155. Structure-Activity Relationship in Ambergris-Type Woody Odorants Possessing a Hydronaphthalene Skeleton

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Dedicated to Dr. *G. Ohloff* on the occasion of his 65th birthday

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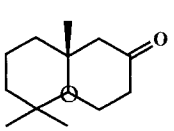
A series of methyl hydronaphthyl alcohols, formates, acetates, and ketones were prepared and their odour properties evaluated. Minor structural changes, even opposite to the osmophoric group, were found to have major effects on the odour. ^{13}C-NMR shift assignments of the hydronaphthyl derivatives are presented.

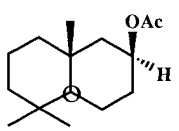
Introduction. – *Ohloff* [1] has given a comprehensive account of structure-activity correlations in ambergris-type odorants. The gross structural features of this group may be described by the presence of a bicyclo[4.4.0]decane (decalin) skeleton carrying at least one alcohol, ether, or ester function as osmophoric group and alkyl substituents at specific positions. Today, there are no ambergris odorants known which do not obey these broad structural limits. However, a compound which fulfills the above structural requirements does not necessarily possess an amber-type odour, and may even not smell at all. Very early, it was recognized that within a given structure, configuration subtleties are also of paramount importance for odour profile and strength. By correlating diastereoisomerism of decalin-type compounds with ambergris odour, *Ohloff et al.* established the 'triaxial rule' of odour sensation [2][3], and finally they could demonstrate that enantiomeric ambergris compounds are distinctly different in odour profile and strength [4–6]. The odour profile so far encountered within substituted decalin derivatives or homologues is dominated by ambergris, woody, vetiver, animal, and camphoraceous scents.

In this publication, we report on a new series of decalin-type compounds in order to gain further insight into critical molecular properties which may relate structure with odour. It was our particular aim to simplify rather than complicate the structure of some known odorants, and to be guided by readily available starting materials in conjunction with straightforward chemistry.

The lead structures were 3,4,4aα,5,6,7,8,8aβ-octahydro-5,5,8aβ-trimethylnaphthalen-2(1*H*)-one ((±)-**1**) [3] and 1,2α,3,4,4aα,5,6,7,8,8aβ-decahydro-5,5,8aβ-trimethylnaphthalen-2β-yl acetate ((±)-**2**; *Polywood*®[1])) [3].



(±)-**1**



Polywood® (±)-**2**

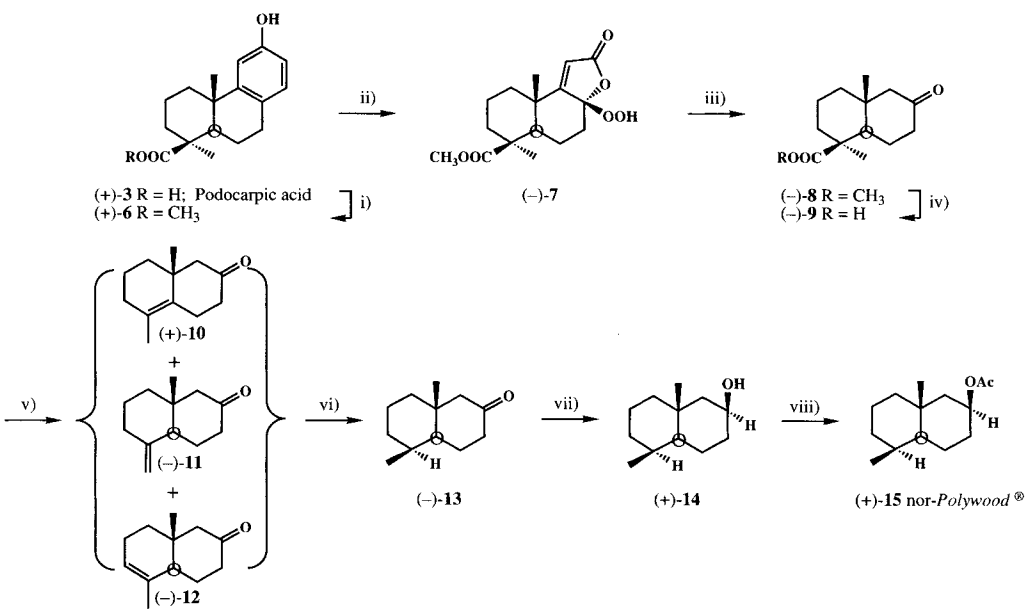
[1]) Registered trademark of *Firmenich S.A.*

As starting materials for the optically active series, podocarpic acid ((+)-**3**), which occurs in the resin of the Javanese pine tree *Podocarpus cupressina* and in New Zealand Kahikatea resin (from *Podocarpus dacrydioides*) [7], was chosen.

The racemic series was synthesized starting from *Hageman*'s ester ((±)-**4**) and isophorone (**5**).

Degradation of Podocarpic Acid (*Scheme 1*). – Podocarpic acid ((+)-**3**), a C_{17} compound, possesses all the C-atoms and the correct chirality of *Polywood*® ((–)-**2**) and of the corresponding ketone (–)-**1**; in addition, the functionality of podocarpic acid, namely a phenol and a COOH group, make it amenable to oxidative degradation. Indeed, *Bell* and *Gravenstock* [8] investigated the reaction of (+)-**3** and especially of its methyl ester (+)-**6** with O_3 yielding lactone (–)-**7** which, upon treatment with NaOH/EtOH/H_2O, underwent a sequence of hydrolysis and *retro*-aldol cleavage[2]) to give the keto-ester (–)-**8** [8]. This compound has the correct absolute configuration and the skeleton of ketone (–)-**1** [6], a constituent of osmanthus oil [10], and into which it could in principle be transformed[3]).

Scheme 1



i) $NaOH/(CH_3)_2SO_4$; ii) $O_3/MeOH/CH_2Cl_2$ –78°; iii) NaOH/EtOH/H_2O; iv) LiI/NMP/reflux; v) $Pb(OAc)_4$/benzene/pyridine/reflux; vi) PtO_2/H_2/AcOH/1 atm; vii) PtO_2/H_2/AcOH/60 psi; viii) Ac_2O/pyridine.

