PREPARATION OF NEW OXIDIZED 18-α-OLEANANE DERIVATIVES

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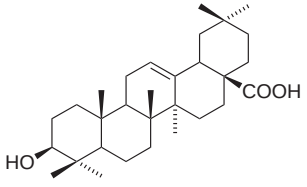
Dedicated to the memory of Professor Jan Sejbal.

19β,28-Epoxy-4,5-seco-3,5-cyclo-18α-olean-3(5)-ene (**2**) is an appropriate compound for oxidations, which lead to new oxidized compounds with potential biological activities. Several oxidations were used such as epoxidation, allylic oxidation, oxidative cleavage of double bond and other ones. From the starting compound epoxides **3a**, **3b** and unsaturated ketone **4** were prepared. This ketone was further oxidized to diketone **6** and anhydride **7**. The double bonds of all unsaturated compounds were cleaved with ruthenium tetroxide to afford new A-seco oleananes. The structure and stereochemistry of the compounds were derived from IR, MS, ^{1}H and ^{13}C NMR spectra (1D and 2D COSY, TOCSY, NOESY, HSQC, HMBC).
Keywords: Triterpenes; Triterpenoids; Oleanane; Oxidation; Seco oleanane; ^{1}H and ^{13}C NMR spectroscopy; X-ray diffractions.

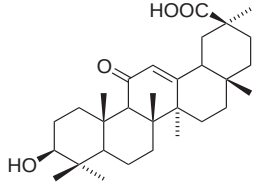
Oleanane derivatives are pentacyclic triterpenes with interesting biological activities[1–7]. Out of them, anti-HIV [8,9] and anti-tumour[10–12] activities are the most studied. For this reason a number of oleanane derivatives were prepared or modified (e.g. glycyrrhetic, ursolic or oleanolic acid) for biological screening. All this compounds should have high activity and simultaneously low toxicity. In the worldwide research of new natural compounds in the field of anti-tumour, anti-HIV and other drugs, a number of structural modifications and derivatizations of pentacyclic triterpenic derivatives were studied. It was found[13–15] that the highly oxidized compounds showed high biological activity. Additional modification could improve their effects.

Many triterpenic or steroid unsaturated ketones, diketones[13,16,17], anhydrides[18,19], lactones[20,21] and other compounds could be found in literature and their preparations and possible biological activities are described. In this contribution, preparation and NMR studies of analogous epoxides, ketones, anhydrides of A-seco oleananes and other oxidized derivatives is presented.

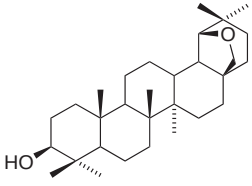
19β,28-Epoxy-4,5-seco-3,5-cyclo-18α-olean-3(5)-ene (**2**; for bond distances and angles of A-ring and atom numbering see Fig. 1) was used as starting material for this investigation. This olefin could be prepared by dehydration of 3β-hydroxy-19β,28-epoxy-18α-oleanane (**1**) (allobetulin) using phosphorus pentachloride[22] or by treatment of the same compound with acid catalysts[23,24] (montmorillonite K10, sulfuric acid etc.).



Oleanolic acid



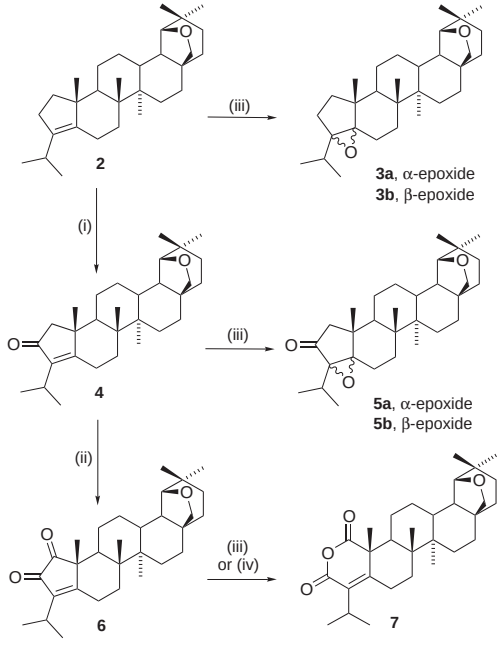
Glycyrrhetic acid



Allobetulin (**1**)

Epoxides **3a**, **3b** were obtained by the modified[25] reaction of olefin **2** with 3-chloroperoxybenzoic acid in chloroform at room temperature (Scheme 1). These reaction conditions afforded above all α-epoxide **3a** in yield over 90%. The yield of β-epoxide **3b** was only around 3%. This ratio did not change by increasing of reaction temperature.

Oxidation of olefin **2** with sodium dichromate in the mixture of benzene/acetic acid leads to a mixture of three compounds, of which the unsaturated ketone **4** was the main product obtained in the yield 65%. Epoxyketone **5b** and epoxide **3a** were the minor products. Treatment of olefin **2** with *tert*-butyl chromate did not lead to higher yields of ketone **4**. In contrast to preparation of epoxides **3a** and **3b**, epoxidation of the unsaturated ketone **4** under the same conditions afforded both epoxyketones **5a** and **5b** in the ratio 3:1. This reaction was much slower than epoxidation of olefin **2**.



(i) $Na_2Cr_2O_7$/benzene, AcOH, r.t.; (ii) SeO_2/dioxane, AcOH, Ac_2O, reflux;
(iii) MCPBA/$CHCl_3$, r.t.; (iv) persteril/$CHCl_3$, r.t.

SCHEME 1

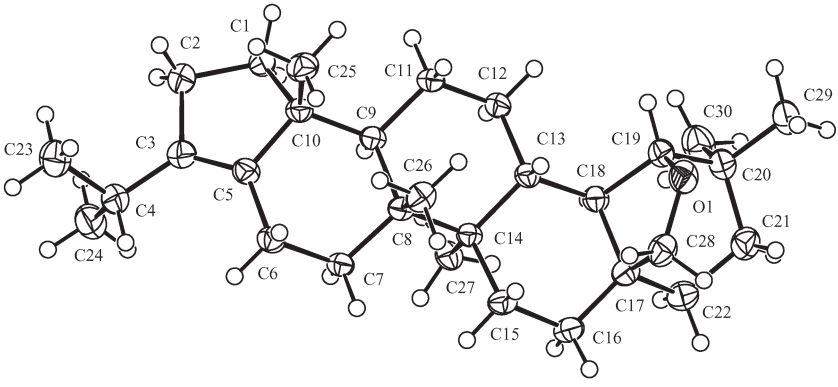
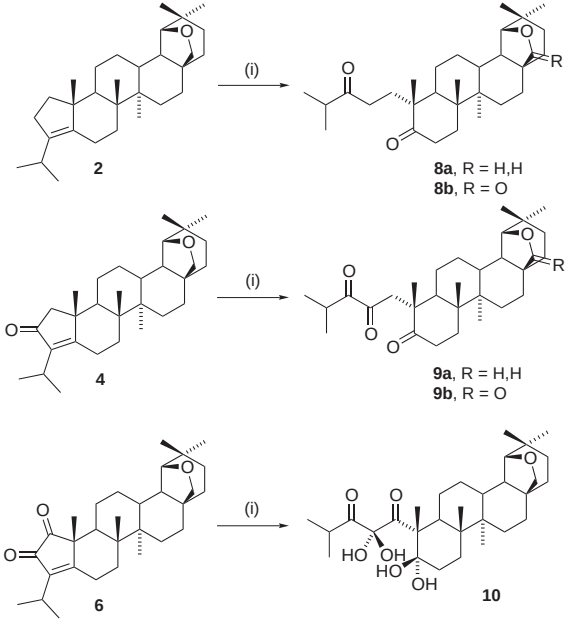


