydrolysis product of (**1a**). The major compound must be a diastereoisomer of (**1d**) at C-1,C-10 as the C-10 methyl and 5-H resonances were comparatively upfield (δ 1.19 and 2.93 respectively) due to a lowered deshielding effect of the C-5 and C-6 β-oriented oxygen substituents.

(1R,4R,5R,6R,10S)-1,10;4,5-*Diepoxy*-11-*hydroxygermacrane*-6,14-*diyl Di*-[(Z)-2-*methylbut*-2-*enoate*] (**7a**).—Compound (**7a**) (molecular formula $C_{25}H_{38}O_7$, M^+ 450) contained a tertiary hydroxy group and gave compounds (**7b**) and (**8**) on acetylation and dehydration respectively as in the case of compounds (**1a**) and (**6a**). The ^1H n.m.r. spectrum showed the presence of two epoxides and two (*Z*)-2-methylbut-2-enoyl groups. A critical comparison of the ^1H n.m.r. and ^{13}C n.m.r. spectra of compounds (**1a**), (**6a**), and (**7a**) revealed that (**7a**) contained one fewer methyl group than (**1a**) but possessed an $-OCH_2-$ moiety, inferring that one of the methyl groups (C-14 or C-15) must have been oxidised to OCH_2 which is further esterified with 2-methylbutenoic acid, thus accounting for the second ester group. The position of this group was deduced by the following evidence.

The chemical shift of the methyl singlet (δ 1.56) was comparable with that of the C-4 methyl in (**1a**). Hence the CH_2OAng group has to be at C-10. The two mutually coupling doublets assignable to this group (δ 3.83 and 4.79) in (**7a**) shifted upfield in the hydrolysed product (**7c**) and downfield in the diacetate (**7d**).

The chemical shifts and the coupling constants for 1-H, 5-H, 6-H, and 7-H were very similar to those observed in compound (**1a**). Based on an inspection of molecular models, and results of the ^{13}C n.m.r. and extensive decoupling studies, the compound may be represented by structure (**7a**).

4ξ,5ξ,11-*Trihydroxygermacran*-6-*yl* (Z)-2-*Methylbut*-2-*enoate* (**9a**).—Compound (**9a**) ($C_{20}H_{36}O_5$, M^+ 356) showed the presence of hydroxy (3 460 cm^{-1}), carbonyl (1 710 cm^{-1}), angelate ester (*m/z* 83; δ 1.98 and 5.15), a secondary methyl (δ 1.03, d, *J* 7 Hz), and three tertiary methyl groups, all attached to carbon atoms bearing oxygen functions (δ 1.19, 1.25, and 1.29). The striking difference between the ^1H n.m.r. spectra of (**9a**) and compounds (**1a**), (**6a**), and (**7a**) was the absence of signals for epoxide protons. On dehydration (**9a**) gave (**10**), confirming the

presence of the hydroxy(methyl)ethyl group at C-7. The double doublet at δ 5.15 (*J* 8, 6 Hz) was assigned to 6-H. The doublet at δ 3.69 moved downfield on acetylation to δ 5.45 and on oxidation (**9a**) gave a hydroxy ketone (**11**) for which the double doublet for 6-H at δ 5.15 for (**9a**) appeared as a doublet at δ 5.84. In addition, there was a downfield shift of the methyl singlet resonance in both (**9b**) and (**11**), revealing the presence of both a hydroxy and a methyl group at C-4, a secondary hydroxy group at C-5, a 2-methylbutenoyl group at C-6, and a hydroxy(methyl)ethyl group at C-7. This was supported by results from irradiation experiments. The structure of the natural compound may thus be respresented as (**9a**).

Experimental

M.p.s were determined in a Kofler block and are uncorrected. Optical rotations were taken for solutions in chloroform, i.r. spectra in Nujol mulls. All ^{1}H n.m.r. spectra were recorded at 90 MHz on a Bruker WH-90 (Spectrospin) spectrometer and ^{13}C n.m.r. were recorded at 23.63 MHz on the same spectrometer. Measurements were made for solutions in $CDCl_3$ with $SiMe_4$ as internal standard. Mass spectra were determined at 70 eV using a direct inlet system.

The plant material collected near Bhimashankar, Maharashtra, India, during January 1980 was shade dried, then powdered, and the powder (2.9 kg) was extracted with acetone to give the extract (170 g, 5.86%). This extract (150 g) was chromatographed over silica gel with acetone–light petroleum (b.p. 60—80 °C) (gradient elution) to collect five broad fractions.