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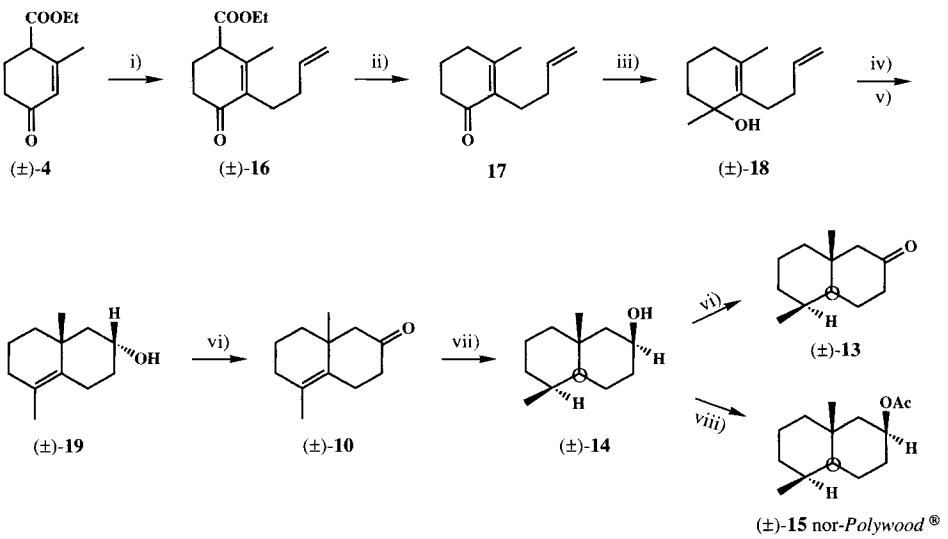
[2]) Preliminary experiments to cleave the lactone acid [9] instead of its ester (–)-**7** gave impure (–)-**9** in low yield.

[3]) For a different method of preparing ketone (–)-**1** and its enantiomer (+)-**1**, see [6].

However, for reasons of synthetic simplicity, we decided to degrade keto-ester (–)-**8** further. Saponification (LiI/DMF [11], or better LiI/NMP) gave oxo-acid (–)-**9**, and $Pb(OAc)_4$ oxidation [12] led to a mixture of the olefinic ketones (+)-**10**, (–)-**11**, and (–)-**12** (17:31:52). Hydrogenation (PtO_2/H_2/AcOH) of this mixture gave crystalline, optically active ketone (–)-**13** (m.p. 69–71°, $[\alpha]_D^{20} = -51.4$, 11.2% yield based on (–)-**9**) which was subsequently transformed into alcohol (+)-**14** and nor-*Polywood*® ((+)-**15**; $[\alpha]_D^{20} = +9.25$, 65% yield based on (–)-**13**). The stereoselectivity of this hydrogenation has its precedent in the hydrogenation of α-, β-, and γ-eudesmol [13] where, as in our case, only one *trans*-fused product is obtained.

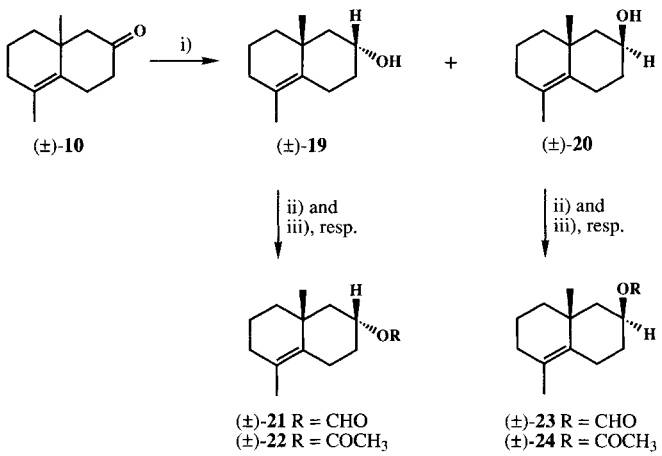
Racemic Decalins from *Hageman*'s Ester ((±)-**4**; *Schemes 2* and *3*). – Racemic ketone (±)-**10** was already described by *Marshall et al.* [14] who synthesized it from *Hageman*'s ester ((±)-**4**; *Scheme 2*). Hydrogenation (PtO_2/H_2/AcOH, 60 psi) led directly to racemic alcohol (±)-**14** which was further acetylated to give racemic nor-*Polywood*® ((±)-**15**). *Jones'* oxidation of (±)-**14** gave racemic ketone (±)-**13**. The unsaturated formates (±)-**21** and (±)-**23** and acetates (±)-**22** and (±)-**24** derived from ketone (±)-**10** were synthesized as depicted in *Scheme 3*.

Scheme 2



i) *NaH/toluene*/CH_2=$CHCH_2CH_2Br$; ii) KOH/EtOH/reflux; iii) CH_3Li/Et_2O; iv) HCOOH; v) KOH/EtOH; vi) $CrO_3/H_2O/H_2SO_4$/acetone; vii) H_2/PtO_2/AcOH/60 psi; viii) Ac_2O/pyridine.

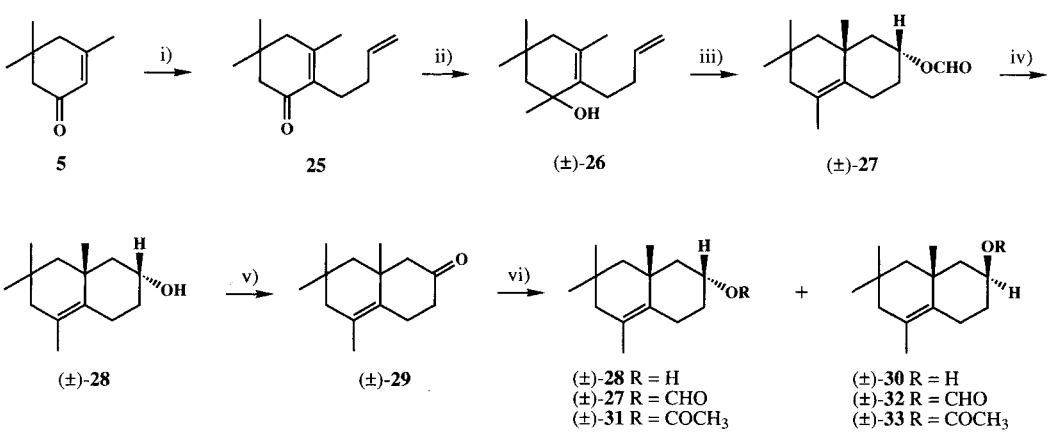
Scheme 3



i) $NaBH_4$/EtOH; ii) $CH_3COOCHO$; iii) Ac_2O/pyridine.

