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SESQUITERPENE LACTONES AND OTHER CONSTITUENTS FROM *TANACETUM PARTHENIUM**

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Key Word Index—*Tanacetum parthenium*; Compositae; sesquiterpene lactones; germacranolides; guaianolides; endoperoxides; secoguaianolides; monoterpenes; pinene derivatives; borneol angelate; spiroketal enol ether polyines.

Abstract—A reinvestigation of the aerial parts of *Tanacetum parthenium* afforded in addition to known compounds three pinene derivatives, two spiroketal enol ether polyines, four germacranolides; and six guaianolides, two of them being endoperoxides, and two secoguaianolides. The structures were elucidated by high field ^{1}H NMR spectroscopy, mass spectroscopy and a few chemical transformations. The biogenetic relationships are discussed briefly.

INTRODUCTION

Tanacetum pathenium (L.) Sch. Bip. has been investigated previously by different groups[1–6]. In addition to several widespread compounds[5, 6] some sesquiterpene lactones were isolated[1–4], two of them, canin and artecanin being rare. We now have again studied this species. The results are discussed in this paper.

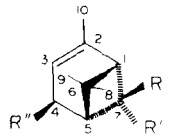
RESULTS AND DISCUSSION

The roots of *T. parthenium* afforded β-farnesene, bicyclogermacrene and the spiroketal enol ethers **11** and **17**[5], while the aerial parts contained a complex mixture of different types of constituents. The less polar fractions afforded germacrene D, β-farnesene, camphor, the α-pinene derivatives **1–7**, bornyl acetate (**8**) and the corresponding angelate **9**, costic acid methyl ester (**10**), the spiroketal enol ethers **11–18** and costunolide (**19**). The structures **2–5** followed from the ^{1}H NMR spectra (Table 1) and the molecular formulae. The ^{1}H NMR signals in the spectrum of **3** were similar to those of chrysanthenyl acetate (**1**). However, the low field signal of the proton under the acetoxy group was a singlet only. Similarly the 5α proton in α-pinene also shows a geminal coupling only. The ^{1}H NMR spectrum of **4** again was similar to that of **3**, only the acetate methyl signal being replaced by those of an angelate residue and the H-7 signal was shifted as usual slightly downfield. Addition of Eu(fod)$_3$ and spin decoupling allowed a clear assignment of all signals, only those of H-1 and H-5 being multiplets. From the data of **5** the presence of the corresponding isovalerate could be clearly deduced, while in the spectrum of **2** the upfield shift of H-7 indicated a hydroxyl group at C-7. The ^{1}H NMR spectral data of **2** and **3** agreed with those reported for *cis*-chrysanthenol and its acetate[7].

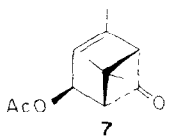
The molecular formula and the ^{1}H NMR spectral data of **7** (Table 1) showed that the oxygen function at C-7 was replaced by a keto group. Accordingly the signals of H-1 and H-5 were shifted downfield. The presence of an additional function at C-4 could be deduced from the low field narrowly split doublet of a doublet of a quartet at δ5.52. Spin decoupling allowed the assignment of all signals. Inspection of a model led to the proposed stereochemistry at C-4, which was further supported by the downfield shift of the H-9 signal. The structure of **9** easily could be deduced from the ^{1}H NMR spectrum too, which was similar to that of **8**. The presence of the corresponding angelate followed from the typical ^{1}H NMR signals (see Experimental). Comparison of the ^{1}H NMR spectra of **13** and **16** (Table 2) with those of **12** and **15** clearly showed that these compounds only differed in the nature of the ester group at C-2. All signals could be assigned by spin decoupling. The stereochemistry was deduced from the absence of a downfield shift of H-5, if compared with the chemical shifts of H-5 in the spectra of **11** and **12**, respectively. The absolute configuration in this group of compounds was determined by detailed CD investigations (unpublished). The more polar fractions obtained by CC using ether and mixtures with methanol gave a very complex mixture of sesquiterpene lactones which could only be separated with difficulty, especially as most compounds were present in very minute amounts.

The main constituent was parthenolide (**22**)[8], which was accompanied by the esters **30** and **31**. Furthermore 3β-hydroxycostunolide (**20**)[9], reynosin (**21**)[10], 3β-hydroxyparthenolide (**23**), artemorin (**24**)[11], the hydroxy ketone **25**, the epoxide of artemorin (**26**) and the corresponding ketone **28**, traces of 8α-hydroxyestafiatin (**29**), canin (**33**)[12],

*Part 454 in the series "Naturally Occurring Terpene Derivatives". For Part 453 see Bohlmann, F., Gupta, R. K., Jakupovic, J., King, R. M. and Robinson, H. (1982) *Phytochemistry* **21** (in press).