FIG. 1

View of molecular structure of starting compound **2** with the atom numbering scheme. The thermal ellipsoids are drawn at 50% probability level. Selected bond distances (in Å) and angles (in °): C(1)–C(2) = 1.540(2) , C(1)–C(10) = 1.554(2), C(2)–C(3) = 1.528(2), C(3)–C(4) = 1.503(2), C(3)–C(5) = 1.329(2), C(5)–C(10) = 1.520(2), C(10)–C(1)–C(2) = 104.7(1), C(1)–C(2)–C(3) = 102.7(1), C(2)–C(3)–C(4) = 121.8(1), C(2)–C(3)–C(5) = 110.6(1), C(3)–C(5)–C(10) = 112.5(1), C(5)–C(10)–C(1) = 101.3(1)

Unsaturated diketone **6** was prepared by oxidation of ketone **4** with selenium dioxide in a mixture of dioxane–acetic acid–acetic anhydride. It should be noted that the reaction must proceed under inert atmosphere, otherwise low amounts of anhydride **7** are observed. Treatment of diketone **6** with 3-chloroperoxybenzoic acid in chloroform afforded only unsaturated anhydride **7**. Epoxydiketones could not be prepared even by oxidation of epoxyketones **5a** and **5b** with selenium dioxide.

The olefin **2**, unsaturated ketone **4** and diketone **6** were used for synthesis of the 4,5-seco oleanane derivatives **8a**, **9a** and **10** (Scheme 2). For the cleavage of the 3(5)-double bond, ruthenium dioxide was used in a catalytic amount[13] (15 mole %). Ruthenium tetroxide was generated in situ from ruthenium dioxide by oxidation with sodium periodate in a two-phase system of isopropyl acetate and water with addition of acetonitrile or dimethyl carbonate for better solubility. Due to long reaction times (20–30 h) the cleavage of unsaturated compounds **2** and **4** afforded also 28-oxo-4,5-seco compounds **8b** and **9b** in low yields. On the other hand cleavage of diketone **6** (reaction time 8 h) afforded only dihydrate of tetraketone **10**, which is typical for polyketones, without any presence of the 28-oxo derivative. Diketones **8a** and **8b** and compound **10** are stable crystalline compounds in

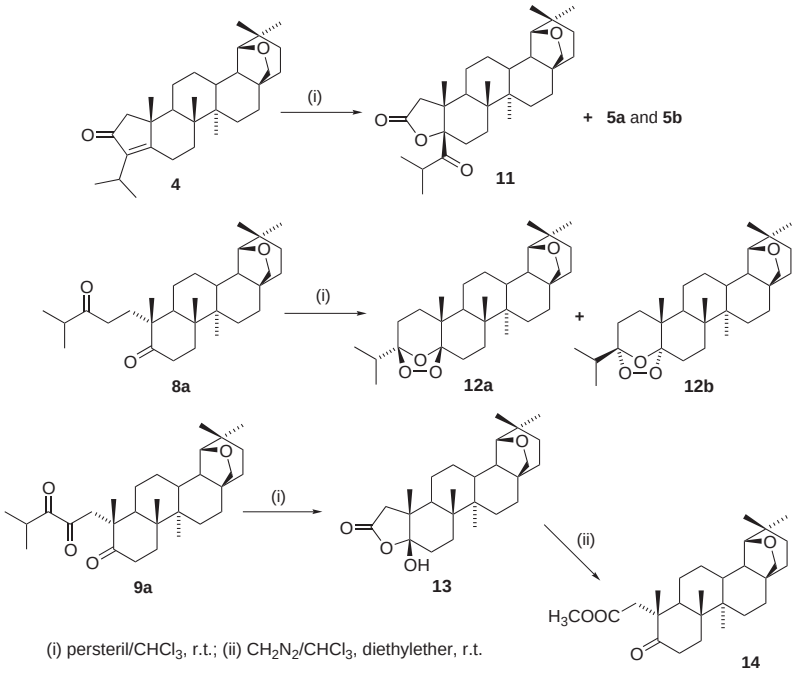


(i) RuO_2, $NaIO_4$/iPrOAc, H_2O, MeCN, r.t.

SCHEME 2

contrast to triketones **9a** and **9b**, which decompose in the presence of oxygen in the course of a few days. The attempt at cleavage of anhydride **7** afforded two major compounds, which decomposed during separation.

Oxidation of compounds **4**, **8a** and **9a** with persteril (solution of peracetic acid, acetic acid, hydrogen peroxide, sulfuric acid and water) in chloroform was used for preparation of other oxidized derivatives (Scheme 3).

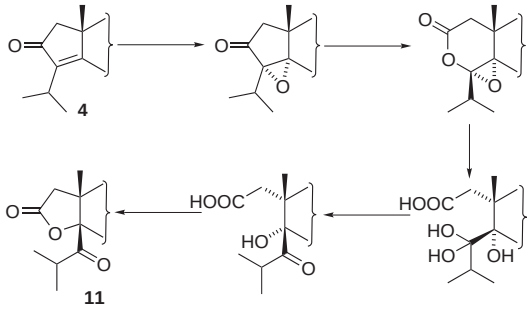


SCHEME 3

In the case of unsaturated ketone **4**, oxolactone **11** was obtained as the major product whereas epoxyketones **5a** and **5b** were minor products. The probable mechanism of formation of oxolactone **11** could be as follows. Unsaturated ketone **4** afforded α-epoxyketone, which was oxidized to epoxylactone. This lactone was then hydrolyzed and simultaneously epoxide ring was opened (with sulfuric acid contained in solution of peracetic acid). After that five membered lactone was formed (Scheme 4).

Diketone **8a** afforded two isomeric ozonides **12a** and **12b** in the ratio 2:1. Similar ozonides, prepared by classical ozonization procedure, were described[26,27]. The same reaction used for triketone **9a** afforded only hydroxylactone **13** with tertiary β-hydroxyl group. Due to easy formation of new A-ring no oxoacid was observed, but treatment of hydroxylactone **13** with

diazomethane in diethyl ether afforded methyl ester of oxoacid **14**. Similar behaviour of oxoacids was described in literature[14].



Probable mechanism of formation of oxolactone **11**

SCHEME 4

NMR DISCUSSION

The structure determination of all prepared compounds is based on the detailed analysis of NMR spectra. The use of standard two-dimensional techniques (COSY, TOCSY, NOESY, HSQC and HMBC) enabled us to make full assignment of all proton and carbon signals for compounds **3a**, **3b**, **4**, **5a**, **5b**, **6**, **7**, **8b**, **9a**, **10**, **11**, **12a**, **12b**, **13** and **14** (cf. Tables I–V). For the other compounds, the assignment of carbon signals is based on DEPT spectra and analogies.