Compound (**1a**).—The second fraction was kept for 3 days to give *crystals*, m.p. 129—130 °C (Found: C, 68.4; H, 9.4. $C_{20}H_{32}O_5$ requires C, 68.15; H, 9.15%); $[\alpha]_D$ −88° (*c* 0.5); $\nu_{max.}$ 3 840 (OH), 1 700 (OCOR), and 1 650 cm^{-1} (C=C); δ_H, Table 1; δ_C, Table 3; *m/z* 302.255 (M^+, $C_{20}H_{32}O_5$, 0.01%), 334 (M^+ − H_2O, 0.3), 234 (M^+ − H_2O − AngOH, 0.3), 219 (234 − Me, 0.5), 205, 83 ($C_4H_7CO^+$, 100), and 55 (83 − CO, 78).

Compound (**6a**).—The first fraction on rechromatography over silica gel gave compound (**6a**) as a solid, m.p. 116—117 °C (Found: C, 71.5; H, 9.8. $C_{20}H_{32}O_4$ requires C, 71.39; H, 9.59%); $[\alpha]_D$ +113.5° (*c* 0.2); $\nu_{max.}$ 3 520 (OH), 1 700 (OCOR), 1 640, and 880 cm^{-1} (C=C); δ_H, Table 1; δ_C, Table 3; *m/z* 336 (M^+), 318 (M^+ − H_2O), 218 (M^+ − H_2O − AngOH), 83 ($C_4H_7CO^+$, 100%), and 55 (83 − CO).

Compound (**7a**).—Obtained, by rechromatography of mother liquor of compounds (**1a**) and (**7a**), as a *gum* (Found: C, 66.8; H, 8.6. $C_{25}H_{38}O_7$ requires C, 66.64; H, 8.50%); $\nu_{max.}$ 3 440 (OH), 1 720 (OCOR), and 1 650 cm^{-1} (C=C); δ_H, Table 1; δ_C, Table 3; *m/z* 450 (M^+), 432 (M^+ − H_2O), 292, 233, 83 ($C_4H_7CO^+$, 100%), and 55 (83 − CO).

Compound (**9a**).—The third fraction on repeated chromatography on silica gel gave compound (**9a**) as a gum (Found: C, 67.5; H, 10.3. $C_{20}H_{36}O_5$ requires C, 67.38; H, 10.18%); $\nu_{max.}$ 3 460 (OH), 1 710 (OCOR), and 1 640 cm^{-1} (C=C); δ_H, Table 1; *m/z* 356 (M^+), 338 (M^+ − H_2O), 238 (M^+ − H_2O − AngOH), 83 ($C_4H_7CO^+$, 100%), and 55 (83 − CO).

Acetylation of Compound (**1a**).—A mixture of compound (**1a**) (100 mg), acetic anhydride (1 ml), and pyridine (1 ml) was refluxed for 2 h. The usual work-up followed by purification by preparative t.l.c. (p.l.c.) gave acetate (**1b**), m.p. 159—160 °C; $\nu_{max.}$ 1 730, 1 715, 1 650, and 1 240 cm^{-1}; δ_H, Table 1; *m/z* 394 (M^+), 334, 234, 219, 83, (100%), and 55.

Hydrogenation of Compound (**1a**).—A solution of compound (**1a**) (200 mg) in ethanol was hydrogenated at atmospheric pressure for 4 h using Pd–C (10%). Usual work-up gave compound (**1c**) as a gum, $\nu_{max.}$ 3 460 (OH) and 1 730 cm^{-1} (C=O); δ_H, Table 1; *m/z* (no M^+), 252, 194, 85, 78, and 57.

Hydrolysis of Compound (**1a**).—A solution of compound (**1a**) (500 mg) in methanol (25 ml) was refluxed with 5% aqueous sodium hydrogen carbonate (5 ml) for 3 h. Usual work-up gave the diol (**1d**), m.p. 129—130 °C; $\nu_{max.}$ 3 380 cm^{-1} (OH); δ_H, Table 1; *m/z* 270 (M^+), 252, and 234.

Acetylation of the Diol (**1d**).—A mixture of (**1d**) (50 mg) in pyridine (0.5 ml) was treated with acetic anhydride (0.5 ml) at room temperature for 12 h. Usual work-up gave the monoacetate (**1e**) (60 mg), m.p. 160—161 °C; $\nu_{max.}$ 3 460 (OH), 1 720 (OCOR), and 1 240 cm^{-1} (OCOR); δ_H, Table 1; *m/z* (no M^+), 294 (M^+ − H_2O), 234, and 43 (100%).