	1	2	3	4	5	6
R	H	OH	OAc	OAng	OiVal	H
R	OAc	H	H	H	H	H
R″	H	H	H	H	H	OH



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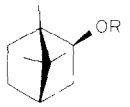
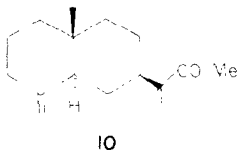


8 R = Ac
9 R = Ang



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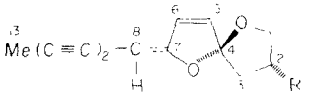
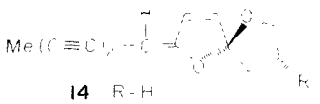
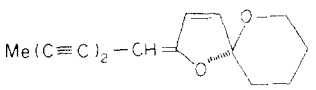


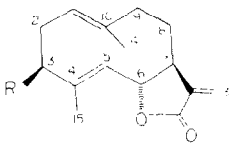
11 R = H
12 R = OAc
13 R = OiVal



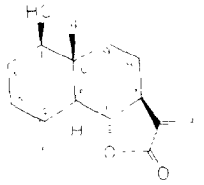
14 R = H
15 R = OAc
16 R = O Val



17 *cis*
18 *trans*



19 R = H
20 R = OH



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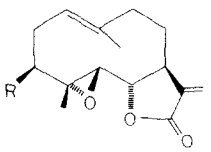
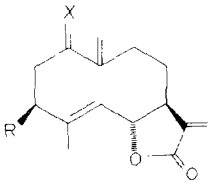
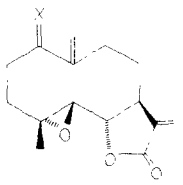


22 R = H
23 R = OH



24 X = β-OH, H R = H
25 X = O, R = OH



26 X = β-OH, H
27 X = β-OAc, H
28 X = O

Table 1. ^{1}H NMR spectral data of compounds **2–5** and **7** (400 MHz, $CDCl_3$, TMS as internal standard)

	2	3	4	Δ*	5	7
H-1	2.1 *m*	2.14 *m*	2.19 *m*	0.43	2.14 *m*	2.87 *brd*
H-3	5.19 *ddq*	5.25 *ddq*	5.26 *ddq*	−0.03	5.25 *ddq*	5.62 *brs*
H-4	2.25 *m*	2.39 *ddq*	2.43 *ddq*	0.0	2.39 *ddq*	5.52 *ddq*
H-4′		2.27 *ddq*	2.29 *ddq*	0.02	2.27 *ddq*	
H-5	2.10 *m*	2.14 *m*	2.19 *m*	0.48	2.14 *m*	3.11 *ddd*
H-7	3.96 *s*	4.51 *s*	4.60 *s*	0.84	4.52 *s*	—
H-8	1.55 *s*	1.43 *s*	1.44 *s*	0.21	1.43 *s*	1.27 *s*
H-9	0.88 *s*	0.90 *s*	0.91 *s*	0.05	0.90 *s*	1.21 *s*
H-10	1.65 *ddd*	1.68 *ddd*	1.70 *ddd*	−0.04	1.69 *ddd*	1.84 *ddd*
OCOR	—	2.08 *s*	6.07 *qq*	0.26	2.21 *d*	2.04 *s*
			2.01 *dq*	0.35	2.14 *m*	
			1.93 *dq*	0.38	0.96 *d*	
					0.95 *d*	

J (Hz): Compounds **2–5**: 3,4 = 3,4′ = 3,10 = 4′,10 = 2; 4,4′ = 17; compound **7**: 1,3 ~ 0.5; 1,5 = 7; 3,4 = 2; 3,5 = 1; 3,10 = 1.5; 4,5 = 4; 4,10 = 1.5.

*Δ-values after addition of $Eu(fod)_3$.

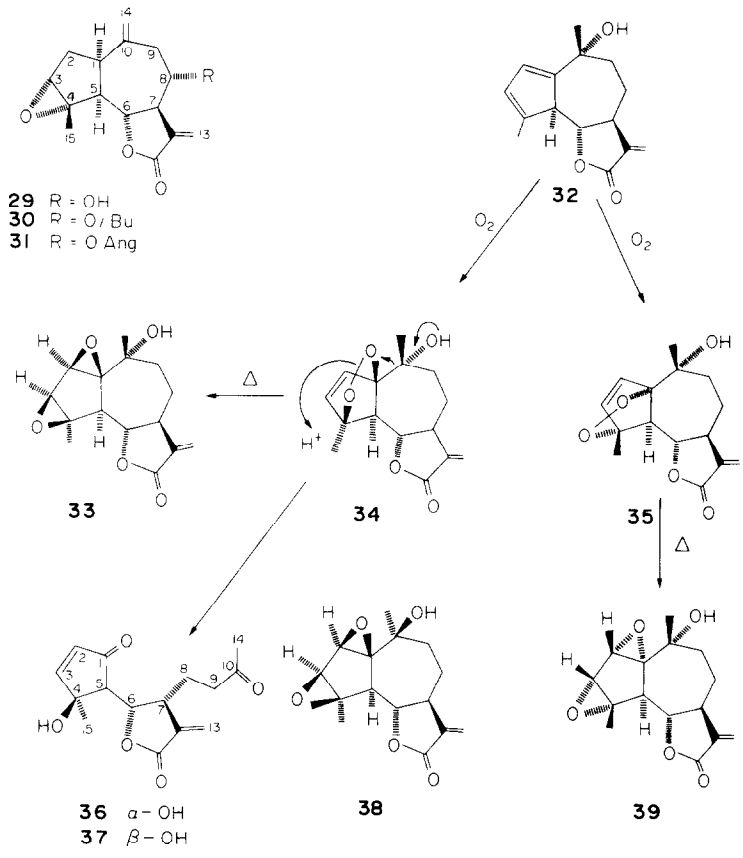


Table 2. ^{1}H NMR spectral data of compounds **13** and **16** (400 MHz, $CDCl_3$, TMS as internal standard)