Racemic Decalins from Isophorone (**5**; *Scheme 4*). – Isophorone (**5**) is a cheap raw material (US$ ~1.0/lb) ideally suited as starting material for the synthesis of more complex fragrance chemicals. It was readily alkylated (NaH/toluene) with 4-bromobut-1-ene to the mono-alkylated ketone **25** (54% yield). Unlike the lower homologue described in [14], and due to severe steric hindrance of one of the two geminal Me groups β to the C=O function, the *Grignard* reaction leading to the allylic alcohol (±)-**26** did not proceed well; instead of methyl addition, a fair amount of enolisation was observed, yielding the starting ketone **25** after aqueous workup. This difficulty could not be overcome by using a different methylating agent (MeLi). The remaining transformations were identical to those described earlier for the lower homologues and are summarized in *Scheme 4*.

Scheme 4

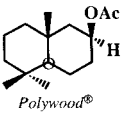


i) NaH/toluene/CH_2=$CHCH_2CH_2Br$; ii) CH_3MgBr/Et_2O; iii) HCOOH; iv) KOH/EtOH/H_2O; v) CrO_3/H_2O/H_2SO_4/acetone; vi) transformations and reagents analogous to the ones described in *Scheme 3*.

Odour Properties of the Compounds Prepared[4]). – As summarized in *Table 1*, all compounds are very different from each other, meaning that none could be substituted for any other; the nor-derivatives, in general, perform less well, being weaker and less tenaceous. The *Polywood*® and nor-*Polywood*® derivatives (±)-**1**, (+)-**1**, (–)-**1**, (±)-**2**, (+)-**2**, (–)-**2**, [3][6], and (±)-**13**, (–)-**13**, (±)-**15**, (+)-**15**[5]) are all woody, amber-like, and earthy, and the equatorial Me group, which is lacking in the nor-series, seems to make a critical contribution to the overall odour profile and tenacity as was already found by *Ohloff et al.* [4] and *Brunke* [15][16] in related ambergris-type compounds. The validity of the 'triaxial rule' is also preserved.

The unsaturated series (±)-**10** and (±)-**19** – (±)-**24** exhibit an odour profile similar to the saturated compounds (±)-**13** – (±)-**15**, with small but significant discrepancies.

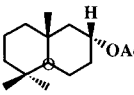
Table 1. *Comparative Odour Profiles of Some Known and New Hydronaphthalene Derivatives*



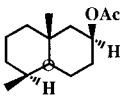
Polywood®

(–)-**2** Woody, dry, amber-like

(±)-**2** Strong woody, very characteristic, dry and warm



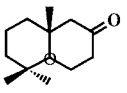
(±)-**34** Weak-to-odourless, woody



Nor-*Polywood*®

(+)-**15** Woody, green, freshly cut wood

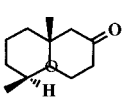
(±)-**15** Similar to (+)-**15**, cedar wood-type scent



Polywood® ketone

(–)-**1** Strong woody, amber-like, with note of damp earth, geosmin

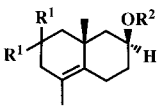
(±)-**1** Similar to (–)-**1**



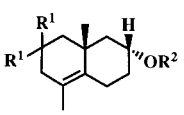
Nor-*Polywood*® ketone

(–)-**13** Woody, orris, earthy, weaker than (±)-**13**

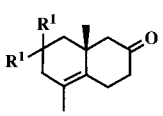
(±)-**13** Similar to (–)-**13**, but stronger



$R^1 = H$, $R^2 = H$	(±)-**20**	Camphoraceous, patchouli without amber note, much stronger than (±)-**19**
$R^1 = H$, $R^2 = CHO$	(±)-**23**	Weak, without precise character
$R^1 = H$, $R^2 = COCH_3$	(±)-**24**	Cedar wood, guaiac, stronger than (±)-**22**
$R^1 = CH_3$, $R^2 = H$	(±)-**30**	Weak without precise character
$R^1 = CH_3$, $R^2 = CHO$	(±)-**32**	Weakly woody, much weaker than (±)-**27**
$R^1 = CH_3$, $R^2 = COCH_3$	(±)-**33**	Slightly woody, weak



$R^1 = H$, $R^2 = H$	(±)-**19**	Camphoraceous, celluloid, relatively weak
$R^1 = H$, $R^2 = CHO$	(±)-**21**	Woody, sawdust, slightly amber
$R^1 = H$, $R^2 = COCH_3$	(±)-**22**	Relatively weak, without precise character
$R^1 = CH_3$, $R^2 = H$	(±)-**28**	Weak, without precise character
$R^1 = CH_3$, $R^2 = CHO$	(±)-**27**	Woody, ionone, orris like in the beginning, then aniseed-like, ionone in final
$R^1 = CH_3$, $R^2 = COCH_3$	(±)-**31**	Slightly woody, weak



$R^1 = H$,	(±)-**10**	Camphoraceous, earthy, rootlike, slightly patchouli, without amber note
$R^1 = CH_3$	(±)-**29**	Strongly woody, then amber, ionone in final

[4]) We thank Drs. *D. Kastner* and *P.A. Blanc*, *Firmenich S.A.*, for the organoleptic evaluation.

[5]) For further *Polywood*® analogues and their odour description, see [1] [2].

A surprise, however, turned out to be the series (±)-**27** – (±)-**33** derived from isophorone **5**. The extra two geminal Me groups render the alcohols (±)-**28** and (±)-**30** practically odourless compared to their parent compounds (±)-**19** and (±)-**20**. In comparison with their parent compounds (±)-**22** and (±)-**24**, the acetates (±)-**31** and (±)-**33** preserve their woody character but are weaker. In the case of the formates, the two geminal Me groups of compounds (±)-**27** and (±)-**32** introduce an ionone character especially for the equatorial formate (±)-**27** which is very strong and reminiscent of the rose ketones, whereas in *Polywood*® the equatorial esters do not smell [1]. Ketone (±)-**29**, having a geminal Me group, was evaluated the best compound of the unsaturated series with a distinct woody scent and an amber- and ionone-like character. The parent ketone (±)-**10** is woody, earthy, but also camphoraceous and lacks the amber note.

