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SESQUITERPENE LACTONES AND OTHER CONSTITUENTS FROM *ERIOCEPHALUS* SPECIES

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Key Word Index—*Eriocephalus* species; Compositae; sesquiterpenes; sesquiterpene lactones; guaianolides; eudesmanolides; germacranolides; eriocephaloide; costic acid derivatives; secoeudesmane, chrysanthemol derivative.

Abstract—The investigation of nine *Eriocephalus* species afforded in addition to known compounds 40 new ones: 10 guaianolides, eight eudesmanolides, a germacranolide, a sesquiterpene lactone with new carbon skeleton, 18 derivatives of costic acid, a seco-eudesmane diketone and a chrysanthemol derivative. The structures were elucidated by high field NMR spectroscopy and a few chemical transformations. The chemotaxonomy of the genus is discussed briefly.

INTRODUCTION

The endemic genus *Eriocephalus* with about 30 species is distributed mainly over South West Africa. All species are small shrubs with very woolly heads after flowering which led to the naming of the genus using the Greek words: erion cephalus = wool headed. Also characteristic for the genus are the heterogeneous heads, the female ray flowers with bifid style, mostly ligulate, the discflowers being tubular, five-toothed and male with perfect stamens and simple, club shaped, truncate styles. The achenes of the rays are flattened, wingless without pappus. Traditionally the genus is placed in the tribe Anthemideae, subtribe Anthemidinae, next to *Athanasia* [1]. However, recently this genus was grouped together with *Brachylaena*, *Tarchonanthus* and *Osmitopsis* [2] in the *Lasiospermum* group with other South African genera [3]. So far little is known on the chemistry. The roots of two species gave dehydrofalcarinone and a degradated diacetylene [4] and from the essential oil of another species azulenes are reported [5]. We have now studied the chemistry of nine species. The results will be discussed in this paper.

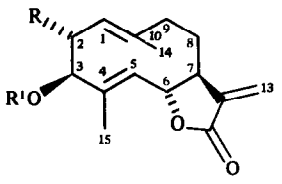
RESULTS AND DISCUSSION

The aerial parts of a new *Eriocephalus* species collected in Namibia afforded camphor, linalyl acetate, nerolidol, spathulenol and several sesquiterpene lactones. In addition to costunolide, hanphylline (**1**) [6] and the 2-hydroxy derivative of the corresponding acetate (**3**) as well as the guaianolides **4a** [7], **5a**, **6a** [8], **7a** and estafiatin (**8**) [9] were isolated. The structure of **3** followed from the molecular formula and the ^{1}H NMR spectrum (Table 2). All signals were assigned in deuteriobenzene by spin decoupling starting with the double doublet at δ3.95, which was due to H-6, as followed from the coupling of the latter with a signal (H-7) which allylic showed couplings with H-13. The configurations at C-2 and C-3 were deduced from the observed couplings.

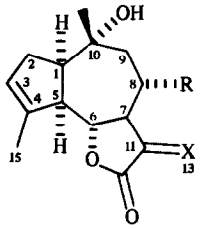
In the ^{1}H NMR spectrum of **5a** (Table 2) a broadened singlet at δ7.82 indicated the presence of a hydroperoxide. In the mass spectrum no molecular ion could be detected. However, in addition to $[M-H_2O]^+$, peaks for $[M-OOH]^+$ and $[M-H_2O_2]^+$ were present. The ^{1}H NMR signal at δ4.65 showed couplings with H-15 (δ1.98 *br s*), H-1 (δ3.31 *m*) and H-3 (δ4.86 *ddd*). These data together with additional sequences which followed from spin decoupling, indicated the presence of a guaianolide with oxygen functions at C-3, C-6 and C-10. The stereochemistry was determined by NOE difference spectroscopy. Saturation of H-14 showed effects on H-9β (4%) and H-6 (6%). Further NOE's were observed between H-1, H-7 (5%) and H-2α (8%) as well as between H-3β and H-2β (7%). The relative position of the hydroperoxy group was deduced from the identical chemical shifts of H-3 in the spectra of **5a** and **5c** which differed from that in **5b** with a hydroxy group at C-3.

The ^{1}H NMR spectral data of **7a** (Table 2) again indicated the presence of a hydroperoxide (δ7.60 *br s*). Reduction with triphenylphosphine afforded the corresponding diol **7b**. A pair of double doublets at δ6.08 and 5.91 in the spectrum of **7a** was shifted to δ5.98 and 5.86, also one of the methyl singlets (H-15) and the H-5 signal were slightly shifted. Accordingly, the hydroperoxy group was at C-4 and not at C-10. Again the configuration at all chiral centres was deduced from the observed NOE's. Thus clear effects were obtained between H-6, H-14 (10%) and H-15 (10%), between H-5 and H-1 (6%), between H-1 and H-2 (8%), between H-7, H-5 (6%), H-1 (4%) and H-9α (3%), between H-15, H-6 (8%), H-3 (4%) and H-14 (6%) as well as between H-14 and H-2 (3%) (in each case the first signal is the saturated one).

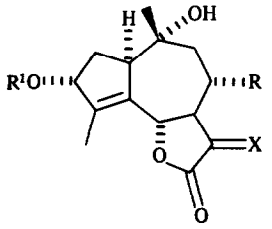
The aerial parts of *E. giessii* sp. nov. afforded several widespread compounds (see Experimental), the known guaianolides rupicolin B [10], **4c** [11], **4d** [12] and **4e** [7] as well as the new ones **4b**, **5b**, **5c**, **6b**, **7c** and **7d**. The structure of **4b** were readily deduced from the ^{1}H NMR spectrum (Table 1) which was very close to those of **4c** [11] and **4d** [12] but differing in the expected way. The ^{1}H NMR spectrum of the guaianolide **5c** (Table 1) was in part close to that of **5a**. However, the exomethylene proton signals were replaced by signals at δ1.34 *d* (H-13)



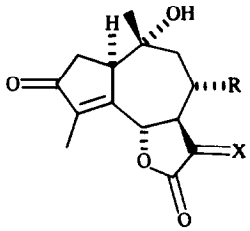
1 R = R¹ = H
2 R = H, R¹ = Ac
3 R = OH, R¹ = Ac



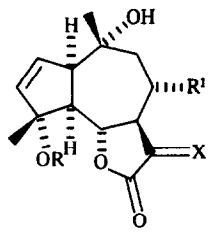
4a R = H, X = CH_2
4b R = OH, X = αMe,H
4c R = OAc, X = αMe,H
4d R = OH, X = CH_2
4e R = OAc, X = CH_2



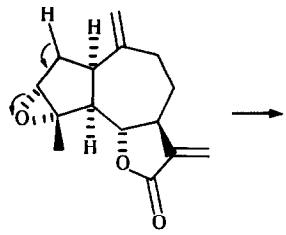
5a R = H, R¹ = OH, X = CH_2
5b R = OAc, R¹ = H, X = αMe,H
5c R = OAc, R¹ = H, X = αMe,H



6a R = H, X = CH_2
6b R = OAc, X = αMe,H



7a R = OH, R¹ = H, X = CH_2
7b R = R¹ = H, X = CH_2
7c R = OH, R¹ = OAc, X = αMe,H
7d R = H, R¹ = OAc, X = αMe,H



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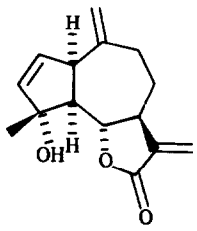

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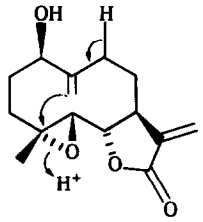

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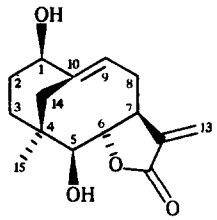


11

and 2.50 *dq* (H-11) indicating the presence of a 11,13-dihydro derivative. An additional low field signal at δ4.97 and an acetate singlet required an acetoxy group which only could be placed at C-8 as followed from spin decoupling. The stereochemistry was deduced from the observed couplings.

The ^{1}H NMR spectrum of **5b** (Table 1) differed from that of **5c** by small shift differences of H-3 typical for the replacement of a hydroxy by a hydroperoxide group. The ^{1}H NMR spectrum of **6b** (Table 1) was in part close to that of **6a**. Again the presence of a 8α-acetoxy group followed from the low field signal at δ5.04 and the methyl doublet at δ1.38 indicated a 11,13-dihydro derivative. Spin decoupling allowed the assignment of all signals and sequences while the configurations followed from the couplings.

The spectral data of **7c** and **7d** showed that again a hydroperoxide and the corresponding carbinol were present. The ^{1}H NMR spectra (Table 1) were in part close to those of **7a** and **7b**. The low field signal at δ5.01 and its coupling indicated the presence of a 8α-acetoxy derivative where the 11,13-double bond was hydrogenated as followed from the typical signals of H-11 and H-13. The aerial parts of *E. merxmüllerii* sp. nov. only gave camphor and those of *E. ambigius* DC caryophyllene epoxide and taraxasteryl acetate.

From the extract of the aerial parts of *E. kingesii* Merxm. et Eberle in addition to squalene, taraxasteryl acetate, dehydrofalcarinol and the monoterpenes **12** and **13** [13] several germacranolides were isolated: costunolide, parthenolide [14], diepoxycostunolide [15], 8α-acetoxyparthenolide [16], artemorin [17], 1β-peroxy-

Table 1. ^{1}H NMR spectral data of compounds **4b**, **5b**, **5c**, **6b**, **7c**, **7d** and **9** (400 MHz, $CDCl_3$, δ-values)

H	4b	5b	5c	6b	7c	7d	9*
1	2.46 *dd*	3.33 *m*	3.32 *m*	3.30 *m*	3.24 *br d*	3.24 *br d*	3.55 *br d*
2	2.23 *br dd*	2.29 *ddd*	2.26 *ddd*	2.57 *d*	6.09 *dd*	5.93 *dd*	5.65 *dd*
2′	2.09 *br dd*	1.93 *ddd*	2.11 *ddd*				
3	5.47 *br s*	4.61 *br d*	4.87 *br d*	—	5.93 *dd*	5.85 *dd*	5.87 *dd*
5	2.64 *br dd*	—	—	—	2.90 *dd*	2.67 *dd*	2.66 *dd*
6	3.94 *dd*	4.61 *br d*	4.77 *br d*	4.96 *br d*	4.30 *dd*	4.34 *dd*	4.17 *dd*
7	2.50 *ddd*	2.41 *ddd*	2.41 *ddd*	2.56 *ddd*	2.18 *ddd*	2.21 *ddd*	2.88 *ddddd*
8	3.78 *br ddd*	4.96 *ddd*	4.97 *ddd*	5.04 *ddd*	5.01 *ddd*	5.01 *ddd*	1.58 *m*
9	2.17 *dd*	2.19 *dd*	2.22 *dd*	2.29 *dd*	2.22 *dd*	2.19 *dd*	1.88 *m*
9′	1.90 *ddd*	1.84 *dd*	1.84 *dd*	1.97 *dd*	1.85 *dd*	1.83 *dd*	1.80 *m*
11	2.41 *dq*	2.51 *dq*	2.50 *dq*	2.60 *dq*	2.54 *dq*	2.56 *dq*	—
13	1.41 *d*	1.35 *d*	1.34 *d*	1.38 *d*	1.35 *d*	1.35 *d*	6.29 *d*
14	1.30 *s*	1.03 *s*	1.04 *s*	1.05 *s*	1.20 *s*	1.19 *s*	4.91 *br s*
15	1.88 *dt*	1.94 *br s*	1.96 *br s*	1.92 *br s*	1.43 *s*	1.46 *s*	1.41 *s*
OAc	—	2.11 *s*	2.11 *s*	2.14 *s*	2.11 *s*	2.12 *s*	—

*H-8′ 1.58 *m*, H-13′ 5.58 *d*, H-14′ 4.72 *br s*.