	13	**16**
H-1α	4.02 *ddd*	4.04 *ddd*
H-1β	4.27 *dd*	4.38 *dd*
H-2β	5.44 *dddd*	5.49 *dddd*
H-3α	2.27 *ddd*	2.28 *ddd*
H-3β	2.63 *dd*	2.74 *dd*
H-5	6.24 *dd*	6.21 *dd*
H-6	6.71 *d*	6.27 *d*
H-8	4.96 *brs*	4.67 *brs*
H-13	1.99 *d*	2.00 *d*
O*i*Val	2.20 *d*	2.21 *d*
	2.10 *tqq*	2.10 *tqq*
	0.95 *d*	0.97 *d*

J (Hz): 1α,1β = 10.5; 1α,2β = 1.5; 1β,2β = 4.5; 1α,3α = 1; 2β,3α = 3.5; 2β,3β = 6.5; 3α,3β = 15; 5,6 = 6; 5,8 = 1.7; 8,13 = 1; (compound **16**: 5,6 = 5.5; 5,8 = 8,13 = 1); O*i*Val: 2′,3′ = 3′,4′ = 3′,5′ = 7.

artecanin (**39**)[12, 13], a further diepoxide, **38**, two endoperoxides (**34** and **35**) as well as the secoguaianolides **36** and **37** were isolated. The latter two, however, could not be separated. The structures of **30** and **31** clearly followed from the ^{1}H NMR spectral data (Table 3), which were similar to those of estafiatin. The presence of an 8α-isobutyrate and angelate respectively followed from the typical signals of the ester residues, while the orientation and the position of these groups could be deduced by spin decoupling in the usual way. In deuteriobenzene all signals of **31** could be assigned. Starting with the signal of H-7, its irradiation collapsed the typical H-13 signals to singlets and the low field signals at δ2.93 and 4.86 to a doublet and a double doublet respectively, H-6–H-8 were assigned by spin decoupling. The observed couplings showed that the ester group was α-orientated, while a *W*-coupling between H-1 and H-9α allowed the determination of the conformation, which agreed nicely with the other couplings observed. As in the spectrum of estafiatin the couplings of H-3 were extremely small, leading to a broadened singlet for H-3 only. The ^{1}H NMR spectral data of a further lactone (Table 3), which was not free from **28**, agreed with the presence of the corresponding alcohol **29**, though the small quantity did not allow further investigations. However, the typical downfield shift of the H-13′ signal clearly indicated the presence of an 8-hydroxy derivative. The ^{1}H NMR spectral data of **23** (Table 4) were similar to those of parthenolide (**22**). Spin decoupling starting with the broadened double doublet at δ5.11 showed that the hydroxyl group was at C-3, while irradiation of the H-6 signal collapsed the doublet at 2.79 to a singlet and the five-fold doublet at 2.73 (H-7) to a four-fold one. Accordingly the ^{1}H NMR spectrum was similar to that of **19** too. The ^{1}H NMR spectrum of **25** (Table 4) indicated the presence of a very flexible system. In

Table 3. ^{1}H NMR spectral data of compound **29–31** (400 MHz, TMS as internal standard)

	29 ($CDCl_3$)	**30** ($CDCl_3$)	**31** (C_6D_6)	**31** ($CDCl_3$)
H-1	3.00 *brddd*	3.00 *brddd*	2.78 *brddd*	3.01 *brddd*
H-2α	*	2.03 *dd*	1.67 *dd*	2.04 *dd*
H-2β	*	1.76 *ddd*	1.14 *ddd*	1.78 *ddd*
H-3	3.36 *brs*	3.37 *brs*	2.91 *brs*	3.38 *brs*
H-5	*	2.40 *m*	1.78 *dd*	2.40 *dd*
H-6	4.03 *dd*	4.10 *dd*	2.93 *dd*	4.12 *dd*
H-7	2.77 *m*	3.17 *dd*	2.62 *dddd*	3.21 *dddd*
H-8	3.95 *m*	5.01 *ddd*	4.86 *ddd*	5.09 *ddd*
H-9α	*	2.4 *m*	2.21 *brd*	2.44 *m*
H-9β	*		1.87 *dd*	
H-13	6.27 *d*	6.23 *d*	6.17 *d*	6.23 *d*
H-13′	6.15 *d*	5.60 *brd*	5.37 *d*	5.61 *d*
H-14	5.08 *brs*	5.10 *brd*	4.77 *brd*	5.08 *brd*
H-14′	4.88 *s*	4.81 *brd*	4.62 *brd*	4.82 *brd*
H-15	1.58 *s*	1.59 *s*	1.59 *s*	1.60 *s*
OAng	—	2.63 *qq*	5.81 *qq*	6.21 *qq*
	—	1.22 *d*	2.01 *dq*	2.03 *dq*
	—	1.20 *d*	1.85 *dq*	1.93 *dq*

*Obscured signals.