The positions of two carbonyl groups in compound **10** were confirmed using HMBC correlations H-23, H-24/C-3 and H-25/C-1 and C-5 together with the geminal coupling constant of proton in position 6 (13.2 Hz). In the case of compound **11**, the position of the substituent on C-5 was assigned using HMBC cross-peaks between C-5 and H-25, H-1α and H-6α. The spatial arrangement on the ring A has been elucidated from the observed contacts in the NOESY spectra (for selected NOESY contacts for compounds **3a**, **3b**, **5b**, **11**, **12a** and **13**, see Table VI).

EXPERIMENTAL

Melting points were determined using a Kofler block and are uncorrected. Optical rotations were measured using $CHCl_3$ solutions (unless otherwise stated) at 20 °C on an Autopol III (Rudolph Research, Flanders, NJ) polarimeter, with an accuracy of ±2; they are given in 10^{-1} deg cm^2 g^{-1}. IR spectra were recorded in chloroform (unless otherwise stated) on Nicolet AVATAR 370 FT IR; wavenumbers are given in cm^{-1}. NMR spectra were recorded on a Varian UNITY INOVA 400 FT spectrometer (^1H NMR spectra at 399.95 MHz, ^{13}C NMR at 100.58 MHz) using $CDCl_3$ solutions (unless otherwise stated), with tetramethylsilane as the

TABLE I
^{1}H chemical shifts and coupling constants (in parentheses) of compounds **3a**, **3b**, **4**, **5a** and **5b**

Proton	**3a**	**3b**	**4**	**5a**	**5b**
1α	1.04	0.94	2.06 d (18.0)	1.64	2.04 d (18.3)
1β	1.18	1.56	2.14 d (18.0)	2.17 dq (15.7,1.4)	1.94 d (18.3)
2a	1.65	1.36	–	–	–
2b	1.65	1.45	–	–	–
4	1.70	1.64	2.74 septet (7.1)	1.83 septet (7.2)	1.65
6α	1.30	1.32	2.72 dt (13.9,3.6)	1.48	1.41
6β	2.07 td (13.3,4.1)	2.01 dddd (13.5,11.2,6.5,0.9)	2.37 td (13.7,4.5)	2.26 td (13.4,4.1)	2.20 td (13.3,4.7)
7a	1.42	1.48	1.41	1.87 td (13.1,3.7)	1.55
7b	1.72	1.48	1.66	1.56	1.58
9α	1.92 dd (13.1,3.4)	1.49	1.61	2.15 dd (13.1,3.2)	1.42
11α	1.36	1.74	1.50	1.46	1.41
11β	1.30	1.66	1.39	1.23	1.41
12α	1.00	0.94	0.94	1.05	0.94
12β	1.63	1.70	1.68	1.70	1.70
13β	1.50	1.50	1.51	1.52	1.53
15α	1.14	1.12	1.12	1.20	1.13
15β	1.63	1.60	1.64	1.65	1.60
16α	1.40	1.40	1.40	1.43	1.40
16β	1.30	1.31	1.30	1.33	1.33
18α	1.50	1.50	1.50	1.52	1.50
19α	3.54 bs	3.55 bs	3.54 bs	3.54 bs	3.53 bs
21α	1.22	1.22	1.22	1.26	1.26
21β	1.50	1.50	1.50	1.54	1.53
22α	1.46	1.43	1.34	1.39	1.47
22β	1.32	1.34	1.44	1.52	1.38
23	0.96 d (7.2)	1.07 d (6.8)	1.17 d (7.2)	1.21 d (6.8)	1.25 d (7.2)
24	1.06 d (6.8)	1.06 d (6.8)	1.16 d (6.8)	1.09 d (7.2)	1.21 d (7.2)
25	0.86 d (0.8)	1.03 s	1.12 s	1.00 d (1.2)	1.18 s
26	1.07 d (0.8)	1.10 s	1.16 d (0.4)	1.11 s	1.14 s
27	0.99 s	0.91 s	0.87 s	1.03 s	0.88 s
28 (*pro-R*)	3.45 d (7.8)	3.46 d (7.8)	3.47 d (7.7)	3.47 d (7.8)	3.47 d (7.8)
28 (*pro-S*)	3.79 dd (7.8,1.7)	3.78 dd (7.8,1.7)	3.79 dd (7.7,1.7)	3.79 dd (7.9,1.5)	3.78 dd (7.8,1.1)
29	0.80 s	0.80 s	0.80 s	0.81 s	0.80 s
30	0.93 s	0.94 s	0.94 s	0.94 s	0.94 s

TABLE II

^{1}H chemical shifts and coupling constants (in parentheses) of compounds **6**, **7**, **8b**, **9a** and **10**

Proton	**6**	**7**	**8b**	**9a**	**10**
1a	–	–	1.68	2.92 d (18.2)	–
1b	–	–	1.84	3.12 d (18.0)	–
2a	–	–	2.26 ddd (17.3,9.9,5.2)	–	–
2b	–	–	2.41 ddd (17.1,10.1,5.7)	–	–
4	2.91 septet (7.0)	3.04 septet (7.0)	2.59 septet (7.0)	3.32 septet (7.0)	3.43 septet (6.9)
6α	2.85 dt (13.4,3.4)	2.88 dt (16.0,3.5)	2.41	2.43 ddd (17.1,4.7,2.4)	1.97 dt (13.1,2.9)
6β	2.53 td (13.4,4.6)	2.36	2.41	2.56 ddd (17.1,14.0,6.0)	1.84 td (13.4,3.8)
7α	1.50	1.40	1.60	2.03 td (13.6,4.7)	1.74 td (13.4,4.1)
7β	1.80 dq (13.1,3.4)	1.64	1.80	1.71	1.36
9α	1.84 dd (12.7,3.1)	2.35	2.07 dd (12.8,3.4)	2.17	1.89 dd (11.8,4.1)
11α	2.12 dq (9.9,3.1)	1.98 dq (13.0,3.4)	1.56	1.42	1.30
11β	1.52	1.42	1.36	1.42	1.30
12α	0.94	1.15	1.06	0.94	0.88
12β	1.70	1.76	1.69	1.74	1.60
13β	1.54	1.57	1.39	1.54	1.43
15α	1.12	1.20	1.30	1.26	1.20
15β	1.60	1.60	1.30	1.62	1.52
16α	1.40	1.44	1.40	1.42	1.44
16β	1.31	1.32	1.90	1.32	1.32
18α	1.50	1.57	1.87	1.54	1.55
19α	3.54 s	3.57 s	3.96 s	3.55 bs	3.55 s
21α	1.25	1.28	1.45	1.26	1.26
21β	1.50	1.54	1.48	1.53	1.49
22α	1.38	1.38	1.55	1.38	1.35
22β	1.47	1.51	1.55	1.50	1.50
23	1.23 d (7.2)	1.24 d (7.2)	1.08 d (7.2)	1.10 d (7.2)	1.18 d (7.2)
24	1.26 d (7.2)	1.22 d (6.8)	1.07 d (6.8)	1.12 d (6.8)	1.10 d (7.2)
25	1.24 s	1.48 s	1.03 s	1.14 s	1.11 s
26	1.23 s	1.17 s	0.94 s	1.17 s	1.02 s
27	0.85 s	0.93 s	0.90 s	0.91 s	0.88 s
28 (*pro-R*)	3.47 d (7.8)	3.48 d (7.9)	–	3.48 d (7.6)	3.47 d (7.9)
28 (*pro-S*)	3.77 dd (7.8,1.4)	3.78 dd (7.9,1.5)	–	3.80 dd (7.6,1.2)	3.77 dd (7.9,1.2)
29	0.80 s	0.81 s	0.97 s	0.79 s	0.80 s
30	0.94 s	0.95 s	1.04 s	0.94 s	0.93 s