J[Hz]: Compound **4b**: 1,2 = 1,2′ = 1,5 = 9; 2,2′ = 15; 2,15 = 3,15 ~ 1.5; 5,6 = 6,7 = 7,8 = 10; 7,11 = 11; 8,9 = 6; 8,9′ = 3.5; 9,9′ = 16; 9′,14 = 0.5; 11,13 = 7; compounds **5b**/**5c**: 1,2 = 5; 1,2′ = 2,3 = 7; 2,3 = 2; 6,7 = 7,8 = 7,11 = 11; 8,9 = 4; 8,9′ = 9,9′ = 12; 11,13 = 7; compound **6b**: 1,2 = 4.5; 6,7 = 7,8 = 7,11 = 11; 8,9 = 4; 8,9′ = 9,9′ = 12; 11,13 = 7; compounds **7b**/**7c**: 1,2 = 2.5; 1,3 = 1,5 = 10; 2,3 = 6; 5,6 = 6,7 = 7,8 = 7,11 = 11; 8,9 = 4; 8,9′ = 9,9′ = 12; 11,13 = 7; compound **9**: 1,2 = 2.5; 1,3 = 1.5; 1,5 = 9; 2,3 = 5.5; 5,6 = 10; 6,7 = 9; 7,8 = 10; 7,8′ = 3; 7,13 = 3.5; 7,13′ = 3.

Table 2. ^{1}H NMR spectral data of compounds **3**, **5a**, **6a**, **7a** and **7b** ($CDCl_3$, 400 MHz, δ-values)

H	3 (C_6D_6)	3	5a*	6a	7a‡	7b
1	4.85 *br d*	5.12 *br d*	3.31 *m*	3.27 *m*	3.19 *ddd*	3.22 *ddd*
2	4.41 *dd*	4.58 *dd*	2.27 *ddd* 2.10 *m*	2.61 *d*	6.08 *dd*	5.98 *dd*
3	5.23 *br d*	5.07 *br d*	4.86 *ddd*	—	5.91 *dd*	5.86 *dd*
5	4.72 *br d*	5.08 *br d*	—	—	2.93 *dd*	2.73 *dd*
6	3.95 *dd*	4.55 *dd*	4.65 *br d*	4.82 *br d*	4.22 *dd*	4.28 *dd*
7	1.80 *m*	2.57 *ddd*	2.89 *ddddd*	3.07 *ddddd*	2.70 *ddddd*	2.72 *ddddd*
8α	1.43 *br dd*	2.14 *m*	2.19 *br dt*	2.31 *br dt*	2.14 *br d*	2.14 *br d*
8β	0.95 *dddd*	1.65 *m*	1.41 *dddd*	1.50 *m*	1.46 *m*	1.48 *m*
9α	1.91 *br dd*	2.42 *br dd*	1.75 *ddd*	1.88 *ddd*	1.76 *ddd*	1.77 *ddd*
9β	1.59 *dt*	2.14 *m*	2.05 *dt*	2.13 *dt*	2.01 *dt*	2.03 *dt*
13	6.28 *d*	6.28 *d*	6.24 *d*	6.33 *d*	6.23 *d*	6.28 *d*
13′	4.98 *d*	5.55 *d*	5.53 *d*	5.62 *d*	5.54 *d*	5.58 *d*
14	1.07 *br s*	1.63 *br s*	0.97 *s*	1.99 *s*	1.07 *br s*	1.11 *br s*
15	1.36 *d*	1.69 *d*	1.98 *br s*	1.95 *br s*	1.40 *s*	1.48 *s*

*OAc 1.80 *s* ($CDCl_3$ 2.17); †OOH 7.82 *br s*; ‡OOH 7.60 *br s*.

J[Hz]: 7,13 = 3.5; 7,13′ = 3; compound **3**: 1,2 = 9.5; 2,3 = 8.5; 5,6 = 10; 6,7 = 9; 7,8α = 8α,9α = 8β,9β ~ 2; 7,8β = 10; 8α,8β = 14; 8α,9β = 6; 8β,9α = 9α,9β = 12; compound **5a**: 1,2α = 1,2β ~ 8; 2α,2β = 15; 2α,3 = 2β,3 ~ 1.5; 6,7 = 11; 6,15 = 1.5; 7,8α = 8α,9α = 8α,9β ~ 3; 7,8β = 12; 8α,8β = 8β,9α = 9α,9β = 13; 8β,9β = 3; compound **6a**: 1,2 = 5; 6,7 = 7,8β = 12; 6,15 = 1.5; 7,8α = 8α,9α = 8α,9β ~ 3; 8α,8β = 9α,9β = 8β,9α = 13; 8β,9β = 3; compounds **7a** and **7b**: 1,2 = 1,3 = 2; 1,5 = 9; 2,3 = 6; 5,6 = 11; 6,7 = 9.5; 7,8α = 8α,9α = 8α,9β ~ 3; 7,8β = 11; 8α,8β = 9α,9β = 13.5; 8β,9α = 13; 8β,9β = 3.

$\Delta^{10(14)}$-costunolide [18] and 3β-acetoxyparthenolide [19], two guaianolides: estafiatin (**8**) and **9**, the eudesmanolides santamarin [20] and reynosin [21] as well as a new type of sesquiterpene lactone named 1β, 5β-dihydroxyeriocephaloide (**11**).

The structure of **12** followed from its ^{1}H NMR spectrum (see Experimental) which was in part close to that of chrysanthemol [22]. A broadened singlet at δ7.76 indicated the presence of a hydroperoxide and a two proton singlet at δ5.00, which showed allylic coupling with a

broadened singlet at δ1.83, as well as a doublet at δ3.96 clearly showed that **12** was a chrysanthemol derivative most likely formed by singlet oxygen attack at the double bond of the latter. The configuration at C-4 could not be determined.

The structure of **9** followed from the molecular formula and the ^{1}H NMR spectrum (Table 1) which showed some similarities with that of **7b**. The presence of the corresponding anhydro derivative followed from the replacement of the methyl singlet (H-14) in the spectrum of **7b** by a pair of broadened singlets at δ4.91 and 4.72 and the down field shift of the H-1 signal in the spectrum of **9** if compared with shift in that of **7b**. The chemical shifts of H-15 and H-5 indicated identical configurations at C-4 and C-5 for the lactones **9** and **7b**.

The structure of **11**, molecular formula $C_{15}H_{20}O_4$, was deduced from the ^{1}H NMR spectrum (see Experimental) though at a first glance the assignment of the observed signals was difficult. A methyl singlet at δ0.98 indicated the presence of an eudesmanolide. This, however, was not in agreement with the sequence obtained by spin decoupling. As the H-7 signal was readily assigned by the coupling with H-13 the sequence H-5 through H-9 could be determined and also the sequence H-1 through H-3. The remaining pair of signals at δ2.22 (*br d*) and 2.17 (*d*) were assigned by the observed W-couplings between the broadened doublet at δ2.22 and H-1α and H-3α. Finally, the proposed structure and the stereochemistry was established by the observed NOE's between H-9α, H-1 (6%) and H-7 (2%), between H-6, H-14 (10%) and H-15 (5%), between H-5, H-7 (7%) and H-2α (7%), between H-7, H-5 (5%) and H-9α (2%) as well as between H-15, H-6 (5%), H-3β (4%) and H-14′ (4%).

Most likely the lactone **11** is derived biogenetically from the 4,5-epoxide of artemorin (**10**) as shown in the Scheme. Lactone **10**, which was not isolated, could be derived from costunolide diepoxide which was present in the plant.

The aerial parts of *E. pauperrimus* Merxm. ex Eberle afforded as main constituent phloracetophenone-2-*O*,4-*O*-dimethyl ether. Furthermore a complex mixture of 18 new eudesmane derivatives, all related to costic acid, was present. Only the 3,8-diacyloxy derivatives **16–19** occurred as methyl esters, while all the other compounds were free acids which, however, could only be separated as their methyl esters **14a**, **15a**, **20a–24a**, **26a–31a** and **33a**.

The structure of **15a** followed from its ^{1}H NMR spectrum (Table 3) which was in part close to that of isocostic acid methyl ester [22]. The presence of an angeloyloxy derivative was deduced from the typical ^{1}H NMR signals. The position of this function was determined by spin decoupling and the configuration at C-3 followed from the observed couplings of H-3 which differed characteristically from those of the corresponding 3-hydroxy eudesma-4,11-dien-12,8β-olide [24]. The same couplings were observed for 3β-angeloyloxy-1-desoxyinvangustin [25].

The ^{1}H NMR spectrum of **16a** (Table 3) indicated that we were dealing with the 8β-acetoxy derivative of **15a**. The configuration at C-8 followed from the small vicinal couplings which required an axial acetoxy group. This was further supported by a downfield shift of H-14. The relative position of the ester groups was deduced from the chemical shift of H-3 which was identical in **15a** and **16**. The spectra of **17–19** (Table 3) clearly showed that these compounds only differed from **16a** by the 3β-acyloxy group, its nature followed from the typical ^{1}H NMR signals of the ester residues.

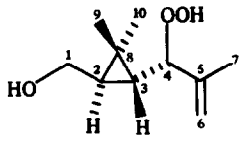
The molecular formula of **14a** was $C_{16}H_{22}O_4$. Accordingly, this ester had no acyloxy group. The nature of the oxygen functions was deduced from the ^{1}H NMR spectrum (Table 3). A pair of signals at δ2.45 and 2.34 showed a geminal coupling of 19 Hz which is typical for protons next to a keto group. Furthermore, the chemical shift of one of the methyl singlets (δ1.38) required an oxygen function at the corresponding carbon. Spin decoupling allowed the assignment of all signals. As the protons at C-6 showed only a vicinal coupling with H-7 no proton was at C-5. Therefore a 4,5-epoxide was very likely. By NOE difference spectroscopy the configuration of some chiral carbons could be determined. Clear effects were observed between H-14, H-6β (5%), H-2β (4%) and H-8β (5%) as well as between H-15 and H-6α (5%). Inspection of models showed that these effects required a 10β-methyl group and most likely an α-epoxide. A clear decision was not possible as the 4-methyl group is quasi-equatorial in both epimers. However, the presence of an α-epoxide was strongly supported by a negative Cotton effect if compared with the observed effects with α-and β-4,5-epoxy steroids [26]. The ^{13}C NMR data agreed well with the proposed structure (see Experimental).

The ^{1}H NMR spectral data of **20a** (Table 3) indicated the presence of a 3β-angeloyloxy derivative with a 5,6-double bond as followed from spin decoupling. The couplings indicated the configuration at C-3 and C-7, while the chemical shift of H-14, which was assigned by the presence of a W-coupling with H-9α, required a 4β-hydroxy group.