Similarly, compound (**1d**) (100 mg) when refluxed with acetic anhydride (1 ml) and pyridine (1 ml) for 24 h followed by usual work-up gave the diacetate (**1f**) (54 mg), m.p. 128—130 °C; $\nu_{max.}$ 1 735, 1 730, 1 250, and 1 240 cm^{-1}; δ_H, Table 1; *m/z* (no M^+), 294 (M^+ − ACOH), 252, and 43 (100%).

Dehydration of Compound (**1a**).—Compound (**1a**) (300 mg) was dissolved in pyridine (1 ml) and the solution was treated with thionyl chloride (0.3 ml) at room temperature for 2 h. Usual work-up gave the anhydro compound (**2a**) (245 mg), m.p. 115—116 °C; $\nu_{max.}$ 1 720 (C=O), 1 640, and 900 cm^{-1} (C=C); δ_H, Table 1; *m/z* 334 (M^+, 100%), 234, 83, and 55.

Hydrolysis of Compound (**2a**).—A solution of the ester (**2a**) (150 mg) in methanol (15 ml) was refluxed with 5% aqueous sodium hydrogen carbonate (1.5 ml) as described earlier, to afford the homoallylic alcohol (**2b**) (80 mg), m.p. 118—119 °C; $\nu_{max.}$ 3 430 (OH) and 1 640 cm^{-1} (C=C); δ_H, Table 1.

Oxidation of the Diol (**1d**).—A solution of the diol (**1d**) (150 mg) in pyridine (2.5 ml) was oxidised with Sarett's reagent [prepared from CrO_3 (200 mg) and pyridine (2 ml)] at room temperature for 48 h. The usual work-up gave the ketone (**3**) (60 mg), m.p. 149—150 °C; $\nu_{max.}$ 1 700 cm^{-1} (C=O); δ_H, Table 1; *m/z* 210 (M^+), 195, 181, 153, 125, 97, 69, 55, and 43.

Reaction of Compound (**1a**) *with Formic Acid*.—A solution of compound (**1a**) (200 mg) was stirred with 90% formic acid (2 ml) at 0 °C for 20 min. After the usual work-up, followed by purification by p.l.c. [acetone–light petroleum (2:3)] the pentaol (**4a**) (8 mg) was obtained as a gum, $\nu_{max.}$ 3 450 (OH), 1 710 (C=O), and 1 640 cm^{-1} (C=C); δ_H, Table 2.

The above reaction also afforded the formate (**4c**) (10 mg), $\nu_{max.}$ 3 500 (OH), 1 720, 1 700 (C=O), and 1 640 cm^{-1} (C=C); δ_H, Table 2.

Acetylation of Compound (**6a**).—Compound (**6a**) (100 mg) was acetylated with acetic anhydride (1 ml) and pyridine (1 ml) at reflux temperature for 24 h. Usual work-up followed by p.l.c. [acetone–light petroleum (1:4)] gave the acetate (**6b**) (77 mg), m.p. 75—76 °C; $\nu_{max.}$ 1 720 (C=O), 1 650, and 880 cm^{-1} (C=C); δ_H, Table 2; *m/z* 378 (M^+), 318, 218, 203, 83, (100%), 55, and 43.

Hydrolysis of Compound (**6a**).—Compound (**6a**) (100 mg) was dissolved in methanol (10 ml) and was hydrolysed by refluxing with 5% aqueous sodium hydrogen carbonate as described earlier, to afford the diol (**6c**) (32 mg) as a gum, $\nu_{max.}$ 3 360 cm^{-1} (OH); δ_H, Table 2; *m/z* 254 (M^+), 236, and 218.

Acetylation of Compound (**7a**).—Compound (**7a**) (50 mg) was refluxed with acetic anhydride (1 ml) and pyridine (1 ml) for 24 h. After the usual work-up and p.l.c. [acetone–light petroleum (3:7)] the monoacetate (**7b**) (26 mg) was obtained as a gum, $\nu_{max.}$ 3 460 (OH) and 1 725 cm^{-1} (C=O); δ_H, Table 2; *m/z* (no M^+), 450 ($M^+ - CO$), 350, 83 (100%), and 55.