TABLE III
^{1}H chemical shifts and coupling constants (in parentheses) of compounds **11**, **12a**, **12b**, **13** and **14**

Proton	**11**	**12a**	**12b**	**13**[a]	**14**
1a	2.52 d (17.3)	1.74	1.74	2.36 d (16.9)	2.43 d (17.3)
1b	2.15 dd (17.2,0.6)	1.64	1.49	2.45 d (16.9)	2.90 d (17.1)
2α	–	1.72	1.88	–	–
2β	–	1.56	1.70	–	–
4	2.92 septet (6.7)	1.99 septet (7.0)	1.99 septet (7.0)	–	–
6α	1.85 dt (15.3,3.2)	1.43	1.58	1.94	2.49
6β	2.35 td (15.1,4.3)	1.96	2.10	1.76	2.49
7α	1.64	1.94	1.60	1.38	1.99
7β	1.34	1.40	1.38	1.26	1.62
9α	1.58	2.19 dd (12.8,3.1)	1.92 dd (12.8,3.2)	1.32	2.29 m (ΣJ=16.0)
11α	1.32	1.53	1.44	1.42	1.45
11β	1.32	1.32	1.24	1.28	1.37
12α	0.96	1.00	0.96	0.90	0.95
12β	1.74	1.70	1.68	1.67	1.72
13β	1.52	1.46	1.48	1.36	1.56
15α	1.18	1.10	1.10	1.16	1.25
15β	1.50	1.58	1.48	1.50	1.56
16α	1.40	1.40	1.42	1.42	1.44
16β	1.30	1.30	1.30	1.23	1.34
18α	1.52	1.46	1.48	1.48	1.55
19α	3.53 s	3.54 s	3.53 s	3.45 s	3.57 s
21α	1.23	1.22	1.24	1.18	1.24
21β	1.49	1.50	1.50	1.42	1.52
22α	1.36	1.34	1.34	1.32	1.36
22β	1.49	1.46	1.44	1.43	1.48
23	1.12 d (7.2)	1.02 d (6.8)	0.99 d (6.8)	–	–
24	1.07 d (6.4)	0.98 d (6.8)	1.02 d (6.8)	–	–
25	1.01 s	0.98 s	1.01 s	1.02 s	1.05 s
26	1.06 s	1.04 s	1.03 s	0.96 s	1.13 s
27	0.89 s	0.97 s	0.93 s	0.81 s	0.93 s
28 (*pro-R*)	3.47 d (7.9)	3.46 d (7.8)	3.45 d (7.8)	3.35 d (7.8)	3.48 d (7.9)
28 (*pro-S*)	3.77 dd (7.9,1.2)	3.77 dd (7.8,1.5)	3.77 dd (7.8,1.7)	3.64 bd (7.8)	3.81 dd (7.9,1.1)
29	0.80 s	0.80 s	0.80 s	0.77 s	0.80 s
30	0.94 s	0.94 s	0.93 s	0.86 s	0.95 s
OH	–	–	–	7.07 s	–
OCH_3	–	–	–	–	3.64 s

[a] Measured in DMSO-d_6.

TABLE IV
^{13}C chemical shifts of compounds **3a**, **3b**, **4**, **5a**, **5b**, **6**, **7**, **8a** and **8b**

Carbon	**3a**	**3b**	**4**	**5a**	**5b**	**6**	**7**	**8a**	**8b**
1	34.83	34.04	54.33	48.81	49.10	201.22	157.04	33.55	33.49
2	23.24	22.91	207.87	211.09	211.73	187.13	159.48	35.75	35.76
3	76.04	75.84	140.18	71.31	70.73	145.42	128.72	214.62	214.64
4	28.48	28.70	24.34	25.09	25.98	25.08	27.84	40.92	40.92
5	76.43	76.59	180.09	78.07	79.04	179.58	171.38	217.20	216.72
6	20.18	20.65	22.15	19.95	20.49	22.41	22.79	35.18	35.06
7	29.83	31.37	33.73	30.36	31.08	33.94	31.26	30.20	29.92
8	41.00	40.93	40.85	40.73	40.92	41.06	41.16	40.69	39.86
9	44.06	42.17	48.91	42.83	45.59	42.91	42.34	44.96	44.95
10	43.54	45.25	44.80	40.49	40.36	46.20	48.59	49.97	49.91
11	23.04	22.74	24.34	23.08	22.85	23.04	24.82	23.57	23.42
12	26.30	26.50	26.25	26.05	26.50	25.64	25.97	26.04	26.07
13	34.39	34.41	34.52	34.26	34.39	34.35	34.65	34.63	36.43
14	40.75	40.57	40.47	41.08	40.78	41.06	39.79	39.57	39.45
15	26.64	26.55	26.58	26.36	26.11	26.29	26.50	26.92	28.34
16	36.75	36.72	36.67	36.69	36.63	36.58	36.59	36.64	25.33
17	41.48	41.49	41.48	41.48	41.46	41.39	41.43	41.58	46.23
18	46.84	46.77	46.67	46.76	46.64	46.50	46.43	46.62	46.47
19	88.01	87.88	87.93	87.95	87.87	87.87	87.80	87.95	85.90
20	36.27	36.25	36.26	36.26	36.24	36.23	36.25	36.30	33.58
21	32.70	32.65	32.63	32.63	32.59	32.58	32.61	32.64	32.26
22	26.23	26.31	26.13	26.13	26.11	26.02	26.11	26.08	31.83
23	19.13	19.56	20.80[a]	17.25	17.55	20.58	20.94	18.31	18.30
24	18.41	19.01	20.90[a]	18.04	18.35	20.20	19.84	18.31	18.30
25	18.19	18.24	22.99	21.04	17.76	17.62	23.31	20.37	20.42
26	15.02	15.13	14.68	15.10	15.00	15.88	15.95	15.64	15.42
27	13.48	13.19	13.22	13.48	13.14	13.08	13.01	13.40	13.51
28	71.28	71.25	71.22	71.22	71.18	71.16	71.24	71.20	179.56
29	24.55	24.49	24.52	24.51	24.49	24.49	24.50	24.56	23.94
30	28.81	28.78	28.76	28.77	28.74	28.71	28.74	28.76	28.70

[a] Signals may be interchanged.