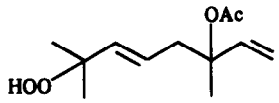
The molecular formula of **21a** indirectly followed from the fragment *m/z* 247 ($C_{16}H_{22}O_2$) which must be formed by loss of OOH, as a singlet at δ7.70 required such a group. The ^{1}H NMR data (Table 4) were close to those of the methyl ester of costic acid. However, the presence of an oxygen function at C-5 was clearly indicated by the missing coupling $J_{5\alpha,6\beta}$. The stereochemistry was confirmed by NOE's between H-14 and H-6β (6%), between H-15′ and H-6α (7%), between H-15 and H-3β (8%) as well as between H-7 and H-6α (4%).

The ^{1}H NMR spectrum of **22a** (Table 4) showed that this compound was the 3β-hydroxy derivative of **21a** by the appearance of a broadened double doublet at δ4.65. The hydroperoxide singlet at δ8.03 was missing in the spectrum of **23a** (Table 4). Furthermore, typical differences in the chemical shifts of H-6α and H-7 indicated the presence of the corresponding 5α-hydroxy compound. The ^{1}H NMR spectrum (Table 4) of **24a** showed that we were dealing with the angelate of **22a**. Accordingly, triphenylphosphine reduction gave the 5α-hydroxy derivative **25a**, its ^{1}H NMR spectrum showed similar changes as those shown by **22a**/**23a**.

The ^{1}H NMR spectrum of **26a** (Table 4) again indicated the presence of a hydroperoxide (δ7.95 *s*) and a singlet at δ1.96 (3H) together with a threefold doublet at δ5.33 an 8β-acetoxy group as the corresponding 8α-acetoxy costic acid showed large couplings for H-8 which together with the 8α-hydroxy compound is present in high concentration in an *Artemisia* species [27]. Triphenylphosphine reduction afforded **27a**, identical with the data of the natural product which could not be separated from **26a** in the corresponding high pressure liquid chromatography fraction. The ^{1}H NMR data of **28a** and **29a** (Table 4) showed that the corresponding



12



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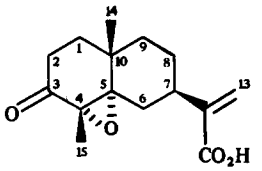

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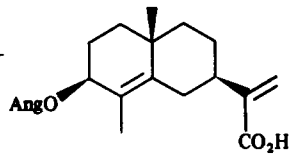

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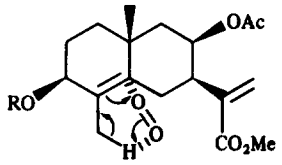
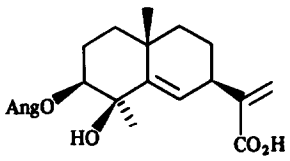


16 17 18 19

R Ang *i*Bu Prop Mesen



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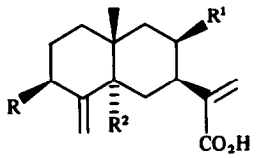


	21	22	23	24	25	26	27	28	29	30	31	32	33
R	H	OH	OH	OAng	OAng	OAng	OAng	O*i*Bu	O*i*Bu	αOH		αOAng	
R^1	H	H	H	H	H	OAc	OAc	OAc	OAc	H	H	H	OAc
R^2	OOH	OOH	OH	OOH	OH	OOH	OH	OOH	OH	OH	OOH	OH	OOH

14a, **15a** and **20a–33a** are the corresponding methylesters

isobutyrates were present. Again these compounds could not be separated. Reduction of **28a** gave **29a**.

The ^{1}H NMR spectra of **30a**, **31a** and **33a** (Table 4) differed characteristically from those of **22a–29a** by the small couplings of H-3, which indicated axial orientated oxygen functions at C-3. The data of **30a** showed that it was the 3-epimer of **23a**. The ^{1}H NMR data were close to those of a corresponding 3α, 5α-dihydroxy eudesmanolide from an *Artemisia* species [27]. Similarly, **31a** was the epimer of **24a**. This was further supported by triphenylphosphine reduction which afforded **32a**, an epimer of **25a**. The ^{1}H NMR data of **33a** indicated the presence of a 8β-acetoxy group. Accordingly, this angelate was the 3-epimer of **26a**. The configuration of **31a** and **33a** also followed from the presence of the hydrogen bonded hydroperoxide proton which appeared as a sharp singlet at δ7.14 (7.16), and which also deshielded H-15. Most likely all the acids are derived from isocostic acid which by allylic oxidation and esterification can be transformed to **16–19** (see Scheme) or by allylic oxidation and epoxidation to **14**. The corresponding 3β-angeloyloxy derivative of the epoxide surely is the precursor of **20** formed by epoxide hydrolysis followed by elimination of water. The acids **21–33** may be biosynthesized by reaction of isocostic acid with singlet oxygen and allylic oxidation. It is remarkable that this species does not produce eudesmanolides, although many of the isolated acids have the oxygen function at C-8 necessary for the formation of alantolactone derivatives. This may indicate that eudesmanolides are usually biosynthesized via the corresponding germacranolides.

The extract of the aerial parts of *E. scariosus* DC afforded in addition to squalene, taraxasteryl acetate and dehydrofalcarinol the eudesmanolides ivangustin [28], ivangustin acetate, already prepared from the alcohol [28], as well as the corresponding 11,13-dihydrolactone **34** which could not be separated from ivangustin acetate. The latter therefore was transformed to the pyrazoline

Table 3. ^{1}H NMR spectral data of compounds **14a**, **15a**, **16–19** and **20a** (400 MHz, $CDCl_3$, δ-values)*

H	14a	15a	16	17	18	19	20a†
2α	2.45 *ddd*	1.99 *m*	1.97 *m*	1.93 *m*	1.94 *dddd*	1.94 *dddd*	1.72 *dddd*
2β	2.34 *ddd*	1.65 *m*	1.66 *m*	1.66 *m*	1.65 *dddd*	1.67 *dddd*	2.14 *dddd*
3	—	5.37 *br t*	5.37 *br t*	5.28 *br t*	5.29 *br t*	5.32 *br t*	4.86 *dd*
6	1.53 *ddd* 2.07 *dd*	2.64 *ddd* 1.85 *br dd*	2.39 *m*	2.39 *m*	2.38 *m*	2.39 *m*	5.79 *br d*
7	2.89 *dddd*	2.44 *dddd*	2.81 *br dd*	2.81 *br dd*	2.81 *br dd*	2.81 *br dd*	3.27 *br ddd*
8	1.77 *br d* 1.65 *m*	1.68 *m* 1.60 *m*	5.25 *ddd*	5.25 *ddd*	5.25 *ddd*	5.26 *dd*	1.85 *dddd* 1.63 *m*
9α 9β	1.65 *m*	1.54 m 1.44 *m*	1.85 dd 1.60 *m*	1.86 dd 1.60 *m*	1.86 dd 1.58 *m*	1.86 dd 1.60 *m*	1.57 m 1.48 *dd*
13	6.21 *br s*	6.19 *br s*	6.30 *br s*	6.30 *br s*	6.30 *br s*	6.30 *br s*	6.18 *d*
13′	5.88 *t*	5.59 *t*	5.60 *t*	5.60 *t*	5.60 *t*	5.60 *t*	5.66 *t*
14	1.08 *s*	1.14 *s*	1.24 *s*	1.25 *s*	1.25 *s*	1.25 *s*	1.37 *s*
15	1.38 *s*	1.63 *br s*	1.62 *br s*	1.60 *br s*	1.60 *br s*	1.62 *br s*	1.41 *s*
OAc	—	—	1.99 *s*	2.00 *s*	1.99 *s*	1.99 *s*	—
OCOR	—	6.02 *qq*	6.03 *qq*	2.56 *qq*	2.35 *q*	5.69 *br s*	6.09 *qq*
		1.99 *dq*	1.87 *dq*	1.18 *d*	1.17 *t*	2.17 *br q*	2.02 *dq*
		1.90 *dq*	1.89 *dq*	1.19 *d*		1.07 *t*	1.94 *dq*
						2.18 *br s*	

*OMe 3.76 *s*.

†In C_6D_6: H-3α 2.78 *br ddd*, H-3β 2.12 *br d*, H-6α 2.39 *br d*, H-6β 1.51 *dd*, H-7 3.23 *br t*, H-8 1.58 *m*, H-9α 1.95 *ddd*, H-9β 1.15 *br d*.

J[Hz]: 7,13′ = 13,13′ = 1; compound **14a**: 1α,2α = 1.5; 1β,2α = 8; 1α,2β = 8; 1β,2β = 11; 2α,2β = 19; 6α,6β = 6β,7 = 13; 6α,7 = 7,8α ~ 3; 7,8β = 10; 8α,8β = 12; compounds **15a** and **16–19**: 1α,2α = 3; 1α,2β = 2α,2β = 1β,2α = 12; 1β,2β = 3; 2α,3 = 6; 2β,3 = 8; 6α,7 ~ 3; 6β,7 = 7,8α ~ 8; 8α,9α ~ 12; 8β,9β ~ 3; 9α,9β = 15; compound **20a**: 1α,1β = 1β,2α = 2α,2β = 2β,3 ~ 12; 1α,2α = 3; 2α,3 = 4.5; 6,7 = 2.3; 7,8α = 6; 7,8β = 10; 8α,8β = 13; 8α,9α = 3; 9α,9β = 13; OAng: 3′,4′ = 7; 3′,5′ = 4′,5′ = 1.5; OiBu: 2′,3′ = 2′4′ = 7; OProp: 2′,3′ = 7; OMesen: 4′,5′ = 7.

Table 4. ^{1}H NMR spectral data of compounds

H	21a*	22a	23a	24a	25a	26a
2α	1.63 *m*	2.04 *dddd*	2.00 *m*	2.04 *m*	2.01 *m*	2.00 *m*
2β	1.20 *m*	1.55 *dddd*	1.55 *m*	1.95 *m*		1.83 *dddd*
3	2.58 *m* 2.17 *m*	4.65 *br dd*	4.68 *br dd*	5.71 *br dd*	5.90 *br dd*	5.68 *br dd*
6α	2.17 *br d*	2.19 *dd*	1.65 *dd*	2.20 *dd*	2.01 *m*	2.07 *m*
6β	1.45 *dd*	1.47 *dd*	1.79 *dd*	1.58 *dd*	1.82 *dd*	
7	2.99 *br t*	2.96 *br t*	3.05 *dddd*	3.04 *dddd*	3.09 *dddd*	3.47 *br dd*
8	1.63 *m*	1.60 *m*	1.60 *m*	1.64 *m* 1.77 *m*	1.62 *m* 1.77 *m*	5.33 *ddd*
9α	1.60 *m*	1.78 *ddd*	1.85 *ddd*	1.83 *ddd*	1.90 *ddd*	1.96 *m*
9β	1.18 *m*	1.32 *ddd*	1.27 *ddd*	1.22 *ddd*	1.27 *ddd*	1.63 *dd*
13	6.21 *br s*	6.23 *br s*	6.19 *br s*	6.20 *br s*	6.21 *br s*	6.32 *br s*
13′	5.60 *t*	5.62 *t*	5.60 *t*	5.62 *t*	5.61 *t*	5.63 *t*
14	0.96 *s*	0.95 *s*	0.88 *s*	0.99 *s*	0.92 *s*	1.11 *s*
15	5.02 *t*	5.34 *d*	5.16 *d*	5.12 *d*	4.93 *d*	5.14 *d*
15′	4.66 *t*	4.82 *d*	4.82 *d*	4.83 *br s*	4.77 *d*	4.98 *br s*
OAc	—	—	—	—	—	1.96 *s*
OCOR	—	—	—	6.12 *qq*	6.10 *qq*	6.15 *qq*
				2.02 *dq*	2.01 *dq*	2.02 *dq*
				1.96 *dq*	1.94 *dq*	1.97 *dq*
OOH	7.70 *s*	8.03 *s*	—	8.05 *s*	—	7.95 *s*

*OMe: 3.76–3.77 *s*.