Hydrolysis of Compound (**7a**).—Compound (**7a**) (50 mg) was hydrolysed with 2% methanolic potassium hydroxide (2 ml) by refluxing for 1 h. After the usual work-up and purification by p.l.c. [acetone–light petroleum (2:3)] the triol (**7c**) (20 mg) was obtained, m.p. 136—137 °C; $\nu_{max.}$ 3 450 cm^{-1} (OH); δ_H, Table 2; *m/z* 286 (M^+), 268, and 250.

Acetylation of the Triol (**7c**).—Triol (**7c**) (10 mg) was treated at room temperature with acetic anhydride and pyridine (0.2 ml each) for 12 h. Usual work-up gave the diacetate (**7d**) as a gum, $\nu_{max.}$ 3 420 (OH), 1 720 (C=O), and 1 250 cm^{-1} (OCOR); δ_H, Table 2; *m/z* (no M^+), 310 (M^+ – AcOH), 292, 232, and 43.

Dehydration of Compound (**7a**).—A solution of compound (**7a**) (50 mg) in pyridine (1 ml) was treated with thionyl chloride (0.05 ml) at room temperature for 2 h to afford, after the usual work-up, the anhydro compound (**8**) (12 mg) as a gum, $\nu_{max.}$ 1 725 (C=O), 1 650, and 900 cm^{-1} (C=C); δ_H, Table 2; *m/z* 432 (M^+), 332, 232, 83 (100%), and 55.

Acetylation of Compound (**9a**).—Compound (**9a**) (25 mg) was acetylated with acetic anhydride (0.5 ml) and pyridine (0.5 ml) at room temperature for 12 h. Usual work-up, followed by p.l.c. [acetone–light petroleum (3:7)], yielded compound (**9b**) (18 mg), m.p. 161—163 °C; $\nu_{max.}$ 3 430 (OH), 1 725, 1 715 (C=O), and 1 650 cm^{-1} (C=C); δ_H, Table 2; *m/z* 430 (M^+), 370, 352, 252, 83 (100%), 55, and 43.

Dehydration of Compound (**9a**).—Compound (**9a**) (50 mg) was dehydrated, as described earlier, to give the alkene (**10**) (15 mg) as a gum, $\nu_{max.}$ 3 490 (OH), 1 710 (C=O), 1 650, and 900 cm^{-1} (C=C); δ_H, Table 2.

Oxidation of Compound (**9a**).—Compound (**9a**) (50 mg) was oxidised by Sarett's reagent as described earlier, to give compound (**11**) (18 mg), m.p. 139—140 °C; $\nu_{max.}$ 3 540 (OH), 1 725, 1 710 (C=O), and 1 650 cm^{-1} (C=C); δ_H, Table 2; *m/z* 354 (M^+), 336, 236, 208, 83, and 55.

Conversion of Diol (**6c**) *into Compound* (**1d**).—A solution of the diol (**6c**) (25 mg) in chloroform (2 ml) was refluxed with MCPBA (30 mg) for 1.5 h to give, after the usual work-up, a mixture of compound (**1d**) and its C-1,C-10 diastereoisomer in the ratio 20:80.

X-*Ray Molecular Structure of Compound* (**1a**).—Crystals were grown from benzene-light petroleum.

Crystal data. $C_{20}H_{32}O_5$, M = 352.5, tetragonal, $a = b$ = 12.769(2), c = 25.039(4) Å, V = 4 082.4 $Å^3$ (by least-squares refinement on diffractometer angles for 25 automatically centred reflections, λ = 0.710 7 Å), space group $P4_32,2$ (No. 96), Z = 8, D_x = 1.147 g cm^{-3}. Colourless needles, crystal dimensions 0.80 × 0.30 × 0.25 mm, μ(Mo-K_α) = 0.87 mm^{-1}.

Data collection and processing. CAD4F-11M diffractometer, ω-2θ mode with scan width 0.80°, ω scan speed 1° min^{-1}, graphite-monochromated Mo-K_α radiation, 3 557 reflections measured ($1.5 \leqslant \theta \leqslant 24°$), 755 unique ($|F_o| \geqslant 3\sigma|F_o|$). No correction for absorption.

Structure analysis and refinement. Direct methods using MULTAN-78,[5] full-matrix least-squares refinement[6] (in two blocks for final anisotropic cycles) with all non-hydrogen atoms anisotropic, hydrogens located from a difference Fourier synthesis. Fourier map (held fixed) weighting scheme[7] w $(8.2 + 1.0|F_o| + 0.02|F_o|^2)^{-1}$ was used. Final R and R_w values were 0.065 and 0.062 respectively. Scattering factors[8] were taken from International Tables.

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