J (Hz): 1α,2α = 7.5; 1α,2β = 11.5; 1α,5α = 8.5; 1α,9α ~ 1; 2α,2β = 14; 2β,3β ~ 1; 5α,6β = 11; 6β,7α = 9; 7α8β = 10; 7α13 = 3.5; 7α13′ = 3; 8β,9α = 2; 8β,9β = 5.5; 9α,9β = 15; 9α,14 ~ 1; 14,14′ = 2; OAng: 3′,4′ = 7; 3′,5′ = 4′,5′ = 1.5.

Table 4. ^{1}H NMR spectral data of compounds **23** and **25–28** (400 MHz, $CDCl_3$, TMS as internal standard)

	23	**25**	**25** (C_6D_6, 60°)	**26**	**27**	**28**†
H-1	5.11 *ddbr*	—	—	4.37 *dd*	5.35 *dd*	—
H-2	2.42 *m*	†	2.81 *t*	2.00 *m*	2.00 *m*	2.97 *ddd*
H-2′		†	2.52 *dd*	1.77 *m*	1.93 *dddd*	2.78 *ddd*
H-3	3.41 *ddbr*	4.59 *m*	4.15 *ddbr*	1.11 *ddd*	1.13 *ddd*	2.33 *ddd*
				2.15 *ddd*	2.16 *ddd*	1.64 *ddd*
H-5	2.79 *d*	5.12 *dbr*	4.81 *dbr*	2.87 *d*	2.89 *d*	2.69 *d*
H-6	3.91 *t*	4.38 *t*	3.93 *t*	3.76 *t*	3.76 *t*	3.65 *t*
H-7	2.73 *ddddd*	2.48 *m*	2.14 *m*	3.26 *ddddd*	3.26 *ddddd*	2.77 *m*
H-8	1.67 *m*	*	*	1.77 *m*	1.76 *dddd*	1.52 *dddd*
H-8′	*	*	*	2.40 *m*	2.40 *m*	2.17 *dddd*
H-9	2.34 *ddbr*	*	*			2.50 *ddd*
H-9′	2.13 *m*	*	*	2.25 *ddbr*	2.2 *m*	2.78 *ddbr*
H-13	6.33 *d*	6.24 *d*	6.12 *d*	6.23 *d*	6.22 *d*	6.28 *d*
H-13′	5.62 *d*	5.49 *d*	4.91 *d*	5.52 *d*	5.51 *d*	5.56 *d*
H-14	1.71 *s br*	5.86 *s*	5.19 *s*	5.23 *s br*	5.09 *s br*	6.05 *s*
H-14′		5.72 *d br*	5.01 *d br*	5.44 *s br*	5.46 *d br*	5.91 *s*
H-15	1.29 *s*	1.76 *d*	1.41 *d*	1.43 *s*	1.46 *s*	1.36 *s*

*Obscured signals.

†In $CDCl_3$–C_6D_6: H-2 2.56 *ddd*, H-2′ 2.43 *ddd*, H-7 2.38 *ddddd*, H-9′ 2.47 *dddd*.

J (Hz): Compound **23**: 1,2 = 11.5; 1,2′ = 5; 2,3 = 10; 2′,3 = 7; 5,6 = 6,7 = 9; 7,8 = 9; 7,8′ ~ 3; 7,13 = 3.5; 7,13′ = 3; compound **25**: 2,2′ = 2,3 = 12; 2′,3 = 6; 5,6 = 6,7 = 10; 7,13 = 3.5; 7,13′ = 3; 9,14′ = 1.5; compounds **26/27**: 1,2 = 5; 1,2′ = 11; 2,2′ = 13; 2′,3 = 12; 2′,3′ = 1.5; 3,3′ = 13; 5,6 = 6,7 = 9.5; 7,8 = 10; 7,8′ = 3; 7,13 = 3.5; 7,13′ = 3; 9,14′ = 1.5; compound **28**: 2,2′ = 14; 2,3 = 6.5; 2,3′ = 13; 2′,3 = 7; 2′,3′ = 2.5; 3,3′ = 13; 5,6 = 6,7 = 9.5; 7,8 = 3; 7,8′ = 9; 7,13 = 3.5; 7,13′ = 3; 8,8′ = 15; 8,9 = 3; 8,9′ = 3; 8′,9 = 5.5; 8′,9′ = 12; 9,9′ = 15; 9′,14 = 9′,14′ = 1.