J[Hz]: 7,13′ = 13,13′ ~ 1; compound **21a**: 3,15 ~ 1.5; 6α,6β = 13; 6β,7 = 12; 7,8β = 10; compounds **22a–33a**: 1α,2β = 2α,2β = 2β,3 ~ 12; 1α,2α = 2α,3 ~ 5; 6α,6β = 6β,7 = 13; 7,8 = 8,9α = 8,9β ~ 3; 9α,9β = 15; (compounds **30a–33a**: 1α,2β = 2α,2β = 12; 1β,2α = 3; 2α,3 = 2β,3 = 2.5).

derivative which was easily separated from **34**. Boranate reduction of ivangustin gave the epimers **34b** and **34c** which by acetylation afforded **34** and **34a**. The ^{1}H NMR spectra of the epimeric acetates were markedly different (Table 5). Inspection of models indicated that the observed couplings required very different conformations. The acetate **34** showed large couplings for H-8 indicating an axial orientation of this proton while H-8 in the epimer **34a** showed small couplings similar to the usual couplings of eudesman-12,8β-olides. The couplings of H-8 in ivangustin, **34** and **34b** also differed slightly. In the pyrazoline of ivangustin again the couplings of H-8 were small. These data indicated that the conformation of these compounds are highly influenced by small changes in the substitution at C-11. The dihydro derivative **34a** most likely is identical with that obtained by catalytic hydrogenation of ivangustin followed by acetylation [28]. As this epimer should be the 11α,13-dihydro derivative, the new acetate must be the 11β,13-dihydroisomer. This was confirmed by the observed NOE's. Saturation of H-14 gave effects with H-6β (6%), H-9β (5%) and H-2β (8%). Clear NOE's also were observed between H-13, H-7 (6%) and H-8 (2%) as well as between H-8, H-7 (10%) and H-1 (6%). These NOE's and the couplings indicated a boat conformation for the middle ring. The ^{13}C NMR spectrum (see Experimental) also agreed with the proposed stereochemistry.

The aerial parts of *E. africanus* L. gave dehydrofalcarinol, 11-hydroxy-5α-hydroperoxyeudesmane [29], 4α,11-dihydroxy-eudesmane [30], the eudesmanolides ivangustin [31] and **35–41** as well as the seco-eudesmane derivative **42**. The ^{1}H NMR spectrum of **35** (Table 5) was in part close to that of ivangustin. In particular, the couplings of H-8 were the same. However, the methyl singlet (H-14) was replaced by a pair of doublets at δ3.61 and 3.48 and the double doublet for H-1 was replaced by a pair of threefold doublets at δ1.87 and 1.31. These results suggested 14-hydroxy desoxyivangustin was present, and all the data agreed with this assumption. The ^{1}H NMR spectrum of **36** (Table 5) clearly indicated that a 11,13-dihydroeudesmanolide was present, again with an oxygen function at C-14 which obviously was an acetoxy group as followed from the methyl singlet at δ2.06 and the downfield shift of the H-14 signals. As in the case of the lactone **34a** the couplings of H-8 were similar as in alantolactone. Therefore, the C-11 methyl was most likely β-orientated.

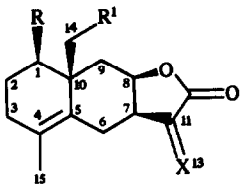
The ^{1}H NMR spectra of **37** and **38** (Table 5) indicated that these lactones differed only in the oxygen function at C-14. Accordingly, the signals of H-14 were shifted downfield in the spectrum of **38** and a methyl singlet at δ2.07 showed the presence of an acetate. The splitting of the H-8 signal again was similar to that of isoalantolactone and most signals were close to those of 5α-hydroperoxyisoalantolactone [29]. The presence of the corresponding 14-acetoxy derivative followed from the signals at δ4.23(*dd*) and 3.87(*d*) and the acetate methyl singlet.

In the ^{1}H NMR spectrum of **39** (Table 5), a methyl doublet at δ1.24 and a doublet quartet at δ2.86 indicated the presence of a 11,13-dihydro derivative of **38**. The stereochemistry was determined by NOE difference spectroscopy. Saturation of H-8 gave NOE's with H-7 (8%) and H-11 (7%) indicating α-orientation of H-7, H-8 and H-11. Further NOE's were observed between H-14′ and H-6β (4%), H-15′ and H-6α (4%), H-15 and H-3β (5%) as well as between OOH and H-3α (3%).

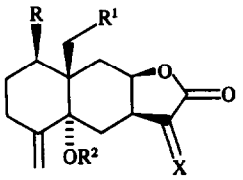
The ^{1}H NMR spectrum of **40** was in part close to that of

21a–33a (400 MHz, $CDCl_3$, δ-values)*

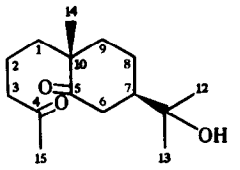
27a	28a	29a	30a	31a	32a	33a
2.00 *m*	2.03 *m*	1.95 *m*	1.86 *ddd*	1.95 *m*	2.03 *m*	1.90 *m*
1.75 *dddd*	1.75 *m*	1.69 *m*	1.77 *br d*	1.90 *m*	1.95 *m*	
5.89 *br dd*	5.58 *br dd*	5.80 *br dd*	4.38 *br t*	5.56 *br t*	5.63 *br t*	5.57 *br t*
1.46 *br dd*	2.04 *m*	1.43 *br dd*	2.10 *dd*	2.57 *br d*	2.12 *dd*	2.32 *br dd*
2.28 *dd*		2.28 *dd*	1.55 *dd*	1.62 *dd*	1.59 *dd*	2.23 *dd*
3.57 *dd dd*	3.47 *br dd*	3.56 *dddd*	2.78 *br t*	2.69 *dddd*	2.76 *br t*	3.04 *dddd*
5.30 *ddd*	5.32 *ddd*	5.27 *ddd*	1.62 *m*	1.60 *m* / 1.68 *m*	1.62 *m*	5.23 *ddd*
2.04 *m*	1.95 *m*	2.00 *m*	1.62 *m*	1.80 *ddd*	1.87 *m*	1.95 *m*
1.61 *dd*	1.62 *dd*	1.60 *dd*	1.18 *m*	1.17 *ddd*	1.23 *m*	1.54 *dd*
6.30 *br s*	6.32 *br s*	6.30 *br s*	6.19 *br s*	6.20 *br s*	6.20 *br s*	6.32 *br s*
5.60 *t*	5.62 *t*	5.59 *t*	5.60 *t*	5.62 *t*	5.61 *t*	5.70 *t*
1.04 *s*	1.09 *s*	1.03 *s*	1.10 *s*	1.11 *s*	1.12 *s*	1.22 *s*
4.98 *d*	5.12 *d*	4.98 *d*	5.53 *br s*	5.86 *s*	5.70 *br s*	5.81 *s*
4.90 *br s*	4.96 *br s*	4.89 *d*	5.31 *br s*	5.80 *s*	5.51 *br s*	5.48 *s*
1.95 *s*	1.95 *s*	1.95 *s*	—	—	—	1.97 *s*
6.11 *qq*	2.66 *qq*	2.63 *qq*	—	6.09 *qq*	6.09 *qq*	6.11 *qq*
2.01 *dq*	1.23 *d*	1.22 *d*	—	2.03 *dq*	2.01 *dq*	2.04 *dq*
1.96 *dq*	1.25 *d*	1.23 *d*		1.94 *dq*	1.90 *dq*	1.94 *dq*
—	7.98 *s*	—		7.16 *s*	—	7.14 *s*



	34	34a	34b	34c	35	36
R	OAc	OAc	OH	OH	H	H
R^1	H	H	H	H	OH	OAc
X	αMe,H	βMe,H	αMe,H	βMe,H	CH_2	βMe,H



	37	38	39	40	41
R	H	H	H	OH	OH
R^1	OH	OAc	OAc	H	H
R^2	OH	OH	OH	OH	H (5βOH)
X	CH_2	CH_2	βMe,H	CH_2	CH_2



42

asperilin [30] and 5α hydroperoxyisoalantolactone [29]. All signals were assigned by spin decoupling (Table 5). The observed couplings showed that this lactone had the usual conformation.

In the ^{1}H NMR spectrum of **41** at room temperature only a few signals could be assigned. Most signals were highly broadened; even the H-14 signal had a halfwidth of 15 Hz. However, at elevated temperature all signals could be assigned by spin decoupling and were close to those of 5β-hydroperoxyisoalanto lactone [29] and other *cis*-decalin derivatives which at room temperature are mixtures of conformers.

The molecular formula of **42** ($C_{15}H_{26}O_3$) together with the IR spectrum indicates that most likely a diketo alcohol was present. This was supported by the ^{1}H NMR spectrum (see Experimental) which showed a methyl singlet at δ2.14 typical for a methyl ketone. In deuteriobenzene most signals could be assigned by spin decoupling. All data agreed with the presence of a seco-eudesmane. The nature of the side chain was supported by the following fragments: *m/z* 196 [M − Me_2C=O, McLafferty]$^+$, 170 [M − C_3H_5COMe, McLafferty]$^+$ and 111 [170 − Me_2COH]$^+$. A positive Cotton effect established the absolute configuration as the octant rule should be valid. The corresponding 11-O-xylopyranoside was previously isolated from an *Iphiona* species [31]. The ^{1}H NMR data are very similar. The aerial parts of *E. ericoides* Druce afforded only the germacranolide **2**.

The overall picture of the chemistry of the genus *Eriocephalus* clearly supports its placement in the tribe Anthemideae. The co-occurrence of dehydrofalcarinol and of several types of sesquiterpene lactones has been reported for many *Artemisia* species [32, 33] but never from *Tarchonanthus* and related genera or from representatives of the *Lasiospermum* group. Most *Ursinia* species contain the rare *cis*-12,6-lactones [34] and, as related genera, typical alicyclic furan sesquiterpenes [35]. Dehydrofalcarinol and related diynes are reported from some South African Anthemideae genera: *Lidbeckia* [36], *Schistostephium* [19], *Peyrousia* [37] and *Thaminophyllum* [37], but only from *Lidbeckia* [36] and *Schistostephium* [19] were different types of sesquiterpene lactones isolated. The latter genus contains costic acid derivatives [19] also present in some *Artemisia* species [27]. Chrysanthemol has been reported from *Artemisia ludoviciana* [22].