TABLE V
^{13}C chemical shifts of compounds **9a**, **9b**, **10**, **11**, **12a**, **12b**, **13** and **14**

Carbon	**9a**	**9b**	**10**	**11**	**12a**	**12b**	**13**[a]	**14**
1	46.17	46.31	210.96	46.12	29.19	31.50	44.36	44.06
2	199.51	199.58	98.88	176.26	25.85	25.83	176.23	172.64
3	203.33	203.40	208.70	215.05	110.84	111.89	–	–
4	33.77	33.81	34.82	37.65	33.64	33.03	–	–
5	216.22	215.83	105.41	94.31	113.09	112.39	108.41	216.25
6	35.50	35.41	29.14	25.79	25.07	25.92	28.04	35.73
7	29.30	29.01	27.19	25.18	30.34	29.06	26.80	28.35
8	40.82	40.00	40.57	38.97	40.16	40.11	40.04	40.65
9	43.42	43.29	35.17	42.47	39.06	44.15	42.32	42.11
10	50.17	49.89	53.96	44.63	41.34	40.92	45.16	48.49
11	23.47	23.32	21.90	23.45	21.65	20.87	23.19	23.46
12	26.36	26.36	25.71	26.22	26.58	26.32	25.98	26.37
13	34.67	36.48	34.52	34.76	34.03	34.27	34.24	34.77
14	39.78	39.70	39.29	40.49	39.75	39.91	38.90	39.52
15	26.79	28.24	26.47	26.52	26.43	26.42	26.10	26.81
16	36.60	25.42	36.25	36.55	36.72	36.69	35.92	36.60
17	41.55	46.22	41.21	41.44	41.48	41.50	40.92	41.56
18	46.54	46.44	46.30	46.55	46.76	46.74	45.93	46.57
19	87.88	85.80	88.05	87.86	87.82	87.97	86.68	87.90
20	36.27	33.56	35.98	36.28	36.23	36.26	35.92	36.28
21	32.60	32.21	32.33	32.61	32.64	32.66	32.40	32.60
22	26.13	31.80	25.71	25.99	26.25	26.12	25.68	26.12
23	17.65	17.61	18.81	19.42	17.46	17.54	–	–
24	17.30	17.23	18.58	18.46	17.01	17.40	–	–
25	22.36	22.40	11.49	18.81	20.68	16.95	16.12	22.92
26	14.92	14.74	14.25	14.32	16.23	14.85	14.03	14.70
27	13.17	13.28	13..01	13.49	12.99	13.30	13.06	13.25
28	71.25	179.63	70.94	71.21	71.23	71.25	70.28	71.27
29	24.52	23.90	24.17	24.53	24.48	24.54	24.17	24.52
30	28.75	28.69	28.34	28.76	28.77	28.79	28.77	28.76
OCH_3	–	–	–	–	–	–	–	51.52

[a] Measured in DMSO-d_6.

internal standard (in ^{13}C NMR, $\delta(CDCl_3)$ 77.00 ppm). Chemical shifts (δ-scale, ppm) and coupling constants (*J*, Hz) in the ^1H NMR spectra were obtained by first-order analysis. EI-MS spectra were recorded on an INCOS 50 (Finigan MAT) spectrometer at 70 eV and an ion source temperature of 150 °C. The samples were introduced from a direct exposure probe at a heating rate of 10 mA/s. Relative abundances stated are given relative to the most abundant ion in the region of $m/z > 180$. TLC was carried out using silica gel 60 F_{254}, detection was by spraying with 10% aqueous H_2SO_4 and heating to 150–200 °C. Column chromatography was performed using silica gel 60 (Merck 7734). The used HPLC system consisted of high pressure pump Gilson (model 361), inject valve Rheodyne, preparative column (25 × 250 mm) with filling Si gel (Biospher 7 μm), differential-refractometrical detector (Laboratorní přístroje, Prague, Czech Republic) connected with PC (software Chromulan) and automatic fraction collector Gilson (model 246). Mixture of ethyl acetate and hexane was used as mobile phase; its composition is given in each experiment. TLC was carried out on Kieselgel 60 F_{254} plates (Merck). Persteril (solution of peracetic acid (32–36%), acetic acid (max. 25%), hydrogen peroxide (5–12%) and sulfuric acid (max. 1%) in water) was purchased from Peroxides, s.r.o., Sokolov, Czech Republic.

Epoxidation of Olefin **2** with MCPBA

3-Chloroperoxybenzoic acid (76%; 800 mg, 4.6 mmol) was added to a solution of olefin **2** (1.0 g, 2.36 mmol) in chloroform (20 ml). The reaction mixture was stirred at room temperature for 5 h, then diluted with chloroform and washed with a 10% solution of potassium iodide, a solution of sodium thiosulfate and sodium hydrogensulfite solution and water. After drying over anhydrous magnesium sulfate the chloroform was distilled off. Separation of products by preparative HPLC (hexane–ethyl acetate 30:1) gave two epoxides **3a** (954 mg, 92%) and **3b** (31 mg, 3%).

3α,5α:19β,28-Diepoxy-4,5-seco-3,5-cyclo-18α-oleanane (**3a**). M.p. 241–243 °C (methanol–chloroform), $[\alpha]_D$ +56 (*c* 0.36); ref.[25] m.p. 246–248 °C). IR: 1452, 1262, 1031. For ^1H NMR, see Table I. For ^{13}C NMR, see Table IV. MS, *m/z* (%): 440 (M^+, 100), 397 (14), 379 (6), 354 (18), 313 (33), 287 (16), 233 (11), 221 (10), 203 (59), 187 (44). For $C_{30}H_{48}O_2$ (440.7) calculated: 81.76% C, 10.98% H; found: 81.78% C, 11.03% H.

TABLE VI
Selected NOESY contacts for compounds **3a**, **3b**, **5b**, **11**, **12a** and **13**

Compound	NOESY contacts
3a	H-4/H-6β, H-25
3b	H-9α/H-24
5b	H-4/H-9α
11	H-4/H-1β, H-6β, H-25
12a	H-9α/H-2α, H-23, H-24
13	OH/H-25 (in DMSO-d_6)

*3*β,*5*β*:19*β,*28-Diepoxy-4,5-seco-3,5-cyclo-18*α*-oleanane* (**3b**). M.p. 182–184 °C (methanol–chloroform), $[\alpha]_D$ +95 (*c* 0.31). IR: 1455, 1260, 1030. For ^{1}H NMR, see Table I. For ^{13}C NMR, see Table IV. MS, *m/z* (%): 440 (M^+, 100), 425 (11), 397 (14), 354 (13), 313 (19), 287 (7), 221 (6), 203 (17), 187 (12). For $C_{30}H_{48}O_2$ (440.7) calculated: 81.76% C, 10.98% H; found: 81.81% C, 11.00% H.

Oxidation of Olefin **2** with Sodium Dichromate

Sodium dichromate (1.32 g, 4.43 mmol) was added to a solution of olefin **2** (2.0 g, 4.72 mmol) and anhydrous sodium acetate (1.7 g, 20.7 mmol) in benzene (20 ml), acetic acid (29 ml) and acetic anhydride (6 ml). The reaction mixture was stirred at room temperature for 25 h. After this time the reaction mixture was diluted with toluene and washed with water, with solution of sodium hydrogencarbonate and again with water. The toluene solution was dried over anhydrous magnesium sulfate and distilled off. Separation of products by column chromatography (hexane–ethyl acetate 9:1) gave unsaturated ketone **4** (1.55 g, 75%). As by-products, epoxide **3a** and epoxyketone **5b** were identified.