deuteriobenzene at elevated temperatures most signals could be assigned by spin decoupling. The presence of a keto group at C-1 followed from the downfield shift of the H-14 signals, while the position of an additional hydroxy group could be assigned from the results of spin decoupling, as the protons with signals at δ2.81 and 2.52, obviously those α to the keto group, were coupled with the proton under the hydroxy group. The stereochemistry at C-5–C-7 followed from the large couplings observed, while those of H-3 favoured a β-orientation of the hydroxy group, if the values were compared with those of **20** with known stereochemistry. The ^{1}H NMR spectrum of **28** (Table 4) showed similarities to that of **25**. However, the hydroxy group at C-3 was missing and the 4, 5-double bond was replaced by an epoxide, as clearly followed from the typical doublet at δ2.69. The latter collapsed to a singlet after irradiation of the triplet at δ3.65, which further changed the signal at 2.77. The latter only could be clearly assigned as that of H-7 after addition of deuteriobenzene by spin decoupling. Since all the remaining signals could be assigned by further spin decoupling the structure was established. Compound **28** already had been prepared from the corresponding peroxy lactone, but no ^{1}H NMR data were reported[14]. Compound **26** was obviously the corresponding alcohol, which could be transformed to **27** by mild acetylation. The ^{1}H NMR data of **26** and **27** (Table 4) showed that the oxygen function was at C-1 by the chemical shifts of H-14 and the couplings of H-8, which indicated the presence of two protons at C-9. Inspection of a model favoured the β-orientation of the hydroxy group at C-1. The presence of a 4, 5-epoxide and a 6, 7-*trans*-lactone followed from the typical signals and couplings. The ^{1}H NMR spectral data of **39** fully agreed with those reported for artecanin (**39**)[12, 15], while those of **33** (Table 5) agreed with those reported for chrysartemin A, its structure being in doubt, but obviously being identical with canin (**33**)[12, 15]. A third isomeric diepoxide showed ^{1}H NMR spectral data (Table 5), which were similar to those of canin, but different in the chemical shift of H-14. Most likely therefore this lactone was **38**, though the minute amount did not allow final confirmation of its structure. The ^{1}H NMR spectra of a pair of endoperoxides (**34** and **35**) (Table 5) again were similar indicating isomeric lactones. The presence of an endoperoxide bridge was supported by the mass spectra, which showed elimination of oxygen, obviously a retro-Diels–Alder fragmentation. Furthermore the pair of low field doublets with a vicinal coupling of 6 Hz required a five-membered ring. Spin decoupling allowed the assignment of the sequence H-5–H-9, which clearly showed that guaianolides were present, where an endoperoxide bridge between C-1 and C-4 should be assumed. The question of the stereochemistry at C-1 and C-4, however, caused problems. Typical differences could be visualized in the chemical shifts of H-2, H-3, H-5 and H-6. Inspection of models indicated that the effect of the peroxide group could not be predicted easily. We therefore have transformed both, **34** and **35**, by the known thermal reaction of cyclopenten endoperoxide[16] to the diepoxide. While the latter only is stable up to $-30°$, **34** and **35** on heating at 100° for 1 hr were surprisingly stable. Only at 150° were both compounds transformed in 10 min nearly quantitatively to **33** and **39**, respectively. As this thermal reaction only can proceed stereospecifically, the configurations of the endoperoxides were settled. Accordingly we have to propose a shielding effect of the peroxide group to explain the shift differences of H-5 and H-6. Most likely **34** and **35** were formed via **32**, which itself, however, was not isolated. Compounds **34** and **35** we have named tanaparthin β- and α-peroxide respectively.

The structures of the two further minor lactones **36** and **37** followed from mass spectral and ^{1}H NMR spectral data (Table 6). The presence of α, β-unsaturated five-membered ring ketones could be deduced from the chemical shifts of the pairs of doublets, while spin decoupling allowed the assignment of the sequence H-5–H-9. Obviously **36** and **37**

Table 5. ^{1}H NMR spectral data of compounds **33–35**, **38** and **39** (400 MHz, $CDCl_3$, TMS as internal standard)

	33	**34**	**34** (C_6D_6)	**35**	**35** (C_6D_6)	**38**	**39**
H-2	3.47 *d*	6.33 *d*	5.85 *d*	6.67 *d*	6.23 *d*	3.68 *sbr*	3.54 *d*
H-3	3.28 *d*	6.28 *d*	5.70 *d*	6.41 *d*	6.08 *d*	3.35 *sbr*	3.28 *d*
H-5	2.55 *d*	2.65 *d*	2.40 *d*	2.34 *d*	1.90 *d*	2.62 *d*	2.83 *d*
H-6	4.23 *dd*	3.74 *t*	3.12 *t*	4.27 *t*	3.99 *t*	4.33 *dd*	4.09 *t*
H-7	3.40 *m*	3.35 *ddddd*	3.03 *ddddd*	3.18 *ddddd*	2.80 *ddddd*	3.40 *m*	3.28 *m*
H-8	*	2.35 *dddd* 1.49 *dddd*	1.90 *dddd* 0.86 *dddd*	2.28 *m* 1.58 *m*	1.79 *dddd* 0.94 *dddd*	*	*
H-9	*	1.73 *dddd* 2.01 *ddd*	1.47 *ddd* 1.10 *ddd*	* *	1.98 *ddd* 1.23 *ddd*	*	*
H-13	6.21 *d*	6.15 *d*	6.05 *d*	6.16 *d*	5.98 *d*	6.20 *d*	6.19 *d*
H-13′	5.50 *d*	5.41 *d*	4.85 *d*	5.43 *d*	4.88 *d*	5.47 *d*	5.41 *d*
H-14	1.14 *s*	1.36 *s*	1.10 *s*	1.44 *s*	1.01 *s*	1.26 *s*	1.11 *s*
H-15	1.55 *s*	1.69 *s*	1.58 *s*	1.73 *s*	1.60 *s*	1.55 *s*	1.55 *s*

*Obscured signals.