Conclusion. – The compounds prepared show that, in the field of olfaction, minor structural changes, such as substituting Me for a H-atom (and *vice versa*) or introducing a double bond, may indeed have a major effect on the odour perceived. This is especially noteworthy for sites which are opposite to the osmophoric group and consequently are not regarded as critical by current structure-activity rules.

Experimental Part

(With the valuable collaboration of *Laurence Lotterio, Cédric Morel*, and *Alain Charpilloz*.)

1. *General.* All reactions were carried out under an inert atmosphere (N_2). *Hageman*'s ester ((±)-**4**), isophorone (**5**), and 4-bromobut-1-ene were purchased from *Fluka AG*, Buchs, and were distilled before use. Solvent was evaporated with a *Büchi Rotavapor-R*. Bulb-to-bulb distillation: *Büchi GKR-50* apparatus with external temp. reading. Anal. GC: *Varian 3400* instrument, *SE 54* (25 m × 0.2 mm) or *DB WAX* (15 m × 0.2 mm), He as vector gas. Prep. GC: *Carlo-Erba Fractovap 2450, SP 1000* 5% on *Chromosorb W* 80–100 mesh, 3 m × 6 mm, He as vector gas. Flash chromatography (FC) [17]: silica gel *60, Merck* (0.040–0.063 mesh). Optical rotation: *Perkin-Elmer-141* polarimeter, in soln. UV: *Kontron* spectrophotometer mod. *Uvikon 820*, in EtOH, λ_{max} in nm (ε). ^{1}H- (360 MHz) and ^{13}C-NMR (90.5 MHz): *Bruker WH 360* instrument modified in an AM model and interfaced to an *Aspect 2000* computer, in $CDCl_3$ with TMS (= 0.00 ppm) as internal standard; *J* and $w_{1/2}$ in Hz. COSY, C,H-CORRELATION (*Bruker* software DISN87 (1987)). ^{13}C-NMR chemical shifts are compiled in *Table 2*. MS: *Finnigan MAT* quadrupole instrument; *m/z* (% rel. abundance). Abbreviation: NMP = *N*-methylpyrrolidone.

2. *(2S,4aS,5S,8aR)-Perhydro-5,8a-dimethylnaphthalen-2-yl Acetate* ((+)-**15**; opt. active nor-*Polywood*®). 2.1. *(1S,4aR)-Perhydro-1,4a-dimethyl-6-oxonaphthalene-1-carboxylic Acid* ((–)-**9**). Compound (–)-**8** [8] (m.p. 64–65°, $[\alpha]_D^{20} = -17.8$ (*c* = 1.1, $CHCl_3$)) (300 mg, 1.26 mmol), 45 ml of NMP, and 1.5 g (11.2 mmol) of anh. LiI were stirred at reflux (191°) for 24 h. After normal aq. acid/base workup, 300 mg of crude (–)-**9** were obtained and recrystallized at –30° in hexane/Et_2O 9:1 to give 175 mg (62%) of pure (–)-**9**. When DMF [11] is used in place of NMP, the reaction is complete only after 170 h at reflux (155°), and (–)-**9** is isolated in the same yield. M.p. 172–175°. $[\alpha]_D^{20} = -14.7$ (*c* = 2.07, MeOH). ^{1}H-NMR: 0.82 (*s*, 3 H); 1.33 (*s*, 3 H). MS: 224 (16, M^+), 209 (7), 196 (3), 178 (13), 163 (31), 147 (25), 136 (15), 121 (72), 109 (100), 95 (58), 79 (44), 67 (45), 55 (59), 41 (60).

2.2. *(8aR)-3,4,6,7,8,8a-Hexahydro-5,8a-dimethylnaphthalen-2(1H)-one* ((+)-**10**), *(4aS,8aR)-3,4,4a,5,6,7,8,8a-Octahydro-8a-methyl-5-methylidenenaphthalen-2(1H)-one* ((–)-**11**), *and (4aR,8aR)-3,4,4a,7,8,8a-Hexahydro-5,8a-dimethylnaphthalen-2(1H)-one* ((–)-**12**). Crude (–)-**9** (12.5 g, 55.8 mmol) was added to a suspension of 37.6 g (85 mmol) of $Pb(OAc)_4$ in 9.4 ml of anh. pyridine and 290 ml of anh. benzene, and the mixture was stirred at reflux, the evolution of CO_2 being followed with a gas meter. After 10 min, the evolution of CO_2 ceased (1.05 l of gas was measured, theory: 1.25 l). The reflux was maintained for 20 min, and after cooling, the mixture was filtered, evaporated, and distilled (*Vigreux* column, b.p. 85–110°/0.8 Torr) to

Table 2. *^{13}C-NMR Data of* **8–17**, **19–25**, *and* **27–33**[a])