*19*β,*28-Epoxy-4,5-seco-3,5-cyclo-18*α*-olean-3(5)-en-2-one* (**4**). M.p. 246–248 °C (methanol–chloroform), $[\alpha]_D$ +40 (*c* 0.38). IR: 1684, 1633, 1384, 1032. For ^{1}H NMR, see Table I. For ^{13}C NMR, see Table IV. MS, *m/z* (%): 438 (M^+, 100), 423 (2), 396 (4), 367 (5), 287 (6), 245 (35), 205 (10), 192 (26). For $C_{30}H_{46}O_2$ (438.7) calculated: 82.14% C, 10.57% H; found: 82.09% C, 10.65% H.

*3*β,*5*β*:19*β,*28-Diepoxy-4,5-seco-3,5-cyclo-18*α*-oleanan-2-one* (**5b**). M.p. 207–209 °C (methanol), $[\alpha]_D$ +113 (*c* 0.26). IR: 1732, 1454, 1031. For ^{1}H NMR, see Table I. For ^{13}C NMR, see Table IV. MS, *m/z* (%): 454 (M^+, 44), 436 (43), 411 (100), 383 (34), 358 (21), 340 (15), 309 (9), 271 (8), 245 (60), 215 (12), 191 (14). For $C_{30}H_{46}O_3$ (454.7) calculated: 79.25% C, 10.20% H; found: 79.29% C, 10.18% H.

Epoxidation of Unsaturated Ketone **4** with MCPBA

3-Chloroperoxybenzoic acid (76%; 400 mg, 1.75 mmol) was added to a solution of ketone **4** (500 mg, 1.14 mmol) in chloroform (10 ml). The reaction mixture was stirred at room temperature for 6 h. It was then diluted with chloroform and washed with a 10% solution of potassium iodide, a solution of sodium thiosulfate, sodium hydrogensulfite solution and water. After drying over anhydrous magnesium sulfate the chloroform was evaporated. Separation of products by preparative HPLC (hexane–ethyl acetate 9:1) gave two epoxyketones **5a** (352 mg, 68%) and **5b** (119 mg, 23%). Epoxyketone **5b** was identical with an authentic sample prepared by oxidation of olefin **1** with sodium dichromate.

*3*α,*5*α*:19*β,*28-Diepoxy-4,5-seco-3,5-cyclo-18*α*-oleanan-2-one* (**5a**). M.p. 262–264 °C (methanol–chloroform), $[\alpha]_D$ +38 (*c* 0.44). IR: 1739, 1031. For ^{1}H NMR, see Table I. For ^{13}C NMR, see Table IV. MS, *m/z* (%): 454 (M^+, 51), 436 (48), 411 (100), 383 (36), 355 (13), 340 (15), 271 (8), 245 (65), 215 (14), 191 (16). For $C_{30}H_{46}O_3$ (454.7) calculated: 79.25% C, 10.20% H; found: 79.34% C, 10.09% H.

Oxidation of Unsaturated Ketone **4** with Selenium Dioxide

A solution of ketone **4** (1.0 g, 2.3 mmol) and SeO_2 (800 mg, 7.2 mmol) in dioxane (20 ml), acetic acid (10 ml) and acetic anhydride (2 ml) was heated under reflux in nitrogen atmosphere for 20 h. After cooling, the precipitated selenium was removed by filtration and fil-

trate was diluted in water and extracted with chloroform. The organic layer was washed with aqueous solution of sodium hydrogencarbonate and water, dried with anhydrous magnesium sulfate and evaporated under reduced pressure. Purification by column chromatography (hexane–ethyl acetate 5:1) afforded diketone **6** (890 mg, 86%) as amorphous powder.

*19*β,*28-Epoxy-4,5-seco-3,5-cyclo-18*α-*olean-3(5)-ene-1,2-dione* (**6**). M.p. 223–226 °C, $[\alpha]_D$ +32 (*c* 0.53). IR: 1756, 1704, 1600, 1031. For ^{1}H NMR, see Table II. For ^{13}C NMR, see Table IV. MS, *m/z* (%): 452 (M^+, 3), 424 (100), 409 (11), 381 (2), 353 (1), 284 (2), 256 (3), 204 (12), 189 (12). For $C_{30}H_{44}O_3$ (452.7) calculated: 79.60% C, 9.80% H; found: 79.71% C, 9.87% H.

Oxidation of Unsaturated Diketone **6** with MCPBA

A solution of diketone **6** (150 mg, 0.33 mmol) and 3-chloroperoxybenzoic acid (150 mg, 0.86 mmol) in chloroform (4 ml) was stirred at room temperature for 5 h. After this time the reaction mixture was diluted with chloroform and washed with a 10% solution of potassium iodide, solution of sodium thiosulfate, sodium hydrogensulfite and water. After drying over anhydrous magnesium sulfate the chloroform was evaporated. Crystallization from methanol–chloroform afforded anhydride **7** (135 mg, 87%).

*19*β,*28-Epoxy-4,5-seco-3,5-cyclo-18*α-*olean-3(5)-ene-1,2-dioic anhydride* (**7**). M.p. 275–277 °C, $[\alpha]_D$ +120 (*c* 0.36). IR: 1790, 1737, 1611, 1005. For ^{1}H NMR, see Table II. For ^{13}C NMR, see Table IV. MS, *m/z* (%): 468 (M^+, 100), 438 (16), 425 (7), 413 (8), 397 (18), 287 (7), 256 (8), 219 (14), 201 (16), 189 (19). For $C_{30}H_{44}O_4$ (468.7) calculated: 76.88% C, 9.46% H; found: 76.85% C, 9.51% H.

Oxidation of Olefin **2** with Ruthenium Tetroxide

A solution of olefin **2** (500 mg, 1.18 mmol) in isopropyl acetate (35 ml) and dimethyl carbonate (10 ml) was added to a mixture of ruthenium tetroxide hydrate (120 mg, 0.91 mmol), sodium periodate (2.5 g, 11.7 mmol), water (20 ml) and concentrated sulfuric acid (0.5 ml). The two phase mixture was stirred vigorously at room temperature for 30 h. After the reaction was complete, isopropyl alcohol was added. The mixture was filtered and the phases were separated. The organic layer was diluted with ethyl acetate, with solution of sodium thiosulfate and sodium hydrogensulfite and water, dried over anhydrous magnesium sulfate and evaporated under reduced pressure. Separation of products by preparative HPLC (hexane–ethyl acetate 5:1) gave diketone **8a** (316 mg, 59%) and diketone **8b** (177 mg, 37%).