Table 5. ^{1}H NMR spectral data of compounds **34–40** and **34a** (400 MHz, $CDCl_3$, δ-values)

H	34	34a	35	36	37	38	39	40	41 (60°)
1	4.75 *dd*	4.71 *t*	1.31 *ddd* 1.87 *ddd*					3.89 *dd*	3.78 *dd*
3α	2.16 *m*	2.21 *br dd*	1.98 *m*	1.97 *m*	2.45 *br dd*	2.44 *br dd*	2.45 *br dd*	2.49 *br ddd*	2.25 *br ddd*
3β	1.95 *br d*	2.02 *br d*			2.26 *br d*	2.27 *br d*	2.27 *br d*	2.28 *ddd*	2.51 *ddd*
6α	2.74 *dd*	2.46 *dd*	2.83 *dd*	2.52 *dd*	2.37 *dd*	2.39 *dd*	2.22 *dd*	2.35 *dd*	2.30 *dd*
6β	1.86 *br dd*	1.71 *m*	1.94 *br dd*	1.60 *m*	1.46 *dd*	1.47 *dd*	1.25 *dd*	1.59 *dd*	1.97 *dd*
7	2.16 *m*	2.30 *m*	3.07 *m*	2.33 *m*	3.32 *br ddd*	3.32 *br ddd*	2.80 *br ddd*	3.30 *br ddd*	3.23 *ddddd*
8	4.46 *ddd*	4.44 *ddd*	4.54 *ddd*	4.44 *ddd*	4.57 *ddd*	4.56 *ddd*	4.53 *ddd*	4.66 *ddd*	4.78 *ddd*
9α	1.95 *m*	1.49 *dd*	1.72 *dd*	1.47 *dd*	1.74 *ddd*	1.77 *ddd*	1.72 *ddd*	1.95 *dd*	1.56 *dd*
9β		2.32 *dd*	1.94 *dd*	2.46 *dd*	2.27 *dd*	2.32 *dd*	2.31 *dd*	2.34 *dd*	2.15 *dd*
11	2.39 *dq*	2.80 *dq*	—	2.78 *dq*	—	—	2.86 *dq*	—	—
13	1.30 *d*	1.23 *d*	6.24 *d*	1.22 *d*	6.18 *d*	6.19 *d*	1.24 *d*	6.19 *d*	6.30 *d*
13′			5.62 *d*		5.67 *d*	5.67 *d*		5.67 *d*	5.63 *d*
14	1.05 *s*	1.16 *s*	3.61 *br d*	4.20 *br d*	3.60 *br d*	4.23 *dd*	4.23 *dd*	0.97 *s*	0.90 *s*
14′			3.48 *br d*	3.94 *d*	3.52 *br d*	3.87 *d*	3.82 *d*		
15	1.63 *br s*	1.64 *br s*	1.70 *br s*	1.68 *br s*	5.11 *br d*	5.17 *br s*	5.17 *br s*	5.18 *br s*	4.98 *br s*
15′					4.79 *br s*	4.87 *br s*	4.90 *br s*	4.90 *br s*	5.11 *br s*
OOH	—	—	—	—	7.11 *s*	7.08 *s*	6.99 *s*	7.51 *s*	—
OAc	1.95 *s*	2.08 *s*	—	2.06 *s*	—	2.07 *s*	2.07 *s*	—	—

J[Hz]: Compound **34**: 1,2α = 5; 1,2β = 12; 3α,3β = 15; 6α,6β = 6β,7 = 13; 6α,7 = 7,8 = 7,11 = 11,13 ~ 7; 8,9α = 5; 8,9β = 9; compound **34a**: 1,2α = 1,2β ~ 8; 2α,3α = 2β,3α = 8; 3α,3β = 17; 6α,6β = 14; 6α,7 = 6; 6β,7 = 10; 7,8 = 3; 7,11 = 11,13 = 7; 8,9α = 4; 8,9β = 2; 9α,9β = 15; compound **35**: 1α,1β = 1α,2β = 2α,2β = 2β,3α ~ 12; 1α,2α = 2β,3α = 2β,3β ~ 3; 6α,6β = 14; 6α,7 = 7,8 ~ 7; 7,13 = 2.3; 7,13′ = 2; 8,9α = 4.5; 8,9α = 8; 9α,9β = 14; compound **36**: 6α,6β = 14; 6α,7 = 6; 6β,7 = 12; 7,8 = 5; 7,11 = 11,13 = 7; 8,9α = 4.5; 8,9β = 2; 9α,9β = 15; 9α,14 = 1; 14,14′ = 11; compounds **37** and **38**: 2β,3α = 3α,3β ~ 13; 6α,6β = 14; 6α,7 = 7; 6β,7 = 12; 7,8 = 5; 7,13 = 1; 8,9α = 5; 8,9β = 9α,14 = 1.5; 9α,9β = 15; 14,14′ = 12; compound **39**: 2β,3α = 3α,3β = 13; 6α,6β = 14; 6α,7 = 5; 6β,7 = 11; 7,8 = 4; 7,11 = 11,13 = 7; 7,13 = 1; 8,9α = 5; 8,9β = 9α,14 = 1.5; 9α,9β = 15; 14,14′ = 11; compound **40**: 1,2α = 4.5; 1,2β = 12; 2α,3α = 2β,3β ~ 5; 2β,3α = 3α,3β = 13; 2β,3α = 2; 6α,6β = 14; 6α,7 = 6; 6β,7 = 11.5; 7,8 = 8,9α = 5; 7,13 = 8,9β ~ 1; 9α,9β = 15; compound **41**: 1,2α = 4; 1,2β = 9.5; 2α,3β = 2β,3β = 2α,3α ~ 4; 2β,3α = 3α,3β = 14; 6α,6β = 15; 6α,7 = 7; 6β,7 = 4; 7,8 = 8; 7,13 = 3; 8,9α = 9; 8,9β = 6; 9α,9β = 14.

Clearly more data are required. However, already a clear relationship of *Eriocephalus* to parts of the tribe Anthemideae is visible. Two of the investigated species gave no characteristic compounds. This phenomenon can be observed in many genera even if the majority of species are characterized by typical constituents.

EXPERIMENTAL

The air-dried plant material was extracted with MeOH–Et_2O–petrol (1:1:1), and the extracts obtained were worked-up as reported previously [38]. The extract of the aerial parts of *Eriocephalus* sp. n. (250 g, voucher M. Müller 3715, collected near Aus-Koppies, Namibia) gave by CC three fractions (1; Et_2O–petrol 1:2:2; Et_2O and 3; Et_2O–MeOH 9:1). TLC of fraction 1 (Et_2O–Petrol, 1:3) gave 20 mg neryl acetate, 30 mg camphor, 10 mg nerolidol and 10 mg spathulenol. TLC of fraction 2 (Et_2O–petrol, 1:1) gave 2 mg costunolide and 30 mg estafiatin (**8**). Fraction 3 was separated by medium pressure chromatography (MPCC) (silica gel, ϕ 30–60 μ, 40 fractions of 20 ml, starting with Et_2O–petrol, 1:3, with increasing amounts of Et_2O, finally Et_2O–MeOH, 9:1). Fractions 4–15 gave 300 mg 8-desoxycumambrin B (**4a**), fractions 16–24 were separated by TLC ($CHCl_3$–C_6H_6–Et_2O–MeOH, 15:15:15:1) affording 30 mg **1** (R_f 0.68) and 3 mg **3** (R_f 0.52). Fractions 25–30 gave by HPLC (MeOH–H_2O, 3:2, always RP 8, *ca* 100 bar) 12 mg **3** (R_t 2.6 min.). Fractions 31–40 gave by HPLC (MeOH–H_2O, 1:1) 3 mg **5a** (R_t 2.8 min.) and a mixture (R_t 2.0 min.) which gave by TLC (Et_2O–MeOH, 50:1) 6 mg **7a** (R_f 0.40) and 1 mg **6a**.

The extract of the aerial parts of *E. giessii* (350 g, voucher M. Müller 3709A, collected from farm plateau LUS 38, Namibia) gave by CC three fractions (1: petrol; 2: Et_2O–petrol, 1:10 and 1:3 and 3: Et_2O and Et_2O–MeOH, 9:1). Fraction 1 gave by TLC 30 mg bicyclogermacrene and fraction 2, 30 mg caryophyllene epoxide and 60 mg spathulenol. Fraction 3 gave by TLC (Et_2O) two bands (3/2 and 3/2). Repeated TLC of 3/1 (Et_2O–$CHCl_3$–C_6H_6–MeOH, 30:30:30:1) gave 5 mg 5-hydroxy-6,7,4′-trimethoxyflavone, 2 mg 5-hydroxy-6,7,3′,4′-tetramethoxyflavone, 2 mg 5,6-dihydroxy-7,3′,4′-trimethoxyflavone, 3 mg pectolinarigenin, 12 mg **4c** (R_f 0.45) and a mixture which gave by HPLC (MeOH–H_2O, 1:1) 3 mg **4d** (R_t 10.3 min.), 3 mg **4c** (R_t 10.8 min.) and 2 mg **4e** (R_t 12.4 min.). Repeated TLC of 3/2 (Et_2O–$CHCl_3$–C_6H_6–MeOH, 10:10:10:1) gave three bands (3/2/1–3/2/3). HPLC of 3/2/1 (MeOH–H_2O, 1:1) gave 5 mg **4b** (R_t 6.2 min.) and HPLC of 3/2/2 (MeOH–H_2O, 1:1) afforded 1 mg rupicolin B (R_t 3.6 min.) and a mixture (R_t 1.8 min.) which gave by repeated HPLC (MeOH–H_2O, 2:3) 6 mg **7c** (R_t 3.8 min.) and a mixture which was separated by TLC (Et_2O–MeOH, 20:1) affording 2 mg **5c** (R_f 0.65) and 2 mg **6b** (R_f 0.48) HPLC of 3/2/3 (MeOH–H_2O, 2:3) gave 1 mg **7d** (R_t 3.3 min.) and 1 mg **5b** (R_t 4.5 min.).

The extract of the aerial parts of *E. kingesii* (180 g, voucher M. Müller 3680, collected from Nautilus Mountain, Westslope, Namibia) gave by CC four fractions (1; petrol, 2; Et_2O–petrol 1:9 and 1:3, 3; Et_2O–petrol 1:1 and 4; Et_2O and Et_2O–MeOH 9:1). TLC of fraction 1 gave 50 mg squalene and of fraction 2 5 mg taraxasteryl acetate. TLC of fraction 3 afforded 10 mg dehydrofalcarinol and MPCC of fraction 4 (Et_2O–petrol 1:1, Et_2O

and Et_2O–MeOH 9:1) gave 48 fractions (20 ml). TLC (Et_2O–petrol, 1:1) of fractions 8 and 9 gave 10 mg costunolide, 5 mg **13**, 15 mg **8** and 180 mg parthenolide. TLC of fractions 10–13 ($CHCl_3$–C_6H_6–Et_2O–MeOH, 30:30:30:1) gave 20 mg parthenolide and three mixtures (10/2–10/4). HPLC (MeOH–H_2O, 7:3) of 10/2 gave 2 mg 1-peroxycostunolide (R_t 1.5 min.), 2 mg 8α-acetoxyparthenolide (R_t 2.3 min.), 1 mg 3β-acetoxyparthenolide (R_t 2.4 min.) and 3 mg parthenolide (R_t 2.6 min.). HPLC of 10/3 (MeOH–H_2O, 7:3) gave 2 mg **12** (R_t 0.8 min.) and 2 mg santamarin (R_t 2.3 min.). HPLC of 10/4 (MeOH–H_2O, 7:3) gave 2 mg reynosin (R_t 1.4 min.) and 1 mg **9** (R_t 2.6 min.). HPLC of MPCC fractions 36–40 (MeOH–H_2O, 3:2) gave 1 mg **11** (R_t 0.8 min.), 5 mg costunolide 1β,10α,4α,5β-diepoxide (R_t 1.3 min.), 3 mg artemorin (R_t 2.5 min.) and 5 mg 7,3′-dimethoxy-5,6,4′-trihydroxyflavone (R_t 4.7 min.).