J (Hz): Compounds **33** and **39**: 2,3 = 1.5; 5,6 = 11.5; 6,7 = 9; (compound **39**: 10); 7,13 = 3.5; 7,13′ = 3; compounds **34** and **35**: 2,3 = 6; 5,6 = 6,7 = 10; 7,8 = 7; 7,8′ = 10; 7,13 = 3.5; 7,13′ = 3; 8,8′ = 14; 8,9 = 7; 8,9′ = 8; 8′,9 = 10; 8′,9′ = 2; 9,9′ = 15; compound **38**: 5,6 – 11.5; 6,7 = 9; 7,13 = 3.5; 7,13′ = 3.

Table 6. ^{1}H NMR spectral data of compounds **36** and **37** (400 MHz, $CDCl_3$, TMS as internal standard)

	36	**37**
H-2	6.07 *d*	6.16 *d*
H-3	7.48 *d*	7.46 *d*
H-5	2.31 *d*	2.31 *d*
H-6	4.46 *dd*	4.56 *dd*
H-7	3.03 *dddt*	
H-8	1.89 *dt*	
H-9	2.53 *m*	
H-13	6.37 *d*	6.36 *d*
H-13′	5.74 *d*	5.74 *d*
H-14	2.20 *s*	2.18 *s*
H-15	1.07 *s*	1.08 *s*

J (Hz): 2,3 = 5.5; 5,6 = 9.5; 6,7 = 3; 7,8 = 7; 7,13 = 2.5; 7,13′ = 2; 8,9 = 7.

only differed in their stereochemistry at C-4. Most likely these secoguaianolides were formed from **34** and **35** respectively. Protonation of the peroxide bridge could induce a fragmentation as shown in the scheme. Though the stereochemistry at C-4 could not be determined, biogenetic considerations would support that the main compound was **37** since the precursor, the endoperoxide **34**, was present in larger amounts as **35**. Compounds **36** and **37** we have named seco-tanapartholide A and B respectively.

The overall picture of the constituents of *Tanacetum parthenium* shows that this species produces a large variety of highly oxygenated compounds especially in the aerial parts, while **11** in the roots is mainly formed, this being an acetylene, widespread in the tribe Anthemideae[17].

EXPERIMENTAL

The fresh plant material, grown from seeds from the Botanical Garden, Liege, voucher 81/1455 (deposited in the Institute of Organic Chemistry, Technical University, Berlin) was extracted with Et_2O–petrol, 1:2. The extract of the aerial parts (2.5 kg) was first treated with MeOH to remove long chain hydrocarbons and was then partially separated by CC (SiO_2) with petrol and increasing amounts of Et_2O and finally Et_2O–MeOH (10:1). The fractions obtained with petrol, with 10–50% Et_2O, Et_2O and Et_2O–MeOH were combined and further separated by TLC (SiO_2). The petrol fraction afforded 10 mg germacrene D and 30 mg β-farnesene, the second fraction after repeated TLC (Et_2O–petrol, 1:10) afforded 60 mg camphor, 3 mg **1**, 5 mg **2**, 3 mg **3**, 3 mg **4**, 2 mg **5**, 8 mg **6**, 3 mg **7**, 3 mg **8**, 2 mg **9**, 2 mg **10**, 20 mg **11**, 10 mg **12**, 3 mg **13**, 1.5 mg **14**, 10 mg **15**, 2 mg **16**, 3 mg **17**, 1.5 mg **18** and 15 mg **19**. The third fraction was separated again by CC (SiO_2) into two fractions (Et_2O–petrol, 1:1; and Et_2O). The first part afforded after TLC (Et_2O–petrol, 3:1) 8 mg **31** and a mixture of **30** and **31**, which was separated by HPLC (reversed phase, MeOH–H_2O, 7:3) affording 5 mg **30**. The second part on repeated TLC (SiO_2) gave 10 mg **20**, 200 mg **22**, 3 mg **23**, 10 mg **24**, 3 mg **25**, 3 mg **28**, 10 mg **34**, 3 mg **35** and a mixture of **21**, **26**, **29** and **35**, which by HPLC (MeOH–H_2O, 3:2) gave 1 mg **21**, 2 mg **26**, 1 mg **29** and 1 mg **35**. The last fraction on repeated TLC (SiO_2) (Et_2O and C_6H_6–$CHCl_3$–Et_2O, 1:1:1) afforded 9 mg **26**, 2 mg **33**, 0.5 mg **36**, 2 mg **37**, 1 mg **38** and 1 mg **39**. Several of the lactones isolated may be crystalline, but due to the minute amounts no crystals, except of **34**, could be obtained.