*19*β,*28-Epoxy-4,5-seco-18*α-*oleanane-3,5-dione* (**8a**). M.p. 111–113 °C (methanol), $[\alpha]_D$ +28 (*c* 0.40); ref.[23] m.p. 113–114 °C. IR: 1700 sh, 1468, 1454, 1386, 1031. ^{1}H NMR (400 MHz, $CDCl_3$): 0.81 s, 3 H; 0.94 s, 6 H; 1.01 s, 3 H; 1.03 s, 3 H; 1.07 d, 3 H, *J* = 6.8; 1.08 d, 3 H, *J* = 6.8 (7 × CH_3); 2.09 dd, 1 H, *J* = 12.7, 3.5 (H-9α); 2.27 ddd, 1 H, *J* = 17.1, 10.1, 5.2 (H-2a); 2.40 ddd, 1 H, *J* = 17.1, 10.2, 5.5 (H-2b); 2.42 dd, 2 H, *J* = 9.0, 5.8 (H-6a, H-6b); 2.60 septet, 1 H, *J* = 6.8 (H-4); 3.47 d, 1 H, *J* = 7.8 (H-28 *pro-R*); 3.55 bs, 1 H (H-19α); 3.78 dd, 1 H, *J* = 7.8, 1.7 (H-28 *pro-S*). For ^{13}C NMR, see Table IV. MS, *m/z* (%): 456 (M^+, 5), 438 (53), 413 (38), 395 (16), 385 (25), 358 (100), 309 (9), 287 (16), 269 (10), 217 (5), 203 (14), 187 (18). For $C_{30}H_{48}O_3$ (456.8) calculated: 78.90% C, 10.59% H; found: 78.85% C, 10.58% H.

*3,5-Dioxo-4,5-seco-18*α-*oleanano-19*β,*28-lactone* (**8b**). M.p. 164–166 °C (methanol), $[\alpha]_D$ +17 (*c* 0.49); ref.[28] m.p. 166–167 °C. IR: 1765, 1701 sh, 1466, 1451, 1388, 971. For ^{1}H NMR, see Table II. For ^{13}C NMR, see Table IV. MS, *m/z* (%): 470 (M^+, 1), 452 (24), 427 (21), 409 (9), 381 (14), 372 (100), 328 (13), 261 (10), 235 (18), 203 (8), 189 (29). For $C_{30}H_{46}O_4$ (470.8) calculated: 76.55% C, 9.85% H; found: 76.54% C, 9.88% H.

Oxidation of Unsaturated Ketone **4** with Ruthenium Tetroxide

A solution of unsaturated ketone **4** (200 mg, 0.46 mmol) in isopropyl acetate (15 ml) and acetonitrile (5 ml) was added to a mixture of ruthenium tetroxide hydrate (50 mg, 0.38 mmol), sodium periodate (1.0 g, 4.7 mmol), water (10 ml) and concentrated sulfuric acid (0.2 ml). The two phase mixture was stirred vigorously at room temperature for 20 h. After this time the reaction mixture was worked up using a procedure similar to that described for diketones **8a** and **8b**. Separation of products by preparative HPLC (hexane–ethyl acetate 5:1) gave triketone **9a** (129 mg, 60%) and triketone **9b** (62 mg, 28%).

*19*β,*28-Epoxy-4,5-seco-18*α-*oleanane-2,3,5-trione* (**9a**). M.p. 131–133 °C, $[\alpha]_D$ +79 (*c* 0.37). IR: 1708, 1702. For ^{1}H NMR, see Table II. For ^{13}C NMR, see Table V. MS, *m/z* (%): 470 (M^+, 1), 455 (2), 428 (1), 399 (100), 381 (32), 369 (21), 356 (74), 325 (8), 285 (7), 256 (8), 219 (10), 191 (22). For $C_{30}H_{46}O_4$ (470.8) calculated: 76.55% C, 9.85% H; found: 76.59% C, 9.98% H.

*2,3,5-Trioxo-4,5-seco-18*α-*oleanano-19*β,*28-lactone* (**9b**). M.p. 138–140 °C, $[\alpha]_D$ +91 (*c* 0.22). IR: 1765, 1707, 1702. ^{1}H NMR (400 MHz, $CDCl_3$): 0.87 s, 3 H; 0.96 s, 3 H; 1.04 s, 3 H; 1.10 s, 3 H; 1.10 d, 3 H, *J* = 6.8; 1.11 d, 3 H, *J* = 6.8; 1.13 s, 3 H (7 × CH_3); 2.16 m, 1 H, Σ*J* = 15.9 (H-9α); 2.43 ddd, 1 H, *J* = 17.2, 4.9, 2.4 (H-6a); 2.54 td, 1 H, *J* = 17.2, 5.8 (H-6b); 2.95 d, 1 H, *J* = 18.3 (H-1a); 3.12 d, 1 H, *J* = 18.3 (H-1b); 3.31 septet, 1 H, *J* = 7.0 (H-4); 3.96 s, 1 H (H-19α). For ^{13}C NMR, see Table V. MS, *m/z* (%): 484 (M^+, 1), 469 (1), 441 (1), 413 (100), 385 (7), 367 (24), 339 (9), 289 (4), 261 (8), 215 (6), 201 (3), 189 (7). For $C_{30}H_{44}O_5$ (484.7) calculated: 74.34% C, 9.15% H; found: 74.61% C, 9.22% H.

Oxidation of Unsaturated Diketone **6** with Ruthenium Tetroxide

A solution of unsaturated diketone **6** (200 mg, 0.44 mmol) in isopropyl acetate (15 ml) and acetonitrile (5 ml) was added to a mixture of ruthenium tetroxide hydrate (50 mg, 0.38 mmol), sodium periodate (1.0 g, 4.7 mmol), water (10 ml) and concentrated sulfuric acid (0.2 ml). The two phase mixture was stirred vigorously at room temperature for 8 h. After this time the reaction mixture was worked up using a procedure similar to that described for diketones **8a** and **8b**. Crystallization from chloroform afforded tetraketone dihydrate **10** (196 mg, 85%).

*19*β,*28-Epoxy-2,2,5,5-tetrahydroxy-4,5-seco-18*α-*oleanane-1,3-dione* (**10**). M.p. 143–145 °C, $[\alpha]_D$ +15 (*c* 0.31). IR: 3563, 1765, 1721, 1030. For ^{1}H NMR, see Table II. For ^{13}C NMR, see Table V. MS, *m/z* (%): 520 (M^+, not found), 484 (21), 416 (17), 385 (9), 369 (7), 358 (100), 340 (6), 327 (14), 288 (3), 269 (11), 245 (10), 201 (15), 189 (19). For $C_{30}H_{48}O_7$ (520.7) calculated: 69.20% C, 9.29% H; found: 69.53% C, 9.48% H.

Oxidation of Unsaturated Ketone **4** with Persteril

A solution of ketone **4** (200 mg, 0.46 mmol) and persteril (6 ml) in chloroform (5 ml) was stirred at room temperature for 5 h. After this time, another portion of persteril (4 ml) was added and the mixture was stirred for 5 h. Then the reaction mixture was diluted with chloroform and washed with a 10% solution of potassium iodide, solution of sodium thiosulfate, sodium hydrogensulfite and water. After drying over anhydrous magnesium sulfate the chloroform was evaporated. Separation of products by preparative HPLC (hexane–ethyl acetate 8:5) gave oxolactone **11** (85 mg, 40%) and epoxyketones **5a** (70 mg, 34%) and **5b** (30 mg, 15%).