The extract of the aerial parts of *E. pauperrimus* (200 g, voucher M. Müller 3701, collected near farm Saraus BET, Namibia) gave by CC three fractions (1; Et_2O–petrol 1:3–3:1,2; Et_2O and 3; Et_2O–MeOH 9:1). Fraction 1 gave 20 mg phloracetophenone-2-*O*-4-*O*-dimethyl ether and fraction 2 gave by TLC (Et_2O–petrol 1:1) four bands (2/1–2/4). HPLC (MeOH–H_2O 4:1) of 2/1 gave 4 mg **18** (R_t 5.2 min.), 3 mg **17** (R_t 7.0 min.), 8 mg **16** (R_t 8.5 min.) and 1 mg **19** (R_t 12.4 min.). After addition of CH_2N_2 2/2 gave by TLC (Et_2O–petrol, 1:1) 9 mg **15a** (R_f 0.68) and a mixture which gave by HPLC (MeOH–H_2O, 3:1) 3 mg **33a** (R_t 5.3 min.), 2 mg **28a** containing 0.3 mg **29a** (R_t 8.3 min.) and 15 mg **26a** containing 2 mg **27a** (R_t 11.0 min.). After addition of CH_2N_2 2/3 gave by TLC (Et_2O–petrol 1:1) 3 mg **20a** (R_f 0.58) and 15 mg **31a** (R_f 0.50). After addition of CH_2N_2 2/4 gave by HPLC (MeOH–H_2O 4:1) 2 mg **14a** (R_t 1.3 min.), 1 mg **21a** (R_t 4.0 min.) and 10 mg **24a** (R_t 7.2 min.). From CC fraction 3 the acids were extracted with K_2CO_3 soln and the isolated acids methylated with CH_2N_2. HPLC (MeOH–H_2O 7:3) gave 16 mg **30a** (R_t 7.8 min) and a mixture which gave by TLC (Et_2O–petrol 3:1, two developments) 10 mg **22a** (R_f 0.45) and 10 mg **23a** (R_f 0.35).

The extract of the aerial parts of *E. merxmülleri* (200 g, voucher M. Müller 3709, collected near farm plateau LUS 38, Namibia) afforded 20 mg camphor and that of *E. ambigius* (240 g, voucher M. Müller 3711, collected in Namibia) gave 10 mg taraxasteryl-acetate and 5 mg caryophylenepoxide.

The extract of the aerial parts of *E. scariosus* (150 g, voucher M. Müller 3706, collected 40 km east of Lüderitz, Namibia) was first separated by CC. The fractions obtained with petrol–Et_2O (1:10), gave by TLC 3 mg squalene and 5 mg taraxasterylacetate. The next fraction (Et_2O–petrol 1:1) gave 2 mg dehydrofalcarinol and the polar fractions (Et_2O and Et_2O–MeOH 9:1) afforded by TLC (Et_2O–petrol 3:1) 10 mg ivangustin, mp 121° (lit. [27] 120–122°) and a mixture of ivangustin acetate and **34** which could not be separated by TLC or HPLC. After addition of CH_2N_2, TLC (Et_2O–petrol 1:1) gave 4 mg **34** (R_f 0.50) and 10 mg of the pyrazolin of ivangustin acetate, mp 140° (lit. [27] 139–141°).

The extract of the aerial parts of *E. africanus* (200 g, voucher 86/173, collected at Chapmans corner, south of Capetown, R.S.A.) was separated by CC into three fractions. 1; petrol and Et_2O–petrol, 1:9 2; Et_2O–petrol 1:1 and Et_2O and 3; Et_2O–MeOH 9:1. Fraction 1 gave noting of interest. TLC of fraction 2 (Et_2O–petrol 1:1) gave 10 mg dehydrofalcarinol, 10 mg 11-hydroxy-5α-hydroperoxyeudesmane and a mixture which gave by repeated TLC four bands (2/3/1–2/3/4). HPLC of 2/3/1 (MeOH–H_2O 7:3) gave 1.5 mg **36** (R_t 5.7 min.). HPLC of 2/3/2 (MeOH–H_2O 3:2)(gave 1.5 mg **39** (R_t 4.2 min) and 2 mg **38** (R_t 4.7 min). HPLC of 2/3/3 (MeOH–H_2O 3:2) gave a mixture of ivangustin and **35** (R_t 7.3 min.) which was separated by TLC ($CHCl_3$–C_6H_6–Et_2O 2:2:1) affording 30 mg ivangustin and 5 mg **35** (R_t 0.62). HPLC of 2/3/4 (MeOH–H_2O 3:2) gave 5 mg **37** (R_t 1.7 min). TLC of fraction 3 (Et_2O–petrol 3:1) gave 100 mg 4α,11-dihydroxy-eudesmane and a mixture which gave by HPLC (MeOH–H_2O 11:9) 10 mg **40** (R_t 3.3 min.), 3 mg **41** (R_t 2.5 min.) and 4 mg **42** (R_t 6.3 min).

The extract of the aerial parts of *E. ericoides* (100 g, voucher 86/151, Botanical Garden, Kirstenbosch, R.S.A.) afforded by CC and TLC (Et_2O–petrol 3:1) 20 mg **2**. Known compounds were identified by comparing the 400 MHz ^1H NMR spectra with those of authentic material.

2α-Hydroxyhanphyllin-3-O-acetate (**3**). Colourless crystals, mp 188°; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3600 (OH), 1765 (γ-lactone), 1750, 1235 (OAc); MS *m/z* (rel. int.): 306.147 $[M]^+$ (4) (calc. for $C_{17}H_{22}O_5$: 306.147), 264 $[M - ketene]^+$ (52), 246 $[M - HOAc]^+$ (26), 231 $[246 - Me]^+$ (20), 218 $[246 - CO]^+$ (23), 180 (50), 162 (62), 121 (58), 97 (100); $[\alpha]_D^{24°} + 131$ ($CHCl_3$; *c* 0.37).

11β,13-Dihydro-epi-ligustrin (**4b**). Colourless crystals, mp 67°; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3620 (OH), 1770 (γ-lactone); MS *m/z* (rel. int.): 266.152 $[M]^+$ (20) (calc. for $C_{15}H_{22}O_4$: 266.152), 248 $[M - H_2O]^+$ (20), 220 $[248 - CO]^+$ (11), 205 $[220 - Me]^+$ (17), 108 (95), 107 (100); $[\alpha]_D^{24°} + 61$ ($CHCl_3$; *c* 0.30).

3α-Hydroperoxi-3-desoxoparishin A (**5a**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3580 (OH), 1770 (γ-lactone); MS *m/z* (rel. int.): 262.121 $[M - H_2O]^+$ (12) (calc. for $C_{15}H_{18}O_4$: 262.121), 247 $[M - OOH]^+$ (15), 246 $[M - H_2O_2]^+$ (19), 228 $[246 - H_2O]^+$ (12), 165 (100); CD (MeCN): $\Delta\varepsilon_{262} - 1.3$.

3α-Hydroxy-8α-acetoxy-3-desoxo-11β,13-dihydroparishin A (**5b**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3620 (OH), 1770 (γ-lactone), 1740, 1230 (OAc); MS *m/z* (rel. int.): 306.147 $[M]^+$ (46) (calc. for $C_{17}H_{22}O_5$: 306.147), 264 $[M - ketene]^+$ (68), 246 $[M - HOAc]^+$ (70), 203 (48), 178 (59), 167 (60), 43 (100).

3α-Hydroperoxi-8α-acetoxy-3-desoxo-11β,13-dihydroparishin A (**5c**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3600 (OH), 3520 (OOH), 1770 (γ-lactone), 1735 (OAc); MS *m/z* (rel. int.): 340 $[M]^+$ (2), 322.142 $[M - H_2O]^+$ (51) (calc. for $C_{17}H_{22}O_6$: 322.142), 306 $[M - H_2O_2]^+$ (74), 264 $[306 - ketene]^+$ (76), 246 $[306 - HOAc]^+$ (75), 167 (88), 111 (100).

8α-Acetoxy-11β,13-dihydroparishin A (**6b**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3630 (OH), 1780 (γ-lactone), 1740 (OAc), 1710 (C=CC=O); MS *m/z* (rel. int.): 322.142 $[M]^+$ (26) (calc. for $C_{17}H_{22}O_6$ 322.142), 280 $[M - ketene]^+$ (8), 262 $[M - HOAc]^+$ (70), 244 $[262 - H_2O]^+$ (5), 219 (33), 193 (32), 111 (71), 58 (100); CD (MeCN): $\Delta\varepsilon_{337} - 2.2$; $\Delta\varepsilon_{323} - 2.5$.

4α-Hydroperoxi-10α-hydroxy-1α,5αH-guaia-2,11(13)-dien-12,6α-olide (**7a**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3600 (OH), 1765 (γ-lactone); MS *m/z* (rel. int.): 280 $[M]^+$ (0.5), 262. 121 $[M - H_2O]^+$ (8) (calc. for $C_{15}H_{18}O_4$: 262.121), 246 $[M - H_2O_2]^+$ (8), 228 $[246 - H_2O]^+$ (12), 167 (100); CD (MeCN): $\Delta\varepsilon_{260}$ 1.1. Addition of triphenylphosphine in $CDCl_3$ afforded the corresponding 4α-hydroxy derivative **7b**, identical with the natural diol.

4α,10α-Dihydroxy-1,5H-guaia-2,11(13)-dien-12,6α-olide (**7b**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3600 (OH), 1765 (γ-lactone): MS *m/z* (rel. int.): 264.136 $[M]^+$ (5) (calc. for $C_{15}H_{20}O_4$ 264.136), 246 $[M - H_2O]^+$ (12), 228 $[246 - H_2O]^+$ (11), 167 (100).

4α-Hydroperoxi-10α-hydroxy-8α-acetoxy-1α,5α,11βH-guaia-2-en-12,6α-olide (**7c**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3540 (OH), 1775 (γ-lactone), 1745 (OAc); MS *m/z* (rel. int.): 322.142 $[M - H_2O]^+$ (6) (calc. for $C_{17}H_{22}O_6$ 322.142), 307 $[322 - Me]^+$ (6), 306 $[M - H_2O_2]^+$ (4.5), 246 $[306 - HOAc]^+$ (24), 167 (100).

4α,10α-Dihydroxy-8-acetoxy-1α,5α,11βH-guaia-2-en-12,6α-olide (**7d**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3620 (OH), 1780 (γ-lactone), 1735 (OAc); MS *m/z* (rel. int.); 309.134 $[M - Me]^+$ (12) (calc. for $C_{16}H_{21}O_6$: 309.134), 306 $[M - H_2O]^+$ (5), 264 $[M - HOAc]^+$ (5), 246 $[306 - HOAc]^+$ (65), 167 (100).