The roots (500 g) gave 20 mg farnesene, 2 mg bicyclogermacrene, 1 g **11** and 50 mg **17**. Known compounds were identified by high ^{1}H NMR spectroscopy and by comparing the data with those of authentic material (MS, IR and TLC).

cis-*Chrysanthenyl angelate* (**4**). Colourless oil, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1715 (C=CCO$_2$R); MS *m/z* (rel. int.): 134.110 [M − AngOH]$^+$ (3) ($C_{10}H_{14}$), 119 [134 − Me]$^+$ (10), 83 [C_4H_7CO]$^+$ (100), 55 [83 − CO]$^+$ (61).

$$[\alpha]_{24°}^{\lambda} = \frac{589}{-12}\ \frac{578}{-12}\ \frac{546}{-14}\ \frac{436\text{ nm}}{-16}\ (CHCl_3;\ c0.2).$$

cis-*Chrysanthenyl isovalerate* (**5**). Colourless oil, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1740 (CO$_2$R); MS *m/z* (rel. int.): 236 [M]$^+$ (0.5), 134.110 [M − RCO$_2$H]$^+$ (18) ($C_{10}H_{14}$), 119 [134 − Me]$^+$ (38), 85 [C_4H_9CO]$^+$ (65), 57 [85 − CO]$^+$ (100).

4β-*Acetoxychrysanthenone* (**7**). Colourless oil, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1790 (Four ring C=O), 1740, 1240 (OAc); MS *m/z* (rel. int.): 208 [M]$^+$ (0.2), 180 [M − CO]$^+$ (0.3), 166.084 [M − ketene]$^+$ (18) ($C_{10}H_{12}O_2$), 149 [M − OAc]$^+$ (7), 148 [M − HOAc]$^+$ (23), 133 [148 − Me]$^+$ (71), 121 [149 − CO]$^+$ (100).

Bornyl angelate (**9**). Colourless oil, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1720, 1650 (C=CCO$_2$R); MS *m/z* (rel. int.): 236.178 [M]$^+$ (7) ($C_{15}H_{24}O_2$), 136 [M − RCO$_2$H]$^+$ (11), 83 [C_4H_7CO]$^+$ (77), 55 [83 − CO]$^+$ (100); ^{1}H NMR ($CDCl_3$): 0.91(*s*), 0.87(*s*), 0.84(*s*) (each 3H), 4.92 *ddd* (*J* = 10, 3.5, 2.5 Hz) (H-1), 6.04(*qq*), 2.00(*dq*) and 1.91(*dq*) (OAng, *J* = 7 and 1.5 Hz).

cis-*Isovalerate* **13**. Colourless gum, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 2150 (C≡C), 1740 (CO$_2$R), 1635 (C=C), 1580 (C=C–OR); MS *m/z* (rel. int.): 300.136 [M]$^+$ (23) ($C_{18}H_{20}O_4$), 214 [M − O=C=CHCHMe$_2$]$^+$ (95), 200 [M − $C_5H_8O_2$]$^+$ (100), 198 [M − RCO$_2$H]$^+$ (51), 185 [200 − Me]$^+$ (44), 85 [C_4H_9CO]$^+$ (59), 57 [85 − CO]$^+$ (100); CD (MeCN) $\Delta\epsilon_{320} + 0.5$.

trans-*Isovalerate* **16**. Colourless gum, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 2150 (C≡C), 1740 (CO$_2$R), 1635 (C=C), 1580 (C=COR), 950 (*trans* C=C); MS *m/z* (rel. int.): 300.136 [M]$^+$ (25) ($C_{18}H_{20}O_4$), 214 (8), 200 (41), 198 (44), 85 (100), 57 (54).

3β-Hydroxyparthenolide (**23**). Colourless gum, IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3610 (OH), 1770 (γ-lactone); MS *m/z* (rel. int.): 264.136 [M]$^+$ (4) ($C_{15}H_{20}O_4$), 246 [M − H_2O]$^+$ (2), 55 [C_4H_7]$^+$ (100).

3β-*Hydroxyanhydroverlotorin* (**25**). Colourless gum, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3605 (OH), 1775 (γ-lactone), 1670 (C=CC=O); MS *m/z* (rel. int.): 262.121 [M]$^+$ (4) ($C_{15}H_{18}O_4$), 244 [M − H_2O]$^+$ (6), 55 [C_4H_7]$^+$ (100).