Compound	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	C(7)	C(8)	C(9)	C(10)	C(11)	C(12)	C(13)	C(14)	R–*C*OO	*C*H$_3$COO
8[b])	42.3[d])	19.6	38.3	44.2	53.0	24.7	42.4[d])	211.1	58.3	39.2	–	–	28.5	17.8	177.1	–
9	42.3[d])	19.5	38.1	44.1	53.1	24.5	42.4[d])	211.2	58.3	39.3	–	–	28.6	18.0	183.1	–
10	39.6	19.4	32.9	127.6	131.6	25.3	41.5	212.2	55.9	38.5	–	–	19.7	26.5	–	–
11	41.3[d])	23.1	36.8	148.8	48.3	25.3	41.8[d])	211.2	56.0	40.2	–	–	107.2	17.2	–	–
12	37.4	22.8	122.1	133.4	45.7	24.7	41.8	211.6	56.0	36.6	–	–	21.2	17.0	–	–
13	41.8[d])	16.7	33.6	32.5	46.0	27.9	42.1[d])	211.6	59.4	38.1	–	–	14.9	19.9	–	–
14	42.3	16.9	33.8	33.6	48.2	22.6	34.8	68.2	50.8	34.2	–	–	15.0	22.0	–	–
15	42.0	17.0	33.7	33.5	47.8	23.1	31.8	70.8	47.3	34.1	–	–	14.9	21.2	170.4	21.5
16[c])	47.8	25.7[d])	34.8	197.3	137.0	24.9[d])	32.9	138.2	114.8	150.2	–	–	–	20.5	172.2	–
17	32.9	22.3	37.9	198.6	135.1	24.8	33.2	138.5	114.5	155.5	–	–	–	21.3	–	–
19	40.3	18.9	33.0	125.3	133.3	24.0	36.9	67.7	51.3	35.7	–	–	19.4	25.5	–	–
20	40.6	18.7	32.9	124.4	135.1	20.0	34.4	67.8	48.5	34.6	–	–	19.3	27.7	–	–
21	40.2	18.9	32.9	125.8	132.5	23.7	32.9	70.8	46.6	35.8	–	–	19.4	25.3	160.7	–
22	40.2	18.9	32.9	125.5	132.8	23.8	32.9	70.8	46.9	35.7	–	–	19.4	25.3	170.7	21.4
23	40.4	18.6	32.9	125.2	133.9	20.5	31.5	70.7	45.1	34.5	–	–	19.3	26.9	160.7	–
24	40.4	18.7	33.0	125.0	134.3	20.6	31.5	70.7	45.1	34.5	–	–	19.3	26.9	170.6	21.6
25	47.1	32.7	51.4	198.6	133.8	24.6	33.3	138.5	114.6	152.8	28.2	28.2	–	21.4	–	–
27	52.6	[e])	46.7[d])	124.0	131.1	23.3	33.0	70.9	46.8[d])	36.4	29.7	30.4	20.0	26.9	160.7	–
28	52.9	[e])	46.9	123.4	131.9	23.6	37.0	67.7	51.2	36.4	29.8	30.5	20.1	27.1	–	–
29	51.7	29.9	46.8	125.9	129.8	24.8	41.8	211.6	56.5	38.7	29.6	29.9	20.2	28.1	–	–
30	53.3	29.8	46.8	122.5	133.8	20.2	34.9	68.0	48.3	35.8	29.8	29.8[d])	19.9	30.3[d])	–	–
31	52.7	[e])	46.7[d])	123.7	131.4	23.4	33.0	70.8	46.8[d])	36.3	29.7	30.3	19.9	26.9	170.5	21.3
32	52.9	29.7	46.8	123.4	132.6	20.6	31.9	70.9	44.8	35.6	29.8	30.2	19.9	29.0	160.8	–
33	53.0	29.7	46.8	123.1	133.0	20.7	32.0	70.9	44.9	35.6	29.8	30.2	19.9	28.9	170.4	21.6

[a]) The assignments are based on 2D experiments (C,H-CORRELATION, COSY) for compounds **10**, **17**, **29**, on comparison with firmly assigned structure of the eudesmane type [19] and on the application of shift rules [20].

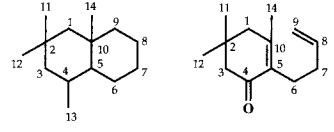
[b]) CH_3O: 51.4.

[c]) C_2H_5O: 61.2, 14.2.

[d]) Values within any horizontal line may be interchanged.

[e]) Not visible.

Numbering used:



give 1.83 g (18.4%) (+)-**10**/(–)-**11**/(–)-**12** (ratio: 17:31:52, estimated by ^{1}H-NMR). The residue was polymeric material. The mixture of ketones was purified by prep. GC. It was not possible to obtain pure (–)-**11** and (–)-**12**, and the $[\alpha]_D^{20}$ given are calculated from those obtained from enriched mixtures (> 80%) of (–)-**11** and (–)-**12**.

Data of (+)-**10**. $[\alpha]_D^{20}$ = +49.11 (*c* = 1.17, $CHCl_3$). ^{1}H-NMR: 1.04 (*s*, 3 H); 1.69 (*s*, 3 H). MS: 178 (38, $M^{+\cdot}$), 163 (93), 150 (37), 135 (20), 121 (40), 105 (52), 93 (100), 79 (80), 65 (27), 55 (32), 41 (19).

Data of (–)-**11**. $[\alpha]_D^{20}$ = –13.4 (*c* = 1.14, $CHCl_3$). ^{1}H-NMR: 0.72 (*s*, 3 H); 4.52 (splitted *s*, 1 H); 4.82 (splitted *s*, 1 H). MS: 178 (14, $M^{+\cdot}$), 163 (10), 145 (12), 135 (27), 118 (37), 107 (37), 93 (53), 79 (100), 67 (61), 55 (37), 41 (28).

Data of (–)-**12**. $[\alpha]_D^{20}$ = –96.6 (*c* = 1.12, $CHCl_3$). ^{1}H-NMR: 0.78 (*s*, 3 H); 1.67 (*s*, 3 H); 5.41 (*m*, 1 H). MS: 178 (33, $M^{+\cdot}$), 163 (58), 150 (27), 135 (12), 121 (28), 105 (39), 93 (64), 81 (100), 67 (38), 55 (44), 41 (24).

2.3. *(4aS,5S,8aR)-3,4,4a,5,6,7,8,8a-Octahydro-5,8a-dimethylnaphthalen-2(1H)-one* ((–)-**13**). A mixture of (+)-**10**, (–)-**11**, and (–)-**12** (890 mg, 5 mmol, 17:31:52) in 25 ml of AcOH were hydrogenated (ambient pressure and temp.) in the presence of 50 mg of PtO_2. After filtration, normal aq. workup and bulb-to-bulb distillation (b.p. 95°/0.1 Torr), 900 mg of crystals were obtained and recrystallized from EtOH to give 550 mg (61.1%) of pure (–)-**13**. M.p. 69–71°. $[\alpha]_D^{20}$ = –51.4 (*c* = 1.82, MeOH). ^{1}H-NMR: 0.89 (*s*, 3 H); 0.93 (*d*, *J* = 7, 3 H); 1.98 (*dd*, *J* = 2, 13, 1 H); 2.15 (*d*, *J* = 13, 1 H); 2.33 (*ddd*, *J* = 7, 11, 13, 1 H); 2.43 (*dddd*, *J* = 2, 2, 5.5, 13, 1 H). MS: 180 (27, $M^{+\cdot}$), 162 (15), 147 (31), 138 (24), 122 (67), 109 (77), 95 (100), 81 (73), 67 (68), 55 (64), 41 (61).