4α-Hydroxy-1α,5αH-guaia-2,10(14),11(13)-trien-12,6α-olide (**9**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3600 (OH), 1765 (γ-lactone); MS *m/z* (rel. int.). 246 $[M]^+$ (6), 231.102 $[M - Me]^+$ (100) (calc.

for $C_{14}H_{15}O_3$: 231.102), 213 $[231-H_2O]^+$ (10), 185 (20), 149 (42), 91 (42); CD (MeCN): $\Delta\varepsilon_{265}-1.1$.

1β,5β-Dihydroxyeriocephaloide (**11**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3620 (OH), 1770 (γ-lactone); MS *m/z* (rel. int.): 264.136 $[M]^+$ (4) (calc. for $C_{15}H_{20}O_4$: 264.136), 246 $[M-H_2O]^+$ (10), 208 (32), 121 (30), 58 (100); ^1H NMR ($CDCl_3$): δ4.41 (*br d*, H-1), 1.98 (*br d*, H-2), 1.84 (*m*, H-2'), 1.77 (*m*, H-3), 1.48 (*m*, H-3'), 3.90 (*br d*, H-5), 4.19 (*dd*, H-6), 2.64 (*ddddd*, H-7), 2.45 (*ddd*, H-8α), 2.37 (*ddd*, H-8β), 5.71 (*t*, H-9), 6.22 and 5.53 (d, H-13), 2.22 (*br d*, H-14), 2.17 (*d*, H-14'), 0.98 (*s*, H-15) (*J* [Hz]: 1,2 = 3; 1,2' = 1,14 = 3,14 ~ 1; 2,2' = 15; 5,6 = 7.5; 6.7 = 9.5; 7,8α = 2.5; 7.8β = 11; 7,13 = 3.5; 7,13' = 3.0; 8α,8β = 14; 8α,9 = 7.5; 14,14' = 12.5; CD (MeCN): $\Delta\varepsilon_{288}-1.9$.

4-Hydroperoxi-4,5-dihydro-chrysanthem-5-en-ol (**12**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3540 (OH); MS *m/z* (rel. int.): 137 $[M-H_2O, CH_2OH]^+$ (100); CIMS *m/z* (rel. int.): 169 $[M+1-H_2O]^+$ (100); ^1H NMR ($CDCl_3$): δ3.64 and 3.57 (*dd*, H-1), 0.87 (*ddd*, H-2), 0.62 (*dd*, H-3), 3.96 (*d*, H-4), 5.00 (*br s*, H-6), 1.83 (*br s*, H-7), 1.25 (*s*, H-9), 1.15 (*s*, H-1), 7.76 (*br s*, OOH) (*J* [Hz]: 1,2 = 7; 1,2' = 8; 1,1' = 11; 2,3 = 5; 3,4 = 10).

4α,5α-Epoxy-3-oxo-4(15)-dihydrocostic acid methyl ester (**14a**). Colourless oil; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1725 (C=CCO_2R), 1705 (C=O); MS *m/z* (rel. int.): 278.152 $[M]^+$ (9) (calc. for $C_{16}H_{22}O_4$: 278.152), 260 $[M-H_2O]^+$ (12), 250 $[M-CO]^+$ (27), 247 $[M-OMe]^+$ (28), 235 $[250-Me]^+$ (17), 203 $[235-MeOH]^+$ (95), 175 $[203-CO]^+$ (45), 161 (94), 133 (100), 107 (74); ^{13}C NMR ($CDCl_3$, C-1 – C-15): δ31.7 *t**, 37.9 *t*, 207.7 *s*, 71.7 *s*, 65.4 *s*, 26.9 *t*, 38.0 *d*, 31.5 *t**, 33.3 *t**, 33.8 *s*, 144.3 *s*, 167.1 *s*, 123.7 *t*, 11.4 *q*, 20.7 *q*; OMe: 51.9 *q* (* assignments may be interchangeable).

3β-Angeloyloxyisocostic acid methyl ester (**15a**). Colourless oil; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1715, 1650, 1620 (C=CCO_2R); MS *m/z* (rel. int.): 346.214 $[M]^+$ (1) (calc. for $C_{21}H_{30}O_4$: 346.214), 315 $[M-OMe]^+$ (0.7), 246 $[M-HOAng]^+$ (100), 231 $[246-Me]^+$ (22), 215 $[246-OMe]^+$ (9), 187 $[215-CO]^+$ (19), 83 $[C_4H_7CO]^+$ (71); $[\alpha]_D^{24°}-26$ ($CHCl_3$; *c* 0.86).

8β-Acetoxy-3β-angeloyloxy-isocostic acid methyl ester (**16**). Colourless crystals, mp 68°: IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1735 (OAc), 1720, 1650, 1630 (C=CCO_2R); MS *m/z* (rel. int.): 404.220 $[M]^+$ (1) (calc. for $C_{23}H_{32}O_6$), 344 $[M-HOAc]^+$ (4), 312 $[344-MeOH]^+$ (1.2), 244 $[344-HOAng]^+$ (48), 229 $[244-Me]^+$ (12), 83 $[C_4H_7CO]^+$ (100), 55 $[83-CO]^+$ (37); $[\alpha]_D^{24°}-51$ ($CHCl_3$; *c* 0.1).

8β-Acetoxy-3β-isobutyryloxyisocostic acid methyl ester (**17**). Colourless crystals, mp 103°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1735 (CO_2R), 1630 (C=C); MS *m/z* (rel. int.): 392.220 $[M]^+$ (0.6) (calc. for $C_{22}H_{32}O_6$ 392.220), 332 $[M-HOAc]^+$ (3), 300 $[332-MeOH]^+$ (1.5), 244 $[332-RCO_2H]^+$ (100), 229 $[244-Me]^+$ (21), 71 $[C_3C_7CO]^+$ (25); $[\alpha]_D^{24°}-32$ ($CHCl_3$; *c* 0.25).

8β-Acetoxy-3β-propionyloxyisocostic acid methyl ester (**18**). Colourless crystals, mp 111°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1735 (CO_2R), 1630 (C=C); MS *m/z* (rel. int.): 378.204 $[M]^+$ (0.8) (calc. for $C_{21}H_{30}O_6$ 378.204), 318 $[M-HOAc]^+$ (3), 304 $[M-EtCO_2H]^+$ (3), 262 $[304-ketene]^+$ (66), 244 $[304-HOAc]^+$ (100), 229 (31), 57 $[EtCO]^+$ (45); $[\alpha]_D^{24°}-30$ ($CHCl_3$; *c* 0.34).

8β-Acetoxy-3β-[4-methylsenecioyloxy]-isocostic acid methyl ester (**19**). Colourless oil; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1730 (CO_2R); MS *m/z* (rel. int.): 418.236 $[M]^+$ (1) (calc. for $C_{24}H_{34}O_6$ 418.236), 358 $[M-HOAc]^+$ (1), 304 $[M-RCO_2H]^+$ (3), 244 $[304-HOAc]^+$ (72), 97 $[C_5H_9CO]^+$ (100).

3β-Angeloyloxy-4β-hydroxy-Δ⁵-costic acid methyl ester (**20a**). Colourless crystals, mp 101°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3560 (OH), 1720, 1625 (C=CCO_2R); MS *m/z* (rel. int.): 362.209 $[M]^+$ (0.2) (calc. for $C_{21}H_{30}O_5$ 362.209), 345 $[M-OH]^+$ (4), 262 $[M-RCO_2H]^+$ (6), 244 $[262-H_2O]^+$ (6), 230 $[262-MeOH]^+$ (6), 83 $[C_4H_7CO]^+$ (100), 55 $[83-CO]^+$ (36); $[\alpha]_D^{24°}+56$ ($CHCl_3$; *c* 0.05).

5α-Hydroperoxycostic acid methyl ester (**21a**). Colourless oil; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3500 (OH), 1720 (C=CCO_2R); MS *m/z* (rel. int.): 249.149 $[M-OMe]^+$ (21) (calc. for $C_{15}H_{21}O_3$ 249.149), 247 $[M-OOH]^+$ (88), 232 $[247-Me]^+$ (31), 215 $[247-MeOH]^+$ (32), 187 $[215-CO]^+$ (36), 95 (100).

3β-Hydroxy-5α-hydroperoxycostic acid methyl ester (**22a**). Colourless crystals, mp 123°: IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3600 (OH), 1720 (C=CCO_2R); MS *m/z* (rel. int.): 263.165 $[M-OOH]^+$ (41) (calc. for $C_{16}H_{23}O_3$ 263.165), 245 $[263-H_2O]^+$ (100), 213 $[245-MeOH]^+$ (52), 185 $[213-CO]^+$ (52); $[\alpha]_D+73$ ($CHCl_3$; *c* 0.04).

3β,5α-Dihydroxycostic acid methyl ester (**23a**). Colourless crystals, mp 131°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3600 (OH), 1720 (C=CCO_2R); MS *m/z* (rel. int.): 280.167 $[M]^+$ (6) (calc. for $C_{16}H_{24}O_4$ 280.167), 262 $[M-H_2O]^+$ (51), 249 $[M-OMe]^+$ (36), 247 $[262-Me]^+$ (28), 230 $[262-MeOH]^+$ (84), 202 $[230-CO]^+$ (41), 95 (100); $[\alpha]_D^{24°}+99$ ($CHCl_3$; *c* 0.19).

3β-Angeloyloxy-5α-hydroperoxycostic acid methyl ester (**24a**). Colourless crystals, mp 133°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3400 (OOH); MS *m/z* (rel. int.): 345.207 $[M-OOH]^+$ (14) (calc. for $C_{21}H_{29}O_4$ 345.207), 245 $[345-AngOH]^+$ (61), 213 $[245-MeOH]^+$ (18), 185 $[213-CO]^+$ (21), 83 $[C_4H_7CO]^+$ (100), 55 $[83-CO]^+$ (64). To 3 mg **24a** in 0.5 ml $CDCl_3$ 10 mg triphenylphosphine was addedd. After 5 min TLC gave 2 mg **25a**, ^1H NMR: Table 4.

8β-Acetoxy-3β-angeloyloxy-5α-hydroperoxycostic acid methyl ester (**26a**) (containing 10% **27a**). Colourless crystals, mp 160°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3500 (OH), 1740 (OAc), 1730 (CO_2R); MS *m/z* (rel. int.): 403.212 $[M-OOH]^+$ (7) (calc. for $C_{23}H_{31}O_6$ 403.212), 343 $[403-HOAc]^+$ (8), 320 $[403-RCO]^+$ (4), 260 $[320-HOAc]^+$ (26), 83 $[C_4H_7CO]^+$ (100), 55 $[83-CO]^+$ (51); $[\alpha]_D^{24°}+37$ ($CHCl_3$; *c* 0.22). To 5 mg **26a** in 0.5 mg $CDCl_3$ 10 mg triphenylphosphine was added. PTLC (Et_2O–petrol 1:1) afforded 4 mg **27a**, identical with the methyl ester of the natural product.