1β-*Hydroxy*-10, 14-*dehydro*-1, 10H-parthenolide (**26**). Colourless gum, which was purified by acetylation (Ac_2O, 1 hr, 70°) leaving **27**, colourless gum, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1785 (γ-lactone), 1745, 1245 (OAc); MS *m/z* (rel. int.): 306.147 [M]$^+$ (1) ($C_{17}H_{22}O_5$), 264 [M − ketene]$^+$ (19), 246 [M − HOAc]$^+$ (39), 205 (54), 109 (79), 91 (85), 81 (100).

$$[\alpha]_{24°}^{\lambda} = \frac{589}{+27}\ \frac{578}{+29}\ \frac{546\text{ nm}}{+33}\ (CHCl_3;\ c0.28).$$

Anhydroverlotorin-4α, 5β-*epoxide* (**28**). Colourless gum, which could not be induced to crystallize IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1780 (γ-lactone), 1670 (C=CC=O); MS *m/z* (rel. int.): 244.110 [M − H_2O]$^+$ (4) ($C_{15}H_{16}O_3$), 233 [M − CHO]$^+$ (18), 205 [233 − CO]$^+$ (33), 53 [C_4H_5]$^+$ (100). $[\alpha]_D = +135°$ ($CHCl_3$; *c*0.2).

8α-*Hydroxyestafiatin* (**29**). Colourless gum, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3600 (OH), 1780 (γ-lactone); MS *m/z* (rel. int.): 262.121 [M]$^+$

(4) ($C_{15}H_{18}O_4$), 247 $[M-Me]^+$ (33), 244 $[M-H_2O]^+$ (5), 233 $[M-CHO]^+$ (17), 205 $[233-CO]^+$ (32), 97 (100).

8α-*Isobutyryloxyestafiatin* (**30**). Colourless gum, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1790 (γ-lactone), 1740 (CO_2R); MS *m/z* (rel. int.): 332.162 $[M]^+$ (10) ($C_{19}H_{24}O_5$), 262 $[M-O{=}C{=}CMe_2]^+$ (6), 244 $[M-RCO_2H]^+$ (24), 229 $[244-Me]^+$ (22), 201 $[229-CO]^+$ (23), 97 (100), 71 $[C_3H_7CO]^+$ (100).

8α-*Angeloyloxyestafiatin* (**31**). Colourless gum, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1785 (γ-lactone), 1720, 1645 ($C{=}CCO_2R$); MS *m/z* (rel. int.): 344.162 $[M]^+$ (2) ($C_{20}H_{24}O_5$), 244 $[M-RCO_2H]^+$ (12), 229 $[244-Me]^+$ (10), 201 $[229-CO]^+$ (12), 97 (52), 83 $[C_4H_7CO]^+$ (100), 55 $[83-CO]^+$ (67).

$$[\alpha]_{24°}^{\lambda} = \frac{589 \quad 578 \quad 546 \quad 436\,nm}{+109 \quad +116 \quad +131 \quad +225} \quad (CHCl_3;\ c0.24).$$

Tanaparthin-β-peroxide (**34**). Colourless crystals, mp 117°, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3580 (OH), 1780 (γ-lactone); MS *m/z* (rel. int.): 278 $[M]^+$ (1.5), 260.105 $[M-H_2O]^+$ (7) ($C_{15}H_{16}O_4$), 246 $[M-O_2]^+$ (26), 228 $[246-H_2O]^+$ (11), 200 $[228-CO]^+$ (21), 111 $[C_6H_7O_2]^+$ (100).

$$[\alpha]_{24°}^{\lambda} = \frac{589 \quad 578 \quad 546 \quad 436\,nm}{-24 \quad -29 \quad -52 \quad -92} \quad (CHCl_3;\ c0.22).$$

5 mg **34** in 0.5 ml C_6D_6 were heated in a sealed NMR tube for 1 hr at 100°. The ^1H NMR spectrum was unchanged. Further heating for 10 min at 150° caused a complete transformation to **33**, identical with canin. The ^1H NMR spectral data in DMSO were identical with those reported[15].

Tanaparthin-α-peroxide (**35**). Colourless gum, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3600 (OH), 1775 (γ-lactone); MS *m/z* (rel. int.): 278 $[M]^+$ (0.5), 260.105 $[M-H_2O]^+$ (4), 246 $[M-O_2]^+$ (23), 228 $[246-H_2O]^+$ (8), 200 $[228-CO]^+$ (17), 111 $(C_6H_7O_2)^+$ (100). 2 mg **35** was heated as above for 10 min at 150°, which led to a complete transformation to **39**, identical with artecanin. The ^1H NMR spectral data in DMSO were identical with those reported[15].

Seco-tanapartholide A and B (**36** and **37**). Not separated colourless gum, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3570 (OH), 1780 (γ-lactone), 1720 (C=O); MS *m/z* (rel. int.): 278.115 $[M]^+$ (7) ($C_{15}H_{18}O_5$), 260 $[M-H_2O]^+$ (19), 217 $[260-MeCO]^+$ (11), 207 $[M-CH_2COMe]^+$ (9), 202 $[260-Me_2CO]^+$ (10) (McLafferty), 189 $[207-H_2O]^+$ (7), 112 $[C_6H_8O_2]^+$ (10) (McLafferty), 189 $[C_6H_7O_2]^+$ (100), 94 $[112-H_2O]^+$ (89).

10-*Epi-canin* (**38**). Colorless gum, IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3590 (OH), 1780 (γ-lactone); MS *m/z* (rel. int.): 278.115 $[M]^+$ (0.5) ($C_{15}H_{18}O_5$), 260 $[M-H_2O]^+$ (5), 55 $[C_4H_7]^+$ (100).

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