2.4. *(2S,4aS,5S,8aR)-Perhydro-5,8a-dimethylnaphthalen-2-ol* ((+)-**14**). A soln. of (–)-**13** (274 mg, 1.52 mmol) in 10 ml of AcOH was hydrogenated 24 h at 20° on a *Parr* apparatus (shaker type) at 60 psi in the presence of 10 mg of PtO_2. After filtration, evaporation, and FC (hexane/Et_2O 1:1), the product was distilled (bulb-to-bulb, b.p. 105°/0.3 Torr) to give 230 mg (83%) of pure (+)-**14**. M.p. 73–75°. $[\alpha]_D^{20}$ = +11.38 (*c* = 2.2, MeOH). ^{1}H-NMR: 0.91 (*d*, *J* = 7, 3 H); 1.14 (*s*, 3 H); 4.11 (*m*, $w_{1/2}$ = 10, 1 H). MS: 182 (6, $M^{+\cdot}$), 164 (25), 149 (100), 135 (32), 121 (35), 108 (58), 95 (76), 81 (75), 67 (69), 55 (62), 41 (61).

2.5. *(2S,4aS,5S,8aR)-Perhydro-5,8a-dimethylnaphthalen-2-yl Acetate* ((+)-**15**, (+)-Nor-*Polywood*®). A soln. of (+)-**14** (1.0 g, 5.5 mmol) in 10 ml of anh. pyridine and 4.16 g (40.8 mmol) of Ac_2O were stirred 5 h at 40–45°. After normal aq. workup, the product was purified by FC (hexane/Et_2O 9:1) and distilled (bulb-to-bulb, b.p. 105°/0.4 Torr) to give 0.99 g (80.5%) of pure (+)-**15**. $[\alpha]_D^{20}$ = +9.25 (*c* = 0.875, MeOH). ^{1}H-NMR: 0.92 (*d*, *J* = 7, 3 H); 1.04 (*s*, 3 H); 2.04 (*s*, 3 H); 5.03 (*m*, $w_{1/2}$ = 8, 1 H). MS: 224 (0, $M^{+\cdot}$), 164 (54), 149 (72), 135 (80), 121 (43), 108 (87), 95 (59), 81 (55), 67 (53), 55 (50), 43 (100).

3. *(2RS,4aRS,5RS,8aSR)-Perhydro-5,8a-dimethylnaphthalen-2-yl Acetate* ((±)-**15**, (±)-Nor-*Polywood*®).

3.1. *(2RS,4aRS,5RS,8aSR)-Perhydro-5,8a-dimethylnaphthalen-2-ol* ((±)-**14**). Compound (±)-**10** [14] (4.0 g, 22.47 mmol), 60 ml of AcOH, and 100 mg of PtO_2 were hydrogenated 24 h at 20° on a *Parr* apparatus (shaker type) at 60 psi. The product was purified as described in *2.4* and recrystallized from hexane at –30° to give 2.50 g (61.9%) of pure (±)-**14**. The analyses (m.p., ^{1}H- and ^{13}C-NMR, MS) were identical to those described in *2.4* for the optically active compound.

3.2. *(4aRS,5RS,8aSR)-3,4,4a,5,6,7,8,8a-Octahydro-5,8a-dimethylnaphthalen-2(1H)-one* ((±)-**13**). To a soln. of (±)-**14** (1.0 g, 5.5 mmol) in 20 ml of acetone at 0° were added 1.5 ml of *Jones'* reagent [18], and the mixture was stirred for 2 h at 20°. A few drops of i-PrOH were added to destroy the excess of *Jones'* reagent, and, after normal aq. workup, 0.87 g of crude (±)-**13** were obtained and purified by FC (hexane/Et_2O 7:3) and bulb-to-bulb distillation (b.p. 80°/0.01 Torr) to give 0.70 g (70.5%) of pure (±)-**13**. The analyses (GC on two capillary columns, MS, ^{1}H- and ^{13}C-NMR) were identical to those described in *2.3* for the optically active compound except the m.p. which is 53–54° for (±)-**13** and 69–71° for (–)-**13**.

3.3. *(2RS,4aRS,5RS,8aSR)-Perhydro-5,8a-dimethylnaphthalen-2-yl Acetate* ((±)-**15**, (±)-Nor-*Polywood*®). Compound (±)-**15** was prepared from (±)-**14** as described in *2.5* for (+)-**15**, and the analyses (^{1}H- and ^{13}C-NMR, MS) were identical. Yield: 81%.

4. *Derivatives of* (±)-**10**. 4.1. *(2RS,8aRS)-1,2,3,4,6,7,8,8a-Octahydro-5,8a-dimethylnaphthalen-2-ol* ((±)-**19**) *and (2RS,8aSR)-1,2,3,4,6,7,8,8a-Octahydro-5,8a-dimethylnaphthalen-2-ol* ((±)-**20**). To a soln. of (±)-**10** [14] (6.5 g, 36.5 mmol) in 65 ml of anh. EtOH at 0°, 1.39 g (36.5 mmol) of $NaBH_4$ were added, and the mixture was stirred for 2 h at 20°. After aq. workup, the product was purified twice by FC (hexane/Et_2O 3:2) to give 3.78 g (57.5%) of pure (±)-**20** and 1.38 g (21%) of pure (±)-**19**. The two compounds were sublimed at 60°/0.04 Torr.

Data of (±)-**20**. M.p. 71–73°. ^{1}H-NMR: 1.27 (*s*, 3 H); 1.62 (*s*, 3 H); 4.13 (*m*, $w_{1/2}$ = 10, 1 H). MS: 180 (18, $M^{+\cdot}$), 165 (34), 147 (100), 136 (6), 119 (21), 105 (51), 91 (53), 79 (33), 67 (22), 55 (21), 41 (13).

Data of (±)-**19**. M.p. 58–60°. ^{1}H-NMR: 1.05 (*s*, 3 H); 1.60 (*s*, 3 H); 3.97 (*m*, $w_{1/2}$ = 22, 1 H). MS: 180 (15, $M^{+\cdot}$), 162 (20), 147 (100), 133 (10), 119 (27), 105 (47), 91 (46), 79 (28), 67 (17), 55 (15), 41 (23).