8β-Acetoxy-3β-angeloyloxy-5α-hydroxycostic acid methyl ester (**27a**). Colourless crystals, mp 172–173°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3620 (OH), 1735 (OAc), 1720, 1650, 1630 (C=CCO_2R); MS *m/z* (rel. int.): 420.215 $[M]^+$ (0.5) (calc. for $C_{23}H_{32}O_7$ 420.215), 360 $[M-HOAc]^+$ (1), 342 $[360-H_2O]^+$ (5), 320 $[M-AngOH]^+$ (10), 260 $[320-HOAc]^+$ (49), 83 $[C_4H_7CO]^+$ (100), 55 $[83-CO]^+$ (60); $[\alpha]_D^{24°}+17$ ($CHCl_3$; *c* 0.23).

8β-Acetoxy-3β-isobutyryloxy-5α-hydroperoxycostic acid methyl ester (**28a**) (containing *ca* 15% **29a**). Colourless crystals, mp 145°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3500 (OH), 1735 (OAc), 1720, 1650, 1630 (C=CCO_2R); MS *m/z* (rel. int.). 391.212 $[M-OOH]^+$ (40) (calc. for $C_{22}H_{31}O_6$ 391.212), 331 $[391-HOAc]^+$ (52), 260 $[331-RCO]^+$ (100), 243 $[331-RCO_2H]^+$ (66), 71 $[C_3H_7CO]^+$ (92). To 3 mg **28a** in 0.5 ml $CDCl_3$ 10 mg triphenylphosphine was added. PTLC (Et_2O–petrol 1:1) gave **29a**, identical with the ester of the natural compound.

8β-Acetoxy-3β-isobutyryloxy-5α-hydroxycostic acid methyl ester (**29a**). Colourless crystals, mp 151°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3600 (OH), 1740 (OAc), 1730 (CO_2R); MS *m/z* (rel. int.): 408.215 $[M]^+$ (0.5) (calc. for $C_{22}H_{32}O_7$ 408.215), 390 $[M-H_2O]^+$ (0.3), 348 $[M-HOAc]^+$ (2), 330 $[348-H_2O]^+$ (11), 320 $[M-RCO_2H]^+$ (20), 260 $[320-HOAc]^+$ (100), 94 (92); $[\alpha]_D^{24°}+16$ ($CHCl_3$; *c* 0.1).

3α, 5α-Dihydroxycostic acid methyl ester (**30a**). Colourless oil; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3600 (OH), 1720 (C=CCO_2R); MS *m/z* (rel. int.): 280.167 $[M]^+$ (5) (calc. for $C_{16}H_{24}O_4$ 280.167), 262 $[M-H_2O]^+$ (86), 247 $[262-Me]^+$ (17), 244 $[262-H_2O]^+$ (18), 230 $[262-MeOH]^+$ (63), 202 $[230-CO]^+$ (100), 107 (96), 95 (98); $[\alpha]_D^{24°}+7$ ($CHCl_3$; *c* 1.57).

3α-Angeloyloxy-5α-hydroperoxycostic acid methyl ester (**31a**). Colourless crystals, mp 80°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3500 (OOH), 1720, 1635 (C=CCO_2R); MS *m/z* (rel. int.): 362.209 $[M]^+$ (1) (calc. for

$C_{21}H_{30}O_5$ 362.209), 345 $[M-OOH]^+$ (7), 245 [345 $-HOAng]^+$ (61), 213 [245 $-MeOH]^+$ (26), 185 [213 $-CO]^+$ (40), 83 $[C_4H_7CO]^+$ (100), 55 [83 $-CO]^+$ (62); $[\alpha]_D^{24°}-16$ ($CHCl_3$; *c* 0.68). Addition of triphenylphosphine afforded the 5α-hydroxy derivative **32a**; ^1H NMR; Table 4.

8β-Acetoxy-3α-angeloyloxy-5α-hydroperoxycostic acid methyl ester (**33a**). Colourless crystals, mp 97°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3400 (OOH), 1720 (C=CCO_2R); MS *m/z* (rel. int.): 420.215 $[M]^+$ (3) (calc. for $C_{23}H_{32}O_7$: 420.215), 403 $[M-OH]^+$ (61), 360 $[M-HOAc]^+$ (2), 343 [403 $-HOAc]^+$ (11), 243 [343 $-AngOH]^+$ (37), 83 $[C_4H_7CO]^+$ (100), 55 [83 $-CO]^+$ (48); $[\alpha]_D^{24°}-11$ ($CHCl_3$; *c* 0.27).

11β,13-Dihydroivangustin acetate (**34**). Colourless oil; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1780 (γ-lactone), 1740 (OAc); MS *m/z* (rel. int.): 292.167 $[M]^+$ (2) (calc. for $C_{17}H_{24}O_4$ 292.167), 232 $[M-HOAc]^+$ (52), 159 (44), 143 (88), 119 (100); ^{13}C NMR ($CDCl_3$, C-1–C-15): δ75.7 *d*, 27.9 *t*, 30.6 *t*, 126.6 *s*, 130.2 *s*, 23.4 *t*, 43.1 *d*, 75.8 *d*, 37.2 *t*, 37.8 *s*, 41.8 *d*, 179.6 *s*, 21.3 *q*, 14.3 *q*, 18.9 *q*; OAc: 170.9 *q*, 21.3 *q* (some signals may be interchangeable); $[\alpha]_D^{24°}+83$ ($CHCl_3$: *c* 0.31).

Transformation of ivangustin to **34**. To 10 mg ivangustin in 2 ml MeOH 10 mg $NaBH_4$ was added. After 5 min. dil. H_2SO_4 was added. The ^1H NMR spectrum indicated that an epimeric mixture of **34b** and **34c** was obtained ($CDCl_3$, δ3.55, 3.46 (*dd*, H-1), 2.75, 2.46 (*dd*, H-6), 1.87, 1.71 (*br dd*, H-6'), 2.30, 2.15 (*m*, H-7), 4.43, 4.49 (*ddd*, H-8), 2.80, 2.39 (*dq*, H-11), 1.29 1.24 (*d*, H-13, 1.06, 1.10 (*s*, H-14), 1.62, 1.63 (*br s*, H-15). Acetylation (Ac_2O, 1 hr, 70°) afforded 3 mg **34** and 3 mg **34a** which could be separated by TLC (Et_2O–petrol 1:1). **34a**: Colourless oil; MS *m/z* (rel. int.): 292.167 $[M]^+$ (3) (calc. for $C_{17}H_{24}O_4$ 292.167), 232 $[M-HOAc]^+$ (60), 159 (47), 143 (100), 119 (78).

14-Hydroxy-desoxyivangustin (**35**). Colourless crystals, mp 137°; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3600 (OH), 1765 (γ-lactone); MS *m/z* (rel. int.): 248.141 $[M]^+$ (4) (calc. for $C_{15}H_{20}O_3$ 248.141), 230 $[M-H_2O]^+$ (6), 218 $[M-CH_2O]^+$ (100), 217 $[M-CH_2OH]^+$ (98), 177 (44), 171 (38); $[\alpha]_D^{24°}+54$ ($CHCl_3$; *c* 0.24).

14-Acetoxy-11α13-dihydrodesoxyivangustin (**36**). Colourless oil; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1780 (γ-lactone), 1740 (OAc); MS *m/z* (rel. int.): 292.168 $[M]^+$ (3) (calc. for $C_{17}H_{24}O_4$ 292.168), 232 $[M-HOAc]^+$ (28), 219 $[M-CH_2OAc]^+$ (62), 177 (32), 145 (100); $[\alpha]_D^{24°}+105$ ($CHCl_3$; *c* 0.02).

14-Hydroxy-5α-hydroperoxy-isoalantolactone (**37**). Colourless crystals, mp 70°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3500 (OH), 1770 (γ-lactone); MS *m/z* (rel. int.): 246.126 $[M-H_2O_2]^+$ (1.3), 217 [246 $-CHO]^+$ (14), 203 (34), 95 (100); $[\alpha]_D^{24°}+223$ ($CHCl_3$; *c* 0.25).

14-Acetoxy-5α-hydroperoxy-isoalantolactone (**38**). Colourless crystals, mp. 173°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3500 (OH), 1775 (γ-lactone); MS *m/z* (rel. int.): 289.144 $[M-OOH]^+$ (12) (calc. for $C_{17}H_{21}O_4$: 289.144), 229 $[289-HOAc]^+$ (81), 217 (66), 83 (100); $[\alpha]_D^{24°}+290$ ($CHCl_3$; *c* 0.15).

14-Acetoxy-5α-hydroperoxy-11α,13-dihydroisoalantolactone (**39**). Colourless crystals, mp 170°; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3500 (OH), 1770 (γ-lactone), 1740 (OAc); MS *m/z* (rel. int.): 291.160 $[M-OOH]^+$ (12) (calc. for $C_{17}H_{23}O_4$ 291.160), 231 [291 $-HOAc]^+$ (100), 219 (93) 145 (81); $[\alpha]_D^{24°}+94$ ($CHCl_3$; *c* 0.2).

5α-Hydroperoxyasperilin (**40**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3620 (OH), 1765 (γ-lactone); MS *m/z* (rel. int.): 280.131 $[M]^+$ (5) (calc. for $C_{15}H_{20}O_5$: 280.131), 247 $[M-OOH]^+$ (29), 246 $[M-H_2O_2]^+$ (29), 229 $[247-H_2O]^+$ (44), 202 (41), 175 (37), 107 (68), 55 (100); $[\alpha]_D^{24°}+144$ ($CHCl_3$; *c* 0.34).

5β-Hydroxyasperilin (**41**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3600 (OH), 1765 (γ-lactone); MS *m/z* (rel. int.): 264.136 $[M]^+$ (14) (calc. for $C_{15}H_{20}O_4$: 264.136), 246 $[M-H_2O]^+$ (40), 228 [246 $-H_2O]^+$ (16), 179 (48), 178 (52), 170 (54), 161 (82), 135 (100), 109 (84); $[\alpha]_D^{24°}+53$ ($CHCl_3$; *c* 0.28).

11-Hydroxy-4,5-seco-eudesmane-4,5-dione (**42**). Colourless oil; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3600 (OH), 1715, 1710 (C=O); MS *m/z* (rel. int.): 254.188 $[M]^+$ (1) (calc. for $C_{15}H_{26}O_3$: 254.188), 196 $[M-Me_2CO]^+$ (6), 170 $[M-H_2C=CHCH_2COMe]^+$ (100), 152 $[170-H_2O]^+$ (55), 111 $[170-Me_2COH]^+$ (82); ^1H NMR (C_6H_6): δ1.60 (*m*, H-2), 2.05 (*m*, H-3), 2.42 (*ddd*, H-6α), 2.25 (*dd*, *H-6β*), 1.37 (*m*, H-7), 1.51 (*m*, H-8α), 0.91 and 0.93 (*s*, H-12, H-13), 0.96 (*s*, H-14), 1.73 (*s*, H-15) (*J* [Hz]: 6α,6β = 14; 6,7 = 3.5; 6α,8α = 2; 6β,7 = 12.5); in $CDCl_3$: δ1.22 and 1.21 (*s*, H-12, H-13), 1.14 (*s*, H-14), 2.14 (*s*, H-15) (others *m*); $[\alpha]_D^{24°}+46$ ($CHCl_3$; *c* 0.39); CD (MeCN): $\Delta\varepsilon_{296}+1.7$.

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