*19*β,*28-Epoxy-5*β-*isobutyryl-3,4,23,24-tetranor-18*α-*oleanano-2,5*α-*lactone* (**11**). M.p. 193–195 °C, $[\alpha]_D$ +77 (*c* 0.26). IR: 1774, 1708, 1450, 1381, 1235, 1032, 960. For ^{1}H NMR, see Table III. For ^{13}C NMR, see Table V. MS, *m/z* (%): 470 (M^+, 1), 455 (2), 437 (1), 428 (1), 413 (1), 399 (100), 381 (74), 369 (37), 358 (11), 287 (4), 229 (10), 215 (9), 203 (10), 189 (13). For $C_{30}H_{46}O_4$ (470.7) calculated: 76.55% C, 9.85% H; found: 76.48% C, 9.88% H.

Oxidation of Diketone **8a** with Persteril

A solution of diketone **8a** (200 mg, 0.44 mmol) and persteril (6 ml) in chloroform (3 ml) was stirred at room temperature for 24 h. Then another portion of persteril (4 ml) was added and the mixture was stirred for 10 h. After this time the reaction mixture was worked up using a procedure similar to that described for oxolactone **11**. Separation of products by preparative HPLC (hexane–ethyl acetate 30:1) gave two isomeric ozonides **12a** (45 mg, 22%) and **12b** (120 mg, 58%).

*(3R,5R)-19*β,*28-Epoxy-4,5-seco-18*α-*oleanan-3(5)-ozonide* (**12a**). M.p. 155–158 °C, $[\alpha]_D$ +96 (*c* 0.27). IR: 1454, 1386, 1039. For ^{1}H NMR, see Table III. For ^{13}C NMR, see Table V. MS, *m/z* (%): 472 (M^+, 2), 440 (3), 424 (8), 411 (7), 401 (6), 383 (11), 358 (6), 330 (13), 299 (9), 259 (100), 215 (10), 203 (19), 189 (19). For $C_{30}H_{48}O_4$ (472.7) calculated: 76.23% C, 10.24% H; found: 76.26% C, 10.23% H.

*(3S,5S)-19*β,*28-Epoxy-4,5-seco-18*α-*oleanan-3(5)-ozonide* (**12b**). M.p. 213–215 °C, $[\alpha]_D$ +35 (*c* 0.19). IR: 1447, 1390, 1100, 1034. For ^{1}H NMR, see Table III. For ^{13}C NMR, see Table V. MS, *m/z* (%): 472 (M^+, 2), 440 (3), 429 (8), 411 (12), 401 (8), 383 (15), 358 (4), 330 (18), 299 (11), 259 (100), 215 (8), 203 (12), 189 (13). For $C_{30}H_{48}O_4$ (472.7) calculated: 76.23% C, 10.24% H; found: 76.31% C, 10.29% H.

Oxidation of Triketone **9a** with Persteril

A solution of triketone **9a** (100 mg, 0.21 mmol) and persteril (6 ml) in chloroform (5 ml) was stirred at room temperature for 20 h. After this time the reaction mixture was worked up using a procedure similar to that described for oxolactone **11**. Purification of product by preparative HPLC (hexane–ethyl acetate 1:1) gave hydroxylactone **13** (75 mg, 85%).

*19*β,*28-Epoxy-5*β-*hydroxy-3,4,23,24-tetranor-18*α-*oleanano-2,5*α-*lactone* (**13**). M.p. 218–220 °C, $[\alpha]_D$ +56 (*c* 0.25). IR: 3584, 1775, 1453, 1382, 925. For ^{1}H NMR, see Table III. For ^{13}C NMR, see Table V. MS, *m/z* (%): 416 (M^+, 44), 398 (20), 386 (13), 372 (8), 357 (77), 345 (100), 339 (21), 327 (10), 245 (9), 219 (6), 203 (15), 187 (22). For $C_{26}H_{40}O_4$ (416.6) calculated: 74.96% C, 9.68% H; found: 74.95% C, 9.71% H.

Reaction of Hydroxylactone **13** with Diazomethane

A solution of diazomethane (0.2 mol/l) in diethyl ether (3 ml) was added to a solution of hydroxylactone **13** (50 mg, 0.12 mmol) in chloroform (1 ml). After 30 min the solvents were evaporated and product was purified by HPLC (hexane–ethyl acetate 7:5) gave methyl ester **14** (45 mg, 86%).

*Methyl 19*β,*28-epoxy-3,4,23,24-tetranor-5-oxo-18*α-*oleanan-2-oate* (**14**). M.p. 133–135 °C, $[\alpha]_D$ +102 (*c* 0.25). IR: 1729, 1695, 1445, 1346, 1178, 1010. For ^{1}H NMR, see Table III. For ^{13}C NMR, see Table V. MS, *m/z* (%): 430 (M^+, 4), 415 (5), 399 (5), 383 (4), 368 (2), 357 (100), 339 (4), 327 (3), 257 (3), 245 (4), 215 (3), 203 (5), 187 (6). For $C_{27}H_{42}O_4$ (430.6) calculated: 75.31% C, 9.83% H; found: 75.30% C, 9.88% H.

Crystal Structure Analysis for Compound **2**

$C_{30}H_{48}O$, M = 424.68, orthorhombic, $P2_12_12_1$ (No. 19), a = 6.5220(1) Å, b = 15.4430(2) Å, c = 24.8160(3) Å, V = 2499.45(6) Å^3, Z = 4, D_x = 1.129 Mg m^{-3}. A colourless crystal of dimensions 0.4 × 0.35 × 0.22 mm was mounted on glass capillary with epoxy glue and measured at Nonius KappaCCD diffractometer by monochromatized MoKα radiation (λ = 0.71073 Å) at 150(2) K. An absorption was neglected (μ = 0.065 mm^{-1}); a total of 42 092 measured reflections in the range h = –8 to 8, k = –20 to 19, l = –32 to 31 (θ_{max} = 27.5°), from which 5743 were unique (R_{int} = 0.043), 5374 observed according to the $I > 2\sigma(I)$ criterion. Cell parameters from 40 322 reflections (θ = 1–27.5°). The structure was solved by direct methods (SIR92)[29] and refined by full-matrix least squares based on F^2 (SHELXL97)[30]. The hydrogen atoms were fixed into idealised positions (riding model) and assigned displacement parameter either H_{iso}(H) = 1.2 U_{eq}(pivot atom), or hydrogen H_{iso}(H) = 1.5 U_{eq}(pivot atom) for methyl moiety. The refinement converged (Δ/σ_{max} = 0.001) to R = 0.041 for observed reflections and wR = 0.117, GOF = 1.005 for 287 parameters and all 5743 reflections. The final difference map displayed no peaks of chemical significance ($\Delta\rho_{max}$ = 0.356, $\Delta\rho_{min}$ = –0.178 e Å^{-3}).

CCDC 283560 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/conts/retrieving.html (or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge, CB2 1EZ, UK; fax: +44 1223 336033; or deposit@ccdc.cam.ac.uk)

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