4.2. *(2RS,8aRS)-1,2,3,4,6,7,8,8a-Octahydro-5,8a-dimethylnaphthalen-2-yl Formate* ((±)-**21**). A soln. of (±)-**19** (1.8 g, 10 mmol) and 15 ml of mixed formic-acetic anhydride (prepared from 17 g of Ac_2O and 93 g of HCOOH, 2 h at 45–50°) were stirred 5 h at 40°. After normal workup, 2.06 g of crude (±)-**21** were obtained and purified by FC (hexane/Et_2O 92:8) and bulb-to-bulb distillation (b.p. 80–90°/0.03 Torr) to give 1.35 g (65%) of pure (±)-**21**. ^{1}H-NMR: 1.11 (*s*, 3 H); 1.62 (*s*, 3 H); 5.20 (*m*, $w_{1/2}$ = 22, 1 H); 8.03 (*s*, 1 H). MS: 208 (3, M^+), 162 (13), 147 (100), 133 (10), 119 (15), 105 (26), 91 (32), 79 (15), 67 (9), 55 (9), 41 (9).

4.3. *(2RS,8aRS)-1,2,3,4,6,7,8,8a-Octahydro-5,8a-dimethylnaphthalen-2-yl Acetate* ((±)-**22**). Compound (±)-**22** was prepared from (±)-**19** as described in *2.5*. Yield: 77.6%. ^{1}H-NMR: 1.10 (*s*, 3 H); 1.61 (*s*, 3 H); 2.02 (*s*, 3 H); 5.06 (*m*, $w_{1/2}$ = 22, 1 H). MS: 222 (2, M^+), 162 (28), 147 (100), 133 (17), 119 (24), 105 (42), 91 (45), 79 (15), 67 (10), 55 (8), 43 (12).

4.4. *(2RS,8aSR)-1,2,3,4,6,7,8,8a-Octahydro-5,8a-dimethylnaphthalen-2-yl Formate* ((±)-**23**). Compound (±)-**23** was prepared from (±)-**20** as described in *4.2*. Yield: 74.5%. ^{1}H-NMR: 1.19 (*s*, 3 H); 1.62 (*s*, 3 H); 5.22 (*m*, $w_{1/2}$ = 9, 1 H); 8.11 (*s*, 1 H). MS: 208 (7, M^+), 162 (14), 147 (100), 138 (8), 119 (18), 105 (38), 91 (58), 79 (27), 67 (18), 55 (15), 41 (10).

4.5. *(2RS,8aSR)-1,2,3,4,6,7,8,8a-Octahydro-5,8a-dimethylnaphthalen-2-yl Acetate* ((±)-**24**). Compound (±)-**24** was prepared from (±)-**20** as described in *2.5*. Yield: 92.7%. ^{1}H-NMR: 1.17 (*s*, 3 H); 1.62 (*s*, 3 H); 2.06 (*s*, 3 H); 5.07 (*m*, $w_{1/2}$ = 8, 1 H). MS: 222 (2, M^+), 168 (28), 147 (100), 133 (13), 119 (18), 105 (36), 91 (48), 79 (20), 67 (14), 55 (13), 43 (18).

5. *Racemic Decalins from* **5**. 5.1. *2-(But-3-en-1-yl)-3,5,5-trimethylcyclohex-2-en-1-one* (**25**). To a suspension of 58.5 g (1.34 mol) of NaH (55–60% in oil) in 1900 ml of anh. toluene, a soln. of 184.92 g (1.34 mol) of **5** in 100 ml of anh. toluene was introduced dropwise at 20°. When 1/3 was introduced, the mixture was heated to 75–80°, and evolution of H_2 started. Remaining **5** was introduced dropwise at 80–90°, and the temp. was maintained at 90° for 15 min, until the evolution of H_2 decreased. The mixture was heated to reflux (~107°) for 1 h, and a soln. of 180.9 g (1.34 mol) of 4-bromobut-1-ene in 100 ml of anh. toluene was rapidly introduced to the cooled mixture (~20°). The mixture was heated to reflux for 4 h, cooled (5°), and was cautiously added to 1 kg of crushed ice. After normal workup, 276.8 g of crude product were obtained which consisted largely (67.4% by GC) of **25**. After two successive distillations (*Vigreux* column, b.p. 121–126°/10 Torr), 139.9 g (54%) of 96% pure **25** were obtained. UV: 245 (10935). ^{1}H-NMR: 1.00 (*s*, 6 H); 1.92 (*s*, 3 H); 2.08 (*m*, 2 H); 2.23 (*m*, $w_{1/2}$ = 7, 4 H); 2.40 (*m*, 2 H); 4.92 (*d*, *J* = 10 , 1 H); 4.98 (*d*, *J* = 17, 1 H); 5.81 (*m*, 1 H). MS: 192 (40, M^+), 177 (47), 163 (51), 151 (11), 136 (12), 121 (20), 107 (18), 95 (90), 81 (20), 67 (100), 55 (20), 41 (51).

5.2. *(2RS,8aRS)-1,2,3,4,6,7,8,8a-Octahydro-5,7,7,8a-tetramethylnaphthalen-2-yl Formate* ((±)-**27**). A soln. of **25** (1.92 g, 10 mmol) in 10 ml of anh. Et_2O was added dropwise to a soln. of MeMgI (prepared from 607.5 mg (25 mmol) of Mg and 3.55 g (25 mmol) of MeI) in 10 ml of anh. Et_2O at 0° (CH_4 was slowly evolved during the addition), and the reaction mixture was heated 2 h at reflux. To the ice-cooled mixture, 10 ml of H_2O were cautiously added, followed by 10% HCl to dissolve the mass of Mg salts. After normal aq. workup, 1.80 g of crude (±)-**26** was obtained contaminated (^{1}H-NMR) with the corresponding olefines. To crude (±)-**26**, 100 ml of HCOOH was added, and the soln. was stirred for 2 h 30 min at 20°. The mixture was poured into 100 ml of H_2O, extracted (3 ×) with hexane and worked up as usual to give 2.17 g of crude (±)-**27** contaminated by 20% of **25**. This mixture was purified by FC (hexane/Et_2O 97:3) and bulb-to-bulb distillation (b.p. 80°/0.1 Torr) to give 1.50 g (63.5%) of (±)-**27**. ^{1}H-NMR: 0.93 (*s*, 3 H); 0.94 (*s*, 3 H); 1.14 (*s*, 3 H); 1.64 (*s*, 3 H); 5.22 (*m*, $w_{1/2}$ = 22, 1 H); 8.01 (*s*, 1 H). MS; 236 (3, M^+), 190 (16), 175 (100), 162 (6), 147 (12), 133 (30), 119 (41), 105 (32), 91 (32), 81 (17), 67 (14), 55 (13), 41 (9).

5.3. *(2RS,8aRS)-1,2,3,4,6,7,8,8a-Octahydro-5,7,7,8a-tetramethylnaphthalen-2-ol* ((±)-**28**). A mixture of (±)-**27** (1.56 g, 6.61 mmol), 3.7 g (66.1 mmol) of KOH, 37 ml of EtOH, and 10 ml of H_2O was stirred at reflux for 1 h. After evaporation, usual workup and recrystallization (2 ×, hexane at –30°), 0.93 g (67.6%) of pure (±)-**28** were obtained. M.p. 84–85°. ^{1}H-NMR: 0.93 (s, 3 H); 0.94 (*s*, 3 H); 1.09 (*s*, 3 H); 1.64 (*s*, 3 H); 3.98 (*m*, $w_{1/2}$ = 22, 1 H). MS: 208 (9, M^+), 193 (23), 175 (100), 161 (4), 147 (22), 133 (60), 119 (60), 105 (47), 91 (51), 79 (35), 67 (23), 55 (28), 41 (28).

Another run starting from 132.48 g (0.69 mol) of **25** was performed without purification of intermediates (±)-**26** and (±)-**27** and gave, after recrystallization (2 ×, hexane at –30°) and FC (hexane/Et_2O 6:1) of the mother liquor, 83.3 g (58% based on **25**) of pure (±)-**28** and 18.18 g (13.7%) of recovered **25**.

5.4. *3,4,6,7,8,8a-Hexahydro-5,7,7,8a-tetramethylnaphthalen-2(1H)-one* ((±)-**29**). Compound (±)-**29** was prepared from (±)-**28** as described in *3.2* and purified by bulb-to-bulb distillation (b.p. 100–110°/0.1 Torr). Yield: 91.6%. ^{1}H-NMR: 0.96 (*s*, 3 H); 0.98 (*s*, 3 H); 1.05 (*s*, 3 H); 1.34 (*d*, *J* = 13, 1 H); 1.42 (*d*, *J* = 13, 1 H); 1.72 (*s*, 3 H); 1.85 (*s*, 2 H); 2.13 (*dd*, *J* = 2.5, 13, 1 H); 2.2–2.44 (*m*, 3 H); 2.47 (*d*, *J* = 13, 1 H); 2.92 (*m*, 1 H). MS: 206 (13, M^+), 191 (46), 178 (42), 163 (12), 149 (26), 133 (100), 121 (39), 107 (61), 93 (48), 79 (28), 69 (16), 55 (23), 41 (23).

5.5. *(2*RS,*8a*SR*)-1,2,3,4,6,7,8,8a-Octahydro-5,7,7,8a-tetramethylnaphthalen-2-ol* ((±)-**30**). Compound (±)-**29** (4.12 g, 20 mmol) was reduced with $NaBH_4$ as described in *4.1* to give, after FC (hexane/Et_2O 1:1) and sublimation (70°/0.01 Torr), 2.57 g (61.8%) of pure (±)-**30** and 1.45 g (34.8%) of (±)-**28** (see *5.3*).

Data of (±)-**30**. M.p. 78–78.5°. ^{1}H-NMR: 0.90 (*s*, 3 H); 0.93 (*s*, 3 H); 1.31 (*s*, 3 H); 1.64 (*s*, 3 H); 4.11 (*m*, $w_{1/2}$ = 8, 1 H). MS: 208 (11, M^+), 193 (34), 175 (100), 161 (3), 147 (18), 133 (53), 119 (48), 107 (38), 91 (39), 79 (24), 67 (21), 55 (24), 41 (26).

5.6. *(2*RS,*8a*RS*)-1,2,3,4,6,7,8,8a-Octahydro-5,7,7,8a-tetramethylnaphthalen-2-yl Acetate* ((±)-**31**). Compound (±)-**31** was prepared from (±)-**28** as described in *2.5*. Yield: 95.6%. ^{1}H-NMR: 0.93 (*s*, 3 H); 0.94 (*s*, 3 H); 1.13 (*s*, 3 H); 1.63 (*s*, 3 H); 2.01 (*s*, 3 H); 5.07 (*m*, $w_{1/2}$ = 22, 1 H). MS: 250 (2, M^+), 190 (25), 175 (100), 161 (7), 147 (13), 133 (35), 119 (47), 105 (37), 91 (33), 81 (26), 67 (19), 55 (17), 43 (30).

5.7. *(2*RS,*8a*SR*)-1,2,3,4,6,7,8,8a-Octahydro-5,7,7,8a-tetramethylnaphthalen-2-yl Formate* ((±)-**32**). Compound (±)-**32** was prepared from (±)-**30** as described in *4.2*. Yield: 95.7%. ^{1}H-NMR: 0.91 (*s*, 3 H); 0.94 (*s*, 3 H); 1.23 (s, 3 H); 1.65 (*s*, 3 H); 5.20 (*m*, $w_{1/2}$ = 9, 1 H); 8.10 (*s*, 1 H). MS: 236 (4, M^+), 190 (13), 175 (100), 161 (3), 147 (8), 133 (25), 119 (32), 105 (27), 91 (28), 81 (20), 67 (17), 55 (14), 41 (16).

5.8. *(2*RS,*8a*SR*)-1,2,3,4,6,7,8,8a-Octahydro-5,7,7,8a-tetramethylnaphthalen-2-yl Acetate* ((±)-**33**). Compound (±)-**33** was prepared from (±)-**30** as described in *2.5*. Yield: 98%. ^{1}H-NMR: 0.90 (*s*, 3 H); 0.93 (*s*, 3 H); 1.22 (*s*, 3 H); 1.64 (*s*, 3 H); 2.06 (*s*, 3 H); 5.04 (*m*, $w_{1/2}$ = 9, 1 H). MS: 250 (2, M^+), 190 (24), 175 (100), 161 (5), 147 (13), 133 (31), 119 (40), 105 (34), 91 (32), 81 (20), 67 (15), 55 (16), 43 (34).

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